Lab 11: Temperature and Heat (M11)

Objectives

- Understand the difference between heat and temperature.
- Learn that heat is another form of energy.
- Measure the specific heat and the latent heat of fusion.

Terms[1]

Heat - Heat is the energy that flows from a hot body to a cold body when they are brought together. We measure heat in calories (cal) or in joules (J) because heat is a form of energy. 1 calorie (cal) = 4.186 joules (J)
Nutritionists use the word 'Calorie', with a capital C, to specify the energy contents of foods. This is unfortunate since: 1 Calorie (Cal) = 1000 cal = 1 kcal.

Temperature - Temperature is a measure of the average kinetic energy of the atoms in an object. Heat absorbed may cause the temperature to increase or cause the body to go through a change of state.

Thermal equilibrium - Two objects are in thermal equilibrium when they are in contact, but no longer exchange heat. If two objects have the same temperature, then they are in thermal equilibrium.

Change of state - During a change of state, heat continues to be absorbed. However, the motion of the atoms causes the bonds to break instead of raising the temperature. The change in the bond structure results in a transformation from solid to liquid or from liquid to gas. The process is reversed when going from gas to liquid or from liquid to solid and energy (e.g., heat of fusion) is released.

Heat capacity - It is the heat that must be supplied or removed to change the temperature of a substance of mass m by 1 ˚C (or 1 K).

Specific heat capacity (or specific heat) *c* - It is the heat that must be supplied or removed to change the temperature of a substance of unit mass (kg or g) by 1 ˚C (or 1 K). The specific heat is equal to the heat capacity of an object divided by its mass. The specific heat is characteristic for a material from which a given object is made. It does not depend

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[1] Sokoloff, David R. and Ronald K. Thornton, *Tools for Scientific Thinking: Heat and Temperature.* Vernier Software: 1993.

on the size or shape of the object. There is a relationship between heat (Q) and temperature changes (ΔT):

$$Q = mc\Delta T \,,$$

where m is the mass and c is the specific heat of the substance.

For water: c = 0.999±0.001 calorie/(gram∗˚C) ≈ 1.00±0.01 calorie/(gram∗˚C) or
c = 4183 J/(kg∗˚C) ≈ 4180 J/(kg∗˚C) at 20 ˚C.

Latent heat of fusion - The latent heat of fusion L_{fusion} is the heat that must be added when a unit mass of a substance changes from solid phase (e.g., ice) to liquid at a constant temperature. It is also equal to the heat that must be removed from that liquid to change into the solid phase at the same temperature (0 ˚C = 32 ˚F for water).

$Q_F = mL_{fusion}$, where: L_{fusion} is the latent heat of fusion, (L_{fusion}) = cal/gram.

For ice ↔ water phase transition: $L_{fusion} = 79.7 \pm 0.1$ cal/gram or $(= 333.7 \pm 0.4$ J/gram$)$

Calorimeter – A container that has particularly good thermal insulation from the outside and has a thermometer inside is usually called a calorimeter. Calorimeters are used in various thermodynamic measurements like heat of fusion or heat of reaction. For example, Dewar containers (thermos bottles) with vacuum thermal insulation could be used as calorimeters. In our lab, calorimeters are simply made of one aluminum can and a Styrofoam thermal insulation.

Set-up:

Warning: Hot plates will be used in this experiment to increase the temperature of water. There is an adjustment knob on the front of the hot plate for the temperature setting. Always turn the knob to "off" when you are not using the hot plate. **Use extreme care** when you are near the water, metal beaker, and hot plate. They **will become very hot**!

We will use the **Celsius scale** for temperature measurements. Remember, the Celsius temperature (T_C) is shifted by 273.15 ˚C from the absolute scale ($T_C = T_K - 273.15$) and is also related to the Fahrenheit scale:

$$T_F = \frac{9}{5}T_C + 32 \quad \text{and} \quad T_C = \frac{5}{9}(T_F - 32).$$

Please note that a change of one degree on the Celsius scale is equal to a change of one Kelvin (the absolute scale):

$$\Delta T = 1 \text{ ˚C} = 1 \text{ K}.$$

Procedure:

Login using your Purdue career account and download lab files for M11. Double-click on the "M11 Activities 1-3" icon that will be used during this lab. Temperature vs. time axes and a digital display of the temperature reading should appear.

Activity 1: The Temperature of the Room

The computer will plot temperature vs. time from the data collected from the thermal sensor located at the end of the temperature probe. Hold the temperature probe in the air and start data recording. Do not touch the probe near the end with the thermal sensor. However, if you wave the probe around or breathe on it, the reading will be distorted. Record the temperature of the room on your data sheet. Convert this Celsius degree measurement into degrees Fahrenheit and into Kelvins.

Activity 2: Cooling with Ice - Heat of Fusion Measurement

Using the scale provided, measure and record the mass of the metal container marked with a "#1". Find the mass of the empty container. Fill this container with approximately ~150 grams of water and measure the mass of container with water. Determine the mass of the water by subtracting the container's mass from the second measurement. <u>Make sure that the temperature sensor is always immersed in water!</u> Put the metal container "#1" on the top of the hot plate. **Do not touch the white top of the hot plate!** It could become extremely hot when turned on!

Turn on the hot plate and set it to "4" by rotating the knob on the right-hand side. <u>Start recording</u> the temperature of water inside the container #1 (i.e., click the "**Start**" button). For your own safety **<u>do not use any higher setting of the hot plate than "4"!</u>** The hot plate is large, so it takes time to worm it up. For a while, you will not see any temperature changes. Please, be patient. This part of the lab is going to take ~15-20 min.

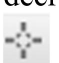
Once the temperature of the water approaches **70 ˚C, turn off the hotplate**. <u>You will not need the hotplate anymore</u>. Leave the container on the hotplate for 2-3 minutes; the temperature of water may go up by 2-3 degrees.

In the meantime, find the **calorimeter**. It consists of an aluminum container with the Styrofoam cup inside. <u>Measure the mass of the empty calorimeter</u> (that is the mass of the can, the Styrofoam cup, and the lid combined). Do not disassemble the calorimeter.

Remove the temperature sensor and carefully pour the **hot** water into the Styrofoam cup, which is located inside the metal can. Immediately, place the lid back on the calorimeter to prevent the occurrence of any heat loss. Continue recording the temperature of water inside the calorimeter. **Do not put the calorimeter on the hot plate.**

Let the probe's temperature reading climb back and stabilize. Wait 3-4 minutes to get a steady temperature reading, i.e., wait for the thermal equilibrium conditions. This will be your initial temperature T_i.

Measure the mass of the aluminum cup not marked with a '#1'. Add about 30-40 grams of ice to the water inside the calorimeter. Usually, you will need three "cylinders" of ice. While quickly removing the lid, do not splash the water when you add the ice to the liquid in the calorimeter (do **not** place the double-wall cup onto the hot plate). Put the lid back on the calorimeter and observe the temperature of the mixture plunge rapidly.

Assume that the initial temperature of ice is 0 ˚C. Remember that the heat will flow from the hot water to the ice. Record the final temperature T_f after the ice has melted, indicated by the stabilization of the temperature reading when thermal equilibrium conditions have been established. There will be 1 - 2 minutes of equilibrium before the temperature begins to slowly decrease. This is caused by heat loss through the calorimeter. You may use the "Smart Tool"  button to read-off values of the temperature from the graph.

Remove the temperature probe and measure the mass of the whole container. After placing the temperature sensor back into the calorimeter, subtract the mass of the water and complete calorimeter to determine the **exact** mass of the added ice.

Calculate the heat gained by ice and the heat lost by water. Are they equal? Make sure that you are using the correct masses of water and ice in calculating heat lost or gained.

Heat Q_L lost by the hot water during cooling from the initial temperature T_i to the final temperature (when the added ice is completely melted) T_f is given by the following expression.

$$Q_L = m_w c_w \left(T_i - T_f\right) \qquad , T_f < T_i$$

Heat Q_G gained by the added ice is used for two separate processes:

1. Melting ice that has been just added (Q_F),
2. Warming up the water from the melted ice (Q_W) to the final equilibrium temperature T_f.

$$Q_G = Q_F + Q_W$$

The heat needed to melt the ice without changing its temperature is given by the following formula:

$Q_F = m_{ice}\, L_{fusion}$ where L_{fusion} is the latent heat of fusion for the ice ↔ water phase transition

Determine the amount of heat gained by the water created from the melted ice as its temperature was raised from 0˚C to T_f. This water has the same mass as the ice before melting, i.e., m_{ice}.

$$Q_W = m_{ice}\, c_w (T_f - 0^\circ\text{C}) = m_{ice}\, c_w T_f$$

Since energy is conserved in the calorimeter, we can equate the heat lost to the heat gained:

$$Q_L = Q_G = Q_F + Q_W \quad \Rightarrow \quad m_w c_w \left(T_i - T_f\right) = m_{ice}\, L_{fusion} + m_{ice}\, c_w T_f$$

The last equation has only one unknown – L_{fusion}. Calculate the experimental value of the latent heat of fusion.

The precisely measured value of the latent heat of fusion is equal to:

$$L_{fusion\ prec} = 79.7 \pm 0.1 \ \text{cal/gram} \ \text{or} \ \left(333.7 \pm 0.4 \ \text{J/gram}\right)$$

Calculate the percent difference between your data and the above, precise value.

Activity 3: Specific Heat of Aluminum

Continue recording the temperature of water. Wait ~2 minutes to get a stable temperature reading. Measure the mass of the aluminum ring. Avoid warming the ring with your hands. You may grab it, but do not hold the ring any longer than it is necessary. When the temperature has become stable record the temperature. This will be your initial temperature T_i for this activity. Next, place the aluminum ring into the water by holding onto the string. Do not splash the water! The aluminum ring is initially at the room temperature T_{room} (you have measured it during *Activity 1*). The temperature of water should drop down by approx. 5-8 degrees Celsius. Allow enough time to achieve the new thermal equilibrium (i.e., equal temperatures of the water and the aluminum cylinder). Usually, it takes approximately 2-3 minutes. The temperature reading should stabilize again. Record the final temperature T_f. You may use the “Smart Tool”  button to read values of the temperature.

Since energy is conserved in the calorimeter, we can equate the heat lost by the hot water inside the calorimeter to the heat gained by the aluminum ring:

$$m_w c_w \left(T_i - T_f\right) = m_{Al} c_{Al} \left(T_f - T_{room}\right) .$$

Therefore
$$c_{Al} = \frac{m_w c_w \left(T_i - T_f\right)}{m_{Al}\left(T_f - T_{room}\right)} ,$$

where: c_w = 1.00 cal/(g ˚C) - specific heat of water.

Calculate the specific heat of aluminum: c_{Al}. Write the result on your data sheet.

The precisely measured value of the specific heat of aluminum is equal to:

$$c_{Al\ prec} = 0.215 \pm 0.002 \ \ \text{cal}/\left(\text{g}\cdot{}^\circ\text{C}\right) = 0.900 \pm 0.008 \ \text{J}/\left(\text{g}\cdot K\right)$$

The specific heat of aluminum is almost five times smaller than the specific heat of water! Calculate the percent difference between your data and the above value.

Note: Do not be surprised if you would get 20% or 30% difference between your results and the precise value. We have neglected the heat capacity of the calorimeter and the thermometer!

Stop data recording. **Print your graph**.

Do not forget to circle, on the printout of the temperature vs. time graph, the section during which ice was added to the calorimeter (label it as '**ice**'), and the section in which aluminum ring was added (label it as '**Al**').

When you are finished, **dump the water** from the calorimeter and quit the program by selecting Quit *Capstone* application. Do not save changes.

Complete the lab report and return it to the lab TA.

Logout from your account.

Make sure to complete the following tasks:

You must submit the answers to the prelaboratory questions online. (4 points)

1. Your completed and verified Data Sheets. (5 points)

3. The temperature vs. time graph (*Activity 3*). (1 point)

   (Title and write your name and those of your partners on each graph.)

3. Return the completed lab report to your lab TA.