Exploring Energy and Temperature

In the figure to the left, the first column represents gas particles with little energy. A thermometer placed in contact with this group of particles would indicate a very low temperature. The column to the right represents particles with a high enough speed and energy to spread out inside the column. A thermometer placed in this group would show a high temperature.

When the state of matter changes its phase, the temperature and energy of matter also changes. At low temperature and energy we have a solid phase. At a medium temperature and energy we have a liquid phase, and at a high temperature and energy we have a gaseous phase.

A simple formula gives us the average speed, V, of water molecules in meters per second (m/s) for a given temperature in degrees Celsius, T:

$$V^2 = 1380(273+T)$$

Problem 1 – What is the speed of an average water molecule near A) the freezing point of water at 0^{o} C? B) The boiling point of water at 100^{o} C?

Problem 2 - The kinetic energy in Joules for all of the water molecules in a gallon of water, which has a mass of about M = 4.0 kilograms, and an average molecule speed of V in meters/sec, is given by the formula:

$$K.E. = \frac{1}{2}MV^2$$

To the nearest Joule, what is the kinetic energy of a 1 gallon of water at the temperatures given in Problem 1?

Problem 3 - If you heated the one gallon of water from 0^{o}C to 100^{o}C, how much 'thermal' energy would you have to add?

Problem 1 - What is the speed of an average water molecule near A) the freezing point of water at 0^o C? B) The boiling point of water at 100^o C?

Answer: From the formula:

A) V = $(1380(273+(+0))^{1/2}$ = $(376740)^{1/2}$ = 614 meters/sec.

B) V = $(1380(273+(100))^{1/2}$ = $(514740)^{1/2}$ = 717 meters/sec.

Problem 2 - The kinetic energy in Joules for all of the water molecules in a gallon of water, which has a mass of about M = 4 kilograms, and an average molecule speed of V in meters/sec, is given by the formula:

$$K.E. = \frac{1}{2} MV^2$$

To the nearest Joule, what is the kinetic energy of a 1 gallon of water at the temperatures given in Problem 1?

Answer: A) For $+0^oC$, we calculated an average speed of 614 m/s, so the kinetic energy of the water is KE = 1/2 $(4.0)(614)^2$ = **753,992 Joules**.
B) For 100^oC we have V = 717 m/s, so KE = $1/2(4.0)(717)^2$ = **1,028,178 Joules.**

Problem 3 - If you heated the one gallon of water from 0^oC to 100^oC, how much 'thermal' energy would you have to add?

Answer: You have to add the difference in energy (1,028,178 – 753,992) = **274,186 Joules** to heat the gallon of water to its boiling point at 100^o C.

Note: A typical hotplate at a temperature of 400 C generates about 1000 Joules/second, so to heat the gallon of water to make it boil would take about 274186/4000 or about 4 minutes at this hotplate setting.