Introduction to the Laws of Thermodynamics

Name________________________________ ID________________________ TA________________

Partners____

Date______________________________________ Section____________________________________

Caution

Use extreme caution when you handle the hot water, otherwise it may result in serious personal injuries.

Equipment needed: Two Styrofoam calorimeters, Outer and inner aluminum cups, a heater to produce hot water, two thermometers, a balance, tongs, and aluminum foil

Hints:
1. Heat radiates easily, so use the lids (aluminum foil, etc.) of cups always.
2. Please take a proper amount of waters. Otherwise, the water will overflow the cup when you mix them.

1. The first law of thermodynamics (Conservation of thermal energy)

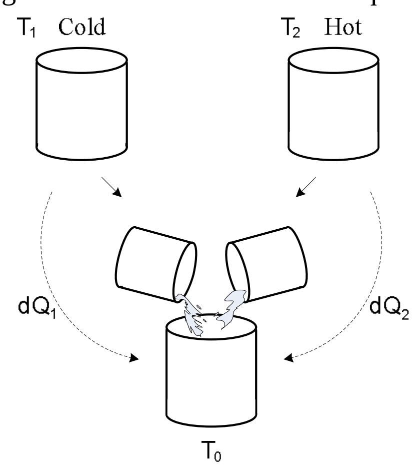
The first law gives the following relationship:

$$dU = dQ - dW$$

where dU is the change of internal energy (total energy), dQ is the change of heat energy, and dW is the change from work. For this part of experiment, there is no mechanical work to produce energy, so $dW = 0$. Thus we have

$$dU = dQ$$

Let us think of the following system. There are two containers with cold and hot water. Each has a temperature, and put them together to have a final state of equilibrium as follows:



The total energy changed, dU, is supposed to be conserved; therefore, $dU_1 = dU_2$. Using the above equation, you obtain $dQ_1 = dQ_2$. The change of heat energy can also be expressed as

$dQ = MC(dT)$, where M is the mass of the object, C is the heat capacity of the object, and dT is the change of temperature. Thus, you can have the following by considering the above figure:

$$M_1 C_W (T_0 - T_1) = M_2 C_W (T_2 - T_0)$$

where C_W is the heat capacity of water.

Procedure:

- **Weigh the cup** (for cold water) **and the other one** (for hot water) **without water.**
  This is to obtain the net mass of water. You always have to subtract the weights from the total mass of cup and water.

Mass of the cup for "cold water": M_{cold} ________________________________(kg)

Mass of the cup for "hot water": M_{hot} ________________________________(kg)

- **Make a lid for each cup with aluminum foil.**

- **Take hot water with a cup, and cold water with the other cup.**
  Take a small amount of waters, like 1/3 of the cup.

- **Weigh these for the total mass.**
  Use always lids to minimize the radiation of heat.

- **Measure the both temperatures at the same time with the PASCO interface.**
  These will be T1 and T2 after stabilized.

- **Pour the cold (hot) water into hot (cold) water, and measure the final temperature.**
  As specified, mix the waters, and stir it with thermometer appropriately. After stabilized, take the data for T0.

- **Calculate the energy transferred by following the data table.**
  The heat capacity of water is 4186 J/kg·K.

Cold to hot or hot to cold ?	Total mass of cup and cold water	Total mass of cup and hot water	Net mass of cold water M1	Net mass of hot water M2	Cold water temperature T1	Hot water temperature T2	Final temperature T0	M_1Cw(T0-T1) (J)	M_2Cw(T2-T0) (J)
Cold→Hot									
Cold→Hot									
Hot→Cold									
Hot→Cold									

Questions:

☑ Is the thermal energy conserved according to your experimental results?

☑ Why some case does not agree to the conservation of thermal energy? (Consider the heat capacitor of cups, heat dissipation, absorption, etc.)

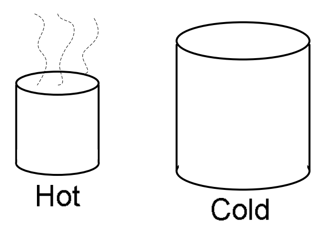
2. The second law of thermodynamics (Entropy)

The second law depicts that we cannot obtain work from heat completely in an isolated system. Systems are exchanging the energy in terms of work, heat energy and others. Entropy is the parameter to indicate the direction of the process which the energy tends to proceed. In an isolated system, the entropy increases; however, in an open system, it can be relative. The change of entropy, *dS*, is given as

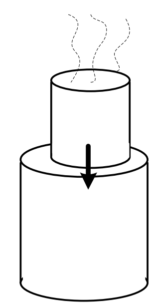
$$dS = \frac{dQ}{T}$$

where dQ is the change of heat and T is the equilibrium or temperature (or average between initial and final temperatures) in the Kelvin temperature scale.

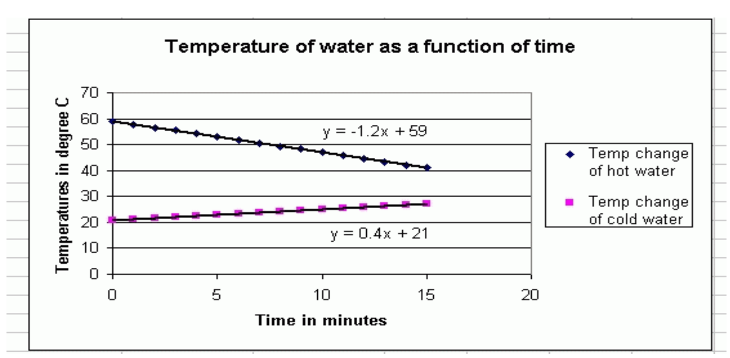
Procedure:



- **Find two aluminum containers. Weigh the small and large cups of calorimeter.**
- **Pour an appropriate amount of hot water into the small cup, and pour cold water into the large cup.**
- **Put the small into the large cup so that they can contact each other.**
  Use the tongs! This is the set-up to measure the heat transfer between two systems.
- **Turn on the interface, and plug two thermometers in the analog channels.**
  Or flexibly use a normal thermometer if necessary.



- **Put the thermometers into both hot and cold systems; then, wait for 15 minutes to have the data. Use a lid made of aluminum foil.**
- **Weigh the total masses of inside cup and outside cup, and calculate the masses of hot and cold water.**
- **From the initial and final temperatures, calculate each entropy.**
  Follow the data sheet. For the hot water, read the note.
- **From the data obtained by DataStudio, plot a graph as shown below.**



Mass of outside cup (larger one) of calorimeter ___________________________ (kg) **(1)**

Mass of inside cup (smaller one) of calorimeter ___________________________ (kg) **(2)**

☑ **Mass of water (excluding the cups masses):**

M_1 = Mass of inside cup (smaller one) + hot water – **(2) =** ___________________________(kg)

M_2 = Mass of outside cup (larger one) + cold water – **(1) =** __________________________(kg)

☑ **Calculation for the entropies:**
(T_i *and* T_f *are initial and final temperatures respectively*.)

<u>Cold water</u>

Heat change: $\Delta Q = M_1 C_W (T_f - T_i)$ = ____________________________(J)

Average temperature: $T_{ave} = (T_f + T_i)/2 + 273.15$ =__________________________ (K)

Entropy: $\Delta S = \Delta Q / T_{ave}$ =____ (J/K)

<u>Hot water</u>

Heat change: $\Delta Q = M_2 C_W (T_f - T_i)$ = ____________________________(J)

Average temperature: $T_{ave} = (T_f + T_i)/2 + 273.15$ =__________________________ (K)

Entropy: $\Delta S^{*} = \Delta Q / T_{ave}$ =____ (J/K)

*Note: In the hot water case, the entropy becomes negative. It seems that the law is violated. In fact the entropy increases in every natural process in an "isolated" system. In addition, only those processes are possible for which the entropy of the system increases or remains a constant. Therefore, the entropy of a non-isolated system may either increase, or decrease, depending on whether heat is added to or taken away from the system.

Questions:

☑ For this <u>incompletely</u> isolated system, which is the <u>magnitude</u> of entropy larger than the other?

☑ Discuss the answer for the previous question by reading the graph. (Think about the meaning of entropy.)

☑ Did you find out that the heat flows from a hot to a cold system by looking at the graph? Also explain it with the signs of entropy. (Read the above note.)