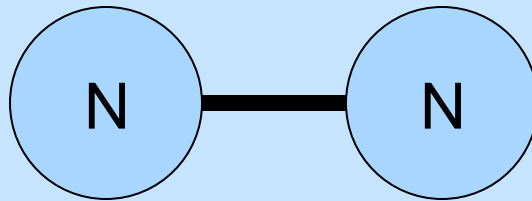


Chapter 3: Sections 3.1-3.7

- Elements: Greeks asked, “What are the most basic substances from which others are formed?” (Important to ask the right question)
- Atoms: Greeks asked, “What are the smallest, indivisible particles?”
- Law of definite proportions:
 - to make CO, add 4 parts C (by mass) to 3 parts O.
 - If you add more C, it just ends up as excess C and not CO.

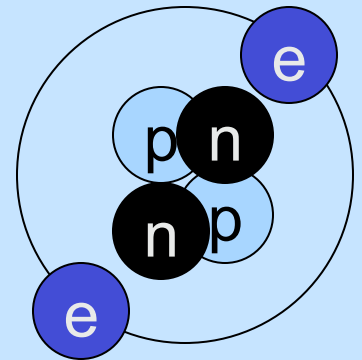
Molecules

- Physical (bound) combinations of atoms
- Examples: H_2O , N_2 , ammonia: NH_3 , carbon monoxide: CO
- chemically bonded with electrons



Sub-atomic particles

- Electron (e):
 - negatively charged
 - outside the nucleus
 - 0.511 MeV rest energy
- Proton (p):
 - positively charged
 - rest energy 938.3 MeV
- Neutron (n):
 - neutrally charged
 - rest energy 939.6 MeV
- Protons and neutrons are sometimes called nucleons.



Sub-atomic particles

- Charge is quantized
 - electron charge $-e = -1.6 \times 10^{-19} \text{ C}$
 - proton charge $+e = +1.6 \times 10^{-19} \text{ C}$
- nucleus has protons and neutrons (except hydrogen nucleus)
- electrons are in outer region
- size scale of outer region = $10^{-10} \text{ m} = 0.1 \text{ nm} = 1 \text{ \AA}$
- size scale of nucleus is $1 \text{ fm} = 10^{-15} \text{ m}$
- Most of the atom is empty space, scaled example: a pea (nucleus) in a football stadium (electron cloud)

Atoms and ions

- atomic number Z = number of protons
 - determines “what element” the atom or ion is
 - hydrogen always has 1 proton
 - helium always has 2 protons
- for neutral atom, number of protons = number of electrons
- for ions, number of protons not equal to number of electrons

isotopes and atomic mass number

- nucleus with same number of protons can have different numbers of neutrons
- These are called “isotopes” of an element
- Some isotopes occur more often than others
- Named with mass number:
 - $A = N + Z$
 - A = atomic mass number
 - Z = number of protons
 - N = number of neutrons
 - $^{12}\text{C} = 6 \text{ protons} + 6 \text{ neutrons}$
 - $^{13}\text{C} = 6 \text{ protons} + 7 \text{ neutrons}$

Mass of p, n, e

- Electron: $m_e = 0.511 \text{ MeV}/c^2 = 9.11 \times 10^{-31} \text{ kg}$
- Proton: $m_p = 938.3 \text{ MeV}/c^2 = 1.673 \times 10^{-27} \text{ kg}$
- Neutron: $m_n = 939.6 \text{ MeV}/c^2 = 1.675 \times 10^{-27} \text{ kg}$
- $m_p \approx m_n \approx m_H \approx 940 \text{ MeV}/c^2 \sim 1 \text{ GeV}/c^2$
- Protons and neutrons about 1800 times more massive than electrons.

Atomic mass number and mass

- Atomic mass, even for a single isotope, isn't exactly equal to the sum of masses of neutrons, protons, and electrons:
 - about 0.1% difference in weights of neutron and proton
 - Difference is the binding energy of nucleus:
 - ${}^4\text{He}$ nucleus (2 p + 2 n) has 28 MeV binding energy. The atom has 28 MeV less mass than predicted for 4 times the mass of a proton; this is in binding energy. It's why fusion produces energy. Fusing nuclei releases binding energy.
 - binding energy is usually 0.7%-0.8%, but is absent in H (only 1 particle)
- Mass of the element is weighted average over naturally occurring isotopes.

Atomic mass unit

- Defined to be exactly 1/12 the mass of ^{12}C
- Unit is called u
- $931.5 \text{ MeV}/c^2 = 1.661 \times 10^{-27} \text{ kg}$
- Table 3.5 from text:

Masses of some isotopes in u (close to integers, usually about off by about 0.1%:

^1H	1.008	^{35}Cl	34.969
^2He	4.003	^{56}Fe	55.939
^{12}C	12	^{208}Pb	207.977
^{16}O	15.995	^{238}U	238.049

N_A and the Mole

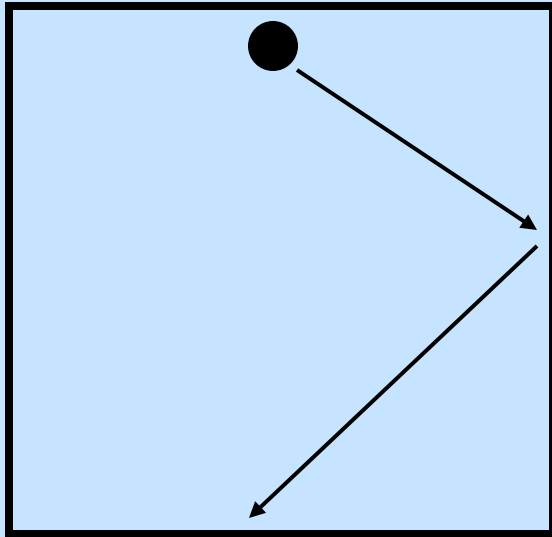
- N_A = Avagadro's number = the number of ^{12}C atoms in 12 grams of ^{12}C = 6.022×10^{23} particles/mole
- units are objects/mole
- N_A is a huge number
- close to number of atoms in 1 g of ^1H , 13 g of ^{13}C , 238 g of ^{238}U .
- equal to number of atoms in 238.049 g of ^{238}U (to within 6 sig figs)
- convenient: 1 mole of C plus 1 mole of O makes 1 mole of CO

Kinetic Theory

Ideal gas consists of noninteracting particles.

- ideal gas law:
 - $pV = nRT$
 - $R =$ universal gas constant $= 8.314 \text{ J/K mole}$
 - n number of moles of gas
 - $p =$ pressure
 - $V =$ volume
 - $T =$ temperature in Kelvin
- with $n=N/N_A$, can rewrite:
 - $pV=Nk_B T$
 - $k_B =$ Boltzmann's constant $= R/N_A$

Microscopic View: Equipartition Theorem



length L
area A
volume $V=AL$

- molecules bouncing off walls; examine right wall
- each bounce off right wall reverses momentum, applies pressure
- timescale $\Delta t = 2L/v_{xi}$
- $F_{xi} = |\Delta p_{xi}|/\Delta t_i = |2mv_{xi}|/\Delta t_i = mv_{xi}^2/L$
- Pressure = sum over forces of all particles/ $A = N m \langle v_x^2 \rangle / V$
- symmetric: $\langle v_x^2 \rangle = \langle v_y^2 \rangle = \langle v_z^2 \rangle$ so $\langle v^2 \rangle = 3 \langle v_x^2 \rangle$ so $pV = Nm \langle v^2 \rangle / 3$
- Compare to $pV = Nk_B T$
- $KE = 1/2 m \langle v^2 \rangle = 3/2 k_B T$ (**Equipartition Theorem**). This defines the meaning of the temperature of the gas
- microscopic explanations of thermodynamics are **statistical mechanics**

Sample Problems

- How many C atoms are there in 1 g of CO₂?
- What is the mass of a single O₂ molecule?
- What happens to a gas in a container when:
 - The volume is doubled and pressure held constant?
 - The temperature is doubled and volume held constant?