We now know that temperature is the average kinetic energy in an atom per degree of freedom (with a factor of 2 and a thrown in). How much energy in total is in an object just due to the kinetic energy of all of its molecules wiggling around due to their temperature? If the average energy per atom is

,

then to get the total kinetic energy due to temperature , we take the average and multiply by the number of atoms

.

Making a substitution we have

.

Dealing with numbers of molecules can be unwieldy, so let’s convert to moles . You will recall from section 12.4 that

where is the gas constant 8.314 J/(mol∙K), meaning we can rewrite our expression as

# Example: Compare total thermal energy to gravitational potential energy

Consider a block of lead with about the same mass as a person, 70kg, sitting on the second floor of a building, 3m above the ground, at room temperature of 20oC. What is the ratio of gravitational potential energy to the total thermal energy due to the block’s temperature?

## Solution

The gravitational potential energy of the block is given by

The thermal energy is given by

Since lead is a 3-D solid, we know that the number of degrees of freedom is 6. To get the number of moles, we look up the molar mass of lead and find it to be 207 g/mol which means that 70kg of lead is

Putting it all together (and converting 20oC to Kelvin) we get a total thermal energy of

Giving us a ratio of

i.e. the thermal energy is over 1000x bigger than the gravitational potential energy!

## Analysis

We see that the internal thermal energy in this case is MUCH bigger than the gravitational potential energy, a common result. This disparity is why, when considering the energies at the microscopic scale, the macroscopic energies can usually be ignored. However, there are situations where energy moves from one scale to another such as a car engine which converts microscopic potential energy in the gasoline into microscopic kinetic energy of hot gas in the engine, into motion of the car. Clearly in these situations, you need to think about both the microscopic and macroscopic scales.

## 

Say we have a container with 0.25mol of argon gas which we can treat as being an ideal gas. How much energy do we need to add as heat to raise the temperature 10oC assuming no work is done?

## Solution

We begin with the First Law of Thermodynamics (Conservation of Energy)

which, given that no work is done goes to

.

All of the energy in this case is thermal kinetic energy. Replacing with , therefore, we have

.

Now, we put in the definition of total thermal kinetic energy to get

which after factorization becomes (note this equation for the next section!)

.

Argon is an ideal gas, so . We know the number of moles and is the gas constant . Moreover, we know the temperature difference . We, as always, need to convert to Kelvins. However, the size of is the same as , only the zero points are different. Therefore . Substituting these values in, we get

The result is positive, so we need to add 31J of heat energy to the system to get the temperature to increase 10oC (which makes sense intuitively).