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.

Name__________**KEY**_________

Lab Day/Time_________________

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

1. Define the following terms:
   A. Temperature: **MEASURE OF THE HOTNESS OR COLDNESS OF A SUBSTANCE. MEASURE OF AVERAGE KINETIC ENERGY OF THE MOLECULES OF THE SUBSTANCE. COLLISION ENERGY OF MOLECULES.**
   B. Heat: **KINETIC ENERGY OF RANDOM MOLECULAR MOTION.**
   C. Internal Energy (also sometimes referred to as Thermal Energy): **TOTAL KINETIC ENERGY OF A SUBSTANCE.**
   D. Conduction: **TRANSFER OF HEAT BY COLLISION OF MOLECULES**
   E. Convection: **TRANSFER OF HEAT BY MOVEMENT OF FLUID SUBSTANCE.**
   F. Radiation: **TRANSFER OF HEAT THROUGH SPACE BY ELECTROMAGNETIC WAVES.**

2. Convert the following temperatures: (Note: $C^o + 273 = K$)
   A. 0 ºC to K **0^o C + 273 = 273 K**
   B. 180 K to ºC **180 K – 273 = -93 ^{o} C**
   C. 50 ºF to K **5(50 -32)/9 = 10 ^{o} C, 10 + 273 = 283 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.

BUTTER MELTING **NOT THE CHANGE OF DAY TO NIGHT**
GASOLINE VAPORIZING IN ENGINE
DRYING AFTER SHOWER **ETC.**

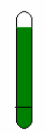
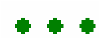
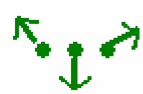
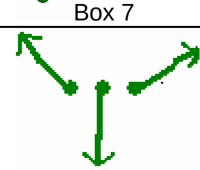
Part A – Temperature, internal energy, and molecular motion

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	
E=0 Box 3	E Box 6	E 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 Kelvins (i.e., absolute zero), the second measures 70 Kelvins (about 19ºC), and the third measures about 700 Kelvins (about 190ºC).

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.

TEMPERATURE IS THE MOLECULES RUNNING INTO EACH OTHER. HEAT IS THE DEGREE OF MOVEMENT OF THE MOLECULES. INTERNAL ENERGY IS THE SUM OF THE MOVEMENT OF THE MOLECULES.

2. *Absolute zero*, which occurs at 0 Kelvins, is the lowest temperature that a material can reach, and. Assume that you have a substance at absolute zero. What do you know about that material's:
    a. motion of the molecules
    NONE

    b. internal energy level
    NONE

3. On the Kelvin temperature scale, room temperature is about 400 Kelvins. What can you say about a substance at room temperature in terms of that material's:
    a. motion of the molecules
    GREATER THAN AT ABSOLUTE ZERO

    b. internal energy level
    GREATER THAN AT ABSOLUTE ZERO

Part B – 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 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 to the coolest.

BLACK WAS WARMEST
FOIL WAS COOLEST

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

BEST: BLACK **WORST: FOIL**

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

WHITE: IT REFLECTS INCOMING RADIANT ENERGY

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.

DARK: IT ABSORBS INCOMING RADIANT ENERGY

Part C – 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.

Initial Questions:

1. Can you tell a difference in their temperatures?

2. Which feels the hottest? ____**_METAL_**___________________________________

3. Which feels the coolest? ____**_WOOD_**____________________________________

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. List the spoons in the order from best conductor to worst.

METAL→PLASTIC→WOOD

2. 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?

PLASTIC: LESS LIKELY TO BURN YOUR HAND

3. 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.

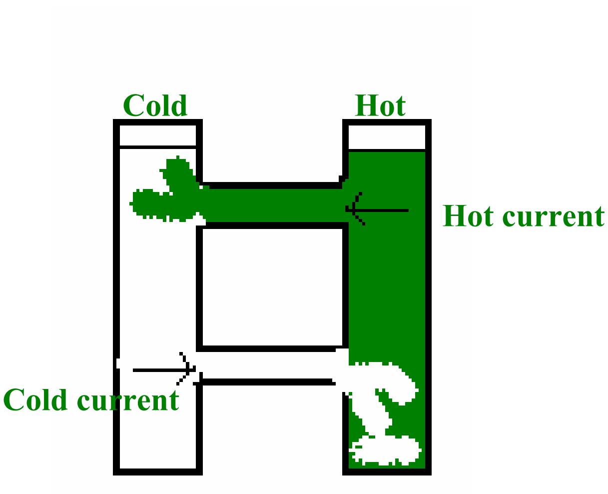
PLYWOOD: WOULD NOT CONDUCT AS MUCH HEAT TO THE OUTSIDE.

Part D – 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. Use arrows to show movement of fluid and label hot currents with H and cold currents with C as well as the temperatures of the two heat reservoirs.



Questions

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

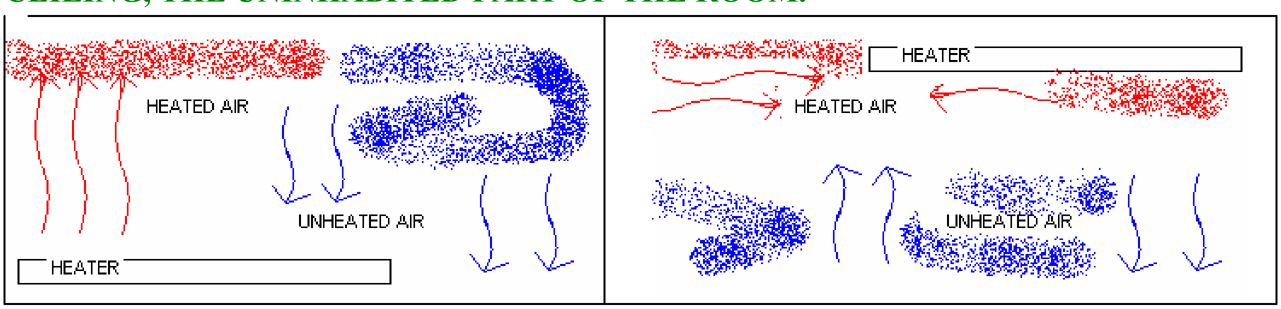
THE HOT FLUID MOVES IN THE UPPER REGIONS TO DISPLACE THE COOL FLUID IN THE LEFT CYLINDER. THE COOL FLUID MOVES IN THE LOWER REGION, TO DISPLACE THE HOT FLUID IN THE RIGHT CYLINDER.

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.

SINCE THE WATER IS HEATED, IT WILL RISE TO THE TOP, AND BE REPLACED AT THE BOTTOM BY COOLER WATER FROM THE TOP OF THE PAN. HEATING WATER STIRS ITSELF.

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.

THE HEATER NEAR THE FLOOR WILL ADD HEAT TO AIR NEAR THE FLOOR. IT WILL RISE BY CONVECTION, PASSING THE PEOPLE IN THE ROOM WHO CAN BE WARMED BY THE WARM AIR. THE WARM AIR DISPLACES COOLER AIR HIGHER IN THE ROOM, THAT GOES DOWN TO BE HEATED. PUTTING THE HEATERS NEAR THE TOP OF THE ROOM WOULD RESULT IN THE WARMTH STAYING NEAR THE CEILING, THE UNINHABITED PART OF THE ROOM.



Part E – Thermal Expansion

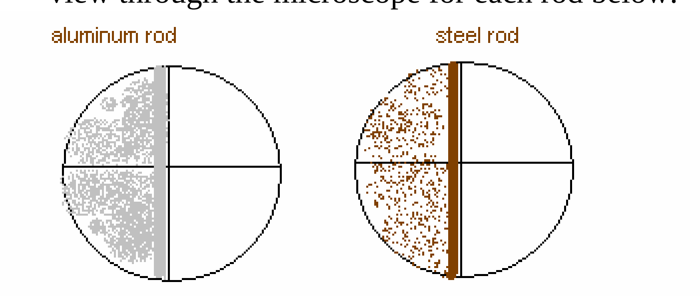
This apparatus consists of 2 different rods inside of hot steam jackets. One end of the rod is fixed in place. A microscope allows you to monitor the other end of the rod as its temperature changes. Before you begin, make sure that both rods are hot (about 100 degrees Celsius or 473 Kelvins). Now, look through the microscope.

Initial Questions:

1. Why does the rod appear to come from one direction when looking through the scope but from another direction when you look at it normally?

LENSES TURN IMAGES OVER

2. The end of the rod should line up with the cross-hairs. If it is not aligned, ask for help. Draw the view through the microscope for each rod below:



Activity:

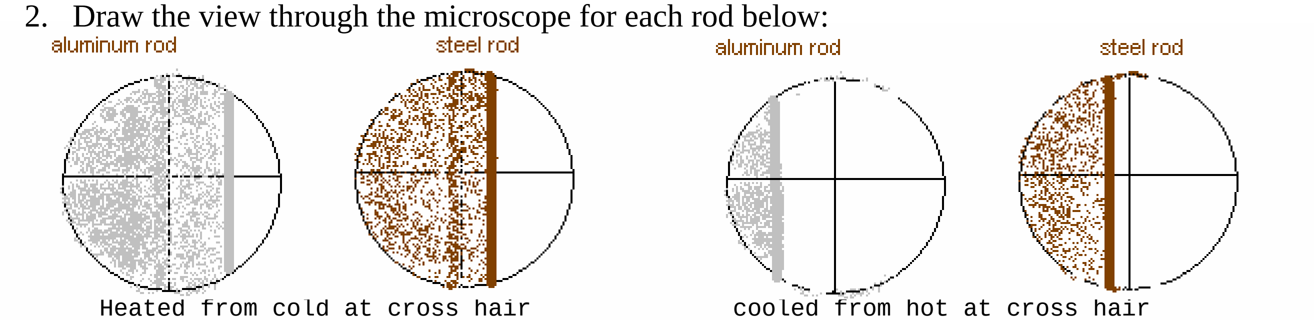
- ✓ Carefully, without burning yourself turn off *both* the hot plates. This stops the flow of steam through the two steam jackets so that the rods will begin to cool.
- ✓ As the temperature changes, watch the two rods. Once the temperature has reached about 35 degrees Celsius, look through the scope on each rod.

Questions:

1. How do they line up to the cross hairs in comparison to how they did before you started? In comparison to each other?

Rods traveled across crosshair upon heating. Rods shrank back across crosshair on cooling
The aluminum rod had greater thermal expansion than the steel rod.

2. Draw the view through the microscope for each rod below:



Hopefully you noticed that the two metals expanded/contracted in different ways. Different materials each expand different amounts as temperature changes. This depends on the "thermal coefficient of expansion." Those materials with small coefficients expand the least, while those with large coefficients expand the most.

3. The rods in this experiment are made from aluminum and iron. Based on your observations, which has the smallest thermal coefficient of expansion? Which has the largest?

STEEL (IRON) ROD HAD SMALLER COEFFICIENT OF EXPANSION THAN ALUMINUM ROD.

4. 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. Why did this happen? How could the builders have built the rails to keep this from happening?

BUILD TRACK WITH SPACES BETWEEN ENDS OF RAILS TO ALLOW FOR THERMAL EXPANSION OF THE STEEL TRACK.

5. If you were building a small model railroad and had to use either aluminum or iron, which would you use to avoid buckling? (Explain your reasoning).

STEEL, LOWER COEFFICIENT OF THERMAL EXPANSION.

Part F – 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.

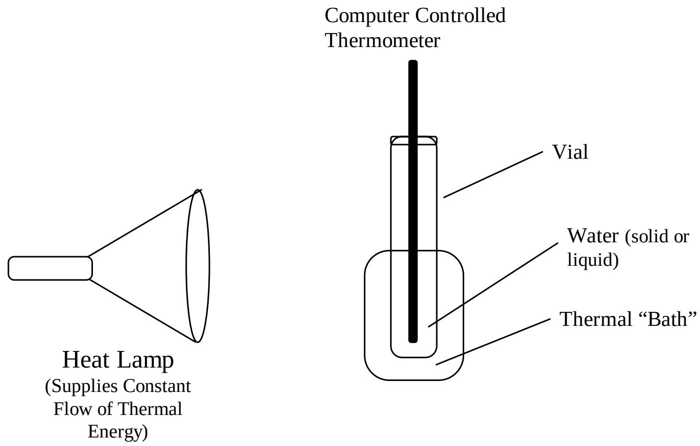


Figure 1: Experimental set up

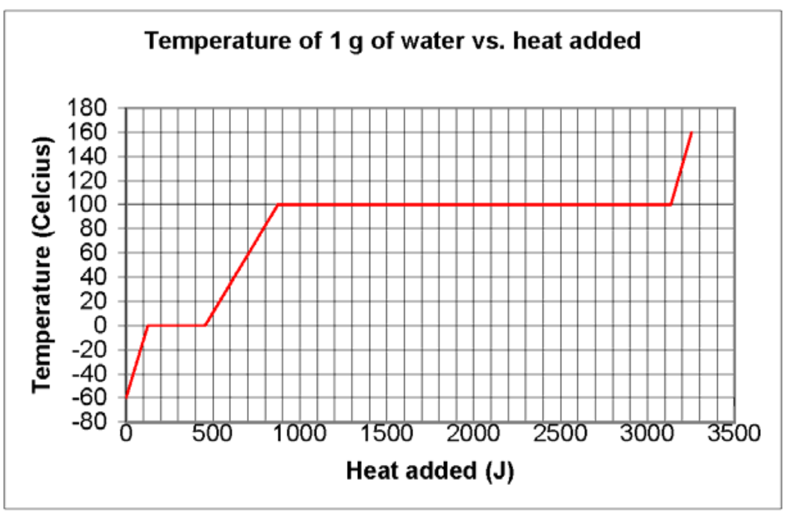
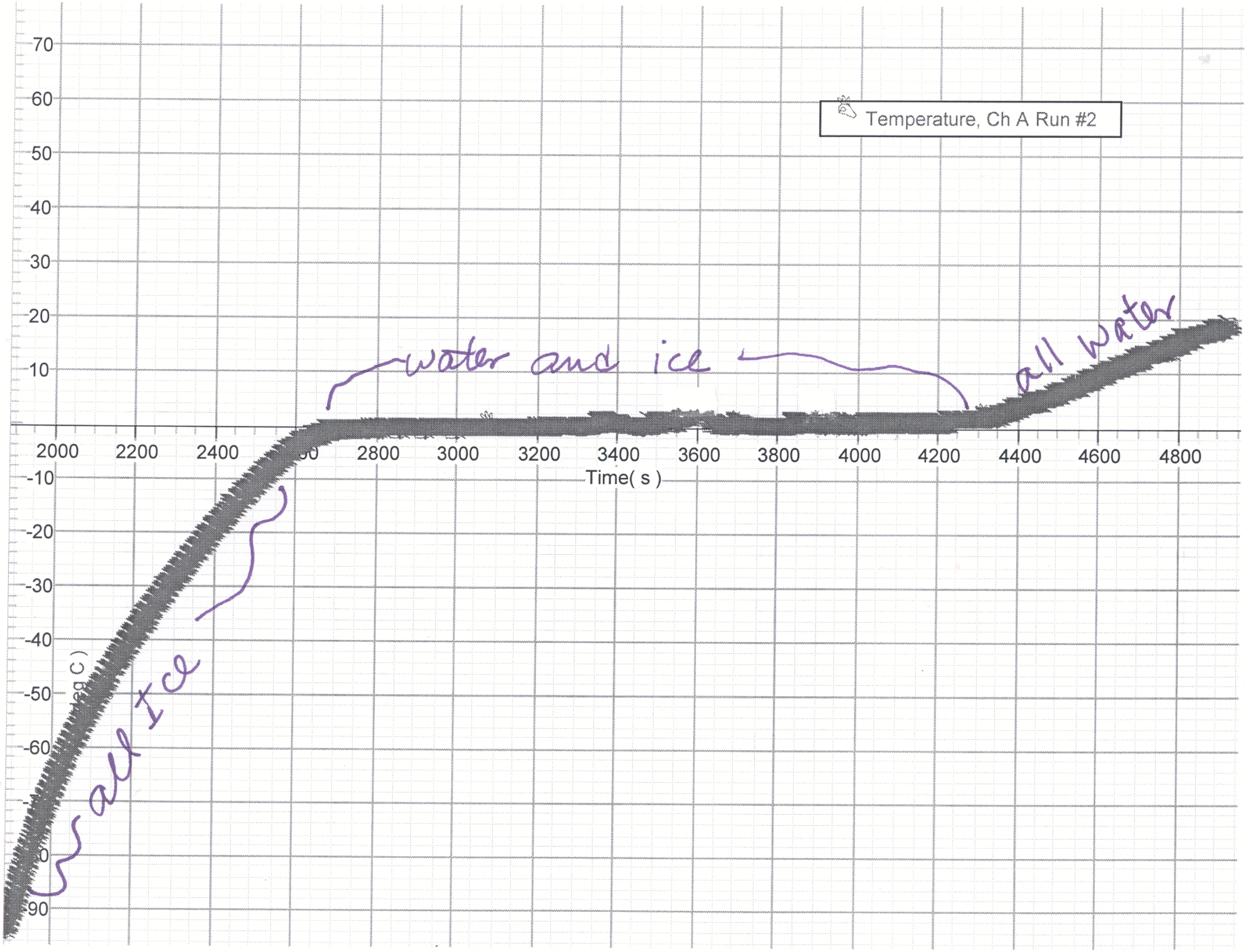


Figure 2: Theoretical graph of the change in temperature of water as heat is added.

Graph 1


Temperature, Ch A Run #2
70
60
50
40
30
20
10
-10
-20
-30
-40
-50
-60
90
2000
2200
2400
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
Time(s)
water and ice
all water
all Ice

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

Questions:

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?

PERHAPS BECAUSE AN ENVELOPE OF COLD AIR SURROUNDED THE WARMING VIAL, AND INHIBITED THE TEMPERATURE INCREASE. ALSO, THE GRAPH OF FIGURE 2 USES 'HEAT ADDED' FOR THE HORIZONTAL SCALE, AND OURS WAS 'TIME'. ANOTHER CONSIDERATION COULD BE THAT THE TEMPERATURE CHANGE OCCURS MORE RAPIDLY WHEN THE TEMPERATURES ARE SIGNIFICANTLY DIFFERENT, BUT MORE SLOWLY WHEN THE TEMPERATURES ARE CLOSER.

4. There is 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.

THE BONDS THAT CREATE THE ICE REQUIRE ENERGY TO BE BROKEN. THE TEMPERATURE STAYS CONSTANT WHEN THE ENERGY IS GOING INTO BREAKING THE BONDS, AND BEGINS TO RISE AFTER NO MORE ICE BONDS ARE PRESENT TO BREAK.

Name________**KEY**____________

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 the Earth? Consider all the possibilities, and explain each.

RADIATION: HEAT IS TRANSMITTED THROUGH EMPTY SPACE BY ELECTROMAGNETIC RADIATION.

CONVECTION OR CONDUCTION CANNOT OCCUR, AS THERE IS NO MATTER TO MOVE OR TRANSFER HEAT IN THE VACUUM OF SPACE BETWEEN US AND THE RED GIANT.

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

CONVECTION: THE MANTLE FLOWS VERY SLOWLY, BRINGING INTERIOR HEAT TO EARTH'S SURFACE.

CONDUCTION: PERHAPS A SIGNIFICANT FACTOR, TRANSMITTING HEAT THROUGH THE MANTLE FROM THE CORE TO THE SURFACE.

RADIATION: NOT A FACTOR, BECAUSE IT IS NOT EMPTY SPACE.

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?

HEAT IS TRANSMITTED THROUGH A SOLID STEEL DOOR BY CONDUCTION

4. What heat transfer mechanism(s) can transfer energy through the vacuum of space?

HEAT IS TRANSMITTED THROUGH THE VACUUM OF SPACE BY RADIATION

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

ADDING HEAT TO WATER BELOW BOILING TEMPERATURE WILL RAISE THE TEMPERATURE OF THE WATER. THE TEMPERATURE OF THE WATER REMAINS CONSTANT UNTIL ALL THE WATER HAS BOILED. IN A CONFINED SYSTEM, THE TEMPERATURE OF THE CAPTURED STEAM WILL RISE WITH ADDITIONAL HEAT ENERGY. THE THERMAL ENERGY OF THE WATER IS INCREASING IN ALL STEPS, BUT GOES INTO RELEASING THE MOLECULES TO STEAM INSTEAD OF RAISING THE TEMPERATURE.

6. 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).

THE WATER WILL GO FROM COOL TO FREEZING IN A CERTAIN LENGTH OF TIME. HOT WATER NEEDS TO BE COOLED FROM HOT TO COOL BEFORE THIS TIME BEGINS. HOT WATER TAKES LONGER TO FREEZE.

GS106
Lab Key #2

Temperature: A measurement of heat
Heat: A type of energy created by the motion of atoms and molecules. It is the energy transferred between two things due to temperature differences
Internal Energy: The total amount of energy in a substance due to the motion of the molecules or the potential energy of the substance. A substance doesn't contain heat it has internal energy.
Conduction: Transfer of heat through a solid by the vibration of molecules
Convection: Transfer of heat through a fluid by density differences
Radiation: Transfer of heat through a vacuum by waves

At absolute zero the heat for the object, the molecular motion and the internal energy are all low to zero

At room temperature there would be molecular motion so there would be internal energy and the transfer of heat

Part A

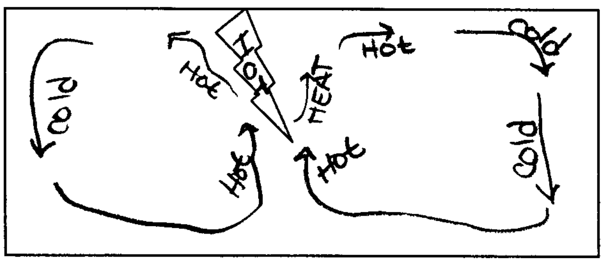
The best absorber would be the black and the worst would be the white paper.

Wearing white on a hot day reflects the heat so you don't get too hot. Just as a Lemur would want to have dark fur in the morning to absorb as much of the suns energy as possible.

Part B

The hottest is the metal spoon and the coolest is the wooden spoon. The best conductor therefore is the metal spoon and the worst would be the wooden one. This shows that metal absorbs and transmits heat much easier than wood. Therefore if I wanted to winterize my home (keep the heat in and the cold out) I would choose wood. This absorbs little of the interior heat and doesn't conduct it to the outside.

Part C

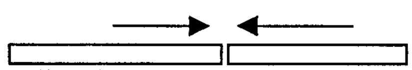


Convection works on density differnces. The hot fluid (be it air or water) has a lower density so it rises. The cold fluid has a higher density so it sinks. As the cold air at the bottom is warmed it rises and the warm air at the top loses it's heat so it begins to sink creating convection cells

Part D
The images in the scopes appear opposite than how they look because most scopes are made with mirrors which reverse the image you see.

You should have noticed for this experiment that the steel (iron) rod expanded more. This means that the iron has the higher thermal coefficient of expansion.

The tracks buckeled because the builders put the rails too close together:

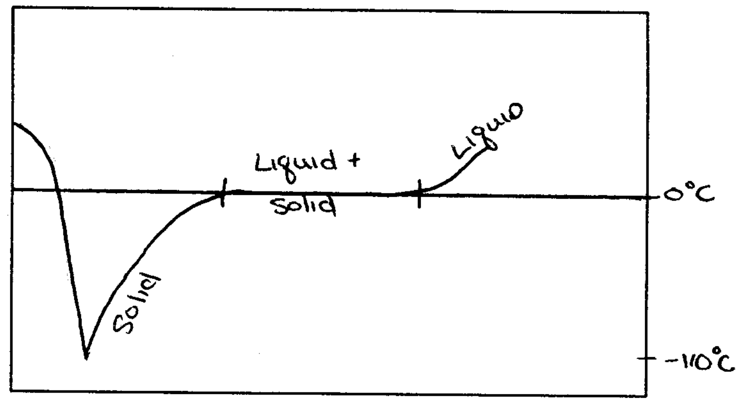


When the rails go hot they expanded and pushed into each other causing the rails to buckle

To build the model you would want to use aluminum rails to prevent any expansion and contraction problems

Part E
Water and phase changes.

The diagram shows the results of the experiment we did in lab. We froze water to about –100°C and then let it warm up. We measured the temperature of the water as the temperature changed. Some things to note. The water stayed at 0°C for about 20 minutes. While it was at this temperature, if you had gone to look in test tube you would have seen both phases (ice and liquid) in the tube. The temperature moved off of 0°C when the ice had all melted. The reason for this is that the energy being taking into the test tube was going to the phase change and not into a temperature change. Therefore the internal energy was increasing for the solution in the tube but the temperature was not.



Post Lab

When heat or energy is transferred through space (a vacuum) it is transferred as radiation. To transfer heat by conduction requires a fluid and there is no fluid in space and to transfer by conduction it requires a solid and space is a vacuum not a solid.

Transferring heat through the earth is done by conduction (solid regions: inner core, mesosphere and crust) and convection (fluid or plastic regions: outer core and asthenosphere)

Heat will transfer by conduction through a door

Temperature of water will increase until the water starts to boil. Then the internal energy will rise but the temperature will stay the same until all the water is converted from the liquid phase to the vapor phase. At this time the temperature will start to rise again.

Hot water takes longer to freeze than cold water. When the temperature difference between two objects is large the transfer of heat is rapid. This is the reason this myth became popular. If we think about hot water cooling down when it first starts to cool it cools very quickly. However, as it gets closer to freezing the heat transfer slows down. By starting with cold water we eliminate this first step of cooling down and go right to the slow part of the process. Both cold and hot water have to go through the slow cooling stage. See below