Chapter 15: Temperature and Matter

Thermal Motion

- The atoms in a substance, e.g. a piece of aluminum, undergo microscopic motion. If you could see them they would appear to be vibrating randomly. As a result they have an average kinetic energy. This random, microscopic motion is called thermal motion.

- The temperature of the aluminum is proportional to the average translational kinetic energy per atom, or molecule, associated with this random, microscopic motion. (I'll just call this the average kinetic energy per atom or molecule.)

- The greater the temperature the greater the thermal motion. (Note that the temperature is proportional to the kinetic energy. If a piece of aluminum and a piece of lead are at the same temperature, the atoms in each have the same average kinetic energy due to thermal motion. However, the lead atoms have a lower average speed because they are more massive than the aluminum atoms, and will have the same KE when they are moving more slowly.)

- There may also be a potential energy associated with this thermal motion. The bonds between atoms in a solid or liquid act like springs, when you compress or stretch them they store potential energy. The vibrations due to thermal motions stretch and compress these bonds (i.e. springs) producing potential energy. Therefore some of the energy associated with this thermal motion is stored as potential energy.

Temperature

- The temperature of a material is proportional to the average (translational) kinetic energy per atom or molecule associated with this thermal motion. This temperature scale is called the absolute or Kelvin temperature. At 0 Kelvin, the thermal motion is a minimum. If I double the average kinetic energy per atom or molecule, I will double the temperature in Kelvin. For example, if the air outside is 200 K and I want to double the average kinetic energy per molecule, I would have to increase the temperature to 400 K.

- 0K is called absolute zero and corresponds to -273°C or -459°F. Water freezes at 273K or 0°C or 32°F. Water boils at 373K or 100°C or 212°F. If I know the temperature in centigrade, T_C, the temperature in Kelvin, T_K, is T_K = T_C + 273

- A change of 1°C is equal to a change of 1K which is equal to a change of 1.8°F.

- When you bring two materials together they will exchange thermal energy until their temperatures are the same. When their temperatures are the same they are said to be in thermal equilibrium.

- The amount of thermal energy transferred from one object to another is called HEAT. Therefore heat is an amount of energy.

Specific Heat and Heat Capacity

- If you want to increase the temperature of a piece of aluminum, you have to increase the average kinetic energy per atom, i.e. you have to add energy to increase the thermal motion.
The amount of energy you must add to increase the temperature of 1 kg of material 1 K is called the specific heat of the material. For instance it takes about 4184 J of energy, or heat, to raise the temperature of 1 kg of liquid water 1 °C or 1 K. The specific heat is 4184 J/(kg•deg.C) or approximately 4200 J/(kg•deg.C).

To raise temperature of a mass, M, of a material T degrees requires an amount of heat

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\text{Heat} = \text{Specific Heat} \times M \times T
\]

Therefore to raise the temperature of 2 kg of water 10 °C requires about (rounding 4184 to 4200)

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4200 \text{ J/(kg deg.C)} \times 2 \text{ kg} \times 10 \text{ °C} = 84,000 \text{ J}
\]

- The specific heat of water is relatively large compared to many other materials. (Lead’s is about 130 J/(kg deg.C) and Aluminum’s is 900 J/(kg deg.C).)
- One reason different substances have different specific heats is that they do not all contain the same numbers of atoms per kilogram. 1 kg of Aluminum contains many more atoms than 1 kg of lead. Also, as you add energy some of it goes to increasing the average kinetic energy per atom, but some may go to increase the potential energy associated with the thermal motion. These potential energies are not the same for all substances.

**Thermal Expansion**

- Most, but not all, materials expand when their temperature increases and shrink as their temperature decreases. Solids and liquids usually expand slowly with an increase in temperature. Gasses tend to expand much more rapidly with temperature changes at a constant pressure.
- One common method of measuring temperature is to use thermal expansion. For example the alcohol in an alcohol-glass thermometer rises when we heat it because the alcohol expands more rapidly than the glass does. (If the glass expanded more rapidly than the liquid, the liquid level would fall when we heated the thermometer.)
- An exception to this is water. If I decrease the temperature of warm water, it will shrink until the temperature reaches 4 °C, but then expand as the temperature decreases below 4 °C to 0 °C. If I cool it any more it will freeze. (If I used water as the liquid in a glass thermometer instead of alcohol, what would happen to the liquid level if it was heated from 2 °C to 4 °C?)