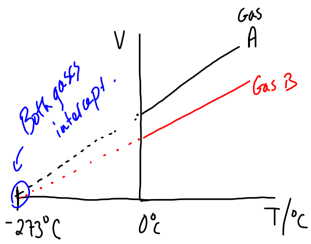
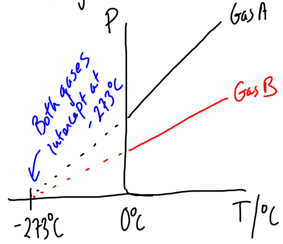
Extrapolation of pressure + volume graphs back to zero:

Charles's Law



Gay Lussac's Law



↖ for an "ideal" gas ↗

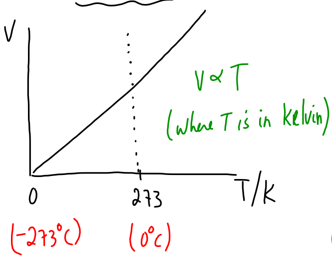
The Kelvin temperature Scale

The kelvin is the SI unit for temperature.

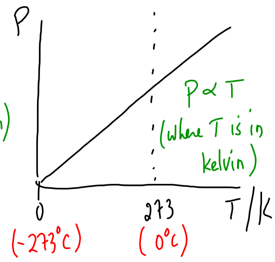
The zero of kelvin is taken to be at -273°C and the size of the kelvin is the same as the size of the Celsius degree.

There are 273 kelvin between -273°C and 0°C.

Charles's Law



Gay Lussac's Law



Converting between kelvin and degrees Celsius.

$$T/K = t/°C + 273$$

Example:

350K = (350 − 273) = 77°C

100°C = (100 + 273) = 373 K

Note that temperature changes are the same i.e. a temperature increase of 40°C = a temperature increase of 40K

Better version of:

Charles's Law - the volume of a fixed mass of gas at constant pressure is proportional to the temperature measured on the Kelvin scale.

Gay Lussac's Law (Pressure Law) - the pressure of a fixed mass of gas at a constant volume is proportional to the temperature measured on the

Absolute Zero

- The temperature at which both the volume and pressure of a gas will be zero.
- The Laws of thermodynamics show that absolute zero (-273°c or 0 K) is the coldest temperature and it can never be reached.

Near absolute zero, some strange things happen:

- superconductivity (electrical resistance is zero)
- superfluidity (viscosity of a fluid is zero)
- at about 10^{-9} K => Bose Einstein condensate. (a new state state of matter)

Formula for temperature

It can be shown using kinetic theory (more... later). that the temperature in Kelvin is related to the mean translational kinetic energy per particle.

$$E_K = \frac{3}{2} k T = \frac{1}{2} m \overline{v^2}$$

← mean kinetic energy ($\frac{1}{2} m \overline{v^2}$)

↑ Temperature in Kelvin (T)

k = Boltzmann's constant $= 1.38 \times 10^{-23}\ J\ K^{-1}$

Conversions:

1. 27°C to kelvin 300 K
2. 100 K to degrees Celsius. -173 °C
3. -100°C to kelvin 173 K
4. a change in temperature of 100°C to kelvin 100K

Internal Energy U

The internal energy (or total internal energy) of a substance is the total energy possessed by all the particles of the substance.

Various Energy Forms:

① Translational Kinetic Energy

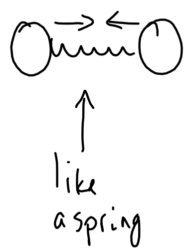
- due to the translational or linear motion.
- random => random translational kinetic energy
- gases + liquids, not solids.

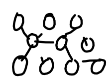
② Rotational Kinetic Energy

- due to the rotational motion
- gases + liquids (fluids) not solids
- rotational kinetic energy of large polyatomic molecules is a very large part of the total internal energy. Single atoms have no rotational kinetic energy

③+④ Vibrational kinetic + potential energy.

- some particles have internal vibratory motion
- all types of substances (solids, liquids + gases) may have this if the structure of their molecules is complex
- solid -> lattice structure





⑤ Bonding Potential Energy

- occurs if there are forces between particles.
- cohesive forces in solids + liquids => if particles are pulled apart, then there will be an increase in potential energy.
- the cohesive forces in gases is very small (zero in an "ideal" gas)

Van der Waals forces

Total Internal Energy

$U = \sum$ (the energies of all the particles in a substance)

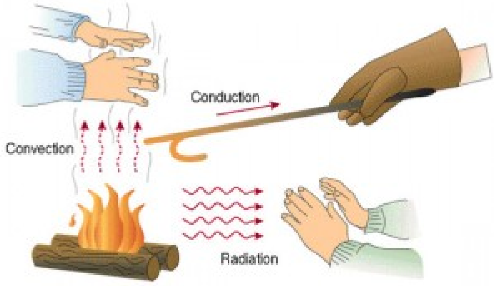
$$U = \sum_{i=1}^{N} \left(E_{k_i \text{ translation}} + E_{k_i \text{ rotation}} + E_{k_i \text{ vibration}} + E_{p_i \text{ vibration}} + E_{p_i \text{ bonding}} \right)$$

We cannot actually measure the total internal energy of a substance, but only the change.

Referring to the energy within the substance not energy due to motion of the substance.

Macroscopic + Microscopic (Temperature/Internal Energy/Thermal Energy)

Recall convection, conduction, radiation } ways to transfer internal energy.



Macroscopic -> big/large scale.

- things that we can measure in the lab.
- mass of a gas, number moles, pressure, volume, temperature, internal energy, thermal energy.
- thermal Physics => thermodynamics.

Microscopic -> small

- individual atoms or molecules that make up a substance
- mass an atom, number of particles, particle speed, particle kinetic energy, particle momentum.
- thermal physics => kinetic theory or statistical mechanics.

Temperature T or θ

macro → direction of flow of internal energy.

micro → average random translational kinetic energy

Internal energy U

Thermal energy Q or ΔQ

* Heat is something that is transferred (like work transferring energy)

The mole and molar mass

Atomic mass scale – based on C^{12} ← mass number (nucleon number)

$(6p + 6n)$
$= 12$ nucleons

- used to using kg as a unit for mass
  ↳ not very practical
- unified atomic mass unit (μ)

$$1\mu = \frac{1}{12} \text{ mass of } C^{12} = 1.661 \times 10^{-27} \text{ kg}$$

If carbon-12 has 12 nucleons then each nucleon has a mass of approximately 1μ (the mass of a proton and a neutron are approximately the same) The mass of an electron is very small compared to the mass of a nucleon.

mass of carbon-12 $= 12\mu$ (definition)
mass of oxygen-16 $\approx 16\mu$ (approximately)
mass of oxygen-16 molecule (O_2) $\approx 32\mu$
mass of water (H_2O) $\approx 18\mu$

Molar Mass → $g\ mol^{-1}$

		molar mass	atomic mass
molar mass	C-12 =	$12 g\ mol^{-1}$	(12μ)
molar mass	O-16 =	$16 g\ mol^{-1}$	(16μ)
molar mass	U-238 =	$238 g\ mol^{-1}$	(238μ)

The Mole → SI unit for the amount of a substance.

1 mol C-12 = 12g
1 mol O-16 = 16g
1 mol U-238 = 238g

Avogadro's Constant

1 atom of carbon-12 has a mass of 12 u

1.661×10^{-27} kg

$= 1.661 \times 10^{-24}$ g

1 mol = 12 g

$$= \frac{12 \text{ u}}{\text{atom}} \left(\frac{1.661 \times 10^{-24} \text{ g}}{1 \text{ u}} \right)$$

$$= \frac{12(1.661 \times 10^{-24}) \text{ g}}{\text{atom}} \left(\frac{1 \text{ mol}}{12 \text{ g}} \right)$$

$$= 1.661 \times 10^{-24} \frac{\text{mol}}{\text{atom}}$$

$\Rightarrow$ 1 atom = 1.661×10^{-24} mol

$$\frac{1}{1.661 \times 10^{-24} \text{ mol/atom}} = 6.02 \times 10^{23} \frac{\text{atoms}}{\text{mol}}$$

1 mol of C-12 has 6.02×10^{23} atoms.

1 mol of anything has 6.02×10^{23} entities.

$$N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$$

$$2.3 \text{ mol C} \left(\frac{12 \text{ g}}{1 \text{ mol C}} \right)$$

Examples

O_2

① What is the mass in kilograms of 1.20×10^{25} molecules of oxygen? (atomic mass of 16 u)

$$x \text{ kg} = 1.20 \times 10^{25} \text{ molecules} \left(\frac{1 \text{ mol}}{6.02 \times 10^{23} \text{ molecules}}\right)\left(\frac{32 \text{ g}}{1 \text{ mol}}\right)\left(\frac{1 \text{ kg}}{1000 \text{ g}}\right)$$

$$x \text{ kg} = 0.64 \text{ kg}$$

② The density of aluminum is 2.7 g cm^{-3} and its molar mass is 27 g mol^{-1}.

- Find the mass of an atom of aluminum in kg.
- Find the number of aluminum atoms per cubic metre.
- Estimate the diameter of an aluminum atom.

③ The world's population is about 6 billion. How many moles of humans are there on Earth?