
energy
thermodynamics
system
reaction
entropy
simulation
submicroscopic
chemical
potential
molecules
temperature
enthalpy
record
data
sketch
evidence
kinetic
law
create
endothermic
exothermic
observations
activity
claim
monitors
water
vocabulary
support
products
reactants
answer
heat
thermal
gas
use
drawing
reactions
exploring
table
explain
motion
calculated
piston
chemistry
representation
process
notes
show
second
hess's
carbon
substance
questions
sketches
first
skill
factors
total
state
unit
help
particles
air
bonds
demonstration
combustion
velocity
mass
time
change
connected
studying
list
many
molecule
three
glass
key
oxygen
following
related
page
fossil
fuel
level
atoms
circle
transformed
formation
symbols
volume
section
scientific
claims
move
used
ordered
free
make
dioxide
identify
less
essential
example
calculate
words
mean
released
fuels
different
car
set
CCC
ke
form
inside
able
left
changes
think
periodic
average
non-spontaneous
cylinder
connecting
food
explanation
spontaneous
scientists
work
initial
values
lessons
pentane
pool
blank
take
write
written
fire
amount
run

The Connected Chemistry Curriculum

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The Connected Chemistry Curriculum

Technology

System Requirements

The Connected Chemistry Curriculum has a software component (a set of *Simulations*) which is available at The Connected Chemistry Curriculum website, connchem.org. This software is necessary to use the curriculum, and is open-source and free of charge.

Besides the CCC software, you will need:

- **A personal computer of recent vintage, with an OpenGL-enabled graphics card.**
- **A 13" screen (or larger), with at least 1280 × 800 (WXGA) pixel resolution**
  For most computer monitors this is not a problem. Projectors, on the other hand, sometimes only manage VGA resolution (640 x 480), which will not allow sufficient room for our Simulations.
- **The latest Java runtime environment (JRE)**
  As of this writing, the latest JRE is Java 6, version 29. Java is free of charge: http://www.java.com/en/download/
- **Macintosh OS X 10.6 (Snow Leopard) or later, or Windows 7 or later**
  Earlier versions of the Macintosh OS or Windows may run, but may suffer performance issues. The software should also run on Linux. None of these options have been tested, however, so make sure you run all simulations before using them live in the classroom.

Troubleshooting

Please consult The Connected Chemistry Curriculum website (connchem.org) for up-to-date troubleshooting information, and to download software

Connected Chemistry

Thermodynamics Unit

Contents

The Connected Chemistry Curriculum

Welcome

Welcome to *The Connected Chemistry Curriculum*! The Connected Chemistry Curriculum, or CCC, is designed to help students learn about chemistry by directly exploring the submicroscopic level of matter and phenomena that form the basis of study in chemistry. Educators designed CCC using direct feedback from teachers, students and researchers. CCC uses computer-based simulations to provide a unique submicroscopic perspective of the chemical world for students.

Activity Icons

These icons will be found throughout the teacher and student manuals.
The icons designate the purpose/theme of the activity or section.

Connecting

Hands-On Activity

Student Simulations

Putting It All Together

Questions

Lab Safety

Sketching (without simulations)

Teacher Demonstration

Wet Lab

Teacher Facilitated Discussion

Chemistry Levels

Introductory Reading

Connected Chemistry

Thermodynamics Unit

Lesson 1: Energy and the First Law

Student's Lesson at a Glance

Lesson Summary

Students explore the topic of energy through making connections with household items. In this curriculum, energy is defined as the ability to do work in a system as a result of the submicroscopic interactions and movement of atoms. Evidence of energy may be observed or measured on the macroscopic level in the form of heat, light, or motion.

Students explore kinetic energy, chemical potential energy, and thermal energy. Students are introduced to the First Law of Thermodynamics and the concept of the conservation of energy through the connection of these ideas to their own body and natural surroundings. Students recall concepts from the Modeling Matter and Gas Laws units to help them explore a CCC simulation that replicates the properties of air inside a car engine at the submicroscopic level. Students learn that in order for the car to move, chemical potential energy needs to be transformed inside the engine of a car.

In the final activity of the lesson, students see how a fire piston can start a fire without matches. Students analyze how this phenomenon is possible with regard to the velocity and kinetic energy of gas molecules. Students create submicroscopic representations of how energy is transformed in the fire piston demonstration.

SWBAT (Students Will Be Able To)

- Define what energy is and where energy can be produced
- Identify the different types of energy
- Identify and explain the First Law of Thermodynamics
- Explain how energy can be transformed and conserved

Essential Vocabulary

Keep a list of all important words from this lesson. This list, in addition to the lists from other lessons, will make studying easier and improve scientific communication skills. The essential vocabulary from the unit is in **bold**. Additional words that will expand your scientific vocabulary are in *italics*.

CCC Reminder

- Students and teachers from many different schools helped designed CCC so that the lessons are more helpful and meaningful for all classroom participants.
- Many questions will ask you “what you think” or “to make predictions.” The only answer that is wrong is the answer that is left blank.
- Prefixes and suffixes on words can help you discover the meaning of a word.
- Use the vocabulary section and note section to take good notes so that studying for tests and quizzes will be easier.
- Supporting claims with evidence is not only a skill that scientists use, but a skill that will help you in other classes and everyday life.
- Draw a key when you are sketching. Symbolic keys can help you and others decode your sketches at a later time.
- Heat and thermal energy are not the seem thing. Define them clearly in your vocabulary section.
- You can add heat or take heat away from a system, but you cannot control the temperature of a system directly.

Notes

Homework

Upcoming Quizzes/Tests

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Please turn to the next page.

Activity 1: Connecting

1. Explain what the following things have in common:

- A diesel engine turning the drive shaft in a car
- A gas-powered furnace warming a house
- A candle burning
- A person eating food

Physicists describe energy as the ability of an object or system to do work onto another object or system. For chemists, **energy** is defined as a property of a substance determined by both the submicroscopic structure of atoms and molecules and their relative motion. Evidence for energy can be observed or measured on the macroscopic level in the form of heat, light, or motion. In this unit, we explore some of the different forms of energy, including kinetic energy, thermal energy, and chemical potential energy. Energy is measured in the unit Joules or in kilojoules (kJ).

Chemical potential energy is the energy related to the position of atoms held together by the attraction and repulsion of protons and electrons at the submicroscopic level. Chemical potential energy is transformed into kinetic energy during chemical reactions.

Kinetic energy is the energy related to the motion of atoms and molecules in a system. An example of kinetic energy is a molecule moving from one place to another in a container.

Thermal energy is the total kinetic energy of the molecules in a substance. Thermal energy can only be measured as temperature on the macroscopic level. As kinetic energy increases, temperature also increases.

While some people use the terms thermal energy and heat interchangeably, heat and thermal energy are not the same thing. **Heat i**s the process by which thermal energy transfers from from one system to another. An object or system does not possess “heat”; instead, an object or system has some degree of thermal energy. Energy can be transformed from one form into another by several other processes similar to heat. For example, from a physics perspective, potential energy can be transformed to kinetic energy when an object changes its position in a gravity field, such as when a ball falls to the ground.

For the following questions, circle one word from each pair of terms.

2. Consider a sample of gas that is composed of molecules with high kinetic energy. The average velocity of these high kinetic energy molecules is **faster** or **slower** than the molecules of a gas with lower

kinetic energy. *Explain your reasoning.*

Chemists also study the transformation of energy, specifically related to molecular structure and molecular motion. One way that chemists apply the study of the transformation of energy is through research on fossil fuels. Fossil fuels come from decomposed plants and animals from millions of years ago. When these plants and animals were alive, they received energy from the sun through heat and radiation. Through photosynthesis and respiration, they transformed this energy into chemical potential energy.

The energy in fossil fuels is "stored" in **hydrocarbons**, which are molecules that consist of long carbon atom chains bonded to hydrogen atoms. Gasoline (octane) is a hydrocarbon that comes from one type of fossil fuel known as crude oil. Through a controlled *combustion* reaction in an engine, the chemical potential energy of gasoline is transformed into kinetic energy used to do work, such as powering a car. As energy is *transformed*, bonds between the carbon atoms and hydrogen atoms in hydrocarbons are broken as new products are formed. When while the term 'broken' implies a bond is a physical structure, remember that a bond is actually an invisible *electromagnetic force* that holds the atoms in a molecule together. As new bonds form in the combustion products, energy is released in the form of heat. The balanced chemical equation for this combustion reaction of octane ($C_8H_{18)}$ is as follows:

$$2\ C_8H_{18}\ (l) + 25\ O_2\ (g) \rightarrow 16\ CO_2\ (g) + 18\ H_2O\ (g) + \text{Energy}$$

No matter what fuel (e.g., wood, gasoline, methane, candle) is burned in a combustion reaction, there are similarities between the reactions.

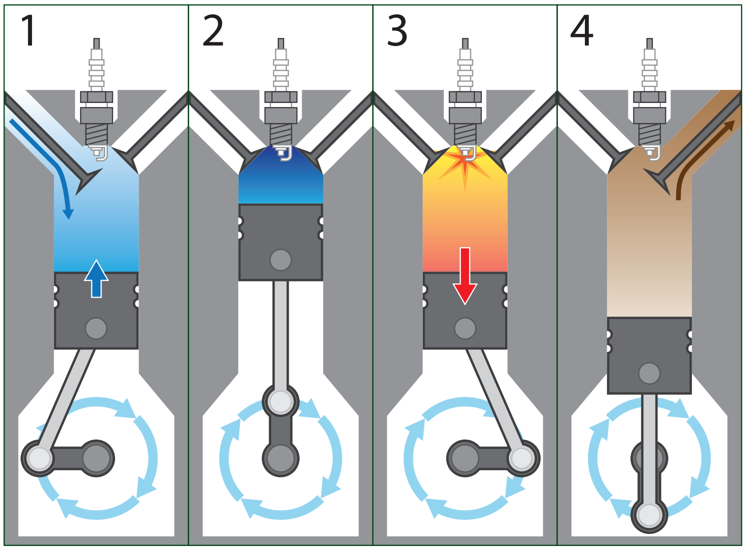
3. What are the products common to all combustion reactions of hydrocarbons?

4. Using your knowledge of gas behavior, what happens to the behavior of gas particles when energy is added to a system? Why?

5. How is energy transferred between molecules at the submicroscopic level?

In a car engine, gasoline combusts when energy, in the form of heat, is added by a spark plug. Gasoline and oxygen will not react unless enough activation energy has been provided to the system by the spark plug. A large amount of thermal energy from the combustion reaction is converted to kinetic energy that pushes a piston. The piston turns a crankshaft and propels the car forward. In order to do work on the macroscopic level, the chemical potential energy of gasoline molecules is converted into thermal and kinetic energy. In this example, we can see how the energy associated with each molecule can be converted into both thermal and kinetic energy.

Four Stroke Cycle



Intake
Air-fuel mixture is drawn in.

Compression
Air-fuel mixture is compressed

Ignition
Explosion forces piston downward

Exhaust
Piston pushes out burned gases

Energy can be transformed, but energy is never created or destroyed. Energy conservation is consistently observed in all systems researched by scientists. From their observations, scientists developed the **First Law of Thermodynamics** (also called the Law of Conservation of Energy). The First Law of Thermodynamics states that energy can be transformed from one form to another, but the total amount of energy available in the entire universe is constant. So, no matter what form energy takes, before or after a transformation, the total amount of energy involved does not change.

6. In your own words, restate the First Law of Thermodynamics.

Activity 2: Demonstrating the First Law of Thermodynamics

Demonstration: *Use Simulation 1, Set 1*

A car's engine is a system composed of different interacting parts. This simulation replicates what happens to the oxygen and fuel inside an engine piston at the submicroscopic level. Octane, a common fuel in cars, is a large hydrocarbon molecule. Butane, a smaller hydrocarbon fuel, is a liquid under pressure. Butane has been substituted for octane in this reaction.

Recall that a system is defined as a bounded environment in which all variables are defined, which are considered independent of the system's surroundings. In the simulation, we define the system to include a piston and all interactions between oxygen molecules and between oxygen molecules and the piston. We exclude everything outside of the piston/air system.

- *Sketch a diagram of the system and record the initial data including labels from the monitors in the chart below at time 0 seconds.*
- *Your teacher will explain how to proceed with the simulation in Activity 3.*

Sketch a submicroscopic representation of the molecules in the simulation. Include the piston.	**Record Data from Monitors**			
	Volume		Temperature	
	Kinetic Energy of Piston		Thermal Energy	
	Chemical Potential Energy		Total Energy of System	
	Time			
	Observations			
Key				

Activity 3: Simulating the First Law of Thermodynamics

Simulation: *Use Simulation 1, Set 1*

- *Working in your small group, using the same simulations as your teacher, push the spark button and allow the simulation to run for 2-3 seconds before pausing. Create a submicroscopic sketch of the system and record data values including labels as you did with your teacher.*
- *Push play for the reaction to continue. Allow the reaction to run for an additional 10-15 seconds before pausing. Create a submicroscopic sketch of the system and record data values including labels.*

<table>
<tr><td rowspan="6">Trial 1</td><td rowspan="6">Sketch a submicroscopic representation of the molecules in the simulation. Include the piston.</td><td colspan="4">Record Data from Monitors</td></tr>
<tr><td>Volume</td><td></td><td>Temperature</td><td></td></tr>
<tr><td>Kinetic Energy of Piston</td><td></td><td>Thermal Energy</td><td></td></tr>
<tr><td>Chemical Potential Energy</td><td></td><td>Total Energy of System</td><td></td></tr>
<tr><td>Time</td><td></td><td colspan="2"></td></tr>
<tr><td colspan="4">Observations</td></tr>
<tr><td rowspan="6">Trial 2</td><td rowspan="6">Sketch a submicroscopic representation of the molecules in the simulation. Include the piston.</td><td colspan="4">Record Data from Monitors</td></tr>
<tr><td>Volume</td><td></td><td>Temperature</td><td></td></tr>
<tr><td>Kinetic Energy of Piston</td><td></td><td>Thermal Energy</td><td></td></tr>
<tr><td>Chemical Potential Energy</td><td></td><td>Total Energy of System</td><td></td></tr>
<tr><td>Time</td><td></td><td colspan="2"></td></tr>
<tr><td colspan="4">Observations</td></tr>
<tr><td colspan="6">Key</td></tr>
</table>

Using data and sketches from activity 2 and 3, circle one answer for each statement.

7. The chemical potential energy of the system changes because the energy is **lost** or **converted.** *(Circle one and support your claim with evidence.)*

8. Explain how the chemical potential, thermal, and kinetic energy changed after the spark was added. *Be sure to explain why the changes occurred (or did not occur) using the submicroscopic level.*

9. As the thermal energy decreased, the kinetic energy of the piston **increased** or **decreased** *(Circle one.).*

10. At what point during the simulation was energy added to the system?

11. If energy is not added to the system what would happen to the reaction?

12. When the thermal energy of the particles decreased, was energy lost? *Explain your answer using the submicroscopic level, and support your claim with evidence.*

13. Does the First Law of Thermodynamics apply to this system? *Support your claim with evidence.*

14. Recall that energy can be transformed from one type into another. Draw a series of pictures representing the piston system to show the transfer of energy from the substances to the piston. Describe the transfer of energy in your diagrams in your own words. Use arrows to represent the flow of energy.

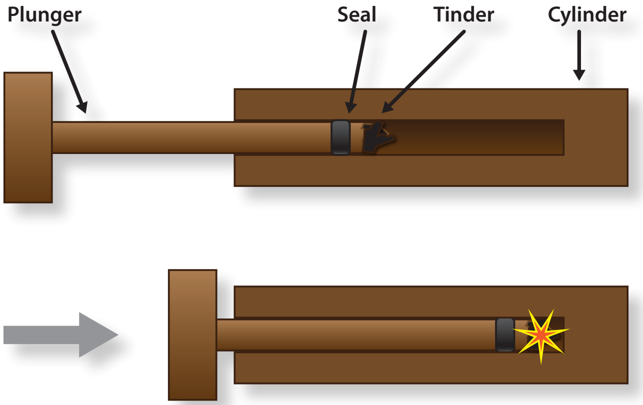
Submicroscopic Drawing
Description
Key

Activity 4: Demonstrating Starting Fire with Air

Demonstration

Before matches and lighters were invented, people used tools such as “fire pistons” to create fire. Early fire pistons, made from hollow animal bones or horns, could be used to generate enough heat to cause tinder (small pieces of flammable material) to catch flame. Using this small flame, people were able to ignite large fires. Modern fire pistons, such as ones used while camping, use this same technology with materials made of metal and wood.

To create a fire piston, a small rod with an airtight circular seal is fitted into a bigger cylinder. The piston generally has a small hole in the bottom into which a piece of *tinder* can be placed. The cylinder is then filled with air, and the piston is pushed down quickly, igniting the dry tinder. The smaller rod can be completely removed from the cylinder, allowing the smoldering tinder to be added to dry leaves to start a fire.



Observe your teacher demonstrate the use of a fire piston.

15. As the piston descends, what happens to the volume of the cylinder?

16. How does decreasing the volume of the cylinder affect the kinetic energy of the gas molecules inside the cylinder? *Support your claim with evidence.*

17. As the kinetic energy of the particles changes, how does the thermal energy of the system change? *Support your claim with evidence.*

18. Sketch a submicroscopic diagram of a fire piston showing how energy is transformed from one form to another. Be sure to include the piston, the air particles, the cylinder, and the tinder in your diagram. Show how energy is conserved according to the First Law of Thermodynamics.

Submicroscopic Drawing
Description
Key

Lesson Reflection Question

19. Explain how the **First Law of Thermodynamics** helps explain **Charles's Law**. Use an example of a balloon filled with a monatomic gas to explain your answer.

Connected Chemistry

Thermodynamics Unit

Lesson 2: Exploring Chemical Potential Energy

Student’s Lesson at a Glance

Lesson Summary

In the Connecting Activity, students explore chemical potential energy through the exploration of fossil fuels, with special attention on gasoline. Students learn that this type of energy differs between fuel types and can be transformed into usable and unusable energy. Following a teacher demonstration of a CCC simulation, students explore how pentane combusts and forms new substances. Students use data collected from the simulation and submicroscopic sketches to answer analysis questions.

SWBAT (Students Will Be Able To)

- Identify what chemical potential energy is and how it is converted into usable and unusable energy
- Identify how chemical potential energy and kinetic energy are related
- Explain the relationship between bond formation and the conversion of energy

Essential Vocabulary

Keep a list of all important words from this lesson. This list, in addition to the lists from other lessons, will make studying easier and improve scientific communication skills. The essential vocabulary from the unit is in bold. Additional words that will expand your scientific vocabulary are in italics.

CCC Reminder

- Students and teachers from many different schools helped designed CCC so that the lessons are more helpful and meaningful for all classroom participants.
- Many questions will ask you “what you think” or “to make predictions.” The only answer that is wrong is the answer that is left blank.
- A chemical bond is an attraction between atoms that allows the formation of substances that contain two or more atoms. Chemical changes that occur are a result of bonds breaking and reforming.
- Use the vocabulary section and note section to take good notes so that studying for tests and quizzes is easier.
- Supporting claims with evidence is not only a skill that scientists use, but a skill that will help you in other classes and everyday life.
- Draw a key when you are sketching. Symbolic keys can help you and others decode your sketches at a later time.
- There is a periodic table and list of common elements used in the back of this book. You will need to refer to the periodic table often.

Notes

Homework

Upcoming Quizzes/Tests

*This page has been left blank.
Please turn to the next page.*

Activity 1: Connecting

Crude oil, a *fossil fuel*, is pumped from the ground and refined to make many other products including gasoline, diesel fuels, and paraffin wax.

1. How else do humans use products made from fossil fuels?

____

____

____

____

The energy of fossil fuels comes from ancient sunlight that prehistoric plants and animals transformed into chemical potential energy they used to survive. Over millions of years, these plants and animals decomposed (via several chemical reactions) into fossil fuels. The high temperatures and pressures deep inside the Earth rearranged the atomic structure of the prehistoric plants and animals to transform them into fossil fuels. This transformation produced molecules with even more chemical potential energy than when the organisms were alive.

Chemical potential energy is a form of potential energy "stored" in the bonds of a chemical compound. Chemical potential energy is similar to potential energy. Potential energy is associated with the fixed position of an object in a gravitational field, like a ball resting on top of a basketball hoop. Chemical potential energy is associated with the fixed position of atoms held together by the attractive and repulsive forces of protons and electrons.

Chemical potential energy can be transformed into other forms of energy (e.g., light, heat) when chemical bonds between atoms form. Conversely, kinetic energy and thermal energy can be transformed into chemical potential energy when chemical bonds between individual atoms break. In fossil fuels, chemical potential energy is converted into kinetic and thermal energy when the atoms in molecules of pentane combust with molecular oxygen to form carbon dioxide and water. As the new bonds form in carbon dioxide and water, kinetic and thermal energy is released.

As fast as they go on the highway, a high performance car can only convert 25% of the chemical potential energy of gasoline into usable kinetic energy. A majority of energy is lost to the environment as unusable thermal energy. The amount of **heat**, represented by the symbol "***q***", that is produced in any reaction depends on the chemical potential energy stored in the substances in the reaction. Different fuels are composed of a variety of compounds with unique amounts of chemical potential energy.

Like car engines, biological organisms convert chemical potential energy of fuels into kinetic energy in order to do work. The most common fuel used by plants and animals is *glucose*, a carbohydrate that living organisms use to provide energy for survival. The chemical formula for glucose is $C_6H_{12}O_6$, and a macroscopic image of liquid glucose is shown in the picture on the right. Like the fossil fuel pentane, glucose is composed of numerous carbon-hydrogen and carbon-carbon bonds. Like the combustion of fossil fuels, glucose combusts to form carbon dioxide and water. As in a car engine, when the new bonds form in carbon dioxide and water, energy is released.

2. Into what energy form(s) does the human body convert the chemical potential energy of sugar? *Support your claims with evidence.*

The body produces energy in a process called cellular respiration that includes the following combustion reaction:

$$C_6H_{12}O_6\,(aq) + 6\ O_2\,(g) \rightarrow 6\ CO_2\,(g) + 6\ H_2O\,(l) + 2800\ \text{kJ heat}$$

3. Draw a potential energy diagram of cellular respiration. *Be sure to label the axes of your diagram.*

4. Does the biological process of respiration follow the Law of Entropy? *Explain your answer.*

5. The combustion of gasoline and glucose reactions both convert chemical potential energy into kinetic energy. 100 calories would be enough for a person on a bicycle to ride three miles; however, driving in a car the same person would only be able to travel 280 feet. Which reaction is more energy efficient? *Support your claim with evidence.*

Activity 2: Demonstrating Chemical Potential Energy

Demonstration: *Use Simulation 4, Set 1*

In a car engine, fuel combusts inside a cylinder. In the ensuing reaction, the formation of new bonds in carbon dioxide and water produces a tremendous amount of energy. The release of chemical potential energy increases the kinetic energy of the gases inside the cylinder. Expansion of these gases pushes the piston, thus the potential energy of the piston is converted into kinetic energy.

- *In the simulation, your teacher will add pentane (a type of liquid fuel) and oxygen gas together and run the simulation for ten seconds. Do not worry if the simulation runs a few seconds over.*
- *Before the simulation starts, sketch a submicroscopic diagram of the system, record your submicroscopic observations, and record the initial data from the monitors in the simulation.*
- *Your teacher will then change the heat level to modify the temperature of the system, start the reaction, and run it for ten seconds. Do not worry if the simulation runs a few seconds over.*
- *Sketch a diagram of the system after pausing the reaction, record your submicroscopic observations, and record the final data from the monitors in the simulation.*

Initial	Sketch a submicroscopic representation of the reaction	Record Data from Monitors		
		Temperature of System		
		Total Energy of System		
		q		
			Chemical Potential Energy	Kinetic Energy
		Pentane		
		Oxygen		
	Explain your drawing, including your symbols	Carbon Dioxide		
		Water		
Heat Level 2	Sketch a submicroscopic representation of the reaction	Record Data from Monitors		
		Temperature of System		
		Total Energy of System		
		q		
			Chemical Potential Energy	Kinetic Energy
		Pentane		
		Oxygen		
	Explain your drawing, including your symbols	Carbon Dioxide		
		Water		
Key				

Activity 3: Simulating Chemical Potential Energy

Simulation: *Use Simulation 4, Set 1*

- *In your small groups, adjust the heat dial to level 5 in the simulation.*
- *Before the simulation starts, sketch a diagram of the system, record your submicroscopic observations and record the initial data from the monitors in the simulation.*
- *Run the simulation for 10 seconds. Do not worry if the simulation runs a few seconds over.*
- *Sketch a diagram of the system and record the data from the monitors in the simulation after pausing.*

<table>
<tr><td rowspan="9">Heat Level 5</td><td rowspan="7">Sketch a submicroscopic representation of the reaction</td><td colspan="3">Record Data from Monitors</td></tr>
<tr><td colspan="2">Temperature of System</td><td></td></tr>
<tr><td colspan="2">Total Energy of System</td><td></td></tr>
<tr><td colspan="2"><i>q</i></td><td></td></tr>
<tr><td colspan="2">Chemical Potential Energy</td><td>Kinetic Energy</td></tr>
<tr><td>Pentane</td><td></td><td></td></tr>
<tr><td>Oxygen</td><td></td><td></td></tr>
<tr><td rowspan="2">Explain your drawing, including your symbols</td><td>Carbon Dioxide</td><td></td><td></td></tr>
<tr><td>Water</td><td></td><td></td></tr>
<tr><td colspan="5">Key</td></tr>
</table>

6. What is the balanced chemical equation for the reaction? *Make sure to include phases.*

7. Why do you have to heat the system to get the reaction to occur? *Support your claim with evidence from the simulation.*

8. Would the products of the combustion reaction have more or less chemical potential energy than the reactants?

9. How can you explain the difference in chemical potential energies between the products and the reactants?

10. Circle one answer for each statement, and support your claim with evidence.

- After combustion, the system became **more ordered** / **less ordered**.
- The entropy of the system **increased** / **decreased**.

Lesson Reflection Questions

11. In a potential energy diagram, the reactions and products have different energies. How is it possible for a reaction to obey the First Law of Thermodynamics when the values differ between products and reactants? *Support your claim with evidence.*

12. The simulation did not have an output for thermal energy. Describe what you think happened to the thermal energy after the heat was added to the system. *Be sure to provide evidence for your answer at the submicroscopic level.*

Connected Chemistry

Thermodynamics Unit

Lesson 3: Enthalpy and Hess's Law

Student's Lesson at a Glance

Lesson Summary

In the Connecting Activity, students are introduced to Hess's Law and enthalpy through the exploration of the chemical reaction found in hand warmers. Students are introduced to the enthalpy of formation as an extension to the role of bonding in the formation of compounds from individual atoms. Following a teacher's example, students learn how to calculate enthalpy values from Hess's Law. Following a teacher demonstration of a reaction in a CCC simulation, students manipulate the simulation to collect data for temperature, entropy, and enthalpy. Students create submicroscopic representations of two reactions, then answer analysis questions. Students determine how position, composition, motion, and molecular interaction affect the enthalpy of the reactions.

SWBAT (Students Will Be Able To)

- Define what enthalpy is and how it is generated
- Define what the enthalpy of formation is
- Define what Hess's Law is and how to calculate values of enthalpy

Essential Vocabulary

Keep a list of all important words from this lesson. This list, in addition to the lists from other lessons, will make studying easier and improve scientific communication skills. The essential vocabulary from the unit is in bold. Additional words that will expand your scientific vocabulary are in italics.

CCC Reminder

- Students and teachers from many different schools helped designed CCC so that the lessons are more helpful and meaningful for all classroom participants.
- The symbol Σ (sigma) means "the sum of."
- Heat and temperature are not the same thing. By adding or removing thermal energy to a system, you are able to change the temperature of the system. Temperature is a macroscopic measurement.
- Use the vocabulary section and note section to take good notes so that studying for tests and quizzes is easier.
- Supporting claims with evidence is not only a skill that scientists use, but a skill that will help you in other classes and everyday life.
- Draw a key when you are sketching. Keys can help you and others decode your sketches at a later time.
- The Δ symbol (delta) is used to mean "change," usually between initial and final values. For example, ΔT = Final temperature - Initial temperature = Change in temperature.

Notes

Homework

Upcoming Quizzes/Tests

Activity 1: Connecting

Hand warmers are frequently used by fans and athletes at sporting events during the late fall and winter. By bending a hand warmer back and forth a few times, the substances inside mix and undergo a physical change that releases thermal energy through heat. In chemistry, thermal energy that is released or absorbed during chemical and physical changes is referred to as enthalpy. **Enthalpy** is represented by the symbol "***H***". The units of measurement for enthalpy are kJ/mol.

Hand warmers contain a supersaturated solution of water and sodium acetate: the water contains many more molecules of sodium acetate than would normally dissolve at room temperature. Bending the hand warmer causes a small disc inside the packet to break, creating a rough surface on which a small solid crystal of sodium acetate forms. Other molecules of sodium acetate collide with this crystal and solidify. This crystallization of the sodium acetate molecules gives off heat.

1. Does every physical change release heat? *Support your claim with evidence from your own experiences.*

____

____

2. Using a combustion reaction (e.g., fuel and oxygen) as an example, what determines how much energy is released?

____

Activity 2: Hess's Law

The "sticks and lines bond model" better helps us understand the relationships between atoms in a compound. It is important to remember that the lines and sticks we use to represent bonds are models just like the computer simulations you have viewed. In reality, a bond is not something physical, but an unseen force between atoms. When any compound forms from the bonding of atoms, a specific amount of heat is released. This heat is called the **heat of formation** (H_f).

When a chemical reaction occurs, heat can be either released or absorbed. This depends on the energy required to break reactant bonds (positive enthalpy) and the energy released by forming bonds between products (negative enthalpy).

Hess's Law states that the total enthalpy of a reaction (ΔH_{rxn}) can be calculated by subtracting the sum of the ΔH of reactant formation from the sum of the ΔH of product formation. Depending on the values of the enthalpies of formation of products and reactants, the total enthalpy of a reaction can be either positive or negative

$$\Delta H_{rxn} = \Sigma \Delta H_{f\ products} - \Sigma \Delta H_{f\ reactants}$$

The symbol Σ (sigma), stands for "the sum of."

With laboratory experiments, chemists have created tables of values for the standard enthalpy of formation (ΔH_f°) for many common compounds. These values are for standard conditions. You can find this table on page 93.

The standard enthalpy of formation is represented as ΔH_f° where the degree symbol denotes the standard conditions (i.e. Pressure = 1 bar, and Temperature = 250°C). The subscript *"f"* stands for formation.

Refer to the table on page 93 in Appendix B as needed to complete the following Activities 3 and 4. While every compound has a unique standard enthalpy of formation on the table, pure elements like H_2 or O_2, are always 0 kJ.

The equation and data below is for standard conditions for the formation of carbon dioxide and was collected from standard enthalpy of formations. For an example of how to calculate Hess's Law using the values from the table, see page 91.

$$\text{C (graphite)} + O_2\text{ (g)} \rightarrow CO_2\text{ (g)}$$

Substance	ΔH_f° kJ/mol
C (graphite)	0
O_2 (g)	0
CO_2 (g)	-393.51

3. Calculate ΔH_{rxn} for the reaction.

Activity 3: Demonstrating Hess's Law

Demonstration: *Use Simulation 7, Set 1*

- *You teacher will demonstrate how Hess's Law works with a simulation. Before the teacher starts the simulation, sketch the initial reactants, record the data from the monitors, and write down your submicroscopic observations.*
- *Your teacher will run the reaction for 30 seconds before pausing it. Create a sketch of the products that have formed after thirty seconds, record data from the monitors, and write down your submicroscopic observations. Do not worry if the simulation runs over a few seconds.*
- *Use your sketches, data, and observations to answer the questions and complete the calculations.*

Initial	**Create a Submicroscopic Sketch of the Simulation**	**Record Data from Monitors**			
		Temperature of System		Entropy of System	
		Enthalpy of Reactant		Enthalpy of Products	
		Moles of Hydrogen Peroxide			
		Record Your Observations			
Time: 30s	**Create a Submicroscopic Sketch of the Simulation**	**Record Data from Monitors**			
		Temperature of System		Entropy of System	
		Enthalpy of Reactant		Enthalpy of Products	
		Moles of Oxygen Gas		Moles of Water Vapor	
		Record Your Observations			
Key					

4. Create a balanced chemical equation for the reaction in the simulation.

5. Show how the enthalpy of the reactants was calculated.

6. Show how the enthalpy of the products was calculated.

7. Calculate the *ΔH* for the reaction using Hess's Law.

8. Do you think the system became more or less ordered after the reaction? *Explain your answer at the submicroscopic level.*

Activity 4: Simulating Hess's Law

Reaction 1: *Use Simulation 7, Set 2*

- *Before starting the simulation, sketch the initial reactants, record the data from the monitors, and write down your observations.*
- *Next, run the reaction for thirty seconds before pausing. Create a sketch of the products, record data from monitors, and write down observations. Do not worry if the simulation runs over a few seconds.*
- *Use your sketches, data, and observations to answer the questions and complete calculations.*

Initial	**Create a Submicroscopic Sketch of the Simulation**	**Record Data from Monitors**			
		Temperature of System		Entropy of System	
		Enthalpy of Reactants		Enthalpy of Products	
		Moles of Propane		Moles of Oxygen Gas	
		Record Your Observations			
Time: 30s	**Create a Submicroscopic Sketch of the Simulation**	**Record Data from Monitors**			
		Temperature of System		Entropy of System	
		Enthalpy of Reactants		Enthalpy of Products	
		Moles of Water Vapor		Moles of Carbon Dioxide Gas	
		Record Your Observations			
Key					

9. Create a balanced chemical equation for the reaction in the simulation.

10. Show how the enthalpy of the reactants was calculated.

11. Show how the enthalpy of the products was calculated.

12. Calculate the *ΔH* for the reaction using Hess's Law.

13. Do you think the system became more or less ordered after the reaction? Explain your answer at the submicroscopic level.

Reaction 2: *Use Simulation 7, Set 3*

Initial	**Create a Submicroscopic Sketch of the Simulation**	**Record Data from Monitors**			
		Temperature of System		Entropy of System	
		Enthalpy of Reactants		Enthalpy of Products	
		Moles of OxygenGas		Moles of Ammonia Gas	
		Record Your Observations			
Time: 30s	**Create a Submicroscopic Sketch of the Simulation**	**Record Data from Monitors**			
		Temperature of System		Entropy of System	
		Enthalpy of Reactants		Enthalpy of Products	
		Moles of Nitric Oxide		Moles of Water Vapor	
		Record Your Observations			
Key					

14. Create a balanced chemical equation for the reaction in the simulation.

15. Show how the enthalpy of the reactants was calculated.

16. Show how the enthalpy of the products was calculated.

17. Calculate the ΔH for the reaction using Hess's Law.

18. Do you think the system became more or less ordered after the reaction? *Explain your answer at the submicroscopic level.*

Lesson Reflection Questions

Consider the previous two reactions. Explain how each submicroscopic observation you noted relates to the enthalpy of the reaction.

19. How does the location of the molecules relate to the enthalpy of the reaction?

20. How does the composition of the molecules relate to the enthalpy of the reaction?

21. How does the motion of the molecules relate to the enthalpy of the reaction?

22. How does the interaction of the molecules relate to the enthalpy of the reaction?

Connected Chemistry

Thermodynamics Unit

Lesson 4: Exothermic and Endothermic Reactions

Student's Lesson at a Glance

Lesson Summary

In the Connecting Activity, students are introduced to exothermic and endothermic reactions through the use of cold packs and hand warmers. Following a teacher demonstration of one reaction using a CCC simulation, students manipulate the heat level in the simulation to collect data. Students make observations and create submicroscopic representations of the reactions. Students calculate the change in enthalpy for the reaction, determine if the entropy of the system has increased or decreased, determine how energy influenced the reaction, and whether the reaction was endothermic or exothermic. In the final activity of the lesson, students are introduced to potential energy diagrams. Students learn what activation energy is and how activation energy relates with transition state. Students compare and contrast the given potential energy diagrams of an exothermic and endothermic reaction. Using the data collected in Activity 2 and 3, students graphically represent the change in potential energy during each of the reactions.

SWBAT (Students Will Be Able To)

- Define endothermic and exothermic reactions
- Identify how energy flows in endothermic and exothermic reactions
- Describe how endothermic and exothermic reactions appear at a submicroscopic level

Essential Vocabulary

Keep a list of all important words from this lesson. This list, in addition to the lists from other lessons, will make studying easier and improve scientific communication skills. The essential vocabulary from the unit is in bold. Additional words that will expand your scientific vocabulary are in italics.

CCC Reminder

- Students and teachers from many different schools helped designed CCC so that the lessons are more helpful and meaningful for all classroom participants.
- Show your work when doing calculations. Include appropriate labels. These practices will make reviewing for tests and checking your work easier.
- Prefixes and suffixes on words can help you discover the meaning of a word.
- Use the vocabulary section and note section to take good notes so that studying for tests and quizzes is easier.
- Supporting claims with evidence is not only a skill that scientists use, but a skill that will help you in other classes and everyday life.
- Draw a key when you are sketching. Symbolic keys can help you and others decode your sketches at a later time.
- There is a periodic table and list of common elements used in the back of this book. You will need to refer to the periodic table often.

Notes

Homework

Upcoming Quizzes/Tests

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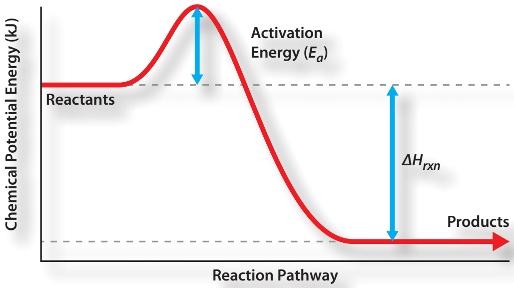
Activity 1: Connecting

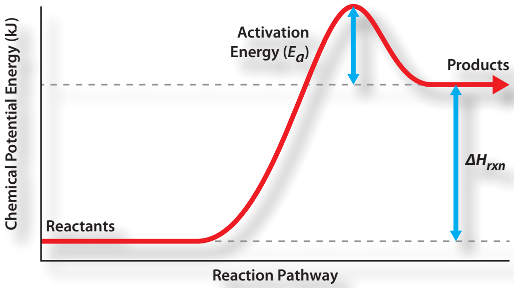
Athletes and trainers often use cold packs to soothe sore muscles and treat sprains. Like hand warmers, cold packs are activated by bending the package. However, unlike hand warmers, cold packs become very cold once activated. Although many reactions release energy to form products, some reactions absorb energy to form products. These reactions, such as the reaction occurring inside cold packs, are examples of an **endothermic** reaction. Reactions such as the one occurring inside the hand warmer are **exothermic** reactions.

1. What does the prefix *exo* mean?

2. What does *thermic* refer to?

In an **exothermic** reaction, like in the hand-warmer or the combustion of fuels, energy is released to the surroundings through the formation of products. In the cold pack reaction, energy is absorbed from the surroundings. When we touch the cold pack, the reaction absorbs heat from our body, which makes us feel cold. When calculating the ΔH_{rxn} for the reaction using Hess's Law, a reaction that has a negative ΔH_{rxn} is exothermic and a reaction that has a positive ΔH_{rxn} is endothermic.





3. Give the potential energy diagrams to the right, explain which is endothermic and which is exothermic. *Provide evidence for your answer. Be sure to include a discussion about bonding in your answer.*

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Activity 2: Graphically Representing the Energy of a Reaction

Part 1

Fuels do not combust with oxygen spontaneously; the reaction requires additional energy from a spark, match, or lighter. **Activation energy** is the additional amount of energy needed by the reaction to move forward. This energy is absorbed by the bonds in the reactants and breaks them into a **transition state**. Bonds are able to be reformed and energy is released.

Potential energy diagrams are useful for showing the flow of energy in a reaction. The diagrams also show the activation energy, represented as the symbol E_a. Since some reactions can move forward and backward, the activation energy has been included for the forward and reverse in the diagram on page 37.

Look at the two potential energy diagrams for a standard exothermic and endothermic reaction. Use them to answer the analysis questions that follow.

4. In the exothermic reaction, how does the potential energy change from reactants to products?

5. In the endothermic reaction, how does the potential energy change from reactants to products?

Circle one from each pair of terms.

6. In the exothermic reaction, heat is **released** or **absorbed.** The ΔH value would be **negative** or **positive**.

7. In the endothermic reaction, heat is **released** or **absorbed**. The ΔH value would be **negative** or **positive**.

8. In the exothermic reaction, the products have a **higher** or **lower** chemical potential energy than the reactants.

9. In the endothermic reaction, products have a **higher** or **lower** chemical potential energy than reactants.

10. Why does the potential energy in the exothermic reaction decrease?

11. Why does the potential energy in the endothermic reaction increase?

12. What is the label "reaction pathway" on the graph referring to?

13. What happens to a reaction is no external energy is supplied to a reaction that has a large activation energy?

14. Dynamite is a highly explosive hydrocarbon; however, it can be transported safely from one location to another. What situations should be avoided while transporting dynamite? Explain why these situations should be avoided based on your knowledge of how combustion reactions occur.

Part 2

Using the data from the three previous simulations from Lesson 3, Activity 4 starting on page 29, graphically represent the change in potential energy during each of the three reactions. Use the diagrams in Activity 1 to help you correctly set up your three graphs. Additional graph paper has been provided on pages 96-97 if needed.

- *Label the change in ΔH on the graph.*
- *Label the axes on the graph.*
- *Connect the points with a line similar to the potential energy graphs in Part 1.*
- *Instead of labeling with the words "products" and "reactants", draw one molecule of each product and reactant on the appropriate place on the line you drew on the graph. Label each molecule with the appropriate chemical formula.*
- *Label the transition state on the graph.*
- *Label where the activation energy is measured on the graph.*
- *Fill in the blanks describing each graph.*

Demonstration

15. This reaction is **endothermic** or **exothermic** *(circle one)*.

16. Energy was **released** or **absorbed** *(circle one)*.

17. The products have **less** or **more** *(circle one)* energy than the reactants.

Reaction 1

18. This reaction is **endothermic** or **exothermic** *(circle one)*.

19. Energy was **released** or **absorbed** *(circle one)*.

20. The products have **less** or **more** *(circle one)* energy than the reactants.

Reaction 2

21. This reaction is **endothermic** or **exothermic** *(circle one)*.

22. Energy was **released** or **absorbed** *(circle one)*.

23. The products have **less** or **more** *(circle one)* energy than the reactants.

Activity 3: Simulating Endothermic and Exothermic Reactions

- *Before starting the simulation, sketch the initial reactants in the submicroscopic system, record the data from the monitors, and write down your observations.*
- *Run the reaction for 15 seconds before pausing it. Do not worry if the simulation runs a few seconds over.*
- *Create a sketch of the products that have formed after 15 seconds, record data from the monitors, and write down your submicroscopic observations.*
- *Use your sketches, data and observations to answer the questions and complete calculations below.*

Reaction 1: *Use Simulation 8, Set 2*

	Create a Submicroscopic Sketch of the Simulation	Record Data from Monitors			
Initial		Temperature of System		Entropy of System	
		Enthalpy of Reactants		Enthalpy of Products	
		Moles of Water		Moles of Bicarbonate Ion	
		Moles of Hydrogen Ion		Moles of Acetate Ion	
		Moles of Sodium Ion		Moles of Carbon Dioxide	
		Record Your Observations			

<table>
<tr><td rowspan="7">Time: 15s</td><td rowspan="7">Create a Submicroscopic Sketch of the Simulation</td><td colspan="4">Record Data from Monitors</td></tr>
<tr><td>Temperature of System</td><td></td><td>Entropy of System</td><td></td></tr>
<tr><td>Enthalpy of Reactants</td><td></td><td>Enthalpy of Products</td><td></td></tr>
<tr><td>Moles of Water</td><td></td><td>Moles of Bicarbonate Ion</td><td></td></tr>
<tr><td>Moles of Hydrogen Ion</td><td></td><td>Moles of Acetate Ion</td><td></td></tr>
<tr><td>Moles of Sodium Ion</td><td></td><td>Moles of Carbon Dioxide</td><td></td></tr>
<tr><td colspan="4">Record Your Observations</td></tr>
<tr><td colspan="6">Key</td></tr>
</table>

1. Create a balanced equation for the reaction. Use Appendix B for enthalpy values.

2. Show how the enthalpy of the reactants was calculated. Use Appendix B for enthalpy values.

3. Show how the enthalpy of the products was calculated.

4. Calculate the ΔH for the reaction using Hess's Law.

5. Did the system become more or less ordered after the reaction? *Support your claim with evidence.*

6. Was this reaction exothermic or endothermic? *Support your claim with two pieces of evidence from the simulation.*

Reaction 2: *Use Simulation 8, Set 3*

- *Create an initial submicroscopic sketch and record data.*
- *Adjust the heat slider to +5, then play the simulation.*
- *Allow the substances to completely react, then pause the simulation to create a submicroscopic sketch and record data from the simulation outputs.*

Initial	**Create a Submicroscopic Sketch of the Simulation**	**Record Data from Monitors**			
		Temperature of System		Entropy of System	
		Enthalpy of Reactants		Enthalpy of Products	
		Moles of Pentane		Moles of Oxygen	
		Record Your Observations			
Time: 15s	**Create a Submicroscopic Sketch of the Simulation**	**Record Data from Monitors**			
		Temperature of System		Entropy of System	
		Enthalpy of Reactants		Enthalpy of Products	
		Moles of Pentane		Moles of Water Vapor	
		Record Your Observations			
Key					

7. Create a balanced equation for the reaction.

8. Show how the enthalpy of the reactants was calculated. Use Appendix B for enthalpy values.

9. Show how the enthalpy of the products was calculated. Use Appendix B for enthalpy values.

10. Calculate the ΔH for the reaction using Hess's Law.

11. Did the system become more or less ordered after the reaction? *Support your claim with evidence.*

12. Was this reaction exothermic or endothermic? *Support your claim with two pieces of evidence from the simulation.*

Activity 4: Capstone Activity

Demonstration: *Use Simulation 8, Set 1*

- *Your teacher will demonstrate how reactions can be classified as endothermic or exothermic with a simulation. Before the teacher starts the simulation, sketch the initial reactants in the submicroscopic system, record the data from the monitors, and write down your observations.*
- *Your teacher will run the reaction for 15 seconds before pausing it. Do not worry if the*

simulation runs a few seconds over.

- *Create a sketch of the products that have formed after 15 seconds, record data from the monitors, and write down your submicroscopic observations. Use your sketches, data and observations to answer the questions and complete calculations below.*

Initial	Create a Submicroscopic Sketch of the Simulation	Record Data from Monitors			
		Temperature of System		Entropy of System	
		Enthalpy of Reactants		Enthalpy of Products	
		Moles of Hydrogen		Moles of Oxygen	
		Record Your Observations			
Time: 15s	Create a Submicroscopic Sketch of the Simulation	Record Data from Monitors			
		Temperature of System		Entropy of System	
		Enthalpy of Reactants		Enthalpy of Products	
		Moles of Water Vapor			
		Record Your Observations			
Key					

1. Create a balanced equation for the reaction.

2. Show how the enthalpy of the reactants was calculated. Use Appendix B for enthalpy values.

Connected Chemistry

Thermodynamics Unit

Lesson 5: Mass, Motion and Energy

Student's Lesson at a Glance

Lesson Summary

This lesson has three activities that demonstrate the relationship between mass, motion, and energy. Following a connecting reading and teacher demonstration of technology, students use a CCC simulation with three gases to determine the relationship between particle mass, particle velocity, and energy. Students conclude the lesson by labeling and analyzing a graphic representation of the average molecular speed of five different gases found in air.

SWBAT (Students Will Be Able To)

- Identify how mass affects the velocity of molecules
- Identify the relationships between mass of molecules, velocity of the molecules, and the energy of molecules in a system

Essential Vocabulary

- Keep a list of all important words from this lesson. This list, in addition to the lists from other lessons, will make studying easier and improve scientific communication skills. The essential vocabulary from the unit is in bold. Additional words that will expand your scientific vocabulary are in italics.

CCC Reminder

- Gas laws and thermodynamics are closely connected. Looking back on concepts and related to gas laws may be helpful in this unit.
- Prefixes and suffixes on words can help you discover the meaning of a word.
- Use the vocabulary section and note section to take good notes so that studying for tests and quizzes is easier.
- Supporting claims with evidence is not only a skill that scientists use, but a skill that will help you in other classes and everyday life.
- Draw a key when you are sketching. Keys can help you and others decode your sketches at a later time.
- Arrows will be helpful in showing both direction and velocity in your submicroscopic sketches.
- There is a periodic table and list of common elements used in the back of this book. You will need to refer to the periodic table often.

Notes

Homework

Upcoming Quizzes/Tests

Activity 1: Connecting

1. Do you think every molecule in a sample of air moves at the same exact velocity? *Support your claim with evidence.*

2. Are the collisions between gas molecules elastic or inelastic? *Be sure to include your own personal definition for the term elastic and how it relates to the submicroscopic level.*

Air is composed of matter; it is a mixture of many types of gases including nitrogen, carbon dioxide, oxygen, argon, and water vapor. These gas molecules are in constant motion. As discussed previously, the velocity of particles is related to the thermal energy in a system. However, thermal energy depends not only the speed of particles, but also on particle mass. Thus, each type of gas in a mixture of air might move with equal velocity, but because they have different masses, they differ in thermal energy.

3. What factors affect the way air molecules move and interact?

4. Does every gas molecule in a sample of air have the same kinetic energy? *Support your claim with evidence.*

5. Consider the picture of the hot air balloon. Are the molecules moving at the same speed inside the balloon as they are on the outside of the balloon?

Activity 2: Demonstrating Mass, Motion, and Energy

Demonstration: *Use Simulation 2, Set 1*

- *Your teacher will start the simulation by adding nitrogen, oxygen, and carbon dioxide to a closed system. These three elements represent some of the gaseous components of air. Temperature is held constant in the simulation.*
- *Using the simulation, create a key and a submicroscopic sketch, gather the required data, and record your observations regarding particle appearance, location, interaction, and motion.*

<table>
<tr><th rowspan="5">Create a submicroscopic sketch of the simulation</th><th colspan="4">Record Data from Monitors</th></tr>
<tr><td>Volume</td><td></td><td>Temperature</td><td></td></tr>
<tr><td>Pressure</td><td></td><td>Total Energy of System</td><td></td></tr>
<tr><td>Mass</td><td></td><td>Total Average Velocity</td><td></td></tr>
<tr><td colspan="4">Record your observations
(appearance, location, interactions, motion)</td></tr>
<tr><th colspan="5">Key</th></tr>
</table>

6. Kinetic energy is calculated with the following equation: $KE = {}^{1}/_{2}\ mV^{2}$. Would you expect the kinetic energy of each type of gas to be the same at constant temperature? Explain why you think your answer is correct.

7. Using data from the simulation, do you think the average velocity of each of the three different gas molecules equal at constant temperature? *Support your claim with evidence.*

Activity 3: Simulating Mass, Motion, and Energy

Simulation: *Use Simulation 2, Set 1*

- *Add nitrogen to the simulation at constant temperature.*
- *Create a key and submicroscopic sketch, gather the required data, and record your observations regarding particle appearance, location, interactions and motion.*
- *Repeat this procedure for oxygen, then for carbon dioxide.*

	Create a Submicroscopic Sketch of the Simulation	**Record Data from Monitors**			
N_2		Volume		Temperature	
		Pressure		Mass	
		Total Energy of System		Total Average Velocity	
		Record Your Observations			

<table>
<tr><td rowspan="5">O_2</td><td rowspan="5">Create a Submicroscopic Sketch of the Simulation</td><td colspan="4">Record Data from Monitors</td></tr>
<tr><td>Volume</td><td></td><td>Temperature</td><td></td></tr>
<tr><td>Pressure</td><td></td><td>Mass</td><td></td></tr>
<tr><td>Total Energy of System</td><td></td><td>Total Average Velocity</td><td></td></tr>
<tr><td colspan="4">Record Your Observations</td></tr>
<tr><td rowspan="5">CO_2</td><td rowspan="5">Create a Submicroscopic Sketch of the Simulation</td><td colspan="4">Record Data from Monitors</td></tr>
<tr><td>Volume</td><td></td><td>Temperature</td><td></td></tr>
<tr><td>Pressure</td><td></td><td>Mass</td><td></td></tr>
<tr><td>Total Energy of System</td><td></td><td>Total Average Velocity</td><td></td></tr>
<tr><td colspan="4">Record Your Observations</td></tr>
<tr><td colspan="6">Key</td></tr>
</table>

8. How does the mass of each gas relate to its average velocity at a constant temperature?

9. Why does the kinetic energy of the system remain constant?

10. Calculate the average kinetic energy of each of the substances. Rank the substances from highest average kinetic energy to lowest average kinetic energy. Recall that $KE = 1/2\ mV^2$. *Support your claim with evidence.*

Lesson Reflection Question

11. As the kinetic energy of the system increases, what other variable(s) change? *Explain why the variables you selected would change.*

Connected Chemistry

Thermodynamics Unit

Lesson 6: Exploring the Second Law

Student's Lesson at a Glance

Lesson Summary

This lesson is composed of four activities. In the Connecting Activity, students are introduced to the Second Law of Thermodynamics, otherwise known as the Law of Entropy. Using a rubber band and a water glass as a demonstration, the process by which chemical potential energy is transformed as ordered systems become disordered is explored. Following the demonstration, students explore from a submicroscopic perspective how chemical potential energy and entropy are related through the Second Law of Thermodynamics. Students use of a CCC simulation of a piston to guide them through this exploration. Students use collected data and their submicroscopic sketches to answer analysis questions. In the final activity, students research and present their answers about four statements on entropy and share evidence to support their claims through a whole-class discussion.

SWBAT (Students Will Be Able To)

- Identify and explain the Second Law of Thermodynamics
- Define entropy and how it applies to systems
- Explain how chemical potential energy and entropy are related

Essential Vocabulary

Keep a list of all important words from this lesson. This list, in addition to the lists from other lessons, will make studying easier and improve scientific communication skills. The essential vocabulary from the unit is in bold. Additional words that will expand your scientific vocabulary are in italics.

CCC Reminder

- Students and teachers from many different schools helped designed CCC so that the lessons are more helpful and meaningful for all classroom participants.
- Many questions ask you "what you think" or "to make predictions." The only answer that is wrong is the answer that is left blank.
- Prefixes and suffixes on words can help you discover the meaning of a word.
- Use the vocabulary section and note section to take good notes so that studying for tests and quizzes is easier.
- Supporting claims with evidence is not only a skill that scientists use, but a skill that will help you in other classes and everyday life.
- Draw a key when you are sketching. Symbolic keys can help you and others decode your sketches at a later time.
- There is a periodic table and list of common elements used in the back of this book. You will need to refer to the periodic table often.

Notes

Homework

Upcoming Quizzes/Tests

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Activity 1: Connecting

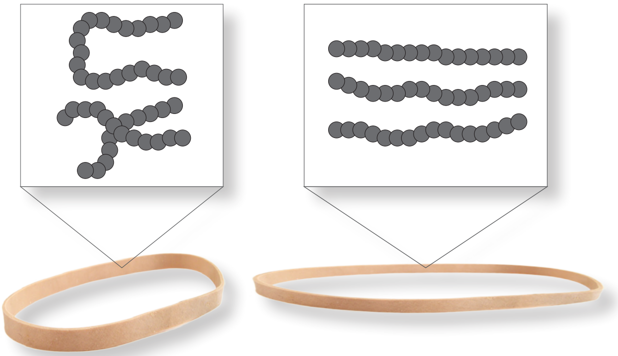
Take a rubber band and stretch it out. Hold it steady.

1. What form(s) of energy is (are) associated with stretching the rubber band?

2. If you release the rubber band, what energy is transformed into what other energy?

The **Second Law of Thermodynamics** states that the potential energy of a system will always decrease after an energy transformation occurs. As the potential energy of a system decreases, the system often becomes more disordered. The process of moving from an ordered to a disordered state is called **entropy** (represented with the symbol *S*). Entropy is measured in units of Joules per kilogram per Kelvin (J/kg•K).

The Second Law of Thermodynamics is also known as the **Law of Entropy.** In a spontaneous transformation, energy is always transformed from an ordered state to an unordered and chaotic state. For example, the rubber molecules in a stretched rubber band are aligned side-by-side in an ordered state. When you release the rubber band, it snaps back into place as the rubber molecules return to a disordered state.



The picture to the right shows rubber molecules in both an unstretched and stretched rubber band. The rubber band's molecules are mainly composed of carbon atoms lined up in chains. Carbon is shown as black atoms; other molecules, such as hydrogen and sulfur, are not shown.

3. According to what you just read, is the potential energy of the rubber band higher when it is stretched or unstretched? *Support your claim with evidence, and sketch a potential energy diagram for each example. Be sure to label the axes on the diagrams.*

To further understand entropy, think about a water glass on the submicroscopic level. The water glass is composed of a very specific arrangement of molecules that are ordered together into one single shape. If the water glass is smashed and breaks into hundreds of tiny pieces, its molecules become divided by a physical process into disordered pieces of many different shapes and sizes. Although the glass pieces are still made of the same compounds, the system has become more disordered.

4. In the smashing the glass example, what do you think has happened to the entropy of the glass? *Support your claim with evidence.*

5. Are particles in a solid more or less ordered than particles in a liquid? *Explain your answer.*

Activity 2: Demonstrating the Second Law

Demonstration: *Use Simulation 3, Set 1*

- Your teacher will display a simulation representing part of the system inside a car engine. In this activity, you will look specifically at how chemical potential energy and entropy change in the system according to the Second Law of Thermodynamics.
- *Sketch a diagram of the system and record the initial data including labels from the monitors in the chart below at time 0.*
- *Your teacher will explain how to proceed with the simulation in Activity 3.*

<table>
<tr><th>Create a submicroscopic sketch of the simulation</th><th colspan="4">Record Data from Monitors</th></tr>
<tr><td rowspan="4"></td><td>Volume</td><td></td><td>Temperature</td><td></td></tr>
<tr><td><i>KE</i> of Piston</td><td></td><td>Thermal Energy</td><td></td></tr>
<tr><td>Chemical Potential Energy</td><td></td><td>Entropy of System</td><td></td></tr>
<tr><td colspan="4">Create a written explanation of your drawing including what the symbols in your drawing mean</td></tr>
<tr><td colspan="5">Key</td></tr>
</table>

Activity 3: Simulating the Second Law

Simulation: *Use Simulation 3. Set 1*

- *Working in your small group, use the same simulations as your teacher. Begin by pushing the spark button and allow the simulation to run for 2-3 seconds before pausing. Create a submicroscopic sketch of the system and record data values, including labels, as you did with your teacher.*
- *Push play for the reaction to continue. Allow the reaction to run for an additional 10-15 seconds before pausing. Create a submicroscopic sketch of the system and record data values including labels.*

Observation 1	Sketch a submicroscopic representation of the molecules in the simulation. Include the piston	Record Data from Monitors			
		Volume		Temperature	
		KE of Piston		Thermal Energy	
		Chemical Potential Energy		Entropy of System	
		Time			
		Create a written explanation of your drawing including what the symbols in your drawing mean			
Observation 2	Sketch a submicroscopic representation of the molecules in the simulation. Include the piston	Record Data from Monitors			
		Volume		Temperature	
		KE of Piston		Thermal Energy	
		Chemical Potential Energy		Entropy of System	
		Time			
		Create a written explanation of your drawing including what the symbols in your drawing mean			
Key					

1. As the volume of the system changed, how did the kinetic energy of the piston change while moving? *Support your claim with evidence.*

2. As the kinetic energy of the piston changed, how did the entropy of the system change? *Support your claim with evidence.*

3. Using your observations from each trial and the information in the paragraph above, explain how the total entropy of the system changes as the piston is pushed up.

4. Why does the piston move after the spark is introduced?

Activity 4: Teacher Facilitated Discussion

Read the following statements and decide if they are true or false. Be ready to share your answers with your class and support your claims with evidence.

Circle your answer and support your claim with evidence.

1. The total entropy of a living organism increases over the lifespan of an organism.
   True or **False**

2. Cleaning up a messy room violates the Second Law of Thermodynamics.
   True or **False**

3. When a car stops moving because it is out of fuel, all of the energy associated with the fuel has been destroyed. **True** or **False**

4. Kinetic energy is always the same as thermal energy.
   True or **False**

Connected Chemistry

Thermodynamics Unit

Lesson 7: Exploring Factors that Affect Entropy

Student's Lesson at a Glance

Lesson Summary

In the Connecting Activity, students recall factors that affect gas behavior and how these same factors will affect entropy. Students are introduced to the idea of how these factors influence a system through an analogy with a game of billiards (pool). Students make predictions about how phase changes, temperature, volume, and the complexity of molecules will affect entropy. Students apply knowledge of phase changes to predict the order of increasing entropy for solids, liquids, gases, and aqueous solutions. Using the CCC simulation, teachers simulate how water molecules in solid ice change over time. Students use data collected from the simulation and their submicroscopic sketches to answer analysis questions. Using the same simulation, students collect data from adding liquid water, adjusting the heat level, adding oxygen gas, and adjusting volume. In the activity, five students explore the complexity of molecules, create sketches, and gather data as their teacher adds one of substance at a time to the simulation. In the final activity, students consider what bonds really are and how they are modeled. The activity concludes with an exploration of the fossil fuel pentane and its isomers.

SWBAT (Students Will Be Able To)

- Identify the factors that affect entropy
- Identify how each of the factors increase or decrease entropy
- Identify and explain the relationship between bonding and entropy

Essential Vocabulary

Keep a list of all important words from this lesson. This list, in addition to the lists from other lessons, will make studying easier and improve scientific communication skills. The essential vocabulary from the unit is in bold. Additional words that will expand your scientific vocabulary are in italics.

CCC Reminder

- Students and teachers from many different schools helped designed CCC so that the lessons are more helpful and meaningful for all classroom participants.
- Many questions will ask you "what you think" or "to make predictions." The only answer that is wrong is the answer that is left blank.
- A chemical bond is an attraction between atoms that allows the formation of substances that contain two or more atoms. Chemical changes that occur are a result of bonds breaking and reforming.
- Use the vocabulary section and note section to take good notes so that studying for tests and quizzes is easier.
- Supporting claims with evidence is not only a skill that scientists use, but a skill that will help you in other classes and everyday life.
- Draw a key when you are sketching. Symbolic keys can help you and others decode your sketches at a later time.
- Gas laws and thermodynamics are closely connected. Looking back on previous concepts and notes you took from gas laws may be helpful in this unit.

Notes

Homework

Upcoming Quizzes/Tests

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Activity 1: Connecting

1. What do you think is the relationship between the states of matter and entropy?

Playing billiards (pool) involves a system, defined as a pool table and fifteen billiard balls, which goes from an ordered state to a disordered state. To start the game, the billiard balls are racked together in an ordered triangle pattern in one single location on the table. The white cue ball is driven into the billiard balls, which causes them to bounce into each other and scatter across the table. After "the break," the system becomes disordered; the high-speed cue stick introduces kinetic energy, ultimately coming from the muscles of the pool player, into the system. The energy of the pool balls, table, pool stick, and player have undergone a change and the entropy of the system has increased.

Other factors beside kinetic energy can cause a change in system entropy. When learning about gas behavior, you explored how temperature, volume, pressure, and the number of gas particles in a system could affect the behavior of particles. In the following lesson, you will explore how these factors, among others, cause changes in entropy.

2. What objects or materials make up the system in the game of pool?

3. In a game of pool, pool balls at rest are an example of what type of energy?

4. When pool balls are in motion, what type of energy is this?

5. Even though pool balls can be reordered over and over, how can the total system and surroundings obey the Second Law of Thermodynamics? *Please explain your answer.*

6. Considering what you already know about matter and energy, make predictions in the table below, about how each process or factor results in an entropic change. Make sure to support your selection with your reasoning.

Process or Factor	Increase or Decrease Entropy (select one); Support your selection with reasoning
A solid becoming a gas	
Temperature of a liquid increasing	
Volume of a gas decreasing	
Molecule complexity increasing	

Complexity is defined here as the number of atoms a molecule has, the bonds the molecule contains, the position and arrangement of the atoms, and how the bonds move.

Activity 2: Demonstrating Phase Change and Entropy

Demonstration: *Use Simulation 5, Set 1*

The location and behavior of molecules changes as state changes occur. This knowledge allows you to apply the Laws of Thermodynamics to understand how energy is transformed during state changes. Taken together, the First and Second Laws of Thermodynamics state that during a state change (e.g., solid to liquid) the total energy of a system is conserved and the total chemical potential energy of the system decreases with a simultaneous increase in the entropy of the system.

7. Consider the following statement: "All matter moves towards greater entropy." Predict the order of the phases of water according to increasing entropies, from the most ordered to least ordered. *Support your claim with evidence from what you already know about each phase.*

8. Where would an aqueous solution be placed in the order of entropies you just completed above? Why?

- *In the following simulation, your teacher will demonstrate how water molecules of solid ice change over time in a system at room temperature. None of the other variables will be manipulated.*
- *Create a submicroscopic sketch of the system, record data from the available monitors, and write down your submicroscopic observations at time 0 s, 5 s, and 15 s.*
- *The teacher will pause the simulation at each time point.*

0 Seconds	**Sketch a submicroscopic representation of the water**	**Record Data from Monitors**			
		Temperature of the System		Entropy of Water	
		Create a written explanation of your drawing including what the symbols in your drawing mean.			
5 Seconds	**Sketch a submicroscopic representation of the water**	**Record Data from Monitors**			
		Temperature of the System		Entropy of Water	
		Create a written explanation of your drawing including what the symbols in your drawing mean.			
15 Seconds	**Sketch a submicroscopic representation of the water**	**Record Data from Monitors**			
		Temperature of the System		Entropy of Water	
		Create a written explanation of your drawing including what the symbols in your drawing mean.			

Key

9. How did the energy change over time? *Be sure to describe how it relates to the states of matter at the submicroscopic level.*

10. Was energy transferred from the water to the chlorine gas or from the chlorine gas to the ice? *Support your claim with evidence.*

11. In your own words, describe the relationship between state change and entropy. *Be sure to use evidence from the simulation to support your claim.*

12. How do molecules behave when there is less entropy?

13. How do molecules behave when there is more entropy?

Activity 3: Simulating Temperature and Entropy

Simulation: *Use Simulation 5, Set 2*

- *Using the previous simulation, add liquid water.*
- *Adjust the heat dial to level one and allow the simulation to run for ten seconds. Do not adjust any other variables in the interface.*
- *Create a submicroscopic sketch of the system, record data from the monitors, and write down your submicroscopic observations.*
- *Conduct two more trials with the heat dial set to levels 2 and 3.*

Heat Level 1	**Sketch a submicroscopic representation of the water**	**Record Data from Monitors**			
		Temperature of the System		Entropy of Water	
		Create a written explanation of your drawing including what the symbols in your drawing mean			
Heat Level 2	**Sketch a submicroscopic representation of the water**	**Record Data from Monitors**			
		Temperature of the System		Entropy of Water	
		Create a written explanation of your drawing including what the symbols in your drawing mean			

<table>
<tr><td rowspan="3">Heat Level 3</td><td rowspan="3">Sketch a submicroscopic representation of the water</td><td colspan="4">Record Data from Monitors</td></tr>
<tr><td>Temperature of the System</td><td></td><td>Entropy of Water</td><td></td></tr>
<tr><td colspan="4">Create a written explanation of your drawing including what the symbols in your drawing mean</td></tr>
<tr><td colspan="6">Key</td></tr>
<tr><td colspan="6"></td></tr>
</table>

14. At what temperature was entropy the greatest? At what temperature was entropy the least?

15. Because entropy changes, would you expect the potential energy of water to change? *Support your claim with evidence.*

16. In your own words, describe the relationship between temperature and entropy.

17. Based on how molecules behave at the submicroscopic level, why does entropy increase with the addition of more energy? How is this similar and different from how billiard balls move in a game of billiards (pool)?

Activity 4: Simulating Volume and Entropy

Simulation: *Use Simulation 5, Set 3*

- *The system in this simulation is an **isobaric** and **isothermic** system, meaning it has a constant pressure and a constant temperature.*
- *Create a submicroscopic sketch of the system, record data from the monitors, and write down submicroscopic observations.*
- *Conduct three trials by adjusting the decreasing volume of the container.*
- *Create a submicroscopic sketch of the system, record data from the monitors, and write down submicroscopic observations for each trial.*

Trial 1	**Sketch a submicroscopic representation of the oxygen**	**Record Data from Monitors**			
		Volume of the Oxygen		Entropy of the Oxygen	
		Create a written explanation of your drawing including what the symbols in your drawing mean			
Trial 2	**Sketch a submicroscopic representation of the oxygen**	**Record Data from Monitors**			
		Volume of the Oxygen		Entropy of the Oxygen	
		Create a written explanation of your drawing including what the symbols in your drawing mean			

	Sketch a submicroscopic representation of the oxygen	Record Data from Monitors			
Trial 3		Volume of the Oxygen		Entropy of the Oxygen	
		Create a written explanation of your drawing including what the symbols in your drawing mean			
Key					

18. At what volume was the entropy of the gas the greatest? At what volume was the entropy of the gas the least?

19. In your own words, describe the relationship between volume of a gas in the container and entropy.

20. Based on how the molecules behave, why does entropy change as volume changes?

Activity 5: Demonstrating Molecule Complexity and Entropy

Use Simulation 6, Sets 1-8

- *Your teacher will add several different substances one at a time to the simulation. Your teacher will not adjust any other variables.*
- *Create a submicroscopic sketch, write the chemical formula, record data from the monitors, and write down observations for each new substance*

H_2 Hydrogen Gas	Sketch a submicroscopic representation of fuel	Entropy of Substance	
		Explain your drawing, including your symbols	
CH_4 Methane Gas	Sketch a submicroscopic representation of fuel	Entropy of Substance	
		Explain your drawing, including your symbols	
H_2O Water Vapor	Sketch a submicroscopic representation of fuel	Entropy of Substance	
		Explain your drawing, including your symbols	
H_2O Liquid Water	Sketch a submicroscopic representation of fuel	Entropy of Substance	
		Explain your drawing, including your symbols	

H_2O Ice	Sketch a submicroscopic representation of fuel	Entropy of Substance	
		Explain your drawing, including your symbols	
CO_2 Carbon Dioxide	Sketch a submicroscopic representation of fuel	Entropy of Substance	
		Explain your drawing, including your symbols	
C_3H_8 Propane	Sketch a submicroscopic representation of fuel	Entropy of Substance	
		Explain your drawing, including your symbols	
C_5H_{12} Pentane	Sketch a submicroscopic representation of fuel	Entropy of Substance	
		Explain your drawing, including your symbols	
Key			

21. Compare and contrast liquid water, water vapor, and ice. How can you account for differences in entropy?

22. Compare and contrast the three fossil fuels propane, methane, and pentane. How can you account for differences in entropy?

23. Considering the structure of water and carbon dioxide, what do you think gives these molecules different entropy values?

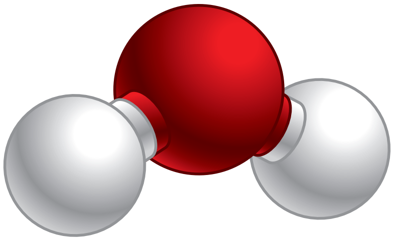
Activity 6: Ideas to Consider - Unseen Bonds

The force that holds a molecule together is known as a bond. This force can stretch, bend, and vibrate without breaking. In describing a complex molecule, we consider the number of atoms a molecule possesses, the location and position of the molecule, the bonds the molecule contains, and how these bonds vibrate.

24. As the molecules in the table in Activity 5 transitioned from simple to more complex, how did the relative entropy of the molecules compare?

25. As the bending, stretching, and vibration of bonds increases, the entropy of a substance **increases** or **decreases**. *Circle one, and support your claim with evidence.*

26. Look at the animation of water molecules your teacher is running. How are bonds represented? Describe the motion of the bonds in the animation. Be as specific as possible.



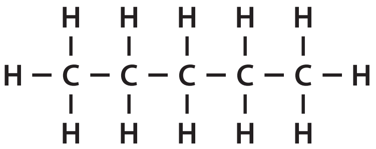
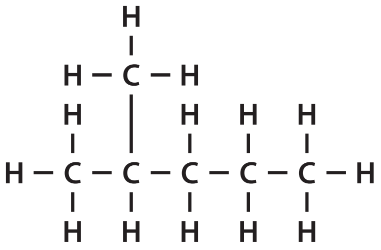
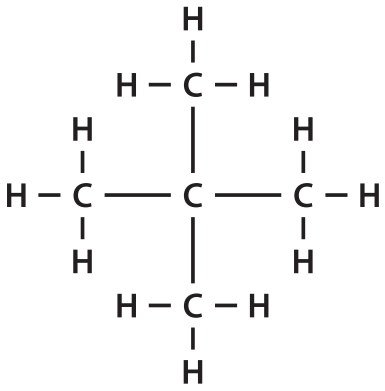
27. How could this way of representing bonds create problems with understanding what bonds really are and how they behave?

28. Consider the CCC representation of a water molecule. How does the Connected Chemistry Curriculum water molecule differ from the ones in the animation?

29. How does what we know about the attraction of subatomic particles help to explain the motion you described in question 26?

Some substances can form **isomers**. An isomer is a compound that has the same number of atoms, but has different atomic arrangements. Even though the substances possess the same number and type of atoms, the isomers can possess different chemical and physical properties.

Isomers of Pentane

pentane	methylbutane	dimethylpropane
		

30. Which isomer is the most flexible and easy to bend? Why?

31. Based on what you have learned about bonds, which isomer is the least flexible and more difficult to bend? Why?

32. Based on your answers for Questions 30 and 31, order the three isomers from greatest entropy to least entropy.

Lesson Reflection Question

33. How are the **First Law of Thermodynamics** and the **Second Law of Thermodynamics** related?

Connected Chemistry

Thermodynamics Unit

Lesson 8: Gibb's Free Energy

Student's Lesson at a Glance

Lesson Summary

Students are introduced to the concept of Gibbs free energy through the continuation of the shattered water glass example from Lesson 2. Students explore the three ways that reactions can progress and how the mathematical calculation of enthalpy and entropy allow a chemist to determine the free energy available. In the final activity, students explore the difference between a spontaneous and non-spontaneous reaction. The connection between free energy and spontaneity is established by students determining the change in free energy for the reactions in Lesson 5 - Activity 2-3. Students test their knowledge gained from the Gibbs activities using an analogy of a ball on a hill.

SWBAT (Students Will Be Able To)

- Define what free energy is and how to calculate it
- Identify how Gibbs free energy and the spontaneity of a reaction are related

Essential Vocabulary

Keep a list of all important words from this lesson. This list, in addition to the lists from other lessons, will make studying easier and improve scientific communication skills. The essential vocabulary from the unit is in bold. Additional words that will expand your scientific vocabulary are in italics.

CCC Reminder

- Students and teachers from many different schools helped designed CCC so that the lessons are more helpful and meaningful for all classroom participants.
- Many questions will ask you "what you think" or "to make predictions." The only answer that is wrong is the answer that is left blank.
- Recall that entropy in a system is always increasing.
- Chemistry and physics are closely related. Researchers from both fields view "work" as a measured value resulting from some form of energy transfer. Work comes in two categories: non-mechanical work and mechanical work. In this lesson you will be introduced to the concept of non-mechanical work. Examples of non-mechanical work include chemical work and electrical work.

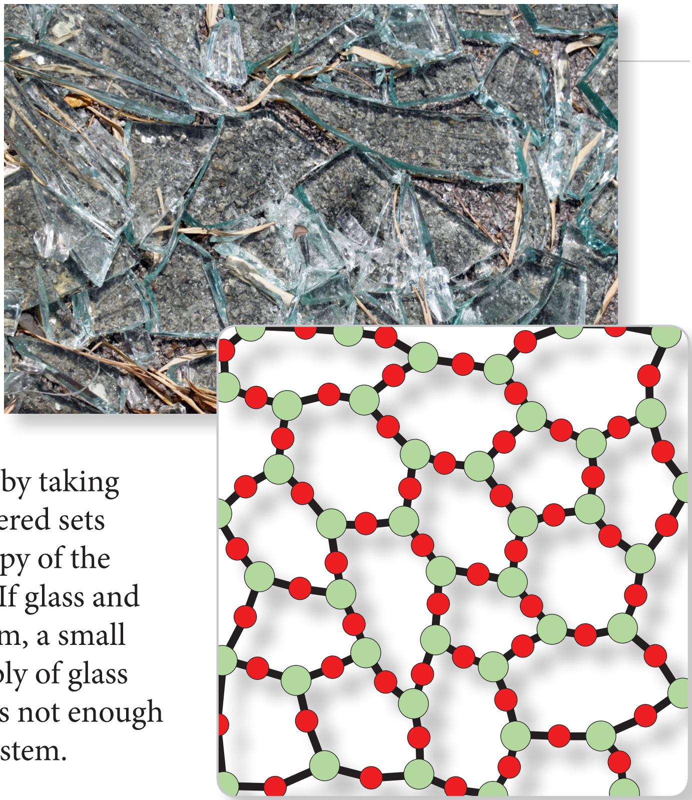
- Use the vocabulary section and note section to take good notes so that studying for tests and quizzes is easier.
- Supporting claims with evidence is not only a skill that scientists use, but a skill that will help you in other classes and everyday life.
- Draw a key when you are sketching. Symbolic keys can help you and others decode your sketches at a later time.
- There is a periodic table and list of common elements used in the back of this book. You will need to refer to the periodic table often.

Notes

Homework

Upcoming Quizzes/Tests

Activity 1: Connecting



Consider the following statement: a piece of shattered glass can never reform into the original glass. Some people may disagree with this statement because with enough time, superglue, and human effort, the glass might be reassembled. The problem is that the person putting the glass together is also contributing to a change in entropy. We increase entropy through the use of energy from the food we eat. Our bodies reduce entropy by taking the energy from food and building new ordered sets of cells. Over time, the total change in entropy of the body always increases and never decreases. If glass and human beings are regarded as a whole system, a small reduction in disorder - such as the reassembly of glass and the development of new human cells - is not enough to change the overall total disorder of the system.

1. Regarding entropy, how is burning a piece of paper similar to shattering a glass?

Glass is made from different types of molecules that are fused together at high temperatures into a solid. Most solids have orderly atomic arrangement, but glass has a random pattern. When glass shatters, energy is absorbed as the intermolecular bonds break between the glass molecules. This means that the enthalpy of the glass has also changed. The glass has moved from a higher state of enthalpy (whole piece of glass) to a lower state of enthalpy (shattered glass).

2. How are burning paper and glass breaking dissimilar?

By combining the values of enthalpy and entropy, we can determine if a reaction will *spontaneously* move forward from reactants to products. Spontaneous reactions move forward without any energy input from its surroundings. Scientists have discovered that reactions which reduce enthalpy while increasing entropy spontaneously move forward. On the other hand, reactions which increase enthalpy while reducing entropy not spontaneously move forward. In 1875, a scientist named Josiah Gibbs proposed a theory to balance these two important concepts of thermodynamics. **Gibbs free energy** is defined as the capacity of a system to do non-mechanical work. In most reactions, this work occurs in the form of heat. "***G***", the symbol that represents Gibbs free energy, is the measure of the non-mechanical work done on a system. Gibbs' theory is represented by the following equation

$$\Delta G = \Delta H - T\Delta S$$

3. Do you think that free energy can be directly measured, such as the value of temperature? *Support your claim with evidence.*

Activity 2: Determining Spontaneity of Reactions

Reactions can be classified as spontaneous or non-spontaneous. A **spontaneous** process releases free energy. A **non-spontaneous** process only happens when outside action on the system introduces energy to drive the process. For instance, emergency ice packs used to treat sports injuries involve a non-spontaneous reaction that takes energy from the surroundings in order to generate the cold-feeling pack. A non-spontaneous process absorbs free energy. When ΔG is negative, a process or chemical reaction proceeds spontaneously in the forward direction. When ΔG is positive, the process proceeds spontaneously in reverse.

In Lesson 5, Activity 2-3 you collected data from three reactions. For each reaction calculate the ΔG using the data. Show work in the space provided. Using your calculations, determine if the process is spontaneous or non-spontaneous based on the value of ΔG. Circle one word from each pair of terms. Recall that ΔG is calculated with the following equation:

$$\Delta G = \Delta H - T\Delta S$$

4. Calculate ΔG for using data collected from the teacher demonstration in Lesson 7 on page 69. *Show your work in the space below.*

5. The reaction in the teacher's demonstration is **spontaneous** or **non-spontaneous**.

6. Calculate ΔG for using data collected from Lesson 7, Activity 3, Reaction 1 on page 72. *Show your work in the space below.*

7. Reaction 1 is **spontaneous** or **non-spontaneous**

8. A spontaneous reaction would **increase** or **decrease** entropy. *Support your answer with evidence.*

9. If ΔG for a given reaction is equal to zero, what do you think would happen when the two reactants combine?

10. A rusting nail is an example of a **spontaneous** or **non-spontaneous** reaction. *Support your answer with evidence.*

11. When combining ammonium nitrate and water in a beaker, the beaker feels cold to the touch. The dissociation taking place in the beaker is an example of a **spontaneous** or **non-spontaneous** process. *Support your answer with evidence.*

12. When making inexpensive jewelry, zinc is often coated with silver or gold through a process called electroplating. Zinc metal is placed in an aqueous solution of silver or gold. An electrical current must be passed through the solution for the redox reaction to occur. The reaction that is taking place is an example of an **spontaneous** or **non-spontaneous** reaction. *Support your answer with evidence.*

Lesson Reflection Questions

13. If a reaction has reached equilibrium, what will the ΔG be for the reaction? Explain your answer.

14. If a reaction is spontaneous, does that mean that the reaction will occur quickly? Provide evidence for your answer.

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Connected Chemistry

Thermodynamics Unit

Lesson 9: Applying Thermodynamics

Student's Lesson at a Glance

Lesson Summary

This lesson is a lab that helps students apply the concept of thermodynamics in a real-world setting. The objective of the lab is to calculate the energy available in selected food items using the calorimetry process. First, in a brief introduction to calorimetry, students are asked to perform a calorimetry experiment on the food items that have been either self-selected or teacher-selected. Specific heat is introduced as a critical component of the lab calculations. Students complete an analysis of the lab that helps to tie together concepts from the thermodynamics unit.

SWBAT (Students Will Be Able To)

- Define the purpose of calorimetry and how it applies to thermodynamics
- Use the scientific method to determine the energy value of selected foods

Essential Vocabulary

Keep a list of all important words from this lesson. This list, in addition to the lists from other lessons, will make studying easier and improve scientific communication skills. The essential vocabulary from the unit is in bold. Additional words that will expand your scientific vocabulary are in italics.

CCC Reminder

- Students and teachers from many different schools helped designed CCC so that the lessons are more helpful and meaningful for all classroom participants.
- Many questions will ask you "what you think" or "to make predictions." The only answer that is wrong is the answer that is left blank.
- Follow lab safety techniques carefully. Inform your teacher if you have any health concerns - such as food allergies or asthma - that may impact your ability to complete the lab.
- Take good notes during your lab to ensure you are able to create a quality lab write-up.
- Use the vocabulary section and note section to take good notes so that studying for tests and quizzes is easier.
- Supporting claims with evidence is not only a skill that scientists use, but a skill that will help you in other classes and everyday life.
- Draw a key when you are sketching. Symbolic keys can help you and others decode your sketches at a later time.
- There is a periodic table and list of common elements used in the back of this book. You will need to refer to the periodic table often.

Notes

Homework

Upcoming Quizzes/Tests

Activity 1: Wet Lab - Calorimetry

Inside your body, a chemical reaction similar to combustion produces the energy your cells need to function. The following lab will help you make connections between thermodynamics and how your body gets the energy it needs to survive.

All foods contain stored energy. The amount of potential energy stored varies depending on the type of food. Athletes may eat high energy foods - such as pasta - to make sure they are ready for the demands of competition. Not all of the stored energy is converted into kinetic energy. As we move, our bodies also produce thermal energy, which is why our body temperature increases. Our bodies convert stored energy in food, known as calories, into chemical energy that allows us to do work. This energy conversion process is called cellular respiration and involves the transformation of chemical potential energy into thermal and kinetic energy.

Combustion reactions are similar to cellular respiration in the body. The similarities include the need for oxygen and sugar (in the form of glucose) as reactants and the production of carbon dioxide and heat as products. A **calorie** is the amount of energy required to raise the temperature of 1 gram (g) of water 1 degree Celsius (°C). The density of water is 1 gram per milliliter (1.00 g/mL); therefore, 1 gram of water is equal to 1 milliliter of water. Caloric values of food are measured in kilocalories (kcal or Calories). There are 1000 calories in a 1 kilocalorie (1 **Calorie**). A food item that is listed as having 90 Calories actually has 90,000 calories. Calories are a way to measure the energy received from the food you eat.

In this wet lab, you will indirectly measure the amount of calories in several food items using a calorimeter. A **calorimeter** is a device that measures the heat generated by a chemical reaction, change of state, or formation of a solution. We will be using a homemade calorimeter that works similarly to a professional calorimeter. A particular food item will be ignited, the calorimeter will trap the heat of the burning food, and the water above will absorb the heat. This heat will cause the temperature (T) of the water to increase. By measuring the change in temperature (ΔT) of a known volume of water, you will be able to calculate the amount of energy in the food tested.

The **specific heat** of water is 1 calorie/gram°C = 4.186 Joule/gram °C which is greater than any other common substance. The specific heat, represented by the symbol "c", is the amount of heat per unit mass required to raise the temperature by one degree Celsius. As a result, water plays a very important role in temperature regulation in biological processes like protein folding.

Sample Calculation

Methane gas is a small hydrocarbon fossil fuel which combusts when oxygen and a spark are added. The balanced equation for the combustion of methane and oxygen is

$$CH_4\ (g) + 2\ O_2\ (g) \rightarrow CO_2\ (g) + 2\ H_2O\ \ (l)$$

1. Look at table in "Appendix B: Enthalpy Data" on page 93 for enthalpy values.

$$\Delta H_f^\circ\ CH_4\ (g) = -\ 74.81\ kJ/mol$$

$$\Delta H_f^\circ \text{ of } O_2\ (g) = 0\ kJ/mol \text{ (recall that pure oxygen is a diatomic element)}$$

$$\Delta H_f^\circ \text{ of } CO_2\ (g) = -\ 393.\ 509\ kJ/mol$$

$$\Delta H_f^\circ \text{ of } H_2O\ (l) = -285.\ 83\ kJ/mol$$

2. Make sure the equation is balanced and multiply by the coefficients. Sum the products and reactants separately.

Products

$$\Sigma\Delta H_{f\,products} = \Delta H_f \text{ of } CO_2\ (g) + \Delta H_f \text{ of } H_2O\ (l)$$

$$\Delta H_f \text{ of } CO_2\ (g) = \Delta H_f^\circ \text{ of } CO_2\ (g) \times 1 \text{ mol of } CO_2\ (g) = -393.\ 509\ kJ/mol \times 1 \text{ mol } CO_2(g)$$

$$= -393.509\ kJ$$

$$\Delta H_f \text{ of } H_2O\ (l) = \Delta H_f^\circ \text{ of } H_2O\ (l) \times 2 \text{ mol of } H_2O\ (l) = -285.\ 83\ kJ/mol \times 2 \text{ mol } H_2O\ (l)$$

$$= -\ 571.66\ kJ$$

$$\Sigma\Delta H_{f\,products} = -393.509\ kJ + (-571.66\ kJ) = -965.17\ kJ$$

Reactants

$$\Sigma \Delta H_{f\ reactants} = \Delta H_f \text{ of } CH_4\text{ (g)} + \Delta H_f^o \text{ of } O_2\text{ (g)}$$

$$\Delta H_f \text{ of } CH_4\text{ (g)} = \Delta H_f^o \text{ of } CH_4\text{ (g)} \times 1 \text{ mol } CH_4\text{ (g)} = -\ 74.8 \text{ kJ/mol} \times 1 \text{ mol } CH_4\text{ (g)}$$

$$= -74.8 \text{ kJ}$$

$$\Delta H_f \text{ of } O_2\text{ (g)} = \Delta H_f \text{ of } O_2\text{ (g)} \times 2 \text{ mol } O_2\text{ (g)} = 0 \text{ kJ/mol} \times 2 \text{ mol } O_2\text{ (g)}$$

$$= 0 \text{ kJ}$$

$$\Sigma \Delta H_{f\ reactants} = -74.8 \text{ kJ} + 0 \text{ kJ} = -74.8 \text{ kJ}$$

3. Use Hess's Law to calculate ΔH_{rxn}

$$\Delta H_{rxn} = \Sigma \Delta H_{f\ products} - \Sigma \Delta H_{f\ reactants}$$

$$-965.1 \text{ kJ} - (-74.8 \text{ kJ}) = -\ 890.3 \text{ kJ}$$

$$\Delta H_{rxn} = -890.3 \text{ kJ}$$

Connected Chemistry

Thermodynamics Unit

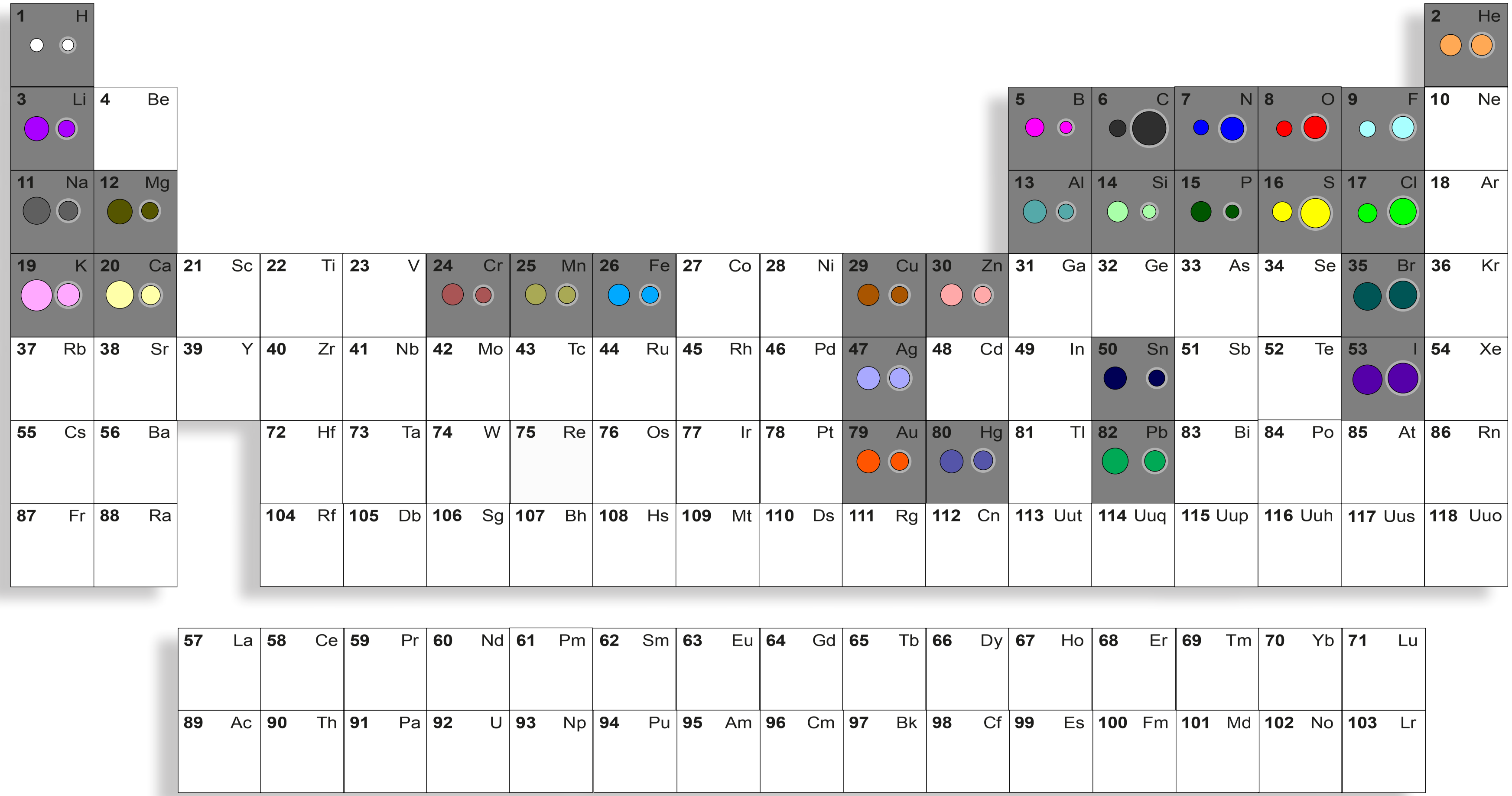
Student Appendix B: Enthalpy Data

Species	ΔH_f^o kJ/mol
H_2 (g)	0
O_2 (g)	0
NH_3 (g)	-45.95
NO (g)	90.25
CH_4 (g)	-74.81
H_2O (g)	-241.83
H_2O (l)	-285.83
CO_2 (g)	-393.509
C_3H_8 (g)	-104.7
C_5H_{12} (l)	-173.5
Na^+ (aq)	-239.7
HCO_3^- (aq)	-691.1
H^+ (aq)	0
$C_2H_3O_2^-$ (aq)	-486
H_2O_2 (l)	-191.17

Kotz, J. C., Treichel, P., & Weaver, G. C. (2006). Chemistry & chemical reactivity. Belmont, CA: Thomson Brooks/Cole.

Masterton, Slowinski & Stanitski (1983). Chemical Principles. CBS Publishing.

Elements Used in the Connected Chemistry Curriculum



1 H ●																	2 He ●
3 Li ●	4 Be											5 B ●	6 C ●	7 N ●	8 O ●	9 F ●	10 Ne
11 Na ●	12 Mg ●											13 Al ●	14 Si ●	15 P ●	16 S ●	17 Cl ●	18 Ar
19 K ●	20 Ca ●	21 Sc	22 Ti	23 V	24 Cr ●	25 Mn ●	26 Fe ●	27 Co	28 Ni	29 Cu ●	30 Zn ●	31 Ga	32 Ge	33 As	34 Se	35 Br ●	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag ●	48 Cd	49 In	50 Sn ●	51 Sb	52 Te	53 I ●	54 Xe
55 Cs	56 Ba		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au ●	80 Hg ●	81 Tl	82 Pb ●	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra		104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo
		57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
		89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	

Name	Symbol	Atomic Number	Atomic Weight
Hydrogen	H	1	1.00794
Helium	He	2	4.00260
Lithium	Li	3	6.941
Boron	B	5	10.811
Carbon	C	6	12.0107
Nitrogen	N	7	14.0067
Oxygen	O	8	15.9994
Fluorine	F	9	18.9984
Sodium	Na	11	22.9898
Magnesium	Mg	12	24.3050
Aluminum	Al	13	26.9815
Silicon	Si	14	28.0855
Phosphorus	P	15	30.9738
Sulfur	S	16	32.065
Chlorine	Cl	17	35.453
Potassium	K	19	39.0983
Calcium	Ca	20	40.078
Chromium	Cr	24	51.9961
Manganese	Mn	25	54.9380
Iron	Fe	26	55.845
Copper	Cu	29	63.54
Zinc	Zn	30	65.38
Bromine	Br	35	79.904
Silver	Ag	47	107.8682
Tin	Sn	50	118.710
Iodine	I	53	126.904
Gold	Au	79	196.967
Mercury	Hg	80	200.59
Lead	Pb	82	207.2