

# Biophysics I

## 5. Structure of matter *Atoms, molecules, crystals*

Károly LILIOM

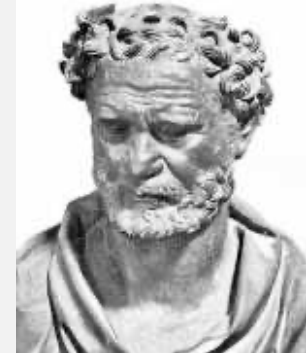
10. 10. 2025.

[karoly.liliom.mta@gmail.com](mailto:karoly.liliom.mta@gmail.com)

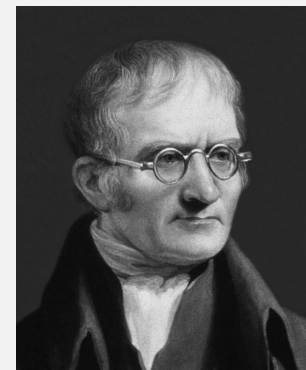
# Development of the atom concept

Democritus (460–370 BC): everything is composed of "atoms," which are physically, but not geometrically, indivisible; that between atoms, there lies empty space; that atoms are indestructible, and have always been and always will be in motion.

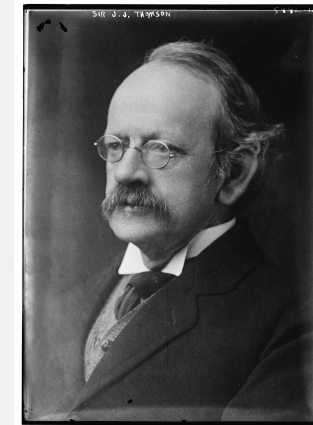
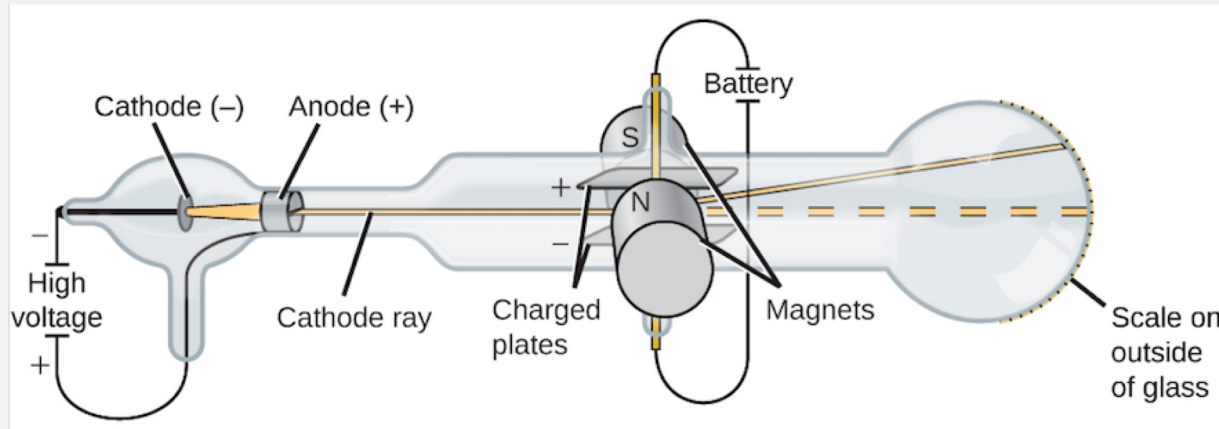
(greek *atomos* means uncuttable)



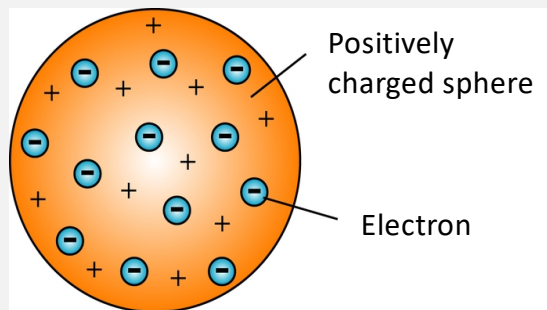
John Dalton (1803-1811) the law of multiple proportions: if the same two elements can be combined to form a number of different compounds, then the ratios of the masses of the two elements in their various compounds will be represented by small whole numbers – so elements react in multiples of some basic indivisible unit of mass.



# Development of the atom concept

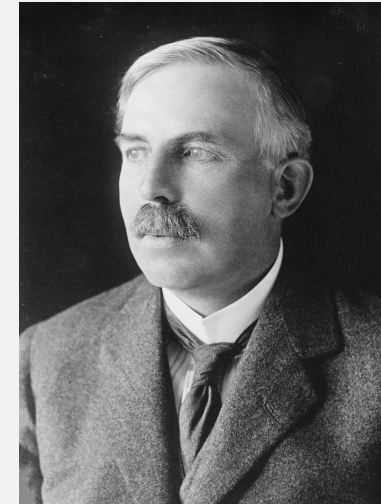
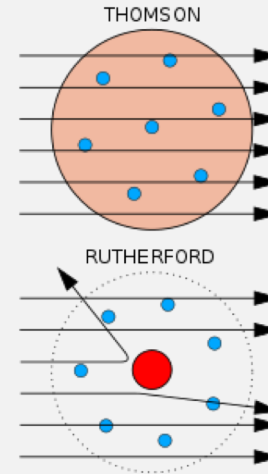
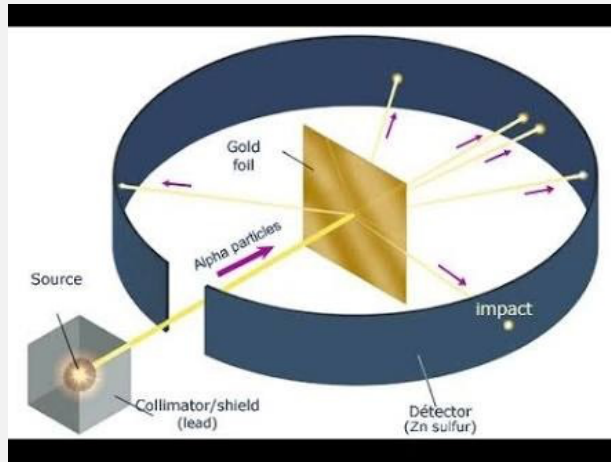


Joseph John Thomson (1897): Discovery of electrons by studying the cathode rays - identical particles with a mass  $\sim 1/2000^{\text{th}}$  the mass of a H atom, independent of the cathode material – it must be the same constituent in all atoms.



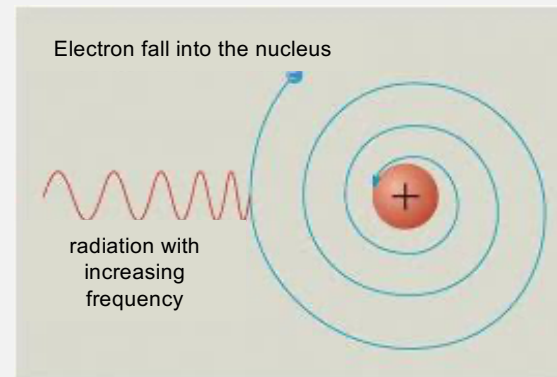
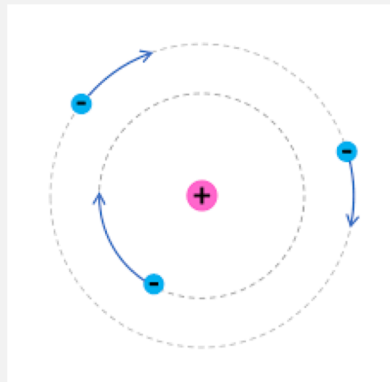
Joseph John Thomson "plum-pudding model" (1904): the positively charged main mass is distributed evenly in the atom, whereas the negatively charged small electrons are moving in it.

# Development of the atom concept

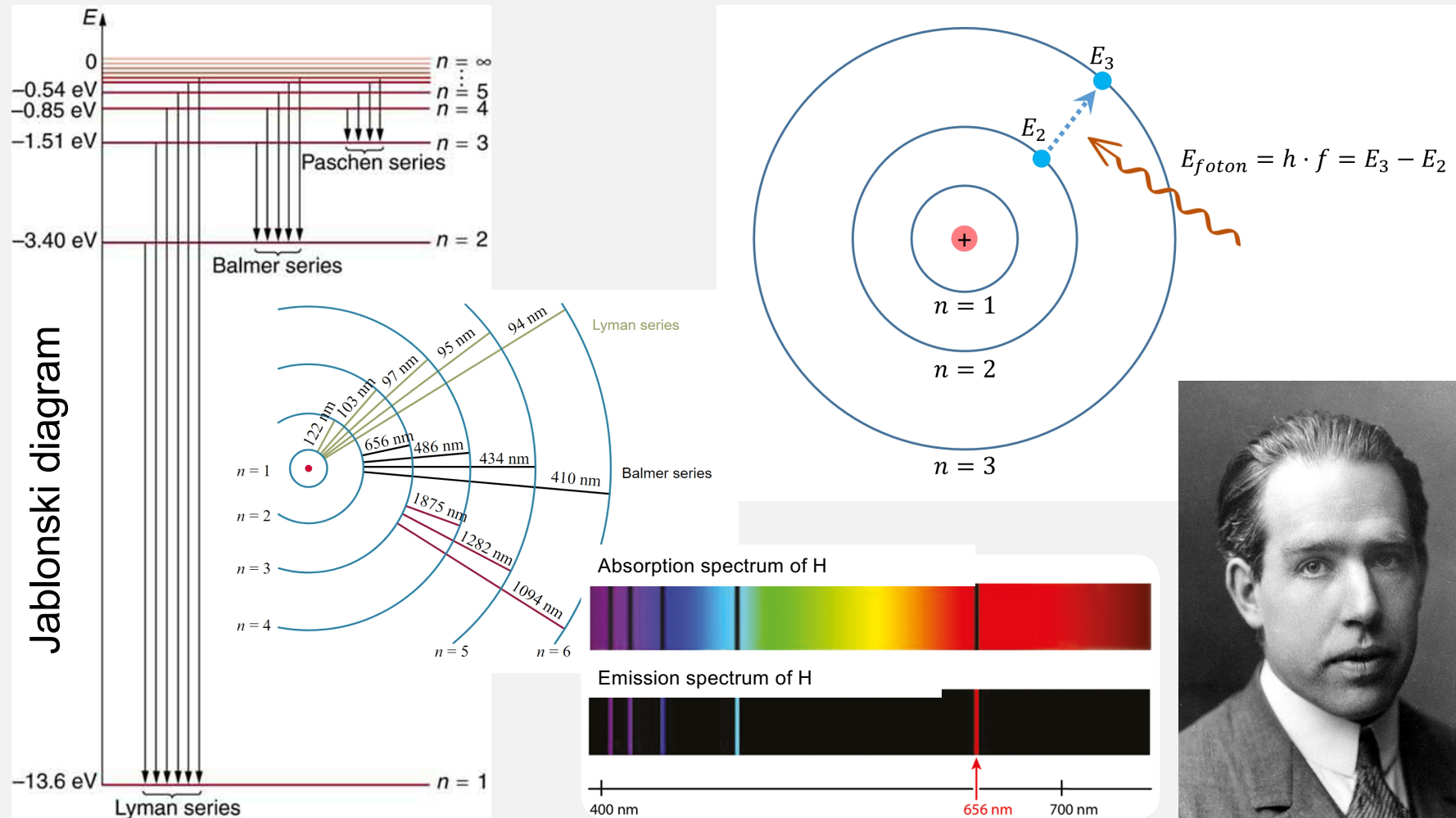


*1909-1911: scattering of  $\alpha$ -particles on gold*

Ernest Rutherford (1911): the majority of mass of an atom is in a small central volume with positive charge (nucleus) and the electrons are orbiting around it in circles governed by the Coulomb interaction.

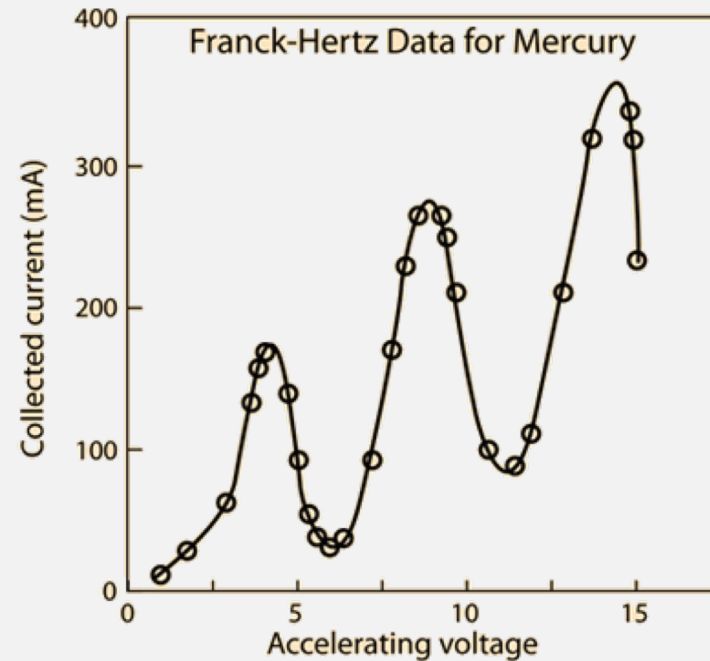
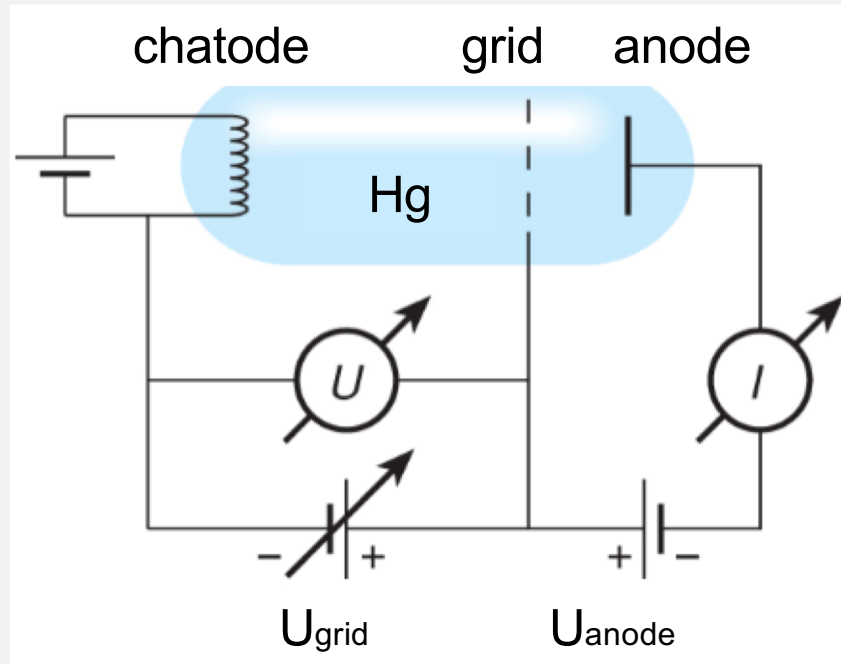


# Development of the atom concept



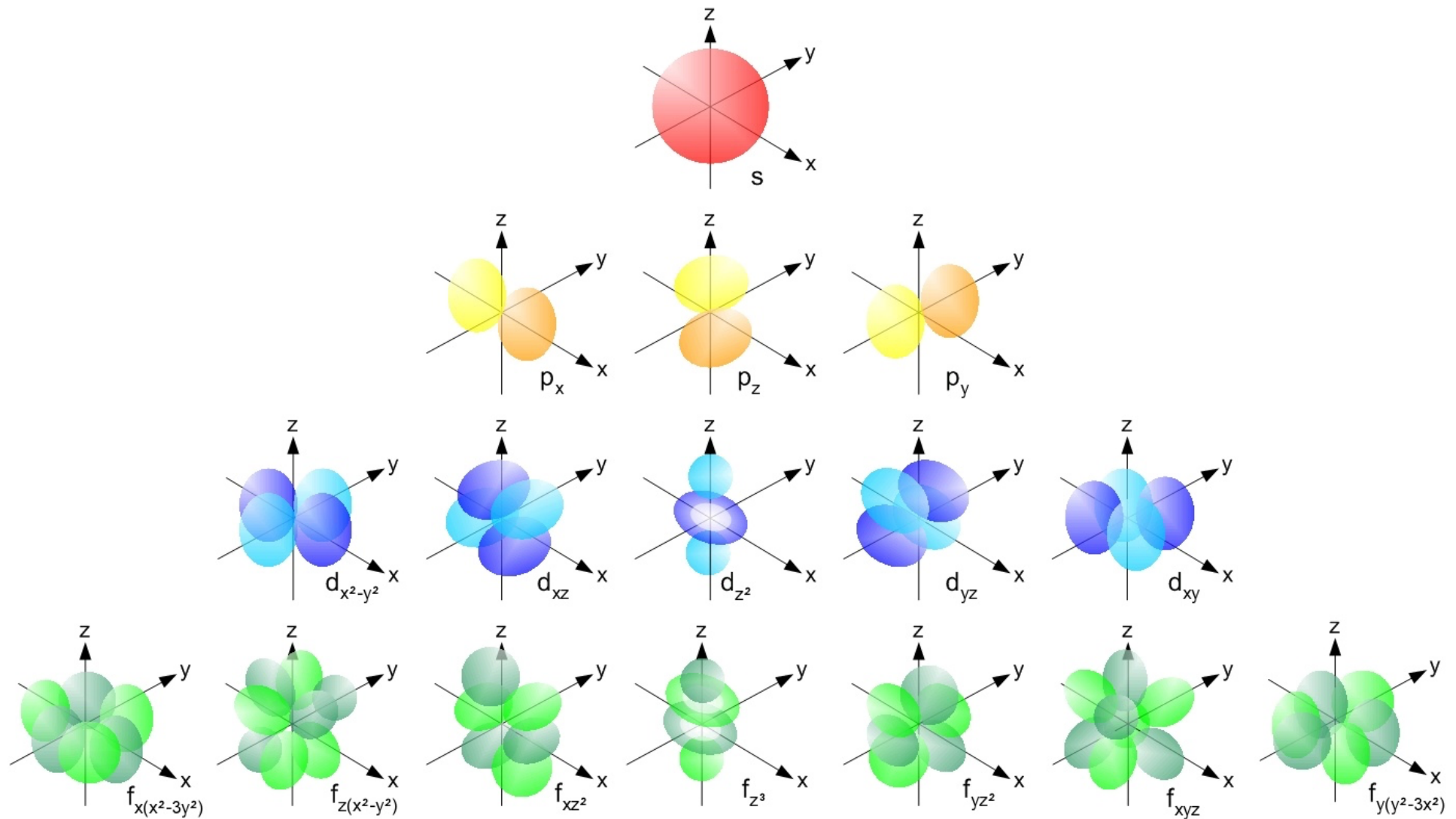
Niels Bohr (1913): There are stationary orbitals with quantized energy levels where electrons are not emitting radiations. Electrons can quantum-jump between these orbitals by absorbing or emitting the energy difference of the orbitals. The stationary orbitals are selected by the rule that the angular momentum is an integer multiple of  $h/2\pi$ .

# Franck – Hertz experiment (1914)



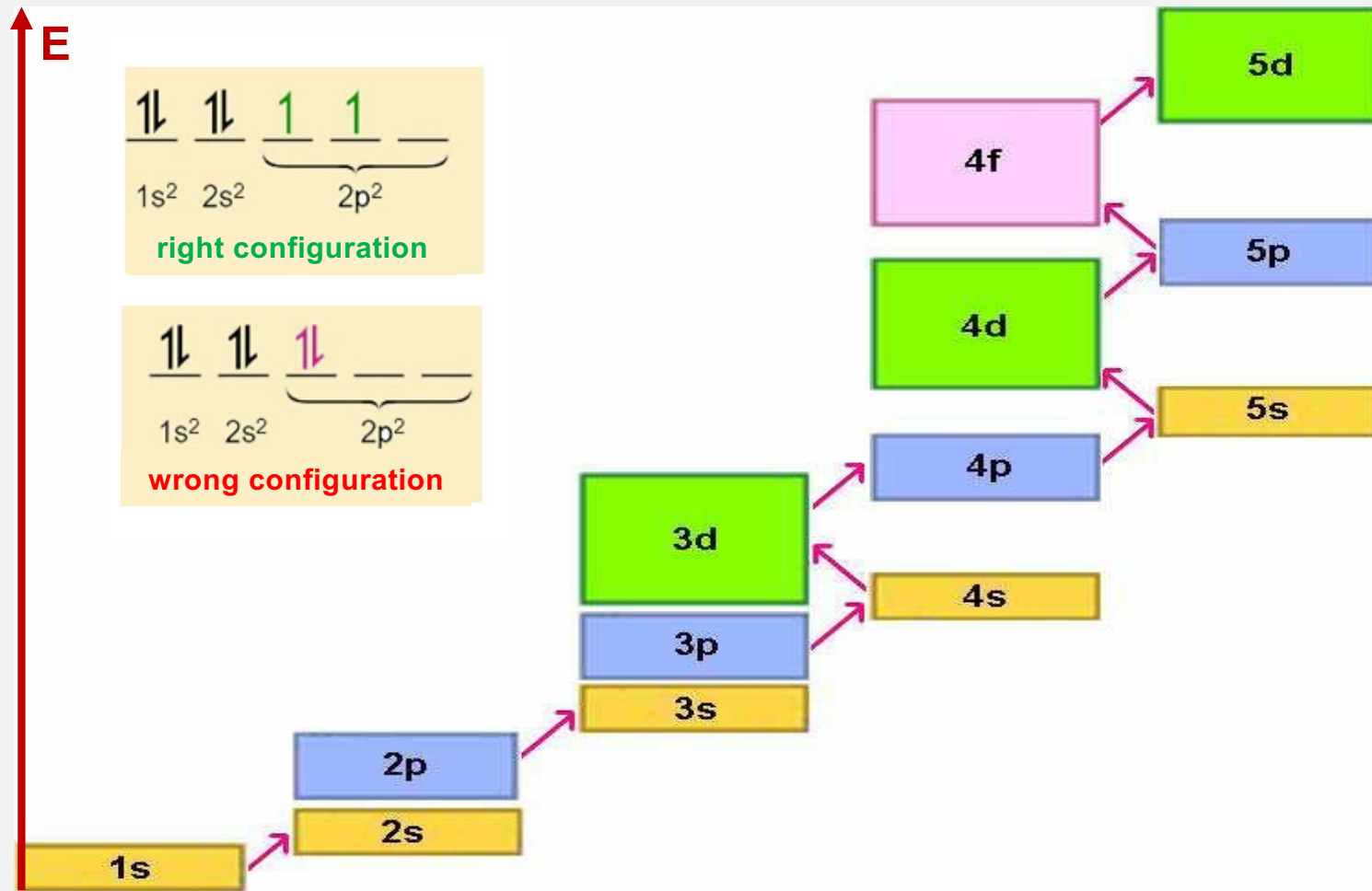
Electrons are colliding elastically with Hg atoms, until they get high enough energy, by increasing the grid voltage, to be able to excite the Hg atoms. At this accelerating voltage, the electrons lose their energy and are not able to reach the anode, so the current drops. Further increasing the accelerating voltage, the electrons collide again elastically until reaching the next energy level of the Hg atom, where they can excite the atoms again.

# Development of the atom concept



Louis de Broglie: electron wave, Ervin Schrödinger: wavefunction, wave equation  
4 quantum numbers (principal, azimuthal, magnetic and spin), Pauli principle.

# Development of the atom concept



**Pauli principle:** in multi-electron systems all electrons are in different quantum states. As a consequence, there may be no two electrons within an atom or molecule with identical 4 quantum numbers. **Hund's law:** in a given electron-configuration the lowest energy state is the one with the highest spin value (maximum multiplicity).

# The Periodic Table of the Elements

By Robert Cerven, version 1.3

group 1																	18		
period 1	1 1.00794 H Hydrogen																	2 4.002602 He Helium	
	2											13	14	15	16	17			
2	3 6.941 Li Lithium	4 9.012182 Be Beryllium											5 10.811 B Boron	6 12.0107 C Carbon	7 14.0067 N Nitrogen	8 15.9994 O Oxygen	9 18.998403 F Fluorine	10 20.1797 Ne Neon	
3	11 22.98976 Na Sodium	12 24.3050 Mg Magnesium											13 26.98153 Al Aluminium	14 28.0855 Si Silicon	15 30.97696 P Phosphorus	16 32.065 S Sulfur	17 35.453 Cl Chlorine	18 39.948 Ar Argon	
4	19 39.0983 K Potassium	20 40.078 Ca Calcium	21 44.95591 Sc Scandium	22 47.867 Ti Titanium	23 50.9415 V Vanadium	24 51.9962 Cr Chromium	25 54.93804 Mn Manganese	26 55.845 Fe Iron	27 58.93319 Co Cobalt	28 58.6934 Ni Nickel	29 63.546 Cu Copper	30 65.38 Zn Zinc	31 69.723 Ga Gallium	32 72.64 Ge Germanium	33 74.92160 As Arsenic	34 78.96 Se Selenium	35 79.904 Br Bromine	36 83.798 Kr Krypton	
5	37 85.4678 Rb Rubidium	38 87.62 Sr Strontium	39 88.90585 Y Yttrium	40 91.224 Zr Zirconium	41 92.90638 Nb Niobium	42 95.96 Mo Molybdenum	(98) 101.07 Tc Technetium	44 102.9055 Ru Ruthenium	45 107.8682 Rh Rhodium	46 106.42 Pd Palladium	47 107.8682 Ag Silver	48 112.411 Cd Cadmium	49 114.818 In Indium	50 118.710 Sn Tin	51 121.760 Sb Antimony	52 127.60 Te Tellurium	53 126.9044 I Iodine	54 131.293 Xe Xenon	
6	55 132.9054 Cs Caesium	56 137.327 Ba Barium	57 174.9668 Lu Lutetium	71 174.9668 Lu Lutetium	72 178.49 Hf Hafnium	73 180.9478 Ta Tantalum	74 183.84 W Tungsten	75 186.207 Re Rhenium	76 190.23 Os Osmium	77 192.217 Ir Iridium	78 195.084 Pt Platinum	79 196.9665 Au Gold	80 200.59 Hg Mercury	81 204.3833 Tl Thallium	82 207.2 Pb Lead	83 208.9804 Bi Bismuth	(210) 84 Po Polonium	(210) 85 At Astatine	(220) 86 Rn Radon
7	(223) 87 Fr Francium	(226) 88 Ra Radium	(262) 103 Lr Lawrencium	(261) 104 Rf Rutherfordium	(262) 105 Db Dubnium	(266) 106 Sg Seaborgium	(264) 107 Bh Bohrium	(277) 108 Hs Hassium	(268) 109 Mt Meitnerium	(271) 110 Ds Darmstadtium	(272) 111 Rg Roentgenium	(285) 112 Cn Copernicium	(284) 113 Uut Ununtrium	(289) 114 Fl Flerovium	(288) 115 Uup Ununpentium	(292) 116 Lv Livermorium	117 Uus Ununseptium	(294) 118 Uuo Ununoctium	

atomic mass or most stable mass number: 55.845

atomic number: 26

1st ionization energy in kJ/mol: 762.5, 1.83

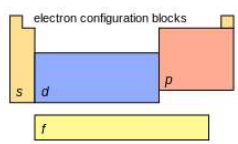
chemical symbol: Fe

name: Iron

electron configuration: [Ar] 3d<sup>6</sup> 4s<sup>2</sup>

oxidation states: +6, +5, +4, +3, +2, +1, -1, -2

- alkali metals
- alkaline metals
- other metals
- transition metals
- lanthanoids
- actinoids
- metalloids
- nonmetals
- halogens
- noble gases
- unknown elements
- radioactive elements have masses in parentheses



- notes
- as of yet, elements 113, 115, 117 and 118 have no official name designated by the IUPAC.
  - 1 kJ/mol = 96.485 eV.
  - all elements are implied to have an oxidation state of zero.

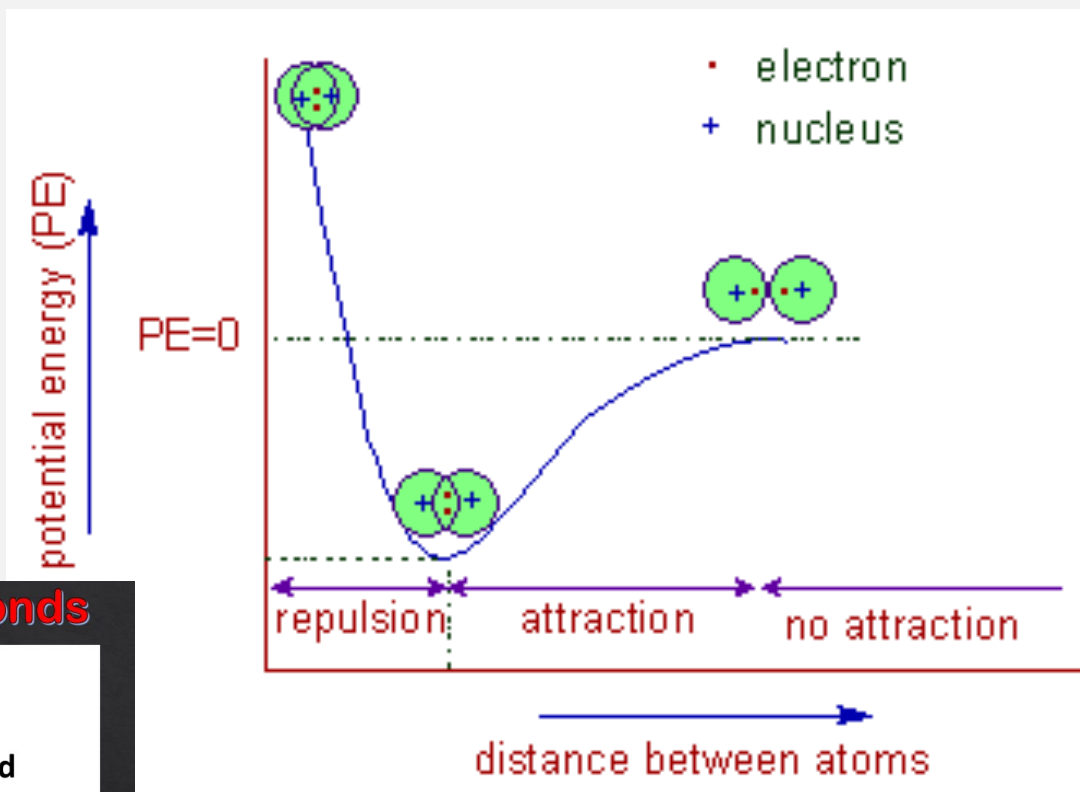
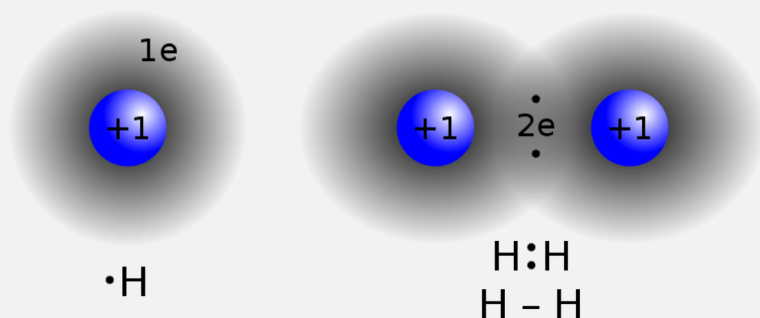
138.9054 57 La Lanthanum	140.116 58 Ce Cerium	140.9076 59 Pr Praseodymium	144.242 60 Nd Neodymium	(145) 61 Pm Promethium	150.36 62 Sm Samarium	151.964 63 Eu Europium	157.25 64 Gd Gadolinium	158.9253 65 Tb Terbium	162.500 66 Dy Dysprosium	164.9303 67 Ho Holmium	167.259 68 Er Erbium	168.9342 69 Tm Thulium	173.054 70 Yb Ytterbium
(227) 89 Ac Actinium	232.0380 90 Th Thorium	231.0358 91 Pa Protactinium	238.0289 92 U Uranium	(237) 93 Np Neptunium	(244) 94 Pu Plutonium	(243) 95 Am Americium	(247) 96 Cm Curium	(247) 97 Bk Berkelium	(251) 98 Cf Californium	(252) 99 Es Einsteinium	(257) 100 Fm Fermium	(258) 101 Md Mendelevium	(259) 102 No Nobelium

Valence electrons (electrons of s and p subshells of the most outer shell) are determining the chemical nature and reactivity of the elements/atoms.

# Primary chemical bonds

covalent, ionic, metallic

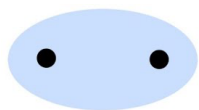
Covalent bond involves the sharing of electron pairs between atoms.



MSJChem  
Tutorials for IB Chemistry

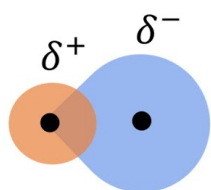
## Polar and non-polar bonds

Non-polar  
covalent bond



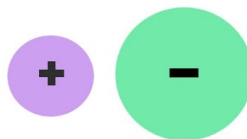
Equal sharing of  
electrons

Polar covalent  
bond



Unequal sharing  
of electrons

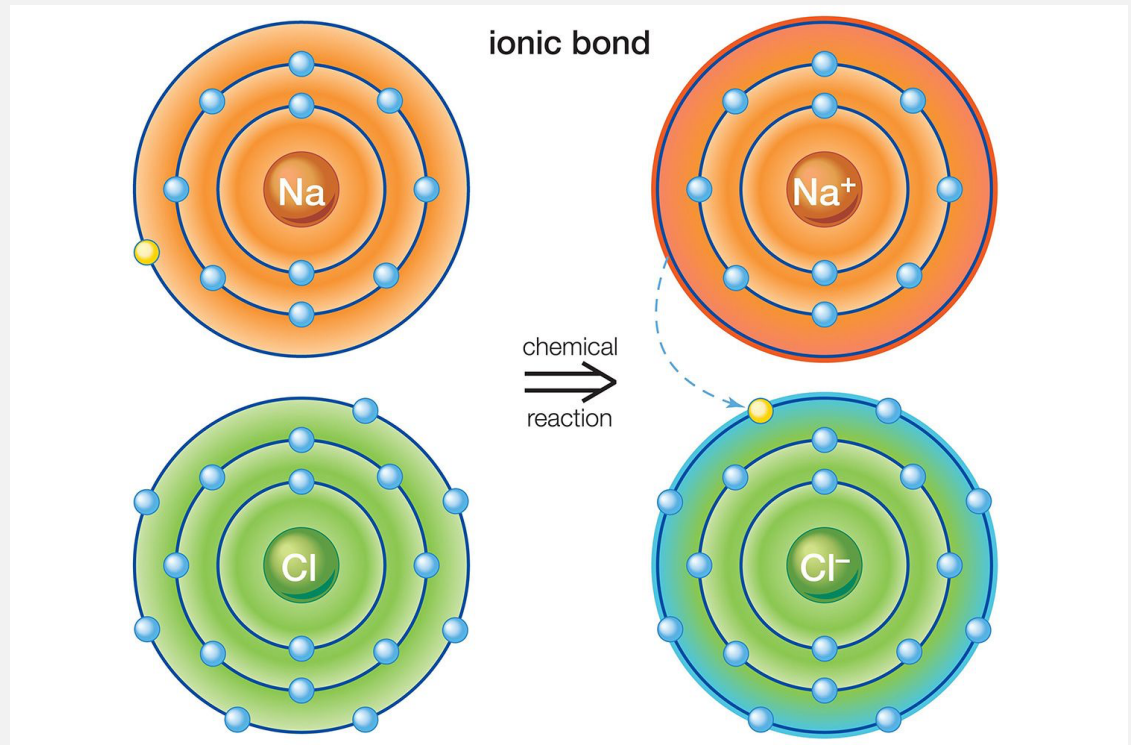
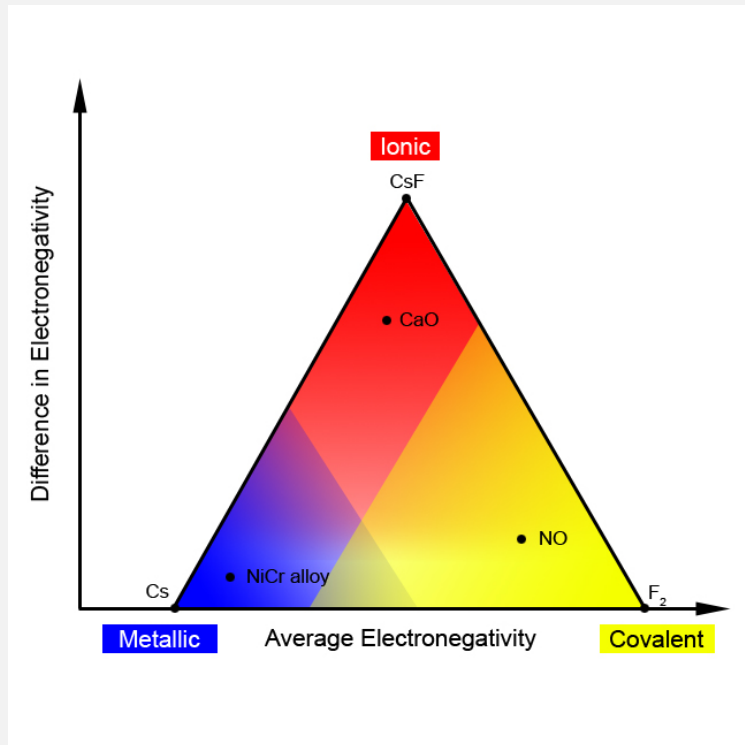
Ionic bond



No sharing of  
electrons in bond

Increasing difference in electronegativity

# Primary chemical bonds



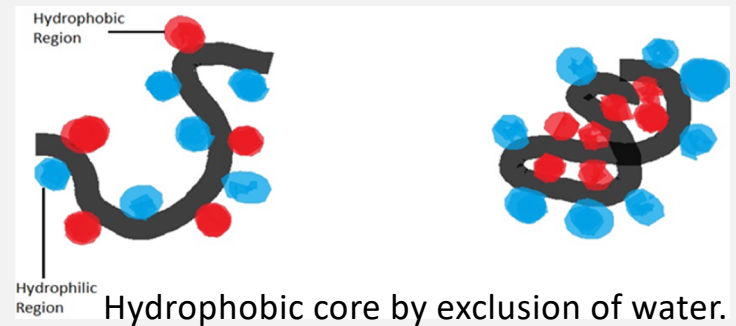
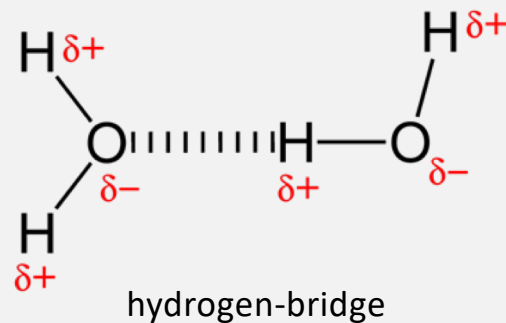
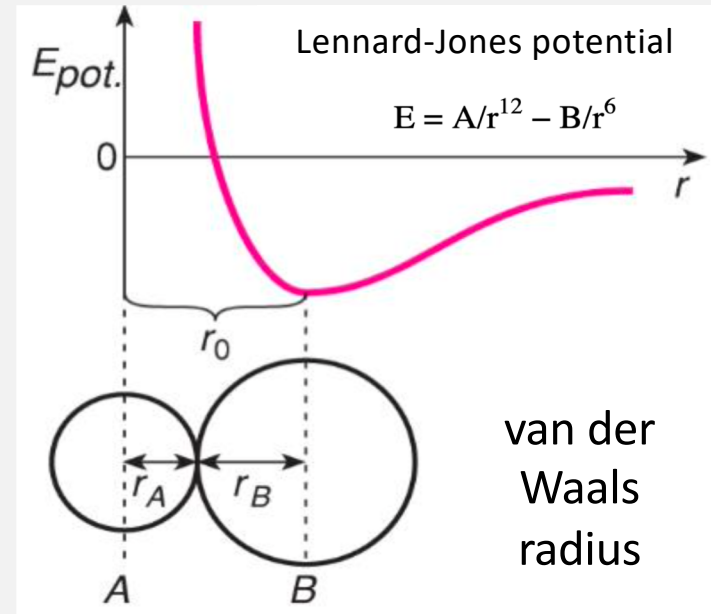
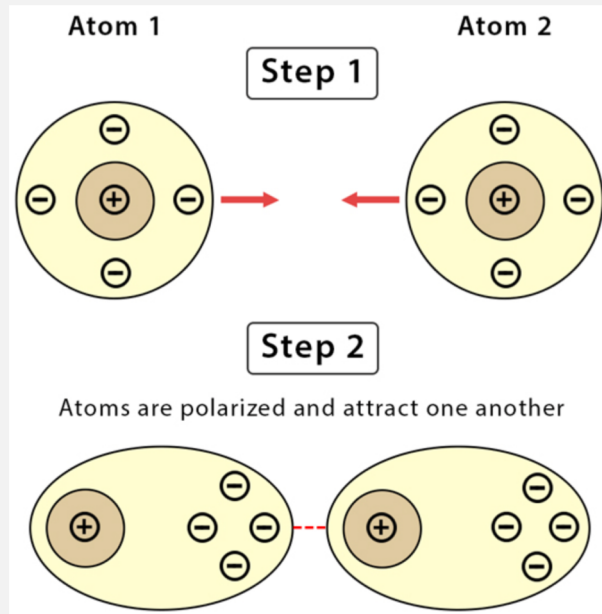
Elektronegativity (Linus Pauling): sum of the energies needed to produce a positive and a negative ion from an atom.

Ionic bond: if there is a great difference in electronegativity of the atoms (*e.g.* NaCl).

Metallic bond: there is an ordered, periodic lattice of the positive ions. The electrons are delocalized, stabilizing the whole structure.

# Secondary interactions

dipole-dipole, van der Waals, H-bridge, hydrophobic  
*weaker by one-two orders of magnitude*

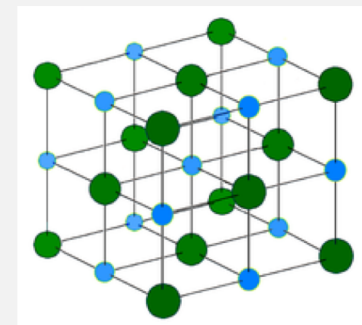
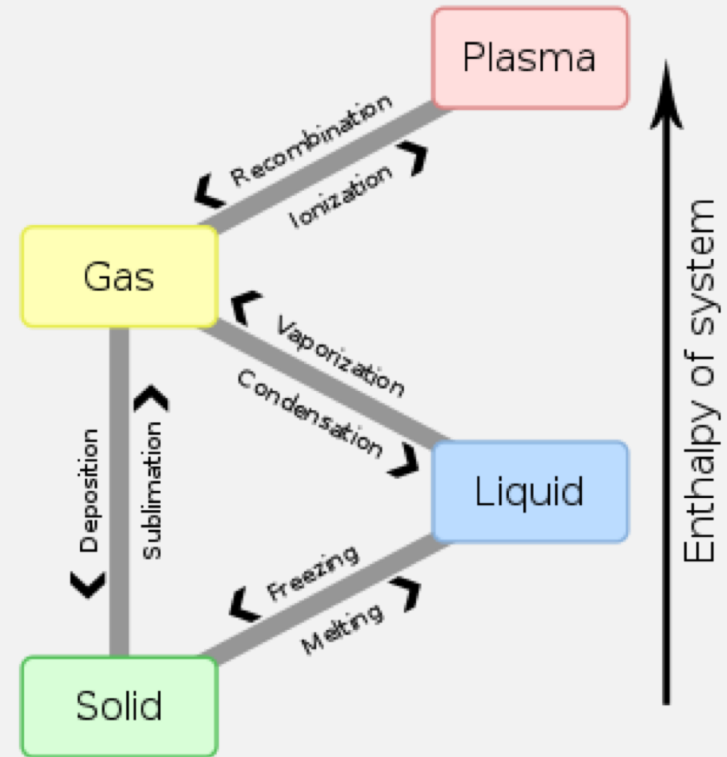


# Phases of matter

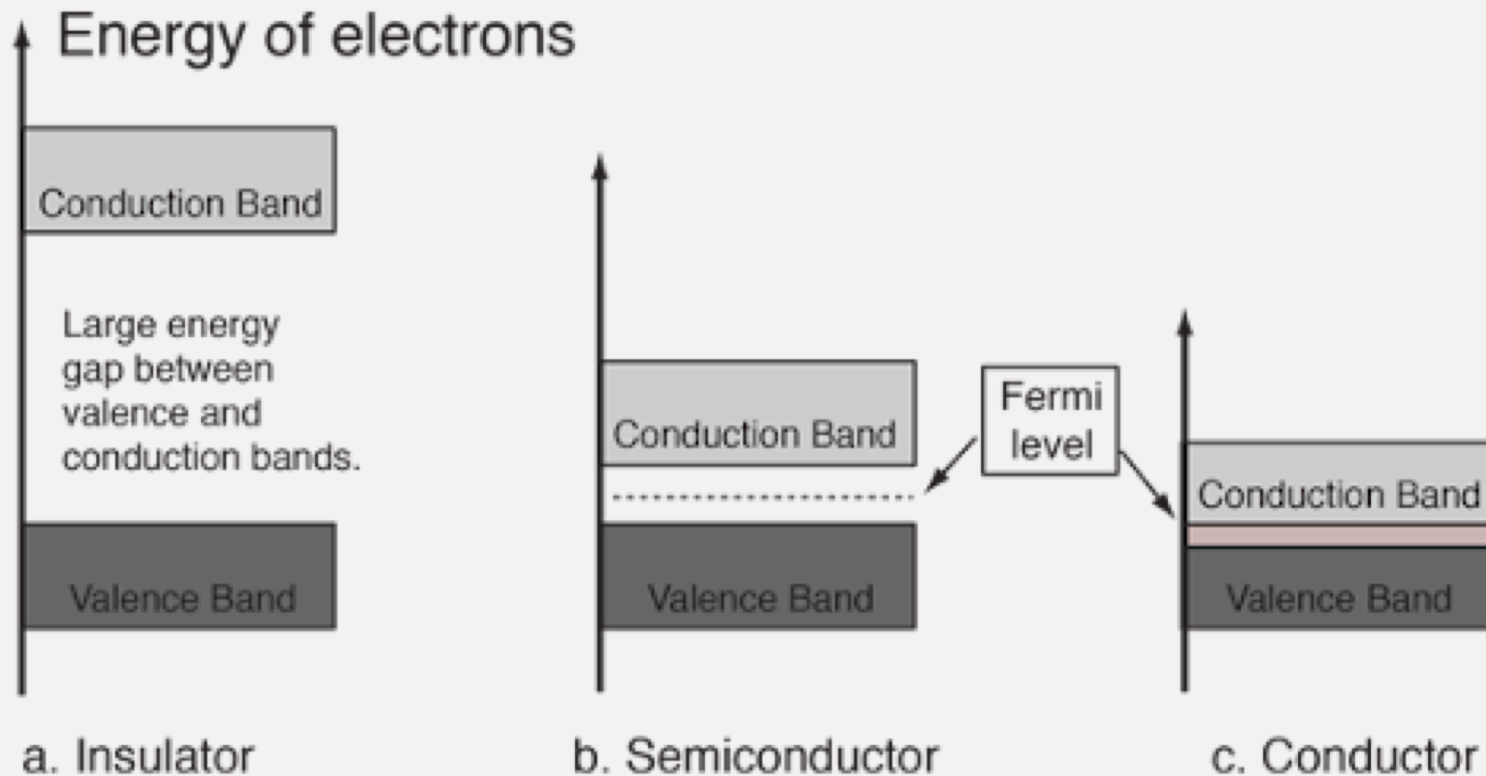
Gases: the particles are moving independently, colliding with each other and with the wall of the container. Ideal gas: the particles are point-like without a volume.

Liquids: there are only short-range order which is dynamic in nature. Particles can roll on each other. A liquid is a nearly incompressible fluid that conforms to the shape of its container but retains a constant volume independent of the pressure. Liquids are usually isotropic.

Crystalline materials: long-range, periodic order exists with many repetition of an elementary cell. Anisotropic.



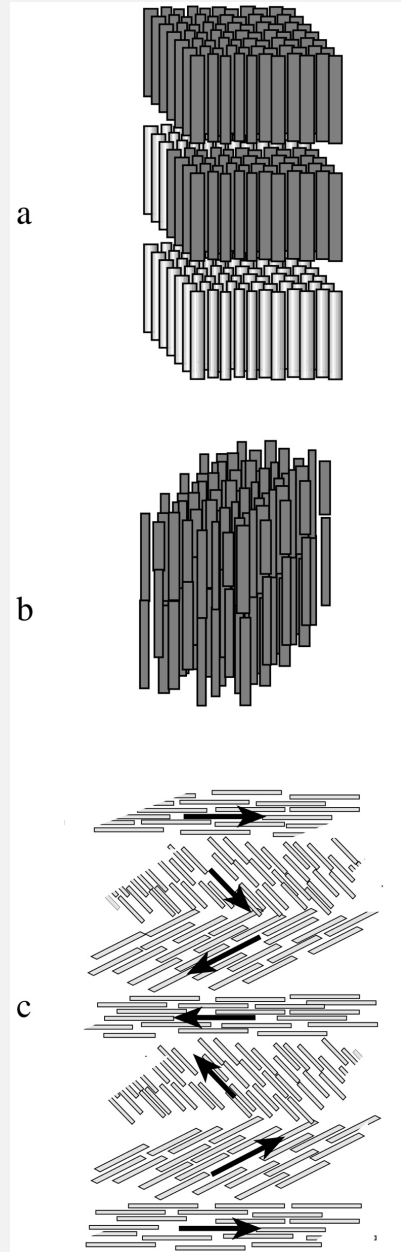
# Band structures of crystals



Energy gap between valence and conduction bands is called forbidden gap. Fermi energy is a hypothetical energy level for the electrons, related to a 50% occupancy.

If the energy gap is bigger than  $>3,1$  eV, the maximum photon energy of a visible light, than the crystal is transparent. Conductors are non-transparent as there are electrons in the conduction band which can absorb visible photon energies.

# Liquid crystal phases



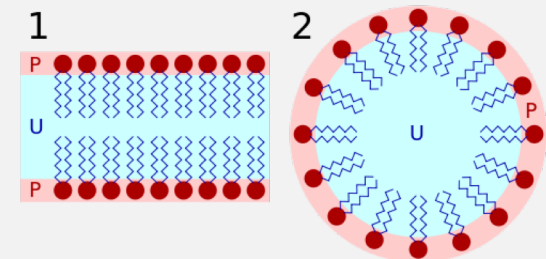
Mesophases can be characterized by the type of ordering. One can distinguish positional order (whether molecules are arranged in any sort of ordered lattice) and orientational order (whether molecules are mostly pointing in the same direction).

- a) smectic phase: both ordering are present
- b) nematic phase: only the orientational ordering is present
- c) cholesteric or twisted nematic phase: a chiral order can be observed due to a fixed angle rotation of asymmetric molecules in the adjacent layers

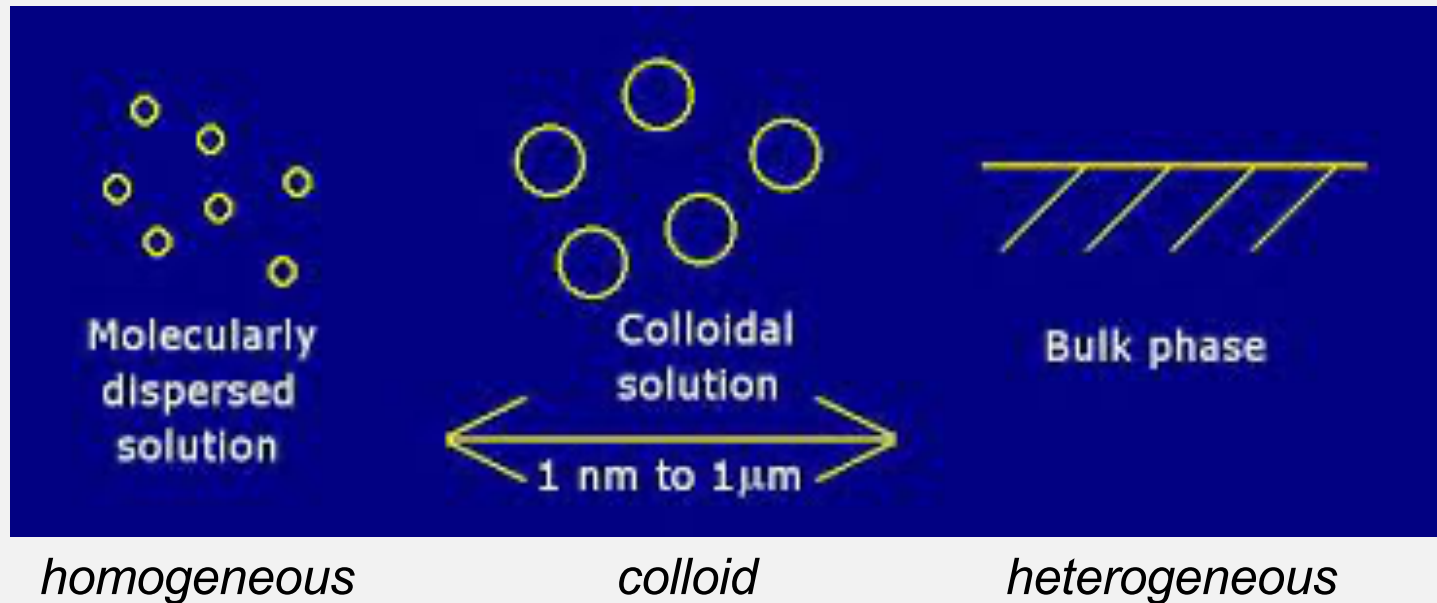
Thermotropic liquid crystals: the ordering depends on the temperature, present only in a certain temperature range.

Lyotropic liquid crystals: the ordering can be observed in certain concentration range, characteristic for amphiphilic molecules.

1) bilayers, 2) micelles



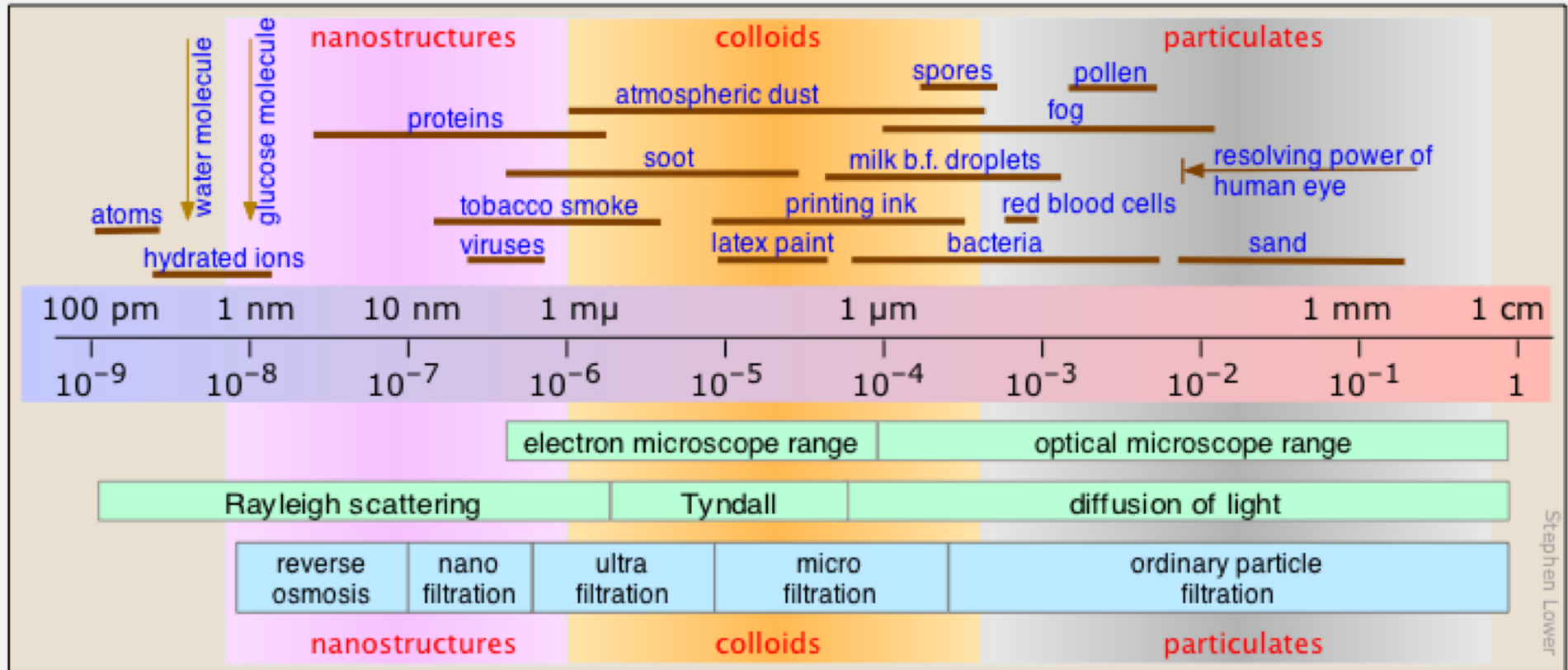
# Colloid state



If particulate matter is dispersed in a homogeneous medium the way that particles have real surfaces (there are inner molecules in the particles which are not in contact with the dispersion medium) than we call this state as colloid phase. Many important biological molecule is forming colloids, like macromolecular colloids (proteins, polysaccharides), or association colloids like cell membranes.

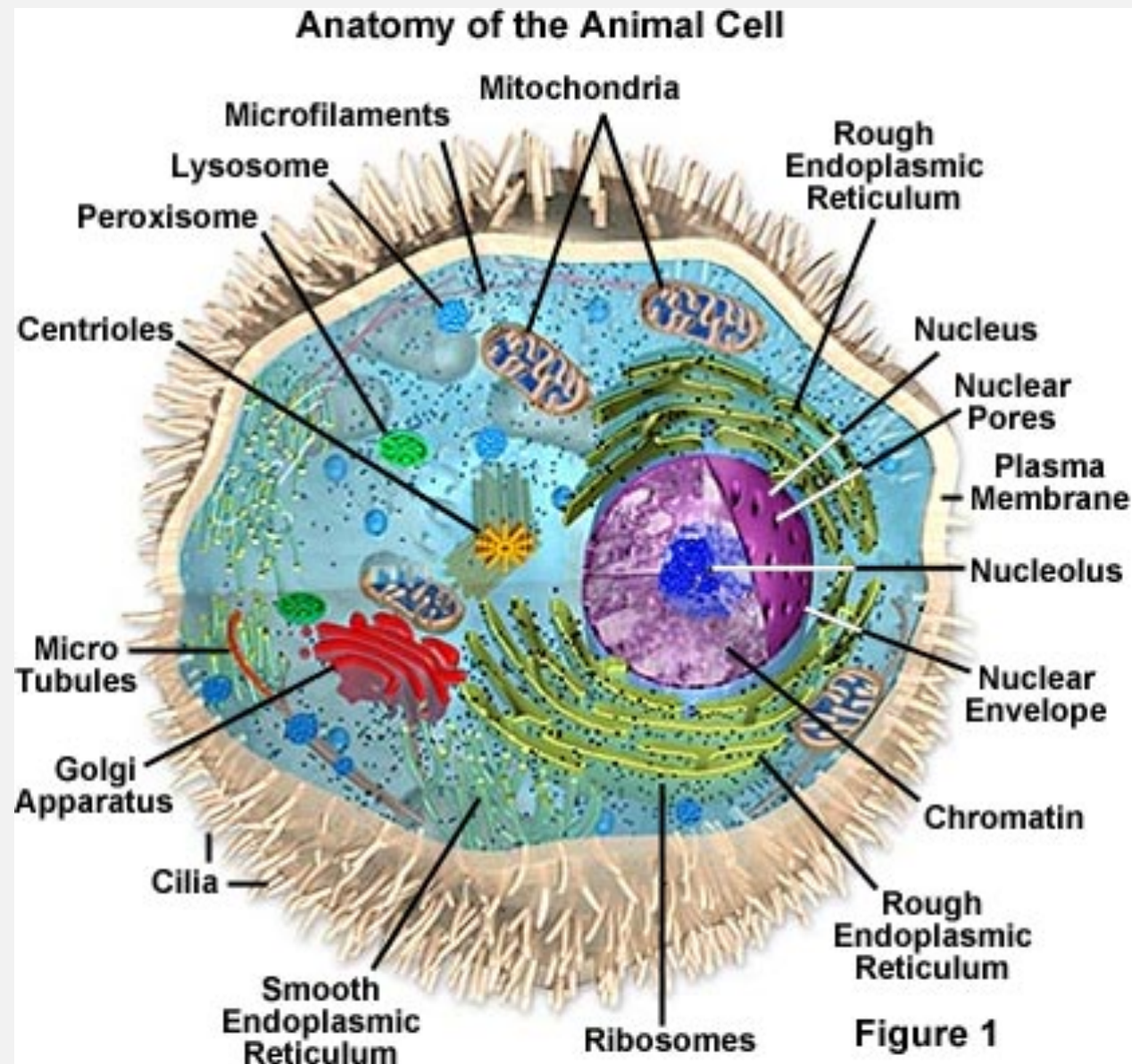
A colloid consists of two distinct phases, a continuous phase (the dispersion medium) and a particulate phase, where the particles generally have dimensions ranging between 2 and 200 nm. The two phases can be liquid-in-liquid (milk), solid-in-liquid (paint), liquid-in-gas (aerosol) and other combinations.

# Typical colloid sizes



Any matter can form colloids. The colloid state depends only on particle sizes, independently of chemical compositions or material characteristics.

# Many biological materials are colloids



# Checklist

developing models of atom

quantized energy levels

Franck-Hertz experiment

Spectrum of the H atom

quantum numbers

Pauli principle

Hund's low

bond types

gas, liquid, solid states

liquid crystals

colloids

Related chapters in  
*Damjanovich, Fidy, Szöllősi: Medical Biophysics*

I. chapter

1.1.1	3.1.1
1.1.2	3.2.1
1.2.1	3.3.1
1.2.2	3.3.2
1.3.1	3.3.3
1.3.3	3.4.1
1.4.1	3.4.2
1.4.2	4.1.1
1.4.3	4.1.2
2.1.1	4.1.3
2.1.2	
2.1.3	
2.1.4	
2.1.5	