Thermal expansion:

\[ \Delta L = \alpha L_0 \Delta T. \]
\[ \Delta A = 2\alpha A_0 \Delta T. \]
\[ \Delta V = 3\alpha V_0 \Delta T. \]

**DENSITY EFFECT:**

\[ \Delta \rho = -3\alpha \rho_0 \Delta T. \]

**NUCLEAR LABELS:**

When we speak of \(^{12}\text{C},^{40}\text{Ca}\) or \(^{208}\text{Pb}\) we are telling you \(A\), the number of nucleons (p and n) in the nucleus of the atom.

**AVOGADRO'S NUMBER:** \(N_A = 6.02 \times 10^{26}\) constituents per \(A\) kg.

**IDEAL GAS LAW:** \(pV = Nk_B T\).

\(k_B\) is a fundamental constant relating energy in J to temperature in K.

Note that for a given gas in a given system, \(pV/T\) is a constant.
DETAILS AND DEFINITIONS:

Atomic mass unit (u or Da): u is 1/12-th of the mass of a $^{12}\text{C}$ atom, which works out to about $1.66 \times 10^{-27}$ kg.

Avogadro’s Number: $N_A = 6.02214 \times 10^{26}$ is the number of atoms in 12 kg of $^{12}\text{C}$. This is called a “kilomole.”

Gas Constant: $R = 8314 \text{ J/kilomole-K}$. $R = N_A k_B$.

Boltzmann’s Constant: $k_B = 1.381 \times 10^{-23} \text{ J/K}$.

The average kinetic energy of a constituent of a system of temperature T is $KE_{avg} = (3/2)k_BT$.

The internal energy of an “ideal” gas is

$$U = (3/2)Nk_BT.$$ 

Here $N$ is the number of constituents.

What makes a gas “ideal” is the assumption that the atoms or molecules have only kinetic energy, and no potential energy due to interaction with one another. Real gases have a behavior surprisingly close to an ideal gas, unless they are very cold and dense.

$$pV = Nk_BT = nRT.$$
INTERNAL ENERGY OF AN IDEAL GAS:

\[ U = (3/2)Nk_BT. \]

RMS SPEED OF A MOLECULE:

\[ v_{\text{rms}} = \sqrt{3k_BT/m}. \]

The Equipartition Concept:

Every separate degree of freedom in a system at temperature \( T \) receives

\[ \frac{1}{2}k_BT \]

Thus a point particle free to move in 3-dimensional space has

\[ 3 \times \frac{1}{2}k_BT = \frac{3}{2}k_BT \]

of energy.
• Calculate the mass of a $^{12}\text{C}$ atom using Avogadro’s number, and using the nucleon mass ($1.67 \times 10^{-27}$ kg).

• What is the pressure of a gas with $10^{27}$ atoms at 300 K in a volume of a cubic meter?

• What volume is occupied by 1 kilomole of a gas at atmospheric pressure and 273 K?

• A gas at a pressure of $10^6$ J/m$^3$, consisting of $10^{26}$ molecules, expands its volume by one cubic meter. By how much did its temperature change?

• A gas undergoes a process where $p_2 = p_1/2$, $V_2 = V_1/3$. What is $T_2/T_1$?

• A gas undergoes a process such that $p_f = p_i/3$, $V_f = V_i/3$, starting at $T_i = 300$ K. If there is 1 kilomole of gas, by what amount $\Delta U$ did the internal energy of the gas change?

• A gas consists of atoms of mass $4 \times 10^{-26}$ kg. If the gas is at 300 K, what is the average KE of a single atom?

If this gas has a pressure of $10^6$ J/m$^3$ and volume of 0.01 m$^3$ what is its total internal energy $U$?

How many kilomoles of gas are there?

How many atoms of gas are there?