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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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.

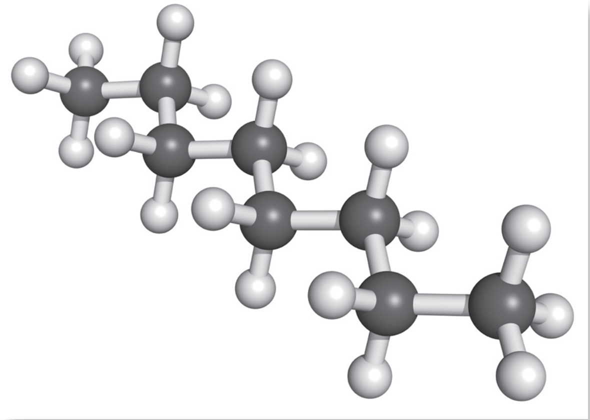
While some people use the terms thermal energy and heat interchangeably, heat and thermal energy are not the same thing. **Heat i**s the process by which thermal energy transfers from from one system to another. An object or system does not possess "heat"; instead, an object or system has some degree 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.

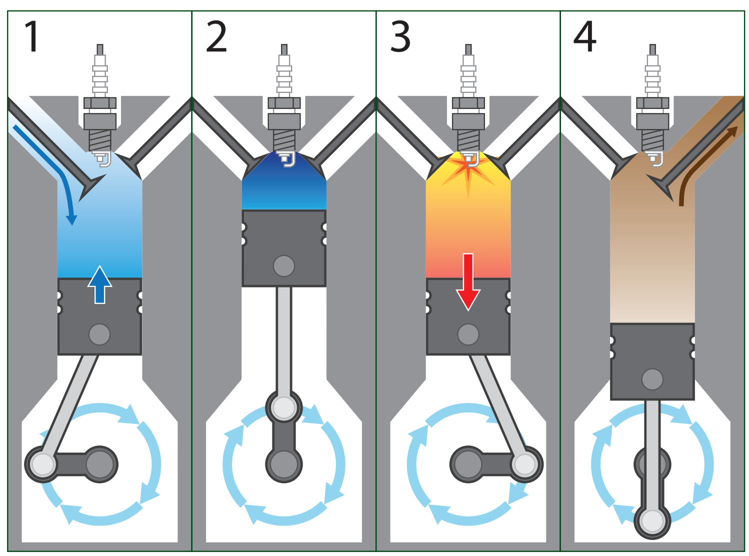
3. What are the products common to all combustion reactions of hydrocarbons?

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.*

Trial 1	**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			
Trial 2	**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					

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.

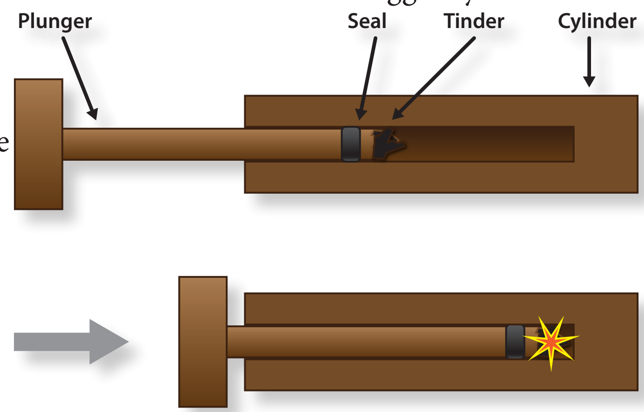
Submicroscopic Drawing
Description
Key

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.