ES 106 Laboratory # 2
HEAT AND TEMPERATURE

Introduction

Heat transfer is the movement of heat energy from one place to another. Heat energy can be transferred by three different mechanisms: *convection*, *conduction,* and *radiation*.

Matter can change from one phase to another with the addition or removal of heat. These changes are called *phase changes*. Phases can change through *melting, freezing, evaporation,* or *condensation* of matter.

Goals and Objectives

- Be able to *define* heat, temperature, internal energy, heat transfer, phase change, absolute zero, radiation, conduction, convection, and thermal expansion
- *List* the mechanisms of heat transfer and types of phase changes
- *Identify* good conductors of thermal energy.

Useful Websites

- http://lamar.colostate.edu/~hillger/temps.htm
- http://www.metric-conversions.org/
- http://www.school-for-champions.com/science/heat_transfer.htm
- http://hyperphysics.phy-astr.gsu.edu/hbase/heacon.html

Name____________________________

Lab Day_____ Time_________________

Pre-lab Questions – Complete these questions before coming to lab.

1. Define the following terms:
   A. Temperature:

   B. Heat:

   C. Internal Energy (also sometimes referred to as Thermal Energy):

   D. Conduction:

   E. Convection:

   F. Radiation:

2. Convert the following temperatures: (Note: $C^{o} + 273 = K$)
   A. $0^{o}C$ to K

   B. 180 K to ^{o}C

   C. $50^{o}F$ to K

3. Give three examples of phase changes that you encounter in your daily life. These phase change examples could be occurring in materials other than water.

4. **Complete Part A, on the following pages, before coming to lab.**

Part A – Temperature, internal energy, and molecular motion

To get started, you will draw three pictures to gain a better understanding of temperature. Start in column 1 of Table 1. In box 1, draw a thermometer. The thermometer's mercury *hasn't* risen at all. In box 2, draw 3 dots. In box 3, write a small capitol "E = 0".

Begin column 2 of the table. In box 4, draw another thermometer. This thermometer's mercury has risen some. In box 5, draw the same three dots. Coming out from each dot, draw a small arrow. Have each arrow point a different direction. In box 6, write a capitol "E" that is mid-sized and bigger than the one before.

Begin your final column of pictures. In box 7, draw a thermometer with the mercury at a very high level. In box 8, draw the three dots with arrows pointing in the same directions as before. Make the arrows much longer than in the previous drawing. In box 9, write a capitol "E" that is much bigger than the other two "E"s.

Table 1:

Column 1	Column 2	Column 3
Box 1	Box 4	Box 7
Box 2	Box 5	Box 8
Box 3	Box 6	Box 9

You have just drawn a depiction of temperature. Thermometers measure the changes in the thermal energy of atoms and molecules that occur as temperature changes. Suppose the first thermometer measures a temperature of about 0 Kelvin (i.e., absolute zero), the second measures 70 Kelvin (about —200ºC), and the third measures about 700 Kelvin (about 425ºC).

The dots represent molecules. In the first column, the molecules were not moving, so there were no arrows. In the second column, the molecules were moving slowly, so there were small arrows. In the third column, the molecules were moving fast and the arrows were big. The "E" represents energy. The first had a small "E", meaning that its thermal energy level was low. The second had more thermal energy, so it had a bigger "E". The final had a big "E" because it had the most thermal energy.

Questions:

1. What is the relationship between temperature, heat, and internal energy? Be sure to compare and contrast these three terms/concepts.

2. *Absolute zero*, which occurs at 0 kelvins, is the lowest temperature that a material can reach. Assume that you have a substance at absolute zero. For this substance, describe what do you know about:
   a. the motion of its molecules

   b. its internal energy level

3. On the Kelvin temperature scale, room temperature is about 300 K. For the substance at room temperature. Refer to your diagram on pg. 2.3.:
   a. What can you say about the motion of its molecules?

   b. What can you say about its internal energy level?

Part B – Heat Transfer

Station 1: Heat Transfer by Radiation
This station consists of two sets of papers, each including a shiny piece, a dull black piece, and white piece. A light shines on one group, while a heating pad warms the second group.

First we will consider the group upon which the light shines. Place your hand on the black piece of paper. Note what you feel. Next, place your hand on the shiny piece. Ask yourself, “Do you feel anything different from the black piece?” Do the same for the white piece of paper, and compare what you feel to the previous two.

Now we will consider the group warmed by the heating pad. Touch each piece of paper. Ask yourself: “Does each give off a different amount of warmth, or are they all constant”?

You just investigated radiation. Radiation occurs when energy is transferred in the form of infrared waves. These waves can either be absorbed or emitted. If a material absorbs these waves, the temperature of the material rises.

Questions

1. Consider the pieces under the light. List these pieces, from the warmest (first) to the coolest.

2. Given this result, which is the best absorber? Which is the worst absorber?

3. Would you rather wear black or white on a hot summer day? Explain your answer.

4. Imagine that you are a lemur and you warm yourself from your surroundings. On cool mornings, would you rather have dark or light fur? Explain your reasoning.

Station 2: Heat Transfer by Conduction

This station has 3 spoons placed in a bowl of hot water. There is a plastic, metal, and wooden spoon. Touch each spoon one by one.

Materials that are hot have fast moving molecules, while things that are cool have slow moving molecules. The water in the bowl, therefore, has fast moving molecules. These molecules are moving around and bump into the slow moving molecules of the spoon. Because they are running into other molecules, the fast molecules lose some of their speed and slow down. The smaller molecules of the spoon pick up this speed. This mechanism of heat transfer is called *conduction.*

All materials conduct heat with different abilities. A material that conducts heat well is a "good thermal conductor". In our spoons-in-hot-water example, given each spoon is in the hot water for the same amount of time, the temperature of a good thermal conductor will be higher than that of a poor one.

Questions

1. Can you tell a difference in their temperatures? ___________________
2. Which feels the hottest? _______________________________________
3. Which feels the coolest? _______________________________________
4. List the spoons in the order from best conductor to worst.
5. Now you've seen that some materials conduct heat better than others. If you were frying yourself an omelet for breakfast, would you rather use a skillet with a metal or a plastic handle? Why?
6. You are building a new house and are given the choice of building the walls out of plywood or sheet metal. Which material should you use if your goal is to lose heat from the house as slowly as possible? Explain your reasoning. (Hint: think about the spoons.)

Station 3: Heat Transfer by Convection

Convection occurs when heat is carried from one place to another through the bulk movement of fluid. When part of a fluid warms, the volume of it expands, and it becomes less dense. The cooler and denser fluid surrounding it pushes the warm fluid upward. As the warm fluid rises, the cooler fluid takes it place. This cooler fluid is then warmed and pushed upward, creating a current. In order for convection to occur, matter must be present and free to move so that it can carry heat.

Activity:
Observe the movement of the fluid in the convection demonstration. In the space below, draw a sketch of the demonstration setup. Label the temperatures of the two heat reservoirs. Use arrows to show movement of fluid and label hot currents with H and cold currents with C.

Questions

1. Write a paragraph detailing your observations and how they help you to visualize a convection process.

2. Let's imagine you are preparing to make macaroni and cheese at home, so you are boiling water in a pan on the stove. Your roommate comes in and tells you that you must stir the water if you want it to get warm. Otherwise the water near the burner will stay hot and the water near the top will stay cold. Explain to your roommate why you do not need to stir the water.

3. Baseboard heaters work by distributing heat throughout the room using convection currents. Explain why the heaters are installed near the floor rather than near the ceiling. Draw a diagram of this situation showing the flow of air in the room.

Part C – Determination of Density by Water Displacement

Density is defined as mass per unit volume (density = mass/volume). The units of density are commonly expressed as grams/cubic centimeter (g/cm^3). As noted in the lab introduction, the density of pure water is 1 g/cm^3; also note that 1 cm^3 = 1 milliliter (1 mL).

Activity:
You will be determining the density of two cylinders composed of unknown metals. Mass will be measured using the balances provided, and volume will be measured by water displacement. Once the densities of the metals are calculated, you will compare your calculated value to a list of standard values to determine the metal that composes your cylinders.

Procedure

1. Select two metal cylinders. Make sure they are different metals (i.e., with different masses).
   Weigh the two metal cylinders and record their masses in Table 1, below.

2. Determine the volume of the cylinders by following these steps:
   a. Place approximately 15 mL of water in a small graduated cylinder. Record this as your initial volume in the table below.
   b. Carefully place the metal cylinder into the graduated cylinder so that it is totally immersed. Record this as you final volume in Table 1. Now determine the volume of the each cylinder by subtraction.

Table 1: Metal Cylinder Data

	Metal Cylinder #1	**Metal Cylinder #2**
Mass		
Final Volume		
Initial Volume		
Volume of cylinder		

3. Calculate the density of each of the two metal cylinders. Be sure to show your work, including units, in the space below.

Density #1 = _____________ **Density #2=** ____________

4. Based on you your calculated densities, determine which metal composes the cylinders. Refer to Table 2: Standard Densities of Some Metals.

   Metal Cylinder #1 ____

   Metal Cylinder #2 ____

Table 2: Standard Densities of Some Metals (g/cm^3).

Metal	**Density** (g/cm^3)
Aluminum	2.70
Brass	8.56
Copper	8.80
Lead	11.00
Steel	7.83

5. Percent error is determined to see how close a measurement is to a standard value. Use the equation below to calculate error:

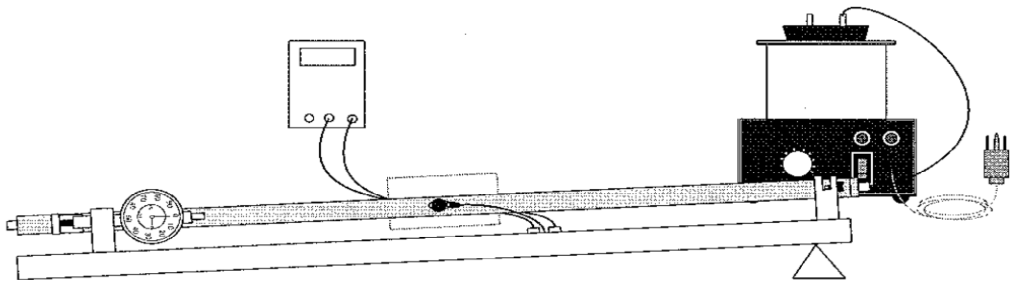
$$\left|\frac{\text{Expected value - Observed value}}{\text{Expected value}}\right| \times 100 = \text{Percent Error}$$

Show your work below for the percent error in your measurements.

<u>Metal Cylinder #1</u> **<u>Metal Cylinder #2</u>**

List and briefly discuss two factors that contributed to the error you just calculated. (Do not cite "human error"! Specify the source of that human-caused error.)

Part D – Thermal Expansion



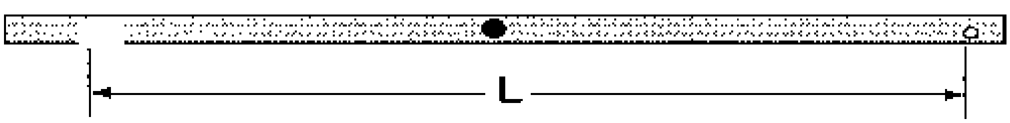
This apparatus consists of copper, steel and aluminum rods connected to a steam generator. One end of the rod is fixed in place. The dial gauge can be used to measure expansion as steam passes through the rod. Before you begin, make sure the rod is at room temperature.

Activity:

1. Turn on the steam generator.

   CAUTION: The steel tank gets **HOT** when the unit is on.

2. Measure the length of the rod at room temperature. Measure from the inner edge of the stainless steel pin on one end, to the inner edge of the angle bracket at the other end. Record your results in Table 3.



3. Turn the outer casing of the dial gauge to align the zero point on the scale with the long indicator needle. As the rod expands, the indicator needle will move in a counter clockwise direction.

4. When steam starts to flow from the steam generator attach the generator tube to the end of the metal rod.

5. As steam begins to flow through the rod, watch the dial gauge. Record the expansion of the rod length as indicated by the displacement of the needle on the dial gauge in Table 3. (Each increment on the dial gauge is equivalent to 0.01 mm of tube expansion.

6. Record the change in length for the steel, copper and aluminum rods.

Table 3	Length at Room Temp. (mm)	Change in Length due to heating (mm)	Length when rod is hot (mm)
Copper			
Steel			
Aluminum			

Hopefully you noticed that the three metals expanded in different amounts. Different materials expand and contract different amounts as temperature changes. This depends on the "thermal coefficient of expansion." Those materials with small coefficients expand or contract the least, while those with large coefficients change volume the most.

7. The rods in this experiment are made from aluminum, steel and copper.

   Based on your observations, which of these has the smallest thermal coefficient of expansion?

   Which has the largest?

8. Does there seem to be a relationship of the density of the material and its thermal coefficient of expansion? If so, what is this relationship?

9. If you were building a small model railroad, would you use aluminum or steel to avoid buckling? (Explain your reasoning).

10. On the way to your friend's apartment, you pass some railroad track. Last summer, the tracks buckled so badly that the trains couldn't use them. Write a short paragraph describing why this happened, and how the builders could have built the rails to keep this from happening.

Part E – Phase Changes

There are (for the purpose of this lab) 3 phases of matter: gas, liquid, and solid. Matter can change from one phase to another depending on the amount of heat added or lost. This change from one form of matter to another is called a *phase change*. A solid can *melt* into a liquid if heat is added. A liquid can *freeze* into a solid if heat is taken away. A liquid can *evaporate* into a gas if heat is supplied, while a gas can *condense* into a liquid if heat is removed. If matter melts, freezes, evaporates, or condenses, it is undergoing a phase change.

This is a group activity using the computer, so your instructor will explain it. A diagram of the set up appears in Figure 1.

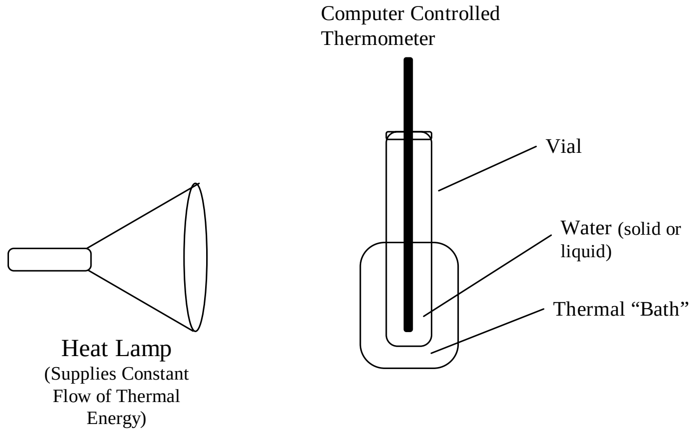


Figure 1: Experimental set up

When heat is added to ice, the temperature increases (see Figure 2). Once the temperature reaches the melting point of 0 degrees Celsius, the ice begins to change phase into a liquid. Even though you are adding heat, the water stays at 0^oC until all of the ice is melted. Once all the ice melts, the added heat allows the water's temperature to increase above 0^oC. When the temperature reaches the boiling point of water, 100^oC, then the water changes from a liquid to a gas. Again, even though you add heat, the temperature remains at 100^oC until all the liquid has turned into a gas. Once it has all evaporated, the temperature begins to rise above 100^oC.

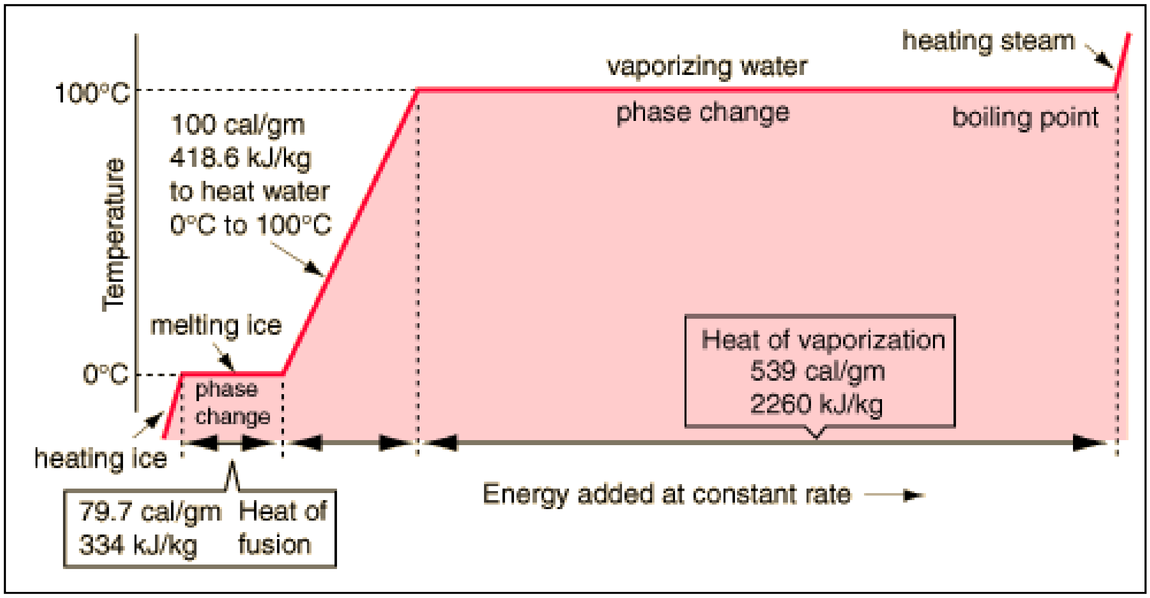


Figure 2: Theoretical graph of the change in temperature of water as heat is added.

1. Label the line segments in Figure 2 where ice is present, where water and ice are present (i.e. melting is taking place), where just water is present, where water and water vapor are present (i.e. boiling is taking place), and where just water vapor is present.

2. Print out a copy of the temperature vs. time graph from the experiment. Identify and label the regions on the graph when the water is solid, is changing from solid to liquid, and is all liquid.

3. Notice that the slope of the curve in Figure 2 changes abruptly when a phase change is reached. The slope of the curve on your experimental graph printout, however, shows a gradual change in slope when the melting phase change is reached. Why do the two graphs have such different shapes?

4. In your experiment, there was always transfer of thermal energy into the water. Why are there regions in which the temperature is not changing? Explain in detail what is happening.

Name________________________

Lab Day/Time_________________

POST-LAB ASSESSMENT

1. What heat transfer mechanism(s) is/are used when infrared energy is transferred from a red giant star to Earth? Consider all the possibilities, and explain each. (What heat transfer mechanism(s) can transfer energy through the vacuum of space?)

2. What heat transfer mechanism(s) is/are used when heat energy from the core of Earth is transferred to the crust? Consider all the possibilities, and explain each.

3. Fire safety guidelines say that if you must escape from a burning building, touch metal doors before you open them. Through what mechanism would heat be transferred from the hot side to the cool side of the door?

4. Describe what happens to the temperature and the thermal energy of water when it boils.

5. The rate of thermal energy transfer of water in an ice cube tray depends on the differences in temperature between the water and the air in the freezer. The closer the objects are in temperature, the slower the thermal energy is transferred. Knowing this, dispel the myth that hot water freezes faster than cold water. (Consider the thermal energy in hot versus cold water placed in the ice cube tray).

6. Imagine that you have a piece of granite with of density 2.65 g/cm^3. If the mass of the piece of granite is 120 g, what is the rock sample's volume? (show your calculations)