

## Lesson 06: Temperature and Kinetic Energy

First, we must note that at the atomic level all atoms and molecules are moving all the time. There is no known instance in the entire universe where even a single atom has stopped moving since the first instants of the universe. This notion evolves from the development of what is sometimes called the kinetic theory of matter. Sometimes, more narrowly, it is referred to as the kinetic theory of gases. This motion is attributed to what we now call the kinetic energy of the atoms and molecules. Kinetic energy is, put most simply, the energy of motion.

Atoms and molecules exhibit various types of motion, sometimes they are doing all these types at the same time. The types of motion include:

- Translation, or movement through space
- Rotation
- Vibration
- Orbital motion of the electrons about the nucleus of each atom
- Orbital motion of the nucleons within the nucleus of each atom
- Motions of the quarks within each nucleon

The last three motions can only be changed at temperatures far, far above normal environmental conditions here on Earth. So, we generally limit our discussion to the first three; Translation, Rotation and Vibration.

In general, to increase the motions in these atomic systems we have to add heat. When we add heat the pace of these motions quickens. When we add heat, that temperature also increases. Conversely, if we remove heat, the motions slow and the temperature also drops. In fact, it turns out that the change in temperature is proportional to the amount of heat added or removed. It was recognized that this fact provides the basis for defining what is known as the absolute temperature scale. That is one in which the absolute temperature is proportional to the total internal kinetic energy. We now call that temperature scale the Kelvin scale.

On the Kelvin scale all motion should come to a halt at zero, since at that temperature there should be no energy of motion left in the atoms. This would be true except for something we now call the zero point energy. Due to quantum effects, even atoms in their lowest state of motion still have some residual motion and by some accountings some residual energy. In this course we take the view that this lowest state of motion actually represents the zero of motion, kinetic energy, and temperature. No slower motions are attainable, no additional energy can be removed, and no lower temperatures can be reached.

The situation that we find following this line of investigation is that heat and kinetic energy are both forms of energy. The distinction between the two can be summarized as follows:

- K Kinetic energy is the energy of motion
- H Heat is energy in motion from one object to another.
- T The absolute temperature of an object is proportional to the average kinetic energy of its constituent atoms and molecules.
- $\Delta T$  The temperature change of an object, measured in absolute temperature units, is proportional the change in the average kinetic energy of its constituent atoms and molecules.

Kinetic energy and heat are obviously very closely related and convert automatically into one another under the right sets of circumstances. As we study both these forms of energy in later chapters it will help your understanding to keep their differences and well as their similarities in mind.

One unfortunate aspect of the proportionality between heat and temperature change, is that the constant of proportionality is different for each substance. There is no universal proportionality constant. The constant of proportionality for a specific substance is called its specific heat. We'll get to that in Lesson 20.

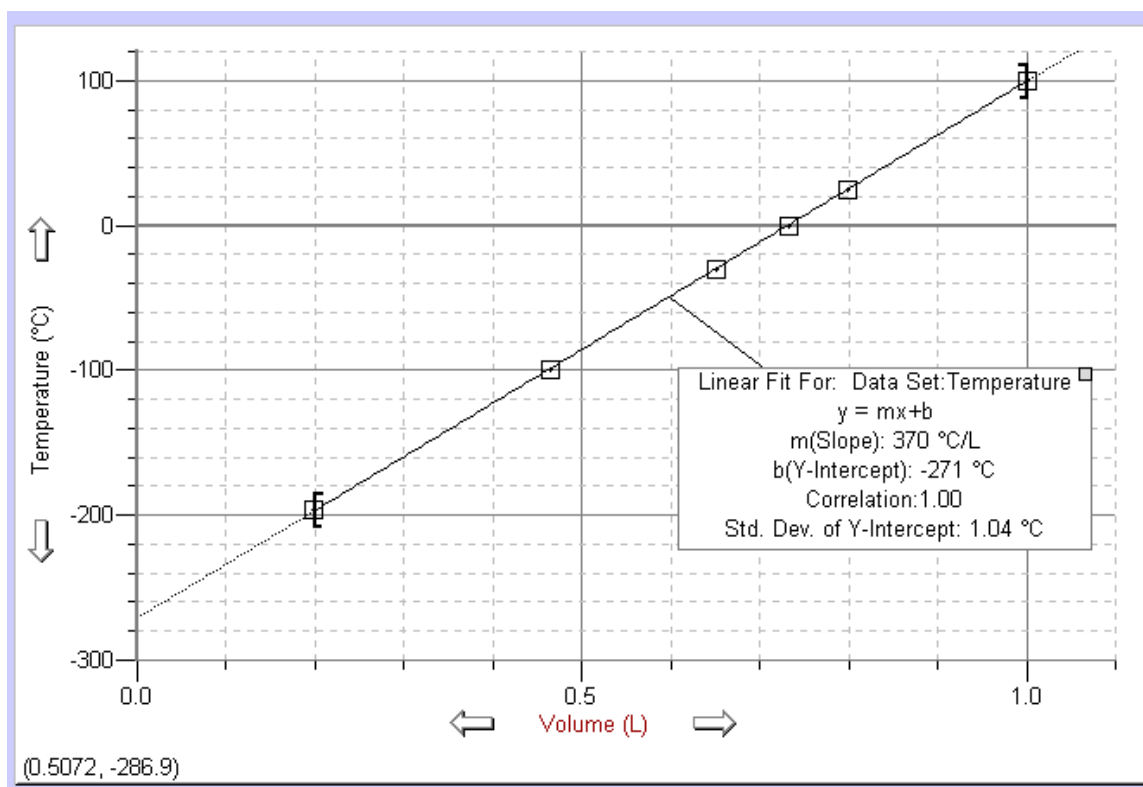
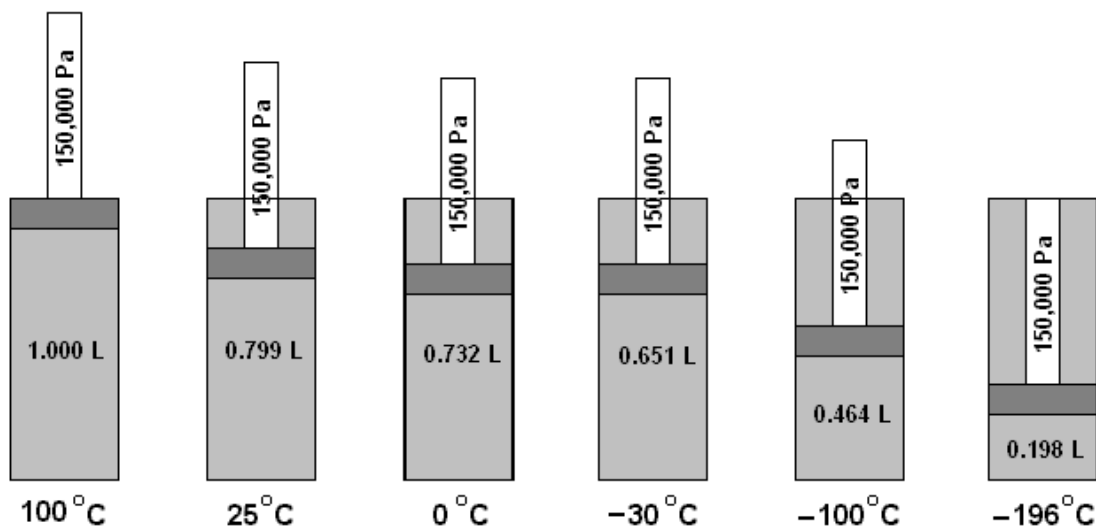
One of the most convincing ways to “prove” that heat is proportional to the temperature change and that absolute temperature is proportional to the amount of motion in a sample of gas, is to cool the gas at constant pressure and measure its changing volume. This will only work until the gas undergoes a phase change to the liquid state, but it is still impressive.

If you can, imagine a one liter sample of helium gas under a constant pressure of 150,000 pascals and at a temperature equal to the boiling temperature of water, 100°C. Here are some of the results you might get while cooling it down to the temperature of liquid nitrogen.

The figure on the next page shows schematic diagrams of the system at various temperatures. It is followed by a graph showing the data. Most importantly, look for the extrapolation to 0 volume. What temperature do you get at that intercept. No experiment is perfect, but it should be close to the Celsius to Kelvin conversion factor.

That is where the volume should go to zero, also. Helium actually turns to a liquid at 4 K, so we never get to see the zero volume state. That's not too surprising. We should have realized that atoms have a finites size and should not be alarmed that, when they get close enough together, they start bumping into each other and the shrinkage stops.

Here are the results of an imaginary experiment. Helium gas is contained at constant pressure and cooled. The piston moves to adapt to the decreasing volume of the gas and keeps the pressure constant. The graph is a plot of temperature vs volume.



This experiment determined that zero volume would occur at  $-271^{\circ}\text{C}$ . That is pretty accurate. The true value is  $-273.16^{\circ}\text{C}$ , which is about 2 standard deviations.