MOLECULES TO THE MAX!

Educators Resource Guide

www.moleculestothemax.com/Educators.html
Welcome to the Educators Resource Guide for Molecules to the MAX!

The lessons and activities in this guide were developed as part of the Molecularium Project to help you explore the exciting nanoscale universe of atoms and molecules with your students. These hands-on inquiry based lessons are aimed at introducing middle school aged students to core concepts of science through engaging activities.

Experience is the best teacher, so these lessons aim to make science fun through discovery based activities. New vocabulary is learned as discoveries are made through experimentation and demonstration. Student handouts for each lesson help to guide discovery and reinforce key concepts.

This guide and additional resources for educators are available at moleculestothemax.com/Educators.html

NATIONAL SCIENCE EDUCATION STANDARDS:

The following science standards specified for grades 5–8 in the National Science Education Standards (National Research Council, 1995) are addressed in this guide and in Molecules to the MAX!

Science as Inquiry (Standard A)
- Develop the abilities necessary to do scientific inquiry
- Develop understanding about scientific inquiry

Physical Science (Standard B)
- Properties and changes of properties in matter.
- All matter is made up of atoms.
- Atoms and molecules are perpetually in motion. The greater the temperature, the faster the motion.
- Atoms may join together to form well-defined molecules.
- Interactions among atoms and/or molecules result in chemical reactions.
- The atoms of any one element are different from the atoms of other elements.
- There are more than 100 elements. Elements combine in a multitude of ways to produce compounds that account for all living and nonliving substances.

Life Science (Standard C)
- All organisms are composed of cells—the fundamental unit of life.
- Hereditary information is contained in genes, located in the chromosomes of each cell.

Earth and Space Science (Standard D)
- Water, which covers the majority of the earth's surface, circulates through the crust, oceans and atmosphere in what is known as the “water cycle.”
- The atmosphere is a mixture of nitrogen, oxygen, and trace gases that include water vapor.
- Clouds, formed by the condensation of water vapor, affect weather and climate.
Next Generation Science Standards

Molecules to the MAX!, NanoSpace and this resource guide help address the following Next Generation Science Standards (NGSS) specified for Middle Schools and the Framework for K-12 Science Education upon which they are based.

Disciplinary Core Ideas

Physical Sciences

- PS1: Matter and its interactions
  - PS1-1: Develop models to describe the atomic composition of simple molecules and extended structures.
  - PS1-2: Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.
  - PS1-3: Gather and make sense of information to describe that synthetic materials come from natural resources and impact society.
  - PS1-4: Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.
  - PS1-5: Develop and use a model to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved.

- PS3: Energy
  - PS3-4: Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.

Life Sciences

- LS1: From molecules to organisms: Structures and processes
  - LS1-1: Conduct an investigation to provide evidence that living things are made of cells; either one cell or many different numbers and types of cells.
  - LS1-2: Develop and use a model to describe the function of a cell as a whole and ways parts of cells contribute to the function.

Earth and Space Sciences

- ESS2: Earth’s systems
  - ESS2-1: Develop a model to describe the cycling of Earth’s materials and the flow of energy that drives this process.
  - ESS2-4: Develop a model to describe the cycling of water through Earth’s systems driven by energy from the sun and the force of gravity.

Crosscutting Concepts

- 1. Patterns
  - Macroscopic patterns are related to the nature of microscopic and atomic-level structure.

- 2. Scale, proportion, and quantity
  - Time, space, and energy phenomena can be observed at various scales using models to study systems that are too large or too small.
  - Phenomena that can be observed at one scale may not be observable at another scale.

  - Matter is conserved because atoms are conserved in physical and chemical processes.

- 4. Structure and function
  - Structures can be designed to serve particular functions by taking into account properties of different materials, and how materials can be shaped and used.

- 5. Stability and change
  - Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and forces at different scales, including the atomic scale.
UNIT 1  
Everything is Made of Atoms!

Anything that takes up space and can be weighed is made of atoms. Atoms are the incredibly small, basic building units of matter.

Students will complete activities that help them comprehend the size and structure of an atom, understand that everything is made of atoms, and that each element has its own characteristics. They will play a game that makes learning the Periodic Table fun.

Vocabulary
- atom
- molecule
- proton
- neutron
- electron
- element
- ion
- isotope

Did You Know?
That the most common element in the universe is hydrogen?
Roughly 75% of the universe’s elemental mass is hydrogen.

LESSON 1  Let’s Go Nano

OBJECTIVES
Students will:
- learn the size of atoms
- learn the size of a nanometer
- learn how to use scientific notation

MATERIALS
Stacks of paper
Scissors
Rulers or micrometers
Pennies

LESSON 2  Anatomy of an Atom

OBJECTIVES
Students will:
- learn the basic structure of an atom
- learn about subatomic particles
- be introduced to the Periodic Table

LESSON 3  Elements as Characters

OBJECTIVES
Students will:
- learn about the properties of different elements
- learn about the Periodic Table and play a game that helps them remember where elements are on it

The Earth’s atmosphere is composed of:
- 78% nitrogen
- 21% oxygen
- 0.9 % argon
Let’s Go Nano!

Students learn just how small an atom really is

1 Discuss: Ask the class what an atom is. Elicit what the class already knows about them. Discuss how incredibly small atoms are and that they are the basic building units of matter. Anything that takes up space and can be weighed is made of atoms. Atoms are smaller than the wavelength of visible light.

2 Explain: The word “atom” comes from the Greek word meaning “indivisible” (lit. “not cuttable”). Around 460 B.C., Democritus, a Greek philosopher, developed the idea of atoms by asking: if you cut something in half and then in half again, how many times would you have to do it before you could cut no further? He believed you would end up with a fundamental indivisible unit of matter he called “atoma” from which everything else is composed.

3 Hand Out: Distribute the Let’s Go Nano handout and have students do the activities in small groups.

4 Discuss Results: Bring the class back together to share and discuss their results.

5 Explain: Scientific notation is used to write very large or very small numbers. A number in scientific notation is written as the product of a number and a power of 10.

- The power of ten tells you how many places to move the decimal point. Example: $1.23 \times 10^{11}$ means the decimal point is moved to the right 11 places (123,000,000,000).

- If the power of ten is negative, the decimal point is moved to the left. This is used for very small numbers. Example: $4.56 \times 10^{-11}$ means that the decimal point is moved to the left 11 places (0.0000000000456).

- Go through and discuss how many atoms wide the different things pictured are. Have students give their answers using scientific notation.

6 Answers:

- The number of atoms in a penny is approximately $2.8 \times 10^{22}$.

- Some scientists estimate there are between $1.0 \times 10^{20} - 1.0 \times 10^{24}$ grains of sand on Earth.

This comparison gives a good idea of just how small atoms really are.
What is an atom?
The word “atom” comes from the Greek word meaning “indivisible” (lit. “not cuttable”). Around 460 B.C., Democritus, a Greek philosopher, developed the idea of atoms by asking: if you cut something in half and then in half again, how many times would you have to do it before you could cut no further? He believed you would end up with a fundamental indivisible unit of matter he called “atoma” from which everything else is made.

**EXPERIMENT 1 Indivisible**

Procedure: Before you begin, read the instructions and guess how many cuts you will be able to make.

Guess ________

1. Cut a sheet of paper in half.
2. Cut it in half again. (Make all cuts perpendicular to the first.)
3. Repeat until you can cut no further.
4. Record the number of cuts you were able to make.
5. Guess how many cuts it would take to obtain a piece of paper as small as an atom.

Record your answer ________

**NANOMETER**

1 millimeter (mm) = 1,000,000 nanometers (nm)

How many nanometers long and wide is this line?

**EXPERIMENT 2 How many atoms thick is a sheet of paper?**

Procedure:

1. Measure the thickness of a stack of 50 sheets of papers in millimeters.
2. Calculate the thickness per page:

   Thickness measured / 50 = ______________mm

3. Convert to nanometers = ______________nm

4. If an atom has a diameter of 0.1 nm, how many atoms thick is a sheet of paper?
5. How many atoms wide are the things pictured on this page?
**Scientific Notation**

*Working with Big and Small Numbers*

Scientists often have to work with very big and very small numbers, especially when talking about atoms. They developed an easier way to express long numbers called scientific notation.

In scientific notation, a number is expressed using a power of 10.

\[ 1000 = 10^3 \] (which is said “10 raised to the third power” or “ten to the third”)

A number in scientific notation is written as the product of a number and a power of 10.

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- If the power of ten is negative, the decimal point is moved to the left. This is used for very small numbers. Example: \(4.56 \times 10^{-11}\) means that the decimal point is moved to the left 11 places (0.0000000000456).

Use scientific notation to express the following numbers:

1. 2,380
2. 45,600
3. 12,000,000
4. 378,000,000,000,000
5. 0.001
6. 0.00000429
7. 0.00000000000000000190
8. 8,070,009
9. 0.00390005
10. 4,800,000,000,000,000

**What do you think?**

How many atoms do you think are in the average penny?

How many grains of sand are there on Earth?
**Scientific Notation**

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Use scientific notation to express the following numbers

1. $2,380 = 2.38 \times 10^3$
2. $45,600 = 4.56 \times 10^4$
3. $12,000,000 = 1.2 \times 10^7$
4. $378,000,000,000,000 = 3.78 \times 10^{14}$
5. $0.001 = 1.0 \times 10^{-3}$
6. $0.00000429 = 4.29 \times 10^{-6}$
7. $0.00000000000000000000190 = 1.9 \times 10^{-21}$
8. $8,070,009 = 8.07 \times 10^6$
9. $0.00390005 = 3.9 \times 10^{-3}$
10. $4,800,000,000,000,000,000 = 4.8 \times 10^{18}$

**What do you think?**

How many atoms do you think are in the average penny?

*Approximately $2.8 \times 10^{22}$*

How many grains of sand are there on Earth?

*Approximately $1.0 \times 10^{24}$*

To see how these very rough estimates were calculated visit:

- Penny: [http://www.1728.com/projects.htm](http://www.1728.com/projects.htm)
Anatomy of an atom
The basic model

Students learn that atoms are made of subatomic particles: protons, neutrons, electrons.

1 Discuss: What are atoms made of? Elicit what the class already knows about subatomic particles by asking them questions. Are there different kinds of atoms? What makes them different? What are the different parts of an atom?

2 Explain: With student’s input create a diagram of an atom on the board and the chart illustrating, explaining and discussing the key concepts before giving any handouts.

3 Distribute: Hand out the Periodic Table first when you are discussing the key concepts. Give them the Anatomy of an Atom Handout and Worksheet. This can be done in class in pairs or as homework.

Key Concepts:

- Atoms are made of smaller parts called subatomic particles.
- Atoms with equal numbers of protons and electrons are stable and have no charge.
- Protons and electrons have equal and opposite charges.
- Protons have a positive electrical charge. Neutrons have no charge and electrons have a negative charge.
- Protons and neutrons make up the nucleus, the dense core of an atom that contains nearly all of the atom’s mass.
- A “cloud” of electrons orbit the nucleus at nearly the speed of light. They are attracted to the nucleus because opposite charges attract.
- Atoms are mostly empty space. Electrons orbit the nucleus at vast distances relative to their size.
- Electrons orbit at different energy levels, often called shells. Each shell can only hold a certain number of electrons.
- Scientists currently have identified 117 different types of atoms called CHEMICAL ELEMENTS. The primary difference between them is the number of subatomic particles. An element’s atomic number is the number of protons in one atom.
- The PERIODIC TABLE OF ELEMENTS organizes all of the known elements in the universe into an ingenious chart that is based on the number of protons and similar chemical properties.
- Columns are groups of elements with similar properties.
- Rows are called periods that are arranged in increasing mass from left to right.

<table>
<thead>
<tr>
<th>Subatomic Particles</th>
<th>Charge</th>
<th>Mass (amu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton</td>
<td>+</td>
<td>1</td>
</tr>
<tr>
<td>Neutron</td>
<td>no charge</td>
<td>1</td>
</tr>
<tr>
<td>Electron</td>
<td>−</td>
<td>1/1837</td>
</tr>
</tbody>
</table>

Atomic Mass Units (amu) are used to measure the mass of atoms. 1 atomic mass unit is the approximate mass of a proton or neutron. Atoms are very light. 1 amu = $1.660 \times 10^{-24}$ grams.
Anatomy of an atom
The basic model

What are atoms made of?
Scientists have discovered that even atoms are composed of smaller parts called subatomic particles. Atoms with an equal number of protons and electrons are stable and have no charge.

Nucleus
The nucleus is a dense core at the center of an atom made of protons and neutrons. It contains 99.9% of the atom's mass.

Protons
Protons are positively charged particles found in the nucleus. Atoms are identified by the number of protons they have.

Neutrons
Neutrons are particles found in the nucleus that have no charge. Atoms of the same element with different number of neutrons are called isotopes.

Electrons
Electrons are negatively charged particles that orbit the nucleus in a "cloud" at nearly the speed of light.

This illustration is not to scale. If an atom's nucleus were the size shown here, the closest electrons would be over 100 meters away.

Chemical Elements — Different kinds of Atoms
Atoms with different numbers of protons have different properties. Scientists currently have isolated 117 different kinds of atoms called chemical elements.

The Periodic Table of Elements organizes all of the known elements in the universe into a chart according to their number of protons, termed their atomic number.

The (atomic) mass number is the total number of protons and neutrons expressed in atomic mass units (amu).

Atoms with the same number of protons, but different numbers of neutrons are isotopes, many of which are radioactive. The mass number is different for each isotope of an element.

How many different elements can you name?

The Periodic Table of Elements
**Anatomy of an atom** The basic model

1. What is located at the center of an atom? ___________________________________________
2. What are the parts of an atom called? _____________________________________________
3. What subatomic particles are located in the nucleus? ________________________________
4. What subatomic particles don’t have a charge? ______________________________________
5. Which subatomic particles are the lightest? _________________________________________
6. What are electrons? _____________________________________________________________
7. What is the Periodic Table of Elements? __________________________________________
8. What is an isotope?_______________________________________________________________
9. What is the atomic number equal to? _______________________________________________
10. What is the atomic mass number equal to? _________________________________________

Use the Periodic Table to fill in the chart below for neutral atoms. Select any element you wish for blank rows.

<table>
<thead>
<tr>
<th>Element</th>
<th>Chemical Symbol</th>
<th>Number of Protons</th>
<th>Number of Electrons</th>
<th>Number of Neutrons</th>
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<tbody>
<tr>
<td>H</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Oxygen</td>
<td></td>
<td></td>
<td></td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>
Hydrogen is the simplest, lightest and most abundant element in the universe. It is estimated that 90% of the universe by weight is composed of hydrogen. Most stars are composed mainly of hydrogen.

**Can you find our characters in the Periodic Table?**

Argon is inert and does not bond with other elements. It makes up almost 1% of Earth's atmosphere.

Oxygen makes up 21% of Earth's atmosphere and about 65% of the mass of the human body. It is the third most abundant element in the universe.

Carbon is present in all known lifeforms. There are nearly ten million known carbon compounds.

**Rare Earth Metals**

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<th>Symbol</th>
<th>Element</th>
<th>Symbol</th>
<th>Element</th>
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**Inert Gases**

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<td>108</td>
<td>Mt</td>
<td>109</td>
</tr>
<tr>
<td>Hs</td>
<td>108</td>
<td>Ds</td>
<td>110</td>
<td>Rg</td>
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<tr>
<td>Ds</td>
<td>110</td>
<td>Uub</td>
<td>112</td>
<td>Uub</td>
<td>113</td>
</tr>
<tr>
<td>Uub</td>
<td>112</td>
<td>Uup</td>
<td>114</td>
<td>Uup</td>
<td>115</td>
</tr>
<tr>
<td>Uup</td>
<td>114</td>
<td>Uuh</td>
<td>116</td>
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<tr>
<td>Uuh</td>
<td>116</td>
<td>Uuo</td>
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<td>Uuo</td>
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**Metalloids**

<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>Element</th>
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<th>Element</th>
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<tbody>
<tr>
<td>B</td>
<td>5</td>
<td>C</td>
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<td>N</td>
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</tr>
<tr>
<td>B</td>
<td>5</td>
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<td>C</td>
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<td>F</td>
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<tr>
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<td>Ne</td>
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**Nonmetals**

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<tr>
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<tr>
<td>C</td>
<td>6</td>
<td>O</td>
<td>8</td>
<td>Ne</td>
<td>10</td>
</tr>
<tr>
<td>O</td>
<td>8</td>
<td>Se</td>
<td>34</td>
<td>Br</td>
<td>36</td>
</tr>
<tr>
<td>Ne</td>
<td>10</td>
<td>Ar</td>
<td>18</td>
<td>Kr</td>
<td>36</td>
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<table>
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<tr>
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<th>Element</th>
<th>Symbol</th>
<th>Element</th>
<th>Symbol</th>
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</tr>
<tr>
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<td>O</td>
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<td>Br</td>
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</tr>
<tr>
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<td>10</td>
<td>Ar</td>
<td>18</td>
<td>Krypton</td>
<td>36</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>Element</th>
<th>Symbol</th>
<th>Element</th>
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</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>5</td>
<td>C</td>
<td>6</td>
<td>N</td>
<td>7</td>
</tr>
<tr>
<td>C</td>
<td>6</td>
<td>O</td>
<td>8</td>
<td>Ne</td>
<td>10</td>
</tr>
<tr>
<td>O</td>
<td>8</td>
<td>Se</td>
<td>34</td>
<td>Br</td>
<td>36</td>
</tr>
<tr>
<td>Ne</td>
<td>10</td>
<td>Ar</td>
<td>18</td>
<td>Krypton</td>
<td>36</td>
</tr>
</tbody>
</table>

**Molecules to the Max!**

**Unit 1 • Lesson 2**

**Handout**
The Character of Elements

Students learn that elements have certain characteristics and learn the Periodic Table

- **Discuss:** In the film Molecules to the MAX! most of the characters are atoms. Of course, atoms are inanimate, don't have faces and can't speak, but different elements have different characteristics and properties.

- **Handout:** Distribute the Character of Elements handout. Have students use the Periodic Table and do research on the internet to fill in information about the different elements. In the last card, have each student choose another element from the Periodic Table and create their own cartoon character with the personality or physical traits that match the properties of the element they select. For example, a reactive element might have a temper or an element that has strong bonds might have big muscles.

- **Presentation:** Have students present their characters to the class, explaining the important properties and characteristics of the element that they have selected.

---

**Memory Game:**
- Hand out the two sheets for the Periodic Table Memory Game. Make enough for students to play in pairs. Cover each element in the table with a separate piece of paper so the students cannot see the element, but can lift the paper to see what is underneath. Cut out the elements on the second page.
- Have the students put the cut out elements upside down on the desk. They can then play the memory game. They have to remember where the elements are on the desk and then create a match by remembering where the element is on the Periodic Table. If they get a match, they can keep the element. The one with the most elements when all of the elements have been uncovered wins. Have them play three times so that they learn it well.
- Finally, have them put away the table and from memory reconstruct the chart by putting the elements that they have in their hand in the correct spot. They should work as a group to come up with the right order.
<table>
<thead>
<tr>
<th>Number</th>
<th>Element</th>
<th>Atomic Mass</th>
<th>Symbol</th>
<th>P:</th>
<th>N:</th>
<th>E:</th>
<th>Properties</th>
<th>Important Uses and Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hydrogen</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Carbon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Oxygen</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Periodic Table Memory Game</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Cut out the element cards and the black cover slips on the other page.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Cover all of the elements on this page with the black covers.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Shuffle the element cards and spread them out face down on the table.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Flip over one of the element cards. Remove one of the cover slips to find a match.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 If a match is found, the player keeps the element card and takes another turn.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 If they do not match, the cover is replaced, the card is turned back over and it is the next player's turn.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 When all of the matches have been found, the player with the most cards wins.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Play the game three times. Then put away the chart and arrange the cards from memory.
Cut out the element cards and the cover slips for the Periodic Table Memory Game.
**UNIT 2  Molecules to the MAX!**

There are literally billions of molecules that can be made from the elements in the Periodic Table. The development of new molecules for medical care is an important area of ongoing research.

In this section students will build important molecules, study the effect of molecule size on mobility, and get a demonstration of how molecules are delivered to the body.

<table>
<thead>
<tr>
<th>LESSON 1</th>
<th>Molecules to the MAX!</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBJECTIVES</td>
<td><strong>Students will:</strong></td>
</tr>
<tr>
<td></td>
<td>• learn how atoms bond to form molecules</td>
</tr>
<tr>
<td></td>
<td>• learn about electron shells and valency</td>
</tr>
<tr>
<td></td>
<td>• learn to draw structural formulas</td>
</tr>
<tr>
<td></td>
<td>• build 3D molecular models</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LESSON 2</th>
<th>Making Molecules</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBJECTIVES</td>
<td><strong>Students will:</strong></td>
</tr>
<tr>
<td></td>
<td>• learn the rules of bonding</td>
</tr>
<tr>
<td></td>
<td>• build molecular models using those rules</td>
</tr>
<tr>
<td>MATERIALS</td>
<td>Gum drops</td>
</tr>
<tr>
<td></td>
<td>Toothpicks</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LESSON 3</th>
<th>Counting with Chemistry</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBJECTIVES</td>
<td><strong>Students will:</strong></td>
</tr>
<tr>
<td></td>
<td>• learn about naming molecules</td>
</tr>
<tr>
<td></td>
<td>• learn about hydrocarbons</td>
</tr>
<tr>
<td></td>
<td>• learn about the greenhouse effect</td>
</tr>
</tbody>
</table>

**Vocabulary**
- molecule
- compound
- chemical formula
- structural formula
- diatomic molecule
- inert
- valency
- valence electrons
- valence shell
- chemical bond
- double bond
- hydrocarbon

**Did You Know?**
That two molecules containing the same atoms, but arranged differently are called isomers?

```
C4H10
butane
```

```
C6H8O6
Vitamin C
```
**Molecules to the MAX!**

*Students learn about molecules and bonding by diagraming their structure*

1. **Discuss:** What is a molecule? Elicit what students already know about them. List as many molecules as they can.

2. **Explain** Electrons orbit the nucleus at different energy levels called shells. Each shell can only hold a certain number of electrons. Draw a shell model of an atom on the board with the first two shells full (see example below.) Explain how atoms seek to fill their outer shell and will share their electrons or give them away in order to fill the shell.

```

<table>
<thead>
<tr>
<th>Shell</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrons</td>
<td>2</td>
<td>8</td>
<td>18</td>
<td>32</td>
<td>50</td>
<td>72</td>
<td>98</td>
</tr>
<tr>
<td>Maximum number of electrons in each shell</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

```

Draw a hydrogen atom with one electron. Show how the first shell is missing one electron, so it bonds to another hydrogen atom to make an \( \text{H}_2 \) molecule. Draw the structural formula and explain it is a two dimensional representation of a molecule’s structure.

H + H = H\(_2\)

Draw a shell model of a helium atom with a full first shell and ask the class what kind of atom it is. Explain that since the first shell is full, it does not bond with other atoms; it is inert. The right-hand column of the Periodic Table lists the inert gases, sometimes called noble gases.

3. **Distribute** the Molecules to the MAX! handout and worksheet after covering the key concepts with the class and have students work in pairs to complete the charts on the page.

4. **Review:** Go over the charts on the handout with the class. Have students volunteer to diagram molecules on the board. Discuss the differences between structural diagrams and molecular models. Point out that the diagrams are helpful to communicate how elements are arranged in a molecule, but don’t show the actual arrangement since molecules are not flat like a page.

**Key Concepts:**

- Atoms combine to form molecules.
- Atoms bond to other atoms by sharing or transferring electrons, which lowers their energy.
- The outermost electrons of an atom, called valence electrons, determine its bonding behavior.
- The shell model of electrons helps to understand bonding.
- Atoms want to fill their outermost shell and will share electrons or transfer them to another atom to do so.
- Some atoms form double and even triple bonds by sharing more than one pair of electrons.
- Atoms with complete shells tend to be inert, which means that they usually don't bond with other atoms.
- The composition of a molecule is shown by its chemical formula.
- A structural formula is a two dimensional representation of a molecule.
- Molecules aren’t two dimensional, so scientists use three dimensional models to better understand molecular structure.

**Example:**

Methane (\( \text{CH}_4 \)) is arranged with the carbon at the center of a tetrahedron with a hydrogen atom at each corner.

H — C — H

H
Molecules to the MAX!

What is a Molecule?

Atoms bond with other atoms to form molecules. Atoms bond with other atoms by sharing or transferring electrons to lower their energy.

- \( \text{H}_2\text{O} \) is the most common molecule on earth. What is it?
- Can you name more molecules?
- Molecules can be made of the same kind of atoms, like \( \text{H}_2 \) or \( \text{O}_2 \), or made of more than one element, like \( \text{H}_2\text{O} \).
- Molecules made of different elements are called compounds.

Bonding Basic

Electrons orbit the nucleus at different energy levels called shells. Each shell can only hold a certain number of electrons. The outermost electrons of an atom, called valence electrons, determine its bonding behavior. Generally, atoms bond to fill their outermost shell and lower their energy.

\[
\begin{align*}
\text{H} & \quad + \quad \text{H} \quad = \quad \text{H}_2 \\
\text{O} & \quad + \quad \text{O} \quad = \quad \text{O}_2
\end{align*}
\]

Hydrogen atoms have only one electron so they bond with other atoms to fill their first shell forming a molecule. Diatomic molecules are formed by just two atoms.

Some atoms share more than one pair of electrons to form double or triple bonds, represented by multiple lines in a structural diagram.

Figure it out: How many electrons are needed to fill the outer shell of the following atoms? Use the Periodic Table to figure out your answers.

<table>
<thead>
<tr>
<th>Element</th>
<th>Total number of electrons</th>
<th>How many electrons in the outer shell?</th>
<th>How many electrons to fill the outer shell?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Helium</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxygen</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neon</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Valency

The number of bonds formed by atoms of a certain element is known as valency (or valence).

Which number in the chart to the left is the valency?
Diagraming Molecules

Make structural diagrams of these molecules. Remember to indicate double and triple bonds as needed. Use an element's valency to determine how many bonds there are. Example: $H_2O$

**Earth’s Atmosphere**

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Gas</th>
<th>Molecular Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>78%</td>
<td>Nitrogen gas</td>
<td>$N_2$</td>
</tr>
<tr>
<td>21%</td>
<td>Oxygen gas</td>
<td>$O_2$</td>
</tr>
<tr>
<td>.04%</td>
<td>Carbon dioxide</td>
<td>$CO_2$</td>
</tr>
</tbody>
</table>

Hydrogen peroxide $H_2O_2$

Ammonia $NH_3$

Acetylene gas (blow torches) $C_2H_2$

Ethylene gas (ripens fruit) $C_2H_4$

Methane gas $CH_4$

Hydrogen cyanide $HCN$

Propane gas (grilling food) $C_3H_8$

Methanol (Wood alcohol) $CH_3OH$

Vinegar $CH_3COOH$
Diagraming Molecules

Make structural diagrams of these molecules. Remember to indicate double and triple bonds as needed. Use an element’s valency to determine how many bonds there are. Example: $\text{H}_2\text{O}$

### Earth’s Atmosphere

<table>
<thead>
<tr>
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<th>Formula</th>
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<td>$\text{N}_2$</td>
</tr>
<tr>
<td>21%</td>
<td>Oxygen gas</td>
<td>$\text{O}_2$</td>
</tr>
<tr>
<td>.04%</td>
<td>Carbon dioxide</td>
<td>$\text{CO}_2$</td>
</tr>
</tbody>
</table>

**Diagram:**

- Hydrogen peroxide: $\text{H}_2\text{O}_2$
- Ammonia: $\text{NH}_3$
- Acetylene gas (blow torches): $\text{C}_2\text{H}_2$
- Ethylene gas (ripen fruit): $\text{C}_2\text{H}_4$
- Methane gas: $\text{CH}_4$
- Hydrogen cyanide: $\text{HCN}$
- Propane gas (grilling food): $\text{C}_3\text{H}_8$
- Methanol (Wood alcohol): $\text{CH}_3\text{OH}$
- Vinegar: $\text{CH}_3\text{COOH}$
Making Molecules

Students build some common molecules and create some of their own.

1 Review: Have students review by listing the building rules for different atoms that they discovered in the last lesson. Complete the chart on the board.

<table>
<thead>
<tr>
<th>Element</th>
<th>Number of electrons</th>
<th>How many electrons to fill the outer shell</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Helium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxygen</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2 Expand: The columns of the Periodic Table indicate groups that have similar valence electrons and properties.

3 Distribute the handout and have students work in pairs to build gumdrop models of the molecules and create their own molecules.

4 Check: Have students volunteer to diagram the structural formulas of the molecules on the board.

5 Presentations: Ask students to present the molecules that they created by drawing the structural formula on the board. Have the rest of the class come up with the chemical formula by looking at the diagram.

- Have students present the results of their research on the molecules they created. Could they find the molecule? (If yes, what was the name? Describe its properties and uses.)

Materials
- toothpicks
- gumdrops (red, green, white, black)
Making Molecules

Atoms are far too small to be easily seen so scientists use models to help them understand how they relate to each other and build molecules.

1. Make models of these molecules using different colored gumdrops to represent different atoms and toothpicks to represent the bonds between them.

   **Molecule**   |  **Formula**
   --- | ---
   Hydrogen   |  H\_2
   Oxygen   |  O\_2
   Water   |  H\_2O
   Carbon Dioxide   |  CO\_2
   Methane   |  CH\_4

2. Create your own molecule by following the rules of valency. Write down the chemical formula, draw the structural diagram and build a molecular model.

   Chemical Formula

   Structural Diagram

3. Research the molecules you create and see if they actually exist.

   Review:
   
<table>
<thead>
<tr>
<th><strong>ELEMENT</strong></th>
<th><strong>COLOR</strong></th>
<th><strong>VALENCY</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>White</td>
<td></td>
</tr>
<tr>
<td>Oxygen</td>
<td>Red</td>
<td></td>
</tr>
<tr>
<td>Carbon</td>
<td>Black</td>
<td></td>
</tr>
<tr>
<td>Nitrogen</td>
<td>Green</td>
<td></td>
</tr>
</tbody>
</table>

Molecules aren’t two dimensional, so scientists use three dimensional models to better understand molecular structure.

Methane (CH\_4) is arranged with the carbon at the center of a tetrahedron with a hydrogen atom at each corner.
Counting with Chemistry

Students learn about how molecules are named, hydrocarbons and the greenhouse effect.

1 Discuss: What is a pentagon? How many sides does it have? How do you know? How about a hexagon? Discuss how the Latin prefixes tell you the number of sides to the shape.

2 Expand: Explain that scientists often use the same prefixes when they are naming molecules so that the name tells about the composition of the molecules.

3 Prefixes: Elicit different numeric prefixes and write them on the board. When stumped, give them a prefix and have them guess its meaning.

4 Pairwork: Distribute the handout and have students work in pairs to complete the questions.

5 Results: Bring the class back together and go over the worksheet together. Ask for volunteers to write the diagrams on the board.

6 Discuss: What is a primary property of hydrocarbons?

- Hydrocarbons are one of the primary sources of energy on the planet because they produce heat when burned. Petroleum is a liquid mixture of mainly hydrocarbons and some other compounds. Natural gas is primarily composed of methane gas.

- The chemical reaction for burning methane is
  \[ \text{CH}_4 + 2 \text{O}_2 \rightarrow 2 \text{H}_2\text{O} + \text{CO}_2 + \text{Energy} \]

- The result of burning hydrocarbons is the release of CO\(_2\) into the Earth's atmosphere which prevents heat from leaving the atmosphere. This has caused a great deal of concern recently since scientists have noticed that the Earth's temperature has been increasing.

- Discuss the greenhouse effect and global warming. Discuss possible solutions?

7 Homework: Have students write about possible problems of global warming and possible solutions.
Counting with Chemistry

The names of molecules usually help to identify their make up. The number of atoms is often indicated by Latin prefixes. Here are some common prefixes used by chemists.

- What do they mean? Can you think of any words using them?
  
  mono-________________________ penta-________________________
  di-________________________ hexa-________________________
  tri-________________________ hepta-________________________
  tetra-________________________ octa-________________________

Write the chemical formula for the following molecules.

1. carbon monoxide _____________________________
2. carbon dioxide _____________________________
3. dihydrogen oxide _____________________________

Guess the name for these compounds:

1. MgO _____________________________
2. CCl₄ _____________________________
3. N₂O₅ _____________________________

HYDROCARBONS:

- Hydrocarbons are compounds made entirely of hydrogen and carbon. They are the main components of petroleum and natural gas.
- The number of carbon atoms in a chain is indicated by these prefixes.
  meth - one
eth - two
prop - three
but - four
pent - five
- Endings: The ending tells you how many bonds there are between the carbons.
  - ane means a single bond
  - ene means there is a double bond
  - yne means there is a triple bond

Draw structural diagrams of these hydrocarbons and figure out their names:

1. CH₄
2. C₂H₄
3. C₄H₁₀
4. C₅H₁₂

Write the chemical formula and structural diagram for:

1. Hexane
2. Propane
3. Propene (also Propylene)
**Counting with Chemistry**

The names of molecules usually help to identify their make up. The number of atoms is often indicated by Latin prefixes. Here are some common prefixes used by chemists.

- What do they mean? Can you think of any words using them?
  - mono- one
  - di- two
  - tri- three
  - tetra- four
  - penta- five
  - hexa- six
  - hepta- seven
  - octa- eight

Write the chemical formula for the following molecules.
1. carbon monoxide – CO
2. carbon dioxide – CO₂
3. dihydrogen oxide – H₂O

**HYDROCARBONS:**

- Hydrocarbons are compounds made entirely of hydrogen and carbon. They are the main components of petroleum and natural gas.
- The number of carbon atoms in a chain is indicated by these prefixes.
  - meth – one
  - eth – two
  - prop – three
  - but – four
  - pent – five
- **Endings:** The ending tells you how many bonds there are between the carbons.
  - -ane means a single bond
  - -ene means there is a double bond
  - -yne means there is a triple bond

Draw structural diagrams of these hydrocarbons and figure out their names:
1. CH₄ – methane
2. C₂H₄ – ethylene
3. C₄H₁₀ – butane
4. C₅H₁₂ – pentane

Write the chemical formula and structural diagram for:
1. Hexane – C₆H₁₄
2. Propane – C₃H₈
3. Propene (also Propylene) – C₃H₆
UNIT 2  States of Matter: Solids Slow, Liquids Flow, Gas is Fast

Students will complete research assignments on the transformation of matter from one state to another while building an understanding of the properties of each phase. In addition, the students will create a chamber to study the water cycle with an emphasis on understanding that each state of \( \text{H}_2\text{O} \) is made up of the same molecules.

### LESSON 1  Transformation of Matter Alert!

**OBJECTIVES**

*Students will:*
- conduct research on the transformation of matter
- create a water cycle chamber

**MATERIALS**
- bottles of distilled water
- funnel
- very hot water
- plastic bottle

### LESSON 2  Solids Slow

**OBJECTIVES**

*Students will:*
- grow snowflake shaped crystals
- observe the precipitation of solid from a solution

**MATERIALS**
- borax
- alum
- water
- hot water
- pipecleaners

### LESSON 3  Gas is Fast...

**OBJECTIVES**

*Students will:*
- learn about the expansion that occurs when liquid transforms to gas
- Observe the formation of a closed cell foam

**MATERIALS**
- Ivory soap
- popcorn
- microwave
Transformation of Matter Alert

Students will explore the states of matter and conduct an experiment that will demonstrate the water cycle on a small scale.

1. Discuss: What is a cloud? Explore what students already know about the water cycle and the states of matter by talking about clouds.

2. Define: What are the states of matter? What are the primary differences between them on an atomic level? List them and their properties on the board. Make a chart.

   SOLIDS Atoms are tightly packed, have a fixed arrangement and vibrate in place. SLOW

   LIQUIDS Atoms are close together, but move around in no fixed arrangement. FLOW

   GASES Atoms are separated and move around freely at high speeds. FAST

3. Discuss: H₂O is the only natural substance that is found in all three states at temperatures normally found on Earth.

   The centigrade scale of temperature is based on the different physical states of H₂O. Ask students to explain. (Water freezes at 0 °C and boils at 100 °C.)

4. Demonstrations: The experiments to the right should be conducted as class demonstrations.

5. Discuss the results. Most people will predict the condensation on the sides but will be surprised when the bottle begins to collapse. Ask them to explain why? What will happen when you open the bottle? Why?

6. Explain. The water was supercooled. This means that it is below the freezing point but has not crystallized due to the lack of impurities to act as a crystallization seed.

7. Expand: Build a terrarium. Using small plastic containers that can be sealed, put in some soil, pea seeds, and enough water to saturate the soil. Place near a window. Every day observe and record changes. (Check online for detailed instructions on how to build great terrariums.)

Materials

- 4 bottles of distilled water
- a freezer

Experiment 1:

Before performing this experiment have students write down their prediction of what will happen and explain why. Have them observe the experiment and record their observations.

PROCEDURE:

1. Pour boiling water into a plastic bottle and seal the cap.

   BE CAREFUL when pouring boiling liquids.

2. Place the bottle in an ice bath. Record observations.

Experiment 2: Supercooled Water

PROCEDURE:

1. Place 4 clear plastic bottles of distilled water into a freezer where they won’t be disturbed or moved. Leave them over night.

   NOTE: MUST USE DISTILLED WATER. This won’t work with regular H₂O.

2. In the morning, they should still be in a liquid state.

3. Move them very carefully to where you will perform this demonstration. DO NOT move quickly or drop.

4. Slowly pour the supercooled water into a bowl.

5. With the next bottle, keep the cap on, lift it slightly off the table and drop it.

6. With the next bottle, leave it on the table and just strike the side suddenly.
Solids Slow...

Students grow borax or alum crystals by precipitation from solution. The cooling rate will effect the crystal size.

1 Review: What is a solid? What is a crystal? List as many different crystals as possible.
   - Sugar, salt, ice, snowflakes, quartz, diamonds, emeralds, rubies and other gemstones are all crystals.

2 Explain: A crystal is a solid whose atoms or molecules are arranged in an orderly repeating pattern in all directions. A unit cell is the simplest unit of a crystal that represents the whole pattern and when stacked together and repeated in three dimensions reproduces the whole crystal.
   - There are a variety of different kinds and crystals are categorized by their unit cell.

3 Handout: Distribute the handout and have students build unit cell models and grow their own crystals.

4 Discuss: After the small groups have set up their glasses to grow their crystal, discuss what they think will happen overnight.

5 Explain: They have created a solution by dissolving a solid (solute) into a liquid (solvent) evenly distributing the solute molecules throughout the solvent. When a solution can dissolve no more solute it is saturated and has reached its solubility limit. If the temperature is then reduced, the solubility limit decreases, and some of the solute is excluded from the solvent. As a result a precipitate (solid) made up of solute atoms nucleates and grows. In this case, the precipitate is a crystal.
   - Can they think of a way to speed up the process? Why?

   >>TEST: Select a glass from one of the small groups to experiment and test the idea. Prepare an ice bath. Carefully put the glass in the bath and observe what happens.

6 Discuss the results. Ask the students to hypothesize what differences there may be between cooling the solution very slowly or extra quickly. Generally, larger crystals have crystallized more slowly than smaller crystals.

   The next day, compare the fast grown crystals with those that grew overnight.

Materials
   - borax
   - gum drops
   - alum (on the spice shelf)
   - toothpicks
   - hot water
   - pipe cleaners
   - jars or glasses

Did you know that there are salt crystals bigger than a large adult? How did they grow so big? They grew very slowly....
Solids are Slow

Model Making: Crystal Unit Cells

A unit cell is the simplest unit of a crystal that represents the whole pattern and which when stacked together and repeated in three dimensions, reproduces the whole crystal. There are a variety of different kinds, and crystals are categorized by their unit cell's pattern.

Modeling Unit Cells

1. Build a cube out of gum drops and toothpicks. This is called a Simple Cubic unit cell (SC).

2. Place a gumdrop in the center of the cube and connect it to all of the corners with toothpicks. This is called Body Centered Cubic (BCC). Iron is BCC at some temperatures.

3. Face Centered Cubic (FCC) unit cells have an atom at the corner of the cube as well as at the center of each face. Copper, aluminum, silver, gold and many other metals are FCC.

• Even a very small crystal is made up of millions of unit cells repeated in all directions.

Grow your own crystal

PROCEDURE:
1. Cut a pipe cleaner into three sections. Twist the pieces together to form a snowflake shape. Tie it to a piece of thread. Tie the other end to a pencil so that it will be suspended above the bottom of the glass.
2. Dissolve 3 tablespoons of borax or 4 oz. of alum in one cup of hot water (boiling if possible) water. Pour the solution into the glass.
3. Suspend the pipe cleaner star in the glass.
4. Put the glass in a cool safe place and let it sit undisturbed overnight.

• What do you think will happen?

• How could you speed up the process?
Gas is Fast!

Students explore the properties of gases with balloons and foams.

1 Review: Blow up a balloon and ask the class what is inside. Review how atoms in gases are moving around at high speeds and expand to entirely fill their containers. Blow up a second balloon to be the same size as the other and ask what will happen if you cool one of the balloons.

2 Hypothesize: What is a hypothesis? A hypothesis is a statement the proposes a possible explanation for some event. Scientists often conduct experiments to test a hypothesis they have formed. This process of asking a question, making a hypothesis and testing it is called the scientific method.

3 Test the Hypothesis: Put one of the balloons into the freezer or ice filled cooler for at least 10 minutes.

4 Predict: What would happen to a bar of Ivory Soap if you put it in a microwave oven? Why?

- Have students write down their hypotheses and present them to the class before conducting the test.

5 Test your hypothesis:

1 Before you begin, measure and weigh the bar of soap.

2 Place it on a plate or in a bowl. Microwave at high power for 90 seconds to 2 minutes.

3 Measure and weigh the results. Have students record their observations.

6 Discuss the results. What happened? Why?

7 Explain: When heated in a microwave, the soap softens and water in the soap turns to gas and expands. The gas can’t escape completely, so it forms bubbles creating a foam. A foam is a material formed with gas trapped in cell–like structures. They can be open or closed cells. A closed cell foam has isolated cells; open cells are all connected. Have students name some foams.

8 Give the handout as homework.

Materials
- balloons
- a bar of Ivory Soap
- popcorn
- microwave

>>EXPAND: Why does popcorn pop? Like with the soap, a small amount of water in the kernel of corn expands as it is heated, causing the starch inside to expand as well, eventually causing the hard shell to burst from the pressure.
Gas is Fast!

QUESTIONS TO CONSIDER:

• What happens to the volume of matter as it transforms from a liquid to a gas?

• Given your answer above, do you think you can explain the principle that causes a turbine to spin in a steam turbine, or an engine's piston to fire?

• Why do hot air balloons rise?
Gas is Fast!

QUESTIONS TO CONSIDER:

• What happens to the volume of matter as it transforms from a liquid to a gas?

The volume increases dramatically.

One mole of water is the size of a cube 1 cm on a side (1mL). The volume of one mole of steam is about 22 liters!! Thus, the volume increases by a factor of more than 20,000.

• Given your answer above, do you think you can explain the principle that causes a turbine to spin in a steam turbine, or an engine’s piston to fire?

If you’ve ever watched a water kettle boiling, you’ll know that steam expands and moves very quickly if it’s directed through a nozzle. In a steam turbine, the steam is channeled past the blades of a turbine (think windmill), which spins around like a propeller and drives the machine as it goes.

Steam turbines were pioneered by British engineer Charles Parsons (1854–1931), who used them to power a famously speedy motorboat called Turbinia in 1889. Since then, they’ve been used in many different ways. Virtually all power plants generate electricity using steam turbines. In a coal-fired plant, coal is burned in a furnace and used to heat water to make steam that spins high-speed turbines connected to electric generators. In a nuclear power plant, the heat that makes the steam comes from atomic reactions.

Unlike water and wind turbines, which place a single rotating turbine in the flow of liquid or gas, steam turbines have a whole series of turbines (each of which is known as a stage) arranged in a sequence inside what is effectively a closed pipe. As the steam enters the pipe, it’s channelled past each stage in turn so progressively more of its energy is extracted. Since steam expands and moves very quickly, steam turbines turn at very high speeds — many times faster than wind or water turbines.

• Why do hot air balloons rise?

Hot air balloons are based on a very basic scientific principle: warmer air rises in cooler air. Essentially, hot air is lighter than cool air, because it has less mass per unit of volume. A cubic foot of air weighs roughly 28 grams (about an ounce). If you heat that air by 100 degrees F, a cubic foot of it weighs about 7 grams less. Therefore, each cubic foot of air contained in a hot air balloon can lift about 7 grams. That’s not much, and this is why hot air balloons are so huge — to lift 1,000 pounds, you need about 65,000 cubic feet of hot air.
### UNIT 4 Chemical Reactions

Chemical reactions are happening around us all the time. From cooking to how soap and water clean up afterwards, chemical reactions are part of everyday life. Students will conduct a series of experiments that demonstrate how chemical reactions result in a chemical change that results in new substances through a new arrangement of the atoms involved. They will learn the difference between endothermic and exothermic reactions. They will use electricity to break down water into oxygen and hydrogen.

#### LESSON 1 Chemical Reactions

**OBJECTIVES**

*Students will:*
- learn about chemical reactions
- conduct an experiment that creates a chemical reaction and observe the results.
- explain the results of the experiment

**MATERIALS**

- plastic soda bottle
- balloon
- vinegar
- baking soda

#### LESSON 2 Thermic Reactions

**OBJECTIVES**

*Students will:*
- learn that all chemical reactions either release heat or absorb it
- conduct experiments and determine if they are endothermic or exothermic

**MATERIALS**

- jar with lid
- thermometer
- steel wool
- vinegar
- baking soda
- citric acid
- freezer bags

#### LESSON 3 Breaking Down Water

**OBJECTIVES**

*Students will:*
- learn about decomposition reactions
- will break down water into hydrogen and oxygen through electrolysis

**MATERIALS**

- 9 volt battery
- two pencils leads
- salt
- electrical wire
- beaker
- test tubes
**Chemical Reactions**

*Students learn about chemical reactions by conducting a few.*

1. **Discuss:** What is a chemical reaction? Ask students to give examples of chemical reactions. They are happening around us all the time.

2. **Explain:** Some chemical substances react with others to form new substances, usually by breaking bonds and changing the arrangement of the atoms. Molecules may break apart and rearrange, but the number of atoms remains the same.

3. **Distribute** the handout and have the students conduct the experiments on it in small groups.

4. **Discuss** the results with the whole class.

5. **Expand:** The chemicals that react with each other are called reactants. The number of atoms on each side of the chemical equation must be the same. After writing this chemical equation on the board, have students count the number of atoms on each side to be sure that they are the same.

6. **Explain:** The fact that the splint ignites when you put it in the beaker after the reaction indicates that oxygen is being produced. This is a common test used to see if oxygen has been produced.

   - Hydrogen peroxide is continually decomposing into water and oxygen. The yeast has an enzyme called catalase that acts as a catalyst, which means it speeds up the reaction.

   - The chemical equation for this reaction is:
   $$2 \text{H}_2\text{O}_2 + \text{catalase (yeast)} \rightarrow 2 \text{H}_2\text{O} + \text{O}_2$$

---

**Experiment 1**

- What happened inside the bottle? What happened to the balloon? Why? How do you know?
- This is an acid-base reaction. Vinegar is an acid and baking soda is a base. When combined they react with each other to form new substances. Chemical reactions can be described with chemical equations.

The chemical equation for this reaction is:
$$\text{CH}_3\text{COOH} + \text{NaHCO}_3 \rightarrow \text{CH}_3\text{COONa} + \text{H}_2\text{O} + \text{CO}_2$$

**Experiment 2**

- What happened when they poured the yeast into the beaker?
- What happened when they put the glowing splint into the beaker?
- What does that indicate?
Chemical Reactions

EXPERIMENT 1
Materials per Group
• plastic soda bottle
• balloon
• 30 ml vinegar
• 1 tsp (4g) baking soda

Procedure:
1. Pour the vinegar into the bottle.
2. Put the baking soda into the balloon by stretching open the mouth.
3. Without spilling any of the baking soda, stretch the mouth of the balloon over the mouth of the bottle.
4. Lift the balloon upright so that the baking soda falls into the vinegar in the bottle. Observe what happens and record your observations.

Results:
1. What happened inside the bottle?

2. What happened to the balloon? Why?

3. Explain your reasoning.

EXPERIMENT 2
Materials per Group
• beaker
• 200 ml hydrogen peroxide
• ½ a packet of yeast

Procedure:
1. Pour hydrogen peroxide into the beaker.
2. Pour in the yeast.
3. Observe and record what happens.
4. Light a splint of wood and blow it out.
5. Put the glowing splint in the beaker.
6. Take it out of the beaker and repeat.
7. Record your observations.

Results:
1. What happened when you poured in the yeast?

2. What happened when you put the glowing splint into the beaker?
Thermic Reactions

Students will discover that some chemical reactions produce heat, while others absorb it.

1 Explain: Chemical reactions always involve a change in energy. Some chemical reactions release energy in the form of heat (exothermic), some absorb it (endothermic).

2 Small Group Experiments:

3 Discuss: Have each group report their results for Experiment 1. What happened to the temperature? Was this an exothermic or endothermic reaction?

Have each group report the results of Experiment 2 and answer the same questions. Compare how similar the results of each group are. Discuss other observations that indicated that a chemical reaction was happening.

4 Expand:

**Experiment 1:** Explain that the acid (vinegar) removes the protective coating on the steel wool and encourages the iron to react with the oxygen in the air to form rust. This process is called oxidation, which releases energy in the form of heat.

This is the chemical equation of that reaction:

\[ 4 \text{Fe (s)} + 3 \text{O}_2 (g) \rightarrow 2 \text{Fe}_2\text{O}_3 (s) \text{ (iron oxide)} \]

**Experiment 2:** Explain how some reactions, like this one, require energy. The decrease in temperature indicates that energy has been absorbed. Notice that after the reaction the mixture returns to room temperature.

This is the chemical equation of that reaction:

\[ \text{H}_3\text{C}_6\text{H}_5\text{O}_7(\text{aq}) + 3 \text{NaHCO}_3(\text{s}) \rightarrow 3 \text{CO}_2(\text{g}) + 3 \text{H}_2\text{O}(\text{aq}) + \text{Na}_3\text{C}_6\text{H}_5\text{O}_7(\text{aq}) \]

citric acid + baking soda → carbon dioxide + water + sodium citrate

(aq) - aqueous solution is a solution in which the solvent is water (s) - solid (g) - gas

**Experiment 1**

**MATERIALS PER GROUP:**
- jar with lid
- thermometer
- steel wool
- vinegar

**PROCEDURE:**
1. Put the thermometer inside the jar. Put the lid on and let it sit for 5 minutes. Record the temperature.
2. Soak the piece of steel wool in vinegar for at least 1 minute, then squeeze out the excess.
3. Wrap the steel wool around the thermometer and put them into the jar and seal it.
4. Record the temperature every minute for five minutes.

**Experiment 2**

**MATERIALS PER GROUP**
- ¼ tsp citric acid
- ¼ tsp baking soda
- 20 ml water
- freezer bag
- thermometer

**PROCEDURE:**
1. Put the water in the plastic bag. Add the citric acid and dissolve. Record the temperature.
2. Hold the bag in your hand and add the baking soda. Notice any difference in temperature with your hand.
3. Record the temperature every minute for five minutes.
**Thermic Reactions**

**EXPERIMENT 1**

**Materials per group:**
- jar with lid
- thermometer
- steel wool
- vinegar

**Procedure:**
1. Put the thermometer inside the jar. Put the lid on and let it sit for 5 minutes. Record the temperature.
2. Soak the piece of steel wool in vinegar for at least one minute, then squeeze out the excess.
3. Wrap the steel wool around the thermometer and put them into the jar and seal it.
4. Record the temperature every minute for five minutes.

**Record your results:**

- - - - - -

**EXPERIMENT 2**

**Materials per group**
- ¼ tsp citric acid
- ¼ tsp baking soda
- 20 ml water
- freezer bag
- thermometer

**Procedure:**
1. Put the water in the plastic bag. Add the citric acid and dissolve. Record the temperature.
2. Hold the bag in your hand and add the baking soda. Notice any difference in temperature with your hand.
3. Record the temperature every minute for five minutes.

**Record your results:**

- - - - - -

**Questions:**
1. What is an endothermic reaction?
   __________________________
2. What is an exothermic reaction?
   __________________________
3. Which experiment was endothermic?
   __________________________
4. Which experiment was exothermic?
   __________________________
Breaking Down $\text{H}_2\text{O}$

_students use electricity to decompose liquid $\text{H}_2\text{O}$ into hydrogen and oxygen gas._

1 **Review:** Ask students, “What is water made of? How do you know? What is the chemical formula for water?” Review all that they have learned and know about $\text{H}_2\text{O}$. Discuss how compounds are formed when 2 or more chemical elements unite and bond through synthesis reactions.

2 **Explain:** Explain how compounds can be broken down into smaller compounds or elements through chemical decomposition reactions. Tell them that they are going to break down water into hydrogen and oxygen gas using electricity.

3 **Experiment:** Electrolysis of Water

4 **Discuss:** Ask the class what do they think is happening. Have them pay attention to the level of water in the test tubes. What do you think the bubbles are? Why? What evidence do they have for their hypothesis?

5 **Demonstrate:** Remove the tube connected to the electrically positive terminal (anode), keeping it upside down. Insert a glowing splint and observe what happens. Do the same for the tube connected to the electrically negative terminal (cathode).

6 **Explain:** Ask them what they thought was in each tube. Why? Discuss how the brighter glow or flames in the first indicate oxygen and how the loud pop in the second showed that it had collected hydrogen which produced a small explosion when ignited.

   This experiment is called the electrolysis of water. This is the formula for the reaction.

   \[ 2 \text{H}_2\text{O}(l) \rightarrow 2\text{H}_2(g) + \text{O}_2(g) \]

7 **Expand:** Talk about how the Hindenber was full of hydrogen and how rockets use this explosive reaction for propulsion.

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**Electrolysis of Water**

**MATERIALS:**
- a 9 volt battery
- two pencil leads
- salt
- electrical wire
- 1 beaker
- 2 test tubes
- burning splint

**PROCEDURE:**
1 Assemble the materials as shown in the illustration on the next page. Do not connect the wires to the battery terminals until you have set up the rest.
2 Fill the beaker with a salt water solution.
3 Connect one wire at a time, noticing what happens as each is connected.
4 Let it run until the level of the water in the test tubes is the same as that in the beaker.
**Breaking Down H₂O**

**Materials:**
- a 9 volt battery
- two pencil leads
- salt
- electrical wire
- 1 beaker
- 2 test tubes
- burning splint

**Procedure:**
1. Assemble the materials as shown in the illustration.  
   **DO NOT** connect the wires to the battery terminals until you have set up the rest.
2. Fill the beaker with a salt water solution.
3. Connect one wire at a time, noticing what happens as each is connected.
4. Let it run until the level of the water in the test tubes is the same as that in the beaker.

**Hypothesis:**
1. What do you think is happening inside the tubes?
2. What do you think the bubbles are? Why?

**Test Hypothesis:**
1. Remove the tube connected to the anode, the electrically positive terminal, keeping it upside down. Insert a glowing splint and observe what happens.
2. Do the same for the tube connected to the cathode, the electrically negative terminal. Record your results.
3. Discuss and explain your results. What happened? Why?
UNIT 5  Carbon is Incredible

Carbon is one of the most remarkable elements. Carbon likes to bond with other atoms and form many different molecules because it has four valence electrons. There are well over a million known carbon compounds. All known life forms are carbon based, as are most polymers and plastics. Organic chemistry is the study of chemical compounds that contain carbon.

Students will learn about the different allotropes of carbon and build Buckyballs and nanotubes. They will explore polymers by making their own and measuring the amount in their favorite chewing gum.

LESSON 1  Buckyballs and Nanotubes

OBJECTIVES  Students will:
• learn about different allotropes of carbon
• make models of nanotubes

MATERIALS  scissors
tape

LESSON 2  Polymer Synthesis

OBJECTIVES  Students will:
• learn about polymers
• make a model of a polymer
• synthesize an actual polymer

MATERIALS  paper clips
disposable plastic cup
stir sticks or plastic spoons
Elmer’s glue
borax

LESSON 3  Polymers, Polymers, Everywhere

OBJECTIVES  Students will:
• understand how common polymers are
• measure the amount of polymer in a piece of chewing gum

MATERIALS  a variety of chewing gums
a sensitive scale

Vocabulary
allotrope
buckyball (C_{60})
Fullerenes
nanotubes
polymer
monomer
graphite
cellulose

Did you Know?
Pure carbon can be one of the hardest substances known (diamonds) or one of the softest (graphite). The only difference is the arrangement of the atoms.

Did you Know?
Carbon is found in all living organisms and considered to be the basis for life.
**Bucky Balls and Nanotubes**

*Students learn about the different allotropes of carbon and their atomic structure.*

1. **Explain:** Some elements exist in multiple forms due to the different arrangements of the atoms and the bonds between them. These different forms are called allotropes. Pure carbon has a number of different allotropes.

2. **Review:** Ask them how many bonds carbon usually makes. Why?

3. **Small groups:** Have them build a carbon crystal model where all of the carbon atoms are at the center of a tetrahedron and are bonded to another carbon atom. Have them study the model and list observations. DO NOT tell them they are building a model of diamond, a very popular and pricey allotrope of carbon.

4. **Discuss:** What properties do you think this substance would have? What do you think it is a model of? What properties does diamond have? Make connections between the properties and the structure.

5. **Explain:** What is graphite? How is it used? Why is it called graphite?
   - Show them a graphene sheet. Explain how carbon in graphite is arranged in a hexagonal lattice (grid) in sheets that are stacked on top of each other. Put another graphene sheet on top of the other. There are weak bonds between the sheets allowing them to slip easily over each other, making graphite an excellent lubricant, slippery and soft. It is also what makes it good for pencil lead. Have students think about and discuss what is happening on an atomic level when you write with a graphite lead.
   - Have them compare and contrast the properties of diamond and graphite. Note that they are both pure carbon. Why do they have such different properties?

6. **Construct:** Build a Nanotube. (Handout 1)
   The discovery in the 1980’s of C₆₀ and C₇₀ inspired scientists around world to investigate these new form of carbon. In 1991, it was discovered that carbon also formed tubes, often called nanotubes.

7. **Distribute:** Distribute the graphene sheets and have students build models of the different types of nanotubes in small groups.

>>**EXPAND:** Another allotrope of carbon was discovered in 1986. C₆₀, a spherical structure of carbon atoms, commonly called a Buckyball, was the first of a whole new class of carbon structures to be discovered. Fullerenes were named for Buckminster Fuller, the extraordinary, world renowned inventor of geodesic domes.

>>**EXPAND:** Discuss how different arrangements result in different properties like conductivity and magnetism. Point out that fullerenes are a recent discovery and that a lot of research is going on to investigate their properties and to try to find practical applications for these exciting new materials.
Nanotubes are made of pure carbon. They are graphene (a single layer of graphite) sheets rolled into a tube. Nanotubes are classified by the hexagonal pattern's orientation and twist into three groups (named after the patterns): 1) Arm chair 2) ZigZag and 3) Chiral, which are anything between Armchair and ZigZag.

Cut out the graphene sheet and make all three types.

To make chiral tubes start with either a zigzag or armchair and slide the hexagonal alignment. Start by moving it one hexagon. Then move it more. You will notice you can vary the twist of the tube by moving the alignment.
Polymer Synthesis
(Make your own polymer)

Students learn about polymers by making their own polymer.

1. Discuss: What is a polymer? Elicit what the class knows and thinks about polymers.

2. Explain: Some atoms, particularly carbon atoms, can join together in long chains to form very long molecules called polymers. The word comes from the Greek “poly” meaning many and “mers” meaning parts. Polymers are formed from long chains of the same smaller molecule called a mer (or monomer) repeated over and over again (often referred to as a “repeat unit”).

3. Make a Model: Give each student at least five paperclips. Explain that each paperclip represents a mer (or monomer). Have each row of students link their chains together. Explain that each of these chains represents a polymer. Explain how some polymer chains will crosslink with each other, creating different properties. Have them crosslink the different chains together at various points between the chains. Notice the effect that crosslinking has on the movement of the individual chains; the more crosslinks, the more rigid it becomes. Many plastics are changed into new materials by varying the amount of crosslinking.

4. Handout: Distribute the Polymer Synthesis handout and have students follow the procedures and make their own polymer.

5. Discuss: Have students report their observations of the properties of the polymer they made. Does it hold its shape? What happens when they stretch it slowly? Quickly? How does it feel?

A lot of water is trapped in this network of linked polymer molecules which makes it feel moist and cool and contributes to the liquid-like properties of the polymer.

6. Expand: What do they think will happen to the polymer if it is left exposed to open air? Have students construct their own experiment to test their hypothesis.

The easiest is to simply leave a piece of the polymer out overnight while putting the rest in a sealed container like a plastic bag.

- What happened to the piece that was left out? Why?

Materials
- Elmer’s Glue
- disposable plastic cup
- borax
- stir sticks or plastic spoons

Most people think of plastic when they hear the word “polymer”, but there are many naturally occurring polymers like rubber, cotton fibers, silk, proteins and cellulose. Synthetic or man-made polymers were first discovered in the late 1800’s. Nylon, the first synthetic fabric, was discovered in 1934. Today, synthetic polymers are everywhere and found in almost every product manufactured (especially in the packaging).
**Polymer Synthesis**  
*(Make your own polymer)*

**Materials:**
- Elmer's glue  
- disposable plastic cup  
- borax  
- stir sticks or plastic spoons

**Procedure:**

1. Prepare a saturated borax solution by adding a tablespoon of Borax to a cup of water. If all of the powder dissolves, add more until you reach the point where no more will dissolve (saturation).

>> **WARNING:** The borax solution should be handled with care. It can irritate the eyes so don’t rub your eyes until you have washed your hands.

2. In a disposable cup, mix 25 ml (5 tsp.) of Elmer’s glue with 20 ml (4 tsp.) of water. Mix well with a stirrer. (You can add a couple of drops of food coloring if you wish to give your polymer some color.)

3. Add 5ml (1 tsp.) of the borax solution and stir quickly for at least two minutes. If there is more liquid in the cup or if it is very sticky, add 4-5 drops of the borax solution.

4. Remove the polymer from the cup with the stirrer and roll it into a ball in your hands. Knead it in your hands for several minutes until it starts to form a nice blob.

5. Play with this polymer and make observations. Roll it, bounce it, stretch it quickly, then slowly. Notice the differences.

**Record any and all observations of this interesting material.**
Polymers, Polymers, Everywhere

Students learn that chewing gum is actually a sweet plastic polymer.

1 Discuss: Polymers are very strong and humans have discovered how to make and use them for many things. Plastics are human made polymers, but there are many natural polymers like cellulose. Cotton fiber is nearly pure cellulose. It is the structural component of green plants’ cell walls and the most common organic compound on earth (33% of all plant matter). Paper made from trees and plants is also mostly cellulose.

2 Game: Point to a polymer. The goal is to point to something with a polymer in it. Take turns. Record a list of as many things as they can think of made with polymers. The list should be very long.

3 Handout: Distribute the handout for this lesson and have students follow the procedure. Have them calculate the percentage of polymer in each type of gum by dividing the weight after chewing by the weight before chewing and multiplying by 100. Record their answers on the chart.

4 Expand: Chewing gum is a sweet, chewable plastic. The main ingredients are the gum base (the chewy part), sweeteners, softeners and flavorings. Originally, the gum base was made from resins from trees, but these days synthetic polymers are used. This makes them very chewy and tough. Many of the polymers used in chewing gums are the same polymers that are used in tires and sneakers.

5 Results: Have students compare the amount of polymer in each type of gum. Which type of gum had the most polymer? Is there a difference between sugarless, regular and bubble gums?

6 Discuss: What have they learned? Had they thought about that before? Why shouldn’t you swallow chewing gum? What happens to gum after it is chewed? What should you do with it?

Materials
- a variety of chewing gums
- a sensitive scale

NOTE: Accuracy is very important for this experiment, so an accurate triple beam balance or sensitive digital scale should be used. Students should be shown how to use these instruments properly, if they don’t know before they begin.
<table>
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<tr>
<th>Type of Gum</th>
<th>Original Weight</th>
<th>Weight after Chewing</th>
<th>Weight Loss</th>
<th>Percentage of Polymer (weight after/weight before) X 100</th>
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BEFORE YOU BEGIN:
- Predict what will happen to the weight of the gum and explain why you think that.

Procedure:
1. Weigh each piece of gum in its wrapper and record its weight in the chart.
2. Unwrap it and save the wrapper.
3. Chew each piece of gum for at least ten minutes.
4. Dry off the chewed piece of gum, put it back on its wrapper and weigh the gum again.
5. Record the new weight and calculate the difference in weight.

Questions:
1. Did it increase or decrease in weight? Why?
2. How has the gum changed? What do you think happened?
3. What remains after chewing?