LAB 11 – THERMAL TOPICS

Goals:
- **Investigate cooling rates**
- **Investigate calorimetry principles using metal bolts and ice**
- **Calculate latent heat of fusion for water**

***** As soon as you start the lab, start boiling about 200-300 ml of water in the medium sized beaker using the hot plate - you will want to calibrate the temperature probes as one of the first activities, and you need the boiling water! *****
Make sure you plan ahead for boiling water to reduce waiting time!

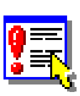
Introduction:

Measuring Temperature: Temperature is a quantity familiar to all of us. Thermometers register changes in temperature by using materials that change their properties as they are heated or cooled. For example, the column of liquid in a common thermometer expands when heated and contracts when cooled. Thus, the length of the column is longer or shorter depending on the temperature, and the instrument can be used to measure temperature. If the length of the column is associated with standard temperature units and scales such as Fahrenheit or Celsius, the thermometer is said to be *calibrated*.

Thermometers: There are many types of thermometers based on different physical properties that change with temperature. You will be using an electronic temperature probe connected to the computer. The probe works much like the digital thermometers available from hardware stores. As the temperature probe is heated or cooled its electrical properties change, and these changes are displayed on the computer screen as temperature readings. Using this temperature probe, you can display the temperature of the objects you touch with the probe. You can also have the computer display the measurements you take as graphs.

Thermal Equilibrium: The temperature probe always measures its own temperature. When you touch the probe to something, it takes a few seconds for the probe and the object to reach a common temperature. After this happens the probe is said to be in *thermal equilibrium* with the object it is touching. Objects reach thermal equilibrium by transferring heat back and forth. An object with the higher temperature transfers heat to an object with a lower temperature. To make accurate temperature measurements it is important to wait until the temperature reading of the probe remains fairly constant (until the temperature probe and the object are in thermal equilibrium).

Preliminary activities



1. Prepare equipment. Look at the online help page for this lab. Connect the temperature probe through the USBLink to a computer. Put the plastic sleeve around the sensor.

2. Load the experiment file. Download the file **Lab11_ThermalTopics.ds** from the lab schedule webpage and open it in DataStudio.

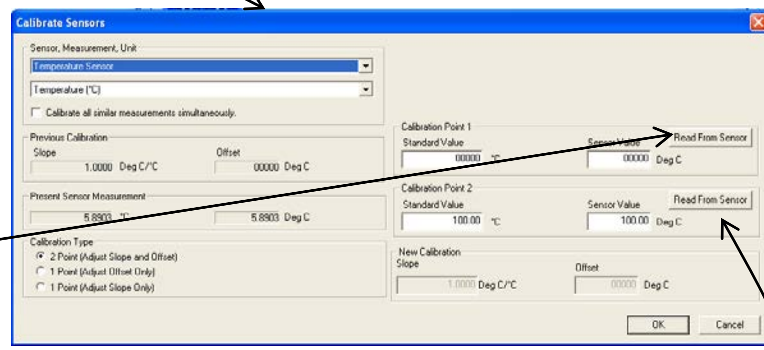
Part 1 - Calibration of the Temperature probe

1. Follow the steps below to calibrate the temperature probe in DataStudio.

1) Click the SETUP button 

in DataStudio. In the window pop-up, click the Calibrate Sensors button 

. This window will pop up.



2) Take some crushed ice, and immerse the temperature probe into some water-ice mixture, which is taken to have a temperature of 0°C; stir the probe for at least 30 seconds and make sure the probe tip does not touch the container. Click this button (Read From Sensor).
The Sensor Value box should now have a number close to 0.

3) Then immerse the temperature probe into boiling water, which is taken to have a temperature of 100°C; again stir the probe for at least 30 seconds. Make sure the probe tip does not touch the container. Click this button (Read From Sensor).
The Sensor value box should now have a number close to 100.

4) Click the OK button. The sensor calibration is complete.

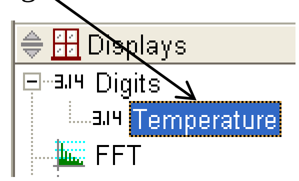
Part 2 Reaching Thermal Equilibrium

You can display a *history* of the probe's temperature by graphing the temperature readings over a period of time. Such temperature histories are often more useful for understanding temperature changes than single readings.

Prediction Answer on the Data/Question sheet
Suppose the temperature probe has been in hot water for some time. You now want to measure the temperature of water and/or air which are both at room temperature. Will it take longer for the probe to reach room temperature in water or air? Explain your reasoning.

Test your prediction.

1. Measure room air temperature. Enable the meter mode in DataStudio by clicking:



Hold the temperature probe motionless in the air, and record the temperature from the meter.

Air Temperature = ______ °C

Additional Setup: You need a source of hot water – put some of the original boiling water in the small beaker - it doesn't have to be boiling. Make sure the temperature is at least 80 degrees.

2. Put probe in water. The temperature probe should be in the hot water. Stir the water with the probe to make sure the temperature is uniform. Set the time axis to about 60 seconds. Set the graph to display

from 10 degrees to 40 degrees. Set up another beaker of room temperature water (water which has been sitting in the room for a long time).

3. Begin graphing temperature. Click on the START button. Let the graph record a few seconds of that constant temperature when the probe is still in the hot water.

4. Switch probe to room temperature water. Quickly move the temperature probe to the room temperature water. Stir and graph for the remainder of the 60 sec. Rename this data run ("water"). [Note: you will be storing several runs – you might find it useful to hide most of them, only show the ones you want to compare with each other. As you add a new one, hide the oldest one, etc.]

Approximately how long did it take the probe to reach room temperature? __________ sec
Measure from the time the temperature starts to drop from the original hot water temp.

5. Hot water to air. Now repeat this experiment moving the temperature probe from the hot water to air instead of room temperature water. Start graphing with the probe in the hot water – let several seconds elapse again, to record the initial temperature. Pull it out and away from the hot cup at the same moment as before, and dry the tip **quickly** with a small piece of paper towel, and then hold it in air. (Note: the temperature may not drop all the way to room temperature in the time allotted, that is no problem - you will still be able to compare the two rates of cooling.)

Question Answer on Data/Question Sheet.
Compare the time it took to reach room temperature to the time it took earlier when you put the probe into the room temperature water? What do you think is the reason for this?

6. Rename "dry still air" data run. Rename your data run ("dry still air"?).

7. Waving in air (dry probe). Repeat this experiment again with the probe starting in the hot water. This time, wave the probe vigorously in the air **after drying it**. [Hold the temperature probe by the **solid part** - don't swing the probe by the wire itself – you will damage the probe! Wave it the way you would "waggle" a pencil, between your fingers.]

Question Answer on Data/Question sheet.
Did it cool down at the same rate as without waving the probe? Explain.

8. Rename "dry moving air" data run. Rename your data run ("dry moving air").

9. Waving probe in air (wet probe). Repeat this experiment one last time. This time, wave the wet probe vigorously in the air without previously drying it.

Question Answer on Data/Question sheet.
Did it cool down at the same rate as waving the dry probe? How low did the temperature go? Did it go below room temperature?

10. Rename "wet moving air" data run. Rename your data run (named "wet moving air"). Save the experiment file, for future reference if necessary.

Questions Answer the questions for Part 2 on the Data/Question sheet.

Part 3 Heat Gain and Loss--Thermal Equilibrium of Hot Metal and Water

In this activity you will examine heat flow when a hot and a cold object are brought in contact with each other by observing temperature changes. You have already observed what characterizes the state of *thermal equilibrium* between the two objects: the objects reach a common temperature, and there is no longer a net heat flow between them.

1. Preparing numerical values. Record on the Data/Question Sheet the masses you will be using in this investigation.

2. Save the experiment file. ***Make sure your Part 2 data is saved*** and then clear all the data and save/rename it ("Lab10_Part3").

3. Make sure the bolt is at 100 degrees. If you haven't already done so, place the metal in boiling water so that it is completely immersed. This temperature should be 100 C.

4. Set up the water and get ready to graph. Put about 50 grams of cool water into the double Styrofoam cup. [You should know exactly how much water there is (determine its mass) - with that number being somewhere near 50 grams.] Put the temperature probe in the cup.

5. Start graphing. Click START, and stir the water constantly during the graphing. Wait 10 seconds to measure the initial temperature of the water.

6. Adding hot metal into cold water. Use the test-tube tongs and lift the metal bolt out and then into the Styrofoam cup. It is important to do this quickly! Try not to bring any hot water "cupped" in the bolt-hole as you transfer the bolt over. Keep stirring. After the temperature stops changing, stop graphing and record the initial and final temperatures of the water on the Data/Question sheet.

7. Calculate the heat transferred to the water in warming up. Use the mass, specific heat and temperature change of the water to calculate the heat transferred to the water. Show your calculations on the Data/Question sheet.

8. Calculate the heat transferred from the metal in cooling down. Use the mass, specific heat and temperature change of the aluminum to calculate the heat transferred from the metal. Show your calculations on the Data/Question sheet.

Questions Answer the following on the Data/Question sheet.

a) After you mixed the metal and the water together, what happened to the temperature of the water? What happened to the temperature of the metal?

b) Does the heat gained by the water equal the heat lost by the metal? If not, what is the percent difference between them?

c) What are the limitations in this experiment that might explain any differences in the previous question? (Suppose the value for ΔT_{metal} was less than what you used. Would that improve the differences? What could cause that?)

9. Calorimetry percent difference calculation. The heat gained by the water should equal the heat lost by the aluminum bolt. You can make a calculation to see how close they are to each other -- the percent difference. Find the percent difference between the heat gain and the heat loss and record it on the

Data/Question sheet. Ideally, this number should be small. For the lab report, use your answers to the above questions to explain the significance of the percent difference you calculate.

10. Save data. Make sure your final data file is saved.

Part 4 Melting Ice with Warm Water

In this activity you will transfer ice to a warm water mixture and by measuring the final temperature, you'll calculate the latent heat of fusion. Data here is used for Part 5.

1. Verify the graph settings. The time axis is set to 10 minutes (600 seconds), and the temperature axis should be set from 0° to 40°C.

2. Weigh the calorimetry cup. The double Styrofoam cup (with the aluminum foil inside) will be called the calorimetry cup. For some of the later measurements, you will need to know the mass of this cup. Find the mass of the calorimetry cup:

cup mass = _________ g ± _________ g (uncertainty of scale)

3. Cup with warm water. Using the mass scale, put about 200 grams of room-temperature water (from the "carboy" water container at the side of the room) into the calorimetry cup. Record the starting mass of the water (this is important, because you will be dumping an unknown amount of ice into the water)!

Total mass of cup and water = ________ grams
Total mass of room temperature water added to double Styrofoam cup = ________ grams
(Subtract the cup mass from the total mass)

4. Prepare the cup/temperature probe. Back at your station, put the temperature probe in the calorimetry cup and stir the water to make sure the probe and the water have come to thermal equilibrium. Prepare the foil "cover" to go over the top of the calorimetry cup.

5. Prepare the ice cubes. Take **1-2** small ice cubes and dry them with a paper towel. This is our unknown amount of ice, but you don't want to transfer water with the ice, just the "dried" ice cubes.

6. Start graphing – and then add ice. Click START to start taking data. Stir the temperature probe and make sure that graph shows the beginning temperature of the mixture. Using the paper towel to hold them, drop the ice cubes carefully into the water and put the foil cap over the top of the calorimetry cup.

7. Graphing and stirring. Continue to stir vigorously as you take the temperature history. **This cannot be stressed enough**: the stirring is very important to make sure the heat becomes distributed evenly around in the mixture -- if one portion heats up more than the other, the graph will reflect that fact.

8. When to stop graphing. Once all the ice has melted (you may have to periodically lift the cap to look in) you want to stop graphing so that you record the temperature as soon after the ice melted as possible. The temperature graph should show a leveling off (at a lower temperature than the initial one).

9. Final temperature. Using the SMART tool, record the temperature range (initial and final). Save the experiment file (with a different name).

10. Measure the final amount of water in the cup. Calculate the mass of ice that was added. To do this, subtract the cup and water mass (from Section 4.3) from the final total mass of the cup and water mass and record your answer on the Data/Question sheet.

Final mass of cup, water, and melted ice = ________g

Mass of ice =________g

Part 5 Thermal Energy Needed to Change Ice to Liquid Water

When ice melts at the melting point temperature, the ice absorbs the thermal energy needed to break down the rigid bonds holding the molecules together in the ice crystal structure. While this transformation takes place, the temperature of the mixture does not increase. But, in our experiment, where did this energy come from . It was provided by cooling the room temperature water.

The thermal energy required to melt one gram of ice when it is already at its melting point is called the **Latent Heat of Fusion**. (This amount of energy is the same as the amount given off when one gram of water is frozen to produce ice.)

You can calculate the approximate Latent Heat of Fusion for the ice to water transition by using your data from Part 4. The heat that leaves the water will melt the ice and then bring that "ice water" up to the final temperature of the mixture. The equations are as follows:

$$\Delta Q_{lost} = \Delta Q_{gained} \quad \Rightarrow \quad m_w c_w \Delta T_w = m_i L_f + m_i c_w \Delta T_i$$

$$L_f = \frac{m_w c_w \left(T_{initial} - T_{final}\right) - m_i c_w \left(T_{final} - 0\right)}{m_i}$$

1. Calculate the latent heat. Use the initial and final temperatures, the mass of the water, the mass of the ice, and calculate the latent heat of fusion. The specific heat capacity of water is used for both the original water and the "new" water created after the ice melted (c_{water} = 1 cal/gC = 4.184 J/gC). Show your calculations on Data/Question sheet.

Questions Answer on the Data/Question sheet.

a) Compare the heat needed to melt one gram of ice with the heat needed to raise the temperature of one gram of water by one degree Celsius. Discuss the result.

b) Compare your value for the Latent Heat of Fusion to the textbook value of 333.5 J/gram. Discuss the limitations in your experimental method that might account for any differences between these two values.

FINAL NOTE-TRANSFER ALL SAVED FILES TO YOUR OWN LAPTOP

Before leaving the lab: CLEANUP TIME!

To protect the life span of the equipment we are using — please make sure to DRY off the temperature probe with paper towel.

DATA/QUESTION SHEET — LAB 11
THERMAL TOPICS

Part 2 Reaching Thermal Equilibrium

Prediction Suppose the temperature probe has been in hot water for some time. You want to measure water and air which are both at room temperature. Will it take longer for the probe to reach room temperature in water or air? Explain your reasoning.

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1. Measure room air temperature.

Air Temperature = _________ ^{o}C

4. Switch probe to room temperature water.

Time for probe to reach room temperature = ____________sec

5. Hot water to air. Probe held still. (Dry probe)

Question How would you compare the time it took to reach room temperature to the time it took earlier when you put the probe in room temperature water? Why is this?

____

____

7. Hot water to air. Waving probe (Dry probe).

Question Did it cool down at the same rate as without waving the probe? Explain.

____

____

9. Hot water to air. Waving probe (Wet probe).

Questions from the End of Part 2:

a) Did the wet probe cool down at the same rate as waving the dry probe? How low did the temperature go? Did it go below room temperature?

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b) Why do you think that the probe takes longer to reach room temperature in air than it does in water?

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c) Why do you think that waving the dry probe around in the air makes it cool at a different rate? What does this do to the air near the probe?

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d) How do you explain the temperature graph that results when the probe is waved in the air while still wet? Hint: why do you feel cool when you get out of a swimming pool on a windy day even if the day is hot?

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Part 3 Heat Gain and Loss—Thermal Equilibrium of Hot Metal and Water

1. Preparing numerical values.

Mass of the double-Styrofoam calorimeter, m_{cup} = ______________g (copy to Part4.3)
Mass of the double-Styrofoam calorimeter + water, $m_{cup+water}$ =____________g
Mass of the water, $m_{cup+water} - m_{cup} = m_{water}$ = _____________g
Specific heat of water: c_{water} = 4.19 J/gC°

Mass of *Aluminum*; m_{al} =_______ g
Specific heat of the aluminum: c_{al} = 0.92 J/gC°

5, Start graphing and measure the temperature of the water.

Initial Temerature of the water, T_o = _______ ^oC

6. Hot metal into cold water.

Initial temperature of the metal: 100 °C
Final temperature of water and metal: T_f = _______ ^oC

7. Calculate the heat transferred to the water in warming up. Use the mass, specific heat and temperatures (from 1,5, and 6) to calculate the heat transferred to the water. Show your calculations.

$$Q_{gain} = m_{water} c_{water} \left(T_f - T_0\right)$$

Heat gained by the water: Q_{gain} = ___________ J

8. Calculate the heat transferred from the metal in cooling down. Use the mass, specific heat and temperature (from 1, 5, and 6) of the aluminum to calculate the heat transferred from the metal. (Remember the metal started at 100 degrees, and dropped to the final temperature – use the correct temperature change!) Show your calculations.

$$Q_{loss} = m_{al}c_{al}(100^oC - T_f)$$

Heat lost by the metal: Q_{loss} =__________ J

Questions a) After you mixed the metal and the water together, what happened to the temperature of the water? What happened to the temperature of the metal?

____

____

b) Does the heat gained by the water equal the heat lost by the metal? If not, what is the percent difference between them?

____

____

c) What are the limitations in this experiment that might explain any differences in the previous question? (Suppose the value for ΔT_{metal} was less than what you used, would that improve the differences? What could cause that?)

____

____

9. Calorimetry percent difference calculation. Find the percent difference between the heat gain, $Q_{gain} = x_1$, and the heat loss, $Q_{loss} = x_2$:

$$\%\ \text{diff} = \frac{|x_1 - x_2|}{\left((x_1 + x_2) / 2 \right)} x100$$

% diff = _________

Part 4 Melting Ice with Warm Water.

3. Mass of room temperature water.

Mass of the calorimetry cup, m_{cup} = _____________g (From Part 3.1)
Mass of the calorimetry cup + water, m_{cup+w} = ___________g (Copy to Part 4.10 also)
Mass of the water, $m_{cup+w} - m_{cup} = m_w$ = ____________g (copy to Part5.1)

9. Temperature range.

$T_{initial}$ = _______^{o}C (Copy to Part 5.1)
T_{final} = ________^{o}C (Copy to Part 5.1)

10. Measure the final amount of water in the cup.

Mass of the calorimetry cup + water, $m_{cup+water}$ =________g (from part 4.3)
Final mass of cup, water, and melted ice, $m_{cup+w+ice}$ = ________g
Mass of ice, $m_{cup+w+ice} - m_{cup+w} = m_i$ =________g (Copy to Part 5.1)

Part 5 Heat Energy Needed to Change Ice to Liquid Water.

1. Calculate the latent heat. Use the initial and final temperatures, the mass of the water, the mass of the ice, find the latent heat of fusion for water. The specific heat capacity of water is used for both the original water and the "new" water created after the ice melted (c_w = 4.19 J/gC^o).

m_w = _______ g m_i = ________ g
$T_{initial}$ = _______ ^{0}C T_{final} = ________ ^{0}C

$$L_f = \frac{m_w c_w\left(T_{initial} - T_{final}\right) - m_i c_w\left(T_{final} - 0\right)}{m_i}$$

Latent Heat of Fusion: ______ joules/gram

Questions a) Compare the heat needed to melt one gram of ice with the heat needed to raise the temperature of one gram of water by one degree Celsius. Discuss the result.

____

____

b) Compare your value for the Latent Heat of Fusion to the textbook value of 335 J/gram. Discuss the limitations in your experimental method that might account for any differences between these two values.

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____

FINAL NOTE – TRANSFER ALL SAVED FILES TO YOUR OWN LAPTOP

Questions/Suggestions → James Nolta - jnolta@LTU.EDU

Portions of this laboratory manual have been adapted from materials originally developed by Priscilla Laws, David Sokoloff and Ronald Thornton for the Tools for Scientific Thinking, RealTime Physics and Workshop Physics curricula. You are free to use (and modify) this laboratory manual only for non-commercial educational uses.