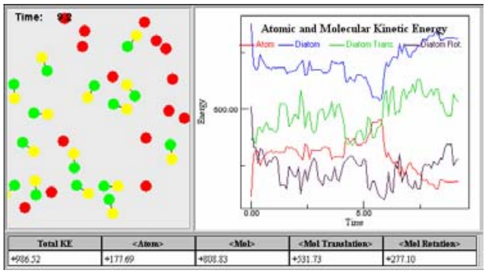
Worksheet for Exploration 20.4: Equipartition Theorem



The kinetic energy of a particle can be due to motion in the x, y, and z directions, as well as to rotations. The equiparition of energy theorem says that the kinetic energy of an atom or particle is, on average, equally distributed between the different modes (different degrees of freedom) available. In a monatomic gas, an individual atom has three degrees of freedom because it can move in the x, y and z directions. The energy per particle has an average value of $(f/2)k_BT$, where f is the number of degrees of freedom, k_B is the Boltzmann constant and T is the temperature. Restart.

a. In **this animation of a monatomic gas in a box**, why do the particles only have 2 degrees of freedom? The table shows the total kinetic energy of all particles in the box, as well as the average kinetic energies of particles in the box (the animation averages over a 10-second period, so you need to wait 10 seconds to read the averages).

b. Record the total energy.

E=_______

c. What is the energy per particle?

Energy/Particle=_______

d. If the energy is given in joules/k_B, what is the temperature inside the box?

Try this animation of a diatomic gas with 20 particles. Notice that the graph shows the total kinetic energy of the diatomic particles, and the kinetic energies of translation (motion in x and y directions) and rotation.

e. Why is the translational kinetic energy, on average, about two times the rotational kinetic energy? (The animation averages over a 10-second interval so you need to wait for the animation to run for at least 10 seconds to read the average values of kinetic energy).

   i. Consider the number of translational and rotational degrees of freedom (remember this is a 2 dimensional box).

f. From the total energy, what is the energy per particle?

g. If the energy is given in joules/k_B, what is the temperature in the box? [Remember that <energy>/particle = $(f/2)k_BT$ and in this case, f = 3 (Why?).]

T=__________

Now, **try a mixture of 20 monatomic particles and 20 diatomic particles.**

h. Why is the temperature of the gas in the box a single value (not one value for atoms and another for molecules)? Hint: think about the air surrounding you at essentially a constant temperature, unless the heater or air-conditioner just turned on and made one section of the air a different temperature. Air is made up of monatomic particles (helium) and diatomic particles (water, oxygen, and nitrogen).

i. After waiting at least 10 seconds, compare the average values of the kinetic energies (for monatomic and diatomic). What value is the average monatomic kinetic energy close to?
   i. Explain why you get the result you do. Consider the number of degrees of freedom.

j. Why should those two values [the two averages that you found in part (i)], averaged over a long period of time, be equal to each other and greater than the rotational kinetic energy of the diatomic particles?

k. Explain why the total energy should be equal to $(2/2)20k_BT + (3/2)20k_BT$.

l. From the total energy (given in joules/k_B), what is the temperature?

T=__________

m. In this animation, if a mixture has 15 atoms, how many diatomic particles should it have so that the average kinetic energies of both particles are the same? Try setting the number of monatomic particles and diatomic particles to check your answer.