Lesson 6
Matter

Introduction: Connecting Your Learning

The previous lessons discussed mechanics and many forms of motion. Lesson 6 introduces the second major topic in physics, which is matter. This lesson covers the atomic nature of matter, including solids, liquids, gases, and plasmas. Many students are familiar with three forms of matter: solids, liquids, and gases. A fourth phase of matter, plasma, has been recognized for some years now. Most recently, a fifth phase of matter, Bose-Einstein condensate, is now recognized as a separate phase, due to research conducted at very low temperatures. Some scientists also include the paramagnetic and ferromagnetic phases of magnetic materials as separate categories.

Heat and temperature are two words that are often used interchangeably, even though it is incorrect to do so. When an object feels hot to the touch, there is a tendency to conclude that the object has heat. If an object feels cold to the touch, one might conclude the object possesses coldness. From a scientific point of view, these conclusions are technically incorrect. It is common to hear the expression, "Close the door, the cold air is coming in," on a cold winter day. This, too, is not technically correct (the warm air is leaving). This lesson illustrates that heat and temperature (although related) are two different concepts. Heat is associated with the energy that naturally flows from a hot object to a cold object as a result of a temperature difference between the objects, and temperature is merely a measure of how hot or cold an object is in relation to some arbitrary reference point (such as the freezing or boiling points of water).

Readings, Resources, and Assignments	
Required Textbook Readings	None

Check Prior Knowledge

Check your prior knowledge by matching these terms. Answers are located at the end of the lesson.

True or False

1. Mixtures can be considered pure compounds.
2. Tension and compression are two words that refer to the same force.
3. A floating object displaces an amount of fluid equal to the weight of the object.

Focusing Your Learning

Lesson Objectives

By the end of this lesson, you should be able to:

1. Differentiate between a solid, liquid, gas, and plasma.
2. Describe Archimedes' Principle.
3. Describe ideal gases in terms of pressure, temperature, volume, and the amount of gas present.
4. Explain the factors that affect heat transfer.
5. Distinguish between convection, conduction, and radiation.
6. Describe the properties of phase changes.

Approaching the Objectives

This lesson is comprised of six sections:

Section 1: Solids

Section 2: Liquids

Section 3: Gases

Section 4: Thermodynamics

Section 5: Alternate Phases of Matter

Section 6: Forms of Heat Transfer

Section 1: Solids

Start this section by viewing the Kahn Academy video on States of Matter.

The way that atoms of a material can interact with one another largely determines whether the material is a solid, liquid, or gas, and this is also largely dependent on the temperature of the matter in question. Solids consist of matter with a definite shape and a definite volume. In solids, the atoms or molecules are closely locked in position and can only vibrate. These closely packed molecules or unit structures form a rigid configuration. A residual electrostatic attractive force holds the molecules or unit structures together, which is generally weaker in a molecular solid such as water (H_2O) compared to an ionic solid such as table salt (NaCl). Solids usually consist of a simple geometric pattern, which repeats over and over in all directions. When this occurs, the solid material is referred to as a crystal. Some crystals allow their electrons to move freely among the atoms. These materials are called metals. Because the electrons are allowed to move freely, they are excellent conductors of heat and electricity (topics covered in future lessons).

In liquids, the atoms or molecules have higher energy, are more loosely held together, and can slide past one another. This is the topic of the next section.

Section 2: Liquids

The liquid phase of matter has definite volume but no definite shape. Spilling a graduated cylinder of water on the floor easily illustrates this. In the graduated cylinder, the volume of the liquid could be measured. However, when the same volume of water is spread over the floor, the shape is completely different. In general, liquid particles move faster than those in solids and slower than those in gases. Liquid particles cannot be easily squeezed together or spread apart. The particles in a liquid are usually slightly further apart than the same particles in solid form. Most liquids are less dense than their solid forms (water is an important exception to this). The solid form of water is less dense than the liquid, and ice floats as a result. The electrostatic forces holding the liquid particles together are weaker than the forces holding the solid together. This weaker force allows the particles to flow past each other, which makes liquids a form of fluid. These forces also cause liquids to exhibit a surface tension.

One very common misconception in beginning physics involves the concept of buoyant force.

If an object is immersed in a fluid such as water or air, there is an upward force on the object. If the object is not accelerating in the upward or downward direction, the buoyant force is equal in magnitude to the weight of the object. The two vectors that appear on the free body diagram are the downward weight and the upward buoyant force. So, what is the magnitude of the buoyant force? The buoyant force is equal to weight of the fluid displaced by the object, not the weight of the object. This is known as the Archimedes Principle. As an example, consider a submerged submarine cruising along at 5 knots. All of sudden the submarine starts to sink, but the weight of submarine has not changed.

Why do you think the submarine started to sink?

Answer - The submarine most likely entered a pocket of less salty water. Less concentrated salt water isn't as dense and therefore weighs less. Since the water displaced now weighs less, the buoyant force is less and the net vector force is downward, so the submarine will experience a downward acceleration.

What action could the submarine take to alleviate this problem?

Answer - The submarine will most likely pump water from its ballast tanks to sea, decreasing its weight. Doing this will balance the weight vector with the buoyant force vector and the submarine can remain at constant depth.

**Activity:**

Math Challenge:

When a crown of mass 14.7 kg is submerged in water, an accurate scale reads only 13.4 kg. Is the crown made of gold? If the conclusion is that the crown is not made of gold, then what is the crown most likely made of? Support your answer. Find the specific gravity (the density of the crown divided by the density of water).

Check your answer at the end of the lesson.

In gases, the atoms or molecules have still more energy and are free of one another, except during occasional collisions. This is the topic of the next section.

Section 3: Gases

Start this section by viewing the Kahn Academy videos on Thermodynamics Part 1 and Part 2 of a gas.

The physics of gases is similar to liquids from the point of view that they are both fluids. They are both capable of exerting a buoyant force on objects. Gases are very different from liquids from the point of view of the electrostatic forces that hold the molecules together. Both liquid and gaseous molecules can move and slide past each other; however gases have the property of compressibility, whereas liquids are nearly incompressible. The compressibility of gases leads to several important relationships between pressure, volume, temperature, and the number of gaseous molecules in the sample.

If the temperature of the gas sample and the number of molecules remain constant, then the product of pressure and volume remains constant. An easy way to visualize this is to consider a piston with a movable top.

If the top of the piston is forced down, the volume decreases and the pressure increases. The increase in pressure is due to the increase in the number of collisions molecules have with the sides of the container. Mathematically this can be stated as:

$$PV = \text{constant}$$

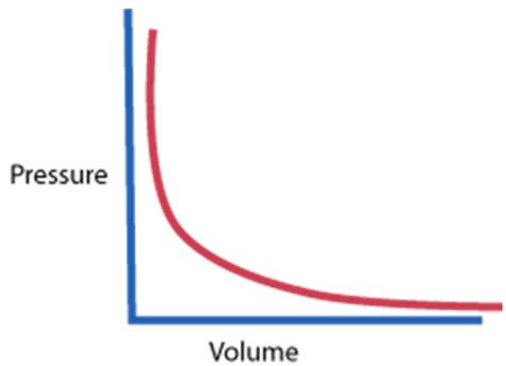
or

$$P_1V_1 = P_2V_2$$

Try it!

Sketch a graph of what a pressure versus volume graph might look like. Hint: It is not a straight line.

Compare your sketch



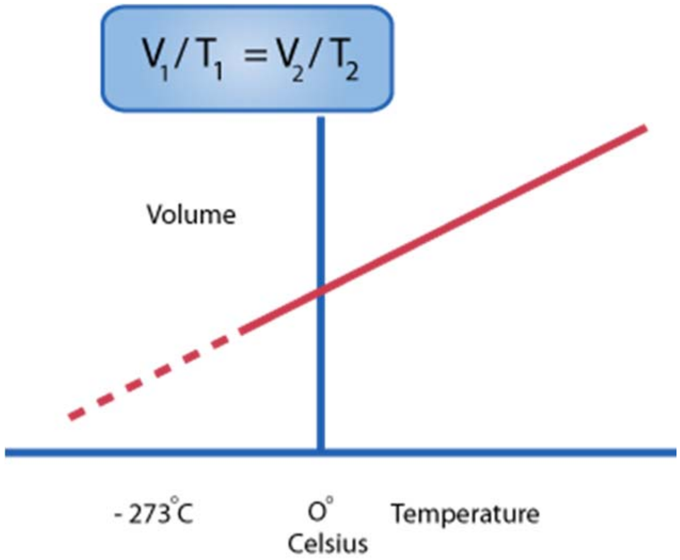
This relationship is referred to as Boyle's Law.

Perform an Internet search and determine the relationship between the volume of a gas and its temperature if the pressure is held constant.

Try it!

Write a mathematical statement using V_1, V_2, T_1, and T_2 and sketch a graph of Volume versus Temperature for a sample of gas.

Compare your formula and sketch.



The variables that describe ideal gases can be combined into one mathematical statement that relates the pressure (P), volume (V), temperature (T), and the number of molecules (n).

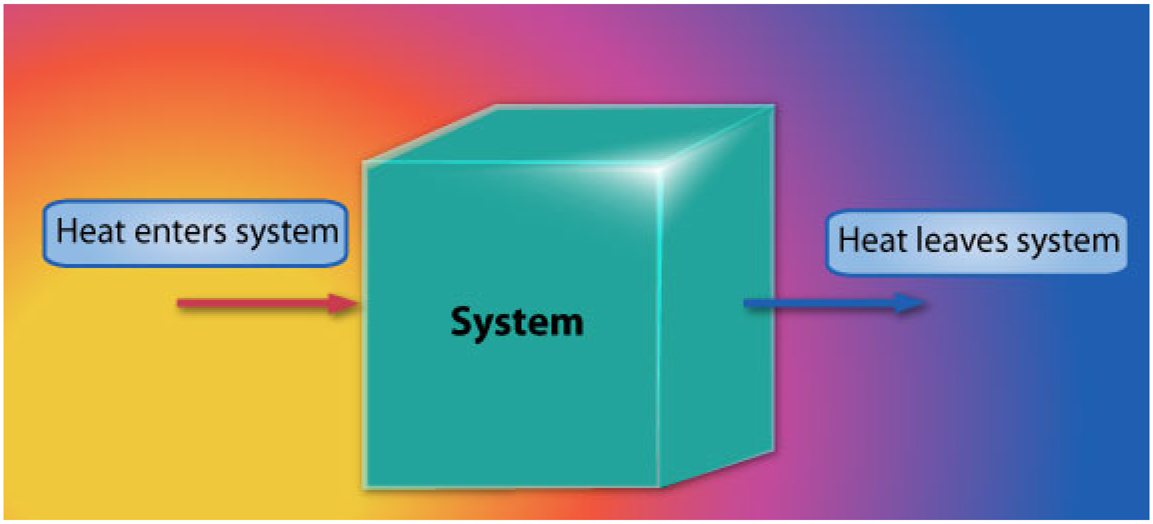
PV = nRT R is a universal constant that need not be memorized R = 0.0821 L atm/mole K

Note:

1. L stands for liter
2. atm is a unit for pressure
3. mole is a number of molecules (6.02×10^{23})
4. T is temperature measured in Kelvin.

Section 4: Thermodynamics

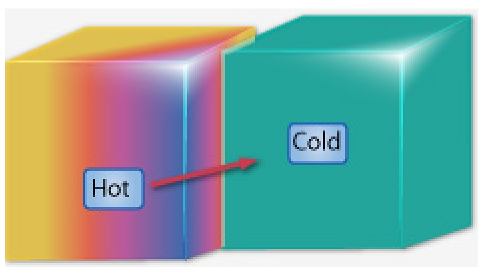
Consider the model shown below:



This model illustrates the First Law of Thermodynamics:

> ***Whenever heat flows into or out of a system, the gain or loss of thermal energy equals the amount of heat transferred.***

The Second Law of Thermodynamics addresses the direction of the heat flow. Without outside assistance, heat always flows from hot objects to cold objects.



If a hot object is placed near a cold object, heat will flow from the hot object to the cold object until the objects reach a thermal equilibrium (the particles in both objects contain the save average kinetic energy and the same temperature).

Can heat flow the other way? Sure, it can, but not alone. The refrigerator is a prime example. Refrigerators must be supplied by an energy source (e.g., electricity or propane) in order to force the heat to flow from cold to hot. This keeps the food cold inside the refrigerator.

The Third Law of Thermodynamics states that absolute zero can never be reached. This implies that no matter how cold it is at least one molecule will process some amount of energy.

Section 5: Alternate Phases of Matter

Relatively new to science are two additional phases of matter. Plasma is an electrified gas consisting of ions and free electrons. Most matter in the universe is plasma. Here on Earth, plasma is much less common but is gaining popularity in the laboratory and for commercial uses such as the plasma TV.

A fifth phase of matter has been identified and named the Bose-Einstein condensate. This phase of matter was predicted well before it was actually discovered. The predictors were Satyendra Nath Bose (not so famous) and Albert Einstein (very famous). In particle physics, all of the particles are either bosons or fermions. This will be discussed in more detail in future lessons dealing with quantum mechanical behavior of matter.

Two examples of materials containing Bose-Einstein condensates are superconductors and super fluids. Superconductors conduct electricity with virtually zero electrical resistance, which means that once a current is started, it flows indefinitely. The liquid in a super fluid also flows forever. In effect, there is no friction. This phase of matter exists only at the coldest temperatures in the universe (within a few billionths of a degree near absolute zero).

Section 6: Forms of Heat Transfer

Conduction

Heat conduction occurs when there is physical contact between a hot object and a cold object. The amount of heat conducted (Q) depends on three parameters: (1) the mass of the objects, (2) the composition of the objects, and (3) the difference in temperature between the objects. Objects that have a larger mass conduct more heat than less massive objects. The larger the temperature difference between the objects, the more heat is conducted. The composition of the object is taken into account by defining a constant for the specific material. This constant is referred to as the specific heat capacity, and the values are found in a variety of scientific tables located in books or on the Internet. Water is a very common substance and serves as a reference. The specific heat of water is defined as 1 calorie per gram per degree Celsius. Other values can be found in terms of the SI unit for heat energy (Joule). Some tables list specific heats in terms of Joules per kilogram per Kelvin. It is necessary to check units carefully when using specific heat values. The use of this concept is referred to as calorimetry.

Convection

Convection is the process where heat is transferred by a moving fluid. This occurs on a large scale in the ocean and the atmosphere where ocean currents and moving air masses carry heat all over the globe. On a smaller scale, heat can be moved throughout a house by using fans to blow air from one part of the house to another. There is no single equation that is used to calculate the amount of heat transfer because it heavily depends on the application.

Radiation

Heat transfer by radiation is also a more complex process where energy is moved by electromagnetic waves. The important point about radiation is that energy may be moved through empty space and does not need a fluid like water or air to carry the energy.

Summarizing Your Learning

This lesson discussed matter from an atomic point of view. The three primary phases of matter were explained along with some of the physical laws that govern them. Finally, a relatively new phase of matter was explored. The details of this phase are beyond the scope of a beginning physics class, but hopefully, they may inspire you to conduct research on your physical word.

Practice Answers

Check Prior Knowledge

Mixtures can be considered pure compounds. FALSE

Tension and compression are two words that refer to the same force. FALSE

A floating object displaces an amount of fluid equal to the weight of the object. FALSE

Section 2: Liquids

Find the specific gravity (the density of the crown divided by the density of water).

The crown has a density of 11.3 kg/m^3. It is most likely made of lead.