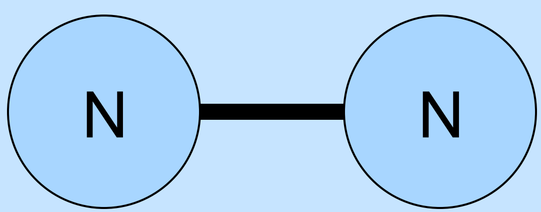
Chapter 3: Sections 3.1-3.7

- 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.

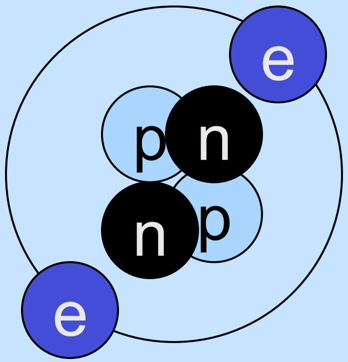
Molecules

- Physical (bound) combinations of atoms
- Examples: H_20, 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 $-e = -1.6 \times 10^{-19}$ C
  - proton charge $+e = +1.6 \times 10^{-19}$ C
- nucleus has protons and neutrons (except hydrogen nucleus)
- electrons are in outer region
- size scale of outer region = 10^{-10} m = 0.1 nm=1 Å
- size scale of nucleus is 1 fm = 10^{-15} 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}C = 6 protons + 6 neutrons
  - ^{13}C = 6 protons + 7 neutrons

Mass of p, n, e

- Electron: $m_e = 0.511$ MeV/c^2 = 9.11×10^{-31} kg
- Proton: $m_p = 938.3$ MeV/c^2 = 1.673×10^{-27} kg
- Neutron: $m_n = 939.6$ MeV/c^2 = 1.675×10^{-27} kg
- $m_p \approx m_n \approx m_H \approx 940$ MeV/c^2 ~ 1 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}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 $MeV/c^2 = 1.661 \times 10^{-27}$ kg
- Table 3.5 from text:

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

^{1}H	1.008	^{35}Cl	34.969
^{2}He	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

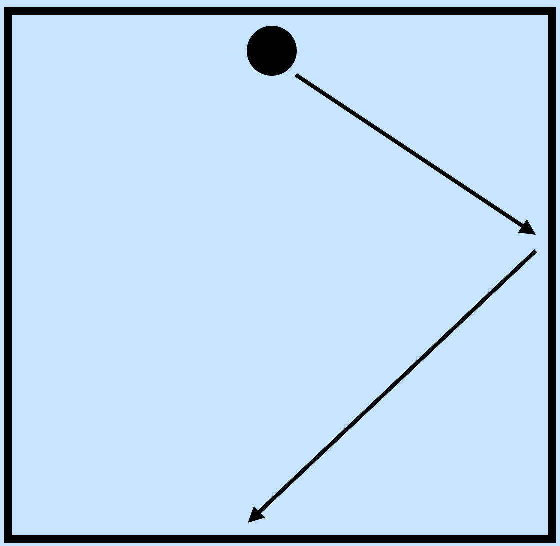
- N_A = Avagadro's number = the number of ^{12}C atoms in 12 grams of ^{12}C = 6.022×10^{23} particles/ mole
- units are objects/mole
- N_A is a huge number
- close to number of atoms in 1 g of ^{1}H, 13 g of ^{13}C, 238 g of ^{238}U.
- equal to number of atoms in 238.049 g of ^{238}U (to within 6 sig 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 J/K mole
  - n number of moles of gas
  - p = pressure
  - V = volume
  - T = temperature in Kelvin
- with $n=N/N_A$, can rewrite:
  - $pV=Nk_BT$
  - 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 $pV = Nk_BT$
- $KE = 1/2\; m\,\langle v^2\rangle = 3/2\; k_BT$ (**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 CO_2?
- What is the mass of a single O_2 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?