Chemical Hazard Analysis for Risk-Based Response

CHARBR-Student Manual

1st Edition, 2nd Printing-September 2024

FEMA

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ACKNOWLEDGMENTS

The development of any National Fire Academy (NFA) course is a complex process aimed at providing students the best possible learning opportunity we can deliver.

There are many players in course development, each of whom plays an equally important part in its success. We want to acknowledge their participation and contribution to this effort and extend our heartfelt thanks for making this quality product.

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ACKNOWLEDGMENTS IN MEMORIAM

Noel "Chris" Waters for his vision, insight, leadership and friendship through the years as the NFA Hazardous Materials Program Chair, instructor and mentor. The contributions Chris made to the emergency response community are invaluable to the nation. He made a difference, and he will be missed.

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COURSE DESCRIPTION

This nine-day course is designed to prepare responders, planners and allied professionals with the knowledge and skills needed to analyze hazardous materials/weapons of mass destruction (WMD) incidents using the risk-based response (RBR) process that utilizes facts, science and circumstances. Primarily focused on the product involved, this analysis will also incorporate information concerning the container, environment and cause. This course supports response personnel and allied professionals seeking specialized training in advanced chemical risk assessment and analysis. The student will be able to effectively communicate the hazards and associated harm identified in a timely and concise manner to make recommendations concerning control zones, personal protective equipment (PPE) and decontamination methods to develop a safer RBR.

Through an interactive, student-centered approach, students will conduct a product hazard analysis and create communication strategies by:

- Conducting an initial product hazard analysis for multiple products using limited information.
- Using the periodic table to identify the general hazards associated with a material for developing an initial product hazard analysis.
- Conducting briefings based on their hazard analysis for hazardous materials/WMD incidents.
- Analyzing the characteristics of molecular size, polarity and shape and how these affect the physical and chemical properties of a material.
- Conducting a product hazard analysis to support an RBR process in a hazard situation.

COURSE GOAL

Upon successful completion of this course, students will be able to conduct a comprehensive product hazard analysis based on the facts, science and circumstances of a hazardous materials/WMD incident. The purpose of this product hazard analysis is to identify the hazards and associated harms and to communicate those hazards to protect responders, the public and the environment through planning and preparedness, using an RBR process.

AUDIENCE, SCOPE AND COURSE PURPOSE

The target audience for this course is emergency responders and allied professionals who are responsible for preventing, preparing for, responding to, mitigating and/or recovering from hazardous materials/WMD incidents.

This curriculum is aligned with National Fire Protection Association (NFPA) 470, *Hazardous Materials/Weapons of Mass Destruction (WMD) Standard for Responders*, 2022 edition.

GRADING METHODOLOGY

Evaluation Plan Summary

Each unit in the course has enabling objectives that build to the unit terminal objective. The unit terminal objectives are directly related to the course goal. Each enabling objective is evaluated on the two tests (the midterm and final exam) and/or a graded performance-based activity.

Students are also provided with a Learning Checkpoint for each unit. These checkpoints are self-administered and self-graded so that students have a tool to measure their progress. These student checkpoints are **not** calculated into the final grade.

Students who do not complete the entire course will be awarded an incomplete (I) grade. In accordance with NFA academic policies, an incomplete (I) grade must be removed by the end of the next semester following the course, or it automatically becomes a failing (F) grade.

If a student fails an on-campus course, the student will not be issued a stipend for that course. The student can reapply for the failed course, or any other NFA course, and go through the random selection process. The student does not have to successfully complete the failed course before attending another NFA course.

https://www.usfa.fema.gov/nfa/admissions/attendance-failure.html.

Graded Components

Students are evaluated on two primary graded components: written exams and activities. These components are weighted as follows.

Evaluated Component	Weight
Midterm Exam and Final Exam (20% each)	40%
Graded Activities (see below)	60%
Total	100%

Graded Activities:

- Activity 4.2: Hazards of Inorganic Nonsalts (10% of final grade).
- Activity 6.8: Hydrocarbon Derivative Incident Scenarios (15% of final grade).
- Activity 12.2: Analysis of Toxicity Considerations (15% of final grade).
- Activity 13.2: Hazard Analysis Briefing to Hazardous Materials Leadership (20% of final grade).

GRADING RUBRICS

Activity 4.2: Hazards of Inorganic Nonsalts (10% of final grade)

Assessment area	Needs improvement (1)	Below expectations (2)	Meets expectations (3)	Exceeds expectations (4)	Points
Hazard analysis Did the group accurately identify decision-making related to the potential hazards based on analysis of the information given?	The group failed to identify two or more potential hazards affecting decision-making.	The group analyzed the scenario and the product involved, did not provide accurate technical data, identified most hazards correctly, but did not provide appropriate decisions.	The group analyzed the scenario and the product involved, presented accurate technical data, and accurately identified all hazards present at the scene described in their scenario, but were unable to defend their rationale for their decision-making.	The group analyzed the scenario and the product involved, estimated the potential hazards accurately, and made sound decisions related to the incident considerations and the severity of the hazards.	____/4 x2 = ____/8
Communication of hazards Did the group present a clear, concise and accurate summary of hazard analysis information appropriate to their audience? Could group members answer questions posed by their audience regarding the chemicals and their hazards clearly and concisely?	Communication was not clear. Information was not well organized. Group members were unable to answer questions.	Information was somewhat organized, but contained some inaccuracies, exaggerations or excessive technical jargon, making details of the presentation inaccessible to their audience. Group members were able to answer some questions when asked by instructor or other students.	Information was very well organized. Group members were able to answer most questions posed by instructor and other students.	The group analyzed the scenario and the chemicals involved, estimated the potential hazards accurately, and made sound decisions related to the prioritization of the severity of the hazards.	____/4 x2 = ____/8
Group collaboration Did group members contribute equally? Did group members effectively collaborate to achieve group objectives?	One or two members of the group did all the work. Some refused to participate or were not allowed to help.	One or two members of the group didn't help complete tasks. Group was constantly covering for group members or not encouraging them to participate. Most members presented.	All group members worked on their own assignments. No one did more work than anyone else. Some communication, but mostly worked separately. All members presented.	All group members worked on their assignments, but also collaborated frequently. Clear connection and communication between the group members. All members presented.	____/4
				Total points:	**____/20**

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Activity 6.8: Hydrocarbon Derivative Incident Scenarios (15% of final grade)

Assessment area	Needs improvement (1)	Below expectations (2)	Meets expectations (3)	Exceeds expectations (4)	Points
Incident consideration Did the group accurately identify decision-making related to the potential hazards based on analysis of the information given?	The group failed to identify potential hazards affecting decision-making.	The group analyzed the scenario and the product involved, did not provide accurate technical data, identified most hazards correctly, but did not provide appropriate decisions.	The group analyzed the scenario and the product involved, presented accurate technical data, and accurately identified all hazards present at the scene described in their scenario, but were unable to defend their rationale for their decision-making.	The group analyzed the scenario and the product involved, estimated the potential hazards accurately, and made sound decisions related to the incident considerations for the severity of the hazards.	____/4 x2 = ____/8
Presentation Did the group present a clear, concise and accurate summary of hazard analysis information appropriate to their audience? Could group members answer questions posed by their audience regarding the chemicals and their hazards clearly and concisely?	Presentation was not clear. Information was not well organized. Group members were unable to answer questions.	Information was somewhat organized, but contained some inaccuracies, exaggerations or excessive technical jargon, making details of the presentation inaccessible to their audience. Group members were able to answer some questions when asked by instructors or other students.	Information was very well organized and mostly clear, concise and accurate. Group members were able to answer most questions posed by instructors and other students.	Information was exceptionally well organized, clear, concise and accurate. Group members were able to answer all questions posed by instructors and other students.	____/4 x2 = ____/8
Group collaboration Did group members contribute equally? Did group members effectively collaborate to achieve group objectives?	One or two members of the group did all the work. Some refused to participate or were not allowed to help.	One or two members of the group didn't help complete tasks. Group was constantly covering for group members or not encouraging them to participate. Most members presented.	All group members worked on their own assignments. No one did more work than anyone else. Some communication was evident, but the group mostly worked separately. All members presented.	All group members worked on their assignments, but also collaborated frequently. Clear connection and communication between the group members was evident. All members presented.	____/4
				Total points:	**____/20**

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Activity 12.2: Analysis of Toxicity Considerations (15% of final grade)

Assessment area	Needs improvement (1)	Below expectations (2)	Meets expectations (3)	Exceeds expectations (4)	Points
Incident consideration Did the group accurately identify decision-making related to the potential hazards based on analysis of the information given?	The group failed to identify potential hazards affecting decision-making.	The group analyzed the scenario and the product involved, did not provide accurate technical data, identified most hazards correctly, but did not provide appropriate decisions.	The group analyzed the scenario and the product involved, presented accurate technical data, and accurately identified all hazards present at the scene described in their scenario, but were unable to defend their rationale for their decision-making.	The group analyzed the scenario and the product involved, estimated the potential hazards accurately, and made sound decisions related to the incident considerations for the severity of the hazards.	____/4 x2 = ____/8
Presentation Did the group present a clear, concise and accurate summary of hazard analysis information appropriate to their audience? Could group members answer questions posed by their audience regarding the chemicals and their hazards clearly and concisely?	Presentation was not clear. Information was not well organized. Group members were unable to answer questions.	Information was somewhat organized, but contained some inaccuracies, exaggerations or excessive technical jargon, making details of the presentation inaccessible to their audience. Group members were able to answer some questions when asked by instructors or other students.	Information was very well organized and mostly clear, concise and accurate. Group members were able to answer most questions posed by instructors and other students.	Information was exceptionally well organized, clear, concise and accurate. Group members were able to answer all questions posed by instructors and other students.	____/4 x2 = ____/8
Group collaboration Did group members contribute equally? Did group members effectively collaborate to achieve group objectives?	One or two members of the group did all the work. Some refused to participate or were not allowed to help.	One or two members of the group didn't help complete tasks. Group was constantly covering for group members or not encouraging them to participate. Most members presented.	All group members worked on their own assignments. No one did more work than anyone else. Some communication was evident, but the group mostly worked separately. All members presented.	All group members worked on their assignments, but also collaborated frequently. Clear connection and communication between the group members was evident. All members presented.	____/4
				Total points:	**____/20**

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Activity 13.2: Hazard Analysis Briefing to Hazardous Materials Leadership (20% of final grade)

Assessment area	Needs improvement (1)	Below expectations (2)	Meets expectations (3)	Exceeds expectations (4)	Points
Hazard analysis Did the group accurately identify and prioritize potential hazards based on analysis of the information given?	The group failed to identify two or more potential hazards.	The group analyzed the scenario and the chemicals involved, provided accurate technical data, and identified most hazards correctly.	The group analyzed the scenario and the chemicals involved, presented accurate technical data, and accurately identified all hazards present at the scene described in their scenario, but were unable to defend their rationale for prioritization of the relative severity of hazards.	The group analyzed the scenario and the chemicals involved, estimated the potential hazards accurately, and made sound decisions related to the prioritization of the severity of the hazards.	____/4 x2 = ____/8
Presentation Did the group present a clear, concise and accurate summary of hazard analysis information appropriate to their audience? Could group members answer questions posed by their audience regarding the chemicals and their hazards clearly and concisely?	Presentation was not clear. Information was not well organized. Group members were unable to answer questions.	Information was somewhat organized, but contained some inaccuracies, exaggerations or excessive technical jargon, making details of the presentation inaccessible to their audience. Group members were able to answer some questions when asked by instructors or other students.	Information was very well organized and mostly clear, concise and accurate. Group members were able to answer most questions posed by instructors and other students.	Information was exceptionally well organized, clear, concise and accurate. Group members were able to answer all questions posed by instructors and other students.	____/4 x2 = ____/8
Group collaboration Did group members contribute equally? Did group members effectively collaborate to achieve group objectives?	One or two members of the group did all the work. Some refused to participate or were not allowed to help.	One or two members of the group didn't help complete tasks. Group was constantly covering for group members or not encouraging them to participate. Most members presented.	All group members worked on their own assignments. No one did more work than anyone else. Some communication was evident, but the group mostly worked separately. All members presented.	All group members worked on their assignments, but also collaborated frequently. Clear connection and communication between the group members was evident. All members presented.	____/4
				Total points:	**____/20**

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SCHEDULE

TIME	DAY 1	TIME	DAY 2
8:00 – 9:15	Introduction, Welcome and Administrative	8:00 – 9:05	Day 1 review Learning Checkpoints (Unit 1 and 2)
9:15 – 9:25	*Break*	9:05 – 9:15	*Break*
9:25 – 10:15	Introduction (cont'd) Unit 1: Product Hazard Analysis and Risk-Based Response Activity 1.1, Part 1: Essential Terms Activity 1.1, Part 2: Physical and Chemical Properties	9:15 – 10:35	Unit 3: Salts (cont'd) Activity 3.3: Hydroxide, Peroxide and Cyanide Salts Activity 3.4: Oxysalts
10:15 – 10:25	*Break*	10:35 – 10:45	*Break*
10:25 – 11:45	Unit 1: Product Hazard Analysis and Risk-Based Response (cont'd) Unit 2: The Periodic Table and Atomic Structure	10:45 – 11:55	Unit 3: Salts (cont'd) Activity 3.5: Identifying Salts and Their Hazards Activity 3.6: Analyzing Salt Hazards
11:50 – 12:50	*Lunch Break*	11:55 – 12:55	*Lunch Break*
12:50 – 1:15	Unit 2: The Periodic Table and Atomic Structure (cont'd)	12:55 – 1:30	Unit 3: Salts (cont'd) Activity 3.6: Analyzing Salt Hazards (cont'd)
1:15 – 1:25	*Break*	1:30 – 1:40	*Break*
1:25 – 3:10	Unit 2: The Periodic Table and Atomic Structure (cont'd) Activity 2.1: The 40 Common Elements Unit 3: Salts Activity 3.1: Getting to Know the Salts	1:40 – 3:15	Unit 4: Inorganic Nonsalts Activity 4.1: Getting to Know the Inorganic Nonsalts
3:10 – 3:20	*Break*	3:15 – 3:25	*Break*
3:20 – 4:45	Unit 3: Salts (cont'd) Activity 3.2: Binary Salts	3:25 – 4:45	Unit 4: Inorganic Nonsalts (cont'd) Activity 4.2: Hazards of Inorganic Nonsalts
4:45 – 4:55	Wrap-up/parking lot review	4:45 – 4:55	Wrap-up/parking lot review
Evening	Orientation to Chemical Reference Databases. Complete Activity 2.1 and any worksheets not completed in class.	Evening	Complete worksheets not completed in class. Complete chemical family summary worksheets (optional).

Note: This schedule is subject to modification by the instructors and approved by the training specialist.

TIME	DAY 3	TIME	DAY 4
8:00 – 9:45	Day 2 review Learning Checkpoint (Unit 3) Unit 4: Inorganic Nonsalts (cont'd) Activity 4.3: Identifying Inorganic Nonsalts and Their Hazards	8:00 – 10:00	Day 3 review Learning Checkpoints (Unit 4 and 5) Unit 6: Hydrocarbon Derivatives (cont'd) Activity 6.1: Functional Group Recognition Activity 6.2: Halogenated Hydrocarbons
9:50 – 10:00	*Break*	10:00 – 10:15	*Break*
10:00 – 11:55	Unit 5: Hydrocarbons and Hydrocarbon Radicals Activity 5.1: Getting to Know the Hydrocarbons	10:15 – 11:55	Unit 6: Hydrocarbon Derivatives (cont'd) Activity 6.3: Nitrogen Compounds
11:55 – 12:55	*Lunch Break*	11:55 – 12:55	*Lunch Break*
12:55 – 2:25	Unit 5: Hydrocarbons and Hydrocarbon Radicals (cont'd) Activity 5.2: Review of Hydrocarbon Families Activity 5.3: Hydrocarbon Radicals and International Union of Pure and Applied Chemistry Naming	12:55 – 2:25	Unit 6: Hydrocarbon Derivatives (cont'd) Activity 6.4: Oxygen-Based Compounds and Sulfur Compounds
2:25 – 2:35	*Break*	2:25 – 2:35	*Break*
2:35 – 4:10	Activity 5.4: Analyzing Hydrocarbon Hazards Unit 5: Hydrocarbons and Hydrocarbon Radicals (cont'd)	2:35 – 3:50	Unit 6: Hydrocarbon Derivatives (cont'd) Activity 6.5: Alcohols, Ketones, Aldehydes, Organic Acids and Esters
4:10 – 4:20	*Break*	3:50 – 4:00	*Break*
4:20 – 4:45	Unit 6: Hydrocarbon Derivatives	4:00 – 4:40	Unit 6: Hydrocarbon Derivatives (cont'd) Activity 6.6: All Hydrocarbon Derivative Families Activity 6.7: Product Hazard Analysis
4:45 – 4:55	Wrap-up/parking lot review	4:40 – 4:50	Wrap-up/parking lot review
Evening	Complete worksheets not completed in class. Complete chemical family summary worksheets (optional).	Evening	Complete Activity 6.6 and any worksheets not completed in class. Complete chemical family summary worksheets (optional).

TIME	DAY 5	TIME	DAY 6
8:00 – 9:50	Day 4 review Unit 6: Hydrocarbon Derivatives (cont'd) Activity 6.7: Product Hazard Analysis (cont'd) Activity 6.8: Hydrocarbon Derivative Incident Scenarios	8:00 – 9:00	Week 1 review
9:50 – 10:05	*Break*	9:00 – 9:10	*Break*
10:05 – 11:40	Unit 6: Hydrocarbon Derivatives (cont'd) Activity 6.8: Hydrocarbon Derivative Incident Scenarios (cont'd)	9:10 – 10:10	Midterm Exam
11:40 – 12:40	*Lunch Break*	10:10 – 10:20	*Break*
12:40 – 2:05	Learning Checkpoint (Unit 6) Unit 7: Gases Activity 7.1: Gases Terminology	10:20 – 11:35	Unit 8: Flammability and Combustion
2:05 – 2:20	*Break*	11:35 – 12:35	*Lunch Break*
2:20 – 4:00	Unit 7: Gases (cont'd) Activity 7.2: Determining Control Zones and Personal Protective Equipment Learning Checkpoint (Unit 7)	12:35 – 1:45	Unit 8: Flammability and Combustion (cont'd) Activity 8.1: Variables Affecting Flammability
4:00 – 4:10	Wrap-up/parking lot review	1:45 – 2:00	*Break*
Evening	Complete worksheets not completed in class. Complete chemical family summary worksheets (optional).	2:00 – 4:50	Unit 8: Flammability and Combustion (cont'd) Activity 8.2: Effect of Size, Polarity and Shape on Physical and Chemical Properties Unit 9: Radioactivity
		4:50 – 5:00	Wrap-up/parking lot review
		Evening	Complete worksheets not completed in class.

TIME	DAY 7	TIME	DAY 8
8:00 – 9:45	Day 6 review Learning Checkpoint (Unit 8) Unit 9: Radioactivity (cont'd) Activity 9.1: Radioactive Isotopes	8:00 – 9:25	Day 7 review Learning Checkpoints (Unit 9, 10 and 11) Unit 12: Toxicity and Chemical Agents (cont'd)
9:45 – 10:00	*Break*	9:25 – 9:30	*Break*
10:00 – 11:45	Unit 9: Radioactivity (cont'd) Unit 10: Corrosives Activity 10.1: Corrosives Definitions	9:20 – 10:10	Unit 12: Toxicity and Chemical Agents (cont'd)
11:45 – 12:45	*Lunch Break*	10:10 – 10:20	*Break*
12:45 – 2:00	Unit 10: Corrosives Activity 10.2: Corrosive Product Analysis and Neutralization Calculations	10:20 – 11:25	Unit 12: Toxicity and Chemical Agents (cont'd) Activity 12.2: Analysis of Toxicity Considerations
2:00 – 2:10	*Break*	11:25 – 12:25	*Lunch Break*
2:10 – 3:50	Unit 11: Oxidizers and Reactive Materials Activity 11.1: Analyzing Hazards of Oxidizers and Reactive Materials	12:25 – 2:10	Unit 13: Comprehensive Hazard Analysis Activity 13.1: The 50 Chemical Activity
3:50 – 4:00	*Break*	2:10 – 2:20	*Break*
4:00 – 4:55	Unit 12: Toxicity and Chemical Agents Activity 12.1: Toxicity Terminology	2:20 – 4:00	Unit 13: Comprehensive Hazard Analysis (cont'd) Activity 13.1: The 50 Chemical Activity (cont'd)
4:55 – 5:05	Wrap-up/parking lot review	4:00 – 4:10	*Break*
Evening	Complete worksheets not completed in class.	4:10 – 4:50	Activity 13.2: Hazard Analysis Briefing to Hazardous Materials Leadership
		4:50 – 5:00	Wrap-up/parking lot review
		Evening	Complete worksheets if not completed in class. Group Work on Activity 13.2 Study for Final Exam

TIME	DAY 9
8:00 – 8:50	Day 8 review Learning Checkpoint (Unit 12)
8:50 – 9:05	*Break*
9:05 – 11:35	Unit 13: Comprehensive Hazard Analysis (cont'd) Activity 13.2: Hazard Analysis Briefing to Hazardous Materials Leadership (cont'd)
11:35 – 12:35	*Lunch Break*
12:35 – 1:50	Unit 13: Comprehensive Hazard Analysis (cont'd) Activity 13.2: Hazard Analysis Briefing to Hazardous Materials Leadership (cont'd)
1:50 – 2:05	*Break*
2:05 – 3:20	Final Exam End of course/certificates

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FIREFIGHTER CODE OF ETHICS

Background

The Fire Service is a noble calling, one which is founded on mutual respect and trust between firefighters and the citizens they serve. To ensure the continuing integrity of the Fire Service, the highest standards of ethical conduct must be maintained at all times.

Developed in response to the publication of the Fire Service Reputation Management White Paper, the purpose of this National Firefighter Code of Ethics is to establish criteria that encourages fire service personnel to promote a culture of ethical integrity and high standards of professionalism in our field. The broad scope of this recommended Code of Ethics is intended to mitigate and negate situations that may result in embarrassment and waning of public support for what has historically been a highly respected profession.

Ethics comes from the Greek word ethos, meaning character. Character is not necessarily defined by how a person behaves when conditions are optimal and life is good. It is easy to take the high road when the path is paved and obstacles are few or non-existent. Character is also defined by decisions made under pressure, when no one is looking, when the road contains land mines, and the way is obscured. As members of the Fire Service, we share a responsibility to project an ethical character of professionalism, integrity, compassion, loyalty and honesty in all that we do, all of the time.

We need to accept this ethics challenge and be truly willing to maintain a culture that is consistent with the expectations outlined in this document. By doing so, we can create a legacy that validates and sustains the distinguished Fire Service institution, and at the same time ensure that we leave the Fire Service in better condition than when we arrived.

FIREFIGHTER CODE OF ETHICS

I understand that I have the responsibility to conduct myself in a manner that reflects proper ethical behavior and integrity. In so doing, I will help foster a continuing positive public perception of the fire service. Therefore, I pledge the following…

- Always conduct myself, on and off duty, in a manner that reflects positively on myself, my department and the fire service in general.
- Accept responsibility for my actions and for the consequences of my actions.
- Support the concept of fairness and the value of diverse thoughts and opinions.
- Avoid situations that would adversely affect the credibility or public perception of the fire service profession.
- Be truthful and honest at all times and report instances of cheating or other dishonest acts that compromise the integrity of the fire service.
- Conduct my personal affairs in a manner that does not improperly influence the performance of my duties, or bring discredit to my organization.
- Be respectful and conscious of each member's safety and welfare.
- Recognize that I serve in a position of public trust that requires stewardship in the honest and efficient use of publicly owned resources, including uniforms, facilities, vehicles and equipment and that these are protected from misuse and theft.
- Exercise professionalism, competence, respect and loyalty in the performance of my duties and use information, confidential or otherwise, gained by virtue of my position, only to benefit those I am entrusted to serve.
- Avoid financial investments, outside employment, outside business interests or activities that conflict with or are enhanced by my official position or have the potential to create the perception of impropriety.
- Never propose or accept personal rewards, special privileges, benefits, advancement, honors or gifts that may create a conflict of interest, or the appearance thereof.
- Never engage in activities involving alcohol or other substance use or abuse that can impair my mental state or the performance of my duties and compromise safety.
- Never discriminate on the basis of race, religion, color, creed, age, marital status, national origin, ancestry, gender, sexual preference, medical condition or handicap.
- Never harass, intimidate or threaten fellow members of the service or the public and stop or report the actions of other firefighters who engage in such behaviors.
- Responsibly use social networking, electronic communications, or other media technology opportunities in a manner that does not discredit, dishonor or embarrass my organization, the fire service and the public. I also understand that failure to resolve or report inappropriate use of this media equates to condoning this behavior.

Developed by the National Society of Executive Fire Officers

A Student Guide to End-of-course Evaluations

Say What You Mean ...

Ten Things You Can Do to Improve the National Fire Academy

The National Fire Academy takes its course evaluations very seriously. Your comments and suggestions enable us to improve your learning experience.

Unfortunately, we often get end-of-course comments like these that are vague and, therefore, not actionable. We know you are trying to keep your answers short, but the more specific you can be, the better we can respond.

Actual quotes from student evaluations:	Examples of specific, actionable comments that would help us improve the course:
1 "Update the materials."	• The (ABC) fire video is out-of-date because of the dangerous tactics it demonstrates. The available (XYZ) video shows current practices. • The student manual references building codes that are 12 years old.
2 "We want an advanced class in (fill in the blank)."	• We would like a class that enables us to calculate energy transfer rates resulting from exposure fires. • We would like a class that provides one-on-one workplace harassment counseling practice exercises.
3 "More activities."	• An activity where students can physically measure the area of sprinkler coverage would improve understanding of the concept. • Not all students were able to fill all ICS positions in the exercises. Add more exercises so all students can participate.
4 "A longer course."	• The class should be increased by one hour per day to enable all students to participate in exercises. • The class should be increased by two days so that all group presentations can be peer evaluated and have written abstracts.
5 "Readable plans."	• The plans should be enlarged to 11 by 17 and provided with an accurate scale. • My plan set was blurry, which caused the dotted lines to be interpreted as solid lines.
6 "Better student guide organization," "manual did not coincide with slides."	• The slide sequence in Unit 4 did not align with the content in the student manual from slides 4-16 through 4-21. • The instructor added slides in Unit 4 that were not in my student manual.
7 "Dry in spots."	• The instructor/activity should have used student group activities rather than lecture to explain Maslow's Hierarchy. • Create a pre-course reading on symbiotic personal relationships rather than trying to lecture on them in class.
8 "More visual aids."	• The text description of V-patterns did not provide three-dimensional views. More photographs or drawings would help me imagine the pattern. • There was a video clip on NBC News (date) that summarized the topic very well.
9 "Re-evaluate pre-course assignments."	• The pre-course assignments were not discussed or referenced in class. Either connect them to the course content or delete them. • The pre-course assignments on ICS could be reduced to a one-page job aid rather than a 25-page reading.
10 "A better understanding of NIMS."	• The instructor did not explain the connection between NIMS and ICS. • The student manual needs an illustrated guide to NIMS.

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UNIT 1:
PRODUCT HAZARD ANALYSIS AND RISK-BASED RESPONSE

TERMINAL OBJECTIVE

The students will be able to:

1.1 Conduct an initial product hazard analysis for multiple products with limited information.

ENABLING OBJECTIVES

The students will be able to:

1.1 Identify the importance of physical and chemical terminology to the product hazard analysis.

1.2 Define risk-based response (RBR), as defined by National Fire Protection Association (NFPA) 470, Hazardous Materials/Weapons of Mass Destruction (WMD) Standard for Responders.

1.3 Define the four considerations in an RBR.

1.4 Describe the six evaluation points used to conduct an initial product hazard analysis.

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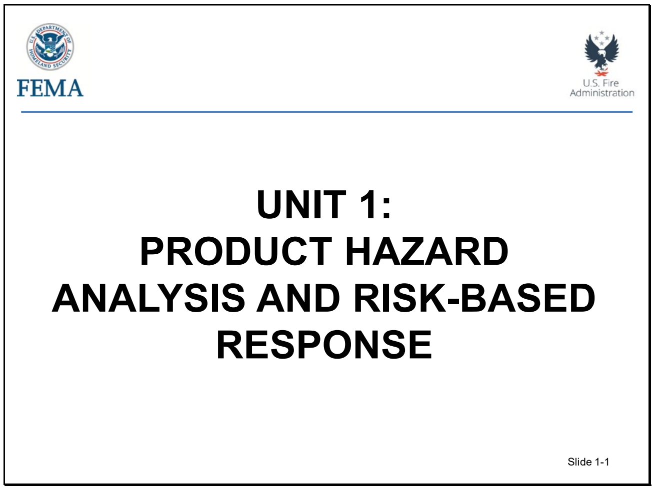
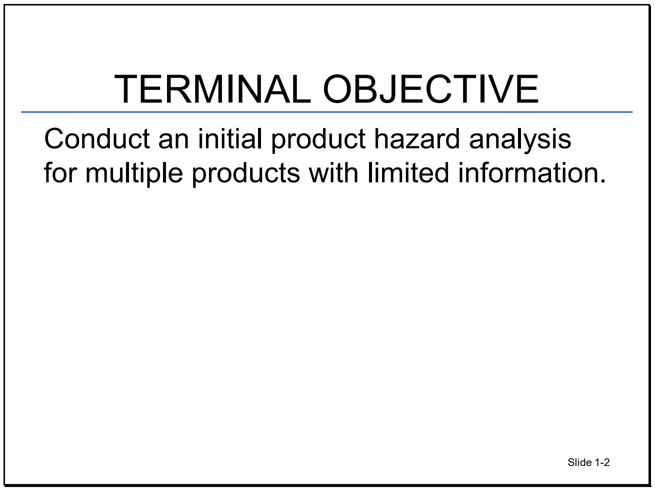


FEMA

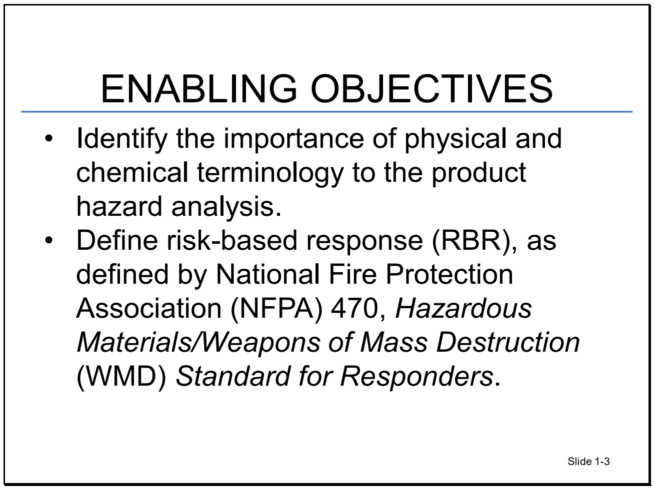
U.S. Fire Administration

UNIT 1:
PRODUCT HAZARD ANALYSIS AND RISK-BASED RESPONSE



TERMINAL OBJECTIVE

Conduct an initial product hazard analysis for multiple products with limited information.



ENABLING OBJECTIVES

- Identify the importance of physical and chemical terminology to the product hazard analysis.
- Define risk-based response (RBR), as defined by National Fire Protection Association (NFPA) 470, *Hazardous Materials/Weapons of Mass Destruction* (WMD) *Standard for Responders*.

ENABLING OBJECTIVES (cont'd)

- Define the four considerations in an RBR.
- Describe the six evaluation points used to conduct an initial product hazard analysis.

I. INTRODUCTION

What do you know about methyl isocyanate?

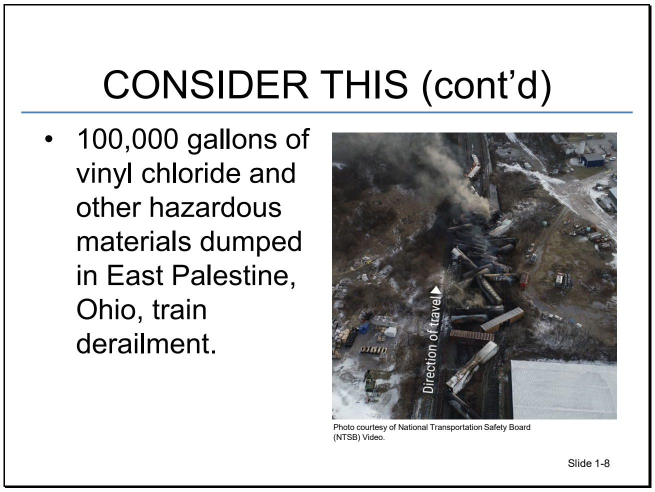
CONSIDER THIS

- 40+ tons of methyl isocyanate gas released over Bhopal, India.
- 3,800+ immediate deaths.
- 500,000+ exposed.

Photo courtesy of CSB Video.

A. Case study information: https://www.csb.gov/on-30th-anniversary-of-fatal-chemical-release-that-killed-thousands-in-bhopal-india-csb-safety-message-warns-it-could-happen-again-/.

What does vinyl chloride mean to you?



CONSIDER THIS (cont'd)

- 100,000 gallons of vinyl chloride and other hazardous materials dumped in East Palestine, Ohio, train derailment.

Photo courtesy of National Transportation Safety Board (NTSB) Video.

B. Case study information: https://www.ntsb.gov/investigations/Pages/RRD23MR005.aspx.

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ACTIVITY 1.1, Part 1

Essential Terms

Purpose

Identify the importance of physical and chemical terminology to the product hazard analysis.

Directions

1. Take five minutes to work independently to identify what you believe to be the five most important terms that must be evaluated when analyzing the hazards of a product.
2. Then, in your group, work together to arrive at a consensus of the five terms from the list that you agree to as the most important. Rank them from one to five in order of importance (with one being the most important).
3. Provide definitions for each of the five terms.
4. Justify why your group chose your five terms and the order you put them in.
5. Record your findings on an easel pad and select a representative to present your group's findings.

List of terms:

- Biological agents and toxins.
  - Bacteria.
  - Viruses.
- Carcinogen.
- Corrosivity.
  - Acid.
  - Base.
  - Concentration.
  - pH scale.
  - Strength.
- Expansion ratio.
  - Liquefied gases.
  - Cryogenics.
- Flammability.
  - Boiling point.
  - Flammable range.
  - Flash point.
  - Ignition (autoignition) temperature.
  - Lower explosive limit (LEL).
  - Upper explosive limit (UEL).
- Persistence.
- Physical state.
  - Solid.
  - Liquid.
  - Gas.
- Poison.
- Products of combustion (toxic).
- Reactivity.
  - Air.
  - Chemical.
  - Energetic.
  - Oxidizers.
  - Polymerization.
  - Water.
- Radiation (ionizing and nonionizing).
- Routes of exposure.
- Specific gravity.
- Vapor density.
- Vapor pressure.
- Toxicity.

ACTIVITY 1.1, Part 2

Physical and Chemical Properties

Purpose

Identify the importance of physical and chemical properties to the product hazard analysis.

Directions

1. Discuss the following questions with your group, referring to the data you found in your product hazard analysis activities from the pre-course.

   List of products researched in the pre-course:

   - Acrolein.
   - Acetic acid (glacial).
   - Malathion.
   - Acetone.
   - Methyl chloride.
   - Cesium 137.
   - Polonium 210.
   - Technetium 99.
   - Potassium 40.
   - Americium 241.

2. Of the chemicals you researched:

   a. Which is the most flammable?

   b. Which has the greatest toxicity risk?

   c. Which has the greatest corrosivity risk?

   d. Which has the greatest reactivity/explosive risk?

   e. Which has the greatest radioactivity risk?

   f. Which data point(s) do you find to be the most important? Why?

   g. Assuming that a release of the product occurred within a structure, what type of personal protection would you select and why?

3. Record your findings on an easel pad and select a representative to present your group's findings.

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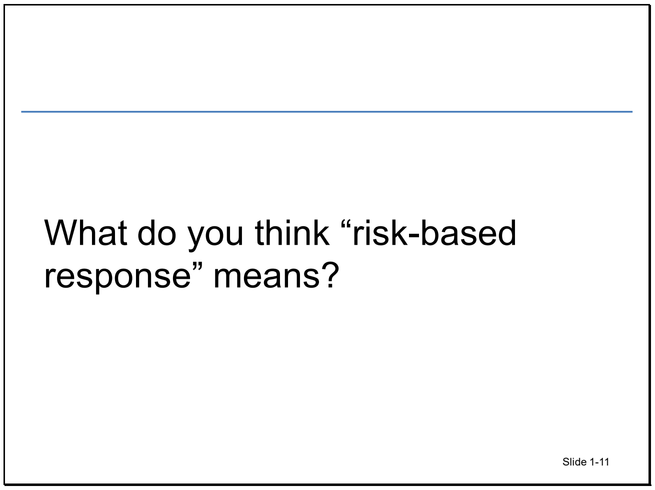
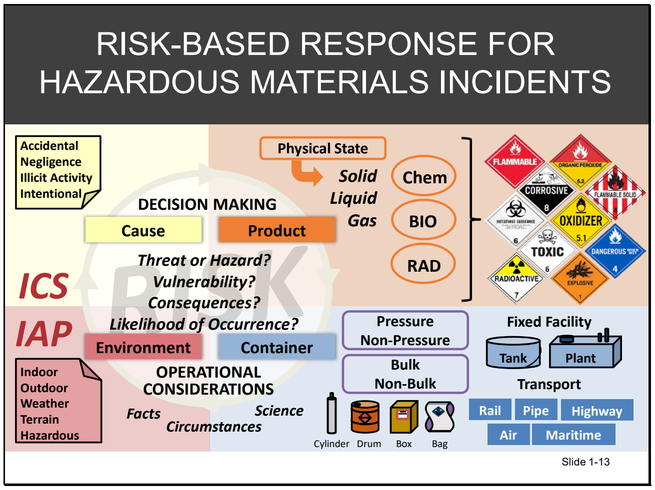
II. RISK-BASED RESPONSE



What do you think “risk-based response” means?

A. Definition: A systematic process, based on the facts, science, and circumstances of the incident, by which responders analyze a problem involving hazardous materials/weapons of mass destruction (WMD) to assess the hazards and consequences, develop an Incident Action Plan (IAP), and evaluate the effectiveness of the plan (NFPA 470, 2022, 3.3.75).

B. The risk-based response (RBR) process.



RISK-BASED RESPONSE FOR HAZARDOUS MATERIALS INCIDENTS

1. Responders must consider:

   a. Product: Consider the hazards created by either the physical or chemical characteristics of the material(s) involved. Is it a solid, liquid or gas? What are its chemical, biological or radiological hazards?

b. Container: Consider characteristics such as internal pressures, types of construction and types of damage incurred. Is it pressurized or non-pressurized? Bulk or non-bulk? What type of container (cylinder, drum, box, bag)? Fixed facility or transport? What method of transport (rail, pipe, highway, air, maritime)?

c. Environment: Consider the physical surroundings of the product and container. Is it indoor or outdoor? What are the weather conditions? What is the terrain like? Is it a hazardous environment?

d. Cause: Consider whether the incident was accidental, intentional, or caused by negligence or illicit activity.

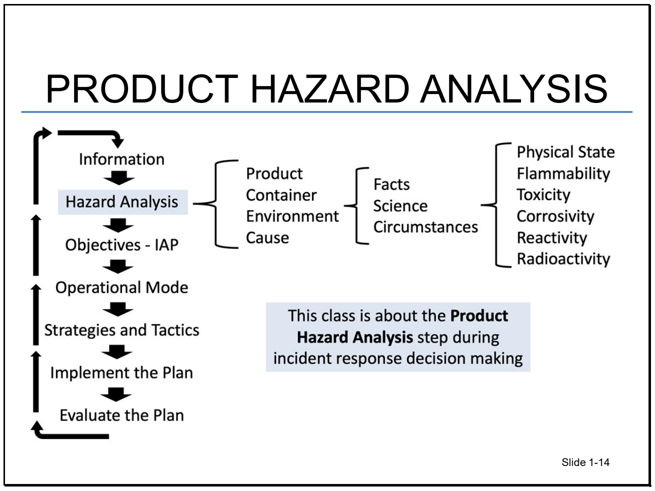
2. Notes about the RBR process:

a. It is not procedural or linear.

b. It is a continual process.

c. Analysis is based on:

- Facts: things that are known or proven to be true.
- Science: a systematically organized body of knowledge on a subject.
- Circumstances: conditions connected with or relevant to an event or action.



PRODUCT HAZARD ANALYSIS

Information
Hazard Analysis
Objectives - IAP
Operational Mode
Strategies and Tactics
Implement the Plan
Evaluate the Plan

Product
Container
Environment
Cause

Facts
Science
Circumstances

Physical State
Flammability
Toxicity
Corrosivity
Reactivity
Radioactivity

This class is about the **Product Hazard Analysis** step during incident response decision making

C. Product hazard analysis (evaluation points).

1. Physical state.

2. Flammability.

3. Toxicity.

4. Corrosivity.

5. Reactivity.

6. Radioactivity.

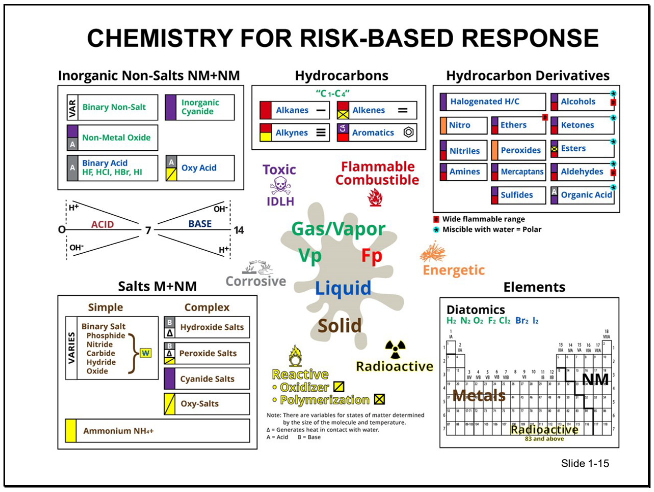
D. Initial product analysis.

1. Determination of primary hazards.

2. Evaluation of safety actions already taken.

3. Timely evaluation of personal protective measures.

4. Guidance until more definitive information can be obtained and analyzed.

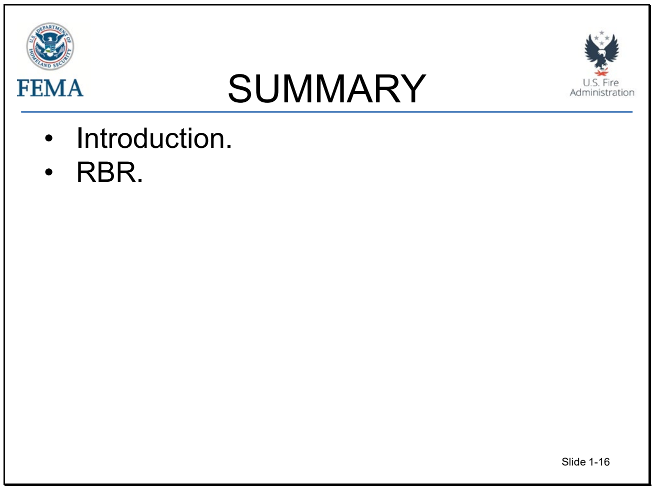


CHEMISTRY FOR RISK-BASED RESPONSE

Note: There are variables for states of matter determined by the size of the molecule and temperature.
Δ = Generates heat in contact with water.
A = Acid B = Base

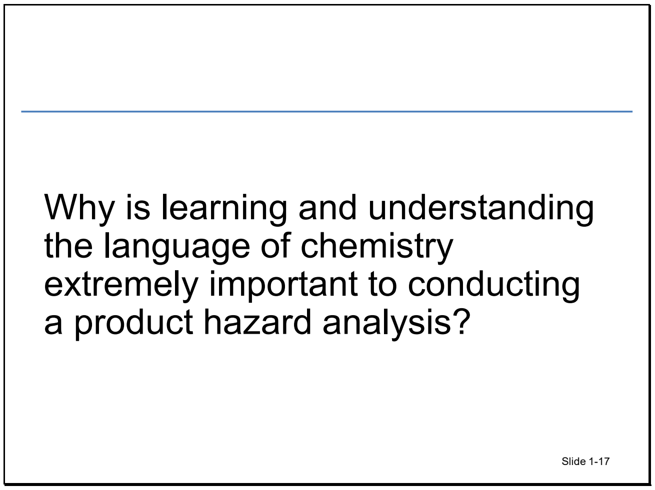
E. Chemistry for Risk-Based Response infographic.

III. SUMMARY

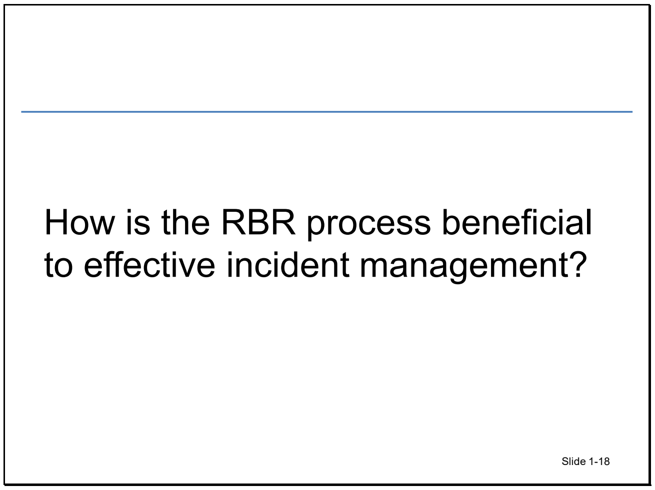


SUMMARY

- Introduction.
- RBR.



Why is learning and understanding the language of chemistry extremely important to conducting a product hazard analysis?



How is the RBR process beneficial to effective incident management?

REFERENCE

National Fire Protection Association. (2022). *Hazardous materials/weapons of mass destruction (WMD) standard for responders* [Standard no. 470]. www.nfpa.org

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UNIT 2: THE PERIODIC TABLE AND ATOMIC STRUCTURE

TERMINAL OBJECTIVE

The students will be able to:

2.1 Use the periodic table to identify elements that may be encountered in incident response.

ENABLING OBJECTIVES

The students will be able to:

2.1 Identify the element, symbol, family, parts, location, charges and weights of an atom.

2.2 Define an isotope.

2.3 Identify the impact of the Duet and Octet rules.

2.4 Identify the two types of bonding.

2.5 Identify the general characteristics of salts and nonsalts.

2.6 Identify potential hazards of selected elements on the periodic table.

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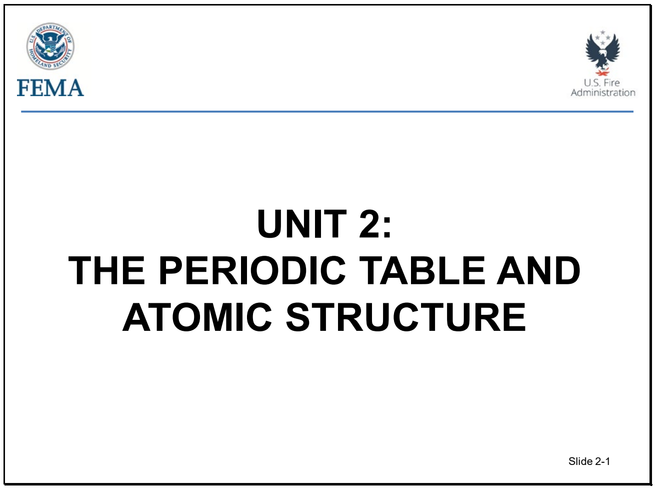
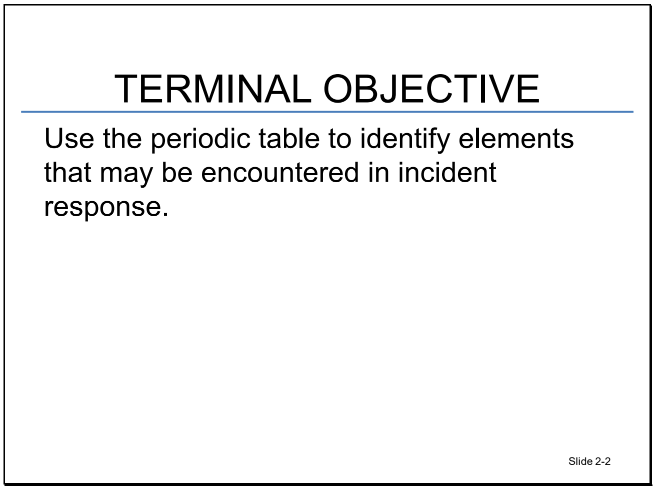


FEMA

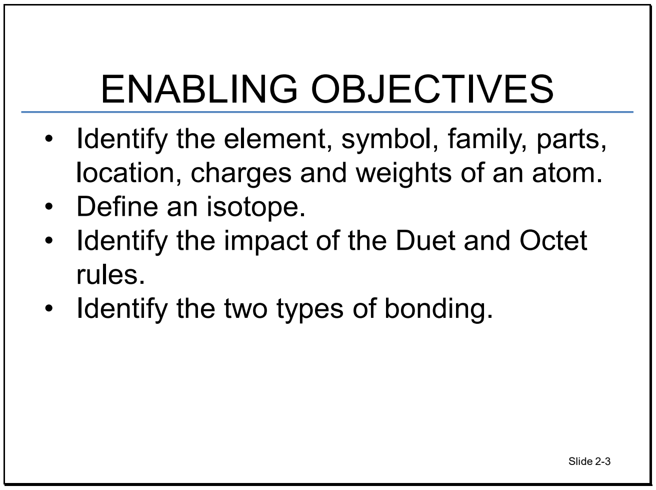
U.S. Fire Administration

UNIT 2:
THE PERIODIC TABLE AND ATOMIC STRUCTURE



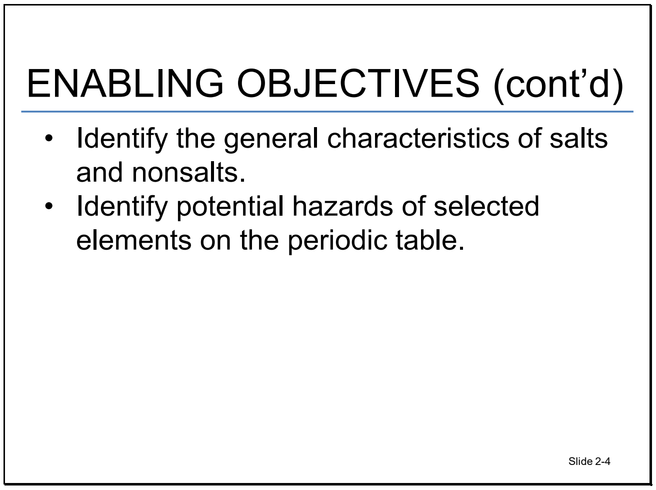
TERMINAL OBJECTIVE

Use the periodic table to identify elements that may be encountered in incident response.



ENABLING OBJECTIVES

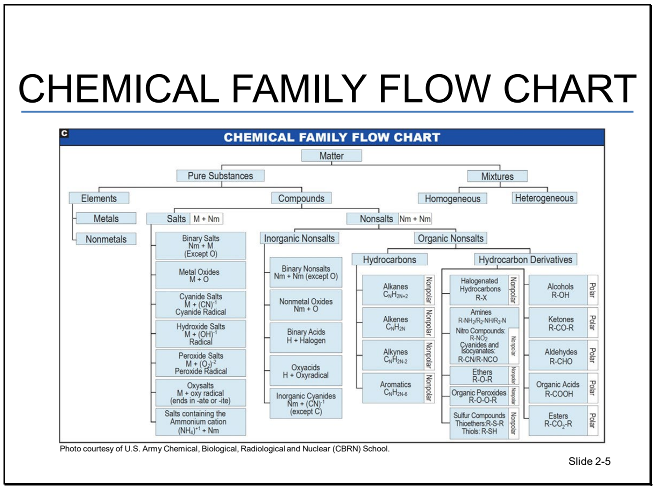
- Identify the element, symbol, family, parts, location, charges and weights of an atom.
- Define an isotope.
- Identify the impact of the Duet and Octet rules.
- Identify the two types of bonding.



ENABLING OBJECTIVES (cont'd)

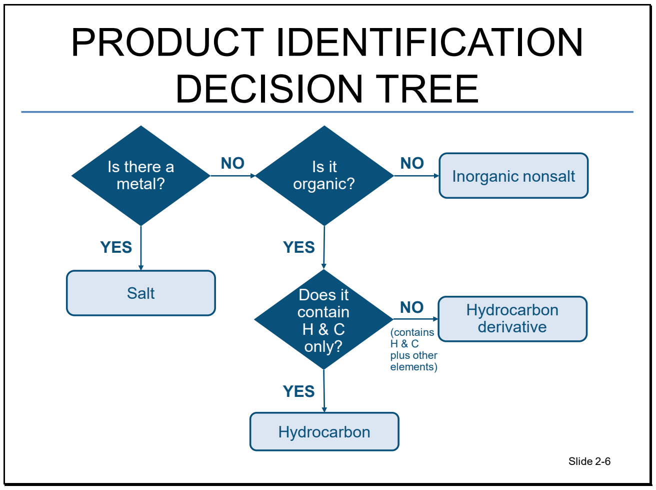
- Identify the general characteristics of salts and nonsalts.
- Identify potential hazards of selected elements on the periodic table.

I. INTRODUCTION



CHEMICAL FAMILY FLOW CHART

Photo courtesy of U.S. Army Chemical, Biological, Radiological and Nuclear (CBRN) School.



PRODUCT IDENTIFICATION DECISION TREE

A. Chemical Family Flow Chart.

1. Chemistry is the science of matter, energy and reactions.

2. Matter:

   a. Is anything that has mass and occupies space.

   b. May be solid, liquid or gas.

   c. May be pure substances or mixtures.

3. Pure substances.

   a. Elements:

      - Are materials that cannot be broken down into any simpler form and still retain the properties of that element.

      - Are arranged on the periodic table according to atomic number.

      - Are organized into families because of the repetition of certain common properties among the elements.

   b. Compounds are two or more elements bound together.

4. Mixtures may be mixtures of compounds, mixtures of compounds and elements, or mixtures of elements that are not joined chemically.

   a. Homogeneous mixtures:

      - Are relatively uniform in composition.

      - Are made up of compounds that mix.

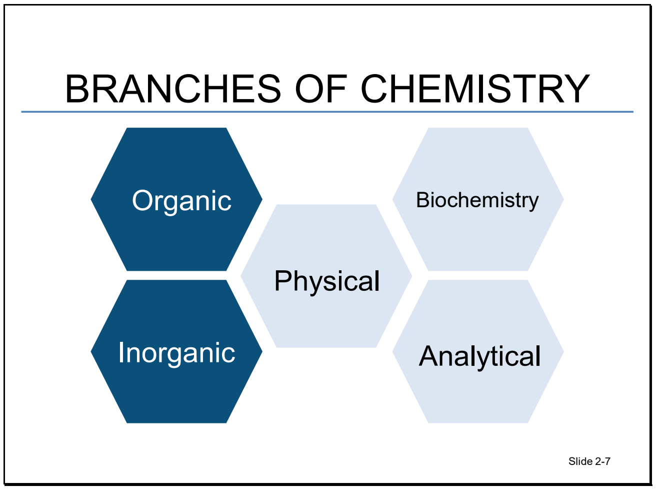
      - Example: Air is a uniform mixture of oxygen, nitrogen and trace elements.

   b. Heterogeneous mixtures:

      - Are mixtures of two or more substances, regardless of whether they are uniformly dispersed.

      - Are made up of compounds that do not mix.

- Example: Street fentanyl may have different strengths in different packages from the same batch, depending on how well the batch was mixed during the cutting process.



BRANCHES OF CHEMISTRY

Organic

Inorganic

Physical

Biochemistry

Analytical

Slide 2-7

B. Branches of chemistry.

1. Inorganic chemistry:

   a. Is the study of all compounds except hydrocarbons and their derivatives.

   b. Generally involves compounds that are not derived from hydrocarbons.

      - Some carbon compounds are studied in inorganic chemistry (e.g., CO_2 and HCN).

      - An example is hydrogen sulfide (H_2S), which contains only hydrogen and sulfur.

2. Organic chemistry:

   a. The study of compounds formed by hydrogen and the elements found in the upper right corner of the periodic table.

   b. Predominantly hydrogen and carbon; however, other elements can be in combination with them.

   c. Sometimes referred to as the hydrocarbons or chemistry of the hydrocarbons.

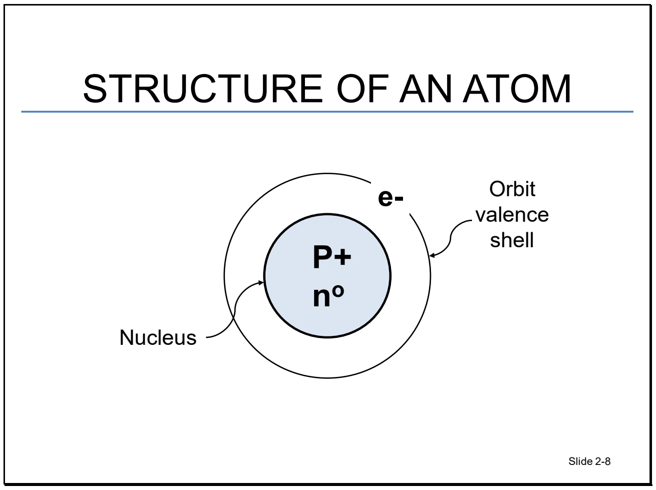
3. The other three branches (which we will not be studying) are:

    a. Analytical chemistry: the study of composition and structures of substances.

    b. Physical chemistry: the study of physical and chemical properties.

    c. Biochemistry: the study of chemical processes on living organisms.

II. INTRODUCTION TO ATOMIC STRUCTURES



STRUCTURE OF AN ATOM

Slide 2-8

A. The atom.

1. The atom is the smallest constituent of the element. It cannot be broken down further and still retain the properties of that element.

2. All elements are composed of atoms, and all matter consists of atoms.

3. The atom consists of:

    a. Protons (positive charge).

    b. Neutrons (no charge).

    c. Electrons (negative charge).

4. Protons and neutrons form the center of the atom, known as the nucleus.

5. The mass of the atom, or the atomic mass, is the combination of protons and neutrons in the nucleus. This is expressed in atomic mass units (AMU).

6. All atoms on the periodic table are electrically neutral because the positive charges of the protons and the negative charges of the electrons are balanced. When an atom loses or gains electrons, the charges are out of balance and it becomes a charged particle, known as an ion.

7. When an atom loses or gains a proton, it becomes a new element with a new number of protons.

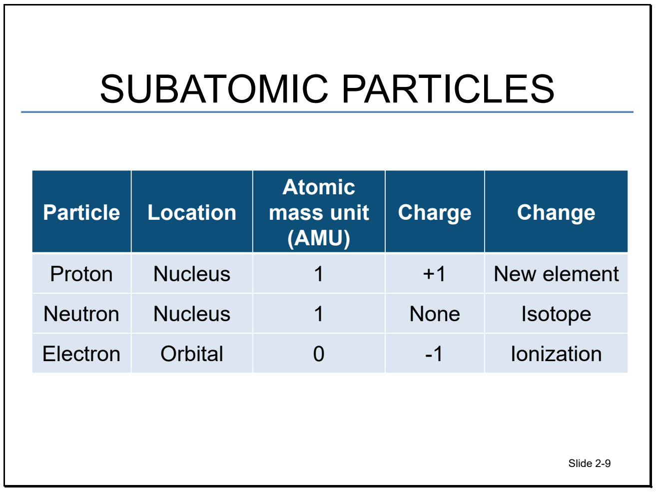
8. When an atom loses or gains a neutron, only the AMU changes, and it becomes an isotope of the element.

    a. An **isotope** is a form of an element with the same atomic number but a different atomic mass than its most common form.

    b. The most common form of an atom is that which is represented on the periodic table.

    c. The number of neutrons in the nucleus of an isotope varies from the number found in the most stable form of that element.

    d. The number of protons in any element will always be the same.



SUBATOMIC PARTICLES

Particle	Location	Atomic mass unit (AMU)	Charge	Change
Proton	Nucleus	1	+1	New element
Neutron	Nucleus	1	None	Isotope
Electron	Orbital	0	-1	Ionization

B. Parts of the atom.

1. Protons.

    a. Are found in the nucleus.

    b. Have an atomic mass of 1.

    c. Have an electrical charge of +1.

d. Always have the same number of protons within an atom of a given element.

e. A change in the number of protons creates a new element.

2. Neutrons.

a. Are found in the nucleus.

b. Have an atomic mass of 1.

c. Consist of a proton and an electron fused together, which cancels out both charges and becomes neutral.

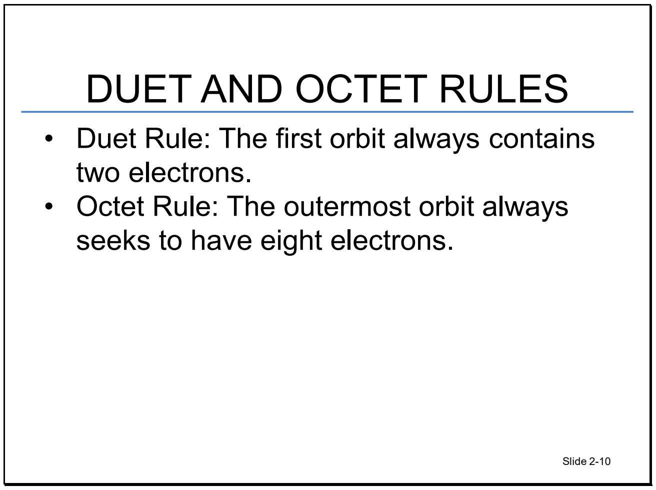
d. The number of neutrons within the nucleus of a given element may vary.

e. A change in the number of neutrons creates an isotope of that element.

f. Because the number of neutrons in an element can fluctuate, the atomic mass may fluctuate. AMUs are always expressed as a decimal instead of a whole number.

3. Electrons.

a. Are found in the orbit around a nucleus.



DUET AND OCTET RULES

- Duet Rule: The first orbit always contains two electrons.
- Octet Rule: The outermost orbit always seeks to have eight electrons.

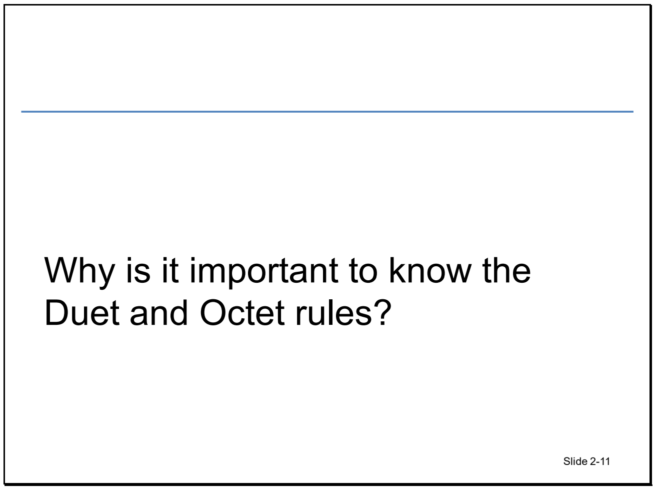
- The Duet Rule: The first orbit always contains two electrons.

- The Octet Rule: The outermost orbit always seeks to have eight electrons.

b. Have an electrical charge of -1.

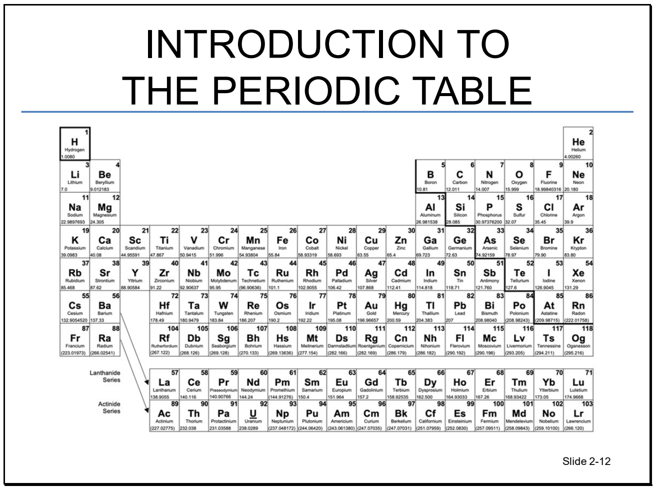
c. Have some mass, but for the purposes of this course, we will consider them to be without mass (1/1,840 of proton).

d. A change in the number of electrons creates ionization.



Why is it important to know the Duet and Octet rules?

III. INTRODUCTION TO THE PERIODIC TABLE



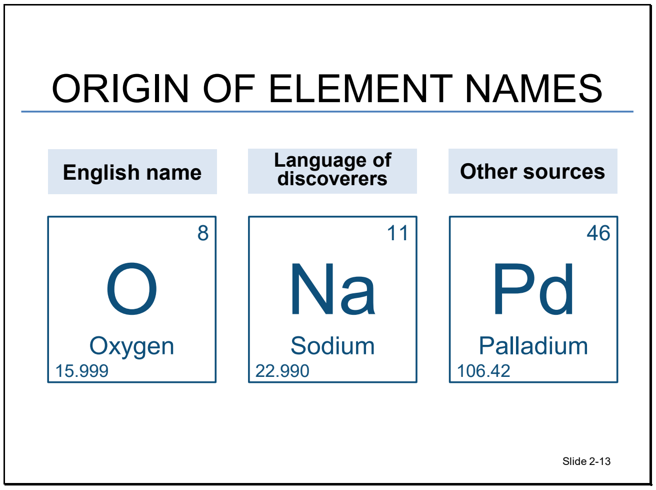
INTRODUCTION TO THE PERIODIC TABLE

A. Element symbols.

1. Each box represents an element.

2. Each element is represented with a symbol consisting of one or two letters.

3. If the symbol is only one letter, it will always be capitalized. If it is two letters, the first will be capitalized while the second remains lowercase.



ORIGIN OF ELEMENT NAMES

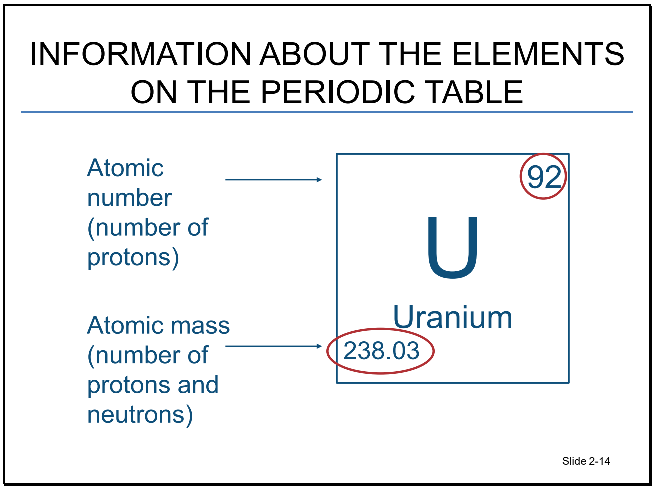
English name	Language of discoverers	Other sources
8 O Oxygen 15.999	11 Na Sodium 22.990	46 Pd Palladium 106.42

B. Origin of element names.

1. Many are taken from the English names.
   a. Oxygen: O.
   b. Hydrogen: H.
   c. Magnesium: Mg.
2. Names may be taken from the language or name of the discoverers.
   a. Sodium: Na (from the Latin word “natrium” for salt).
   b. Iron: Fe (from the Latin word “ferrum”).
   c. Iridium: Ir (from the Greek word “iris” for rainbow).
   d. Potassium: K (from the Latin word “kalium” for potash).
   e. Rhodium: Rh (from the Greek word “rhodon” for rose).
   f. Curium: Cm (named after Marie Curie).
   g. Einsteinium: Es (named after Albert Einstein).
3. Some names come from other sources.
   a. Palladium: Pd (from the asteroid Pallas).
   b. Americium: Am (named after the Americas).

c. Europium: Eu (named after Europe).

4. Approximately 40 elements are used frequently in this course.



INFORMATION ABOUT THE ELEMENTS ON THE PERIODIC TABLE

Atomic number (number of protons)

Atomic mass (number of protons and neutrons)

Slide 2-14

C. Information about the elements on the periodic table.

1. Atomic number.

a. The atomic number is the number of protons in the nucleus, which is equal to the number of electrons in orbit around the nucleus.

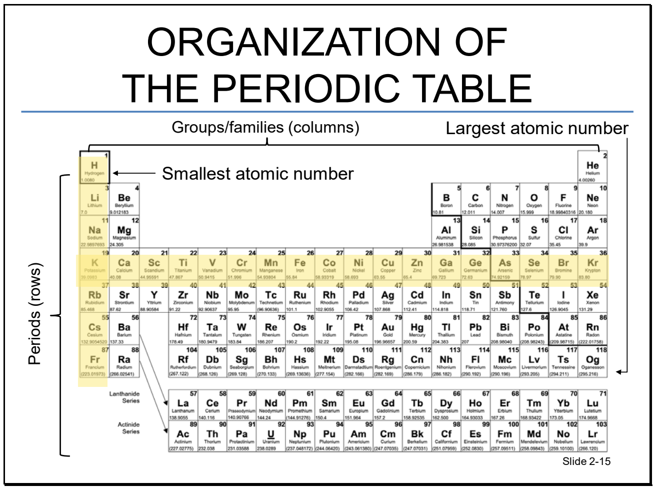
b. Elements on the periodic table have the same number of protons as electrons while neutrons vary.

2. Atomic mass or weight.

a. Atomic mass equals the number of protons plus the number of neutrons.

b. For our purposes in this course, the terms atomic mass and atomic weight are used interchangeably.

IV. ORGANIZATION OF THE PERIODIC TABLE



ORGANIZATION OF THE PERIODIC TABLE

Groups/families (columns)

Largest atomic number

Smallest atomic number

Periods (rows)

Slide 2-15

A. Periodicity of the elements.

1. The elements are arranged on the periodic table according to atomic number. Within the periodic table, we see repetition, which is called periodicity.

2. In 1869, Dimitri Mendeleev discovered the predicted placement of the elements, even for those that had not been discovered as of yet. This original scheme was organized based upon mass.

B. Position on the periodic table.

1. The position on the periodic table is important in determining the type of general physical and chemical properties an element exhibits.

2. Elements are listed on the periodic table from left to right, top to bottom, in increasing order of the atomic number, which has a bearing on the electrons and thus the combination or breakdown of compounds.

3. Chemical behavior is determined by the number of electrons in the outer orbit.

4. **Periods** are rows. They represent the number of orbits for all elements in that period (or row).

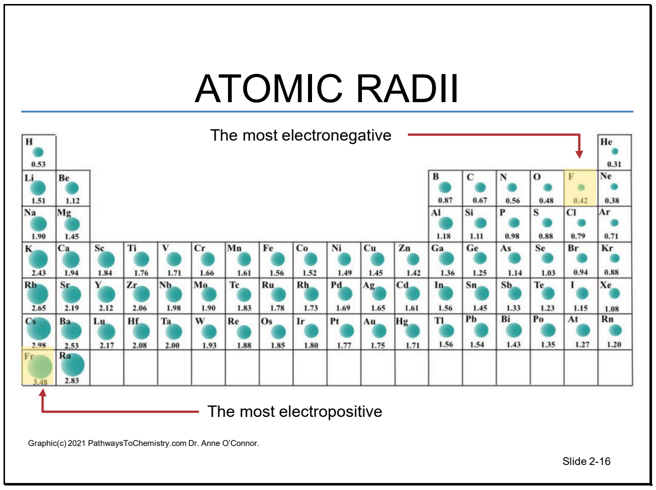
   a. Moving left to right, atoms become physically smaller (atomic radius) and atomically heavier.

   b. Moving right to left, atoms become physically larger (atomic radius) and atomically lighter.

5. **Groups** (families) are columns and have similar properties.

   a. Groups (or families) represent the number of electrons in the outermost orbit for all elements in that group or family. The transition metals and the rare earth metals have fluctuating numbers of electrons in their outermost orbit.

   b. Moving from top to bottom, the atoms become heavier and their physical states change from gases to solids.



ATOMIC RADII

The most electronegative

H 0.53																	He 0.31
Li 1.51	Be 1.12											B 0.87	C 0.67	N 0.56	O 0.48	F 0.42	Ne 0.38
Na 1.90	Mg 1.45											Al 1.18	Si 1.11	P 0.98	S 0.88	Cl 0.79	Ar 0.71
K 2.43	Ca 1.94	Sc 1.84	Ti 1.76	V 1.71	Cr 1.66	Mn 1.61	Fe 1.56	Co 1.52	Ni 1.49	Cu 1.45	Zn 1.42	Ga 1.36	Ge 1.25	As 1.14	Se 1.03	Br 0.94	Kr 0.88
Rb 2.65	Sr 2.19	Y 2.12	Zr 2.06	Nb 1.98	Mo 1.90	Tc 1.83	Ru 1.78	Rh 1.73	Pd 1.69	Ag 1.65	Cd 1.61	In 1.56	Sn 1.45	Sb 1.33	Te 1.23	I 1.15	Xe 1.08
Cs 2.98	Ba 2.53	Lu 2.17	Hf 2.08	Ta 2.00	W 1.93	Re 1.88	Os 1.85	Ir 1.80	Pt 1.77	Au 1.75	Hg 1.71	Tl 1.56	Pb 1.54	Bi 1.43	Po 1.35	At 1.27	Rn 1.20
Fr 3.48	Ra 2.83																

The most electropositive

Graphic(c) 2021 PathwaysToChemistry.com Dr. Anne O'Connor.

6. Electronegativity and atomic radii.

   a. Electronegativity is the ability to strip, or attract, electrons from other elements when forming compounds. The electronegativity of an atom has a relationship with its atomic radii.

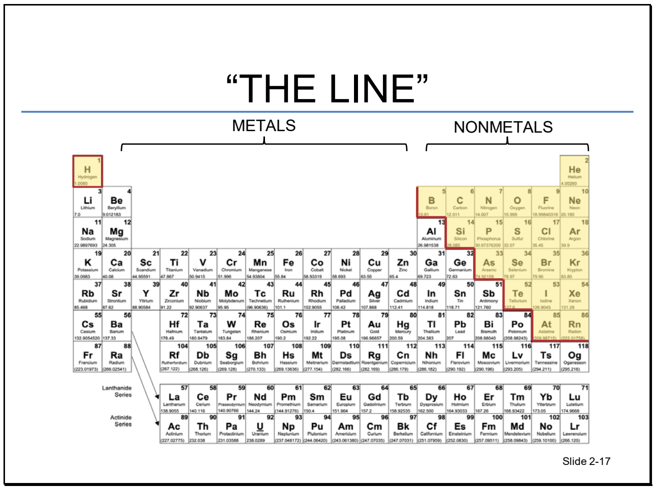
   b. From left to right and from bottom to top, electronegativity increases.

   c. Small distances from the nucleus to the outer perimeter of the electron cloud give rise to elements that are very electron drawing.

   d. Elements in Group VII at the far top right have the smallest radii and will be the most electronegative. (Disregard the noble gases VIII; they are satisfied and will not display electronegativity because of the Octet Rule.)

   e. The elements at the far bottom left of the table have the largest radii and will be the most electropositive, meaning they easily give away electrons and become a positively charged ion (cation).

f. Longer distances from the nucleus to the outer perimeter of the electron cloud cause elements to allow their outer electrons to be stripped or taken more easily.



“THE LINE”

C. The arrangement of elements on the periodic table and the division between metals and nonmetals is referred to as “The Line.”

1. Draw a line under hydrogen and then under boron, stair-stepping down until you come to astatine.

2. Elements above and to the right of The Line are considered nonmetals. These are electron drawing, or electronegative.

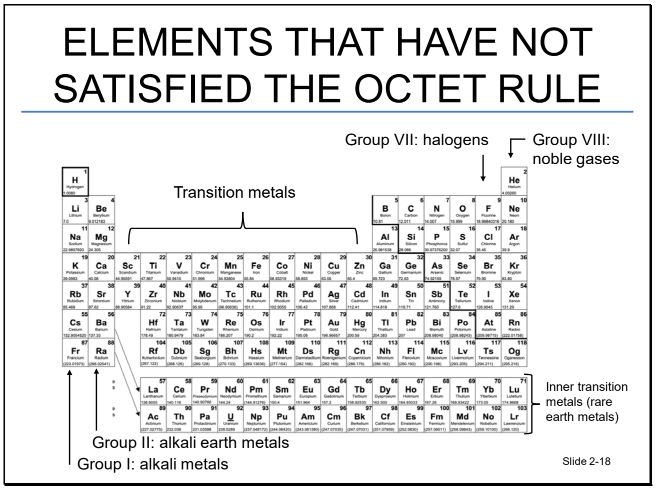
3. Elements below and to the left of The Line are considered metals. These are electron giving, or electropositive.

4. The elements along the border between the metals and nonmetals have properties similar to both, depending on the reaction. These are called metalloids.

D. Except for noble gases (Column VIII), no elements satisfy the Duet and Octet rules. As a result, these elements will give, take or share electrons to form new compounds.

It is more meaningful, and perhaps easier, to remember representative elements by their group name, rather than the Roman numeral of the column on the periodic table.

V. ELEMENTS THAT HAVE NOT SATISFIED THE OCTET RULE


ELEMENTS THAT HAVE NOT SATISFIED THE OCTET RULE

Slide 2-18

A. Group I: alkali metals.

1. Can form highly water-reactive compounds depending on the element it combines with. The resulting hydroxide solution can be very caustic and destructive to skin and respiratory tree.

2. Produce hydrogen gas and heat on contact with water, which usually causes violent ignition.

B. Group II: alkali earth metals.

1. Same general properties (much less severe) as the alkali metals.

2. Dangerous to try extinguishment due to potentially explosive reactions with water and CO_2.

3. Forms alkaline solution when mixed with water.

C. Group VII: halogens.

1. Most reactive of all the nonmetals.

2. Very toxic and some are carcinogens.

3. Highly irritating to the skin.

4. Do not burn but are potent oxidizers.

D. Group VIII: noble gases (inert gases).

1. Are in the most stable configuration. The Duet and Octet rules are satisfied.

2. Other elements try to achieve this stability through giving, taking or sharing electrons.

E. Transition metals.

1. The short columns in the middle of the chart (groups 3 to 12) make up the transition metals. These have variable valences.

2. Some can be very toxic and add toxicity to compounds.

3. They are polluting (heavy metals) materials.

4. Transition metals have more complicated electron configurations.

5. These metals do not follow all the rules.

6. The Roman numerals for these columns will not indicate how many electrons will be in the outermost orbit.

7. Transition elements can lose a varying number of electrons.

   a. An old system of suffixes ("-ous" and "-ic") indicates the charge of the transition ion.

   b. "-ous" for the lower valence or oxidative state. Example: ferrous Fe^{+2}.

   c. "-ic" for the higher valence or oxidative state. Example: ferric Fe^{+3}.

8. The Stock System uses a Roman numeral in the name to indicate the valence of the transition metal. (Example: iron II oxide or iron III oxide.)

9. Most transition metals are traditionally used within chemical processes and not as large bulk chemicals.

F. Inner transition metals (rare earth metals).

1. The separated rows at the bottom of the chart are rare earth metals.

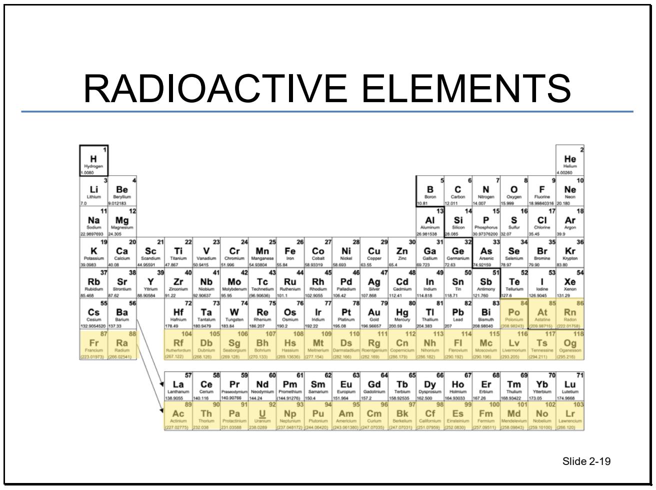
   a. Lanthanides.

   b. Actinides.

2. They are rare and have radioactive potential. Many are highly radioactive.

3. Some occur naturally; others are synthetically made through neutron bombardment. Some only exist for milliseconds in the laboratory.

4. Most are not transported or stored in large quantities.



RADIOACTIVE ELEMENTS

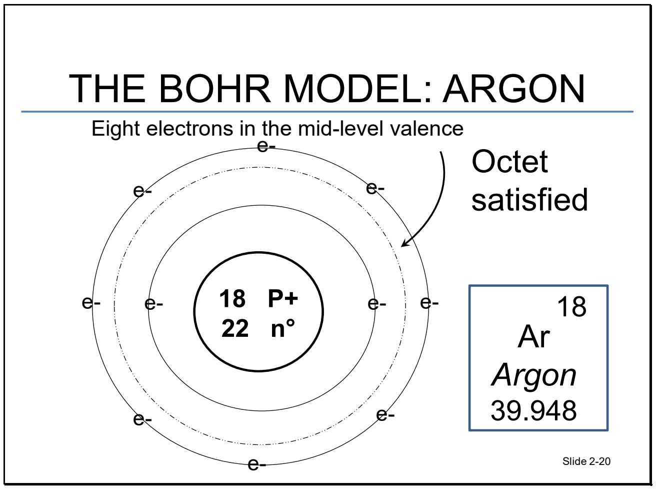
Slide 2-19

G. Radioactive elements.

1. Generally speaking, all elements with atomic number 83 or greater on the periodic table are radioactive. (There are no nonradioactive forms of these elements.)

2. Every element, depending on the isotope, has the potential to be radioactive.

VI. THE BOHR MODEL



THE BOHR MODEL: ARGON

Eight electrons in the mid-level valence

Octet satisfied

Slide 2-20

A. Introduction to the Bohr Model.

1. Named after the Danish scientist, Niels Bohr.

2. A nucleus is positively charged due to P+.

3. Surrounding the positively charged nucleus are the negatively charged electrons in the shells or orbits.

4. Arranged in centric shells or orbits are the pathways for the electrons. These can also be called valences or clouds.

5. The Bohr Model represents concentric circles of electrons as ever-increasing circles out from the nucleus.

6. The electrons in each shell or orbit have discrete energy levels.

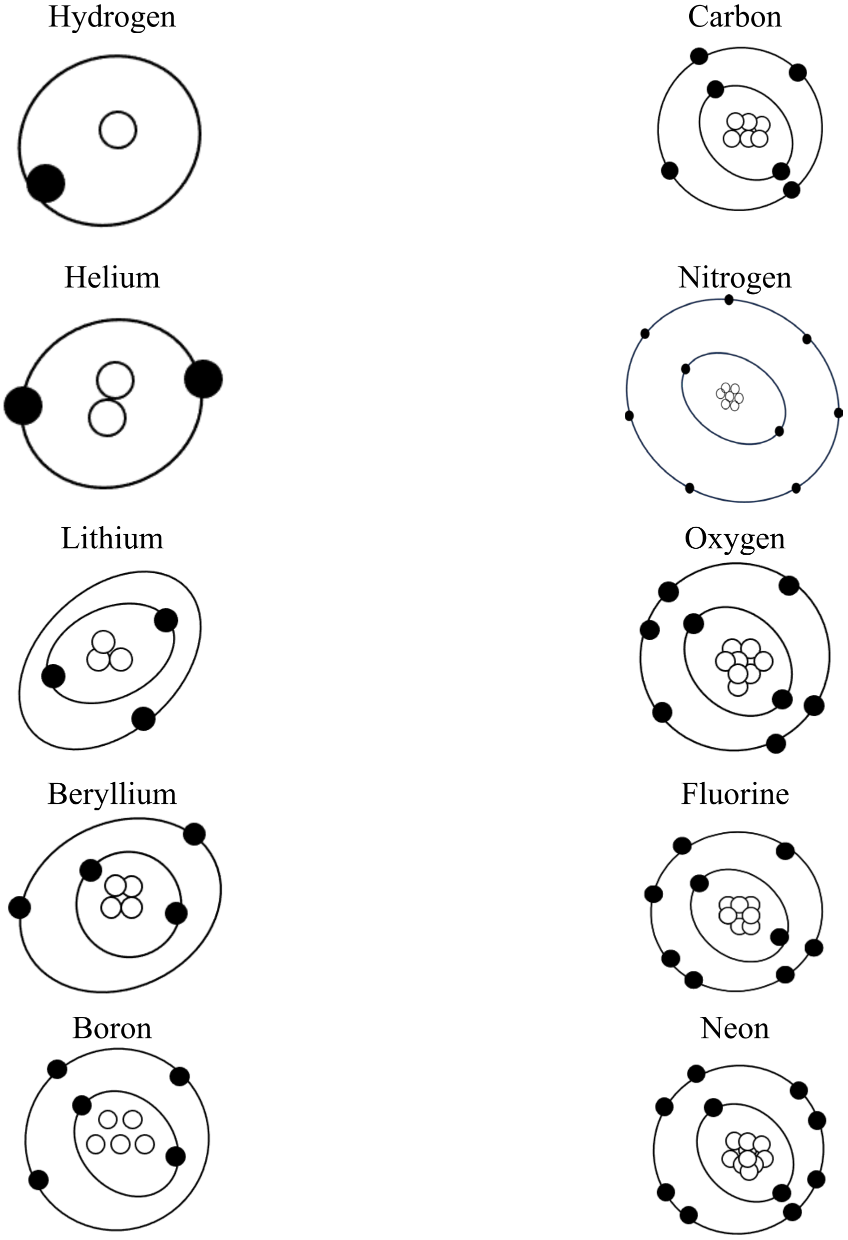
7. A maximum number of electrons can exist within each centric shell.

B. Inadequacies of the Bohr Model.

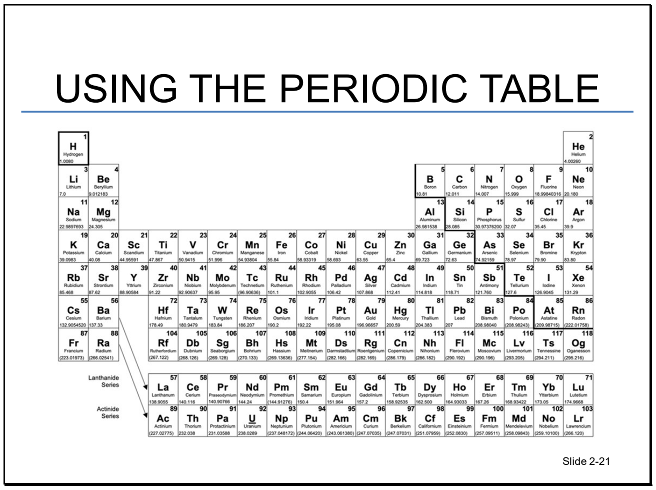
1. The Bohr Model explains most of the observable chemical reactions but fails to explain more complicated atoms and reactions.

2. This theory works well for simple atoms like hydrogen, but not for heavier, more complex compounds.

Figure 2.1: The Bohr Model of Atomic Structures — Examples



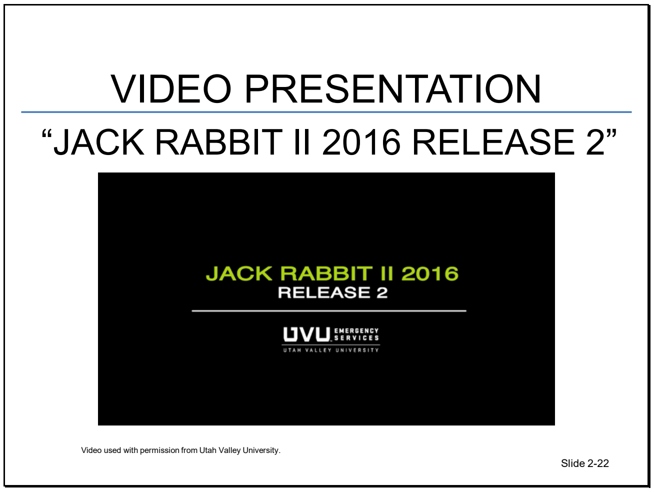
VII. USING THE PERIODIC TABLE



USING THE PERIODIC TABLE

A. Periodic table practice questions.

B. Example of a diatomic gas.



VIDEO PRESENTATION

“JACK RABBIT II 2016 RELEASE 2”

Video used with permission from Utah Valley University.

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ACTIVITY 2.1

The 40 Common Elements

Purpose

Identify the name of the element and the location of the element on the periodic table given an element symbol from the list of 40 common elements in this course.

Directions

1. Complete Worksheet A: The 40 Common Elements.
   a. Given either the symbol or atomic number, provide the element's name, number or name of the group to which the element belongs, and number of valence electrons. Also complete the missing symbol or atomic number.
   b. Complete the first five elements in class and finish the worksheet in the evening.
2. Optionally, as homework, complete Handout 2-1 to help familiarize yourself with the location of key elements on the periodic table.
   a. Number the periodic table with the atomic number, beginning with hydrogen.
   b. Denote the metal/nonmetal dividing line.
   c. Label the five families by name (alkali metals, alkali earth metals, transition metals, halogens, noble gases.)
   d. Add the element symbol and name of the 40 common elements.

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ACTIVITY 2.1 (cont'd)

40 Common Elements and Their Symbols

Symbol	Element
H	Hydrogen
Li	Lithium
Na	Sodium
K	Potassium
Cs	Cesium
Fr	Francium
Be	Beryllium
Mg	Magnesium
Ca	Calcium
Ba	Barium
U	Uranium
Pu	Plutonium
Cr	Chromium
Mn	Manganese
Fe	Iron
Co	Cobalt
Ni	Nickel
Cu	Copper
Ag	Silver
Au	Gold

Symbol	Element
Hg	Mercury
Zn	Zinc
B	Boron
Si	Silicon
As	Arsenic
Al	Aluminum
Sn	Tin (Stannum)
Pb	Lead (Plumbum)
C	Carbon
N	Nitrogen
O	Oxygen
P	Phosphorous
S	Sulfur
F	Fluorine
Cl	Chlorine
Br	Bromine
I	Iodine
He	Helium
Ne	Neon
Ar	Argon

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ACTIVITY 2.1 (cont'd)

Worksheet A: The 40 Common Elements

#	Symbol	Atomic number	Element name	Group number or name	#
1.	H				
2.		3			
3.	Na				
4.		19			
5.	Cs				
6.		87			
7.	Be				
8.		12			
9.	Ca				
10.		56			
11.	U				
12.		94			
13.	Cr				
14.		25			
15.	Fe				

16.		27			
17.	Ni				
18.		29			
19.	Ag				
20.		79			
21.	Hg				
22.		30			
23.	B				
24.		14			
25.	As				
26.		13			
27.	Sn				
28.		82			
29.	C				
30.		7			
31.	O				
32.		15			

33.	S				
34.		9			
35.	Cl				
36.		35			
37.	I				
38.		2			
39.	Ne				
40.		18			

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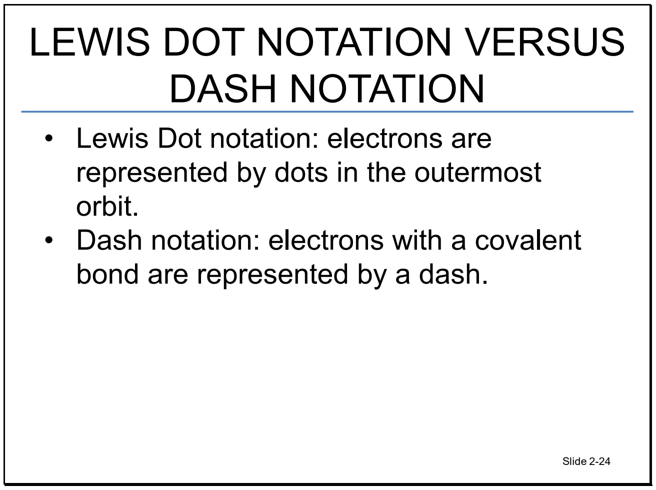
VIII. LEWIS DOT NOTATION VERSUS DASH NOTATION



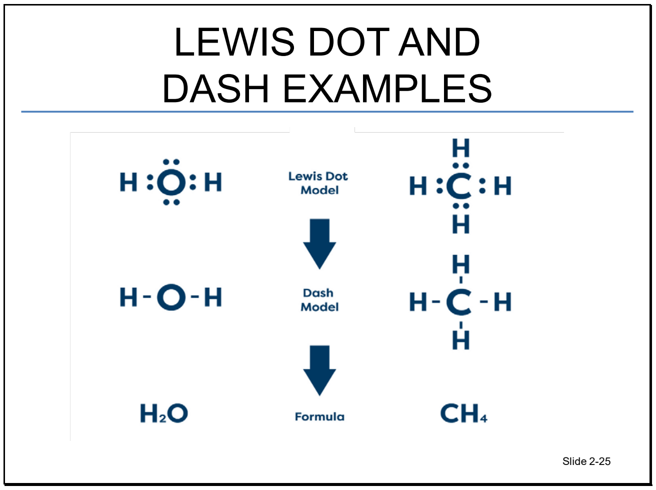
LEWIS DOT NOTATION VERSUS DASH NOTATION

- Lewis Dot notation: electrons are represented by dots in the outermost orbit.
- Dash notation: electrons with a covalent bond are represented by a dash.

A. Lewis Dot notation: Uses a dot to represent the electrons in the outermost orbit of the element.

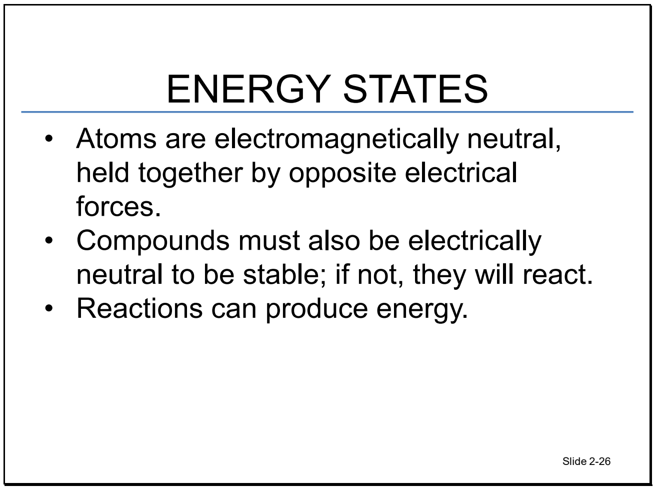
B. Dash notation: Shared electrons in a covalent bond are represented by a dash.

C. We do not draw ionic compounds (when electrons are transferred), only covalent compounds (when they are shared).



LEWIS DOT AND DASH EXAMPLES

IX. INTRODUCTION TO BONDING



ENERGY STATES

- Atoms are electromagnetically neutral, held together by opposite electrical forces.
- Compounds must also be electrically neutral to be stable; if not, they will react.
- Reactions can produce energy.

A. Energy states.

1. All atoms, the elements on the periodic table, are electromagnetically neutral.

2. Atoms are held together by opposite electrical forces of the protons and the electrons.

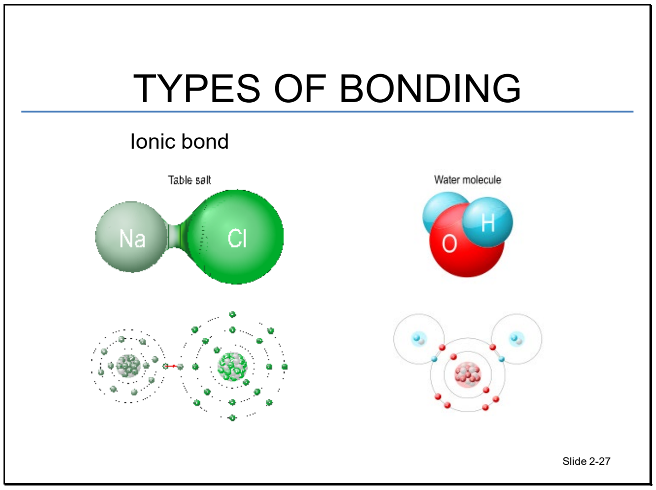
3. The speed of the electrons keeps them from being drawn into the nucleus.

4. Compounds must also be electrically neutral to be stable. If not, they will continue to react.

5. Atoms and molecules can exist within a particular energy state. These states are characterized by energy levels.

6. When an atom or molecule changes its state of matter, it absorbs or emits just enough energy to bring it into the desired state of matter.

7. A reaction can produce energy based on the energy state and the amount of energy placed into the reaction.



TYPES OF BONDING

Ionic bond

B. Types of bonding.

1. This course will focus on two types of bonding:

   a. **Ionic** bonding: Atoms gain or lose electrons becoming ions attracted by opposite charges. Salts are ionically bonded.

   b. **Covalent** bonding: Atoms share electrons to satisfy the outer orbit. Nonsalts are covalently bonded.

2. There is a third type that is not discussed in this course: **Coordinate covalent** bonding: Atoms can have a combination of ionic and covalent bonding as in the ammonium cation, NH_4^+.

3. Elements that gain or lose electrons are in an unstable state if not in combination with other elements. In nature we see this combination.

   a. They have not satisfied the requirements of the outermost orbital (Octet Rule).

   b. The nature of an atom (or molecule) is to achieve stability.

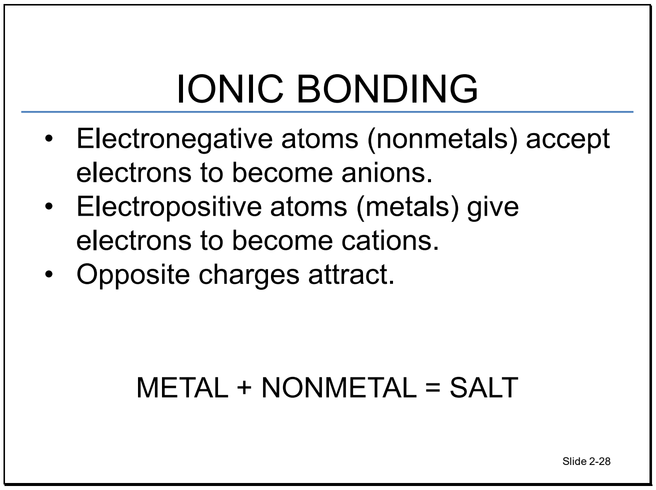
   c. Diatomic gases are one element that combines two atoms together to find stability (O_2, H_2, N_2, Cl_2, F_2, etc.).

4. The elements will achieve stability to comply with the laws of nature. They achieve stability through bonding.

   a. Electrons may be gained (ionic) to form a negatively charged ion called an anion (-).

b. Electrons may be given up (ionic) to form a positively charged ion called a cation (+).

c. Electrons may be shared (covalent), which occurs between nonmetals which have electronegative characteristics.



IONIC BONDING

- Electronegative atoms (nonmetals) accept electrons to become anions.
- Electropositive atoms (metals) give electrons to become cations.
- Opposite charges attract.

METAL + NONMETAL = SALT

C. Ionic bonding (M + NM).

1. Occurs between a metal and a nonmetal.

2. Large metals hold electrons very loosely (large atomic radii) and become electropositive after losing the electrons.

3. Small nonmetals pull very hard on electrons (small atomic radii) and become electronegative after gaining the electrons.

4. Metals will give up electrons to nonmetals.

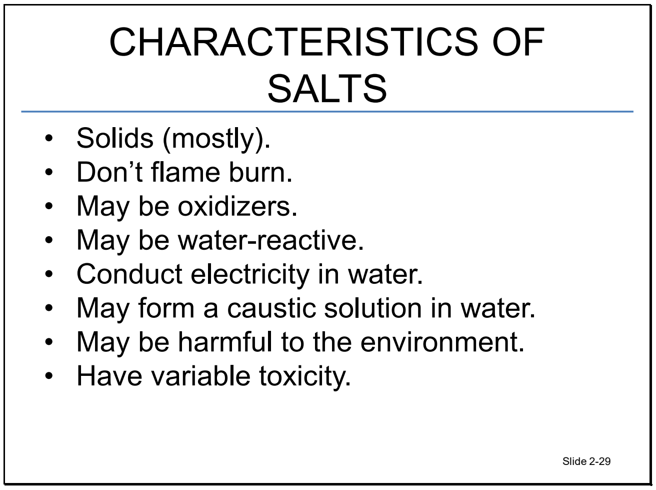
5. Since each individual atom is no longer electrically neutral, it no longer can be an atom.

6. The resultant particles are called **ions**.

a. When electrons are gained, the resulting ion will have a negative charge and is called an **anion** (a nonmetal).

b. When electrons are given up, the resulting ion will have a positive charge and is called a **cation** (a metal).

c. The resulting molecule is held together by the opposite charges that are present within the molecule.



CHARACTERISTICS OF SALTS

- Solids (mostly).
- Don’t flame burn.
- May be oxidizers.
- May be water-reactive.
- Conduct electricity in water.
- May form a caustic solution in water.
- May be harmful to the environment.
- Have variable toxicity.

7. Characteristics of ionically bonded compounds (salts) include:

   a. Most are solids.

   b. Don’t flame burn.

   c. May be oxidizers.

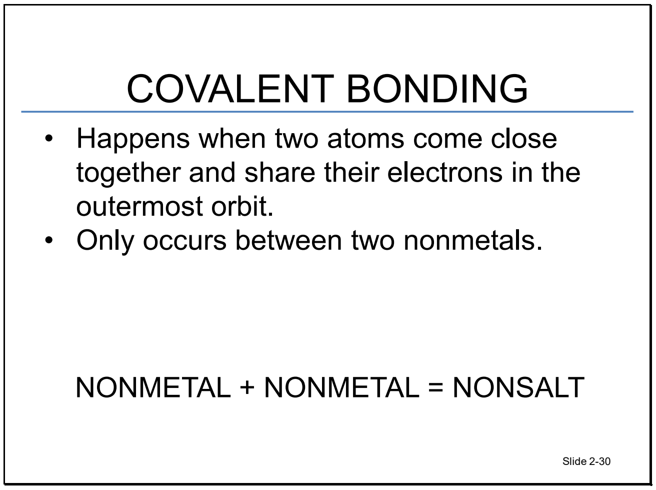
   d. May be water-reactive.

   e. Will conduct electricity in water.

   f. May form a caustic solution when mixed with water.

   g. May be harmful to the environment.

   h. Have variable toxicity.



COVALENT BONDING

- Happens when two atoms come close together and share their electrons in the outermost orbit.
- Only occurs between two nonmetals.

NONMETAL + NONMETAL = NONSALT

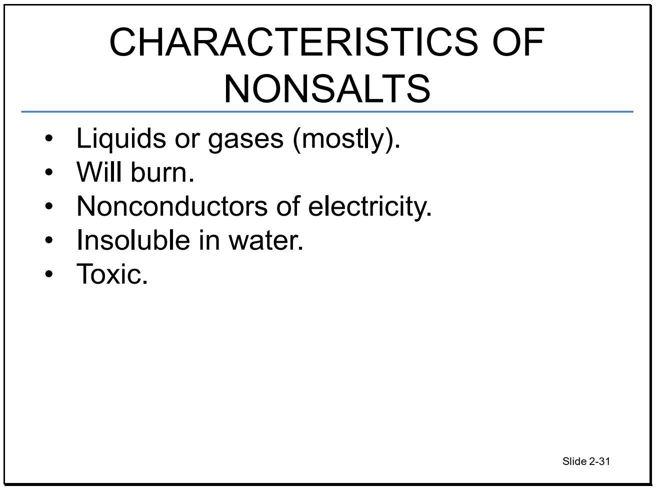
D. Covalent bonding (NM + NM).

1. A covalent bond is formed when two atoms come close together and share the electrons within the outer orbital, satisfying each atom's outermost shell.

2. Occurs only between two nonmetals.

3. Each possesses a relative size and ability to attract.

4. This relative size and electronic attraction are the basis for the covalent bond.



CHARACTERISTICS OF NONSALTS

- Liquids or gases (mostly).
- Will burn.
- Nonconductors of electricity.
- Insoluble in water.
- Toxic.

Slide 2-31

5. Characteristics of covalently bonded compounds (nonsalts) include:

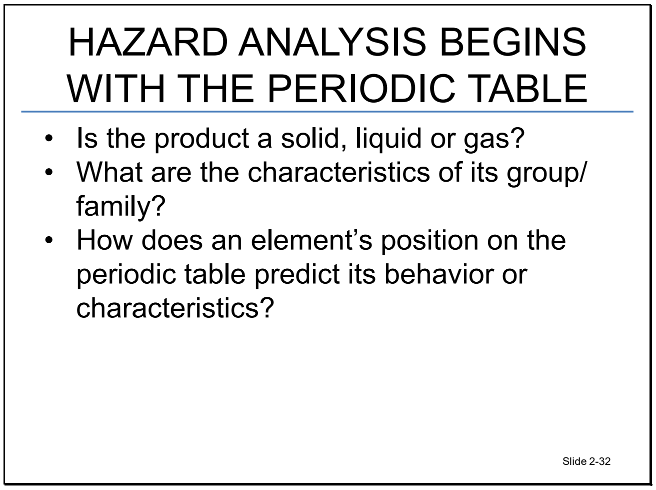
   a. Most are liquids or gases.

   b. Will burn.

   c. Nonconductors of electricity (no loss and gaining of electrons) due to no ionization.

   d. Insoluble in water. Some will mix with water (polar compounds). Not water reactive.

   e. Toxic.



HAZARD ANALYSIS BEGINS WITH THE PERIODIC TABLE

- Is the product a solid, liquid or gas?
- What are the characteristics of its group/ family?
- How does an element's position on the periodic table predict its behavior or characteristics?

E. Basic product hazard analysis begins with the periodic table.

1. Is the product a solid, liquid or gas?

   a. **Solids** are predominantly metals (as elements) and salts (as compounds). Solids have the traits and hazards of the salts. Metals, other than some being toxic, are not hazardous.

   b. **Liquids** are predominantly nonmetals in compounds as only two elements are liquids (Br and Hg). These will have the traits and hazards of the nonsalts.

   c. **Gases** are nonmetals in compounds with other nonmetals or have formed diatomic gases and will have the traits of the nonsalts.

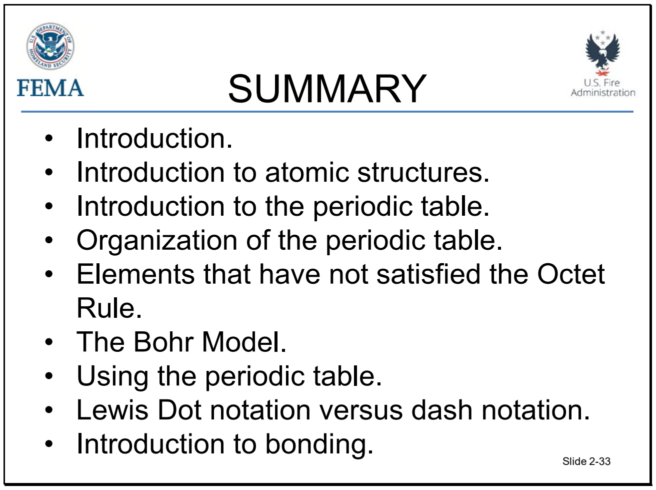
2. The elements in the compound will bring the characteristics of its group or family to the compound.

   a. Many of the transition metals are toxic as heavy metals and poisons.

   b. Many of the rare earth metals are radioactive and therefore toxic.

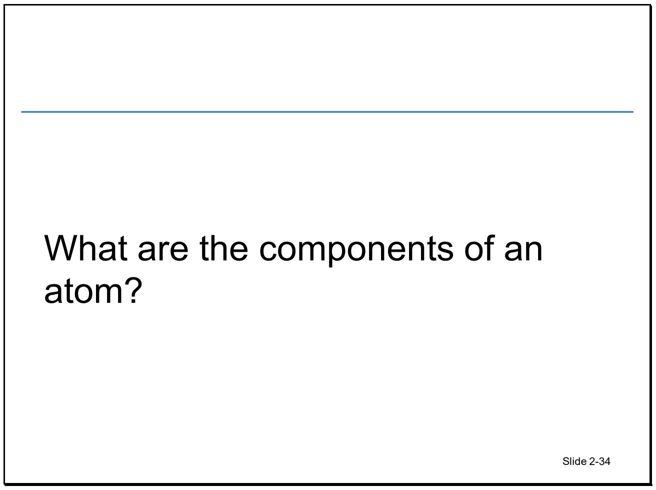
   c. The noble gases have obtained the octet and therefore will only bond with other elements in compounds if the electrons are forced off the atom through temperature, pressure or other reaction.

X. SUMMARY

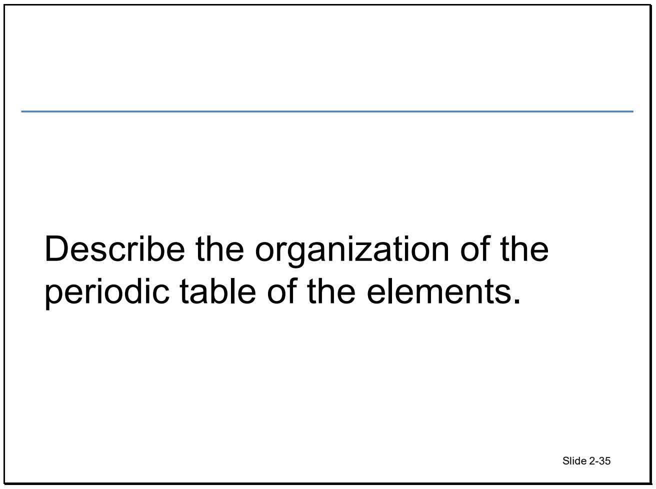


SUMMARY

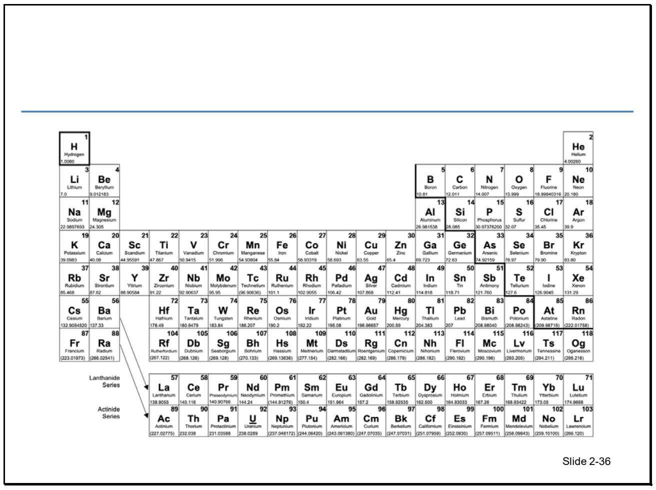
- Introduction.
- Introduction to atomic structures.
- Introduction to the periodic table.
- Organization of the periodic table.
- Elements that have not satisfied the Octet Rule.
- The Bohr Model.
- Using the periodic table.
- Lewis Dot notation versus dash notation.
- Introduction to bonding.

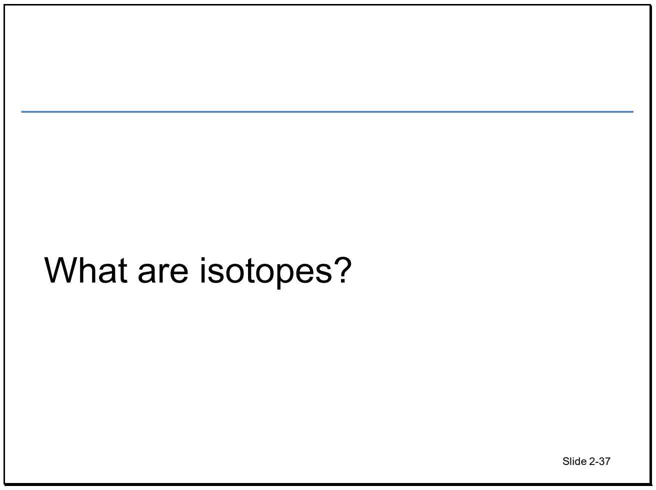


What are the components of an atom?

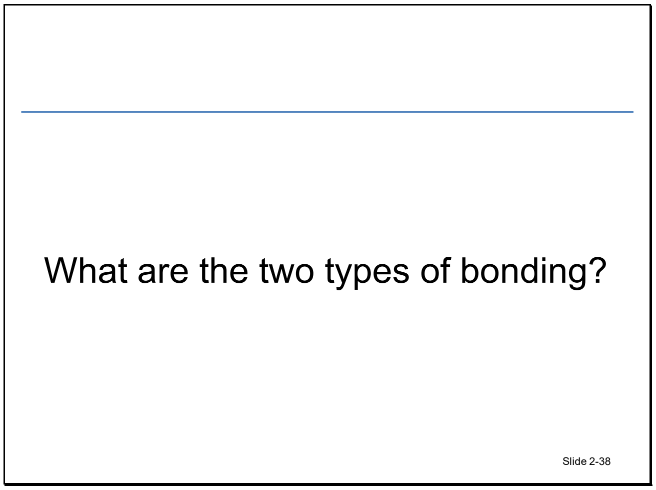


Describe the organization of the periodic table of the elements.

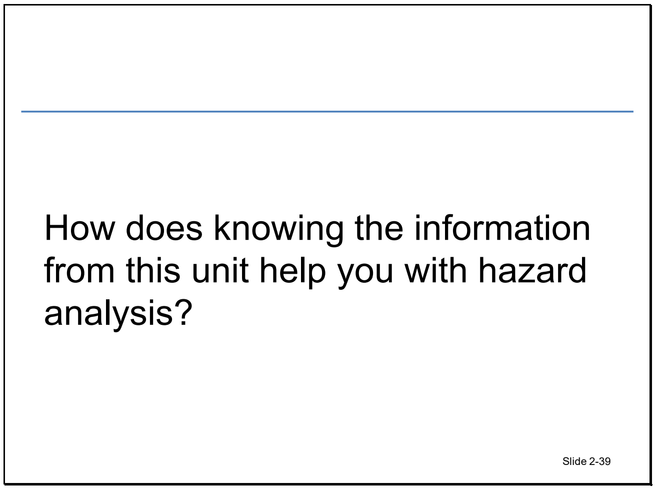




What are isotopes?



What are the two types of bonding?



How does knowing the information from this unit help you with hazard analysis?

APPENDIX A

PERIODIC TABLE

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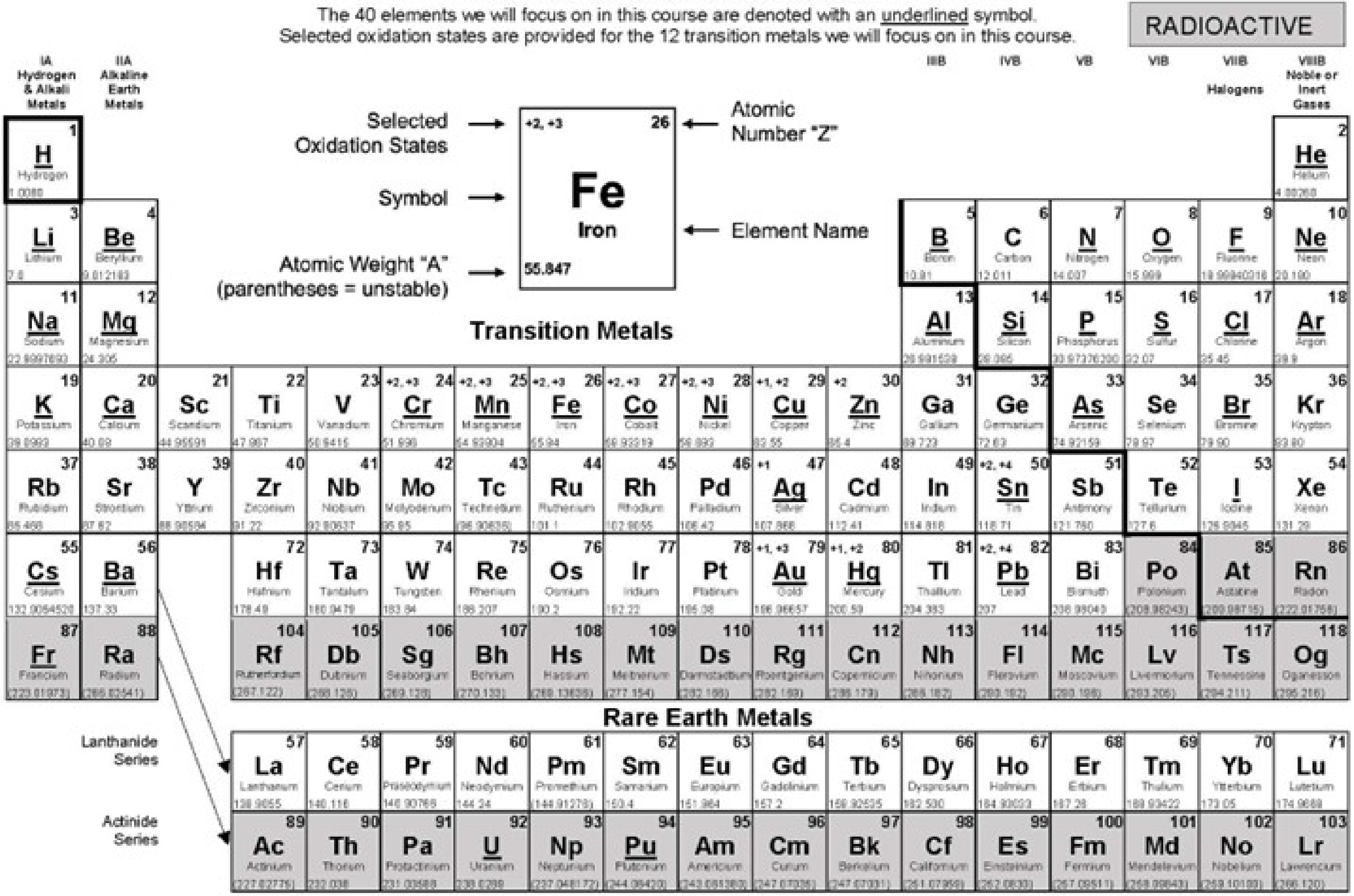
The Periodic Table of the Elements

The 40 elements we will focus on in this course are denoted with an underlined symbol.
Selected oxidation states are provided for the 12 transition metals we will focus on in this course.



Source: https://pubchem.ncbi.nlm.nih.gov/periodic-table/

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APPENDIX B

COMMON CATIONS FOR TRANSITION METALS

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Common Cations for Transition Metals

Element	Common oxidation states	Alternate (classical)	Systematic (IUPAC)
Copper (Cu)	+1, +2	Cuprous (+1) Cupric (+2)	Copper I Copper II
Mercury (Hg)	+1, +2	Mercurous (+1) Mercuric (+2)	Mercury I Mercury II
Iron (Fe)	+2, +3	Ferrous (+2) Ferric (+3)	Iron II Iron III
Tin (Sn)	+2, +4	Stannous (+2) Stannic (+4)	Tin II Tin IV
Cobalt (Co)	+2, +3	Cobaltous (+2) Cobaltic (+3)	Cobalt II Cobalt III
Chromium (Cr)	+2, +3	Chromous (+2) Chromic (+3)	Chromium II Chromium III
Manganese (Mn)	+2, +3	Manganous (+2) Manganic (+3)	Manganese II Manganese III
Lead (Pb)	+2, +4	Plumbous (+2) Plumbic (+4)	Lead II Lead IV
Zinc (Zn)	+2	Zinc (+2)	Zinc II
Nickel (Ni)	+2, +3	Nickelous (+2) Nickelic (+3)	Nickel II Nickel III
Silver (Ag)	+1	Silver (+1)	Silver I
Gold (Au)	+1, +3	Aurous (+1) Auric (+3)	Gold I Gold III

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UNIT 3:
SALTS

TERMINAL OBJECTIVE

The students will be able to:

3.1 Conduct a hazard analysis for an incident involving a salt compound.

ENABLING OBJECTIVES

The students will be able to:

3.1 Identify the hazards of binary salt, hydroxide salt, cyanide salt, peroxide salt, oxysalt and salts containing the ammonium cation, given the name or formula.

3.2 Identify the types of salts and associated hazards, given a scenario involving salt compounds.

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FEMA

U.S. Fire Administration

UNIT 3:
SALTS

TERMINAL OBJECTIVE

Conduct a hazard analysis for an incident involving a salt compound.

ENABLING OBJECTIVES

- Identify the hazards of binary salt, hydroxide salt, cyanide salt, peroxide salt, oxysalt and salts containing the ammonium cation, given the name or formula.
- Identify the types of salts and associated hazards, given a scenario involving salt compounds.

I. INTRODUCTION

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ACTIVITY 3.1

Getting to Know the Salts

Purpose

Analyze the hazards and characteristics of a solid product.

Directions

1. Work with your group to analyze the hazards of your assigned product, which may include one of the following:
    a. Potassium permanganate.
    b. Sodium hydroxide.
    c. Aluminum phosphide.
    d. Ammonium nitrate.
    e. Barium peroxide.
    f. Cadmium oxide.
    g. Potassium cyanide.
2. Use available databases to fill out a Product Hazard Analysis Worksheet. You will not be able to complete the entire worksheet; fill it out with the information you can find. Be sure to include the physical state.
3. Record any significant findings of the analysis, including primary hazards of the product, on an easel pad.
4. Be prepared to present to the class as if you are briefing an entry team.

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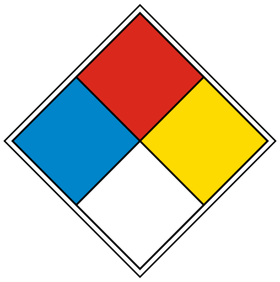
ACTIVITY 3.1 (cont'd)

Product Hazard Analysis Worksheet



Group Number: ________ **Presenter:** ________________________

Temp: _________ **°F** **R/H:** _________**%**

Product Name:_________________________________ **Family:**_________________________

Data Points	**Result**	**No Data**	**Hazard Consideration**
Physical Properties			
Physical State			
Vapor Pressure			
Boiling Point			
Vapor Density			
Specific Gravity			
Solubility			
Flammability			
Flash Point			
LEL/UEL			
Flammable Range			
Ignition Temp.			
Toxicity			
Route of Exposure			
IDLH			
PEL/REL/STEL			
S/S of Exposure			
Biological			
Corrosivity			
pH			
Concentration			
Reactivity/Explosion			
Radioactivity			
Decay Mode	☐ **N/A** ☐ α ☐ β ☐ γ		
Half Life			

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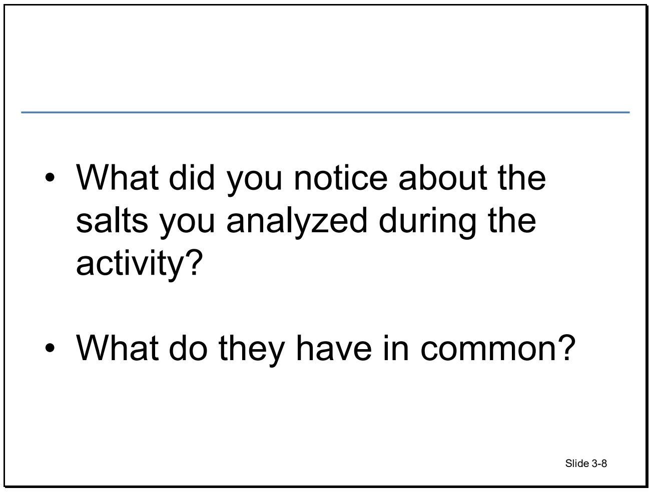
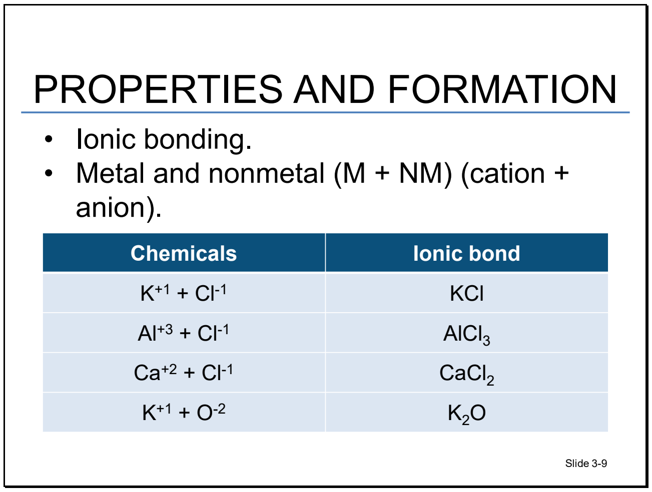
II. PROPERTIES AND FORMATION OF SALTS



- What did you notice about the salts you analyzed during the activity?
- What do they have in common?



PROPERTIES AND FORMATION

- Ionic bonding.
- Metal and nonmetal (M + NM) (cation + anion).

Chemicals	Ionic bond
$K^{+1} + Cl^{-1}$	KCl
$Al^{+3} + Cl^{-1}$	$AlCl_3$
$Ca^{+2} + Cl^{-1}$	$CaCl_2$
$K^{+1} + O^{-2}$	K_2O

A. Properties of the salts.

1. Most are solids unless made into solutions.
2. Most dissolve in water or react with water.
3. Most conduct electricity when dissolved in water.
4. Generally, salts do not burn with a flame, though some will glow-burn.
5. Some are oxidizers that can enhance combustion.
6. Many are very toxic, either systemically or locally.
    a. Local damage occurs at the point of contact (examples: acids and bases).

b. Systemic toxicity affects a system within the body.

B. Definition of salt: a compound created through ionic bonding between a metal and a nonmetal (M + NM).

1. Atoms seek to satisfy the outermost valence or shell through the Duet or Octet rule.

2. Metals combine with nonmetals.

3. Metals generally give up their outermost electrons.

4. Nonmetals generally accept electrons necessary to fill their outer valence.

5. The compound, when formed, will be electrically neutral.

C. Formation: Salts are always formed through ionic bonding.

1. Metals give up electrons, thus becoming electropositive (more positive charges after losing electrons).

2. Nonmetals accept electrons, thus becoming electronegative (more negative charges after gaining electrons).

3. The resulting compound is called a salt.

D. Formulas.

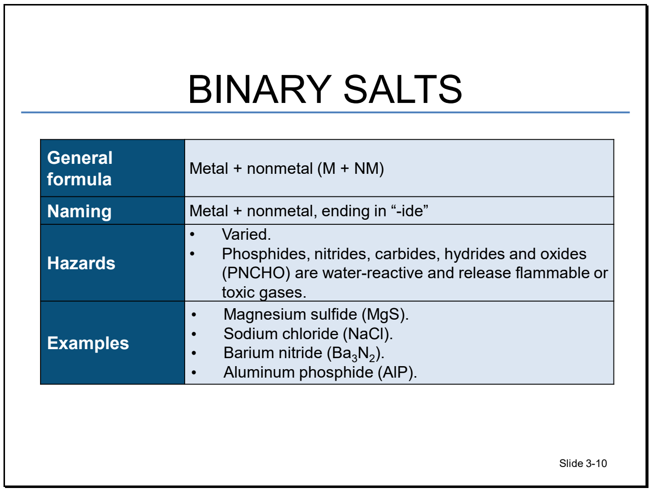
1. We do not draw the structures of salts. We simply balance the formulas.

2. Ionic bonding is the exchange of electrical charges. If we know the charges, we can balance the formula and understand how to name it.

Table 3.1 Additional formulas for ionic bonding

Chemicals	Ionic bond (salt compound)
$K^{+1} + Cl^{-1}$	KCl
$Al^{+3} + Cl^{-1}$	$AlCl_3$
$Ca^{+2} + Cl^{-1}$	$CaCl_2$
$K^{+1} + O^{-2}$	K_2O

III. BINARY SALTS



BINARY SALTS

General formula	Metal + nonmetal (M + NM)
Naming	Metal + nonmetal, ending in “-ide”
Hazards	• Varied. • Phosphides, nitrides, carbides, hydrides and oxides (PNCHO) are water-reactive and release flammable or toxic gases.
Examples	• Magnesium sulfide (MgS). • Sodium chloride (NaCl). • Barium nitride (Ba_3N_2). • Aluminum phosphide (AlP).

A. Formula and naming.

1. Formula: metal + nonmetal (M + NM).

2. Naming.

   a. Name the metal first.

   b. Then name the nonmetal, changing the ending to “-ide.”

B. Hazards.

1. Hazards are varied.

2. Many are toxic. Some are harmless.

3. Many are water reactive.

4. The following salts have specific hazards noted when in contact with moisture: the phosphides, nitrides, carbides, hydrides and oxides (known by the acronym PNCHO, pronounced “Poncho”).

   When in contact with moisture:

   a. Phosphides release the highly poisonous phosphine gas.

   b. Nitrides release severely irritating, poisonous and flammable ammonia gas.

   c. Carbides release highly flammable and unstable acetylene gas.

d. Hydrides release tremendous heat and the very flammable hydrogen gas.

e. Oxides release heat and form very caustic solutions (hydroxide).

C. Binary salt with transition metals.

1. The present-day nomenclature uses the “-ide” ending discussed above.

2. Naming of transition metals can be classic or systematic.

a. Classic.

- Uses the “-ous” suffix for the lower valence metal and the “-ic” suffix for the higher valence metal.

- Example: cupric, cuprous for copper materials.

b. Systematic.

- Uses a Roman numeral to identify the valence of the metal.

- Examples: copper I, copper II. These numerals note the charge: Cu^{+1} and Cu^{+2}.

Table 3.2 Common cations for transition metals

Element	Common oxidation states	Alternate (classical)	Systematic*
Copper (Cu)	+1, +2	Cuprous (+1) Cupric (+2)	Copper I Copper II
Mercury (Hg)	+1, +2	Mercurous (+1) Mercuric (+2)	Mercury I Mercury II
Iron (Fe)	+2, +3	Ferrous (+2) Ferric (+3)	Iron II Iron III
Tin (Sn)	+2, +4	Stannous (+2) Stannic (+4)	Tin II Tin IV
Cobalt (Co)	+2, +3	Cobaltous (+2) Cobaltic (+3)	Cobalt II Cobalt III
Chromium (Cr)	+2, +3	Chromous (+2) Chromic (+3)	Chromium II Chromium III
Manganese (Mn)	+2, +3	Manganous (+2) Manganic (+3)	Manganese II Manganese III
Lead (Pb)	+2, +4	Plumbous (+2) Plumbic (+4)	Lead II Lead IV
Zinc (Zn)	+2	Zinc (+2)	Zinc II
Nickel (Ni)	+2, +3	Nickelous (+2) Nickelic (+3)	Nickel II Nickel III
Silver (Ag)	+1	Silver (+1)	Silver I
Gold (Au)	+1, +3	Aurous (+1) Auric (+3)	Gold I Gold III

***International Union of Pure and Applied Chemistry (IUPAC).**

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ACTIVITY 3.2

Binary Salts

Purpose

Identify the hazards of binary salts based on a name or formula.

Directions

1. Work with your group to complete the Binary Salts Worksheet for your assigned salt compounds.
2. Based on the name or formula provided, fill in the hazards.
3. Be prepared to share your answers.
4. If not completed in the time allotted, complete the activity as homework.

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ACTIVITY 3.2 (cont'd)

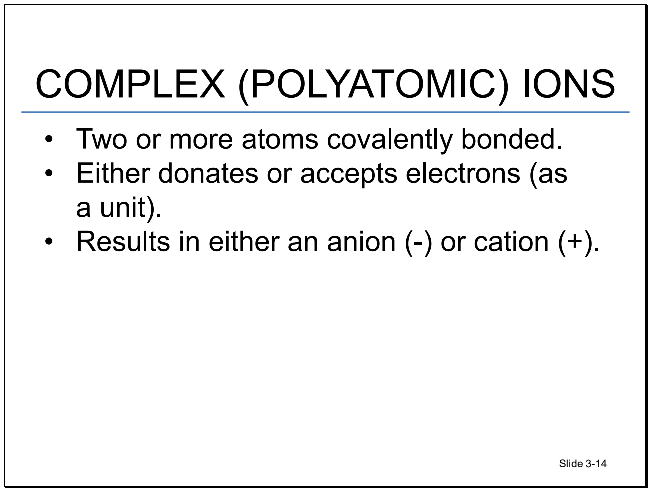
Binary Salts Worksheet

Complete the chart by filling in the chemical name or formula as well as the hazards based on the name or formula given.

#	Chemical name or formula	Hazards
1.	$MgCl_2$	
2.	Cupric phosphide	
3.	Zinc II nitride	
4.	Sodium hydride	
5.	Pb_3N_2	
6.	Plumbic bromide	
7.	Fe_2O_3	
8.	CaC_2	
9.	Sodium oxide	
10.	AlP	

#	Chemical name or formula	Hazards
11.	Mercurous fluoride	
12.	Cobalt II hydride	
13.	Calcium oxide	
14.	Ca_3P_2	
15.	Li_3N	
16.	SnS_2	
17.	Iron III phosphide	
18.	CuO	
19.	LiH	
20.	Barium nitride	

IV. COMPLEX (POLYATOMIC) IONS



COMPLEX (POLYATOMIC) IONS

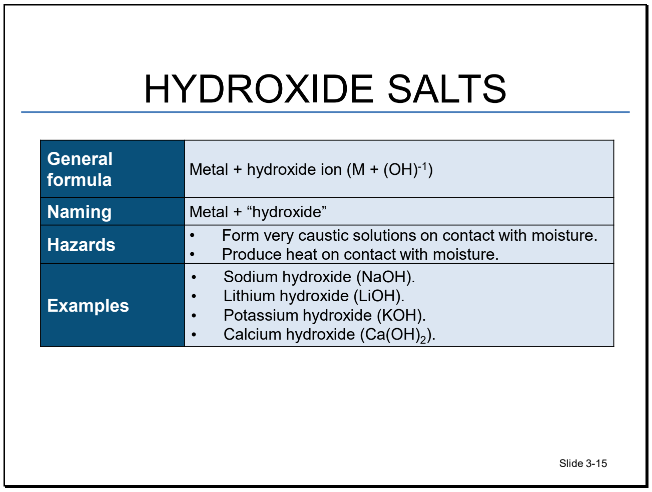
- Two or more atoms covalently bonded.
- Either donates or accepts electrons (as a unit).
- Results in either an anion (-) or cation (+).

A. We have seen that a metal and a nonmetal can form a bond.

B. Metals and nonmetals can form complex ions.

1. This ion is the "replacement" for the singular nonmetal.
2. It acts as a singular atom.
3. The overall valences are due to the covalent bonds within the complex ion.
4. This complex ion donates or accepts an electron.
5. This can become extremely complicated, so for this course, we will look at specific ions: those that are most common and least complex.

V. HYDROXIDE SALTS (METAL HYDROXIDES)



HYDROXIDE SALTS

General formula	Metal + hydroxide ion (M + $(OH)^{-1}$)
Naming	Metal + "hydroxide"
Hazards	• Form very caustic solutions on contact with moisture. • Produce heat on contact with moisture.
Examples	• Sodium hydroxide ($NaOH$). • Lithium hydroxide ($LiOH$). • Potassium hydroxide (KOH). • Calcium hydroxide ($Ca(OH)_2$).

A. General formula/bonding.

1. Metal + hydroxide ion $(M + (OH)^{-1})$.
2. A hydroxide ion contains oxygen and hydrogen covalently bonded.
3. The hydroxide anion $(OH)^{-1}$ acts as a single anion.
4. It will act like a nonmetal in ionic reactions.
5. It is willing to accept one electron.

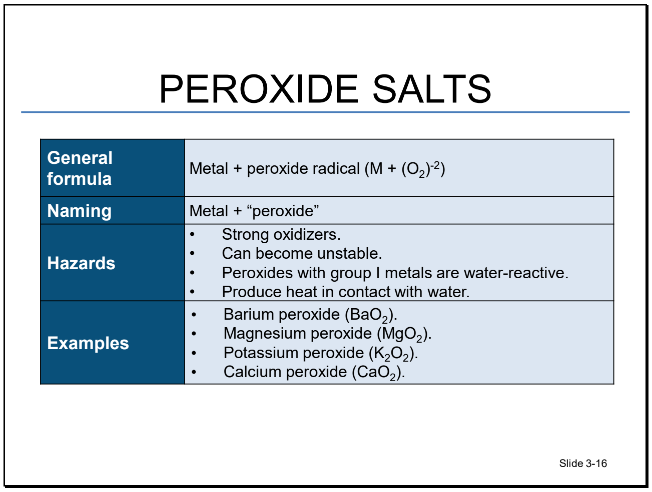
B. Naming.

1. Name the metal first.
2. Follow the metal name with "hydroxide."

C. Hazards.

1. They form very caustic solutions on contact with moisture (pH levels of 12 or higher).
2. They produce heat on contact with moisture.
3. They can cause severe burns when contacting moisture of the skin.
4. Generally, they are more reactive than the metal oxides (a type of binary salt).
5. In general, Family I elements will form the most reactive and caustic solutions.

VI. PEROXIDE SALTS



PEROXIDE SALTS

General formula	Metal + peroxide radical $(M + (O_2)^{-2})$
Naming	Metal + "peroxide"
Hazards	• Strong oxidizers. • Can become unstable. • Peroxides with group I metals are water-reactive. • Produce heat in contact with water.
Examples	• Barium peroxide (BaO_2). • Magnesium peroxide (MgO_2). • Potassium peroxide (K_2O_2). • Calcium peroxide (CaO_2).

A. General formula/bonding.

1. Metal + peroxide radical (M + $(O_2)^{-2}$).

2. Contains two oxygen atoms covalently bonded.

3. The complex ion acts as a singular anion.

4. It will act like a nonmetal in the ionic reaction.

5. It will accept two electrons.

6. It can become very unstable under certain conditions.

B. Naming.

1. Name the metal first.

2. Follow the metal with “peroxide.”

C. Hazards.

1. Strong oxidizers = evolve oxygen.

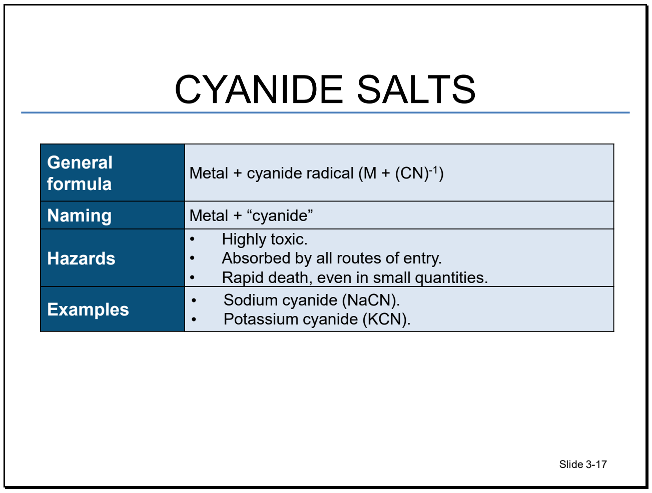
2. Can become unstable, especially with exposure to water.

3. If the peroxide is involved with a Group I metal, they will be water reactive.

4. Produce heat when in contact with water, which may ignite ordinary combustibles.

5. Sensitive to heat, light, pressure and shock.

VII. CYANIDE SALTS (METAL CYANIDES)



CYANIDE SALTS

General formula	Metal + cyanide radical (M + $(CN)^{-1}$)
Naming	Metal + “cyanide”
Hazards	• Highly toxic. • Absorbed by all routes of entry. • Rapid death, even in small quantities.
Examples	• Sodium cyanide (NaCN). • Potassium cyanide (KCN).

Slide 3-17

A. General formula/bonding.

1. Metal + cyanide radical (M + $(CN)^{-1}$).

2. Contains carbon and nitrogen covalently bonded — a triple bond between the C and the N.

3. The cyanide ion complex acts as a single anion.

4. It will act like a nonmetal in ionic reactions.

5. Due to its valence configuration, it will accept one electron.

B. Naming.

1. Name the metal first.

2. Follow the metal name with “cyanide.”

C. Uses: gold and silver extraction, pest control, electroplating, precursor in organic chemistry.

D. Hazards.

1. Highly toxic and flammable gas.

2. Absorbed by all routes of entry.

3. Rapid death, even in small quantities.

4. Hydrogen cyanide gas is produced when the salt contacts any acid. To a lesser extent, hydrogen cyanide can also be produced in contact with water.

ACTIVITY 3.3

Hydroxide, Peroxide and Cyanide Salts

Purpose

Identify the name or chemical formula of hydroxide salt compounds and the hazards of the family.

Directions

1. Working individually or with your group, complete the Hydroxide, Peroxide and Cyanide Salts Worksheet.
2. Identify the salt family and describe the hazards associated with the family.
3. If not completed in the time allotted, complete the activity as homework.

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ACTIVITY 3.3 (cont'd)

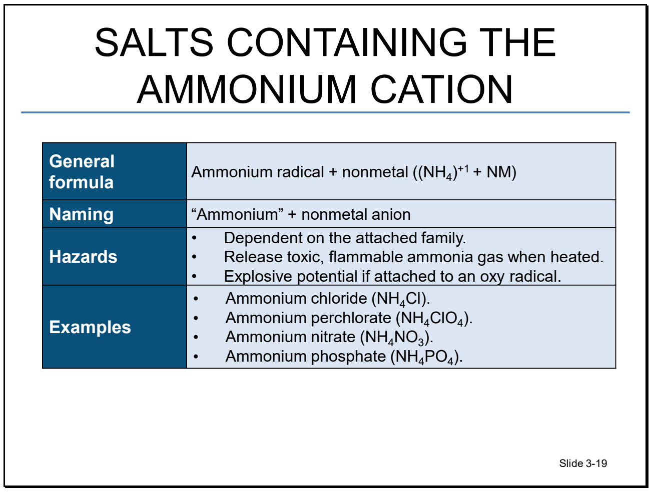
Hydroxide, Peroxide and Cyanide Salts

Complete the chart by identifying the salt family and hazards associated with the family.

#	Chemical name or formula	Family	Hazards
1.	Lithium hydroxide		
2.	Barium peroxide		
3.	Sodium cyanide		
4.	KOH		
5.	LiCN		
6.	Calcium peroxide		
7.	$Ca(OH)_2$		
8.	Copper II cyanide		
9.	Aluminum hydroxide		
10.	K_2O_2		
11.	Potassium cyanide		

#	Chemical name or formula	Family	Hazards
12.	$Mg(OH)_2$		
13.	$Sn(CN)_4$		
14.	Magnesium peroxide		
15.	Sodium hydroxide		
16.	$Ca(CN)_2$		
17.	Na_2O_2		
18.	Mercurous hydroxide		

VIII. SALTS CONTAINING THE AMMONIUM CATION



SALTS CONTAINING THE AMMONIUM CATION

General formula	Ammonium radical + nonmetal ($(NH_4)^{+1}$ + NM)
Naming	"Ammonium" + nonmetal anion
Hazards	• Dependent on the attached family. • Release toxic, flammable ammonia gas when heated. • Explosive potential if attached to an oxy radical.
Examples	• Ammonium chloride (NH_4Cl). • Ammonium perchlorate (NH_4ClO_4). • Ammonium nitrate (NH_4NO_3). • Ammonium phosphate (NH_4PO_4).

A. Compounds are "ammonium salts" due to the attachment of the ammonium cation. **These are not considered a stand-alone salt family. The salt family to which the ammonium cation is attached still brings all the associated hazards of that salt's family, in addition to hazards of the ammonium cation.**

B. General formula.

1. Ammonium radical + a nonmetal ($(NH_4)^{+1}$ + NM).

2. The name represents the ammonium ion and the attached family.

C. Naming.

1. Name the ammonium cation first. Names begin with "ammonium."

2. Follow this with the name of the attached anion.

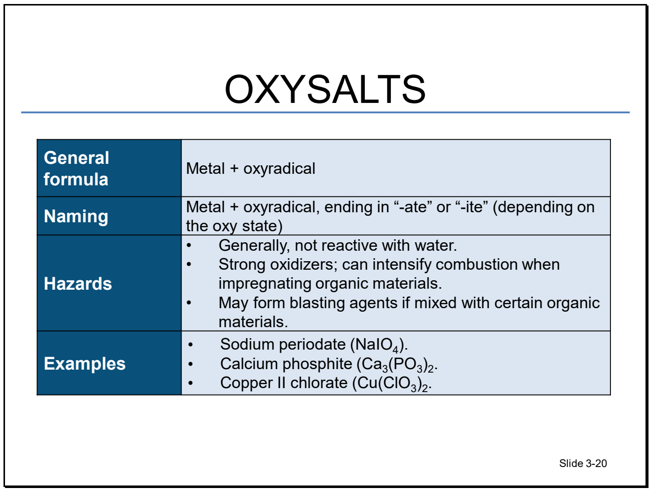
D. Hazards.

1. The hazard depends on the attached family.

2. Hawley's Condensed Chemical Dictionary provides the hazards of ammonium salts. When heated, they will release ammonia gas, which is flammable and toxic by inhalation and forms caustic substances in moisture (such as when in contact with skin).

3. Any time the ammonium cation is attached to an oxyradical, explosive potential could be a concern. This is because the ammonium cation becomes a fuel for the oxidizer. This will be discussed further in the oxysalts family.

IX. OXYSALTS



OXYSALTS

General formula	Metal + oxyradical
Naming	Metal + oxyradical, ending in "-ate" or "-ite" (depending on the oxy state)
Hazards	• Generally, not reactive with water. • Strong oxidizers; can intensify combustion when impregnating organic materials. • May form blasting agents if mixed with certain organic materials.
Examples	• Sodium periodate ($NaIO_4$). • Calcium phosphite ($Ca_3(PO_3)_2$. • Copper II chlorate ($Cu(ClO_3)_2$.

Slide 3-20

A. Formula: metal + oxyradical.

1. The radical is dependent on the oxygen state.

2. Oxygen content can vary.

3. The oxyradical is commonly a nonmetal bonded with oxygen. However, it can be certain metals bonded with oxygen.

4. The oxyradical has specific states and a corresponding valence charge, regardless of the oxygen content. The valence charge does not change while the oxygen content may change.

B. Common elements that form oxyradicals.

Table 3.3 Common oxyradicals (normal oxy states)

	-1 Valence		-2 Valence		-3 Valence
FO_3	Fluorate	CO_3	Carbonate	BO_3	Borate
ClO_3	Chlorate	CrO_4	Chromate	PO_4	Phosphate
BrO_3	Bromate	SO_4	Sulfate	AsO_4	Arsenate
IO_3	Iodate				
NO_3	Nitrate				
MnO_3	Manganate				

C. Naming.

1. Name the metal first.

2. Name the oxyradical based on the oxygen content as it relates to the normal oxy state on the chart.

3. All names end in “-ate” or “-ite,” depending on the oxygen content compared to the normal oxy state.

   a. One more oxygen than normal oxy state: per- prefix + -ate suffix.

   b. Normal oxy state: -ate suffix.

   c. One less oxygen than the normal oxy state: -ite suffix.

   d. Two less oxygen than the normal oxy state: hypo- prefix + -ite suffix.

Table 3.4 Oxyradical naming examples

Oxygen content	+1	Normal	-1	-2
Prefix	Per-	n/a	n/a	Hypo-
Suffix	-ate	-ate	-ite	-ite
Examples	Perchlorate Perbromate	Chlorate Sulfate	Chlorite Sulfite	Hypochlorite Hyposulfite

D. Hazards.

1. Generally, not reactive with water.

2. Strong oxidizers; can intensify combustion when impregnating organic materials.

3. May form blasting agents if mixed with certain organic materials.

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ACTIVITY 3.4

Oxysalts

Purpose

Identify the name or chemical formula of oxysalt compounds and the hazards of the family.

Directions

1. Working individually or with your group, complete **both** oxysalts worksheets by filling in the missing formula or chemical name. Refer to Table 3.3 as needed.
2. For each chemical that has specific hazards, describe the hazards.
3. If not completed in the time allotted, complete the activity as homework.

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ACTIVITY 3.4 (cont'd)

Oxysalts Worksheet 1

Complete the chart by filling in the proper chemical name or formula.

	Chemical name	Formula
1.	Sodium perchlorate	
2.		$Ca(IO_2)_2$
3.	Copper II iodate	
4.		Na_3PO_2
5.	Potassium chlorate	
6.		$KMnO_4$
7.		Na_3PO_4

Describe the hazards associated with oxysalts.

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ACTIVITY 3.4 (cont'd)

Oxysalts Worksheet 2

	Iodate	Chlorate	Bromate	Carbonate	Phosphate
Sodium					
Calcium					
Copper II					
Potassium					

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ACTIVITY 3.5

Identifying Salts and Their Hazards

Purpose

Analyze all families of salts, including name, general formula, hazards and any special rules.

Directions

1. Working with your group, complete the Identifying Salts and Their Hazards Worksheet by identifying the chemical family (from the list below) and hazards of the family.
   a. Binary salt.
   b. Hydroxide salt.
   c. Peroxide salt.
   d. Cyanide salt.
   e. Oxysalt.
2. If not completed in the time allotted, complete the activity as homework.

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ACTIVITY 3.5 (cont'd)

Identifying Salts and Their Hazards Worksheet

#	**Chemical name or formula**	**Chemical family**	**Hazards**
1	NaCN		
2	NH_4OH		
3	aluminum nitride		
4	copper II chloride		
5	$Mg(MnO_4)_2$		
6	Li_2O		
7	KOH		
8	lithium sulfide		

#	Chemical name or formula	Chemical family	Hazards
9	MgF_2		
10	iron III sulfite		
11	calcium oxide		
12	$Be(ClO)_2$		
13	ferric oxide		
14	$NaOH$		
15	$AlCl_3$		
16	lithium hydroxide		

#	Chemical name or formula	Chemical family	Hazards
17	$Ba_3(PO_5)_2$		
18	MgO_2		
19	sodium oxide		
20	calcium permanganate		
21	LiNO		
22	sodium hydride		
23	$Mg(OH)_2$		
24	$KMnO_2$		

#	Chemical name or formula	Chemical family	Hazards
25	Ba_3N_2		
26	calcium peroxide		
27	Li_3PO_5		
28	potassium sulfide		
29	MgO		
30	$NaClO$		
31	barium hydroxide		
32	$Ca(CN)_2$		

#	Chemical name or formula	Chemical family	Hazards
33	ammonium perchlorate		
34	KCN		
35	copper II phosphide		

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ACTIVITY 3.6

Analyzing Salt Hazards

Purpose

Identify the type of salt and the potential hazards involved, given a description of a substance involved in an incident.

Directions

1. Review the scenario with your group.
2. Identify the formulas of the salts given and the hazards associated with them using the Analyzing Salt Hazards Worksheet.
3. The instructor will facilitate a discussion about the hazards with the class at the end of the activity.
4. Be prepared to answer questions.

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ACTIVITY 3.6 (cont'd)

Salt Hazards Scenario

You have been called to a chemical warehouse. The owner is concerned that there may be a problem. They are not familiar with any of the chemicals. The owner only knows the names or formulas (from the Safety Data Sheets (SDSs)) and the customers who purchase the chemicals.

About a week ago, one of their employees placed a pallet of chemicals in the back portion of the warehouse. The employee was unaware that these chemicals were not supposed to be stored in this area. Over the long holiday weekend, the sprinkler system that serves that portion of the warehouse burst. The night crew cleaned up with rags and mops and stored these after use in the front storeroom.

The chemicals include:

- Potassium peroxide.
- Magnesium peroxide.
- Calcium peroxide.
- Lead IV carbonite.
- Potassium perbromate.
- Calcium phosphite.

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ACTIVITY 3.6 (cont'd)

Analyzing Salt Hazards Questions

1. Use the worksheet to sort the chemicals by family and record the hazards associated with them.

2. What are your concerns with the chemicals involved?

____

____

____

3. Upon further analysis of the facility map, you see that the sprinkler system is fed through a section of the warehouse that has the following chemicals:

   - Potassium hydride.
   - Calcium carbide.
   - Magnesium phosphide.
   - Magnesium oxide.
   - Iron II oxide.
   - Copper II oxide.

   Failure of this section of the system has been noted at other incidents that you have been to in the past.

   Update the worksheet with these chemicals.

4. What are your concerns with the above chemicals and where they are stored?

____

____

____

5. Your technical specialist — hazardous materials research (science/research officer) tells you that a large supply of the following chemicals was identified on the Tier II reporting form. The Tier II form lists the following chemicals:

    - Potassium hydroxide.
    - Magnesium hydroxide.
    - Lithium hydroxide.
    - Potassium cyanide.
    - Sodium cyanide.
    - Ammonium chloride.
    - Ammonium nitrate.

    Update the worksheet with these chemicals.

6. What are your concerns?

    ___

    ___

    ___

ACTIVITY 3.6 (cont'd)

Analyzing Salt Hazards Worksheet

Use this space to sort the chemicals by family and record your responses about the hazards.

Salt family	Chemical name	Formula	Hazards for this family
Peroxide salts			
Oxysalts			
Binary salts			
Metal hydroxides			
Cyanide salts			
Salts containing the ammonium cation			

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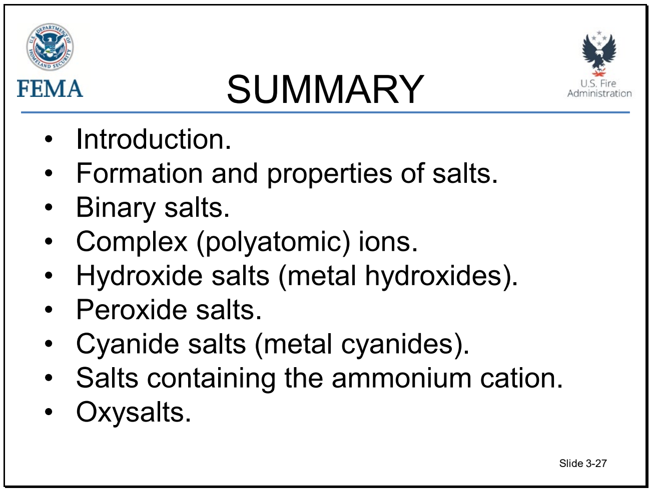
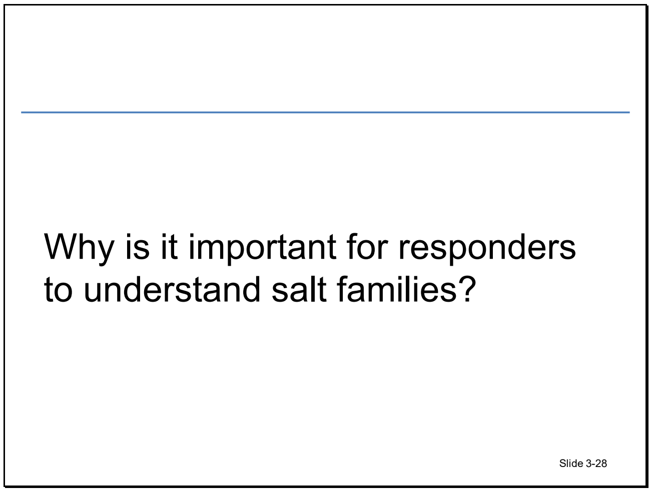
X. SUMMARY

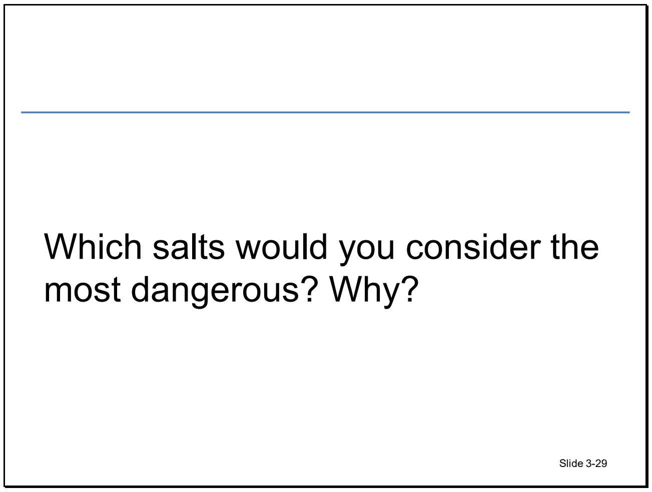


SUMMARY

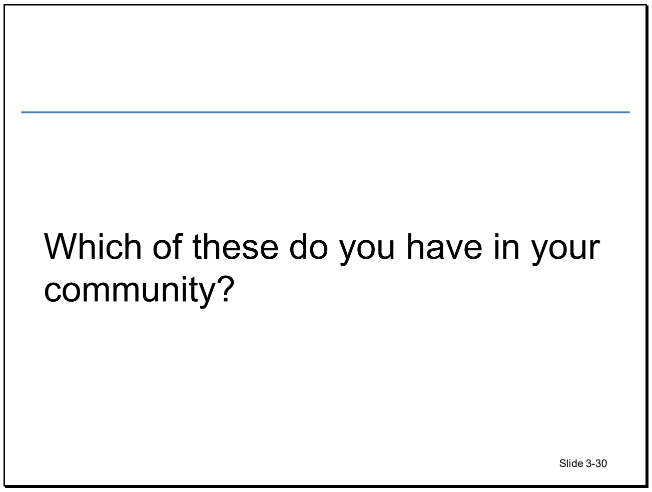
- Introduction.
- Formation and properties of salts.
- Binary salts.
- Complex (polyatomic) ions.
- Hydroxide salts (metal hydroxides).
- Peroxide salts.
- Cyanide salts (metal cyanides).
- Salts containing the ammonium cation.
- Oxysalts.



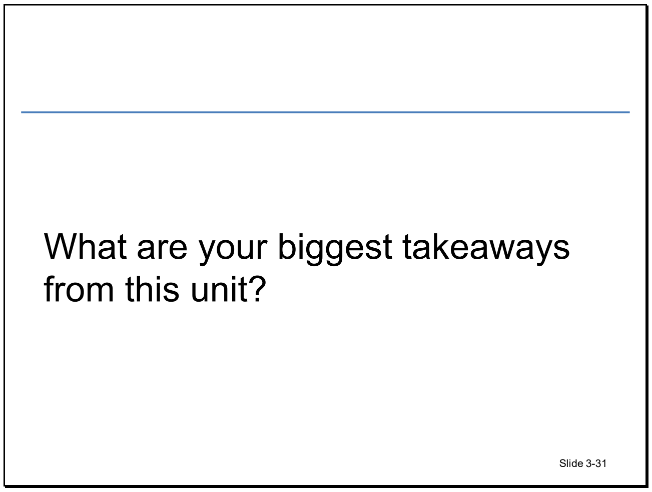
Why is it important for responders to understand salt families?



Which salts would you consider the most dangerous? Why?



Which of these do you have in your community?



What are your biggest takeaways from this unit?

APPENDIX A

CHEMICAL FAMILY SUMMARY WORKSHEETS FOR THE SALTS

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CHEMICAL FAMILY SUMMARY WORKSHEET: BINARY SALTS

General formula:

Naming conventions (classical/IUPAC)

What are the general hazards associated with this family?

What are the common uses or applications of this family?
Remarks or other considerations?
Common examples (optional)
Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: CYANIDE SALTS

General formula:
Naming conventions (classical/IUPAC)
What are the general hazards associated with this family?

What are the common uses or applications of this family?
Remarks or other considerations?
Common examples (optional)
Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: METAL OXIDES

General formula:
Naming conventions (classical/IUPAC)
What are the general hazards associated with this family?

What are the common uses or applications of this family?
Remarks or other considerations?
Common examples (optional)
Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: HYDROXIDE SALTS

General formula:
Naming conventions (classical/IUPAC)
What are the general hazards associated with this family?

What are the common uses or applications of this family?

Remarks or other considerations?

Common examples (optional)

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: PEROXIDE SALTS

General formula:
Naming conventions (classical/IUPAC)
What are the general hazards associated with this family?

What are the common uses or applications of this family?

Remarks or other considerations?

Common examples (optional)

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: OXYSALTS

General formula:

Naming conventions (classical/IUPAC)

What are the general hazards associated with this family?

What are the common uses or applications of this family?
Remarks or other considerations?
Common examples (optional)
Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: SALTS CONTAINING AMMONIUM

General formula:
Naming conventions (classical/IUPAC)
What are the general hazards associated with this family?

What are the common uses or applications of this family?

Remarks or other considerations?

Common examples (optional)

Sources of additional information (optional)

APPENDIX B

CHEMICAL FAMILY SUMMARY WORKSHEETS FOR THE SALTS: ANSWER KEYS

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CHEMICAL FAMILY SUMMARY WORKSHEET: BINARY SALTS

General formula:

Metal + nonmetal except oxygen

Naming conventions (classical/IUPAC)

Classical:

Name the metal first.

Name the nonmetal next with "-ide" ending (chlorine> chloride, hydrogen> hydride, carbon> carbide).

If transition metal is used, refer to transitional metal worksheet for conventional naming method.

IUPAC:

For salts with transitional metals, name metal first with Roman numeral indicating its valent state. Then name the nonmetal.

What are the general hazards associated with this family?

Hazards are dependent on the base metal. Hazards are varied except for the PNCHO salts, which have specific hazards when mixed with water:

P*hosphides — produce phosphene gas.*
N*itrides — produce ammonia gas.*
C*arbides — produce acetylene gas.*
H*ydrides — produce hydrogen gas and heat.*
O*xides — release heat and form very caustic solutions.*

What are the common uses or applications of this family?

Remarks or other considerations?

Common examples (optional)

Na^{+1} $(CN)^{-1}$	*NaCN*	*Sodium cyanide*
K^{+1} $(CN)^{-1}$	*KCN*	*Potassium cyanide*

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: CYANIDE SALTS

General formula:

Metal + cyanide radical
$M + (CN)^{-1}$

Naming conventions (classical/IUPAC)

Name the metal first, followed by "cyanide."

What are the general hazards associated with this family?

Extremely toxic; flammable gas; absorbed by all routes of entry.

What are the common uses or applications of this family?
Remarks or other considerations?
Common examples (optional)
Potassium cyanide KCN *Sodium cyanide NaCN*
Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: METAL OXIDES

General formula:

Metal + oxygen

Naming conventions (classical/IUPAC)

Name the metal first, followed by "oxide."

What are the general hazards associated with this family?

When mixed with water, will form a caustic solution and may release significant amounts of heat. This heat may be enough to ignite nearby combustibles. May burn skin from reaction with moisture on skin. Heat of reaction will cause spattering of caustic solution.

In general, the further to the left the metal is on the periodic table, the more intense the reaction.

What are the common uses or applications of this family?

Remarks or other considerations?

Common examples (optional)

Mg+2 O-2	*MgO*	*Magnesium oxide*	
Ca^{+2} O^{-2}	CaO	*Calcium oxide*	
Be^{+2} O^{-2}	BeO	*Beryllium oxide*	
Na^{+1} O^{-2}	Na_2O	*Sodium oxide*	
Fe^{+2} O^{-2}	FeO	*Iron II oxide*	*Ferrous oxide*
Sn^{+4} O^{-2}	SnO_2	*Tin IV oxide*	*Stannic oxide*
Cu^{+2} O^{-2}	CuO	*Copper II oxide*	*Cupric oxide*

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: HYDROXIDE SALTS

General formula:

Metal + hydroxide radical $(OH)^{-1}$

Naming conventions (classical/IUPAC)

Name the metal first, followed by "hydroxide."

What are the general hazards associated with this family?

When mixed with water, will generate heat and form a caustic liquid. Will burn skin when it reacts with moisture. Heat can ignite nearby combustibles.

In general, the further left on the periodic table the metal is, the more intense the reaction.

Generally, more reactive than metal oxides.

What are the common uses or applications of this family?

Remarks or other considerations?

Common examples (optional)

$Na^{+1} (OH)^{-1}$	$NaOH$	*Sodium hydroxide*	
$Li^{+1} (OH)^{-1}$	$LiOH$	*Lithium hydroxide*	
$K^{+1} (OH)^{-1}$	KOH	*Potassium hydroxide*	
$Ca^{+1} (OH)^{-1}$	$CaOH$	*Calcium hydroxide*	
$Pb^{+4} (OH)^{-1}$	$Pb(OH)_4$	*Lead IV hydroxide*	*Plumbic hydroxide*
$Mg^{+2} (OH)^{-1}$	$Mg(OH)_2$	*Magnesium hydroxide*	

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: PEROXIDE SALTS

General formula:

Metal + peroxide radical $(O_2)^{-2}$

Naming conventions (classical/IUPAC)

Name the metal first, followed by "peroxide."

What are the general hazards associated with this family?

Very strong oxidizers. Can become unstable and sensitive to heat, light and pressure shock.

When mixed with water, will give off oxygen gas and produce heat that may ignite nearby combustibles.

May be corrosive to skin.

What are the common uses or applications of this family?

Remarks or other considerations?

Water-reactive

Common examples (optional)

$Ba^{+2} (O_2)^{-2}$	BaO_2	*Barium peroxide*	
$Mg^{+2} (O_2)^{-2}$	MgO_2	*Magnesium peroxide*	
$K^{+1} (O_2)^{-2}$	K_2O_2	*Potassium peroxide*	
$Ca^{+2} (O_2)^{-2}$	CaO_2	*Calcium peroxide*	
$Hg^{+1} (O_2)^{-2}$	Hg_2O_2	*Mercury I peroxide*	*Mercurous peroxide*

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: OXYSALTS

General formula:

Metal + oxy radical

Naming conventions (classical/IUPAC)

Name the metal first, followed by the name of the element attached to the oxygen in the radical with the prefix and ending that denotes the amount of oxygen in the radical. See the table below.

Common oxyradicals (normal oxy states)

	-1 Valence		-2 Valence		-3 Valence
FO_3	Fluorate	CO_3	Carbonate	BO_3	Borate
ClO_3	Chlorate	CrO_4	Chromate	PO_4	Phosphate
BrO_3	Bromate	SO_4	Sulfate	AsO_4	Arsenate
IO_3	Iodate				
NO_3	Nitrate				
MnO_3	Manganate				

What are the general hazards associated with this family?

Generally, not water reactive.

Strong oxidizers can cause the combustion of organic materials or intensify combustion.

May form blasting agents when mixed with organic materials.

What are the common uses or applications of this family?

Remarks or other considerations?

Water-soluble

Common examples (optional)

$NaIO_4$	*Sodium periodate*
$NaIO_3$	*Sodium iodate*
$NaIO_2$	*Sodium iodite*
$NaIO$	*Sodium hypoiodite*
$Ca_3(PO_3)_2$	*Calcium phosphite*
$Cu(ClO_3)_2$	*Copper II chlorate (cupric chlorate)*
$KBrO_4$	*Potassium perbromate*
Na_2CO_2	*Sodium carbonite*
$Ca(ClO)_2$	*Calcium hypochlorite*
$NaBrO_3$	*Sodium bromate*
$Pb(CO_2)_2$	*Lead IV carbonite (plumbic carbonite)*
$Hg(BrO)_2$	*Mercury II hypobromite (mercuric hypobromite)*
$MgSO_4$	*Magnesium sulfate (Epsom salt)*

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: SALTS CONTAINING AMMONIUM

General formula:

Ammonium radical $(NH_4)^{+1}$ *+ nm or other radical*

Naming conventions (classical/IUPAC)

Call it ammonium followed by the attached complex.

What are the general hazards associated with this family?

Hazards are dependent on the attachment.

What are the common uses or applications of this family?

Remarks or other considerations?

Common examples (optional)

$(NH_4)^{+1}\ Cl^{-1}$	NH_4Cl	*Ammonium chloride*
$(NH_4)^{+1}\ Br^{-1}$	NH_4Br	*Ammonium bromide*
$(NH_4)^{+1}\ (NO_3)^{-1}$	NH_4NO_3	*Ammonium nitrate*

Sources of additional information (optional)

UNIT 4:
INORGANIC NONSALTS

TERMINAL OBJECTIVE

The students will be able to:

4.1 Justify scene control, detection, personal protective equipment (PPE) and decontamination considerations, given a scenario involving an inorganic nonsalt compound.

ENABLING OBJECTIVES

The students will be able to:

4.1 Analyze a name or a formula to identify the families of inorganic nonsalt compounds and their hazards.

4.2 Recommend scene control, detection, PPE and decontamination considerations based on a product hazard analysis for an incident involving an inorganic nonsalt compound.

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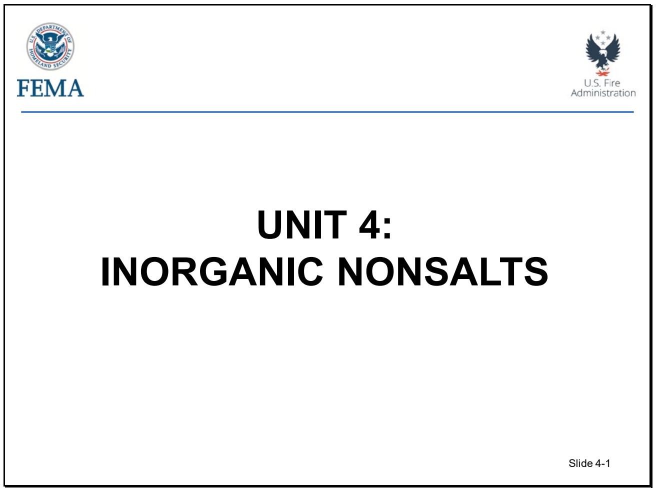
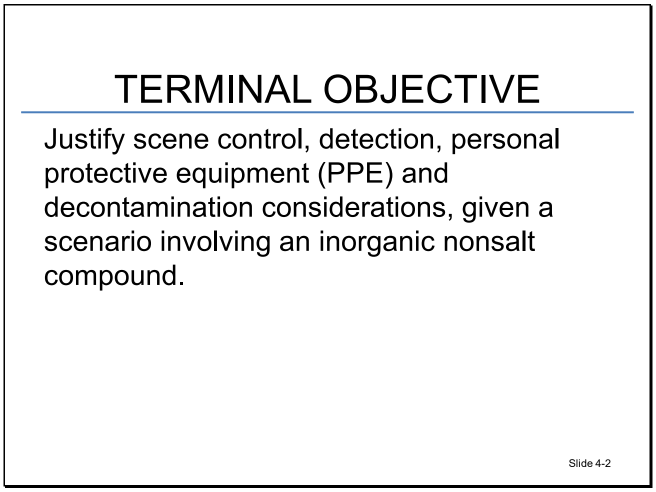


FEMA

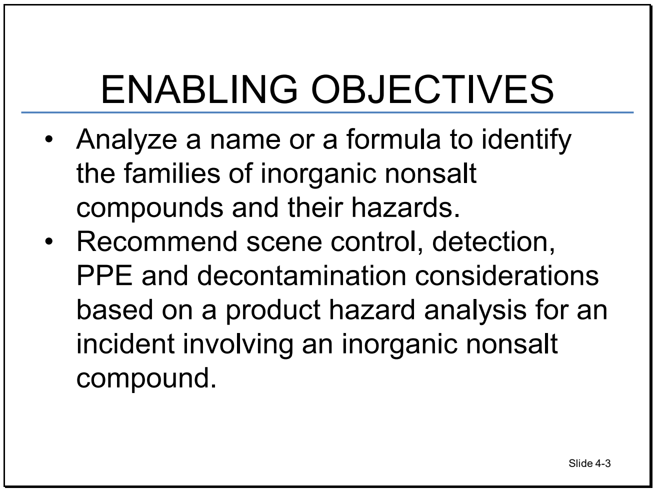
U.S. Fire Administration

UNIT 4:
INORGANIC NONSALTS



TERMINAL OBJECTIVE

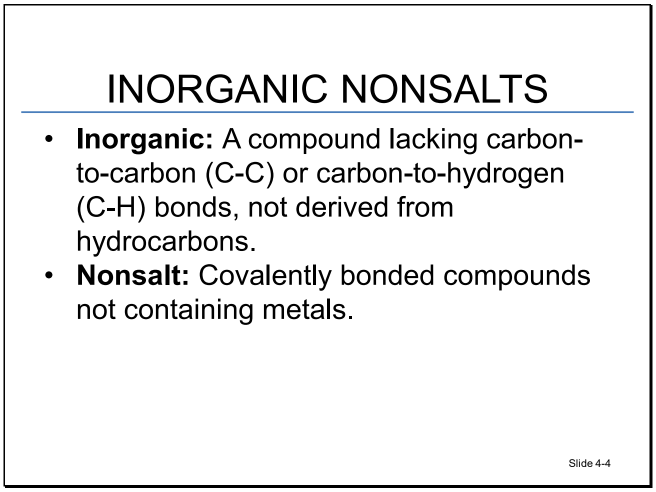
Justify scene control, detection, personal protective equipment (PPE) and decontamination considerations, given a scenario involving an inorganic nonsalt compound.



ENABLING OBJECTIVES

- Analyze a name or a formula to identify the families of inorganic nonsalt compounds and their hazards.
- Recommend scene control, detection, PPE and decontamination considerations based on a product hazard analysis for an incident involving an inorganic nonsalt compound.

I. INTRODUCTION



INORGANIC NONSALTS

- **Inorganic:** A compound lacking carbon-to-carbon (C-C) or carbon-to-hydrogen (C-H) bonds, not derived from hydrocarbons.
- **Nonsalt:** Covalently bonded compounds not containing metals.

Definitions.

A. Inorganic: a compound lacking carbon-to-carbon (C-C) or carbon-to-hydrogen (C-H) bonds, not derived from hydrocarbons.

B. Nonsalt: covalently bonded compounds not containing metals.

ACTIVITY 4.1

Getting to Know the Inorganic Nonsalts

Purpose

Evaluate the characteristics and hazards of inorganic nonsalt families.

Directions

1. Work with your group to conduct a product hazard analysis of your assigned chemical from the list below.

    a. Phosphorus trichloride.

    b. Sulfur dioxide.

    c. Nitric acid.

    d. Hydrogen bromide.

    e. Cyanogen chloride.

2. Complete the Product Hazard Analysis Worksheet. You may use your text and electronic or printed resources.

3. Record significant findings on an easel pad.

4. Choose a spokesperson to discuss your findings with the class.

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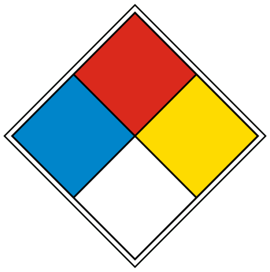

ACTIVITY 4.1 (cont'd)

Product Hazard Analysis Worksheet

Group Number: ________ **Presenter:** ________________________

Temp: _________ °F **R/H:** _________%

Product Name:_________________________________ **Family:**__________________________

Data Points	Result	No Data	Hazard Consideration
Physical Properties			
Physical State			
Vapor Pressure			
Boiling Point			
Vapor Density			
Specific Gravity			
Solubility			
Flammability			
Flash Point			
LEL/UEL			
Flammable Range			
Ignition Temp.			
Toxicity			
Route of Exposure			
IDLH			
PEL/REL/STEL			
S/S of Exposure			
Biological			
Corrosivity			
pH			
Concentration			
Reactivity/Explosion			
Radioactivity			
Decay Mode	☐ **N/A** ☐ α ☐ β ☐ γ		
Half Life			

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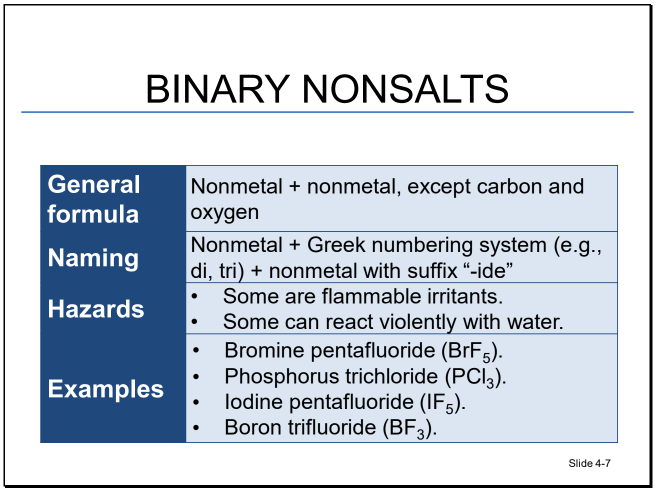
II. INTRODUCTION TO INORGANIC NONSALTS



BINARY NONSALTS

General formula	Nonmetal + nonmetal, except carbon and oxygen
Naming	Nonmetal + Greek numbering system (e.g., di, tri) + nonmetal with suffix "-ide"
Hazards	• Some are flammable irritants. • Some can react violently with water.
Examples	• Bromine pentafluoride (BrF_5). • Phosphorus trichloride (PCl_3). • Iodine pentafluoride (IF_5). • Boron trifluoride (BF_3).

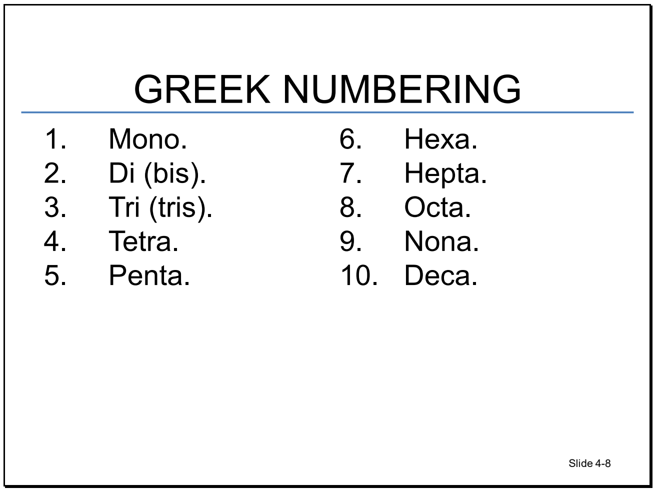
A. Binary nonsalts.

1. General formula: nonmetal + nonmetal, except carbon and oxygen.

2. Naming:

   a. Name each nonmetal with an "-ide" ending.

   b. Identify the number of the second nonmetal using the Greek numbering system (attach it to the second nonmetal).



GREEK NUMBERING

1. Mono.
2. Di (bis).
3. Tri (tris).
4. Tetra.
5. Penta.
6. Hexa.
7. Hepta.
8. Octa.
9. Nona.
10. Deca.

3. Hazards:

   a. Binary nonsalts have a variety of hazards.

   b. Some are flammable and/or irritants.

c. Some can react violently with water.

4. Examples:

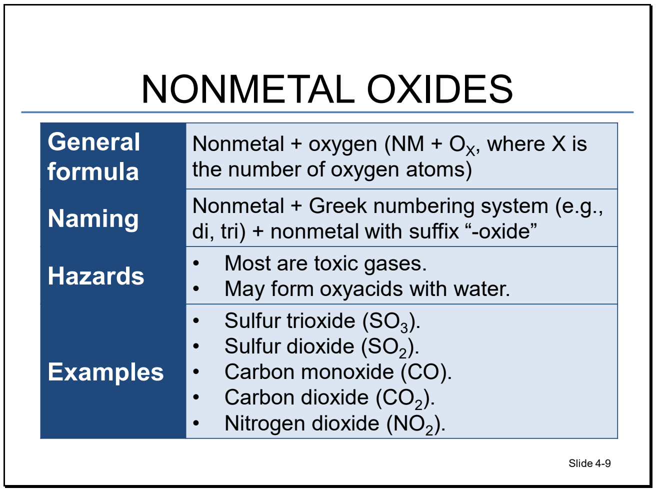
a. BrF_5: Bromine pentafluoride.

b. PCl_3: Phosphorus trichloride.

c. IF_5: Iodine pentafluoride.

d. BF_3: Boron trifluoride.

e. H_2S: Hydrogen sulfide.



NONMETAL OXIDES

General formula	Nonmetal + oxygen (NM + O_X, where X is the number of oxygen atoms)
Naming	Nonmetal + Greek numbering system (e.g., di, tri) + nonmetal with suffix “-oxide”
Hazards	• Most are toxic gases. • May form oxyacids with water.
Examples	• Sulfur trioxide (SO_3). • Sulfur dioxide (SO_2). • Carbon monoxide (CO). • Carbon dioxide (CO_2). • Nitrogen dioxide (NO_2).

B. Nonmetal oxides.

1. General formula: nonmetal + oxygen, or nonmetal + O_X, where X is the number of oxygen atoms.

2. Naming.

a. Name the nonmetal.

b. Name the oxide using Greek nomenclature for the number of oxygen atoms it contains, ending in “-oxide.”

3. Hazards.

a. Most are toxic gases.

b. When mixed with water, may form oxyacids.

4. Examples.

   a. SO_3: sulfur trioxide.

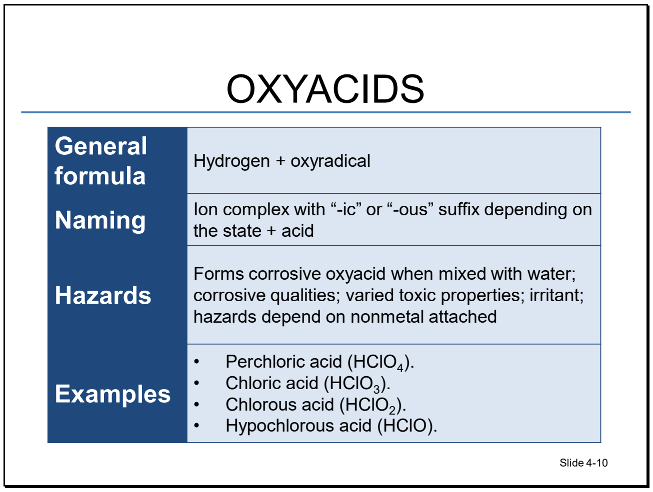
   b. SO_2: sulfur dioxide.

   c. CO: carbon monoxide.

   d. CO_2: carbon dioxide.

   e. NO_2: nitrogen dioxide.

5. Uses: produced by the industrial process, products of combustion and internal combustion engine.



OXYACIDS

General formula	Hydrogen + oxyradical
Naming	Ion complex with "-ic" or "-ous" suffix depending on the state + acid
Hazards	Forms corrosive oxyacid when mixed with water; corrosive qualities; varied toxic properties; irritant; hazards depend on nonmetal attached
Examples	• Perchloric acid ($HClO_4$). • Chloric acid ($HClO_3$). • Chlorous acid ($HClO_2$). • Hypochlorous acid (HClO).

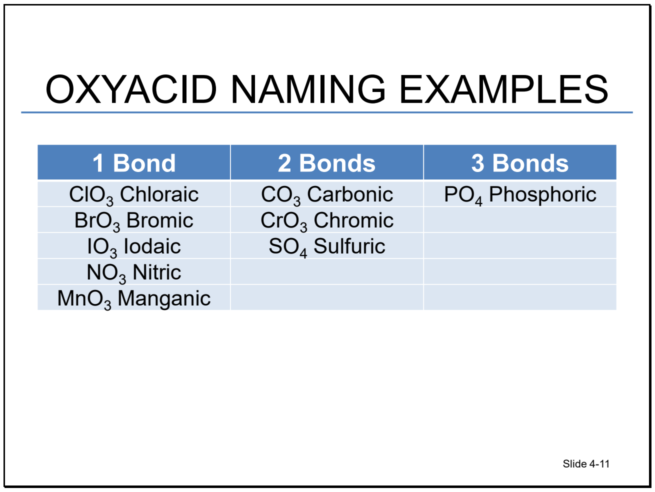
Slide 4-10

C. Oxyacids.

1. General formula: hydrogen + oxyradical.

   a. The radical is most often a nonmetal bonded with oxygen; however, it can be a metal with oxygen.

   b. The oxyradical has specific states and a corresponding valence charge regardless of the oxygen content.



OXYACID NAMING EXAMPLES

1 Bond	2 Bonds	3 Bonds
ClO_3 Chloraic	CO_3 Carbonic	PO_4 Phosphoric
BrO_3 Bromic	CrO_3 Chromic	
IO_3 Iodaic	SO_4 Sulfuric	
NO_3 Nitric		
MnO_3 Manganic		

2. Naming.

   a. Name ends in “-ic” or “-ous” depending on the state.

   b. Name the ion complex.

   c. Names are derived from the base state:

      - One oxygen above normal: use the prefix “per-” and the suffix “-ic.”

      - Normal state: use the suffix “-ic.”

      - One oxygen below normal state: use the suffix “-ous.”

      - Two oxygens below normal state: use the prefix “hypo-” and the suffix “-ous.”

3. Hazards.

   a. A strong inorganic acid is formed when a nonmetal combines with an oxygen complex. It forms a corrosive oxyacid when mixed with water.

   b. Strong corrosive qualities and may be a strong oxidizer.

   c. Specific hazards are dependent on the nonmetal attached.

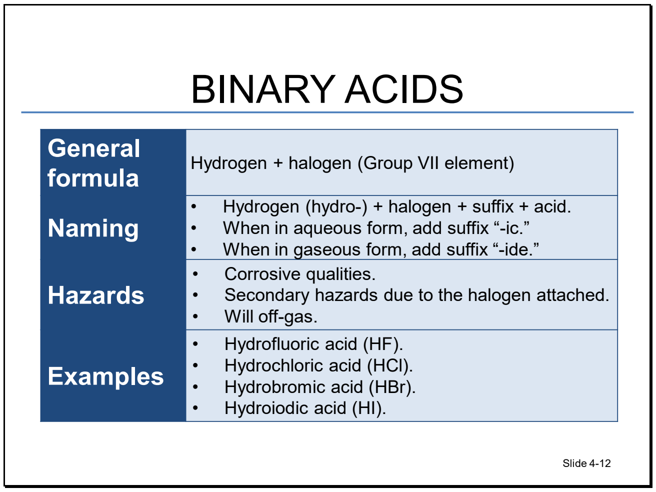
4. Examples.

   a. $HClO_4$: perchloric acid.

b. $HClO_3$: chloric acid (normal state).

c. $HClO_2$: chlorous acid.

d. $HClO$: hypochlorous acid.



BINARY ACIDS

General formula	Hydrogen + halogen (Group VII element)
Naming	• Hydrogen (hydro-) + halogen + suffix + acid. • When in aqueous form, add suffix "-ic." • When in gaseous form, add suffix "-ide."
Hazards	• Corrosive qualities. • Secondary hazards due to the halogen attached. • Will off-gas.
Examples	• Hydrofluoric acid (HF). • Hydrochloric acid (HCl). • Hydrobromic acid (HBr). • Hydroiodic acid (HI).

Slide 4-12

D. Binary acids.

1. General formula: hydrogen + halogen (Group VII element).

   a. This family of compounds has a very specific number of compounds, as it is associated with the combination of hydrogen and a nonmetal from the halogen group.

   b. Also known as the "acid gases" or "hydrogen halides."

2. Naming: based on the halogen from which it was derived.

   a. Name the hydrogen with "hydro-."

   b. Name the halogen.

   c. When in gaseous form, add the suffix "-ide" to the name of the halogen. When in the aqueous form, name the halogen with the suffix "-ic."

   d. End the entire name with "acid."

3. Hazards.

   a. Corrosive qualities.

  b. Secondary hazards due to the halogen attached.

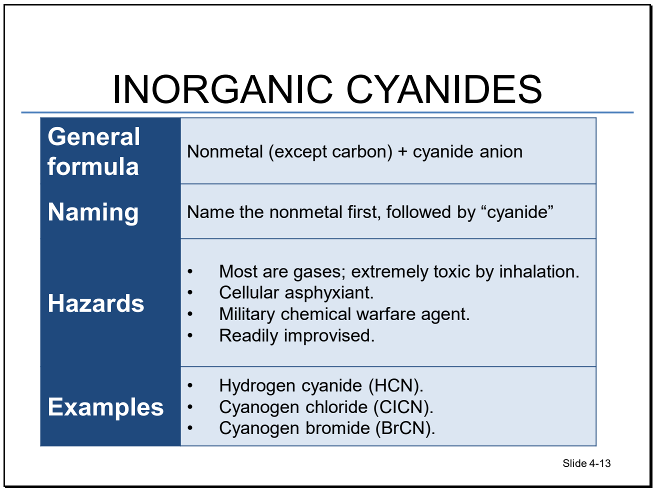
4. Examples.

  a. HF: hydrofluoric acid.

  b. HCl: hydrochloric acid.

  c. HBr: hydrobromic acid.

  d. HI: hydroiodic acid.



INORGANIC CYANIDES

General formula	Nonmetal (except carbon) + cyanide anion
Naming	Name the nonmetal first, followed by “cyanide”
Hazards	• Most are gases; extremely toxic by inhalation. • Cellular asphyxiant. • Military chemical warfare agent. • Readily improvised.
Examples	• Hydrogen cyanide (HCN). • Cyanogen chloride (ClCN). • Cyanogen bromide (BrCN).

E. Inorganic cyanides.

1. General formula: nonmetal (except carbon) + cyanide anion (CN^{-1}).

2. Naming.

  a. Name the nonmetal first, followed by the word “cyanide.”

  b. Or use the prefix “cyanogen.” Then name the nonmetal.

3. Hazards.

  a. Most are gases (BrCN is a crystalline) that are extremely toxic by inhalation.

  b. Interrupts cellular ability to use oxygen (cellular asphyxiant).

  c. Military chemical warfare agent.

  d. Readily improvised.

4. Examples.

   a. HCN: hydrogen cyanide.

   b. CNCl: cyanogen chloride.

   c. BrCN: cyanogen bromide.

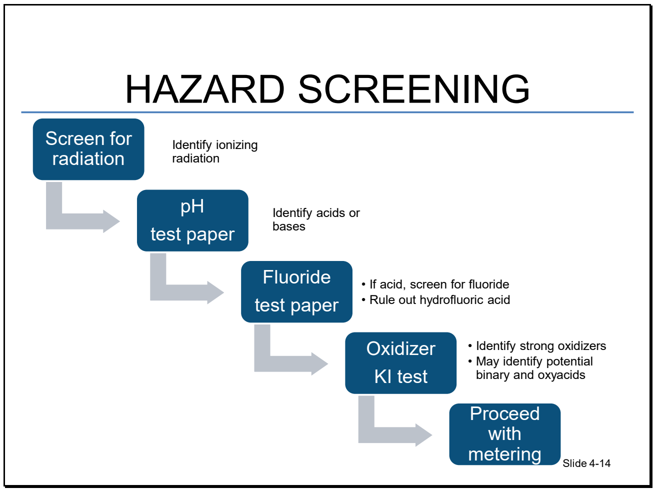
5. Uses.

   a. Chemical warfare agents.

   b. Chemical precursor.

   c. Gold and silver extraction.

   d. Jewelry manufacture.



HAZARD SCREENING

Screen for radiation
- Identify ionizing radiation

pH test paper
- Identify acids or bases

Fluoride test paper
- If acid, screen for fluoride
- Rule out hydrofluoric acid

Oxidizer KI test
- Identify strong oxidizers
- May identify potential binary and oxyacids

Proceed with metering

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ACTIVITY 4.2

Hazards of Inorganic Nonsalts

Purpose

Evaluate the materials involved in an incident.

Directions

After responding to an incident at a waterflood station involving hydrogen sulfide gas, you are preparing to make an entry into the environment to determine the airborne hazards and status of possible victims. The incident has attracted numerous observers, including media, the public and industry officials.

1. Working with your group, conduct a hazard analysis of the scenario.
2. Complete the Product Hazard Analysis Worksheet.
3. Describe how the information you found impacts your decision-making related to each of the following incident considerations:
    a. Scene control.
    b. Personal protective equipment (PPE).
    c. Detection.
    d. Decontamination.
    e. Product Hazard Analysis.

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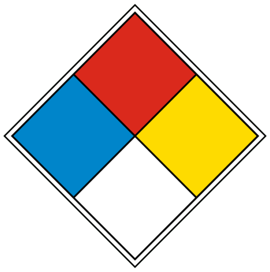

ACTIVITY 4.2 (cont'd)

Product Hazard Analysis Worksheet

Group Number: ________ **Presenter:** ________________________

Temp: _________ °F **R/H:** _________%

Product Name:_________________________________ **Family:**___________________________

Data Points	Result	No Data	Hazard Consideration
Physical Properties			
Physical State			
Vapor Pressure			
Boiling Point			
Vapor Density			
Specific Gravity			
Solubility			
Flammability			
Flash Point			
LEL/UEL			
Flammable Range			
Ignition Temp.			
Toxicity			
Route of Exposure			
IDLH			
PEL/REL/STEL			
S/S of Exposure			
Biological			
Corrosivity			
pH			
Concentration			
Reactivity/Explosion			
Radioactivity			
Decay Mode	☐ **N/A** ☐ α ☐ β ☐ γ		
Half Life			

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ACTIVITY 4.3

Identifying Inorganic Nonsalts and Their Hazards

Purpose

Identify the family and hazards of various inorganic nonsalts.

Directions

1. Complete the worksheet individually or working with your table group.
2. Based on the formula or chemical name provided, identify the family to which the chemical belongs. Fill in the general hazards of the family.
3. If not completed in the time allotted, complete the activity during the evening session.

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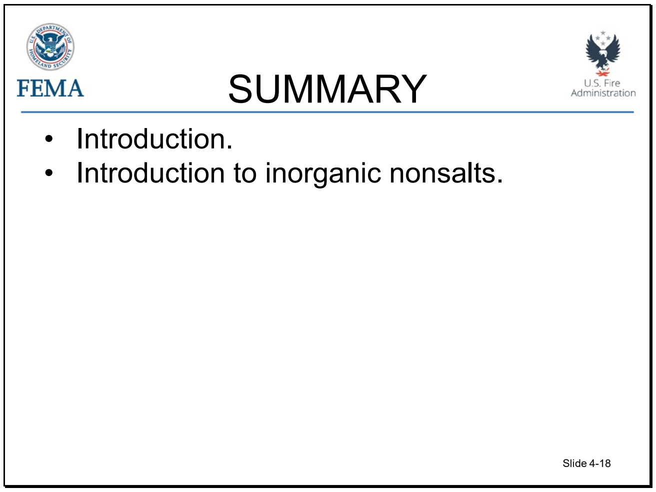
ACTIVITY 4.3 (cont'd)

Identifying Inorganic Nonsalts and Their Hazards

#	Name or formula	Family	General hazards
1.	SO_3		
2.	Boron trifluoride		
3.	N_2O_4		
4.	Sulfur dioxide		
5.	NH_3		
6.	Phosphorus pentoxide		
7.	Phosphorus trihydride (phosphene)		
8.	ClO_2		
9.	Silicon tetrahydride (silane)		
10.	Phosphoric acid		
11.	HCl		
12.	Cyanogen chloride		
13.	H_2SO_4		
14.	Hydrofluoric acid		
15.	CNI		

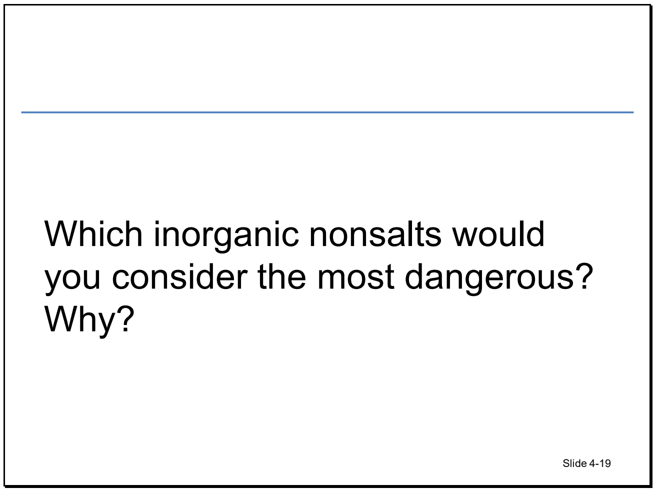
#	Name or formula	Family	General hazards
16.	Hypochlorous acid		
17.	$HBrO_4$		
18.	Hydrogen iodide		
19.	HNO_3		
20.	Bromine pentafluoride		

III. SUMMARY

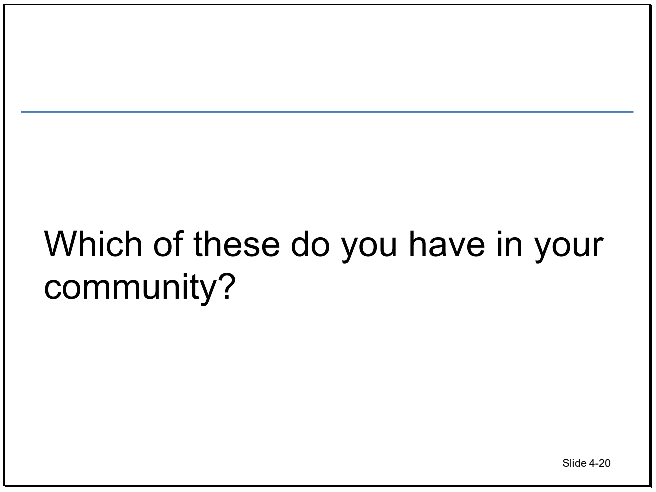


SUMMARY

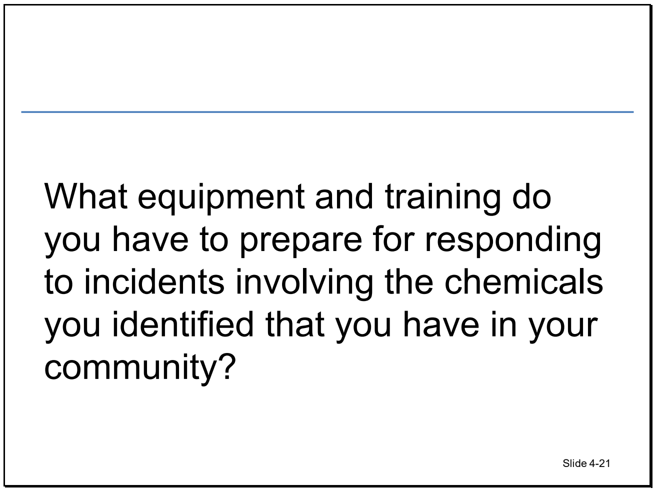
- Introduction.
- Introduction to inorganic nonsalts.



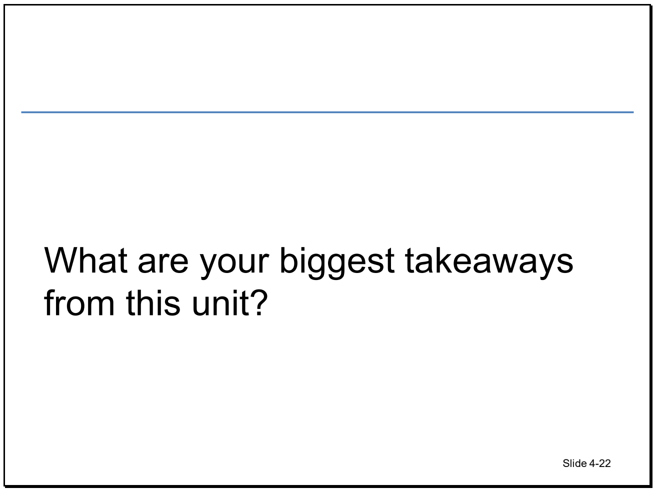
Which inorganic nonsalts would you consider the most dangerous? Why?



Which of these do you have in your community?



What equipment and training do you have to prepare for responding to incidents involving the chemicals you identified that you have in your community?



What are your biggest takeaways from this unit?

APPENDIX A

CHEMICAL FAMILY SUMMARY WORKSHEETS FOR THE INORGANIC NONSALTS

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CHEMICAL FAMILY SUMMARY WORKSHEET: BINARY NONSALT

General formula:
Naming conventions (classical/International Union of Pure and Applied Chemistry (IUPAC))
What are the general hazards associated with this family?

What are the common uses or applications of this family?
Remarks or other considerations?
Common examples (optional)
Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: NONMETAL OXIDES

General formula:
Naming conventions (classical/IUPAC)
What are the general hazards associated with this family?

What are the common uses or applications of this family?
Remarks or other considerations?
Common examples (optional)
Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: BINARY ACIDS (HYDROGEN HALIDES)

General formula:
Naming conventions (classical/IUPAC)
What are the general hazards associated with this family?

What are the common uses or applications of this family?
Remarks or other considerations?
Common examples (optional)
Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: INORGANIC ACIDS (OXYACIDS)

General formula:

Naming conventions (classical/IUPAC)

What are the general hazards associated with this family?

What are the common uses or applications of this family?
Remarks or other considerations?
Common examples (optional)
Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: INORGANIC CYANIDES

General formula:
Naming conventions (classical/IUPAC)
What are the general hazards associated with this family?

What are the common uses or applications of this family?
Remarks or other considerations?
Common examples (optional)
Sources of additional information (optional)

APPENDIX B

CHEMICAL FAMILY SUMMARY WORKSHEETS FOR THE INORGANIC NONSALTS: ANSWER KEYS

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CHEMICAL FAMILY SUMMARY WORKSHEET: BINARY NONSALT

General formula:

nonmetal + nonmetal except O (no carbon)

Naming conventions (classical/International Union of Pure and Applied Chemistry (IUPAC))

Classical:
Use the Latin prefixes for the number of each nonmetal.
Name the first nonmetal.
Name the second, with an "-ide" ending.

What are the general hazards associated with this family?

Variety of hazards.
Some react violently with water.

What are the common uses or applications of this family?

Remarks or other considerations?

Common examples (optional)

BrF_5	*Bromine pentafluoride*
PCl_3	*Phosphorous trichloride*
IF_3	*Iodine trifluoride*
BF_3	*Boron trifluoride*

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: NONMETAL OXIDES

General formula:

nonmetal + Ox (X= number of oxygen)

Naming conventions (classical/IUPAC)

Classical:

Name the nonmetal first, followed by oxide with the Latin prefix for the number of oxygens (monoxide-1, dioxide-2, trioxide-3).

What are the general hazards associated with this family?

Most are toxic gases — produced by industrial processes and combustion.

What are the common uses or applications of this family?

Remarks or other considerations?

Common examples (optional)

SO_3	*Sulfur trioxide*
SO_2	*Sulfur dioxide*
CO	*Carbon monoxide*
CO_2	*Carbon dioxide*
NO_2	*Nitrogen dioxide*

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: BINARY ACIDS (HYDROGEN HALIDES)

General formula:

H + X (X= element from halogen family)

Naming conventions (classical/IUPAC)

Classical:

Gas form — hydrogen, then name halogen with an “-ide" ending.
Aqueous form — hydrogen, then name the halogen with an "-ic" ending and call it an acid.

What are the general hazards associated with this family?

Corrosive.
Secondary hazards from the halogen attached.

What are the common uses or applications of this family?

Remarks or other considerations?

Common examples (optional)

HF

- *Hydrogen fluoride*
- *Hydrofluoric acid*

HCl

- *Hydrogen chloride*
- *Hydrochloric acid*

HBr

- *Hydrogen bromide*
- *Hydrobromic acid*

HI

- *Hydrogen iodide*
- *Hydroiodic acid*

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: INORGANIC ACIDS (OXYACIDS)

General formula:

H + polyatomic nonmetal or poly nonmetal (oxyradicals)

Naming conventions (classical/IUPAC)

Classical:

Name the oxyradical first, using the naming chart below to denote number of oxygens in oxyradical, followed by acid.

- *-1*
  - ClO_3
  - BrO_3
  - IO_3
  - NO_3
  - MnO_3
- *-2*
  - CO_3
  - CrO_3
  - SO_4
- *-3*
  - PO_4

Normal state +1
per-_____-ic
Normal state of oxygen
-ic
Normal state -1
-ous
Normal -2
hypo- -ous

What are the general hazards associated with this family?

Corrosive, and some are toxic.

What are the common uses or applications of this family?

Remarks or other considerations?

Common examples (optional)

H_3PO_4	*Phosphoric acid*
H_2CO_3	*Carbonic acid*
$HClO$	*Hypochlorous acid*
HNO_3	*Nitric acid*
HNO_2	*Nitrous acid*
H_2SO_5	*Persulfuric acid (Caro's acid)*
H_2SO_4	*Sulfuric acid*
H_2SO_3	*Sulfurous acid*
H_2SO_2	*Hyposulfurous acid*

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: INORGANIC CYANIDES

General formula:

Nonmetal (except carbon) + cyanide anion

Naming conventions (classical/IUPAC)

Classical:
Nonmetal + "cyanide," or "cyanogen + nonmetal."

What are the general hazards associated with this family?

Extremely toxic; interrupts aerobic metabolism.

What are the common uses or applications of this family?
Remarks or other considerations?
Common examples (optional)
Sources of additional information (optional)

UNIT 5:
HYDROCARBONS AND HYDROCARBON RADICALS

TERMINAL OBJECTIVE

The students will be able to:

5.1 Justify scene control, detection, personal protective equipment (PPE) and decontamination considerations, given a scenario involving hydrocarbon families.

ENABLING OBJECTIVES

The students will be able to:

5.1 Analyze a name or formula to identify the hydrocarbon family and associated hazards.

5.2 Identify hydrocarbon radicals, given a name or formula.

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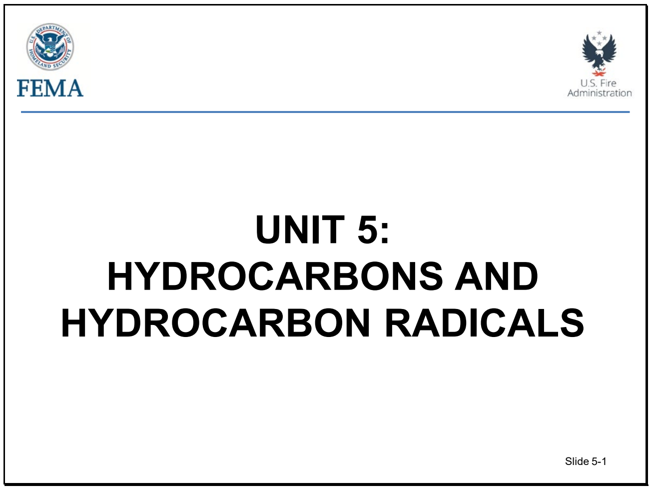
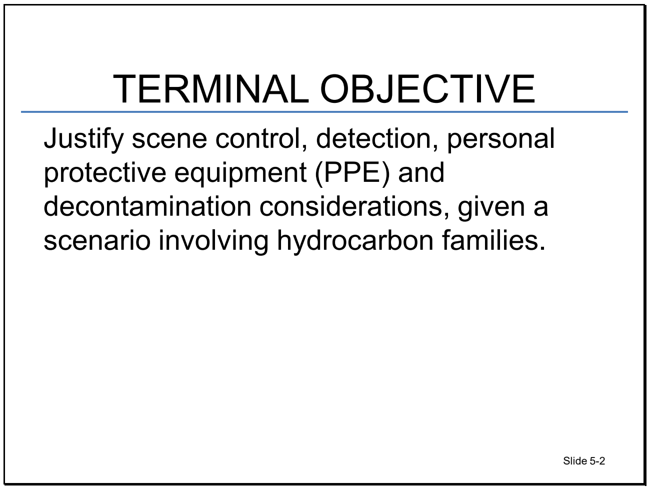


UNIT 5:
HYDROCARBONS AND HYDROCARBON RADICALS

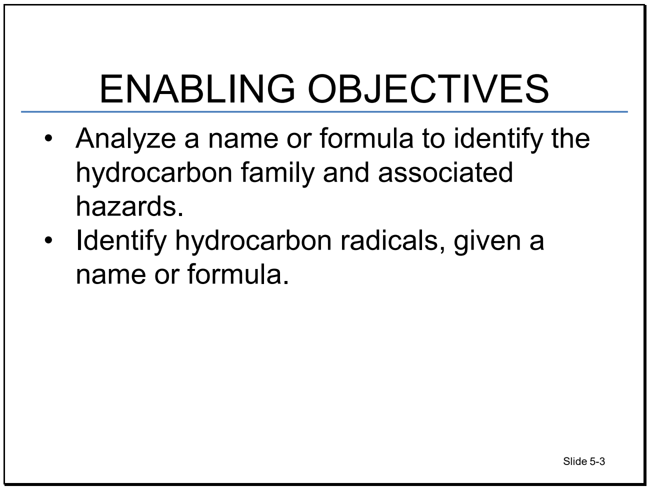
Slide 5-1



TERMINAL OBJECTIVE

Justify scene control, detection, personal protective equipment (PPE) and decontamination considerations, given a scenario involving hydrocarbon families.

Slide 5-2



ENABLING OBJECTIVES

- Analyze a name or formula to identify the hydrocarbon family and associated hazards.
- Identify hydrocarbon radicals, given a name or formula.

Slide 5-3

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ACTIVITY 5.1

Getting to Know the Hydrocarbons

Purpose

Research the characteristics and hazards of hydrocarbon families.

Directions

1. With your group, research the characteristics and hazards of your assigned hydrocarbon family.
    a. Alkane.
    b. Alkene.
    c. Alkyne.
    d. Aromatic.
2. Record significant findings on your group's easel pad.
3. Be prepared to present your findings to the class.

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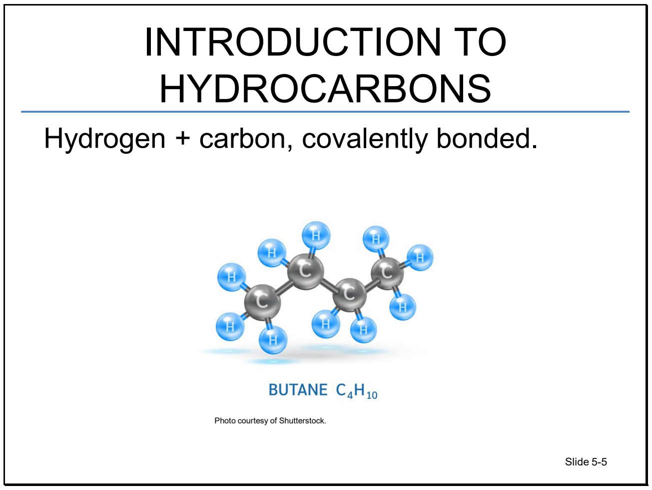
I. HYDROCARBON FAMILIES



INTRODUCTION TO HYDROCARBONS

Hydrogen + carbon, covalently bonded.

Photo courtesy of Shutterstock.

Slide 5-5

A. Introduction to hydrocarbons.

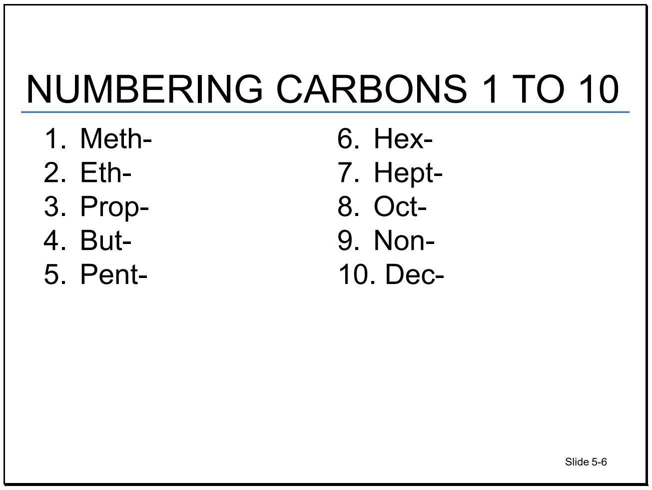
1. Definition: Compounds consisting of hydrogen and carbon.

2. Bonding and basic nomenclature.

    a. Hydrogen and carbon are above the line, so they will share electrons, thus creating a covalent bond.

    b. Carbon wants to bond four times (in family IV).

    c. Hydrogen wants to bond one time (in family I).



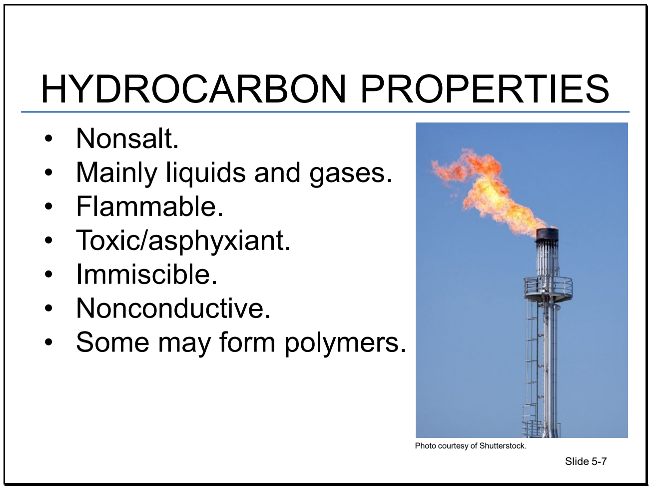
NUMBERING CARBONS 1 TO 10

1. Meth-
2. Eth-
3. Prop-
4. But-
5. Pent-
6. Hex-
7. Hept-
8. Oct-
9. Non-
10. Dec-

Slide 5-6

    d. The bond is depicted with the dash method. Each dash indicates a shared pair of electrons covalently bonded.

e. The prefix depends on the number of carbons in the molecule as shown on the slide.



HYDROCARBON PROPERTIES

- Nonsalt.
- Mainly liquids and gases.
- Flammable.
- Toxic/asphyxiant.
- Immiscible.
- Nonconductive.
- Some may form polymers.

Photo courtesy of Shutterstock.

3. Properties.

a. Nonsalt.

b. Mainly liquids and gases (some solids).

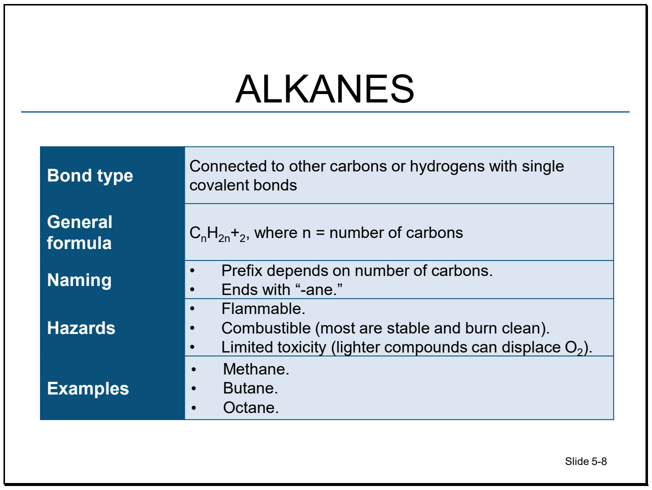
c. Flammable (due to the hydrocarbon content).

d. With the exception of aromatic hydrocarbons, toxicity is primarily through simple asphyxiation.

e. Immiscible.

f. Do not conduct electricity in water; no ionization.

g. Some may be monomers that may form polymers.



ALKANES

Bond type	Connected to other carbons or hydrogens with single covalent bonds
General formula	$C_nH_{2n}+_2$, where n = number of carbons
Naming	• Prefix depends on number of carbons. • Ends with "-ane."
Hazards	• Flammable. • Combustible (most are stable and burn clean). • Limited toxicity (lighter compounds can displace O_2).
Examples	• Methane. • Butane. • Octane.

B. Alkane family.

1. Bond type: connected to other carbons or hydrogens with single covalent bonds.

2. General formula: C_nH_{2n+2}.

    a. Where n = number of carbons.

    b. Solve for number of hydrogens.

    c. Example: C_3H_8 is the single-bonded propane. 2 x 3 (carbons) + 2 = 8 (hydrogens).

3. Naming.

    a. The prefix depends on the number of carbons in the molecule.

    b. Ends in the suffix "-ane."

    c. Examples: methane, butane, octane.

4. Hazards.

    a. Flammable.

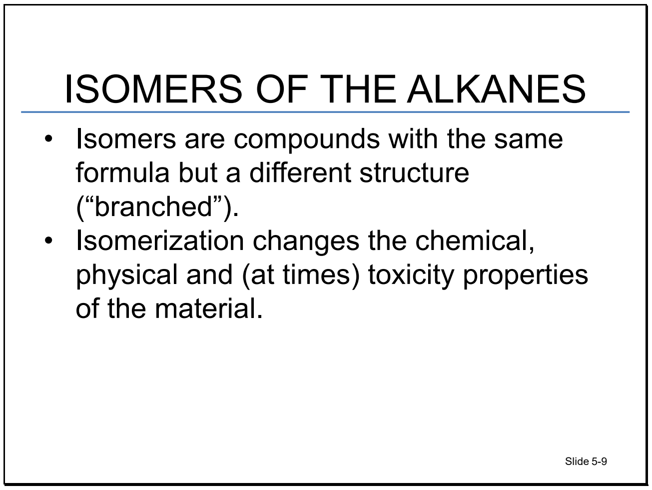
    b. Combustible (most are stable and burn clean).

    c. Limited toxicity (heavier-than-air compounds can displace O_2).

5. Uses.

    a. Fuels.

    b. Lubricants.



ISOMERS OF THE ALKANES

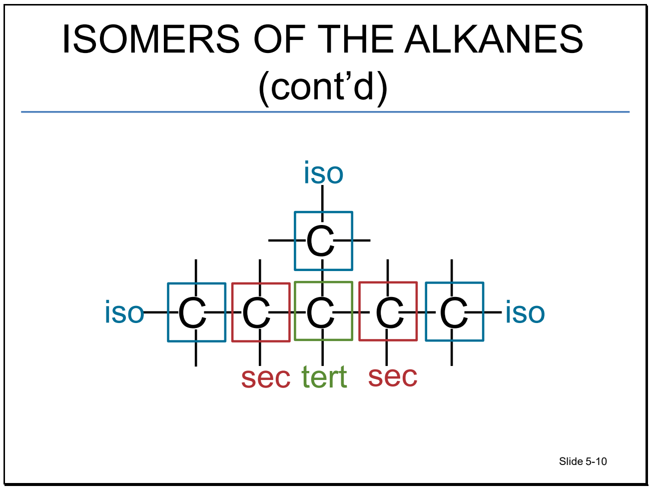
- Isomers are compounds with the same formula but a different structure ("branched").
- Isomerization changes the chemical, physical and (at times) toxicity properties of the material.

6. Isomers of the alkanes.

   a. Isomer: a compound with the same formula but a different structure.

   b. They are also referred to as “branched.”

   c. Carbons are aligned in a different manner.



ISOMERS OF THE ALKANES (cont’d)

Slide 5-10

   d. Alignment of carbons is described in the nomenclature for isomers, using prefixes to indicate the position of the carbon on the chain:

      - “Iso-” when the attachment is on a carbon at the end of a branched chain.

      - “Sec-” when the attachment is on a secondary carbon (carbon attached to two other carbons).

      - “Tert-” when the attachment is on the back of a branch (one carbon that is attached to three other carbons).

   e. Isomerization changes the chemical, physical and (at times) toxicity properties of the material.

   f. Larger molecules have isomers that lead to the need for a more precise naming scheme. This naming scheme is referred to as the International Union of Pure and Applied Chemistry (IUPAC) Naming System.

7. IUPAC naming rules for alkanes.

   a. Find the longest continuous chain — the “main chain,” e.g., pentane, hexane.

b. Assign numbers to the carbons from the end of the main chain that will give the substituent (or radical) its lowest number.

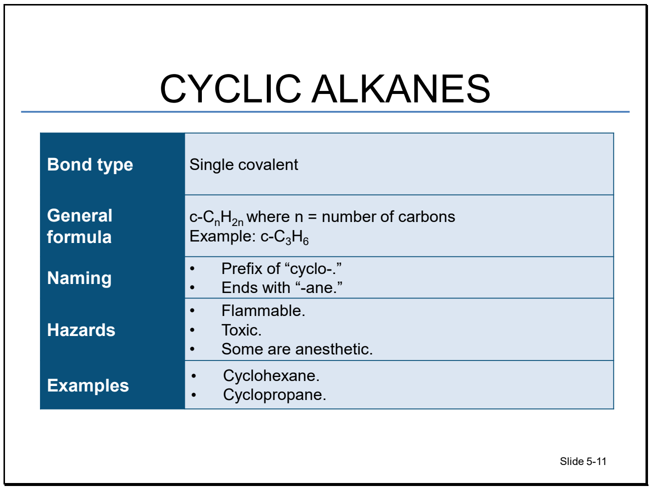
c. Designate the position of each substituent by the number of the carbon it's attached to, e.g., 2-methyl, 3-ethyl.

d. Name substituents alphabetically, e.g., 3-ethyl, 2-methyl.

e. Substituents are named as prefixes to the main chain.

f. Repeating substituents numbers are used together with "di-," "tri," "tetra-," e.g., 2,2-dimethyl; 2,3,4-trimethyl.

g. Name the main chain last, e.g., 2,2-dimethyl pentane; 2,3,4-trimethyl octane.



CYCLIC ALKANES

Bond type	Single covalent
General formula	c-C_nH_{2n} where n = number of carbons Example: c-C_3H_6
Naming	• Prefix of "cyclo-." • Ends with "-ane."
Hazards	• Flammable. • Toxic. • Some are anesthetic.
Examples	• Cyclohexane. • Cyclopropane.

Slide 5-11

C. Cyclic alkanes.

1. Bond type: single covalent.

2. General formula: c-C_nH_{2n}.

a. Where n = number of carbons, e.g., c-C_3H_6.

b. They always have two fewer hydrogens than their noncyclic counterpart.

c. Do not follow the same general formula as the alkanes.

d. Cyclic in shape.

e. Two hydrogens are lost to allow the ends of the chain to reconnect to them.

f. Results in a general formula of C_nH_{2n}, as compared to the noncyclic alkane general formula of C_nH_{2n+2}.

3. Naming.

a. Prefix of "cyclo-."

b. Ends with "-ane."

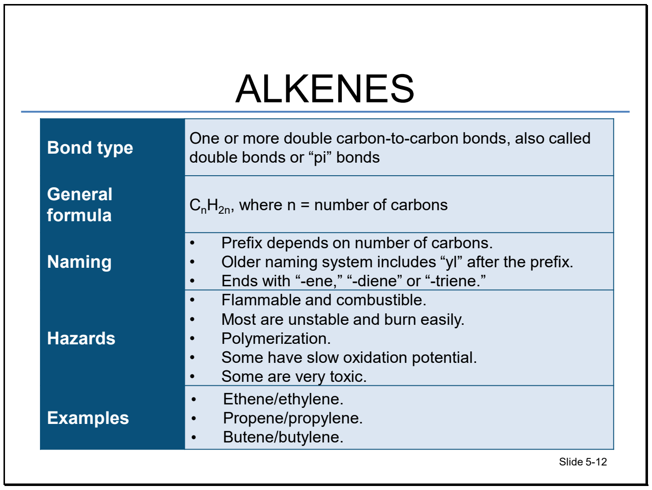
4. Properties: Physical properties will vary.

5. Hazards.

a. Flammable.

b. Toxic.

c. Some have anesthetic properties (e.g., cyclopropane).



ALKENES

Bond type	One or more double carbon-to-carbon bonds, also called double bonds or "pi" bonds
General formula	C_nH_{2n}, where n = number of carbons
Naming	• Prefix depends on number of carbons. • Older naming system includes "yl" after the prefix. • Ends with "-ene," "-diene" or "-triene."
Hazards	• Flammable and combustible. • Most are unstable and burn easily. • Polymerization. • Some have slow oxidation potential. • Some are very toxic.
Examples	• Ethene/ethylene. • Propene/propylene. • Butene/butylene.

Slide 5-12

D. Alkene family.

1. Bond type.

a. One or more double carbon-to-carbon bonds.

b. Double bonds or "pi" bonds are more reactive than single bonds due to the higher number of electrons occupying that space.

2. General formula: C_nH_{2n}.

a. Where n = number of carbons.

b. Solve for number of hydrogens, e.g., C_3H_6 is the double-bonded propene. 2 x 3 (carbons) = 6 (hydrogens).

c. The general formula for the “-ene” family does not work for compounds with multiple double bonds.

d. Note that “2n” is also the general formula for a cyclical single-bonded compound. However, cyclic compounds are differentiated by the small “c-” in front of the formula, e.g., cyclopropane, c-C_3H_6.

3. Naming.

a. The prefix depends on the number of carbons in the molecule, e.g., ethene, propene, butene.

b. Older naming system (still commonly used) includes “yl” after the numeric prefix, e.g., ethylene, propylene, butylene.

c. Ends in the suffix “-ene.”

d. Multiple pi bonds in the same compound would be indicated in the suffix of the name.

  - “-ene” if only a single pi bond.
  - “-diene” if there are two pi bonds.
  - “-triene” if there are three pi bonds.

e. It is possible to see a formula that denotes where these bonds appear, e.g., ethene $H_2C = CH_2$ or $H_2C: CH_2$.

f. IUPAC naming rules state that alkenes with four or more carbons (butene, pentene, etc.) should have a number in front of the name to indicate where the double bond is in the structure.

  - For instance, $H_2C=CH-CH_2-CH_3$ would be 1-butene whereas $H_3C-CH=CH-CH_3$ would 2-butene.
  - This distinction is important due to these isomers having slightly different properties.

4. Hazards.

a. Flammable and combustible; most are unstable and burn easily.

b. Polymerization.

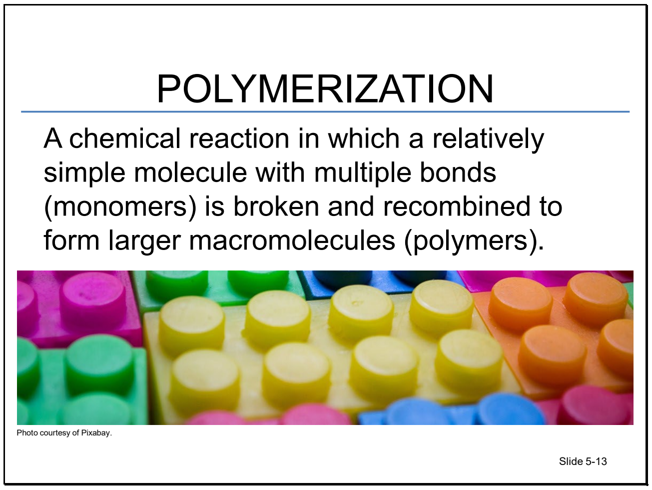
c. Some have slow oxidation potential. Easily broken bonds with the addition of oxygen or some other catalyst.

d. Some are very toxic.

5. Uses.

a. Plastics manufacture.

b. Synthetics.



POLYMERIZATION

A chemical reaction in which a relatively simple molecule with multiple bonds (monomers) is broken and recombined to form larger macromolecules (polymers).

Photo courtesy of Pixabay.

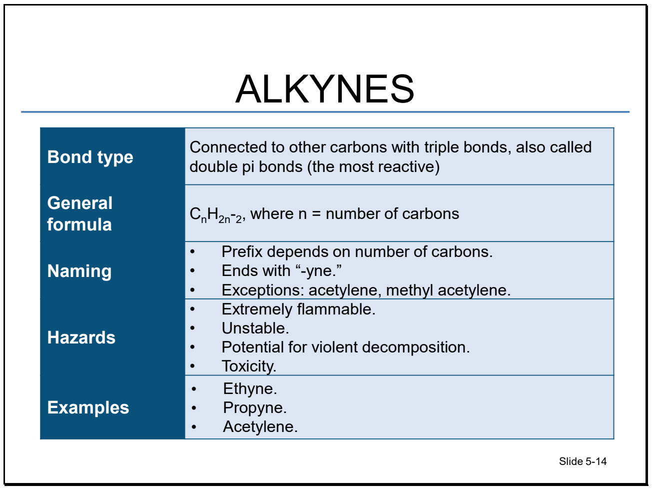
6. Polymerization.

a. The alkenes can also be called monomers. They are the building blocks of plastics, which are known as polymers.

b. **Polymerization** is a chemical reaction in which a relatively simple molecule with one or more multiple bonds (monomers) is broken and recombined to form larger macromolecules (polymers).

- Monomer means one part.
- Polymer means many parts.
- In a controlled setting, this is the process used to make plastics.
- When uncontrolled, the reaction is violent and can be similar to a boiling liquid expanding vapor explosion (BLEVE).

- This reaction is usually prevented in shipment due to the addition of inhibitors to the compound.



ALKYNES

Bond type	Connected to other carbons with triple bonds, also called double pi bonds (the most reactive)
General formula	C_nH_{2n-2}, where n = number of carbons
Naming	• Prefix depends on number of carbons. • Ends with "-yne." • Exceptions: acetylene, methyl acetylene.
Hazards	• Extremely flammable. • Unstable. • Potential for violent decomposition. • Toxicity.
Examples	• Ethyne. • Propyne. • Acetylene.

E. Alkyne family.

1. Bond type.

   a. Compounds composed of carbon and hydrogen, where one or more carbons are connected to other carbons in the molecule with triple bonds, also called double pi bonds.

   b. Double pi bonds are the most reactive due to an even greater number of electrons in between two carbons.

2. General formula: C_nH_{2n-2}.

   a. Where n = number of carbons.

   b. Solve for number of hydrogens.

   c. Example: C_3H_4 is the triple-bonded propyne, e.g., 2 x 3 (carbons) – 2 = 4 (hydrogens).

3. Naming.

   a. The prefix depends on the number of carbons in the molecule.

      - Examples: ethyne, propyne.

      - Exceptions to naming convention: acetylene, methyl acetylene.

- Acetylene is a common name that has carried over to modern times since the naming of the molecule in 1860.

b. Ends in the suffix "-yne."

c. Other "-yne" compounds besides ethyne and propyne are not common due to their instability.

4. Hazards.

a. Extremely flammable, e.g., acetylene has a flammable range of 2% to 100%.

b. Unstable and reactive.

c. Potential for violent decomposition due to the double pi bond.

d. Toxicity.

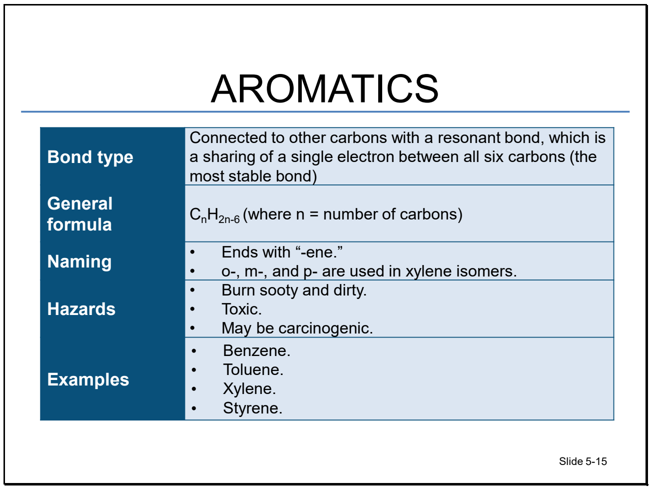
5. Uses.

a. High-energy fuel.

b. High-temperature processes.

c. Chemical intermediate.

d. Cutting, welding and brazing.



AROMATICS

Bond type	Connected to other carbons with a resonant bond, which is a sharing of a single electron between all six carbons (the most stable bond)
General formula	C_nH_{2n-6} (where n = number of carbons)
Naming	• Ends with "-ene." • o-, m-, and p- are used in xylene isomers.
Hazards	• Burn sooty and dirty. • Toxic. • May be carcinogenic.
Examples	• Benzene. • Toluene. • Xylene. • Styrene.

F. Aromatic family.

1. Bond type.

a. Connected to other carbons with a **resonant** bond, which is a sharing of a single electron between all six carbons. It “resonates” between the carbons so that all six are satisfied.

b. The resonant bond is the most stable of all the bonds — tightly held electron.

c. Resonant bonds are unique and will be seen in several of the chemical families that will be discussed in this program, particularly the aromatic hydrocarbons.

d. In a resonant bond, each bonding electron contributes to the bonds within the entire structure. This alternating, or “resonating” of the electron, is demonstrated in the diagrams below (in 3b).

2. General formula: C_nH_{2n-6}.

   a. Where n = number of carbons.

   b. Examples:

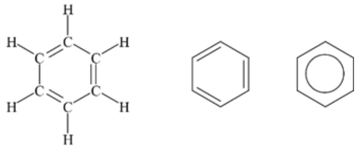
      - C_6H_6 is benzene.
      - C_7H_8 is toluene.
      - C_8H_{10} is xylene.
      - $C_6H_5CH{=}CH_2$ is styrene.

3. Naming.

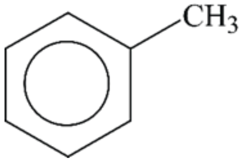
   a. Ends in the suffix “-ene.”

   b. There are four main parents in the aromatic family, sometimes called the “BTXS Group” (benzene, toluene, xylene, styrene). These were originally thought to be double-bonded compounds, thus the “-ene” suffix.

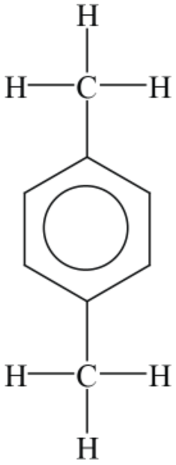
      - Benzene C_6H_6.



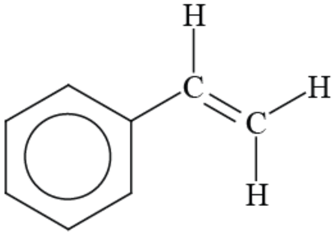
- Toluene $C_6H_5CH_3$.



- Xylene $C_6H_4(CH_3)_2$.



- Styrene $C_6H_5(C_2H_3)$.



c. Aromatics have carbons numbered 1 through 6, starting at the number 1 carbon at the top of the structure in the 12 o'clock position, continuing clockwise 1 through 6.

- Ortho o- "next to."

- Meta m- "separated by one."

- Para p- "opposite."

4. Hazards.

a. Flammable and burn sooty and dirty.

b. Toxic.

   c. May be carcinogenic.

   d. Styrene has a polymerization hazard.

5. Uses: extensively used as carrier and intermediate.

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ACTIVITY 5.2

Review of Hydrocarbon Families

Purpose

Analyze four families of hydrocarbons, including name, general formula, chemical structure and general hazards.

Directions

1. Working individually or with your table group, complete the All Hydrocarbon Families Worksheet.
2. Fill in the missing family and general hazards on the worksheet.
3. The instructor will be available to assist with answers to questions, as necessary.
4. Complete the activity as homework.

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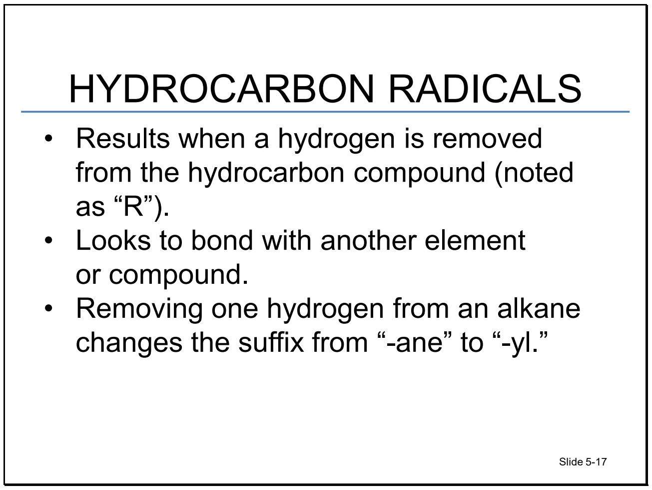
ACTIVITY 5.2 (cont'd)

All Hydrocarbon Families Worksheet

#	Name or formula	Family	General hazards
1.	isohexane		
2.	m-xylene		
3.	(C_4H_{10})		
4.	(C_4H_8)		
5.	propene		
6.	cyclobutane		
7.	(C_5H_{10})		
8.	($CH_3CH_2CH_3$)		
9.	isobutane		
10.	pentane		
11.	(i-C_4H_8)		
12.	(C_4H_6)		
13.	cyclopropane		

#	Name or formula	Family	General hazards
14.	toluene		
15.	(C_2H_4)		
16.	(C_2H_2)		
17.	pentyne		
18.	propyne		
19.	(C_6H_6)		
20.	($C_6H_5C_2H_3$)		

II. HYDROCARBON RADICALS



HYDROCARBON RADICALS

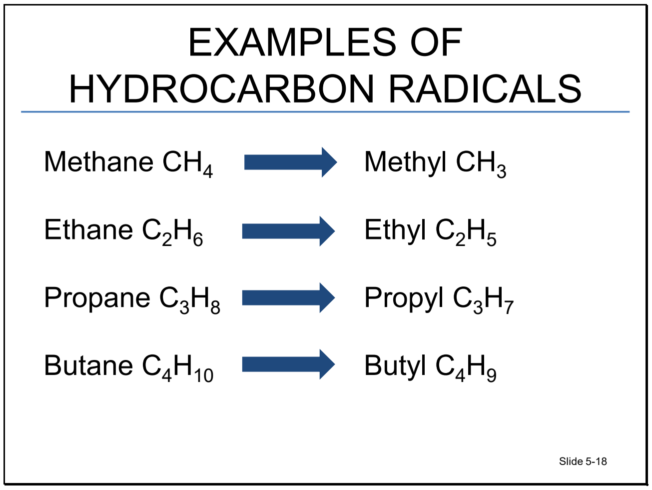
- Results when a hydrogen is removed from the hydrocarbon compound (noted as “R”).
- Looks to bond with another element or compound.
- Removing one hydrogen from an alkane changes the suffix from “-ane” to “-yl.”

A. Introduction to hydrocarbon radicals.

1. When you remove one or more hydrogens from the hydrocarbon compound, you get what is referred to as a hydrocarbon radical noted as “R.”

2. Hydrocarbon radicals (R) have an open bonding site to accept a bond from another element or compound (it does not exist for long as a radical) that is looking to bond.

3. Removing one hydrogen from any of the alkanes changes the suffix from “-ane” to “-yl.” This leaves an open bonding site that needs to be satisfied.



EXAMPLES OF HYDROCARBON RADICALS

Methane CH_4 → Methyl CH_3

Ethane C_2H_6 → Ethyl C_2H_5

Propane C_3H_8 → Propyl C_3H_7

Butane C_4H_{10} → Butyl C_4H_9

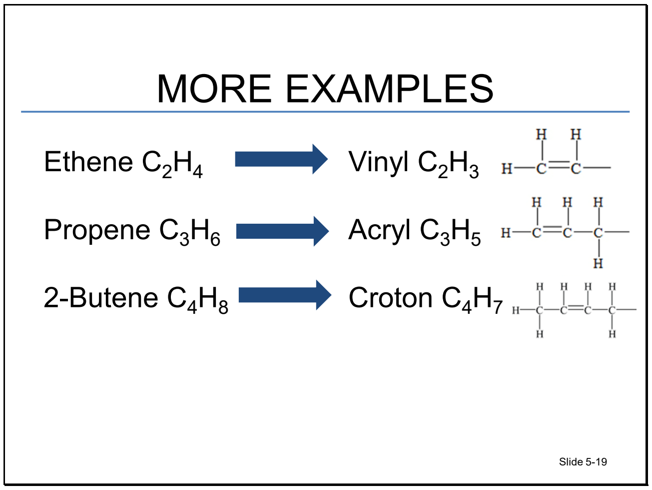
a. Methane CH_4 becomes Methyl CH_3.

b. Ethane C_2H_6 becomes Ethyl C_2H_5.

c. Propane C_3H_8 becomes Propyl C_3H_7.

d. Butane C_4H_{10} becomes Butyl C_4H_9.

4. The same can be applied to all of the alkanes. Whenever an alkane has a suffix of "-yl," it is a radical.



MORE EXAMPLES

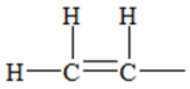
Ethene C_2H_4 → Vinyl C_2H_3

Propene C_3H_6 → Acryl C_3H_5

2-Butene C_4H_8 → Croton C_4H_7

B. Other common radicals.

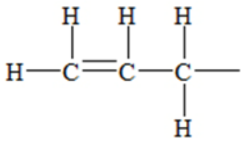
1. Ethene C_2H_4 radical is Vinyl C_2H_3.



Vinyl

C_2H_3

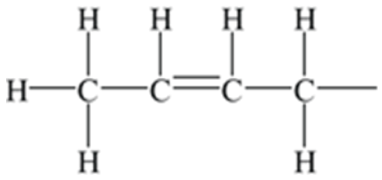
2. Propene C_3H_6 radical is Acryl (or in some cases, Allyl) C_3H_5.

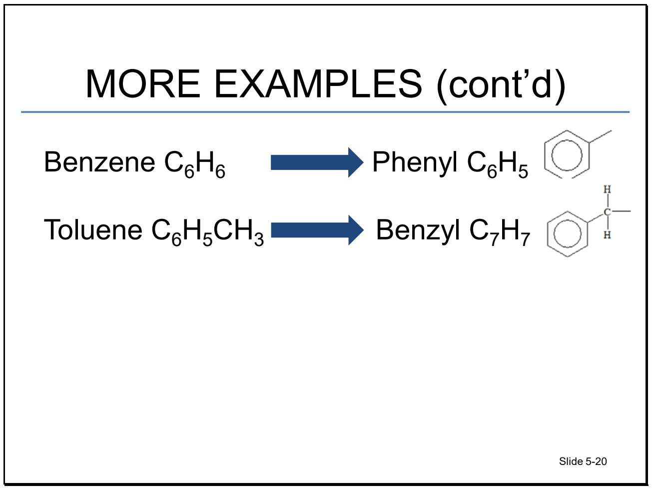


Acryl

C_3H_5

3. 2-Butene C_4H_8 radical is Croton C_4H_7.



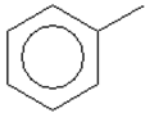


MORE EXAMPLES (cont'd)

Benzene C_6H_6 → Phenyl C_6H_5

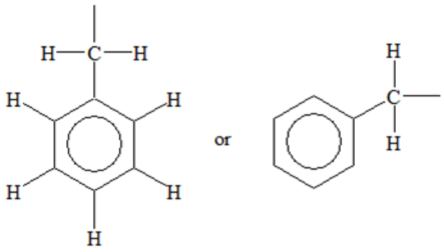
Toluene $C_6H_5CH_3$ → Benzyl C_7H_7

4. Benzene C_6H_6 radical is Phenyl C_6H_5.

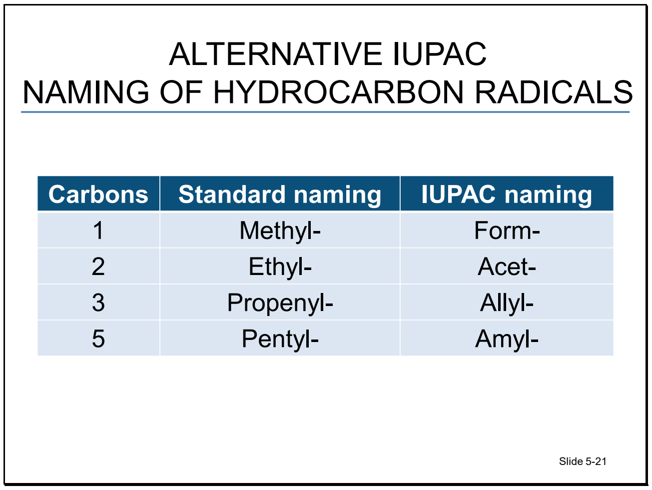


Phenyl
C_6H_5

5. Toluene $C_6H_5CH_3$ radical is Benzyl C_7H_7. The bond site is on the methyl group, not the benzene ring.



Benzyl
C_7H_7

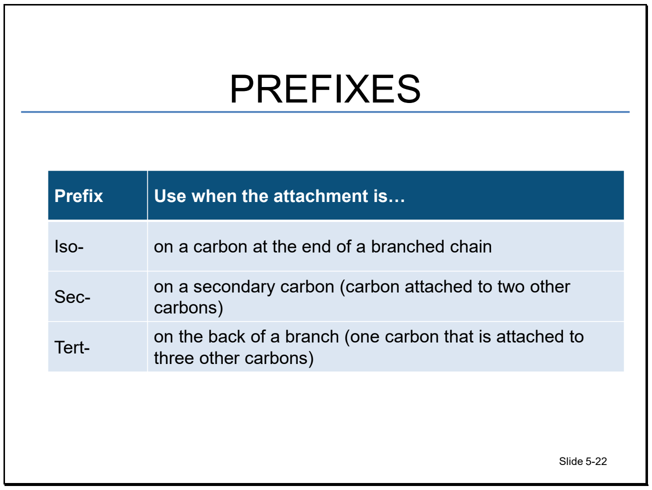


ALTERNATIVE IUPAC NAMING OF HYDROCARBON RADICALS

Carbons	Standard naming	IUPAC naming
1	Methyl-	Form-
2	Ethyl-	Acet-
3	Propenyl-	Allyl-
5	Pentyl-	Amyl-

C. Number of carbons — alternative IUPAC naming of hydrocarbon radicals.

1. 1 carbon — Methyl- — Form-.
2. 2 carbons — Ethyl- — Acet-.
3. 3 carbons — Propenyl- — Allyl-.
4. 5 carbons — Pentyl- — Amyl-.



PREFIXES

Prefix	Use when the attachment is…
Iso-	on a carbon at the end of a branched chain
Sec-	on a secondary carbon (carbon attached to two other carbons)
Tert-	on the back of a branch (one carbon that is attached to three other carbons)

D. Prefixes.

1. In general, the following prefixes are used to denote different levels of branching in a radical.

    a. Iso- is used when the attachment is on a carbon at the end of a branched chain.

b. Sec- is used on a secondary carbon (carbon attached to two other carbons).

c. Tert- is used on the back of a branch (one carbon that is attached to three other carbons).

2. These terms are primarily utilized for propyl and butyl radicals, but may be encountered in larger radicals (pentyl, hexyl) as well.

Table 5.1 Naming of hydrocarbon radicals

Base	Bond	Family	Radical name
Methane	Single	Alkane	Methyl/form-
Ethane	Single	Alkane	Ethyl/acet-
Propane	Single	Alkane	Propyl/propenyl/allyl
Butane	Single	Alkane	Butyl
Pentane	Single	Alkane	Pentyl/amyl
Ethene	Double	Alkene	Vinyl
Propene	Double	Alkene	Acryl
2-Butene	Double	Alkene	Croton
Benzene	Resonate	Aromatic	Phenyl
Toluene	Resonate	Aromatic	Benzyl

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ACTIVITY 5.3

Hydrocarbon Radicals and International Union of Pure and Applied Chemistry Naming

Purpose

Identify at least eight hydrocarbon radicals (four alkane radicals, two alkene radicals and two aromatic radicals) as well as the name or formula and bond using the IUPAC convention for hydrocarbons, hydrocarbon radicals and isomers of hydrocarbon compounds.

Directions

1. Working individually, complete the Hydrocarbon Radicals Worksheet and the Hydrocarbon International Union of Pure and Applied Chemistry Naming Worksheet.

2. Participate in the classroom discussion following the activity.

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ACTIVITY 5.3 (cont'd)

Hydrocarbon Radicals Worksheet

#	Name	Formula	Family
1.		$C_6H_5CH_{2-}$	
2.	propyl		
3.		i-C_3H_{7-}	
4.	phenyl		
5.	vinyl		
6.		C_4H_{9-}	
7.	croton		
8.	tert-butyl		

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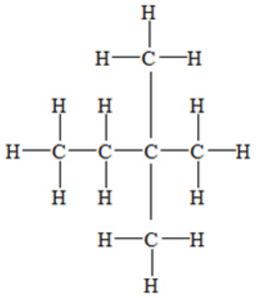
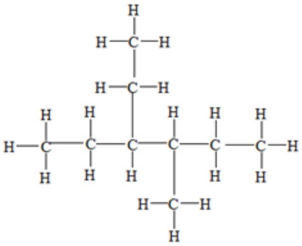
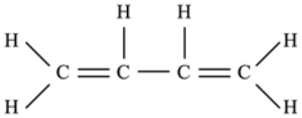
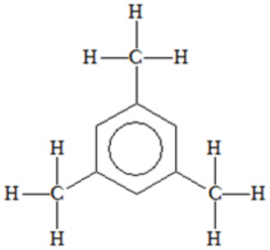
ACTIVITY 5.3 (cont'd)

Hydrocarbon International Union of Pure and Applied Chemistry Naming Worksheet

#	Name	Structure	Formula	Bond
1.	2,2, dimethyl butane			
2.			i-C_9H_{20}	
3.			$CH_2(CH)_2CH_2$ or C_4H_6	
4.			$C_6H_3(CH_3)_3$	

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ACTIVITY 5.4

Analyzing Hydrocarbon Hazards

Purpose

Determine scene control, detection, personal protective equipment (PPE) and decontamination considerations based on an analysis of hydrocarbon hazards.

Directions

1. Review your assigned scenario with your group.
2. Research the characteristics and hazards of the chemical involved in the scenario.
3. Complete the Hydrocarbon Analysis Worksheet and the Product Hazard Analysis Worksheet.
4. Record significant findings on your group's easel pad.
5. Be prepared to present your findings and recommendations to the class.

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ACTIVITY 5.4 (cont'd)

Scenarios

Scenario 1

Your unit is dispatched to a warehouse in response to a chemical spill. Upon your arrival, a forklift operator informs you that the forklift breached a metal drum containing hexane that is now leaking.

Scenario 2

Your unit is called to I-95 in response to a motor vehicle collision with a hazardous materials leak. While you're on your way, the engine company on scene advises that an MC-331 is involved. They report that the placard is "red and has the number 1010" on it.

Scenario 3

You are dispatched to a welding supply warehouse in response to a gas leak. Upon your arrival, an employee advises that he can hear a hissing sound coming from a group of acetylene cylinders in the corner.

Scenario 4

You are dispatched to a fuel depot for a reported fuel spill. Upon your arrival, property representatives advise you that a rail car has a slight leak from the belly valve. The placard on the side of the rail car is red and is numbered "1294."

Scenario 5

You are dispatched to a university chemistry lab, where a research chemist spilled a large flask of liquid on the floor. The chemist says that it is cyclohexane.

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ACTIVITY 5.4 (cont'd)

Hydrocarbon Analysis Worksheet

Scenario	
Chemical name	
Chemical formula	
Family	
Properties	
Hazards	
PPE recommendations	
Decontamination recommendations	
Control zone recommendations	Small leak: Large leak:

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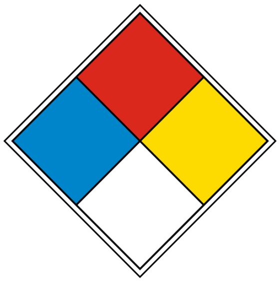
ACTIVITY 5.4 (cont'd)

Product Hazard Analysis Worksheet



Group Number: ________ **Presenter:** ________________________

Temp: _________ °F **R/H:** _________%

Product Name:_________________________________ **Family:**_________________________

Data Points	Result	No Data	Hazard Consideration
Physical Properties			
Physical State			
Vapor Pressure			
Boiling Point			
Vapor Density			
Specific Gravity			
Solubility			
Flammability			
Flash Point			
LEL/UEL			
Flammable Range			
Ignition Temp.			
Toxicity			
Route of Exposure			
IDLH			
PEL/REL/STEL			
S/S of Exposure			
Biological			
Corrosivity			
pH			
Concentration			
Reactivity/Explosion			
Radioactivity			
Decay Mode	☐ N/A ☐ α ☐ β ☐ γ		
Half Life			

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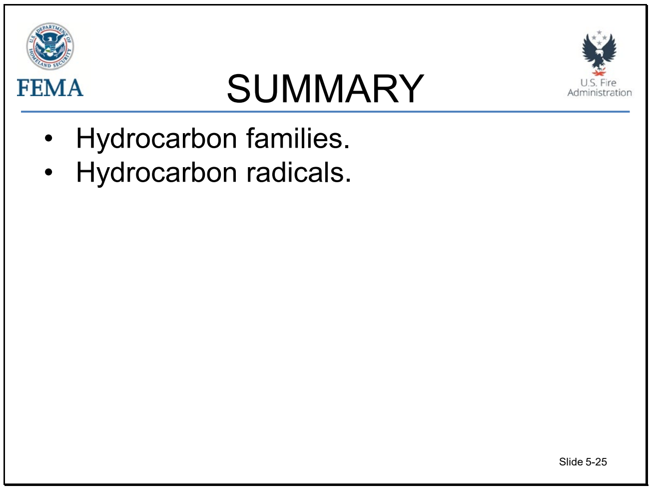
III. SUMMARY

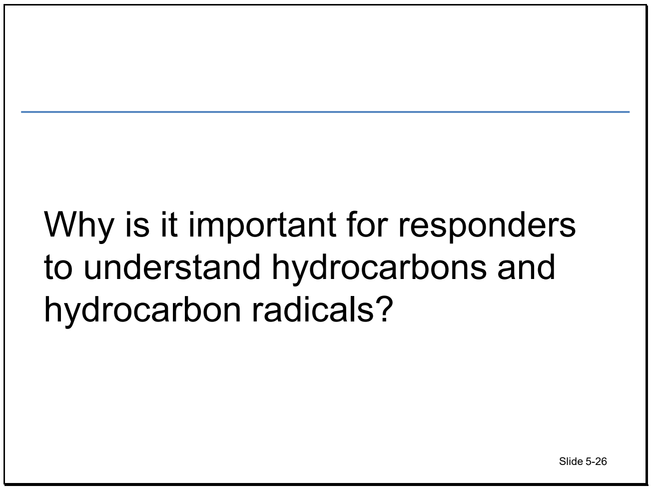


FEMA

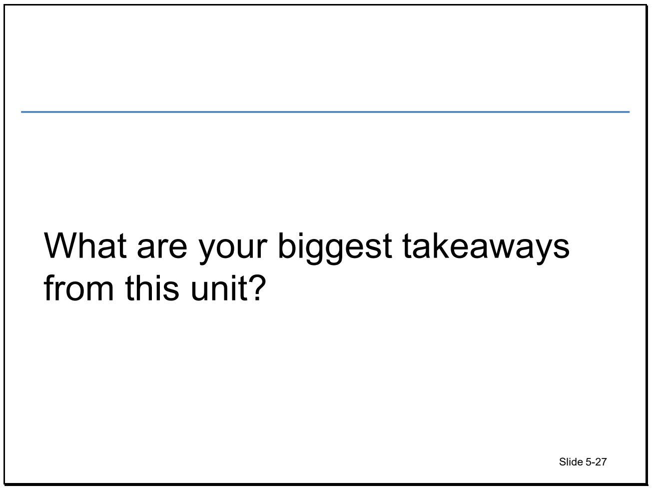
SUMMARY

U.S. Fire Administration

- Hydrocarbon families.
- Hydrocarbon radicals.



Why is it important for responders to understand hydrocarbons and hydrocarbon radicals?



What are your biggest takeaways from this unit?

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APPENDIX A

CHEMICAL FAMILY SUMMARY WORKSHEETS FOR THE HYDROCARBONS

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CHEMICAL FAMILY SUMMARY WORKSHEET: ALKANE HYDROCARBONS

General formula:
Naming conventions (classical/International Union of Pure and Applied Chemistry (IUPAC))
What are the general hazards associated with this family?

What are the common uses or applications of this family?
Remarks or other considerations?
Common examples (optional)
Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: ALKENE HYDROCARBONS

General formula:
Naming conventions (classical/IUPAC)
What are the general hazards associated with this family?

What are the common uses or applications of this family?
Remarks or other considerations?
Common examples (optional)
Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: ALKYNE HYDROCARBONS

General formula:
Naming conventions (classical/IUPAC)
What are the general hazards associated with this family?

What are the common uses or applications of this family?
Remarks or other considerations?
Common examples (optional)
Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: AROMATIC HYDROCARBONS

General formula:
Naming conventions (classical/IUPAC)
What are the general hazards associated with this family?

What are the common uses or applications of this family?
Remarks or other considerations?
Common examples (optional)
Sources of additional information (optional)

APPENDIX B

CHEMICAL FAMILY SUMMARY WORKSHEETS FOR THE HYDROCARBONS: ANSWER KEYS

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CHEMICAL FAMILY SUMMARY WORKSHEET: ALKANE HYDROCARBONS

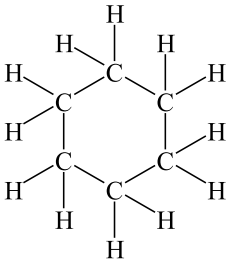
General formula:
C_nH_{2n+2} *(n= number of carbons)* ***ALL SINGLE BONDS***
Naming conventions (classical/International Union of Pure and Applied Chemistry (IUPAC))
Classical: *Use the prefix designating the number of carbons in the longest chain.* *Use the ending "-ane."* ***IUPAC:*** *Find the longest chain, then start at the end nearest to the attachment and number the carbons.* *Designate where the attachments are located by a number.* *Name the attachments.* *Name the longest chain.*
What are the general hazards associated with this family?
Varying degrees of combustibility, from highly flammable to combustible. *Short chain hydrocarbons may cause asphyxiation.* *Heavy hydrocarbons are subject to boil over.*

What are the common uses or applications of this family?

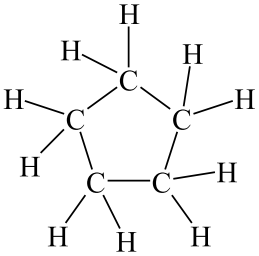
Predominately fuels.

Remarks or other considerations?

Cyclic alkanes do not follow general formula. Water insoluble.

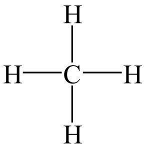


Cyclohexane C_6H_{12}

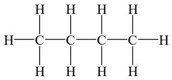


Cyclopentane C_5H_{10}

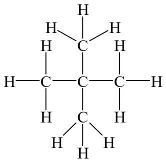
Common examples (optional)



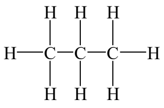
Methane — CH_4



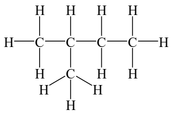
Butane — C_4H_{10}



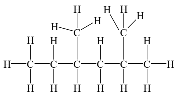
Tertiary pentane — tC_5H_{12}



Propane — C_3H_8



Isopentane — iC_5H_{12}



2,4, dimethyl hexane — $(CH_3)_2\ C_6H_{12}$

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: ALKENE HYDROCARBONS

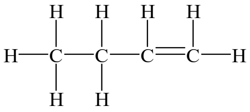
General formula:
C_nH_{2n} *(n = number of carbons)* ***AT LEAST ONE DOUBLE BOND***
Naming conventions (classical/IUPAC)
Classical: *Use the prefix for the number of carbons in the chain.* *Use the suffix "-ene."*
What are the general hazards associated with this family?
Double bond is unstable. *Double bond departs potential for polymerization.* *Some are extremely toxic.* *Have slow oxidization potential.* *If mixed with an oxidizer, will result in hypergolic reaction.*

What are the common uses or applications of this family?

Manufacturing of plastics.

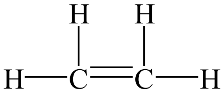
Remarks or other considerations?

Common examples (optional)



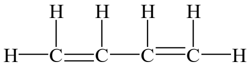
$\mathrm{H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\overset{H}{C}=\overset{H}{C}-H}$

Butene



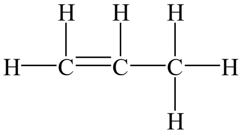
$\mathrm{H-\overset{H}{C}=\overset{H}{C}-H}$

Ethylene — C_2H_4



$\mathrm{H-\overset{H}{C}=\overset{H}{C}-\overset{H}{C}=\overset{H}{C}-H}$

Butadiene



$\mathrm{H-\overset{H}{C}=\overset{H}{C}-\underset{H}{\overset{H}{C}}-H}$

Propylene — C_3H_6

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: ALKYNE HYDROCARBONS

General formula:

$C_n H_{2n-2}$ *(n= number of carbons)* ***TRIPLE BOND***

Naming conventions (classical/IUPAC)

Classical:
Use prefix signifying number of carbons.
Use "-yne" ending.

What are the general hazards associated with this family?

Very unstable and reactive.
Pressure sensitive.

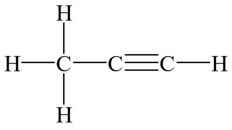
What are the common uses or applications of this family?

Fuels where high energy output is needed.

Remarks or other considerations?

Common examples (optional)

$H-C\equiv C-H$ *Ethyne or acetylene —* C_2H_2



$$H-\overset{\displaystyle H}{\underset{\displaystyle H}{C}}-C\equiv C-H$$

Propyne or methyl acetylene — C_3H_4

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: AROMATIC HYDROCARBONS

General formula:

C_nH_N *(n= number of carbons)* ***Resonant bonds***

Naming conventions (classical/IUPAC)

Classical:
See structures below.

What are the general hazards associated with this family?

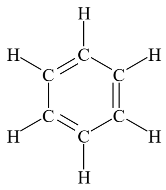
Combustible.
Highly toxic.
May be carcinogenic.

What are the common uses or applications of this family?

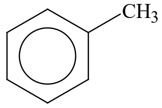
Solvents for paints.

Remarks or other considerations?

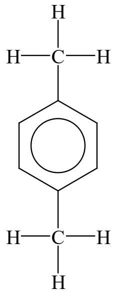
Common examples (optional)



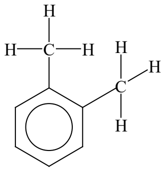
Benzene — C_6H_6



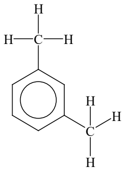
Toluene — C_7H_8 or $C_6H_5\ CH_3$



Paraxylene — $_pC_6H_4\ (CH_3)_2$



Orthoxylene-$_oC_8H_{10}$ or $C_6H_4\ (CH_3)_2$



$_mC_6H_4\ (CH_3)_2$

Sources of additional information (optional)

UNIT 6:
HYDROCARBON DERIVATIVES

TERMINAL OBJECTIVE

The students will be able to:

6.1 Justify scene control, detection, personal protective equipment (PPE) and decontamination considerations, given a scenario involving hydrocarbon derivatives.

ENABLING OBJECTIVES

The students will be able to:

6.1 Identify the functional group within the compound.

6.2 Define hydrogen bonding and polarity.

6.3 Analyze a name or formula to identify the hydrocarbon derivative family and associated hazards.

6.4 Demonstrate the basics of communicating the hazards of the product.

6.5 Conduct a hazard analysis for an incident involving hydrocarbon derivatives.

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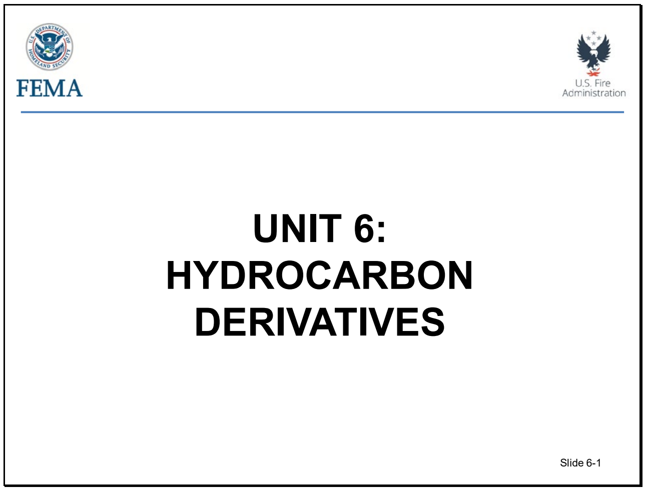
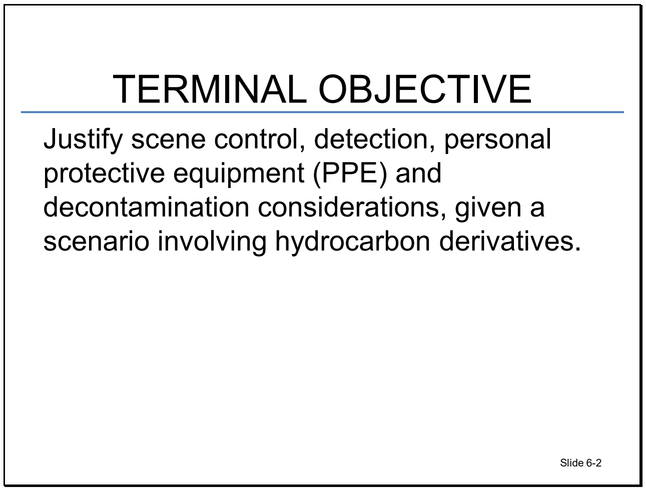


FEMA

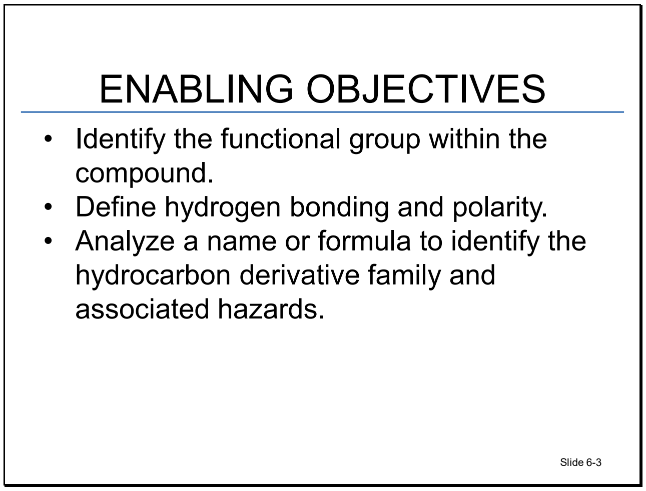
U.S. Fire Administration

UNIT 6:
HYDROCARBON DERIVATIVES



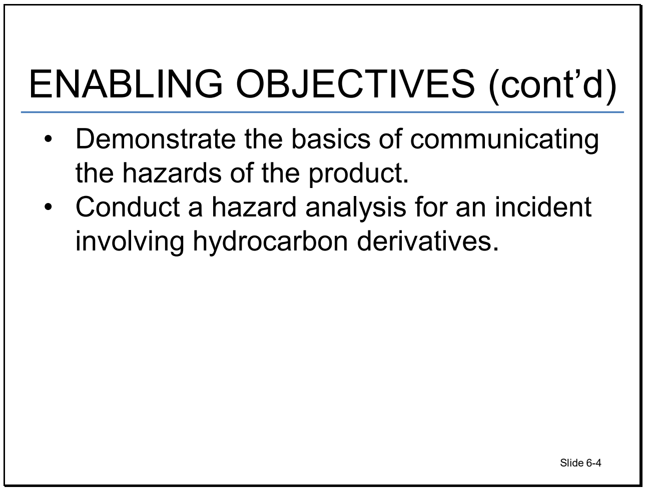
TERMINAL OBJECTIVE

Justify scene control, detection, personal protective equipment (PPE) and decontamination considerations, given a scenario involving hydrocarbon derivatives.



ENABLING OBJECTIVES

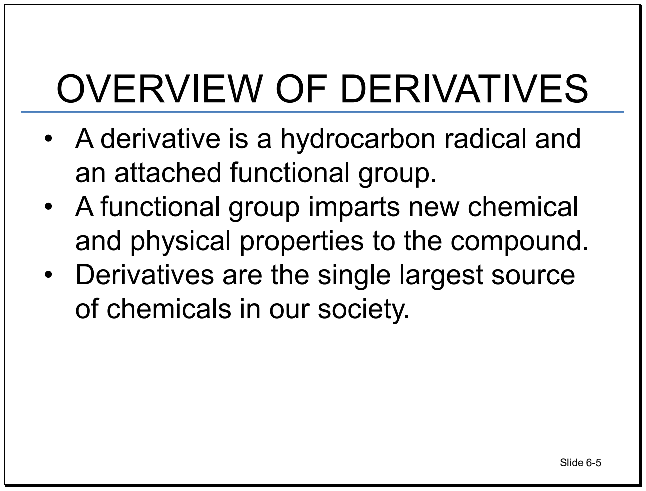
- Identify the functional group within the compound.
- Define hydrogen bonding and polarity.
- Analyze a name or formula to identify the hydrocarbon derivative family and associated hazards.



ENABLING OBJECTIVES (cont'd)

- Demonstrate the basics of communicating the hazards of the product.
- Conduct a hazard analysis for an incident involving hydrocarbon derivatives.

I. INTRODUCTION



OVERVIEW OF DERIVATIVES

- A derivative is a hydrocarbon radical and an attached functional group.
- A functional group imparts new chemical and physical properties to the compound.
- Derivatives are the single largest source of chemicals in our society.

A. Hydrocarbon derivatives are composed of a hydrocarbon radical and an attached functional group.

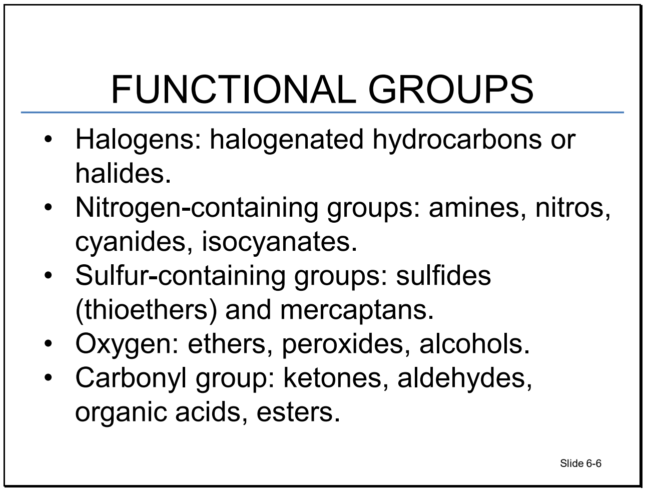
B. A radical is a hydrocarbon compound with one or more hydrogen removed to allow the attachment of another component.

C. A functional group imparts new chemical and physical properties to the compound.

D. Derivatives are the single largest source of chemicals in our society.

E. Weapons of mass destruction (WMD) compounds typically have more than one functional group attached with the hydrocarbon radical.

II. INTRODUCTION TO FUNCTIONAL GROUPS



FUNCTIONAL GROUPS

- Halogens: halogenated hydrocarbons or halides.
- Nitrogen-containing groups: amines, nitros, cyanides, isocyanates.
- Sulfur-containing groups: sulfides (thioethers) and mercaptans.
- Oxygen: ethers, peroxides, alcohols.
- Carbonyl group: ketones, aldehydes, organic acids, esters.

Slide 6-6

A. What are functional groups?

1. One or more atoms attached to hydrocarbon radicals which impart new physical and chemical characteristics to the hydrocarbon compound.

2. In addition to the hydrocarbons to which they are attached, most derivatives are based on:

    a. The halogens.

    b. Nitrogen.

    c. Sulfur.

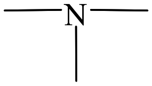
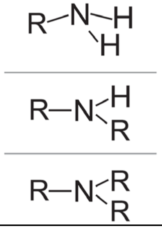
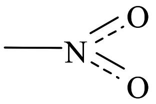
    d. Oxygen.

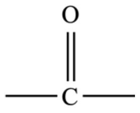
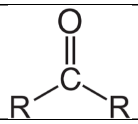
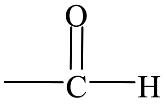
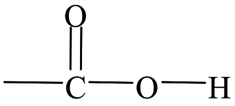
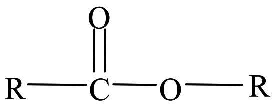
    e. Carbonyl group.

3. Derivatives constitute the largest quantity of hazardous materials manufactured for commercial, industrial and agricultural consumption.

B. The 13 functional groups we will discuss in this class are in Table 6.1.

Table 6.1: 13 functional groups for the 13 hydrocarbon derivative families

Family	General formula	Structural formula
Halogenated hydrocarbons Any of the halogens attached to a hydrocarbon Naming: ends in "-ide" or International Union of Pure and Applied Chemistry (IUPAC)	R-X	R−X
Nitrogen compounds Functional groups based on nitrogen		
Amines: Nitrogen attached to 1, 2 or 3 hydrocarbon radicals Naming: ends in "-amine"	$R-NH_2$ R_2NH R_3N	
Nitros: Radical attached to nitrogen and two oxygens The bond between the nitrogen and two oxygens is considered shared Naming: starts or ends with "nitro"	$R-NO_2$	
Nitriles (organic cyanides): Carbon with a triple bond to nitrogen Naming: ends in "-nitrile"	R-CN	$—C\equiv N$
Isocyanates: Carbon with a triple bond to nitrogen and a triple bond to oxygen Naming: Ends in "-isocyanate"	R-NCO	$—N=C=O$
Oxygen compounds Functional groups based on oxygen		
Ethers: A single oxygen between two radicals Naming: Ends in "-ether"	R-O-R	—O—

Family	General formula	Structural formula
Organic peroxides: Two covalently bonded oxygen atoms between two radicals Naming: ends in "-peroxide" or "peroxy" in the name	R-O_2 -R	—O—O—
Sulfur compounds Functional group based on sulfur		
Sulfides (thioethers): Similar to an ether except with S instead of O Naming: ends in "-sulfide;" when more than one S: "-disulfide," "-trisulfide," etc.	R-S-R	—S—
Mercaptans: A radical is dropped, and H replaces it Naming: ends in "-mercaptan"	R-SH	—SH
Hydroxyl group compounds		
Alcohols: An HC radical attached to O and H Naming: ends in "-alcohol" or "-ol"	R-OH	—O —H
Carbonyl group compounds All these compounds are based on carbon double bonded to oxygen. This starting point is called the carbonyl group.		 $-\overset{\displaystyle O}{\overset{\|}{C}}-$
Ketones: A carbonyl with a radical on both sides Naming: ends in "-ketone" or "-none"	R-CO-R	
Aldehydes: A carbonyl with a radical on one side and H on the other side Naming: ends in "-aldehyde" or "-al"	R-CHO	 $-\overset{\displaystyle O}{\overset{\|}{C}}-H$
Organic acids (carboxyl group): A carbonyl with a radical on one side and O and H on the other Naming: ends in "-oic acid" or "-ic acid"	R-COOH	 $-\overset{\displaystyle O}{\overset{\|}{C}}-O-H$
Esters: A carbonyl with a radical on one side and O and another radical attached to the O on the other Naming: begins with naming the R attached to the oxygen first. Ends in "-ate" Nothing is named "ester"	R-CO_2-R R-COO-R	 $R-\overset{\displaystyle O}{\overset{\|}{C}}-O-R$

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ACTIVITY 6.1

Functional Group Recognition

Purpose

Practice recognizing functional groups within both a written formula and chemical name, which is essential in assessing hazards.

Directions

1. Complete the Functional Group Recognition Worksheet individually, referring to the general formulas and naming rules for each of the functional groups that are on the whiteboard.

2. Using the information you have learned in this course and your Student Manual (SM), find and circle the functional groups within each of the formulas and names.

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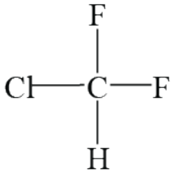
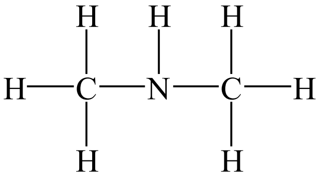
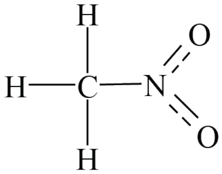
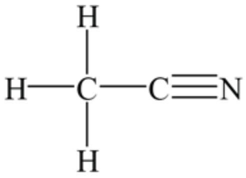
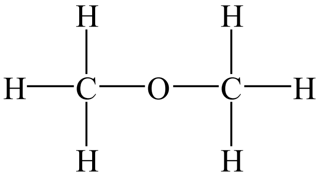
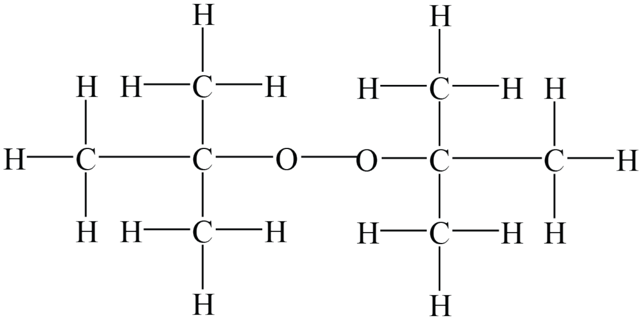
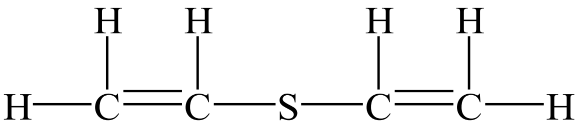
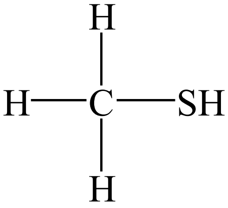
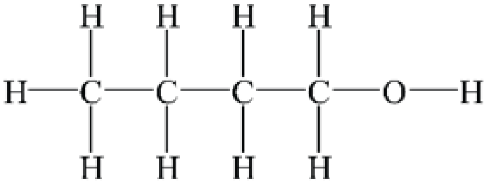
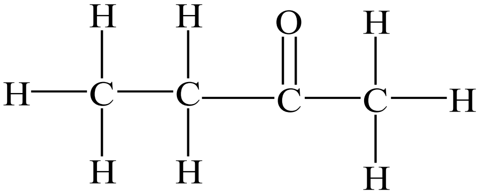
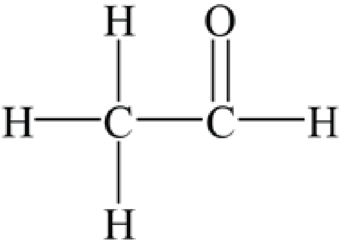
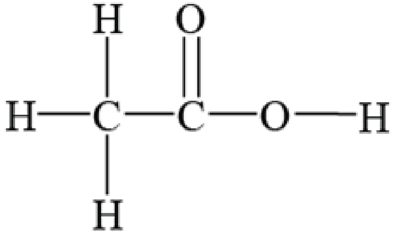
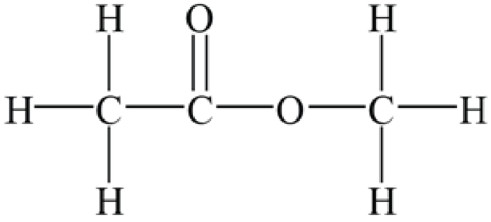
ACTIVITY 6.1 (cont'd)

Functional Group Recognition Worksheet

Circle the functional group(s) in the formula **and** structure for each chemical.

#	Family	Name and formula	Structure
1.	Halogenated hydrocarbon	Chlorodifluoromethane $CHClF_2$	
2.	Amine	Dimethylamine $(CH_3)_2NH$	
3.	Nitro	Nitromethane CH_3NO_2	
4.	Nitrile (organic cyanide)	Acetonitrile CH_3CN	
5.	Ether	Dimethylether CH_3OCH_3	

#	Family	Name and formula	Structure
6.	Organic peroxide	t-Butylperoxide (tertiary butylperoxide) t-$(C_4H_9)_2O_2$	
7.	Sulfide	Divinylsulfide $(C_2H_3)_2S$	
8.	Mercaptan	Methylmercaptan CH_3SH	
9.	Alcohol	Butanol C_4H_9OH	
10.	Ketone	Methylethylketone $C_2H_5COCH_3$	
11.	Aldehyde	Acetylaldehyde CH_3CHO	

#	Family	Name and formula	Structure
12.	Organic acid	Ethanoic acid CH_3COOH	
13.	Ester	Methylacetate CH_3COOCH_3	

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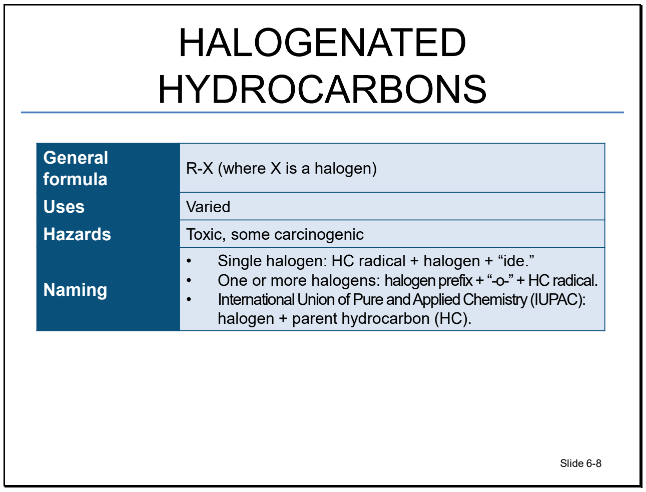
III. HALOGENATED HYDROCARBONS



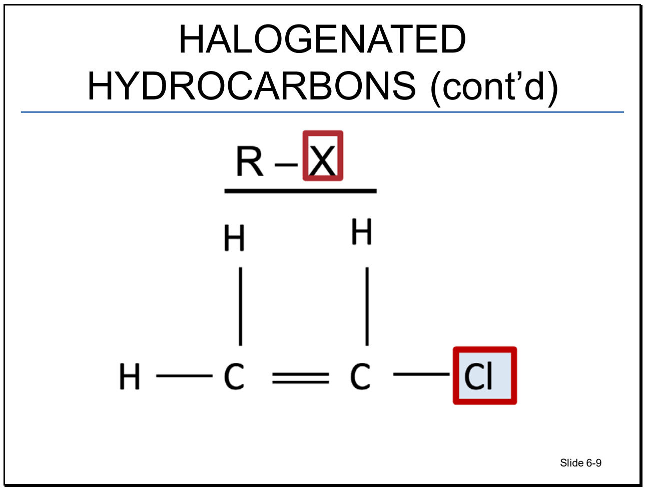
HALOGENATED HYDROCARBONS

General formula	R-X (where X is a halogen)
Uses	Varied
Hazards	Toxic, some carcinogenic
Naming	• Single halogen: HC radical + halogen + “ide.” • One or more halogens: halogen prefix + “-o-” + HC radical. • International Union of Pure and Applied Chemistry (IUPAC): halogen + parent hydrocarbon (HC).

A. General formula.

1. R-X.

2. R refers to the hydrocarbon radical.



HALOGENATED HYDROCARBONS (cont’d)

3. “X” is any of the halogen (Group VII) elements: fluorine, chlorine, bromine or iodine.

B. Formation and naming.

1. Hydrocarbon has one or more hydrogen removed.

2. Resulting radical must bond.

3. Since hydrogen was sharing one electron, it is easy to replace it with a halogen, which also will share one electron.
    a. Methane becomes methyl (CH_4 to CH_3).
    b. Add substitute with chlorine to make CH_3Cl.
    c. Naming: methyl chloride (common); chloromethane (IUPAC).
4. Additional halogens can be added.
5. Longer chain hydrocarbon radicals can also be used.
6. Location of the functional group can be important.
    a. This can serve to change physical, chemical and toxicological properties.
    b. In IUPAC nomenclature, location is defined clearly using a number to indicate the carbons to which the halogens are attached.
7. If only one of the halogens is present, the radical is usually named first, followed by the halogen.
8. The ending of the halogen is changed to end in "-ide" (ethyldichloride).
    a. Chloride.
    b. Fluoride.
    c. Bromide.
    d. Iodide.
9. If more than one halogen is present, the halogens are named first, alphabetically, with the ending changed to "-o."
    a. Fluoro.
    b. Chloro.
    c. Bromo.
    d. Iodo.

10. This is followed by the name of the hydrocarbon compound (called the main chain) from which it was created (bromochloromethane).

11. Naming isomers.

    a. Start at the functional group and try to draw a line through all of the carbons. If it is necessary to trace back over the line, it is an isomer; it's branched.

    b. For butane, the rules concerning "iso," "sec" and "tert" apply when naming hydrocarbon derivatives.

C. Uses: varied.

1. Propellants.

2. Solvents and cleaners.

3. Degreasers.

4. Pesticides.

5. Refrigerants (gases).

6. Extinguishing agents.

D. Hazards: Most are extremely toxic; some flammable or combustible; some are carcinogens.

E. Examples.

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ACTIVITY 6.2

Halogenated Hydrocarbons

Purpose

Identify the hazards of the compound using chemical data, given the name, formula or structure of a halogenated hydrocarbon compound.

Directions

1. As a group, complete the Product Hazard Analysis Worksheets for the compounds listed below. (You may choose to divide the work among group members.)
    a. Methyl chloride.
    b. Dichloromethane (methyl dichloride).
    c. Vinyl chloride.
    d. 1,1,1-dichlorofluoroethane
    e. 1,1,1-trichloroethane
2. You may not be able to complete every data point. Focus on the following:
    a. Physical state.
    b. Flammability (% lower explosive level (LEL) and Vp).
    c. Toxicity (permissible exposure limit (PEL)/immediately dangerous to life or health (IDLH)).
    d. Corrosivity (pH).
    e. Reactivity.
    f. Radioactivity.
3. If not completed in the time allotted, complete the activity as homework.

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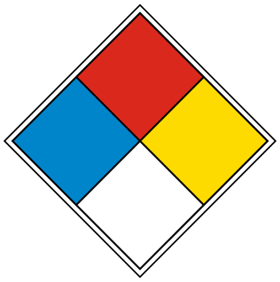
ACTIVITY 6.2 (cont'd)

Product Hazard Analysis Worksheet 1



Group Number: ________ **Presenter:** ________________________

Temp: _________ **°F** **R/H:** _________**%**

Product Name: ________________________________ **Family:** ________________________

Data Points	Result	No Data	Hazard Consideration
Physical Properties			
Physical State			
Vapor Pressure			
Boiling Point			
Vapor Density			
Specific Gravity			
Solubility			
Flammability			
Flash Point			
LEL/UEL			
Flammable Range			
Ignition Temp.			
Toxicity			
Route of Exposure			
IDLH			
PEL/REL/STEL			
S/S of Exposure			
Biological			
Corrosivity			
pH			
Concentration			
Reactivity/Explosion			
Radioactivity			
Decay Mode	☐ N/A ☐ α ☐ β ☐ γ		
Half Life			

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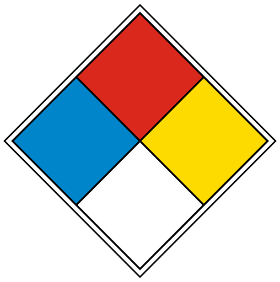

ACTIVITY 6.2 (cont'd)

Product Hazard Analysis Worksheet 2

Group Number: ________ **Presenter:** ________________________

Temp: _________ °F **R/H:** _________%

Product Name: ________________________________ **Family:** ________________________

Data Points	**Result**	**No Data**	**Hazard Consideration**
Physical Properties			
Physical State			
Vapor Pressure			
Boiling Point			
Vapor Density			
Specific Gravity			
Solubility			
Flammability			
Flash Point			
LEL/UEL			
Flammable Range			
Ignition Temp.			
Toxicity			
Route of Exposure			
IDLH			
PEL/REL/STEL			
S/S of Exposure			
Biological			
Corrosivity			
pH			
Concentration			
Reactivity/Explosion			
Radioactivity			
Decay Mode	☐ N/A ☐ α ☐ β ☐ γ		
Half Life			

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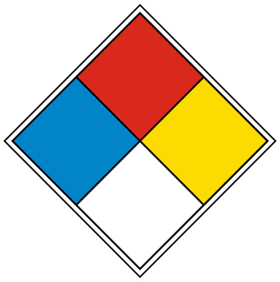
ACTIVITY 6.2 (cont'd)

Product Hazard Analysis Worksheet 3



Group Number: ________ **Presenter:** ________________________

Temp: _________ **°F** **R/H:** _________**%**

Product Name: ________________________________ **Family:** ________________________

Data Points	**Result**	**No Data**	**Hazard Consideration**
Physical Properties			
Physical State			
Vapor Pressure			
Boiling Point			
Vapor Density			
Specific Gravity			
Solubility			
Flammability			
Flash Point			
LEL/UEL			
Flammable Range			
Ignition Temp.			
Toxicity			
Route of Exposure			
IDLH			
PEL/REL/STEL			
S/S of Exposure			
Biological			
Corrosivity			
pH			
Concentration			
Reactivity/Explosion			
Radioactivity			
Decay Mode	☐ **N/A** ☐ α ☐ β ☐ γ		
Half Life			

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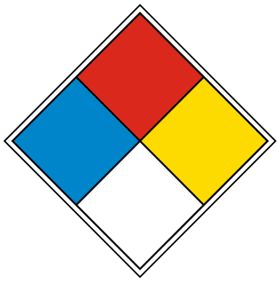
ACTIVITY 6.2 (cont'd)

Product Hazard Analysis Worksheet 4



Group Number: ________ **Presenter:** ________________________

Temp: _________ **°F** **R/H:** _________**%**

Product Name: ________________________________ **Family:** ________________________

Data Points	Result	No Data	Hazard Consideration
Physical Properties			
Physical State			
Vapor Pressure			
Boiling Point			
Vapor Density			
Specific Gravity			
Solubility			
Flammability			
Flash Point			
LEL/UEL			
Flammable Range			
Ignition Temp.			
Toxicity			
Route of Exposure			
IDLH			
PEL/REL/STEL			
S/S of Exposure			
Biological			
Corrosivity			
pH			
Concentration			
Reactivity/Explosion			
Radioactivity			
Decay Mode	☐ N/A ☐ α ☐ β ☐ γ		
Half Life			

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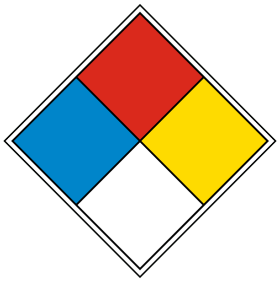
ACTIVITY 6.2 (cont'd)



Product Hazard Analysis Worksheet 5

Group Number: ________ **Presenter:** ________________________

Temp: _________ °F **R/H:** _________%

Product Name: ________________________________ **Family:** ________________________

Data Points	Result	No Data	Hazard Consideration
Physical Properties			
Physical State			
Vapor Pressure			
Boiling Point			
Vapor Density			
Specific Gravity			
Solubility			
Flammability			
Flash Point			
LEL/UEL			
Flammable Range			
Ignition Temp.			
Toxicity			
Route of Exposure			
IDLH			
PEL/REL/STEL			
S/S of Exposure			
Biological			
Corrosivity			
pH			
Concentration			
Reactivity/Explosion			
Radioactivity			
Decay Mode	☐ N/A ☐ α ☐ β ☐ γ		
Half Life			

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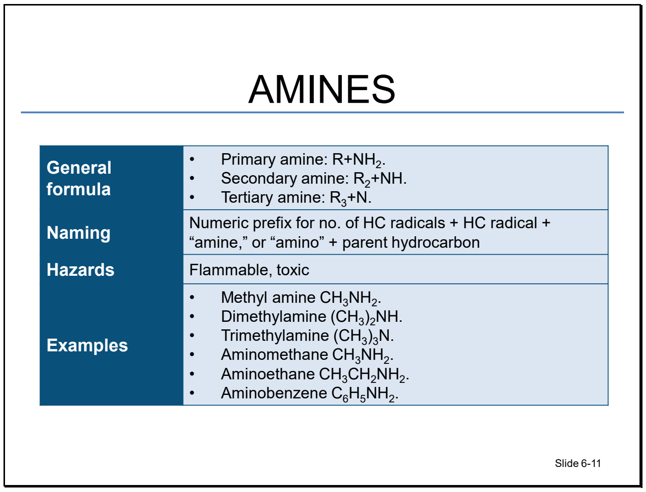
IV. AMINES



AMINES

General formula	• Primary amine: R+NH_2. • Secondary amine: R_2+NH. • Tertiary amine: R_3+N.
Naming	Numeric prefix for no. of HC radicals + HC radical + “amine,” or “amino” + parent hydrocarbon
Hazards	Flammable, toxic
Examples	• Methyl amine CH_3NH_2. • Dimethylamine $(CH_3)_2NH$. • Trimethylamine $(CH_3)_3N$. • Aminomethane CH_3NH_2. • Aminoethane $CH_3CH_2NH_2$. • Aminobenzene $C_6H_5NH_2$.

Slide 6-11

A. General formula.

1. Hydrocarbon with one or more hydrogens replaced by an amine functional group.

2. Hydrocarbon backbone radical represented by “R.”

3. Amine functional group represented by $-NH_2$.

4. There may be varying numbers of radicals on the amine group.

    a. With one radical, it is called a primary amine, having the general formula, $R-NH_2$.

    b. With two radicals, it is called a secondary amine, having the general formula, R_2-NH.

    c. With three radicals and no hydrogen, it is called a tertiary amine, having the general formula, R_3-N.

5. All of these types of amines (primary, secondary, tertiary) are common and should be considered extremely hazardous.

B. Formation.

1. Hydrocarbon has one or more hydrogen removed.

2. Resulting radical must react with something.

3. Each hydrogen shares one electron.

4. An amine functional group (NH_2) can replace any hydrogen on the HC backbone.

C. Naming.

1. First, name the hydrocarbon radical.
2. If there is more than one of the same radical, use the numeric prefix.
    a. "Di-": two of the same radical.
    b. "Tri-": three of the same radical.
3. An alternative naming convention uses the prefix "amino-," followed by the name of the hydrocarbon from which it was created. **This only applies to amines with one radical.**
    a. Aminomethane CH_3NH_2.
    b. Aminoethane $CH_3CH_2NH_2$.
    c. Aminobenzene $C_6H_5NH_2$.

D. Uses.

1. Plastic manufacturing.
2. Corrosion inhibitor in paints.
3. Formation of insecticides.
4. Blister chemical warfare agents.
5. Manufacture of some medicines.

E. Hazards.

1. All are extremely toxic by all routes. Strong irritants.
2. All amines will burn.
3. Unsaturated backbones with amines hold polymerization potentials.
4. Can create caustic solutions on contact with moisture (>11 pH).
5. Toxic to the renal and hepatic systems.

F. Examples.

1. Methylamine (CH_3NH_2).

2. Dimethylamine $(CH_3)_2NH$.

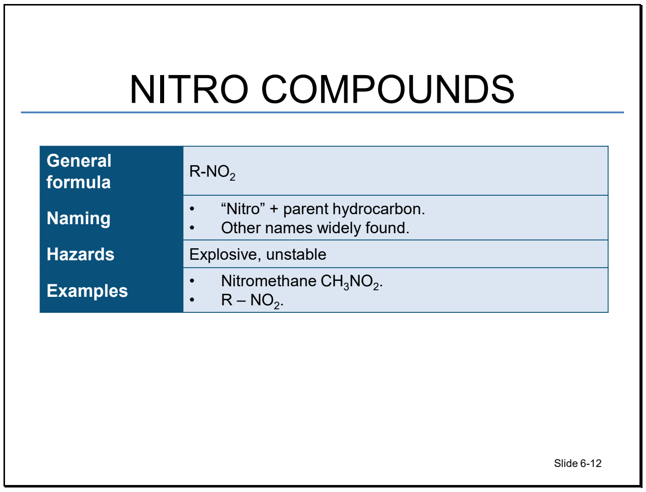
3. Trimethylamine $(CH_3)_3N$.

4. Aminomethane CH_3NH_2.

5. Aminoethane $CH_3CH_2NH_2$.

6. Aminobenzene $C_6H_5NH_2$.

V. NITRO COMPOUNDS



NITRO COMPOUNDS

General formula	R-NO_2
Naming	• "Nitro" + parent hydrocarbon. • Other names widely found.
Hazards	Explosive, unstable
Examples	• Nitromethane CH_3NO_2. • R – NO_2.

A. General formula.

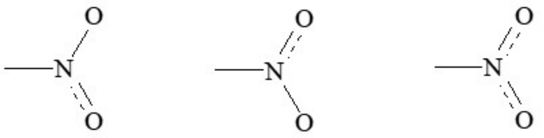
1. A nitro compound is a hydrocarbon with one or more hydrogen atoms removed and replaced by a nitro functional group.

2. Nitro functional group — NO_2.

3. The bond between the nitrogen and the two oxygens is referred to as a "shared" resonant bond.

4. The shared bond can be seen in the structural formula for the nitro functional group, as in the figure on the slide.

Figure 6.1 Resonant bond in NO2



B. Naming.

1. Generally, the word “nitro-” is used as a prefix.
2. This is followed by the hydrocarbon.
3. “Di-,” “tri-,” “tetra-” and other prefixes may be used to denote number of nitro functional groups used.

C. Uses.

1. Explosives.
2. Processing of leather.
3. Metal etching.
4. Manufacturing of some medications.
5. Chemical intermediates.

D. Hazards.

1. Many are what is referred to as an “ideal explosive.”
2. Some may be extremely unstable, while others require high energy for initiation.
3. Toxic by all routes.
4. Can cause irritation to the skin and vasodilation.

E. Examples.

Figure 6.2 Nitromethane CH_3NO_2

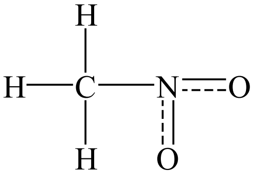


Figure 6.3 Trinitrotoluene (TNT) $C_6H_2CH_3(NO_2)_3$

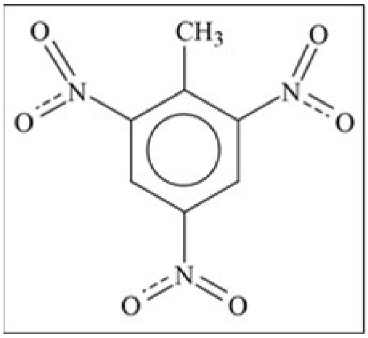
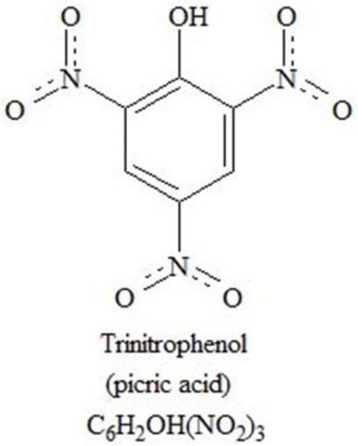
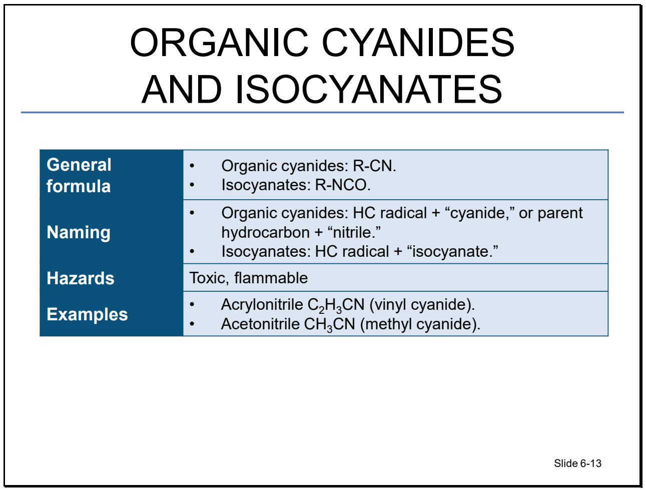


Figure 6.4 Trinitrophenol (picric acid) $C_6H_2(NO_2)_3OH$



VI. ORGANIC CYANIDES AND ISOCYANATES



ORGANIC CYANIDES AND ISOCYANATES

General formula	• Organic cyanides: R-CN. • Isocyanates: R-NCO.
Naming	• Organic cyanides: HC radical + "cyanide," or parent hydrocarbon + "nitrile." • Isocyanates: HC radical + "isocyanate."
Hazards	Toxic, flammable
Examples	• Acrylonitrile C_2H_3CN (vinyl cyanide). • Acetonitrile CH_3CN (methyl cyanide).

A. General formula.

1. A hydrocarbon backbone (radical) with a hydrogen removed and replaced by a cyanide functional group.

2. Organic cyanides.

   a. General formula: R-CN.

   b. Structural formula:

$$-\mathrm{C}\equiv\mathrm{N}$$

3. Isocyanates.

   a. General formula: R-NCO.

   b. The isocyanates are all extremely toxic and are commercially used in the manufacturing of resins, dyes, polymers and electronics.

   c. The nature of the double and triple bonds lends these chemicals to be common monomers.

B. Naming.

1. Organic cyanides.

a. Common naming convention:

- The HC radical is named first.
- Ends in "-cyanide" based on the cyanide functional group.

b. IUPAC naming convention:

- "Nitrile" for the nitrile functional group.
- Nitrile functional group is a cyanide, a C triple bonded to an N but then attached to an HC radical, not a metal.
- When naming them as a nitrile, you name the hydrocarbon backbone first then end with "-nitrile."

2. Common naming convention for isocyanates: Name the hydrocarbon radical first, followed by "-isocyanate."

C. Uses.

1. Extractants for animal and vegetable oils and certain rare metals.
2. Solvent.
3. Chemical intermediate.
4. Manufacturing of resins, dyes and plastics.
5. Pesticide fumigants.

D. Hazards.

1. Extreme toxicity.

   a. The covalent cyanide compounds are not as toxic as the ionic compounds, but still deserve the utmost respect.

   b. The salts are less likely to be a hazard in fires, whereas the nonsalts can be of great concern.

   c. Acrylonitrile is a suspected carcinogen.

   d. Interrupts the body's ability to properly use oxygen (chemical asphyxiant).

        e. Can be rapidly lethal, depending upon dose.

        f. Extremely flammable, depending on HC backbone.

E. There are two very widely used organic cyanides. Examples:

    1. Acrylonitrile C_2H_3CN (vinyl cyanide).

    2. Acetonitrile CH_3CN (methyl cyanide).

ACTIVITY 6.3

Nitrogen Compounds

Purpose

Identify the hazards of the compound, given the name or chemical formula and structure of a nitrogen-based hydrocarbon derivative compound.

Directions

1. Complete the Nitrogen Compounds Worksheet individually or working in your table group.
2. Fill in the missing formula and chemical name for the given compounds on the worksheet. Describe the general hazards of the compound.
3. The instructor will be available to assist with answers to questions as necessary.
4. If not completed in the time allotted, complete the activity as homework.

Hazards of the compounds that should be considered:

- Physical state.
- Flammability.
- Toxicity.
- Reactivity.

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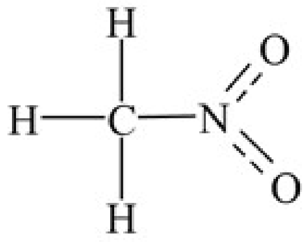
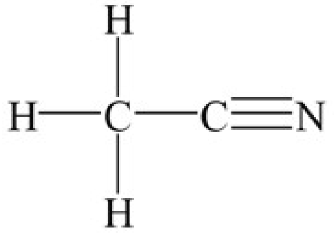
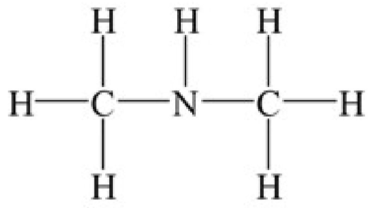
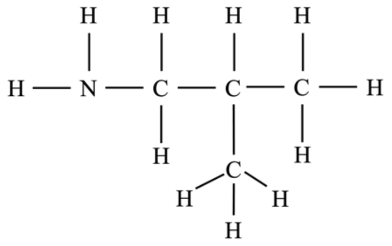
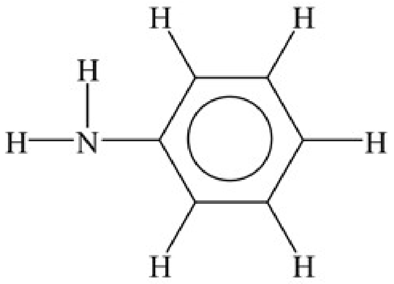
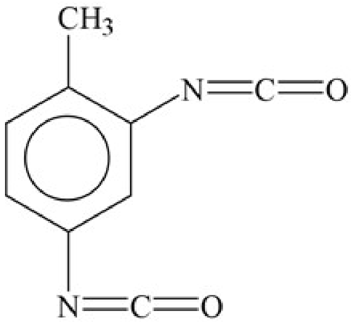
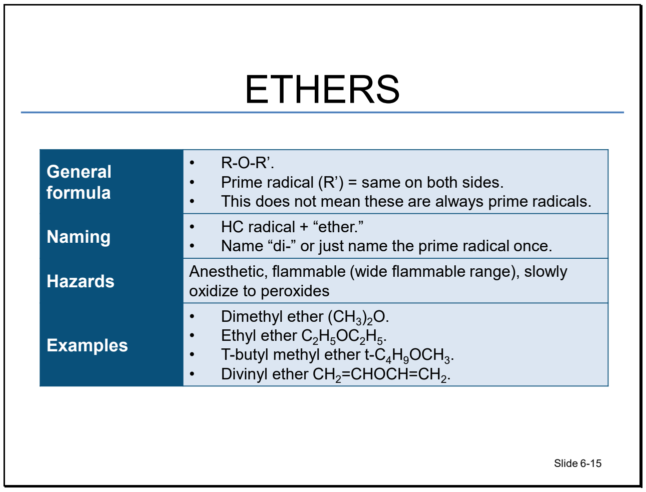
ACTIVITY 6.3 (cont'd)

Nitrogen Compounds Worksheet

#	Name	Structure	Formula	Hazards
1.			CH_3NO_2	
2.			CH_3CN	
3.	Dimethylamine			

#	Name	Structure	Formula	Hazards
4.	Isobutylamine			
5.	Phenylamine			
6.	Toluene di isocyanate (toluene 2,4-di isocyanate)			

VII. ETHERS



ETHERS

General formula	• R-O-R'. • Prime radical (R') = same on both sides. • This does not mean these are always prime radicals.
Naming	• HC radical + "ether." • Name "di-" or just name the prime radical once.
Hazards	Anesthetic, flammable (wide flammable range), slowly oxidize to peroxides
Examples	• Dimethyl ether $(CH_3)_2O$. • Ethyl ether $C_2H_5OC_2H_5$. • T-butyl methyl ether t-$C_4H_9OCH_3$. • Divinyl ether $CH_2{=}CHOCH{=}CH_2$.

Slide 6-15

A. General formula.

1. Oxygen attached between two hydrocarbon radicals.

2. The radicals can be prime radicals, meaning it's the same radical on both sides and need only be named once. Indicated by: R-O-R'. This does not mean that the radicals are always prime radicals.

B. Naming.

1. Name the hydrocarbons first in alphabetical order (e.g., ethyl methyl ether).

2. Follow this with the name "ether."

3. If it is a prime radical, the same radical on both sides of the oxygen, name the radical once instead of using "di." Either way is commonly seen.

4. Diethyl ether can be called ethyl ether. Since it is a given that there must be two radicals, by using the name ethyl, it is implied that both radicals are ethyl radicals.

C. Uses.

1. Formerly used as anesthetics.

2. Solvents for dyes.

3. Gasoline additives.

D. Hazards.

1. It's an unstable arrangement for the oxygen. It comes apart easily.

2. Interposed oxygen (-O-) is a weak bond, which causes the material to be subject to an oxidation process once exposed to air.

    a. This slow oxidation process results in compounds known as organic peroxides.

    b. Opened containers of ether should not be stored for greater than three to six months, depending upon the ether.

3. They slowly oxidize with air to form very unstable organic peroxides.

4. Extremely flammable.

5. Anesthetic and toxic.

6. Some are carcinogens.

7. Central nervous system (CNS) depressant.

8. Ethers with multiple bonds will, like all other unsaturated compounds, tend to polymerize.

E. Examples.

1. Dimethyl ether, commonly called methyl ether $(CH_3)_2O$ (or CH_3OCH_3 or C_2H_6O).

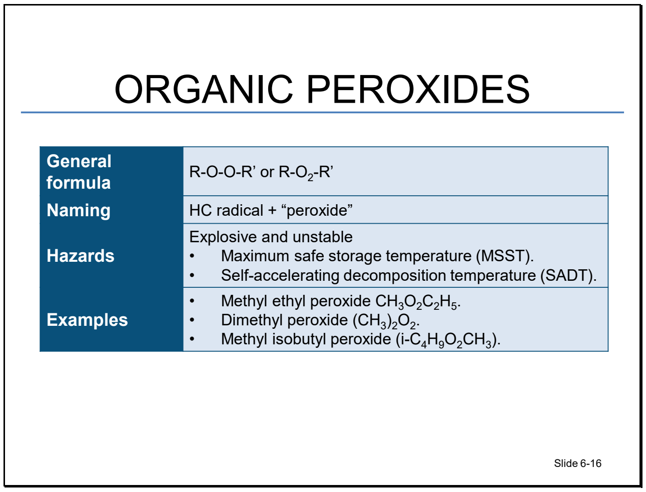
2. Ethyl ether, $C_2H_5OC_2H_5$ (commonly referred to as ether; also known as diethyl ether).

3. T-butyl methyl ether, t-$C_4H_9OCH_3$.

4. Divinyl ether, $CH_2{=}CHOCH{=}CH_2$ (also known as vinyl ether).

5. Ethylene oxide is a type of ether referred to as a cyclical ether. Ethylene oxide is a carcinogen, highly irritating, with a flammable range of 3%-100% in air.

VIII. ORGANIC PEROXIDES



ORGANIC PEROXIDES

General formula	R-O-O-R’ or R-O_2-R’
Naming	HC radical + “peroxide”
Hazards	Explosive and unstable • Maximum safe storage temperature (MSST). • Self-accelerating decomposition temperature (SADT).
Examples	• Methyl ethyl peroxide $CH_3O_2C_2H_5$. • Dimethyl peroxide $(CH_3)_2O_2$. • Methyl isobutyl peroxide (i-$C_4H_9O_2CH_3$).

A. General formula.

1. As with the ethers, two hydrocarbon radicals, which may be prime, one attached to each side of a peroxide functional group consisting of two oxygens.

2. R-O-O-R or (R-O_2-R’).

3. Referred to as the bivalent O-O group.

B. Naming.

1. Many names are complex and confusing.

2. Peroxides often contain other functional groups outside the scope of this course.

3. Will generally contain the word “peroxide” or “peroxy.”

4. Start the name with the HC radical and then end the name with “-peroxide.”

5. It is important to recognize the O_2 functional group in the formula.

C. Uses.

1. Used as monomers, initiators of other chemical reactions such as polymerization.

2. Oxidizers.

3. Bleaching agents.
4. Other chemical manufacturing processes.

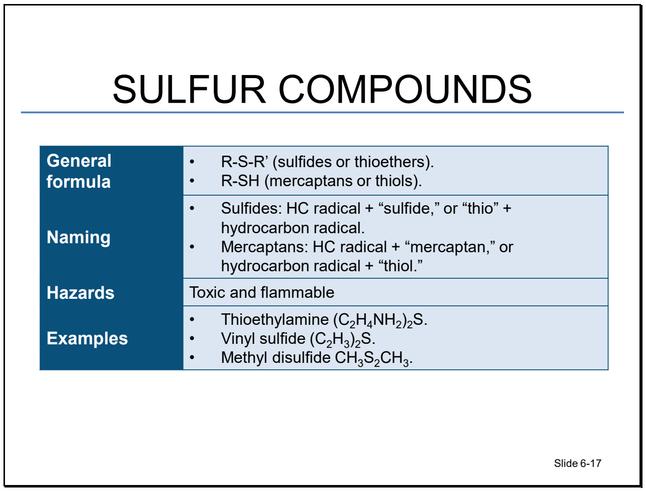
D. Hazards.

1. Some become very unstable when heated (explosive potential).
2. Readily release free radical oxygen, which leads to chain reactions.
3. All are potent oxidizers.
4. Data should include an entry called the maximum safe storage temperature (MSST). Above this temp, it will begin to break down and become increasingly unstable.
5. Can be initiated by other energy sources such as shock, light and contamination.
6. The self-accelerating decomposition temperature (SADT) of an organic peroxide is the temperature at which violent breakdown will occur, and it can't be stopped.
7. Highly flammable.
8. May be corrosive, especially if "acid" is part of the name.
9. Some are very toxic.

E. Examples.

1. Methyl ethyl peroxide $CH_3O_2C_2H_5$.
2. Dimethyl peroxide $(CH_3)_2O_2$.
3. Methyl isobutyl peroxide ($i\text{-}C_4H_9O_2CH_3$).

IX. SULFUR COMPOUNDS



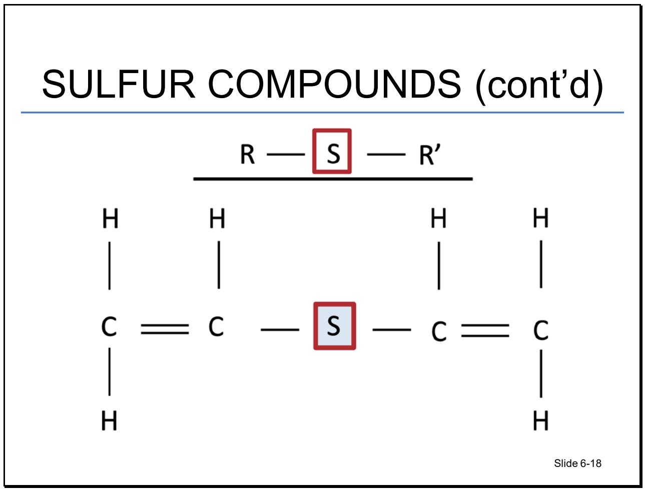
SULFUR COMPOUNDS

General formula	• R-S-R' (sulfides or thioethers). • R-SH (mercaptans or thiols).
Naming	• Sulfides: HC radical + "sulfide," or "thio" + hydrocarbon radical. • Mercaptans: HC radical + "mercaptan," or hydrocarbon radical + "thiol."
Hazards	Toxic and flammable
Examples	• Thioethylamine $(C_2H_4NH_2)_2S$. • Vinyl sulfide $(C_2H_3)_2S$. • Methyl disulfide $CH_3S_2CH_3$.

A. General formula.

1. R-S-R' (thioethers or sulfides).

a. Like the ethers, can have the same (prime) or different radicals on either side.



SULFUR COMPOUNDS (cont'd)

b. "Thio-" is a term used to indicate the presence of sulfur. Therefore, sulfides are sometimes referred to as "thioethers" or simply "thio" in the name.

2. R-SH (thiols or mercaptans).

a. "-thiol" is the IUPAC-approved suffix added to this group of compounds, because the oxygen of the hydroxyl group is replaced by sulfur.

    b. The suffix “-mercaptans,” meaning “mercury-seizing,” is still used in place of “-thiol,” although this is an outdated naming convention.

    c. Not to be confused with “thio,” which is a sulfur compound where “thiol” is a mercaptan compound.

B. Naming.

  1. Naming rules are similar to ethers.

    a. “Thio-” is used as a prefix with the sulfide functional group.

    b. The term “thiol” is an IUPAC convention for the mercaptans.

  2. Name the hydrocarbon radical, and then say “sulfide” or “mercaptan.” If there is more than one sulfur, use “-disulfide,” “-trisulfide,” etc.

  3. If the radical is prime, naming should reflect just one radical.

C. Uses.

  1. Sulfides: primarily used as chemical intermediates or additives. Many are WMD precursors.

  2. Mercaptans: commonly used as odorants, but may also be used as chemical intermediaries in chemical processes and in the manufacture of rubber and plastics. Frequently added to natural gas and propane.

D. Hazards.

  1. Toxic.

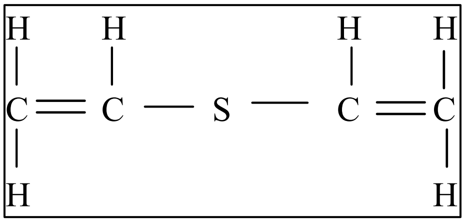
  2. Flammable.

E. Examples.

  1. Thioethylamine — $(C_2H_4NH_2)_2S$.

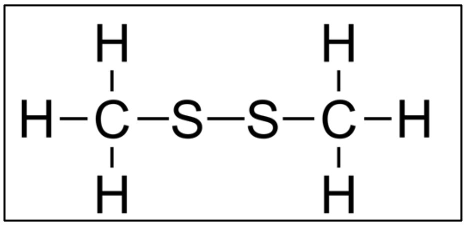
  2. Vinyl sulfide (divinyl sulfide) — $(C_2H_3)_2S$.

Figure 6.5 Vinyl sulfide (divinyl sulfide)



3. Some may have multiple sulfur atoms. Dimethyl disulfide — $CH_3S_2CH_3$.

Figure 6.6 Dimethyl disulfide (methyl disulfide)



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ACTIVITY 6.4

Oxygen-Based Compounds and Sulfur Compounds

Purpose

Identify the chemical formula, name, family and hazards of the compound, given the name, structure or chemical formula of an oxygen-based or sulfur hydrocarbon derivative compound.

Directions

1. Complete the Oxygen-Based Compounds (Ethers and Peroxides) and Sulfur Compounds (Sulfides and Mercaptans) Worksheet individually or working in your table group.

2. Fill in the missing formula and chemical name for the given compounds on the worksheet. Identify the family to which each compound belongs and describe the general hazards of the compound.

3. The instructor will be available to assist with answers to questions as necessary.

4. If not completed in the time allotted, complete the activity as homework.

Hazards of the compounds that should be considered:

- Physical state.
- Flammability.
- Toxicity.
- Corrosivity.
- Reactivity.
- Radioactivity.

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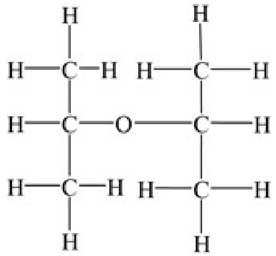
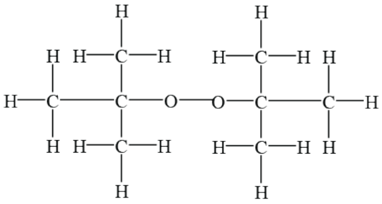
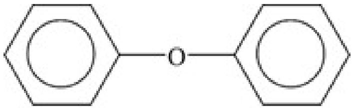
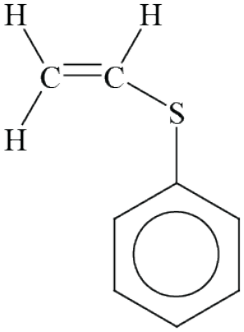
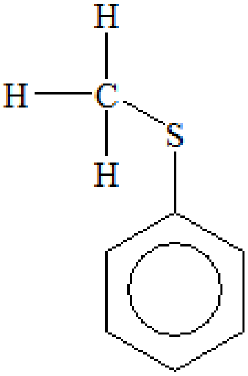
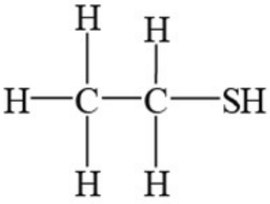
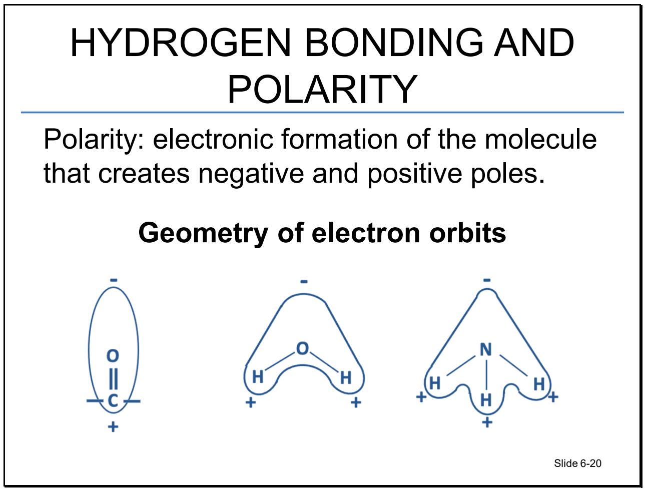
ACTIVITY 6.4

Oxygen-Based Compounds (Ethers and Peroxides) and Sulfur Compounds (Sulfides and Mercaptans) Worksheet

#	Name	Structure	Formula	Hazards
1.	Diisopropyl ether, or isopropyl ether			
2.			$(C_4H_9)_2O_2$	
3.	Phenyl ether, or diphenyl ether			

#	Name	Structure	Formula	Hazards
4.			$C_6H_5SC_2H_3$	
5.	Methyl phenyl sulfide			
6.			C_2H_5SH	

X. HYDROGEN BONDING AND POLARITY



HYDROGEN BONDING AND POLARITY

Polarity: electronic formation of the molecule that creates negative and positive poles.

Geometry of electron orbits

Slide 6-20

Geometry yields polarity.

A. In the simple sense, **polarity** is an electronic formation (electron fields) of the molecule that creates negative and positive poles. The nucleus creates a "+" end and the electron cloud creates the "–" end, which is essentially a magnet.

B. Electron-drawing elements, the nonmetals, will pull the electron field away, creating a negative pole (e^-) while exposing the positively charged nucleus due to the + charge on protons (P^+).

C. Like structures will dissolve like structures.

D. Nonpolar substances do not have this capability and are water insoluble. The hydrocarbon family, for example, has no polarity because there are no + or – poles.

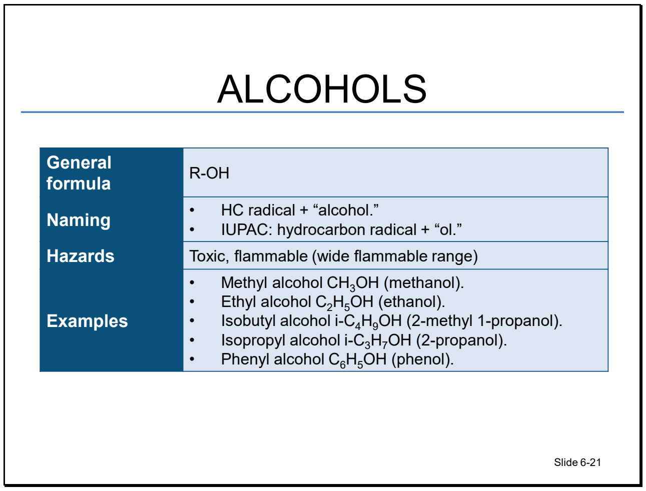
E. Hydrocarbons satisfy each other completely within the Octet Rule. There is no OH hydrogen bonding in pure hydrocarbons. The HC bond is not electron-drawing, so no poles are exposed.

F. Hydrogen bonding is the arrangement of OH within a molecule resulting in an exposed positively charged proton. This results in attraction between polar molecules. It is a weak force that is able to create a simple bond between hydrogen and oxygen. Water is an example of hydrogen bonding (H-OH).

    1. In several chemical families, you will see mild polarity and higher boiling temperatures. Some of this is due to the polarity and hydrogen bonding that occurs between molecules. A carbonyl has polarity due to the O pulling electrons toward one end of the molecule.

2. Although polarity and its inherent concerns cannot be seen or measured in the field, understanding which chemical family has these potentials can give rise to appropriate mitigation efforts, for example, using nonpolar foam on polar fuels.

XI. ALCOHOLS



ALCOHOLS

General formula	R-OH
Naming	• HC radical + "alcohol." • IUPAC: hydrocarbon radical + "ol."
Hazards	Toxic, flammable (wide flammable range)
Examples	• Methyl alcohol CH_3OH (methanol). • Ethyl alcohol C_2H_5OH (ethanol). • Isobutyl alcohol i-C_4H_9OH (2-methyl 1-propanol). • Isopropyl alcohol i-C_3H_7OH (2-propanol). • Phenyl alcohol C_6H_5OH (phenol).

Slide 6-21

A. General formula.

1. General formula: R-OH.

2. Structural formula:

   —O—H

3. Hydrocarbon radical attaches to the alcohol functional group.

4. "R" is the hydrocarbon radical.

5. "OH" is the hydroxyl group. The functional group for the alcohols is called the hydroxyl group.

B. Naming.

1. One naming system consists of naming the radical, followed by the word "alcohol."

2. In IUPAC naming, the end of the hydrocarbon radical is changed to "-ol."

3. Variations.

a. Alcohols have one hydroxyl group -OH.

—O—H.

b. Glycols have two hydroxyl groups (IUPAC term: “-diols”).

c. Glycerols have three hydroxyl groups.

C. Uses: Alcohols have a wide range of uses.

D. Hazards.

1. Range in toxicity from mild to severe.

   a. Ethanol is consumed by humans in low to moderate concentrations.

   b. Methyl alcohol, butyl alcohol and phenol are all extremely toxic.

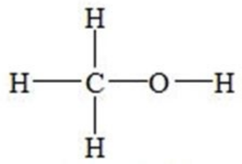
2. Assume all alcohols are poisonous in the absence of data indicating otherwise.

3. Can slow-oxidize at room temperature over time into very toxic aldehydes and then into carboxylic acids. “Old” alcohols may, in fact, be acids.

4. All have wide flammable ranges, but flash points (Fp) vary greatly depending upon hydrocarbon radical size. They all burn.

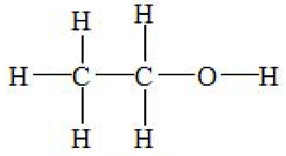
E. Examples.

1. Methyl alcohol CH_3OH (methanol).



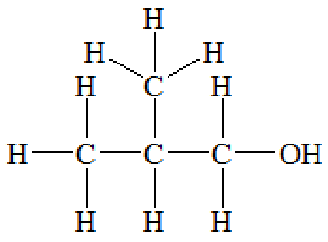
$$H-\overset{\displaystyle H}{\underset{\displaystyle H}{C}}-O-H$$

2. Ethyl alcohol C_2H_5OH (ethanol).

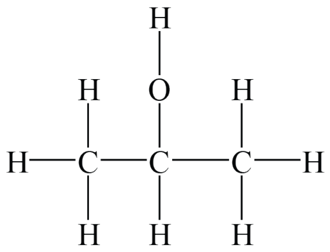


$$H-\overset{\displaystyle H}{\underset{\displaystyle H}{C}}-\overset{\displaystyle H}{\underset{\displaystyle H}{C}}-O-H$$

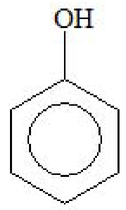
3. Isobutyl alcohol i-$C_4H_{10}O$ (2-methyl 1-propanol).



4. Isopropyl alcohol i-C_3H_7OH (2-propanol).

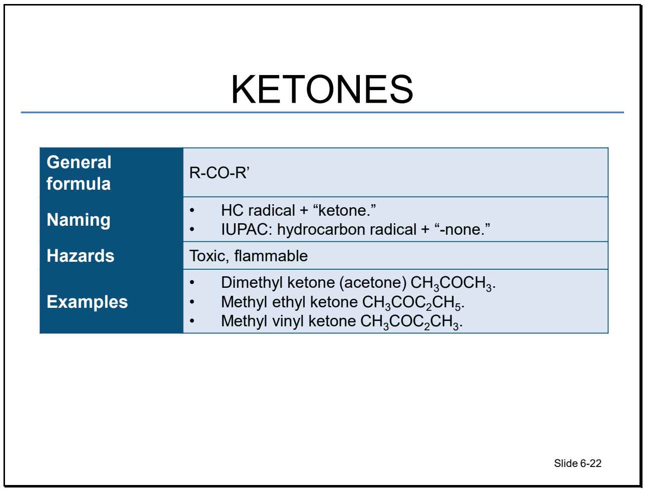


5. Phenyl alcohol C_6H_5OH (phenol).



Phenol
C_6H_5OH

XII. KETONES



KETONES

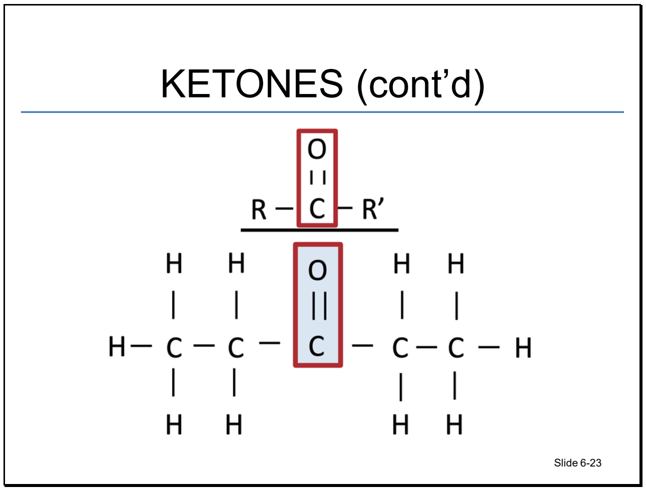
General formula	R-CO-R’
Naming	- HC radical + “ketone.” - IUPAC: hydrocarbon radical + “-none.”
Hazards	Toxic, flammable
Examples	- Dimethyl ketone (acetone) CH_3COCH_3. - Methyl ethyl ketone $CH_3COC_2CH_5$. - Methyl vinyl ketone $CH_3COC_2CH_3$.

Slide 6-22

A. General formula.

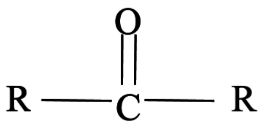
1. R-CO-R’.

2. Structural formula:



KETONES (cont’d)

Slide 6-23



$$R-\overset{O}{\overset{\|}{C}}-R$$

3. Comprising the ketone functional group and two hydrocarbon radicals which could be prime.

4. The ketone functional group consists of a carbonyl.

5. The carbonyl is a carbon double bonded to an oxygen with two remaining unpaired electrons on the carbon.

B. Naming.

1. The hydrocarbon radical is named first. If the radical is prime, it should only be named once, not using di-. If the radicals are not the same, generally name the smallest one first.

2. Followed by the term "ketone."

3. In IUPAC naming, the hydrocarbon chain is named based upon the number of carbons in the "main chain" (including the carbonyl carbon), and the ending is changed to "-none." The name starts with a numeral designating the number of the carbon the carbonyl is attached to.

C. Uses.

1. The main and almost exclusive use is that of a solvent in paints, varnishes and glues.

2. Ketones are slightly polar due to the polarity of the carbonyl.

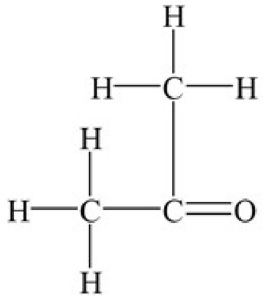
D. Hazards.

1. Toxic.

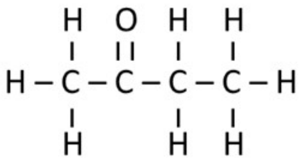
2. Flammable.

E. Examples.

1. Dimethyl ketone (methyl ketone) $(CH_3)_2CO$ or CH_3COCH_3. This can be named "2-propanone" using IUPAC. A trade name for this compound is "acetone."

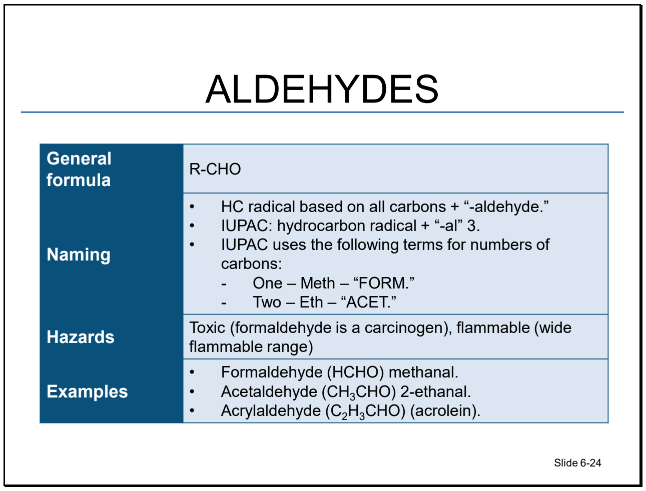


2. Methyl ethyl ketone $CH_3COC_2H_5$. IUPAC would call this 2-butanone.



3. Methyl vinyl ketone $CH_3COC_2CH_3$.

XIII. ALDEHYDES



ALDEHYDES

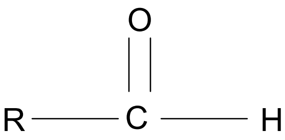
General formula	R-CHO
Naming	• HC radical based on all carbons + “-aldehyde.” • IUPAC: hydrocarbon radical + “-al” 3. • IUPAC uses the following terms for numbers of carbons: - One – Meth – “FORM.” - Two – Eth – “ACET.”
Hazards	Toxic (formaldehyde is a carcinogen), flammable (wide flammable range)
Examples	• Formaldehyde (HCHO) methanal. • Acetaldehyde (CH_3CHO) 2-ethanal. • Acrylaldehyde (C_2H_3CHO) (acrolein).

Slide 6-24

A. General formula.

1. R-CHO.

2. Structural formula:



$$R-\overset{\overset{\displaystyle O}{\|}}{C}-H$$

3. Carbonyl group attached to a hydrocarbon radical and a hydrogen.

4. Hydrocarbon radical on one side. Hydrogen on the opposing side.

5. Count all of the carbons in the compound when naming, including the carbonyl.

6. The formula always ends in “CHO.”

B. Naming.

1. Counting all the carbons (including the carbonyl carbon), name the hydrocarbon radical appropriate for the number of total carbons then end with "-aldehyde."

2. In IUPAC, name the main chain and change the ending to "-al."

3. IUPAC uses the following terms for numbers of carbons:

   a. One – Meth – "FORM."

   b. Two – Eth – "ACET."

C. Uses.

1. Solvents.

2. Disinfectants.

3. Preservatives.

4. Unsaturated aldehydes are used in manufacturing of some plastics.

5. Manufacturing of some pesticides.

D. Hazards.

1. Toxic by inhalation.

2. Wide flammable ranges.

3. Mildly to severely irritating.

   a. Can be a sensitizer.

   b. Later chemical exposures can result in anaphylactic reactions.

4. Formaldehyde is a carcinogen.

5. Polymerization hazard.

6. May have slow oxidation potential.

   a. Oxidize into organic acids.

b. Can then undergo hypergolic combustion in contact with potent oxidizers.

7. Some low molecular weight (MW) aldehydes can oxidize into organic peroxides.

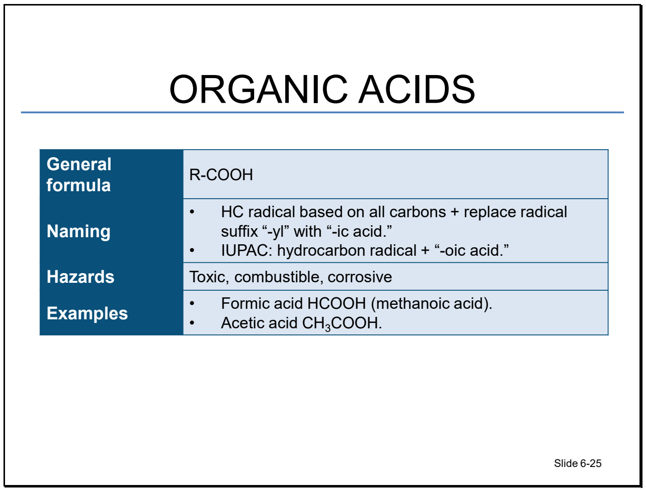
E. Examples.

1. Formaldehyde (HCHO) methanal.

2. Acetaldehyde (CH_3CHO) 2-ethanal.

3. Acrylaldehyde (C_2H_3CHO) (acrolein).

XIV. ORGANIC ACIDS



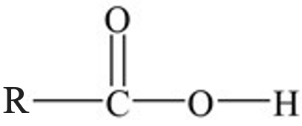
ORGANIC ACIDS

General formula	R-COOH
Naming	• HC radical based on all carbons + replace radical suffix “-yl” with “-ic acid.” • IUPAC: hydrocarbon radical + “-oic acid.”
Hazards	Toxic, combustible, corrosive
Examples	• Formic acid HCOOH (methanoic acid). • Acetic acid CH_3COOH.

A. General formula.

1. R-COOH.

2. Structural formula:



$$R-\overset{\overset{\displaystyle O}{\|}}{C}-O-H$$

3. Hydrocarbon radical attached to organic acid functional group.

4. The organic acid functional group (COOH) is also called a carboxyl group; the organic acids are also referred to as carboxylic acids.

B. Naming.

1. Common naming convention:

   a. Name the hydrocarbon radical based on a count of all the carbons including the C of the carbonyl.

   b. The presence of the COOH group in the formula readily identifies the compound as an organic acid. These are never noted as CO_2H in the formula — always COOH at the end of the formula.

   c. Then, replace the "-yl" suffix of the hydrocarbon radical with "-ic acid."

   d. Examples: formic acid, acetic acid and acrylic acid are the main ones.

2. IUPAC naming convention.

   a. Count the total carbons and name the appropriate hydrocarbon main chain.

   b. Change the ending to "-oic" and add "acid."

   c. Examples: methanoic acid and ethanoic acid.

C. Uses.

1. Plastic production.

2. Water purification.

3. Solvents.

4. Decalcification.

D. Hazards.

1. Some are very toxic.

   a. Some carboxylic compounds are found within the body and are an important component of the life process.

   b. Can be mild to severe irritants.

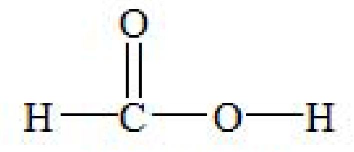
2. These acids are flammable or combustible depending on the HC backbone.

3. Upon contact with water, an acidic solution is produced because these acids will mix; they are very polar.

4. Will also produce hydrogen gas on contact with certain metals.

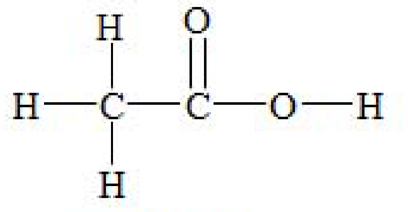
E. Examples:

1. Formic acid HCOOH (methanoic acid), because it has only one carbon.



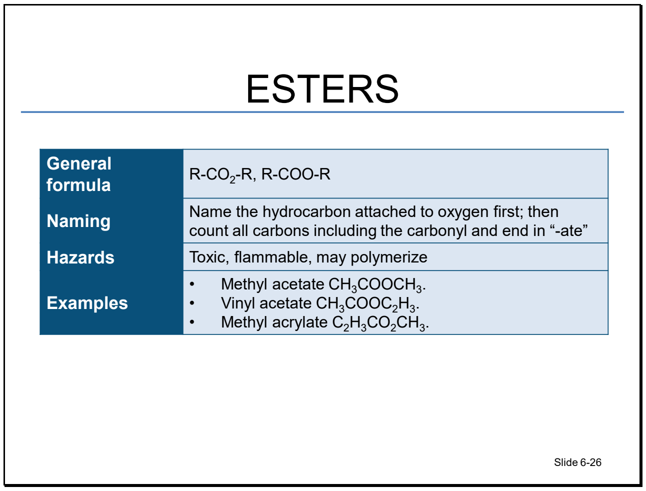
$$H-\overset{\overset{O}{\|}}{C}-O-H$$

2. Acetic acid CH3COOH (ethanoic acid), because it has two carbons.



$$H-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-\overset{\overset{O}{\|}}{C}-O-H$$

XV. ESTERS



ESTERS

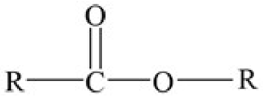
General formula	R-CO_2-R, R-COO-R
Naming	Name the hydrocarbon attached to oxygen first; then count all carbons including the carbonyl and end in "-ate"
Hazards	Toxic, flammable, may polymerize
Examples	• Methyl acetate CH_3COOCH_3. • Vinyl acetate $CH_3COOC_2H_3$. • Methyl acrylate $C_2H_3CO_2CH_3$.

Slide 6-26

A. General formula.

1. R-COO-R.

2. Structural formula:



3. Hydrocarbon radical attached to either side of an ester group (COO). These radicals are not prime.

B. Naming.

1. The first word in the name is the radical attached to the oxygen.

   a. Hydrogen only = formate.

   b. Methyl radical = acetate.

   c. Vinyl radical = acrylate.

2. Count the carbon of the carbonyl in the naming of the second radical.

C. Uses.

1. Food additives. Saturated esters have a sweet odor and are used as candy and food flavorings.

2. Plastic manufacturing.

3. Phosphate and sulfite esters are primary components as precursors in WMD agents.

D. Hazards.

1. Some, when unsaturated, can be very hazardous and unstable.

2. Unsaturated esters are very toxic. Some esters have low toxicity.

   a. Unsaturated esters can react spontaneously with oxygen at room temperature.

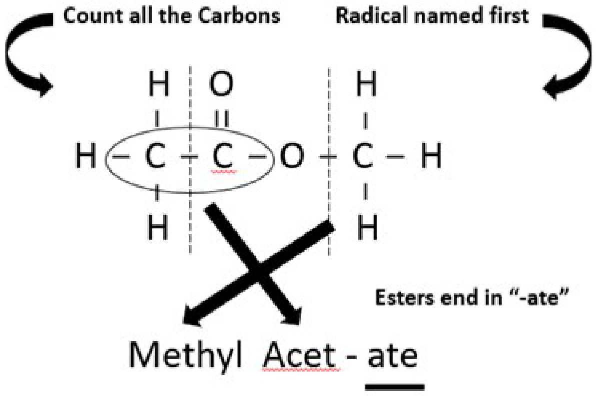
   b. Unsaturated esters are subject to polymerization.

3. May cause hypersensitivity.

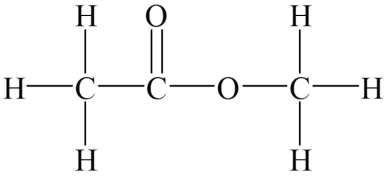
4. All esters are flammable/combustible.

E. Examples.

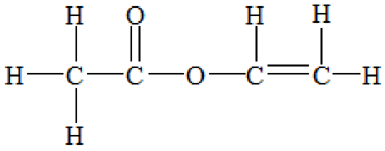
Figure 6.7: Ester functional group with a methyl attached to the oxygen and a methyl attached to the carbonyl



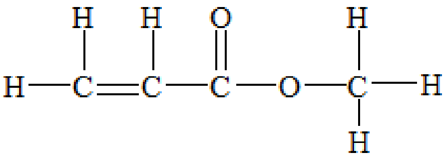
1. Methyl acetate.



2. Vinyl acetate.



3. Methyl acrylate.



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ACTIVITY 6.5

Alcohols, Ketones, Aldehydes, Organic Acids and Esters

Purpose

Identify the chemical formula, name, family and hazards of the compound, given the name or chemical formula and structure of a hydrocarbon derivative compound.

Directions

1. Complete the Alcohols, Ketones, Aldehydes, Organic Acids and Esters Worksheet individually or working in your table group.

2. Fill in the missing formula or chemical name for the given compounds on the worksheet. Identify the family to which each compound belongs and describe the general hazards of the compound.

3. The instructor will be available to assist with answers to questions as necessary.

4. If not completed in the time allotted, complete the activity as homework.

Hazards of the compounds that should be considered:

- Physical state.
- Flammability.
- Toxicity.
- Corrosivity.

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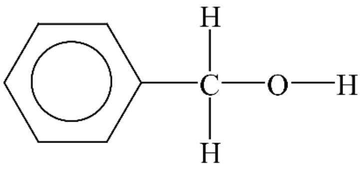
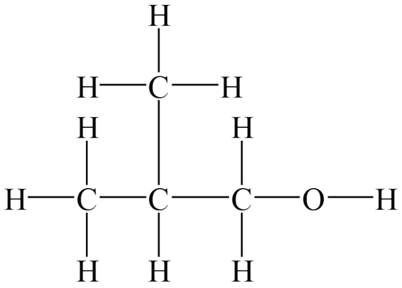
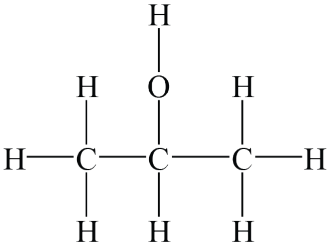
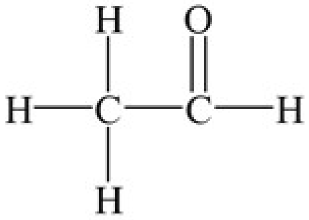
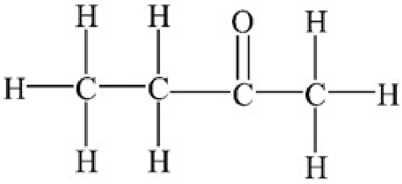
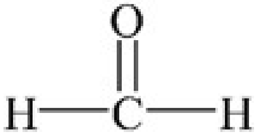
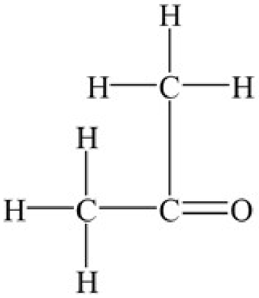
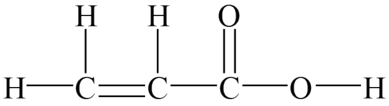
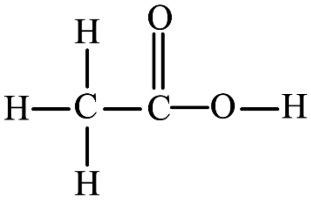
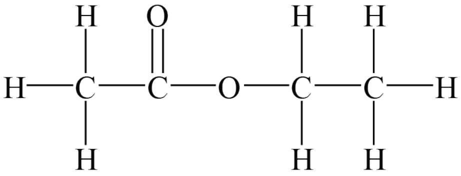
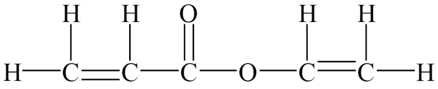
ACTIVITY 6.5 (cont'd)

Alcohols, Ketones, Aldehydes, Organic Acids and Esters Worksheet

#	Name	Structure	Formula	Hazards
1.	Benzyl alcohol			
2.	Isobutyl alcohol 2-methyl propanol			
3.			i-C_3H_7OH	
4.			CH_3CHO	
5.	Methyl ethyl ketone			

#	Name	Structure	Formula	Hazards
6.	Formaldehyde			
7.			$(CH_3)_2CO$	
8.	Acrylic acid 2-propenoic acid			
9.			CH_3COOH	
10.	Ethyl acetate			
11.			$(C_2H_3)_2COO$	

ACTIVITY 6.6

Homework: All Hydrocarbon Derivative Families

Purpose

Analyze families of hydrocarbons and hydrocarbon derivatives, including name, general formula, any special rules and hazards of the compound.

Directions

1. As homework, complete the All Hydrocarbon Derivative Families Worksheet individually or working with members from your table group.

2. Fill in the missing formula and chemical name for the given compounds on the worksheet. Identify the family to which each compound belongs and describe the general hazards of the compound.

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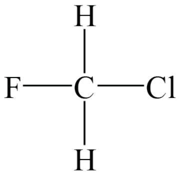
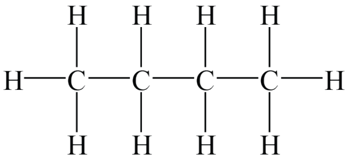
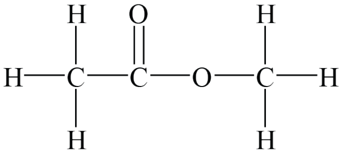
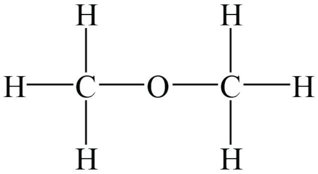
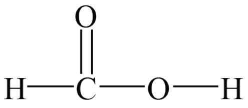
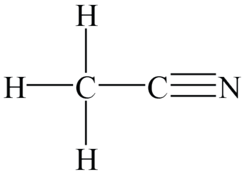
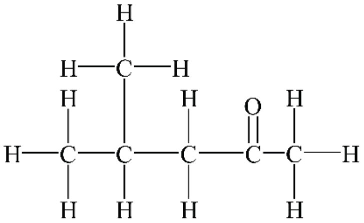
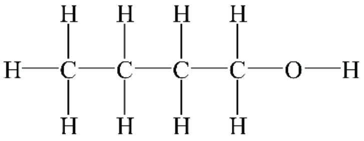
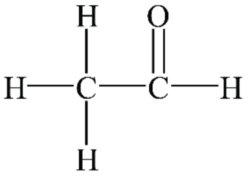
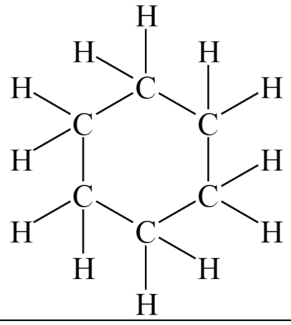
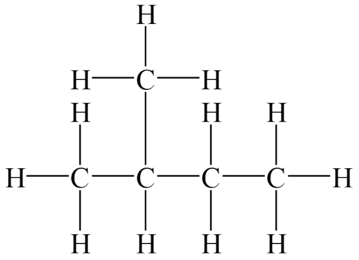
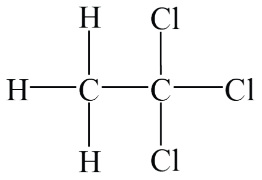
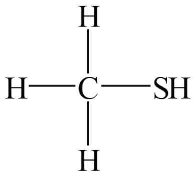
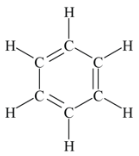
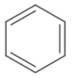
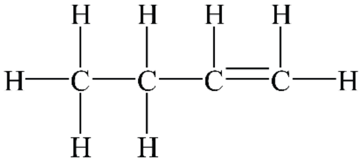
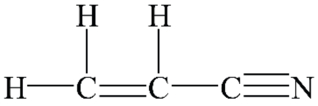
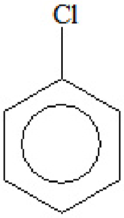
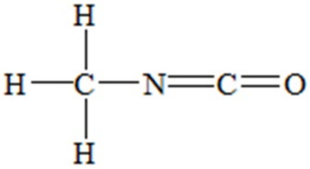
ACTIVITY 6.6 (cont'd)

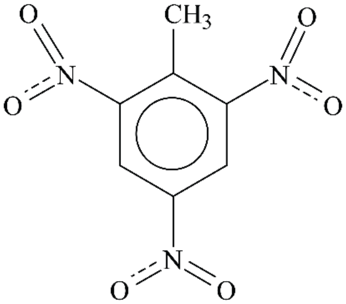
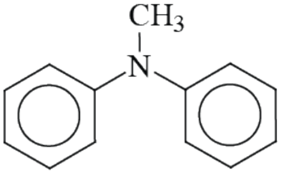
All Hydrocarbon Derivative Families Worksheet

#	Name	Structure	Formula	Family and general hazards
1.	Chlorofluoromethane			
2.	Butane			
3.	Methyl acetate			
4.	Dimethyl ether Methyl ether			

#	Name	Structure	Formula	Family and general hazards
5.	Formic acid			
6.	Methyl cyanide Acetonitrile			
7.			i-$C_4H_9COCH_3$	
8.			C_4H_9OH	
9.			CH_3CHO	

#	Name	Structure	Formula	Family and General Hazards
10.			c-C_6H_{12}	
11.			i-C_5H_{12}	
12.			$C_2H_3Cl_3$	
13.			CH_3SH	
14.		  	C_6H_6	

#	Name	Structure	Formula	Family and General Hazards
15.	1-Butene (1-butylene)			
16.	Vinyl cyanide Acrylonitrile			
17.	Phenyl chloride Chlorobenzene			
18.	Methyl isocyanate			

#	Name	Structure	Formula	Family and General Hazards
19.	2,4,6 Trinitrotoluene			
20.			$(C_6H_5)_2NCH_3$	

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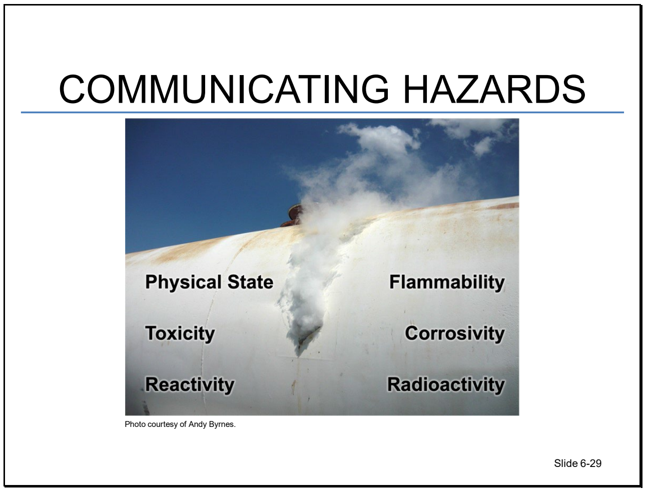
XVI. COMMUNICATING HAZARDS



COMMUNICATING HAZARDS

Physical State

Flammability

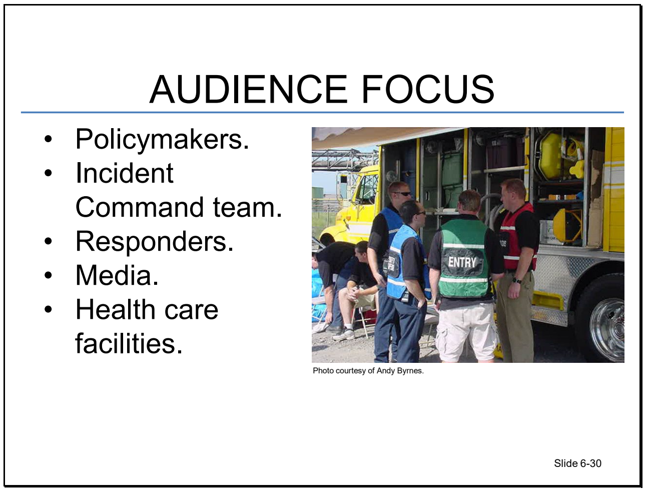
Toxicity

Corrosivity

Reactivity

Radioactivity

Photo courtesy of Andy Byrnes.



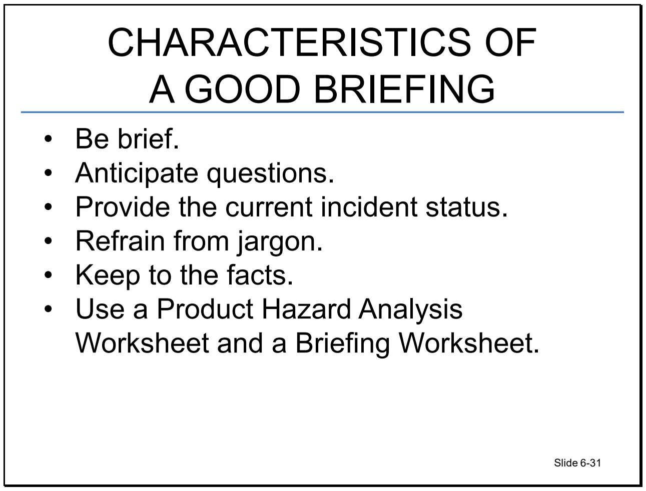
AUDIENCE FOCUS

- Policymakers.
- Incident Command team.
- Responders.
- Media.
- Health care facilities.

Photo courtesy of Andy Byrnes.

A. Audience focus.

1. Policymakers.
2. Incident Command team.
3. Responders.
4. Media.
5. Health care facilities.

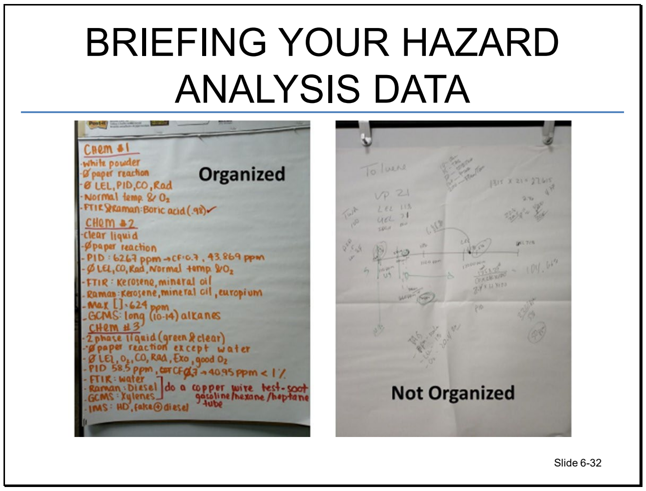


CHARACTERISTICS OF A GOOD BRIEFING

- Be brief.
- Anticipate questions.
- Provide the current incident status.
- Refrain from jargon.
- Keep to the facts.
- Use a Product Hazard Analysis Worksheet and a Briefing Worksheet.

B. Characteristics of a good briefing.

1. Be brief.
2. Anticipate questions.
3. Provide the current incident status.
4. Refrain from jargon/technical data that the audience won't understand.
5. Keep to the facts.
6. Use a Product Hazard Analysis Worksheet and a Briefing Worksheet to help guide you.



BRIEFING YOUR HAZARD ANALYSIS DATA

Organized

Not Organized

C. Organized versus disorganized information.

ACTIVITY 6.7

Product Hazard Analysis

Purpose

Analyze a given product using limited information and communicate the hazards of the product.

Group assignments

Group/scenario	Section(s)	Audience
1	Physical properties	Responders/entry team
2	Flammability	Incident Command team
3	Toxicity	Public Information Officer (PIO)
4	Corrosivity and reactivity	Safety Officer
5	Radioactivity	Medical professionals

Directions

1. Working with your group, review your assigned scenario and answer the following questions:

   a. How would the information you have at this point allow you to select personal protective equipment (PPE)?

   ____

   ____

   ____

   b. What type of monitoring or detection materials might be helpful?

   ____

   ____

   ____

c. What decontamination considerations might be necessary?

____

____

____

2. Work with your group to complete your assigned section(s) of the Product Hazard Analysis Worksheet for your scenario using electronic or paper resources.

3. How does the information you found for your assigned section(s) of the Product Hazard Analysis Worksheet impact your decision-making related to each of the following?

a. Scene control.

____

____

____

b. PPE.

____

____

____

c. Detection.

____

____

____

d. Decontamination.

____

____

____

4. What would you need to communicate to your assigned target audience?

____

____

____

5. Be prepared to share your findings.

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ACTIVITY 6.7 (cont'd)

Scenarios

Scenario 1

It's 1330 and 88°F with a wind-speed of 20 mph and relative humidity of 44%. You've been called to a DOT 406 spill at a gas station with a placard marked 1993. Your estimate is that 10 gallons have spilled.

Scenario 2

It's 1615 and 101°F with a wind-speed of 10 mph and relative humidity of 84%. A 50-pound brown paper bag, which is plastic lined, has broken open on the freeway offramp, releasing a white, flaky substance. Traffic has been driving through it. There is a corrosive label on the bag.

Scenario 3

It's 0945 and 9°F with a wind-speed of 7 mph and relative humidity of 64%. You're responding to a high school lab storage closet where a 1-gallon white plastic jug dropped and split open, spilling a dark yellow/orange, viscous liquid. There are no labels or markings on the jug. The teacher calls it trinitrophenol.

Scenario 4

It's 1015 and 58°F with a wind-speed of 13 mph and relative humidity of 74%. A local recycling center has reported an abandoned 55-gallon paper drum, plastic lined, with no label. The bottom is crushed on one side, and an opaque green liquid is leaking from the bottom ring. Your estimate is 2 gallons in the spill.

Scenario 5

It is 1735 on a Tuesday afternoon. The temperature is 68°F, winds are 3 mph, and the relative humidity is 64%. You are dispatched to a two-car motor vehicle crash involving a construction company pickup and a passenger vehicle. There are injuries in both vehicles. There is debris from the pickup truck thrown around the scene, including a Troxler 3241-C concrete gauge. The law enforcement officer on scene advises that his radiation pager begins to vibrate and beep as he approaches the debris field.

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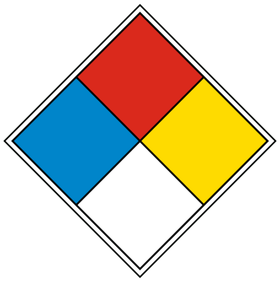
ACTIVITY 6.7 (cont’d)

Product Hazard Analysis Worksheet



Group Number: ________ **Presenter:** ________________________

Temp: _________ °F **R/H:** _________%

Product Name: ________________________________ **Family:** ________________________

Data Points	Result	No Data	Hazard Consideration
Physical Properties			
Physical State			
Vapor Pressure			
Boiling Point			
Vapor Density			
Specific Gravity			
Solubility			
Flammability			
Flash Point			
LEL/UEL			
Flammable Range			
Ignition Temp.			
Toxicity			
Route of Exposure			
IDLH			
PEL/REL/STEL			
S/S of Exposure			
Biological			
Corrosivity			
pH			
Concentration			
Reactivity/Explosion			
Radioactivity			
Decay Mode	☐ N/A ☐ α ☐ β ☐ γ		
Half Life			

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ACTIVITY 6.8

Hydrocarbon Derivative Incident Scenarios

Purpose

Describe one or more hydrocarbon derivatives involved in an incident and identify the formula, chemical name, family and potential hazards of the compounds. Analysis of the product should include the facts, science and circumstances of the incident.

Directions

1. Review your assigned scenario with your table group.
2. Create a product hazard analysis for the scenario using the Product Hazard Analysis Worksheets.
3. Prepare an incident briefing focused on the hazard(s) you are most concerned about without over-analysis.
4. You may use any electronic or printed resources.
5. Once your group has completed its hazard analysis, write your findings on an easel pad.
6. Be prepared to discuss your findings with the class. Presentations will be 10 minutes each, with five minutes for questions.
7. Refer to the rubric for scoring criteria.

Hazards of the compounds that should be considered:

- Physical state.
- Flammability.
- Toxicity.
- Corrosivity.
- Reactivity.
- Radioactivity.

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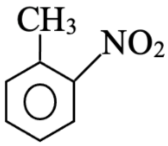
ACTIVITY 6.8 (cont'd)

Hydrocarbon Derivative Incident Scenarios

Scenario 1

A violent explosion occurred in a chemical distillation tower at First Chemical Corporation in Pascagoula, Mississippi, sending heavy debris over a wide area. No one was seriously injured or killed in the incident, which occurred early on a Sunday morning. One nitrotoluene storage tank at the site was punctured by the explosion's debris, igniting a fire that burned for several hours.

Chemical	**Nitrotoluene**
Family	
Formula for this material	
Chemical structure	
General hazards	

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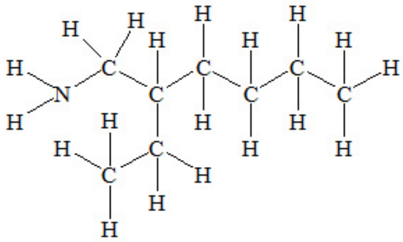
ACTIVITY 6.8 (cont'd)

Hydrocarbon Derivative Incident Scenarios

Scenario 2

On Wednesday, April 8, 1998, in Paterson, New Jersey, during a mixing operation involving 2-ethylhexylamine, an explosion occurred injuring several employees, two critically.

Chemicals	**2-ethylhexylamine (3-methylaminoheptane)**
Family and general formula	
Formula for this material	
Chemical structure	
General hazards	

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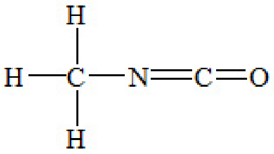
ACTIVITY 6.8 (cont’d)

Hydrocarbon Derivative Incident Scenarios

Scenario 3

In the early hours of Monday, Dec. 3, 1984, an explosion at the Union Carbide plant released a deadly cocktail of poisonous gas made up of methyl isocyanate and up to 20 other chemicals.

Chemicals	**Methyl isocyanate**
Family and general formula	
Formula for this material	
Chemical structure	
General hazards	

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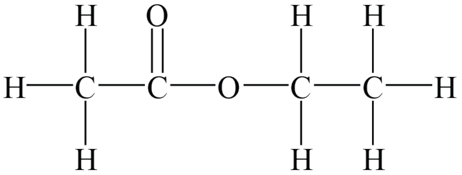
ACTIVITY 6.8 (cont'd)

Hydrocarbon Derivative Incident Scenarios

Scenario 4

On Oct. 29, 2007, at about 1 p.m., a fire and a series of explosions occurred at the Barton Solvents Des Moines, Iowa, chemical distribution facility. The initial fire started in the packaging area while a 300-gallon portable steel tank, known as a tote, was being filled with ethyl acetate, a flammable solvent.

Chemical	**Ethyl acetate**
Family and general formula	
Formula for this material	
Chemical structure	
General hazards	

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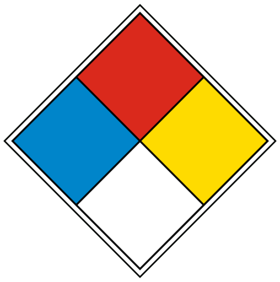
ACTIVITY 6.8 (cont'd)

Product Hazard Analysis Worksheet



Group Number: ________ **Presenter:** ________________________

Temp: _________ **°F** **R/H:** _________**%**

Product Name: ________________________________ **Family:** ________________________

Data Points	Result	No Data	Hazard Consideration
Physical Properties			
Physical State			
Vapor Pressure			
Boiling Point			
Vapor Density			
Specific Gravity			
Solubility			
Flammability			
Flash Point			
LEL/UEL			
Flammable Range			
Ignition Temp.			
Toxicity			
Route of Exposure			
IDLH			
PEL/REL/STEL			
S/S of Exposure			
Biological			
Corrosivity			
pH			
Concentration			
Reactivity/Explosion			
Radioactivity			
Decay Mode	☐ N/A ☐ α ☐ β ☐ γ		
Half Life			

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ACTIVITY 6.8 (cont'd)

Briefing Worksheet

Group number: ______________________ **Audience:** _________________________

Topic	**Notes**
Current situation and details	
Hazard/safety concerns	
Audience impact	
Recommendations	
Incident response objectives **(for briefing responders only)**	**Control zones:** **PPE:** **Decontamination:**

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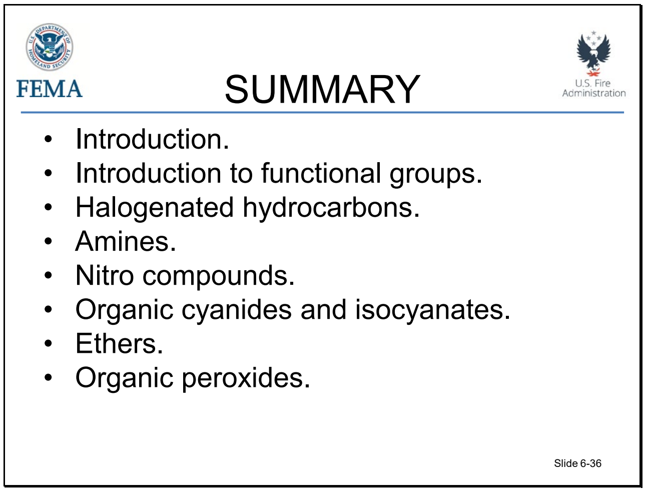
XVII. SUMMARY

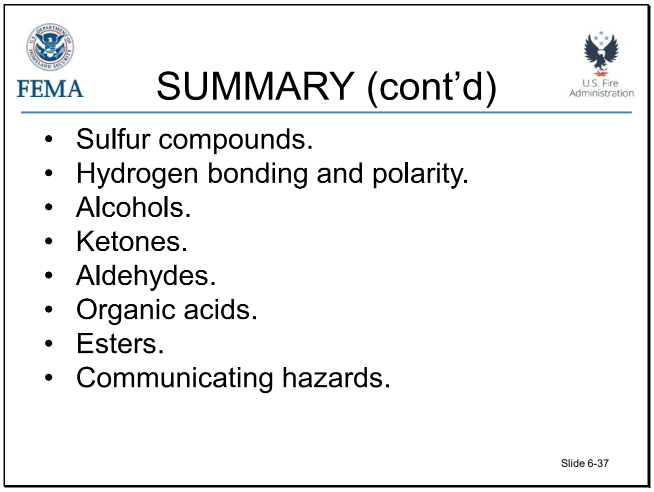


FEMA

U.S. Fire Administration

SUMMARY

- Introduction.
- Introduction to functional groups.
- Halogenated hydrocarbons.
- Amines.
- Nitro compounds.
- Organic cyanides and isocyanates.
- Ethers.
- Organic peroxides.

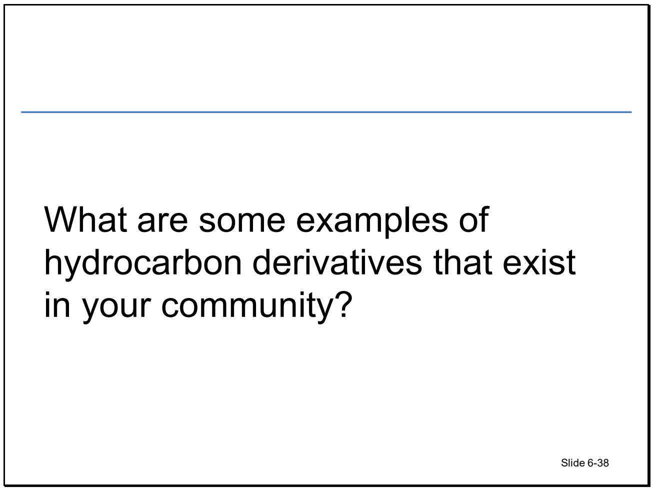


FEMA

U.S. Fire Administration

SUMMARY (cont’d)

- Sulfur compounds.
- Hydrogen bonding and polarity.
- Alcohols.
- Ketones.
- Aldehydes.
- Organic acids.
- Esters.
- Communicating hazards.



What are some examples of hydrocarbon derivatives that exist in your community?

How can you effectively plan for a response to an incident involving these chemicals?

APPENDIX A

DETAILED HYDROCARBON DERIVATIVE INCIDENT SCENARIOS

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Scenario 1: Nitrotoluene

"(Pascagoula, Mississippi, Oct. 15, 2003) Investigators from the U.S. Chemical Safety and Hazard Investigation Board (CSB) have concluded that the October 2002 plant explosion here occurred because First Chemical Corporation had not effectively evaluated the hazards of a chemical process that ran out of control. The blast blew the top off a distillation tower that was approximately 145 feet tall and propelled tons of fiery debris in the air, raining down onto adjacent industrial facilities and narrowly missing nearby hazardous chemical tanks.

"The investigators' report, which will be presented and voted on at a public meeting of the five-member board today, said that plant operators were unaware that a dangerous chemical reaction was taking place inside the tower. The process involved mononitrotoluene (MNT), a chemical related to TNT that can be explosive when exposed to high temperatures. Operators thought the process had been shut down weeks earlier, with all sources of heat removed. Unrecognized by plant personnel, the valves used to shut off steam to the tower had deteriorated. Steam was leaking through the shutoff valves, heating the 1,200 gallons of MNT in the column to a critical temperature of over 450°F (232.2°C), initiating a violent reaction as the material decomposed.

"The tower exploded at 5:25 a.m. on Sunday, Oct. 13, 2002. Three plant employees were injured when glass windows shattered into the control room where they were working. The CSB report said the room was located too close to the MNT tower and was not reinforced to withstand blast pressure. A projectile from the explosion pierced an MNT storage tank some distance away, igniting a fire that burned for almost three hours. Other debris landed a few feet from a large cylinder of anhydrous ammonia without doing serious damage. Area residents were directed to seek shelter in their homes, though the CSB learned at a public meeting later that this direction was not effectively communicated to them. Additionally, residents were not aware of the appropriate action to take while they sought shelter."

Sources:

https://www.csb.gov/first-chemical-corp-reactive-chemical-explosion/

https://www.csb.gov/investigators-present-final-report-on-first-chemical-corp-explosion-cite-inadequate-safety-systems-lack-of-warning-devices/

Scenario 2: Mixing Operation Explosion

“On Wednesday, April 8, 1998, at 8:18 p.m., an explosion and fire occurred during the production of Automate Yellow 96 Dye at the Morton International, Inc., (now Rohm & Haas) plant in Paterson, New Jersey. The explosion and fire were the consequence of a runaway reaction, which over pressurized a 2,000-gallon capacity chemical reactor vessel (or kettle) and released flammable material that ignited. Because of the serious nature of the incident, including injuries to nine employees, the release of potentially hazardous materials into the community, and extensive damage to the plant, the CSB initiated an incident investigation.

“The Paterson plant manufactures a series of dye products. Yellow 96 Dye was produced by the mixing and reaction of two chemicals, ortho-nitro chlorobenzene (o-NCB) and 2-ethylhexylamine (2-EHA). The dye was used to tint petroleum fuel products. The investigation team determined that the reaction accelerated beyond the heat-removal capability of the kettle. The resulting high temperature led to a secondary runaway decomposition reaction, causing an explosion which blew the hatch off the kettle and allowed the release of the kettle contents. The initial runaway reaction was most likely caused by a combination of the following factors: (1) The reaction was started at a temperature higher than normal; (2) the steam used to initiate the reaction was left on for too long; and (3) the use of cooling water to control the reaction rate was not initiated soon enough.

“The explosion ejected flammable vapors from the kettle into the second floor of the production building. The explosion and flash fires inside the building injured nine workers. The flashing eruption of chemicals broke through the building roof, ignited, and formed a large fireball above the building, spattering the adjacent neighborhood with a yellow-brown mixture of compounds that included Yellow 96 Dye and o-NCB. Workers’ injuries included burns, contusions, and twisted joints. Two employees were badly burned and required extended hospitalization. All of the employees were able, some with assistance, to escape the site of the explosion.”

Sources:

https://www.csb.gov/assets/1/20/morton_report.pdf

https://www.csb.gov/morton-international-inc-runaway-chemical-reaction/

Scenario 3: Bhopal, India

In the early hours of Monday, December 3, 1984, an explosion at the Union Carbide plant released a deadly mix of poison gas made up of methyl isocyanate, hydrogen cyanide, monomethyl amine and carbon monoxide, as well as up to 20 other chemicals. A toxic cloud of methyl isocyanate (MIC) gas enveloped the hundreds of shanties and huts surrounding a pesticide plant in Bhopal, India. The wind carried the clouds of gas out over the surrounding community, exposing more than 500,000 people to the poisons.

Later, as the deadly cloud slowly drifted in the cool night air through streets in surrounding sections, sleeping residents awoke, coughing, choking and rubbing painful stinging eyes. Four months after the tragedy, the Indian government reported to its Parliament that 1,430 people had died.

In 1991, the official Indian government panel, charged with tabulating deaths and injuries, updated the count to more than 3,800 dead and approximately 11,000 with disabilities. By 1999, the toxic gas had killed at least 16,000 according to local estimates; tens of thousands continue to suffer.

Indian officials contend that the incident occurred during routine maintenance operations at the factory when a large quantity of water entered one of the storage tanks through leaking valves and corroded pipes, triggering a runaway reaction. Union Carbide contends that the gas was formed when a disgruntled plant employee, apparently bent on spoiling a batch of methyl isocyanate, added water to a storage tank. The water caused a reaction that built up heat and pressure in the tank, quickly transforming the chemical compound into a lethal gas that escaped.

Source:

https://www.csb.gov/on-30th-anniversary-of-fatal-chemical-release-that-killed-thousands-in-bhopal-india-csb-safety-message-warns-it-could-happen-again-/

Scenario 4: Explosions Involving Ethyl Acetate at a Chemical Distribution Facility

On Oct. 29, 2007, at about 1 p.m., a fire and a series of explosions occurred at the Barton Solvents Des Moines, Iowa, chemical distribution facility. The initial fire started in the packaging area while a 300-gallon portable steel tank, known as a tote, was being filled with ethyl acetate, a flammable solvent.

An operator placed the fill nozzle in the fill opening on the top of the tote and suspended a steel weight on the nozzle to keep it in place. After opening the valve to begin the filling process, the operator walked across the room to do other work. As the tote was filling, he heard a "popping" sound and turned to see the tote engulfed in flames, with the fill nozzle laying on the floor discharging ethyl acetate. Before evacuating, employees tried unsuccessfully to extinguish the fire with a hand fire extinguisher. The fire spread rapidly to the wood-framed warehouse, igniting a large volume of flammable and combustible liquids.

One of the employees received minor injuries, and one firefighter was treated for heat-related illness. A large plume of smoke and rocketing barrels and debris triggered an evacuation of businesses surrounding the facility. The main warehouse structure was destroyed, and Barton's business was significantly interrupted. The CSB published a case study to underscore the need for effective bonding and grounding and for fire protection practices that should be observed when handling flammable liquids.

Sources:
https://www.csb.gov/barton-solvents-flammable-liquid-explosion-and-fire/

https://www.csb.gov/csb-finds-static-spark-set-off-fire-and-explosions-at-barton-solvents-des-moines-facility-investigation-finds-equipment-not-intended-for-flammable-service-or-properly-bonded-and-grounded/

APPENDIX B

OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION GUIDANCE ON CYANIDE ANTIDOTE KITS MARCH 2020

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OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION

1. Standard Interpretations
2. **Cyanide Antidotes**

Standard Number:

1910.126(e) 1910.151 1910.151(a) 1910.1000

OSHA requirements are set by statute, standards, and regulations. Our interpretation letters explain these requirements and how they apply to particular circumstances, but they cannot create additional employer obligations. This letter constitutes OSHA's interpretation of the requirements discussed. Note that our enforcement guidance may be affected by changes to OSHA rules. Also, from time to time we update our guidance in response to new information. To keep apprised of such developments, you can consult OSHA's website at https://www.osha.gov.

March 31, 2020

MEMORANDUM FOR
REGIONAL ADMINISTRATORS
STATE PLAN DESIGNEES
THROUGH:
LOREN SWEATT
Principal Deputy Assistant Secretary
FROM:
LEE ANNE JILLINGS, Acting Director
Directorate of Technical Support and Emergency Management
PATRICK J. KAPUST, Acting Director
Directorate of Enforcement Programs
SUBJECT:
Cyanide Antidotes

This memorandum serves as new guidance to address outdated information provided in OSHA's archived memo dated May 17, 1988, from the Office of Occupational Medicine, and entitled "Cyanide Antidote Kits." The prior memo stated in part, "*Amyl Nitrite continues to require a physician's prescription and the administration of this drug in an emergency situation by the designated first aide responder is the medically accepted initial response. According to current literature, hydroxy cobalamine has had limited use as an alternative intravenous medication to the widely accepted sodium nitrite protocol.*"[1]

This memo provides the following updated information regarding cyanide antidotes:

- Amyl nitrite (which was given via inhalation) is no longer available in cyanide antidote kits in the U.S. and is no longer an acceptable initial therapeutic response.
- Currently, the available cyanide antidotes are hydroxocobalamin, sodium nitrite, and sodium thiosulfate.

- The three available antidotes are given via intravenous (IV) infusion and, therefore, can only be administered by qualified healthcare professionals.

Rationale

Antidote kits containing inhaled amyl nitrite are no longer commercially available.[2] The U.S. Food and Drug Administration (FDA) stated, as of September 2018, that the only products approved for cyanide poisoning are the following: Cyanokit (hydroxocobalamin injection), Nithiodote (sodium nitrite and sodium thiosulfate for intravenous infusion), sodium nitrite injection, and sodium thiosulfate injection.[3] In 2018, an expert consensus panel determined that hydroxocobalamin is the preferred antidote, but sodium nitrite and sodium thiosulfate are also acceptable.[2] In light of the experts' recommendation to use hydroxocobalamin, and the absence of amyl nitrite on the FDA list of approved cyanide antidotes,[3] amyl nitrite is no longer an acceptable antidote option.

Employers that offer antidote therapy for cyanide poisoning should provide one of the FDA-approved products. Ideally, cyanide antidotes should be given soon after exposure to unconscious victims with known or strongly suspected cyanide poisoning.[2,4,5] Because all currently FDA-approved cyanide antidotes are IV infusions, they should only be given by healthcare professionals whose scope of practice includes administration of IV drugs. Employers should heed all aspects of the antidote's "Indications and Usage" labeling. In addition to specific antidotes, cyanide poisoning requires other therapeutic interventions. Depending on the scenario, victims might require cardiopulmonary resuscitation, supplemental 100% oxygen, decontamination, and other supportive care.[4,5] Most cyanide exposures will result in activation of emergency medical services (EMS). EMS providers could assist with administration of antidotes or non-specific therapies. Therefore, when there is a foreseeable risk of cyanide exposure, employers should communicate with their local EMS agency to plan for exposure controls, hazard recognition, training, and treatment availability.

Inspection guidance

Due to the acute and lethal hazards presented by cyanide poisoning, an employer covered under OSHA's standard, Medical Services and First Aid, 29 CFR 1910.151(a), with a workplace that has a foreseeable risk of cyanide exposure, must consult with a physician or other licensed health care professional (PLHCP). This consultation shall ensure that emergency medical services, including those equipped with effective cyanide antidotes, are readily available in the event of an acute cyanide overexposure in the workplace. The absence of such consultation is enforceable as a serious violation.

Specifically, this medical consultation should address workplace-specific considerations, such as appropriate storage and replenishment of medical supplies (e.g., FDA-approved antidote drugs, intravenous supplies), and pre-placement of emergency medical equipment and first-aid supplies (e.g., portable oxygen tanks, automated external defibrillators, or AEDs). Where appropriate, consultation shall also address on-site staffing, training, and licensing requirements of first aid and medical responders; wait times for EMS/ambulance arrival; when and how intravenous drugs can be administered; worker susceptibility, etc. Compliance officers shall bring any deficiencies in the availability of medical supplies or personnel to the attention of their supervisor and, as needed, to their Regional Office for further evaluation.

Additionally, for workplaces with potential cyanide exposures, other applicable OSHA standards may include, but are not limited to: 29 CFR 1910 Subpart E, Exit Routes and Emergency Planning; Subpart H, Hazardous Materials – Dipping and Coating Operations; Subpart I, Personal Protective Equipment; 29 CFR 1910.94 Ventilation; and 29 CFR 1910.1200, Hazard Communication.

If you have any questions, please contact Dr. Michael Hodgson, hodgson.michael@dol.gov,

(202) 693-1768, with the Office of Occupational Medicine and Nursing, Directorate of Technical Support and Emergency Management, or Dr. Dionne Williams, williams.dionne@dol.gov, (202) 693-2140, with the Directorate of Enforcement Programs.

References

1. Archived OSHA memorandum "Cyanide Antidote Kits," dated May 17, 1988. Available at: https://www.osha.gov/laws-regs/standardinterpretations/1988-05-17-0

2. Dart RC, Goldfrank LR, Erstad BL, et al. Expert consensus guidelines for stocking of antidotes in hospitals that provide emergency care. Annals of Emergency Medicine 2018;71(3):314-325. Available at: https://www.annemergmed.com/article/S0196-0644(17)30657-1/fulltext

3. U.S. Food and Drug Administration (FDA). Products approved for chemical emergencies: products for cyanide poisoning. Updated September 27, 2018. Available at: https://www.fda.gov/drugs/bioterrorism-and-drug-preparedness/products-approved-chemical-emergencies

4. Agency for Toxic Substances and Disease Registry (ATSDR). Medical management guidelines for hydrogen cyanide (HCN).

5. U.S. Department of Health & Human Services, Chemical Hazards Emergency Medical Management (CHEMM). Hydrogen cyanide – emergency department/hospital management.

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APPENDIX C

CHEMICAL FAMILY SUMMARY WORKSHEETS FOR THE HYDROCARBON DERIVATIVES

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CHEMICAL FAMILY SUMMARY WORKSHEET: HALOGENATED HYDROCARBONS

General formula:
Naming conventions (classical/International Union of Pure and Applied Chemistry (IUPAC))
What are the general hazards associated with this family?

What are the common uses or applications of this family?
Remarks or other considerations?
Common examples (optional)
Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: AMINES

General formula:
Naming conventions (classical/IUPAC)
What are the general hazards associated with this family?

What are the common uses or applications of this family?

Remarks or other considerations?

Common examples (optional)

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: NITRO COMPOUNDS

General formula:
Naming conventions (classical/IUPAC)
What are the general hazards associated with this family?

What are the common uses or applications of this family?

Remarks or other considerations?

Common examples (optional)

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: ORGANIC CYANIDES AND ISOCYANATES

General formula:
Naming conventions (classical/IUPAC)
What are the general hazards associated with this family?

What are the common uses or applications of this family?

Remarks or other considerations?

Common examples (optional)

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: ETHERS

General formula:
Naming conventions (classical/IUPAC)
What are the general hazards associated with this family?

What are the common uses or applications of this family?
Remarks or other considerations?
Common examples (optional)
Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: ORGANIC PEROXIDES

General formula:
Naming conventions (classical/IUPAC)
What are the general hazards associated with this family?

What are the common uses or applications of this family?

Remarks or other considerations?

Common examples (optional)

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: SULFIDES AND MERCAPTANS

General formula:
Naming conventions (classical/IUPAC)
What are the general hazards associated with this family?

What are the common uses or applications of this family?
Remarks or other considerations?
Common examples (optional)
Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: ALCOHOLS

General formula:
Naming conventions (classical/IUPAC)
What are the general hazards associated with this family?

What are the common uses or applications of this family?
Remarks or other considerations?
Common examples (optional)
Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: KETONES

General formula:
Naming conventions (classical/IUPAC)
What are the general hazards associated with this family?

What are the common uses or applications of this family?
Remarks or other considerations?
Common examples (optional)
Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: ALDEHYDES

General formula:

Naming conventions (classical/IUPAC)

What are the general hazards associated with this family?

What are the common uses or applications of this family?
Remarks or other considerations?
Common examples (optional)
Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: ORGANIC ACIDS

General formula:
Naming conventions (classical/IUPAC)
What are the general hazards associated with this family?

What are the common uses or applications of this family?

Remarks or other considerations?

Common examples (optional)

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: ESTERS

General formula:

Naming conventions (classical/IUPAC)

What are the general hazards associated with this family?

What are the common uses or applications of this family?
Remarks or other considerations?
Common examples (optional)
Sources of additional information (optional)

APPENDIX D

CHEMICAL FAMILY SUMMARY WORKSHEETS FOR THE HYDROCARBON DERIVATIVES: ANSWER KEYS

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CHEMICAL FAMILY SUMMARY WORKSHEET: HALOGENATED HYDROCARBONS

General formula:

R + X X = halon [F, Cl, Br, I]

Naming conventions (classical/International Union of Pure and Applied Chemistry (IUPAC))

Classical:

Name the radical first, followed by the halogen, with the prefix indicating the number and an "-ide" ending.
If more than one halogen is present, use "di," "tri," etc.
End the halon with "-o" ending, followed by the name of the hydrocarbon.

IUPAC:

Count the number of carbons from the first FG, number the carbons so the FG carbon has the lowest number.
Then write the number of the carbon the FG is bonded to.
Name the halogen with an "-o" ending.
Name the main chain it's attached to.

What are the general hazards associated with this family?

Most are extremely toxic.
Some compounds may burn.
Some are suspected carcinogens.
Unsaturated backbones tend to impart the ability to polymerize.

What are the common uses or applications of this family?

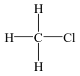
Propellants.
Solvents and cleaners.
Degreasers.
Pesticides.
Gases are used as refrigerants.

Remarks or other considerations?

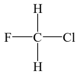
AKA halides	*Alkyl halides*	*If attached to an alkane*
	Aryl halides	*If attached to an aromatic*
	Vinylic halides	*If attached to a vinyl*

Water insoluble.
Nonpolar.
Fire extinguishing agents.

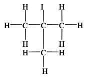
Common examples (optional)



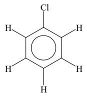
Methyl chloride — CH_3Cl



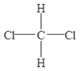
Fluorochloromethane — CH_2FCl



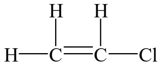
Tertiary butyl iodide — $_tC_4H_9I$



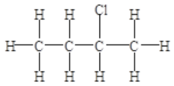
Phenyl chloride — C_6H_5CI



Dichloromethane — CH_2Cl_2



Vinyl chloride — C_2H_3Cl



Secondary butyl chloride — $_sC_4H_9Cl$

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: AMINES

General formula:

$R + NH_2$
$R_2 + NH$
$R_3 + N$

Naming conventions (classical/IUPAC)

Classical:
Name the radical first. If more than one, use prefix "di-" or "tri-" followed by "-amine."

***IUPAC**:*
Start with "amino-," then name the hydrocarbon radical or main chain it's attached to.
Use the carbon number it's attached to; then "di-," "tri-," etc., for number of amines; then name the main chain.

What are the general hazards associated with this family?

Extremely toxic by all routes to kidneys and liver (strong irritant).
Flammable.
Unsaturated backbones will polymerize.
Create caustic solution in contact with moisture. (>11 pH).

What are the common uses or applications of this family?

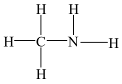
Plastics manufacturing.
Corrosion inhibitor in paints.
In formation of insecticides.
Blister warfare agents.
In manufacturing of medicines.

Remarks or other considerations?

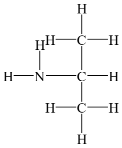
Amine group with one radical	*Primary amine*
Amine group with two radicals	*Secondary amine*
Amine group with three radicals	*Tertiary amine*

Water insoluble.
Nonpolar.

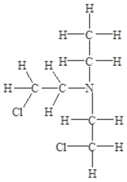
Common examples (optional)



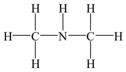
Methylamine — CH_3NH_2



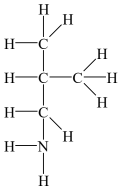
Isopropylamine — $_iC_3H_7NH_2$



bis-(2chloroethyl) ethylamine — $(C_2H_4Cl)_2NC_2H_5$



Dimethylamine — $(CH_3)_2NH$



Isobutylamine — $_iC_4H_9NH$

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: NITRO COMPOUNDS

General formula:

$R\text{-}NO_2$

Naming conventions (classical/IUPAC)

Classical:

Use the prefix "nitro-" first.
Then name the hydrocarbon backbone it's attached to.
Use "di-" or "tri-" indicating the number of nitro groups.

IUPAC:

Number the carbons with nitros attached and then use "di-" or "tri-" followed by the main chain hydrocarbon named last.

What are the general hazards associated with this family?

Extremely unstable.
Explosive.
Toxic by all routes.
Skin irritation and vasodilatation.

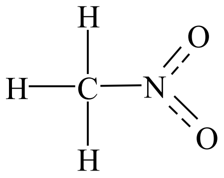
What are the common uses or applications of this family?

Explosives.
Processing leather.
Metal etching.
Manufacturing of some medications.
Chemical intermediates.

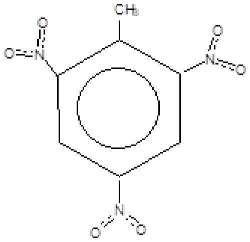
Remarks or other considerations?

Water insoluble.
Nonpolar.

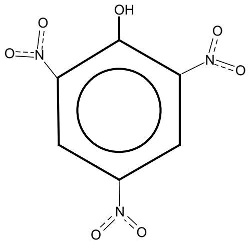
Common examples (optional)



Nitromethane — CH_3NO_2



Trinitrotoluene (TNT) — $C_6H_2CH_3(NO_2)_3$



Trinitrophenol (picric acid) — $C_6H_2OH(NO_2)_3$

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: ORGANIC CYANIDES AND ISOCYANATES

General formula:

R-CN (cyanide)
R-OCN (cyanate)
R-NCO (isocyanate)
R-SCN (thiocyanate)

Naming conventions (classical/IUPAC)

Cyanide:
Name the radical first, followed by "-cyanide."

Isocyanate:
Count all the C's, including the one in the cyanide, name the radical, followed by "-nitrile."
For cyanates:
Name radical first, followed by -cyanate, -isocyanate, or -thiocyanate.

What are the general hazards associated with this family?

Extremely toxic, rapidly fatal depending on dose.
Acrylonitrile is a suspected carcinogen.
Chemical asphyxiants.
Flammable.

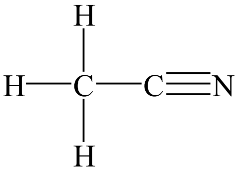
What are the common uses or applications of this family?

Varied.
Extractant for animal/vegetable oils.
Solvent.
Chemical intermediate — WMD precursor.
Manufacturing of plastics.
Pesticide fumigant.

Remarks or other considerations?

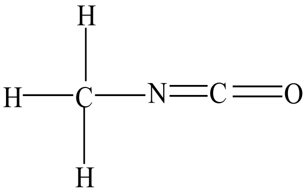
Water insoluble.
Nonpolar.

Common examples (optional)



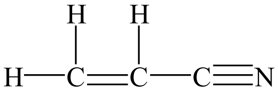
$\mathrm{H-\overset{H}{\underset{H}{C}}-C\equiv N}$

Methyl cyanide or acetonitrile — CH_3CN



$\mathrm{H-\overset{H}{\underset{H}{C}}-N=C=O}$

Methyl isocyanate — CH_3NCO



$\mathrm{H-\overset{H}{C}=\overset{H}{C}-C\equiv N}$

Vinyl cyanide or acrylonitrile — C_2H_3CN

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: ETHERS

General formula:

R-O-R'

Naming conventions (classical/IUPAC)

Name the radicals first, smallest to largest, followed by "-ether."
If both radicals are the same, or prime radicals, just name the radical; no prefix such as di- or tri- is necessary.

What are the general hazards associated with this family?

Extremely flammable, wide flammable range.
Anesthetic and toxic.
Some are carcinogens.
Slow oxidization potential.
Forms peroxides.

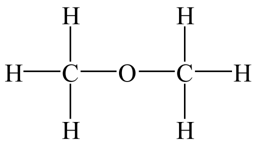
What are the common uses or applications of this family?

Formerly used as anesthetics.
Solvents for dyes.
Gasoline additives.

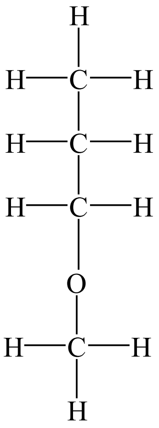
Remarks or other considerations?

Water insoluble.
Nonpolar.

Common examples (optional)

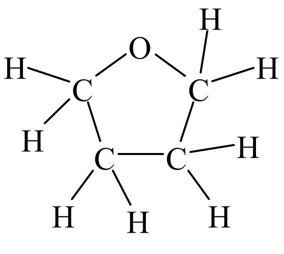


Dimethyl ether/methyl ether — $CH_3OCH_3/(CH_3)_2O$



Methyl propyl ether — $CH_3OC_3H_7$

Sources of additional information (optional)



Tetrahydrofuran — C_4H_8O

CHEMICAL FAMILY SUMMARY WORKSHEET: ORGANIC PEROXIDES

General formula:
R-O-O-R or R-O_2-R
Naming conventions (classical/IUPAC)
Classical: *Name the HC radical(s) first, then call it "-peroxide."*
What are the general hazards associated with this family?
Very unstable when heated, energy can make these materials explode. *Potent oxidizers.* *Self-accelerating decomposition temperature (SADT).* *Maximum safe storage temperature (MSST).* *Extremely flammable.* *Toxic.*

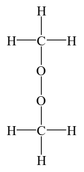
What are the common uses or applications of this family?

Initiators for chemical reactions — common monomers.
Other chemical manufacturing processes.

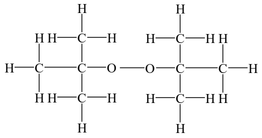
Remarks or other considerations?

Insoluble.
Nonpolar.
Temperature control is critical. These are refrigerated or frozen compounds.
Can be explosive.

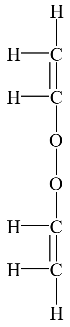
Common examples (optional)



Dimethyl peroxide; methyl peroxide — $CH_3O_2CH_3$ CH_3OOCH_3



. *Di-tert-butyl peroxide —* $_tC_4H_9O_{2t}C_4H_9$



Divinyl peroxide; vinyl peroxide — $(C_2H_3)_2O_2$

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: SULFIDES AND MERCAPTANS

General formula:

R-S-R (thioethers or sulfides)
R-SH (mercaptans)

Naming conventions (classical/IUPAC)

Classical:
Name the radical(s) first, followed by "-sulfide."
Use "di-" or "tri-" prefix for more than one sulfide.

IUPAC:
"Thio-" used as a prefix to the HC radical which may be prime when naming the sulfides.
"Thiol-" used as a prefix to the HC radical which may be prime when naming the mercaptans.

What are the general hazards associated with this family?

Toxic and flammable.
Severe skin irritants.
H_2S affects the body the same way as cyanide does.
When they burn, they make SO, SO_2, SO_3.

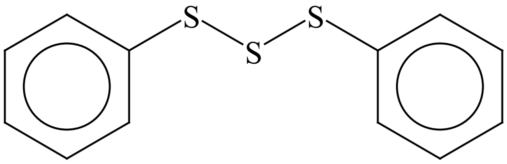
What are the common uses or applications of this family?

Odorants.

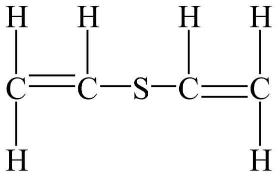
Remarks or other considerations?

Insoluble.
Nonpolar.

Common examples (optional)

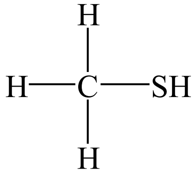


Diphenyl trisulfide — $C_6H_5S_3C_6H_5$



$H_2C{=}CH{-}S{-}CH{=}CH_2$

Vinyl sulfide — $C_2H_3SC_2H_3$



$H{-}C(H)(H){-}SH$

Methyl mercaptans — CH_3SH

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: ALCOHOLS

General formula:

R-OH

Naming conventions (classical/IUPAC)

Classical:

Name the radical first, followed by "-alcohol."

Alcohols: Have one hydroxyl group.
Glycols: Have two hydroxyl groups.
Glycerols: Have three hydroxyl groups.

IUPAC:

Name the hydrocarbon radical attached to the OH first then end with an "-ol." (methyl + OH= methanol).

What are the general hazards associated with this family?

Range of toxicity varies depending on concentration.
Methyl alcohol, butyl alcohol and phenol all very toxic.
Slowly oxidize at room temp over time into aldehydes and carboxylic acids.

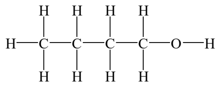
What are the common uses or applications of this family?

Intoxicants.
Sterilization in medicine.

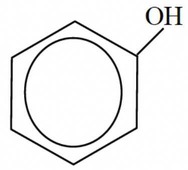
Remarks or other considerations?

Very soluble in water.
Super polar.

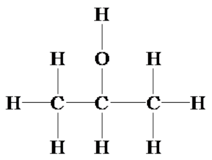
Common examples (optional)



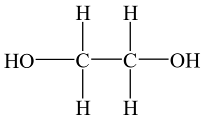
Butyl alcohol (butanol) — C_4H_9OH



Phenyl alcohol — C_6H_5OH



Isopropyl alcohol (2, propanol) — $_iC_3H_7OH/CH_3CHOHCH_3$



Ethylene glycol — CH_2OHCH_2OH

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: KETONES

General formula:

R-CO-R

Naming conventions (classical/IUPAC)

Classical:
Name the HC radical(s) first, followed by "ketone." If the radical is prime, then only name it once, not using di-.

IUPAC:
Count all the carbons in the main chain, including the one for the carbonyl.
Number the carbons, starting at the end closest to the carbonyl.
Give the number of the carbon that makes up the carbonyl.
Name the main chain ending with "-one."

What are the general hazards associated with this family?

Very toxic due to narcotic effects.
Flammable.

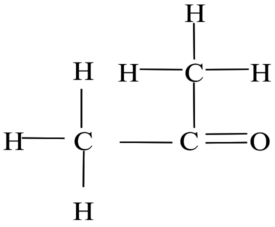
What are the common uses or applications of this family?

Solvents.

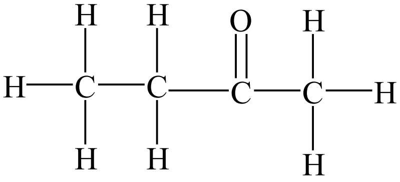
Remarks or other considerations?

Water-soluble.
Slightly polar.

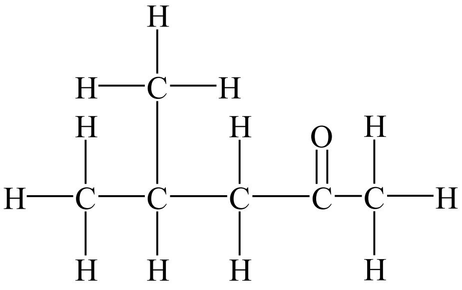
Common examples (optional)



Acetone - methyl ketone - 2- propanone — CH_3COCH_3



Methyl ethyl ketone - 2- butanone — $C_2H_5COCH_3$



Methyl isobutyl ketone - 2 methyl 4 pentanone — ${}_iC_4H_9COCH_3$

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: ALDEHYDES

General formula:

R-CHO

Naming conventions (classical/IUPAC)

Classical:
Count all the carbons, including the carbon in the carbonyl. Name the radical main chain with that many carbons, followed by "aldehyde."
1 C – FORM
2 C – ACET
3 C – ACRYL (double bond)

IUPAC:
Count all the carbons; name the hydrocarbon main chain with an "-al" ending.

What are the general hazards associated with this family?

Poisonous.
Mild to severe irritants, can be sensitizers.
Slow oxidization potential — into organic acids.
Flammable.
Formaldehyde is a known carcinogen.

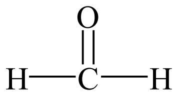
What are the common uses or applications of this family?

Solvents.
Disinfectants.
Preservatives.
Plastics.

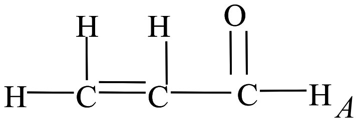
Remarks or other considerations?

Water-soluble.
Polar.

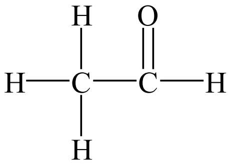
Common examples (optional)



Formaldehyde methanal — HCHO



Acrylaldehyde — C_2H_3CHO



Acetaldehyde 2- ethanal — CH_3CHO

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: ORGANIC ACIDS

General formula:

R-COOH

Naming conventions (classical/IUPAC)

Classical:

Count all the carbons, including the C of the carbonyl. Name the main chain radical with an "-ic" ending, followed by -acid.

What are the general hazards associated with this family?

Some are very toxic.
Flammable/combustible.
On contact with water, forms acidic solutions.
When in contact with certain metals, produces hydrogen gas.

What are the common uses or applications of this family?

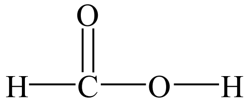
Plastic production.
Water purification.
Solvents.
Decalcification.

Remarks or other considerations?

Water-soluble.
Polar.

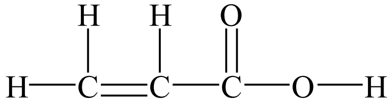
Common examples (optional)

Formic acid
Methanoic
HCOOH



$$\mathrm{H{-}\overset{\overset{\displaystyle O}{\|}}{C}{-}O{-}H}$$

Acrylic acid
C_2H_3COOH



$$\mathrm{H{-}\overset{\overset{\displaystyle H}{|}}{C}{=}\overset{\overset{\displaystyle H}{|}}{C}{-}\overset{\overset{\displaystyle O}{\|}}{C}{-}O{-}H}$$

Sources of additional information (optional)

CHEMICAL FAMILY SUMMARY WORKSHEET: ESTERS

General formula:

R-COO-R

Naming conventions (classical/IUPAC)

Classical:

Name the back side radical first, then count all the carbons on the front side, and name the radical with an "-ate" ending.

What are the general hazards associated with this family?

Tend to be toxic.
Unsaturated esters react with oxygen at room temperature.
Flammable to combustible.
May cause hypersensitivity.

What are the common uses or applications of this family?

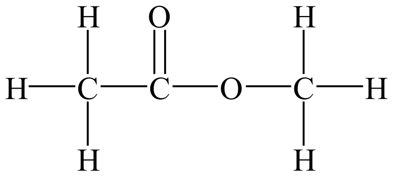
Plastics.

Remarks or other considerations?

Water-soluble.
Super polar.

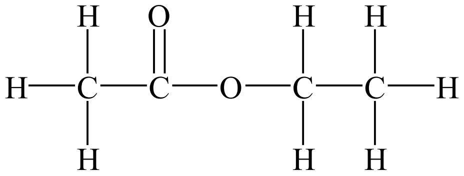
Common examples (optional)

Methyl acetate
CH_3COOCH_3



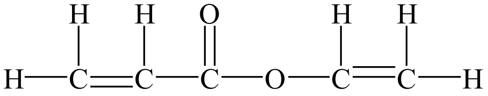
$$\begin{array}{ccccccccccc} & & H & & O & & & & H & & \\ & & \vert & & \Vert & & & & \vert & & \\ H & - & C & - & C & - & O & - & C & - & H \\ & & \vert & & & & & & \vert & & \\ & & H & & & & & & H & & \end{array}$$

Ethyl acetate
$CH_3COOC_2H_5$



$$\begin{array}{ccccccccccccc} & & H & & O & & & & H & & H & & \\ & & \vert & & \Vert & & & & \vert & & \vert & & \\ H & - & C & - & C & - & O & - & C & - & C & - & H \\ & & \vert & & & & & & \vert & & \vert & & \\ & & H & & & & & & H & & H & & \end{array}$$

Vinyl acrylate
$C_2H_3CO_2C_2H_3$



$$\begin{array}{ccccccccccccc} & & H & & H & & O & & & & H & & H & & \\ & & \vert & & \vert & & \Vert & & & & \vert & & \vert & & \\ H & - & C & = & C & - & C & - & O & - & C & = & C & - & H \end{array}$$

Sources of additional information (optional)

UNIT 7:
GASES

TERMINAL OBJECTIVE

The students will be able to:

7.1 Develop response objectives for products that exist as gases in their ambient state.

ENABLING OBJECTIVES

The students will be able to:

7.1 Identify the laws and physical properties of gases.

7.2 Differentiate among compressed gasses, liquified compressed gasses and cryogenic liquids.

7.3 Conduct a product hazard analysis for an incident involving a gas.

7.4 Determine recommended control zones and personal protective equipment (PPE) requirements.

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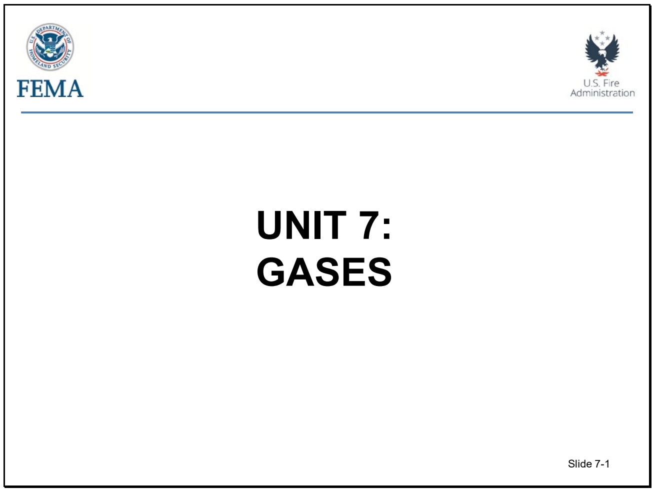
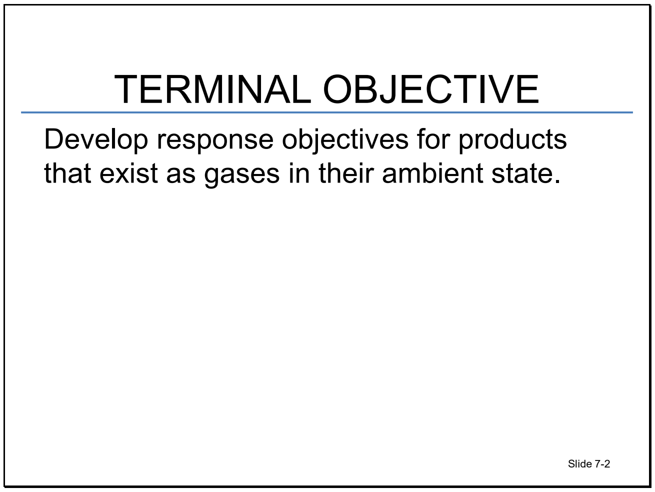
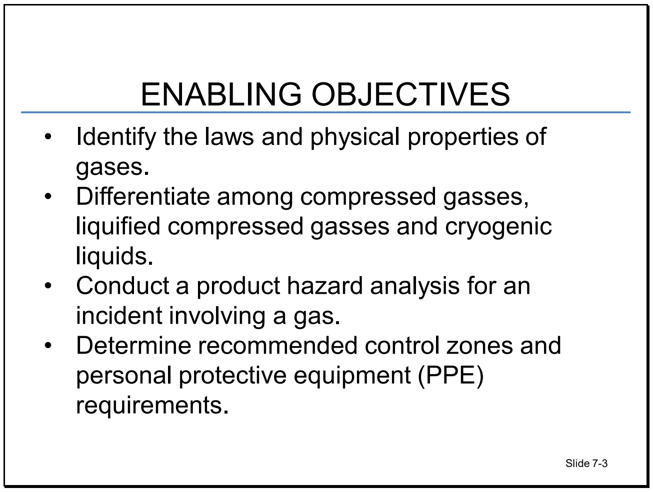


UNIT 7:
GASES



TERMINAL OBJECTIVE

Develop response objectives for products that exist as gases in their ambient state.



ENABLING OBJECTIVES

- Identify the laws and physical properties of gases.
- Differentiate among compressed gasses, liquified compressed gasses and cryogenic liquids.
- Conduct a product hazard analysis for an incident involving a gas.
- Determine recommended control zones and personal protective equipment (PPE) requirements.

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ACTIVITY 7.1

Gases Terminology

Purpose

Define key terms related to gases.

Directions

Working with your group, match the terms on the worksheet with their definitions.

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ACTIVITY 7.1 (cont'd)

Gas Terminology Matching Worksheet

Answer	Term	Choice	Definition
	1. Noble gases	A	A molecule containing two atoms of the same element.
	2. Neutral buoyancy	B	The pressure exerted by the surface of a liquid and some solids against atmospheric pressure, and a measure of a tendency of the substance to become a gas or vapor.
	3. Diatomic molecule	C	0°Kelvin, -273°C, -460°F.
	4. Auto-refrigeration	D	The physical property of a gas floating or sinking in relation to air, based on the molecular weight of the gas.
	5. Boyle's law	E	A gas that has been liquefied through the application of pressure and is stored at ambient temperature.
	6. Charles's law	F	A gas that has been compressed and is stored at ambient temperature.
	7. Vapor density	G	The pressure that must be applied to a gas at its critical temperature to convert the gas to a liquid.
	8. Critical temperature	H	A gas that has been liquefied through cooling and is stored at temperatures below -130°F.
	9. Critical pressure	I	A term used to describe a gas that will neither sink nor float in air.
	10. Critical point	J	Gases that are inert; found in Group VIII of the periodic table.
	11. Compressed gas	K	As temperature increases, kinetic energy increases; thus, pressure increases.
	12. Liquefied compressed gas	L	As volume increases, pressure decreases; as volume decreases, pressure increases (at a given temperature).
	13. Cryogenic gases	M	The temperature above which a gas cannot be converted to a liquid regardless of pressure.
	14. Vapor pressure	N	The transition point between the gaseous and liquid state of a substance.
	15. Absolute zero	O	A process by which a liquid converts to a large volume of gas (usually from a leak) resulting in a rapid reduction of temperature.

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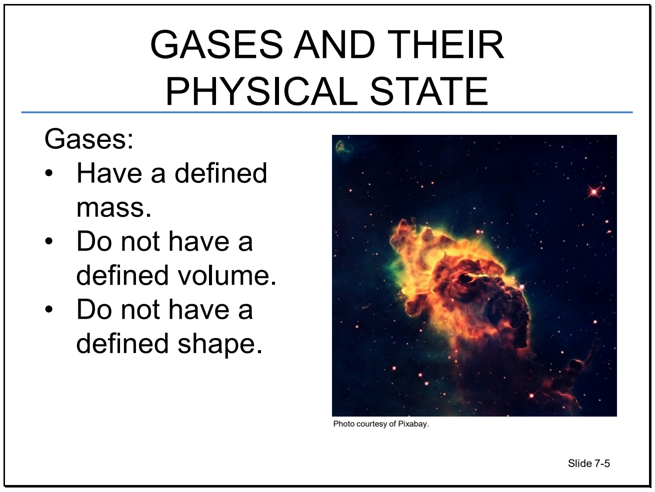
I. GASES AND THEIR PHYSICAL STATE



GASES AND THEIR PHYSICAL STATE

Gases:
- Have a defined mass.
- Do not have a defined volume.
- Do not have a defined shape.

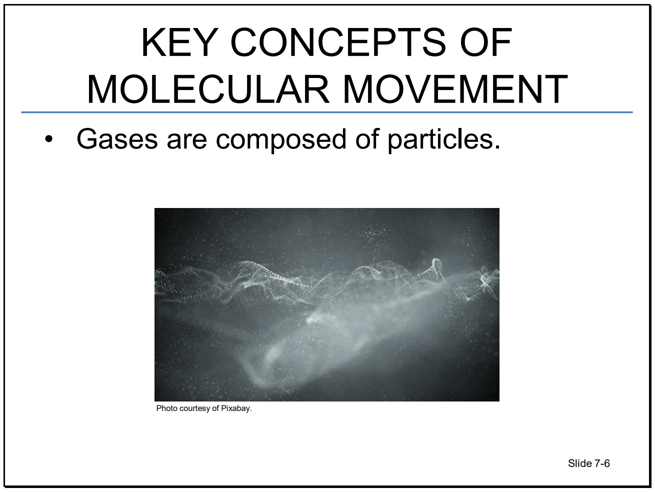
Photo courtesy of Pixabay.

A. Review of gases definition.

   1. Have a defined mass.

   2. Do not have a defined volume.

   3. Do not have a defined shape.



KEY CONCEPTS OF MOLECULAR MOVEMENT

- Gases are composed of particles.

Photo courtesy of Pixabay.

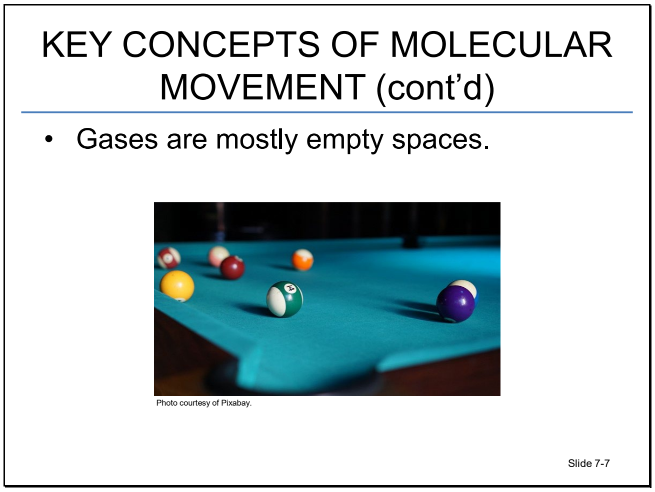
B. Key concepts of molecular movement.

   1. Gases are composed of particles.

      a. Atoms of inert (noble) gases.

      b. Diatomic molecules.

c. Small inorganic or organic molecules.



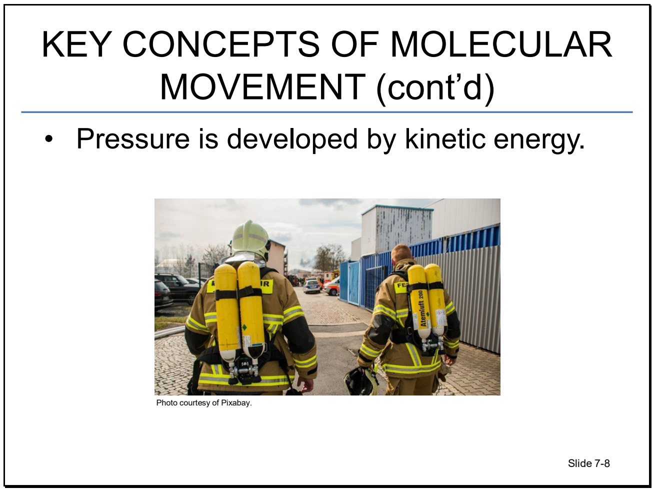
KEY CONCEPTS OF MOLECULAR MOVEMENT (cont'd)

- Gases are mostly empty spaces.

Photo courtesy of Pixabay.

Slide 7-7

2. Gases are mostly empty spaces.



KEY CONCEPTS OF MOLECULAR MOVEMENT (cont'd)

- Pressure is developed by kinetic energy.

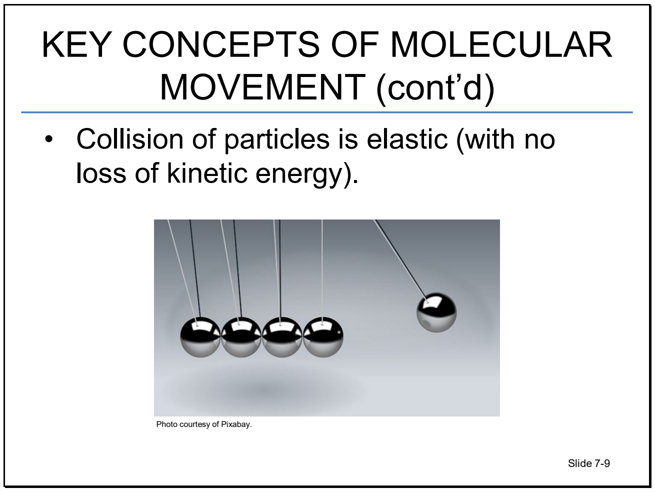
Photo courtesy of Pixabay.

Slide 7-8

3. Pressure is developed by kinetic energy.

   a. The kinetic energy of moving gas particles striking the walls of a closed container.

   b. The greater the number of particles in the same volume container at the same temperature, the greater the pressure.



KEY CONCEPTS OF MOLECULAR MOVEMENT (cont'd)

- Collision of particles is elastic (with no loss of kinetic energy).

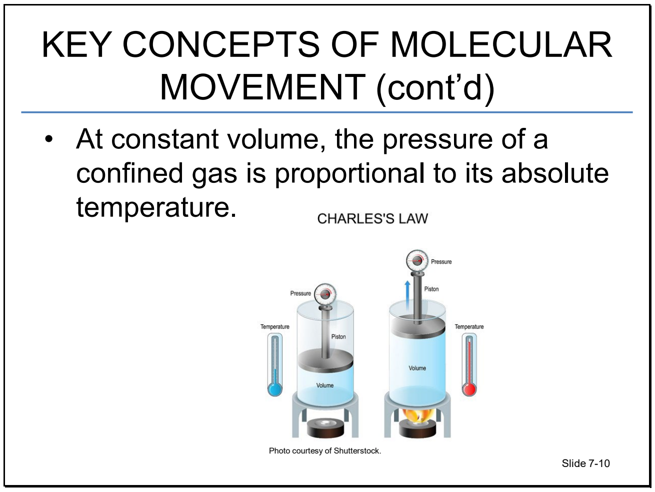
Photo courtesy of Pixabay.

Slide 7-9

4. Collision of particles is elastic.

   a. As particles collide with each other, the collision is said to be elastic; that is, there is no loss of kinetic energy (energy of motion).

   b. Kinetic energy is simply transferred from one particle to the next.



KEY CONCEPTS OF MOLECULAR MOVEMENT (cont'd)

- At constant volume, the pressure of a confined gas is proportional to its absolute temperature.

CHARLES'S LAW

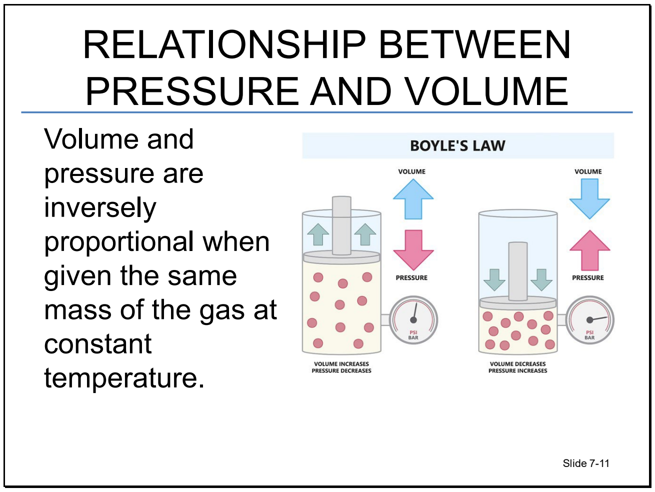
Photo courtesy of Shutterstock.

Slide 7-10

5. At constant volume, the pressure of a confined gas is proportional to its absolute temperature. This is known as Charles's law.

   a. The average kinetic energy of a gas is proportional to its temperature. As temperature increases, kinetic energy increases, which in turn causes molecules to strike the sides of the container more frequently.

   b. This results in increased pressure.



RELATIONSHIP BETWEEN PRESSURE AND VOLUME

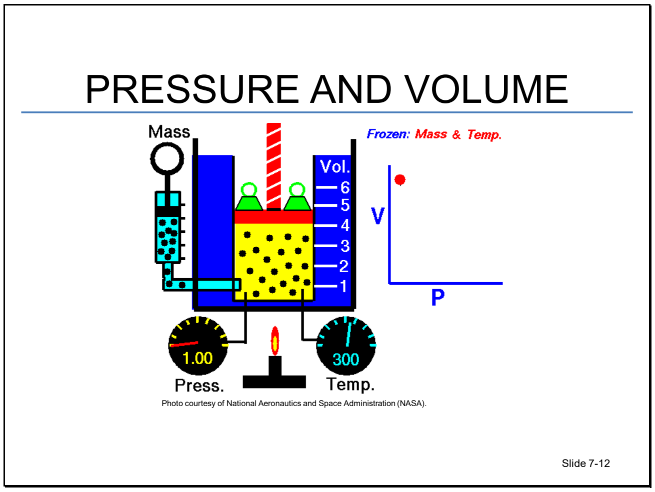
Volume and pressure are inversely proportional when given the same mass of the gas at constant temperature.

Slide 7-11

C. Relationship between pressure and volume.

1. Boyle's law states that the volume and pressure of a sample of gas varies inversely with the temperature constant.

2. If, at a constant temperature, the volume of the container is reduced to half of its original, but the amount of gas within the container remains unchanged, then the pressure in the container will double and vice versa.



PRESSURE AND VOLUME

Photo courtesy of National Aeronautics and Space Administration (NASA).

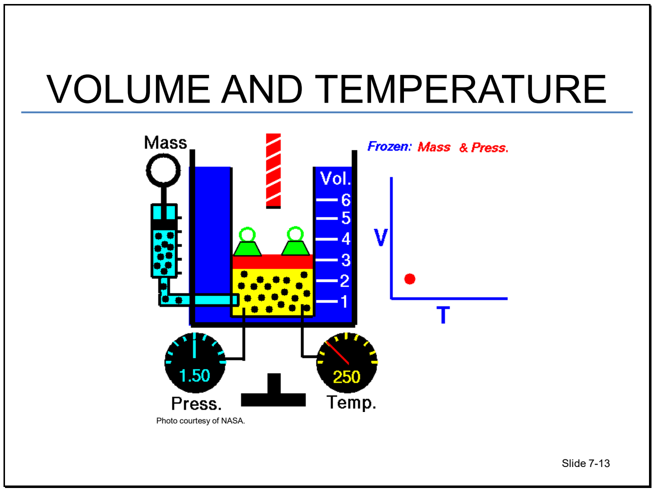
Slide 7-12

3. For more information about the animation: https://www.grc.nasa.gov/WWW/K-12/airplane/aboyle.html.

D. Volume and temperature.

1. Volume and temperature are directly proportional, as long as pressure remains constant.

2. As gas gets hotter, it requires more volume.

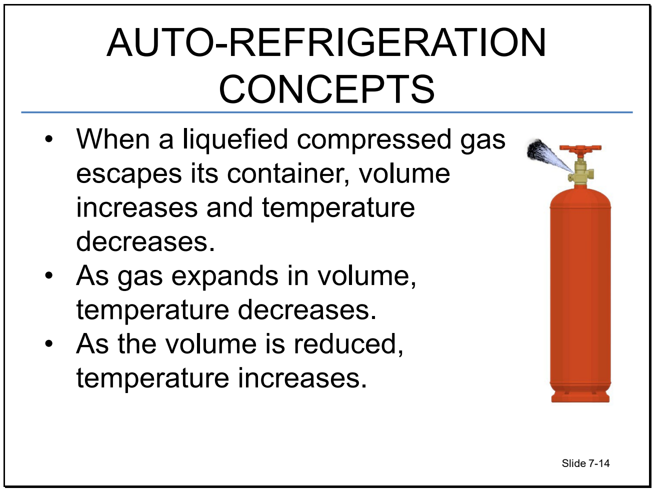


VOLUME AND TEMPERATURE

Photo courtesy of NASA.

Slide 7-13

3. For more information about the animation: https://www.grc.nasa.gov/WWW/K-12/airplane/aglussac.html.



AUTO-REFRIGERATION CONCEPTS

- When a liquefied compressed gas escapes its container, volume increases and temperature decreases.
- As gas expands in volume, temperature decreases.
- As the volume is reduced, temperature increases.

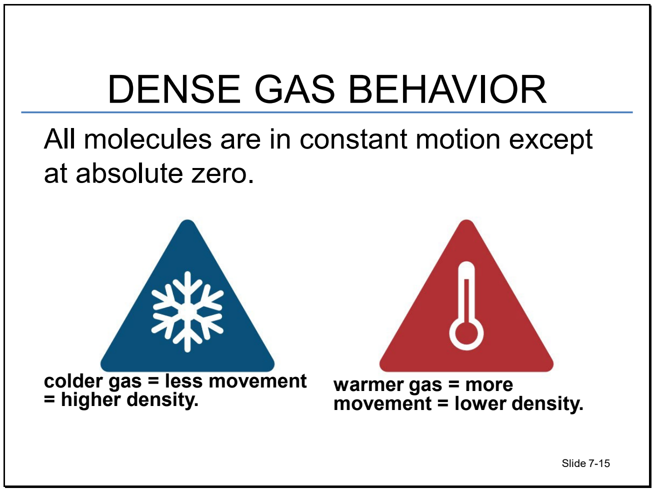
Slide 7-14

E. Auto-refrigeration concepts.

1. When a liquefied compressed gas escapes its container, then the volume of the gas increases and its temperature decreases.

2. As a gas expands in volume, temperature goes down. V↑=T↓.

3. As the volume of the same amount of gas is reduced or compressed, the temperature will increase.



DENSE GAS BEHAVIOR

All molecules are in constant motion except at absolute zero.

colder gas = less movement = higher density.

warmer gas = more movement = lower density.

F. Dense gas behavior.

1. All molecules are in constant motion except at absolute zero (0ºKelvin, -273ºC, -460ºF).

2. Therefore, molecules of gases are constantly striking each other and the walls of their container.

3. The colder the gas becomes, the closer the molecules come to each other.

4. Therefore, as gases get colder, the density of the gas gets higher.

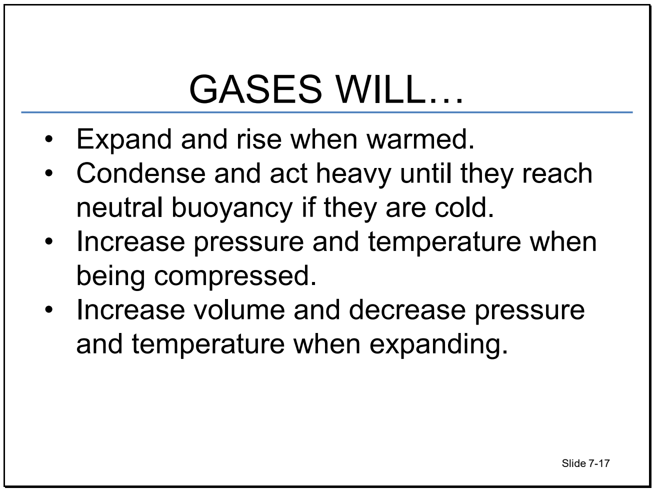
5. Conversely, as you warm gases, the space between molecules increases so that the density decreases.

6. This explains why cold air is denser than warm air.

VIDEO PRESENTATION

“SEWARD AMMONIA SPILL
(PART 2)”

https://youtu.be/qIi4_Poo2HY



GASES WILL…

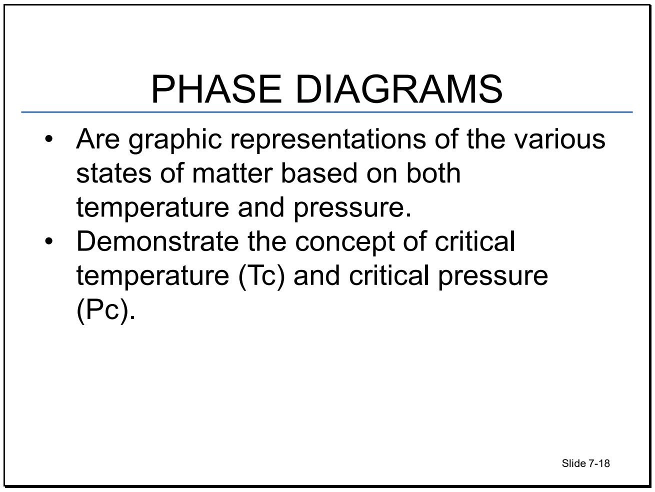
- Expand and rise when warmed.
- Condense and act heavy until they reach neutral buoyancy if they are cold.
- Increase pressure and temperature when being compressed.
- Increase volume and decrease pressure and temperature when expanding.

Slide 7-17

Table 7.1: Gas laws/behavior

Temperature and volume relationship	Temperature and pressure relationship	Volume and pressure relationship	Temperature and density relationship
If the pressure remains constant, then: T↑=V↑	If the container volume remains constant, then: T↑=P↑	If the temperature remains constant, then: V↑= P↓	As gases get colder, they increase in density. T↓=D↑

II. CRITICAL TEMPERATURE AND PRESSURE



PHASE DIAGRAMS

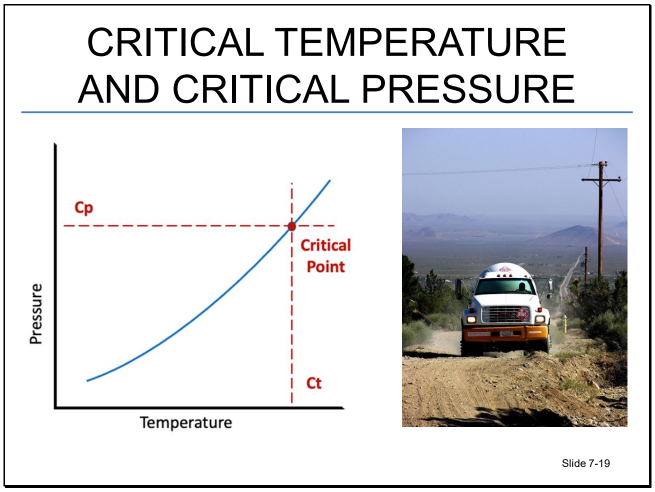
- Are graphic representations of the various states of matter based on both temperature and pressure.
- Demonstrate the concept of critical temperature (Tc) and critical pressure (Pc).

Slide 7-18

A. Phase diagrams:

1. Are graphic representations of the various states of matter based on both temperature and pressure.

2. Demonstrate the concepts of critical temperature (Tc) and critical pressure (Pc).



CRITICAL TEMPERATURE AND CRITICAL PRESSURE

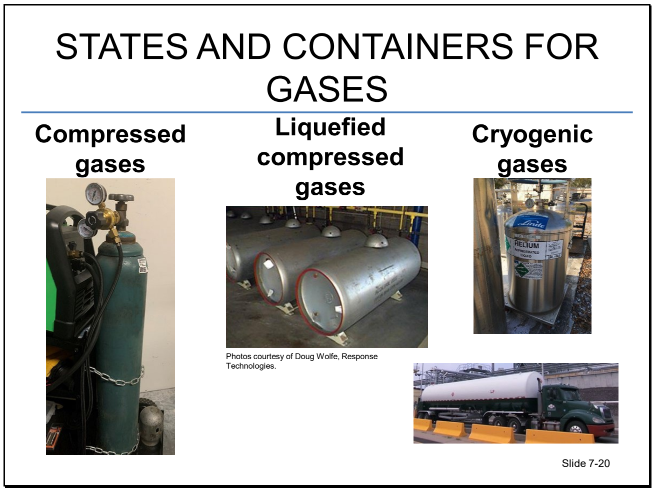
Slide 7-19

B. Key terms.

1. Tc: The temperature above which a gas cannot be converted to a liquid regardless of pressure.

2. Pc: The pressure that must be applied to a gas at its Tc to convert the gas to a liquid.

3. Critical point: The transition point between the gaseous and liquid state of a substance.



STATES AND CONTAINERS FOR GASES

Photos courtesy of Doug Wolfe, Response Technologies.

Slide 7-20

C. States and containers for gases.

1. Compressed gases.

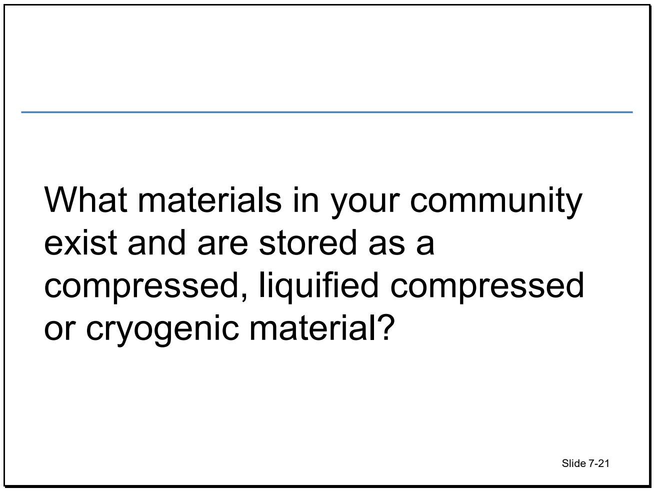
2. Liquefied compressed gases.

3. Cryogenic gases.

   a. Cryogenic gases are gases that possess sufficient kinetic energy that they cannot be converted into a liquid phase through the application of pressure. These gases must be cooled and stored in a liquid state at temperatures of -130°F (-90°C) or colder.

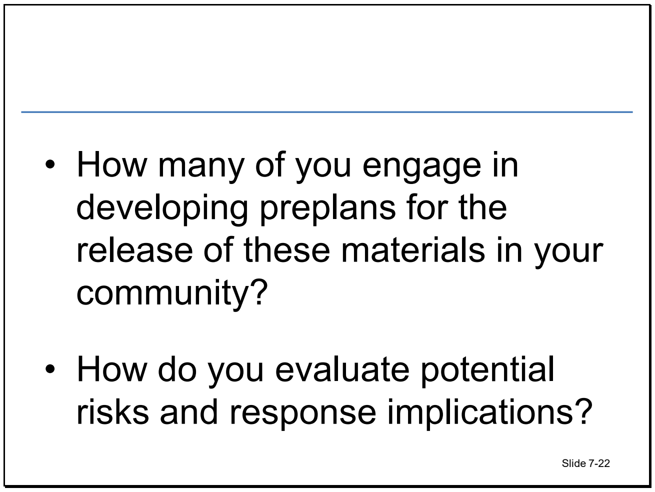
   b. Cryogenic liquids are gases that have been converted to liquids by cooling them to -130°F (-90°C) or colder.

III. ESTIMATING MOVEMENT OF GASES



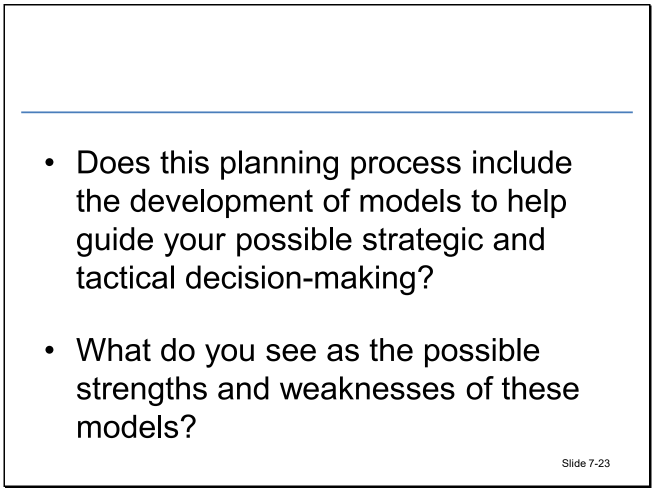
What materials in your community exist and are stored as a compressed, liquified compressed or cryogenic material?

Slide 7-21



- How many of you engage in developing preplans for the release of these materials in your community?
- How do you evaluate potential risks and response implications?

Slide 7-22

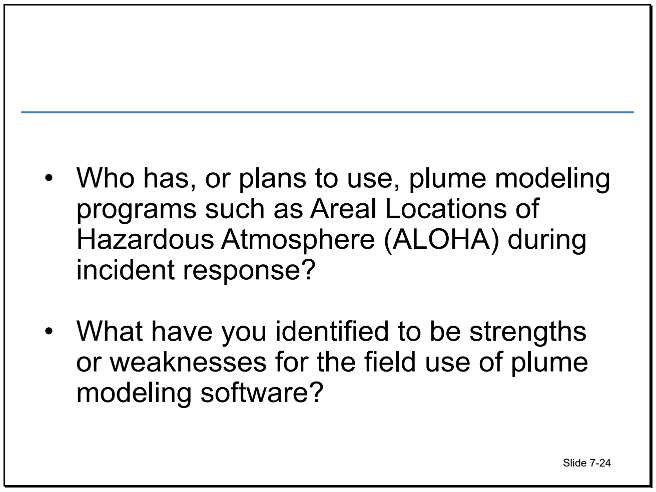


- Does this planning process include the development of models to help guide your possible strategic and tactical decision-making?
- What do you see as the possible strengths and weaknesses of these models?

Slide 7-23

A. Preplanning should include predictive model development.

B. Modeling can be used in the field.



- Who has, or plans to use, plume modeling programs such as Areal Locations of Hazardous Atmosphere (ALOHA) during incident response?
- What have you identified to be strengths or weaknesses for the field use of plume modeling software?

Slide 7-24

C. Developing models at the time of the incident comes with some challenges:

1. Determining an accurate release rate.

2. Integrating accurate environmental data.

3. Integrating "microclimate" impacts such as air movement around structures.

4. Topography, particularly with heavier-than-air gases.

5. Thermal dynamics of liquid phase release of gases.

VIDEO PRESENTATION

“CHLORINE SPILL (FESTUS, MISSOURI)”

https://www.youtube.com/watch?v=QIJFo6NGwws&t=4s

VIDEO PRESENTATION

“JACK RABBIT PROGRAM”

https://www.uvu.edu/es/jack-rabbit/

VIDEO PRESENTATION

“LET’S POUR LIQUID NITROGEN ON THE FLOOR!”

https://www.youtube.com/watch?v=gvuOhpsI9yQ&t=100s

D. Limitations of the infield modeling means that models will be wrong. However, they can be very helpful.

  1. Estimates can be determined.

  2. All estimates should be verified with real-time monitoring.

ACTIVITY 7.2

Determining Control Zones and Personal Protective Equipment

Purpose

Evaluate data for a scenario involving a gas and identify recommended control zones and personal protective equipment (PPE) requirements based on location relative to release.

Directions

1. Working with your group, review your assigned scenario and associated data.
2. Complete the Product Hazard Analysis Worksheet for the material in your scenario.
3. Using the exposure limits you identified and the plume model provided, develop a response for the questions on the worksheet.
4. Be prepared to present your findings and recommendations to the class.

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ACTIVITY 7.2 (cont'd)

Overarching Scenario and Worksheet

A flatbed tractor-trailer carrying numerous cylinders of your assigned chemical was struck by possible road debris causing a leak from one of the cylinders. Using modeling software and the best information available, personnel have attempted to predict the dispersion of the material.

Using the modeling data provided for your assigned scenario, develop your response to the following questions.

1. What physical and chemical characteristics do you consider to be important factors to the apparent size of the dispersion model?

___

___

___

2. Based upon this or other available data, what distance would you recommend for public protection measures?

___

___

___

3. At approximately what distance from the source would you anticipate immediately dangerous to life or health (IDLH) concentrations?

___

___

___

4. What type of PPE would you recommend for personnel working in the potentially IDLH environment?

___

___

___

5. Based upon this or other available data, what distance would you recommend for public protection measures?

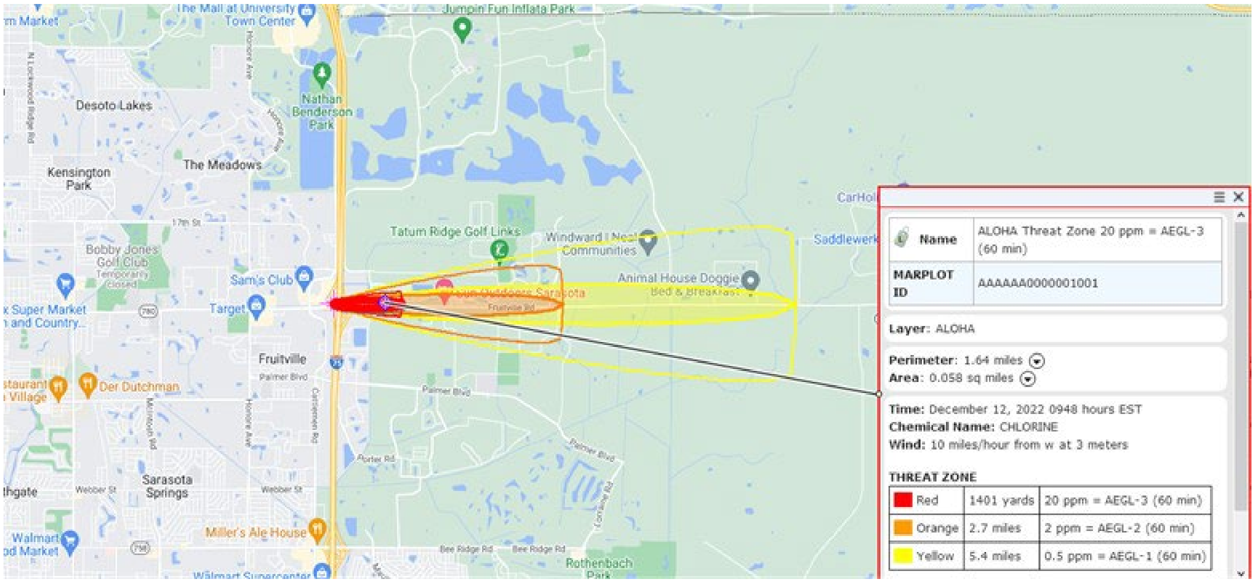
____

____

____

ACTIVITY 7.2 (cont'd)

Scenario 1: Chlorine Gas



Name	ALOHA Threat Zone 20 ppm = AEGL-3 (60 min)
MARPLOT ID	AAAAAA0000001001

Layer: ALOHA

Perimeter: 1.64 miles

Area: 0.058 sq miles

Time: December 12, 2022 0948 hours EST

Chemical Name: CHLORINE

Wind: 10 miles/hour from w at 3 meters

THREAT ZONE

🟥 Red	1401 yards	20 ppm = AEGL-3 (60 min)
🟧 Orange	2.7 miles	2 ppm = AEGL-2 (60 min)
🟨 Yellow	5.4 miles	0.5 ppm = AEGL-1 (60 min)

Site data

- Location: Sarasota Springs, Florida.
- Building air exchanges per hour: 0.88 (unsheltered single storied).
- Time: Dec. 12, 2022, 0948 hours Eastern Standard Time (EST) (using computer's clock).

Chemical data

- Chemical name: chlorine.
- CAS number: 7782-50-5.
- Molecular weight: 70.91 g/mol.
- Acute Exposure Guideline Levels (AEGL)-1 (60 min.): 0.5 parts per million (ppm).
- AEGL-2 (60 min.): 2 ppm.
- AEGL-3 (60 min.): 20 ppm.
- IDLH: 10 ppm.
- Ambient boiling point: -29.3°F.
- Vapor pressure (Vp) at ambient temperature: greater than 1 atmosphere (atm).
- Ambient saturation concentration: 1,000,000 ppm or 100.0%.

Threat zone

- Model run: heavy gas.
- Red: 1,401 yards — (20 ppm = AEGL-3 (60 min)).
- Orange: 2.7 miles — (2 ppm = AEGL-2 (60 min)).
- Yellow: 5.4 miles — (0.5 ppm = AEGL-1 (60 min)).

Atmospheric data (manual input)

- Wind: 10 mph from west at 3 meters.
- Ground roughness: urban or forest.
- Cloud cover: 5 tenths.
- Air temperature: 70°F.
- Stability class: D.
- No inversion height.
- Relative humidity: 50%.

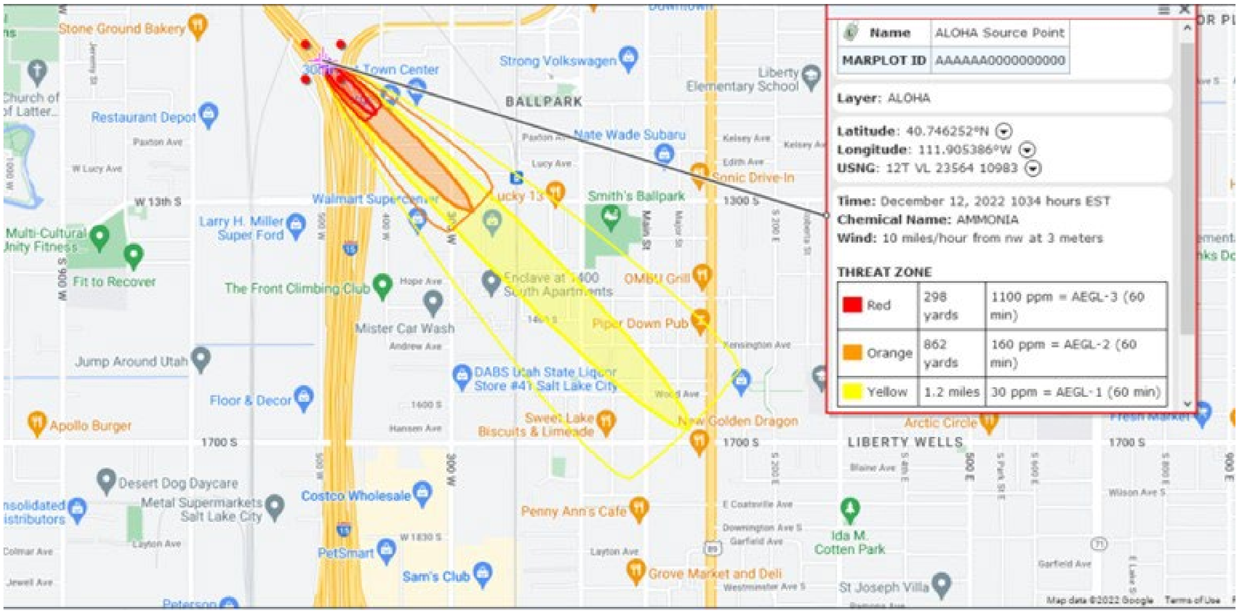
Source strength

- Leak from hole in horizontal cylindrical tank.
- Nonflammable chemical is escaping from tank.
- Tank diameter: 3 feet; tank length: 8 feet.
- Tank volume: 423 gallons.
- Tank contains liquid.
- Internal temperature: 70°F.
- Chemical mass in tank: 1.99 tons.
- Tank is 80% full.
- Circular opening diameter: 0.5 inches.
- Opening is 0 feet from tank bottom.
- Release duration: 10 minutes.
- Max average sustained release rate: 420 pounds/min. (averaged over a minute or more).
- Total amount released: 3,980 pounds.

Note: The chemical escaped as a mixture of gas and aerosol (two-phase flow).

ACTIVITY 7.2 (cont'd)

Scenario 2: Anhydrous Ammonia



Name	ALOHA Source Point
MARPLOT ID	AAAAAA0000000000

Layer: ALOHA

Latitude: 40.746252°N
Longitude: 111.905386°W
USNG: 12T VL 23564 10983

Time: December 12, 2022 1034 hours EST
Chemical Name: AMMONIA
Wind: 10 miles/hour from nw at 3 meters

THREAT ZONE

🟥 Red	298 yards	1100 ppm = AEGL-3 (60 min)
🟧 Orange	862 yards	160 ppm = AEGL-2 (60 min)
🟨 Yellow	1.2 miles	30 ppm = AEGL-1 (60 min)

Site data

- Location: Tampa, Florida.
- Building air exchanges per hour: 0.88 (unsheltered single storied).
- Time: Dec. 12, 2022, 1034 hours EST (using computer's clock).

Chemical data

- Chemical name: ammonia.
- CAS number: 7664-41-7.
- Molecular weight: 17.03 g/mol.
- AEGL-1 (60 min.): 30 ppm.
- AEGL-2 (60 min.): 160 ppm.
- AEGL-3 (60 min.): 1,100 ppm.
- IDLH: 300 ppm; lower explosive limit (LEL): 150,000 ppm; upper explosive limit (UEL): 280,000 ppm.
- Ambient boiling point: -28.2°F.
- Vp at ambient temperature: greater than 1 atm.
- Ambient saturation concentration: 1,000,000 ppm or 100.0%.

Threat zone

- Model run: heavy gas.
- Red: 298 yards — (1,100 ppm = AEGL-3 (60 min.)).
- Orange: 862 yards — (160 ppm = AEGL-2 (60 min.)).
- Yellow: 1.2 miles — (30 ppm = AEGL-1 (60 min.)).

Atmospheric data (manual input)

- Wind: 10 mph from northwest at 3 meters.
- Ground roughness: urban or forest.
- Cloud cover: 5 tenths.
- Air temperature: 70°F.
- Stability class: D.
- No inversion height.
- Relative humidity: 50%.

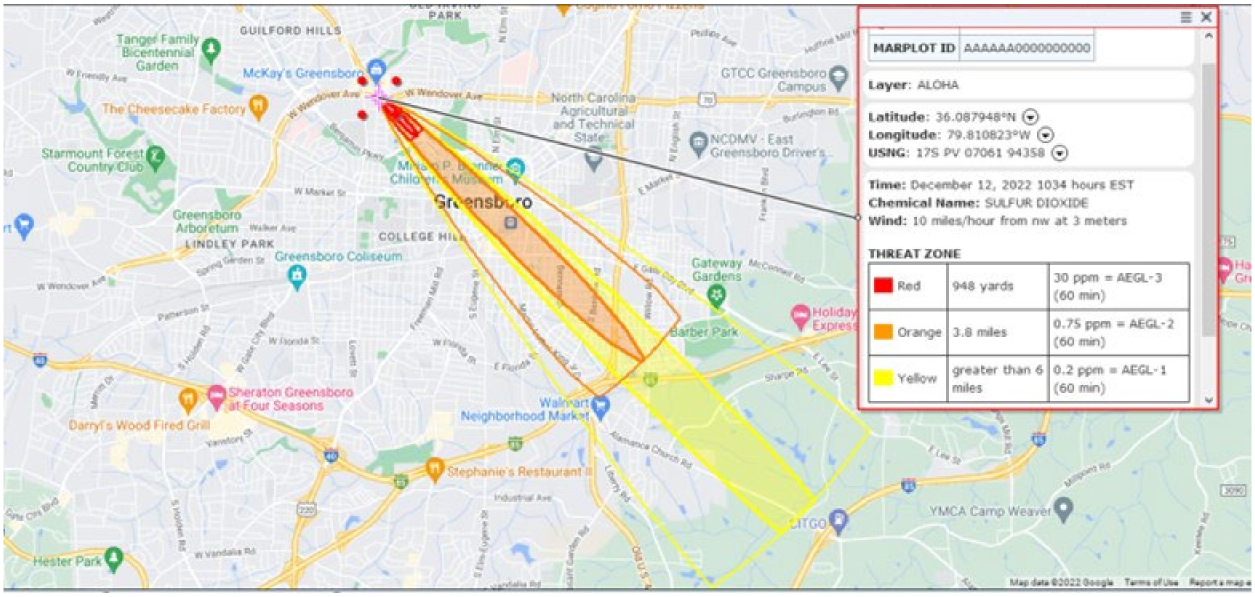
Source strength

- Leak from hole in horizontal cylindrical tank.
- Flammable chemical is escaping from tank (not burning).
- Tank diameter: 3 feet; tank length: 8 feet.
- Tank volume: 423 gallons.
- Tank contains liquid.
- Internal temperature: 70°F.
- Chemical mass in tank: 0.86 tons.
- Tank is 80% full.
- Circular opening diameter: 0.5 inches.
- Opening is 0 feet from tank bottom.
- Release duration: 6 minutes.
- Max average sustained release rate: 315 pounds/min. (averaged over a minute or more).
- Total amount released: 1,720 pounds.

Note: The chemical escaped as a mixture of gas and aerosol (two-phase flow).

ACTIVITY 7.2 (cont'd)

Scenario 3: Sulfur Dioxide



MARPLOT ID	AAAAAA0000000000

Layer: ALOHA

Latitude: 36.087948°N
Longitude: 79.810823°W
USNG: 17S PV 07061 94358

Time: December 12, 2022 1034 hours EST
Chemical Name: SULFUR DIOXIDE
Wind: 10 miles/hour from nw at 3 meters

THREAT ZONE

🟥 Red	948 yards	30 ppm = AEGL-3 (60 min)
🟧 Orange	3.8 miles	0.75 ppm = AEGL-2 (60 min)
🟨 Yellow	greater than 6 miles	0.2 ppm = AEGL-1 (60 min)

Site data

- Location: Greensboro, North Carolina.
- Building air exchanges per hour: 0.88 (unsheltered single storied).
- Time: Dec. 12, 2022, 1034 hours EST (using computer's clock).

Chemical data

- Chemical name: sulfur dioxide.
- CAS number: 7446-9-5.
- Molecular weight: 64.06 g/mol.
- AEGL-1 (60 min.): 0.2 ppm.
- AEGL-2 (60 min.): 0.75 ppm.
- AEGL-3 (60 min.): 30 ppm.
- IDLH: 100 ppm.
- Ambient boiling point: 14.0°F.
- Vp at ambient temperature: greater than 1 atm.
- Ambient saturation concentration: 1,000,000 ppm or 100.0%.

Threat zone

- Model run: heavy gas.
- Red: 948 yards — (30 ppm = AEGL-3 (60 min.)).
- Orange: 3.8 miles — (0.75 ppm = AEGL-2 (60 min.)).
- Yellow: greater than 6 miles — (0.2 ppm = AEGL-1 (60 min.)).

Atmospheric data (manual input)

- Wind: 10 mph from northwest at 3 meters.
- Ground roughness: urban or forest.
- Cloud cover: 5 tenths.
- Air temperature: 70°F.
- Stability class: D.
- No inversion height.
- Relative humidity: 50%.

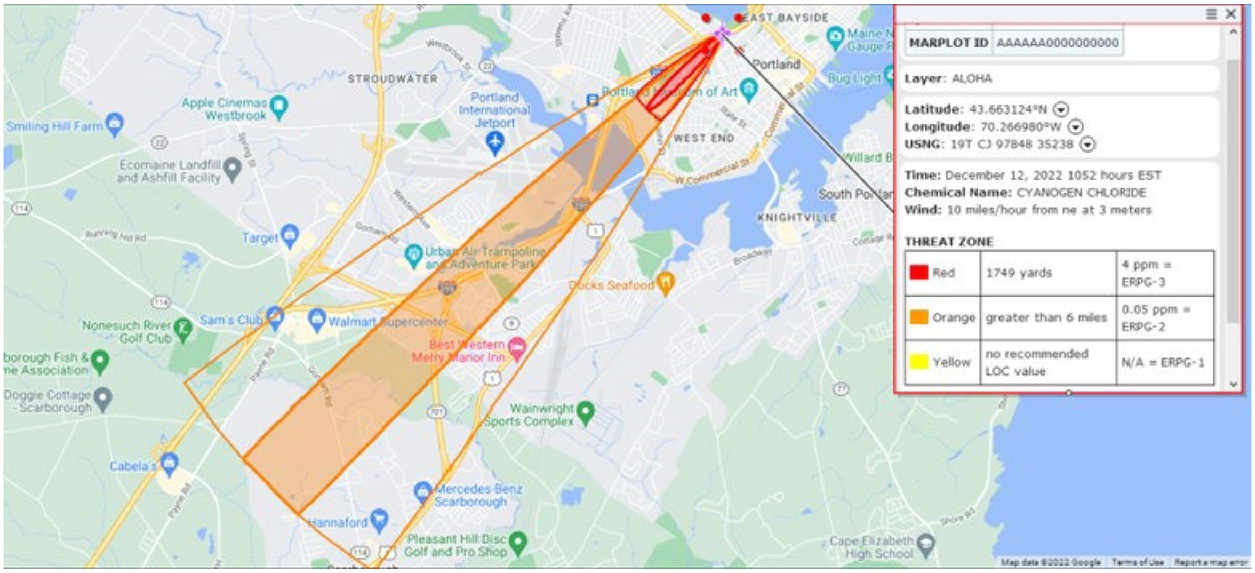
Source strength

- Leak from hole in horizontal cylindrical tank.
- Nonflammable chemical is escaping from tank.
- Tank diameter: 3 feet; tank length: 8 feet.
- Tank volume: 423 gallons.
- Tank contains liquid.
- Internal temperature: 70°F.
- Chemical mass in tank: 1.95 tons.
- Tank is 80% full.
- Circular opening diameter: 0.5 inches.
- Opening is 0 feet from tank bottom.
- Release duration: 15 minutes.
- Max average sustained release rate: 271 pounds/min. (averaged over a minute or more).
- Total amount released: 3,900 pounds.

Note: The chemical escaped as a mixture of gas and aerosol (two-phase flow).

ACTIVITY 7.2 (cont'd)

Scenario 4: Cyanogen Chloride Gas



MARPLOT ID AAAAAA0000000000

Layer: ALOHA

Latitude: 43.663124°N
Longitude: 70.266980°W
USNG: 19T CJ 97848 35238

Time: December 12, 2022 1052 hours EST
Chemical Name: CYANOGEN CHLORIDE
Wind: 10 miles/hour from ne at 3 meters

THREAT ZONE

🟥 Red	1749 yards	4 ppm = ERPG-3
🟧 Orange	greater than 6 miles	0.05 ppm = ERPG-2
🟨 Yellow	no recommended LOC value	N/A = ERPG-1

Site data

- Location: Portland, Maine.
- Building air exchanges per hour: 0.88 (unsheltered single storied).
- Time: Dec. 12, 2022, 1052 hours EST (using computer's clock).

Chemical data

- Chemical name: cyanogen chloride gas.
- CAS number: 506-77-4.
- Molecular weight: 61.47g/mol.
- Emergency response plan guidelines (ERPG)-1: N/A.
- ERPG-2: 0.05ppm.
- ERPG-3: 4 ppm.
- Ambient boiling point: 55.1°F.
- Vp at ambient temperature: greater than 1 atm.
- Ambient saturation concentration: 1,000,000 ppm or 100.0%.

Threat zone

- Model run: heavy gas.
- Red: 1,749 yards — (4 ppm = ERPG-3).
- Orange: greater than 6 miles — (0.75 ppm = ERPG-2).
- Yellow: no recommended level of concern (LOC) value — (N/A = ERPG-1).

Atmospheric data (manual input)

- Wind: 10 mph from northeast at 3 meters.
- Ground roughness: urban or forest.
- Cloud cover: 5 tenths.
- Air temperature: 70°F.
- Stability class: D.
- No inversion height.
- Relative humidity: 50%.

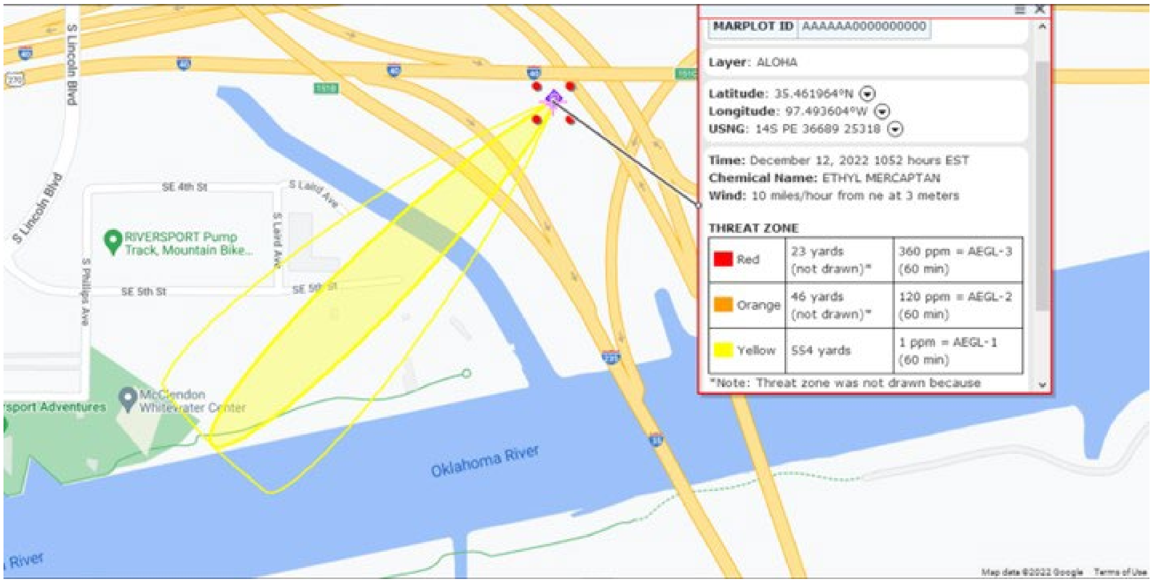
Source strength

- Leak from hole in horizontal cylindrical tank.
- Flammable chemical is escaping from tank (not burning).
- Tank diameter: 3 feet; tank length: 8 feet.
- Tank volume: 423 gallons.
- Tank contains liquid.
- Internal temperature: 70°F.
- Chemical mass in tank: 1.67 tons.
- Tank is 80% full.
- Circular opening diameter: 0.5 inches.
- Opening is 0 feet from tank bottom.
- Release duration: 34 minutes.
- Max average sustained release rate: 107 pounds/min. (averaged over a minute or more).
- Total amount released: 3,900 pounds.

Note: The chemical escaped as a mixture of gas and aerosol (two-phase flow).

ACTIVITY 7.2 (cont'd)

Scenario 5: Ethyl Mercaptan Gas



MARPLOT ID AAAAAA0000000000

Layer: ALOHA

Latitude: 35.461964°N
Longitude: 97.493604°W
USNG: 14S PE 36689 25318

Time: December 12, 2022 1052 hours EST
Chemical Name: ETHYL MERCAPTAN
Wind: 10 miles/hour from ne at 3 meters

THREAT ZONE

🟥 Red	23 yards (not drawn)*	360 ppm = AEGL-3 (60 min)
🟧 Orange	46 yards (not drawn)*	120 ppm = AEGL-2 (60 min)
🟨 Yellow	554 yards	1 ppm = AEGL-1 (60 min)

*Note: Threat zone was not drawn because

Site data

- Location: Oklahoma City, Oklahoma.
- Building air exchanges per hour: 0.88 (unsheltered single storied).
- Time: Dec. 12, 2022, 1052 hours EST (using computer's clock).

Chemical data

- Chemical name: ethyl mercaptan gas.
- CAS number: 75-8-1.
- Molecular weight: 62.13 g/mol.
- AEGL-1 (60 min.): 1 ppm.
- AEGL-2 (60 min.): 120 ppm.
- AEGL-3 (60 min.): 360 ppm.
- IDLH: 500 ppm; LEL: 28,000 ppm; UEL: 180,000 ppm.
- Ambient boiling point: 95°F.
- Vp at ambient temperature: 0.60 atm.
- Ambient saturation concentration: 597,845 ppm or 59.8%.

Threat zone

- Model run: Gaussian.
- Red: 23 yards — (360 ppm = AEGL-3 (60 min.)); Note: Threat zone was not drawn because effects of near-field patchiness make dispersion predictions less reliable for short distances.
- Orange: 46 yards — (120 ppm = AEGL-2 (60 min.)).
- Yellow: 554 yards — (1 ppm = AEGL-1 (60 min.)).

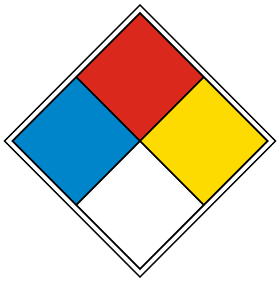
Atmospheric data (manual input)

- Wind: 10 mph from northeast at 3 meters.
- Ground roughness: urban or forest.
- Cloud cover: 5 tenths.
- Air temperature: 70°F.
- Stability class: D.
- No inversion height.
- Relative humidity: 50%.

Source strength

- Leak from hole in horizontal cylindrical tank.
- Flammable chemical is escaping from tank (not burning).
- Tank diameter: 3 feet; tank length: 8 feet.
- Tank volume: 423 gallons.
- Tank contains liquid.
- Internal temperature: 70°F.
- Chemical mass in tank: 1.18 tons.
- Tank is 80% full.
- Circular opening diameter: 0.5 inches.
- Opening is 0 feet from tank bottom.
- Ground type: concrete.
- Max puddle diameter: unknown.
- Release duration: Areal Locations of Hazardous Atmosphere (ALOHA) limited to 1 hour.
- Max average sustained release rate: 8.5 pounds/min. (averaged over a minute or more).
- Total amount released: 648 pounds.

Note: The chemical escaped as a liquid and formed an evaporating puddle. The puddle spread to a diameter of 4.9 yards.



ACTIVITY 7.2 (cont'd)

Product Hazard Analysis Worksheet

Group Number: ________________ **Presenter:** ____________________

Temp: _________ **°F** **R/H:** _________**%**

Product Name:_________________________________ **Family:**___________________________

Data Points	**Result**	**No Data**	**Hazard Consideration**
Physical Properties			
Physical State			
Vapor Pressure			
Boiling Point			
Vapor Density			
Specific Gravity			
Solubility			
Flammability			
Flash Point			
LEL/UEL			
Flammable Range			
Ignition Temp.			
Toxicity			
Route of Exposure			
IDLH			
PEL/REL/STEL			
S/S of Exposure			
Biological			
Corrosivity			
pH			
Concentration			
Reactivity/Explosion			
Radioactivity			
Decay Mode	☐ **N/A** ☐ **α** ☐ **β** ☐ **γ**		
Half Life			

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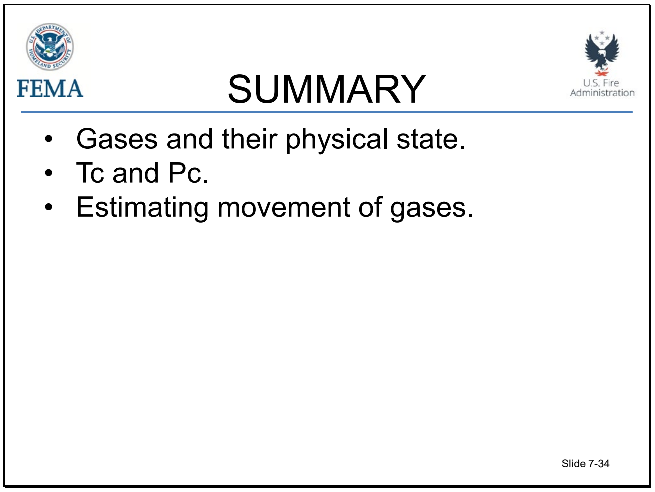
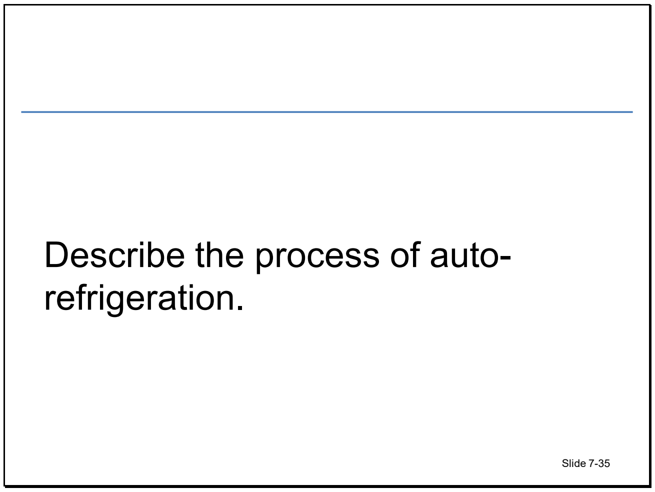
IV. SUMMARY

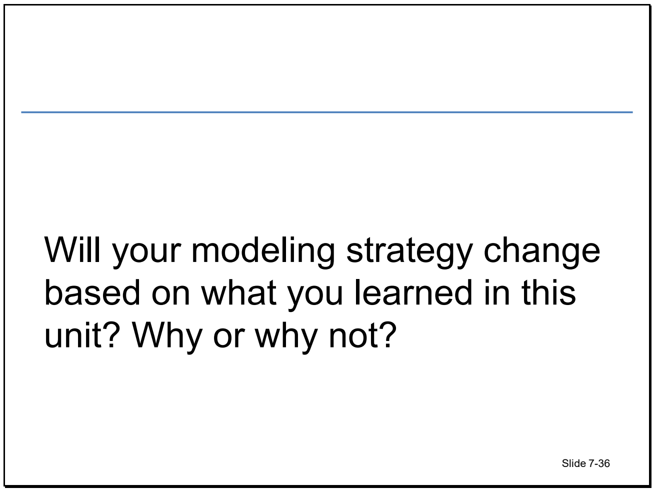


SUMMARY

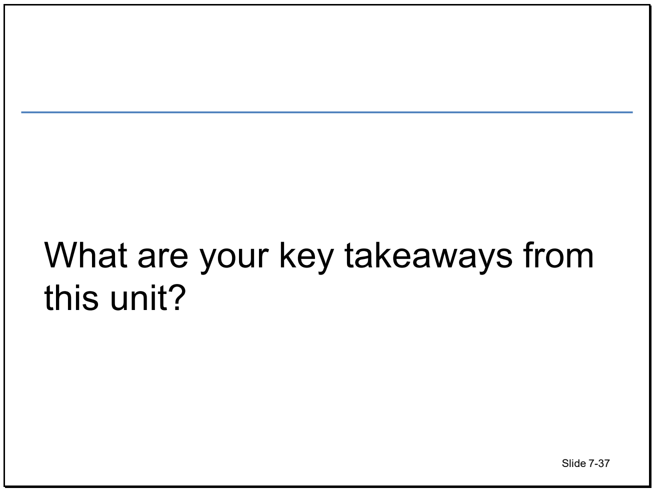
- Gases and their physical state.
- Tc and Pc.
- Estimating movement of gases.



Describe the process of auto-refrigeration.



Will your modeling strategy change based on what you learned in this unit? Why or why not?



What are your key takeaways from this unit?

APPENDIX

CRITICAL TEMPERATURES AND PRESSURES OF SOME GASES

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Critical Temperatures and Pressures of Some Gases

Product	Critical temperature	Critical pressure
Chlorine	290°F (143.8°C)	1,116.8 psi (7,700 kPa)
Ammonia	270.3°F (132.4°C)	1,636 psi (11,280 kPa)
Ethane	88.1°F (31.17°C)	706.5 psi (4,871.4 kPa)
Carbon dioxide	87.8°F (31.04°C)	1,070.4 psi (7,380 kPa)
Methane	-116.1°F (-82.3°C)	672.9 psi (4,640 kPa)
Oxygen	-181.5°F (-118.6°C)	732.4 psi (5,050 kPa)
Argon	-188.3°F (-122.4°C)	706.3psi (4,870 kPa)
Nitrogen	-232.4°F (-146.9°C)	491.6 psi (3,390 kPa)
Hydrogen	-399.9°F (-239.95°C)	188.5 psi (1,300 kPa)
Helium	-450.3°F (-267.96°C)	32.9 psi (227 kPa)

Gas	T_c (°F)	T_c (°C)	P_c (psi, lb/sq.in)	BP (°F)	BP (°C)
Air	-220.9	-140.5	547	-	-
Ammonia (NH_3)	270	132.4	1636	-27.4	-33
Carbon dioxide (CO_2)	87.8	31	1071.6	-110	-79
Chlorine			1118.7		
Hydrogen (H)	-400	-240	188.2	-423	-253
Hydrogen chloride			1198		
Isobutane			529.2		
Isobutylene			580		
Methane			673.3		
Nitrogen (N)	-232.6	-147	492.4	-321	-195
Oxygen (O_2)		-118.6	732	-297	-183
Propane			617.4		
Water			3206.2		

UNIT 8: FLAMMABILITY AND COMBUSTION

TERMINAL OBJECTIVE

The students will be able to:

8.1 Determine response objectives by summarizing the significance of terms related to flammability and combustion.

ENABLING OBJECTIVES

The students will be able to:

8.1 Identify how physical and chemical properties affect the degree of flammability or combustibility.

8.2 Analyze the effects of molecular size, polarity and shape on vapor pressure (Vp), flash point (Fp), boiling point (Bp), vapor concentration/content (Vc), vapor density (Vd) and heat output.

8.3 Identify the chemical families that may have energetic properties.

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FEMA

U.S. Fire Administration

UNIT 8: FLAMMABILITY AND COMBUSTION

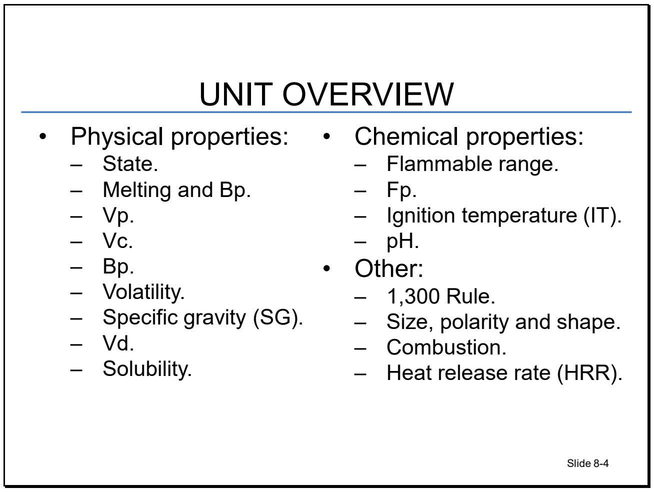
TERMINAL OBJECTIVE

Determine response objectives by summarizing the significance of terms related to flammability and combustion.

ENABLING OBJECTIVES

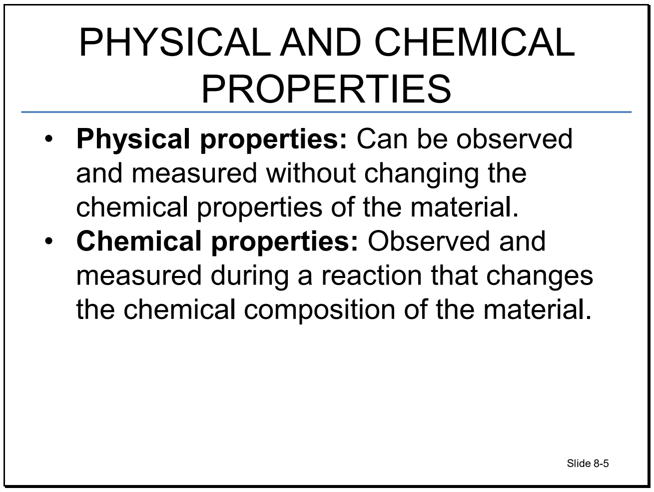
- Identify how physical and chemical properties affect the degree of flammability or combustibility.
- Analyze the effects of molecular size, polarity and shape on vapor pressure (Vp), flash point (Fp), boiling point (Bp), vapor concentration/content (Vc), vapor density (Vd) and heat output.
- Identify the chemical families that may have energetic properties.

I. INTRODUCTION



UNIT OVERVIEW

- Physical properties:
  - State.
  - Melting and Bp.
  - Vp.
  - Vc.
  - Bp.
  - Volatility.
  - Specific gravity (SG).
  - Vd.
  - Solubility.
- Chemical properties:
  - Flammable range.
  - Fp.
  - Ignition temperature (IT).
  - pH.
- Other:
  - 1,300 Rule.
  - Size, polarity and shape.
  - Combustion.
  - Heat release rate (HRR).



PHYSICAL AND CHEMICAL PROPERTIES

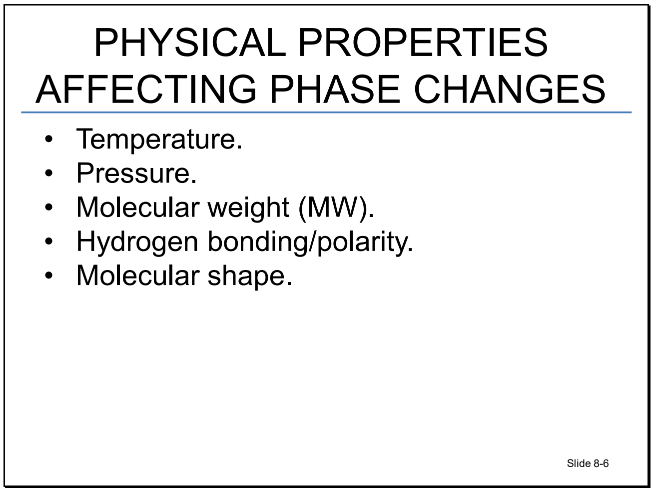
- **Physical properties:** Can be observed and measured without changing the chemical properties of the material.
- **Chemical properties:** Observed and measured during a reaction that changes the chemical composition of the material.

A. Foundational definitions.

1. **Physical properties:** can be observed and measured without changing the chemical properties of the material. Color, odor, viscosity, solubility and boiling point (Bp) are examples.

2. **Chemical properties:** observed and measured during a reaction that changes the chemical composition of the material. Heat release rate (HRR), flash point (Fp), ignition temperature (IT) and decomposition are examples.

B. Physical and chemical properties of flammable and combustible products.



PHYSICAL PROPERTIES AFFECTING PHASE CHANGES

- Temperature.
- Pressure.
- Molecular weight (MW).
- Hydrogen bonding/polarity.
- Molecular shape.

1. Physical properties.

   a. Physical state and changes in the physical state or “phase changes.”

   b. The variables that affect those phase changes:

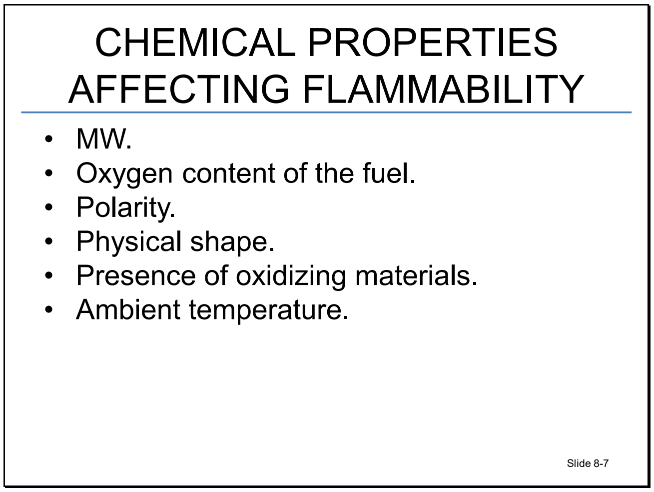
      - Temperature.
      - Pressure.
      - Molecular weight (MW).
      - Hydrogen bonding/polarity.
      - Molecular shape.

   c. Vapor pressure (Vp) and equilibrium.

      - Vapor concentration/content (Vc).
      - Specific gravity (SG) and vapor density (Vd).
      - Bp.
      - Volatility.

   d. Solubility.

      - SG.
      - Temperature.
      - Polarity.



CHEMICAL PROPERTIES AFFECTING FLAMMABILITY

- MW.
- Oxygen content of the fuel.
- Polarity.
- Physical shape.
- Presence of oxidizing materials.
- Ambient temperature.

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2. Chemical properties.

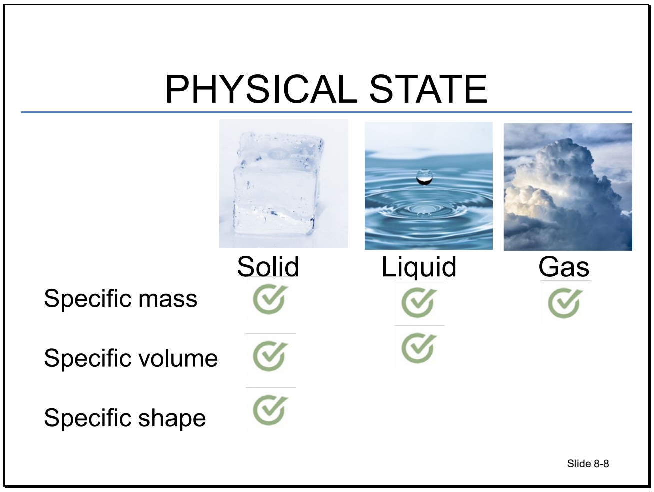
   a. Flammability.

      - Fp.
      - Flammable range.
      - IT.

   b. Variables that affect flammability:

      - MW.
      - Oxygen content of the fuel.
      - Polarity.
      - Physical shape.
      - Presence of oxidizing materials.
      - Ambient temperature.

II. PHYSICAL STATE



PHYSICAL STATE

	Solid	Liquid	Gas
Specific mass	✓	✓	✓
Specific volume	✓	✓	
Specific shape	✓		

A. Definitions.

B. Relationships between the three primary states of matter.

1. Solids:

   a. Have specific mass, occupy a specific volume and have a specific shape.

   b. Atoms closely packed.

   c. Specific arrangement of molecules, atoms or ions.

   d. Atomic, ionic or molecular movement noted as vibration.

   e. Only a few specific products that are solids are flammable or combustible. Except for certain elemental metals and pyrophoric compounds, most solids will not generally burn. Mass plays a part in a solid's ability to burn.

   f. Finely divided solids can be very flammable, even explosive in the form of combustible dusts.

      - The "Five-Foot Rule" says that if vision is obscured at five feet, the dust may be in a flammable range.

2. Liquids.

   a. Have specific mass and occupy a specific volume but have no specific shape.

b. Molecular distance varies depending on MW and polarity.

c. In some instances, distances may be reflected by viscosity.

  - Highly viscous liquids get progressively more sluggish until they approach solidification. These compounds have high carbon content (large molecules) and are therefore less volatile. They have low ITs.

  - Low-viscosity liquids are said to be "lively." When spun in a bottle or beaker, they form a vortex. These low-viscosity liquids have lower carbon content (smaller molecules), and the MW is lower. They are more volatile and have higher ITs.

  - As a rule of thumb, highly viscous liquids are difficult to ignite at normal ambient temperatures.

d. Molecular movement is random and in all directions.

e. Most hazardous products that are liquids have flammable or combustible properties. In the case of any liquids releases, ignition sources should be controlled.

f. Liquids cannot be compressed. Water will only reduce 1% in volume when placed under 33,000 pounds per square inch (psi) of pressure.

3. Gases.

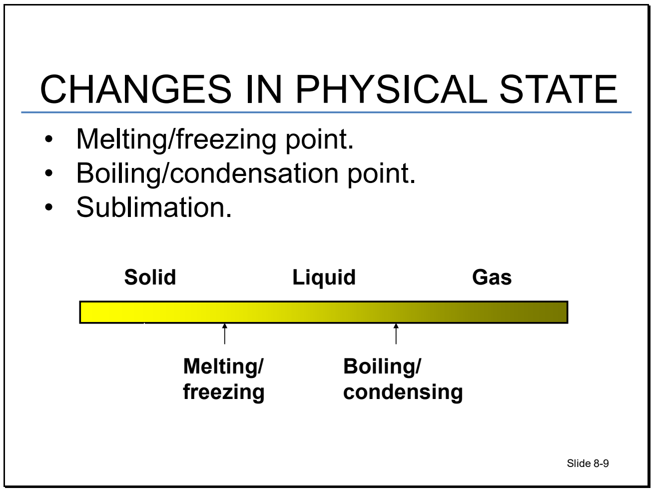
a. Have specific mass but have no specific volume or shape.

b. Atomic or molecular distance varies depending on its pressure.

c. Pressure will compress all gases.

d. Gases may simply compress or liquefy depending on their critical temperature (Tc) and critical pressure (Pc).

e. Many hazardous products that are gases are toxic or asphyxiants and may be flammable or combustible. In the case of any gas release, ignition sources should be controlled.



CHANGES IN PHYSICAL STATE

- Melting/freezing point.
- Boiling/condensation point.
- Sublimation.

Solid **Liquid** **Gas**

Melting/ freezing **Boiling/ condensing**

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C. Changes in physical state.

1. Many products can exist in more than one physical state at normal temperature and pressure (68°F and 14.7 psi). Examples are water, dry ice (CO_2), hexane, methanol and dimethyl ketone (DMK).

    a. It is well-known that liquid water will freeze and become a solid at 32°F (0°C) at normal atmospheric pressure.

    b. A temperature of 32°F is known as both the freezing point and the melting point for water depending on which way the temperature is moving.

    c. In very cold-weather climates in the northern United States, these points are more critical to consider.

    d. For water, both the freezing point and melting point are exactly the same and are well-defined.

    e. Some products exist in multiple physical states. An example is dry ice, which is both a solid and, after sublimation, a gas (CO_2) at normal temperatures and pressures. Liquids will have vapors present above their liquid surfaces. Remember, it is the gas or the vapor that burns, not the solid or the liquid.

2. At 212°F (100°C), at sea level, liquid water begins to boil at normal atmospheric pressure as it begins the transition or phase change from a liquid state to a vapor.

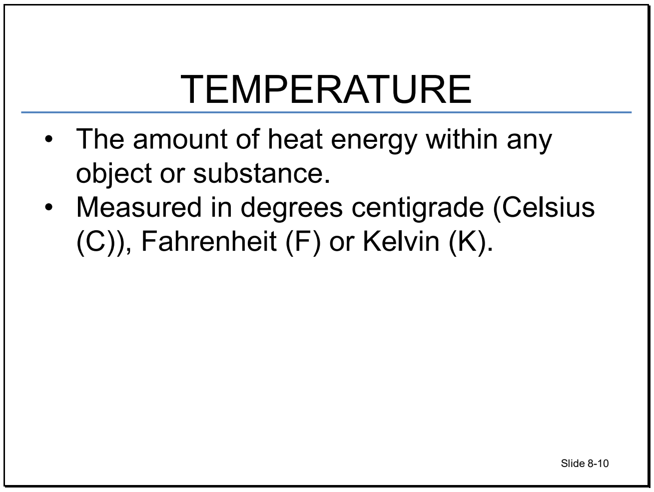
    The specific temperature at which a liquid boils is directly related to the atmospheric pressure in the environment. This is known as the Bp.

3. While possible, products rarely exist in all three states of matter in the natural environment.

Table 8.1: Melting point, vapor pressure and physical state at 68°F (20°C)

Substance	Melting point (F)	Vp (mmHg)	Physical state
Dry ice (CO_2)	-109°	56 atm	Gas
Hexane	-137°	153	Liquid
Methanol	-144°	127	Liquid
DMK	-139°	231	Liquid
Benzene	41°	95	Liquid
Phenol	109°	0.35	Solid

III. VARIABLES AFFECTING PHYSICAL STATE



TEMPERATURE

- The amount of heat energy within any object or substance.
- Measured in degrees centigrade (Celsius (C)), Fahrenheit (F) or Kelvin (K).

A. Temperature.

1. An indication of the amount of heat energy within any object or substance.

2. The greater the amount of heat, the greater the atomic, ionic or molecular movement.

    a. As the movement increases, so does interatomic, ionic or molecular distance, resulting in a phase change.

    b. Conversely, as cooling (removing of energy) decreases movement, it also decreases interatomic, ionic or molecular distance, resulting in a phase change.

3. Units of measure:

   a. Degrees centigrade or Celsius (C):

      - Used by most countries worldwide except the U.S.

      - 100°C = water's Bp.

      - 0°C = water's freezing point.

   b. Degrees Fahrenheit (F):

      - Used in the U.S. and a few other countries and territories.

      - 212°F = water's Bp.

      - 32°F = water's freezing point.

   c. Converting between Celsius and Fahrenheit scales:

      - °F = (°C x 1.8) +32

      - °C = (°F - 32) x 0.56

   d. Degrees Kelvin (K).

      - The standard International System of Units (SI) of thermodynamic temperature.

      - 373.15°K = water's Bp.

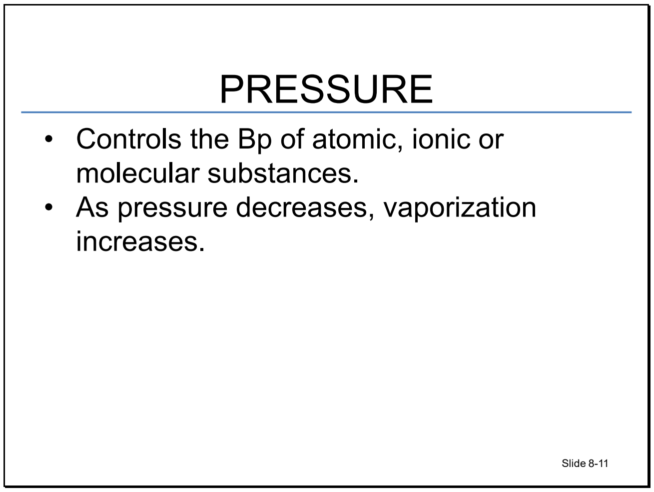
      - 273.15°K = water's freezing point.

4. Vibration causes a number of reactions in solids.

   a. In most natural and manmade polymeric solids, molecular vibration (heat input) causes pyrolytic decomposition of molecules as opposed to melting. Thermoplastics melt and break down to their monomer, which then burns. Examples include polyethylene, polypropylene and nylon. Thermoset plastics resist heat and chemicals. Examples include some polyesters (fiberglass, body putty, etc.), phenol-formaldehyde (Bakelite), furan resin (cements, adhesives, etc.) and epoxy.

   b. In energetic and unstable solids, vibration causes chemical bond breakage that initiates decomposition.

c. Decomposition may range from vigorous combustion to an explosive reaction. Examples include organic peroxides and some oxidizers.



PRESSURE

- Controls the Bp of atomic, ionic or molecular substances.
- As pressure decreases, vaporization increases.

Slide 8-11

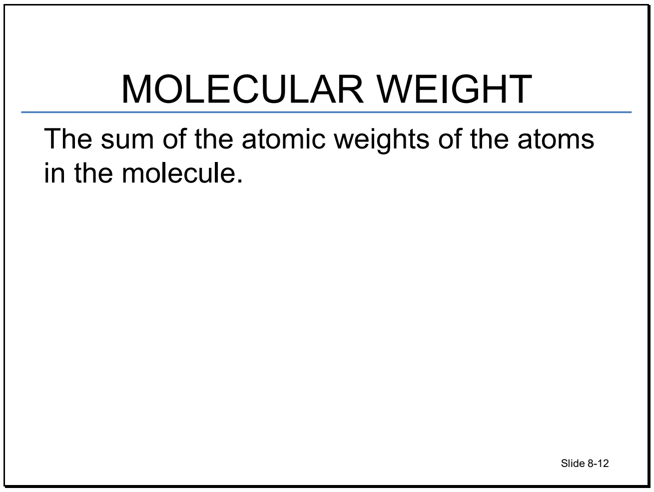
B. Pressure.

1. In the absence of atmospheric pressure, only solids and gases (as in a vacuum or outer space) exist.

2. Atmospheric pressure controls the Bp of atomic, ionic or molecular substances.

3. As pressure decreases, the amount of vaporization increases at a given temperature.

4. As pressure increases, the amount of vaporization decreases at a given temperature.



MOLECULAR WEIGHT

The sum of the atomic weights of the atoms in the molecule.

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C. MW.

1. The MW is the sum of the atomic weights of the atoms in the molecule.

2. Calculating MW:

   a. Use the chemical formula and the periodic table.

   b. Find the atomic weight of each atom in the molecule.

   c. Multiply the atomic weight by the number of atoms of the element in the compound.

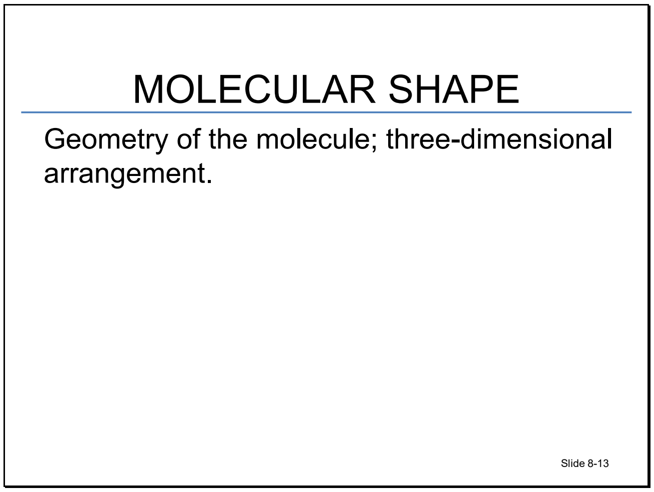
   d. Add all the weights together to get the MW.

Table 8.2: Molecular weight example

Atom	Number of atoms in a molecule of SO_2	Atomic weight	Total atomic weight
Sulfur	1	32	32
Oxygen	2	16	32
		MW of SO_2	**64**

3. Lower MW hydrocarbons and derivatives tend to be gases or low-viscosity liquids: lively, light liquids that can be spun into a vortex easily — a low resistance to flow.

4. Higher MW hydrocarbons and derivatives tend to be higher viscosity liquids to semisolid compounds and eventually combustible solids such as asphalt tar ingots, or “kegs” with 30 carbons and 50 hydrogens among other additive atoms such as oxygen and nitrogen.

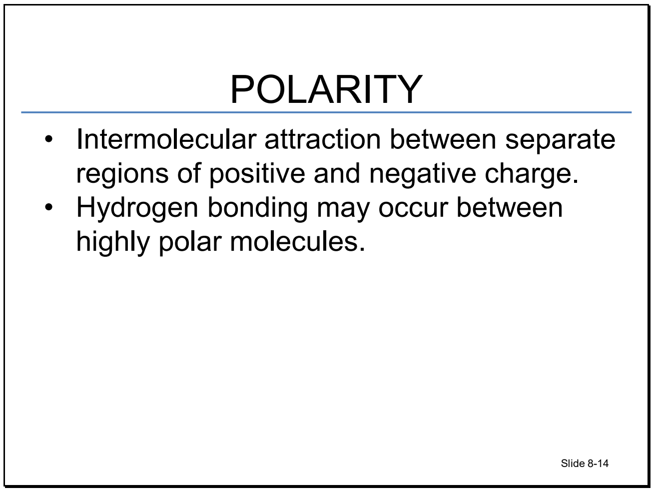


MOLECULAR SHAPE

Geometry of the molecule; three-dimensional arrangement.

D. Molecular shape.

1. Branched compounds generally can pack more closely due to a physically smaller molecular shape.
2. Cyclic compounds have a mid-degree of closeness.
3. Straight chain compounds are generally the least tightly packed.



POLARITY

- Intermolecular attraction between separate regions of positive and negative charge.
- Hydrogen bonding may occur between highly polar molecules.

E. Polarity.

1. Intermolecular attraction caused by the polarity of atoms, molecules or ions decreases distance, magnetic attraction and chemical reactivity.
2. This raises the density of the substance.
3. Hydrogen bonding may occur between highly polar molecules. Hydrogen bonding is where an OH exists in the molecule.

4. With an MW of 18, water should be a gas, but is not due to hydrogen bonding or high polarity. Many products mix, or dissociate, in water. Pure hydrocarbon substances are not one of these products.

5. As polarity increases:

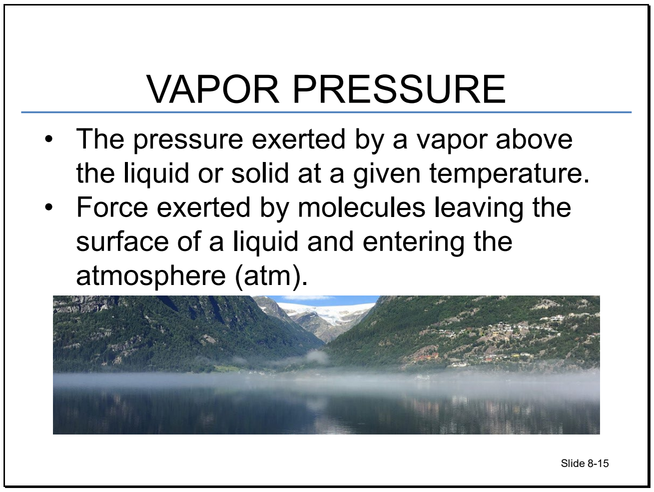
   a. Vp decreases. The polarity holds the molecule together, taking more energy to liberate it into a vapor.

   b. Bp increases for the same reasons.

   c. Physical states tend to gravitate more toward liquid and solid states.

   d. Water solubility increases. More OH bonding in the molecule will more readily mix with the OH bonds in water.

IV. VAPOR PRESSURE

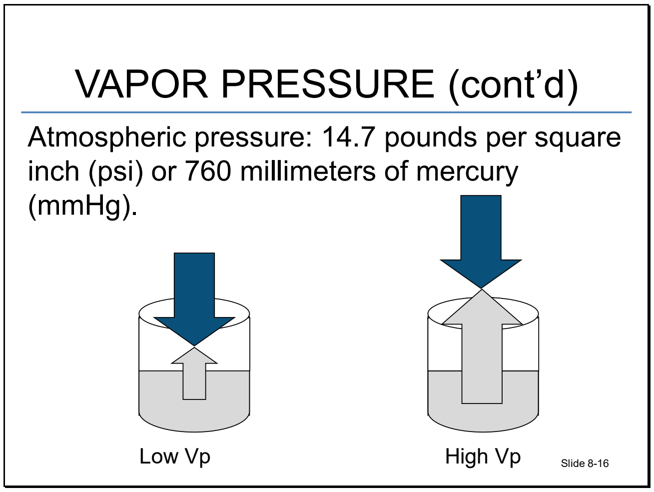


VAPOR PRESSURE

- The pressure exerted by a vapor above the liquid or solid at a given temperature.
- Force exerted by molecules leaving the surface of a liquid and entering the atmosphere (atm).

A. Introduction.

1. Vp is defined as the pressure exerted by a vapor above the liquid or solid at a given temperature in a closed system. The higher the Vp, the faster the liquid or solid's evaporation rate. It relates to the tendency of particles to escape from the liquid or solid.



VAPOR PRESSURE (cont'd)

Atmospheric pressure: 14.7 pounds per square inch (psi) or 760 millimeters of mercury (mmHg).

Low Vp

High Vp

2. A force measured in millimeters of mercury (mmHg) (also commonly measured in atmosphere (atm), psi, millibars and TORR). Most commonly: 1 atm = 760 mmHg = 14.7 psi. Products with a Vp above any of these points are considered gases.

3. Vp is a concern in a storage container and less of a concern when open to the atm. High Vp = High Vc. High Vc is a concern outside of a container, as in a spill. High Vp inside a container may overcome the design pressure of that container and it may come apart catastrophically.

4. Vp is present with solids that sublimate.

5. Vp is present to some degree or another above all liquids.

B. Mechanism.

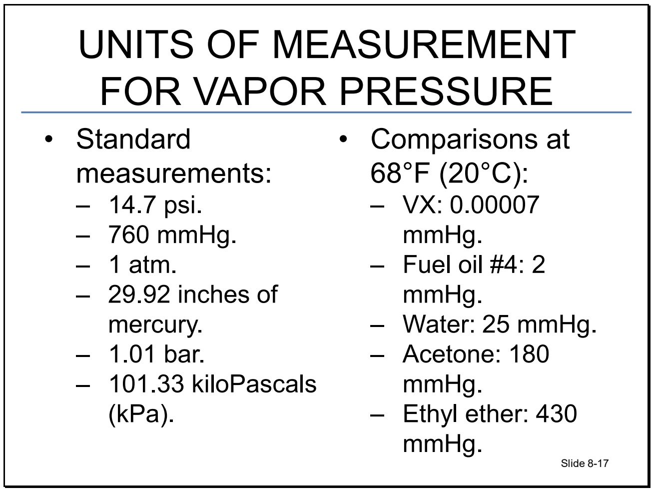
1. Kinetic molecular theory states that all molecules are constantly in motion, except at absolute zero (-459°F).

2. Molecular movement provides the force.

3. Thus, it is temperature dependent.

    a. The lower the temperature of the substance, the lower its Vp.

    b. The higher the temperature of the substance, the higher its Vp.



UNITS OF MEASUREMENT FOR VAPOR PRESSURE

- Standard measurements:
  - 14.7 psi.
  - 760 mmHg.
  - 1 atm.
  - 29.92 inches of mercury.
  - 1.01 bar.
  - 101.33 kiloPascals (kPa).
- Comparisons at 68°F (20°C):
  - VX: 0.00007 mmHg.
  - Fuel oil #4: 2 mmHg.
  - Water: 25 mmHg.
  - Acetone: 180 mmHg.
  - Ethyl ether: 430 mmHg.

C. Units of measurement.

1. Multiple options for measuring pressure in general.

2. Standard atmospheric pressure measurements at sea level:

   a. 14.7 psi.

   b. 760 mmHg.

   c. 1 atm.

   d. 29.92 inches of mercury.

   e. 1.01 bar.

   f. 101.33 kiloPascals (kPa).

3. Vp comparisons at 68°F (20°C):

   a. VX — 0.00007 mmHg.

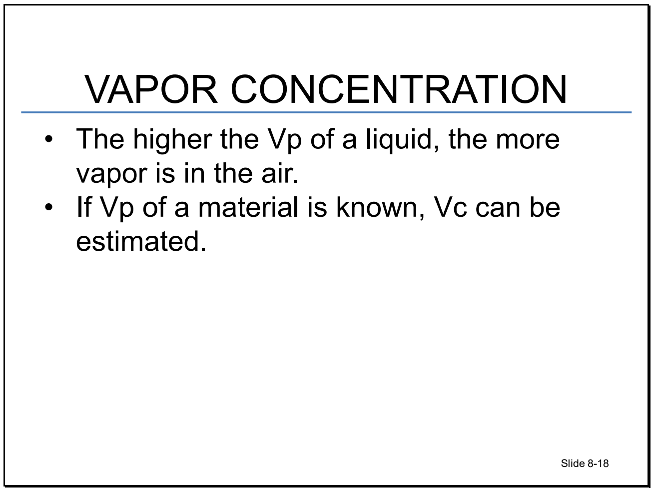
   b. Fuel oil #4 — 2 mmHg.

   c. Water — 25 mmHg.

   d. Acetone — 180 mmHg.

   e. Ethyl ether — 430 mmHg.

V. VAPOR CONCENTRATION



VAPOR CONCENTRATION

- The higher the Vp of a liquid, the more vapor is in the air.
- If Vp of a material is known, Vc can be estimated.

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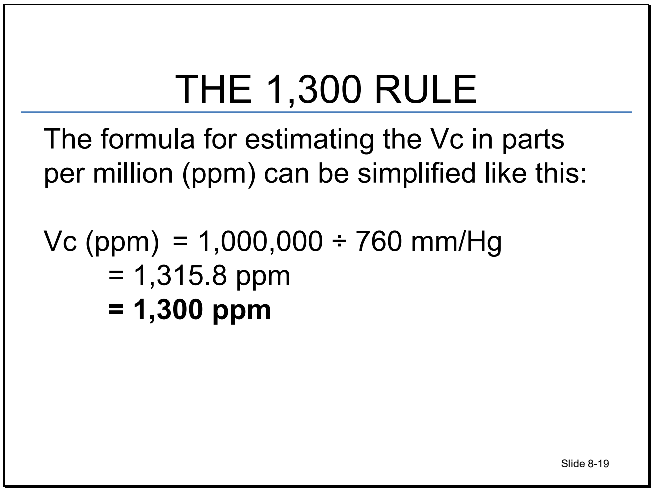
A. The higher the Vp of a liquid, the more concentrated its vapor will be when mixed with air in the open environment or in a container. The higher the Vp, the more vapor is in the air (Vc).

B. If the Vp of a material is known, the approximate maximum saturation of vapors (Vc) that the material may produce can be estimated using the 1,300 Rule.



THE 1,300 RULE

The formula for estimating the Vc in parts per million (ppm) can be simplified like this:

Vc (ppm) = 1,000,000 ÷ 760 mm/Hg
= 1,315.8 ppm
= 1,300 ppm

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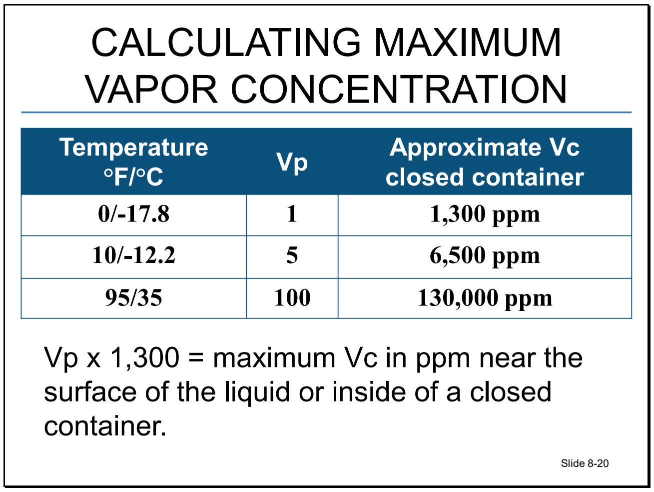
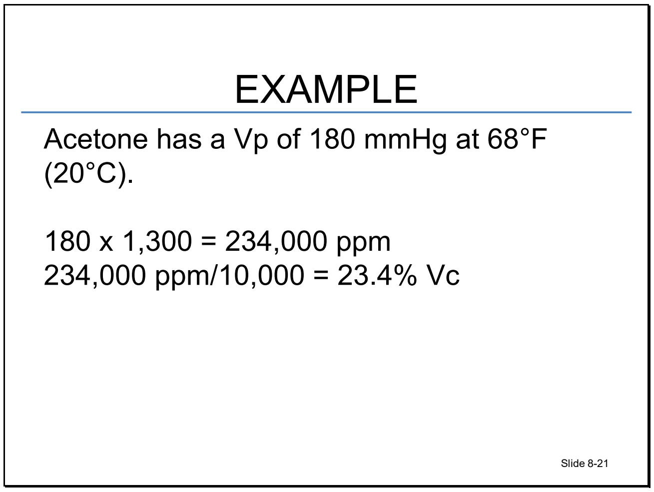


CALCULATING MAXIMUM VAPOR CONCENTRATION

Temperature °F/°C	Vp	Approximate Vc closed container
0/-17.8	1	1,300 ppm
10/-12.2	5	6,500 ppm
95/35	100	130,000 ppm

Vp x 1,300 = maximum Vc in ppm near the surface of the liquid or inside of a closed container.



EXAMPLE

Acetone has a Vp of 180 mmHg at 68°F (20°C).

180 x 1,300 = 234,000 ppm
234,000 ppm/10,000 = 23.4% Vc

C. Example: calculating Vc.

1. Acetone has a Vp of 180 mmHg at 68°F (20°C).

2. 180 x 1,300 = 234,000 parts per million (ppm).

3. 234,000 ppm/10,000 = 23.4% Vc.

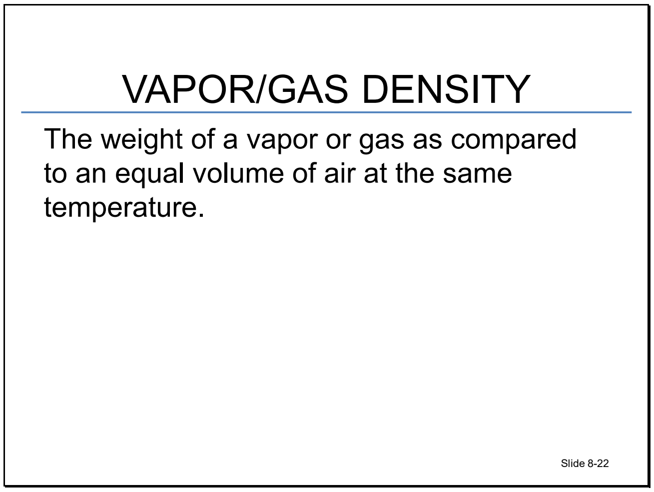
4. Flammable range of acetone is 2% to 13%, so it is likely too rich to burn in storage at 68°F.

5. At 68°F, the air can hold 234,000 ppm of acetone.

6. If the temperature is higher, the Vp and Vc will be higher.

7. If the temperature is lower, the Vp and the Vc will be lower.

VI. VAPOR/GAS DENSITY



VAPOR/GAS DENSITY

The weight of a vapor or gas as compared to an equal volume of air at the same temperature.

A. The weight of a vapor or gas as compared to an equal volume of air. Air = 1.

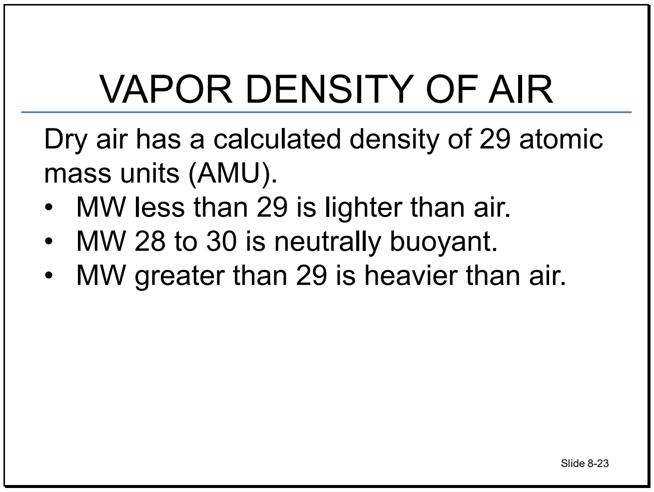
B. Vd may also be called the vapor or gas SG or relative gas density (RGasD) at normal pressure and temperatures.

1. Involves the comparison of the given gas or vapor in comparison to air.

2. Critical that both the gas or vapor and the air are at the same temperature.

3. If not at the same temperature, comparison is invalid.

4. If gas or vapor is at a different temperature than the air, they will behave differently due to different density. Cold gases act heavy and slow until they reach neutral buoyancy (same temperature as the air). Hot gases and vapors move faster and farther.



VAPOR DENSITY OF AIR

Dry air has a calculated density of 29 atomic mass units (AMU).

- MW less than 29 is lighter than air.
- MW 28 to 30 is neutrally buoyant.
- MW greater than 29 is heavier than air.

C. Vd of air.

1. Dry air has a calculated density of 29 atomic mass units (AMU).

2. If MW is less than 29, the gas or vapor is lighter than air and its Vd will be < 1.

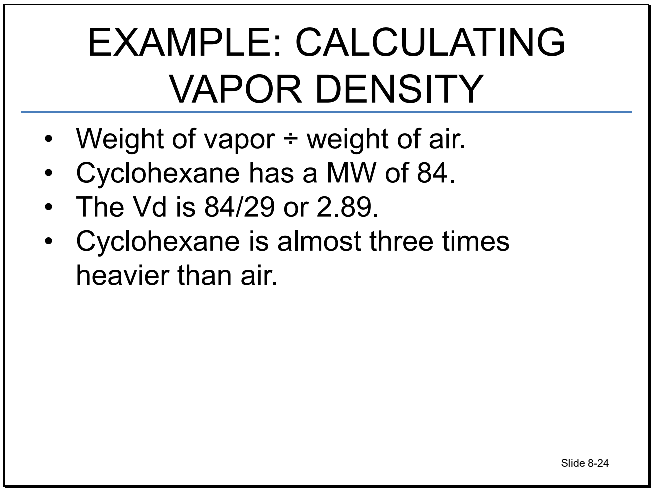
3. If MW of the gas is between about 28 and 30, the gas or vapor is neutrally buoyant.

4. If MW is greater than 29, the gas or vapor is heavier than air and will have a Vd of > 1.

Table 8.3: Chemical makeup of the atmosphere excluding water vapor

Gas	Symbol	Content
Nitrogen	N_2	78.084%
Oxygen	O_2	20.947%
Argon	Ar	0.934%
Carbon dioxide	CO_2	0.035%
Neon	Ne	18.182 parts per million
Helium	He	5.24 parts per million
Methane	CH_4	1.70 parts per million
Krypton	Kr	1.14 parts per million
Hydrogen	H_2	0.53 parts per million
Nitrous oxide	N_2O	0.31 parts per million
Carbon monoxide	CO	0.10 parts per million
Xenon	Xe	0.09 parts per million
Ozone	O_3	0.07 parts per million
Nitrogen dioxide	NO_2	0.02 parts per million
Iodine	I_2	0.01 parts per million
Ammonia	NH_3	trace

Source: https://www.noaa.gov/jetstream/atmosphere



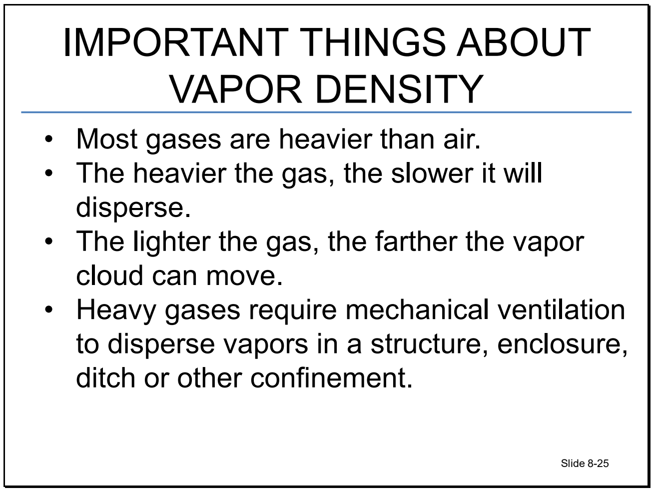
EXAMPLE: CALCULATING VAPOR DENSITY

- Weight of vapor ÷ weight of air.
- Cyclohexane has a MW of 84.
- The Vd is 84/29 or 2.89.
- Cyclohexane is almost three times heavier than air.

Slide 8-24

D. How to calculate Vd.

1. To calculate Vd, divide the MW of the vapor by the weight of air (29 AMU).
2. Cyclohexane has a MW of 84 ($c\text{-}C_6H_{12}$).
3. The Vd of cyclohexane is 84/29 or 2.89.
4. Cyclohexane is almost three times heavier than air.



IMPORTANT THINGS ABOUT VAPOR DENSITY

- Most gases are heavier than air.
- The heavier the gas, the slower it will disperse.
- The lighter the gas, the farther the vapor cloud can move.
- Heavy gases require mechanical ventilation to disperse vapors in a structure, enclosure, ditch or other confinement.

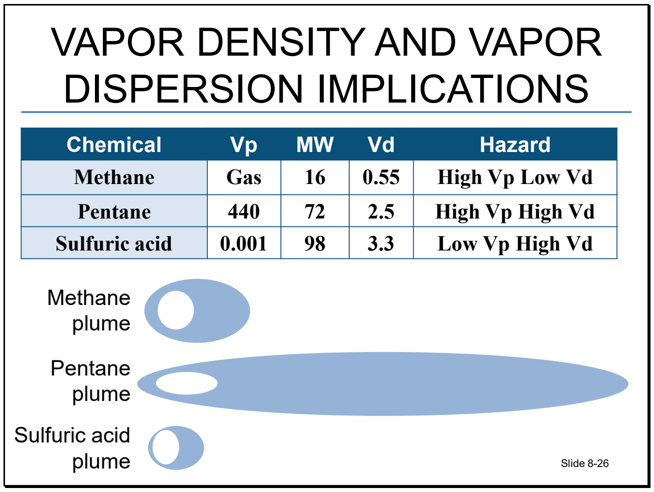
Slide 8-25

E. Important things about Vd.

1. Most gases are heavier than air.
2. The heavier the gas, the slower it will disperse.
3. The lighter the gas or vapor, the farther the plume can move downwind or rise in air.

4. Heavy gases require mechanical ventilation to disperse vapors in a structure, enclosure, ditch or other confinement.

5. Plume behavior is affected by wind speed regardless of Vd.



VAPOR DENSITY AND VAPOR DISPERSION IMPLICATIONS

Chemical	Vp	MW	Vd	Hazard
Methane	Gas	16	0.55	High Vp Low Vd
Pentane	440	72	2.5	High Vp High Vd
Sulfuric acid	0.001	98	3.3	Low Vp High Vd

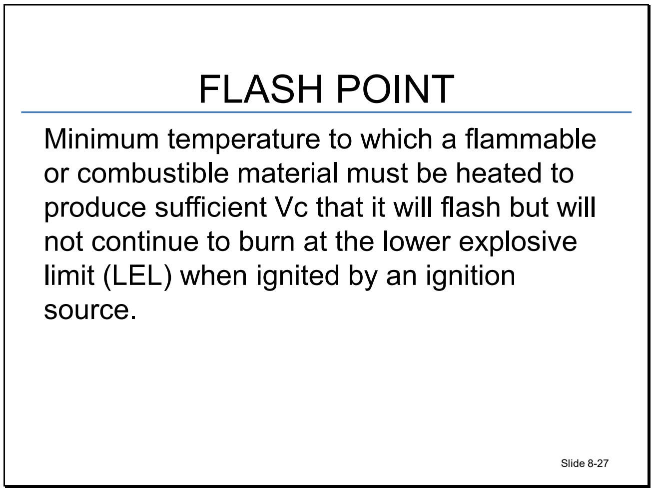
Methane plume

Pentane plume

Sulfuric acid plume

Slide 8-26

VII. FLASH POINT



FLASH POINT

Minimum temperature to which a flammable or combustible material must be heated to produce sufficient Vc that it will flash but will not continue to burn at the lower explosive limit (LEL) when ignited by an ignition source.

Slide 8-27

A. Introduction.

1. Fp is the minimum temperature to which a flammable or combustible material must be heated to produce sufficient Vc that it will flash but will not continue to burn when ignited by an ignition source.

2. Directly related to Bp:

a. Low Bp, low Fp.

b. High Bp, high Fp.

3. Ignition will not occur unless there is an ignition source present.

4. When at the Fp, ignition will cause the available vapor to flash but will not sustain combustion because the vapor has been consumed.

5. Based on the temperature of the liquid and not the ambient temperature, although Fp should always be considered in the context of ambient temperature, asking: “Is the material ready to burn at this temperature?”

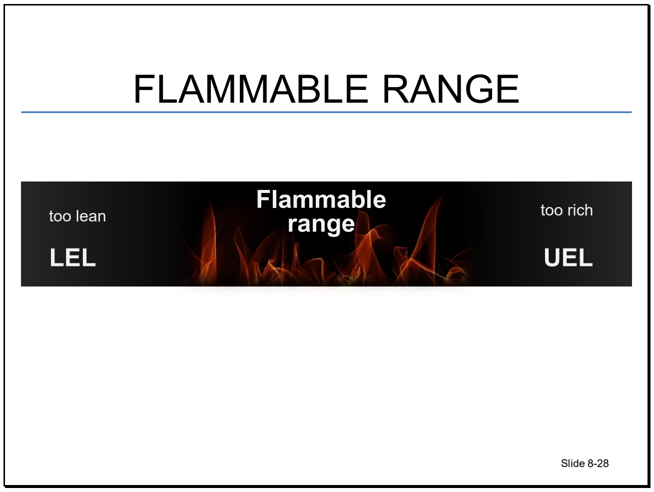
6. Fp is a critical data point when choosing personal protective equipment (PPE).

B. Fire point.

1. Generally, a few degrees above the Fp.

2. At fire point, Vc is sufficient to sustain combustion.

VIII. FLAMMABLE RANGE



FLAMMABLE RANGE

too lean

LEL

Flammable range

too rich

UEL

Slide 8-28

A. Overview of flammable range.

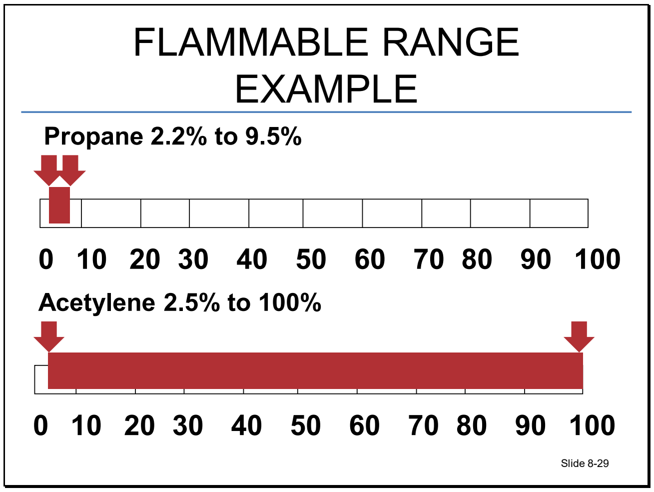
1. The lower explosive limit (LEL) is the minimum percentage of vapor needed for combustion to occur. Percentage below LEL is too lean to burn (unless in an oxidizer-enriched environment).

2. The upper explosive limit (UEL) is the maximum percentage of vapor needed for combustion to occur. Percentage above UEL is too rich to burn (unless in an oxidizer-enriched environment).

3. The range between the LEL and UEL of a flammable gas or vapor is referred to as the explosive or flammable range.

   a. When a Vc in air is found in this range and an ignition source is present, combustion will occur. The ignition source must be as hot as the IT of the vapor or gas in order to ignite it.

   b. The flammable range is the percentage of the vapor or gas in air necessary for combustion to occur.



FLAMMABLE RANGE EXAMPLE

Propane 2.2% to 9.5%

0 10 20 30 40 50 60 70 80 90 100

Acetylene 2.5% to 100%

0 10 20 30 40 50 60 70 80 90 100

Slide 8-29

B. Flammable range example: propane versus acetylene.

1. Propane has an LEL of 2.2% and a UEL of 9.5%.

2. Acetylene has an LEL of 2.5% and a UEL of 100%.

VARIABLES AFFECTING FLAMMABILITY

- Oxygen content.
- Other oxidizers.

Slide 8-30

C. Variables affecting flammability.

1. Oxygen content within the molecule.
    a. Oxygen allows vapors to burn richer.
    b. Alcohols, ethers and aldehydes tend to have wide flammable ranges.
2. Other oxidizers.

ACTIVITY 8.1

Variables Affecting Flammability

Purpose

Identify how physical and chemical properties affect the degree of flammability of a compound.

Directions

1. Working with your group, answer the five questions on the worksheet related to determining the properties that may affect the degree of flammability of a given compound.

2. Identify the highest or lowest, most or least, etc., for each question.

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ACTIVITY 8.1 (cont'd)

Variables Affecting Flammability Worksheet

Question	Highest/most	Lowest/least
1. Regarding MW, which of the following compounds would have the highest degree of flammability? And the lowest? a. Butane. b. Ethylene. c. Benzene. d. Hexane.		
2. Regarding viscosity, which of the following compounds would be the most volatile? And the least volatile? a. 10W-30 motor oil. b. Gasoline. c. Paraffin wax. d. Mineral oil.		
3. Regarding the strength of an oxidizer, which of the following compounds would contribute to combustion? Any of these that would not? a. Potassium permanganate. b. Calcium peroxide. c. Nitrous acid. d. Sodium oxide.		
4. Regarding physical state at ambient temperature, which of the following compounds has the highest Vp? And the lowest? a. Styrene. b. Propane. c. Naphthalene. d. Aluminum oxide.		
5. Regarding Vd, which of the following compounds has the highest? And the lowest? a. Butane. b. Hydrogen peroxide. c. Sulfur dioxide. d. Ammonia.		

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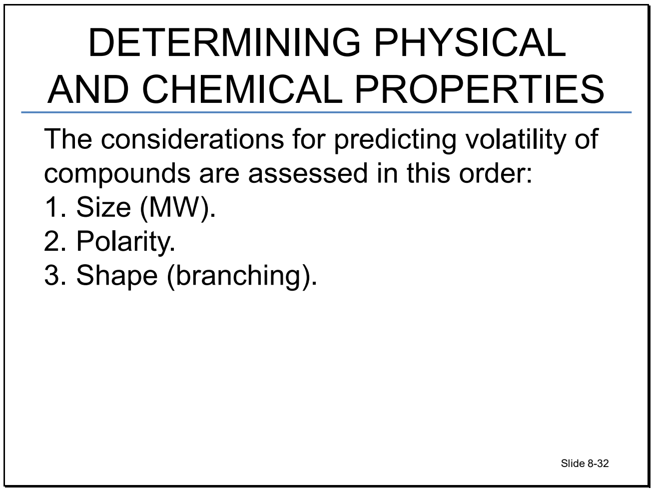
IX. DETERMINING PHYSICAL AND CHEMICAL PROPERTIES



DETERMINING PHYSICAL AND CHEMICAL PROPERTIES

The considerations for predicting volatility of compounds are assessed in this order:

1. Size (MW).
2. Polarity.
3. Shape (branching).

Slide 8-32

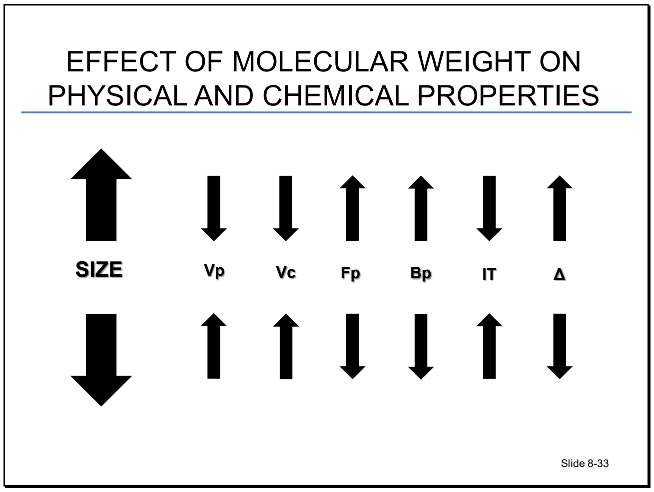
Introduction: The considerations for predicting volatility of compounds are assessed in this order:

A. Size (MW).

B. Polarity.

C. Shape (branching).

X. CONSIDERATION 1: SIZE (MOLECULAR WEIGHT)



EFFECT OF MOLECULAR WEIGHT ON PHYSICAL AND CHEMICAL PROPERTIES

SIZE	Vp	Vc	Fp	Bp	IT	Δ
↑	↓	↓	↑	↑	↓	↑
↓	↑	↑	↓	↓	↑	↓

Slide 8-33

A. Small compound principles: The smaller the compound (AMU):

   1. The more volatile it is. Sometimes referred to as “light” compounds. In other words, it has a low tolerance for heat due to its smaller mass, and so ignites at low temperatures. The lower MW in hydrocarbons are known as light ends. The small sizes give them a higher IT.

   2. The greater the pressure exerted by the vapor against atmospheric pressure. The liquid readily absorbs ambient temperature and liberates vapor easily due to its smaller mass, so it volatilizes easily. This results in **high Vp**.

   3. The higher the volume of vapor that will be liberated at normal atmospheric pressures and temperatures. This is very closely related to Vp. High Vp results in **higher Vc in enclosed areas**.

   4. The harder it is to auto-ignite. With fewer C-H bonds to be affected by oxidation, it is harder to ignite without the presence of an outside ignition source. It takes a lot of energy to create enough friction between these small molecules to create the necessary ignition energy, so small compounds have a **high auto-ignition temperature**.

   5. The lower the heat output in combustion pound for pound. Heat is released every time a chemical bond is broken. With fewer bonds, less heat can be released. Small compounds have **low heat output**, sometimes noted by a delta = Δ.

B. Large compound principles: The larger the compound (AMU):

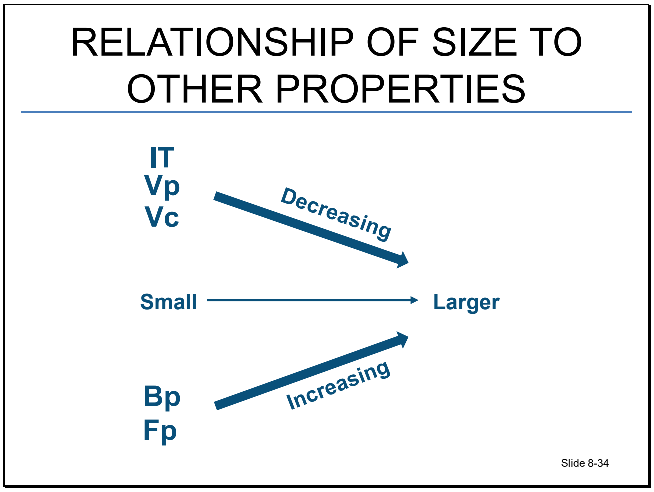
   1. The less volatile it is. Sometimes referred to as “heavy” compounds. These compounds are also viscous with a high resistance to flow, which is a physical sign that they are less volatile. In other words, they have a HIGH tolerance for heat due to their larger mass and volatilize at HIGHER temperatures.

   2. The less pressure exerted by the vapor against atmospheric pressure. The liquid does not readily absorb ambient temperature, and it is difficult to liberate vapor easily due to its larger mass. This results in **low Vp**.

   3. The lower the volume of vapor liberated at normal atmospheric pressures and temperatures. This is related to Vp. Low Vp results in **low Vc**. A large compound will not liberate a lot of vapor at 70°F when they have an Fp well above ambient temperatures.

   4. The easier it is to auto-ignite. With more C-H bonds to be affected by oxidation, it is easier to ignite without the presence of an outside ignition source. It takes less energy to create enough friction between these large molecules to create the necessary ignition energy, so large compounds have **low auto-ignition temperature**.

5. The higher the heat output. Heat is released every time a chemical bond is broken. The more bonds, the more heat can be released. Large compounds have **high heat output**, sometimes noted by a delta = Δ.



RELATIONSHIP OF SIZE TO OTHER PROPERTIES

IT
Vp
Vc

Decreasing

Small → Larger

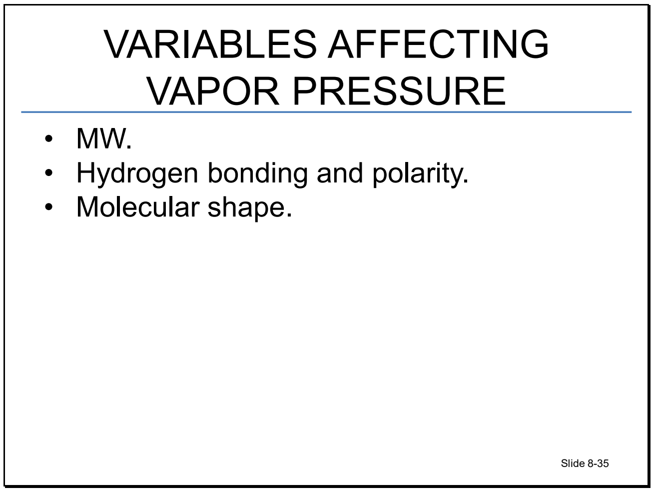
Increasing

Bp
Fp

C. Relationship of size (MW) to Bp, Fp, Vp, Vc, IT and heat output.

1. To illustrate these principles, we draw an "Arrow Chart."

2. This chart visually depicts what is happening to these values as the compared molecules get larger.



VARIABLES AFFECTING VAPOR PRESSURE

- MW.
- Hydrogen bonding and polarity.
- Molecular shape.

D. Variables affecting Vp.

1. MW within hydrocarbon or derivative family:

a. Low MW members have the highest Vp (lighter).

b. High MW members have the lowest Vp (heavier).

2. Hydrogen bonding and polarity:

   a. Hydrogen bonding is the strongest form of intermolecular attraction.

   b. It acts to reduce the degree of molecular movement, lowering the Vp.

   c. Hydrogen-bonded substances have a lower Vp compared to nonpolar or polar substances of the same MW.

   d. MW within a given hydrogen-bonded family is the primary predictor of relative Vp within the family (size).

   e. When both polarity and hydrogen bonding are present, the functional group is known as the carboxyl functional group (COOH).

   f. Found in organic acids (carboxylic) and dicarboxylic acids.

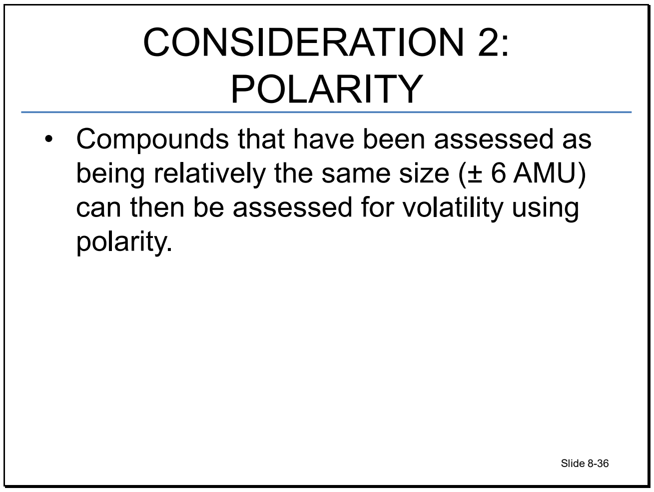
   g. Intermolecular attractions are at their strongest with carbonyl polarity and hydrogen bonding combined.

   h. As a result, Vp is significantly lower.

   i. Carboxyl or dicarboxylic groups also tend to produce solids at relatively low MW.

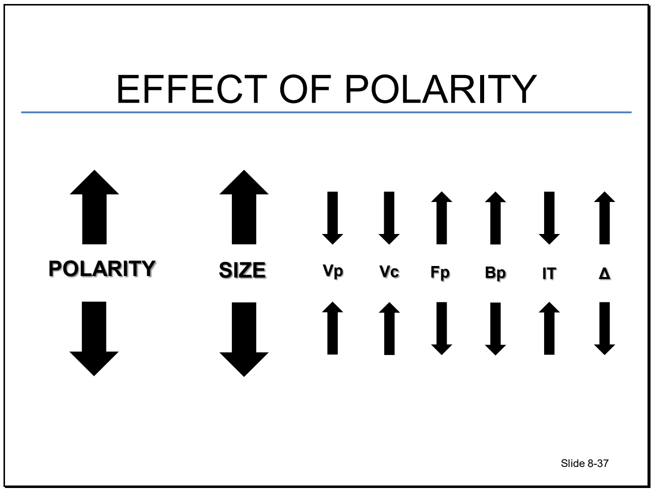
3. Molecular shape.

XI. CONSIDERATION 2: POLARITY



CONSIDERATION 2: POLARITY

- Compounds that have been assessed as being relatively the same size (± 6 AMU) can then be assessed for volatility using polarity.



EFFECT OF POLARITY

POLARITY	SIZE	Vp	Vc	Fp	Bp	IT	Δ
↑	↑	↓	↓	↑	↑	↓	↑
↓	↓	↑	↑	↓	↓	↑	↓

A. Compounds that have been assessed as being relatively the same size (± 6 AMU) can then be assessed for volatility using polarity.

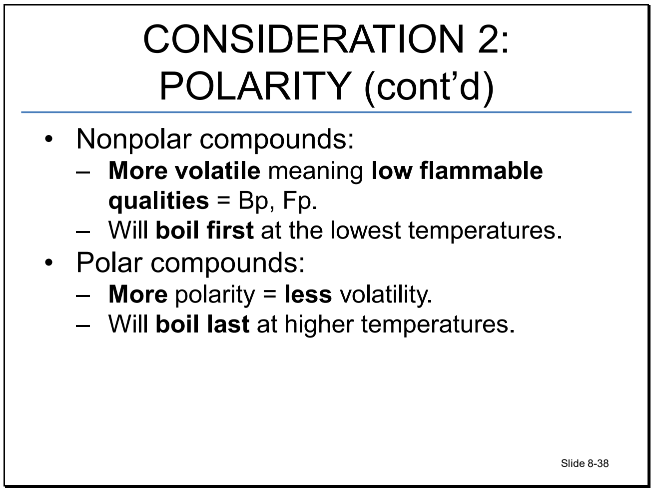
1. Hydrocarbons have no polarity because there are no polar covalent bonds, just H and C, while some hydrocarbon derivatives, such as alcohols and the carboxyl family, are polar.

2. Intermolecular attraction is caused by polarity.

3. Polarity acts to reduce the degree of molecular movement and thus a reduction in the Vp.

4. Polar substances have lower Vp than nonpolar substances of the same MW. The polarity holds the molecule together.

5. MW within a given polar family is the primary predictor of relative Vp within the family (size).



CONSIDERATION 2: POLARITY (cont'd)

- Nonpolar compounds:
  - **More volatile** meaning **low flammable qualities** = Bp, Fp.
  - Will **boil first** at the lowest temperatures.
- Polar compounds:
  - **More** polarity = **less** volatility.
  - Will **boil last** at higher temperatures.

B. Nonpolar compounds.

1. Many, even most, compounds you will encounter will have a hydrocarbon backbone or substituent.

2. When you have a pure compound containing only carbon and hydrogen, the fuel and oil families, then there is no polarity to be considered, and you would then consider branching after size.

3. Hydrocarbons are either saturated, unsaturated, aromatic or mixtures.

    a. Carbon and hydrogen bond together, with neither atom being strong enough to expose positive or negative charges of either nucleus.

    b. So, with no charges to attract each other, they independently exist without linking together; the compounds are said to be nonpolar.

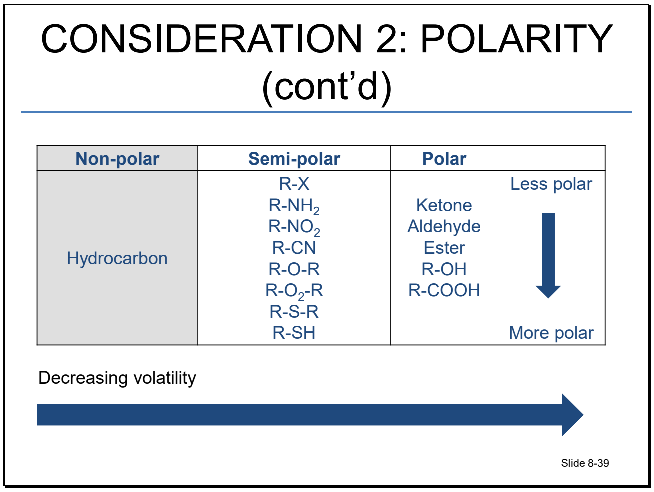
4. Nonpolar compounds do not have the charges that attract the molecules together, so they are easier to liberate from the liquid state and are **more volatile** meaning **low flammable qualities** — low Bp and Fp.

5. We say that nonpolar compounds **boil first** at the lowest temperatures.

C. Polar compounds.

1. When hydrocarbon backbones carry functional groups as substituents to the molecule, they inherit the polarity of the functional group, since the backbone itself has no polarity.

2. The general polarity of the different functional groups has been provided to help you make predictions.



CONSIDERATION 2: POLARITY (cont'd)

Non-polar	Semi-polar	Polar
Hydrocarbon	R-X $R\text{-}NH_2$ $R\text{-}NO_2$ R-CN R-O-R $R\text{-}O_2\text{-}R$ R-S-R R-SH	Less polar Ketone Aldehyde Ester R-OH R-COOH More polar

Decreasing volatility

3. The more polarity a functional group contains, the harder it is (the more energy required) to create vapors in enough quantities to possess volatility. So, **more polarity = less volatility**.

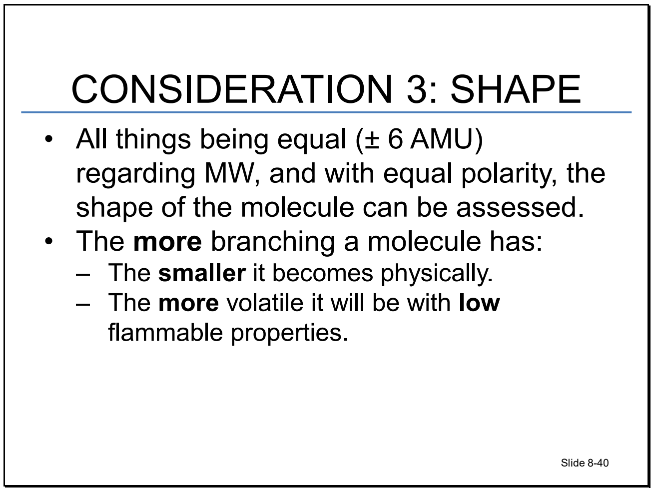
4. In general, the more or less polar functional groups are depicted in the table on the slide. Individual compounds may prove this table inaccurate.

5. Polarity involves the ability for an electronegative element to draw electrons away from other elements in the compound, thus creating a field of negative electrons around that element and exposing the positive nucleus (protons). This provides the molecule with a negative and positive pole, which attract other molecules, creating a polar bond.

6. Compounds with this polar bond require more energy to break the molecules from each other and liberate vapors. So compounds with more polarity, we say, **boil last** at higher temperatures.

7. “Hydrogen bonding,” which is the OH of a molecule, and “carbonyl bonding,” which is the CO in the molecule, both possess strong polarity. Alcohol compounds possessing OH bonding have strong polarity, and organic acids having both OH and CO types of bonding have the strongest polarity.

XII. CONSIDERATION 3: SHAPE



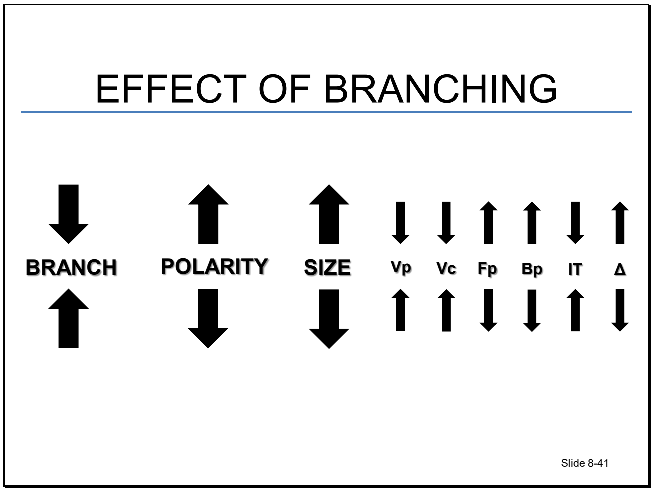
CONSIDERATION 3: SHAPE

- All things being equal (± 6 AMU) regarding MW, and with equal polarity, the shape of the molecule can be assessed.
- The **more** branching a molecule has:
  - The **smaller** it becomes physically.
  - The **more** volatile it will be with **low** flammable properties.

A. Assessing molecular shape.

1. All things being equal (± 6 AMU) regarding MW, and with equal polarity, the shape of the molecule can be assessed.

2. Think of it as being physically smaller and more compact; thus, the molecule has an easier time (requires less energy) being liberated from the liquid state into vapor.



EFFECT OF BRANCHING

↓	↑	↑	↓	↓	↑	↑	↓	↑
BRANCH	**POLARITY**	**SIZE**	**Vp**	**Vc**	**Fp**	**Bp**	**IT**	**Δ**
↑	↓	↓	↑	↑	↓	↓	↑	↓

Slide 8-41

3. The **more branching** a molecule has, the **smaller** it becomes physically, and thus is considered **more volatile** with **low flammable properties**.

    a. Example: Octane, a long chain molecule, has an Fp of 56°F (13.3°C), where iso-octane (same size and polarity), being branched, has an Fp of 40°F (4.4°C).

    b. It takes less energy to liberate iso-octane vapors, and so it is considered **more** volatile than normal octane.

B. Summary of considerations.

1. When making predictions regarding the volatility of a compound based on **size, polarity and branching**, you should be able to make assessments without the benefit of having a database with definitive values.

2. This is a skill that a technical specialist — hazardous materials research will develop, so that initial decisions can be made based solely on the relationships between physical state, viscosity, ambient temperatures, the compound, the functional group and the circumstances of the release.

ACTIVITY 8.2

Effect of Size, Polarity and Shape on Physical and Chemical Properties

Purpose

Determine the effect of varying size, polarity and shape on a compound with regard to that compound's physical and chemical properties.

Directions

1. Working with your group, complete each worksheet:
   a. Effect of Size (Molecular Weight) Worksheet.
   b. Effect of Polarity Worksheet.
   c. Effect of Shape Worksheet.
2. Research and find the required data for each material.
3. Come to a consensus on ranking the materials from the lowest Bp, etc., to the highest on a scale from 1 (lowest) to 5 (highest). Rank Vc as "no," "low" or "high" based on its relationship to the Vp.
   a. < 25 mmHg: NO.
   b. < 100 mmHg: LOW.
   c. > 100 mmHg: HIGH.
4. When the data is not immediately known, fill in the table with your predictions.
5. Select a representative for your group to share your findings.

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ACTIVITY 8.2 (cont'd)

Effect of Size (Molecular Weight) Worksheet

No.	Compound	Formula	MW	Bp ranking	Fp ranking	Vp ranking	Vc ranking	IT (°F) ranking
1	Methane							
2	Butane							
3	Propane							
4	Octane							
5	Hexane							

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ACTIVITY 8.2 (cont'd)

Effect of Polarity Worksheet

No.	Compound	Formula	NP/P	MW	Bp ranking	Fp ranking	Vp ranking	Vc ranking	IT (°F) ranking
1	Acetic acid								
2	Trimethyl amine								
3	Propanal								
4	Butane								
5	Propanol								

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ACTIVITY 8.2 (cont'd)

Effect of Shape Worksheet

No.	Compound	Formula	MW	Bp ranking	Fp ranking	Vp ranking	Vc ranking	IT (°F) ranking
1	Secondary butanol							
2	Isobutyl alcohol							
3	Butanol							
4	Tertiary butanol							
5	Neopentane							

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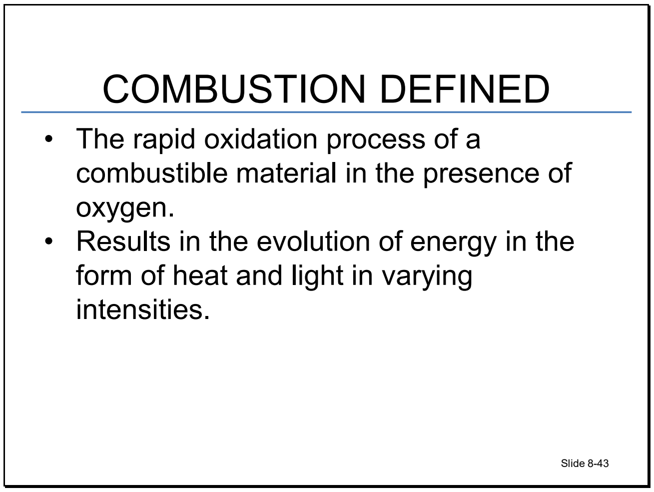
XIII. COMBUSTION

A. Overview.

1. This section explores the process of combustion, including its definition and chemical reaction. It also describes the byproducts of combustion, heat output and flammability of the various functional groups.

2. Due to the frequency of flammable or combustible hazardous materials releases, the understanding of the combustion process and how to defeat it is critical.



COMBUSTION DEFINED

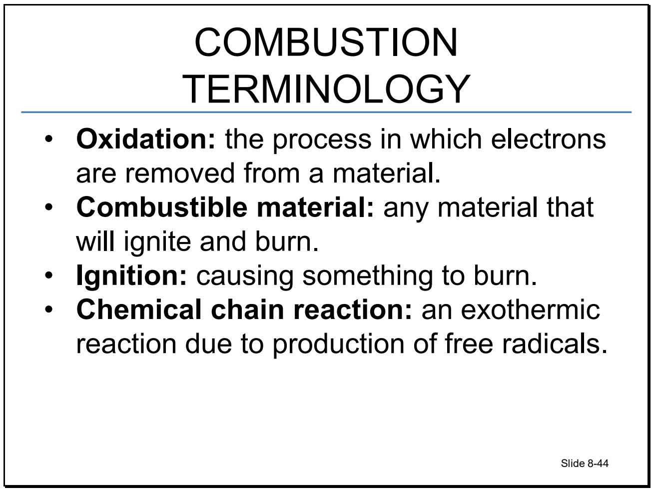
- The rapid oxidation process of a combustible material in the presence of oxygen.
- Results in the evolution of energy in the form of heat and light in varying intensities.

B. Definition: The rapid oxidation process of a combustible material in the presence of oxygen. Once ignited, will result in the evolution of energy in the form of heat and light in varying intensities.

Table 8.4: Most frequently released flammable/combustible liquids (2021)

Hazard division	Hazard class	Incidents	Hospitalized	Non-hospitalized	Fatalities	Damage
3	Flammable — combustible liquid	11,525	1	8	2	$16,455,285
8	Corrosive material	7,870	3	12	0	$8,545,783
5.1	Oxidizer	1,751	0	2	0	$1,100,138
9	Miscellaneous hazardous material	760	0	0	0	$5,741,712
2.2	Nonflammable compressed gas	401	0	1	0	$41,855
6.1	Poisonous materials	372	0	0	0	$848,358
5.2	Organic peroxide	225	0	0	0	$528,571
2.2	Flammable gas	134	0	0	0	$4,500
2.1	Flammable gas	123	0	0	0	$4,201,158
4.1	Flammable solid	76	0	0	0	$6,265,315

Source: https://www.fmcsa.dot.gov/regulations/hazardous-materials/incident-spill-reporting-preventions



COMBUSTION TERMINOLOGY

- **Oxidation:** the process in which electrons are removed from a material.
- **Combustible material:** any material that will ignite and burn.
- **Ignition:** causing something to burn.
- **Chemical chain reaction:** an exothermic reaction due to production of free radicals.

Slide 8-44

C. Oxidation.

1. The process in which electrons are removed from a material.

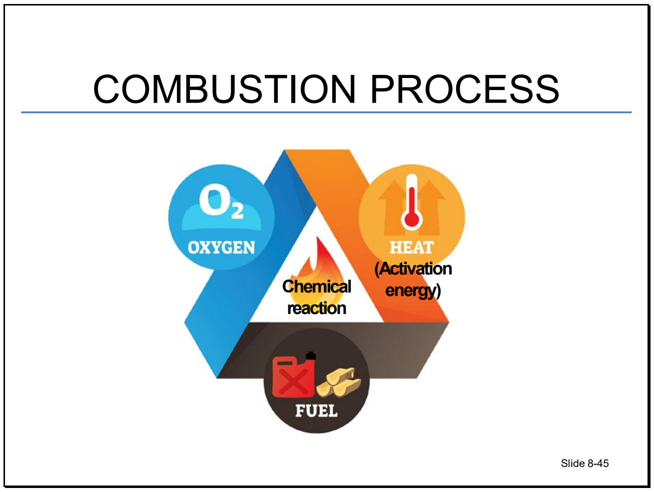
2. Any process in which oxygen combines with an element or material.

3. Rapid oxidation occurs in the presence of 20.9% oxygen in air.
    a. Fire.
    b. A chemical reaction.

D. Combustible material.
    1. Any material that will ignite and burn.
    2. Fuel.

E. Ignition.
    1. Causing something to burn.
    2. Heat input begins the oxidation reaction.
    3. Any ignition source for flammable and combustible products must be at least as hot as the IT of that product or it will not have enough energy to ignite it.

F. Chemical chain reaction:
    1. An exothermic chemical reaction due to the production of free radicals.
    2. Free radicals: electrically charged, highly reactive parts of molecules.
    3. A small amount of energy is released every time a chemical bond is broken. Enough bonds break to cause ignition and maintain combustion as long as the bonds are still being broken — or the combustible fuel is still being decomposed by the reaction.
    4. Free radicals combine with oxygen or with the elements that form the fuel material producing intermediate combustion products (new substances) and even more free radicals and increasing the speed of the oxidation reaction.



COMBUSTION PROCESS

Slide 8-45

G. The combustion process.

Oxidation reduction reaction:

1. The fuel is the reducing agent (solid, liquid, gas).

2. Oxygen, in its many forms, is the oxidizing agent. Oxidizers added to the reaction or oxidizing elements in the molecule contribute to the speed, temperature and brightness of the heat and light. Oxidizers will also widen a flammable range making it easier to ignite.

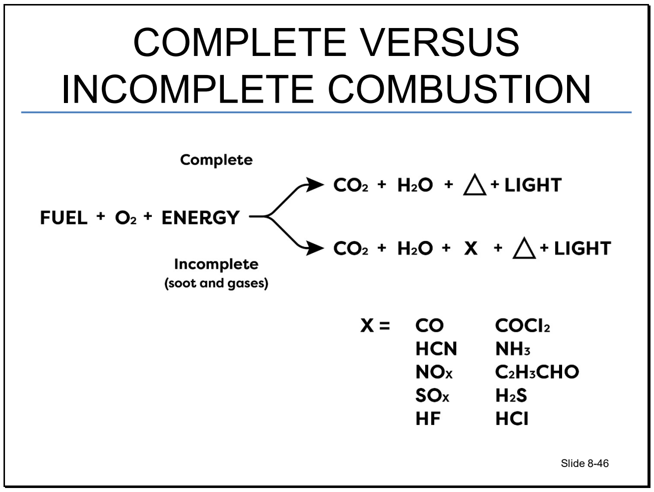
3. Initiated by heat of ignition.

4. Must be above the fuel's IT.

5. Once ignited, a chemical chain reaction begins.

    a. Formulation of free radicals: molecules unsatisfied and reactive with other radicals.

    b. Unpaired electrons ("free"): somewhat stable at lower temperatures, becoming more unstable at higher temperatures.



COMPLETE VERSUS INCOMPLETE COMBUSTION

Complete

$FUEL + O_2 + ENERGY \rightarrow CO_2 + H_2O + \Delta + LIGHT$

$\rightarrow CO_2 + H_2O + X + \Delta + LIGHT$

Incomplete
(soot and gases)

X = CO $COCl_2$
HCN NH_3
NO_x C_2H_3CHO
SO_x H_2S
HF HCl

Slide 8-46

6. Products of the complete combustion process.

   a. The oxygen and fuel are in balance (excellent fuel source and plenty of available oxygen).

   b. Carbon dioxide.

   c. Water.

   d. Heat and light.

   e. Little or no visible smoke.

7. Products of the incomplete combustion process:

   a. The oxygen and fuel are unbalanced (poor fuel or insufficient oxygen).

   b. Carbon monoxide.

   c. Free carbon — soot.

   d. Thick visible smoke/polycyclic aromatic hydrocarbons (PAHs).

   e. Water.

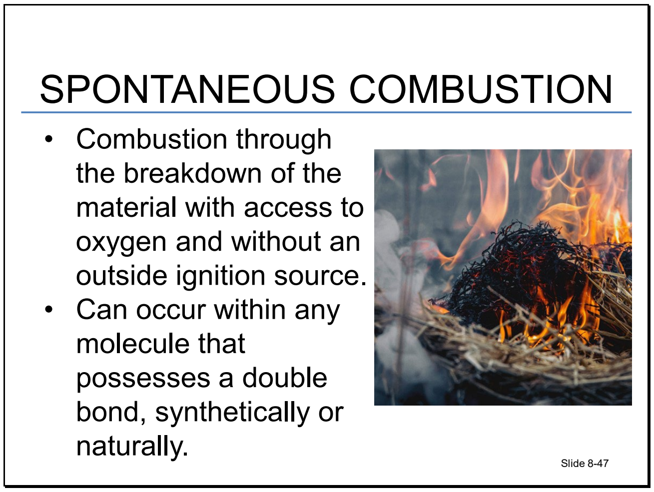
   f. Toxic gases.

      Materials that are common:

      - CO — carbon monoxide.

- $COCl_2$ — phosgene.
- HCN — hydrogen cyanide.
- Many aldehydes (especially formaldehyde, a confirmed carcinogen); acrolein (acrylaldehyde).
- NOx and SOx (oxides of nitrogen and sulfur).
- Acid gases (hydrogen + halons).

8. Reduced amount of heat and light.



SPONTANEOUS COMBUSTION

- Combustion through the breakdown of the material with access to oxygen and without an outside ignition source.
- Can occur within any molecule that possesses a double bond, synthetically or naturally.

H. Spontaneous combustion.

1. Combustion through the breakdown of the material with access to oxygen and without an outside ignition source. Internal heat provides the ignition through the breakdown of molecular bonds.

2. Usually organic materials (e.g., hay, straw, coal).

   a. Can be esters, aldehydes and ethers.

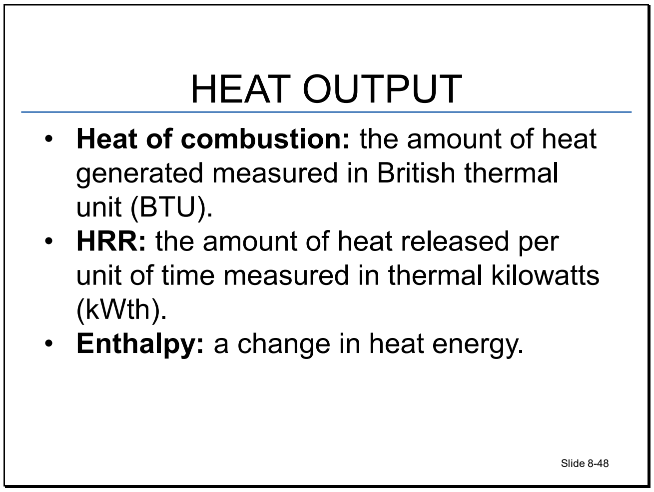
   b. Biodiesel production and turpentine are two common examples.

   c. Large animal/vegetable oils such as linseed, whale oil, soybean oil or cottonseed oils.

3. Can occur within any molecule that possesses a double bond synthetically or naturally. These double bonds slowly react with oxygen until enough heat is created to produce ignition.

4. Sometimes called Slow Oxidation Potential.

5. Typically, these materials have low ITs and readily react with available oxygen.



HEAT OUTPUT

- **Heat of combustion:** the amount of heat generated measured in British thermal unit (BTU).
- **HRR:** the amount of heat released per unit of time measured in thermal kilowatts (kWth).
- **Enthalpy:** a change in heat energy.

Slide 8-48

I. Heat output.

1. Heat of combustion:

   a. The amount of heat generated.

   b. Measured in British thermal units (BTUs): The amount of energy required to raise the temperature of one pound of water one degree Fahrenheit.

   c. More or less heat energy is released depending on the fuel makeup.

2. HRR:

   a. The amount of heat released per unit of time.

   b. Measured in thermal kilowatts (kWth).

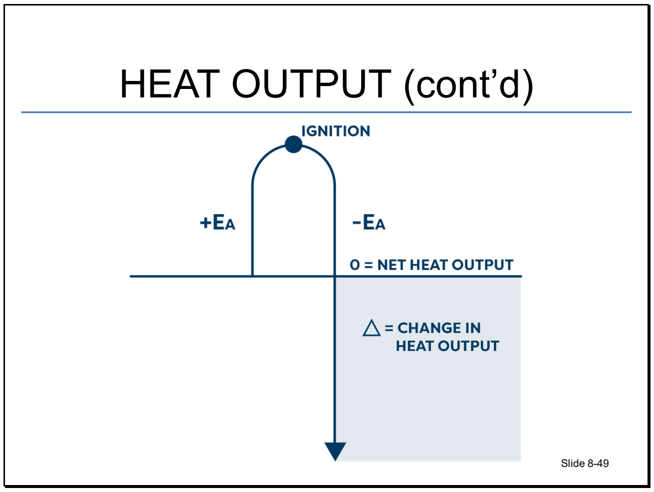
      - Thermal watts (Wth); kWth: 1,000 W; megawatts (MWth): 1 million W.

      - Thermal energy (th), not electrical.

      - 1 watt = 1 joule/second (J/s).

   c. The amount of power (energy) being generated by a material.

d. The higher the oxygen concentration, the more available the oxygen in the combustion process = higher HRR.



HEAT OUTPUT (cont'd)

3. Enthalpy: change in heat energy.

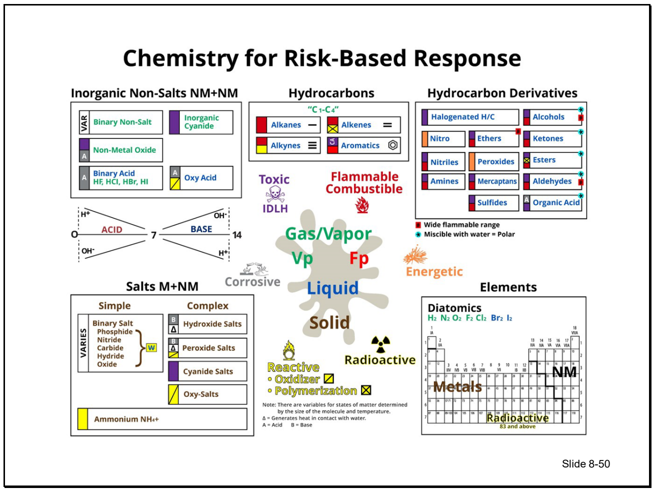
   a. Activation energy (+Ea) is the energy of ignition put into the process to begin the reaction (ignition).

   b. The reaction begins (at ignition), and the fuel is consumed and produces energy (HRR).

   c. The process gives back the energy (-Ea) that was required to initiate the process, and any energy produced after that is a measure of the fuel's efficiency or change in energy output which is enthalpy.

      - The efficiency of a fuel is that fuel's ability to give back more energy than it took to ignite it.

      - Example: Fuel A took 4,000 BTU to ignite, and after ignition produced 6,000 BTU of energy. This produced an overall net change of 2,000 BTU.



Chemistry for Risk-Based Response

Inorganic Non-Salts NM+NM

VAR Binary Non-Salt

Inorganic Cyanide

A Non-Metal Oxide

A Binary Acid HF, HCl, HBr, HI

A Oxy Acid

Hydrocarbons

"C_1-C_4"

Alkanes —

Alkenes =

Alkynes ≡

CA Aromatics ⌬

Hydrocarbon Derivatives

Halogenated H/C

Alcohols

Nitro

Ethers

Ketones

Nitriles

Peroxides

Esters

Amines

Mercaptans

Aldehydes

Sulfides

A Organic Acid

■ Wide flammable range

✱ Miscible with water = Polar

H^+ ACID 0 7 BASE 14 OH^- OH^- H^+

Toxic IDLH

Flammable Combustible

Gas/Vapor

Vp

Fp

Liquid

Solid

Corrosive

Energetic

Radioactive

Reactive
- Oxidizer ◪
- Polymerization ☒

Note: There are variables for states of matter determined by the size of the molecule and temperature.
Δ = Generates heat in contact with water.
A = Acid B = Base

Salts M+NM

Simple

VARIES Binary Salt
Phosphide
Nitride
Carbide
Hydride
Oxide
} W

Complex

B Δ Hydroxide Salts

B Δ Peroxide Salts

Cyanide Salts

Oxy-Salts

Ammonium NH_4^+

Elements

Diatomics

H_2 N_2 O_2 F_2 Cl_2 Br_2 I_2

NM

Metals

Radioactive
83 and above

J. Combustibility attributes of the families.

1. Salts: will not burn, although some will support combustion if an oxidizing salt.

    a. Binary salts.

    b. Metal oxides.

    c. Hydroxide salts.

    d. Peroxide salts (oxidizers).

    e. Cyanide salts.

    f. Ammonium compounds.

    g. Oxysalts (oxidizers).

2. Hydrocarbons: will burn; provide the flammable or combustible backbone of the hydrocarbons derivatives.

    a. Alkanes.

    b. Alkenes.

    c. Alkynes.

    d. Aromatics.

3. Hydrocarbon derivatives: may burn; combustibility of the family varies among different elements.

    a. Alkyl halide.

    b. Amine.

    c. Nitro.

    d. Organic cyanide.

    e. Ether.

    f. Organic peroxide.

    g. Ketone.

    h. Aldehyde.

    i. Ester.

    j. Sulfide.

    k. Mercaptan.

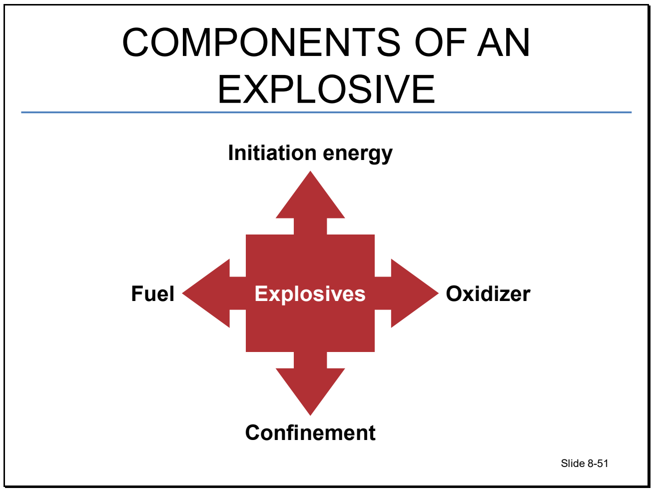
    l. Organic acid.

    m. Alcohol.

XIV. ENERGETIC MATERIALS

A. Energetic materials are also known as explosive materials (those capable of creating an explosion). These materials undergo extremely rapid decomposition.

B. Definition of an explosion: a high-speed oxidation reaction resulting in the release of energy and tremendous amounts of gas to perform some form of work.



COMPONENTS OF AN EXPLOSIVE

Initiation energy

Fuel

Explosives

Oxidizer

Confinement

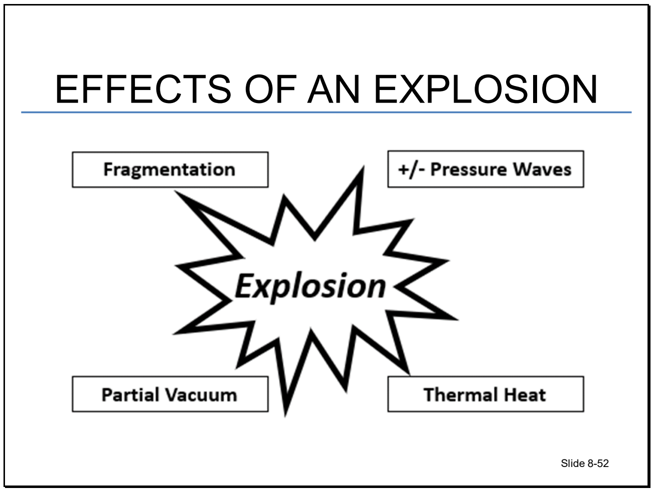
C. Four components of an explosive.

1. Initiation energy: Must be sufficient energy input to begin the process of instantaneous combustion.

2. Oxidizer: The oxygen in air (20.9%) is not sufficient to support the combustion process. Oxidizers must be mixed with the fuels to support the speed of the reaction.

3. Fuel: The combustible material which is reduced by the reaction.

4. Confinement: Provides the energy feedback which intensifies the explosion reaction. The strength of the "container" plays a role in the amplification of the reaction.



EFFECTS OF AN EXPLOSION

Fragmentation

+/- Pressure Waves

Explosion

Partial Vacuum

Thermal Heat

D. Effects of an explosion.

1. Chemical reactions are considered to be the conversion of reactants to products (expressed as “reactants” → “products”).

2. Internal energy stored within the bonds of reactants and products differ.

3. If the internal energy of the products is less than the reactants, then the reaction is exothermic.

4. If the internal energy of the products is greater than the reactants, then the reaction is endothermic; therefore, energy has been added.

5. Types of oxidation reactants:

    a. Fuel-oxidizer mixtures.

    b. Mixtures of compounds: one serving as the fuel and the second serving as the oxidizer.

E. Also called binary explosives.

1. NH_4NO_3 + fuel oil.

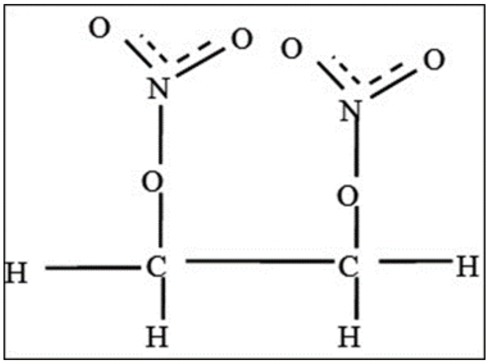
2. $NH_4NO_3 + CH_3NO_3$ (commonly seen as a chempac™ — a common binary explosive).

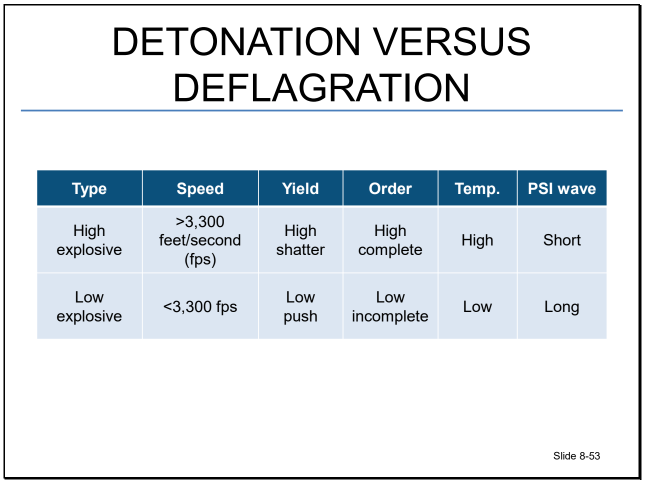
3. Fuel oils are heavy mixtures and consist of hydrocarbon backbones of around 15 or more carbons.

4. Fuel/oxidizer within the same molecule.

5. An example of this type of explosive is nitroglycol $(CH_2)_2(NO_3)_2$.

Figure 8.1: Nitroglycol

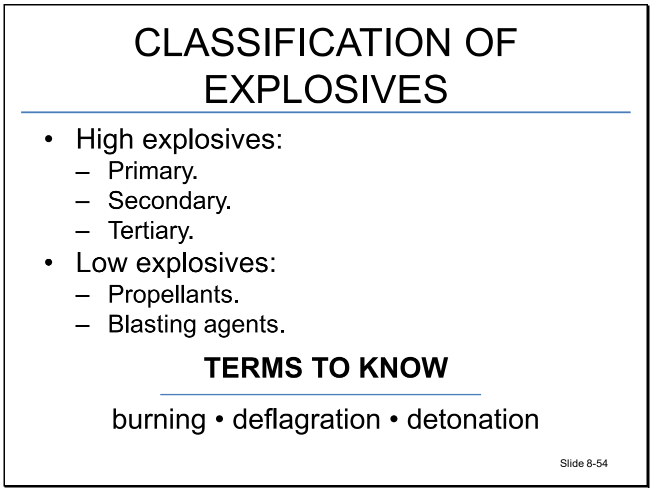




DETONATION VERSUS DEFLAGRATION

Type	Speed	Yield	Order	Temp.	PSI wave
High explosive	>3,300 feet/second (fps)	High shatter	High complete	High	Short
Low explosive	<3,300 fps	Low push	Low incomplete	Low	Long

F. Detonation versus deflagration.



CLASSIFICATION OF EXPLOSIVES

- High explosives:
  - Primary.
  - Secondary.
  - Tertiary.
- Low explosives:
  - Propellants.
  - Blasting agents.

TERMS TO KNOW

burning • deflagration • detonation

G. Classification of explosives.

1. High explosives. Primarily detonate and can be further subdivided into primary (initiators), secondary or tertiary explosives, depending on their sensitivity to initiation.

   a. Primary or initiators: can be made to detonate very easily.

   b. Secondary:

      - Do not progress from rapid burning to detonation.
      - Generally, cannot be initiated with electrostatic discharges.
      - Require shock waves to propagate ignition.

c. Tertiary. Insensitive high explosives.

2. Low explosives:

    a. Pyrotechnics: Greek for “manipulation of fire.”

    b. Propellants.

    c. Produce gas to perform mechanical work.

    d. Small- and large-bore guns and rocket propellants.

    e. Blasting agents.

3. Burning, deflagration and detonation:

    a. Magnitudes of speed <1,125 feet/second (fps).

    b. All explosives burn.

    c. Deflagration: a very rapid autocombustion as a surface phenomenon.

        - Burning rates occur at below 3,300 fps.

        - The term deflagration also refers to the ability to move from a deflagration-to-detonation transition (DDT).

        - Deflagration produces a pushing type of pressure wave.

    d. Detonation: almost instantaneous combustion rate.

        - Much faster; almost instantaneous.

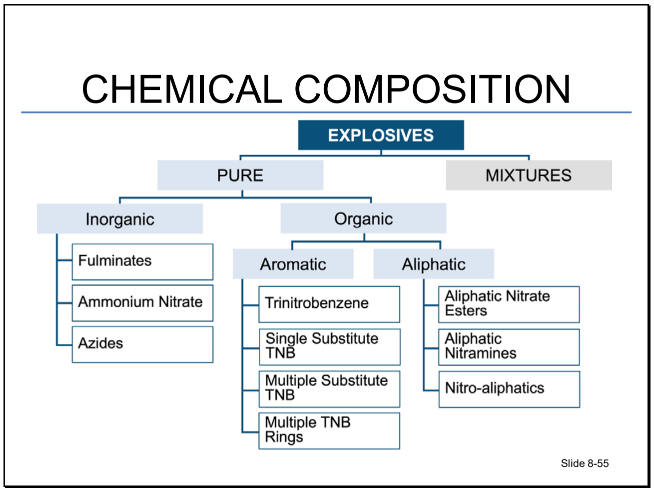
        - Burning rates occur at above 3,300 fps. Some up to 28,000 fps.

        - Detonation rates and pressure waves will produce a shattering type of effect.

    e. Rate of reaction depends on:

        - Geometry of the material (size, shape, surface area).

        - Molecular makeup — bonding strain and oxygen balance.



CHEMICAL COMPOSITION

EXPLOSIVES

- PURE
  - Inorganic
    - Fulminates
    - Ammonium Nitrate
    - Azides
  - Organic
    - Aromatic
      - Trinitrobenzene
      - Single Substitute TNB
      - Multiple Substitute TNB
      - Multiple TNB Rings
    - Aliphatic
      - Aliphatic Nitrate Esters
      - Aliphatic Nitramines
      - Nitro-aliphatics
- MIXTURES

H. Chemical composition of explosives.

1. Inorganic explosives.

   a. Fulminate salts ($M + (CNO)^{-1}$).

      - Mercury II fulminate ($Hg(CNO)_2$) is an older explosive and is one of the first inorganic explosives created.
      - Silver fulminate ($AgCNO$).

   b. Ammonium nitrate (NH_4NO_3).

      - In itself is actually a poor explosive and is over-oxidized.
      - Very hard to initiate.
      - When mixed with other explosives or fuels, it is much more effective.

   c. Azides ($M + (N_3)^{-1}$):

      - Lead II azide (PbN_6).
      - Silver azide (AgN_3).
      - Sodium azide (NaN_3). This is a propellant used in airbag activators.
      - Azides are mostly solids and are extremely sensitive.

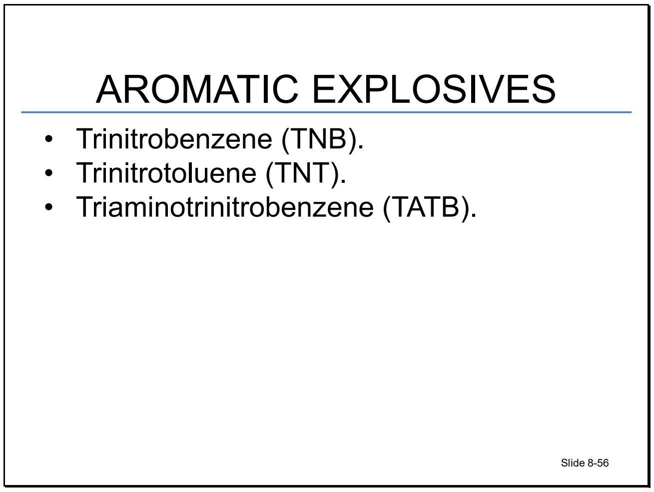
2. Organic explosives.

   a. Most common of all explosives.

   b. Aromatic explosives are based on the resonant bonded benzene ring.

   c. Aliphatic explosives are those organic explosives not formed by aromatics.

   d. Notice the formulas are full of CHNO elements.



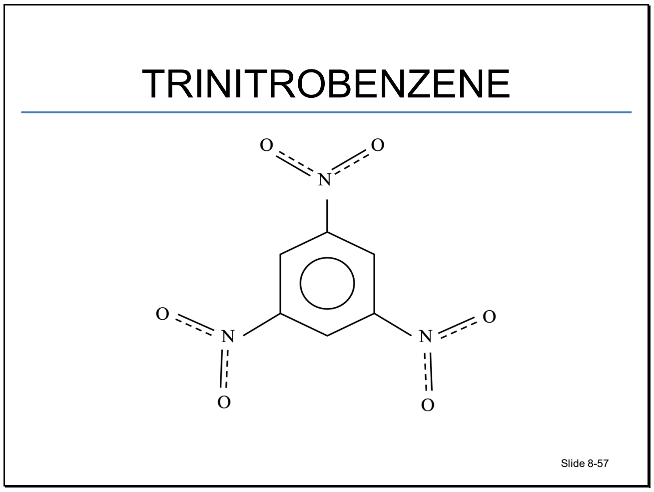
AROMATIC EXPLOSIVES

- Trinitrobenzene (TNB).
- Trinitrotoluene (TNT).
- Triaminotrinitrobenzene (TATB).

3. Aromatic explosives.

   a. Nitrated benzene ring (generally three nitro groups).

      - All solid, crystalline materials.

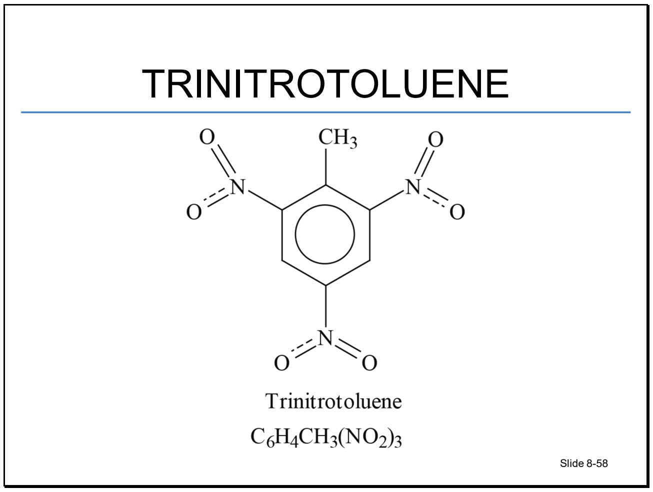


TRINITROBENZENE

- Trinitrobenzene (TNB) is the basic starting point, and three types of aromatic explosives are created from there.

b. Singly substituted TNB.

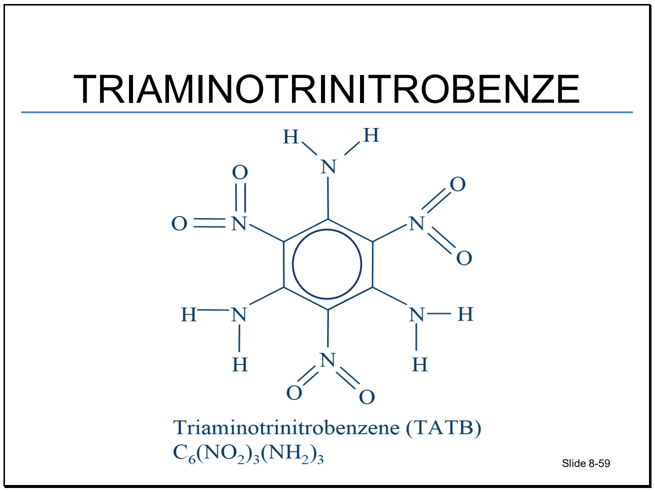
- The TNB has one hydrogen replaced with an additional functional group.



TRINITROTOLUENE

Trinitrotoluene

$C_6H_4CH_3(NO_2)_3$



TRIAMINOTRINITROBENZE

Triaminotrinitrobenzene (TATB)

$C_6(NO_2)_3(NH_2)_3$

- Example: Trinitrotoluene (TNT) — $C_6H_2CH_3(NO_2)_3$.

- Various other items can be added to the TNB molecule to create other explosives, such as chlorine (-Cl), organic acids (-COOH) or an amine functional group ($-NH_2$), to name a few.

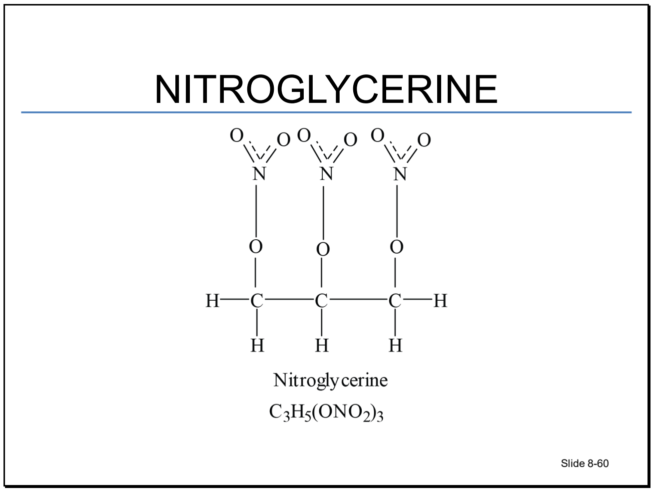
c. Multiple substituted TNB has two or more substituted groups.

d. Multiple TNB rings. These tend to be very specialized but stable explosives.

4. Aliphatic explosives: nitrate esters.

a. Overview:

- First mass-produced explosives.
- Most common aliphatic explosives.
- Nitrate group — O-NO_2.
- Tend to be very sensitive to impact due to moderate to high Vps.
- Oily insoluble liquids.

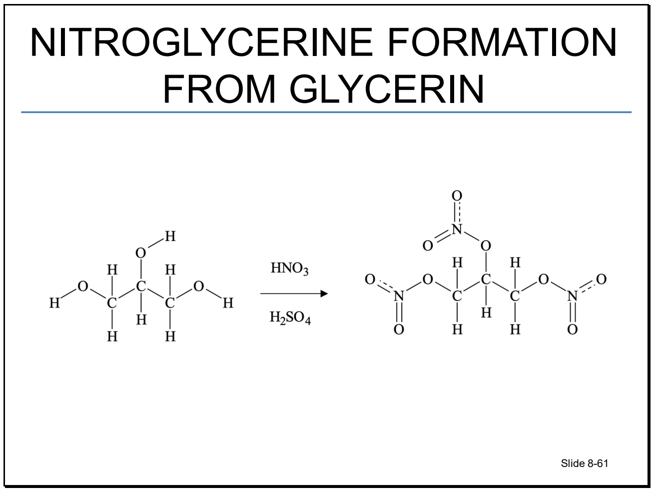


NITROGLYCERINE

Nitroglycerine

$C_3H_5(ONO_2)_3$

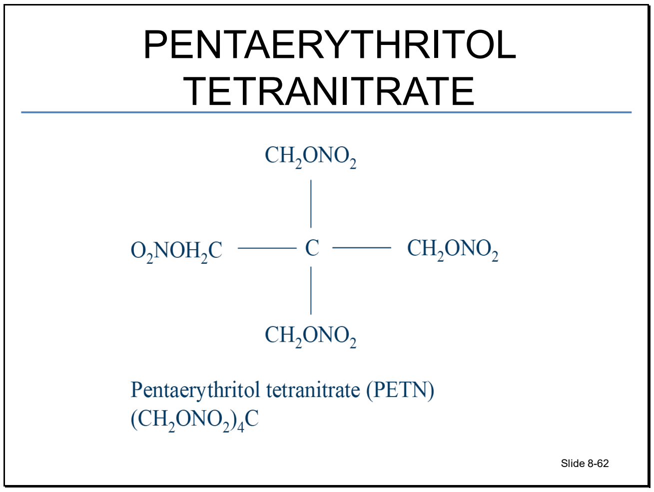
Slide 8-60



NITROGLYCERINE FORMATION FROM GLYCERIN

Slide 8-61

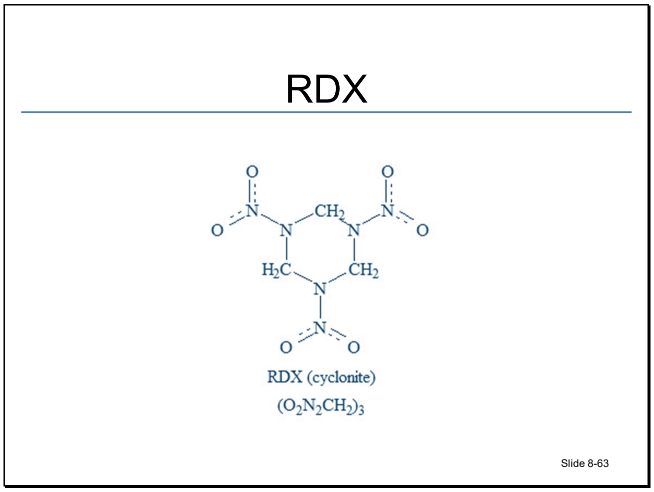
- Nitroglycerine is made by nitrating glycerine $C_3H_5(OH)_3$.



PENTAERYTHRITOL TETRANITRATE

Pentaerythritol tetranitrate (PETN)
$(CH_2ONO_2)_4C$

- Pentaerythritol tetranitrate (PETN).



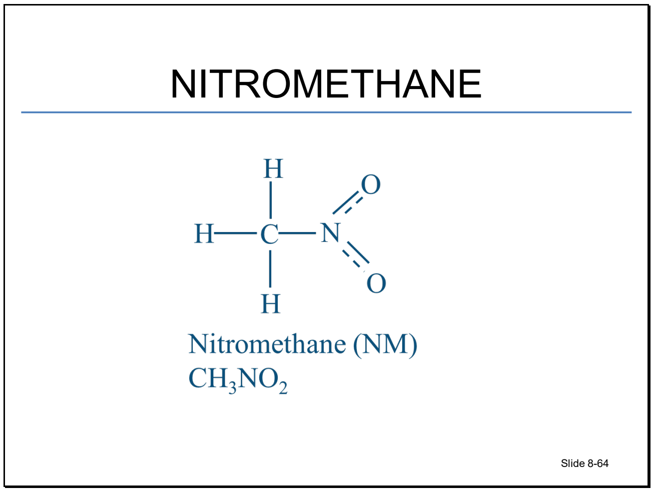
RDX

RDX (cyclonite)
$(O_2N_2CH_2)_3$

- Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX).

b. Nitro-aliphatic:

- NO_2.
- Nitro group bonded directly to the carbon. Does not bond through the oxygen as in the nitrates or through the nitrogen as do the nitramines.



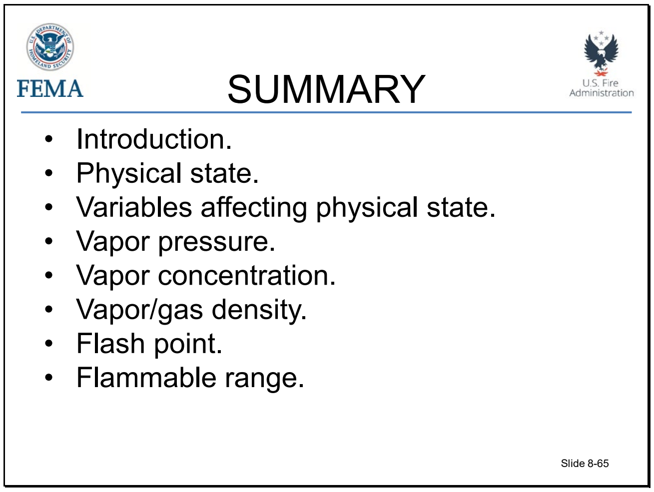
NITROMETHANE

Nitromethane (NM)
CH_3NO_2

Slide 8-64

- Example: NM CH_3NO_2.

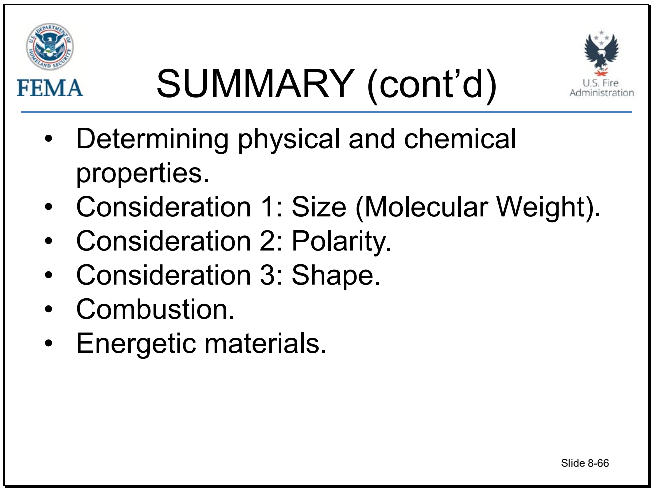
XV. SUMMARY



SUMMARY

- Introduction.
- Physical state.
- Variables affecting physical state.
- Vapor pressure.
- Vapor concentration.
- Vapor/gas density.
- Flash point.
- Flammable range.

Slide 8-65



SUMMARY (cont'd)

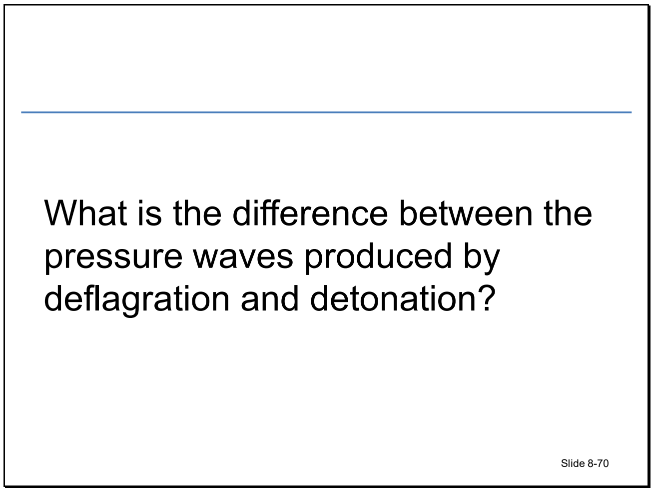
- Determining physical and chemical properties.
- Consideration 1: Size (Molecular Weight).
- Consideration 2: Polarity.
- Consideration 3: Shape.
- Combustion.
- Energetic materials.

Slide 8-66

What is the significance of knowing a product’s physical and chemical properties? How would you apply this in an incident?

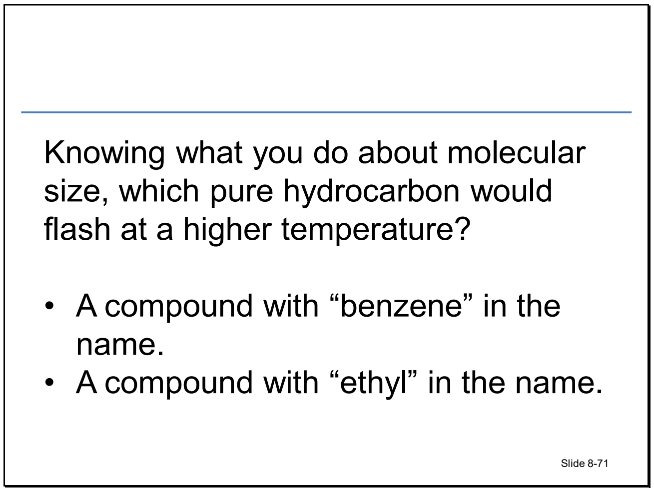
How is a product’s viscosity related to its volatility?

What are the effects of MW, polarity and branching on a compound’s physical and chemical properties?



What is the difference between the pressure waves produced by deflagration and detonation?

Slide 8-70



Knowing what you do about molecular size, which pure hydrocarbon would flash at a higher temperature?

- A compound with “benzene” in the name.
- A compound with “ethyl” in the name.

Slide 8-71

APPENDIX

CENTIGRADE FAHRENHEIT CONVERSION TABLE

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Centigrade Fahrenheit Conversion Table

Centigrade °C (°F - 32) x 0.56	Fahrenheit °F (°C x 1.8) +32	Significant temperatures and common reference points
-250	-418	
-225	-373	
-200	-328	
-175	-283	
-150	-238	
-129	-200	Cryogenic
-125	-193	
-100	-148	
-80	-112	
-60	-76	
-40	-40	
-30	-22	
-20	-4	
-10	14	
0	32	Water freezes
5	41	
10	50	
15	59	
20	68	Common reference temperature
25	77	
30	86	
35	95	
40	104	100°F = National Fire Protection Association (NFPA) flammable/combustible Flash point (Fp)
45	113	
50	122	
55	131	
60	140	140°F = U.S. Department of Transportation (DOT) flammable/combustible Fp
65	149	
70	158	
75	167	
80	176	
85	185	
90	194	
95	203	
100	212	Water boils
110	230	
120	248	
130	266	
140	284	
150	302	
175	347	
200	392	

UNIT 9:
RADIOACTIVITY

TERMINAL OBJECTIVE

The students will be able to:

9.1 Analyze the hazards of ionizing radiation to determine protective measures.

ENABLING OBJECTIVES

The students will be able to:

9.1 Identify isotopes and radioactive elements.

9.2 Identify three common forms of ionizing radiation.

9.3 Analyze ionizing radiation by comparing and contrasting units of measure.

9.4 Apply the concepts of safety for ionizing radiation.

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FEMA

U.S. Fire Administration

UNIT 9:
RADIOACTIVITY

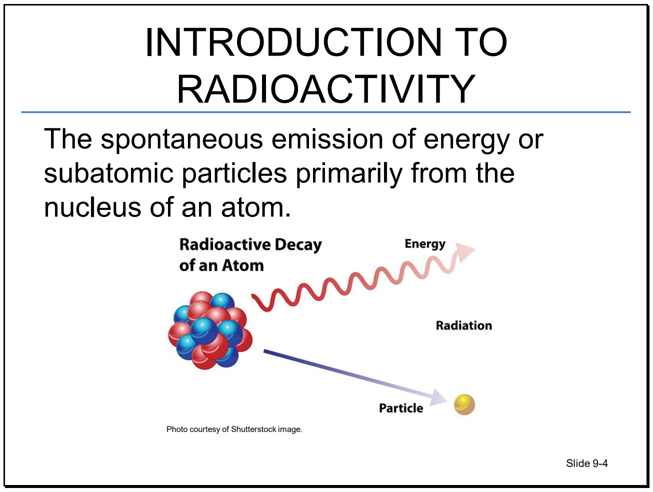
TERMINAL OBJECTIVE

Analyze the hazards of ionizing radiation to determine protective measures.

ENABLING OBJECTIVES

- Identify isotopes and radioactive elements.
- Identify three common forms of ionizing radiation.
- Analyze ionizing radiation by comparing and contrasting units of measure.
- Apply the concepts of safety for ionizing radiation.

I. INTRODUCTION TO RADIOACTIVITY



INTRODUCTION TO RADIOACTIVITY

The spontaneous emission of energy or subatomic particles primarily from the nucleus of an atom.

Photo courtesy of Shutterstock image.

A. Radioactivity.

1. Definition: The spontaneous emission of energy or subatomic particles primarily from the nucleus of an atom.

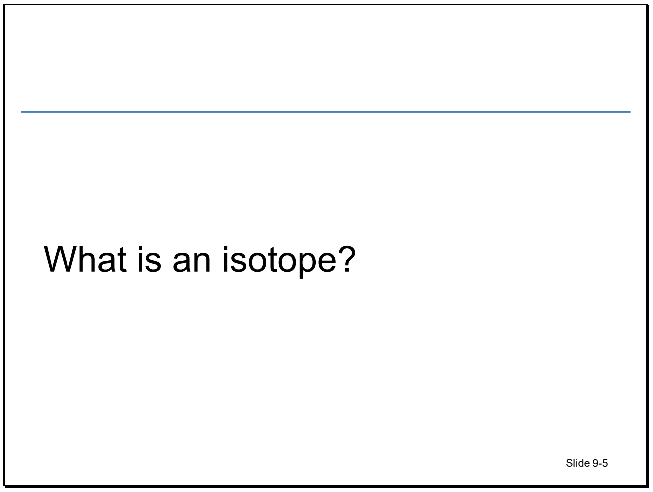
2. Our concern is the development of “ionizing” radiation.

    a. This refers to the ability of the radiation to ionize chemical compounds resulting in chemical changes.

    b. Ionization, if you recall, is the development of charged materials (elements or molecules). It is the process by which an atom or a molecule acquires a negative or positive charge by gaining or losing electrons.

3. An unstable nucleus will decompose or “decay” to maintain a stable proton-to-neutron ratio.

B. Isotope.



What is an isotope?

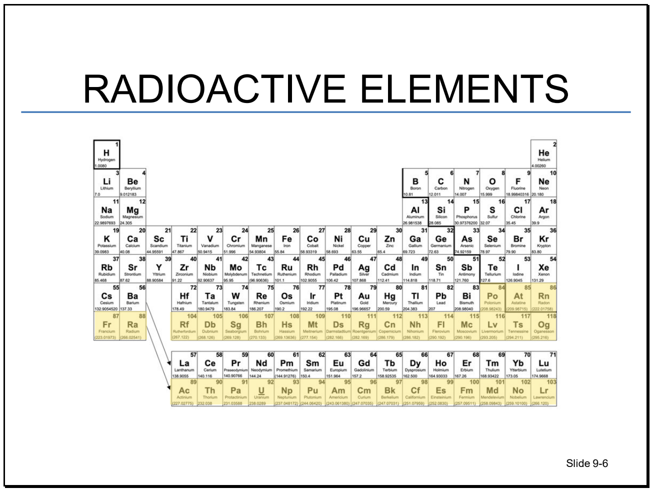
1. Atoms are most stable when they have approximately a one-to-one proton-to-neutron ratio.

    a. The most common form of elements is that which is shown on the periodic table.

    b. This ratio varies slightly with the element.

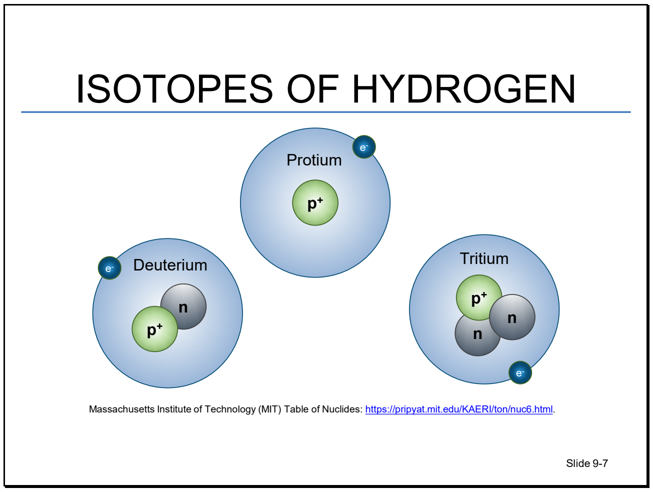
    c. If there are too few neutrons, positively charged protons near each other begin to repel each other, and the nucleus becomes unstable. It will begin to decay due to repulsive effects.

    d. If there are too many neutrons, the nucleus begins to become unstable simply because the mass has become too great, and it will begin to decay.



RADIOACTIVE ELEMENTS

    e. Elements with an atomic number greater than 83 have no stable form and are radioactive.



ISOTOPES OF HYDROGEN

Massachusetts Institute of Technology (MIT) Table of Nuclides: https://pripyat.mit.edu/KAERI/ton/nuc6.html.

2. All elements on the periodic table have isotopes. Many will undergo radioactive decay; some will not.

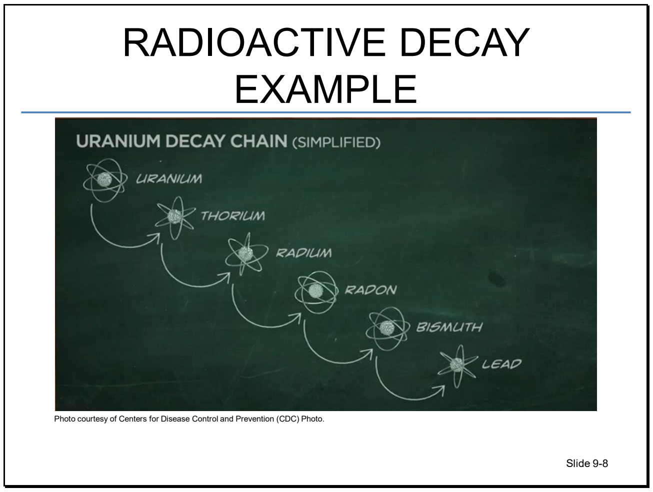
3. Hydrogen examples:

   a. Protium (${}_{1}\mathrm{H}^{1}$) is the most common form of hydrogen.

   b. Hydrogen with a single neutron (${}_{1}\mathrm{H}^{2}$) is called deuterium (Greek for "second") and is not radioactive. It constitutes 0.0156 percent of all hydrogen atoms — a very small quantity which results in the average atomic mass we see on the periodic table.

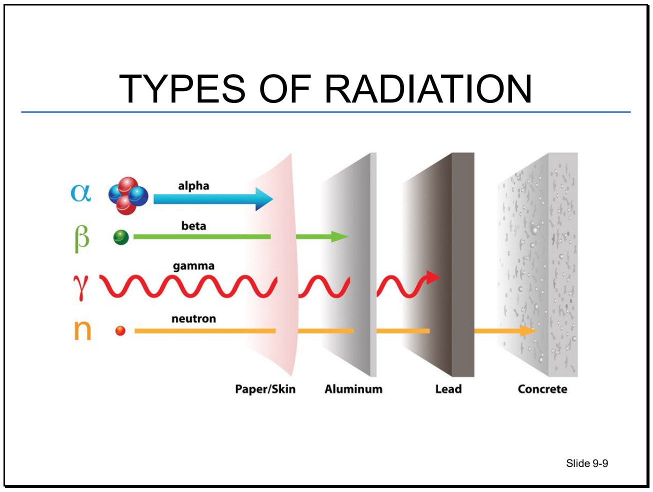
   c. Hydrogen with two neutrons (${}_{1}\mathrm{H}^{3}$) is called tritium (Greek for "third") and is found in small trace amounts. It is created by cosmic radiation interaction with our atmosphere.

II. MODES OF DECAY



RADIOACTIVE DECAY EXAMPLE

Photo courtesy of Centers for Disease Control and Prevention (CDC) Photo.



TYPES OF RADIATION

A. Introduction.

1. Remember, to achieve a nucleus that has a stable proton-to-neutron ratio, the nucleus will undergo various modes of decay.

2. We will discuss the three most common forms: alpha, beta and gamma, as well as the less common, but nevertheless very dangerous, neutron radiation.

B. Alpha α decay.

1. An alpha particle is a subatomic particle comprised of two protons and two neutrons.

2. It is a nucleus of helium but has no electrons.

3. It travels one to two inches in the air and ionizes air to gain two electrons; thus, it becomes an atom of helium.

4. Depending on the isotope, the release of an alpha particle may result in the release of gamma energy.

5. The particles will not harm the body. However, ingesting or inhalation of the source materials will cause ionization of lung or gastrointestinal (GI) tract tissues, which can produce severe adverse health effects and death.

C. Beta β decay.

1. A beta particle is a fast-moving, energetic electron or positron emitted from an atomic nucleus.

2. Beta particles can be either positively charged (positron) or negatively charged (negatron).

3. Beta particles can travel many feet in air.

4. They are easily repelled by thin sheets of aluminum.

5. They can penetrate the skin layer and result in beta burns similar to first-degree thermal burns.

6. Beta particles do not penetrate the body to ionize internal tissue.

7. As with alpha particles, their greatest risk occurs when the source isotope is inhaled or ingested resulting in severe damage to pulmonary or GI tissue.

8. Depending upon the isotope, gamma energy may or may not be released with beta decay.

D. Neutron radiation.

1. Neutron radiation is seen in cases involving spontaneously fissionable radioactive isotopes.

2. These materials are extremely neutron heavy.

3. Examples include uranium-235, plutonium-239 and uranium-233.

4. They have no charge but are very penetrating.

5. As they move through materials and strike nuclei of other atoms, this can cause them to break off particles resulting in new, potentially radioactive isotopes.

E. Gamma γ radiation.

1. Gamma is the release of energy from the nucleus as it decays and transitions from a higher to a lower energy state. The excess energy must be released as an electromagnetic wave of high-intensity energy (photon), which is called gamma. (This is different from other forms of radiation, which are particles.)

2. Gamma has no mass.

3. It travels great distances.

4. It passes through the human body and ionizes tissue such as the organs and genetic material.

5. Gamma radiation creates a significant risk to humans during external exposure.

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ACTIVITY 9.1

Radioactive Isotopes

Purpose

Research characteristics and health effects of five common isotopes.

Directions

1. Work with your table group to research one of the following five isotopes, as assigned by the instructor. You may use your text materials, internet resources or Appendix B: Table of Radionuclides found at the end of this unit.
    a. Americium-241.
    b. Technetium-99.
    c. Radon-222.
    d. Potassium-40.
    e. Cobalt-60.
2. For each isotope, identify information concerning:
    a. Mode of decay.
    b. The time required for it to lose 50% of its radioactivity by decay (half-life).
    c. Whether the isotope releases gamma.
    d. How it is commonly found or used.
    e. Potential health effects.
3. Record the information on an easel pad.
4. Be prepared to discuss your findings with the class.

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ACTIVITY 9.1

Radioactive Isotopes Worksheet

Isotope	Mode of decay	Half-life	Gamma release?	Common locations and uses	Potential health effects
Americium-241					
Technetium-99					

Isotope	Mode of decay	Half-life	Gamma release?	Common locations and uses	Potential health effects
Radon-222					
Potassium-40					

Isotope	Mode of decay	Half-life	Gamma release?	Common locations and uses	Potential health effects
Cobalt-60					

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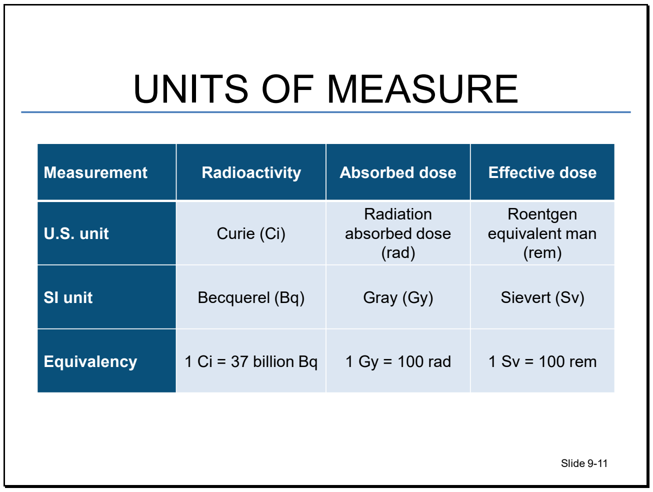
III. UNITS OF MEASURE



UNITS OF MEASURE

Measurement	Radioactivity	Absorbed dose	Effective dose
U.S. unit	Curie (Ci)	Radiation absorbed dose (rad)	Roentgen equivalent man (rem)
SI unit	Becquerel (Bq)	Gray (Gy)	Sievert (Sv)
Equivalency	1 Ci = 37 billion Bq	1 Gy = 100 rad	1 Sv = 100 rem

A. Radioactivity. Units to measure the level of ionizing radiation released by a material:

1. Curie (Ci).

   a. The official unit of measure used in the United States.

   b. The required amount of a radioactive isotope necessary to generate 3.7 x 10^{10} (37 billion) disintegrations per second.

   c. Approximately 1 gram of radium equals 1 Ci.

   d. 1 Ci equals 37 billion becquerel (Bq).

2. Bq.

   a. International unit of measure.

   b. Equals one disintegration per second.

B. Absorbed dose. Units to measure the amount of energy deposited per unit mass in an object or person:

1. Radiation absorbed dose (rad): The amount of ionizing radiation absorbed by the body.

2. Gray (Gy): An International System of Units (SI) unit of measure similar to the rad.

C. Effective dose: Units to indicate the potential for long-term health effects, used to set regulatory limits.

  1. Roentgen equivalent man (rem).

    a. Rem is an older unit of measure more commonly used by emergency responders in the U.S.

    b. It is the amount of energy absorbed by human tissue combined with the medical effects for the type of radiation.

    c. Rem is the unit of measure used to calculate dose in the human body.

    d. 1 rem = 1,000 milli-roentgens (mR).

    e. 1 mR = 1,000 micro-roentgens (µR).

    f. Natural background radiation is between 8 and 16 µR/hr.

    g. First action level twice background.

      - The action normally taken is to investigate why the background is increasing.

    h. Second action level 2 milli-roentgens per hour (mR/Hr) (2,000 µR/Hr) — action hot zone.

    i. 5 rem total dose (5,000 mR) — any emergency activity.

    j. 10 rem total dose (10,000 mR) — protection of critical property.

    k. 25 rem total dose (25,000 mR) — life saving.

    l. Any high level of exposure must be voluntary.

    m. Toxic dose low ($TD_{(low)}$) 100 rem total dose.

    n. Lethal dose 50 ($LD_{(50)}$) 500 rem total dose.

    o. Loosely translated, 1 Gy ≅ 100 rem.

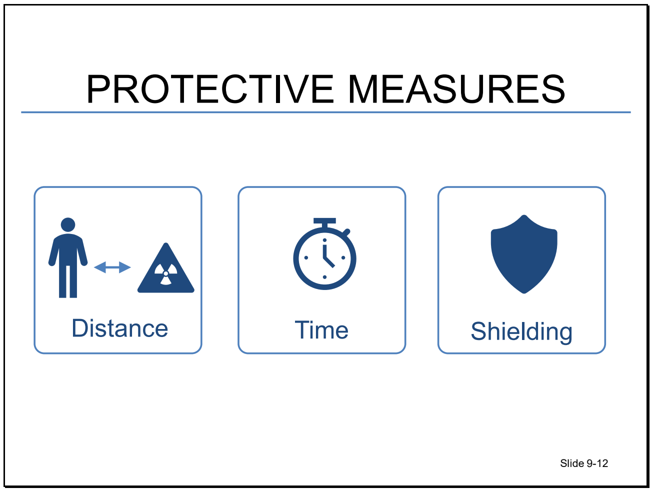
  2. Sievert (Sv).

    a. An SI unit of measure representing health risks of ionizing radiation.

b. 1 Sv = 100 rem.

- To convert Sv to rem, multiply Sv by 100.
- To convert rem to Sv, divide rem by 100.

IV. PROTECTIVE MEASURES



PROTECTIVE MEASURES

Distance

Time

Shielding

A. Overview of distance, time and shielding.

1. Distance: Total dose is inversely proportional to the square of the distance from the source.

2. Time: Total dose is directly proportional to duration of exposure. Therefore, limiting exposure time is the primary protective measure.

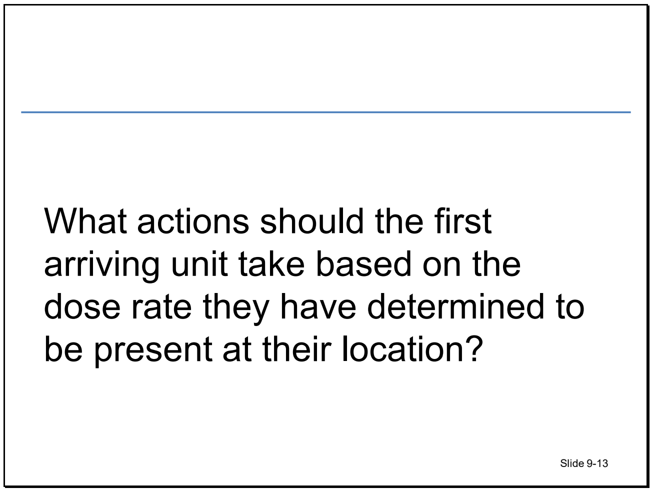
3. Shielding: The greater the mass between the source and the responder, the greater the protection value.

B. Consider this scenario:

1. Your response team has been dispatched to an explosion at a food irradiation facility. This facility uses high-level cobalt-60 to treat fruits and vegetables to eliminate bacteria and harmful pests. The process uses a conveyor system to move pallets of food into an irradiation chamber. This chamber contains a core constructed of racks of cobalt-60 rods that is stored underground in a vault when not in use.

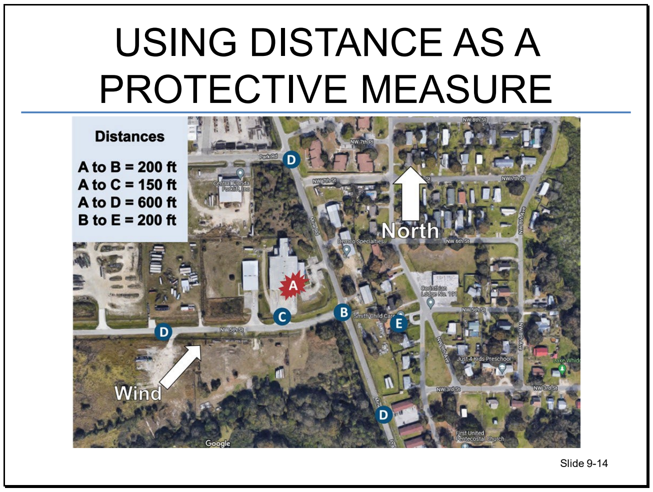
2. An explosion (non-nuclear in nature) has occurred from an undetermined cause. The explosion has resulted in a breach of the southeast corner of the irradiation chamber ("A"). The wall of the chamber and the building itself have partially collapsed.

3. The first arriving unit has taken a position at "B," 200 feet away from the breach. Using personal radiation detection devices, they have determined that the dose rate at their location is 8mR/Hr (0.08mSv/Hr).



What actions should the first arriving unit take based on the dose rate they have determined to be present at their location?

Slide 9-13



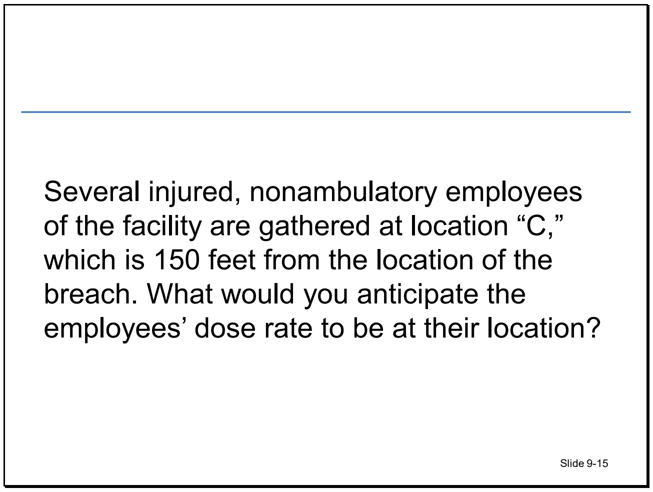
USING DISTANCE AS A PROTECTIVE MEASURE

Distances

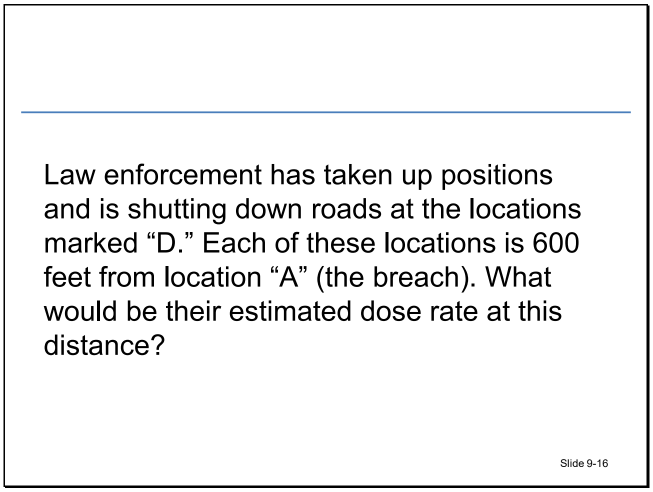
A to B = 200 ft
A to C = 150 ft
A to D = 600 ft
B to E = 200 ft

Slide 9-14

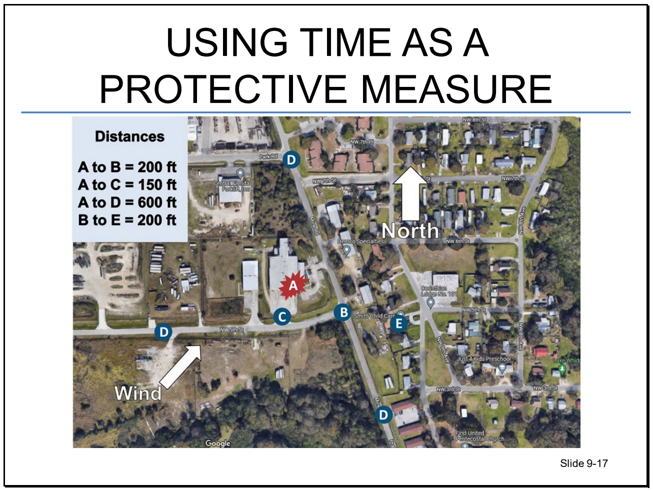
C. Using distance as a protective measure.



Several injured, nonambulatory employees of the facility are gathered at location “C,” which is 150 feet from the location of the breach. What would you anticipate the employees’ dose rate to be at their location?



Law enforcement has taken up positions and is shutting down roads at the locations marked “D.” Each of these locations is 600 feet from location “A” (the breach). What would be their estimated dose rate at this distance?



USING TIME AS A PROTECTIVE MEASURE

Distances

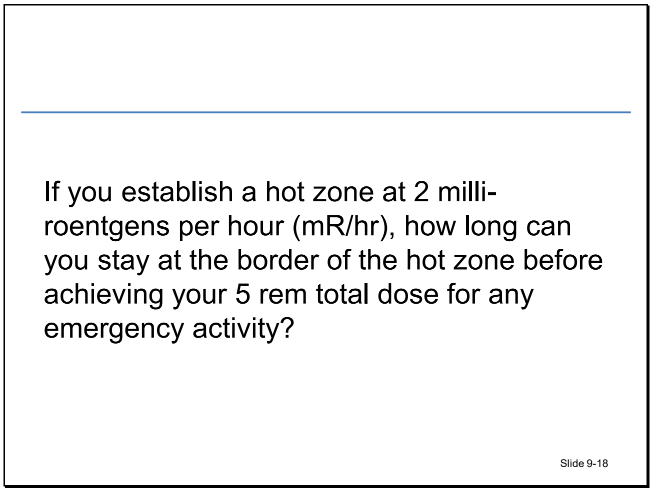
A to B = 200 ft
A to C = 150 ft
A to D = 600 ft
B to E = 200 ft

D. Using time as a protective measure.

1. Determine the dose rate using detection equipment or other technical information; find that rate in the left column of the table.

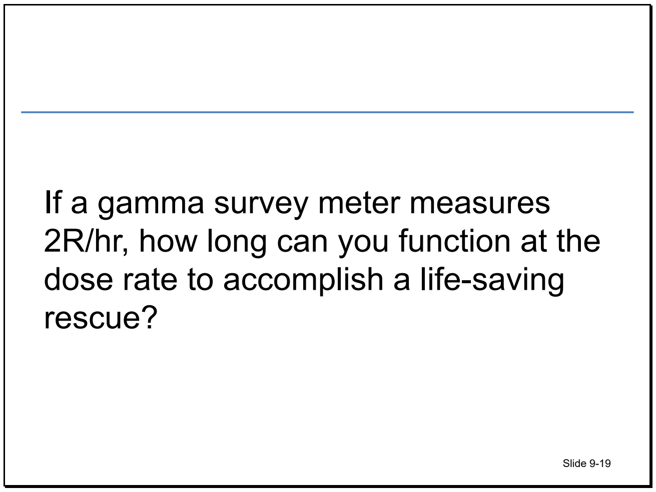
2. Read across the row to the established maximum total dose for the anticipated activity.

3. The intersection of the row and column identifies the allowable time to "stay" at that dose rate.



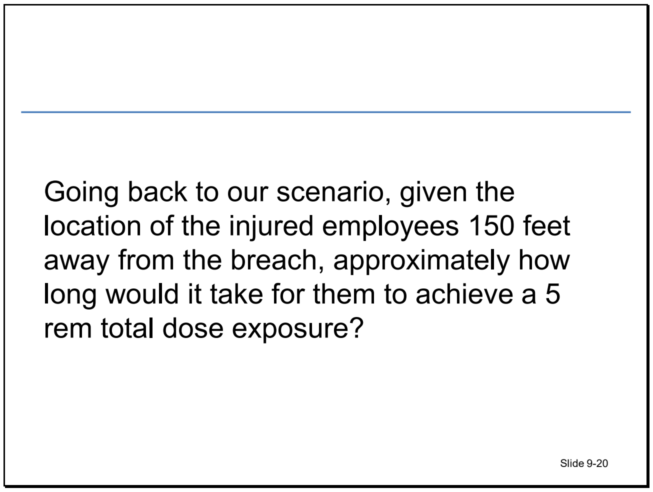
If you establish a hot zone at 2 milli-roentgens per hour (mR/hr), how long can you stay at the border of the hot zone before achieving your 5 rem total dose for any emergency activity?

Slide 9-18



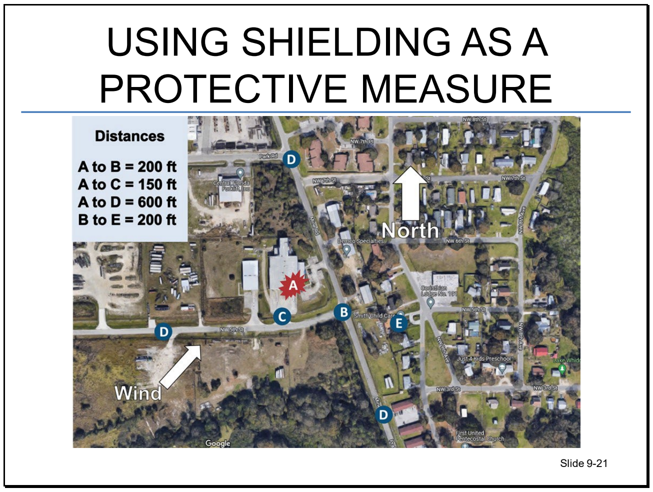
If a gamma survey meter measures 2R/hr, how long can you function at the dose rate to accomplish a life-saving rescue?

Slide 9-19



Going back to our scenario, given the location of the injured employees 150 feet away from the breach, approximately how long would it take for them to achieve a 5 rem total dose exposure?

Slide 9-20



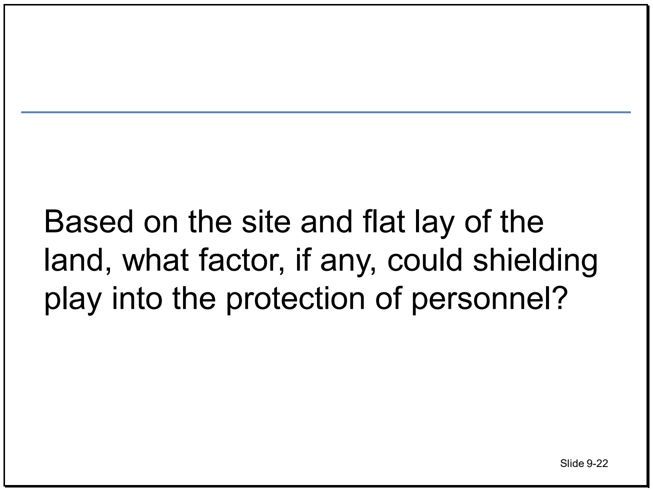
USING SHIELDING AS A PROTECTIVE MEASURE

Distances

A to B = 200 ft
A to C = 150 ft
A to D = 600 ft
B to E = 200 ft

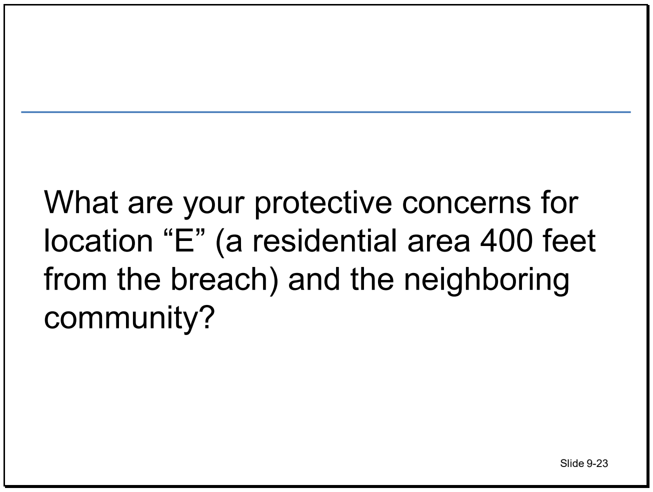
Slide 9-21

E. Using shielding as a protective measure.



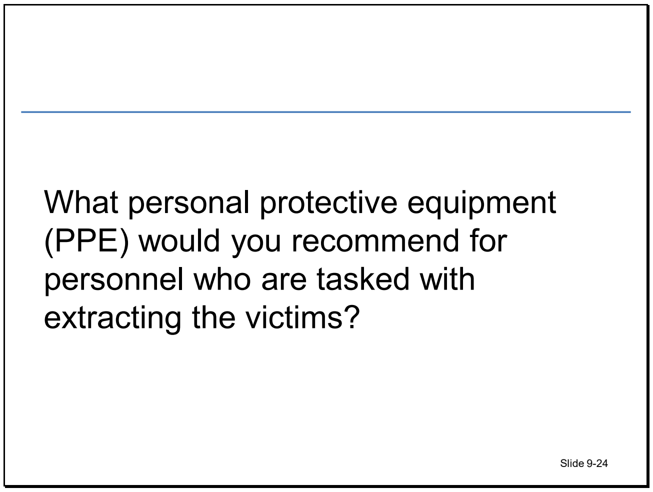
Based on the site and flat lay of the land, what factor, if any, could shielding play into the protection of personnel?

Slide 9-22

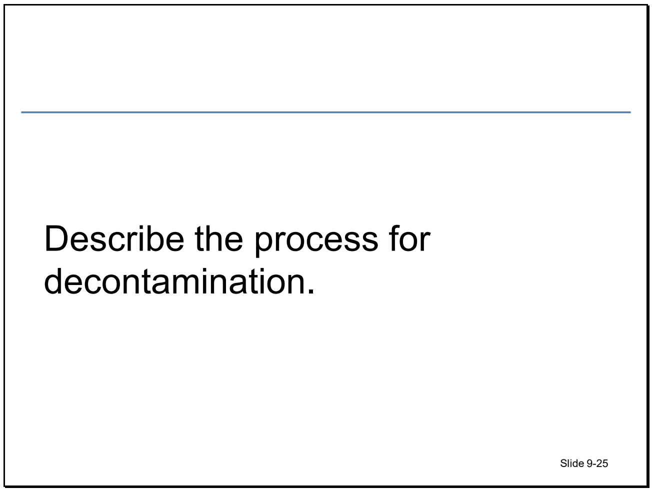


What are your protective concerns for location “E” (a residential area 400 feet from the breach) and the neighboring community?

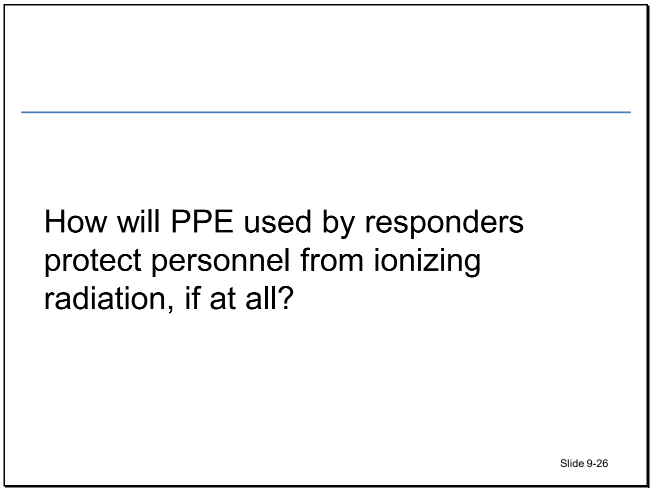
Slide 9-23



What personal protective equipment (PPE) would you recommend for personnel who are tasked with extracting the victims?

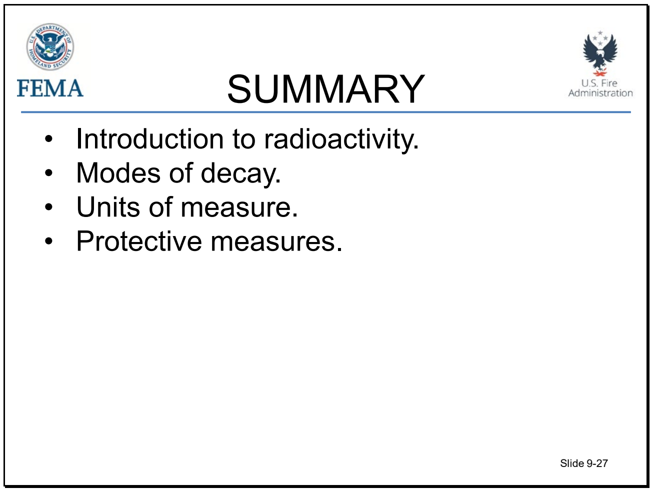


Describe the process for decontamination.



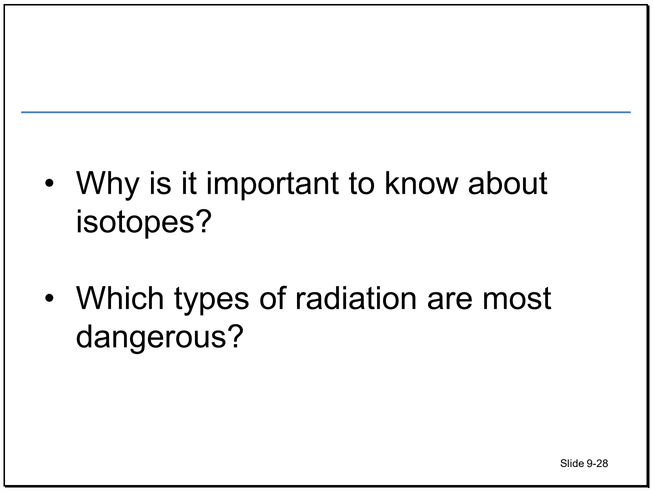
How will PPE used by responders protect personnel from ionizing radiation, if at all?

V. SUMMARY

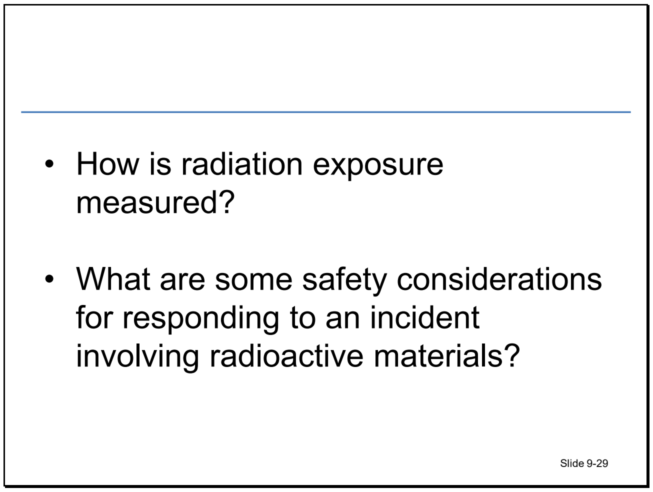


SUMMARY

- Introduction to radioactivity.
- Modes of decay.
- Units of measure.
- Protective measures.



- Why is it important to know about isotopes?
- Which types of radiation are most dangerous?



- How is radiation exposure measured?
- What are some safety considerations for responding to an incident involving radioactive materials?

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APPENDIX A

CENTERS FOR DISEASE CONTROL AND PREVENTION GLOSSARY OF RADIOLOGICAL TERMS

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CDC RADIATION EMERGENCIES

Glossary of Radiological Terms

Absolute risk: the proportion of a population expected to get a disease over a specified time period. *See also* risk, relative risk.

Absorbed dose: the amount of energy deposited by ionizing radiation in a unit mass of tissue. It is expressed in units of joule per kilogram (J/kg), and called "gray" (Gy). *For more information, see* "Primer on Radiation Measurement" *at the end of this document.*

Activity (radioactivity): the rate of decay of radioactive material expressed as the number of atoms breaking down per second measured in units called becquerels or curies.

Acute exposure: an exposure to radiation that occurred in a matter of minutes rather than in longer, continuing exposure over a period of time. *See also* chronic exposure, exposure, fractionated exposure.

Acute Radiation Syndrome (ARS): a serious illness caused by receiving a dose greater than 50 rads of penetrating radiation to the body in a short time (usually minutes). The earliest symptoms are nausea, fatigue, vomiting, and diarrhea. Hair loss, bleeding, swelling of the mouth and throat, and general loss of energy may follow. If the exposure has been approximately 1,000 rads or more, death may occur within 2 – 4 weeks. *For more information, see CDC's fact sheet* "Acute Radiation Syndrome" *at* http://www.bt.cdc.gov/radiation/ars.asp.

Air burst: a nuclear weapon explosion that is high enough in the air to keep the fireball from touching the ground. Because the fireball does not reach the ground and does not pick up any surface material, the radioactivity in the fallout from an air burst is relatively insignificant compared with a surface burst. *For more information, see Chapter 2 of CDC's Fallout Report at* http://www.cdc.gov/nceh/radiation/fallout/falloutreport.pdf.

Alpha particle: the nucleus of a helium atom, made up of two neutrons and two protons with a charge of +2. Certain radioactive nuclei emit alpha particles. Alpha particles generally carry more energy than gamma or beta particles, and deposit that energy very quickly while passing through tissue. Alpha particles can be stopped by a thin layer of light material, such as a sheet of paper, and cannot penetrate the outer, dead layer of skin. Therefore, they do not damage living tissue when outside the body. When alpha-emitting atoms are inhaled or swallowed, however, they are especially damaging because they transfer relatively large amounts of ionizing energy to living cells. *See also* beta particle, gamma ray, neutron, x-ray.

Ambient air: the air that surrounds us.

Americium (Am): a silvery metal; it is a man-made element whose isotopes Am-237 through Am-246 are all radioactive. Am-241 is formed spontaneously by the beta decay of plutonium-241. Trace quantities of americium are widely used in smoke detectors, and as neutron sources in neutron moisture gauges.

Atom: the smallest particle of an element that can enter into a chemical reaction.

Atomic number: the total number of protons in the nucleus of an atom.

Atomic mass unit (amu): 1 amu is equal to one twelfth of the mass of a carbon-12 atom.

Atomic mass number: the total number of protons and neutrons in the nucleus of an atom.

Atomic weight: the mass of an atom, expressed in atomic mass units. For example, the atomic number of helium-4 is 2, the atomic mass is 4, and the atomic weight is 4.00026.

Background radiation: ionizing radiation from natural sources, such as terrestrial radiation due to radionuclides in the soil or cosmic radiation originating in outer space.

Becquerel (Bq): the amount of a radioactive material that will undergo one decay (disintegration) per second. *For more information, see* "Primer on Radiation Measurement" *at the end of this document.*

Beta particles: electrons ejected from the nucleus of a decaying atom. Although they can be stopped by a thin sheet of aluminum, beta particles can penetrate the dead skin layer, potentially causing burns. They can pose a serious direct or external radiation threat and can be lethal depending on the amount received. They also pose a serious internal radiation threat if beta-emitting atoms are ingested or inhaled. *See also* alpha particle, gamma ray, neutron, x-ray.

Bioassay: an assessment of radioactive materials that may be present inside a person's body through analysis of the person's blood, urine, feces, or sweat.

Biological Effects of Ionizing Radiation (BEIR) Reports: reports of the National Research Council's committee on the Biological Effects of Ionizing Radiation. *For more information, see* http://www.nap.edu/books/0309039959/html/.

Biological half-life: the time required for one half of the amount of a substance, such as a radionuclide, to be expelled from the body by natural metabolic processes, not counting radioactive decay, once it has been taken in through inhalation, ingestion, or absorption. *See also* radioactive half-life, effective half-life.

Carcinogen: a cancer-causing substance.

Chain reaction: a process that initiates its own repetition. In a fission chain reaction, a fissile nucleus absorbs a neutron and fissions (splits) spontaneously, releasing additional neutrons. These, in turn, can be absorbed by other fissile nuclei, releasing still more neutrons. A fission chain reaction is self-sustaining when the number of neutrons released in a given time equals or exceeds the number of neutrons lost by absorption in non-fissile material or by escape from the system.

Chronic exposure: exposure to a substance over a long period of time, possibly resulting in adverse health effects. *See also* acute exposure, fractionated exposure.

Cobalt (Co): gray, hard, magnetic, and somewhat malleable metal. Cobalt is relatively rare and generally obtained as a byproduct of other metals, such as copper. Its most common radioisotope, cobalt-60 (Co- 60), is used in radiography and medical applications. Cobalt-60 emits beta particles and gamma rays during radioactive decay.

Collective dose: the estimated dose for an area or region multiplied by the estimated population in that area or region. *For more information, see* "Primer on Radiation Measurement" *at the end of this document.*

Committed dose: a dose that accounts for continuing exposures expected to be received over a long period of time (such as 30, 50, or 70 years) from radioactive materials that were deposited inside the body. *For more information, see* "Primer on Radiation Measurement" *at the end of this document.*

Concentration: the ratio of the amount of a specific substance in a given volume or mass of solution to the mass or volume of solvent.

Conference of Radiation Control Program Directors (CRCPD): an organization whose members represent state radiation protection programs. *For more information, see the CRCPD website:* http://www.crcpd.org.

Contamination (radioactive): the deposition of unwanted radioactive material on the surfaces of structures, areas, objects, or people where it may be external or internal. *See also* decontamination.

Cosmic radiation: radiation produced in outer space when heavy particles from other galaxies (nuclei of all known natural elements) bombard the earth. *See also* background radiation, terrestrial radiation.

Criticality: a fission process where the neutron production rate equals the neutron loss rate to absorption or leakage. A nuclear reactor is "critical" when it is operating.

Critical mass: the minimum amount of fissile material that can achieve a self-sustaining nuclear chain reaction.

Cumulative dose: the total dose resulting from repeated or continuous exposures of the same portion of the body, or of the whole body, to ionizing radiation. *For more information, see* "Primer on Radiation Measurement" *at the end of this document.*

Curie (Ci): the traditional measure of radioactivity based on the observed decay rate of 1 gram of radium. One curie of radioactive material will have 37 billion disintegrations in 1 second. *For more information, see* "Primer on Radiation Measurement" *at the end of this document.*

Cutaneous Radiation Syndrome (CRS): the complex syndrome resulting from radiation exposure of more than 200 rads to the skin. The immediate effects can be reddening and swelling of the exposed area (like a severe burn), blisters, ulcers on the skin, hair loss, and severe pain. Very large doses can result in permanent hair loss, scarring, altered skin color, deterioration of the affected body part, and death of the affected tissue (requiring surgery). *For more information, see CDC's fact sheet* "Acute Radiation Syndrome," *at* http://www.bt.cdc.gov/radiation/ars.asp.

Decay chain (decay series): the series of decays that certain radioisotopes go through before reaching a stable form. For example, the decay chain that begins with uranium-238 (U-238) ends in lead-206 (Pb- 206), after forming isotopes, such as uranium-234 (U-234), thorium-230 (Th-230), radium-226 (Ra-226), and radon-222 (Rn-222).

Decay constant: the fraction of a number of atoms of a radioactive nuclide that disintegrates in a unit of time. The decay constant is inversely proportional to the radioactive half-life.

Decay products (or daughter products): the isotopes or elements formed and the particles and high- energy electromagnetic radiation emitted by the nuclei of radionuclides during radioactive decay. Also known as "decay chain products" or "progeny" (the isotopes and elements). A decay product may be either radioactive or stable.

Decay, radioactive: disintegration of the nucleus of an unstable atom by the release of radiation.

Decontamination: the reduction or removal of radioactive contamination from a structure, object, or person.

Depleted uranium: uranium containing less than 0.7% uranium-235, the amount found in natural uranium. *See also* enriched uranium.

Deposition density: the activity of a radionuclide per unit area of ground. Reported as becquerels per square meter or curies per square meter.

Deterministic effects: effects that can be related directly to the radiation dose received. The severity increases as the dose increases. A deterministic effect typically has a threshold below which the effect will not occur. *See also* stochastic effect, non-stochastic effect.

Deuterium: a non-radioactive isotope of the hydrogen atom that contains a neutron in its nucleus in addition to the one proton normally seen in hydrogen. A deuterium atom is twice as heavy as normal hydrogen. *See also* tritium.

Dirty bomb: a device designed to spread radioactive material by conventional explosives when the bomb explodes. A dirty bomb kills or injures people through the initial blast of the conventional explosive and spreads radioactive contamination over possibly a large area — hence the term "dirty." Such bombs could be miniature devices or large truck bombs. A dirty bomb is much simpler to make than a true nuclear weapon. *See also* radiological dispersal device.

Dose (radiation): radiation absorbed by person's body. Several different terms describe radiation dose. *For more information, see* "Primer on Radiation Measurement" *at the end of this document.*

Dose coefficient: the factor used to convert radionuclide intake to dose. Usually expressed as dose per unit intake (e.g., sieverts per becquerel).

Dose equivalent: a quantity used in radiation protection to place all radiation on a common scale for calculating tissue damage. Dose equivalent is the absorbed dose in grays times the quality factor. The quality factor accounts for differences in radiation effects caused by different types of ionizing radiation. Some radiation, including alpha particles, causes a greater amount of damage per unit of absorbed dose than other radiation. The sievert (Sv) is the unit used to measure dose equivalent. *For more information, see* "Primer on Radiation Measurement" *at the end of this document.*

Dose rate: the radiation dose delivered per unit of time.

Dose reconstruction: a scientific study that estimates doses to people from releases of radioactivity or other pollutants. The dose is reconstructed by determining the amount of material released, the way people came in contact with it, and the amount they absorbed.

Dosimeter: a small portable instrument (such as a film badge, thermoluminescent dosimeter [TLD], or pocket dosimeter) for measuring and recording the total accumulated dose of ionizing radiation a person receives.

Dosimetry: assessment (by measurement or calculation) of radiation dose.

Effective dose: a dosimetric quantity useful for comparing the overall health effects of irradiation of the whole body. It takes into account the absorbed doses received by various organs and tissues and weighs them according to present knowledge of the sensitivity of each organ to radiation. It also accounts for the type of radiation and the potential for each type to inflict biologic damage. The effective dose is used, for example, to compare the overall health detriments of different radionuclides in a given mix. The unit of effective dose is the sievert (Sv); 1 Sv = 1 J/kg. *For more information, see* "Primer on Radiation Measurement" *at the end of this document.*

Effective half-life: the time required for the amount of a radionuclide deposited in a living organism to be diminished by 50% as a result of the combined action of radioactive decay and biologic elimination. *See also* biological half-life, decay constant, radioactive half-life.

Electron: an elementary particle with a negative electrical charge and a mass 1/1837 that of the proton. Electrons surround the nucleus of an atom because of the attraction between their negative charge and the positive charge of the nucleus. A stable atom will have as many electrons as it has protons. The number of electrons that orbit an atom determine its chemical properties. *See also* neutron.

Electron volt (eV): a unit of energy equivalent to the amount of energy gained by an electron when it passes from a point of low potential to a point one volt higher in potential.

Element: 1) all isotopes of an atom that contain the same number of protons. For example, the element uranium has 92 protons, and the different isotopes of this element may contain 134 to 148 neutrons. 2) In a reactor, a fuel element is a metal rod containing the fissile material.

Enriched uranium: uranium in which the proportion of the isotope uranium-235 has been increased by removing uranium-238 mechanically. *See also* depleted uranium.

Epidemiology: the study of the distribution and determinants of health-related states or events in specified populations; and the application of this study to the control of health problems.

Exposure (radiation): a measure of ionization in air caused by x-rays or gamma rays only. The unit of exposure most often used is the roentgen. *See also* contamination.

Exposure pathway: a route by which a radionuclide or other toxic material can enter the body. The main exposure routes are inhalation, ingestion, absorption through the skin, and entry through a cut or wound in the skin.

Exposure rate: a measure of the ionization produced in air by x-rays or gamma rays per unit of time (frequently expressed in roentgens per hour).

External exposure: exposure to radiation outside of the body.

Fallout, nuclear: minute particles of radioactive debris that descend slowly from the atmosphere after a nuclear explosion. *For more information, see Chapter 2 of CDC's Fallout Report at* http://www.cdc.gov/nceh/radiation/fallout/falloutreport.pdf.

Fissile material: any material in which neutrons can cause a fission reaction. The three primary fissile materials are uranium-233, uranium-235, and plutonium-239.

Fission (fissioning): the splitting of a nucleus into at least two other nuclei that releases a large amount of energy. Two or three neutrons are usually released during this transformation. *See also* fusion.

Fractionated exposure: exposure to radiation that occurs in several small acute exposures, rather than continuously as in a chronic exposure.

Fusion: a reaction in which at least one heavier, more stable nucleus is produced from two lighter, less stable nuclei. Reactions of this type are responsible for the release of energy in stars or in thermonuclear weapons.

Gamma rays: high-energy electromagnetic radiation emitted by certain radionuclides when their nuclei transition from a higher to a lower energy state. These rays have high energy and a short wavelength. All gamma rays emitted from a given isotope have the same energy, a characteristic that enables scientists to identify which gamma emitters are present in a sample. Gamma rays penetrate tissue farther than do beta or alpha particles, but leave a lower concentration of ions in their path to potentially cause cell damage. Gamma rays are very similar to x-rays. *See also* neutron.

Geiger counter: a radiation detection and measuring instrument consisting of a gas-filled tube containing electrodes, between which an electrical voltage but no current flows. When ionizing radiation passes through the tube, a short, intense pulse of current passes from the negative electrode to the positive electrode and is measured or counted. The number of pulses per second measures the intensity of the radiation field. Geiger counters are the most commonly used portable radiation detection instruments.

Genetic effects: hereditary effects (mutations) that can be passed on through reproduction because of changes in sperm or ova. *See also* teratogenic effects, somatic effects.

Gray (Gy): a unit of measurement for absorbed dose. It measures the amount of energy absorbed in a material. The unit Gy can be used for any type of radiation, but it does not describe the biological effects of the different radiations. *For more information, see* "Primer on Radiation Measurement" *at the end of this document.*

Half-life: the time any substance takes to decay by half of its original amount. *See also* biological half- life, decay constant, effective half-life, radioactive half-life.

Health physics: a scientific field that focuses on protection of humans and the environment from radiation. Health physics uses physics, biology, chemistry, statistics, and electronic instrumentation to help protect individuals from any damaging effects of radiation. *For more information, see the Health Physics Society website:* http://www.hps.org/.

High-level radioactive waste: the radioactive material resulting from spent nuclear fuel reprocessing. This can include liquid waste directly produced in reprocessing or any solid material derived from the liquid wastes having a sufficient concentration of fission products. Other radioactive materials can be designated as high-level waste, if they require permanent isolation. This determination is made by the U.S. Nuclear Regulatory Commission on the basis of criteria established in U.S. law. *See also* low-level waste, transuranic waste.

Hot spot: any place where the level of radioactive contamination is considerably greater than the area around it.

Ingestion: 1) the act of swallowing; 2) in the case of radionuclides or chemicals, swallowing radionuclides or chemicals by eating or drinking.

Inhalation: 1) the act of breathing in; 2) in the case of radionuclides or chemicals, breathing in radionuclides or chemicals.

Internal exposure: exposure to radioactive material taken into the body.

Iodine: a nonmetallic solid element. There are both radioactive and non-radioactive isotopes of iodine. Radioactive isotopes of iodine are widely used in medical applications. Radioactive iodine is a fission product and is the largest contributor to people's radiation dose after an accident at a nuclear reactor.

Ion: an atom that has fewer or more electrons than it has protons causing it to have an electrical charge and, therefore, be chemically reactive.

Ionization: the process of adding one or more electrons to, or removing one or more electrons from, atoms or molecules, thereby creating ions. High temperatures, electrical discharges, or nuclear radiation can cause ionization.

Ionizing radiation: any radiation capable of displacing electrons from atoms, thereby producing ions. High doses of ionizing radiation may produce severe skin or tissue damage. *See also* alpha particle, beta particle, gamma ray, neutron, x-ray.

Irradiation: exposure to radiation.

Isotope: a nuclide of an element having the same number of protons but a different number of neutrons.

Kiloton (Kt): the energy of an explosion that is equivalent to an explosion of 1,000 tons of TNT. One kiloton equals 1 trillion (10^{12}) calories. *See also* megaton.

Latent period: the time between exposure to a toxic material and the appearance of a resultant health effect.

Lead (Pb): a heavy metal. Several isotopes of lead, such as Pb-210 which emits beta radiation, are in the uranium decay chain.

Lead Federal Agency (LFA): the federal agency that leads and coordinates the emergency response activities of other federal agencies during a nuclear emergency. After a nuclear emergency, the Federal Radiological Emergency Response Plan (FRERP, available at http://www.fas.org/nuke/guide/usa/doctrine/national/frerp.htm) will determine which federal agency will be the LFA.

Local radiation injury (LRI): acute radiation exposure (more than 1,000 rads) to a small, localized part of the body. Most local radiation injuries do not cause death. However, if the exposure is from penetrating radiation (neutrons, x-rays, or gamma rays), internal organs may be damaged and some symptoms of acute radiation syndrome (ARS), including death, may occur. Local radiation injury invariably involves skin damage, and a skin graft or other surgery may be required. *See also CDC's fact sheet "Acute Radiation Syndrome" at* http://www.bt.cdc.gov/radiation/ars.asp.

Low-level waste (LLW): radioactively contaminated industrial or research waste such as paper, rags, plastic bags, medical waste, and water-treatment residues. It is waste that does not meet the criteria for any of three other categories of radioactive waste: spent nuclear fuel and high-level radioactive waste; transuranic radioactive waste; or uranium mill tailings. Its categorization does not depend on the level of radioactivity it contains.

Megaton (Mt): the energy of an explosion that is equivalent to an explosion of 1 million tons of TNT. One megaton is equal to a quintillion (10^{18}) calories. *See also* kiloton.

Molecule: a combination of two or more atoms that are chemically bonded. A molecule is the smallest unit of a compound that can exist by itself and retain all of its chemical properties.

Neoplastic: pertaining to the pathologic process resulting in the formation and growth of an abnormal mass of tissue.

Neutron: a small atomic particle possessing no electrical charge typically found within an atom's nucleus. Neutrons are, as the name implies, neutral in their charge. That is, they have neither a positive nor a negative charge. A neutron has about the same mass as a proton. *See also* alpha particle, beta particle, gamma ray, nucleon, x-ray.

Non-ionizing radiation: radiation that has lower energy levels and longer wavelengths than ionizing radiation. It is not strong enough to affect the structure of atoms it contacts but is strong enough to heat tissue and can cause harmful biological effects. Examples include radio waves, microwaves, visible light, and infrared from a heat lamp.

Non-stochastic effects: effects that can be related directly to the radiation dose received. The effect is more severe with a higher dose. It typically has a threshold, below which the effect will not occur. These are sometimes called deterministic effects. For example, a skin burn from radiation is a non-stochastic effect that worsens as the radiation dose increases. *See also* stochastic effects.

Nuclear energy: the heat energy produced by the process of nuclear fission within a nuclear reactor or by radioactive decay.

Nuclear fuel cycle: the steps involved in supplying fuel for nuclear power plants. It can include mining, milling, isotopic enrichment, fabrication of fuel elements, use in reactors, chemical reprocessing to recover the fissile material remaining in the spent fuel, reenrichment of the fuel material refabrication into new fuel elements, and waste disposal.

Nuclear tracers: radioisotopes that give doctors the ability to "look" inside the body and observe soft tissues and organs, in a manner similar to the way x-rays provide images of bones. A radioactive tracer is chemically attached to a compound that will concentrate naturally in an organ or tissue so that an image can be taken.

Nucleon: a proton or a neutron; a constituent of the nucleus of an atom.

Nucleus: the central part of an atom that contains protons and neutrons. The nucleus is the heaviest part of the atom.

Nuclide: a general term applicable to all atomic forms of an element. Nuclides are characterized by the number of protons and neutrons in the nucleus, as well as by the amount of energy contained within the atom.

Pathways: the routes by which people are exposed to radiation or other contaminants. The three basic pathways are inhalation, ingestion, and direct external exposure. *See also* exposure pathway.

Penetrating radiation: radiation that can penetrate the skin and reach internal organs and tissues. Photons (gamma rays and x-rays), neutrons, and protons are penetrating radiations. However, alpha particles and all but extremely high-energy beta particles are not considered penetrating radiation.

Photon: discrete "packet" of pure electromagnetic energy. Photons have no mass and travel at the speed of light. The term "photon" was developed to describe energy when it acts like a particle (causing interactions at the molecular or atomic level), rather than a wave. Gamma rays and x-rays are photons.

Pitchblende: a brown to black mineral that has a distinctive luster. It consists mainly of urananite (UO_2), but also contains radium (Ra). It is the main source of uranium (U) ore.

Plume: the material spreading from a particular source and traveling through environmental media, such as air or ground water. For example, a plume could describe the dispersal of particles, gases, vapors, and aerosols in the atmosphere, or the movement of contamination through an aquifer (For example, dilution, mixing, or adsorption onto soil).

Plutonium (Pu): a heavy, man-made, radioactive metallic element. The most important isotope is Pu- 239, which has a half-life of 24,000 years. Pu-239 can be used in reactor fuel and is the primary isotope in weapons. One kilogram is equivalent to about 22 million kilowatt-hours of heat energy. The complete detonation of a kilogram of plutonium produces an explosion equal to about 20,000 tons of chemical explosive. All isotopes of plutonium are readily absorbed by the bones and can be lethal depending on the dose and exposure time.

Polonium (Po): a radioactive chemical element and a product of radium (Ra) decay. Polonium is found in uranium (U) ores.

Prenatal radiation exposure: radiation exposure to an embryo or fetus while it is still in its mother's womb. At certain stages of the pregnancy, the fetus is particularly sensitive to radiation and the health consequences could be severe above 5 rads, especially to brain function. *For more information, see CDC's fact sheet,* "Possible Health Effects of Radiation Exposure on Unborn Babies," *at* http://www.bt.cdc.gov/radiation/prenatal.asp.

Protective Action Guide (PAG): a guide that tells state and local authorities at what projected dose they should take action to protect people from exposure to unplanned releases of radioactive material into the environment.

Proton: a small atomic particle, typically found within an atom's nucleus, that possesses a positive electrical charge. Even though protons and neutrons are about 2,000 times heavier than electrons, they are tiny. The number of protons is unique for each chemical element. *See also* nucleon.

Quality factor (Q): the factor by which the absorbed dose (rad or gray) is multiplied to obtain a quantity that expresses, on a common scale for all ionizing radiation, the biological damage (rem) to an exposed person. It is used because some types of radiation, such as alpha particles, are more biologically damaging internally than other types. *For more information, see* "Primer on Radiation Measurement" *at the end of this document.*

Rad (radiation absorbed dose): a basic unit of absorbed radiation dose. It is a measure of the amount of energy absorbed by the body. The rad is the traditional unit of absorbed dose. It is being replaced by the unit gray (Gy), which is equivalent to 100 rad. One rad equals the dose delivered to an object of 100 ergs of energy per gram of material. *For more information, see* "Primer on Radiation Measurement" *at the end of this document.*

Radiation: energy moving in the form of particles or waves. Familiar radiations are heat, light, radio waves, and microwaves. Ionizing radiation is a very high-energy form of electromagnetic radiation.

Radiation sickness: *See also* acute radiation syndrome (ARS), *or the CDC fact sheet* "Acute Radiation Syndrome," *at* http://www.bt.cdc.gov/radiation/ars.asp.

Radiation warning symbol: a symbol prescribed by the Code of Federal Regulations. It is a magenta or black trefoil on a yellow background. It must be displayed where certain quantities of radioactive materials are present or where certain doses of radiation could be received.

Radioactive contamination: the deposition of unwanted radioactive material on the surfaces of structures, areas, objects, or people. It can be airborne, external, or internal. *See also* contamination, decontamination.

Radioactive decay: the spontaneous disintegration of the nucleus of an atom.

Radioactive half-life: the time required for a quantity of a radioisotope to decay by half. For example, because the half-life of iodine-131 (I-131) is 8 days, a sample of I-131 that has 10 mCi of activity on January 1, will have 5 mCi of activity 8 days later, on January 9. *See also:* biological half-life, decay constant, effective half-life.

Radioactive material: material that contains unstable (radioactive) atoms that give off radiation as they decay.

Radioactivity: the process of spontaneous transformation of the nucleus, generally with the emission of alpha or beta particles often accompanied by gamma rays. This process is referred to as decay or disintegration of an atom.

Radioassay: a test to determine the amounts of radioactive materials through the detection of ionizing radiation. Radioassays will detect transuranic nuclides, uranium, fission and activation products, naturally occurring radioactive material, and medical isotopes.

Radiogenic: health effects caused by exposure to ionizing radiation.

Radiography: 1) *medical:* the use of radiant energy (such as x-rays and gamma rays) to image body systems. 2) *industrial:* the use of radioactive sources to photograph internal structures, such as turbine blades in jet engines. A sealed radiation source, usually iridium-192 (Ir-192) or cobalt-60 (Co-60), beams gamma rays at the object to be checked. Gamma rays passing through flaws in the metal or incomplete welds strike special photographic film (radiographic film) on the opposite side.

Radioisotope (radioactive isotope): isotopes of an element that have an unstable nucleus. Radioactive isotopes are commonly used in science, industry, and medicine. The nucleus eventually reaches a stable number of protons and neutrons through one or more radioactive decays. Approximately 3,700 natural and artificial radioisotopes have been identified.

Radiological or radiologic: related to radioactive materials or radiation. The radiological sciences focus on the measurement and effects of radiation.

Radiological dispersal device (RDD): a device that disperses radioactive material by conventional explosive or other mechanical means, such as a spray. *See also* dirty bomb.

Radionuclide: an unstable and therefore radioactive form of a nuclide.

Radium (Ra): a naturally occurring radioactive metal. Radium is a radionuclide formed by the decay of uranium (U) and thorium (Th) in the environment. It occurs at low levels in virtually all rock, soil, water, plants, and animals. Radon (Rn) is a decay product of radium.

Radon (Rn): a naturally occurring radioactive gas found in soils, rock, and water throughout the United States. Radon causes lung cancer and is a threat to health because it tends to collect in homes, sometimes to very high concentrations. As a result, radon is the largest source of exposure to people from naturally occurring radiation.

Relative risk: the ratio between the risk for disease in an irradiated population to the risk in an unexposed population. A relative risk of 1.1 indicates a 10% increase in cancer from radiation, compared with the "normal" incidence. *See also* risk, absolute risk.

Rem (roentgen equivalent, man): a unit of equivalent dose. Not all radiation has the same biological effect, even for the same amount of absorbed dose. Rem relates the absorbed dose in human tissue to the effective biological damage of the radiation. It is determined by multiplying the number of rads by the quality factor, a number reflecting the potential damage caused by the particular type of radiation. The rem is the traditional unit of equivalent dose, but it is being replaced by the sievert (Sv), which is equal to 100 rem. *For more information, see* "Primer on Radiation Measurement" *at the end of this document.*

Risk: the probability of injury, disease, or death under specific circumstances and time periods. Risk can be expressed as a value that ranges from 0% (no injury or harm will occur) to 100% (harm or injury will definitely occur). Risk can be influenced by several factors: personal behavior or lifestyle, environmental exposure to other material, or inborn or inherited characteristic known from scientific evidence to be associated with a health effect. Because many risk factors are not exactly measurable, risk estimates are uncertain. *See also* absolute risk, relative risk.

Risk assessment: an evaluation of the risk to human health or the environment by hazards. Risk assessments can look at either existing hazards or potential hazards.

Roentgen (R): a unit of exposure to x-rays or gamma rays. One roentgen is the amount of gamma or x- rays needed to produce ions carrying 1 electrostatic unit of electrical charge in 1 cubic centimeter of dry air under standard conditions.

Sensitivity: ability of an analytical method to detect small concentrations of radioactive material.

Shielding: the material between a radiation source and a potentially exposed person that reduces exposure.

Sievert (Sv): a unit used to derive a quantity called dose equivalent. This relates the absorbed dose in human tissue to the effective biological damage of the radiation. Not all radiation has the same biological effect, even for the same amount of absorbed dose. Dose equivalent is often expressed as millionths of a sievert, or micro-sieverts (µSv). One sievert is equivalent to 100 rem. *For more information, see* "Primer on Radiation Measurement" *at the end of this document.*

S.I. units: the Systeme Internationale (or International System) of units and measurements. This system of units officially came into being in October 1960 and has been adopted by nearly all countries, although the amount of actual usage varies considerably. *For more information, see* "Primer on Radiation Measurement" *at the end of this document.*

Somatic effects: effects of radiation that are limited to the exposed person, as distinguished from genetic effects, which may also affect subsequent generations. *See also* teratogenic effects.

Stable nucleus: the nucleus of an atom in which the forces among its particles are balanced. *See also* unstable nucleus.

Stochastic effect: effect that occurs on a random basis independent of the size of dose. The effect typically has no threshold and is based on probabilities, with the chances of seeing the effect increasing with dose. If it occurs, the severity of a stochastic effect is independent of the dose received. Cancer is a stochastic effect. *See also* non-stochastic effect, deterministic effect.

Strontium (Sr): a silvery, soft metal that rapidly turns yellow in air. Sr-90 is one of the radioactive fission materials created within a nuclear reactor during its operation. Stronium-90 emits beta particles during radioactive decay.

Surface burst: a nuclear weapon explosion that is close enough to the ground for the radius of the fireball to vaporize surface material. Fallout from a surface burst contains very high levels of radioactivity. *See also* air burst. *For more information, see Chapter 2 of CDC's Fallout Report at* http://www.cdc.gov/nceh/radiation/fallout/falloutreport.pdf .

Tailings: waste rock from mining operations that contains concentrations of mineral ore that are too low to make typical extraction methods economical.

Thermonuclear device: a "hydrogen bomb." A device with explosive energy that comes from fusion of small nuclei, as well as fission.

Teratogenic effect: birth defects that are not passed on to future generations, caused by exposure to a toxin as a fetus. *See also* genetic effects, somatic effects.

Terrestrial radiation: radiation emitted by naturally occurring radioactive materials, such as uranium (U), thorium (Th), and radon (Rn) in the earth.

Thorium (Th): a naturally occurring radioactive metal found in small amounts in soil, rocks, water, plants, and animals. The most common isotopes of thorium are thorium-232 (Th-232), thorium-230 (Th- 230), and thorium-238 (Th-238).

Transuranic: pertaining to elements with atomic numbers higher than uranium (92). For example, plutonium (Pu) and americium (Am) are transuranics.

Tritium: (chemical symbol H-3) a radioactive isotope of the element hydrogen (chemical symbol H). *See also* deuterium.

Unstable nucleus: a nucleus that contains an uneven number of protons and neutrons and seeks to reach equilibrium between them through radioactive decay (i.e., the nucleus of a radioactive atom). *See also* stable nucleus.

UNSCEAR: United Nations Scientific Committee on the Effects of Atomic Radiation. *See also* http://www.unscear.org/.

Uranium (U): a naturally occurring radioactive element whose principal isotopes are uranium-238 (U-238) and uranium-235 (U-235). Natural uranium is a hard, silvery-white, shiny metallic ore that contains a minute amount of uranium-234 (U-234).

Uranium mill tailings: naturally radioactive residue from the processing of uranium ore. Although the milling process recovers about 95% of the uranium, the residues, or tailings, contain several isotopes of naturally occurring radioactive material, including uranium (U), thorium (Th), radium (Ra), polonium (Po), and radon (Rn).

Whole body count: the measure and analysis of the radiation being emitted from a person's entire body, detected by a counter external to the body.

Whole body exposure: an exposure of the body to radiation, in which the entire body, rather than an isolated part, is irradiated by an external source.

X-ray: electromagnetic radiation caused by deflection of electrons from their original paths, or inner orbital electrons that change their orbital levels around the atomic nucleus. X-rays, like gamma rays can travel long distances through air and most other materials. Like gamma rays, x-rays require more shielding to reduce their intensity than do beta or alpha particles. X-rays and gamma rays differ primarily in their origin: x-rays originate in the electronic shell; gamma rays originate in the nucleus. *See also* neutron.

Primer on Radiation Measurement

In the aftermath of a radiological emergency the public will see radiation and its potential hazards described in many different and sometimes confusing ways. This primer is intended to help journalists and community leaders understand these terms.

Activity or radioactivity is measured by the number of atoms disintegrating per unit time. A ***becquerel*** is 1 disintegration per second. A ***curie*** is 37 billion disintegrations per second, which is the number of disintegrations per second in 1 gram of pure radium. A disintegrating atom can emit a beta particle, an alpha particle, a gamma ray, or some combination of all these, so becquerels or curies alone do not provide enough information to assess the risk to a person from a radioactive source.

Disintegrating atoms emit different forms of radiation — alpha particles, beta particles, gamma rays, or x- rays. As radiation moves through the body, it dislodges electrons from atoms, disrupting molecules. Each time this happens, the radiation loses some energy until it escapes from the body or disappears. The energy deposited indicates the number of molecules disrupted. The energy the radiation deposits in tissue is called the ***dose***, or more correctly, the ***absorbed dose***. The units of measure for absorbed dose are the ***gray*** (1 joule per kilogram of tissue) or the ***rad*** (1/100 of a gray*)*. The ***cumulative dose*** is the total absorbed dose or energy deposited by the body or a region of the body from repeated or prolonged exposures.

Alpha particles, beta particles, gamma rays, and x-rays affect tissue in different ways. Alpha particles disrupt more molecules in a shorter distance than gamma rays. A measure of the biologic risk of the energy deposited is the ***dose equivalent***. The units of dose equivalent are ***sieverts*** or ***rem***. Dose equivalent is calculated by multiplying the absorbed dose by a ***quality factor***.

Sometimes a large number of people have been exposed to a source of ionizing radiation. To assess the potential health effects, scientists often multiply the exposure per person by the number of persons and call this the ***collective dose***. Collective dose is expressed as “person-rem” or “person-sieverts.”

Abbreviations for Radiation Measurements

When the amounts of radiation being measured are less than 1, prefixes are attached to the unit of measure as a type of shorthand. This is called scientific notation and is used in many scientific fields. The table below shows the prefixes for radiation measurement and their associated numeric notations.

Prefix	Equal to	How Much Is That?	Abbreviation	Example
atto-	1 X 10^{-18}	.000000000000000001	A	aCi
femto-	1 X 10^{-15}	.000000000000001	F	fCi
pico-	1 X 10^{-12}	.000000000001	p	pCi
nano-	1 X 10^{-9}	.000000001	n	nCi
micro-	1 X 10^{-6}	.000001	µ	µCi
milli-	1 X 10^{-3}	.001	m	mCi
centi-	1 x 10^{-2}	.01	c	cSv

When the amount to be measured is 1,000 (i.e., 1 X 10^{3}) or higher, prefixes are attached to the unit of measure to shorten very large numbers (also scientific notation). The table below shows the prefixes used in radiation measurement and their associated numeric notations.

Prefix	Equal to	How Much Is That?	Abbreviation	Example
kilo-	1 X 10^{3}	1,000	k	kCi
mega-	1 X 10^{6}	1,000,000	M	MCi
giga-	1 X 10^{9}	1,000,000,000	G	GBq
tera-	1 X 10^{12}	1,000,000,000,000	T	TBq
peta-	1 X 10^{15}	1,000,000,000,000,000	P	PBq
exa-	1 x 10^{18}	1,000,000,000,000,000,000	E	EBq

Health Effects of Radiation Exposure

Exposure to radiation can cause two kinds of health effects. ***Deterministic effects*** are observable health effects that occur soon after receipt of large doses. These may include hair loss, skin burns, nausea, or death. ***Stochastic effects*** are long-term effects, such as cancer. The radiation dose determines the severity of a deterministic effect and the probability of a stochastic effect.

The object of any radiation control program is to prevent any deterministic effects and minimize the risk for stochastic effects. When a person inhales or ingests a radionuclide, the body will absorb different amounts of that radionuclide in different organs, so each organ will receive a different ***organ dose***.

Federal Guidance Report 11 (FGR-11) from the Environmental Protection Agency (EPA) lists ***dose conversion factors*** for all radionuclides. This report can be downloaded from http://www.epa.gov/radiation/pubs.htm. The dose conversion factor for each organ is the number of rem delivered to that organ by each curie or becquerel of intake of a specific radioisotope.

External, Internal, and Absorbed Doses

A person can receive an ***external dose*** by standing near a gamma or high-energy beta-emitting source. A person can receive an ***internal dose*** by ingesting or inhaling radioactive material. The external exposure stops when the person leaves the area of the source. The internal exposure continues until the radioactive material is flushed from the body by natural processes or decays.

A person who has ingested a radioactive material receives an internal dose to several different organs. The absorbed dose to each organ is different, and the sensitivity of each organ to radiation is different. FGR-11 assigns a different weighting factor to each organ. To determine a person's risk for cancer, multiply each organ's dose by its weighting factor, and add the results; the sum is the ***effective dose equivalent*** ("effective" because it is not really the dose to the whole body, but a sum of the relative risks to each organ; and "equivalent" because it is presented in rem or sieverts instead of rads or gray).

Committed and Total Effective Dose Equivalents

When a person inhales or ingests a radionuclide, that radionuclide is distributed to different organs and stays there for days, months, or years until it decays or is excreted. The radionuclide will deliver a radiation dose over a period of time. The dose that a person receives from the time the nuclide enters the body until it is gone is the ***committed dose***. FGR-11 calculates doses over a 50-year period and presents the ***committed dose equivalent*** for each organ plus the ***committed effective dose equivalent*** (CEDE).

A person can receive both an internal dose and an external dose. The sum of the committed effective dose equivalent (CEDE) and the external dose is called the ***total effective dose equivalent*** (TEDE).

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APPENDIX B

TABLE OF RADIONUCLIDES

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TABLE OF RADIONUCLIDES

Radionuclide	Half Life	Decay Mode	Internal Toxicity Class	ALI (mCi)	Container Posting Level (mCi)	Γ R/h @ 1 cm per mCi	TVL mm Pb	Radiation Types KeV (% per decay)
^{3}H	12.35 Y	β	Low	80	1	-	-	Betas: 19 (100%)
^{11}C	20.38 M	β+, EC	Low	400	1	5.97	13.7	Positrons: 960 (99.7%) Gammas: 511 (199.5%)
^{13}N	9.97 M	β+	Low		1	5.97	13.7	Positrons: 1,199 (99.8%) Gammas: 511 (199.6%)
^{14}C	5,730 Y	β	Moderate	2	1	-	-	Betas: 156 (100%)
^{15}O	122.24 S	β+	Low			5.97	13.7	Positrons: 1,732 (99.9%) Gammas: 511 (199.8%)
^{18}F	109.77 M	β+	Low	70	1	5.8	13.7	Positrons: 634 (96.7%) Gammas: 511 (193.4%)
^{22}Na	2.6 Y	β+, EC	High	0.4	0.01	12	26.6	Positrons: 545 (89.8%) Gammas: 511 (180%) 1,275 (99.9%)
^{24}Na	15 H	β	Moderate	4	0.1	18.4	52	Betas: 1,390 (99.9%) Gammas: 1,386 (100%) 2,754 (100%)
^{32}P	14.29 D	β	High	0.4	0.01	-	-	Betas: 1,710 (100%)
^{33}P	25.4 D	β	Moderate	3	0.1	-	-	Betas: 250 (100%)
^{35}S	87.44 D	β	Moderate	2	0.1	-	-	Betas: 167 (100%)
^{36}Cl	301,000 Y	β	High	0.2	0.010	-	-	Betas: 714 (98%)
^{40}K	1.3 x 10^{9}Y	β, EC	High	0.3	0.1	0.7	38.7	Betas: 1,312 (89.3%) Gammas: 1,460 (10.7%)
^{42}K	12.36 H	β	Moderate	5	1	1.4	39.8	Betas: 1,996 (17.5%) 3,521 (82%) Gammas: 1,525 (18%)

DECAY MODES: α = Alpha Decay, β = Beta Decay, β+ = Positron Decay, EC = Electron Capture, IT = Isomeric Transition (gamma) Decay,
SF = Spontaneous Fission ALI = Annual Limit on Intake, Γ = Specific Gamma Ray Constant, TVL = Tenth Value Layer

Radionuclide	Half Life	Decay Mode	Internal Toxicity Class	ALI (mCi)	Container Posting Level (mCi)	Γ R/h @ 1 cm per mCi	TVL mm Pb	Radiation Types KeV (% per decay)
^{45}Ca	163 D	β	Moderate	0.8	0.1	-	-	Betas: 257 (100%)
^{46}Sc	83.83 D	β	High	0.2	0.01	10.9	29.1	Betas: 357 (100%) Electrons: 140 (38%) Gammas: 889 (100%) 1,121 (100%) 143 (62%)
^{47}Ca	4.53 D	β	Moderate	0.8	0.1	5.7	34.4	Betas: 691 (81.7%) 1,988 (18%) Gammas: 489(7.0%) 808(6.9%) 1297 (74.9%)
^{48}V	16.24 D	β+	Moderate	0.6	0.1	15.6	30.1	Positrons: 698 (50%) Gammas: 983 (100%) 1,312 (97.5%) 2,240 (2.4%) 511 (100%) 944 (7.7%)
^{51}Cr	27.7 D	EC	Low	20	1	0.2	6.3	Gammas: 320 (9.8%)
^{54}Mn	312.5 D	EC	Moderate	0.8	0.1	4.7	24.6	Gammas: 835 (100%)
^{55}Fe	2.7 Y	EC	Moderate	2	0.1	-	-	X-rays: 6 (28%)
^{57}Co	270.9 D	EC	Moderate	0.7	0.1	0.9	0.7	Gammas: 122 (85.5%) 136 (10.6%)
^{59}Fe	44.53 D	β	High	0.3	0.01	6.4	33.6	Betas: 273 (45.2%) 465 (53.1%) Gammas: 192 (3.0%) 1,099 (56.5%) 1,292 (43.2%)
^{60}Co	5.27 Y	β	High	0.030	0.001	13.2	34.8	Betas: 318 (100%) Gammas: 1,173 (100%) 1,332 (100%)
^{63}Ni	96 Y	β	Moderate	0.8	0.1	-	-	Betas: 66 (100%)
^{67}Ga	3.26 D	EC	Low	7	1	1.1	4.7	Electrons: 84 (26.8%) Gammas: 93 (36%) 185 (19.7%) 300 (15.9%) 394 (4.5%)

DECAY MODES: α = Alpha Decay, β = Beta Decay, β+ = Positron Decay, EC = Electron Capture, IT = Isomeric Transition (gamma) Decay, SF = Spontaneous Fission ALI = Annual Limit on Intake, Γ = Specific Gamma Ray Constant, TVL = Tenth Value Layer

Radionuclide	Half Life	Decay Mode	Internal Toxicity Class	ALI (mCi)	Container Posting Level (mCi)	Γ R/h @ 1 cm per mCi	TVL mm Pb	Radiation Types KeV (% per decay)
^{68}Ge	288 D	EC	High	0.1	0.010	5.51	14.4	Positrons: 836 (84%) Gammas: 511 (178%) 1,077 (3.3%) 1,883 (0.1%) X-rays: 9 (39%) 10 (5.5%)
^{74}As	17.76 D	β+	Moderate	0.8	0.1	4.4	16.8	Betas: 718 (16%) 1,353 (19%) Positrons: 944 (27%) 944 (27%) 945 (27%) Gammas: 10 (5.1%) 511 (59%) 596 (60%) 608 (5.5%)
^{75}Se	119.8 D	EC	Moderate	0.5	0.1	2.1	4.6	Gammas: 121 (16.7%) 136 (59.2%) 265 (59.8%) 280 (25.2%) 401 (11.4%)
^{85}Kr	10.72 Y	β			1	0.4	2.8	Betas: 687 (99.6%) Gammas: 51.4 (43.4%)
^{85}Sr	64.84 D	EC	Moderate	2	0.1	3.0	13.9	Gammas: 514 (99.2%) 15 (8.7%)
^{86}Rb	18.66 D	β	Moderate	0.5	0.1	0.5	31.3	Betas: 698 (8.8%) 1,774 (94%) Gammas: 1,076 (8.8%)
^{89}Sr	50.5 D	β	High	0.1	0	-	26.8	Betas: 1,491 (100%)
^{90}Sr/Y	29.12 Y	β	Very High	0.004	0.0001	-	-	Betas: 546 (100%) 2,284 (100%)
^{90}Y	64.0 H	β	High	0.4	0.01	-	-	Betas: 2,284 (100%)
^{95}Nb	35.15 D	β	Moderate	1	0.1	4.3	22.5	Betas: 160 (100%) Gammas: 766 (100%)
^{99}Mo	2.75 D	β	Moderate	1	0.1	1.8	20.5	Betas: 436 (17.3%) 1,214 (82.7%) Gammas: 181 (6.2%) 740 (12.8%)
^{99m}Tc	6.02 H	IT	Low	80	1	0.6	0.9	Electrons: 119 (8.8%) 137 (1.1%) Gammas: 140 (89%)

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Radionuclide	Half Life	Decay Mode	Internal Toxicity Class	ALI (mCi)	Container Posting Level (mCi)	Γ R/h @ 1 cm per mCi	TVL mm Pb	Radiation Types KeV (% per decay)
^{103}Pd	16.96 D	EC	Low	6	0.1	1.48	0.02	X-Rays: 20.1 (28.7%) 20.2 (54.4%) 22.7 (16.9%)
^{109}Cd	464 D	EC	High	0.04	0.001	1.8	-	Electrons: 63 (42%) 84 (44%) 88 (10%) X-rays: 22 (84%) 25 (18%)
^{110m}Ag	249.9 D	IT, β	High	0.09	0.01	-	-	Betas: 22 (67.3%) 531 (30.5%) Gammas: 658 (94.4%) 678 (10.7%) 687 (6.5%)707 (16.7%) 764 (22.4%) 818 (7.3%) 885 (72.6%) 938 (34.3%) 1,384 (24.3%) 1,505 (13.1%)
^{111}In	2.83 D	EC	Moderate	4	0.1	3.4	2.2	Electrons: 145 (8.4%) 219 (4.9%) Gammas: 171 (90.2%) 245 (94%) X-rays: 23 (68%) 26 (15%)
^{113}Sn	115.1 D	IT	Moderate	0.5	0.1	1.7	0.05	Electrons: 20 (13%) X-rays: 24 (60%) 27 (13%)
^{115m}Cd	44.6 D	β	High	0.05	0.01	0.2	30.1	Betas: 616 (98%) 1,621 (98%)
^{123}I	13.2 H	EC	Moderate	3	0.1	1.3	1	Electrons: 127 (13.6%) Gammas: 159 (83%) X-rays: 27 (70.6%) 31 (16%)
^{125}I	60.14 D	EC	High	0.04	0.001	0.7	0.06	Electrons: 23 (19.7%) 31 (12.3%) Gammas: 35 (6.5%) X-rays: 27 (112%) 31 (25.4%)
^{129}I	1.6 x 10^7 Y	β	High	0.005	0.001	0.6	0.08	Betas: 152 (100%) Electrons: 34 (11%) Gammas: 40 (7.5%) X-rays: 30 (57%) 34 (13%)

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Radionuclide	Half Life	Decay Mode	Internal Toxicity Class	ALI (mCi)	Container Posting Level (mCi)	Γ R/h @ 1 cm per mCi	TVL mm Pb	Radiation Types KeV (% per decay)
^{131}I	8.04 D	β	High	0.03	0.001	2.1	9.6	Betas: 334 (7.4%) 606 (89.3%) Gammas: 284 (6.2%) 364 (81.2%) 637 (7.3%)
^{133}Ba	10.74 Y	EC	Moderate	0.7	0.1	2.4	5.8	Electrons: 45 (48%) 75 (7.4%) Gammas: 81 (33%) 276 (6.9%) 303 (17.8%) 356 (60%) 383 (8.7%) X-rays: 31 (97%) 35 (22.8%)
								Betas: 346 (99.3%)
^{133}Xe	5.25 D	β	-	-	1	0.1	0.4	Electrons: 45 (53.3%)
								Gammas: 81 (36.5%)
								X-rays: 31 (38.9%)
^{137}Cs	30.0 Y	β	High	0.1	0.01	3.5	18.9	Betas: 512 (94.6%) 1,173 (5.4%) Electrons: 624 (8.1%) Gammas: 662 (90%)
								Betas: 435 (71%) 580 (29.5%)
^{141}Ce	32.5 D	β	Moderate	0.7	0.1	0.4	0.9	Electrons: 103 (18.8%)
								Gammas: 145 (48.4%)
								X-rays: 36 (13.8%)
^{150}Eu	34.2 Y	EC	High	0.02	0.001	-	-	Electrons: 5 (45.9%) 5 (45.9%) 6 (27.1%) 1 (150%) Gammas: 334 (94%) 584 (51.5%) 737 (9.4%) 748 (5.1%) 1,049 (5.2%) X-rays: 40 (65.4%) 45 (8.3%)
^{152}Eu	13.33 Y	β, EC	High	0.02	0.001	-	-	Betas: 696 (13.6%) 1,475 (8.4%) Electrons: 5 (73.4%) 33 (5.7%) 75 (19.5%) 114 (10.6%)

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Radionuclide	Half Life	Decay Mode	Internal Toxicity Class	ALI (mCi)	Container Posting Level (mCi)	Γ R/h @ 1 cm per mCi	TVL mm Pb	Radiation Types KeV (% per decay)
^{153}Gd	242 D	EC	High	0.1	0.01	0.8	0.2	Electrons: 55 (32.2%) 49 (8.1%) 95 (5.1%) Gammas: 70 (2.6%) 97 (32%) 103 (22.2%) X-rays: 41 (100.5%) 47 (25.3%)
								Betas: 247 (27.9%) 569 (36.5%) 839 (17.4%)
^{154}Eu	8.8 Y	β, EC	High	0.02	0.001	6.3	29.1	1,844 (11.4%)
								Gammas: 723 (19.7%) 873 (11.5%) 1,005
								(17.9%) 127 (35.5%)
^{169}Yb	32.01 D	EC	Moderate	0.7	0.1	1.8	1.6	Electrons: 50 (34.9%) 100 (5.6%) 118 (10.3%) 120 (51.6%) 139 (12.4%) Gammas: 63 (42%) 110 (17%) 131 (12%) 177 (22%) 197 (36%) 307 (10%) X-rays: 50 (147%) 58 (39%)
^{186}Re	3.78 D	β	Moderate	2	0.1	0.2	0.8	Betas: 1,070 (94%) 1,076 (71%) Gammas: 137 (9.5%)
^{188}Re	16.98 H	β	Moderate	2	0.1	0.3	16.8	Betas: 2,120 (71.4%) Gammas: 155 (15%)
^{192}Ir	74.02 D	β, EC	High	0.2	0.001	4.8	20	Betas: 536 (41.4%) 672 (48.3%) Gammas: 296 (29%) 308 (29.7%) 317 (82.8%) 468 (48%) 604 (8.2%) 612 (5.3%)
^{198}Au	2.7 D	β	Moderate	1	0.1	2.4	10.1	Betas: 961 (98.6%) Gammas: 412 (95.5%)
^{201}Tl	3.04 D	EC	Low	20	1	0.4	0.9	Electrons: 84 (15.4%) Gammas: 167 (10%) X-rays: 69 (27.4%) 71 (46.5%) 80 (20.5%)

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Radionuclide	Half Life	Decay Mode	Internal Toxicity Class	ALI (mCi)	Container Posting Level (mCi)	Γ R/h @ 1 cm per mCi	TVL mm Pb	Radiation Types KeV (% per decay)
^{203}Hg	46.6 D	β	Moderate	0.5	0.1	1.3	4.7	Betas: 212 (100%) Electrons: 194 (16.9%) 264 (4.4%) Gammas: 279 (77.3%) X-rays: 71 (4.7%) 73 (8.0%)
^{206}Bi	.24 D	EC	Moderate	0.6	0.1	17.2	26	Electrons: 96 (22.2%) 256 (5.6%) Gammas: 516 (40%) 803 (98.9%) 881 (66.2%) 1,719 (32%)
^{207}Bi	38 Y	EC	High	0.4	0.01	8.3	25.8	Electrons: 976 (7.0%) Gammas: 570 (97.7%) 1,064 (75%) 1,770 (6.8%)
^{208}Po	2.93 Y	α	High	0.014	0.000001	-	-	Alphas: 5,110 (100%)
^{210}Pb	22.3 Y	β	Very High	0.0002	0.00001	0.0	0.2	Betas: 17 (80.2%) 63 (19.8%) Electrons: 8 (33.6%) 30 (57.9%) 43 (18.1%) Gammas: 11 (24%)
^{210}Po	138.38 D	α	Very High	0.0006	0.0001	-	-	Alphas: 5,305 (100%)
^{222}Rn	3.82 D	α	High	0.1	0.001	-	-	Alphas: 5,490 (99.9%)
^{226}Ra	1,600 Y	α	Very High	0.0006	0.0001	-	-	Alphas: 4,602 (5.6%) 4,785 (94.6%)
^{228}Th	1.91 Y	α	Very High	0.00001	0.000001	-	-	Alphas: 5,341 (26.7%) 5,423 (72.7%) Electrons: 9 (9.6%) 65 (19.1%) 80 (5.2%) X-rays: 12 (9.6%)
^{238}Pu	87.74 Y	α, SF	Very High	0.000007	0.000001	-	-	Alphas: 5,457 (28.3%) 5,499 (71.6%) Electrons: 10 (9.1%) 22 (20.7%) 38 (7.6%) X-rays: 14 (11.6%)

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Radionuclide	Half Life	Decay Mode	Internal Toxicity Class	ALI (mCi)	Container Posting Level (mCi)	Γ R/h @ 1 cm per mCi	TVL mm Pb	Radiation Types KeV (% per decay)
^{238}U	4.5 x 10^9 Y	α, SF	Very High	0.00004	0.1	-		Alphas: 4,147 (23%) 4,196 (77%) Electrons: 10 (8.2%) 29 (16.8%) 44 (6.1%) X-rays: 13 (9%)
^{239}Pu	24,065 Y	α	Very High	0.000006	0.000001	-	-	Alphas: 5,105 (11.5%) 5,143 (15.1%) 5,155 (73.3%) Electrons: 7 (19%)
^{241}Am	432.2 Y	α	Very High	0.000006	0.000001	0.1	0.4	Alphas: 5,443 (12.8%) 5,486 (85.2%) Gammas: 60 (35.9%)
^{244}Cm	18.11 Y	α, SF	Very High	0.00001	0.000001	-	-	Alphas: 5,763 (23.6%) 5,805 (76.4%) Electrons: 10 (6.9%) 20 (17.2%) 37 (6.3%) X-rays: 14 (10.3%)
^{250}Cf	13.08 Y	α	Very High	0.000009	0.000001	-	-	Alphas: 5,989 (16.2%) 6,031 (83.4%) Electrons: 18 (12%) X-rays: 15 (7.8%)
^{252}Cf	2.638 Y	α, SF	Very High	0.00002	0.000001	-	-	Alphas: 6,076 (15.2%) 6,118 (81.6%) Electrons: 19 (11.2%) X-rays: 15 (7.3%)

DECAY MODES: α = Alpha Decay, β = Beta Decay, β+ = Positron Decay, EC = Electron Capture, IT = Isomeric Transition (gamma) Decay, SF = Spontaneous Fission ALI = Annual Limit on Intake, Γ = Specific Gamma Ray Constant, TVL = Tenth Value Layer

APPENDIX C

RADIOLOGICAL STAY TIME TABLE

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RADIOLOGICAL STAY TIME TABLE

		ALL EMERGENCY ACTIVITIES				PROTECT PROPERTY	LIFE SAVING	LIFE-SAVING VOLUNTEER ONLY		POTENTIALLY LETHAL DOSES	
		100 mrem 0.1rem	1 rem	2 rem	5 rem	10 rem	25 rem	50 rem	100 rem	300 rem	LD$_{(50)}$ 500 rem
SAFE AREAS	10 ∝R/hr	1 yr									
	50 ∝R/hr	12 wk	2 yr								
	100 ∝R/hr	6 wk	1 yr								
	500 ∝R/hr	8 day	12 wk	24 wk	1 yr						
	750 ∝R/hr	5.5 day	8 wk	16 wk	40 wk	1.5 yr					
	1 mR	4 day	6 wk	12 wk	30 wk	1 yr					
HOT LINE	2 mR/hr	50 hr	3 wk	6 wk	15 wk	30 wk	74 wk				
DANGER ---- HOT ZONE OPERATIONS ---- DANGER	5 mR/hr	20 hr	8 day	16 day	6 wk	12 wk	30 wk	1 yr			
	7.5 mR/hr	13 hr	5.5 day	11 day	4 wk	8 wk	20 wk	40 wk	80 wk		
	10 mR/hr	10 hr	4 day	8 day	3 wk	6 wk	15 wk	30 wk	1 yr		
	20 mR/hr	5 hr	2 day	4 day	10 day	3 wk	7 wk	15 wk	30 wk	2 year	
	30 mR/hr	3.3 hr	33 hr	3 day	1 wk	2 wk	5 wk	10 wk	20 wk	60 wk	
	40 mR/hr	2.5 hr	1 day	2 day	5 day	11 day	4 wk	8 wk	15 wk	1 yr	
	50 mR/hr	2 hr	20 hr	40 hr	4 day	8 day	3 wk	6 wk	12 wk	35 wk	1 yr
	75 mR/hr	80 min	13 hr	1 day	3 day	5.5 day	2 wk	4 wk	8 wk	24 wk	40 wk
	100 mR/hr	1 hr	10 hr	20 hr	2 day	4 day	10 day	3 wk	6 wk	18 wk	30 wk
	200 mR/hr	30 min	5 hr	10 hr	1 day	2 day	5 day	11 day	3 wk	9 wk	15 wk
	300 mR/hr	20 min	3 hr	7 hr	16 hr	32 hr	3 day	1 wk	2 wk	6 wk	10 wk
	400 mR/hr	15 min	2.5 hr	5 hr	12 hr	1 day	2.5 day	5.5 day	11 day	31 day	52 day
	500 mR/hr	12 min	2 hr	4 hr	10 hr	19 hr	2 day	4 day	8 day	25 day	40 day
	750 mR/hr	8 min	78 min	2.6 hr	6.5 hr	13 hr	33 hr	3 day	5.5 day	16 day	4 wk
	1000 mR/hr	6 min	1 hr	2 hr	5 hr	10 hr	25 hr	40 hr	4 day	12 day	3 wk
	1.5 R/hr	3 min	40 min	78 min	3.5 hr	6.5 hr	16.5 hr	33 hr	3 day	8 day	14 day
	2 R/hr	3 min	30 min	1 hr	2.5 hr	5 hr	13 hr	25 hr	2 day	6 day	11 day
	3 R/hr	2 min	20 min	40 min	100 min	200 min	8 hr	16 hr	1.5 day	4 day	1 wk
	4 R/hr	90 sec	15 min	30 min	75 min	2.5 hr	6.5 hr	13 hr	1 day	3 day	6 day
	5 R/hr	72 sec	12 min	24 min	1 hr	2 hr	5 hr	10 hr	20 hr	2.5 day	4 day
	7.5 R/hr	48 sec	8 min	16 min	40 min	78 min	200 min	6.5 hr	13 hr	40 hr	3 day
LIFE SAVING ONLY	10 R/hr	36 sec	6 min	12 min	30 min	1 hr	2.5 hr	5 hr	10 hr	30 hr	50 hr
	20 R/hr	18 sec	3 min	6 min	15 min	30 min	75 min	2.5 hr	5 hr	15 hr	1 day
	30 R/hr	10 sec	2 min	4 min	10 min	20 min	50 min	96 min	3 hr	10 hr	17 hr
	40 R/hr	9 sec	90 sec	3 min	7.5 min	15 min	38 min	75 min	2.5 hr	7.5 hr	12 hr
	50 R/hr	7 sec	72 sec	80 sec	6 min	12 min	30 min	1 hr	2 hr	6 hr	10 hr
	75 R/hr	5 sec	50 sec	100 sec	4 min	8 min	20 min	40 min	80 min	4 hr	6.5 hr
	100 R/hr	4 sec	30 sec	1 min	3 min	6 min	15 min	30 min	1 hr	3 hr	5 hr
	200 R/hr	2 sec	18 sec	30 msec	90 sec	3 min	7 min	15 min	30 min	90 min	2.5
LETHAL POTENTIAL	300 R/hr	1 sec	10 sec	20 sec	1 min	2 min	5 min	10 min	20 min	1 hr	100 min
	400 R/hr	1 sec	9 sec	15 sec	45 sec	90 sec	3.5 min	7.5 min	15 min	45 min	75 min
	500 R/hr	1 sec	7 sec	15 sec	30 sec	72 sec	3 min	6 min	12 min	36 min	1 hr
	750 R/hr	1 sec	5 sec	9 sec	24 sec	48 sec	2 min	4 min	8 min	24 min	40 min
	1000 R/hr	1 sec	3 sec	7 sec	18 sec	36 sec	90 sec	3 min	6 min	18 min	

Initial Action Levels

Normal Background	8 - 16 ∝R/hr
Potential Contamination	2x'sBackground
Hot Line	2 mR/hr

EPA Established Exposure Limits

Any Emergency Activity Limit	5 rem total dose
Protect Significant Property	10 rem total dose
Life Saving Rescue	25 rem total dose
Mild toxic affects	50-100 rem dose
LD$_{(50)}$	500 rem total dose

1 sievert (1 Sv)= 100 REM (100 R)

1 milli sievert (1 mSv) = 100 milli REM (100 mR)

UNIT 10:
CORROSIVES

TERMINAL OBJECTIVE

The students will be able to:

10.1 Create response objectives based on a hazard analysis of an incident involving corrosive materials.

ENABLING OBJECTIVES

The students will be able to:

10.1 Define terms related to corrosivity (pH, strength, concentration, acid, base, neutralization).

10.2 Determine the type and amount of neutralization materials required.

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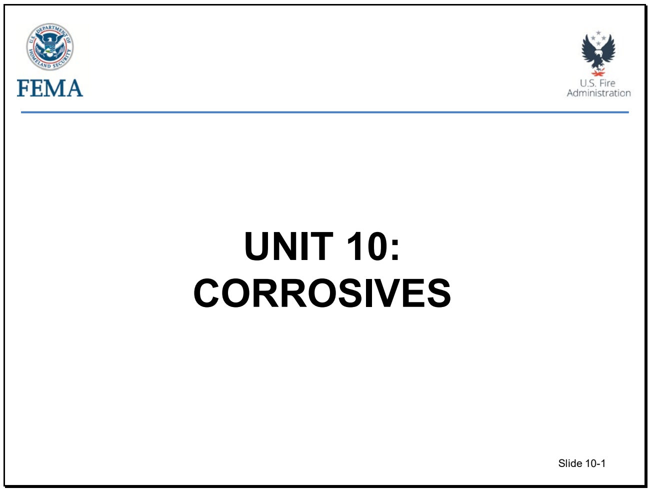
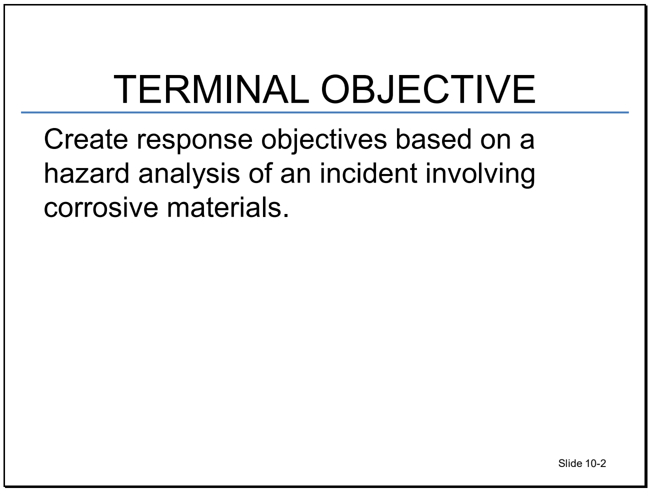


FEMA

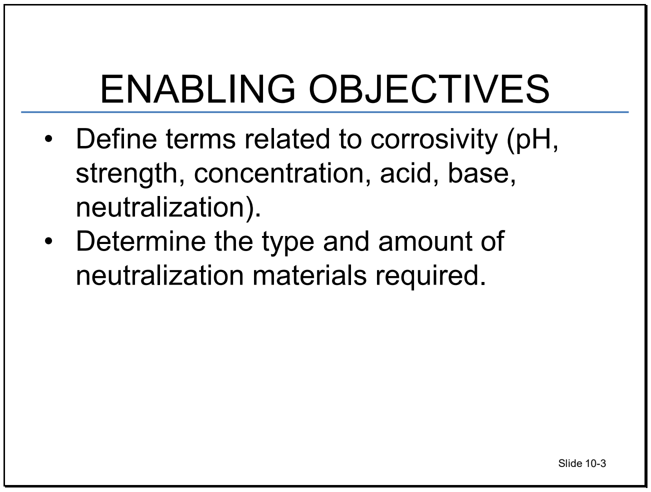
U.S. Fire Administration

UNIT 10:
CORROSIVES



TERMINAL OBJECTIVE

Create response objectives based on a hazard analysis of an incident involving corrosive materials.



ENABLING OBJECTIVES

- Define terms related to corrosivity (pH, strength, concentration, acid, base, neutralization).
- Determine the type and amount of neutralization materials required.

I. INTRODUCTION

CORROSIVE MATERIALS

Any solid, liquid or gas that burns, irritates or destructively attacks organic tissues.

Photo courtesy of Pixabay.

Terminology.

A. A **corrosive** product is any solid, liquid or gas that burns, irritates or destructively attacks human tissues and metals.

   1. Acids: attack metals and will also burn the skin and mucus membranes.

   2. Caustics (also known as bases or alkaline): attack human tissues and cause severe irritation and destruction resulting in deep tissue necrosis.

B. After flammable liquids, corrosives are the most frequently released products.

C. When a responder reports that they have a “corrosive material,” that doesn’t say much about the material.

D. More detail is necessary because very different tactics will be needed for acids vs. bases, not to mention being able to determine which neutralization methods are used.

E. First responders should understand the relationships between the different terms associated with corrosive materials.

ACTIVITY 10.1

Corrosive Definitions

Purpose

Define terminology related to corrosive materials.

Directions

1. Working with your group and without using electronic sources, define the following six terms related to corrosive materials as you understand them.

   a. pH.

   ____

   ____

   ____

   b. Strength.

   ____

   ____

   ____

   c. Concentration.

   ____

   ____

   ____

   d. Acid.

   ____

   ____

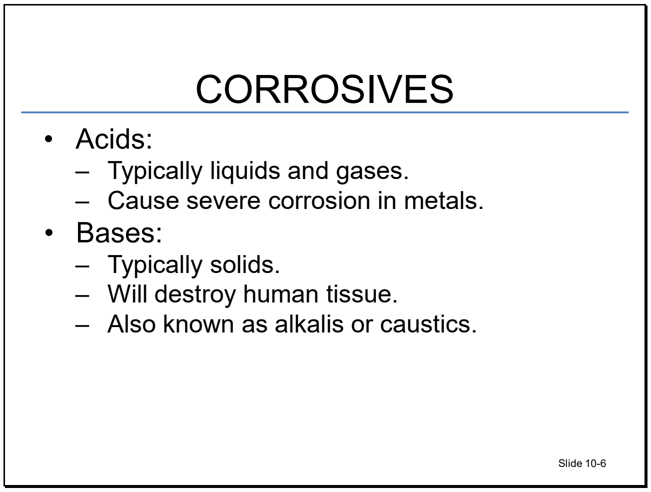
   ____

e. Base.

f. Neutralization reaction.

2. Explain generally how these terms are interrelated.

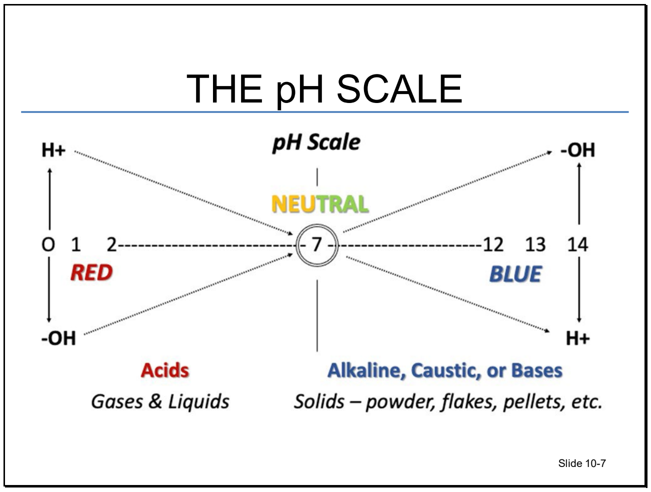
II. INTRODUCTION TO CORROSIVES



CORROSIVES

- Acids:
  - Typically liquids and gases.
  - Cause severe corrosion in metals.
- Bases:
  - Typically solids.
  - Will destroy human tissue.
  - Also known as alkalis or caustics.

Slide 10-6



THE pH SCALE

pH Scale

Acids

Gases & Liquids

Alkaline, Caustic, or Bases

Solids – powder, flakes, pellets, etc.

Slide 10-7

A. Corrosives come in all physical states.

1. Acids.

   a. Are typically liquids and gases.

   b. Cause severe corrosion primarily in metals.

   c. Acid gases can form liquid acids in contact with moisture, including the human body.

   d. When the acid releases the H^+ ion, it rips away its electron.

      – The H^+ now looks for an electron which is readily given up by most metals.

- This makes the acid an **anion** and makes the metal a **cation**.
- When anions and cations combine, corrosion occurs.

2. Bases.

   a. Are typically solids unless made into solutions.

   b. Will cause destruction to human tissues.

   c. Are also called alkalis or caustics.

VIDEO PRESENTATION

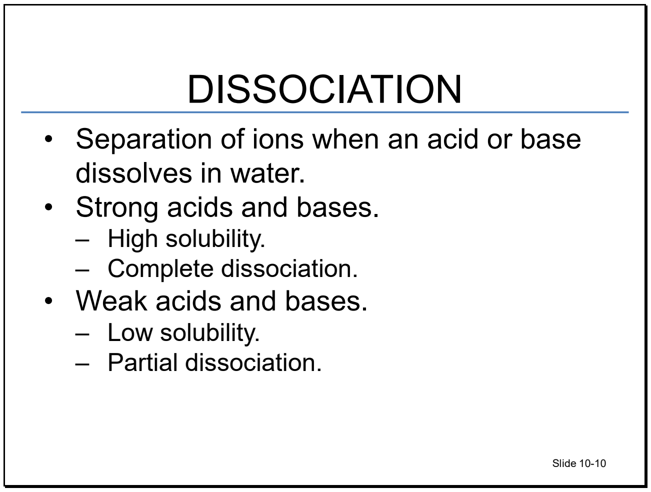
"COKE CANS IN ACID AND BASE - PERIODIC TABLE OF VIDEOS"

https://www.youtube.com/watch?v=WnPrtYUKke8

VIDEO PRESENTATION

"VAPORIZING CHICKEN IN ACID"

https://www.youtube.com/watch?v=CTVd_WxbIGI



DISSOCIATION

- Separation of ions when an acid or base dissolves in water.
- Strong acids and bases.
  - High solubility.
  - Complete dissociation.
- Weak acids and bases.
  - Low solubility.
  - Partial dissociation.

Slide 10-10

B. Dissociation and dissolution.

1. Dissociation.

a. Is the separation of ions.

b. Occurs when an acid or base dissolves in water.

c. Degree depends on solubility of the corrosive in water.

– Strong acids and bases = high solubility = complete dissociation.

– Weak acids and bases = low solubility = only partial dissociation.

d. Bases dissociate and form OH^{-1} (hydroxyl) ions.

e. Acids dissociate and form H^+ (hydronium) ions.

f. These ions are H_2O pulled apart — ionized.

2. Dissolution.

a. Is the process of dissolving.

b. Generally requires substances that are both polar (mixed with water or a solvent such as ether) or both nonpolar.

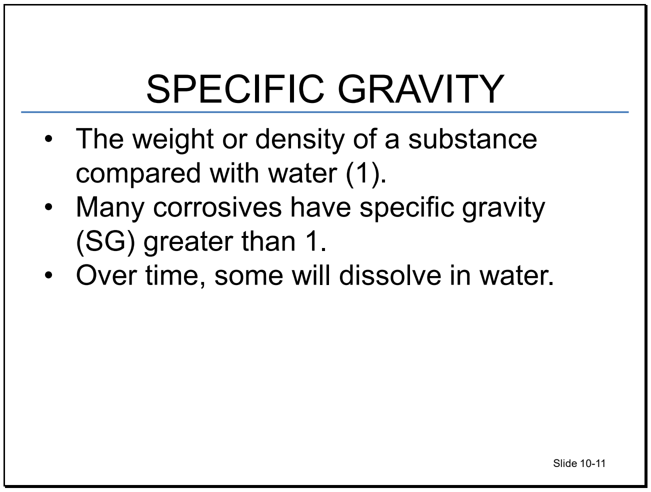
– Solvent.

– Solute.

c. Anhydrous, glacial and fuming are highly concentrated = 35%-98%.

d. Dilute concentrations 10% or less are mostly water.

III. DENSITY AND TEMPERATURE OF CORROSIVES



SPECIFIC GRAVITY

- The weight or density of a substance compared with water (1).
- Many corrosives have specific gravity (SG) greater than 1.
- Over time, some will dissolve in water.

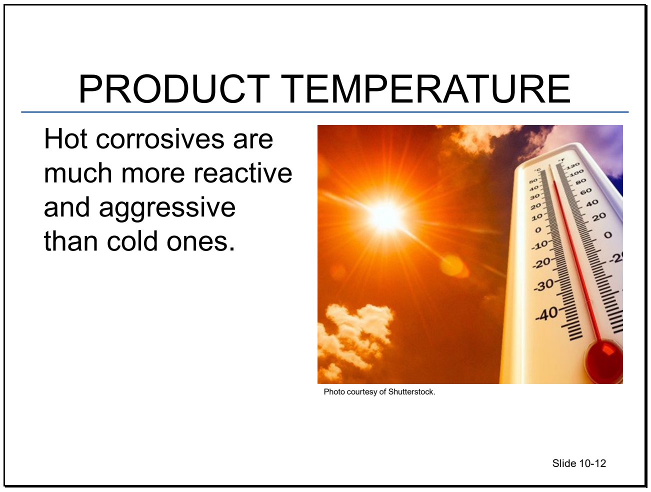
Slide 10-11

A. Specific gravity (SG).

1. Is the weight or density of a substance compared to water (with water being 1).

2. Many corrosives have SGs greater than 1.

3. Over time, some of these will dissolve in water.



PRODUCT TEMPERATURE

Hot corrosives are much more reactive and aggressive than cold ones.

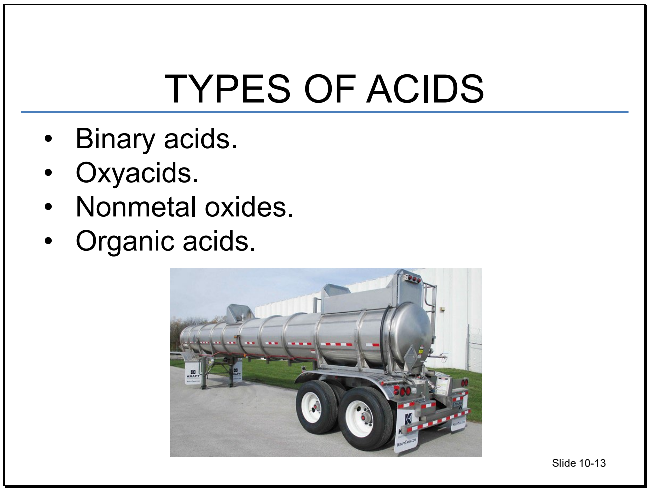
Photo courtesy of Shutterstock.

Slide 10-12

B. Product temperature.

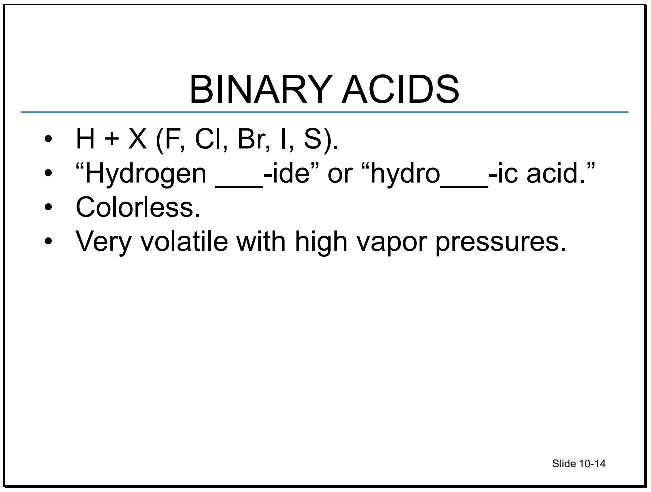
1. Is a concern with corrosives.
2. Hot acids and bases are much more reactive and aggressive than cold ones.
3. A hot corrosive is a very reactive and aggressive corrosive.

IV. TYPES OF ACIDS



TYPES OF ACIDS

- Binary acids.
- Oxyacids.
- Nonmetal oxides.
- Organic acids.

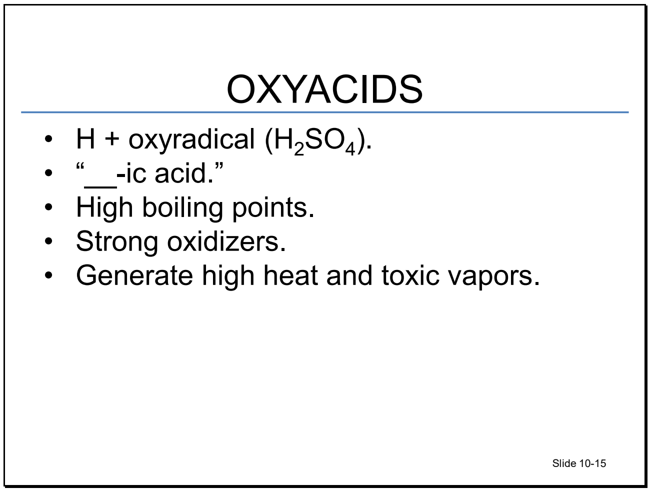


BINARY ACIDS

- H + X (F, Cl, Br, I, S).
- “Hydrogen ___-ide” or “hydro___-ic acid.”
- Colorless.
- Very volatile with high vapor pressures.

A. Binary acids.

H + X (F, Cl, Br, I, S) name “Hydrogen” first, ends in “-ide.”

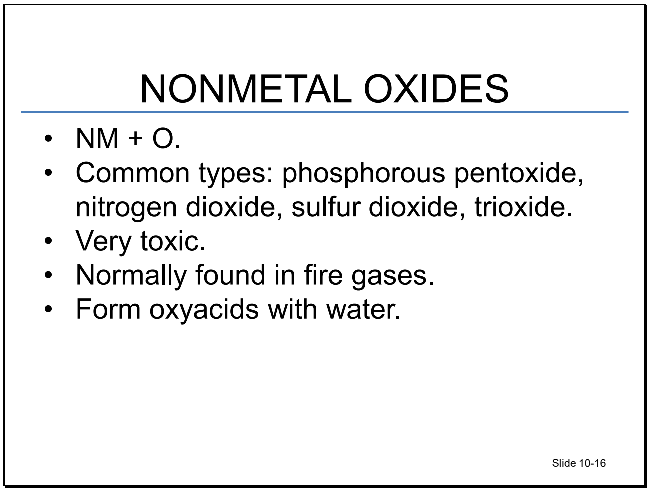


OXYACIDS

- H + oxyradical (H_2SO_4).
- "__-ic acid."
- High boiling points.
- Strong oxidizers.
- Generate high heat and toxic vapors.

B. Oxyacids.

H + oxyradical (H_2SO_4) = Needs 2 H attached to the oxyradical.

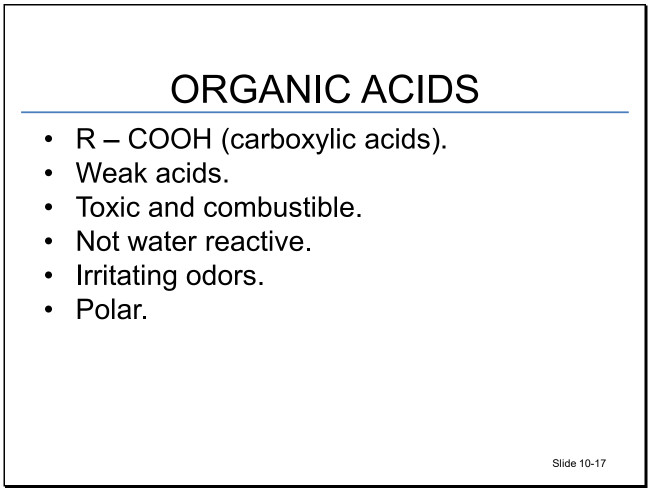


NONMETAL OXIDES

- NM + O.
- Common types: phosphorous pentoxide, nitrogen dioxide, sulfur dioxide, trioxide.
- Very toxic.
- Normally found in fire gases.
- Form oxyacids with water.

C. Nonmetal oxides.

Combination of a nonmetal and oxygen (NM + O).



ORGANIC ACIDS

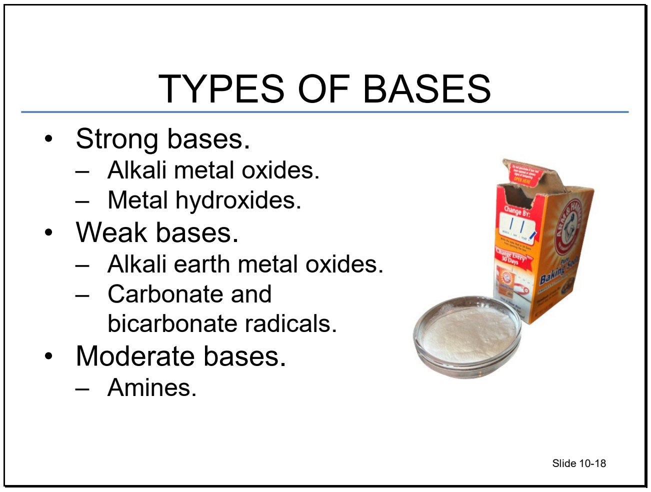
- R – COOH (carboxylic acids).
- Weak acids.
- Toxic and combustible.
- Not water reactive.
- Irritating odors.
- Polar.

Slide 10-17

D. Organic acids.

Combination of hydrogen and carbon, forming the carboxylic acid family.

V. TYPES OF BASES



TYPES OF BASES

- Strong bases.
  - Alkali metal oxides.
  - Metal hydroxides.
- Weak bases.
  - Alkali earth metal oxides.
  - Carbonate and bicarbonate radicals.
- Moderate bases.
  - Amines.

Slide 10-18

A. Strong bases.

1. Alkali metal oxides (very strong).

2. Metal hydroxides.

B. Weak bases.

1. Alkali earth metal oxides.

2. Carbonate (CO_3) and bicarbonate (HCO_3) radicals.

a. Excellent for neutralization.

b. Will yield water, carbon dioxide and salt.

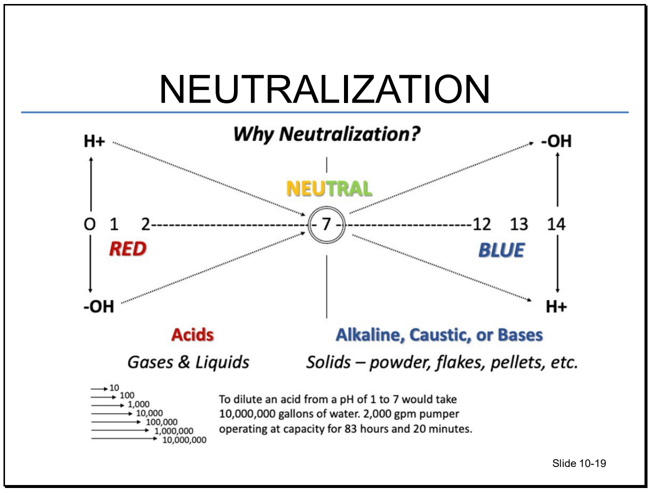
C. Moderate bases.

Amines.

1. Nitrogen-bearing compounds.

2. Are toxic and produce toxic and flammable vapors like ammonia (NH_3), HCN and nitrogen oxides.

VI. NEUTRALIZATION



NEUTRALIZATION

Why Neutralization?

Acids

Gases & Liquids

Alkaline, Caustic, or Bases

Solids – powder, flakes, pellets, etc.

To dilute an acid from a pH of 1 to 7 would take 10,000,000 gallons of water. 2,000 gpm pumper operating at capacity for 83 hours and 20 minutes.

Slide 10-19

A. How it works.

1. Strong acids and bases can be neutralized with a weak source of the opposite.

2. When acids and bases contact each other, they immediately react, and the active ingredient of both corrosive materials (H+ and OH-) is eliminated.

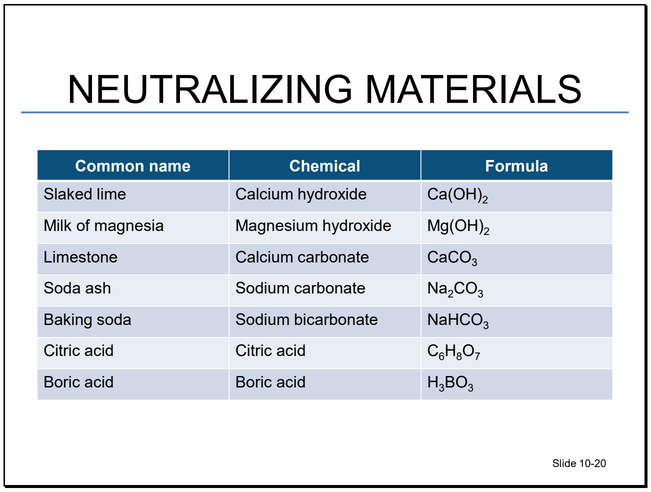
3. The neutralization reaction is exothermic.

$$H + OH = H_2O + \text{Heat}$$

4. Either one or the other must be in water for this reaction to occur.

5. Neutralization is not done as a manner of decontamination for responders since the reaction is exothermic.

6. The stronger the neutralizing agent is, the more heat is generated.



NEUTRALIZING MATERIALS

Common name	Chemical	Formula
Slaked lime	Calcium hydroxide	$Ca(OH)_2$
Milk of magnesia	Magnesium hydroxide	$Mg(OH)_2$
Limestone	Calcium carbonate	$CaCO_3$
Soda ash	Sodium carbonate	Na_2CO_3
Baking soda	Sodium bicarbonate	$NaHCO_3$
Citric acid	Citric acid	$C_6H_8O_7$
Boric acid	Boric acid	H_3BO_3

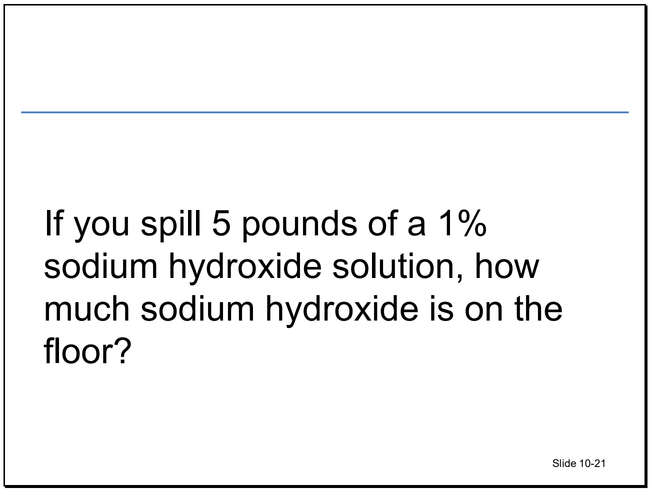
Slide 10-20

B. Common names for neutralizing materials.

Table 10.1: Common names for neutralizing materials

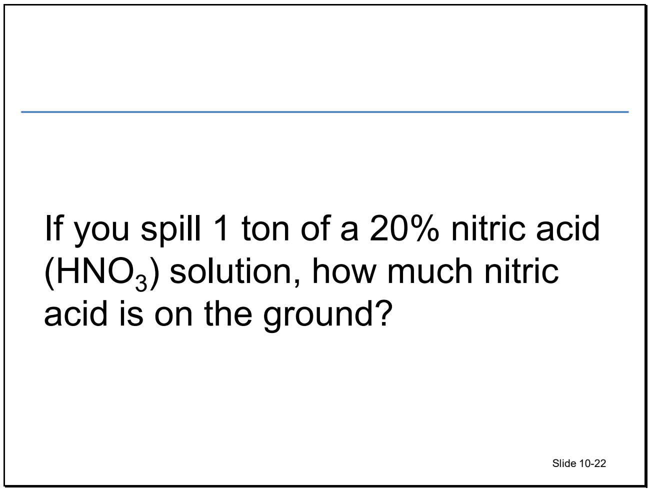
Common name	Chemical name	Chemical formula	Common uses
Slaked lime	Calcium hydroxide	$Ca(OH)_2$	Tanning leather, cement mixes
Milk of magnesia	Magnesium hydroxide	$Mg(OH)_2$	Antacid, laxative, pharmaceuticals
Limestone	Calcium carbonate	$CaCO_3$	Steel manufacturing, mining, water treatment
Soda ash	Sodium carbonate	Na_2CO_3	Detergents, household cleaning compounds
Baking soda	Sodium bicarbonate	$NaHCO_3$	Cooking, food preparation
Citric acid	Citric acid	$C_6H_8O_7$	Antioxidant, preservative, antimicrobial
Boric acid	Boric acid	H_3BO_3	Fireproofing, antiseptic, preservative

C. Determining spills.



If you spill 5 pounds of a 1% sodium hydroxide solution, how much sodium hydroxide is on the floor?

Slide 10-21



If you spill 1 ton of a 20% nitric acid (HNO_3) solution, how much nitric acid is on the ground?

Slide 10-22

D. Dealing with density.

1. If you have a known volume of a material, you must know the density of the material to determine its weight.

   a. 1 ml of water weighs 1 gram.

   b. 1 ml of mercury weighs 13.55 grams.

   c. They have the same volume but different densities.

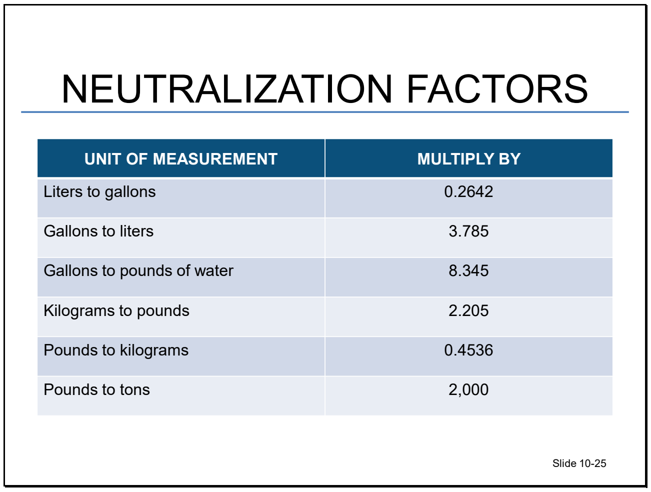
If 1 gallon of water weighs about 8.3 pounds, how much does 200 gallons weigh?

If sulfuric acid (H_2SO_4) has an SG of 1.84, how much does 200 gallons of sulfuric acid weigh?

2. All acids are very dense liquids.

   a. This density is why the U.S. Department of Transportation (DOT) 412, acid hauler, has such a small diameter.

   b. A gallon of sulfuric weighs around 15 pounds.



NEUTRALIZATION FACTORS

UNIT OF MEASUREMENT	MULTIPLY BY
Liters to gallons	0.2642
Gallons to liters	3.785
Gallons to pounds of water	8.345
Kilograms to pounds	2.205
Pounds to kilograms	0.4536
Pounds to tons	2,000

Slide 10-25

E. Neutralization factors.

1. H+ vs. OH- in the process.

   a. The ability of a base to "suck up" an acid and vice versa is dependent on the number of bond sites left over after the reaction.

   b. If HCl combines with $NaHCO_3$ (sodium bicarbonate), the metal (Na) combines with the nonmetal (Cl) to form a salt (NaCl).

   c. The remaining oxysalt radical carbonate (CO_3), which is in column -2, has two bonding sites, one of which is already taken up by the H+ in the formula, leaving only -1 bonding site for the H+ in the acid.

   d. $NaHCO_3$ will combine with HCl specifically on a 1:1 ratio. This results in the formation of H_2CO_3 (carbonic acid), a weak acid with a pH near neutral.

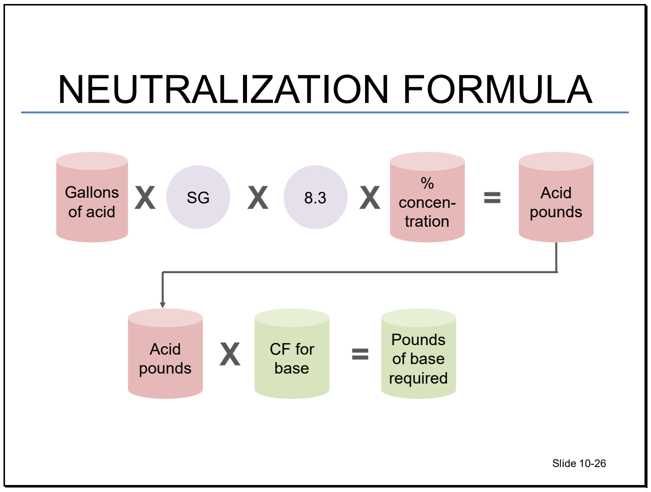
2. Conversion formulas.

Table 10.2: Conversion factors

Units of measurement	Multiply by	Example compound	SG
Liters to gallons	0.2642	HNO_3	1.5
Gallons to liters	3.785	H_2SO_4	1.84
Gallons to pounds of H_2O	8.345	HCl 30%	1.19
Kilograms to pounds	2.205	HF 50%	1.15
Pounds to kilograms	0.4536	$HClO_4$	1.76
Pounds to tons	2,000	H_2O	1

Table 10.3: Measurement equivalents

This	Equals this
1 liter	0.2642 gallon
1 gallon	3.785 liters
1 gallon of H_2O	8.345 pounds
1 kilogram	2.205 pounds
1 pound	0.4536 kilograms
1 ton	2,000 pounds
1 pound	16 ounces
1 ounce	28.4 grams
1 pound	454 grams



NEUTRALIZATION FORMULA

Gallons of acid X SG X 8.3 X % concentration = Acid pounds

Acid pounds X CF for base = Pounds of base required

F. Neutralization formula.

Gallons of acid x SG x 8.3 x % concentration = acid pounds x Correction Factors (CFs) for base = **pounds of base required.**

G. Neutralization example.

1. 1,000-gallon spill of 50% sulfuric acid.
2. Your available base is sodium carbonate.
3. 1,000 gallons x 1.84 x 8.3 x 0.5 = 7,663 pounds of sulfuric acid.
4. 7,663 x 1.082 = 8,292 pounds of sodium carbonate needed.

Table 10.4: Specific gravities and correction factors for bases

Neutralizing agent	Sulfuric SG 1.84	Nitric SG 1.50	Hydrochloric SG 1.19	Phosphoric SG 1.42
Sodium carbonate (soda ash)	1.082	0.841	1.452	1.622
Calcium hydroxide (lime)	0.755	0.587	1.014	1.622
Sodium bicarbonate (baking soda)	1.673	1.302	2.247	2.541

ACTIVITY 10.2

Corrosive Product Analysis and Neutralization Calculations

Purpose

Determine response objectives for an incident involving a spill of a corrosive material.

Directions

1. Review your assigned scenario with your group.
2. Create response objectives regarding:
   a. Appropriate personal protective equipment (PPE).
   b. Initial isolation zone distance.
   c. Appropriate decontamination methods.
3. If neutralization should be requested, complete a neutralization calculation using the following general formula:
   a. Quantity of acid discharged x SG of the acid x weight of water 8.33 x the percentage of concentration = **weight of the acid in pounds.**
   b. Weight of the acid discharged in pounds x acid/base conversion factor for the base = **estimated weight of the neutralizing agent in pounds.**
4. Complete a Product Hazard Analysis Worksheet for the acid.
5. Share your work on your easel pad.
6. Choose a representative to report your conclusions to the class.

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ACTIVITY 10.2 (cont'd)

Scenarios

Scenario 1

A technician at the State Crime Lab spilled 5 gallons of 34% HCl on the lab floor. The Hazard Response Team (HRT) brought sodium bicarb ($NaHCO_3$) to the call.

Scenario 2

A local soda bottling plant reports a spill of 110 gallons of 50% phosphoric acid on the production floor and trough system. The HRT has sodium carbonate (Na_2CO_3) on hand if needed.

Scenario 3

A low-speed derailment in a switching yard results in an acid car on its side. Rail personnel estimate 2,000 gallons of 50% HNO_3 (nitric) in pooling. Fortunately, a large amount of soda ash (Na_2CO_3) is in the yard.

Scenario 4

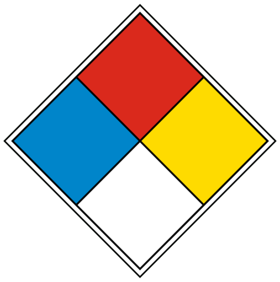
A local refinery is requesting an HRT for a 2-inch fill line that has burst while loading a highway tanker with 3,400 gallons of 35% sulfuric acid. The Emergency Response Team (ERT) at the refinery locates slaked lime ($Ca(OH)_2$) if needed.

Scenario 5

A local high school chemistry teacher has broken a 2.5 liter glass jar of 30% HCl (hydrochloric acid) in his lab. The HRT arrives with a 50 pound bag of sodium bicarb ($NaHCO_3$).

Scenario 6

Over the weekend, a 55 gallon stainless steel drum of 98% H_2SO_4 (sulfuric acid), located on an outside loading dock, was full but now has apparently leaked out all of the acid onto the dock and the slope drain below it. The facility has 500 pounds of sodium carbonate (Na_2CO_3) on hand for such an incident.



ACTIVITY 10.2 (cont'd)

Product Hazard Analysis Worksheet

Group Number: ________ **Presenter:** ________________________

Temp: _________ **°F** **R/H:** _________**%**

Product Name:_________________________________ **Family:**_________________________

Data Points	Result	No Data	Hazard Consideration
Physical Properties			
Physical State			
Vapor Pressure			
Boiling Point			
Vapor Density			
Specific Gravity			
Solubility			
Flammability			
Flash Point			
LEL/UEL			
Flammable Range			
Ignition Temp.			
Toxicity			
Route of Exposure			
IDLH			
PEL/REL/STEL			
S/S of Exposure			
Biological			
Corrosivity			
pH			
Concentration			
Reactivity/Explosion			
Radioactivity			
Decay Mode	☐ **N/A** ☐ α ☐ β ☐ γ		
Half Life			

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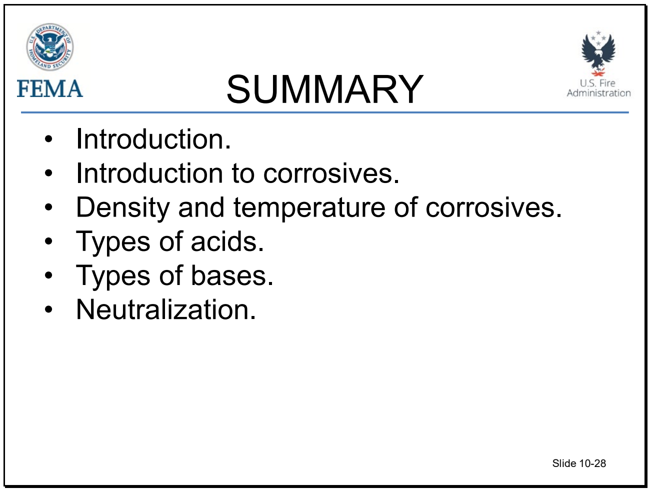
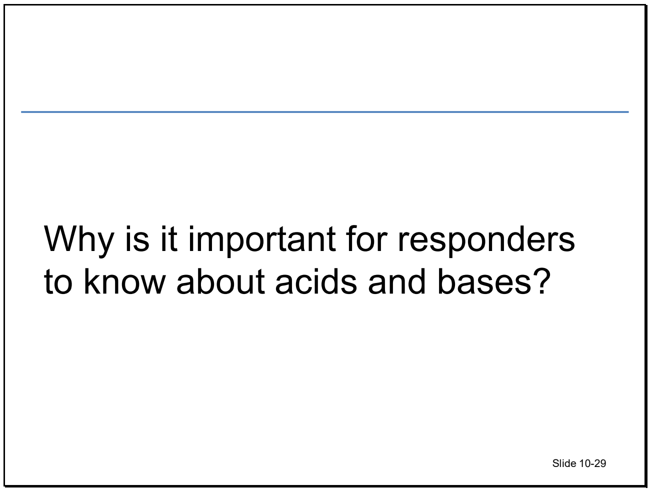
VII. SUMMARY

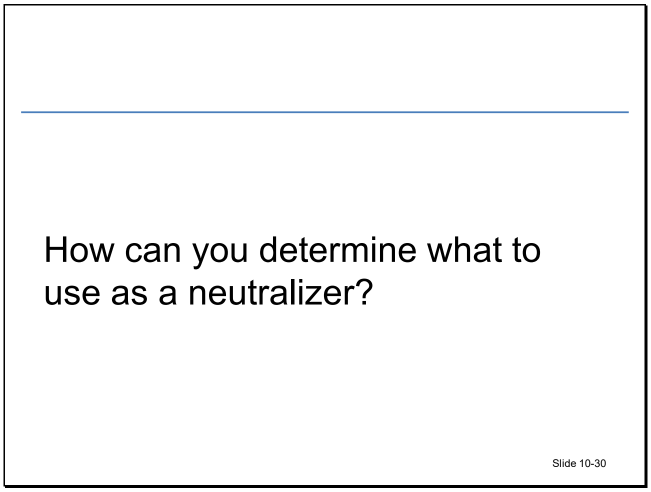


SUMMARY

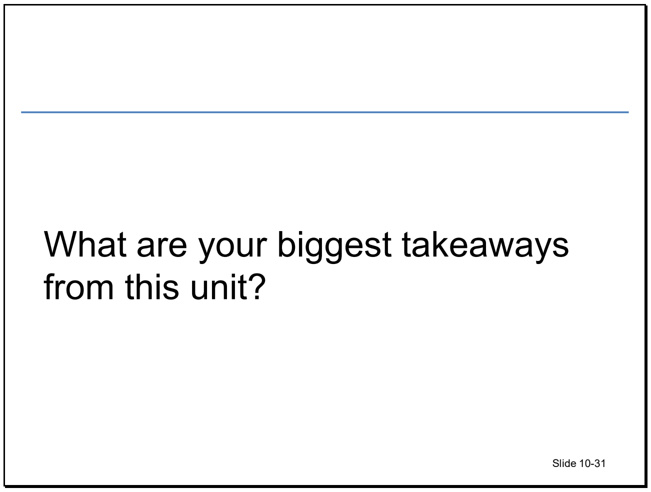
- Introduction.
- Introduction to corrosives.
- Density and temperature of corrosives.
- Types of acids.
- Types of bases.
- Neutralization.



Why is it important for responders to know about acids and bases?



How can you determine what to use as a neutralizer?



What are your biggest takeaways from this unit?

UNIT 11:
OXIDIZERS AND REACTIVE MATERIALS

TERMINAL OBJECTIVE

The students will be able to:

11.1 Analyze the hazards of products classified as oxidizers or reactive materials.

ENABLING OBJECTIVES

The students will be able to:

11.1 Create response objectives based on a hazard analysis of oxidizers and reactive materials.

11.2 Determine protective measures for an incident involving oxidizers and reactive materials.

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FEMA

U.S. Fire Administration

UNIT 11:
OXIDIZERS AND REACTIVE MATERIALS

TERMINAL OBJECTIVE

Analyze the hazards of products classified as oxidizers or reactive materials.

ENABLING OBJECTIVES

- Create response objectives based on a hazard analysis of oxidizers and reactive materials.
- Determine protective measures for an incident involving oxidizers and reactive materials.

I. INTRODUCTION

AGGRESSIVE MATERIALS

Corrosive materials

Reactive materials

Oxidizers

Slide 11-4

A. Aggressive materials: The term aggressive chemicals or aggressive materials is often used in hazardous materials to indicate a material that is:

1. Corrosive.

2. Oxidizing.

3. Chemically reactive: a chemical's tendency to interact with other chemicals.

B. The reactivity of a material must be considered when using common spill control substances such as diatomaceous earth, sawdust or other absorbent substances.

C. Most unwanted chemical reactions occur when corrosives and oxidizers come in contact with other substances.

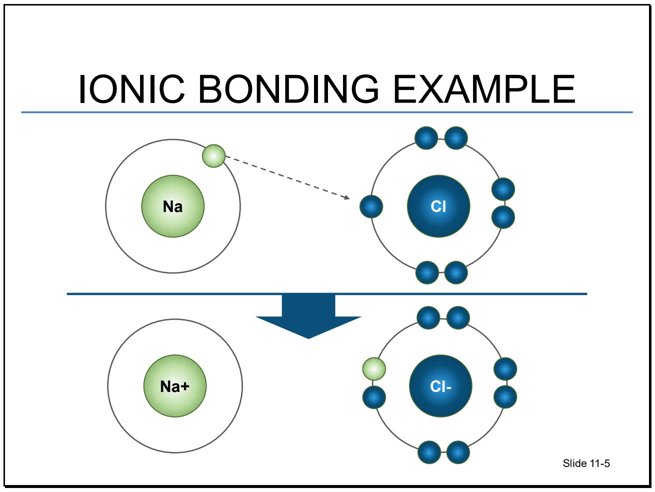
D. Additionally, some chemically reactive substances may react violently under certain circumstances.

II. OXIDATION AND OXIDIZERS

A. We commonly think of oxidation when we discuss combustion. However, there are actually two definitions that can be applied to this process as it relates to our study of hazardous materials.

B. In the case of combustion, oxidation is the gaining of oxygen by another substance or element.

C. The second way we can define oxidization is the taking of electrons.



IONIC BONDING EXAMPLE

1. As we saw in our discussion of the different types of bonding, we found that the transfer of electrons from one element to another element was called ionic bonding.

2. Ionic bonding is a form of oxidation.

3. The element that gives up an electron is being oxidized.

4. This can also happen between compounds where one compound takes electrons from another.

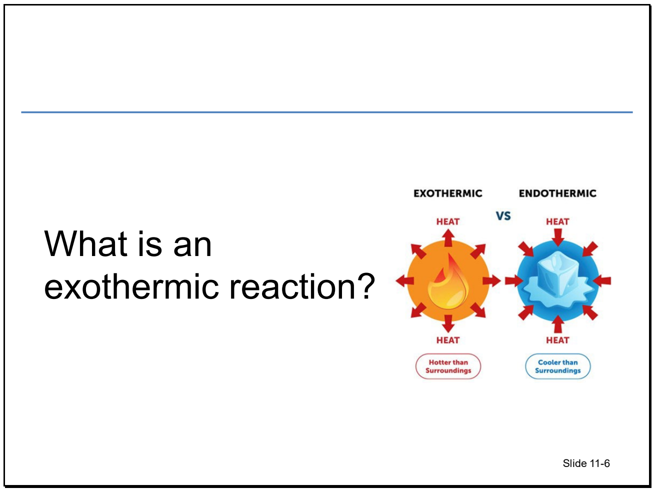
5. The compound that loses electrons is being oxidized, and the compound that is taking the electrons (the oxidizer) is being reduced.

6. Therefore, the process of reduction is coupled to an oxidation reaction. An oxidation-reduction reaction is also called “redox.”

III. HAZARDOUS OXIDATION REACTIONS

A. Exothermic reactions.

1. If the oxidizer is strong enough, it can cause other materials to react exothermically.



What is an exothermic reaction?

2. When the redox reaction occurs with a material that holds a large amount of stored energy, such as fuels, then exothermic reactions such as “hypergolic” combustion can occur.

3. Take care to avoid the contact of oxidizers with combustible materials. The violence of the reaction is difficult to predict and should always be met with caution.

VIDEO PRESENTATION

“POTASSIUM PERMANGANATE AND GLYCERIN DEMONSTRATION”

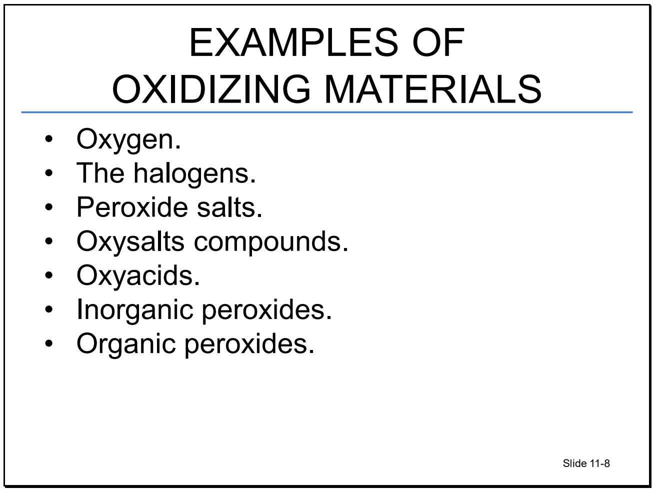
https://www.youtube.com/watch?v=tctWbvMnIHQ

B. Endothermic reaction.

1. In this case, more energy is required to facilitate the reaction than is released.

2. An example is the reaction of ammonium nitrate (an oxidizer) with water (a reducing agent), creating a sensation of cold.

3. That sensation of cold is due to the reaction absorbing energy.



EXAMPLES OF OXIDIZING MATERIALS

- Oxygen.
- The halogens.
- Peroxide salts.
- Oxysalts compounds.
- Oxyacids.
- Inorganic peroxides.
- Organic peroxides.

C. Examples of oxidizing materials.

1. Oxygen.

   a. Found in Group VI of the periodic table, oxygen is the most commonly encountered oxidizer.

   b. During the combustion process, oxygen readily bonds to elements that have been made available through the pyrolysis (thermal decomposition) process.

   c. Atmospheric oxygen is only present in a 21% concentration. Therefore, it does not readily oxidize most materials. However, it does have the ability to oxidize materials on a slower, less violent basis. We call it “fire” at its fastest.

   d. An example is atmospheric oxygen oxidizing iron to form iron oxide or rust.

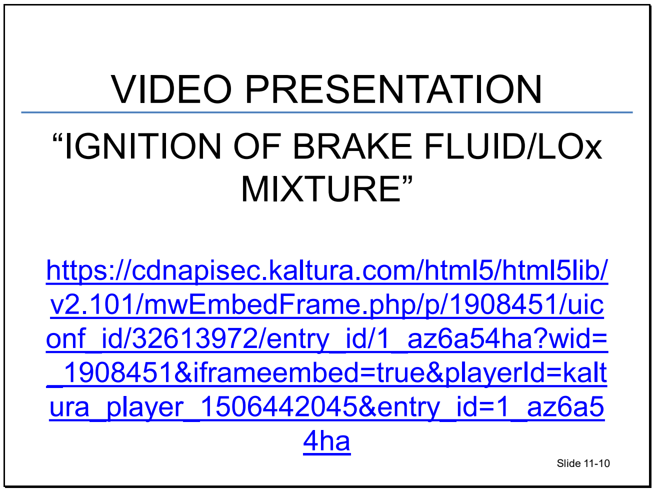
   e. Highly concentrated oxygen, such as liquid oxygen, will create a supercharged combustion environment should ignition occur. This will result in highly sensitized organic substances and hydrocarbons and will violently ignite and burn in the presence of an ignition source.

VIDEO PRESENTATION

"DROPPING A MATCH INTO LIQUID OXYGEN"

https://www.youtube.com/shorts/Z6rhk95-FVU

Slide 11-9



VIDEO PRESENTATION

"IGNITION OF BRAKE FLUID/LOx MIXTURE"

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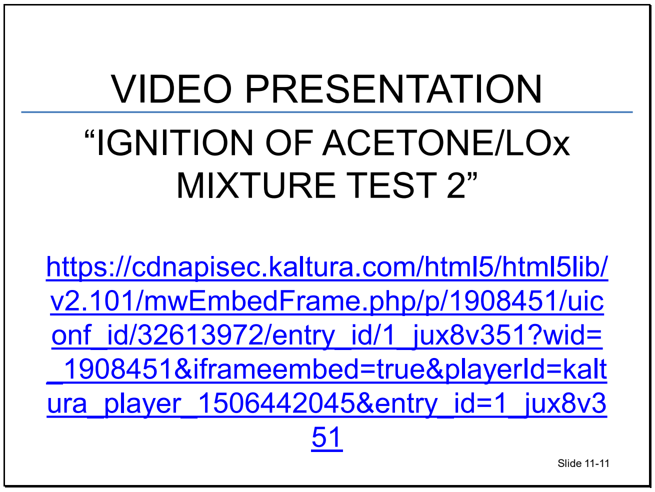

VIDEO PRESENTATION

"IGNITION OF ACETONE/LOx MIXTURE TEST 2"

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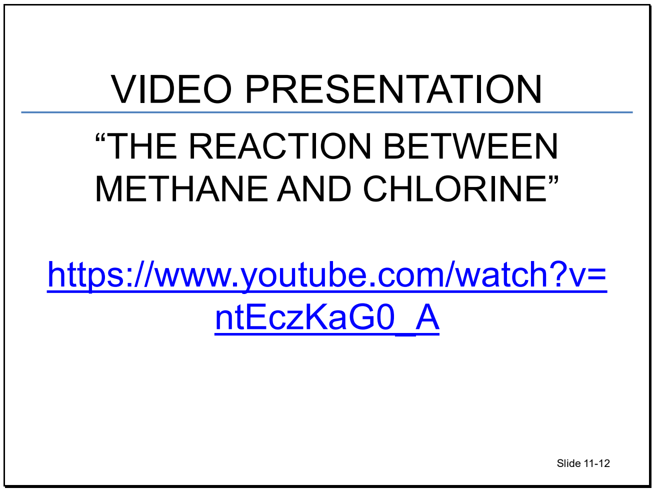
Slide 11-11

2. The halogens.

   a. The elements in Group VII of the periodic table are strongly electronegative.

b. Therefore, they will take, or aggressively share, electrons from other elements or compounds.

c. Halogens are very reactive because they add one more electron to their outer shell, a behavior making halogens oxidizers.



VIDEO PRESENTATION

“THE REACTION BETWEEN METHANE AND CHLORINE”

https://www.youtube.com/watch?v=ntEczKaG0_A

3. Peroxide salts.

   a. These materials are aggressively oxidized.

   b. Unlike diatomic oxygen in air, the reactivity of peroxide salts is due to the (-O-O-) peroxide which is a very unstable arrangement for oxygen.

4. Oxysalts compounds.

   a. The oxysalt compounds all have varying degrees of ability to oxidize other materials.

   b. In particular, the chlorates and nitrates are very strong oxidizers.

5. Oxyacids.

   a. Closely related to the oxysalts, the oxyacids were discussed in Unit 4: Inorganic Nonsalts. Oxysalts are combined with metals, and oxyacids are combined with hydrogen.

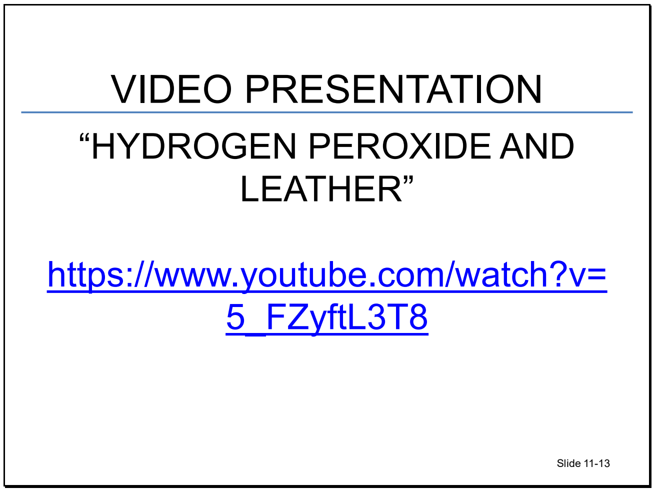
   b. Many of these strong acids also have oxidizing capabilities.

6. Inorganic peroxides.

   a. Hydrogen peroxide (H_20_2) is a strong oxidizer. In high concentration, it can cause organic materials to spontaneously combust.

   b. Household medicinal hydrogen peroxide is only a 3% concentration.

   c. Hydrogen peroxide can be found in concentrations as great as 70% to 90%.



VIDEO PRESENTATION

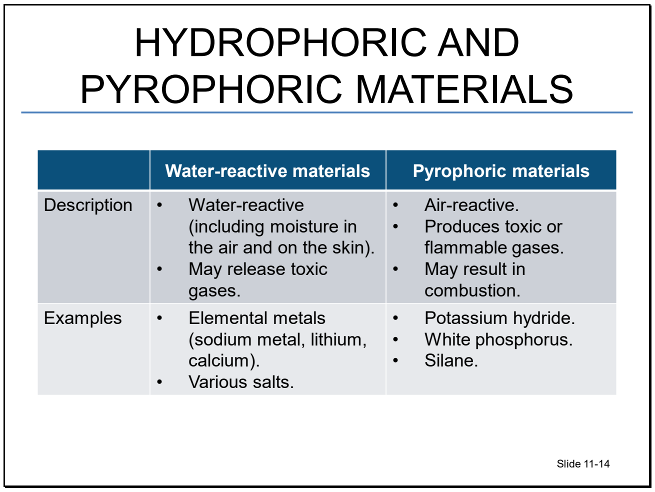
“HYDROGEN PEROXIDE AND LEATHER”

https://www.youtube.com/watch?v=5_FZyftL3T8

7. Organic peroxides.

   a. Organic peroxides, while an oxidizer, have other very unique hazards.

   b. These were discussed when we talked about hydrocarbon derivatives.



HYDROPHORIC AND PYROPHORIC MATERIALS

	Water-reactive materials	Pyrophoric materials
Description	• Water-reactive (including moisture in the air and on the skin). • May release toxic gases.	• Air-reactive. • Produces toxic or flammable gases. • May result in combustion.
Examples	• Elemental metals (sodium metal, lithium, calcium). • Various salts.	• Potassium hydride. • White phosphorus. • Silane.

D. Water-reactive and pyrophoric materials.

  1. The following substances can be solids, liquids or gases.

  2. Water-reactive.

    a. Materials that react when in contact with water (including moisture in the air and on the skin).

    b. Depending on the material involved, toxic gases may be released.

    c. Examples: elemental metals (sodium metal, lithium, calcium), various salts.

  3. Pyrophoric.

    a. Air-reactive materials.

    b. They produce toxic or flammable gas or result in combustion.

    c. Examples: potassium hydride, white phosphorus, silane.

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ACTIVITY 11.1

Analyzing Hazards of Oxidizers and Reactive Materials

Purpose

Analyze hazards associated with oxidizers and reactive materials.

Directions

1. Review the scenario with your table group.
2. Research the hazards of the materials involved in the incident and complete the Product Hazard Analysis Worksheet.
3. How does the information you found impact your decision-making related to each of the following incident considerations?
   a. Scene control.
   b. Personal protective equipment (PPE).
   c. Detection.
   d. Decontamination.
   e. Product hazard analysis.
4. Be prepared to share your group's findings and recommendations.

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ACTIVITY 11.1 (cont'd)

Scenario

A vehicle accident has occurred between an electric automobile with lithium-ion batteries and a commercial 28-foot cargo van for a pool supply company. Although the car is damaged, the damage does not appear to involve the lithium-ion batteries. The cargo van has overturned, destroying the cargo area and spilling its contents onto the asphalt road and grassy shoulder.

The following items have been spilled throughout the area:

- Multiple (six to eight) 100-pound fiberboard drums of calcium hypochlorite.
- A pallet of 40-pound bags of pool salt (sodium chloride).
- 180 gallons of diesel fuel from saddle tanks.

The very busy major roadway is shut down, and afternoon rush hour is approaching. All occupants of the vehicles are out and being attended to by medical personnel. None are contaminated.

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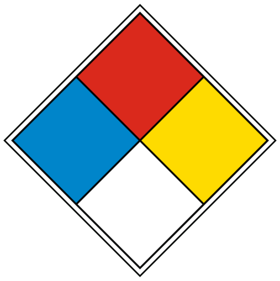
ACTIVITY 11.1 (cont'd)

Product Hazard Analysis Worksheet 1



Group Number: ________ **Presenter:** ________________________

Temp: _________ °F **R/H:** _________%

Product Name:_________________________________ **Family:**_________________________

Data Points	Result	No Data	Hazard Consideration
Physical Properties			
Physical State			
Vapor Pressure			
Boiling Point			
Vapor Density			
Specific Gravity			
Solubility			
Flammability			
Flash Point			
LEL/UEL			
Flammable Range			
Ignition Temp.			
Toxicity			
Route of Exposure			
IDLH			
PEL/REL/STEL			
S/S of Exposure			
Biological			
Corrosivity			
pH			
Concentration			
Reactivity/Explosion			
Radioactivity			
Decay Mode	☐ **N/A** ☐ α ☐ β ☐ γ		
Half Life			

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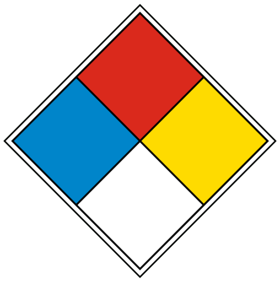
ACTIVITY 11.1 (cont'd)

Product Hazard Analysis Worksheet 2



Group Number: ________ **Presenter:** ________________________

Temp: _________ **°F** **R/H:** _________**%**

Product Name:_________________________________ **Family:**_________________________

Data Points	Result	No Data	Hazard Consideration
Physical Properties			
Physical State			
Vapor Pressure			
Boiling Point			
Vapor Density			
Specific Gravity			
Solubility			
Flammability			
Flash Point			
LEL/UEL			
Flammable Range			
Ignition Temp.			
Toxicity			
Route of Exposure			
IDLH			
PEL/REL/STEL			
S/S of Exposure			
Biological			
Corrosivity			
pH			
Concentration			
Reactivity/Explosion			
Radioactivity			
Decay Mode	☐ **N/A** ☐ α ☐ β ☐ γ		
Half Life			

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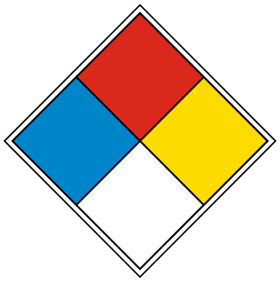
ACTIVITY 11.1 (cont'd)

Product Hazard Analysis Worksheet 3



Group Number: ________ **Presenter:** ________________________

Temp: _________ **°F** **R/H:** _________**%**

Product Name:_________________________________ **Family:**_________________________

Data Points	**Result**	**No Data**	**Hazard Consideration**
Physical Properties			
Physical State			
Vapor Pressure			
Boiling Point			
Vapor Density			
Specific Gravity			
Solubility			
Flammability			
Flash Point			
LEL/UEL			
Flammable Range			
Ignition Temp.			
Toxicity			
Route of Exposure			
IDLH			
PEL/REL/STEL			
S/S of Exposure			
Biological			
Corrosivity			
pH			
Concentration			
Reactivity/Explosion			
Radioactivity			
Decay Mode	☐ **N/A** ☐ α ☐ β ☐ γ		
Half Life			

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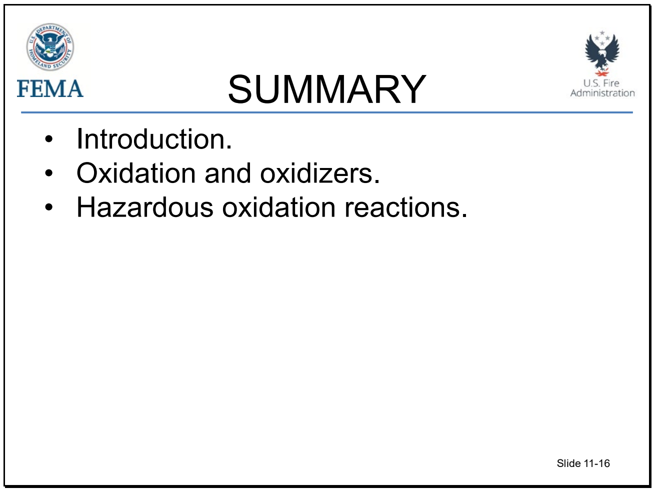
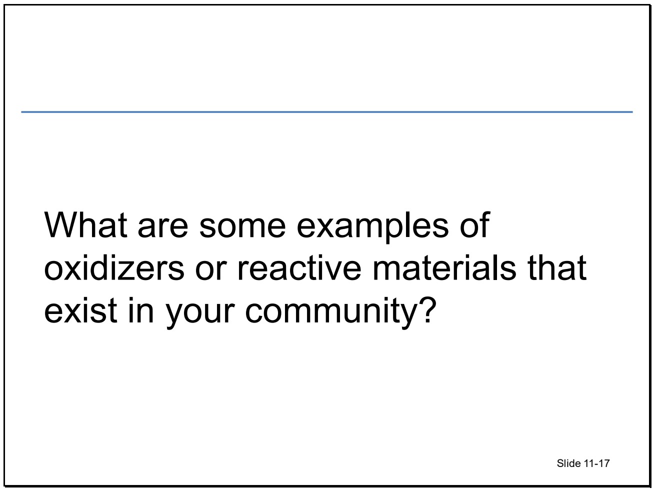
IV. SUMMARY

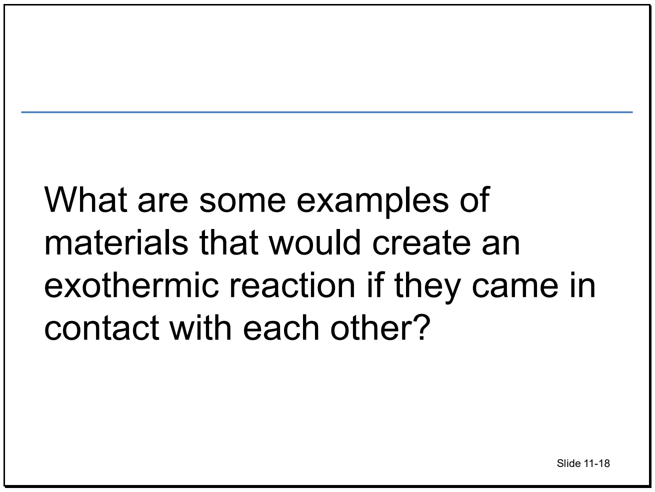


SUMMARY

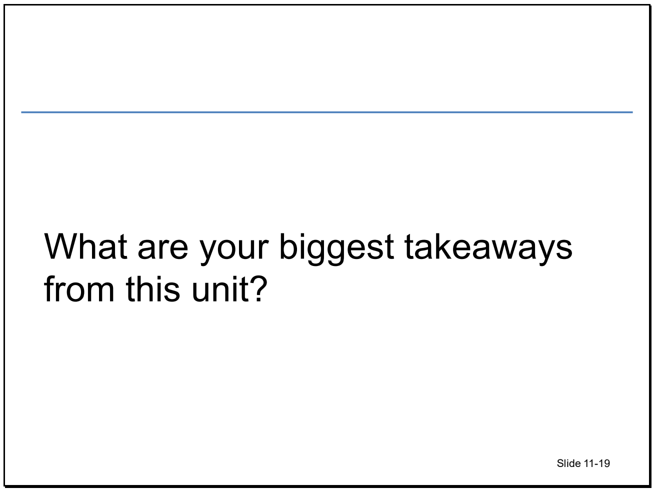
- Introduction.
- Oxidation and oxidizers.
- Hazardous oxidation reactions.



What are some examples of oxidizers or reactive materials that exist in your community?



What are some examples of materials that would create an exothermic reaction if they came in contact with each other?



What are your biggest takeaways from this unit?

UNIT 12:
TOXICITY AND CHEMICAL AGENTS

TERMINAL OBJECTIVE

The students will be able to:

12.1 Conduct a briefing concerning the hazards of a substance involved in an incident with a focus on the toxicity consideration that is appropriate for the target audience.

ENABLING OBJECTIVES

The students will be able to:

12.1 Identify terms important to the evaluation of the toxicity of products.

12.2 Analyze the toxicity of various chemical families and chemical agents.

12.3 Develop response objectives for an incident involving potentially toxic products.

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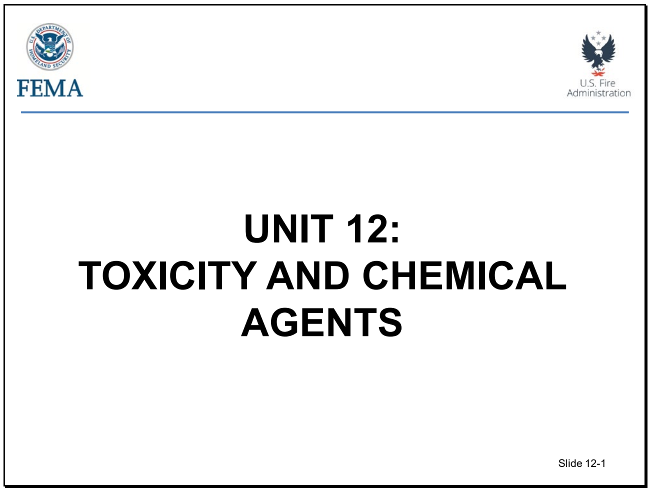
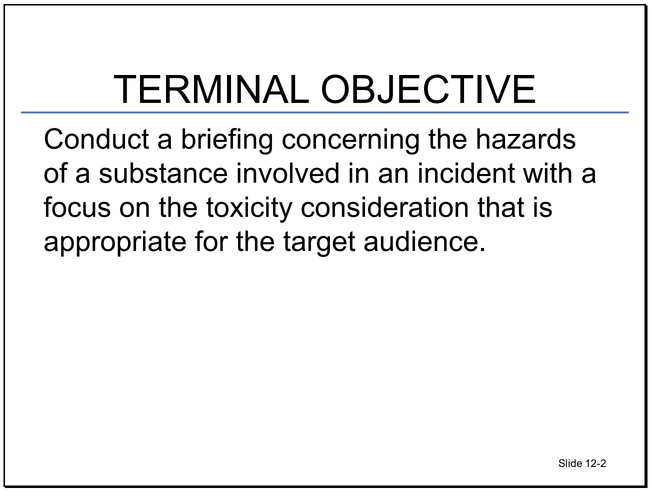


FEMA

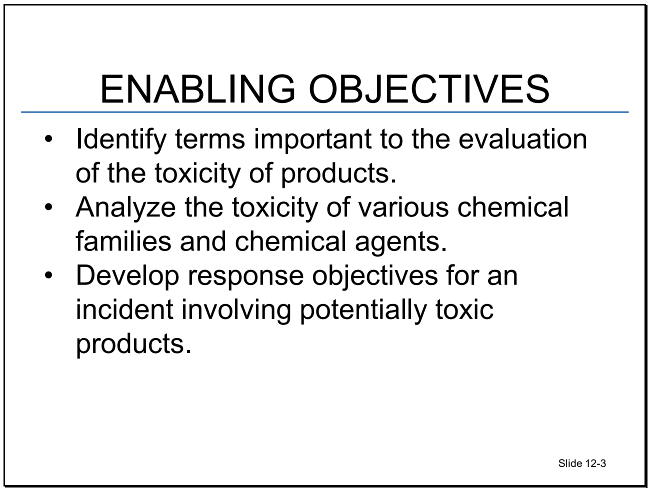
U.S. Fire Administration

UNIT 12: TOXICITY AND CHEMICAL AGENTS



TERMINAL OBJECTIVE

Conduct a briefing concerning the hazards of a substance involved in an incident with a focus on the toxicity consideration that is appropriate for the target audience.

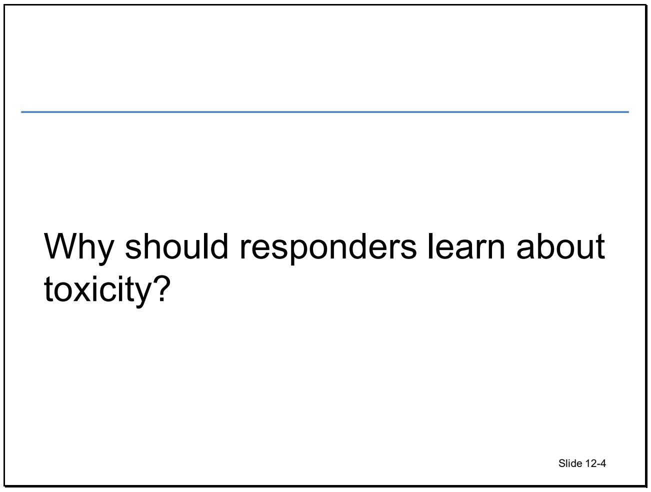


ENABLING OBJECTIVES

- Identify terms important to the evaluation of the toxicity of products.
- Analyze the toxicity of various chemical families and chemical agents.
- Develop response objectives for an incident involving potentially toxic products.

I. INTRODUCTION

Relevance.



Why should responders learn about toxicity?

A. When conducting a product hazard analysis on chemical materials, it is essential that the toxicity characteristics of the material be evaluated.

B. The key points of this evaluation must include several key characteristics, which we will discuss throughout this unit:

1. Route of exposure.
2. Dose.
3. Airborne concentration.
4. Exposure limits.
5. Toxicity considerations by chemical family.

ACTIVITY 12.1

Toxicity Terminology

Purpose

Define key terms related to toxicity.

Directions

1. Working with your group, match the terms on the worksheet with their definitions.
2. Once you are finished, the instructor will facilitate a discussion on any terms that may not be fully clear.

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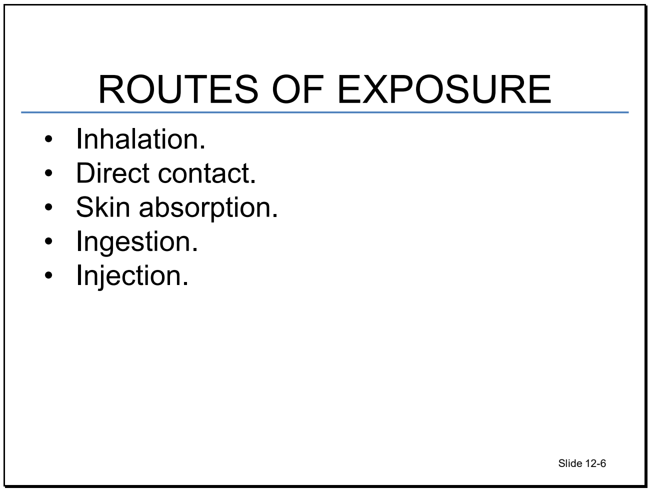
ACTIVITY 12.1 (cont'd)

Toxicity Terminology Matching Worksheet

Term	**Answer**	**Choice**	**Definition**
Irritant	_________	A.	Capable of creating cancer in a subject.
ppm	_________	B.	Counts per minute of radioactive activity.
Mutagen	_________	C.	The lowest amount of absorbed material that has been documented to cause toxic/nonlethal health effects.
Teratogen	_________	D.	The amount of a substance obtained within the body that would result in lethal effects in 50% of the population.
Mg/m^3	_________	E.	Unit of measure for radiological exposure which is used to quantify the effects roentgen absorbed dose.
Dose	_________	F.	Immediately dangerous to life or health as defined by National Institute for Occupational Safety and Health (NIOSH).
Dose response	_________	G.	The maximum concentration to which no unprotected exposure should occur.
LD_{50}	_________	H.	Causes alteration of human tissue which may or may not result in carcinogenic effects.
LC_{50}	_________	I.	The amount of pathogen necessary to manifest its pathogenicity.
TD_{low}	_________	J.	U.S. Department of Transportation (DOT) term for materials that present a toxic inhalation hazard.
PEL	_________	K.	The number of airborne particles of a given substance in comparison to the volume of air.
REL	_________	L.	A comparison of the amount absorbed by the body and the resulting effects.
TLV	_________	M.	International System of Units (SI) representing health risks of ionizing radiation.
STEL	_________	N.	Latency between exposure to a pathogen and onset of symptoms.
Ceiling (C)	_________	O.	A substance that causes inflammation or other discomfort in the body.
Infectious dose	_________	P.	The amount to which an individual could be exposed for 15 minutes as a result of respiratory protective equipment failure.
Carcinogen	_________	Q.	A measured weight of solids or low vapor pressure materials in a volume of air.
IDLH	_________	R.	8-hour time weighted average (TWA) exposure limits enforced by Occupational Safety and Health Administration (OSHA).

Term	Answer	Choice	Definition
TIH	__________	S.	SI unit of measure for the absorbed energy per mass of tissue.
Incubation period	__________	T.	Capable of damaging the developing fetus.
cpm	__________	U.	The median airborne concentration that would result in lethal effects in 50% of the population.
REM	__________	V.	An amount taken into or absorbed by the body.
sievert (Sv)	__________	W.	10-hour TWA exposure limits established by NIOSH.
Gray (Gy)	__________	X.	8-hour TWA exposure limits established by ACGIH.

II. ROUTES OF EXPOSURE



ROUTES OF EXPOSURE

- Inhalation.
- Direct contact.
- Skin absorption.
- Ingestion.
- Injection.

A. Basic concepts.

1. Definition: how the material enters the body.

2. Route of exposure versus route of entry: Depending on the characteristics of the material, one might be exposed to a substance without incurring an absorbed dose. An example might be exposure to propane vapors without actual absorption into the body.

3. Route of exposure is the primary factor for selection of appropriate personal protective equipment (PPE) and other means of protecting personnel and civilians.

4. Overview of routes of exposure.

   a. Inhalation.

   b. Direct contact (not technically a route of entry into the body unless it leads to an absorbed dose).

   c. Skin absorption.

   d. Ingestion.

   e. Injection.

B. Inhalation.

1. The primary route of exposure for most hazardous materials.

2. Can have direct local effects on the respiratory tract or systemic effects on other organs or functions within the body.

    a. Local effects to the respiratory system:

        - Tend to be irritant or corrosive in nature.

        - Result in inability to properly exchange oxygen in the lungs.

        - Can result in secondary effects to other systems, such as the central nervous system (CNS) or cardiovascular system.

    b. Systemic effects secondary to pulmonary injury:

        - Reference materials will often list these secondary effects. One must pay particular attention to the primary effect on the pulmonary system.

        - Only by reducing the impact to the pulmonary system can one begin to reduce the reduction of oxygenation.

C. Direct contact with skin tissue can result in a variety of local effects, including:

    1. Mild irritation.

    2. Corrosive effects from acids or alkalis.

    3. Thermal injuries or dermatitis (inflammation of the skin).

D. Direct contact with acids results in a condition called coagulative necrosis which is a type of cell death that occurs when blood flow to cells stops or slows. The dead skin serves to limit deeper penetration. An exception to this general finding is that of hydrofluoric acid, which is deeply penetrating.

E. Direct contact with alkalis results in a condition called liquefactive necrosis or liquefication of protein. This allows for much deeper skin penetration.

F. Absorption.

    1. There is no active “take-up” mechanism in the skin. Absorption through the skin is typically passive diffusion.

2. Factors that increase skin absorption:

    a. Lipid solubility such as seen in many nonpolar hydrocarbons and their derivatives.

    b. Concentration of the material.

    c. Molecular weight.

    d. Use of skin care and cleaning products such as lotions and hand sanitizer.

    e. Once absorbed through the skin, it can be transported in the blood to target organs.

G. Ingestion.

1. During a proper response by personnel, is an unlikely route of exposure.

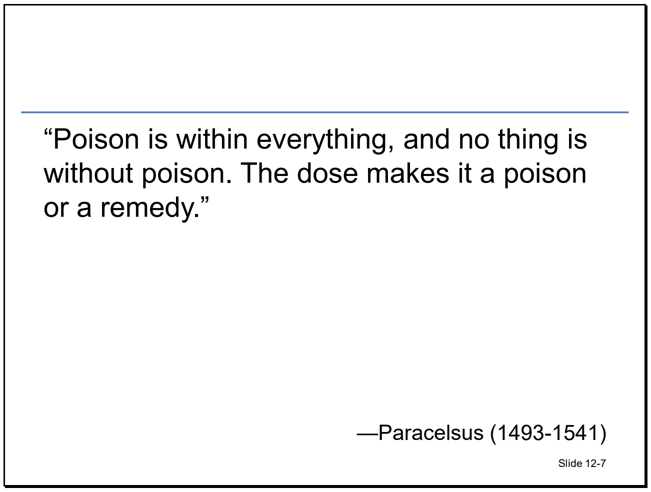
2. However, improper decontamination, hand to mouth activities and eating contaminated food/water, can result in this route becoming a factor.

H. Injection hazards include:

1. Sharp objects such as jagged metal debris that has been contaminated.

2. High-pressure gases or fluid systems like hydraulics.

III. THE DOSE MAKES THE POISON



"Poison is within everything, and no thing is without poison. The dose makes it a poison or a remedy."

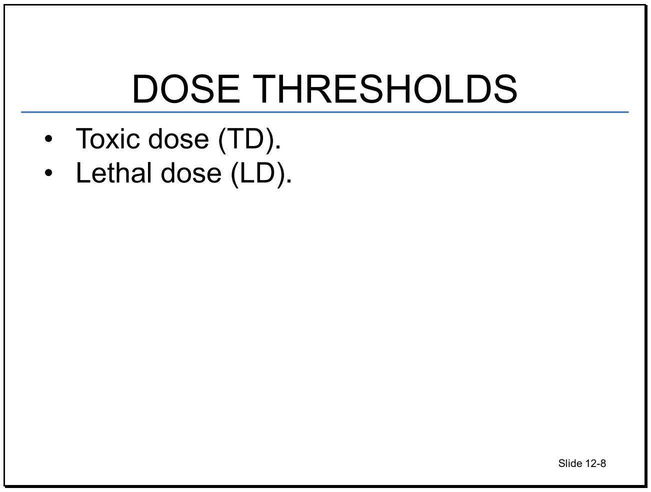
—Paracelsus (1493-1541)

Slide 12-7

A. Definition and measurement.

1. Dose is the amount that is actually received into the body by a route of exposure.

2. Generally expressed as a measure of weight per body mass (mg/kg).



DOSE THRESHOLDS

- Toxic dose (TD).
- Lethal dose (LD).

Slide 12-8

B. Overview of dose thresholds.

1. Calculating the amount of a chemical received is virtually impossible in the field, whereas radiological doses are more easily determined with proper detection devices. However, understanding the dose that can be tolerated can provide an indication of the level of risk.

2. With many materials, there is a threshold of exposure and dose that may be tolerated without adverse health effects.

3. These tolerated thresholds are generally considered to be much lower or even nonexistent when dealing with carcinogens.

4. Doses are calculated in scientific studies and generally expressed as:

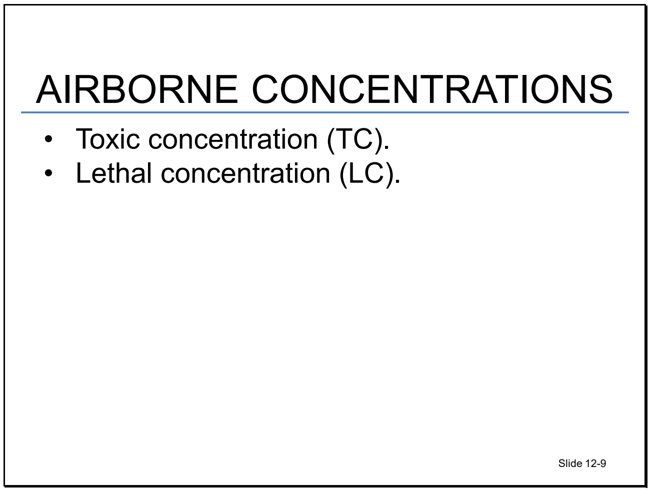
   a. Toxic dose (TD): resulting in toxic but nonlethal effects.

   b. Lethal dose (LD): resulting in death.

5. This is then projected over a population such as:

   a. (low): The lowest dose at which toxic or lethal effects were observed.

   b. (50): The dose at which 50% of the population would exhibit toxic or lethal effects.



AIRBORNE CONCENTRATIONS

- Toxic concentration (TC).
- Lethal concentration (LC).

C. Overview of airborne concentrations.

1. We are most familiar with information concerning airborne concentrations.

2. As with dose, scientific studies typically express airborne concentrations using the same toxic and lethal nomenclature.

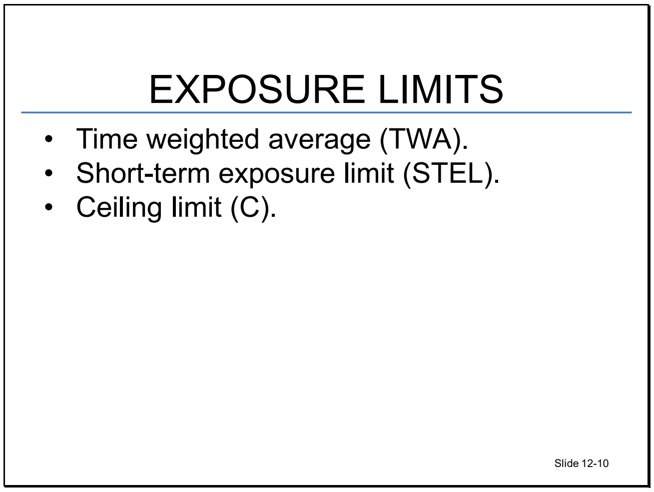
   a. TC: toxic (airborne) concentration.

   b. LC: lethal (airborne) concentration.

3. These values would also provide low and 50% effect levels (e.g., TC$_{(low)}$ or LC$_{(50)}$). You may also see other percentages, depending on the reference source used (i.e., LC$_{25}$).

4. Concentration levels are applicable to the inhalation route of exposure unless noted otherwise.

IV. EXPOSURE LIMITS



EXPOSURE LIMITS

- Time weighted average (TWA).
- Short-term exposure limit (STEL).
- Ceiling limit (C).

A. Definition and measurement.

1. An exposure limit is an upper, lower or legal limit used as a safety measure to prevent health and safety risks from exposure to toxic or unsafe substances.

2. Exposure limits are expressed as:

    a. TWAs.

    b. Short-term exposure limits (STELs).

    c. Ceiling limits (Cs).

3. The primary producers of exposure limit data are:

    a. OSHA.

    b. NIOSH.

    c. ACGIH.

4. Data concerning exposure limits are the most common risk assessment factors that we have for toxicity in the field.

B. TWA.

1. Exposure limits are all expressed based upon the TWA unit of measure.

2. TWAs are an expression of the average amount of exposure that can be received over a period of time. Generally, that time is eight or 10 hours average over a 40-hour work week depending upon the reporting agency.

3. TWAs are reported by the three different agencies mentioned above.

    a. OSHA permissible exposure limit (PEL).

        - These limits are legally enforceable.

        - They are based on an 8-hour workday.

    b. NIOSH recommended exposure limit (REL).

        - NIOSH is a function of the Centers for Disease Control and Prevention (CDC); they are charged with doing research and making recommendations to OSHA for legal status.

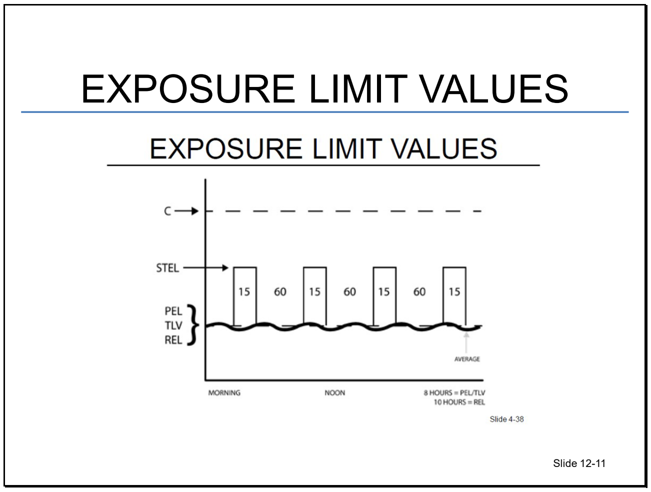
- NIOSH recommends exposure limit changes to OSHA, but those recommendations are not legally enforceable until adopted by Congress and signed into law.

- NIOSH bases its RELs on a 10-hour workday.

c. ACGIH threshold limit value® (TLV®).

- ACGIH is a private-sector consensus standard organization for industrial hygiene, much like National Fire Protection Association (NFPA) is a standard organization for the fire service.

- ACGIH reports its data on an 8-hour workday.



EXPOSURE LIMIT VALUES

C. Exposure limits.

1. STEL.

a. Unprotected exposure.

b. 15-minute exposure.

c. No more than four times a day.

d. At least one hour between exposures.

e. TWA must be maintained.

2. Ceiling (C): no unprotected exposure above the ceiling.

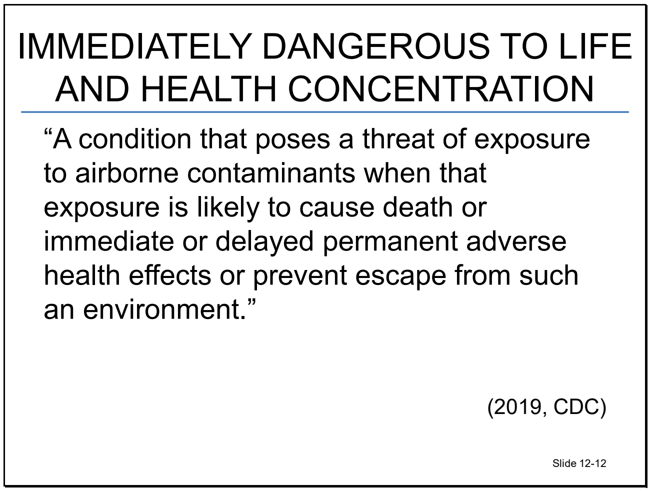
3. Parts per million (ppm): A measure of volume.

4. Milligrams per cubic meter of air (Mg/M^3).

   a. A measure of weight.

   b. We cannot directly read this unit of measure with typical detection equipment.

   c. Used in cases of airborne solids or low vapor pressure liquids at ambient temperature.



IMMEDIATELY DANGEROUS TO LIFE AND HEALTH CONCENTRATION

"A condition that poses a threat of exposure to airborne contaminants when that exposure is likely to cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment."

(2019, CDC)

Slide 12-12

D. Immediately dangerous to life or health (IDLH) concentration.

1. NIOSH definition: "A condition that poses a threat of exposure to airborne contaminants when that exposure is likely to cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment" (2019, CDC).

2. These values are reported by NIOSH.

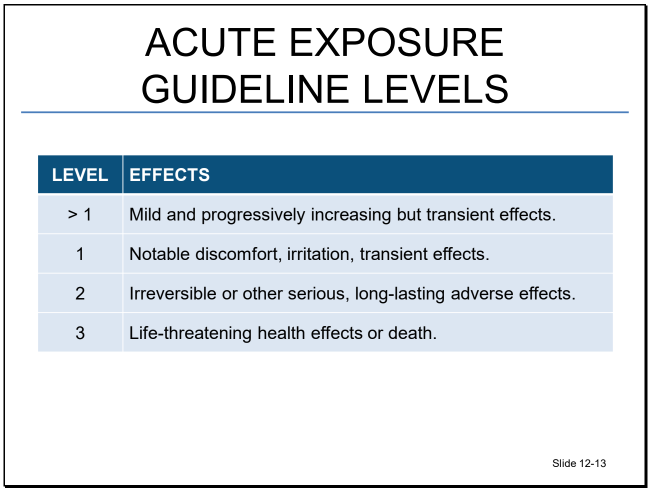
3. As a safety margin, they are based on the consequence of up to a 30-minute exposure.

   However, this is not meant to imply that personnel should work in the environment for that amount of time. Immediate exit is indicated.

4. IDLH also contains notices for:

   a. Notation **Ca** for potential occupational carcinogens.

   b. Concentrations at 10% of the LEL.



ACUTE EXPOSURE GUIDELINE LEVELS

LEVEL	EFFECTS
> 1	Mild and progressively increasing but transient effects.
1	Notable discomfort, irritation, transient effects.
2	Irreversible or other serious, long-lasting adverse effects.
3	Life-threatening health effects or death.

Slide 12-13

E. Acute Exposure Guideline Levels (AEGL).

1. Describe the human health effects from once-in-a-lifetime, or rare, exposure to airborne chemicals.

2. Used when dealing with chemical spills or other catastrophic exposures.

3. AEGL values represent threshold levels for the general public. They should be used to guide public protection considerations.

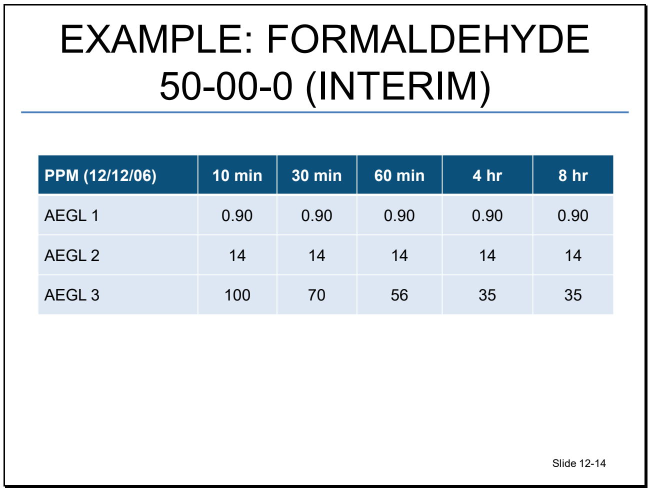
4. AEGL levels of exposure.

    a. **Below level 1:** Adverse effects can be seen in exposures below level 1. Could produce mild and progressively increasing but transient effects.

    b. **Level 1:** Notable discomfort, irritation or certain asymptomatic nonsensory effects. Not disabling and are transient.

    c. **Level 2:** Irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.

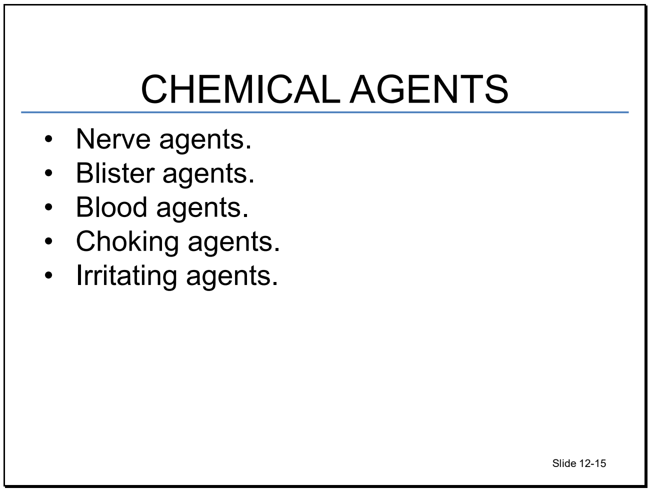
    d. **Level 3:** Life-threatening health effects or death.



EXAMPLE: FORMALDEHYDE 50-00-0 (INTERIM)

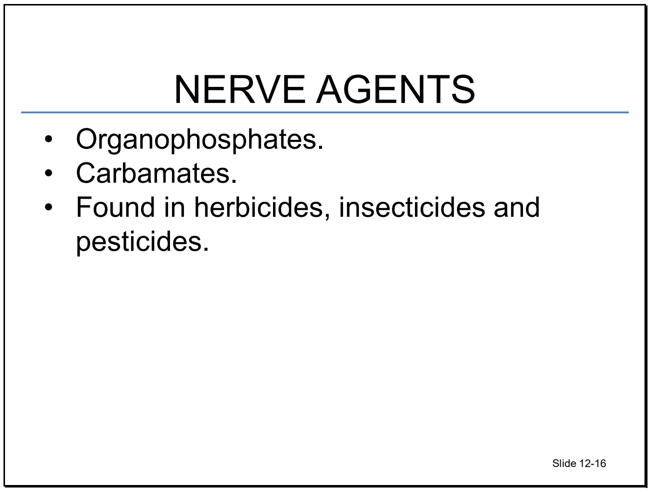
PPM (12/12/06)	10 min	30 min	60 min	4 hr	8 hr
AEGL 1	0.90	0.90	0.90	0.90	0.90
AEGL 2	14	14	14	14	14
AEGL 3	100	70	56	35	35

V. CHEMICAL AGENTS



CHEMICAL AGENTS

- Nerve agents.
- Blister agents.
- Blood agents.
- Choking agents.
- Irritating agents.



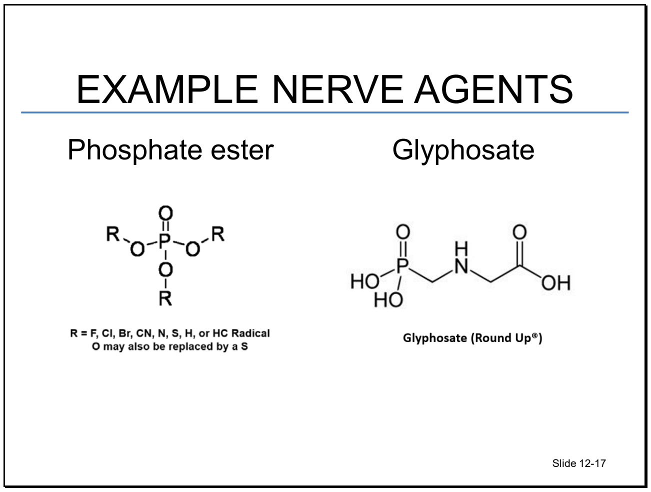
NERVE AGENTS

- Organophosphates.
- Carbamates.
- Found in herbicides, insecticides and pesticides.

A. Nerve agents.

1. Organophosphates.

   a. The main components of herbicides, insecticides and pesticides.



EXAMPLE NERVE AGENTS

Phosphate ester

Glyphosate

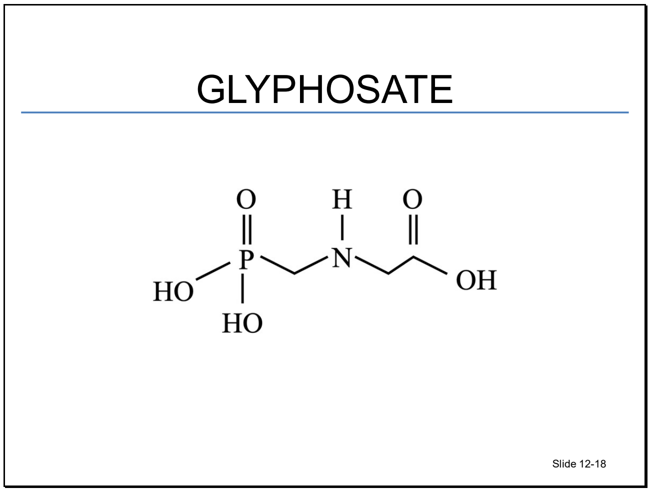
R = F, Cl, Br, CN, N, S, H, or HC Radical
O may also be replaced by a S

Glyphosate (Round Up®)

   b. These components are commercially available and constitute the "poor man's nerve agents" by concentrating the compounds to increase effect. One example of this is the glyphosate Round Up®.

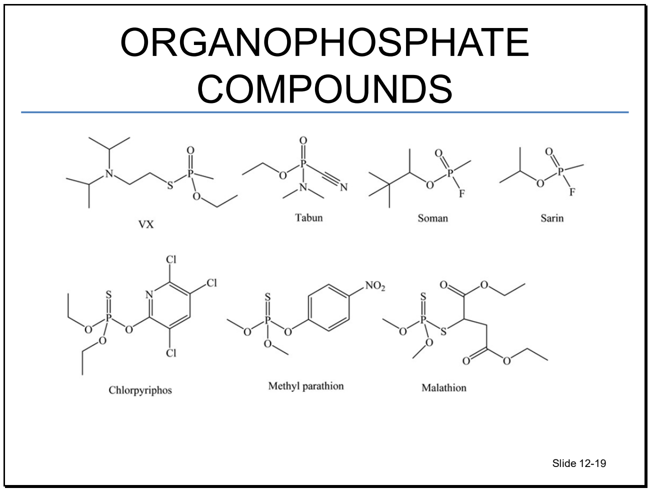
   c. The functional group would be the phosphate ester.

   d. Other hydrocarbon (HC) radicals and toxic elements are added to the phosphate ester and give these compounds greater lethality and different physical and chemical properties.



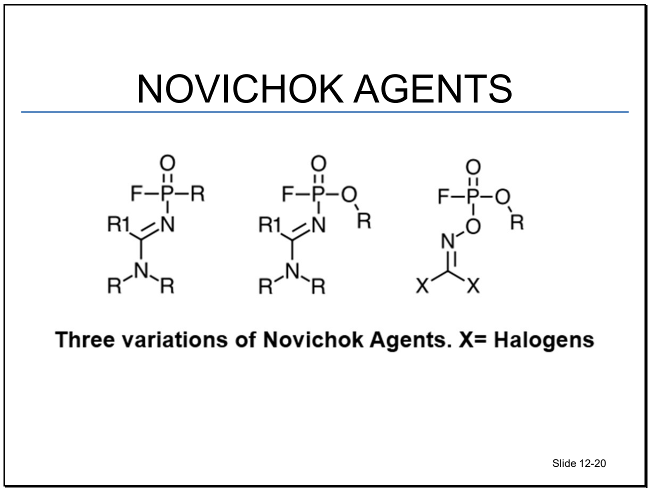
GLYPHOSATE

   e. These compounds have very low vapor pressure and are skin contact toxins. There is no such thing as a nerve gas, which is a term held over from decades ago in the military where a gas mask was used as PPE.



ORGANOPHOSPHATE COMPOUNDS

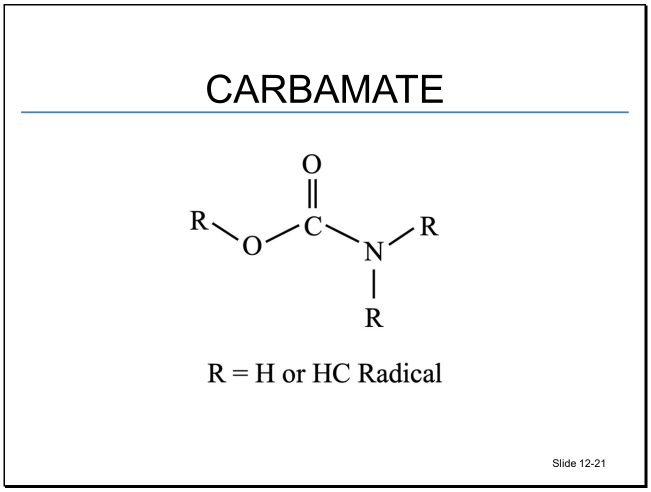
f. These affect the human organism by inhibiting the production and use of the enzyme acetylcholinesterase (AChE), which regulates neurotransmission of nerve signals in the CNS. This results in the "SLUDGEM" symptoms: salivation, lacrimation, urination, defecation, gastrointestinal cramping, emesis and miosis (pinpoint pupils).



NOVICHOK AGENTS

Three variations of Novichok Agents. X= Halogens

g. Recently, Novichok agents have been weaponized and disabled and killed victims. These are considered fourth generation agents, which are more persistent and are at least as toxic as VX if not possessing greater toxicity.



CARBAMATE

R = H or HC Radical

2. Carbamates.

   a. Another family of esters or “carbamic acids” used in the components of insecticides in agricultural settings.

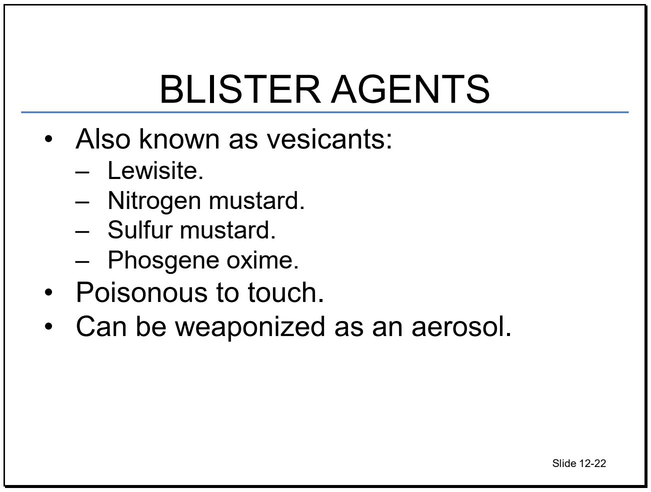
   b. These components are commercially available and constitute the “poor man’s nerve agents” by concentrating the compounds to increase effect. One example of this is the carbamate “Aldicarb®.”

   c. The functional group would be the “carbamates” derived from esters, or when an H attaches to the O it is called a carbamic acid (COOH).

   d. Other HC radicals and toxic elements are added to the carbamate and give these compounds greater lethality and different physical and chemical properties.

   e. These compounds have very low vapor pressure and are skin contact toxins.

   f. These affect the human organism by inhibiting the production and use of the enzyme acetylcholinesterase (AChE), which regulates neurotransmission of nerve signals in the CNS. This results in the SLUDGEM symptoms.

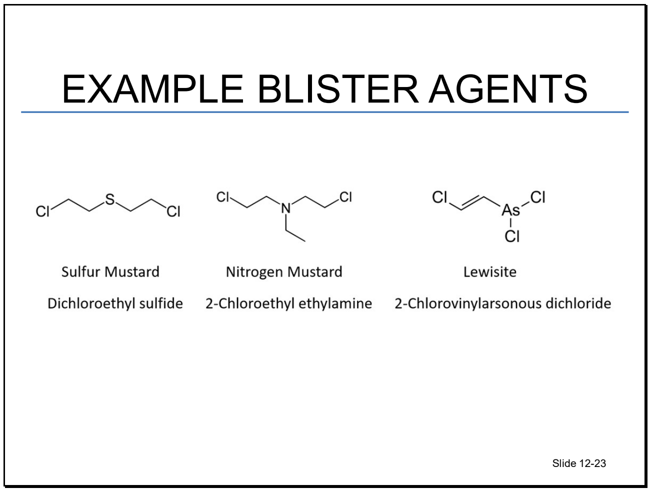


BLISTER AGENTS

- Also known as vesicants:
  - Lewisite.
  - Nitrogen mustard.
  - Sulfur mustard.
  - Phosgene oxime.
- Poisonous to touch.
- Can be weaponized as an aerosol.

B. Blister agents (vesicants).

1. Blister agents are toxic compounds that affect the skin, eyes and lungs.



EXAMPLE BLISTER AGENTS

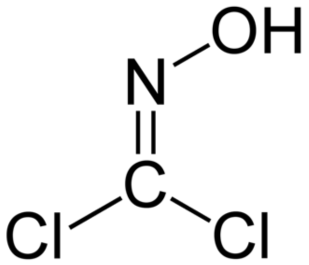
Sulfur Mustard	Nitrogen Mustard	Lewisite
Dichloroethyl sulfide	2-Chloroethyl ethylamine	2-Chlorovinylarsonous dichloride

2. There are three main blister agents: lewisite, nitrogen mustard and sulfur mustard. Sulfur mustard is an oily yellowish brown color liquid with a mustard (or garlic) odor. These can be manufactured from other N and S precursors. Blister agents have no viable commercial or industrial uses and are not easy to obtain, so they must be made.

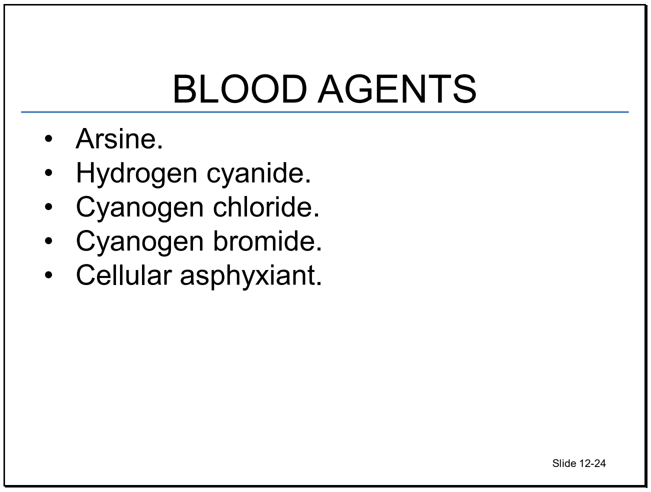
3. Another compound closely related is phosgene oxime. This compound is called an “urticant” or a “nettling agent,” which causes severe irritation of the skin and mucus membranes.

4. These agents are skin contact poisons, which can also be breathed in if weaponized as an aerosol.

Figure 12.1: Phosgene oxime



Phosgene Oxime

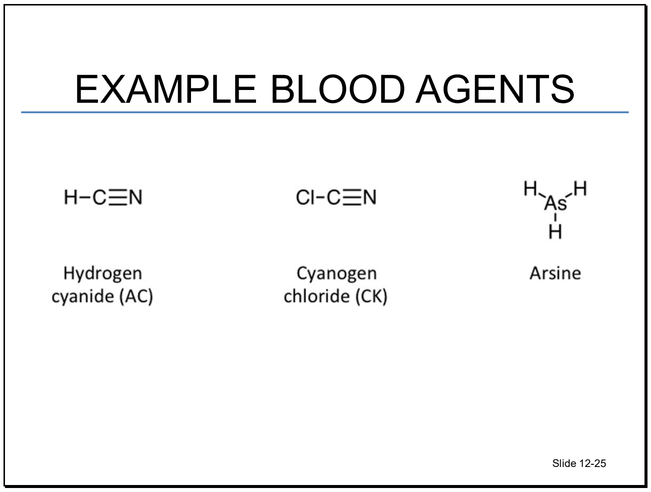


BLOOD AGENTS

- Arsine.
- Hydrogen cyanide.
- Cyanogen chloride.
- Cyanogen bromide.
- Cellular asphyxiant.

C. Blood agents.

1. The blood agents are arsine, hydrogen cyanide, cyanogen chloride and cyanogen bromide. The term “cyanogen” as we use it here refers to a C triple bonded with an N (CN). This is also a term given to a very toxic gas which combines two CNs together $(CN)_2$. The cyanogen agents all have a slight almond odor that only 10% of the population can smell.



EXAMPLE BLOOD AGENTS

$H-C\equiv N$

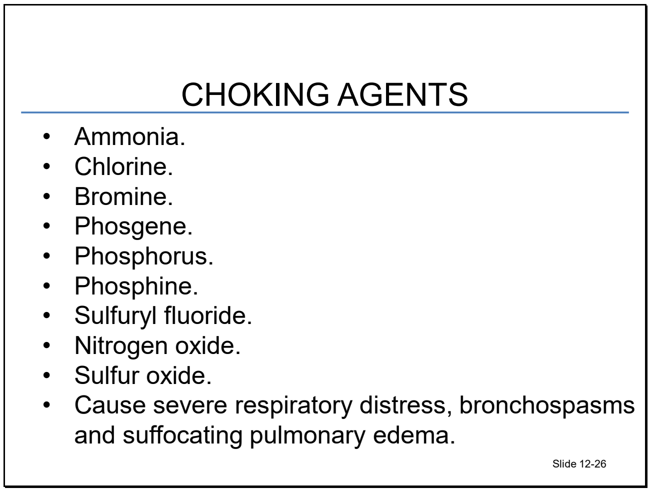
Hydrogen cyanide (AC)

$Cl-C\equiv N$

Cyanogen chloride (CK)

Arsine

2. Blood agents affect the body by interrupting the ability to use oxygen properly at the cellular level and impairing the synthesis of adenosine triphosphate (ATP), which is the body's energy plant.



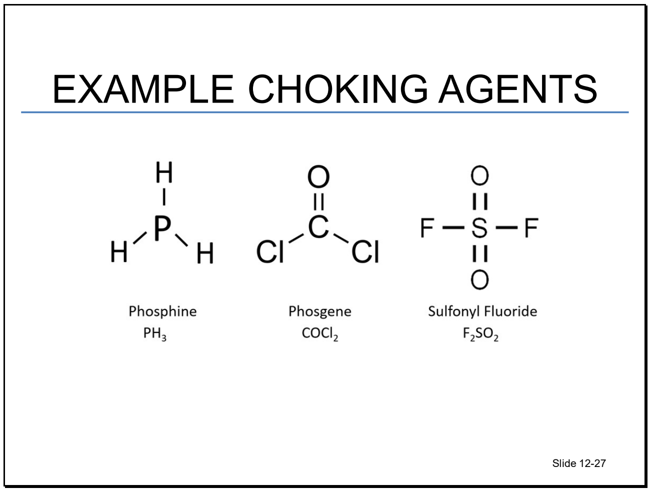
CHOKING AGENTS

- Ammonia.
- Chlorine.
- Bromine.
- Phosgene.
- Phosphorus.
- Phosphine.
- Sulfuryl fluoride.
- Nitrogen oxide.
- Sulfur oxide.
- Cause severe respiratory distress, bronchospasms and suffocating pulmonary edema.

D. Choking agents.

1. A choking agent is a chemical that causes severe respiratory distress, bronchospasms and suffocating pulmonary edema as well as immediate mucus membrane irritation.

2. These compounds are typically toxic industrial chemicals (TICs) that are common and widely transported, stored and used in industry, commercial and agricultural processes.



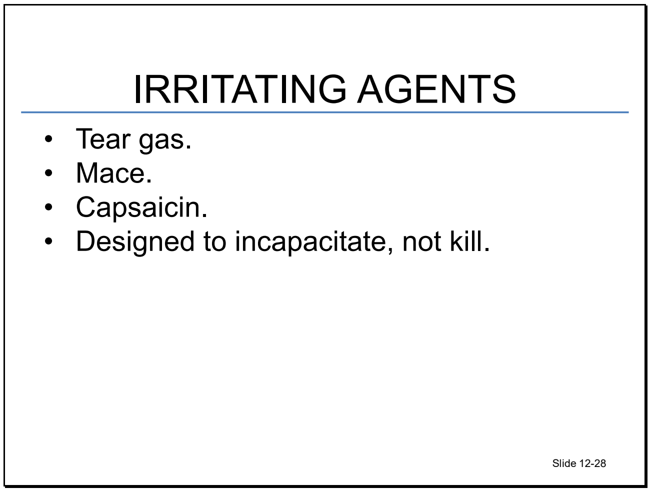
EXAMPLE CHOKING AGENTS

Phosphine
PH_3

Phosgene
$COCl_2$

Sulfonyl Fluoride
F_2SO_2

3. Examples: ammonia, chlorine, bromine, phosgene, phosphorus, phosphine, sulfuryl fluoride, nitrogen oxide and sulfur oxide.



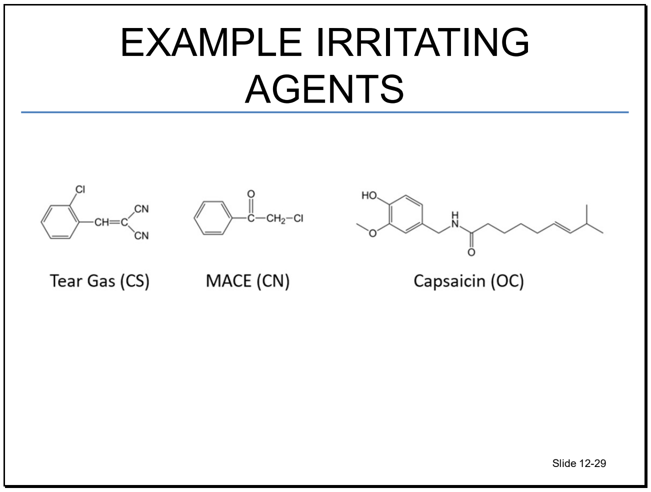
IRRITATING AGENTS

- Tear gas.
- Mace.
- Capsaicin.
- Designed to incapacitate, not kill.

E. Irritating agents.

1. Irritating compounds are designed not to kill but to incapacitate victims.

2. Many of these compounds are carried by law enforcement agencies and, when used for riot control, are not considered weapons of mass destruction (WMDs) in the truest sense.



EXAMPLE IRRITATING AGENTS

Tear Gas (CS)

MACE (CN)

Capsaicin (OC)

3. Some of these agents are micro pulverized powders suspended in a propellant, are not water-soluble and can persist on the skin causing lasting irritation.

VI. TOXICITY BY CHEMICAL FAMILY

TOXICITY BY CHEMICAL FAMILY

See the Appendix: Toxicity Considerations by Chemical Family for:

- Chemical family.
- Protocol reference.
- Example materials.
- Toxicity considerations.

A. The chemical families discussed in this program all present with some general toxicity considerations, which are outlined in the Appendix: Toxicity Considerations by Chemical Family at the end of this unit.

B. This information, combined with reference data concerning the specific chemical involved, can provide guidance concerning adverse effects.

C. Some materials may have very unique considerations.

ACTIVITY 12.2

Analysis of Toxicity Considerations

Purpose

Analyze the potential toxic effect of materials involved in a situation and communicate those concerns to a specific audience.

Directions

1. Working with your group, review the situation and your assigned product.
    a. Acrylonitrile (organic cyanide).
    b. Oleum (oxyacid).
    c. Anhydrous ammonia (binary nonsalt).
    d. Crotonaldehyde (aldehyde).
    e. Methylene chloride (halogenated hydrocarbon).
2. First, use the Product Hazard Analysis Worksheet and any electronic or printed resources to evaluate possible health risks.
3. Next, use the Toxicity Hazard Assessment Worksheet to more thoroughly evaluate possible health risks and effects. Assess the signs and symptoms of exposure and develop a recommendation for PPE and decontamination. Include a summary of the information on the easel pad.
4. Record significant information from both worksheets on an easel pad to substantiate your hazard analysis.
5. Prepare a five-minute briefing for the audience specified in your assigned scenario using the Briefing Worksheet. This briefing should be focused on the possible health effects of the materials that are substantiated by physical and chemical properties.
6. Be prepared to answer questions from others in the class.

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ACTIVITY 12.2 (cont'd)

Toxicity Scenarios

Situation 1: acrylonitrile (organic cyanide)

Your group is assigned to assess the toxicity considerations for an incident involving a rolled-over DOT407 highway cargo tank containing 4,000 gallons of acrylonitrile, UN 1093. The accident occurred on a section of interstate highway through a metropolitan area. It is anticipated that responders will make entry to conduct a container damage assessment. You are tasked with providing information concerning the potential toxicity of this material.

You will be asked to brief command personnel while they develop their incident action plan. The target audience includes: the Incident Commander (IC), Incident Safety Officer, Hazmat Group Leader and Assistant Safety Officer for Hazardous Materials.

Situation 2: oleum (oxyacid)

Your group has been assigned to assess the toxicity considerations for an incident involving a release of oleum from a 10,000-gallon aboveground storage tank at a local industrial facility. An entry team is being prepared to make entry into the area with appropriately selected PPE.

The Hazardous Materials Safety Officer and Entry Leader will conduct a preentry briefing. You have been tasked with providing a short briefing concerning the toxicity considerations for this material as part of the preentry briefing.

Situation 3: anhydrous ammonia (binary nonsalt)

Over the past several months, a local cold storage facility has incurred several minor releases of anhydrous ammonia. Today, a major release of several thousand pounds of ammonia has occurred and was released to the outside environment. The leak is being controlled by entry teams at this time.

Several local elected officials have descended on the scene due to the increased public awareness and concern over this facility and its continued history of leaks. The Public Information Officer (PIO) has been tasked with briefing local officials, and you are to participate in that briefing by providing an overview of the toxicity considerations of the material.

Situation 4: crotonaldehyde (aldehyde)

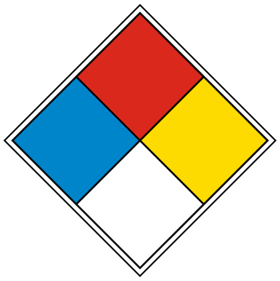
Your group has been assigned to assess the toxicity considerations for an incident at a local chemical manufacturing facility. While connecting a non-bulk container of crotonaldehyde to a chemical injection system, a leak occurred, resulting in exposure for several employees. These employees have been decontaminated and transported to the hospital for further treatment.

The local media is on scene and has requested a press briefing. Incident Command has tasked the PIO to brief the press. You have been assigned to participate in that briefing to discuss the toxicity considerations of the product.

Situation 5: methylene chloride (halogenated hydrocarbon)

During a lab session in the chemistry department of a large local university, a 2 liter glass bottle of methylene chloride fell from a counter and broke open, exposing several students. All students were immediately flushed with water from a built-in decontamination shower. After exiting the building, several of the students complained of dizziness and nausea. Those symptomatic students were further decontaminated and transported to the hospital for medical evaluation.

Approximately 20 other students were in the room at the time of the release. To aid in the evaluation and triage of the remaining students, the medical group supervisor and the triage unit leader are requesting information concerning the toxicity considerations.



ACTIVITY 12.2 (cont'd)

Product Hazard Analysis Worksheet

Group Number: ________ **Presenter:** ________________________

Temp: _________ **°F** **R/H:** _________**%**

Product Name:_________________________________ **Family:**_________________________

Data Points	Result	No Data	Hazard Consideration
Physical Properties			
Physical State			
Vapor Pressure			
Boiling Point			
Vapor Density			
Specific Gravity			
Solubility			
Flammability			
Flash Point			
LEL/UEL			
Flammable Range			
Ignition Temp.			
Toxicity			
Route of Exposure			
IDLH			
PEL/REL/STEL			
S/S of Exposure			
Biological			
Corrosivity			
pH			
Concentration			
Reactivity/Explosion			
Radioactivity			
Decay Mode	☐ N/A ☐ α ☐ β ☐ γ		
Half Life			

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ACTIVITY 12.2 (cont'd)

Toxicity Hazard Assessment Worksheet

IDENTIFICATION

AGENT NAME: ______________

AGENT TYPE:

C.A.S. No.: - - ______________

FORMULA:

CHEMICAL FAMILY:

MILITARY DESIGNATION:

PRIMARY SIGNS AND SYMPTOMS

EYES

- Immediate Onset ☐
- Delayed / slow onset ☐
- Dilated Pupils ☐
- Pinpoint Pupils (miosis) ☐
- Involuntary Closing ☐
- Tearing ☐
- Darkened Vision ☐
- Blurred Vision ☐
- Irritation ☐
- Pain or Burning ☐
- Reddening ☐
- Feeling of "grit" ☐
- Corneal opacity ☐

NERVOUS SYS

- Immediate Onset ☐
- Delayed / slow onset ☐
- Sympathetic Response (fight or flight) ☐
- Confusion ☐
- Loss of eye/hand coordination ☐
- Loss of consciousness ☐
- Paralysis ☐
- Flaccid paralysis ☐
- Seizures ☐
- Fasciculation ☐
- Headache ☐

CARDIOVASCULAR

- Bradycardia ☐
- Tachycardia ☐
- Tachy-dysrhythmias ☐

RESPIRATORY

- Immediate Onset ☐
- Delayed Onset ☐
- Pulmonary Irritation ☐
- Coughing ☐
- Chest Tightness ☐
- Dyspnea ☐
- Pulmonary edema ☐
- Delayed pulmonary edema ☐
- Wheezing ☐
- Rales and/or Ronchi ☐
- Rapid Respiratory Arrest ☐

DIGESTIVE/ URINARY

- Salivation ☐
- Defecation ☐
- Urination ☐
- Painful Urination ☐

SKIN

- Immediate Onset ☐
- Delayed Onset ☐
- Redness ☐
- Cyanosis ☐
- Clammy / Diaphoretic ☐
- Gray dead skin ☐
- Irritation ☐
- Pain, burning ☐
- Blistering ☐
- Fasciculation ☐
- Discoloration ☐

APPEARANCE

- Immediate Onset ☐
- Delayed Onset ☐
- Nausea / Vomiting (Emesis) ☐
- Running nose ☐
- Hyper secretions ☐
- Muscle twitching ☐
- Bleeding from mouth ☐

What are the potential effects that may result from exposure to this material?

What are your suggested PPE requirements and decontamination procedures?

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ACTIVITY 12.2 (cont'd)

Briefing Worksheet

Group number: ______________________________ **Audience:** ______________________________

Topic	Notes
Current situation and details	
Hazard/safety concerns	
Audience impact	
Recommendations	
Incident response objectives **(for briefing responders only)**	**Control zones:** **PPE:** **Decontamination:**

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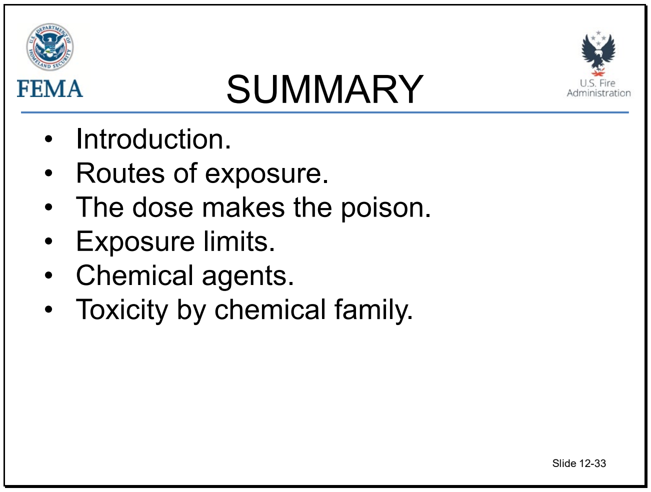
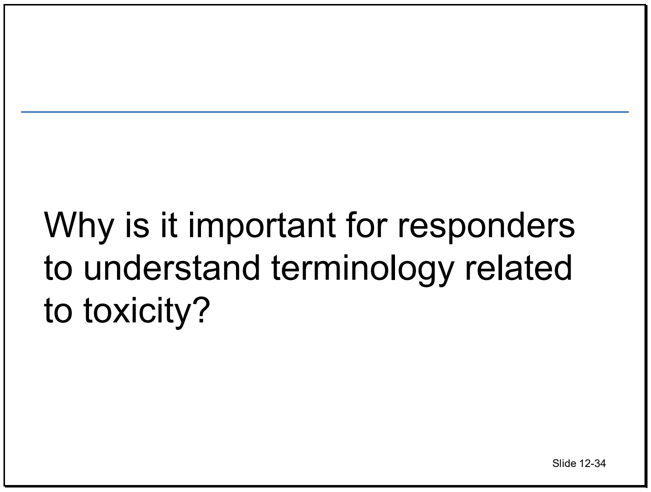
VII. SUMMARY

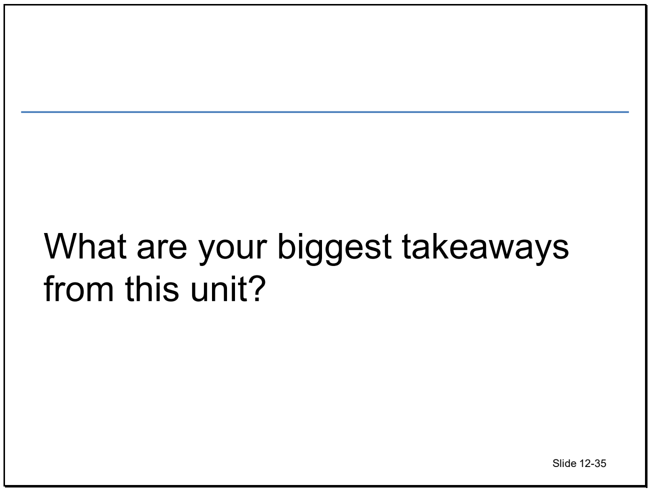


SUMMARY

- Introduction.
- Routes of exposure.
- The dose makes the poison.
- Exposure limits.
- Chemical agents.
- Toxicity by chemical family.



Why is it important for responders to understand terminology related to toxicity?



What are your biggest takeaways from this unit?

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REFERENCE

Centers for Disease Control and Prevention. (2019, May 10). *Immediately dangerous to life or health (IDLH) values*. https://www.cdc.gov/niosh/idlh/default.html

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APPENDIX

TOXICITY CONSIDERATIONS BY CHEMICAL FAMILY

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SALTS

Chemical family	Protocol reference	Example materials	Toxicity considerations
Nitride salts	Secondary ammonia exposure Irritant corrosive	Sodium nitride	Releases ammonia gas in contact with water. Ammonia gas is a highly water-soluble gas that results in irritation and burning of the moist mucus membranes. These effects in the upper respiratory tract result in respiratory irritation and distress at relatively low concentrations.
Carbide salts	Supportive, potential thermal burns	Calcium carbide	Predominant effects are related to the release of flammable acetylene gas and the potential for burns.
Hydride salts	Supportive, potential thermal burns	Calcium hydride Lithium aluminum hydride	Predominant effects are related to the release of flammable hydrogen gas and the potential for burns.
Phosphide salts	Agency for Toxic Substances and Disease Registry (ATSDR) Phosphine Irritant corrosive, inhalation	Phosphides Aluminum phosphide Zinc phosphide	Predominant effects are related to the release of phosphine gas on contact with water. This gas is a profound respiratory irritant that can result in acute respiratory distress syndrome (ARDS) and pulmonary edema, as well as cardiovascular failure and central nervous system (CNS) depression secondary to hypoxia.
Oxide salts (metal oxides)	Supportive Irritant corrosive topical	Calcium oxide (quick lime)	Forms alkaline corrosive liquids on contact with water. Highly irritating to skin and mucus membranes and can cause severe corrosive burns.
Hydroxide salts	ATSDR sodium hydroxide Alkaline compounds Irritant corrosive topical	Sodium hydroxide, potassium hydroxide	Mixing of hydroxides with water or moisture results in the creation of highly alkaline solutions. Alkaline agents result in liquefaction necrosis that results in the saponification of fats and proteins. This results in deep tissue destruction that limits the effectiveness of surface irrigation.
Peroxides salts	Irritant corrosive injuries	Potassium peroxide Sodium peroxide	Peroxides are irritating to the skin and mucus membranes. They can cause corrosive burns and severe respiratory irritation. Peroxide salts are highly reactive with water, heat, light and shock. They are profound oxidizers that will support/stimulate the combustion process. Commonly used in explosives and rocket fuels.

Chemical family	Protocol reference	Example materials	Toxicity considerations
Oxysalts	Irritant corrosive	Potassium chlorate Potassium permanganate Calcium hypochlorite Lead chromate Potassium nitrate	Irritating to the skin and mucus membranes. May result in corrosive burns to the skin. Some oxysalt compounds are strong oxidizers and may enhance or stimulate the combustion process. Nitrates and nitrites may cause methemoglobinemia.
Cyanide salts	ATSDR hydrogen cyanide Cyanide Asphyxiant, cellular	Potassium cyanide Sodium cyanide	When cyanide salts come into contact with acids, they form hydrogen cyanide (HCN) gas. Hydrogen cyanide bonds to the Fe^{+3} (Ferric) iron in the energy production area of the cells of the body. When this occurs, it prohibits the cell from properly using oxygen in the protection of energy. Therefore it "shuts down" the aerobic metabolism of all energy-producing cells. The earliest effects are seen in the CNS due to the high biological oxygen demands of those cells. This results in rapid CNS effects, seizures and respiratory arrest.

INORGANIC NONSALTS

Chemical family	Protocol reference	Example materials	Toxicity considerations
Binary nonsalts	Profound respiratory irritants **Hydrogen sulfide see:** ATSDR hydrogen sulfide	Phosphine Bromine pentafluoride Hydrogen sulfide	Widely variable effects. These materials are toxic to multiple systems depending upon the specific compound. For example, phosphine (hydrogen phosphide or phosphorus tri-hydride) is destructive to the tissues of the heart and lungs. Bromine pentafluoride is primarily a respiratory irritant. Hydrogen sulfide is a cellular toxic that prohibits the proper use of oxygen in a manner very similar to cyanides.
Nonmetal oxides	ATSDR nitrogen oxides Supportive respiratory irritant	Nitrogen oxide(s) Sulfur oxide(s)	In short-term high-dose exposures, many nonmetal oxides are irritants to the mucus membranes and the respiratory tract. They form corrosive liquids on contact with moisture. Low-dose chronic exposures hold the potential for metal fume fevers and other chronic health effects.
Inorganic acids	Irritant corrosive	Perchloric acid Nitric acid Sulfuric acid Chromic acid	Highly corrosive by contact. Very damaging to the respiratory tract and a profound respiratory irritant. Acids damage tissue by coagulation necrosis that results in the formation of a protective eschar that impedes the deep penetration of the acid. Damage remains predominantly superficial.
Inorganic cyanides	ATSDR hydrogen cyanide Asphyxiant, cellular	Cyanogen chloride Hydrogen cyanide Hydrocyanic acid	Profound cellular asphyxiant. Bonds to the Fe^{+3} (Ferric) iron in the energy production area of the cells of the body and inhibits oxidative phosphorylation. When this occurs, it prohibits the cell from properly using oxygen in the protection of energy. Therefore it "shuts down" the aerobic metabolism of all energy-producing cells. The earliest effects are seen in the CNS due to the high biological oxygen demands of those cells. This results in rapid CNS effects, seizures and respiratory arrest.
Binary acids (acid gases)	ATSDR Hydrogen chloride Hydrogen fluoride Irritant corrosive Hydrofluoric acid	Hydrochloric acid Hydrofluoric acid Hydroiodic acid	Strong acid gases. They are highly corrosive by contact and cause coagulation necrosis of the tissues. Very damaging to the respiratory tract. Acids damage tissue by coagulation necrosis that results in the formation of a protective eschar that impedes the deep penetration of the acid. Damage remains predominantly superficial. Hydrofluoric acid is unusual as it causes liquefaction necrosis, and it has uniquely systemic toxicity related to being a calcium seeker. It binds to calcium stores within the body. Acute exposures result in low blood and plasma calcium levels that can lead to hypotension and cardiac arrest. Chronic exposure results in loss of bone mass and conditions similar to osteoporosis.

HYDROCARBONS

Chemical family	Protocol reference	Example materials	Toxicity considerations
Alkanes	ATSDR gasoline Hydrocarbons	Methane, propane, octane Gasoline and fuel oils	Primary effect is hypoxia due to displacement of oxygen by the heavier alkanes. However, inhalation of high concentrations of petroleum products can result in chemical pneumonitis. Also, gasoline vapors can irritate the myocardium resulting in cardiac effects.
Cyclo-alkanes	Supportive Sedative/anesthetic	Cyclo propane Cyclo butane	Cyclopropane and cyclopentane are CNS depressants. Cyclobutane is a simple asphyxiant.
Alkenes	Hydrocarbons	Ethylene Butadiene	Alkenes are toxic by displacement of oxygen. In addition, some alkenes like butadiene are irritants to the mucus membranes and the lungs.
Alkynes	Hydrocarbons	Acetylene	Alkynes affect the respiratory system and the CNS.
Aromatics	ATSDR Benzene, toluene and xylene Aromatic hydrocarbons	Benzene, xylene, toluene	Aromatics are skin absorbable. They damage the liver, kidneys and blood cell production, resulting in anemia and CNS depression. Benzene is a known human carcinogen.

DERIVATIVES

Chemical family	Protocol reference	Example materials	Toxicity considerations
Halogenated hydrocarbons	ATSDR Trichloroethylene Methylene chloride Methyl bromide	Halogen gases Methyl chloride Chloroform	Widely variable depending upon the material. Halogenated hydrocarbons may result in displacement of ambient oxygen. Most are toxic to the liver and kidneys at varying degrees. Chloroform is a profound CNS depressant. Some result in anemia due to depression of blood cell formation within the body.
Amines	ATSDR aniline	Phenylamine (Aniline) Aminobenzene Methylamine Butyl amine (1-aminobutane)	Aniline (phenyl amine) produces methemoglobinemia. Amines are irritants and form alkaline solutions. Damaging to the liver and kidneys. Severely damaging to mucus membranes, upper respiratory tract, skin and eyes.
Organic cyanides	ATSDR acrylonitrile	Acrylonitrile Methyl cyanide	Less toxic than the inorganic cyanides and cyanide salts. However, capable of interrupting the production of ATP during oxidative phosphorylation, resulting in cellular asphyxiation. In addition, organic cyanides are very irritating to mucus membranes, skin, eyes and the respiratory tract.
Isocyanates	ATSDR toluene diisocyanate Irritant corrosive inhalation	Toluene diisocyanate TDI Methylisocyanate Diphenylmethane diisocyanate (MDI)	Severely irritating. Damaging to the eyes, mucus membranes and respiratory tract at low concentrations. May produce non-cardiogenic pulmonary edema hours after exposure. Has high odor threshold in comparison to toxic level.
Nitro compounds	ATSDR	Nitromethane Trinitrotoluene Nitrobenzene Dinitrophenol (alcohol)	Potent vasodilators. They result in hypotension and are CNS depressants. Some (e.g., nitroethane) are liver and renal toxic and irritating to the respiratory tract.
Ethers and epoxides	ATSDR ethylene oxide Hydrocarbon sedative	Ether (diethyl ether) Ethylene oxide	CNS depressant. Result in necrosis. Some are irritating to the eyes and respiratory tract. In addition to CNS depression, ethylene oxide is a severe irritant to the respiratory tract and may result in delayed onset non-cardiogenic pulmonary edema.

Chemical family	Protocol reference	Example materials	Toxicity considerations
Organic peroxides	Irritant corrosive topical	Benzyl peroxide Hydrogen peroxide	Organic peroxides are unstable, reactive materials that can violently decompose. Hydrogen peroxide is a strong oxidizer (depending upon strength). All are severely irritating to the skin and mucus membranes.
Sulfides (thioethers)	Irritant corrosive topical Hydrogen sulfide — cellular asphyxiant	Thioethylamine Vinyl sulfide Hydrogen sulfide	Irritating to the mucus membranes and respiratory tract. Hydrogen sulfide (although not technically an organic compound) is a strong inhibitor of oxidative phosphorylation resulting in cellular asphyxiation.
Mercaptans (thiols)	Supportive Irritant corrosive topical, inhalation	Thiolmethane Methyl mercaptan Ethanethiol Ethylmercaptan	Irritating to the mucus membranes and respiratory tract.
Alcohols	Hydrocarbon ATSDR phenol Methanol Ethylene glycol	Phenol Ethylene glycol (antifreeze) Methanol Methyl alcohol Isopropyl alcohol	Toxicity and effects vary widely depending upon the alcohol. Phenol is corrosive to the tissues and results in initial CNS stimulation, followed by CNS depression that can result in seizures and coma. Ethylene glycol and methanol are metabolized by the liver to form toxic acidic metabolites. These metabolites, such as formaldehyde, formic acid and glycolic acid result in profound metabolic acidosis. Treatment is directed at ethanol therapy and involves the use of cofactors such as thiamine and pyridoxine.
Ketones	Hydrocarbon sedative	Methyl ethyl ketone Acetone Dimethyl ketone Cyclohexanone	Predominant exposure routes are inhalation and ingestion. Dermal contact can result in local irritation. Effects vary with the ketone involved and range from CNS depression to metabolic acidosis. Treatment is predominantly supportive and directed toward the route of exposure.
Aldehydes	Irritant corrosive topical, inhalation	Formaldehyde Formalin	Formaldehyde is a strong mucosal irritant. Systemic effects include CNS depression and severe metabolic acidosis as well as pulmonary tract irritation and possible non-cardiogenic pulmonary edema. Skin effects include dermal sensitization and irritation.

Chemical family	Protocol reference	Example materials	Toxicity considerations
Organic acids	Irritant corrosive topical	Acetic acid Formic acid Ethanoic acid	Weak acids. Irritating to the mucus membranes. Acids damage tissue by coagulation necrosis that results in the formation of a protective eschar that impedes the deep penetration of the acid. Damage remains predominantly superficial.
Phosphoric esters	ATSDR parathion Cholinergic pesticides Organophosphates	Parathion Malathion Sarin (GB) Soman, tabun, VX Military nerve agents	Phosphoric esters are commonly referred to as organophosphates. These materials are rapidly absorbed through the skin and respiratory tract to competitively inhibit acetylcholinesterase (AChE). This results in over-accumulation of acetylcholine in the neuroeffector junctions at the skeletal muscles and in the autonomic nervous system. This results in overstimulation of the parasympathetic nervous system.

UNIT 13:
COMPREHENSIVE HAZARD ANALYSIS

TERMINAL OBJECTIVE

The students will be able to:

13.1 Analyze chemical information in an accurate and timely manner in order to determine the hazards and the relative severity of the hazards of the given compounds.

ENABLING OBJECTIVES

The students will be able to:

13.1 Predict physical and chemical properties of a compound based on knowledge of the chemical composition, chemical family and hazards associated with the chemical compound.

13.2 Predict hazards posed by various compounds.

13.3 Prioritize severity of hazards.

13.4 Produce a presentation with a clear, concise and accurate summary of hazard analysis information for a technical audience.

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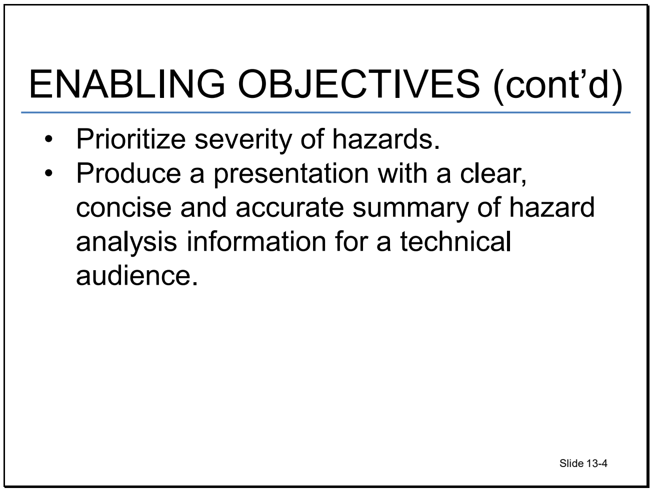
UNIT 13: COMPREHENSIVE HAZARD ANALYSIS

TERMINAL OBJECTIVE

Analyze chemical information in an accurate and timely manner in order to determine the hazards and the relative severity of the hazards of the given compounds.

ENABLING OBJECTIVES

- Predict physical and chemical properties of a compound based on knowledge of the chemical composition, chemical family and hazards associated with the chemical compound.
- Predict hazards posed by various compounds.



ENABLING OBJECTIVES (cont'd)

- Prioritize severity of hazards.
- Produce a presentation with a clear, concise and accurate summary of hazard analysis information for a technical audience.

ACTIVITY 13.1

The 50 Chemical Activity

Purpose

Predict physical and chemical properties based on knowledge of chemical composition, chemical family and the hazards associated with the chemical compound.

Directions

1. You will work in a small group with a few of your classmates for this activity. Your instructor will facilitate the formation of groups; your group for this activity may or may not be the same group you have worked with at your table throughout the course.

2. During this activity, teamwork and group problem-solving are strongly encouraged. Each group will demonstrate the ability to work within a team environment to **process chemical information** and **predict how a compound causes harm**.

3. **Technical accuracy is important;** however, reference books and electronic databases are not to be used during this activity. You may use only the collective knowledge of your group and the information you have learned in the course so far to complete the worksheet. **Job aids provided by your instructor or study aids that you've created during the course may be used; however, use of the Student Manual (SM) is not permitted**. The objective of this activity is to reinforce the information you have learned in the course.

4. Your instructor will provide you with a list of 50 chemicals. Either the chemical name or formula has been provided for each of the 50 chemicals.

5. Your instructor will review the process to follow for this activity. The instructor will walk through the first five chemicals, demonstrating the reasoning process to determine the answers for each field in the worksheet.

6. Your group's task is to determine which chemical family each chemical belongs to and the general hazards of that chemical family, and then once determined, predict the compound's physical and chemical properties. You will have two hours to work within your group to complete this task. Your predictions should be made based only on the given chemical name or formula; your knowledge of the seven salts, five inorganic nonsalts, four hydrocarbon families and 13 hydrocarbon derivatives you have learned about during class; and your knowledge of the implications of size, polarity and branching on physical and chemical properties.

7. Once you've determined the chemical name, formula, family and general hazards for each compound, your group should then predict the basic physical and chemical properties of each compound. Go through each compound one at a time and complete predictions for one compound before moving on to the next compound in the worksheet. This process will provide for the opportunity to work together as a group, using the group's collective knowledge to discuss each chemical and to predict that compound's properties. This activity is a team effort.

8. During the activity, your instructors will serve as mentors in a supportive learning environment.

9. Once you have made your predictions as a group, the instructors will debrief the activity by providing the answers for each compound via a PowerPoint presentation. Each compound will be reviewed individually, and the actual physical and chemical properties data will be compared to your predictions. Any differences between the two will be discussed in order to facilitate learning and reinforce knowledge. The potential consequences of inaccuracy when conducting a hazards analysis will also be an emphasis of discussion.

#	Chemical name	Formula	Family	Hazard(s)	Phys state	Vp @ ~68°F(1)	Burn	Solubility	Toxicity	Corrosivity
1	Cyclohexene	c-C_6H_{10}	Alkene hydrocarbon	Flammable, may polymerize	S [✓ L] G	[✓ High] Low None	[✓ Flammable] Combustible No	Soluble Slightly sol. [✓ Insoluble]	High [✓ Low] No	Acid Base [✓ N/A]
2	Acetic acid	CH_3COOH	Organic acid	Combustible Corrosive Toxic	S [✓ L] G	High [✓ Low] None	Flammable [✓ Combustible] No	[✓ Soluble] Slightly sol. Insoluble	High [✓ Low] No	[✓ Acid] Base N/A
3	Dichloromethane	CH_2Cl_2	Halogenated hydrocarbon	Combustible Toxic	S [✓ L] G	[✓ High] Low None	Flammable [✓ Combustible] No	Soluble [✓ Slightly sol.] Insoluble	[✓ High] Low No	Acid Base [✓ N/A]
4	Lithium hydride	LiH	Binary salt	NCHP Water reactive, when mixed with water, releases hydrogen gas	[✓ S] L G	High Low [✓ None]	Flammable Combustible [✓ No]	Soluble [✓ Slightly sol.] Insoluble	High [✓ Low] No	Acid Base [✓ N/A]
5	Hydrogen cyanide	HCN	Inorganic cyanide	Toxic, flammable	S L [✓ G]	[✓ High] Low None	[✓ Flammable] Combustible No	[✓ Soluble] Slightly sol. Insoluble	[✓ High] Low No	Acid Base [✓ N/A]
6	Potassium hydroxide				S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
7		SO_2			S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A

#	Chemical name	Formula	Family	Hazard(s)	Phys state	Vp @ ~68°F(1)	Burn(2)	Solubility	Toxicity	Corrosivity
8	Chlorine				S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
9	Vinyl acetate				S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
10	Gasoline	N/A (hydrocarbon mixture)			S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
11		CH_2CHCN			S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
12	Dimethyl sulfide				S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
13		$(CH_3)_2NH$			S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
14		C_4H_9SH			S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A

#	Chemical name	Formula	Family	Hazard(s)	Phys state	Vp @ ~68°F(1)	Burn(2)	Solubility	Toxicity	Corrosivity
15	Picric acid				S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
16		c-C_6H_{12}			S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
17		HNO_3			S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
18	Propane				S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
19		PH_3			S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
20		CH_3CHO			S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
21	1,3 - xylene				S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A

#	Chemical name	Formula	Family	Hazard(s)[†]	Phys state	Vp @ ~68°F(1)	Burn(2)	Solubility	Toxicity	Corrosivity
22		KCN			S L G	High Low None	Flammable Combustible No	Soluble Slightly Sol. Insoluble	High Low No	Acid Base N/A
23	Vinyl chloride				S L G	High Low None	Flammable Combustible No	Soluble Slightly Sol. Insoluble	High Low No	Acid Base N/A
24		$Ca(OH)_2$			S L G	High Low None	Flammable Combustible No	Soluble Slightly Sol. Insoluble	High Low No	Acid Base N/A
25	Styrene				S L G	High Low None	Flammable Combustible No	Soluble Slightly Sol. Insoluble	High Low No	Acid Base N/A
26		Na_2O_2			S L G	High Low None	Flammable Combustible No	Soluble Slightly Sol. Insoluble	High Low No	Acid Base N/A
27	Acetylene				S L G	High Low None	Flammable Combustible No	Soluble Slightly Sol. Insoluble	High Low No	Acid Base N/A
28		HF			S L G	High Low None	Flammable Combustible No	Soluble Slightly Sol. Insoluble	High Low No	Acid Base N/A

#	Chemical name	Formula	Family	Hazard(s)	Phys state	Vp @ ~68°F[(1)]	Burn[(2)]	Solubility	Toxicity	Corrosivity
29	Methyl ethyl ketone				S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
30	Ethylene				S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
31		H_3PO_4			S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
32	Zinc II phosphide				S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
33	2, 4, 6 trinitrotoluene				S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
34	Thallium I nitrate				S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
35		CH_3COCH_3			S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A

#	Chemical name	Formula	Family	Hazard(s)	Phys state	Vp @ ~68°F(1)	Burn(2)	Solubility	Toxicity	Corrosivity
36	Sulfuric acid				S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
37	Formaldehyde				S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
38	Carbon dioxide				S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
39	Hydrochloric acid				S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
40	Ammonia				S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
41		$CH_3OC_2H_3$			S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
42		CaO			S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A

#	Chemical name	Formula	Family	Hazard(s)	Phys state	Vp @ ~68°F$^{(1)}$	Burn$^{(2)}$	Solubility	Toxicity	Corrosivity
43		NH_4ClO_4			S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
44	Methanol				S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
45	Hydrogen peroxide				S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
46	Diethyl ether				S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
47	Benzene				S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
48		i-C_3H_7OH			S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A
49		CaC_2			S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A

#	Chemical name	Formula	Family	Hazard(s)	Phys state	Vp @ ~68°F(1)	Burn(2)	Solubility	Toxicity	Corrosivity
50	1, 3 butadiene				S L G	High Low None	Flammable Combustible No	Soluble Slightly sol. Insoluble	High Low No	Acid Base N/A

(1) Although defining vapor pressure (Vp) as high or low is only an approximate and subjective measurement, for the purpose of this activity, you may use the following general guideline: **below 25 millimeters of mercury (mmHg) is low; above 180 mmHg is high.**

(2) Flammability and combustibility criteria are based on the U.S. Department of Transportation (DOT) definition of "flammable" and "combustible." It is assumed that all chemicals in this activity are at less than 100°F.

(3) Characterizing a chemical as soluble, slightly soluble or insoluble should take into consideration the polarity of the chemical and whether it exists in a gaseous state, since gases can be dissolved in water.

(4) "Ca" stands for carcinogen.

(5) "WR" stands for water reactive.

ACTIVITY 13.2

Hazard Analysis Briefing to Hazardous Materials Leadership

Purpose

Process chemical information in an accurate and timely manner in order to determine both the hazards and the relative severity of the hazards of the given compounds. Present a clear, concise and accurate summary of hazard analysis information to an audience of hazardous materials leadership.

Directions

1. Review your assigned scenario and list of chemicals.
2. Do a comparative analysis of the five chemicals.
   a. Describe the chemical characteristics of each chemical.
   b. Identify the hazards of each chemical.
   c. Rank the chemicals in order of hazard severity.
3. Be prepared to brief hazardous materials leadership (hazardous materials group supervisor, safety officer, entry officer, decontamination officer, etc.) on the chemical hazards clearly and concisely and provide answers to any questions the hazardous materials leadership may have.
4. You will have 60 minutes and may use electronic sources and printed references to gather technical data and assemble your briefing material.
5. Your group will take 15 minutes to present to another group of peers, who will evaluate the presentation and provide suggestions for improvement. The evaluating group will also ask critical questions regarding the data and point out aspects that the presenting group should strengthen.
6. Your group will also take 15 minutes to listen to and evaluate the group that just evaluated your presentation.
7. After completing both evaluations, the groups will take another 30 minutes to make corrections to their presentations.

8. Provide the audience with your analysis of what type of operation is going on in the scenario based on what the facts, science and circumstances support. Your presentation should last no longer than 20 minutes, including time for questions and discussion. Each member of the team will be expected to answer questions regarding the chemicals.

9. Refer to the grading rubric for this activity for scoring criteria. Each member is awarded the team's score, which is applied to your final grade. This activity is worth 20% of your final grade for the class.

ACTIVITY 13.2 (cont'd)

Scenarios

Scenario 1: Vacant warehouse

It is July, 94°F and 72% humidity in a vacant warehouse. Elevation is 660 feet. You are presented with five chemicals:

1. Phosphorous trichloride.
2. Diisopropylaminoethanol.
3. Ethanol.
4. Dimethyl polysulfide.
5. Calcium carbonate.

Scenario 2: Basement in a residential home

It is June, 80°F and 59% humidity in the basement of a residential home. Elevation is 5,670 feet. You are presented with five chemicals:

1. Dimethyl methylphosphonate.
2. Dimethyl sulfoxide.
3. Thio diglycol.
4. Phosphorus trichloride.
5. Anhydrous ammonia.

Scenario 3: 12-foot by 20-foot storage unit

It is January, 14°F and 62% humidity in a 12-foot by 20-foot storage unit. Elevation is 2,150 feet. You are presented with five chemicals:

1. Ammonium nitrate.
2. Diesel fuel.
3. Nitric acid.
4. Toluene.
5. Sulfur hexafluoride.

Scenario 4: Mobile home

It is August, 105°F and 41% humidity in a mobile home. Elevation is 3,673 feet. You are presented with five chemicals:

1. Red phosphorous.
2. Acetone.
3. Sodium hydroxide.
4. HCl.
5. Calcium carbonate.

Scenario 5: Manufacturing building

It is March, 38°F and 67% humidity in a large, open manufacturing building. Elevation is 385 feet. You are presented with five chemicals:

1. Acrylonitrile.
2. Benzoyl peroxide.
3. Styrene.
4. Vinyl chloride.
5. Ammonium phosphate.

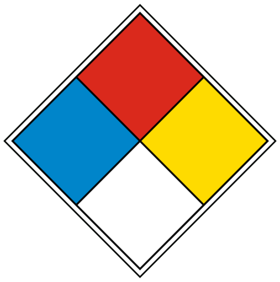
Scenario 6: Box truck

It is May, 64°F and 52% humidity, and a box truck is parked suspiciously. Elevation is 4,545 feet. In the truck you are presented with five chemicals:

1. Methanol.
2. Sulfuric acid.
3. Trichloroethylene.
4. 2 butanone.
5. Calcium sulfate.

ACTIVITY 13.2 (cont'd)

Product Hazard Analysis Worksheet 1



Group Number: ________ **Presenter:** ________________________

Temp: _________ °F **R/H:** _________%

Product Name:_________________________________ **Family:**_________________________

Data Points	Result	No Data	Hazard Consideration
Physical Properties			
Physical State			
Vapor Pressure			
Boiling Point			
Vapor Density			
Specific Gravity			
Solubility			
Flammability			
Flash Point			
LEL/UEL			
Flammable Range			
Ignition Temp.			
Toxicity			
Route of Exposure			
IDLH			
PEL/REL/STEL			
S/S of Exposure			
Biological			
Corrosivity			
pH			
Concentration			
Reactivity/Explosion			
Radioactivity			
Decay Mode	☐ **N/A** ☐ α ☐ β ☐ γ		
Half Life			

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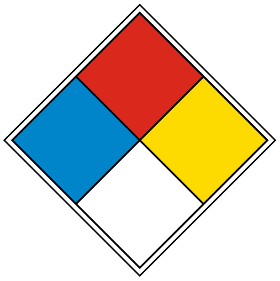

ACTIVITY 13.2 (cont'd)

Product Hazard Analysis Worksheet 2

Group Number: ________ **Presenter:** ________________________

Temp: _________ **°F** **R/H:** _________**%**

Product Name:________________________________ **Family:**________________________

Data Points	Result	No Data	Hazard Consideration
Physical Properties			
Physical State			
Vapor Pressure			
Boiling Point			
Vapor Density			
Specific Gravity			
Solubility			
Flammability			
Flash Point			
LEL/UEL			
Flammable Range			
Ignition Temp.			
Toxicity			
Route of Exposure			
IDLH			
PEL/REL/STEL			
S/S of Exposure			
Biological			
Corrosivity			
pH			
Concentration			
Reactivity/Explosion			
Radioactivity			
Decay Mode	☐ **N/A** ☐ α ☐ β ☐ γ		
Half Life			

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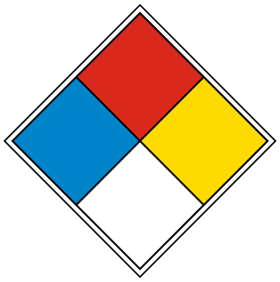
ACTIVITY 13.2 (cont’d)

Product Hazard Analysis Worksheet 3



Group Number: ________ **Presenter:** ________________________

Temp: _________ **°F** **R/H:** _________**%**

Product Name:_________________________________ **Family:**_________________________

Data Points	**Result**	**No Data**	**Hazard Consideration**
Physical Properties			
Physical State			
Vapor Pressure			
Boiling Point			
Vapor Density			
Specific Gravity			
Solubility			
Flammability			
Flash Point			
LEL/UEL			
Flammable Range			
Ignition Temp.			
Toxicity			
Route of Exposure			
IDLH			
PEL/REL/STEL			
S/S of Exposure			
Biological			
Corrosivity			
pH			
Concentration			
Reactivity/Explosion			
Radioactivity			
Decay Mode	☐ **N/A** ☐ α ☐ β ☐ γ		
Half Life			

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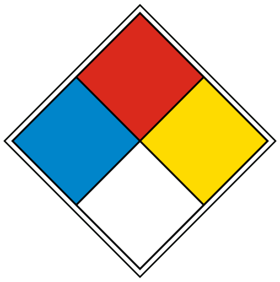
ACTIVITY 13.2 (cont'd)

Product Hazard Analysis Worksheet 4



Group Number: ________ **Presenter:** ________________________

Temp: _________ **°F** **R/H:** _________**%**

Product Name:_________________________________ **Family:**_________________________

Data Points	Result	No Data	Hazard Consideration
Physical Properties			
Physical State			
Vapor Pressure			
Boiling Point			
Vapor Density			
Specific Gravity			
Solubility			
Flammability			
Flash Point			
LEL/UEL			
Flammable Range			
Ignition Temp.			
Toxicity			
Route of Exposure			
IDLH			
PEL/REL/STEL			
S/S of Exposure			
Biological			
Corrosivity			
pH			
Concentration			
Reactivity/Explosion			
Radioactivity			
Decay Mode	☐ **N/A** ☐ α ☐ β ☐ γ		
Half Life			

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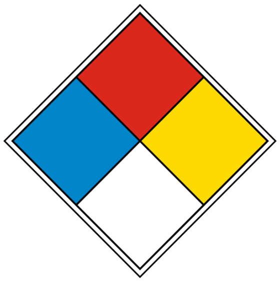
ACTIVITY 13.2 (cont'd)

Product Hazard Analysis Worksheet 5



Group Number: ________ **Presenter:** ________________________

Temp: _________ **°F** **R/H:** _________**%**

Product Name:_________________________________ **Family:**_________________________

Data Points	**Result**	**No Data**	**Hazard Consideration**
Physical Properties			
Physical State			
Vapor Pressure			
Boiling Point			
Vapor Density			
Specific Gravity			
Solubility			
Flammability			
Flash Point			
LEL/UEL			
Flammable Range			
Ignition Temp.			
Toxicity			
Route of Exposure			
IDLH			
PEL/REL/STEL			
S/S of Exposure			
Biological			
Corrosivity			
pH			
Concentration			
Reactivity/Explosion			
Radioactivity			
Decay Mode	☐ **N/A** ☐ α ☐ β ☐ γ		
Half Life			

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ACTIVITY 13.2 (cont'd)

Briefing Worksheet

Group number: ______________________________ Audience: __________________

Topic	Notes
Current situation and details	
Hazard/safety concerns	
Audience impact	
Recommendations	
Incident response objectives (for briefing responders only)	Control zones: PPE: Decontamination:

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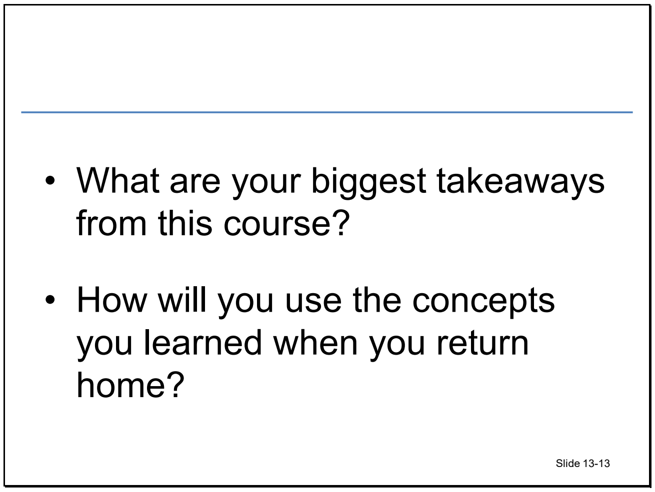
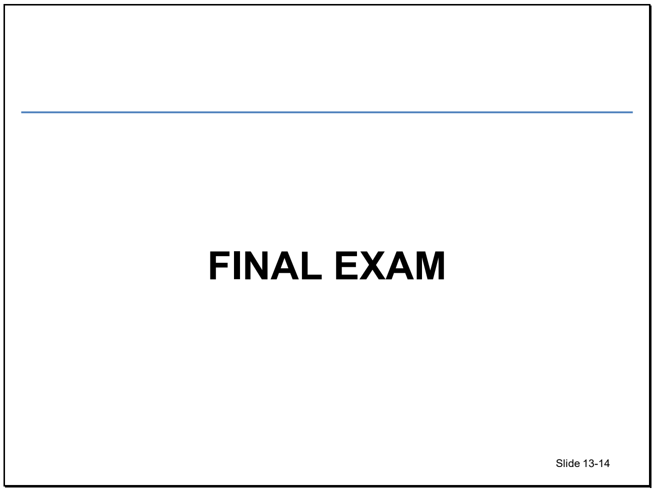
I. SUMMARY



- What are your biggest takeaways from this course?
- How will you use the concepts you learned when you return home?

II. END OF COURSE



FINAL EXAM

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APPENDIX A

EXAM PREP WORKSHEET

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Exam Prep Worksheet

This worksheet is designed as a study aid to help you reinforce your understanding of the concepts. Answers are provided in Appendix B.

1. Match the chemical formula on the left with the compound's name on the right.

a.	Na_2S	Potassium peroxide
b.	K_3PO_5	Sodium sulfate
c.	$Ba(OH)_2$	Potassium perphosphate
d.	Na_2SO_4	Sodium sulfide
e.	K_2O_2	Barium hydroxide

2. Write the formula for each of the following compounds.

   a. Lithium hydroxide: ______________________________

   b. Aluminum sulfide: ______________________________

   c. Potassium permanganate: ______________________________

   d. Magnesium peroxide: ______________________________

   e. Calcium oxide: ______________________________

3. Balance each formula, then name the compound.

   a. $Ca\ SO_4$: ______________________________

   b. $Al_2\ O_3$: ______________________________

   c. $Mg\ S$: ______________________________

   d. $Li\ ClO_3$: ______________________________

   e. $Na_3\ N$: ______________________________

4. Identify each of the following compounds as a salt or a nonsalt.

   a. $CaCl_2$: ______________________________

   b. CCl_4: ______________________________

   c. $Al_2(O_2)_3$: ______________________________

   d. SO_2: ______________________________

5. Identify the name, family and hazard for each of the following.

   a. PH_3: ______________________________

   b. SO_4: ______________________________

   c. HF: ______________________________

   d. HNO_3: ______________________________

   e. CNCl: ______________________________

6. Name three elements in the alkali family.

   1. ______________________________

   2. ______________________________

   3. ______________________________

7. Name three alkali earth metals.

   1. ______________________________

   2. ______________________________

   3. ______________________________

8. Name three halogens.

   1. ______________________________

   2. ______________________________

   3. ______________________________

9. List three factors that affect the flash point of a material.

   1. ____________________

   2. ____________________

   3. ____________________

10. Name each of the following hazardous materials.

    a. C_6H_6: ____________________

    b. C_3H_8: ____________________

    c. $CH_3COC_2H_3$: ____________________

    d. $CH_3COOC_2H_3$: ____________________

    e. $CH_3OC_2H_5$: ____________________

    f. $CH_3OOC_2H_5$: ____________________

    g. $c\text{-}C_6H_{12}$: ____________________

    h. CH_3COOH: ____________________

    i. $CH_3SC_2H_5$: ____________________

    j. C_2H_3CN: ____________________

11. Define each of the following terms.

    a. Ionic bond: ____________________

    b. Covalent bond: ____________________

    c. Isotope: ____________________

    d. Isomer: ____________________

12. Name the compound and list the hazards.

    a. $C_2H_3COCH_3$: ______

    b. HCOOH: ______

    c. $C_2H_5OCH_3$: ______

    d. CH_3OOCH_3: ______

    e. $CH_3COOC_2H_5$: ______

    f. CH_3COOH: ______

    g. CH_3NHCH_3: ______

    h. CH_3OH: ______

    i. CH_2Cl_2: ______

    j. C_2H_5SH: ______

    k. $C_6H_3CH_3(NCO)_2$: ______

13. Which of these compounds has the lowest boiling point?

    a. Isobutane. b. Octane. c. Decane. d. Benzene.

14. Indicate all of the compounds with a wide flammable range.

    a. Diethyl amine. b. Acetaldehyde. c. Vinyl acetate. d. Acetone.

    e. Ethyl ether. f. Propanol. g. All of these.

15. Which group of compounds is polar?

    a. Alkanes. b. Aldehydes. c. Aromatics. d. Alkenes.

16. Which of these compounds has the highest ignition temperature?

    a. Propane. b. Decane. c. Iso-octane. d. Octane.

17. Name the hydrocarbon family for each of the following.

a. C_4H_8: ______________________________

b. C_6H_{10}: ______________________________

c. C_6H_6: ______________________________

d. C_6H_{14}: ______________________________

e. C_7H_8: ______________________________

18. Write the formula, family and hazards for each of the following.

a. Cycloheptane.

Formula: ______________________________

Family: ______________________________

Hazards: ______________________________

b. Isobutane.

Formula: ______________________________

Family: ______________________________

Hazards: ______________________________

c. Toluene.

Formula: ______________________________

Family: ______________________________

Hazards: ______________________________

d. Propyne.

Formula: ______________________________

Family: ______________________________

Hazards: ______________________________

e. Butyne.

Formula: ____________________

Family: ____________________

Hazards: ____________________

f. Vinyl acetate.

Formula: ____________________

Family: ____________________

Hazards: ____________________

g. Isopropyl ether.

Formula: ____________________

Family: ____________________

Hazards: ____________________

h. Nitrobenzene.

Formula: ____________________

Family: ____________________

Hazards: ____________________

i. Ethanoic acid.

Formula: ____________________

Family: ____________________

Hazards: ____________________

j. Dipropyl amine.

Formula: ____________________

Family: ____________________

Hazards: ____________________

APPENDIX B

EXAM PREP WORKSHEET ANSWER KEY

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Exam Prep Worksheet — Answer Key

This worksheet is designed as a study aid to help you reinforce your understanding of the concepts.

1. Match the chemical formula on the left with the compound's name on the right.

a.	Na_2S	**e**	Potassium peroxide
b.	K_3PO_5	**d**	Sodium sulfate
c.	$Ba(OH)_2$	**b**	Potassium perphosphate
d.	Na_2SO_4	**a**	Sodium sulfide
e.	K_2O_2	**c**	Barium hydroxide

2. Write the formula for each of the following compounds.

a.	Lithium hydroxide	**$LiOH$**
b.	Aluminum sulfide	**Al_2S_3**
c.	Potassium permanganate	**$KMnO_4$**
d.	Magnesium peroxide	**MgO_2**
e.	Calcium oxide	**CaO**

3. Balance each formula, then name the compound.

a.	$Ca\ SO_4$	**calcium sulfate**
b.	$Al_2\ O_3$	**aluminum oxide**
c.	$Mg\ S$	**magnesium sulfide**
d.	$Li\ ClO_3$	**lithium chlorate**
e.	$Na_3\ N$	**sodium nitride**

4. Identify each of the following compounds as a salt or a nonsalt.

a.	$CaCl_2$	**salt**
b.	CCl_4	**nonsalt**
c.	$Al_2(O_2)_3$	**salt**
d.	SO_2	**nonsalt**

5. Identify the name, family and hazard for each of the following.

a.	PH_3	**phosphorous trichloride**	**binary nonsalt**	**vary**
b.	SO_4	**sulfur tetraoxide**	**nonmetal oxide**	**toxic/corrosive**
c.	HF	**hydrogen fluoride**	**binary acid**	**corrosive**
d.	HNO_3	**nitric acid**	**oxyacid**	**oxidizer/corrosive**
e.	CNCl	**cyanogen chloride**	**inorganic cyanide**	**toxic**

6. Name three elements in the alkali family. (Answers may vary.)

   1. **Li.**
   2. **K.**
   3. **Na.**

7. Name three alkali earth metals. (Answers may vary.)

   1. **Ca.**
   2. **Mg.**
   3. **Be, Ba.**

8. Name three halogens. (Answers may vary.)

   1. **F.**
   2. **Cl.**
   3. **Br, I.**

9. List three factors that affect the flash point of a material.

   1. **Molecular weight (MW).**

   2. **Polarity.**

   3. **Branching.**

10. Name each of the following hazardous materials.

a.	C_6H_6	**benzene**
b.	C_3H_8	**propane**
c.	$CH_3COC_2H_3$	**methyl vinyl ketone**
d.	$CH_3COOC_2H_3$	**vinyl acetate**
e.	$CH_3OC_2H_5$	**methyl ethyl ether**
f.	$CH_3OOC_2H_5$	**methyl ethyl peroxide**
g.	c-C_6H_{12}	**cyclohexane**
h.	CH_3COOH	**acetic acid**
i.	$CH_3SC_2H_5$	**methyl ethyl sulfide**
j.	C_2H_3CN	**vinyl cyanide or acrylonitrile**

11. Define each of the following terms.

a.	Ionic bond	**A chemical bond involving transferred electrons**
b.	Covalent bond	**A chemical bond involving shared electrons**
c.	Isotope	**Atoms with the same number of protons and different numbers of neutrons**
d.	Isomer	**Molecules with the same number of atoms, where atoms are organized in different shapes**

12. Name the compound and list the hazards.

a.	$C_2H_3COCH_3$	**vinyl methyl ketone**	**F, Narc**
b.	$HCOOH$	**methanoic acid**	**T, Corr, may burn**
c.	$C_2H_5OCH_3$	**ethyl methyl ether**	**F, Anes, Forms Per., Wide FR, Slow Ox.**
d.	CH_3OOCH_3	**dimethyl peroxide**	**Explosive**
e.	$CH_3COOC_2H_5$	**ethyl acetate**	**F, T, Poly**
f.	CH_3COOH	**acetic acid**	**may burn, T, Corr**
g.	CH_3NHCH_3	**dimethyl amine**	**F, T**
h.	CH_3OH	**methyl alcohol**	**F, T, Wide FR, Slow Ox.**
i.	CH_2Cl_2	**dichloromethane**	**T.**
j.	C_2H_5SH	**ethyl mercaptan**	**F, T.**
k.	$C_6H_3CH_3(NCO)_2$	**phenyl methyl diisocyanate**	**Toxic, Ca**

13. Which of these compounds has the lowest boiling point?

a. Isobutane. b. Octane. c. Decane. d. Benzene.

14. Indicate all of the compounds with a wide flammable range.

a. Diethyl amine. **b. Acetaldehyde.** c. Vinyl acetate. d. Acetone.

e. Ethyl ether. **f. Propanol.** g. All of these.

15. Which group of compounds is polar?

a. Alkanes. **b. Aldehydes.** c. Aromatics. d. Alkenes.

16. Which of these compounds has the highest ignition temperature?

a. Propane. b. Decane. c. Iso-octane. d. Octane.

17. Name the hydrocarbon family for each of the following.

a.	C_4H_8	**Alkene**
b.	C_6H_{10}	**Alkyne**
c.	C_6H_6	**Aromatic**
d.	C_6H_{14}	**Alkanes**
e.	C_7H_8	**Aromatic**

18. Write the formula, family and hazards for each of the following.

   a. Cycloheptane.

      Formula: **c-C_7H_{14}.**

      Family: **Alkanes.**

      Hazards: **Flam/Comb.**

   b. Isobutane.

      Formula: **i-C_4H_{10}.**

      Family: **Alkanes.**

      Hazards: **Flam/Comb.**

   c. Toluene.

      Formula: **C_7H_8.**

      Family: **Aromatics.**

      Hazards: **Comb/Ca.**

   d. Propyne.

      Formula: **C_3H_4.**

      Family: **Alkynes.**

      Hazards: **Flam/Unstable.**

e. Butyne.

Formula: **C_4H_6.**

Family: **Alkynes.**

Hazards: **Flam/Unstable.**

f. Vinyl acetate.

Formula: **$CH_3COOC_2H_3$.**

Family: **Esters.**

Hazards: **Tox/Flam.**

g. Isopropyl ether.

Formula: **$CH_3OC_3H_7$.**

Family: **Ethers.**

Hazards: **Tox/Flam.**

h. Nitrobenzene.

Formula: **$C_6H_5NO_2$.**

Family: **Nitros.**

Hazards: **Tox/Exp/Ca.**

i. Ethanoic acid.

Formula: **CH_3COOH.**

Family: **Organic acids.**

Hazards: **Flam/Corr.**

j. Dipropyl amine.

Formula: **$(C_3H_7)_2NH$.**

Family: **Amines.**

Hazards: **Tox/Flam.**

APPENDIX

BACKGROUND TEXT

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Table of Contents

List of Tables

List of Figures

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PRODUCT HAZARD ANALYSIS AND RISK-BASED RESPONSE

This chapter of the text corresponds to Unit 1 of the course.

According to National Fire Protection Association (NFPA) 470, *Hazardous Materials/Weapons of Mass Destruction (WMD) Standard for Responders* (2022 version), a risk-based response (RBR) is a systematic process of hazard analysis based on the facts, science and circumstances of the incident. Using this process, responders analyze a problem involving hazardous materials/weapons of mass destruction (WMD) to assess the hazards and consequences, develop an Incident Action Plan (IAP), and evaluate the effectiveness of the plan.

RBR is not procedural or linear. It is a continual process in which analysis is based on facts, science and circumstances.

- **Facts:** things that are known or proven to be true.
- **Science:** a systematically organized body of knowledge on a subject.
- **Circumstances:** conditions connected with or relevant to an event or action.

When conducting an RBR, responders consider:

- **Product:** Consider the hazards created by either the physical or chemical characteristics of the material(s) involved. Is it a solid, liquid or gas? What are its chemical, biological or radiological hazards?

- **Container:** Consider characteristics such as internal pressures, types of construction and types of damage incurred. Is it pressurized or nonpressurized? Bulk or nonbulk? What type of container (cylinder, drum, box, bag)? Fixed facility or transport? What method of transport (rail, pipe, highway, air, maritime)?

- **Environment:** Consider the physical surroundings of the product and container. Is it indoor or outdoor? What are the weather conditions? What is the terrain like? Is it a hazardous environment?

- **Cause:** Consider whether the incident was accidental, intentional or caused by negligence or illicit activity.

In addition, responders analyze the following six evaluation points related to the product's physical and chemical properties:

- Physical state.
- Flammability.
- Toxicity.
- Corrosivity.
- Reactivity.
- Radioactivity.

These topics are discussed in detail later in this document.

During the initial product analysis, responders perform the following four steps:

1. Determination of primary hazards.
2. Evaluation of safety actions already taken.
3. Timely evaluation of personal protective measures.
4. Guidance until more definitive information can be obtained and analyzed.

THE PERIODIC TABLE AND ATOMIC STRUCTURE

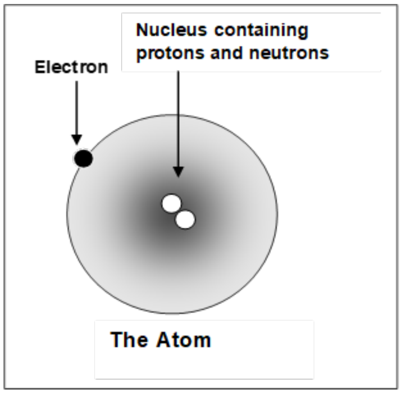
This chapter of the text corresponds to Unit 2 of the course.

The atom

The **atom** is the smallest constituent of the element. It cannot be broken down further and still retain the properties of that element. All elements are composed of atoms, and all matter consists of atoms.

The atom consists of **protons, neutrons** and **electrons.** The **nucleus** of the atom contains protons and neutrons, and it is where the positive charge resides. (Protons are positively charged, and neutrons have no charge.) The **electrons** orbit the nucleus and contain the **negative charge** of the atom.

Figure 1: The atom



Proton

- Is found in the nucleus.
- Has an atomic mass of 1.
- Has an electrical charge of +1.
- The number of protons is always the same within an atom of a given element.

Neutron

- Is found in the nucleus.
- Has an atomic mass of 1.
- Has no electrical charge.
- The number of neutrons within the nucleus of a given element can vary (resulting in isotopes).

Electron

- Is found in orbit around the nucleus.
- Is essentially weightless (1/1,840 of the proton).
- Has an electrical charge of -1.
- Has very little mass; for the purpose of this course, we will consider it to be without mass.

Table 1: Characteristics of subatomic particles

Particle	Location	AMU	Charge
Proton	Nucleus	1 AMU	+1
Neutron	Nucleus	1 AMU	None
Electron	Orbital	0	-1

Duet and Octet rules

The Duet Rule and Octet Rule affect the stability of an element and how elements form bonds.

- **The Duet Rule:** The first orbit always contains two electrons.
- **The Octet Rule:** The outermost orbit always seeks to have eight electrons.

You will learn more about these rules later in this chapter.

Atomic number

The **atomic number** indicates the number of protons in the nucleus of the atom. Electrons must equal the number of protons; therefore, the atomic number also indicates the number of electrons in the **neutral** atom. Because of this, all elements are electrically neutral on the periodic table.

Atomic mass

The **atomic mass** of the atom is the total of protons and neutrons contained within the nucleus of that atom. It is measured in **atomic mass units (AMU)**. It is the weight of the nucleus since the majority of the weight is contained in the protons and neutrons. The **mass number** refers to the number of protons plus the number of neutrons. Atomic mass is rounded to the nearest whole number.

The number of neutrons in the nucleus of an atom may vary, but the number of protons will always be the same. If the number of protons changes, it becomes a new element. When the number of neutrons varies from the number found in the most stable form of that element, it is called an **isotope**. An isotope is a form of an element with the same atomic number but a different atomic mass than its most common form (that found on the periodic table).

On the periodic table:

Proton = P+
Neutron = n°
Electron = e-

Atomic mass (A number) = P+ and n°
Atomic number (Z number) = P+
Atomic number = same number of P+ as e-

The periodic table

The elements

Depending on which chemistry text you are reading, there are around 118 elements. Of these, there are 92 elements formed naturally (1 to 92), and the remaining elements are made as the result of human intervention/creation. The elements after bismuth (83) are naturally radioactive. In this course, not all of them will be of interest to us.

In 1869, Dimitri Mendeleev discovered the predicted placement of elements, even for those that had not been discovered yet. This original scheme was organized based on increasing atomic mass (weight).

The system is a continual loop starting at hydrogen and ending within the inner transitional metals.

It is important that you be able to move easily about the periodic table and quickly recognize the symbols of the elements. It is necessary that you commit to memory the location, names and symbols of the most important elements that will be addressed during this course. These “important elements” are listed below.

Table 2: Important elements and their symbols

Symbol	Element
H	Hydrogen
Li	Lithium
Na	Sodium
K	Potassium
Cs	Cesium
Fr	Francium
Be	Beryllium
Mg	Magnesium
Ca	Calcium
Ba	Barium
U	Uranium
Pu	Plutonium
Cr	Chromium
Mn	Manganese
Fe	Iron
Co	Cobalt
Ni	Nickel
Cu	Copper
Ag	Silver
Au	Gold

Symbol	Element
Hg	Mercury
Zn	Zinc
B	Boron
Si	Silicon
As	Arsenic
Al	Aluminum
Sn	Tin (Stannum)
Pb	Lead (Plumbum)
C	Carbon
N	Nitrogen
O	Oxygen
P	Phosphorous
S	Sulphur
F	Fluorine
Cl	Chlorine
Br	Bromine
I	Iodine
He	Helium
Ne	Neon
Ar	Argon

The periodic table of elements is the most basic tool for the study of chemistry. Each box represents an element. Each element is represented with a symbol consisting of one or two letters. Many of the symbols are based on the English word for that element, but in some instances, they are derived from Greek or Latin words.

Many are taken from the English names:

- Oxygen is **O**.
- Hydrogen is **H**.
- Magnesium is **Mg**.

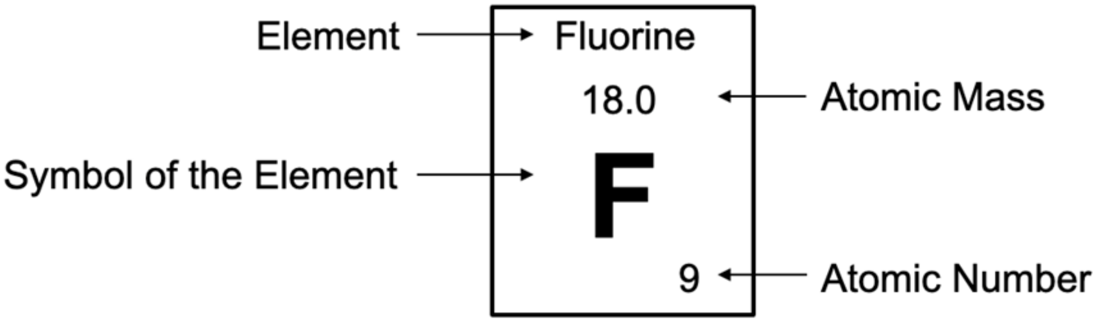
Some names are taken from the language or name of the discoverers, or other sources:

- Sodium is **Na** from the Latin “natrium” (for salt).
- Iron is **Fe** from the Latin “ferrum” (for iron).
- Iridium is **Ir** from the Greek “iris” (for rainbow).
- Potassium is **K** from the Latin “kalium” (for potash).
- Rhodium is **Rh** from the Greek “rhodon” (for rose).
- Curium is **Cm** (named after Marie Curie).

- Einsteinium is **Es** (named after Albert Einstein).
- Palladium is **Pd** (from the asteroid Pallas).
- Americium is **Am** (named after the Americas).
- Europium is **Eu** (named after Europe).

If the symbol is only one letter, it will always be capitalized, but if it is two letters, the first will be capitalized while the second remains lower case.

Figure 2: An element on the periodic table



Although the basic internal layout and contents of the boxes on a periodic table vary depending upon publisher and use, there are contents common to all. Within each box, you may see the name of the element. The whole number is the **atomic number**. The symbol is next, and the number with either a decimal or in parentheses is the **atomic mass (mass number)**. In addition, information such as electron shell configuration, oxidation states and electronegativity may be present. However, for our immediate purposes, we will use periodic tables that contain only the symbol, the atomic number, the atomic mass (or mass number) and, in some cases, some of the selected oxidation states of the elements.

Remember that the atomic number is equal to the number of protons in the nucleus, which also represents the number of electrons in the shells (orbital). The mass number is the number of protons and neutrons within the nucleus. Remember, the atomic mass is the total of the neutrons and protons found in the nucleus of an atom. The number of protons will always be the same, but the number of neutrons may vary. That is why the atomic mass listed on the periodic table is listed as a decimal. The number on the periodic table is an average weight of all the atoms for that particular element. If an atom has a differing number of neutrons from the most stable form of that element, it is called an **isotope.** Not all isotopes are radioactive, but some are.

Position and grouping

Position on the periodic table is important in determining the type of general physical and chemical properties an element will exhibit.

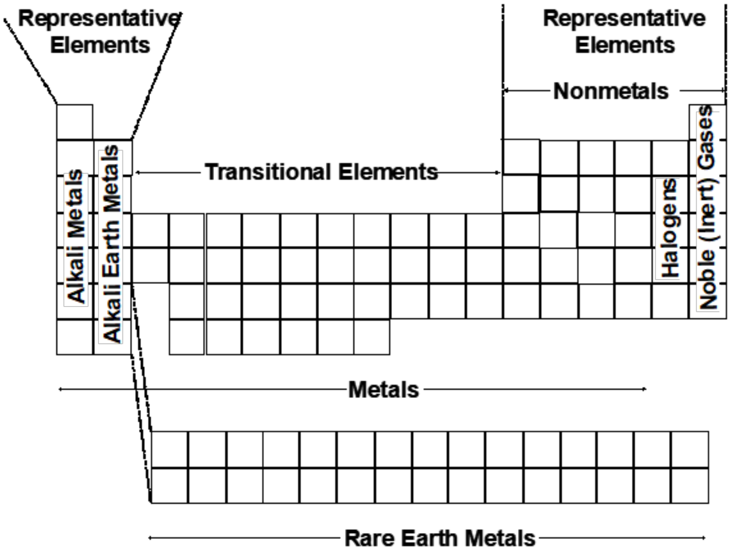
Moving **down a column vertically,** the atomic mass increases and "orbits" of electrons are added, so the elements become **heavier and larger in atomic radius.**

Each row represents an orbit. For example, sodium (Na) is in the third row, which equals three orbits.

Moving **across a row horizontally** from left to right, the atomic mass increases. However, the positively charged nucleus exerts greater control over the orbiting electrons, pulling them closer to the nucleus. Therefore, the elements become **smaller in atomic radius and heavier.**

This greater control of the electrons is termed **electronegativity** (tending to attract electrons to form a chemical bond). **The number of electrons in the outer orbital determines chemical behavior.**

Figure 3: Position and grouping of elements on the periodic table



Elements are listed on the periodic table **in increasing order of the atomic number** (which has a bearing on the electrons and thus the combination or destruction of compounds).

Elements can be divided into **metals and nonmetals.** The elements along the border between the metals and nonmetals have properties similar to both, dependent on the reaction they enter into, and are called metalloids. Depending on conditions, these bordering elements can either give or take electrons. As seen in the figure on the next page, a line can be drawn below hydrogen and across, going under boron and then stair-stepping down one and over one. Elements above and to the right of "The Line" are nonmetals.

The **nonmetal elements** are in the upper right-hand corner of the chart. Those, along with hydrogen, are seen predominantly within organic chemistry.

Elements below and to the left of The Line are metals. Metals and nonmetal combinations are seen predominantly in inorganic compounds and are called **salts.**

Metals are solids except for mercury, which is a liquid at room temperature. They tend to be crystalline in nature and have a characteristic metallic luster. They conduct heat and electricity, are malleable, and form hydroxides with moisture and/or water. Nonmetals are usually poor conductors of electricity, cannot be hammered into sheets or drawn into wire, and their oxides will form acids with water. They are solids or gases, with the only liquid being bromine at room temperature and ambient pressure.

Figure 4: The periodic table with "The Line" separating metals and nonmetals

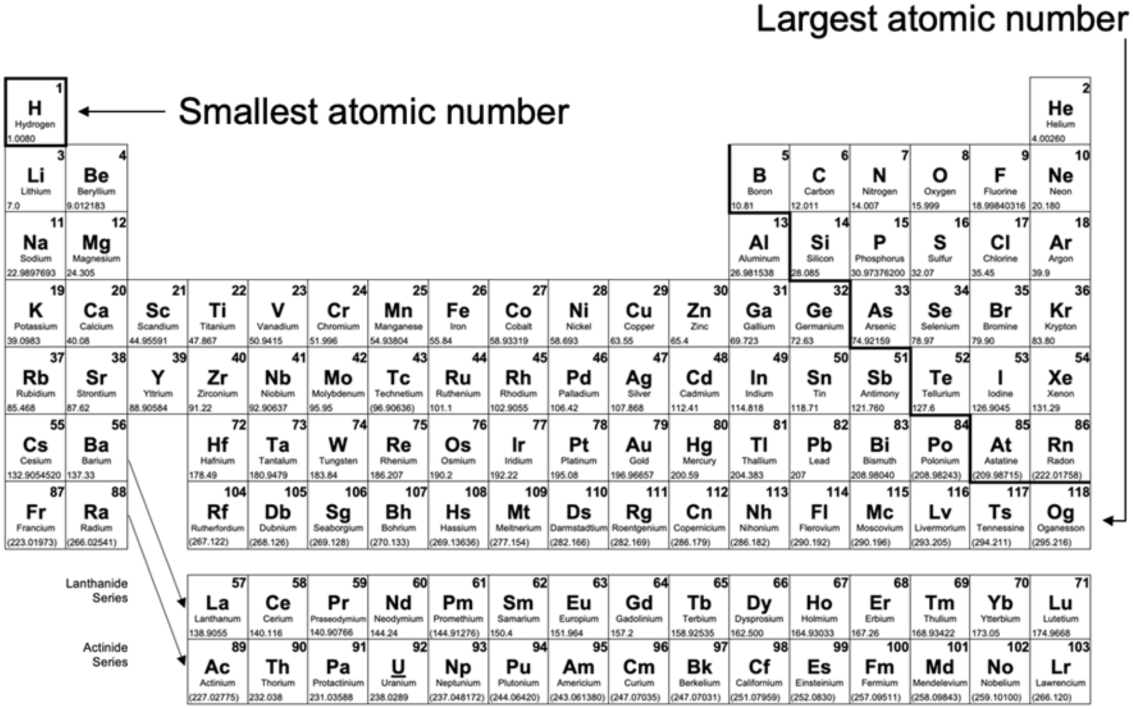


Figure 5: Characteristics of metals and nonmetals

Characteristic	Metals	Nonmetals
Physical state	Solid (except Hg)	Solids, liquids or gases
Appearance	Metallic or crystalline	Variable
Malleable	Yes	No
Conduct heat and electricity	Well	Poorly

The larger vertical columns on the table are known as the **representative groups** and contain the representative elements. Representative elements are elements that have not achieved the Octet Rule. The short columns in the middle of the chart are the **transitional metals.** The heavy line separates the metals and the nonmetals.

The vertical columns or groups are known as **families,** and all members of each family have similarities in the way they react chemically.

From top to bottom and right to left:

- Gas to solid.
- Atomic radius increases.
- Metallic qualities increase.

From bottom to top and left to right:

- Stronger electronegativity.
- Increase of ionization potentials.
- Decrease in atomic radius.

The first family is under the heading IA (Group I) and is known as the **alkali metals.** Hydrogen is not considered part of this family and is actually a nonmetal. Group II is called the **alkali earth metals.**

Again, we see that elements within the group have similar properties. Group VII is the **halogen group or family.** Group VIII is called the **noble or inert gas group or family.**

The two separated rows at the bottom of the table are rare earth metals. Many are radioactive, and several only exist in the lab for fractions of a second.

Group I — The alkali metals

The alkali metals can form highly water-reactive compounds depending on the element they combine with. Compounds with these metals result in solutions that can be very caustic and destructive to the skin and respiratory tree. They produce hydrogen gas and heat on contact with water, which usually causes violent reactivity.

Group II — The alkali earth metals

Compounds with the alkali earth metals have the same basic properties as the alkali metals, though less severe; they are not as aggressive, but are still dangerous.

Group VII — The halogens

The halogens are the most reactive of the nonmetals. They are very toxic and highly irritating to the skin. The halogens do not burn but are potent oxidizers. Oxidative qualities decrease as you move down the halogens from fluorine (F) to iodine (I).

Group VIII — The noble gases (inert gases)

The noble gases are in the most stable configuration. Other elements try to reach this stability through reactions. These are not technically representative elements since they have achieved the Octet Rule.

Transition metals

Transition metals do not follow all the rules. While the metals from the representative groups will always give up the same number of electrons when they become ions, some of the **transition metals** will be capable of losing different numbers of electrons, so the resulting ion can have varying charges. If you have the formula available, you can determine the number of electrons given up by the transitional metal by identifying the number of electrons the nonmetal can accept. For example, you know that oxygen always has six electrons in its outer (or valence) ring, while copper (Cu) will contribute one or two electrons from its outer ring.

Therefore, oxygen can accept two electrons to satisfy the Octet Rule. It will always accept only two — no more and no less. So, if you have the formula for iron oxide (iron II oxide), you can determine that the iron, in this case, gives up two electrons (iron II and +2) = FeO.

Figure 6: Formula for iron II oxide, showing charges

$$\boxed{Fe^{+2}\ O^{-2}}$$

Iron (Fe) gives away two electrons, creating two positive charges because the atom has two more positive protons than electrons now and becomes a Fe^{+2} **cation** (a positively charged ion).

Oxygen (O) attracts two electrons creating two negative charges because the atom has two more negative electrons than protons now and becomes a O^{-2} **anion** (a negatively charged ion).

You know that each iron must give up two electrons. This could also be called ferrous oxide or iron II oxide. The Roman numerals in the name of the compound will indicate how many electrons were given up by the metal. The older style ending “-ic” indicates the metal ion with the higher charge (Fe^{+3}), and the ending "-ous" indicates the lower charge (Fe^{+2}). We will investigate this further later.

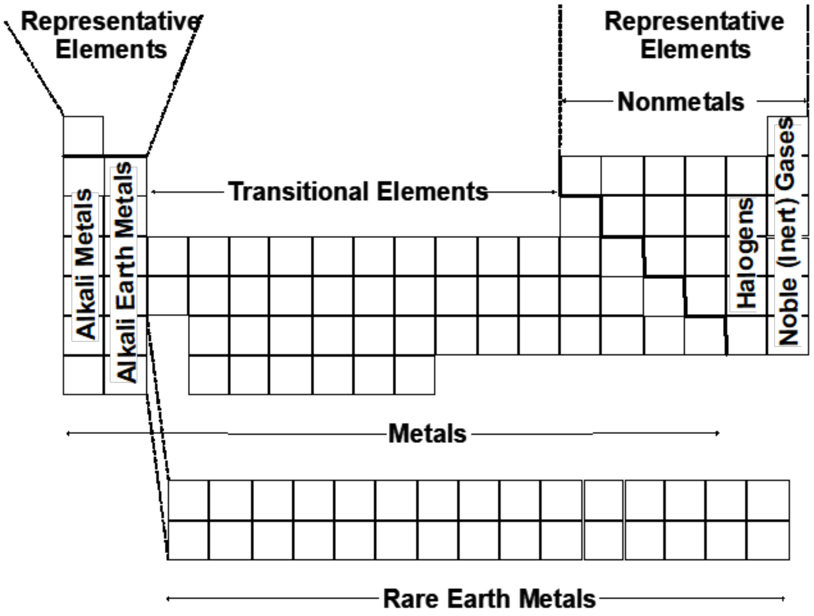
Inner transition metals (rare earth metals)

The inner transitional metals are the rare earth metals found in the region of the periodic table underneath the transitional metals. The two main periods in this group are:

1. Lanthanides.
2. Actinides.

Some of these elements occur naturally, while others are synthetically made through neutron bombardment. These elements are rare and have radioactive potential. These elements are not shipped in bulk.

Figure 7: Rare earth metals are located at the bottom of the periodic table



Electronegativity and atomic radii

The electronegativity of an atom has a relationship with its atomic radii, and thus, the potential of releasing or gaining electrons. Small distances from the nucleus to the outer perimeter of the electron orbits give rise to elements that attract electrons. Fluorine (F) is an example of this. Large distances from the nucleus to the outer perimeter of the electron orbit lose or give up electrons easily. Francium (Fr) is an example of this.

From left to right and from bottom to top, electronegativity increases. The elements at the far top right, such as fluorine (F), have the smallest radii. The elements at the bottom left, such as francium (Fr), have the largest radii.

Isotopes

As discussed previously, an isotope is an element with the same atomic number but a different atomic mass. The different mass is caused by a variation in the number of neutrons. Not all isotopes are radioactive. Isotopes may also be called **nuclides.** There are three different forms of isotopes:

- Natural — nonradioactive.
- Natural — radioactive.
- Man-made — radioactive (made through bombardment with neutrons).

A number attached to the chemical name indicates the isotope.

- Carbon-12 is the most stable form of carbon. Noted: $^{12}6$ C.
- Carbon-14, which is used to date test materials and contains eight neutrons instead of six, is an isotope. Noted: $^{14}6$ C.

Another example is hydrogen. Hydrogen has three isotopes:

1. Hydrogen (protium) $^{1}_{1}H$ (no neutrons).
2. Deuterium $^{2}_{1}H$ (1 neutron).
3. Tritium $^{3}_{1}H$ (2 neutrons).

Electron configuration

The way an element will behave chemically is a function of its electron configuration. Therefore, it is important that you understand how electrons align themselves around the nucleus of an atom. We already know that **electrons have a charge of -1 and protons have charge of +1.** Because all atoms must be electrically neutral, the electrons have to equal the protons. By looking at the atomic number on the periodic table, you can determine the number of protons, thereby determining the number of electrons that orbit the nucleus.

The electrons will configure themselves in **orbits** or **shells** around the nucleus. The number of electrons found in the outer shell of the atom is extremely important because this outermost ring is responsible for the atom entering into chemical reactions. The greatest number of electrons that can be in the first orbit is two (Duet Rule). The most that can be in the outermost ring is eight (Octet Rule).

Duet Rule: If an atom has only one shell (such as helium), it will never have more than two electrons in that shell. When it contains two electrons in its only shell, the atom achieves stability through the Duet Rule.

Octet Rule: If an atom has more than one shell, it achieves stability when it has eight electrons in the outermost shell.

The orbits between the nucleus and the outermost orbit don't enter reactions because they are filled. You can use the periodic table to tell you how many electrons are in the outer shell by figuring out the family the element is in. The Roman numeral at the top of the periodic table over the vertical columns will identify the number of electrons in the outer shell (this method cannot be used for the transitional metals because they vary).

All elements continually attempt to become stable. For stability to exist, the outer electron ring must contain eight electrons. As previously mentioned, this is called the Octet Rule and is a major determinant in chemical reactions. The exception to this rule is helium, which is stable with just two electrons in the outer ring, the only ring being in the first row. Helium has achieved the Duet Rule. As you can see, the noble gases have eight electrons in the outer ring; therefore, they are already stable, having achieved the Octet Rule. This is why they are called inert — because they will not enter into chemical reactions unless electrons are forced off the atom's outer ring. Just by looking at the periodic table, one can see that very few elements have achieved stability. It is this lack of stability (among many other factors) that drives elements to react chemically.

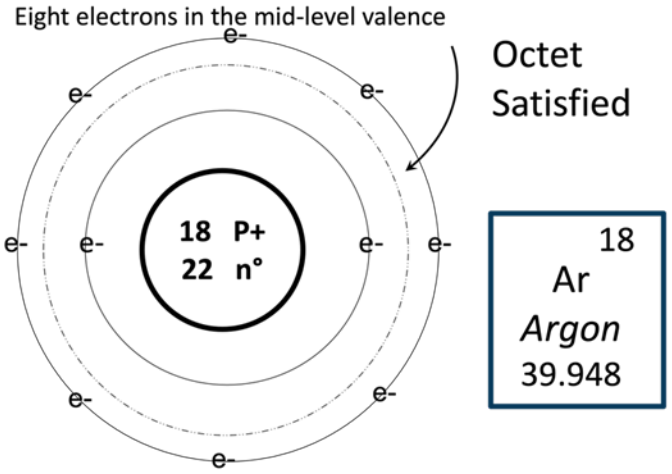
Another name for the charge of an atom is the **valence** number or oxidation state. The outermost shell — the one that contains the electron(s) that will engage in chemical reaction — is called the **valence shell.**

Oxygen, commonly called O_2, is an example of a **diatomic** molecule, from "di," meaning two, and "atomic," meaning atom. A single atom of oxygen has only six electrons in its outer ring. To become stable, another atom of oxygen will share electrons to form a covalently bonded molecule of oxygen (O_2). This is how we see stable oxygen in nature because there must be eight electrons in the outer orbit of electrons. We will discuss the covalent bonding process in much greater detail later in the course.

Bohr Model and dash model

The Bohr Model represents electrons orbiting the nucleus like planets orbiting the sun. This concept of using concentric circles works for the simple molecules in basic inorganic chemistry.

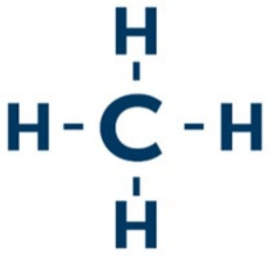
Figure 8: The Bohr Model (argon)



However, when we start to look at issues such as the movement of electrons in the transitional metals, the ability of elements to take on a variety of oxidation states, or the unique stability of certain compounds such as benzene, the Bohr Model does not stand up to the level of understandable explanation.

More complex molecules make the Bohr Model ineffective, so the **dash model** is a way of showing the structure of more complex organic molecules sharing electrons represented by a dash between atoms.

Figure 9: The dash model (methane CH_4)



Introduction to bonding

Achieving stability

Noble gases have eight electrons in the outer shell. This satisfies the need to be stable according to the **Octet Rule.** Noble gases have achieved the highest level of stability.

This level of stability can be achieved in two ways:

- Atoms can gain or lose electrons.
- Atoms can share electrons.

Hydrogen and helium atoms achieve stability by meeting the **Duet Rule.** If only one shell is present, the atom can be stable by having two electrons in a full first orbit. All members of each group tend to exhibit similar chemical characteristics. This is because they all have the same number of electrons in the outer electron shell or orbital.

Bonding

Most elements are in an unstable state if not in combination with other elements. They have not satisfied the requirements of the outermost orbital. The nature of an atom (or molecule) is to achieve stability. The elements will achieve stability to comply with the laws of nature.

- Electrons may be gained (ionic bonding).
- Electrons may be given up (ionic bonding).
- Electrons may be shared (covalent bonding).

Ionic bonding: metal + nonmetal (M + NM)

Ionic bonding occurs only between a metal and a nonmetal. Large metals (large atomic radii) hold electrons very loosely. Small nonmetals (small atomic radii) pull very hard on electrons. Metals will tend to give up electrons to nonmetals. The resultant compound is called a salt.

- Most salts are solids.
- Often, they are water soluble or water reactive.
- Usually, they conduct electricity through ionization in water.
- They are noncombustible but may support combustion as oxidizers.
- They have variable toxicity.

Since the individual atom is no longer electrically neutral, having gained or lost electrons, it can no longer be an atom. The resultant charged particles are called **ions.** When electron(s) are gained, the resulting atom will have a negative charge and will be called an **anion** (usually a nonmetal). When an electron(s) is given up, the resulting atom will have a positive charge and is called a **cation** (usually a metal). The atoms are then held together by the attraction of opposite charges that are present within the molecule.

By placing energy into an atom or molecule, an electron is released. This releasing of energy is called the **ionization potential.** Photoionization detectors (PIDs) and flame ionization detectors (FIDs) use this principle to “see” chemical compounds.

Covalent bonding: nonmetal + nonmetal (NM + NM)

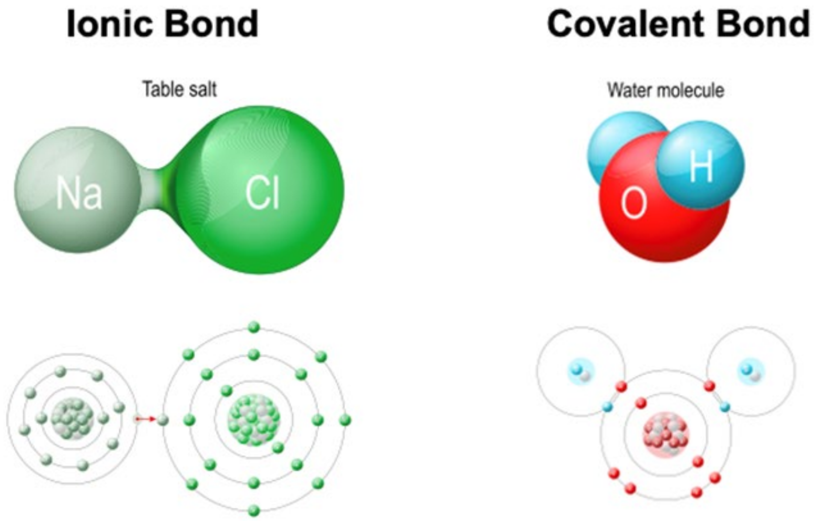
A covalent bond may be formed when two nonmetal atoms come close together and share the electrons within the outer orbit, satisfying each outermost shell. Each possesses a relative size and ability to attract. This relative size and electron sharing are the basis for the covalent bond. Covalent compounds are known as the nonsalts.

Other types of bonds

Resonant bonds are unique and will be seen in several of the chemical families that will be discussed in this program, particularly the aromatics and nitro compounds. In a resonant bond, each bonding electron contributes to the bonds within the entire structure. The electron resonates or moves within the molecule in such a way that it can contribute to more than one bond. Think of an electron attached to the tip of the blade of a fan. When the fan is turned on you can't really see the individual blade, only the resonating blades of the fan. This creates a stable type of bond. These resonant bonds will be discussed in greater detail later in the course.

Coordinate covalent bonds are too complex for the objectives of this course. This type of bonding explains some of the ionic and covalent rule bending required by some atoms to exist. More information can be sought after by curious students, but it is not vital that you understand this type of bond for now.

Figure 10: Ionic and covalent bonds (Shutterstock images)



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SALTS

This chapter corresponds with Unit 3 of the course.

Introduction

A salt is a compound created through ionic bonding between a metal and a nonmetal.

In this course, we will be concerned with six types of salts or ionic compounds:

- Binary salts.
- Cyanide salts.
- Hydroxide salts.
- Peroxide salts.
- Oxysalts.
- Salts containing the ammonium cation.

Properties of the salts

Salts are always formed through ionic bonding. Metals give up electrons, and nonmetals accept electrons. The resulting ions are held together by opposing charges.

Most are solids unless made into solutions. Most dissolve in water or react with water, and most conduct electricity when dissolved in water. Generally, they do not burn with a flame, though some will glow-burn.

Some salts are oxidizers that can enhance combustion. Many are very toxic, either systemically or locally.

- Local damage occurs at the point of contact.
- Systemic toxicity affects a physiological system within the body.

Binary salts

Binary salts are composed of a metal and a nonmetal. The metal will be named first in the formula followed by the nonmetal. The nonmetal's name will be altered to end in "-ide." For example, chlorine becomes chloride.

Table 3: Examples of binary salts

Chemical name	Formula
Potassium chloride	KCl
Mercury II chloride	$HgCl_2$
Calcium oxide	CaO
Sodium hydride	NaH
Sodium fluoride	NaF
Sodium sulfide	Na_2S

Special hazards of the binary salts

The hazards of the binary salts vary. They range from harmless salts like sodium chloride to poisons like sodium fluoride. **"PNCHO"** (pronounced "poncho") is an acronym mnemonic used to remember the binary salts that have specific hazards:

- **P**hosphides.
- **N**itrides.
- **C**arbides.
- **H**ydrides.
- **O**xides.

These nonmetal ions can react with water or moisture to produce flammable gases, toxic gases, caustic liquids and/or heat.

Phosphides

Phosphides release highly toxic phosphine gas when in contact with moisture.

Nitrides

Nitrides release severely irritating ammonia gas when in contact with moisture.

Carbides

Carbides release highly explosive and unstable acetylene gas when in contact with moisture.
The carbide ion is two carbons triple bonded together: $(C{\equiv}C)^{-2}$.

Hydrides

Hydrides release tremendous heat and the highly flammable hydrogen gas when in contact with moisture. They can ignite easily.

Oxides

Oxides release intense heat and form very caustic hydroxide solutions when in contact with moisture. The intensity of this reaction relates to the metal's location on the periodic table of elements. The further to the left on the periodic table, the more intense the reaction (Family I elements).

Binary salt with transition metals

Since transition metals can have multiple valences, we use naming conventions (classic and systematic) to differentiate between them.

The **classic** system uses the "-ous" suffix for the lower valence metal and the "-ic" suffix for the higher valence metal. An example of this is "cuprous" for a copper ion with a +1 charge and "cupric" for a copper ion with a +2 charge.

The **systematic** system uses a Roman numeral to identify the valence of the metal. An example of this is "Copper I" for a copper ion with a +1 charge and "Copper II" for a copper ion with a +2 charge.

Table 4: Common cations for transition metals

Element	Common oxidation states	Alternate (classical)	Systematic (IUPAC)
Copper (Cu)	+1, +2	Cuprous (+1) Cupric (+2)	Copper I Copper II
Mercury (Hg)	+1, +2	Mercurous (+1) Mercuric (+2)	Mercury I Mercury II
Iron (Fe)	+2, +3	Ferrous (+2) Ferric (+3)	Iron II Iron III
Tin (Sn)	+2, +4	Stannous (+2) Stannic (+4)	Tin II Tin IV
Cobalt (Co)	+2, +3	Cobaltous (+2) Cobaltic (+3)	Cobalt II Cobalt III
Chromium (Cr)	+2, +3	Chromous (+2) Chromic (+3)	Chromium II Chromium III
Manganese (Mn)	+2, +3	Manganous (+2) Manganic (+3)	Manganese II Manganese III
Lead (Pb)	+2, +4	Plumbous (+2) Plumbic (+4)	Lead II Lead IV
Zinc (Zn)	+2	Zinc (+2)	Zinc II
Nickel (Ni)	+2, +3	Nickelous (+2) Nickelic (+3)	Nickel II Nickel III
Silver (Ag)	+1	Silver (+1)	Silver I
Gold (Au)	+1, +3	Aurous (+1) Auric (+3)	Gold I Gold III

Complex (polyatomic) ions

We have seen that a metal and a nonmetal can form a bond. Nonmetals and nonmetals can form a radical, which we will call a **complex ion.** This ion is the “replacement” for the singular nonmetal. It acts as a singular atom. The overall valences are due to the covalent bonds within the complex ion. This complex ion donates or accepts an electron. These complex ions can become extremely complicated, so for this course we will look at specific ions.

Hydroxide salts

Hydroxide salts consist of a metal and the hydroxide ion: $(OH)^{-1}$. The hydroxide ion is a complex anion and will act as the nonmetal in ionic bonding. The hydrogen and oxygen have covalently bonded and have one electron to gain.

The metal is named first, followed by “hydroxide.”

Table 5: Examples of hydroxide salts

Chemical name	Formula
Potassium hydroxide	KOH
Sodium hydroxide	$NaOH$
Calcium hydroxide	$Ca(OH)_2$

In contact with moisture, these salts will produce a very caustic solution and generate intense heat.

Peroxide salts

Peroxide salts consist of a metal and a peroxide anion. The peroxide ion consists of two oxygen atoms bonded that have gained two electrons: $(O_2)^{-2}$.

The metal is named first, followed by the word "peroxide."

Table 6: Examples of peroxide salts

Chemical name	Formula
Sodium peroxide	Na_2O_2
Calcium peroxide	CaO_2

Peroxide salts will liberate oxygen and heat and form corrosive liquids when dissolved in water. These salts are considered strong oxidizers. Oxidizers are covered in more detail in a later section.

Cyanide salts (metal cyanides)

The cyanides are found in inorganic and organic chemistry. Cyanide salts are formed from a metal and the cyanide complex anion: $(CN)^{-1}$.

They are named by naming the metal then adding the word "cyanide" to the name. In industry, synonyms are commonly applied to this chemical family.

Cyanide salts form very hazardous chemicals. Cyanide ions are nonmetals, so they will gain electrons.

All cyanides are toxic by every route. There are some identifying characteristics associated with cyanide poisoning, such as the "bitter almond" smell or taste, though a large portion of the population is unable to detect this. When mixed with an acid, these salts will liberate the very toxic hydrogen cyanide gas. To a lesser extent, hydrogen cyanide can also be produced when these salts are in contact with water.

Table 7: Examples of cyanide salts

Chemical name	Formula
Sodium cyanide	$NaCN$
Potassium cyanide	KCN

Salts containing the ammonium cation

Another important complex cation is the ammonium ion: $(NH_4)^{+1}$. The complex ion is positively charged and consists of one nitrogen atom bonded to four hydrogen atoms. It will act like a metal in chemical reactions since they lose electrons. This cation is found in many hazardous materials, predominantly fertilizers and oxidizers. They are named by naming the ammonium ion, then the nonmetal.

These compounds are referred to as “ammonium salts” due to the attachment of the ammonium cation; however, they are not considered a stand-alone salt family. The salt family to which the ammonium cation is attached still brings all the associated hazards of that salt’s family, in addition to hazards of the ammonium cation.

Table 8: Examples of salts containing the ammonium cation

Chemical name	Formula
Ammonium chlorate	NH_4ClO_3
Ammonium fluoride	NH_4F
Ammonium bisulfate	NH_4HSO_4

Oxysalts

Oxysalts consist of a metal and an oxyradical, also known as an **oxyanion** (two or more elements, one of which must be oxygen, acting together as a complex anion).

The metal is named first, followed by the appropriate name for the oxyradical. The name of an oxyradical will depend on its oxygen state (or “oxystate”) from the oxysalt table.

The hazard with the oxysalts is that they are potent oxidizers. They will intensify the combustion of impregnated combustibles. They may also form blasting agents if mixed with certain organic materials.

Table 9: Common oxyradicals (normal oxygen states)

	-1 valence		**-2 valence**		**-3 valence**
FO_3	Fluorate	CO_3	Carbonate	BO_3	Borate
ClO_3	Chlorate	CrO_4	Chromate	PO_4	Phosphate
BrO_3	Bromate	SO_4	Sulfate	AsO_4	Arsenate
IO_3	Iodate				
NO_3	Nitrate				
MnO_3	Manganate				

Table 10: Oxyradical naming examples

Oxygen content	+1	Normal	-1	-2
Prefix	Per-	n/a	n/a	Hypo-
Suffix	-ate	-ate	-ite	-ite
Examples	Perchlorate Perbromate	Chlorate Sulfate	Chlorite Sulfite	Hypochlorite Hyposulfite

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INORGANIC NONSALTS

This chapter corresponds to Unit 4 of the course.

Introduction to the inorganic nonsalts

Inorganic compounds are generally classified as those compounds that do not contain carbon. However, there are exceptions to this statement as we will see in this discussion. Some examples include carbon monoxide (CO), carbon dioxide (CO_2) and inorganic cyanides containing the cyanide (CN) functional group.

Most nonsalts are liquids and gases, and a few are solids. Depending on the inorganic nonsalt, their prevailing hazards tend to be toxicity, corrosivity and water reactivity. Many are poisonous. Since they are covalently bonded, they are still classified as nonsalts. Here is a brief look at each of the inorganic nonsalt classes covered in this class.

Binary nonsalts

The inorganic nonsalts that have only two elements (which closely resemble the familiar class of salts) are called the binary nonsalts. They are called **binary** due to the presence of only two elements. These are formed by a nonmetal and a nonmetal combining. However, they will not contain oxygen or carbon. Since only two elements can be present, there must be a nonmetal that needs only one element to share its electrons. The halogens and hydrogen are good candidates for an element.

There are simple rules for naming these compounds. First, identify the element donating the fewest atoms to the compound; then name the second element with the ending “-ide.” An example would be nitrogen trihydride: NH_3. We know this compound by its common name, ammonia.

The associated hazards of the binary nonsalts are varied. Some are flammable and/or irritants, and some can react violently with water. The ones involving the halogen family are considered toxic. Those with hydrogen atoms (hydrides) are poisonous and water reactive. The gas that is produced is hydrogen, and the heat released during the liberation of the gas is usually sufficient to ignite the gas.

Nonmetal oxides

The nonmetal oxides family of inorganic nonsalts is commonly produced as the result of combustion and/or incomplete combustion; thus, they are referred to commonly as the “fire gases.” Combining oxygen with another nonmetal forms these compounds.

Many of them use a complex bond type called a “coordinate covalent bond,” in which the covalently shared electrons are shared even further. Many times, an entire semester in college chemistry is devoted to understanding the coordinate covalent bonding concept. To put it simply, it is like a game of musical chairs where there are more players than spots — except in this concept, no member (element) gets to escape from the bond. Because of the complexity of this type of bond, we will not attempt to show structures of many of these compounds because they are beyond the scope of this program.

To name these compounds, we name the nonmetal and add the word "-oxide." Because there is usually more than one oxygen present, we add a prefix ("di-" or "tri-") that designates the number of oxygen atoms present. An example would be sulfur dioxide: SO_2.

Most of these compounds are colorless, but some, like those containing nitrogen, will have a reddish-brown color. In their pure state when released into the air, they will produce a white vapor cloud upon contact with the humidity in the air. These nonmetal oxides are responsible for producing much of the "acid rain" making environmental news.

The hazards of these compounds include:

- Instant formation of very corrosive oxyacids when contacting moisture.
- Toxicity.
- They are strong oxidizers.
- Stimulation of combustion.

Also, the nitrogen compounds can cause a toxic process called methemoglobinemia.

Oxyacids (inorganic acids)

Oxyacids are formed by the combination of hydrogen with a complex ion discussed in the salts section of this course. The complex ions are known as oxyradicals. These are the same groups as the oxyanions; however, since no charge is involved in the bonding process, they are now referred to as oxyradicals and should be somewhat familiar to you. The oxyradical table discussed in the salts section of this course will be revisited here. As discussed in the salts section, it is possible to increase and decrease the oxygen content in the oxyradical. The same can occur in the oxyacids. Most of these oxyacids are liquids at ambient temperatures.

The oxyacids are the most hazardous of all the acids. All are very strong corrosives and strong oxidizers. Generally, they do not burn but may decompose in the presence of heat to the very toxic nonmetal oxides. Sulfuric acid (H_2SO_4), a member of the oxyacid family, accounts for the most widely produced nonpetroleum hazardous material each year worldwide.

Naming the oxyacids

Oxyacids are formed by hydrogen plus an oxyanion. In this case, the "-ate" and "-ite" suffixes for the anion are replaced with "-ic" and "-ous" respectively. The new anion name is then followed by the word "acid."

Using the base oxyradical state, some examples are:

- Chloric acid: $HClO_3$.
- Perchloric acid: $HClO_4$.
- Chlorous acid: $HClO_2$.

In the last example (chlorous acid), the "-ous" ending designates one fewer oxygen in the oxyradical. If there were two fewer oxygen molecules (HClO), it would be called hypochlorous acid. The naming will be consistent throughout all the possible oxyions/oxyradicals that are available.

To name the oxyacids, we must identify the base oxyradical state. This will end in "-ic acid."

Table 11: Oxyacid naming

Anion name	Acid name
Per----ate	per----ic acid
----ate	----ic acid
----ite	----ous acid
hypo----ite	hypo----ous acid

For example, perchlorate (ClO_4) becomes perchloric acid ($HClO_4$). Hypochlorite (ClO) becomes hypochlorous acid (HClO).

Table 12: Oxyacid naming examples

1 bond	2 bonds	3 bonds
ClO_3 Chloric	CO_3 Carbonic	PO_4 Phosphoric
BrO_3 Bromic	CrO_3 Chromic	
IO_3 Iodic	SO_4 Sulfuric	
NO_3 Nitric		
MnO_3 Manganic		

Binary acids (acid gases)

The binary acids are actually gases in their pure form. Some texts may refer to the binary acids as the acid gases. They are formed from hydrogen and a nonmetal from Group VII (the halogens).

Binary acids dissociate into hydrogen atoms and anions in water. When these gases come into contact with water or moisture, they form acids, hence the name "acid gases." When naming these binary acids, you merely add "hydro-" (denoting the presence of water) to the beginning and "-ic acid" to the end of the anion name.

Examples:

HF	Hydrogen fluoride + H_2O → hydrofluoric acid.
HCl	Hydrogen chloride + H_2O → hydrochloric acid.
HBr	Hydrogen bromide + H_2O → hydrobromic acid.
HI	Hydrogen iodide + H_2O → hydroiodic acid.

The binary acids are very corrosive poisons and generally are not flammable in themselves. Another differentiating factor from the oxyacids is that binary acids are not oxidizers.

Inorganic cyanides

The inorganic cyanides consist of a nonmetal (except carbon) and the cyanide anion. They are named by various means. Generally, name the nonmetals first, followed by the word "cyanide," or use the prefix "cyanogen," and then name the nonmetal.

Some common examples include:

- Hydrogen cyanide (HCN), also known as hydrocyanic acid, or prussic acid. It is a chemical warfare agent (CWA).
- Cyanogen chloride (ClCN) is also a CWA. Its toxic properties are very similar to HCN.
- Cyanogen bromide (BrCN) is a highly irritating toxic material. Its toxic properties are very similar to HCN.
- Cyanogen iodide (ICN) is used in taxidermy.

All are extremely toxic. They prevent the cells of the body from using oxygen and shut down aerobic metabolism.

HYDROCARBONS AND HYDROCARBON RADICALS

This chapter corresponds to Unit 5 of the course.

Introduction to hydrocarbons

Hydrocarbons are compounds that contain **only** carbon and hydrogen. No other element forms such strong bonds to as many other atoms as does carbon. Since carbon requires four more electrons to form an octet, it can form one, two, three or even four bonds with other atoms. In addition, those bonds can be single, double or triple bonds. This makes carbon unique. In fact, carbon can form more compounds than the total number of compounds formed by all the other elements combined.

Hydrocarbons are nonsalts. Their form is mainly liquids and gases, although some are solids. They are flammable and toxic.

Principle types of hydrocarbons

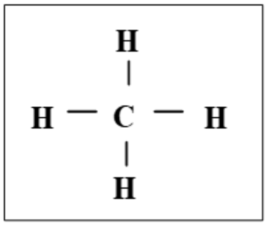
To simplify the vast numbers of compounds that can be created, hydrocarbons are divided into the following general categories:

- Alkanes.
- Cyclic alkanes.
- Alkenes.
- Alkynes.
- Aromatics.

The vast majority of hydrocarbons come from petroleum (crude oil) and coal tar (obtained from bituminous coal), as well as some other minor sources. All hydrocarbons are bonded covalently, since both carbon and hydrogen are nonmetals. Consider the electron configuration of hydrogen and carbon. Hydrogen has one electron in its outer ring and must have two to be stable (Duet Rule). Carbon has four and must have eight to be stable (Octet Rule). None of the four electrons in the outer ring of carbon are paired, so all are available to form covalent bonds. This configuration makes carbon one of the most important elements in the study of hazardous materials.

Carbon will not only form covalent bonds with other nonmetals but is also capable of forming covalent bonds with itself. For carbon to bond with itself, however, there must be some other element present, usually hydrogen. The simplest of all hydrocarbons is the compound created when one carbon and four hydrogens are combined. Since the carbon needs to share four pairs of electrons, and the hydrogen needs to share one each, the compound will look like the figure below.

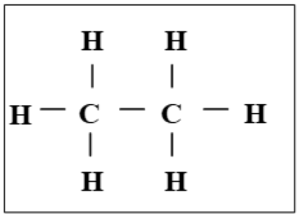
Figure 11: Example hydrocarbon structure (simple)



$$\begin{array}{ccccc} & & H & & \\ & & | & & \\ H & - & C & - & H \\ & & | & & \\ & & H & & \end{array}$$

This is methane gas and is the smallest of the hydrocarbon compounds. It is also possible to have additional carbons present as represented below:

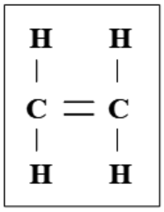
Figure 12: Example hydrocarbon structure (additional carbons)



$$\begin{array}{ccccccc} & & H & & H & & \\ & & | & & | & & \\ H & - & C & - & C & - & H \\ & & | & & | & & \\ & & H & & H & & \end{array}$$

It is also possible for the carbon to form multiple covalent bonds with itself, as long as the rules of stability are adhered to:

Figure 13: Example hydrocarbon structure (double bond)



$$\begin{array}{ccc} H & & H \\ | & & | \\ C & = & C \\ | & & | \\ H & & H \end{array}$$

In the above structure, there is a double bond between the two carbons. This bond is less stable than the single carbon-to-carbon bond. This is because the bonds repel each other, so that one of the electron pairs shared between the carbons is forced out of the plane between the nuclei of the carbon atoms. This type of bond is called a **pi bond** and will also exist when there is a triple carbon-to-carbon bond (called a **double pi bond**). This triple bond is even more unstable than the double bond.

Figure 14: Example hydrocarbon structure (triple bond)

$$H - C \equiv C - H$$

Oxygen tends to attack these pi bonds and cause them to break, thereby creating a reaction which releases heat.

Alkane hydrocarbons (paraffins)

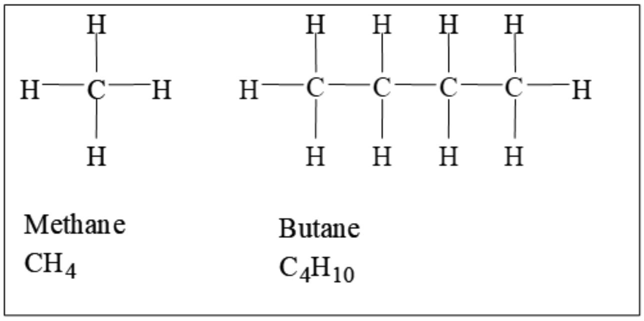
The **alkanes** (paraffins) consist of hydrocarbon compounds that contain only single carbon-to-carbon bonds. Many of these compounds will sound familiar since they are common fuels.

All names of the alkanes will end in "-ane." The prefix depends on the number of carbons in the molecule (see the table below). This family is also called the saturated hydrocarbons since the molecules are saturated completely with hydrogen.

Table 13: Naming of alkane hydrocarbons

Number of carbons	Name
1	Methane
2	Ethane
3	Propane
4	Butane
5	Pentane
6	Hexane
7	Heptane
8	Octane
9	Nonane
10	Decane

Figure 15: Example structures of alkane hydrocarbons



The general formula for the straight chain alkanes is C_nH_{2n+2}. This formula simply states that, given the number of carbons (n), there would be twice the number of hydrogens plus two. Therefore, if the chain contained 2 carbons, then "H" would equal 2 x 2 + 2, or six hydrogens.

Another important point for you to realize is that, as the molecule of a hydrocarbon gets larger, the weight will also increase. That is why the smaller hydrocarbons will normally exist as gases and the larger compounds will be liquids and even solids. Paraffin wax is merely an alkane containing 17 carbons in the molecule.

Isomers of the alkanes

Although we will not study any of the larger alkanes, you must be aware that not all alkanes are of the straight chain configuration. Sometimes, the alkanes will be branched. This is called an **isomer,** defined as a compound with the same molecular formula as another compound, but with a different structure. We denote an isomer's formula with the prefix "i-" designation. The most common alkane isomers are isobutane and isopentane.

Figure 16: Butane, C_4H_{10}

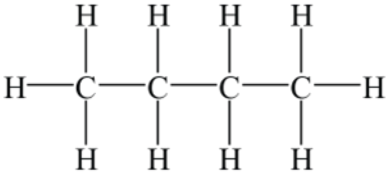
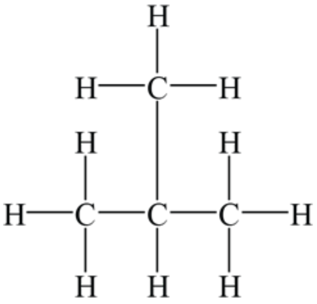


Figure 17: Isobutane, i-C_4H_{10}

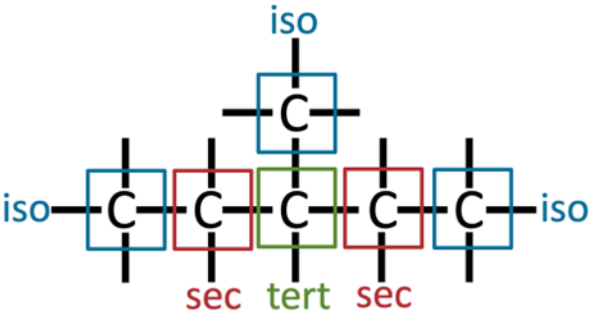


Alignment of carbons is described in the nomenclature for isomers, using prefixes to indicate the position of the carbon on the chain:

- "Iso-" when the attachment is on a carbon at the end of a branched chain.
- "Sec-" when the attachment is on a secondary carbon (carbon attached to two other carbons).
- "Tert-" when the attachment is on the back of a branch (one carbon that is attached to three other carbons).

Isomerization changes the chemical and physical properties of the material, and at times, its toxicity as well.

Figure 18: Isomers of the alkanes



The naming system described above begins to break down when we have isomers of larger molecules. Both of the following isomers can be named “isohexane,” but we can clearly see that they do not have the same structure.

Figure 19: Isohexane, i-C_6H_{14}

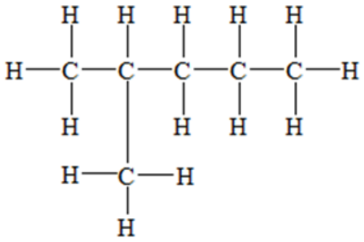
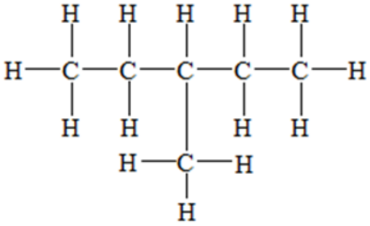


Figure 20: Isohexane, i-C_6H_{14}



We then see the need for the International Union of Pure and Applied Chemistry (IUPAC) Naming System.

International Union of Pure and Applied Chemistry naming rules for alkanes

Larger molecules have isomers that lead to the need for a more precise naming scheme. This naming scheme is referred to as the IUPAC Naming System.

The IUPAC naming rules for alkanes are listed below:

1. Find the longest continuous chain — the "main chain."

   Pentane; hexane.

2. Assign numbers to the carbons from the end of the main chain that will give the substituent (or radical) its lowest number.

3. Designate the position of each substituent by the number of the carbon it's attached to.

   2-methyl; 3-ethyl.

4. Name substituents alphabetically.

   3-ethyl; 2-methyl.

5. Substituents are named as prefixes to the main chain.

6. Repeating substituents numbers are used together with "di-," "tri-," and "tetra-."

   2,2-dimethyl; 2,3,4-trimethyl.

7. Name the main chain last.

   2,2-dimethyl pentane; 2,3,4-trimethyl octane

If we revisit the isohexane examples from above, we see that we can give them more specific IUPAC names using the rules.

Figure 21: 2-methyl pentane, i-C_6H_{14}

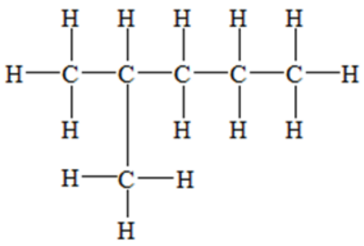
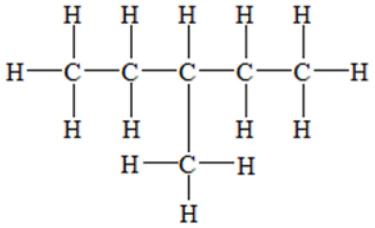


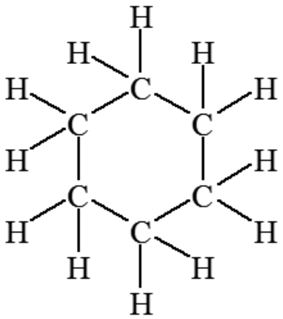
Figure 22: 3-methyl pentane, i-C_6H_{14}



Cyclic alkanes

The cyclic alkanes are named with a prefix of "cyclo-" indicating a cyclical structure.

Figure 23: Cyclohexane (c-C_6H_{12})



The general formula for the cyclic alkanes is c- C_nH_{2n}, where n represents the number of carbons. Cyclic alkanes always have two fewer hydrogens than their noncyclic counterpart. The two hydrogens are lost to allow the ends of the chain to reconnect to them.

Physical properties of the cyclic alkanes will vary. They are flammable and toxic. Some, such as cyclopropane, have anesthetic properties.

Alkene (olefin) hydrocarbons

The **alkenes** will contain at least one double carbon-to-carbon bond. All the alkenes will be named just like the alkanes, except that the ending is changed to "-ene." For example, if the compound has two carbons and contains a double carbon-to-carbon bond, it is called ethene. Propane becomes propene, and so forth.

These hydrocarbons are also called unsaturated hydrocarbons, since the molecule does not contain the maximum number of hydrogen atoms possible for the number of carbon atoms present.

The formula for the alkenes is C_nH_{2n}, where n represents the number of carbons. As you will notice, there is no corresponding alkene for methane since there is only one carbon present, so the double bond between two carbons is not possible.

Additionally, like the alkane family, some alkenes have isomers. Below are the structures of two butene isomers. Both have the formula C_4H_8. However, notice that 1-butene has the double bond between the first and second carbons, while 2-butene has the double bond between the second and third carbons. To differentiate between the two butene isomers, we add the number of the first carbon of the double bond to the front of the name. The first example would then be 1-butene, and the second example would be 2-butene.

Figure 24: 1-butene

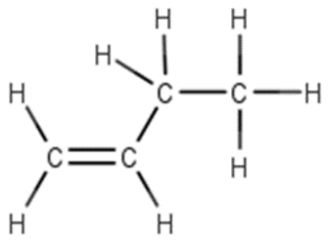
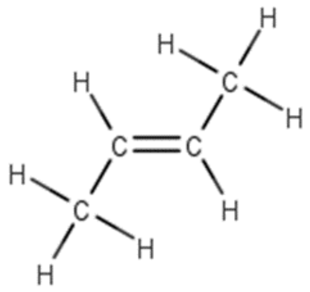


Figure 25: 2-butene



If more than one double carbon-to-carbon bond is present, it is called a polyunsaturated compound and will have the suffix "-diene." An example is butadiene.

Since the unsaturated compounds contain at least one pi bond (or out-of-plane bond), it is not as stable as the saturated hydrocarbons. You should always consider unsaturated hydrocarbon compounds to be highly reactive.

The alkenes can also be called monomers. Monomers are the building blocks of plastics, which are known as polymers.

Polymerization is a chemical reaction in which a relatively simple molecule with one or more multiple bonds **(monomer)** is broken and recombined to form larger macromolecules **(polymers).**

In a controlled setting, polymerization is the process used to make plastics. When uncontrolled, the reaction is violent and can be similar to a boiling liquid expanding vapor explosion (BLEVE).

Alkyne hydrocarbons

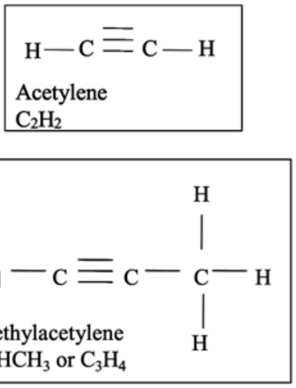
One other important unsaturated hydrocarbon compound is the **alkyne** family. In the alkynes, there is one triple carbon-to-carbon bond.

The general formula for the alkynes is C_nH_{2n-2}, where n represents the number of carbons.

The only alkynes that are common enough to concern us are ethyne and propyne. As you can see, the name is like the other families we have discussed except that the ending is changed to "-yne." We know ethyne as acetylene gas, an unstable compound used in cutting and welding. Propyne is known as methyl acetylene.

The alkynes are extremely flammable, unstable, reactive and toxic.

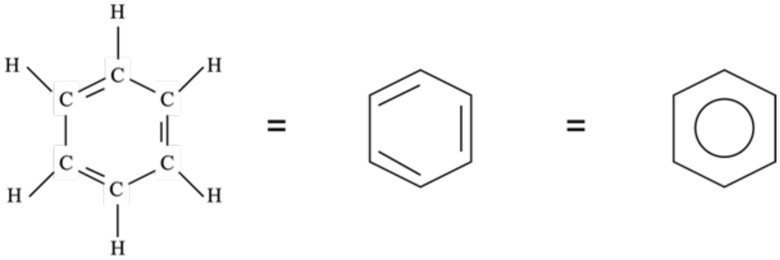
Figure 26: Example alkyne hydrocarbon structures



Aromatic hydrocarbons

The **aromatic** compounds are called such because of their sweet odor. Do not let this odor fool you, as all the aromatics are highly toxic. The aromatic hydrocarbons are hydrocarbon compounds that contain the benzene ring. The benzene ring is cyclical in shape and contains a unique type of carbon-to-carbon bonding known as resonant bonding. This is a very stable bond, and, for the most part, the aromatics tend to be very stable even though they are all toxic.

Figure 27: Three ways to represent the benzene ring structure

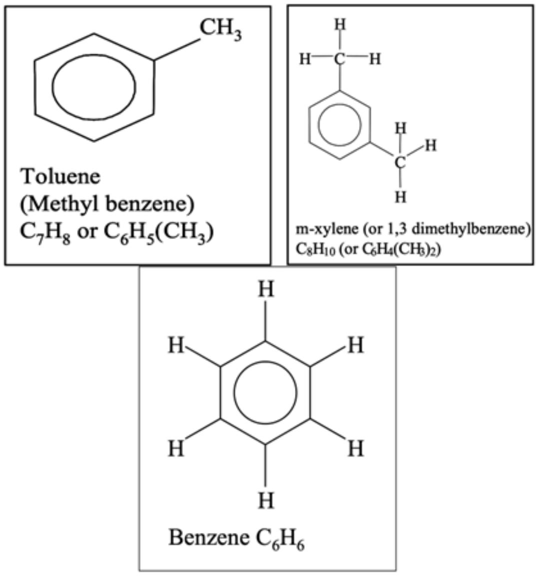


The general formula for the aromatics is C_nH_{2n-6}, where n represents the number of carbons. Their names end in the suffix "-ene."

In the study of hazardous materials, the most important and most common aromatic hydrocarbons are benzene, toluene, xylene and styrene. You may hear these referred to as the "BTXS Group" of the hydrocarbons.

The aromatics are flammable and toxic, and they burn sooty and dirty. Some may be **carcinogenic** — that is, known to cause cancer. For example, benzene is a confirmed carcinogen, and styrene is a suspected carcinogen.

Figure 28: Example aromatic hydrocarbon structures

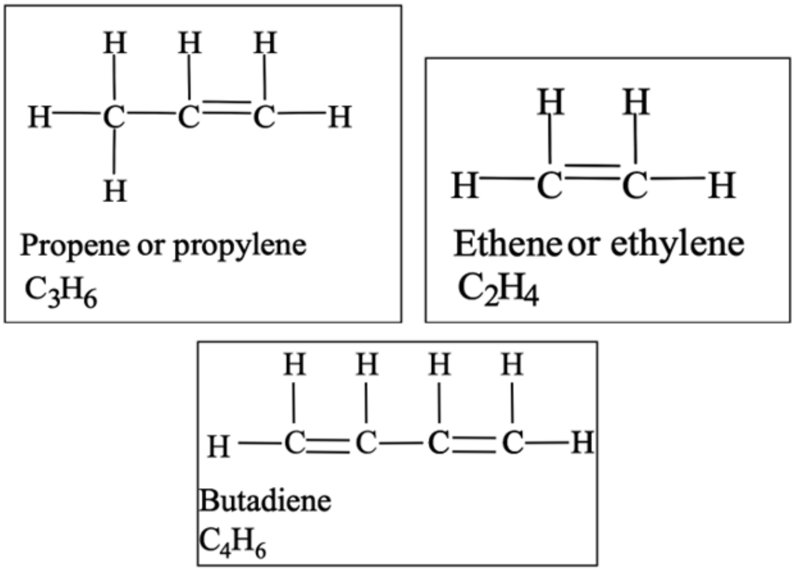


Toluene
(Methyl benzene)
C_7H_8 or $C_6H_5(CH_3)$

m-xylene (or 1,3 dimethylbenzene)
C_8H_{10} (or $C_6H_4(CH_3)_2$)

Benzene C_6H_6

Figure 29: Examples of branched hydrocarbons



Propene or propylene
C_3H_6

Ethene or ethylene
C_2H_4

Butadiene
C_4H_6

Hydrocarbon radicals

Once one or more hydrogen atoms are removed from a hydrocarbon, it becomes a hydrocarbon radical, also known as a hydrocarbon **backbone.**

Once a radical is created from an alkane, the name is altered slightly. The "**-ane**" ending is dropped and replaced by "**-yl**." Thus, methane becomes **methyl,** ethane becomes **ethyl** and so forth.

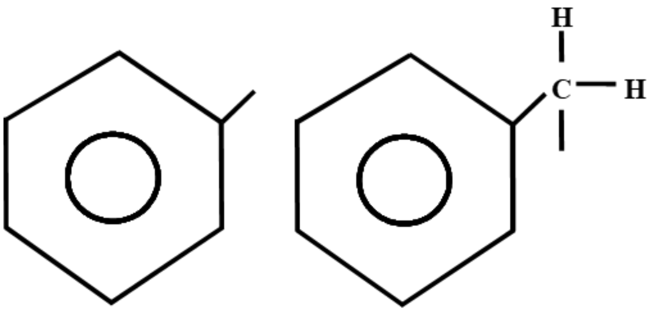
The alkenes are a bit different. The new name for alkene radicals will be **vinyl** for radicals created from ethane (or ethylene), and **acryl** (or in some cases, **allyl**) for radicals created from propene (or propylene). And lastly, the **croton** radical is derived from the four-carbon alkene hydrocarbon compound. These are the only alkene radicals we are concerned with in this course.

For the aromatics, when the hydrocarbon radical is formed from benzene, the resulting hydrocarbon radical is named **phenyl**. When the hydrocarbon radical is formed from toluene, the resulting radical is named **benzyl.**

Table 14: Naming of hydrocarbon radicals

Base	Bond	Family	Radical name
Methane	Single	Alkane	Methyl-/form-
Ethane	Single	Alkane	Ethyl-/acet-
Propane	Single	Alkane	Propyl/propenyl/allyl
Butane	Single	Alkane	Butyl
Pentane	Single	Alkane	Pentyl/amyl
Ethene	Double	Alkene	Vinyl
Propene	Double	Alkene	Acryl
2-Butene	Double	Alkene	Croton
Benzene	Resonate	Aromatic	Phenyl
Toluene	Resonate	Aromatic	Benzyl

Figure 30: Phenyl and benzyl



Radicals also can be made from isomers. Below are some common ones.

Figure 31: Isobutyl

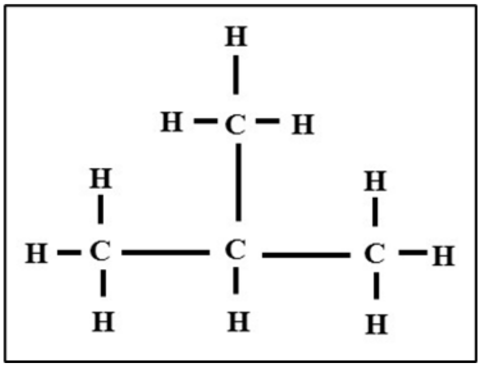


Figure 32: Secondary butyl

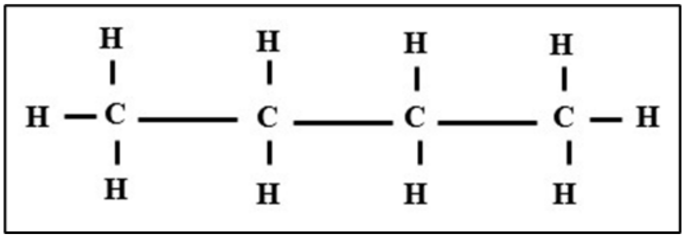
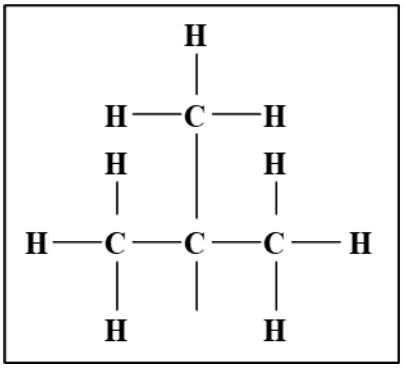


Figure 33: Tertiary butyl



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HYDROCARBON DERIVATIVES

This chapter corresponds to Unit 6 of the course.

Introduction to functional groups

Earlier, you learned about organic compounds made up of only hydrogen and carbon — the hydrocarbons. Because carbon can form long chains, hydrocarbon compounds exist of ever-increasing sizes. There's a wide variety of hydrocarbon compounds that are used mainly for fuels and making polymers (plastics).

In addition, hydrocarbons also serve as the "backbone" for other compounds known as **hydrocarbon derivatives,** which have new chemical and physical properties due to the removal of hydrogen atoms from the hydrocarbon backbone and substitution with a **functional group** of atoms. The hydrocarbon with a hydrogen removed is called a "radical."

Hydrocarbon derivatives make up the single largest source of chemicals in our society and account for the largest percentage of all hazardous materials we encounter in the field.

Hydrocarbon derivatives are used in industrial applications and as solvents, cleaners, insecticides, disinfectants, explosives, CWAs, plastic manufacturing, food additives, preservatives and hundreds of other applications.

As we progress through this section, we will discuss a wide variety of functional groups or "attachments" that can be applied to a hydrocarbon backbone to create new hydrocarbon derivatives.

What are functional groups?

Functional groups are one or more atoms attached to hydrocarbon radicals to impart new physical and chemical characteristics to the hydrocarbon.

In addition to the hydrocarbons to which they are attached, most hydrocarbon derivatives are composed of:

- The halogens.
- Nitrogen.
- Sulfur.
- Oxygen.
- Phosphorus.
- Carbonyl group.

Hydrocarbon derivatives constitute the largest quantity of hazardous materials manufactured for commercial, industrial and agricultural consumption.

When we are writing the general formula for a hydrocarbon derivative, the sign for the hydrocarbon backbone will be "R-." The "R-" is understood to represent any hydrocarbon backbone or radical. The following are the functional groups that we deal with in this course:

Table 15: Functional groups

Functional groups	Elements
Halogens	-X (F, Cl, Br, I)
Nitro	$-NO_2$
Amine	$-NH_2$ -NH -N
Nitriles or cyanide	-CN
Isocyanate	-NCO
Ether	-O-
Peroxide	-O-O-
Sulfide	-S-
Mercaptan	-SH
Hydroxyl or alcohol	-OH
Carbonyl: ketone	-CO-
Carbonyl: ester	-COO-
Carbonyl: aldehyde	-CHO
Carbonyl: organic or carboxylic acid	-COOH

If a second hydrocarbon radical is needed to complete the compound, it is represented by "-R." Now you can see that all the different hydrocarbon radicals will have a general formula as follows:

Table 16: Formulas

Hydrocarbon derivatives	Formulas
Halogenated hydrocarbons	R-X (F, Cl, Br, I)
Nitros	$R-NO_2$
Amines	$R-NH_2$ R_2-NH R_3-N
Nitriles (cyanides)	R-CN
Isocyanate	R-NCO
Ethers	R-O-R
Organic peroxides	R-O-O-R
Sulfide	R-S-R
Mercaptan	R-SH
Alcohols	R-OH
Ketones	R-CO-R
Esters	R-COO-R
Aldehydes	R-CHO
Organic acids	R-COOH

The hydrocarbons are named by first naming the hydrocarbon radical and then the functional group, ending in “-ide.” Examples:

- Halogenated hydrocarbon: R-X.
- Methyl chloride: CH_3Cl.

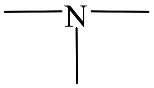
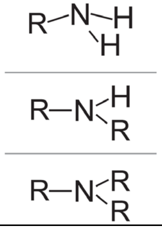
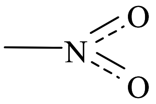
Many times, the compounds will have a second, more common name that persists because of tradition. Using IUPAC rules, methyl chloride may also be called chloromethane. Although these names will not follow our naming scheme, it is necessary that you know they exist.

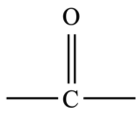
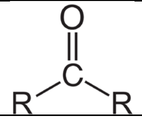
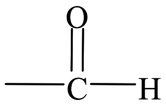
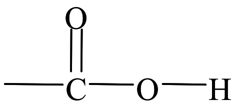
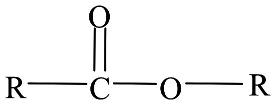
For example, trichloroethane would be called ethyl trichloride under our naming scheme. You shouldn’t have any trouble recognizing either name if you think about the actual contents of the compound.

There are many variations in the naming of chemicals, but we will try to stick to the ones that are important in the world of hazardous materials response.

We will look at derivatives based on the functional groups:

Table 17: 13 functional groups for the 13 hydrocarbon derivative families

Family	General formula	Structural formula
Halogenated hydrocarbons: Any of the halogens attached to a hydrocarbon. Naming: ends in "-ide" or IUPAC.	R-X	R–X
Nitrogen compounds: Functional groups based on nitrogen.		 $-\underset{\vert}{N}-$
Amines: Nitrogen attached to one, two or three hydrocarbon radicals. Naming: ends in "-amine."	$R-NH_2$ R_2NH R_3N	
Nitros: Radical attached to nitrogen and two oxygens. The bond between the nitrogen and two oxygen is considered "shared." Naming: starts or ends with "nitro."	$R-NO_2$	
Nitriles (organic cyanides): The functional group is carbon with a triple bond to nitrogen. Naming: ends in "-nitrile."	R-CN	$-C\equiv N$
Isocyanates: Naming: ends in "-isocyanate."	R-NCO	$-N=C=O$
Oxygen compounds: Functional groups based on oxygen.		
Ethers: A single oxygen between two radicals. Naming: ends in "-ether."	R-O-R	$-O-$
Organic peroxides: Two covalently bonded oxygen atoms between two radicals. Naming: ends in "-peroxide" or "peroxy" in the name.	$R-O_2-R$	$-O-O-$
Sulfur compounds: Functional group based on sulfur.		
Sulfides (thioethers): Similar to an ether except with S instead of O. Naming: ends in "-sulfide." If more than one S "-disulfide," "-trisulfide," etc.	R-S-R	$-S-$

Family	General formula	Structural formula
Mercaptans: A radical is dropped, and an H replaces it. Naming: ends in "-mercaptan."	R-SH	—SH
Hydroxyl group compounds:		
Alcohols: An HC radical attached to an O and H. Naming: ends in "-alcohol" or "-ol."	R-OH	—O—H
Carbonyl group compounds: All these compounds are based on carbon double bonded to oxygen. This starting point is called the "carbonyl group."		 $-\overset{\overset{O}{\Vert}}{C}-$
Ketones: A carbonyl with a radical on both sides. Naming: ends in "-ketone" or "-none."	R-CO-R	 $R-\overset{\overset{O}{\Vert}}{C}-R$
Aldehydes: A carbonyl with a radical on one side and H on the other side. Naming: ends in "-aldehyde" or "-al."	R-CHO	 $-\overset{\overset{O}{\Vert}}{C}-H$
Organic acids (carboxyl group): A carbonyl with a radical on one side and O and H on the other. Naming: Ends in "-oic acid" or "-ic acid."	R-COOH	 $-\overset{\overset{O}{\Vert}}{C}-O-H$
Esters: A carbonyl with a radical on one side and O and another radical attached to the O on the other. Naming: begins with naming the R attached to the oxygen first; ends in "-ate." Nothing is named "ester."	$R-CO_2-R$ R-COO-R	 $R-\overset{\overset{O}{\Vert}}{C}-O-R$

Halogenated hydrocarbons

Also called alkyl halides, the halogenated hydrocarbons are any of the halogens attached to a hydrocarbon. The general formula for the halogenated hydrocarbons is R-X, where "R" represents any hydrocarbon radical, and "X" represents any of the Group VII (halogen) elements.

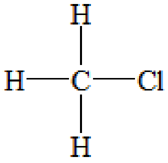
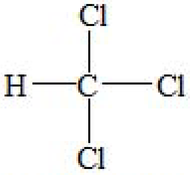
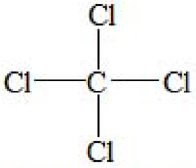
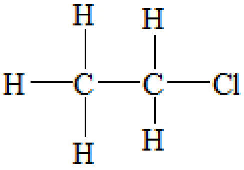
The classical method of naming the halogenated hydrocarbons is two-fold:

1. The name of the hydrocarbon backbone is given, such as methyl, ethyl, vinyl or phenyl.

2. This prefix is followed by the halogen with an "-ide" ending.

If using the IUPAC nomenclature method for naming halogenated hydrocarbons, one would first name the halogen(s), followed by the complete name of the hydrocarbon backbone to which it is attached. The table below lists examples of both naming systems.

Table 18: Naming examples

Formula	Structure	Classical name	IUPAC
CH_3Cl		Methyl chloride	Chloromethane
$CHCl_3$		Methyl trichloride (aka: chloroform)	Trichloromethane
CCl_4		Carbon tetrachloride	Tetrachloromethane
CH_3CH_2Cl		Ethyl chloride	Chloroethane
$Cl_2C_6H_4$		Phenyl dichloride	1,4 Dichlorobenzene

Most of the halogenated hydrocarbons are extremely toxic. Some are flammable or combustible, and some are carcinogens.

Very few halogenated hydrocarbons are found in nature. They are predominately manmade for uses such as solvents, refrigerants, anesthetics and insecticides.

Amines

Amines consist of nitrogen attached to one, two or three hydrocarbon radicals. Generally, they are derived from a reaction involving ammonia (NH_3) in which any or all of the hydrogens are replaced by a hydrocarbon radical.

There are three possible general formulas:

1. R-NH2 (primary amines) — one radical.
2. R2NH (secondary amines) — two radicals.
3. R3N (tertiary amines) — three radicals.

When naming the amines with multiple radicals, use “di-,” “tri-,” etc., as prefixes.

For amines with only one radical, an alternative naming convention uses the prefix “amino-” followed by the name of the hydrocarbon from with it was created. Examples include:

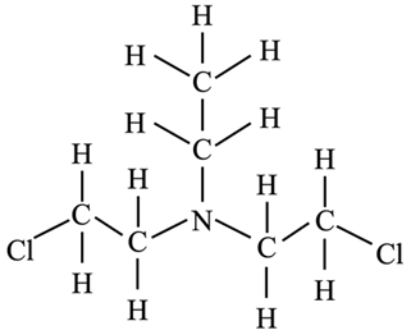
- Aminomethane CH_3NH_2.
- Aminoethane $CH_3CH_2NH_2$.
- Aminobenzene $C_6H_5NH_2$.

Industrial amines all tend to be very toxic due to their capability to irritate tissue. Additionally, they are toxic to the kidneys, and they are flammable or combustible. As we will see, if we attach any unsaturated backbone, like a “vinyl” radical, to an amine, we will impart the ability for the compound to polymerize.

There are extensive applications for the amines. Naturally occurring biological amines are seen widely in nature. Their industrial applications include the manufacturing of plastics, insecticides and medications, and additives to paints to prevent oxidization.

Another application of the amines that has significant safety implications is that of the manufacturing of common CWAs, such as blister agents or vesicants. For example, 2-chloroethyl ethyl amine shown below represents the CWA HN1 nitrogen mustard.

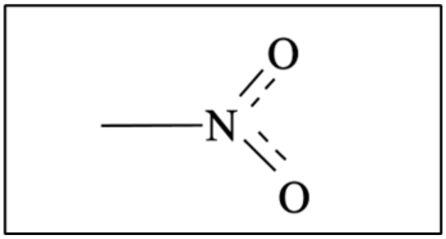
Figure 34: 2-chloroethyl ethyl amine, $(C_2H_4Cl)_2NC_2H_5$



Nitro compounds

Nitro compounds consist of a radical attached to a nitrogen and two oxygen atoms. The bond between the nitrogen and the two oxygens is referred to as a "shared" resonant bond, which lends a measure of instability to the compound. This structure is referred to as the nitrogen or "nitro" functional group.

Figure 35: Nitro functional group



Thus, the general formula for the nitro compounds becomes $R\text{-}NO_2$. When naming the nitro compounds, generally, the prefix "nitro-" is used, followed by the hydrocarbon. Numerical prefixes such as "di-," "tri-" and "tetra-" may be used to denote the number of nitro functional groups used.

The unique aspects of the nitro group stem from both the functional group's potential instability and its oxygen content. Connect this group to the fuel methane, and we have "nitromethane (NM)," a commonly used racing fuel additive. As we compress the fuel containing this additive in the chamber of the racing engine, we excite the shared bond within the nitro functional group. This bond then releases its stored potential energy, as well as oxygen, to further support the combustion process.

Many of the nitro compounds form what are commonly referred to as the "ideal explosives." Trinitrobenzene (TNB), trinitrotoluene (TNT) and trinitrophenol (picric acid) are just some examples of the ideal explosives represented by the general formula CHNO.

Hazards of the nitros include flammability and explosive potential. In addition, they have various toxic effects, such vasodilation (widening of blood vessels).

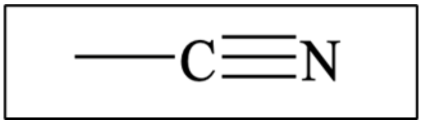
Other than explosives, uses of the nitro compounds include processing of leather, metal etching, chemical manufacturing processes and the manufacture of medications.

Organic cyanides and isocyanates

We saw the cyanides as compounds combined with metals, called the cyanide salts. Now we see the cyanides combined with the hydrocarbons — with no metal attached. In this case, we can refer to them as the organic cyanides. Currently, the more correct term using the IUPAC rules is the "nitriles." We'll explain where that term comes from in a moment.

The functional group is carbon with a triple bond to nitrogen.

Figure 36: Cyanide functional group



Therefore, the general formula is R-CN.

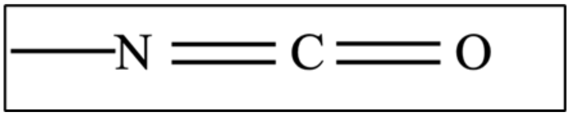
Naming these compounds using the common naming convention is very simple. Use the radical name, such as methyl, and add the term "cyanide." Examples are methyl cyanide or vinyl cyanide.

In IUPAC nomenclature, the term "nitrile" is used to represent the carbon triple-bonded to nitrogen. Therefore, rather than look at the cyanide radical attached to a hydrocarbon backbone, IUPAC looks at the nitrile attached to a hydrocarbon backbone. To name in this manner, you name the hydrocarbon radical based on **all** the carbons and add the IUPAC suffix of "nitrile." Therefore, methyl cyanide becomes acetyl nitrile, and vinyl cyanide becomes acrylonitrile.

Obviously, when talking about cyanides, toxicity becomes a significant concern. Cyanide compounds can stop the proper use of oxygen by the cells of the body. Therefore, they are cellular asphyxiants. However, the organic cyanides do not tend to be as toxic as the cyanide salts. Two very notable exceptions to that statement are hydrogen cyanide (HCN), also known as hydrocyanic acid, and cyanogen chloride (CNCl). Both are gaseous CWAs. These materials are extremely toxic and flammable gases that can undergo violent polymerization. It is important to note, however, that they are not classified as truly "organic" compounds, because they are not derived from hydrocarbons.

Another nitrogen compound closely related to the nitriles are the **isocyanates,** which have a general formula of R-NCO.

Figure 37: Isocyanate functional group



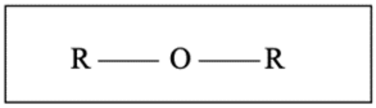
The isocyanates are all extremely toxic, more so by irritation and direct damage to the respiratory tract. The isocyanates have a history of catastrophic accidents. They are commercially used in the manufacturing of resins, dyes, polymers and electronics. Typically, you name the hydrocarbon radical and then end with "-isocyanate," as in methylisocyanate.

Oxygen compounds

Ethers

The ethers have the general formula R-O-R'. They have a single oxygen bonded between two radicals. The tick mark after the second "R" indicates that the second radical is prime and is the same radical as the first. If we name one radical, it is assumed that the second is the same.

Figure 38: Ethers



Naming of the ethers is simply the radical(s), in alphabetical order, followed by the term "ether." An example is ethyl methyl ether. Diethyl ether can also be called ethyl ether. Since it is a given that there must be two radicals, by using the name "ethyl," it is implied that both radicals are "ethyl" radicals. We call these prime radicals.

Ethers were formerly used as anesthetics. They are now used as solvents for dyes and as gasoline additives.

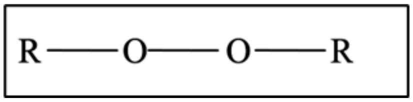
Since oxygen is found within the molecular structure, the ethers provide some oxygen for their own combustion process. Therefore, ethers have a very wide flammable range. The oxygen between two radicals is also an unstable arrangement. After being exposed to air, ethers will slowly begin to become oxidized, and they will take on another oxygen to convert from ethers to compounds known as organic peroxides, which are extremely unstable. In the case of isopropyl ether, it will break down into peroxides in about 90 days.

Ethers are extremely flammable, anesthetic and toxic. Some are carcinogens. They also act as a central nervous system (CNS) depressant. Like all other unsaturated compounds, ethers with multiple bonds will tend to polymerize.

Organic peroxides

In the case of the organic peroxides, we have two covalently bonded oxygen atoms between two radicals: R-O2-R' or R-O-O-R'. The radicals can be prime radicals (the same on both sides).

Figure 39: Organic peroxides



Naming of the organic peroxides can be confusing, but the name generally contains the word "peroxide" or "peroxy."

The organic peroxides have an overabundance of oxygen; therefore, they are all oxidizers. However, what is significantly more important is the fact that the radical in the organic peroxide is a hydrocarbon compound, which serves as a fuel. Therefore, within one molecule you have both the fuel and the oxygen to support combustion. These compounds are extremely flammable and can be unstable.

In addition to having a fuel and oxygen within the same molecule, single covalent bonds between two oxygen atoms increase the potential problems, because this oxygen arrangement is extremely unstable. The oxygen-to-oxygen single bond is very easily broken. As with any covalent bond, such breakage would result in the release of energy. That energy release would then impact the next peroxide molecule, causing it to break and release energy. That energy then impacts the next, and the next, and so forth. Therefore, it becomes evident that these compounds are extremely dangerous. In fact, the energy (heat) required to begin this process may only be ambient temperature. Most of these peroxides need to be refrigerated or kept in freezers for safe handling, while others can be handled at room temperature. But all of them are subject to decomposition with too much heat. The question simply becomes, "How much?"

Two terms that are very important when discussing organic peroxides are:

- Maximum safe storage temperature (MSST).
- Self-accelerating decomposition temperature (SADT).

The first term, MSST, is pretty much self-explanatory. If not kept below the specific temperature, decomposition will begin. However, once the temperature of the peroxide reaches the SADT, then an uncontrollable chain reaction will occur and will be impossible to stop.

Organic peroxides are used as bleaching agents, and because they are oxidizers, they are used to start polymerization reactions as monomers. If you have an industry that is polymerizing materials to make plastics and foams, chances are you have organic peroxides on site.

Sulfur compounds

Sulfides (thioethers)

The two major sulfur-containing derivatives that we will discuss are the sulfides (also known as the thioethers) and the mercaptans, more correctly referred to as the "thiol" compounds.

The sulfides have a general formula of R-S-R'. Remember, the tick mark after the second "R" indicates that the second radical is prime and is the same radical as the first. Therefore, when naming, if only one radical is named, it is assumed that the second is the same. So, dimethyl sulfide could also simply be called methyl sulfide.

The more accurate current-day naming of the sulfides is that of the IUPAC terminology, which uses the prefix "-thio" for sulfides.

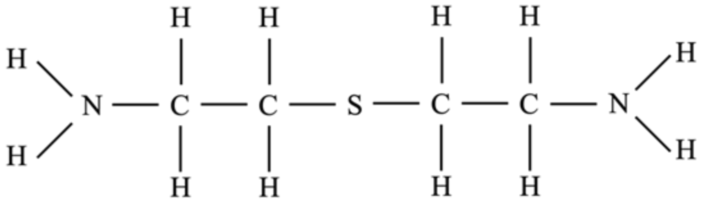
Examples:

- Dimethyl sulfide would become thiomethane or thiomethyl ether.
- Diethyl sulfide would become thioethyl ether.

Even though the naming can become quite complicated, it really is simple to understand what you are dealing with if you just analyze the parts. For example, consider thioethylamine. "Thio'" represents a sulfur compound, "ethyl" represents a double carbon chain, and "amine" represents nitrogen.

Therefore, thioethylamine would represent the following structure:

Figure 40: Thioethylamine $(C_2H_4NH_2)_2S$



We may be eager to place hydrogen sulfide into this category, but it is not organic in nature. Therefore, H_2S is classified as a binary nonsalt.

Mercaptans (thiol)

The mercaptans or "thiol" compounds are also derivatives based on sulfur. Rather than having a radical on both sides of the sulfur, the second radical is replaced by a hydrogen. Therefore, the general formula is expressed as R-SH.

Figure 41: Mercaptan functional group

$$—SH$$

These are very commonly encountered materials with extremely disagreeable odors. They are highly water soluble and irritating to the respiratory tract. They are used commonly as odorants in natural gas and propane to provide warning properties. They are also used as chemical intermediates in chemical processes, and in the manufacture of rubber and plastics.

Alcohols

The alcohol family consists of a hydrocarbon backbone, or radical, attached to the hydroxyl functional group -OH. Therefore, the general formula for the alcohol family of compounds is R-OH and structurally appears as shown below.

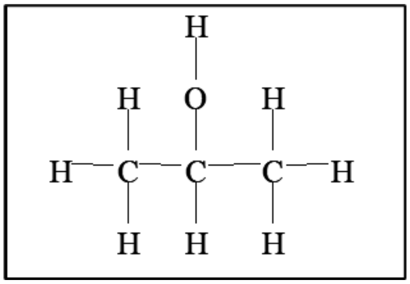
Figure 42: Alcohol (hydroxyl) functional group

$$R—O—H$$

This is not the hydroxide ion that was created in the hydroxide salt, as there is no electrical charge developed in the covalent bond between the functional group and the hydrocarbon radical. More simply put, there is no metal in the compound.

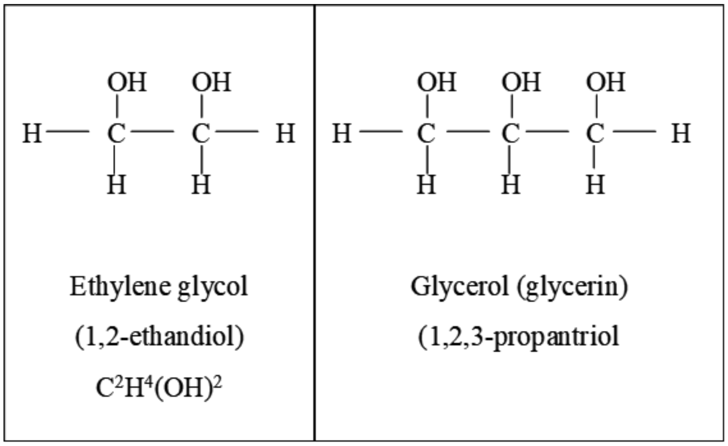
The classical naming of the alcohols is simply the hydrocarbon radical followed by alcohol, such as CH_3OH being named methyl alcohol. C_2H_5OH would be called ethyl alcohol. We more commonly see the terms methanol and ethanol used. This naming method follows IUPAC nomenclature, which has the longest continuous hydrocarbon named, dropping the -e ending of the parent hydrocarbon and adding “-ol” to indicate the alcohol. We can even identify the location of the hydroxyl attachment in IUPAC naming. As an example, isopropyl alcohol would be named 2-propanol. In addition, in IUPAC naming, if two, three or four hydroxyl functional groups are attached, then the ending is changed to “-diol,” “-triol” and “-tetrol.”

Figure 43: Isopropyl alcohol i-C_3H_7OH (2-propanol)



The terms glycol and glycerol are often encountered as well. In the case of these compounds, the glycols contain two hydroxyl groups, and the glycerols contain three hydroxyl groups. Examples of these are ethylene glycol and glycerol, pictured next.

Figure 44: Ethylene glycol and glycerol



Ethylene glycol
(1,2-ethandiol)
$C^2H^4(OH)^2$

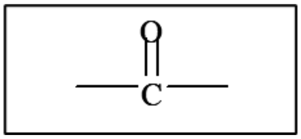
Glycerol (glycerin)
(1,2,3-propantriol

All the short-chain alcohols are flammable with wide flammable ranges. Toxicity varies widely. Methanol is extremely toxic and causes profound damage to the optic nerve, resulting in blindness. Ethanol is widely consumed in alcoholic beverages and is a CNS depressant. Isopropyl alcohol is rubbing alcohol. Assume all alcohols are poisonous in the absence of data indicating otherwise.

Carbonyl compounds

Before discussing the next several families of derivatives, we must first discuss the basis of their functional group. The ketones, aldehydes, esters and organic acids are based upon the carbonyl structure as a starting point. The carbonyl consists of a carbon double bonded to an oxygen. At least one hydrocarbon radical will be attached to this structure, and a wide variety of possibilities exist.

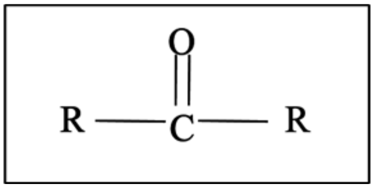
Figure 45: Carbonyl structure



Ketones

The first derivative involving the carbonyl are the ketones, with the general formula R-CO-R.

Figure 46: Ketone functional group



The naming of the ketones in classical terms is related to the prime radical. That is, you need only name one hydrocarbon radical if both are the same. Therefore, CH_3COCH_3 could be referred to as methyl ketone or dimethyl ketone.

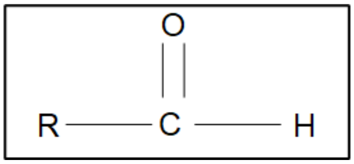
In IUPAC nomenclature, you count all the carbons (including the carbon within the carbonyl), name the appropriate hydrocarbon chain of that length, and change the ending to "-none" to represent the ketone family. Then, to communicate the location of the carbonyl, you prefix the name with the number of the carbon to which it is attached. For example, dimethyl ketone would be called 2-propanone. Methyl ethyl ketone (MEK) $CH_3COC_2H_5$ would be 2-butanone, naming the main chain and ending with "-none."

The ketones are used as solvents in paints, varnishes and some glues. Except for acetone, the ketones are highly toxic. They are irritants and produce narcotic-like effects. The ketones are also flammable, and ketones created from unsaturated hydrocarbon backbones may be very reactive. The ketones are also considered polar.

Aldehydes

With the aldehydes, rather than using a second radical as seen in the ketones, the radical is replaced by a hydrogen. Therefore, the general formula is R-CHO.

Figure 47: Aldehyde functional group



In naming the aldehydes, you count all the carbons, name the appropriate chain, and end the name in "aldehyde." Therefore, the 2-carbon aldehyde CH_3CHO would be ethyl aldehyde. In IUPAC naming, you name the hydrocarbon backbone and change the ending to "-al." Thus, ethyl aldehyde would also be called ethanal.

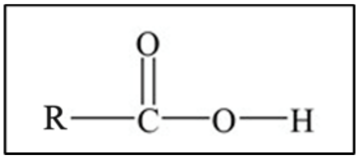
Aldehydes are reactive compounds capable of being oxidized. The short chain aldehydes, like formaldehyde or methanal, will undergo polymerization because they are monomers. Aldehydes are toxic by inhalation, have wide flammable ranges, and are mildly to severely irritating. Formaldehyde (HCHO) is a carcinogen.

Aldehydes are used as solvents, disinfectants, preservatives and in the manufacturing of some pesticides. Unsaturated aldehydes are used in the manufacturing of some plastics.

Organic acids

When alcohols or aldehydes oxidize to take on another oxygen, they form the derivative called organic acids, with a general formula R-COOH.

Figure 48: Organic acids functional group



The organic acid functional group (COOH) is also called a carboxyl group. The organic acids are also referred to as carboxylic acids.

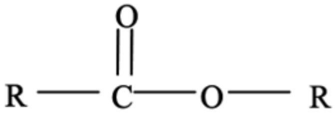
When naming, count all the carbons in the compound. Then replace the "-yl" suffix of the hydrocarbon radical with "-ic acid." For example, if a methyl radical were added to the organic acid functional group, the resulting compound would be ethanoic acid, because there are two carbons present when counting the C of the carbonyl.

The hazards of organic acids are toxicity, corrosivity and, to a lesser degree, flammability. Due to polarity (intermolecular attraction), these compounds are usually combustible if they burn at all. Organic acids are used in plastic production, water purification, solvents and decalcification.

Esters

The ester derivatives are based on the general formula R-COO-R. A hydrocarbon radical is attached to each side of an ester group (COO).

Figure 49: Ester functional group



Esters are created through a process known as esterification. Esterification occurs when an organic acid is combined with an alcohol and the compound is dehydrated ($-H_2O$). The result is an ester and water.

If the hydrocarbon radical attached to the carbon of the carbonyl of the functional group is a vinyl radical, the molecule is an acrylate. If the radical attached to the carbon of the carbonyl of the ester group is a methyl radical, it is called an acetate. You can count the carbon of the carbonyl in naming the compound. The rest of the name comes from the radical attached to the oxygen of the functional group. For example, if the radical attached to the oxygen is a methyl radical, and the radical attached to the carbonyl is a vinyl radical, the molecule would be methyl acrylate. If a vinyl radical is attached to the oxygen, and a methyl radical is attached to the carbonyl of the ester functional group, the compound would be called vinyl acetate. Name the radical attached to the oxygen, then the radical attached to the carbonyl (counting the carbon of the carbonyl), and then end in “-ate.”

The general hazards associated with the esters are flammability and the ability to polymerize. Some esters, when unsaturated, can be very hazardous and unstable. Unsaturated esters are also very toxic. Esters are used as food additives as well as in plastic manufacturing. Phosphate and sulfite esters are primary components as precursors in WMD agents.

Basic IUPAC derivative naming

The following will help to summarize some of the considerations concerning the methods of IUPAC naming.

1. Locate the longest carbon chain (the main chain). This will be the base name for the compound.

2. Number the carbons of the main chain, giving the functional group or hydrocarbon the lowest number.

3. Then find the functional group attached. The ending will be based on the type of derivative. Some of the derivatives, like the halogenated hydrocarbons, use their conventional naming systems.

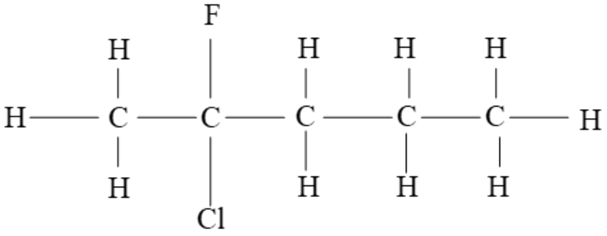
Some various families of derivatives use the suffixes shown in the table below.

Table 19: International Union of Pure and Applied Chemistry naming of hydrocarbon derivatives

Chemical family	IUPAC suffix
Ketones	"one"
Alcohol	"ol"
Amines	"amine"
Nitriles	"nitrile"
Organic peroxides	"peroxide"
Organic acids	"-ic acid"
Aldehyde	"al"

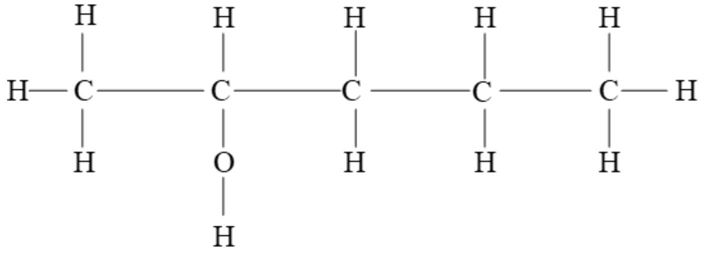
Using the previous rules to name the hydrocarbon derivatives, here are some examples of the naming system in action. Notice the main chain carbons are numbered here from left to right, giving the halons the lowest number: 2.

Figure 50: 2,2-chlorofluoropentane



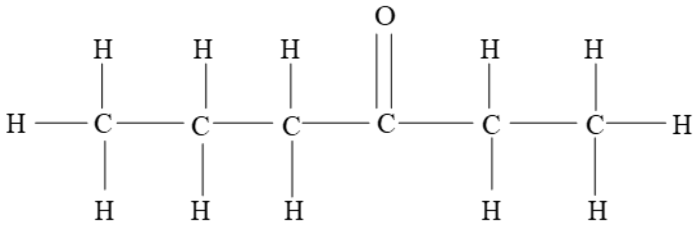
- 2,2 represents the location of the functional groups.
- Halogens changed to end in "-o."
- Pentane represents the five-carbon main chain.

Figure 51: 2, pentanol



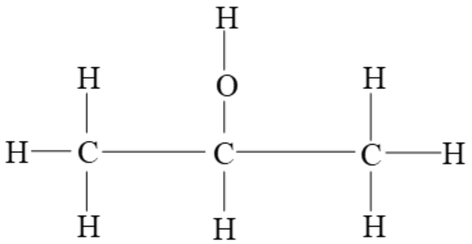
- 2 represents the location of the alcohol functional group.
- Pent- represents the number of carbons in the main chain.
- Alcohol is represented by the "-ol" ending.

Figure 52: 3, hexanone



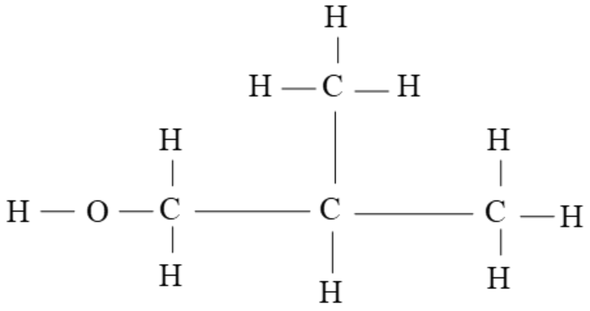
- 3 represents the location of the ketone functional group.
- Hex- represents the number of carbons in the main chain.
- Ketone is represented by the "-none" ending.

Figure 53: 2, propanol



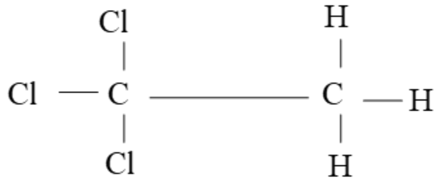
- 2 represents the location of the alcohol functional group.
- Propan- represents the number of carbons in the main chain.
- Alcohol is represented by the "-ol" ending.

Figure 54: 2-methyl, 1-propanol



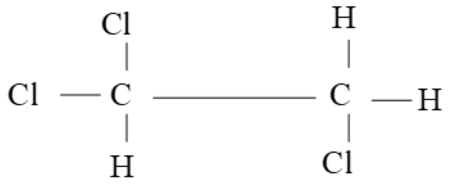
- 2 represents the location where the methyl radical is attached.
- Methyl- indicates the number of carbons in the attached radical.
- 1 represents the location of the alcohol functional group.
- Propan- indicates the number of carbons in the main chain.
- Alcohol is represented by the "-ol" ending.

Figure 55: 1,1,1 trichloroethane (CCl_3CH_3)



- The 1s represent the location of the halogens on the compound.
- Tri- indicates there are three repeating functional groups.
- Ethane indicates there are two carbons in the main chain.

Figure 56: 1,1,2 trichloroethane ($CHCl_2CH_2Cl$)



- Numerals indicate the location of the functional groups on the molecule.
- Tri- indicates there are three repeating functional groups.
- Ethane indicates there are two carbons in the main chain.

GASES AND FLAMMABILITY/COMBUSTION

This text corresponds to Units 7 and 8 of the course.

Overview of physical and chemical properties

Physical properties of a substance can be observed and measured without changing the chemical properties of the material. Some examples are color, odor, viscosity, solubility and boiling point (Bp).

Chemical properties of a substance are those that can be observed and measured during a reaction that changes the chemical composition of the material. Some examples are heat release rate (HRR), flash point (Fp), ignition temperature (IT) and decomposition.

In our discussion of these properties, we will consider the following major items:

- Physical state and changes in that physical state or "phase changes."
- The variables that affect those phase changes (molecular weight (MW), hydrogen bonding and molecular shape).
- Vapor pressure (Vp) and equilibrium.
- Vapor concentration/content (Vc).
- Volatility: Fp, flammable range, and IT.
- Specific gravity (SG) and vapor density (Vd).
- Solubility.
- Energetic materials.
- Thermodynamics.

Physical state

We will consider the three basic **states of matter**: solids, liquids and gases.

Solids

Solids have specific mass, occupy a specific volume, and have a specific shape. Molecules, atoms or ions in solid states have very close packing. Solids have specific arrangements of molecules, atoms or ions. If the molecules of a solid have ionic (and, in some cases, covalent) bonds, they will routinely form a crystalline lattice (crystalline structure). Atomic, ionic or molecular movement primarily consists of vibration. Some solids will pyrolyze (thermally decompose), while others will not.

Many solids are easily handled and have little or no Vp, which is the force exerted by molecules leaving the surface of a liquid and entering the atmosphere. If these solids don't get wet, aren't touched, and don't become airborne, responders have little to worry about. However, most radioactive materials are solids, and many energetic materials and water-reactive materials are solids. In addition, finely divided solids can be very flammable, even explosive in the form of combustible dusts. The “Five-Foot Rule” says that if vision is obscured at 5 feet, the dust may be in a flammable range.

Liquids

Liquids have specific mass and occupy a specific volume, but they have no specific shape. In atomic and ionic liquids (solution mixtures), the distance between molecules varies, depending on MW and polarity. In some instances, atomic size or molecular distance may be reflected by viscosity. Atomic, ionic or molecular movement is random and occurs in all directions.

Above every liquid is a vapor. Vapors can be reactive, toxic, flammable, corrosive or a combination of hazards. Liquids have varying degrees of Vp. Those with high Vp have high Vc and low Fp and Bp; we call them “volatile.” Larger molecules have higher viscosity and lower volatility due to size. Polar compounds are also less volatile.

Most hazardous products that are liquids have flammable or combustible properties. Handling liquids safely involves vapor suppression and vapor dispersion activities, along with eliminating ignition sources. Liquid spills will require spill control measures because they move with terrain.

Liquids cannot be compressed. Water will only reduce 1% in volume when placed under 33,000 pounds per square inch (psi) of pressure.

Gases

Gases have specific mass but no specific volume or shape. Atomic or molecular distance varies, depending on its pressure. Gases may simply compress or liquefy, depending on their critical temperature (Tc) and critical pressure (Pc). Gases heat up when compressed (called **adiabatic heating**) and cool down when they are decompressed (called **adiabatic cooling**).

Gases have variable hazards. Many hazardous products that are gases are toxic or asphyxiants as well as being flammable or combustible. In the case of gas releases, ignition sources should be controlled. Gases are obedient to wind when outdoors and ventilation when released indoors. Staying upwind from any vapor or gas is critical. Controlling the exit opening when ventilating gases from structures is also critical. High-pressure containers for gases are very robust but will often fail if subjected to external high thermal temperatures. If relief valving is not functioning or is not present, internal pressures can overcome the designed pressure of the container, and these can rupture violently.

Changes in physical state

Most materials can exist in more than one physical state. A common example is ordinary water. It is well known that liquid water will freeze and become a solid at 32°F (0°C) at normal atmospheric pressure. This is known as the **freezing point** for water. Alternatively, this temperature can be referred to as its **melting point.** For water, the freezing point and melting point are the same and are well-defined.

At 212°F (100°C), at sea level, liquid water begins to boil at normal atmospheric pressure as it begins a transition or phase change from a liquid state to a vapor or gas. The specific temperature at which a liquid boils under a given set of environmental conditions is known as its **Bp.** If the boiling takes place at normal atmospheric pressure, the more appropriate and accurate phrase to use is normal Bp, or Bp at one atmosphere.

Some solids will undergo a process called **sublimation** over time or upon heating. In this process, the solid material transforms directly to a gaseous state without first going through the liquid state. A good example is solid carbon dioxide, also known as "dry ice." Carbon dioxide can become a liquid only in confinement under special conditions of storage.

Variables that affect physical state

Temperature

Temperature is an indication of the amount of heat within any object or substance. The greater the amount of heat (temperature), the greater the atomic, ionic or molecular movement. This is **kinetic energy.** As the movement increases, so does interatomic, ionic or molecular distance, resulting in state change. Conversely, as cooling decreases movement, it also decreases interatomic, ionic or molecular distance, resulting in state changes.

Kinetic energy, or vibration, causes a number of reactions in solids. In most natural and manmade polymeric solids, molecular vibration causes pyrolytic decomposition of molecules as opposed to melting. In energetic and unstable solids, vibration causes chemical bond breakage that initiates decomposition. Decomposition may range from a violent combustion to an explosive reaction. Examples include organic peroxides and some oxidizers.

Pressure

Pressure (including ambient atmospheric pressure) is another variable affecting physical states and state changes. In the absence of atmospheric pressure (as in a vacuum or outer space), only solids and gases exist. Atmospheric pressure controls the Bp of substances. As pressure decreases, the amount of vaporization increases at a given temperature because the vapor doesn't have as much pressure to overcome and will achieve its Bp earlier, meaning at a lower temperature. As pressure increases, the opposite occurs; the amount of vaporization decreases at a given temperature, and there is more pressure to overcome and thus a higher Bp.

When the temperature rises sufficiently so that a liquid's Vp exceeds the atmospheric pressure, the liquid has reached its Bp. As such, every liquid has a Vp of 760 millimeters of mercury (mmHg) when it is at its Bp at sea level.

Molecular weight

A third variable affecting state changes is MW. Lower MW hydrocarbons and derivatives tend to be gases or low viscosity liquids. Higher MW hydrocarbons and derivatives tend to go from liquids to high viscous liquids, and eventually to semi-solids and solids.

To calculate MW:

- Use the chemical formula and the periodic table.
- Find the atomic weight of each atom in the molecule.
- Multiply the atomic weight by the number of atoms of the element in the compound.
- Add all the weights together to get the total MW.

Table 20: Molecular weight example

Atom	Number of atoms in a molecule of SO_2	Atomic weight	Total atomic weight
Sulfur	1	32	32
Oxygen	2	16	32
		MW of SO_2	**64**

Molecular shape

Branched compounds generally can pack more closely due to smaller molecular size. Cyclic compounds have a mid-degree of closeness. Straight chain compounds are generally the least tightly packed. The molecule "acts" smaller than it is and will have higher volatility.

Polarity

A **polar** molecule is a molecule with a positive charge on one end and a negative charge on the other. It becomes electromagnetic.

Polarity is a variable affecting physical states. Intermolecular attraction caused by the polarity of atoms, molecules or ions decreases distance, magnetic attraction and chemical reactivity. Polarity refers to the physical properties of compounds of the substance.

Hydrogen bonding, when OH exists in the molecule, may occur between highly polar molecules. With a MW of 18, water should be a gas, but is not due to its hydrogen bonding (high polarity). It is held together by molecular attraction of the "magnets."

As polarity increases, Vp decreases. The polarity holds the molecule together, taking more energy to liberate it into a vapor. Bp increases for the same reasons. Water solubility also increases. More OH bonding in the molecule will more readily mix with the OH bonds in water.

Vapor pressure

Mechanism

Vp is defined as the pressure exerted by a vapor above the liquid or solid at a given temperature in a closed system. Molecular movement provides the force of Vp, thus making the magnitude of Vp temperature dependent.

There is a direct relationship between temperature and Vp. The lower the temperature of the substance, the lower its Vp will be. The higher the temperature of the substance, the greater its Vp will be. The higher the Vp, the faster the liquid's or solid's evaporation rate.

Likewise, the higher the Vp of a liquid, the more concentrated its vapor will be when mixed with air. In other words, a high Vp equals a high Vc.

The higher the content of vapor in the air, the higher the concentration of vapors. High Vc is a concern outside of a container, as in a spill. High Vp inside a container may overcome the design pressure of that container, and it may come apart catastrophically.

If the Vp of a material is known, the approximate maximum saturation of vapors (Vc) that the material may produce in the headspace of any container at 68°F (20°C) can be estimated using the 1300 Rule:

- Vp x 1300 = parts per million (ppm).
- ppm/10,000 = % in air.

For example, the Vp of methanol is 127 mmHg. We multiply 127 by 1300 to get 165,000 ppm. Then we divide that number by 10,000 to get the Vc, which is 16.5%. The flammable range of methanol is 6%-36%, so a 16% Vc is within the flammable range.

Variables that affect vapor pressure

Molecular weight and polarity

Vp also occurs with solids that sublimate (change directly from a solid to a gas). Vp is present, to some degree or another, in all liquids.

The same variables affecting physical states and state changes also apply to Vp. MW within the hydrocarbon or derivative family plays a role. Low MW members have the highest Vp. High MW members have the lowest Vp. Small molecules simply evaporate faster.

Polarity within the hydrocarbon or derivative family also affects Vp. Intermolecular attraction caused by polarity acts to reduce the degree of molecular movement, and thus also reduces Vp. Thus, polar substances have lower Vp than nonpolar substances of the same MW. MW within a given polar family is the primary predictor of relative Vp within the family.

Hydrogen bonding

Hydrogen bonding is a form of intermolecular attraction. The effect of hydrogen bonding is to reduce the degree of molecular movement significantly, thus reducing the Vp. For this reason, hydrogen-bonded substances have the lowest Vp in comparison to nonpolar and even polar substances of the same MW. More polarity holds the molecules together.

Polarity and hydrogen bonding

When polarity and hydrogen bonding are both present, the functional group is known as the carboxyl. This carboxyl is found in organic acids (carboxylic COOH) and dicarboxylic acids. Here, intermolecular attractions are at their strongest. As a result, Vp is decreased significantly. Carboxyl or dicarboxylic groups also tend to produce solids at relatively low MW.

Shape

Branched compounds have the highest Vp because of their physically smaller molecular size. Cyclic compounds have a midlevel Vp. Straight chain compounds have the lowest Vp, especially in larger compounds, because molecules are longer and act bigger.

Units of measurement for vapor pressure

There are multiple options for measuring pressure in general. Vp is primarily related to solids and liquids expressed in mmHg or atmospheres (atm). Standard atmospheric pressure is expressed in the following units of measurement:

- Psi.
- mmHg.
- Inches of mercury.
- Bars.
- kiloPascals (kPa).

The closer a Vp is to 1 atm, the higher the product's propensity for vapor production at a given pressure and temperature. The following standard atmospheric pressure measurements at sea level are equivalent to 1 atm:

- 14.7 psi.
- 760 mmHg.
- 1 atm.
- 29.92 inches of mercury.
- 1.01 bar.
- 101.33 kPa.

For an interpretation of Vp (mmHg) at 68°F (20°C) and sea level atmospheric pressure, here are some milestone Vp comparisons:

- VX — 0.00007 mmHg.
- Fuel oil #4 — 2 mmHg.
- Water — 25 mmHg.
- Acetone — 180 mmHg.
- Ethyl ether — 430 mmHg.

Vp can be thought of in a different term, miles per hour (mph), where mmHg = mph. It is a measure of how fast the solid or liquid is vaporizing. Water is vaporizing at 25 mph while acetone is going 180 mph — it's vaporizing seven times faster than water. Any product over 760 mmHg is considered a gas.

Vapor/gas density

Vd is the weight of a vapor or gas as compared to an equal volume of air (air = 1). Thus, vapors or gases with Vd less than 1.0 are lighter than air in the natural environment, while those with values greater than 1.0 are heavier. In this way, Vd is similar to the concept of SG, and it may also be called the vapor or gas SG or relative gas density (RGasD) at normal pressure and temperatures.

It is critical when measuring Vd that both the gas/vapor and air are at the same temperature. If the vapor and air are not at the same temperature, this comparison is invalid. If gas or vapor is at a different temperature than the air, it will behave differently due to different densities. Cold gases and vapors will initially fall, acting as a dense gas. These gases and vapors will assume the higher ambient temperature and become neutrally buoyant and move with the air currents.

Vd can be calculated using MW. Dry air has a calculated density of 29 AMU. If the MW is less than 29, the gas or vapor is lighter than air, and its Vd will be less than 1. If the MW is between about 28 and 30, the gas or vapor is neutrally buoyant. If the MW is greater than 30, the gas or vapor is heavier than air and will have a Vd of more than 1.

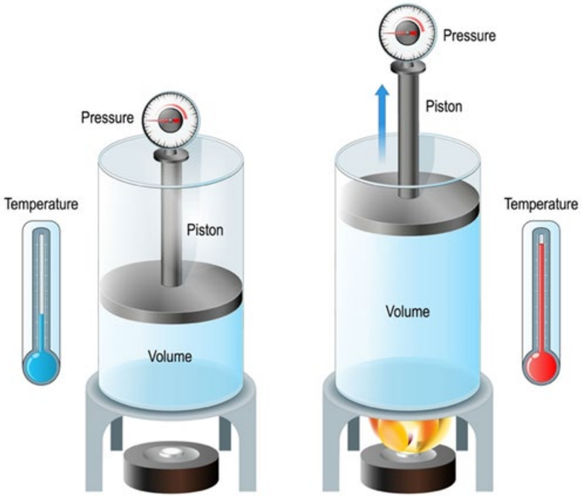
A shortcut method of calculating Vd is to divide the MW of the material by the MW of air, which is approximately 29 based upon the weight mixture of gases that comprise air. Therefore, benzene, with a MW of 78, would have a Vd of 2.7, or would be essentially 2.7 times heavier than air (78/29 = 2.7). While this will work for general estimates, one must remember that, for example, benzene vapors in the natural environment will never be pure. Rather, the vapors will be mixed with some percentage of air and the density will thereby change.

Principles of gas behavior

Five key concepts of molecular movement

1. Gases are composed of particles. **Diatomic molecules** like O_2 or N_2 exist as gases at ambient temperatures and pressures.
2. Gas molecules are mostly empty spaces. Imagine a pool table with balls scattered about. Most of the area is empty.
3. Pressure is developed by kinetic energy of moving gas particles striking the walls of a container. The greater the number of particles in the same volume container at the same temperature, the greater the pressure.
4. As particles collide with each other, the collision is said to be elastic. That is, there is no loss of **kinetic energy** (energy of motion). Kinetic energy is simply transferred from one particle to the next.
5. At constant volume, the pressure of a confined gas is proportional to its absolute temperature. This is known as **Charles's law.** The average kinetic energy of a gas is proportional to its temperature. As temperature increases, kinetic energy increases, which in turn causes molecules to strike the sides of the container more frequently. This results in increased pressure.

Figure 57: Charles's law (Shutterstock image)

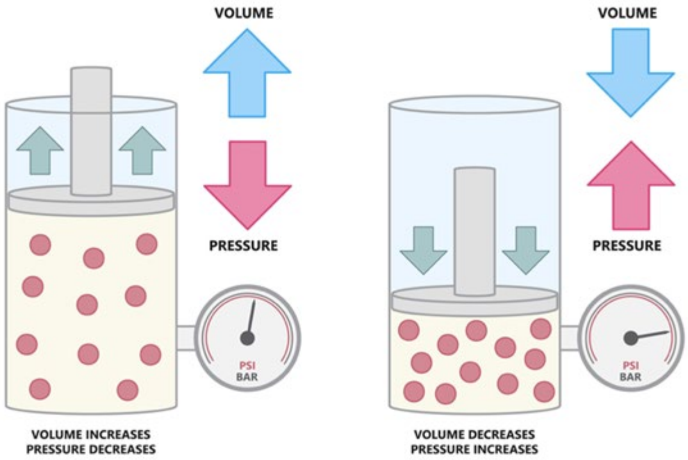


Relationships between pressure, volume and temperature

Pressure and volume

Pressure and volume have an inverse relationship. **Boyle's law** states that volume and pressure of a sample of gas vary inversely with the pressure of the temperature constant. If, at a constant temperature, the volume of the container is reduced to half of its original volume, but the amount of gas within the container remains unchanged, then the pressure in the container will double.

Figure 58: Boyle's law (Shutterstock image)



Volume and temperature

Volume and temperature are directly proportional, as long as pressure remains constant. As gas gets hotter, it requires more volume. In other words, warm gases expand.

Auto-refrigeration concepts

When a liquefied compressed gas escapes its container, then the volume of the gas increases, and its temperature decreases. As a gas expands in volume, temperature goes down. As the volume of the same amount of gas is reduced or compressed, the temperature will increase.

In other words, gases that are decompressing (expanding) increase in volume and decrease in pressure and temperature. Conversely, gases under compression increase in pressure and temperature.

Dense gas behavior

All molecules are in constant motion except at absolute zero (0 Kelvin, -273ºC or -460ºF). Therefore, molecules of gas are constantly striking each other and walls of their container.

The colder the gas becomes, the closer to each other the molecules become. Therefore, as gases get colder, the density of the gas gets higher. In other words, cold gases condense.

Conversely, as you warm gases, the space between molecules increases, so the density decreases. This explains why cold air is denser than warm air.

Table 21: Gas laws/behavior

Temperature and volume relationship	Temperature and pressure relationship	Volume and pressure relationship	Temperature and density relationship
If the pressure remains constant, then: T↑=V↑	If the container volume remains constant, then: T↑=P↑	If the temperature remains constant, then: V↑= P↓	As gases get colder, they increase in density. T↓=D↑

Critical temperature and pressure

Related to the discussion of gas behavior are the concepts of Tc and pressure.

(T_c) is the temperature at or above which a gas cannot be converted to a liquid regardless of pressure.

(P_c) is the pressure that must be applied to a gas at its Tc to convert the gas to a liquid.

Critical point is the transition point between the gaseous and liquid state of a substance.

States and containers for gases

Because the volume of a gas decreases as pressure increases, we can compress gas for easier storage and transportation. Oxygen, nitrogen, helium and argon are all examples of nonliquefied **compressed gases.**

Many other gases, such as natural gas, are shipped and stored as **liquefied compressed gases.**

Cryogenic gases are those that possess sufficient kinetic energy that they cannot be converted into a liquid phase through the application of pressure. **Cryogenic liquids** are gases that have been converted to liquids by cooling them to -130°F (-90°C) or colder.

Estimating movement of gases

As discussed earlier, gases are obedient to wind when outdoors. In the event of a release of hazardous gases, their movement will be affected by many factors, including the temperature and the physical properties of the substance. For this reason, plume modeling is critical for responding to these types of incidents. Knowing where the gas will go is helpful for making response decisions such as where to establish control zones and evacuation points.

Preplanning should include predictive model development. Modeling can also be done in the field; however, developing models at the time of an incident comes with some challenges. It can be difficult to determine an accurate release rate and integrate accurate environmental data and "microclimate" impacts such as air movement around structures. Topography can also present challenges, particularly with gases that are heavier than air. Another challenge is the thermal dynamics of liquid phase release of gases.

Limitations of infield modeling means that models will be wrong; however, they can still be very helpful for determining estimates — which should always be verified with real-time monitoring.

Key concepts of flammability/combustibility

Flash point

Fp is the minimum temperature to which a flammable or combustible material must be heated to produce sufficient Vc that it will flash but will not continue to burn when ignited by an ignition source.

The Fp is directly related to the Bp. If a substance has a low Bp, it has a correspondingly low Fp. Likewise, a high Bp means a high Fp. Ignition will not occur at the Fp unless there is an ignition source present. When at the Fp, ignition may simply be a quick vapor flash that will not result in sustained combustion. This is based on the temperature of the liquid and not necessarily the ambient temperature.

Fire point

The **fire point** (also known as flame point) is the minimum temperature to which a substance must be heated so it produces enough vapor to support sustained combustion in the presence of an ignition source. It is generally a few degrees above the Fp. Fire point is less of a concern than Fp because it is not the lowest possible temperature at which combustion will occur.

Flammable versus combustible

The NFPA identifies **flammable** materials as those substances with a Fp of less than 100°F (38°C). These materials are considered able to burn at normal ambient room temperatures.

On the other hand, **combustible** materials are said to have a Fp greater than 100°F (38°C). These materials must be preheated or warmed to evolve sufficient vapors depending on ambient temperature.

The U.S. Department of Transportation (DOT) uses a higher temperature to differentiate between flammable and combustible liquids. In DOT terms, substances with a Fp of less than 140°F (60°C) are classified as flammable, and those with a Fp greater than 140°F (60°C) are classified as combustible.

Flammable range

Flammable range refers to the range between the **lower explosive limit (LEL)** and **upper explosive limit (UEL),** expressed as a percentage. The LEL is the minimum percentage of vapor needed for combustion to occur. A percentage below LEL is too lean to burn (unless the substance is in an oxidizer-enriched environment). The UEL is the maximum percentage of vapor needed for combustion to occur. A percentage above UEL is too rich to burn (unless the substance is in an oxidizer-enriched environment).

When a Vc in air is found in the range between the LEL and UEL, and an ignition source is present, combustion will occur. The greater the difference between the LEL and UEL, the wider the flammable range, indicating the greater possibility of being an ignitable mixture.

For example, propane has an LEL of 2.2% and a UEL of 9.5%. Its flammable range is 7.3%. Acetylene has an LEL of 2.5% and a UEL of 100%. Its flammable range is very wide, at 97.5%.

Variables affecting the physical and chemical properties of compounds

To predict the volatility of compounds, consider their size, polarity and shape (branching) — in that order.

Consideration 1: Size (molecular weight)

Small compound principles

The smaller the compound (atomic mass), the more volatile it is. In other words, small (or “light”) compounds have a low tolerance for heat due to their smaller mass, so they ignite at low temperatures in the presence of an ignition source. Hydrocarbons with low MW are known as light ends. The small sizes give them a higher auto-IT (no ignition source required). It takes more energy for small molecules to create enough kinetic heat to ignite. Big molecules collide more easily and will auto-ignite at lower temperatures.

In addition, the smaller the compound, the greater the pressure exerted by the vapor against atmospheric pressure. The liquid readily absorbs ambient temperature and liberates vapor easily due to its smaller mass, so it volatilizes easily. This results in high Vp.

Smaller compounds result in a higher volume of vapor being liberated at normal atmospheric pressures and temperatures. High Vp results in higher Vc in enclosed areas. A small compound will liberate a lot of vapors at 70°F (21.1°C) when they have a Fp well below zero.

Smaller compounds are also harder to auto-ignite. With fewer C-H bonds affected by oxidation, it is harder to ignite without the presence of an outside ignition source. It takes a lot of energy to create enough “friction” between these small molecules to create the necessary ignition energy, so small compounds have a high auto-IT.

Large compound principles

Larger or “heavy” compounds (with larger atomic mass) are less volatile. These compounds are also viscous with a high resistance to flow, which is a physical sign that they are less volatile. In other words, they have a high tolerance for heat due to their larger mass, and they volatilize at higher temperatures.

The larger the compound, the less pressure exerted by the vapor against atmospheric pressure. The liquid does not readily absorb ambient temperature, and it is difficult to liberate vapor easily due to its larger mass. This results in low Vp.

In addition, larger compounds result in a lower volume of vapor being liberated at normal atmospheric pressures and temperatures. Low Vp results in low Vc. A large compound will not liberate a lot of vapors at 70°F when they have a Fp well above ambient temperatures.

The larger the compound, the easier it is to auto-ignite. With more C-H bonds to be affected by oxidation, it is easier to ignite without the presence of an outside ignition source. It takes less energy to create enough “friction” between these large molecules to create the necessary ignition energy, so large compounds have low auto-ITs.

Finally, the larger the compound, the higher the heat output. Heat is released every time a chemical bond is broken. The more bonds, the more heat can be released. Large compounds have high heat output, sometimes noted by a delta symbol (Δ).

Consideration 2: Polarity

Compounds that have been assessed as being relatively the same size (± 6 AMU) can then be assessed for volatility using polarity.

Nonpolar compounds

If you have a pure compound containing only carbon and hydrogen (the fuel and oil families), there is no polarity to be considered, and you would then consider branching after size.

Many, even most, compounds you will encounter will have a hydrocarbon backbone or substituent. Hydrocarbons are either saturated, unsaturated, aromatic or mixtures. Carbon and hydrogen bond together, with neither atom being strong enough to expose positive or negative charges of either nucleus. So, with no charges to attract each other, they independently exist without linking together; the compounds are said to be nonpolar.

Nonpolar compounds do not have the charges that attract the molecules together, so they are easier to liberate from the liquid state and are more volatile, meaning low flammable qualities — low Bp and Fp. Nonpolar compounds boil first at the lowest temperatures.

Polar compounds

When hydrocarbon backbones carry functional groups as substituents to the molecule, they inherit the polarity of the functional group, since the backbone itself has no polarity.

Polarity involves the ability for an electronegative element to draw electrons away from other elements in the compound, thus creating a field of negative electrons around that element and exposing the positive nucleus (protons) of the other element. This provides the molecule with a negative and positive pole, which attracts other molecules, creating a polar bond. It becomes a “magnet” of sorts. Compounds with this polar bond require more energy to break the molecules from each other and liberate vapors. So, compounds with more polarity boil last, at higher temperatures.

The more polarity a functional group contains, the harder it is (the more energy required) to create vapors in enough quantities to possess volatility. So, more polarity results in less volatility.

The general polarity of the different functional groups has been provided in the table below to help you make predictions. Individual compounds may prove this table inaccurate.

Table 22: Polarity of functional groups

Non-polar	Semi-polar	Polar (listed from least to most polar)
Hydrocarbon	R-X $R\text{-}NH_2$ $R\text{-}NO_2$ R-CN R-O-R $R\text{-}O_2\text{-}R$ R-S-R R-SH	Ketone Aldehyde Ester R-OH R-COOH
More volatile		Less volatile

“Hydrogen bonding,” which is the OH of a molecule, and “carbonyl bonding,” which is the CO in the molecule, both possess strong polarity. Alcohol compounds possessing OH bonding have strong polarity, and organic acids having both OH and CO types of bonding (COOH) have the strongest polarity.

Consideration 3: Shape (branching)

All things being equal (± 6 AMU) regarding MW, and with equal polarity, the shape of the molecule can be assessed. Think of it as being physically smaller and more compact; thus, the molecule has an easier time being liberated from the liquid state into vapor (that is, it requires less energy).

The more branching a molecule has, the smaller it becomes physically, and thus is considered more volatile with low flammable properties. For example, octane, a long chain molecule, has an Fp of 56°F (13.3°C), where iso-octane, which has the same size and polarity but is branched, has an Fp of 40°F (4.4°C). It takes less energy to liberate iso-octane vapors, and so it is considered more volatile than normal octane.

Combustion

This section explores the process of combustion, including its definition and chemical reaction. It also describes the by-products of combustion, heat output and flammability of the various functional groups.

Due to the frequency of flammable or combustible hazardous materials releases, the understanding of the combustion process and how to defeat it is critical.

Combustion is defined as the rapid oxidation process of a combustible material in the presence of oxygen. Once ignition occurs, combustion will result in the evolution of energy in the form of heat and light in varying intensities.

Combustion terminology

Oxidation is the process in which electrons are removed from a material, or any process in which oxygen combines with an element or material. Rapid oxidation occurs in the presence of 20.9% oxygen in air; this rapid oxidation is more commonly known as fire.

Combustible material is defined as any material that will ignite and burn. It is also referred to as **fuel.**

Ignition means causing something to burn. Heat input begins the oxidation reaction. Any ignition source for flammable and combustible products must be at least as hot as the IT of that product or it will not have enough energy to ignite it.

A **chemical chain reaction** is an exothermic chemical reaction (meaning that it releases energy in the form of heat), due to the production of **free radicals.** These are electrically charged, highly reactive parts of molecules. A small amount of energy is released every time a chemical bond is broken. When enough bonds break, ignition will occur. Combustion will be maintained as long as the bonds are still being broken — or the combustible fuel is still being decomposed by the reaction. Free radicals combine with oxygen or with the elements that form the fuel material, producing intermediate combustion products (new substances) and even more free radicals, and increasing the speed of the oxidation reaction.

The combustion process

The combustion process is a chemical reaction requiring fuel, an oxidizing agent and heat. It is an oxidation reduction reaction.

- The fuel is the reducing agent and may be a solid, liquid or gas.

- Oxygen, in its many forms, is an oxidizing agent. Oxidizers added to the reaction or oxidizing elements in the molecule contribute to the speed, temperature and brightness of the heat and light. Oxidizers will also widen the flammable range, making the fuel easier to ignite.

- The process is initiated by the heat of ignition. For ignition to occur, the temperature must be above the fuel's **IT.**

Once ignition occurs, the chemical chain reaction results in free radicals and unpaired (or "free") electrons. These free electrons are somewhat stable at lower temperatures but become more unstable at higher temperatures.

If the combustion process is complete — meaning that there is an excellent fuel source and plenty of available oxygen — the process results in the following products: carbon dioxide, water, heat, light, and little or no visible smoke.

If the combustion process is incomplete — meaning that there is poor fuel or insufficient oxygen — the process results in the following products: carbon monoxide, free carbon (soot), water, and thick, visible smoke and/or polycyclic aromatic hydrocarbons (PAHs).

Incomplete combustion can result in toxic gases being released. Besides carbon monoxide, some common toxic gases that are products of incomplete combustion are phosgene ($COCl_2$), hydrogen cyanide (HCN), aldehydes (including formaldehyde and acrolein), oxides of nitrogen (NOx) and sulfur (SOx), and acid gases (hydrogen plus halons).

Spontaneous combustion

Spontaneous combustion is defined as combustion through the breakdown of the material with access to oxygen and without an outside ignition source. Internal heat provides ignition through the breakdown of molecular bonds. It usually occurs with organic materials such as hay, straw and coal. Other materials that can spontaneously combust include esters, aldehydes and ethers. Examples include biodiesel products, turpentine, and animal or vegetable oils. This will NOT occur with single-bonded pure hydrocarbons.

Spontaneous combustion can occur within any molecule that possesses a double bond synthetically or naturally. These double bonds slowly react with oxygen until enough heat is created to produce ignition. This is sometimes known as Slow Oxidation Potential. Typically, these materials have low ITs and readily react with available oxygen.

More combustion terminology

Heat of combustion refers to the amount of heat generated and is measured in **British thermal units (BTU).** A BTU is defined as the amount of energy required to raise the temperature of 1 pound of water 1°F.

The **HRR** is the amount of heat released per unit of time. It is measured in thermal kilowatts (kWth). It refers to the amount of power (or energy) being generated by a material. The higher the available oxygen in the combustion process, the higher the HRR.

Enthalpy refers to a change in heat energy. The activation energy (+Ea) is the energy of ignition put into the process to begin the reaction (ignition). The reaction begins (at ignition), and the fuel is consumed and produces energy (HRR). The process gives back the activation energy (-Ea) that was required to initiate the process, and any energy produced after that is a measure of the fuel’s efficiency or change in energy output.

The efficiency of a fuel is that fuel's ability to give back more energy than it took to ignite it. For example, if a fuel takes 4,000 BTU to ignite, and after ignition produces 6,000 BTU of energy, this produces an overall net change of 2,000 BTU.

Combustibility attributes of the families

The table below summarizes the combustibility attributes of the various families discussed in this course. As a rule of thumb, combustibility is seen with the presence of the carbon-carbon (C–C) or carbon-hydrogen (C–H) bond, which releases energy when the bond breaks during combustion.

Table 23: Combustibility attributes of the families

Category	Families	Attributes
Salts	• Binary salts • Hydroxide salts • Peroxide salts (oxidizers) • Cyanide salts • Oxysalts (oxidizers) • Salts containing ammonium	Will not burn, although some will support combustion if an oxidizing salt.
Hydrocarbons	• Alkanes • Alkenes • Alkynes • Aromatics	Will burn; provide the flammable or combustible hydrocarbon backbone of the hydrocarbon derivatives.
Hydrocarbon derivatives	• Amines • Nitro compounds • Organic cyanides and isocyanates • Ethers • Organic peroxides • Sulfur compounds • Alcohols • Ketones • Aldehydes • Organic acids • Esters	May burn; combustibility of the family varies among different elements and will depend on the hydrocarbon backbone.

Energetic materials

Energetic materials are also known as explosive materials (those capable of creating an explosion). These materials undergo extremely rapid decomposition.

An **explosion** is defined as a high-speed oxidation reaction resulting in the release of energy and tremendous amounts of gas to perform some form of work.

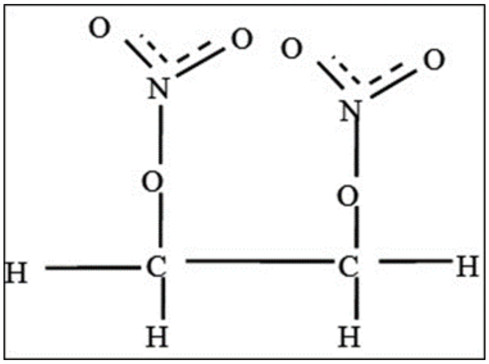
Four components of an explosive

The following components must be present for a material to be explosive:

1. Fuel: The combustible material which is reduced by the reaction.
2. Oxidizer: Oxidizers must be mixed with the fuels to support the speed of the reaction. The oxygen in air (20.9%) is not sufficient to support the combustion process.
3. Initiation energy: There must be sufficient energy input to begin the process of instantaneous combustion.
4. Confinement: Provides the energy feedback which intensifies the explosion reaction. The strength of the container plays a role in the amplification of the reaction.

Chemical reactions are the conversion of reactants to products. Types of oxidation reactants include fuel-oxidizer mixtures and mixtures of compounds (in which one serves as the fuel and the second serves as the oxidizer). These mixtures, in which the fuel and oxidizer exist within the same molecule, are also called **binary explosives.** An example is nitroglycol: $(CH_2)_2(NO_3)_2$.

Figure 59: Nitroglycol



Detonation versus Deflagration

Deflagration is a very rapid auto-combustion as a surface phenomenon. Burning rates occur at below 3,300 feet per second. The term deflagration also refers to the ability to move from a deflagration-to-detonation transition (DDT). It produces a pushing type of pressure wave.

Detonation is an almost instantaneous combustion rate. Burning rates occur at above 3,300 feet per second — some up to 28,000 feet per second! Detonation rates and pressure waves will produce a shattering type of effect.

The rate of the reaction depends on the geometry of the material (size, shape and surface area) as well as its molecular makeup (bonding strain and oxygen balance).

Table 24: Detonation versus deflagration

Type	Speed	Yield	Order	Temp.	PSI wave
Detonation	>3,300 ft/sec.	High shatter	High complete	High	Short
Deflagration	<3,300 ft/sec.	Low push	Low incomplete	Low	Long

Classification of explosives

High explosives primarily detonate and can be further subdivided into primary (initiators), secondary or tertiary explosives, depending on their sensitivity to initiation.

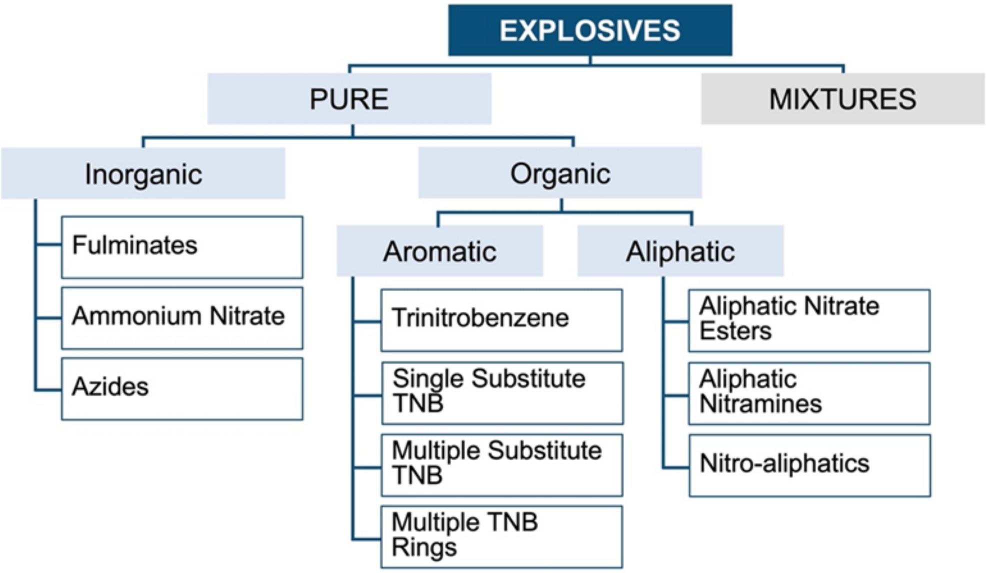
- Primary explosives or initiators can be made to detonate very easily.
- Secondary explosives do not progress from rapid burning to detonation and generally cannot be initiated with electrostatic discharges. Secondary explosives require shock waves to propagate ignition.
- Tertiary explosives are high explosives that are insensitive to initiation of detonation.

Low explosives like pyrotechnics (which is Greek for “manipulation of fire”) can produce gas to perform mechanical work and are used for small- and large-bore guns, rocket propellants or blasting agents.

Chemical composition of explosives

The following graphic demonstrates the various explosives commonly encountered. This discussion proceeds from left to right, from inorganic to aromatic, aliphatic and then to mixtures.

Figure 60: Classifications of explosives



Inorganic explosives

Ammonium nitrate, NH_4NO_3, an inorganic explosive, is a poor explosive by itself and is over-oxidized. It is very hard to initiate, but when mixed with other explosives or fuels, it is much more effective. (However, it can be an explosive by itself.)

Other examples of inorganic explosives are listed below.

Fulminate salts:

- Mercury II fulminate, $Hg(CNO)_2$ — This is an older explosive and one of the first inorganic explosives created.
- Silver fulminate, AgONC.

Azides ($M + (N_3)^{-1}$) — mostly solids; extremely sensitive:

- Lead II azide (PbN6).
- Silver azide (AgN3).
- Sodium azide (NaN3) — This is a propellant used in air bag activators.

Organic explosives

Organic explosives are the most common of all explosives. Aromatic explosives are based on the resonant-bonded benzene ring. Aliphatic explosives (nitrate esters) are those organic explosives without the alternating single and double bond found in the aromatic ring.

Aromatic explosives

- Nitrated benzene ring (generally three nitro groups — TNT).
- All solid, crystalline materials.
- TNB is the basic starting point, and three types of aromatic explosives are created from there.
- Singly substituted TNB (has one hydrogen replaced with an additional functional group).

RADIOACTIVITY

This chapter corresponds to Unit 9 of the course.

Radioactivity is the spontaneous emission of energy or subatomic particles primarily from the nucleus of an atom. Our concern is the development of **ionizing radiation.** This refers to the ability of the radiation to ionize chemical compounds resulting in chemical changes.

Ionization, if you recall, is the development of charged materials (elements or molecules). It is the process by which an atom or a molecule acquires a negative or positive charge by gaining or losing electrons.

An unstable nucleus will decompose or “decay” to maintain a stable proton-to-neutron ratio. Atoms are most stable when they have approximately a one-to-one proton-to-neutron ratio. If there are too few neutrons, positively charged protons near each other begin to repel each other, and the nucleus becomes unstable. It will begin to decay due to repulsive effects. If there are too many neutrons, the nucleus begins to become unstable simply because the mass has become too great, and it will begin to decay.

For the purposes of this course, the rule of thumb is that all elements with an atomic number above 83 are radioactive and have no stable form. However, bismuth (83) is very weakly radioactive, and technetium (43) and promethium (61) are also radioactive in all forms.

All elements have isotopes. Many will undergo radioactive decay, but some will not.

Hydrogen isotope examples:

- Protium (1H1) is the most common form of hydrogen.
- Hydrogen with a single neutron (1H2) is called deuterium (Greek for “second”) and is not radioactive. It constitutes 0.0156% of all hydrogen atoms—a very small quantity which results in the average atomic mass we see on the periodic table.
- Hydrogen with two neutrons (1H3) is called tritium (Greek for “third”) and is found in small trace amounts. It is created by cosmic radiation interaction with our atmosphere.

Modes of decay

To achieve a nucleus that has a stable proton-to-neutron ratio, the nucleus will undergo various modes of decay. We will discuss the three most common forms: alpha, beta and gamma. We have also heard of less common, but nevertheless very dangerous, neutron radiation.

Alpha decay

An **alpha** particle is a subatomic particle comprised of two protons and two neutrons. It is a nucleus of helium but has no electrons. It travels 1 to 2 inches in the air and ionizes air to gain two electrons;

thus, it becomes an atom of helium. Depending on the isotope, the release of an alpha particle may result in the release of gamma energy.

The particles will not harm the body. However, ingesting or inhaling the source materials will cause ionization of lung or gastrointestinal (GI) tract tissues, which can produce severe adverse health effects and death.

Beta decay

A **beta** particle is a fast-moving, energetic electron or positron emitted from an atomic nucleus. Beta particles can be either positively charged (positron) or negatively charged (negatron). They can travel many feet in air and are easily repelled by thin sheets of aluminum. They can penetrate the skin layer and result in beta burns similar to first-degree thermal burns.

Beta particles do not penetrate the body to ionize internal tissue. As with alpha particles, their greatest risk occurs when the source isotope is inhaled or ingested resulting in severe damage to pulmonary or GI tissue. Depending upon the isotope, gamma energy may or may not be released with beta decay.

Neutron radiation

Neutron radiation is seen in cases involving spontaneously fissionable radioactive isotopes. These materials are extremely neutron heavy. Examples include uranium-235, plutonium-239 and uranium-233.

Neutron particles have no charge but are very penetrating. As they move through materials and strike nuclei of other atoms, this can cause them to break off particles resulting in new, potentially radioactive isotopes.

Gamma radiation

Gamma is the release of energy from the nucleus as it decays and transitions from a higher to a lower energy state. The excess energy must be released as an electromagnetic wave of high-intensity energy (photon), which is called gamma. (This is different from other forms of radiation, which are particles.)

Gamma has no mass and travels great distances. It passes through the human body and ionizes tissue such as the organs and genetic material. Gamma radiation creates a significant risk to humans during external exposure.

Units of measure

Ionizing radiation

Units to measure the level of ionizing radiation released by a material are the curie (Ci) and the becquerel (Bq).

The **curie** is the official unit of measure used in the United States. It is defined as the required amount of a radioactive isotope necessary to generate 3.7×10^{10} (37 billion) disintegrations per second. Approximately 1 gram of radium equals 1 Ci.

The **becquerel** is an international unit of measure that equals 1 disintegration per second. 1 Ci equals 37 billon Bq.

Absorbed dose

Units to measure the amount of energy deposited per unit mass in an object or person are:

- **Radiation absorbed dose (rad):** The U.S. unit of measure for the amount of energy (100 ergs) absorbed by 1 gram of material.

- **Gray (Gy):** An International System of Units (SI) unit of measure for the absorbed energy per mass of tissue.

Effective dose

Units to indicate the potential for long-term health effects are roentgen equivalent man (rem) and sievert (Sv). These units are used to set regulatory limits.

Roentgen equivalent man

Rem is an older unit of measure more commonly used by emergency responders in the United States. It is the amount of energy absorbed by human tissue combined with the medical effects for the type of radiation. Rem is the unit of measure used to calculate dose in the human body. Loosely translated, one gray is approximately equivalent to 100 rem.

- 1 rem = 1,000 mR.
- 1 mR = 1,000 µR.

Natural background radiation is between 8 and 16 µR/hr. Any high exposure must be voluntary.

Sievert

A sievert (Sv) is an SI unit of measure representing health risks of ionizing radiation. 1 Sv is equal to 100 rem. To convert Sv to rem, multiply Sv by 100. To convert rem to Sv, divide rem by 100.

Protective measures

Measures to protect against ionizing radiation exposure are distance, time and shielding.

- Distance: Total dose is inversely proportional to the square of the distance from the source.
- Time: Total dose is directly proportional to duration of exposure. Therefore, limiting exposure time is the primary protective measure.
- Shielding: The greater the mass between the source and the responder, the greater the protection value.

Time

Time is probably the best protective measure from exposure to gamma radiation. Total dose is directly proportional to duration of exposure. Therefore, knowing your dose rate of exposure and limiting exposure time is the primary protective measure. The “Stay Time Table” on the next page demonstrates the effectiveness of time to self-protection.

Table 25: Radiological stay time table

RADIOLOGICAL STAY TIME TABLE

		ALL EMERGENCY ACTIVITIES				PROTECT PROPERTY	LIFE SAVING	LIFE-SAVING VOLUNTEER ONLY		POTENTIALLY LETHAL DOSES	
		100 mrem 0.1rem	1 rem	2 rem	5 rem	10 rem	25 rem	50 rem	100 rem	300 rem	$LD_{(50)}$ 500 rem
SAFE AREAS	10 ∝R/hr	1 yr									
	50 ∝R/hr	12 wk	2 yr								
	100 ∝R/hr	6 wk	1 yr								
	500 ∝R/hr	8 day	12 wk	24 wk	1 yr						
	750 ∝R/hr	5.5 day	8 wk	16 wk	40 wk	1.5 yr					
	1 mR	4 day	6 wk	12 wk	30 wk	1 yr					
HOT LINE	2 mR/hr	50 hr	3 wk	6 wk	15 wk	30 wk	74 wk				
DANGER .... HOT ZONE OPERATIONS .... DANGER	5 mR/hr	20 hr	8 day	16 day	6 wk	12 wk	30 wk	1 yr			
	7.5 mR/hr	13 hr	5.5 day	11 day	4 wk	8 wk	20 wk	40 wk	80 wk		
	10 mR/hr	10 hr	4 day	8 day	3 wk	6 wk	15 wk	30 wk	1 yr		
	20 mR/hr	5 hr	2 day	4 day	10 day	3 wk	7 wk	15 wk	30 wk	2 year	
	30 mR/hr	3.3 hr	33 hr	3 day	1 wk	2 wk	5 wk	10 wk	20 wk	60 wk	
	40 mR/hr	2.5 hr	1 day	2 day	5 day	11 day	4 wk	8 wk	15 wk	1 yr	
	50 mR/hr	2 hr	20 hr	40 hr	4 day	8 day	3 wk	6 wk	12 wk	35 wk	1 yr
	75 mR/hr	80 min	13 hr	1 day	3 day	5.5 day	2 wk	4 wk	8 wk	24 wk	40 wk
	100 mR/hr	1 hr	10 hr	20 hr	2 day	4 day	10 day	3 wk	6 wk	18 wk	30 wk
	200 mR/hr	30 min	5 hr	10 hr	1 day	2 day	5 day	11 day	3 wk	9 wk	15 wk
	300 mR/hr	20 min	3 hr	7 hr	16 hr	32 hr	3 day	1 wk	2 wk	6 wk	10 wk
	400 mR/hr	15 min	2.5 hr	5 hr	12 hr	1 day	2.5 day	5.5 day	11 day	31 day	52 day
	500 mR/hr	12 min	2 hr	4 hr	10 hr	19 hr	2 day	4 day	8 day	25 day	40 day
	750 mR/hr	8 min	78 min	2.6 hr	6.5 hr	13 hr	33 hr	3 day	5.5 day	16 day	4 wk
	1000 mR/hr	6 min	1 hr	2 hr	5 hr	10 hr	25 hr	40 hr	4 day	12 day	3 wk
	1.5 R/hr	3 min	40 min	78 min	3.5 hr	6.5 hr	16.5 hr	33 hr	3 day	8 day	14 day
	2 R/hr	3 min	30 min	1 hr	2.5 hr	5 hr	13 hr	25 hr	2 day	6 day	11 day
	3 R/hr	2 min	20 min	40 min	100 min	200 min	8 hr	16 hr	1.5 day	4 day	1 wk
	4 R/hr	90 sec	15 min	30 min	75 min	2.5 hr	6.5 hr	13 hr	1 day	3 day	6 day
	5 R/hr	72 sec	12 min	24 min	1 hr	2 hr	5 hr	10 hr	20 hr	2.5 day	4 day
	7.5 R/hr	48 sec	8 min	16 min	40 min	78 min	200 min	6.5 hr	13 hr	40 hr	3 day
LIFE SAVING ONLY	10 R/hr	36 sec	6 min	12 min	30 min	1 hr	2.5 hr	5 hr	10 hr	30 hr	50 hr
	20 R/hr	18 sec	3 min	6 min	15 min	30 min	75 min	2.5 hr	5 hr	15 hr	1 day
	30 R/hr	10 sec	2 min	4 min	10 min	20 min	50 min	96 min	3 hr	10 hr	17 hr
	40 R/hr	9 sec	90 sec	3 min	7.5 min	15 min	38 min	75 min	2.5 hr	7.5 hr	12 hr
	50 R/hr	7 sec	72 sec	80 sec	6 min	12 min	30 min	1 hr	2 hr	6 hr	10 hr
	75 R/hr	5 sec	50 sec	100 sec	4 min	8 min	20 min	40 min	80 min	4 hr	6.5 hr
	100 R/hr	4 sec	30 sec	1 min	3 min	6 min	15 min	30 min	1 hr	3 hr	5 hr
	200 R/hr	2 sec	18 sec	30 msec	90 sec	3 min	7 min	15 min	30 min	90 min	2.5
LETHAL POTENTIAL	300 R/hr	1 sec	10 sec	20 sec	1 min	2 min	5 min	10 min	20 min	1 hr	100 min
	400 R/hr	1 sec	9 sec	15 sec	45 sec	90 sec	3.5 min	7.5 min	15 min	45 min	75 min
	500 R/hr	1 sec	7 sec	15 sec	30 sec	72 sec	3 min	6 min	12 min	36 min	1 hr
	750 R/hr	1 sec	5 sec	9 sec	24 sec	48 sec	2 min	4 min	8 min	24 min	40 min
	1000 R/hr	1 sec	3 sec	7 sec	18 sec	36 sec	90 sec	3 min	6 min	18 min	

Initial Action Levels

Normal Background	8 - 16 ∝R/hr
Potential Contamination	2x'sBackground
Hot Line	2 mR/hr

EPA Established Exposure Limits

Any Emergency Activity Limit	5 rem total dose
Protect Significant Property	10 rem total dose
Life Saving Rescue	25 rem total dose
Mild toxic affects	50-100 rem dose
$LD_{(50)}$	500 rem total dose

1 sievert (1 Sv)= 100 REM (100 R)

1 milli sievert (1 mSv) = 100 milli REM (100 mR)

Distance

Total dose is inversely proportional to the square of the distance from the source. Therefore, if you double your distance from the source, you reduce your exposure to ¼ of the original dose rate. As an example, if you were receiving 100 mR/hr at 10 feet from a radioactive source and doubled your distance to 20 feet away, then you would reduce your dose rate to 25mR/hr.

Table 26: Distance example (doubled)

100 mR/hr at 10 feet	2 x (double) 20 feet	2 x 2 = 4	¼ of the original dose (25 mR/hr)
Original dose at 10 feet	Increased distance from the source	Square the increased distance from the source.	New exposure rate is the inverse of the squared value.

Using the same example, if we tripled our distance from the source, the dose would be ⅑ of the original dose.

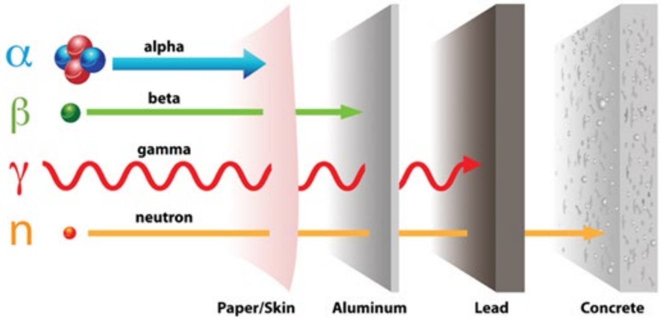
Table 27: Distance example (tripled)

100 mR/hr at 10 feet	3x (triple) 30 feet	3 x 3 = 9	⅑ of the original dose (11 mR/hr)
Original dose at 10 feet	Increased distance from the source	Square the increased distance from the source.	New exposure rate is the inverse of the squared value.

Shielding

Shielding is the third protective measure for radiation exposure. The greater the mass between the source and the responder, the greater the protection value. The type of radiation matters. While alpha particles can be stopped by a sheet of paper, several inches of lead may be required to block gamma radiation.

Figure 61: Shielding illustration (Shutterstock image)



Personal protective equipment

Personal protective equipment (PPE) for alpha or beta radiation would include garments to minimize contamination and the prevention of inhalation or ingestion of the source material. This would include the use of standard respiratory protective equipment and proper decontamination.

PPE is ineffective at preventing gamma radiation or neutrons from passing through the body but will help to limit contamination. As with any type of radioactive material, prevention of inhalation or ingestion of materials emitting gamma radiation must be prevented. In addition, limiting exposure to gamma radiation to as low as reasonably achievable (ALARA) is essential.

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CORROSIVES

This chapter corresponds to Unit 10 of the course.

Corrosives terminology

A **corrosive** product is any solid, liquid or gas that burns, irritates or destructively attacks human tissues and metals. After flammable liquids, corrosives are the most frequently released products. When a responder reports that they have a "corrosive material," that doesn't say much about the material. More level of detail is necessary because very different tactics will be needed for acids vs. bases, not to mention being able to determine which neutralization methods are used. First responders should understand the relationships between the different terms associated with corrosive materials.

- **pH:** A measure of how acidic or basic a substance is. pH denotes "potential of hydrogen" and is a measure of hydrogen ion concentration. The pH scale goes from 0 to 14, with 7 being neutral. At the lower end of the scale are acids, and at the higher end are bases.
- **Strength:** The amount of ionization or dissociation that a particular acid or base undergoes in water.
- **Concentration:** The amount of acid or base in water.
- **Acid:** Materials that, when dissolved in water, will dissociate hydrogen ions (H+) and form hydronium ions (H_3O+).
- **Base:** Materials that produce hydroxide ions (OH^{-1}) when dissolved in water.
- **Neutralization reaction:** An acid-base reaction in which an acid reacts with a base to form a salt and water.

Introduction to corrosives

Corrosives come in all physical states. Acids are typically liquids and gases, while bases are typically solids, unless they are made into solutions.

Acids cause severe corrosion, primarily in metals. Acid gases can form liquid acids in contact with moisture, including the human body. When the acid releases the H+ ion, it rips away its electron. The H+ now looks for an electron, which is readily given up by most metals. This makes the acid an anion and the metal a cation. When anions and cations combine, corrosion occurs.

Bases, also known as alkalis or caustics, cause destruction to human tissues. This is because the body is composed of fats, oils and fatty acids — which all contain esters — as well as proteins, which are amino carboxylic acids or natural polymers. Caustic materials break down esters and amino acids, the building blocks of the body.

Bases break down (or dissolve) natural polymers into smaller parts, which are generally water soluble. Most cleaning agents and detergents for organic materials are mild caustics for this purpose.

Dissociation and dissolution

Dissociation is the separation of ions. It occurs when an acid or base dissolves in water. The degree to which dissociation occurs depends on the solubility of the corrosive in water. Strong acids and bases are highly soluble and will completely dissociate. Weak acids and bases have low solubility and will only partially dissociate.

Bases dissociate and form OH^{-1} (hydroxyl) ions. Acids dissociate and form H+ (hydronium) ions. These ions are water (H_2O) that is pulled apart — ionized.

Dissolution is the process of dissolving. It generally requires two substances — a solvent and a solute — that are both polar (mixed with water or a solvent such as ether) or both nonpolar.

Density and temperature of corrosives

SG is the weight or density of a substance compared to water (with water being equal to 1). Many corrosives have SGs greater than 1. Over time, some of these will dissolve in water.

Product temperature is a concern with corrosives. Hot acids and bases are much more reactive and aggressive than cold ones. A hot corrosive is a very reactive and aggressive corrosive.

Types of acids and bases

Types of acids

- Binary acids: H + X (F, Cl, Br, I, S); These names begin with hydrogen and end with "-ide."
- Oxyacids: H + oxyradical (H_2SO_4).
- Nonmetal oxides: NM + O.
- Organic acids: HC + COOH (carboxylic acid family).

Types of bases

Strong bases

- Alkali metal oxides.
- Metal hydroxides.

Weak bases

- Alkali earth metal oxides.
- Carbonate (CO_3) and bicarbonate (HCO_3) radicals. These are excellent neutralization materials that will yield water, carbon dioxide and salt.

Moderate bases

Amines are moderate bases. These are nitrogen-bearing compounds that are toxic and produce toxic, flammable vapors like ammonia (NH_3), HCN and nitrogen oxides (NOx).

Neutralization

Strong acids and bases can be neutralized with a weak source of the opposite. When acids and bases contact each other, they immediately react and the active ingredient of both corrosive materials (H^+ and OH^-) is eliminated.

The neutralization reaction is exothermic. That is, it releases heat.

$$\boxed{\mathbf{H + OH = H_2O + Heat}}$$

Either the acid or base must be in water for this reaction to occur. Neutralization is not done as a manner of decontamination for responders since the reaction is exothermic. The stronger the neutralizing agent is, the more heat is generated.

The ability of a base to “suck up” an acid and vice versa is dependent on the number of bond sites left over after the reaction. For example, if HCl combines with $NaHCO_3$ (sodium bicarbonate), the metal (Na) combines with the nonmetal (Cl) to form a salt (NaCl).

The remaining oxysalt radical carbonate (CO_3) has two bonding sites, one of which is already taken up by the H^+ in the formula, leaving only -1 bonding site for the H^+ in the acid.

$NaHCO_3$ will combine with HCl specifically on a 1:1 ratio. This results in the formation of H_2CO_3 (carbonic acid), a weak acid with a pH near neutral.

Table 28: Common names for neutralizing materials

Common name	Chemical name	Chemical formula	Common uses
Slaked lime	Calcium hydroxide	$Ca(OH)_2$	Tanning leather, cement mixes
Milk of magnesia	Magnesium hydroxide	$Mg(OH)_2$	Antacid, laxative, pharmaceuticals
Limestone	Calcium carbonate	$CaCO_3$	Steel manufacturing, mining, water treatment
Soda ash	Sodium carbonate	Na_2CO_3	Detergents, household cleaning compounds
Baking soda	Sodium bicarbonate	$NaHCO_3$	Cooking, food preparation
Citric acid	Citric acid	$C_6H_8O_7$	Antioxidant, preservative, antimicrobial
Boric acid	Boric acid	H_3BO_3	Fireproofing, antiseptic, preservative

Neutralization requires knowing how much of a material has been spilled. For example, if you spill 1 ton of 20% nitric acid (HNO_3) solution, that means 400 pounds of nitric acid has been spilled.

2,000 lbs. x 0.2 = 400 lbs.

But what if you don't know the weight of the material? If you have a known volume of a material, you must know the density of the material to determine its weight:

- 1 ml of water weighs 1 gram.
- 1 ml of mercury weighs 13.55 grams.
- They have the same volume but different densities.

All acids are very dense liquids. For example, a gallon of sulfuric acid weighs around 15 pounds!

Table 29: Conversion factors

Units of measurement	Multiply by	Example compound	SG
Liters to gallons	0.2642	HNO_3	1.5
Gallons to liters	3.785	H_2SO_4	1.84
Gallons to pounds of H_2O	8.345	HCl 30%	1.19
Kilograms to pounds	2.205	HF 50%	1.15
Pounds to kilograms	0.4536	$HClO_4$	1.76
Pounds to tons	2,000	H_2O	1

Table 30: Measurement equivalents

This	Equals this
1 liter	0.2642 gallon
1 gallon	3.785 liters
1 gallon of H_2O	8.345 pounds
1 kilogram	2.205 pounds
1 pound	0.4536 kilograms
1 ton	2,000 pounds
1 pound	16 ounces
1 ounce	28.4 grams
1 pound	454 grams

Neutralization formula

To determine how much of a neutralizing agent will be required, use the following formula:

Gallons of acid x SG x 8.3 x % concentration = acid lbs. x Correction Factors (CF) for base = lbs. of base required

Example:

- There has been a 1,000-gallon spill of 50% sulfuric acid.
- Your available base is sodium carbonate.
- 1,000 gallons x 1.84 x 8.3 x 0.50 = 7,663 lbs. of sulfuric acid.
- 7,663 x 1.082 = 8,292 lbs. of sodium carbonate needed.

Table 31: Specific gravities and correction factors for bases

Neutralizing agent	Sulfuric SG 1.84	Nitric SG 1.50	Hydrochloric SG 1.19	Phosphoric SG 1.42
Sodium carbonate (soda ash)	1.082	0.841	1.452	1.622
Calcium hydroxide (lime)	0.755	0.587	1.014	1.622
Sodium bicarbonate (baking soda)	1.673	1.302	2.247	2.541

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OXIDIZERS AND REACTIVE MATERIALS

This chapter corresponds to Unit 11 of the course.

Aggressive materials

The term “aggressive materials” (or aggressive chemicals) is often used in hazardous materials response to indicate a material that is:

- Corrosive (it will burn, irritate or destructively attack human tissue or metal).
- Oxidizing (it will evolve oxygen).
- Chemically reactive (it will interact with other chemicals).

The reactivity of a material must be considered when using common spill control substances, such as diatomaceous earth, sawdust or other absorbent substances.

Most unwanted chemical reactions occur when corrosives and oxidizers come into contact with other substances. In addition, some chemically reactive substances may violently react under certain circumstances.

Introduction to oxidizers

Oxidizers contain two or more covalently bonded oxygen atoms and/or halogen atoms. A variety of materials can be oxidizers. Examples include halogens, oxygen, peroxide salts, oxysalts, oxyacids, organic peroxides and organic peroxy acids.

Oxidizers, as a class, are reactive and support combustion through the release of oxygen, heat or both. The reactions can be violent and explosive. Contact between oxidizers and flammable or combustible materials can be extremely hazardous. Oxidizers are recognized by name or by formula. A general rule of thumb is that you should treat a compound as an oxidizer if it has any of the following as part of the name:

- The prefix “hypo-” or “per-.”
- The “-ate,” “-ite” or “peroxide” ending.
- “Peroxy.”

Oxidation and reduction

Previously, you learned chemical change involves electrons. In many cases, the chemical change consists of electrons moving from one element to another. The terms oxidation and reduction are used to describe this movement.

Oxidation describes the removal or loss of an electron during a reaction. A fuel is oxidized when its electrons are removed and taken by another material, called an oxidizing agent or oxidizer. Oxidizers, simply stated, are those materials that gain or steal electrons, usually by grabbing the electron from the fuel.

Reduction is the exact opposite of oxidation. An electron is received by a material, usually an oxidizing agent, during reduction. The reducing agent (the fuel) supplies or donates the electrons to the oxidizing agent.

Every oxidation reaction is accompanied by a reduction reaction. Oxidation, the gaining of an electron, cannot occur without reduction, the loss of an electron. An oxidation-reduction reaction is also known as “redox.”

Hazardous oxidation reactions

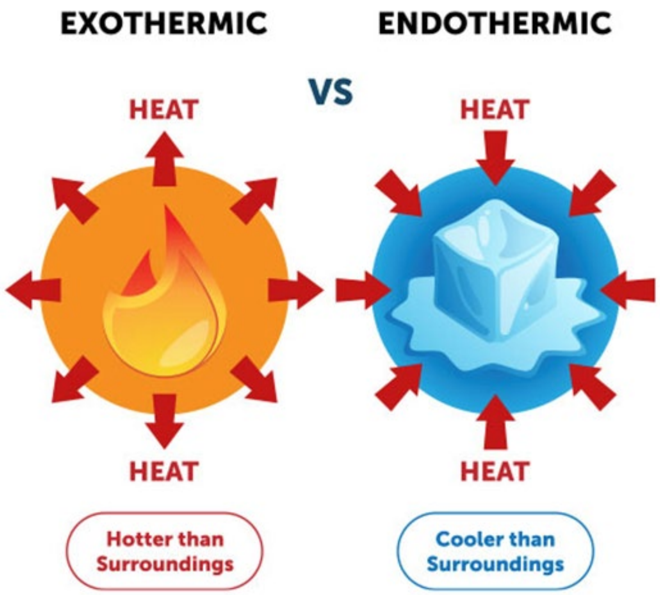
If an oxidizer is strong enough, it can be an **exothermic** reaction — one in which the release of energy from the oxidized material exceeds the amount of energy required to carry out the reaction. In simple terms, the reaction emits heat.

When the reduction reaction occurs with a material that holds a large amount of stored energy, such as fuels, then exothermic reactions such as **hypergolic combustion** (or ignition on contact, without a spark) can occur.

Take care to avoid the contact of oxidizers with combustible materials. The violence of the reaction is difficult to predict and should always be met with caution.

Some reactions are **endothermic** — meaning that more energy is required to facilitate the reaction than is released, creating a sensation of cold. An example is the reaction of ammonium nitrate (an oxidizer) with water (a reducing agent).

Figure 62: Exothermic versus endothermic



Examples of oxidizing materials

Inorganic oxidizers do not have hydrocarbon chains as part of their chemical makeup. In fact, they have no carbon at all. These materials include oxygen, halogen gases, oxysalts, oxyacids, metal peroxide salts and inorganic peroxides. Most solid inorganic peroxides are water-soluble.

Oxygen

Oxygen is the most commonly encountered oxidizer. It can act as an oxidizer in both its pure form and in combination with other elements, such as air. Oxygen in the air can react with materials with Slow Oxidation Potential (e.g., linseed oil) to produce combustion. Oxygen in the air can also react with ethers, aldehydes and alcohols to produce unstable organic peroxides.

Elemental oxygen, in both its gaseous and liquid states, can react violently with hydrocarbon-based materials. Oxygen gas in contact with oil or grease can cause violent combustion or an explosion when ignited. Liquid oxygen (which is highly concentrated oxygen) will create a supercharged combustion environment should ignition occur. This will result in highly sensitized organic substances and hydrocarbons and will violently ignite and burn in the presence of an ignition source.

Halogens

The halogens (Group VII on the periodic table) have oxidizing properties because those elements are extremely electronegative. **Electronegativity** is the tendency to attract electrons during chemical reactions. Whenever an atom or molecule gains electrons during a chemical reaction, it is the "oxidizer," and the molecule that loses electrons has been "reduced." Halogens are very reactive because they add one more electron into their outer shells — a behavior making halogens oxidizers. They become most stable by being reduced (adding an electron) and oxidizing other materials.

Oxysalts

Oxysalts are oxyradicals combined with Group I (alkali) metals; they tend to be more chemically active than combinations of oxyradicals and Group II (alkaline earth) metals. The ammonium ion $(NH_4)^+$ has a chemical behavior similar to the Group I metals and can combine with oxyradicals to form ammonium oxysalts. In particular, chlorates and nitrates are very strong oxidizers.

Oxyacids

Oxyacids are oxyradicals combined with hydrogen. Many of the oxyacids are oxidizers in addition to being very corrosive.

Nitric acid (HNO_3) in concentrations above 40% is extremely corrosive and probably the best example of an oxidizing oxyacid. Nitric acid is commonly used to manufacture rocket propellants and explosives.

Perchloric acid ($HClO_4$) is another strong oxyacid. It has such strong oxidizing properties that it can readily react with combustible materials to cause ignition. Perchloric acid at 100% concentration is unstable and can detonate if it comes in contact with a cellulose-based material.

Chromic acid (CrO_3 or H_2CrO_4) is another oxyacid that can cause ignition in contact with combustible materials because of its oxidizing properties. These acids are first dissolved in a small amount of water, then added to concentrated sulfuric acid (H_2SO_4).

Peroxide salts

Most of the metal peroxide salts, which are strong oxidizers, are combinations of the peroxide functional group (-O-O-) and a Group I alkali metal or Group 2 alkaline earth metal. Many of these salts are also water reactive.

The most common inorganic peroxide is hydrogen peroxide (H_2O_2). In its concentrated form, it is highly corrosive, toxic and sensitive (reactive) to contamination (especially organic matter). Concentrated hydrogen peroxide is a common industrial chemical. In this course, hydrogen peroxide is classified as a nonmetal oxide; however, its inherent hazard as an oxidizer, particularly when it is concentrated, should be emphasized here.

Other reactive materials

Water-reactive materials

Water-reactive materials are those that react when in contact with water, including moisture in the air and on the skin. The water-reactive material breaks the bonds of the water molecule, which releases heat and hydrogen gas, creating an alkaline solution. Depending on the material involved, toxic gases may also be released.

Examples of water-reactive materials include elemental metals — including sodium metal, lithium and calcium — and various salts.

Pyrophoric materials

Pyrophoric materials react with air to produce toxic or flammable gas, or the reaction may result in combustion. Examples include potassium hydride, white phosphorus and silane.

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TOXICITY AND CHEMICAL AGENTS

This chapter corresponds to Unit 12 of the course.

Toxicity

When conducting a product hazard analysis on chemical materials, it is essential to evaluate the toxicity characteristics of the material considering the following points at a minimum:

- Route of exposure.
- Dose.
- Dose thresholds.
- Exposure limits.
- Airborne concentration.
- Toxicity considerations by chemical family.

The chemical families discussed in this course all present with some general toxicity considerations, summarized in the appendix of your Student Manual (SM) for this unit. This information, combined with reference data concerning the specific chemical involved, can provide guidance concerning adverse effects. Keep in mind that some materials may have unique considerations.

Route of exposure

Route of exposure, or how the material enters the body, is the primary factor for selection of appropriate PPE and other means of protecting personnel and civilians.

Routes of exposure include inhalation, contact/absorption, ingestion and injection.

Inhalation

Inhalation is the primary route of exposure for most hazardous materials. It can have direct local effects on the respiratory tract or systemic effects on other organs or functions within the body.

Toxic materials tend to be irritants or corrosive in nature. They can result in the inability to properly exchange oxygen in the lungs. Secondary effects to other systems, such as the CNS or cardiovascular system, may occur.

Direct contact/absorption

Although contact is not a route of exposure as listed by NFPA, it is listed by National Institute for Occupational Safety and Health (NIOSH), Agency for Toxic Substances and Disease Registry (ATSDR) and the Environmental Protection Agency (EPA). Direct contact can result in local effects, including irritation, corrosive effects (from acids or alkalis), dermatitis or thermal injuries.

If the material is absorbed through the skin, it can be transported in the blood to target organs. Some materials are more readily absorbed, such as many nonpolar hydrocarbons and their derivatives, due to lipid solubility.

Ingestion

During a proper response by personnel, it is unlikely that hazardous materials will be ingested. However, improper decontamination, hand-to-mouth activities and eating contaminated food or water can result in this route becoming a factor.

Injection

Injection hazards include sharp objects such as jagged metal debris that has been contaminated, or high-pressure gases or fluid systems like hydraulics.

Dose

Dose is the amount taken into or absorbed by the body by a route of exposure. It is generally expressed as a measure of weight per body mass (mg/kg).

Calculating the amount of a chemical received is virtually impossible in the field, whereas radiological doses are more easily determined with proper detection devices. However, understanding the dose that can be tolerated can provide an indication of the level of risk.

Dose thresholds

With many materials, there is a threshold of exposure and dose that may be tolerated without adverse health effects. This **dose threshold** is generally considered to be much lower or even nonexistent when dealing with carcinogens. Doses are calculated in scientific studies and generally expressed as:

- Toxic dose (TD): resulting in toxic but nonlethal effects.
- Lethal dose (LD): resulting in death.

This is then projected over a population such as:

- (low): The lowest dose at which toxic or lethal effects were observed.
- (50): The dose at which 50% of the population would exhibit toxic or lethal effects.
- (25): The dose at which 25% of the population would exhibit toxic or lethal effects.

Airborne concentrations

The **airborne concentration** is how much of a material is in the air, generally measured in ppm or milligrams per cubic meter (mg/m^3)of air.

As with dose thresholds, airborne concentrations are typically expressed using the same toxic or lethal nomenclature:

- TC: toxic airborne concentration.
- LC: lethal airborne concentration.

These values would also provide low and 50% effect levels. For example, TC(low) indicates the lowest airborne concentration at which toxic or lethal effects would be observed. Likewise, LC(50) indicates the airborne concentration at which half the population would exhibit toxic or lethal effects. You may also see other percentages, depending on the reference source used, such as LC(25).

Concentration levels are applicable to the inhalation route of exposure unless noted otherwise.

Exposure limits

Exposure limits are legal limits used as safety measures to prevent health and safety risks from exposure to toxic or unsafe substances. An exposure limit may be expressed as a:

- **Time weighted average (TWA):** An expression of the average amount of exposure that can be received over a period of time, generally 8 or 10 hours average over a 40-hour work week.
- **Short-term exposure limit (STEL):** Average exposure over a short period of time, generally 15 minutes, as long as the TWA is not exceeded.
- **Ceiling limit (C):** The maximum exposure limit that cannot be exceeded for any length of time.

Permissible exposure limits

The Occupational Safety and Health Administration (OSHA), which is the main federal agency enforcing safety and health legislation, publishes **permissible exposure limits (PELs).** These limits are legally enforceable in the United States and are published based on an 8-hour average.

The PEL is the maximum amount or airborne concentration of a substance to which a worker may be legally exposed. Most PELs have been defined for substances that are dangerous when inhaled, but some are for substances that are dangerous when absorbed through the skin or eyes.

A PEL may be defined in either of two ways:

1. A TWA concentration. This average concentration must not be exceeded during any 8-hour workday of a 40-hour work week.

2. A ceiling value, which must not be exceeded at any time during the workday.

Current PELs are listed in the Code of Federal Regulations (CFR). Workers' exposure may not exceed these standards and OSHA has the power to warn, cite and fine violators.

Recommended exposure limits

The NIOSH provides recommendations to OSHA and publishes **recommended exposure limits (RELs).** RELs are used in the rule-making process but are not enforceable by law themselves until adopted by Congress and signed into law. RELs are based on a 10-hour workday.

RELs are science-based recommendations rather than legal standards. They are based on animal and human studies. An REL is defined in up to three ways:

1. A TWA concentration that NIOSH recommends not be exceeded for up to a 10-hour workday during a 40-hour work week.

2. A ceiling value, which NIOSH recommends not be exceeded at any time during the workday (unless noted otherwise).

3. A short-term (STEL) value, which NIOSH recommends not be exceeded for longer than 15 minutes during a workday (unless noted otherwise).

Threshold Limit Value

The American Conference of Governmental Industrial Hygienists (ACGIH) is a nonprofit organization that researches and develops exposure limits called **threshold limit values (TLVs®),** which are based on an 8-hour workday.

The TLV is a workplace exposure standard representing a level below which nearly all workers may be repeatedly exposed without respiratory protection and without suffering any adverse health effects. A TLV may be expressed as a TWA (TLV-TWA), a TLV-STEL or as a C (TLV-C).

A TLV has three components:

1. A TLV-TWA concentration that ACGIH recommends not be exceeded for up to an 8-hour workday during a 40-hour work week.
2. A C value (TLV-C), which ACGIH recommends not be exceeded at any time during the workday.
3. A short-term (STEL) value (TLV-STEL), which ACGIH recommends not be exceeded for longer than a specified brief period of time (usually 15 minutes) during a workday.

TLVs have been recommended for more than 700 hazardous substances and are based on available animal and human exposure studies. The goal is to minimize workers' exposure to hazardous concentrations as much as possible.

TLVs are recommended values that should not be exceeded in a workplace, rather than legal limits. They do not guarantee protection to all workers and are not intended to be used for community (general public) exposure.

Immediately dangerous to life or health

Another limit that is critical to know is **the immediately dangerous to life or health (IDLH)** value. The IDLH value identifies the concentration in air of any toxic, corrosive or asphyxiant substance that creates (according to NIOSH and OSHA) a "condition that poses a threat of exposure to airborne contaminants when that exposure is likely to cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment."

IDLH values are established (1) to ensure that the worker can escape from a given contaminated environment in the event of failure of the respiratory protection equipment and (2) to indicate a maximum level above which only a highly reliable breathing apparatus, providing maximum worker protection, is permitted.

IDLH values are reported by NIOSH. As a safety margin, they are based on the consequence of up to a 30-minute exposure. However, this is not meant to imply that personnel should work in the environment for that amount of time. Immediate exit is indicated.

The NIOSH Pocket Guide lists IDLH values as well as notices for potential occupational carcinogens (Ca) and concentrations at 10% of the LEL.

Acute Exposure Guideline Levels

Acute Exposure Guideline Levels (AEGLs) describe the human health effects from once-in-a-lifetime (or rare) exposure to airborne chemicals. They are used when dealing with chemical spills or other catastrophic exposures.

AEGLs are considered the best public exposure guidelines to date, because they undergo a rigorous review process and are designed as guidelines for nearly all members of the general public, including sensitive individuals. The disadvantage of using AEGLs is that final AEGLs have been defined for only a few dozen chemicals.

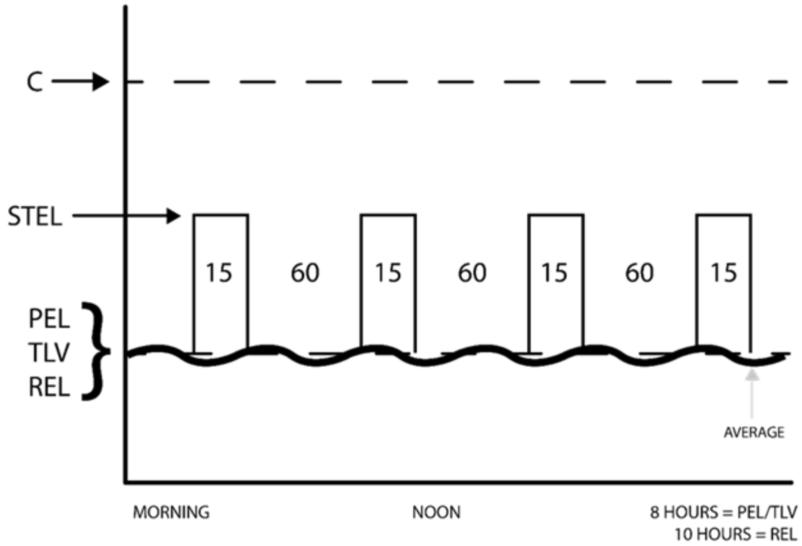
AEGLs are expressed in tiers that define the airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience certain effects as listed below:

- **Below Level 1:** Mild and progressively increasing but transient effects.
- **AEGL-1:** Notable discomfort, irritation or certain asymptomatic nonsensory effects that are not disabling and are transient and reversible upon cessation of exposure.
- **AEGL-2:** Irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.
- **AEGL-3:** Life-threatening health effects or death.

Each level is developed for each of five exposure periods: 10 minutes, 30 minutes, one hour, four hours and eight hours.

AEGLs, when available, may be the best choice to use as a public protective action level. However, personal judgment and experience should be used for selecting an action level and for interpreting the data obtained from using it.

Figure 63: Illustration of the time frames for exposure indicated by several exposure limit values



Toxicity terms

C: The acceptable maximum peak value. At no time should this level or limit be exceeded.

Dose: A quantity or concentration of a material inhaled, ingested, injected or absorbed at a certain time.

Dose/rate: The amount of radioactive material exposure over a given period of time.

Dose/response: A cause-and-effect relationship between the concentration of the material and the magnitude of the effect. The more toxic the exposure, the greater the effect.

Exposure: The state of being exposed to or in physical contact with a material. Unconfined exposures are outdoors; confined exposures are indoors where the concentration may be greater and where there may be less viability of the victims.

Exposure limits: A collection of values based on the best available information and scientific testing designed to protect workers and responders.

LC_{50}: Concentration level at which 50% of the test population died when exposed by inhalation for a specified period of time. Standard measurement used by descriptive toxicologists.

LD_{50}: Lethal dose at which half of the test population died following exposure. Standard measurement used by descriptive toxicologists. Dose is usually given in milligrams per kilogram of body weight of the test animal and refers to dosages administered by ingestion, absorption or injection as a route of exposure.

Odor threshold: Level at which most people can detect the odor of a substance. Great variation in individual responses to odors and in data from various reference sources. Average figure normally based on empirical research. Usually expressed in ppm.

Poison or poisonous: A material that is toxic in extremely low doses. All materials can be toxic depending on dose; however, not all materials are poisonous.

ppm: Units used to express the concentration of a gas or vapor in air (as molecules of chemical per million molecules of air). A 1% concentration of a vapor or gas in air is equal to 10,000 ppm (1% of 1 million).

STEL: Unless otherwise stated, an exposure limit for a short period of time.

TWA: Maximum 15-minute exposure without respiratory protection in place, no more than four times per workday, with a minimum of 60 minutes rest cycle between exposures.

Toxic: A material capable of causing death or serious injury.

Toxicity: The ability of a substance to cause harm to humans.

Toxicant: Any poisonous substance.

Toxicology: The scientific study of adverse effects that occur in living organisms due to chemicals. It involves observing and reporting symptoms, mechanisms, detection and treatments of toxic substances, in particular relation to the poisoning of humans.

Chemical agents

Along with understanding the toxicity of hazardous materials, responders must understand various types of chemical agents that may be encountered during incident response. This section will discuss the following:

- Nerve agents.
- Blister agents.
- Blood agents.
- Choking agents.
- Irritating agents.

Nerve agents

We'll discuss two main types of nerve agents: the organophosphates and carbamates.

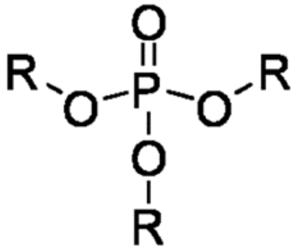
Organophosphates

Organophosphates are the main components of herbicides, insecticides and pesticides. They are important in agriculture, accounting for approximately 40% of the total global pesticide usage. But they are also produced as CWAs. 200,000 tons of these agents are thought to be stored throughout the world.

Organophosphates are generally toxic, primarily due to their ability to irreversibly inhibit the enzyme acetylcholinesterase (AChE), which regulates neurotransmission of nerve signals in the CNS. This results in the "SLUDGEM" symptoms: salivation, lacrimation, urination, defecation, GI cramping, emesis and miosis (pinpoint pupils).

Organophosphates are partially water soluble and can easily enter the soil and ground water. Being mutagenic, they have been linked to a number of nervous and immune system-related diseases. In both developing and developed countries, organophosphates are also a common cause of poisoning by occupational exposure or deliberate self-harm and environmental contamination.

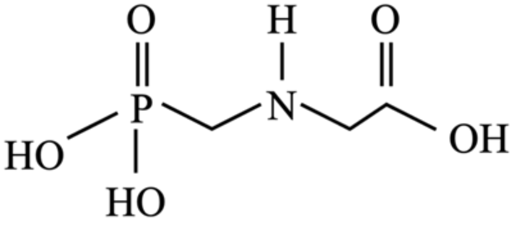
Figure 64: Phosphate ester



R = F, Cl, Br, CN, N, S, H, or HC Radical
O may also be replaced by a S

Organophosphates are commercially available and constitute the "poor man's nerve agents" by concentrating the compounds to increase effect. One example of this is the glyphosate "Round Up®," whose functional group is the phosphate ester.

Figure 65: Glyphosate (Round Up®)



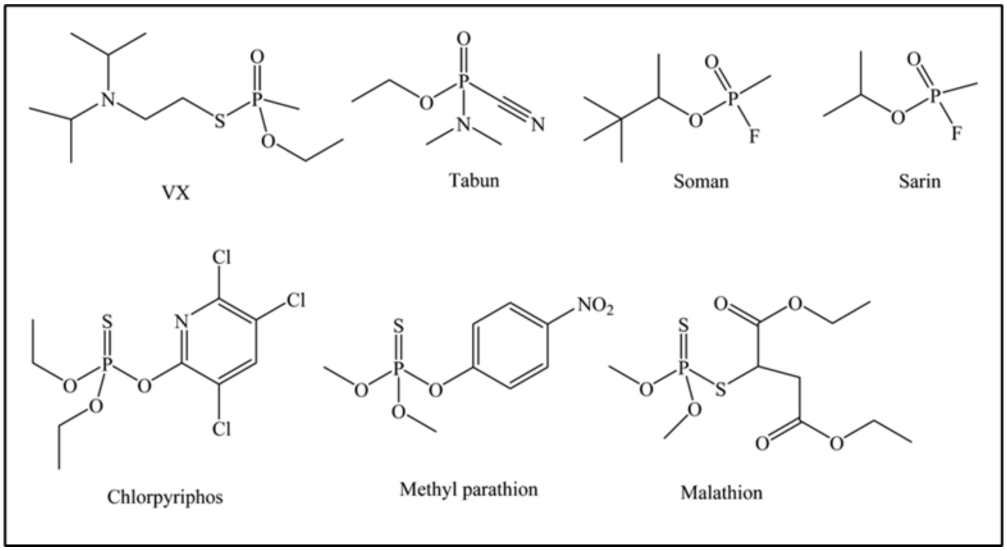
Other hydrocarbon radicals and toxic elements are added to the phosphate ester and give these compounds greater lethality and different physical and chemical properties.

These compounds have very low Vp and are skin contact toxins. There is no such thing as a "nerve gas," which is a term held over from decades ago in the military where a "gas mask" was used as PPE.

These compounds affect the human organism by inhibiting the production and use of AChE.

Recently, Novichok agents have been weaponized and have disabled and killed victims. These are considered "4th Generation" agents which are more persistent and are at least as toxic as VX (short for "venomous agent X"), which is one of the most toxic of the known CWAs — perhaps more so.

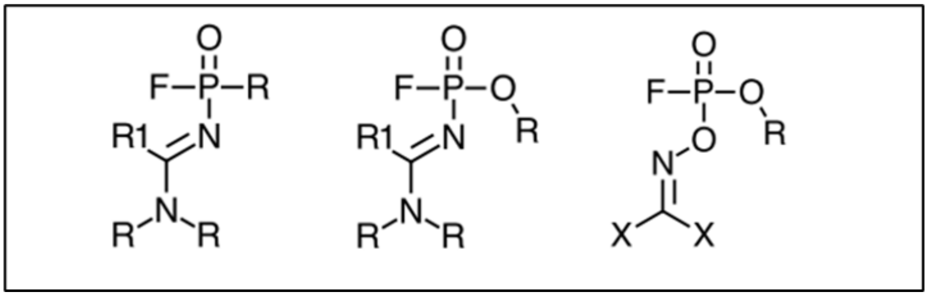
Figure 66: Warfare and commercially available organophosphate compounds



“Organophosphate-degrading metallohydrolases: Structure and function of potent catalysts for applications in bioremediation.”

By: Schenk, G., Mateen, I., Ng, T., Pedroso, M., Miti, N., Jafelicci, M., Marques, R., Gahan, L., & Ollis, D.

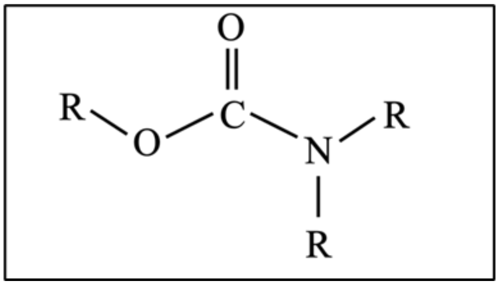
Figure 67: Three variations of Novichok agents (X = halogens)



Carbamates

Carbamates are another family of esters or “carbamic acids” used in the components of insecticides in agricultural settings.

Figure 68: Carbamate (R = H or HC radical)



Like organophosphates, these components are commercially available and constitute the "poor man's nerve agents" by concentrating the compounds to increase effect. One example of this is the carbamate "Aldicarb®."

The functional group is the "carbamates," derived from esters, or when a hydrogen attaches to the oxygen, it is called a carbamic acid (COOH).

Other hydrocarbon radicals and toxic elements are added to the carbamate and give these compounds greater lethality and different physical and chemical properties.

These compounds have very low Vp and are skin contact toxins. They affect the human organism by inhibiting the production and use of AChE as discussed earlier.

Blister agents (vesicants)

Blister agents are toxic compounds that affect the skin, eyes and lungs. There are three main blister agents: lewisite, nitrogen mustard and sulfur mustard. Sulfur mustard is an oily, yellowish-brown liquid with a mustard (or garlic) odor. These can be manufactured from other N and S precursors. Blister agents have no viable commercial or industrial uses and are not easy to obtain, so they must be made.

Another closely related compound is "phosgene oxime." This compound is called an "urticant" or "nettling agent," which causes severe irritation of the skin and mucus membranes. These agents are skin contact poisons which can also be breathed in if weaponized as an aerosol.

Figure 69: Blister agents

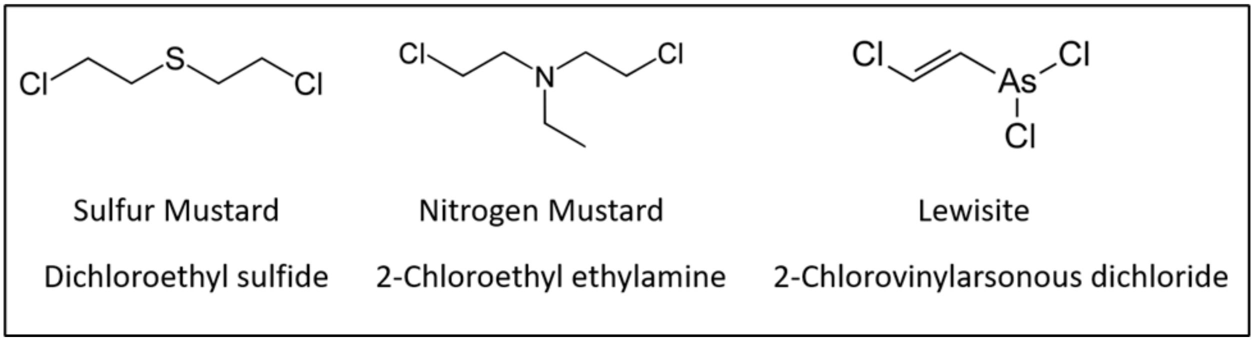
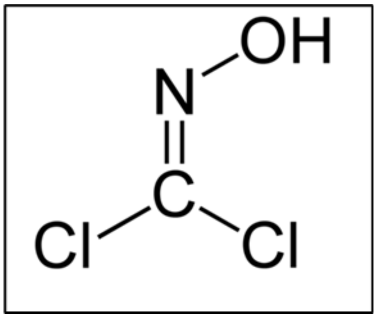


Figure 70: Phosgene oxime

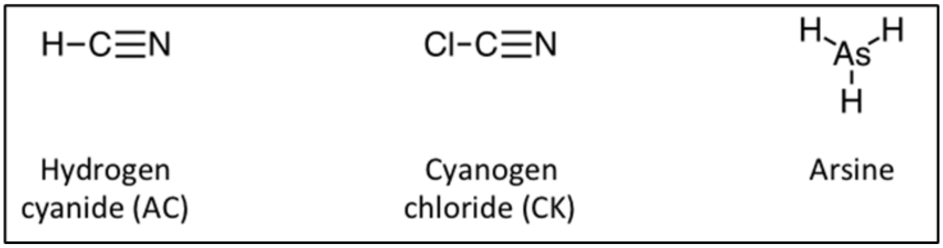


Blood agents

The **blood agents** are arsine, hydrogen cyanide, cyanogen chloride and cyanogen bromide. The term “cyanogen,” as we use it here, refers to a carbon triple bonded with a nitrogen (CN). This is also a term given to a very toxic gas, which combines two CNs: $(CN)_2$. The cyanogen agents all have a slight almond odor that only 10% of the population can smell.

Blood agents affect the body by interrupting the ability to use oxygen properly at the cellular level and impairing the synthesis of adenosine triphosphate (ATP), which is the body’s energy plant.

Figure 71: Blood agents



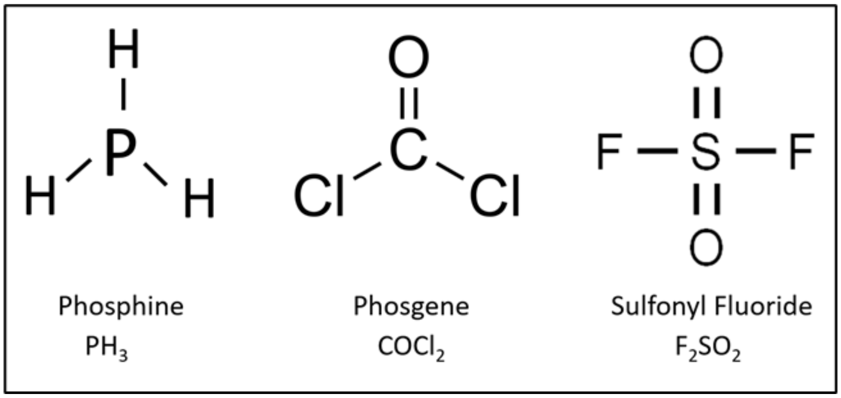
Choking agents

A **choking agent** is a chemical that causes severe respiratory distress, bronchospasms and suffocating pulmonary edema as well as immediate mucus membrane irritation.

These compounds are typically **toxic industrial compounds (TICs)** that are common and widely transported, stored and used in industry, commercial and agricultural processes.

Examples: ammonia, chlorine, bromine, phosgene, phosphorus, phosphine, sulfuryl fluoride, NOx and SOx.

Figure 72: Choking agents



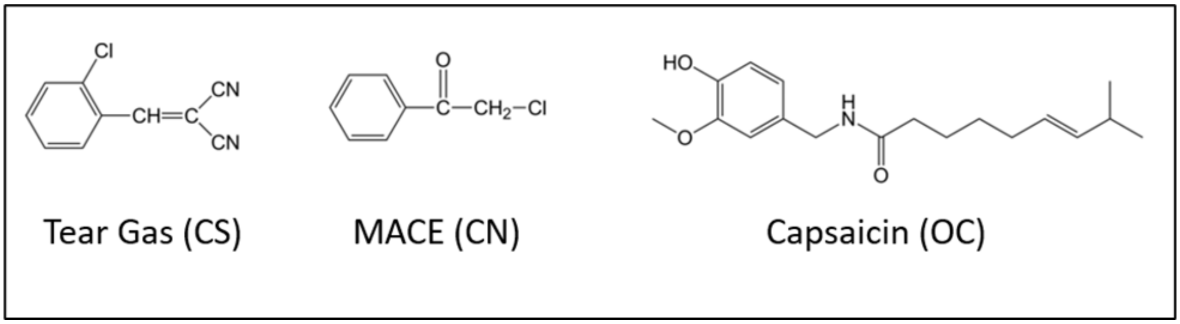
Irritating agents

Irritating agents are compounds that are not designed to kill, but rather to incapacitate victims.

Many of these compounds are carried by law enforcement agencies and, when used for riot control, are not considered WMDs in the truest sense.

Some of these agents are micro-pulverized powders suspended in a propellant, are not water soluble, and can persist on the skin causing lasting irritation.

Figure 73: Irritating agents



GLOSSARY/ACRONYMS

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GLOSSARY

acid	Acids are materials that, when dissolved in water, will dissociate hydrogen ions (H^+) and form hydronium ions (H_3O^+). Aqueous solutions with an increased ratio of hydrogen ions (H^+) to hydroxide ions ($OH\text{-}^1$), compared with the ratio found in water, are described as acid solutions. Acids are referred to as **strong** or **weak** according to their tendency to dissociate (H^+) ions into water and form hydronium (H_3O^+). Therefore, strong acids readily or completely dissociate their hydrogens to form H_3O, while weak acids only dissociate a small percentage of their hydrogen atoms to form H_3O^+. Do not confuse strength with concentration. See concentration.
acute	This term can be used to describe exposure or physiologic effects. When expressing exposure, acute refers to a relativity short-term exposure to high concentrations. When expressing physiologic or toxic effects, “acute” implies that the effect of the toxic exposure occurs within a short period of time.
base	Bases (or caustics) are materials that produce hydroxide ions (OH^{-1}) when dissolved in water. Most caustic materials are solids until mixed with water. Hydroxide salts and oxides of metal oxides typically form bases (caustics) when mixed with water. The hydroxide ion in these compounds is dissociated when the compounds dissolve in water. A base is strong or weak according to the fraction of molecules that dissociates (ionizes) into hydroxyl ion in the solution. A base’s strength in solution is expressed by pH. Caustics do tissue damage by chemically converting protein molecules into a liquid through a process called saponification. This results in liquefaction necrosis of tissue.
boiling point (Bp)	The point at which vapor pressure of a material is equal to or exceeds atmospheric pressure. At the boiling point, the liquid will evaporate at its fastest possible rate. The boiling point of a liquid will vary directly with atmospheric pressure. At higher elevations or within a vacuum, where atmospheric pressure is less, the boiling point of the material will be less.
chronic	When discussing exposures, chronic exposures are typically low dose or repeated exposures over extended periods of time from weeks, to months, to years. Chronic effects implies that the effect of the toxic exposure occurs over a long time or with long-term adverse effects.

concentration	The amount of a given substance within a mixture. In a corrosive (acidic or basic) solution, concentration is the amount of an acid or a base in water. The concentration of a solution is expressed in several different ways: percentage, molarity and normality.
cryogenic liquid	Gases liquefied by cooling the gas to extremely cold temperatures. Generally, cryogenic liquids have a temperature of -130°F/-90°C or colder.
endothermic reaction	A reaction that absorbs heat.
exothermic reaction	A reaction that emits heat.
flammable range	A material's flammable or explosive range is the difference between its upper and lower explosive limits. The lower explosive limit is the minimum concentration of a vapor in air, below which a flame does not propagate in the presence of an ignition source. The upper explosive limit is the maximum vapor concentration in air, above which a flame does not propagate. If the vapor-to-air mixture is below the lower explosive limit, the mixture is described as being too lean to burn. If it is above the upper explosive limit, it is too rich to burn. When the vapor-to-air ratio is somewhere between the lower explosive limit and upper explosive limit, it is said to be in its flammable range. Within this range, fires and explosions can occur, provided an ignition source is present.
flash point (Fp)	The minimum temperature at which a flammable/combustible liquid must be heated to produce sufficient vapor to burn in the presence of an ignition source. At its flash point, a particular flammable or combustible liquid may not yet be hot enough to reach its lower flammable limit, which is where it will give off enough vapor to sustain combustion; instead, the combustion process may burn through this vapor much faster than the rate at which the liquid releases the vapor. When combustion is only sustained for a very brief period of time, it appears as a "flash" of visible flame that promptly extinguishes.
hazard	The capability of causing harm. Hazards can be associated with the product(s) involved, the container for the product(s) and its characteristics, the environment, or the cause of an incident involving a product, particularly if the incident cause is an intentional act.

immediately dangerous to life or health (IDLH)	Immediately dangerous to life or health is a data point, expressed as a concentration of a given substance, used to describe the concentration or dose of a material that poses an immediate threat to life, or would cause irreversible or delayed adverse health effects, or would interfere with an individual's ability to escape from a dangerous atmosphere. Self-contained breathing apparatus must be worn in these environments.
ignition temperature (IT)	(Synonyms: ignition point, autoignition point, autoignition temperature.) The minimum temperature required to initiate or cause self-sustained combustion in any substance in the absence of a spark or flame.
isomer	Two compounds with the same chemical formula but with different structural formulas are isomers of one another. Isomers of two or more molecules will have the same number and kind of atoms and hence the same molecular weight, but differ in respect to the arrangement or configuration of the atoms.
isotope	An element that has the same position on the periodic table (the same atomic number), but a different atomic mass than other forms, or species, of that same element. The difference in atomic mass is due to the increase or reduction of the number of neutrons in the atom as compared with the most common form as represented on the periodic table.
miscibility	The ability of materials to dissolve into a uniform mixture. The ability of a liquid or gas to form a uniform mixture with another liquid or gas. Miscibility is a physical change.
oxidation	Oxidation describes the removal or loss of an electron during a reaction. It is the process in which electrons are removed from a material. Any process in which oxygen combines with another element or compound.
pH	The measure of the ratio of hydrogen ions (H^+) or hydroxyl (OH^{-1}) in a solution in comparison to water; the more hydrogen ions (H^+) there are, the more strongly acidic the solution is. The more hydroxide ions (OH^-) there are in a solution, the more basic the solution is.

polymerization	A chemical reaction in which relatively simple molecules (monomers) are broken and recombined to form larger macromolecules (polymers). Industrially, polymerization is performed by subjecting unsaturated or otherwise reactive substances to conditions that will bring about combination. Polymerization reactions are usually carried out by using a catalyst or initiator (often an oxidizer), heat, light or pressure. Depending upon the monomer, polymerization can evolve tremendous heat and volumetric expansion of the polymer and result in violent container failures.
risk	The potential for a hazard (product, container, environment or cause) to impact life, property or the environment. Risk has four components: threat/hazard, vulnerability, consequences, and likelihood of occurrence.
risk-based response (RBR)	A systematic process, based on the facts, science and circumstances of the incident, by which responders analyze a problem involving hazardous materials/weapons of mass destruction to assess the hazards and consequences, develop an Incident Action Plan, and evaluate the effectiveness of the plan (National Fire Protection Association 470, *Hazardous Materials/Weapons of Mass Destruction (WMD) Standard for Responders*).
routes of exposure	The route(s) of exposure of a toxic product determines the type of required personal protective equipment after flammability has been assessed. The routes of exposure are: inhalation, skin contact, skin absorption, ingestion and injection.
solubility	The ability of one product to be dissolved by another. Solubility is often expressed as a percentage concentration that is achievable in 100 milliliters of water. For example, a material with a 2 percent water solubility would mean that 2 grams of the substance could be mixed uniformly in 100 milliliters of water at a given temperature prior to achieving saturation.

spontaneous combustion	Combustion through the breakdown of a material with access to oxygen (exposure to air), but without an external ignition source. Internal heat provides the ignition through the breakdown of molecular bonds. Spontaneous combustion can occur within any molecule that possesses a double bond, synthetically or naturally. These double bonds slowly react with oxygen until enough heat is created to produce ignition. Spontaneous combustion usually occurs within organic materials, such as hay, straw or coal; esters, aldehydes and ethers; large animal or vegetable oils such as linseed, whale, soybean or cottonseed oils. Materials that are capable of spontaneous combustion are sometimes said to have Slow Oxidation Potential. Typically, these materials have low ignition temperatures and readily react with available oxygen.
states of matter	For the purpose of this course, there are three primary states of matter: solid, liquid and gas. **Solids** have specific mass, occupy a specific volume and have a specific shape. **Liquids** have specific mass, occupy a specific volume, but have no specific shape. **Gases** have specific mass, but have no specific volume or shape.
strength	Strength is the amount of ionization or dissociation that a particular acid or base undergoes. A strong acid will virtually or totally dissociate within an aqueous solution, forming high concentrations of hydrogen (H^+) ions in the solution. A strong base will virtually or totally dissociate in an aqueous solution, forming high concentrations of hydroxide (OH^-) ions in the solution. The strength of an acidic or basic solution is expressed as pH.
sublimation	Sublimation is a process by which a solid transforms directly into a gas without first changing into a liquid. A sublimating solid is capable of giving off vapors, and therefore, will be listed in reference materials as having a vapor pressure.
vapor density (Vd)	The weight of a vapor at a given temperature and pressure. Vapor density of a substance is measured by comparing the total molecular weight of the vapor to the weight of dry air, which has an approximate weight of 29 atomic mass units. Vapor density is expressed as a ratio of a vapor's weight to the weight of dry air; therefore, vapor density of a particular vapor can be calculated by dividing the molecular weight of the vapor by the molecular weight of air. Then, the vapor can be described as being heavier than air if its vapor density is greater than 1, or lighter than air if its vapor density is less than 1.

vapor pressure (Vp)	The pressure exerted by molecules escaping the surface of a liquid and some sublimating solids against atmospheric pressure at a given temperature (typically 68°F/°C). It also represents pressure that a gaseous material exerts against the sides of an enclosed container. Vapor pressure for liquids and solids at room temperature are most commonly expressed in millimeters of mercury, whereas the vapor pressures of gases are generally expressed in either pounds per square inch or atmospheres.
water reactivity	A spontaneous chemical reaction of a substance with water, generally involving the release of heat energy. Examples include the water reactivity of the alkali metals, alkali earth metals, anhydrides, carbides, nitrides and phosphides. In the case of the alkali metals and alkaline earth metals, the reaction involves the breaking of bonds within the water molecule, resulting in the release of heat and flammable hydrogen gas. In other cases, the hydrogen atoms from water are combined with other atoms within the reaction to form highly flammable or toxic products.

ACRONYMS

ABS	acrylonitrile, butadiene and styrene
AEGL	Acute Exposure Guideline Level
ALARA	as low as reasonably achievable
ALOHA	Areal Locations of Hazardous Atmosphere
AMU	atomic mass unit
ANFO	ammonium nitrate/fuel oil
APR	air-purifying respirator
ARDS	acute respiratory distress syndrome
ARS	acute radiation syndrome
ATSDR	Agency for Toxic Substances and Disease Registry
BLEVE	boiling liquid expanding vapor explosion
BTU	British thermal unit
C	ceiling limit
CAMEO	Computer-Aided Management of Emergency Operations
CBRN	chemical, biological, radiological and nuclear
CDC	Centers for Disease Control and Prevention
CF	Correction Factor
CFR	Code of Federal Regulations
CNS	central nervous system
CSB	U.S. Chemical Safety and Hazard Investigation Board
CWA	chemical warfare agent
DDT	deflagration-to-detonation transition

DOT	U.S. Department of Transportation
EEGL	emergency exposure guidance level
EMS	emergency medical services
EPA	Environmental Protection Agency
ERDSS	Emergency Response Decision Support System
ERG	Emergency Response Guidebook
ERPG	emergency response plan guidelines
ERT	Emergency Response Team
FGAN	fertilizer grade ammonium nitrate
FID	flame ionization detector
FMCSA	Federal Motor Carrier Safety Administration
GI	gastrointestinal
HRR	heat release rate
HRT	Hazard Response Team
IAB	InterAgency Board
IAP	Incident Action Plan
IC	Incident Commander
IG	Instructor Guide
IUPAC	International Union of Pure and Applied Chemistry
LC	lethal concentration
LD	lethal dose
LEL	lower explosive limit
LNG	liquefied natural gas

LOC	level of concern
MIT	Massachusetts Institute of Technology
MSST	maximum safe storage temperature
MW	molecular weight
NASA	National Aeronautics and Space Administration
NCI	National Cancer Institute
NFA	National Fire Academy
NFPA	National Fire Protection Association
NIMS	National Incident Management System
NIOSH	National Institute for Occupational Safety and Health
NTSB	National Transportation Safety Board
OSHA	Occupational Safety and Health Administration
PAH	polycyclic aromatic hydrocarbon
Pc	critical pressure
PEL	permissible exposure limit
PEPCON	Pacific Engineering and Production Company of Nevada
PID	photoionization detector
PIO	Public Information Officer
PNCHO	phosphides, nitrides, carbides, hydrides and oxides
PPE	personal protective equipment
REL	recommended exposure limit
REM	roentgen equivalent man
RGasD	relative gas density

SADT	self-accelerating decomposition temperature
SAW	Student Activity Worksheet
SCBA	self-contained breathing apparatus
SDS	Safety Data Sheet
SG	specific gravity
SI	International System of Units
SLUDGEM	salivation, lacrimation, urination, defecation, gastrointestinal cramping, emesis and miosis
SM	Student Manual
SOG	standard operating guideline
SOP	standard operating procedure
STEL	short-term exposure limits
TC	toxic concentration
Tc	critical temperature
TD	toxic dose
TIC	toxic industrial compound
TLV	threshold limit value
TWA	time weighted average
UEL	upper explosive limit
UL	Underwriter Laboratories
USFA	U.S. Fire Administration
Vc	vapor concentration/content
WIIFM	What’s in it for me?
WMD	weapon of mass destruction