# SPECIFIC HEAT CAPACITY AND HEAT OF FUSION

**Apparatus on each table:** Thermometer, metal cube, complete calorimeter, outer calorimeter can (aluminum only), balance, 4 styrofoam cups, graduated container, cube lifting tool
**On back counter:** coffee urn heating water, large bucket of ice

**THEORY:** The change in kinetic energy of molecules in matter is referred to as thermal energy transfer or simply "heat" and is symbolized by letters $\Delta Q$. Like all types of energy, the SI units for heat are Joules. Any material is capable of gaining, losing, or storing heat, yet the exact quantity depends on the amount of material, the type of material, and the temperature change that the material undergoes.

For example, using exactly the same heating system, it takes much longer and therefore much more energy to boil a large pot of water than it does to boil a small cup of water. Thus, the amount of heat that the material absorbs is dependent on the mass (m) of the material.

Additionally, a cup of water warmed through a temperature change of 50 $C^{\circ}$ requires only half as much heat energy as the same cup of water warmed through a temperature change of 100 $C^{\circ}$. Therefore, the ability to hold heat is dependent on the temperature change ($\Delta T$) as well as the mass.

The final consideration is the type or composition of the material. A piece of iron will not be able to hold as much heat energy as a piece of wood of the same mass that is heated through the same temperature change. (This is why iron metal may feel either hotter or colder than wood when at exactly the same temperature as the wood. The energy either escapes from iron to your hand more readily or is absorbed into iron from your hand more readily.)

The precise amount of ***heat energy it takes to raise the temperature of a unit mass of material by one $C^{\circ}$ is called the*** ***<u>specific heat capacity</u> (c)*** and is intrinsic to the type of material. Remember, the process is reversible so the specific heat capacity also indicates the amount of energy removed from a unit mass in order to lower its temperature by one $C^{\circ}$.

Defining the change in heat or the amount of heat supplied or removed from an object as $\Delta Q$, the temperature change as $\Delta T$ and the mass of the object as m, the specific heat capacity, c, is expressed as

$$c = \Delta Q/(m\ \Delta T) \quad \text{or} \quad \Delta Q = mc\Delta T$$

The amount of heat gained or lost may be measured in joules, calories, or nutritional Calories (4186 joules=1000 calories= 1 Calorie). The object mass may be measured in kilograms or grams and the temperature change in degrees Celsius or Kelvin. Most commonly, the specific heat capacity then has the units cal/(gm $^{o}$C) or J/(Kg $^{o}$C). A calorie is defined as the amount of heat required to change the temperature of one gram of water by 1 celsius degree. Since it takes 1 calorie to raise the temperature of water by one degree Celsius, the specific heat capacity of water is 1.00 cal/(gm $^{o}$C). Nevertheless, because the Joule is the standard SI unit for energy and the Kilogram the SI unit for mass, the specific heat capacity of water must be converted to Joules/(Kg $^{o}$C) for use in today's experiment.

In order to determine the specific heat capacity of an unknown material, a "method of mixtures" procedure will be used. The principle of conservation of energy states that no energy may be created or destroyed but only changed in form. If the method of mixtures occurs in an isolated system where no energy can enter or leave, the only change which can occur is the transfer of heat from one object to another. Thus, the hot material(s) will lose heat to the cool object(s) until such time as the temperatures of all the objects will be equal (reach equilibrium). If more than one object is losing or gaining heat, the total heat lost by all of those objects losing heat will be equal to the total of the heat gained by those objects gaining heat. By convention, any gain of heat energy is indicated by a positive $+\Delta Q$, and a loss by a negative $-\Delta Q$. Because each substance has its own distinct specific heat capacity, c there must always be a separate $\Delta Q$ expression for each material in a given system.

As you may know, it is not always the case that an object must have a temperature change in order to gain or lose heat. If the object changes its state from a solid to a liquid or from a liquid to a gas, it must also gain heat. The amount of heat gained is given by

$$\Delta Q = m\ H$$

During this change of state, the object will gain heat but the temperature will not change because, rather than increasing the molecular kinetic energy, the heat will instead be used to break bonds between molecules. Similarly, if the object is converted from a gas to a liquid or from a liquid to a solid, heat removed from the object allows bonds to form. The amount of heat required to cause the state change will be dependent on the amount of material which changed state as well as on the type of material of which the object is composed. (Since $\Delta T$ is zero, it is not relevant here, nor is the expression $mc\Delta T$.) The ***heat of fusion*, $H_f$, is the amount of heat needed to change unit mass of a solid to a liquid** at the same temperature. The ***heat of vaporization*, $H_v$, is the amount of heat needed to change unit mass of liquid to a gas** at the same temperature. The unit for the heat of fusion or heat of vaporization may be cal/gm, J/gm, or Cal/kg. For today's laboratory experiment, we will strictly use SI units Joules, kilograms, and Celsius degrees for our calculations.

**PROCEDURE:**

1. Determine the mass of each of the two dry double-walled styrofoam containers. From the tap, fill one container about one-third of the way with cold water, and place very hot tap water in the other container to about the same level. Determine the mass of cold water and the mass of hot water. Determine the temperature of each container of water. ***Immediately*** after measuring the temperatures, pour the cold water into the hot water, cover, stir gently and find the experimental equilibrium temperature with the thermometer. Though it has a quite large specific heat capacity, the styrofoam cup has very little mass and negligible $\Delta T$ (which is why you can hold boiling hot coffee without getting burned), so the $\Delta Q$ expression for the cup can be neglected. The cold water gained heat and the hot water lost heat. Since we consider all of the heat lost from the hot water as being gained by the cold, you should now be able to calculate a theoretical equilibrium temperature from $-\Delta Q_{hot} = +\Delta Q_{cold}$, or

$$-m_h c\ (T_e - T_h) = +m_c c\ (T_e - T_c)$$

You know the two masses and the hot and cold temperatures as well as c for water (4186 J/kg °C). Therefore, you can solve for $T_e$. (Don't plug in the $T_e$ that you measured with the thermometer! Solve for it!) Find the %diff between your calculated and measured values. If it is greater than 15%, repeat step 1.

2. Determine the mass of the dry inner aluminum can of the calorimeter (today better referred to as a "joulemeter"!) Fill it nearly half full of cold water. Determine the mass of cold water. Place the can into the calorimeter. Measure the temperature of the water and inner can. If the water's been in the can for at least a few minutes, they will have reached equilibrium and the can will have the same initial temperature as the water.

3. Get a styrofoam container of very hot water from the coffee urn. The instant before you pour enough of the hot water into the calorimeter inner can to nearly fill it, quickly measure the initial temperature of the hot water.

4. Stir until equilibrium is reached in the system and record the temperature. This time, the hot water lost heat, the cold water gained heat *as did the can*. Determine the amount of hot water you poured into the calorimeter. Using the information recorded, determine the specific heat capacity of the inner can of the calorimeter. Again use $-\Delta Q_{hot} = +\Delta Q_{cold}$
this time including a $\Delta Q$ expression for the container, which we cannot neglect as we did the Styrofoam:

$$-m_h C_w\ (T_e - T_h) = +m_c C_w\ (T_e - T_c) + m_{can} C_{can}\ (T_e - T_{can})$$

5. Empty the inner container and refill approximately half full with cold water. Determine the mass and temperature of the cold water just before obtaining a hot object from your boiling pot. Note temperature of the boiling water which should be the same as the hot object. Place the hot object into your container of water. Gently stir the contents until an equilibrium temperature is reached. When the temperature stops rising, the equilibrium has been reached. Remove the object, dry it and determine its mass. The object lost heat and the water and can gained heat. Determine the specific heat capacity of the object. Use the specific heat capacity to identify the object from a list of possibilities. If you have taken poor measurements, be prepared to repeat all of step 5 before continuing.

6. Fill your inner container 2/3 full of hot water from the coffee urn. Determine the mass of water and its temperature. Drop three cubes or spoonfuls of ice into the hot water and gently stir until the ice is all melted. Record the equilibrium temperature. Determine the amount of water in the container. The difference in water mass before and after ice was added is the mass of ice which melted. The ice melted at 0°C and became cold water at 0°C. This cold water then warmed to the equilibrium temperature. The hot water from the urn cooled, giving its heat to the ice and then to the cold water. From the data recorded determine the heat of fusion of the ice. Calculate %error vs. value from textbook. Again from $-\Delta Q_{hot} = +\Delta Q_{cold}$

$$-m_h C_w (T_e - T_h) = +m_i C_w (T_e - 0) + m_{can} C_{can} (T_e - T_h) + m_i H_f$$

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Textbook Specific Heat Capacities at 25˚C and 101300 Pa

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|---|---|
| Aluminum | 900 J/kgC |
| Copper | 387 |
| Iron | 448 |
| Lead | 128 |
| Brass | 380 |
| Glass | 837 |
| Ice | 2090 |
| Wood | 1700 |
| Alcohol | 2400 |
| Mercury | 140 |
| Water | 4186 |
| Steam | 2010 |

Step 1.

Mass of styrofoam cup #1_________    Mass of cup #2 __________

mass of cold water ______________    mass of hot water __________

Temp of cold water ______________    Temp of hot water __________

Exper. Equilib. Temp. _______  Calculated Equilib. Temp.________

%difference _____________

Steps 2, 3, & 4

Mass of inner can _____________

Mass of cold water ____________    Temp. of cold water _________

Temp of hot water ____________    Mass of hot water __________

Equilibrium Temp. _____________   Specific Heat of inner can ____

5.

Mass of inner can ______  Actual heat capacity of can 900 J/kgC

Mass of cold water ____________    Temp. of cold water _________

Temp of hot object ____________    Mass of hot object __________

Equilibrium Temp. _____________   Specific Heat of object _______

6.

Mass of hot water _____________    Temp. of hot water __________

Mass of ice and water _________    Mass of ice melted __________

Temp. of ice __________    Temp of ice at melting ___________

Equilibrium temp. _______    Exp.Heat of fusion for ice ______

Textbook Heat of fusion for ice: 334944 J/Kg  %error ____________