

# Biophysics I

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

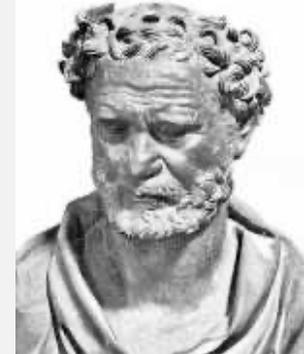
Károly LILIOM

04. 10. 2024.

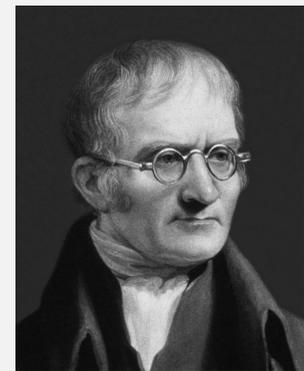
[karoly.liliom.mta@gmail.com](mailto:karoly.liliom.mta@gmail.com)

# Development of the atom concept

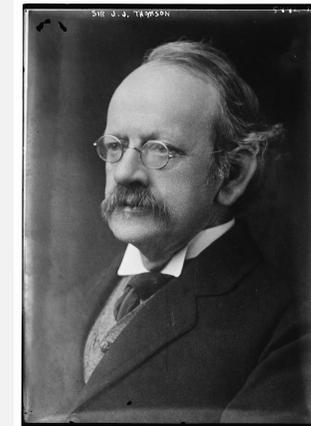
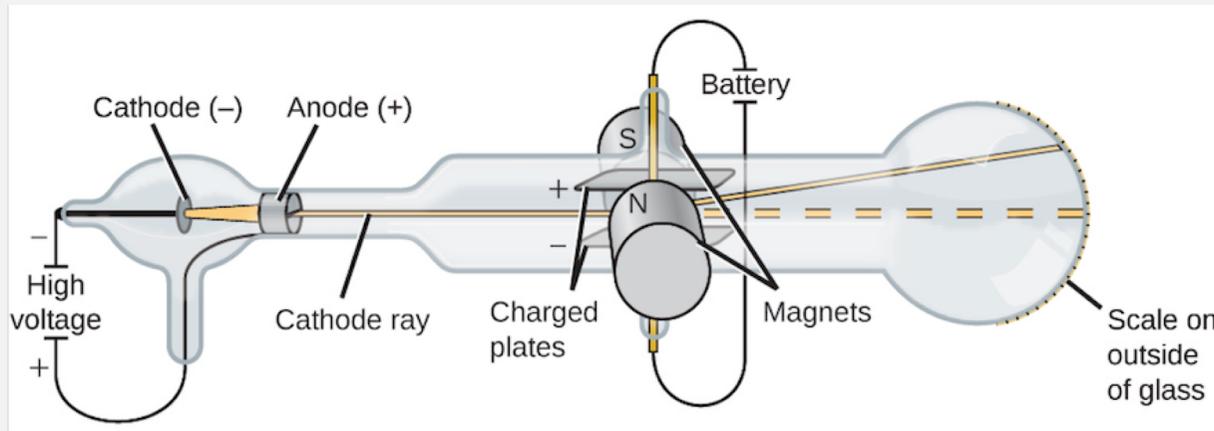
Democritus (460–370 BC): everything is composed of "atoms," which are physically, but not geometrically, indivisible; that between atoms, there lies empty space; that atoms are indestructible, and have always been and always will be in motion.  
(greek *atomos* means uncuttable)



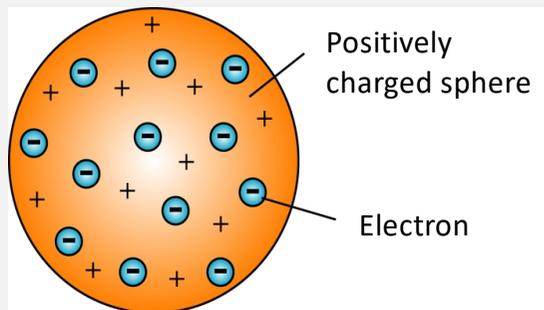
John Dalton (1803-1811) the law of multiple proportions: if the same two elements can be combined to form a number of different compounds, then the ratios of the masses of the two elements in their various compounds will be represented by small whole numbers – so elements react in multiples of some basic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



# Development of the atom concept

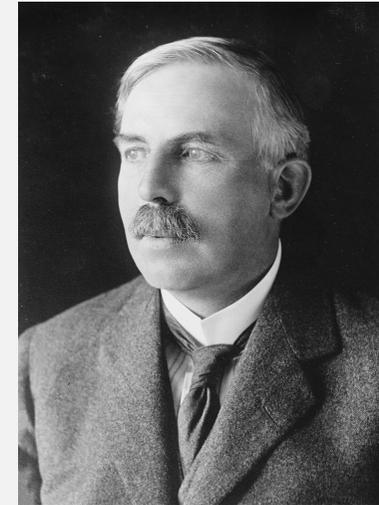
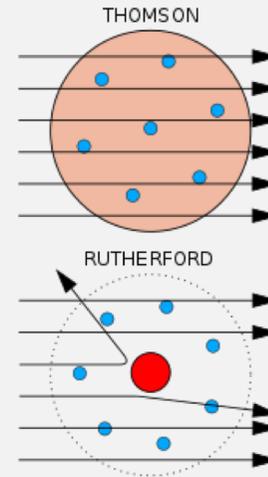
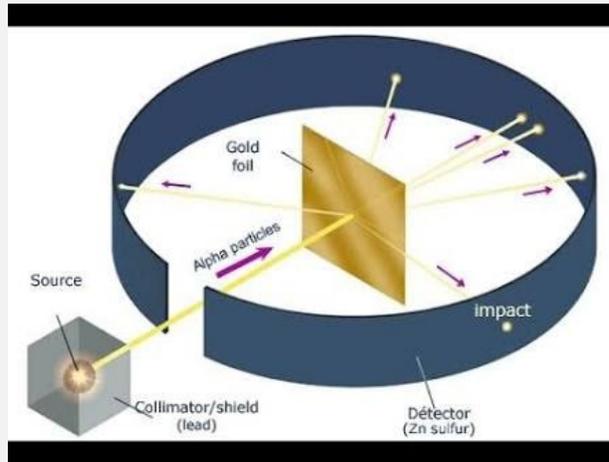


Joseph John Thomson (1897): Discovery of electrons by studying the cathode rays - identical particles with a mass  $\sim 1/2000^{\text{th}}$  the mass of a H atom, independent of the cathode material – it must be the same constituent in all atoms.



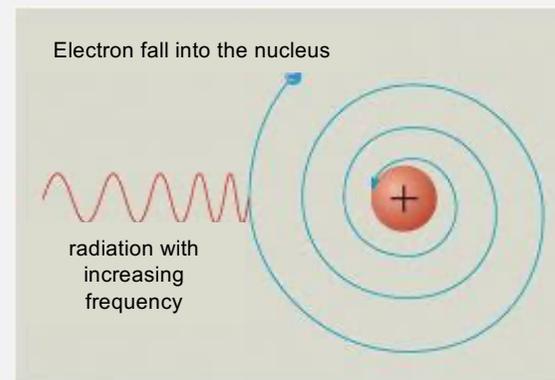
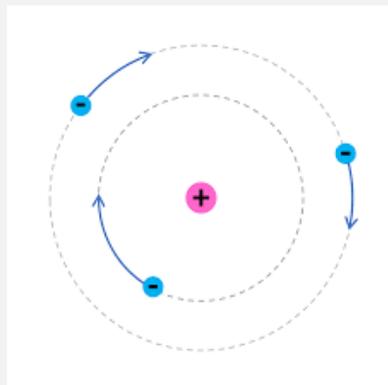
Joseph John Thomson "plum-puding model" (1904): the positively charged main mass is distributed evenly in the atom, whereas the negatively charged small electrons are moving in it.

# Development of the atom concept

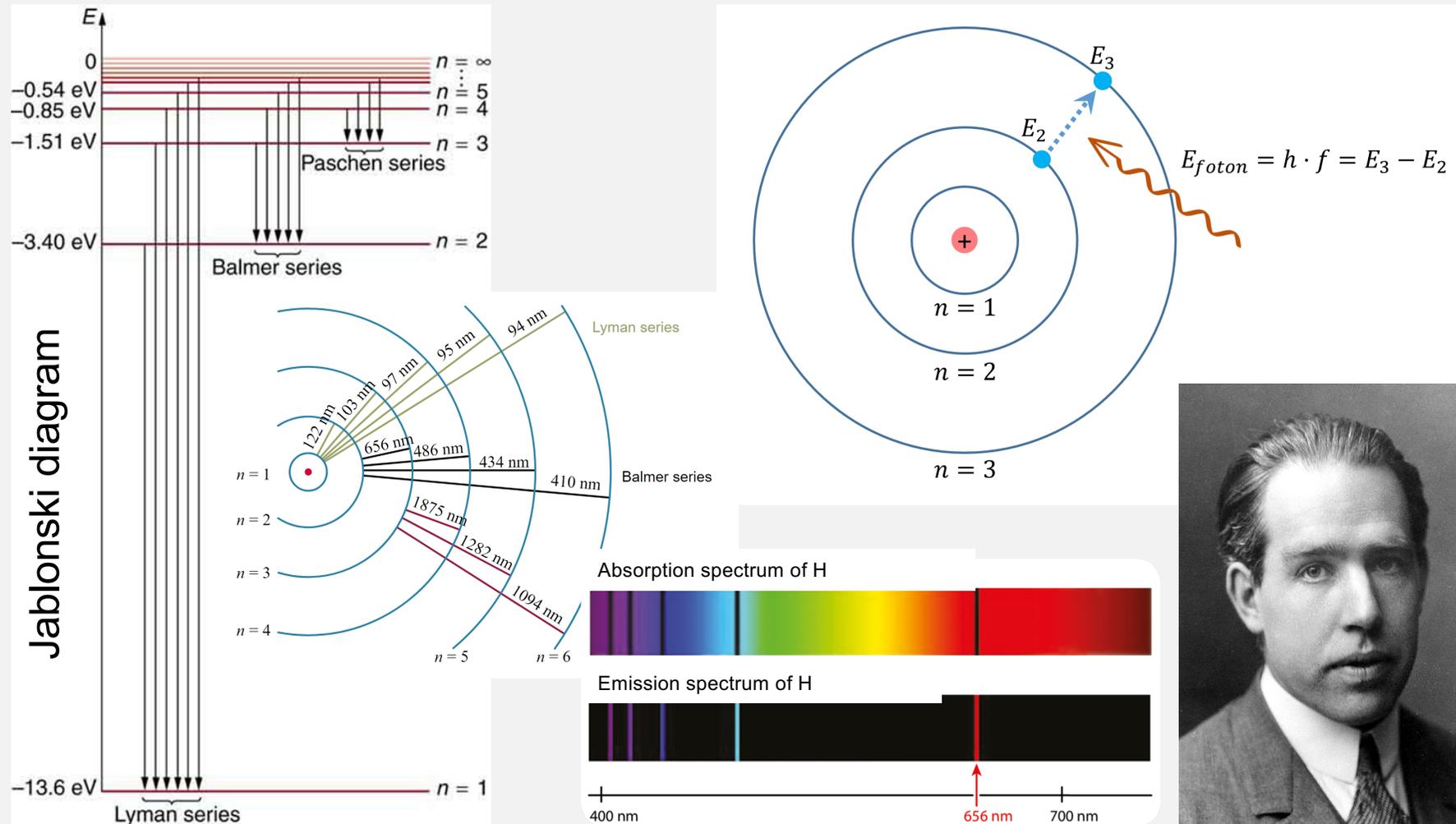


*1909-1911: scattering of  $\alpha$ -particles on gold*

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.

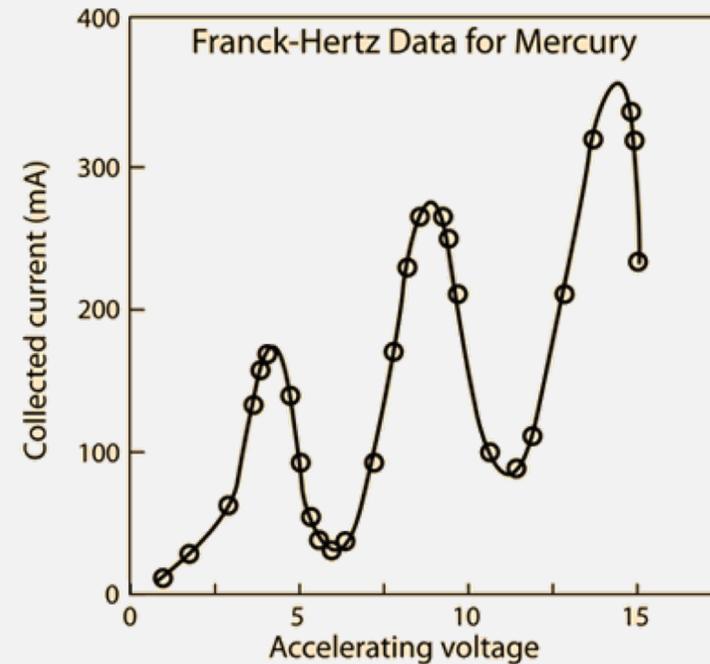
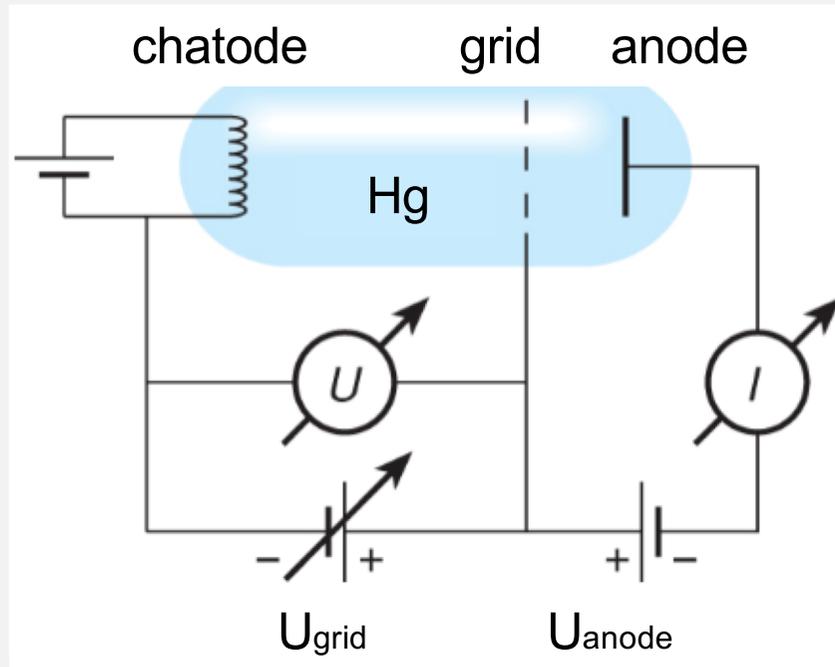


# Development of the atom concept



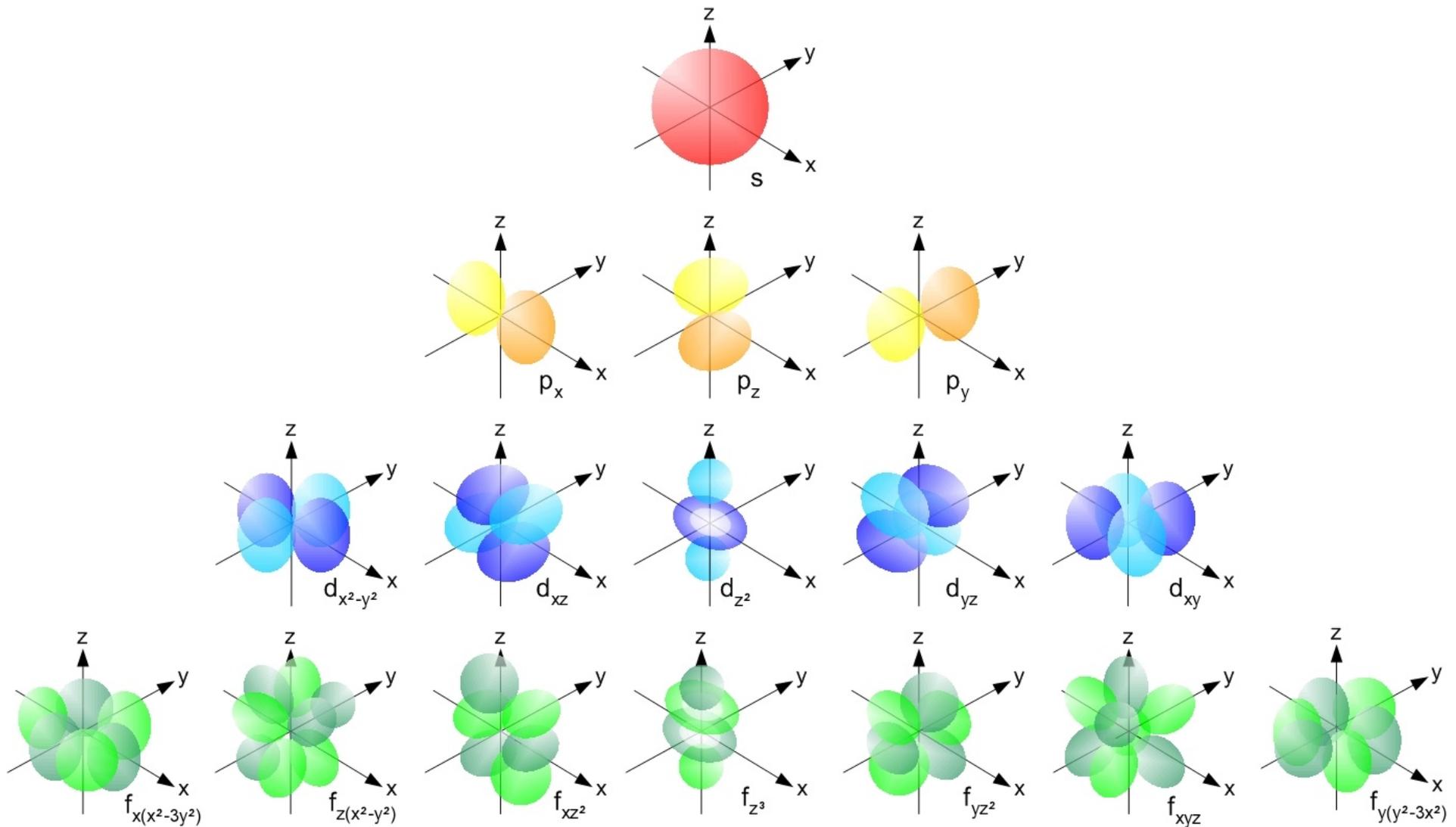
Niels Bohr (1913): There are stationary orbitals with quantized energy levels where electrons are not emitting radiations. Electrons can quantum-jump between these orbitals by absorbing or emitting the energy difference of the orbitals. The stationary orbitals are selected by the rule that the angular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

# Franck – Hertz experiment (1914)



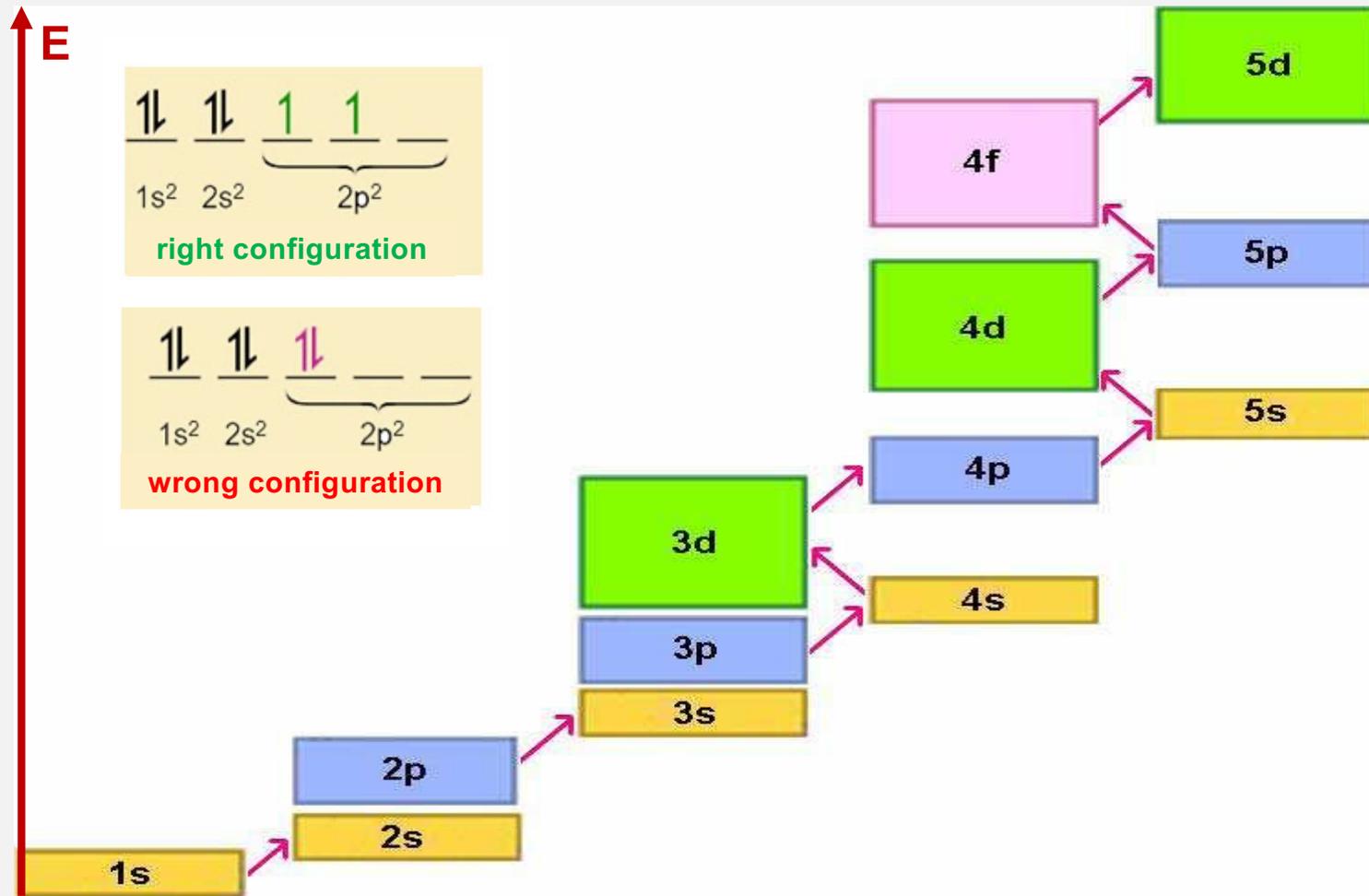
Electrons are colliding elastically with Hg atoms, until they get high enough energy, by increasing the grid voltage, to be able to excite the Hg atoms. At this accelerating voltage, the electrons lose their energy and are not able to reach the anode, so the current drops. Further increasing the accelerating 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																	2	
	H Hydrogen																	He Helium	
	2	3	4											5	6	7	8	9	10
2	Li Lithium	Be Beryllium											B Boron	C Carbon	N Nitrogen	O Oxygen	F Fluorine	Ne Neon	
3	Na Sodium	Mg Magnesium											Al Aluminium	Si Silicon	P Phosphorus	S Sulfur	Cl Chlorine	Ar Argon	
4	K Potassium	Ca Calcium	Sc Scandium	Ti Titanium	V Vanadium	Cr Chromium	Mn Manganese	Fe Iron	Co Cobalt	Ni Nickel	Cu Copper	Zn Zinc	Ga Gallium	Ge Germanium	As Arsenic	Se Selenium	Br Bromine	Kr Krypton	
5	Rb Rubidium	Sr Strontium	Y Yttrium	Zr Zirconium	Nb Niobium	Mo Molybdenum	Tc Technetium	Ru Ruthenium	Rh Rhodium	Pd Palladium	Ag Silver	Cd Cadmium	In Indium	Sn Tin	Sb Antimony	Te Tellurium	I Iodine	Xe Xenon	
6	Cs Caesium	Ba Barium	Lu Lutetium	Hf Hafnium	Ta Tantalum	W Tungsten	Re Rhenium	Os Osmium	Ir Iridium	Pt Platinum	Au Gold	Hg Mercury	Tl Thallium	Pb Lead	Bi Bismuth	Po Polonium	At Astatine	Rn Radon	
7	Fr Francium	Ra Radium	Lr Lawrencium	Rf Rutherfordium	Db Dubnium	Sg Seaborgium	Bh Bohrium	Hs Hassium	Mt Meitnerium	Ds Darmstadtium	Rg Roentgenium	Cn Copernicium	Uut Ununtrium	Fl Flerovium	Uup Ununpentium	Lv Livermorium	Uus Ununseptium	Uuo Ununoctium	

atomic mass or most stable mass number

1st ionization energy in kJ/mol

chemical symbol

name

electron configuration

atomic number

electronegativity

oxidation states most common are bold

alkali metals

alkaline metals

other metals

transition metals

lanthanoids

actinoids

metalloids

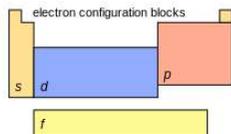
nonmetals

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.

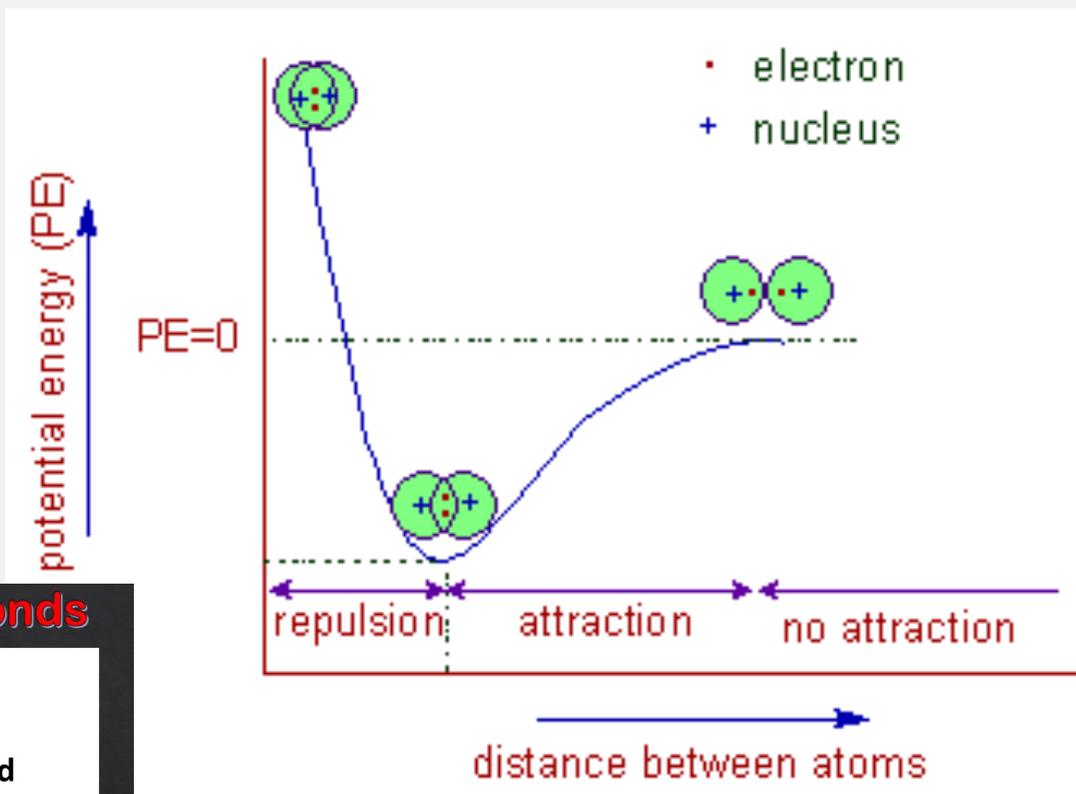
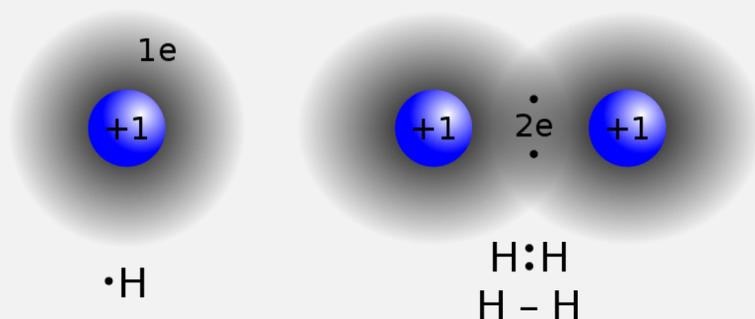
138.9054 57 La Lanthanum	140.116 58 Ce Cerium	140.9076 59 Pr Praseodymium	144.242 60 Nd Neodymium	(145) 61 Pm Promethium	150.36 62 Sm Samarium	151.964 63 Eu Europium	157.25 64 Gd Gadolinium	158.9253 65 Tb Terbium	162.500 66 Dy Dysprosium	164.9303 67 Ho Holmium	167.259 68 Er Erbium	168.9342 69 Tm Thulium	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

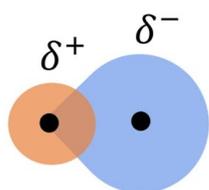
## Polar and non-polar bonds

Non-polar  
covalent bond



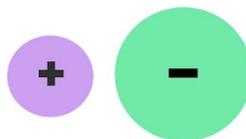
Equal sharing of  
electrons

Polar covalent  
bond



Unequal sharing  
of electrons

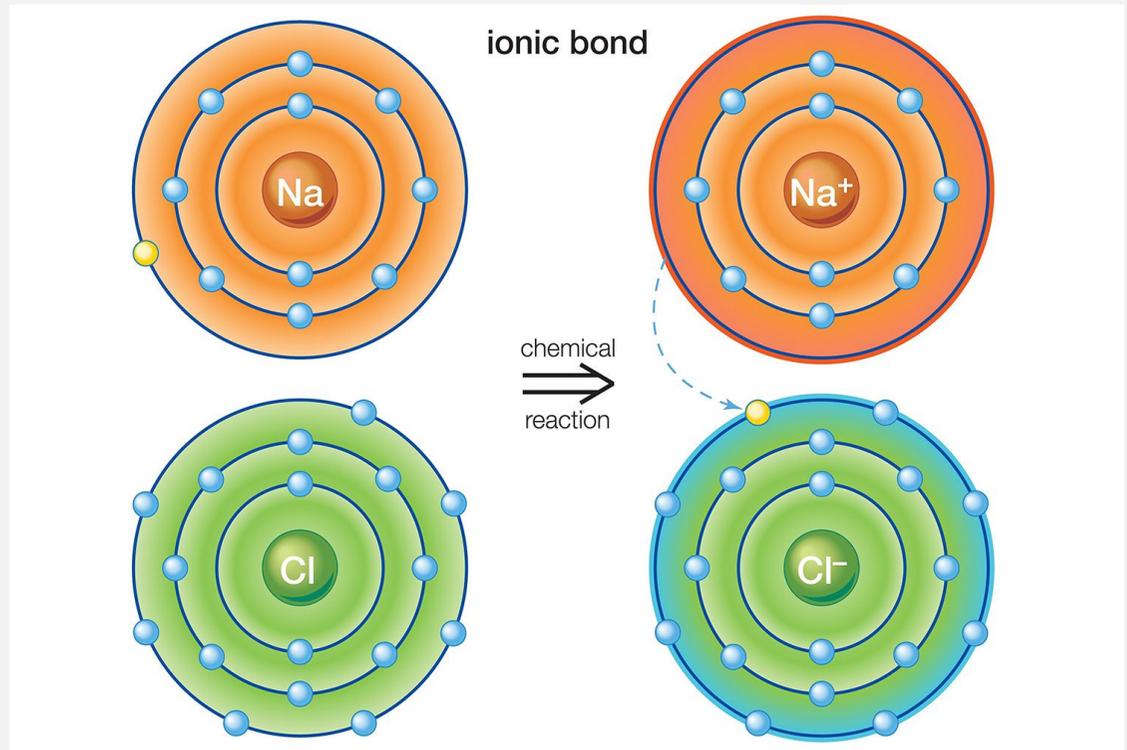
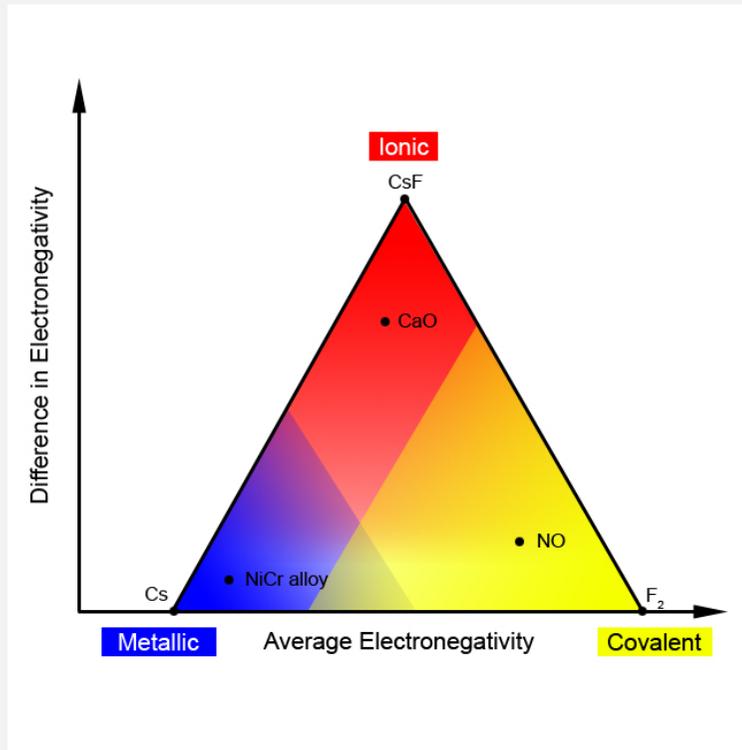
Ionic bond



No sharing of  
electrons in bond

Increasing difference in electronegativity

# Primary chemical bonds



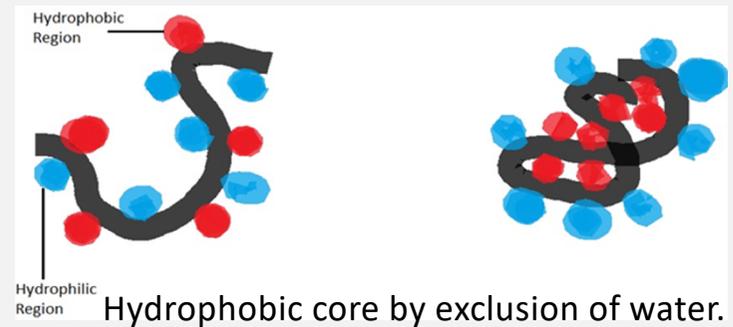
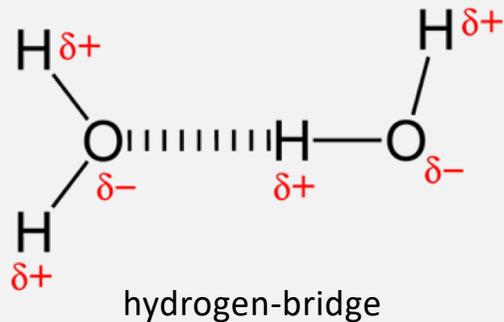
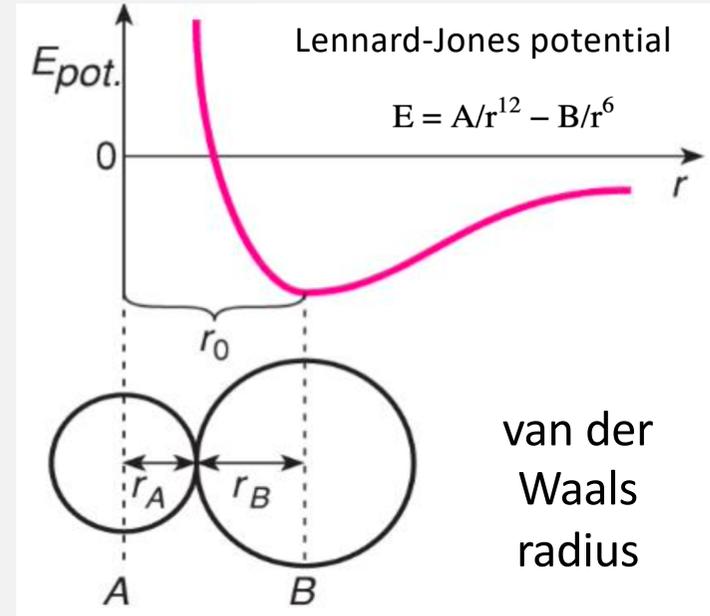
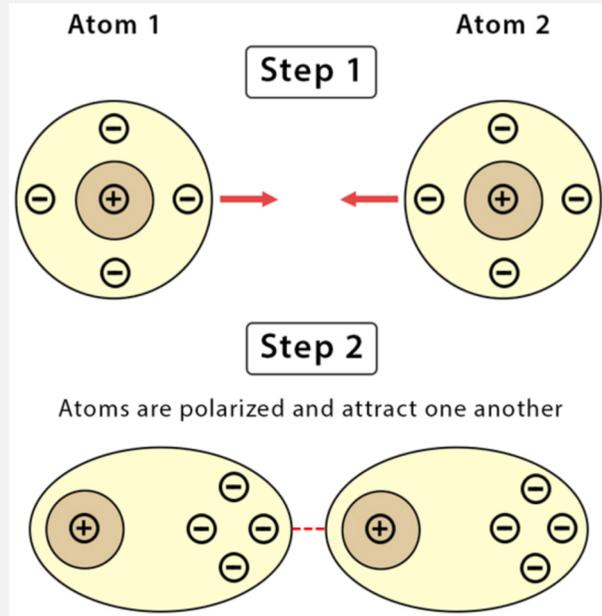
Elektronegativity (Linus Pauling): sum of the energies needed to produce a positive and a negative ion from an atom.

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*

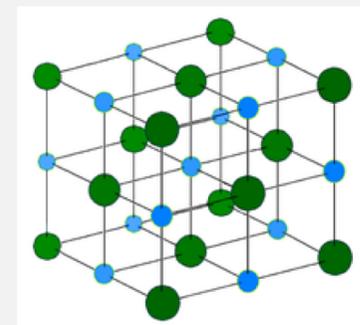
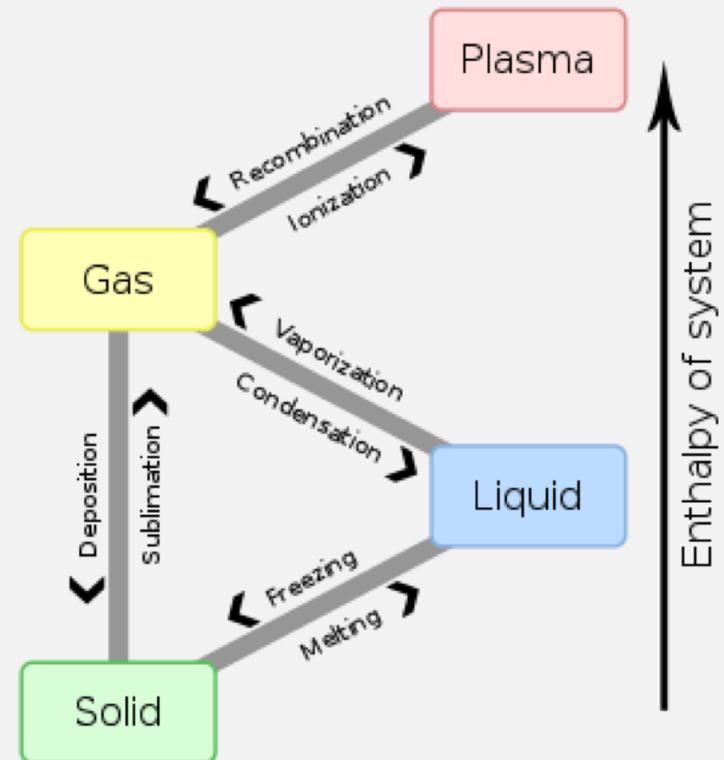


# Phases of matter

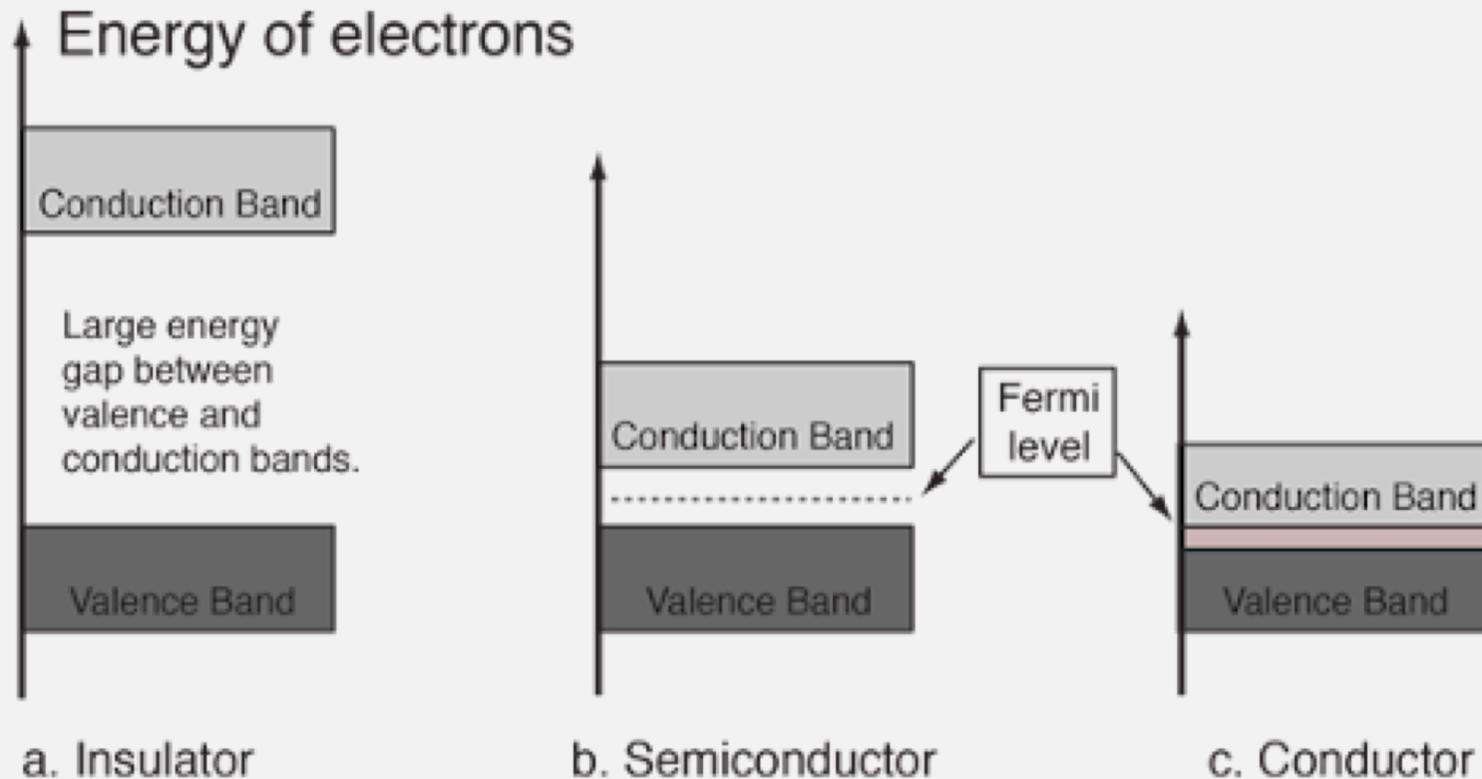
Gases: the particles are moving independently, colliding with each other and with the wall of the container. Ideal gas: the particles are point-like without a volume.

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.



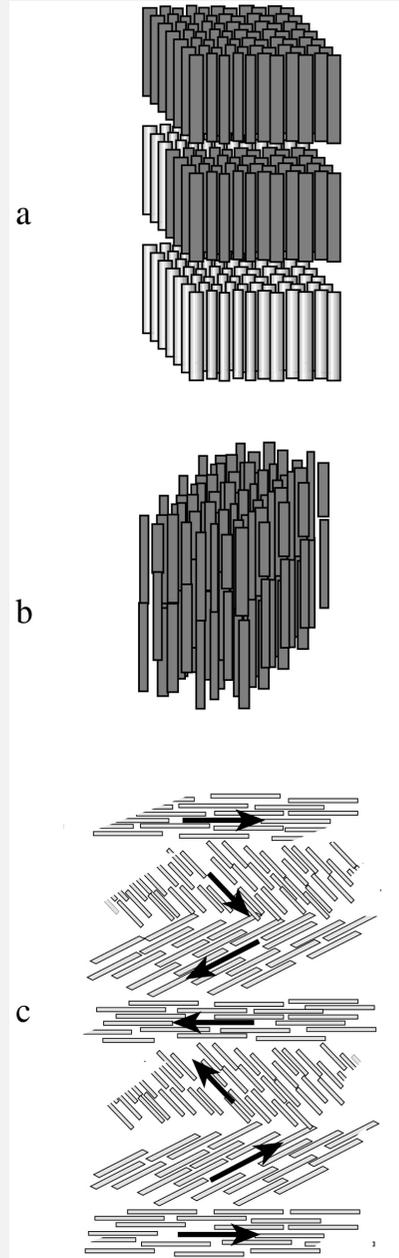
# Band structures of crystals



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



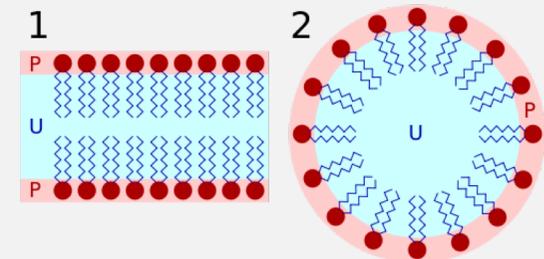
Mesophases can be characterized by the type of ordering. One can distinguish positional order (whether molecules are arranged in any sort of ordered lattice) and orientational order (whether molecules are mostly pointing in the same direction).

- 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

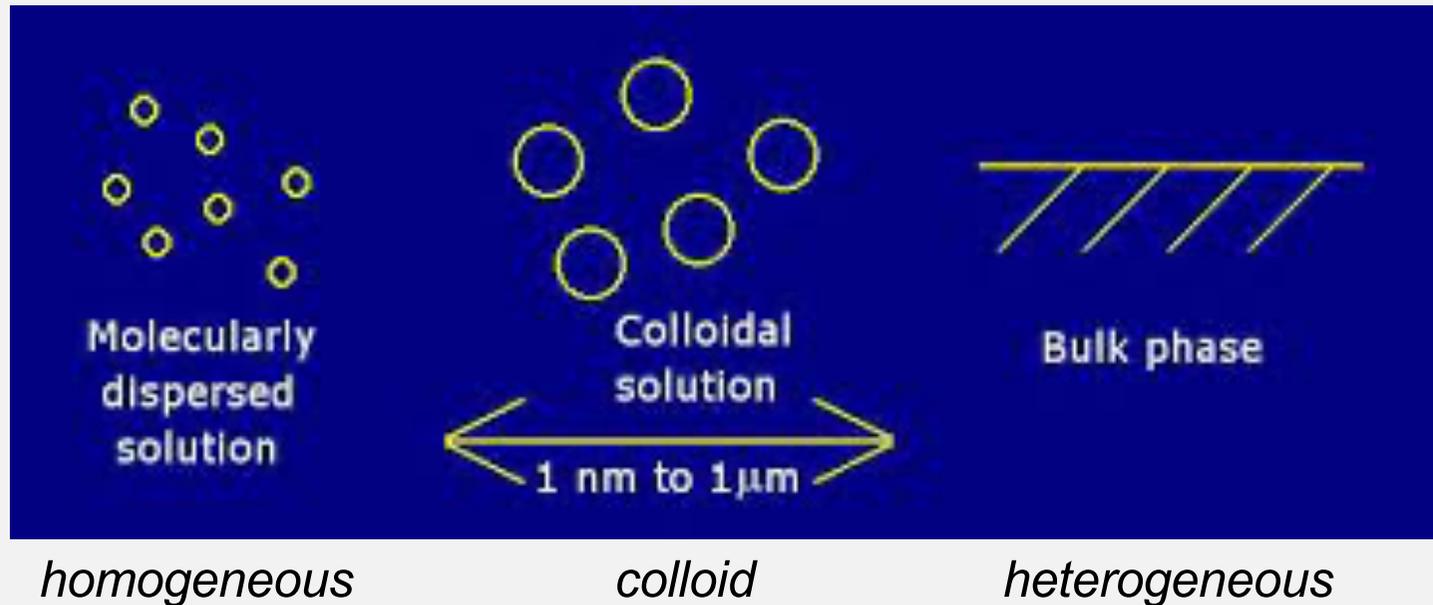
Thermotropic liquid crystals: the ordering depends on the temperature, present only in a certain temperature range.

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

1) bilayers, 2) micelles



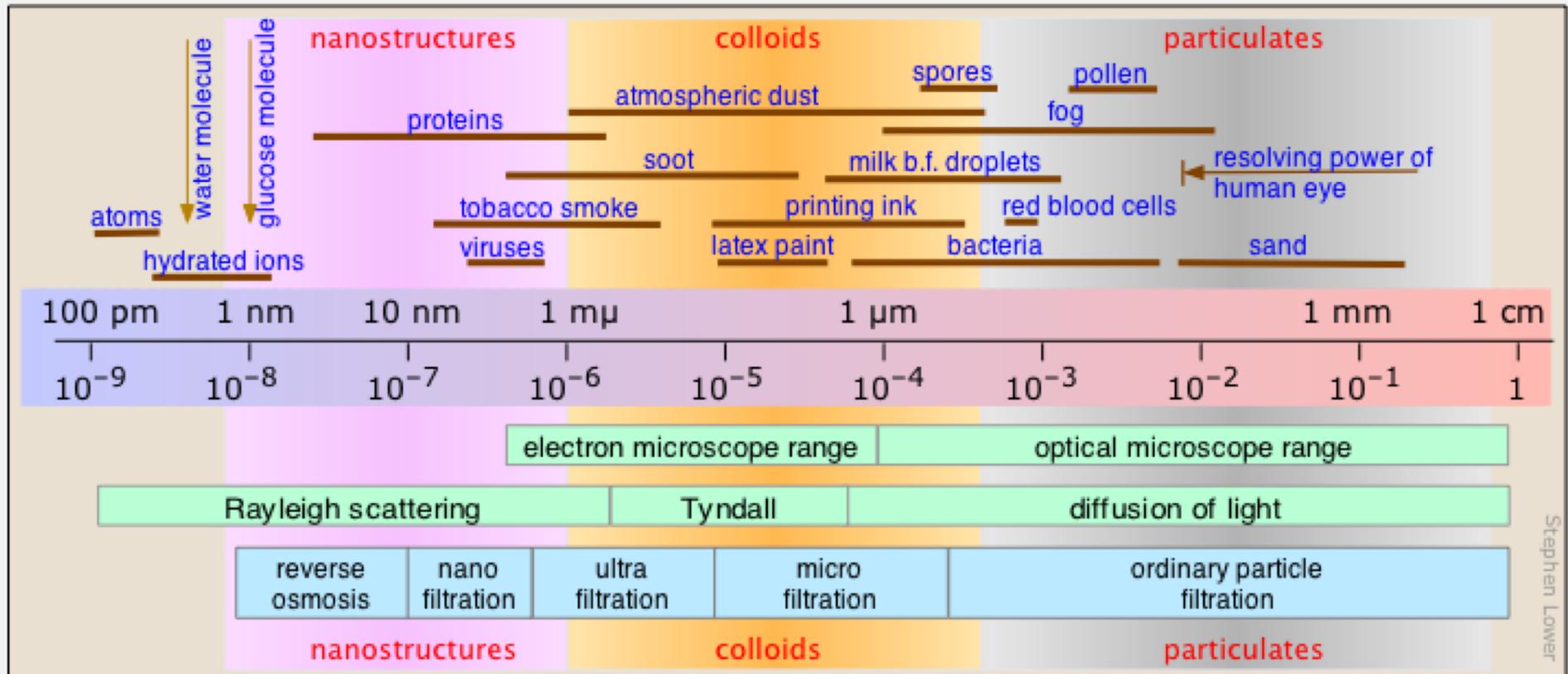
# Colloid state



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) then 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.

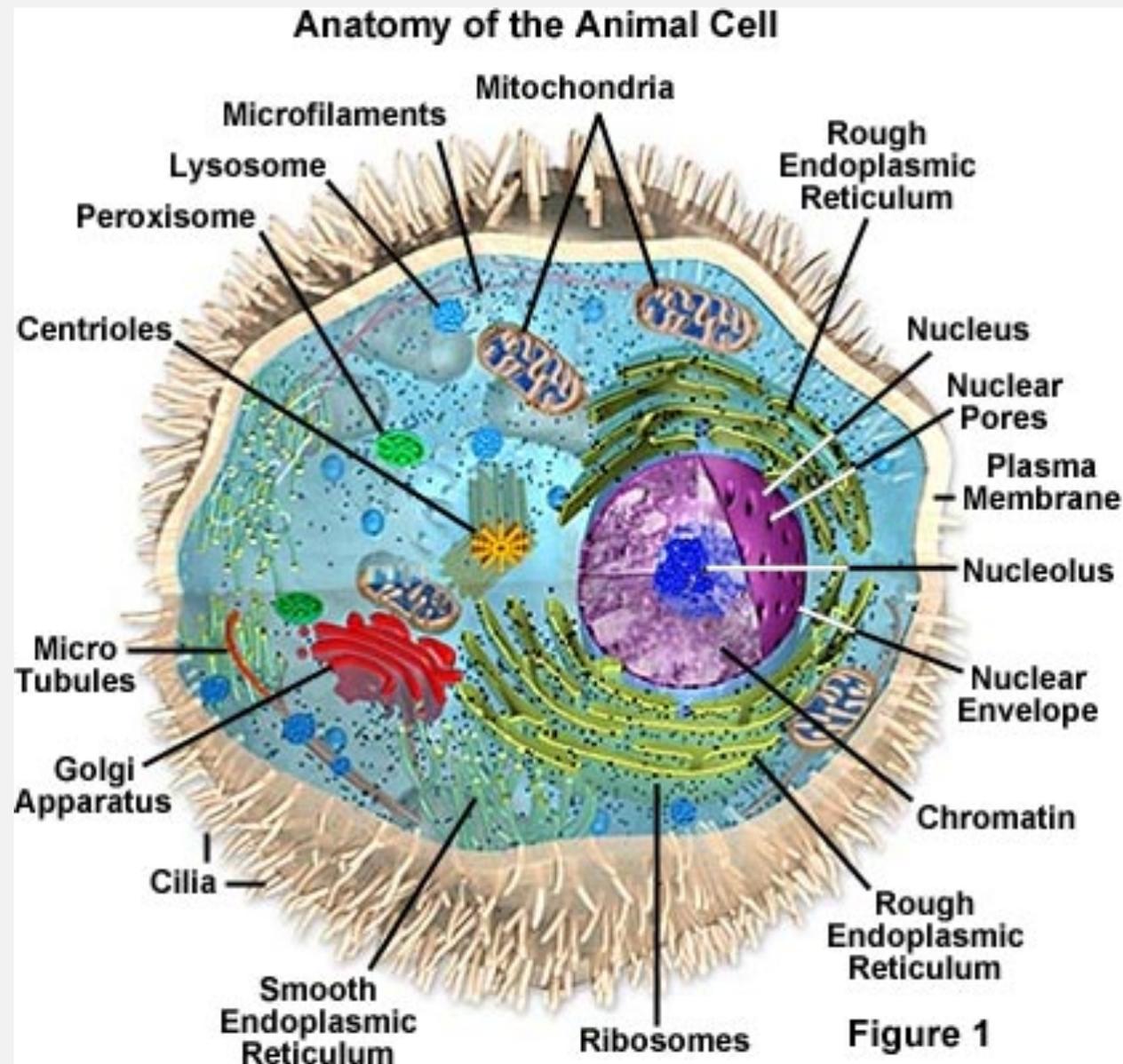
A colloid consists of two distinct phases, a continuous phase (the dispersion medium) and a particulate phase, where the particles generally have dimensions ranging between 2 and 200 nm. The two phases can be liquid-in-liquid (milk), solid-in-liquid (paint), liquid-in-gas (aerosol) and other combinations.

# 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, Szöllösi: 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	