Supplemental Activity: Heat Exchange

Part 1: Mixing Warm and Cold Water

The amount of heat required to raise the temperature of a substance is given by the following formula:

$$Q = mc\Delta T$$

Where Q is the heat absorbed or released in Joules, m is the mass in kilograms, c is the specific heat capacity (4.186 kJ/kg$^\circ$C for water), and ΔT is the change in temperature in $^\circ$C. If a substance absorbs heat, then Q is positive; if a substance releases heat, then Q is negative.

When hot water is added to cold water, heat will flow from the hot water to the cold water until the combined mixture reaches thermal equilibrium. For a thermally insulated system there will be no net energy exchanged with the surroundings. If we apply the law of conservation of energy to our system:

$$\Delta E = 0 = Q_{\text{lost by hot water}} + Q_{\text{gained by cold water}}$$

In order for net energy to be zero, the energy gained by the cold water must be equal in magnitude to the energy lost by the hot water.

Objective: To show that energy is conserved when two samples of water at different temperatures are mixed together.

Overview of Experiment: You will add a sample of cold water to a sample of hot water and measure the equilibrium temperature. The amount of heat gained by the cold water will be equal in magnitude to the amount of heat lost by the hot water.

Equipment: hot plate, 2 beakers (one large and one medium), graduated cylinder, squeeze bottle, 2 Styrofoam cups, digital balance, 2 thermometers, and water.

Procedure:

1. Prepare the hot water. The hot water from the tap is not quite hot enough for this experiment. Use the hot plate and a large beaker to heat up about 250 ml of water. Be careful; monitor the temperature of the water so that the beaker does not get too hot to touch with your bare hand. Ideally the hot water should be between 60° and 80°C.
2. Fill a squeeze bottle with cold tap water and use the graduated cylinder to measure 25 ml of tap water into one of the Styrofoam cups. (Determine the water level in the graduated cylinder by reading the location of the bottom of the meniscus that the water column forms.)
3. Eventually we want to know the mass of the water not the volume of water. Since the density of water is 1.0 gram/ml. 25 ml of water will have a mass of 25 grams or 0.025 kilograms. The conversion from milliliters to kilograms has already been done for you in the data table.
4. Record the temperature of the tap water sample first—it will be at room temperature and will not be changing while it is in the cup. Record this temperature in the data table.
5. When the hot water is between 60°C and 80°C, measure 25 ml of hot water into the second Styrofoam cup. Place this Styrofoam cup in a beaker to stabilize the cup, and put a thermometer in the cup with the hot water.
6. Hold the room temperature sample above the hot water as you prepare to pour it into the hot water sample. Just before you pour the cold water into the hot water, record the temperature of the hot water.
7. Then, immediately pour the room temperature water into the hot water and quickly record the temperature of the resulting mixture.
8. Next try mixing different volumes of water. For trial 2, mix 60 ml of cold water with 30 ml of hot water. For trial 3, mix 30 ml of cold water with 60 ml of hot water. Record your results on the next page.

Data Table for Trial 1: Equal Volumes of Water

Cold Water				Hot Water			After Mixing
Trial	Volume (ml)	Mass (kg)	Initial Temperature (°C)	Volume (ml)	Mass (kg)	Initial Temperature (°C)	Final Temperature (°C)
1	25	0.025		25	0.025		

Calculations:

1) Calculate the temperature change for each sample and write your answers in the box below: $\Delta T = T_{final} - T_{initial}$

Temperature Change for Cold Water	Temperature Change for Hot Water

2) Calculate the heat gained by the cold water and the heat lost by the hot water and write your answers in the box below.

$Q = mc\Delta T$

Q = heat absorbed or lost in kilojoules (1 kJ = 1000 J)
ΔT = Change in temperature in °C
m = mass in kilograms
c = specific heat capacity (4.186 kJ/kg °C for water)

Q for Cold Water (kJ)	Q for Hot Water (kJ)

3) Calculate the percent difference using the formula below:

$$\%\text{difference} = \left|\frac{\text{heat lost - heat gained}}{\text{heat lost}}\right|$$

(Ignore all negative signs. Just use the absolute values of the quantities found.)

Data Table for Trial 2: Twice as Much Cold Water

Cold Water				Hot Water			After Mixing
Trial	Volume (ml)	Mass (kg)	Initial Temperature (°C)	Volume (ml)	Mass (kg)	Initial Temperature (°C)	Final Temperature (°C)
2	60	0.060		30	0.030		

Temperature Change for Cold Water	Temperature Change for Hot Water

Q for Cold Water (kJ)	Q for Hot Water (kJ)

Percent Difference	

Data Table for Trial 3: Twice as Much Hot Water

Cold Water				Hot Water			After Mixing
Trial	Volume (ml)	Mass (kg)	Initial Temperature (°C)	Volume (ml)	Mass (kg)	Initial Temperature (°C)	Final Temperature (°C)
3	30	0.030		60	0.060		

Temperature Change for Cold Water	Temperature Change for Hot Water

Q for Cold Water (kJ)	Q for Hot Water (kJ)

Percent Difference	

Questions for Part 1:

1. Does the hot water ***always*** change by the same amount as the cold water? In other words, if the hot water cooled by twenty degrees, does the cold water increase by twenty degrees?

2. In which trial did the cold water have the biggest temperature change? Why?

3. Energy will always flow from the hot water to the cold water until the combined mixture reaches the same temperature. In terms of energy, why is it that when the hot water sample is much larger than the cold water sample, the cold water has the biggest temperature change?

Part 2: Experimentally Determining the Specific Heat of Aluminum

Objective: to determine the specific heat of metal.

Overview of Experiment: You will heat an aluminum sample and add it to a cup of cold water. When hot metal is added to cold water, heat from the metal will flow from the metal to the water until they reach thermal equilibrium. The heat gained by the water will be equal in magnitude to the heat lost by the metal.

Equipment: hot plate, steam generator, aluminum sample, (2) thermometers, Styrofoam cup, water, and digital balance.

Procedure:

1. Fill your steam generator about three-quarters full with water, place it on the hot plate, and turn the hot plate on to full power. Once the hot plate has been turned on, do not touch the surface of the hot plate or the steam generator. Failure to follow these instructions could lead to severe burns.
2. Place a weighing boat on the balance and zero the balance. Fill the specimen cup about three-quarters full of aluminum metal and add it to the weighing boat. Record the mass of the aluminum metal in the data table.
3. Put the aluminum metal back in the specimen cup and place the specimen cup into the steam generator. Insert one thermometer into the specimen cup. Leave the metal in the steam generator until the temperature of the metal exceeds 80°C.
4. Place an empty Styrofoam cup on the balance and zero the balance. Add cold water to the cup on the balance until the cup is about one-half full of water. Record the mass of water in the data table and put this Styrofoam cup in a beaker.
5. Measure the temperature of the water in the cup and record this temperature in the data table.
6. Once the aluminum metal has achieved the desired temperature you will add the metal to the Styrofoam cup with cold water. However, you need to take and record the temperature of the metal *immediately* before you pour the metal. So, hold the specimen cup over the Styrofoam cup, measure the temperature of the metal and then carefully pour the metal into the Styrofoam cup. Do not splash any of the cold water out of the cup.

7. Hold one thermometer so that it records the temperature of the water, not the metal. Hold the second thermometer so that it touches the metal at the bottom of the cup. Observe both thermometers and record the equilibrium temperature.
8. When you are done carefully pour the water out of the cup. Put the aluminum metal on a paper towel to dry and leave it by the sink.

Mass of Cold Water (kilograms)	Temperature of Cold Water Before Mixing (°C)	Mass of Aluminum Metal (kilograms)	Temperature of Hot Aluminum Before Mixing (°C)	Final Temperature (°C)

Calculations and Questions for Part 2

1. Use the formula: $Q = mc\Delta T$ to calculate the amount of heat gained by the water. In the formula, m is the mass of cold water in kilograms, c = 4.186 kJ/kg°C, and ΔT is the temperature change of the cold water. You are solving for Q. Show your work in the space below.

2. Using the fact that the heat lost by the metal equals the heat gained by the metal, use the formula: $Q = mc\Delta T$ to calculate the specific heat of aluminum. In the formula, Q is the amount of heat lost by aluminum, m is the mass of

aluminum, ΔT is the change of temperature of aluminum, and you are solving for c, the specific heat of aluminum. Show your work in the space below.

3. The specific heat of aluminum is known to be 0.900 kJ/kg °C. Calculate a percent difference between this theoretical value and your experimental value. Show your work in the space below.

$$\%\text{difference} = \left| \frac{\text{Theoretical - Experimental}}{\text{Theoretical}} \right| \times 100$$

4. What is the main source of error in this experiment? How would you modify this experiment to minimize the error?