Heat and Heat Capacity

Today, we will discuss matters of energy. **Heat**, denoted q, is thermal energy exchanged between systems that are in contact. In order to raise or lower the temperature of a system, *heat* must be added or removed from that system. When heat is added to a system, the atoms and molecules in that system move faster and have more collisions with one another. When heat is added the temperature goes up. When heat is removed, the molecules slow down and have less collisions causing the temperature to decrease.

Heat always flows from the object that is higher in temperature to the object which is lower in temperature. This, in turn, will stabilize the temperatures of the two substances which are in contact. If the substances continue to stay in contact, the temperatures will eventually settle and become equivalent.

Energy is measured in the SI unit called a *joule*. Energy is often calculated in terms of **work**. Work is a type of energy which can be used to perform tasks and cause changes in objects with mass. We can remember the units for energy through learning and knowing the definition for work. Work is defined as a force acting across a distance ($W = Fd$). To remember the units for energy we must learn and remember the formulas for force ($F = ma$), acceleration ($a = \frac{\triangle v}{\triangle t}$), and velocity ($v = \frac{\triangle x}{\triangle t}$) as well as the standard units for those calculations. These are central and fundamental definitions that are worth learning. It will save a lot of confusion in the long run.

$$Work = Force \times distance$$

$$Force = mass \times acceleration$$

Force has units $kg \cdot \frac{m}{s^2}$. This is the definition of 1 Newton ($1\ kg \cdot \frac{m}{s^2} = 1\ N$).

The **kilogram** (kg) is the SI unit for *mass*. The unit for *acceleration* is **meters per second squared** (m/s^2). This comes from the definitions of velocity and acceleration.

$$acceleration = \frac{change\ in\ velocity}{change\ in\ time} \qquad velocity = \frac{change\ in\ distance}{change\ in\ time}$$

The **meter** is the SI unit for *distance*. Distance divided by time gives velocity the units meters per second (m/s). Therefore, acceleration has units $\frac{m/s}{s} = m/s^2$).

Once more, a joule is a force across a distance (unit: *newton-meter* | $N \cdot m$). Therefore:

$$1\ J = 1\ N \cdot m = 1\ (kg \cdot \frac{m}{s^2}) \cdot m = 1\ kg \cdot \frac{m^2}{s^2}.$$

Heat can be calculated in its own special way. The joule is also the unit for heat energy. I defined the joule using work to provide intuition about how energy relates to motion and mass. The calculation for heat also involves mass and motion, but in a more subtle way. The formula to solve for heat (q) is as follows:

$$q = mC_s(\triangle T) \qquad\qquad \triangle T = T_{final} - T_{initial}$$

If a change in temperature occurs, the heat transferred by an object in question can be calculated by multiplying **mass** (m), the material's **specific heat capacity** (C_s), and the **change in temperature** ($\triangle T$). **Heat capacity** is a physical property of matter that defines the amount of heat that you have to supply a certain material in order to produce a certain change in temperature. Remember, temperature has to do with the speed of atoms/molecules and their collisions. In this way it becomes apparent how work is related to heat. Heat is just tiny, molecular-scale work! Measuring temperature change is our large scale way of keeping up with many tiny accelerations and forces (collisions) acting on tiny molecular/atomic masses.

The SI unit for specific heat capacity is $\frac{J}{kg \cdot K}$, where K is the temperature in Kelvin scale. A change in one degree is the same "distance" in Kelvin as it is in Celsius ($T_{Kelvin} = T_{Celsius} + 273$), so specific heat capacity can also be expressed as $\frac{J}{kg \cdot {}^\circ C}$. Our lab thermometer measures Celsius so we will use this unit.

Notice how the units for the heat formula all cancel to joules:

$$q = mC_s(\triangle T) \qquad \text{yields the units} \qquad kg \times \frac{J}{kg \cdot {}^\circ C} \times^\circ C \Rightarrow J.$$

If you heat a metal cube and then transfer it into a cup of room temperature water, the cube will transfer heat into the water. Remember, heat always flows from the hotter object into the cooler object. As a result of this heat, the temperatures of each object will change. The metal will have a negative change in temperature because it decreases in temperature. The water will have a positive change in temperature because it will increase in temperature. The metal and water will probably not have the same temperature change since their masses and heat capacities are different. One thing is true, however. The heat absorbed by the water is equal but opposite to the heat released by the metal. The same amount of heat is exchanged between the two objects. In thermodynamics, absorbed heat is positive and released heat is negative.

$$q_{water} = -q_{metal}$$

We will use $_w$ to denote water and $_m$ to denote metal. This gives us the equation:

$$m_w C_w(\triangle T_w) = -[m_m C_m(\triangle T_m)]$$

The specific heat capacity of water is a known value: $C_w = 4.184\ \frac{J}{g \cdot {}^\circ C}$. Our masses will be in grams so this is a more convenient unit than the C_w value with kg in the denominator.

It is simple to perform an experiment where you measure and record the **mass** and **temperature change** for both the *metal* and *water*. Let's perform this experiment to calculate the heat capacity of the metal. Here is the above equation solved for the specific heat capacity of the metal.

$$C_m = -\frac{m_w C_w(\triangle T_w)}{m_m(\triangle T_m}$$

Data and Observations:

Mass of Water:

Mass of Metal:

Initial Temperature of Water:

Initial Temperature of Metal:

Final Temperature of Water:

Final Temperature of Metal:

$\triangle T_{water} = T_f - T_i =$

$\triangle T_{metal} = T_f - T_i =$

$C_m = -\frac{m_w C_w(\triangle T_w)}{m_m(\triangle T_m} =$

Calculate the percent error for your value vs. the literature value:

$$\%\ error = \frac{Experimental\ Value - Literature\ Value}{Literature\ Value} =$$