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\(^\circ\) C? B) The boiling point of water at 100\(^\circ\) 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\(^\circ\)C to 100\(^\circ\)C, how much 'thermal' energy would you have to add?

Space Math  \hspace{1cm}  http://spacemath.gsfc.nasa.gov
Problem 1 - What is the speed of an average water molecule near A) the freezing point of water at 0°C? B) The boiling point of water at 100°C?

Answer: From the formula:

A) \[ V = \sqrt{1380(273+(+0))} = \sqrt{376740} = 614 \text{ meters/sec.} \]

B) \[ V = \sqrt{1380(273+(100))} = \sqrt{514740} = 717 \text{ meters/sec.} \]

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 kg, 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°C, we calculated an average speed of 614 m/s, so the kinetic energy of the water is \[ KE = \frac{1}{2}(4.0)(614)^2 = 753,992 \text{ Joules.} \]

B) For 100°C we have \( V = 717 \text{ m/s}, so \( KE = \frac{1}{2}(4.0)(717)^2 = 1,028,178 \text{ Joules.} \)

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

Answer: You have to add the difference in energy \( (1,028,178 - 753,992) = 274,186 \text{ Joules} \) to heat the gallon of water to its boiling point at 100°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.