Biophysics I

5. Structure of matter
Atoms, molecules, crystals

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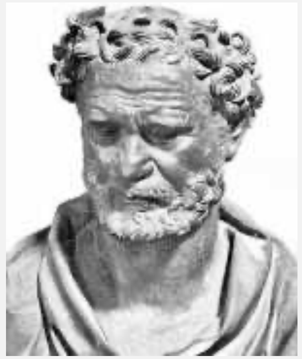
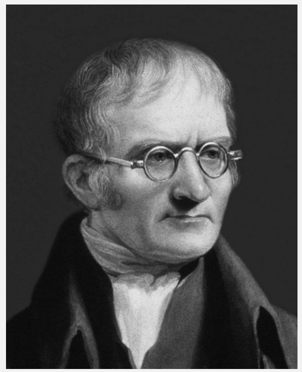
Development of the atom concept

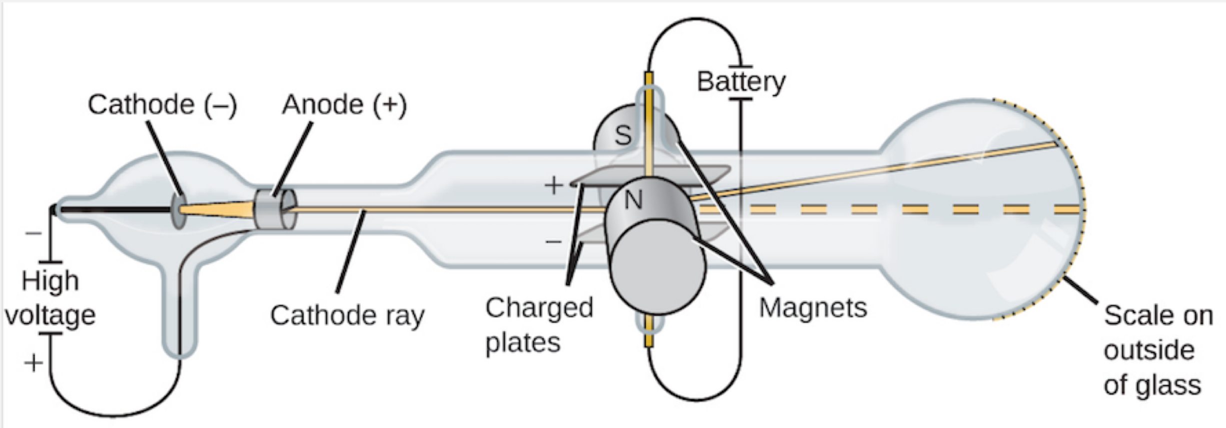
Democritus (460–370 BC): everything is composed of "atoms," which are physically, but not geometrically, indivisible; that between atoms, there lies empty space; that atoms are indestructible, and have always been and always will be in motion.
(greek *atomos* means uncuttable)

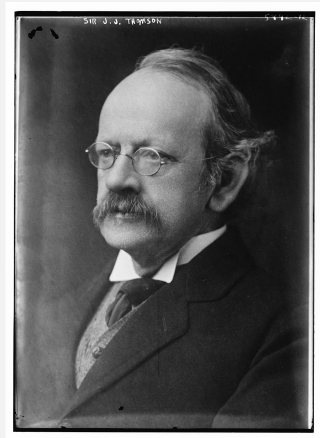


John Dalton (1803-1811) the law of multiple proportions: if the same two elements can be combined to form a number of different compounds, then the ratios of the masses of the two elements in their various compounds will be represented by small whole numbers – so elements react in multiples of some basic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

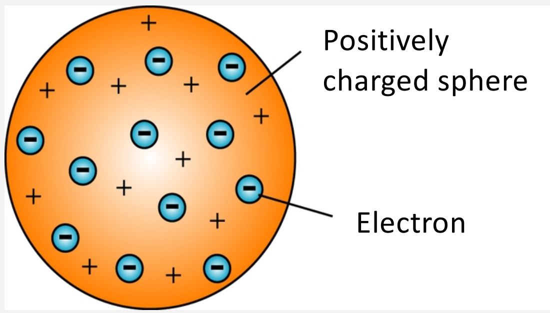


Development of the atom concept



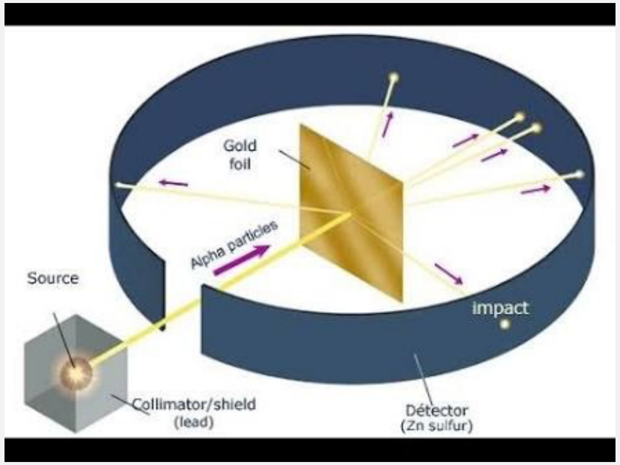


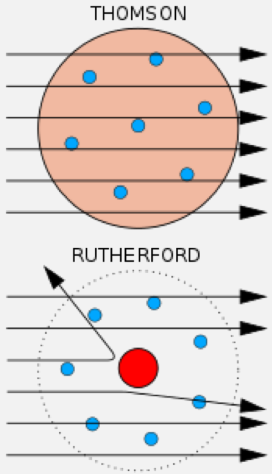
Joseph John Thomson (1897): Discovery of electrons by studying the cathode rays - identical particles with a mass ~1/2000th the mass of a H atom, independent of the cathode material – it must be the same constituent in all atoms.

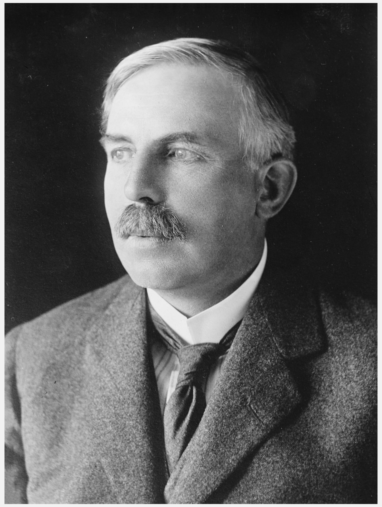


Joseph John Thomson ”plum-puding model” (1904): the positively charged main mass is distributed evenly in the atom, whereas the negatively charged small electrons are moving in it.

Development of the atom concept

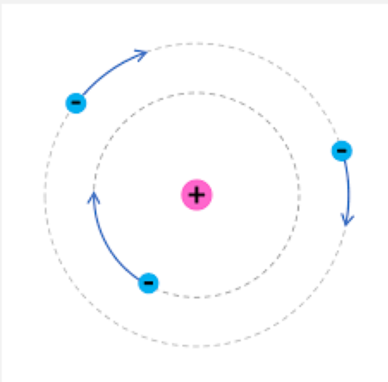


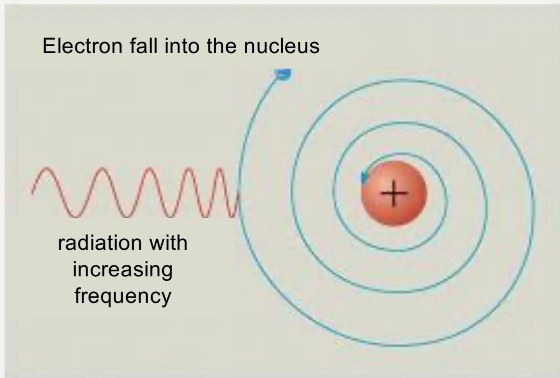




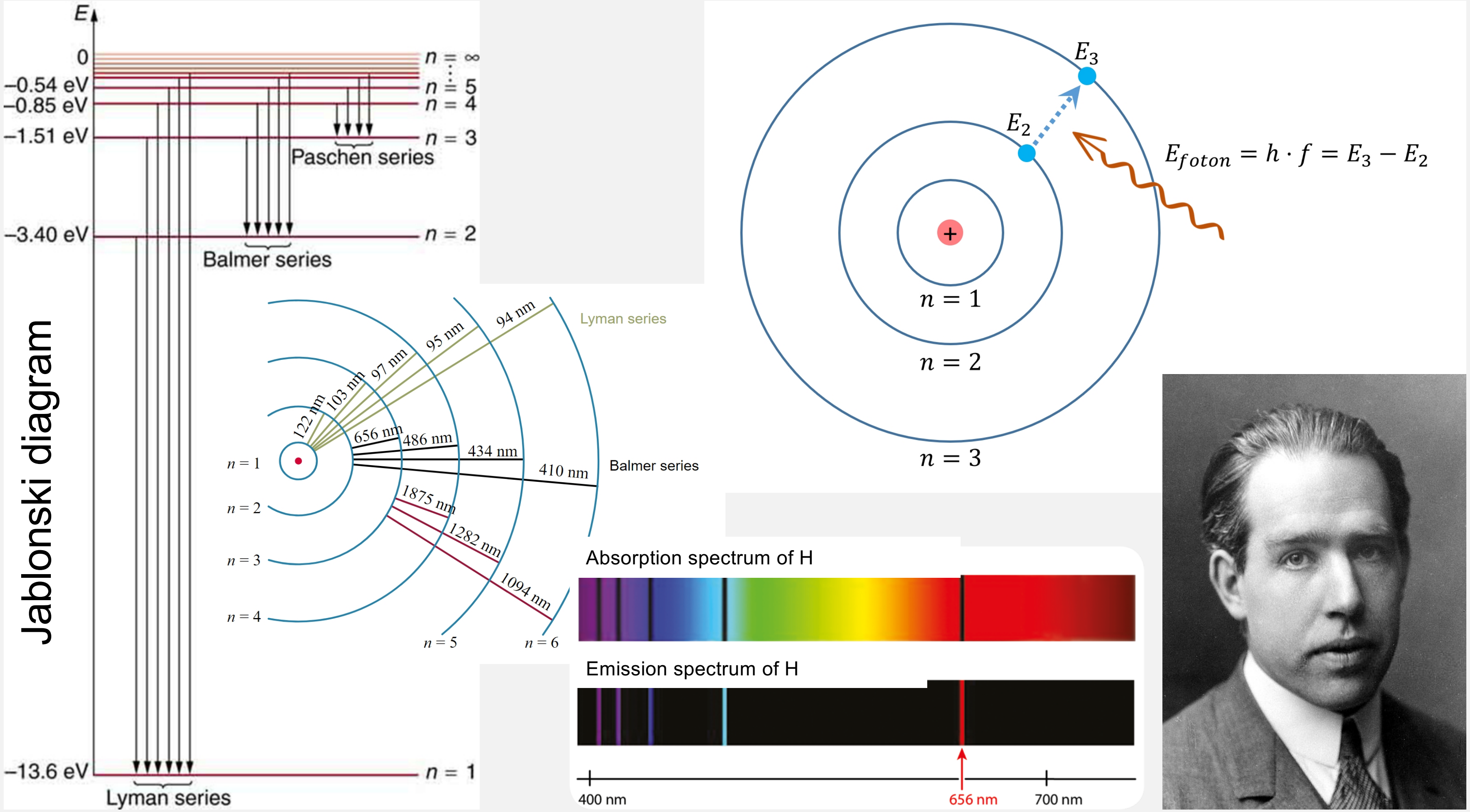
1909-1911: scattering of α-particles on gold

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 gowerned by the Coulomb interaction.



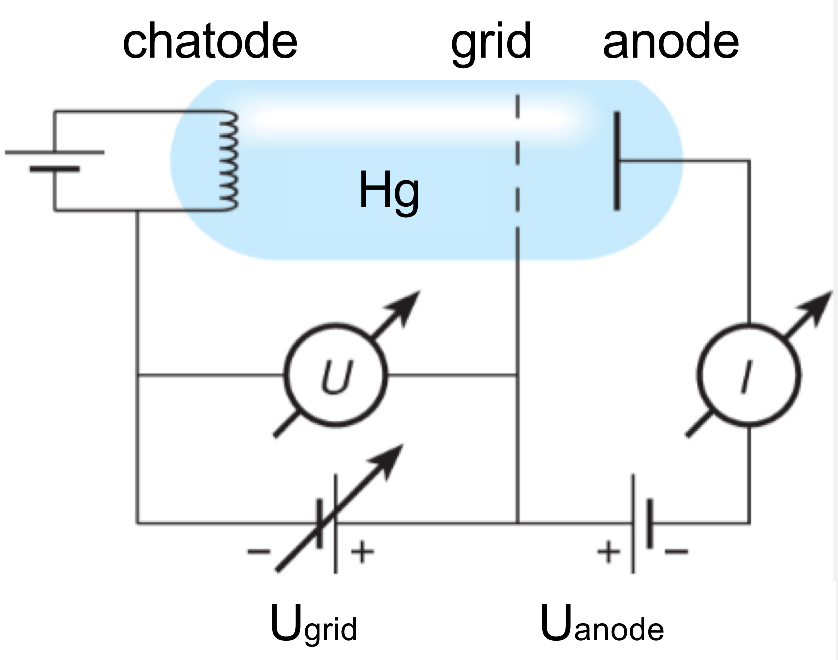


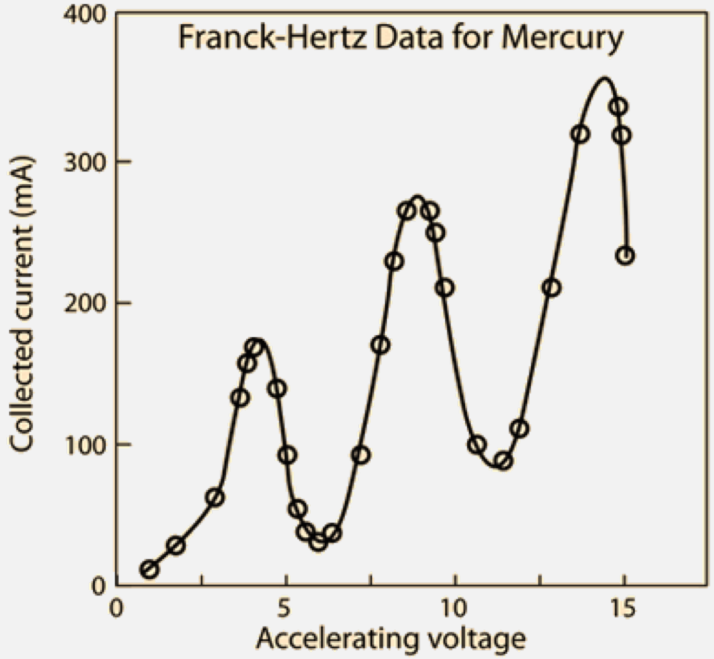
Development of the atom concept



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/2π.

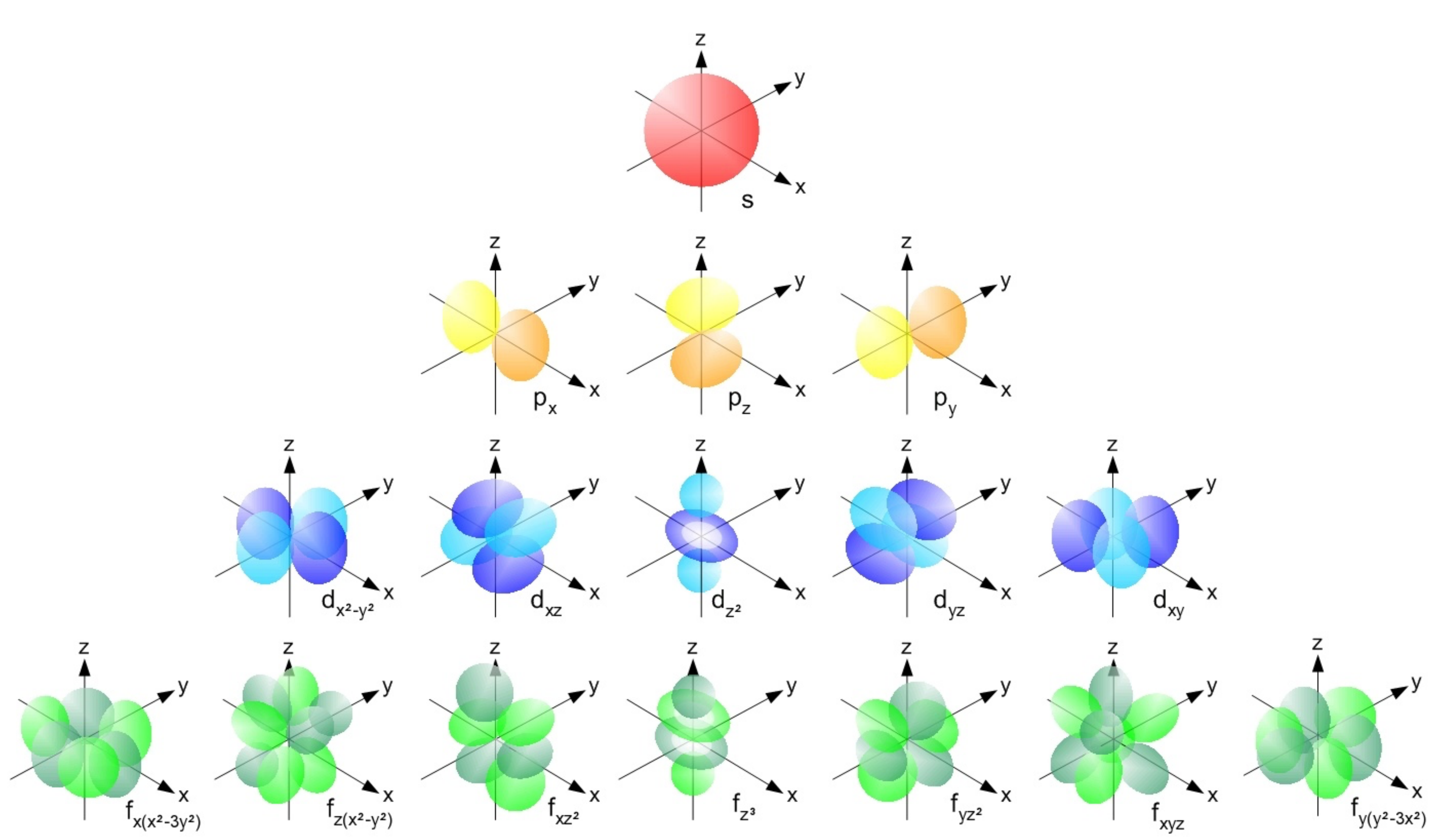
Franck – Hertz experiment (1914)





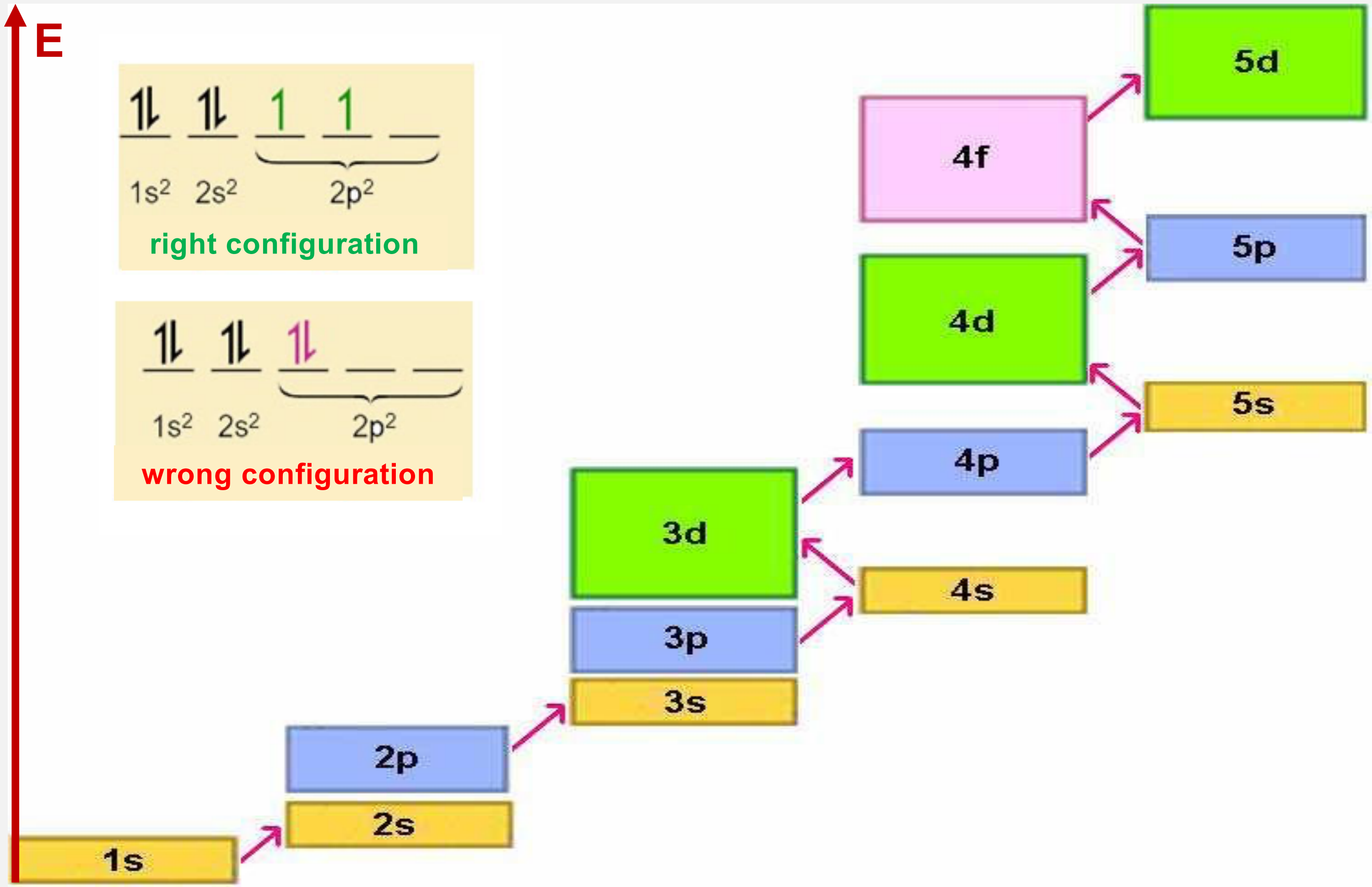
Electrons are colliding elastically with Hg atoms, until they get high enough energy, by increasing the grid voltage, to be able to excite the Hg atoms. At this accelerating voltage, the electrons loose their energy and not able to reach the anode, so the current drops. Further incresing the accelerating 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

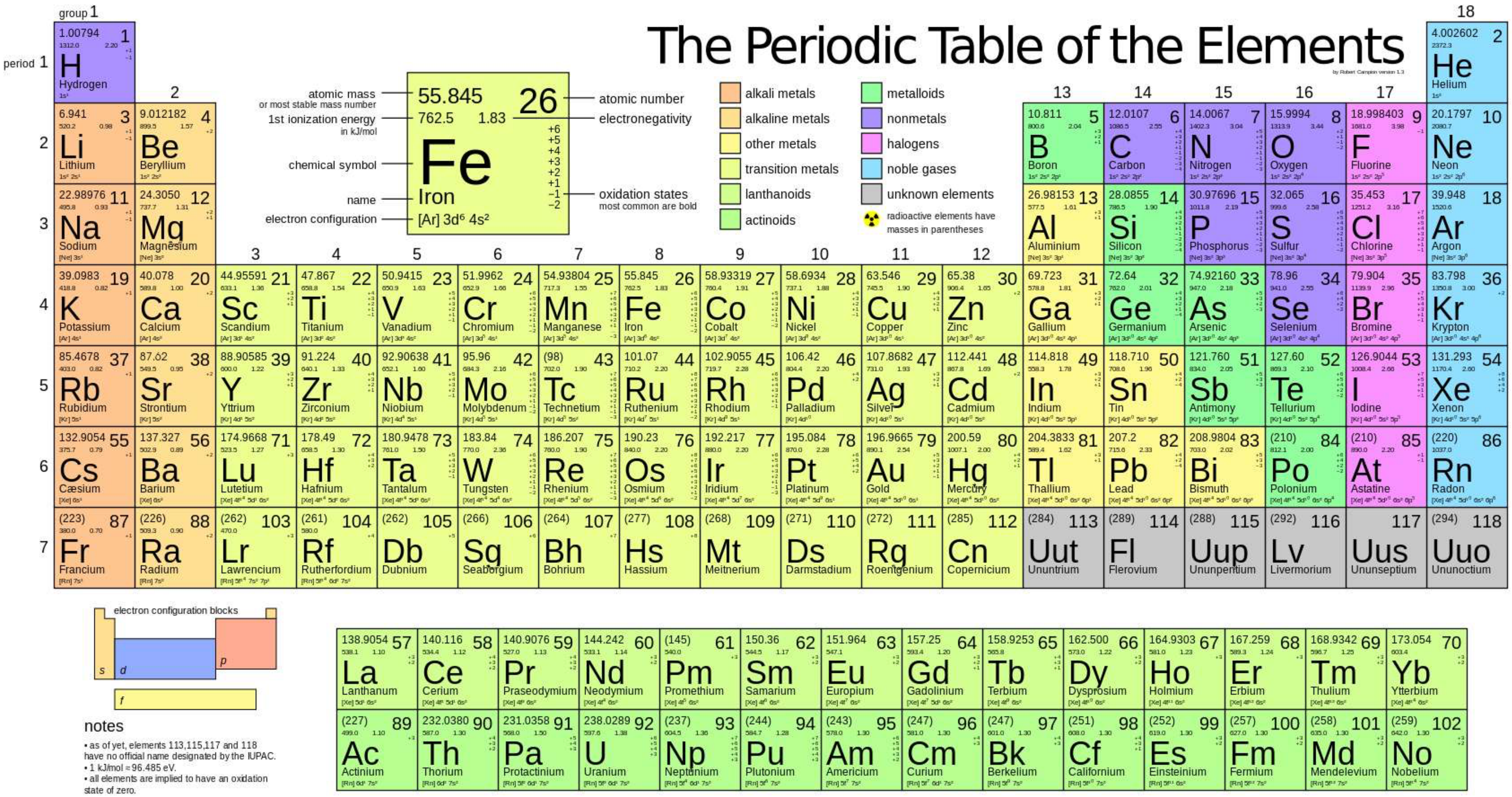


Louis de Broglie: electron wave, Ervin Schrödinger: wavefunction, wave equation
4 quantum numbers (principal, azimuthal, magnetic and spin), Pauli principle.

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).

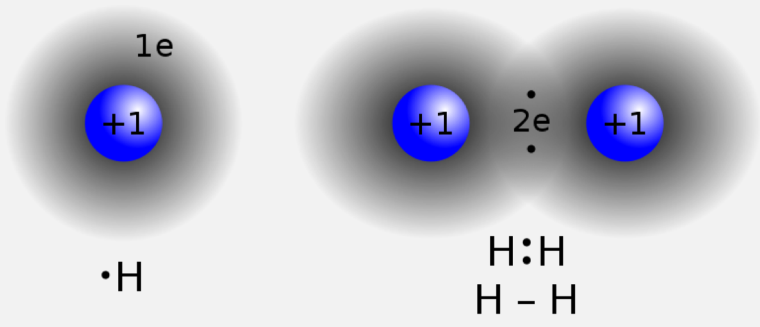


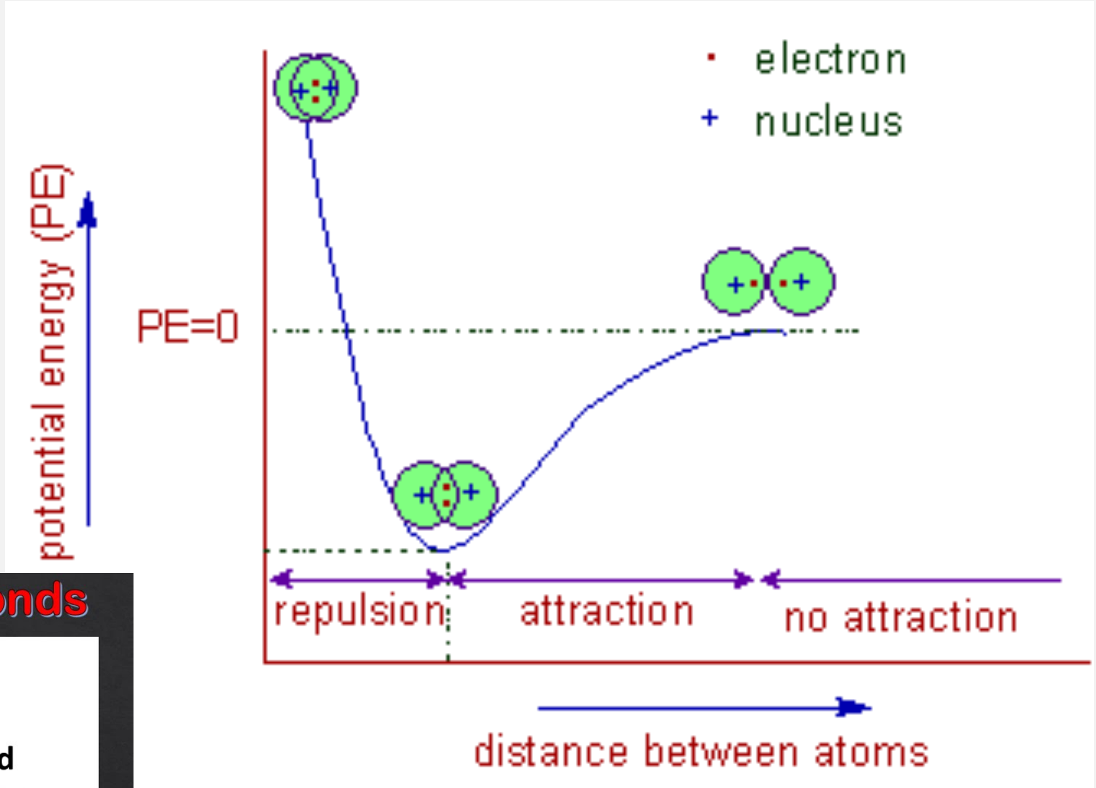
Valence electrons (electrons of *s* and *p* subshells of the most outer shell) are determining the chemical nature and reactivity of the elements/atoms.

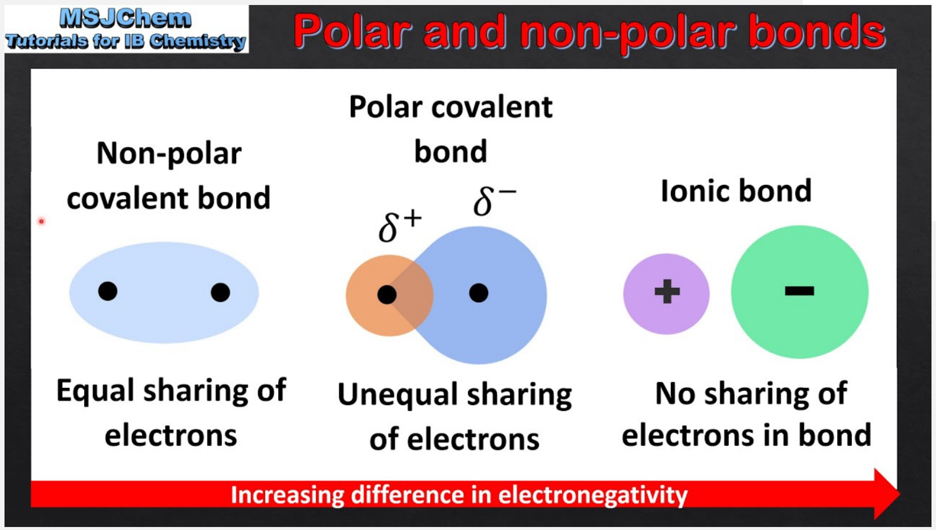
Primary chemical bonds

covalent, ionic, metallic

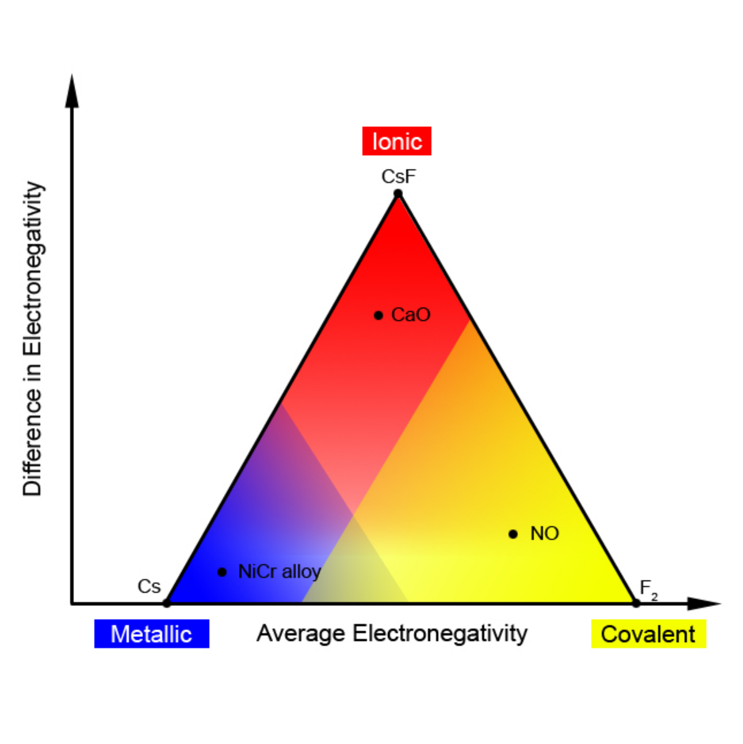
Covalent bond involves the sharing of electron pairs between atoms.

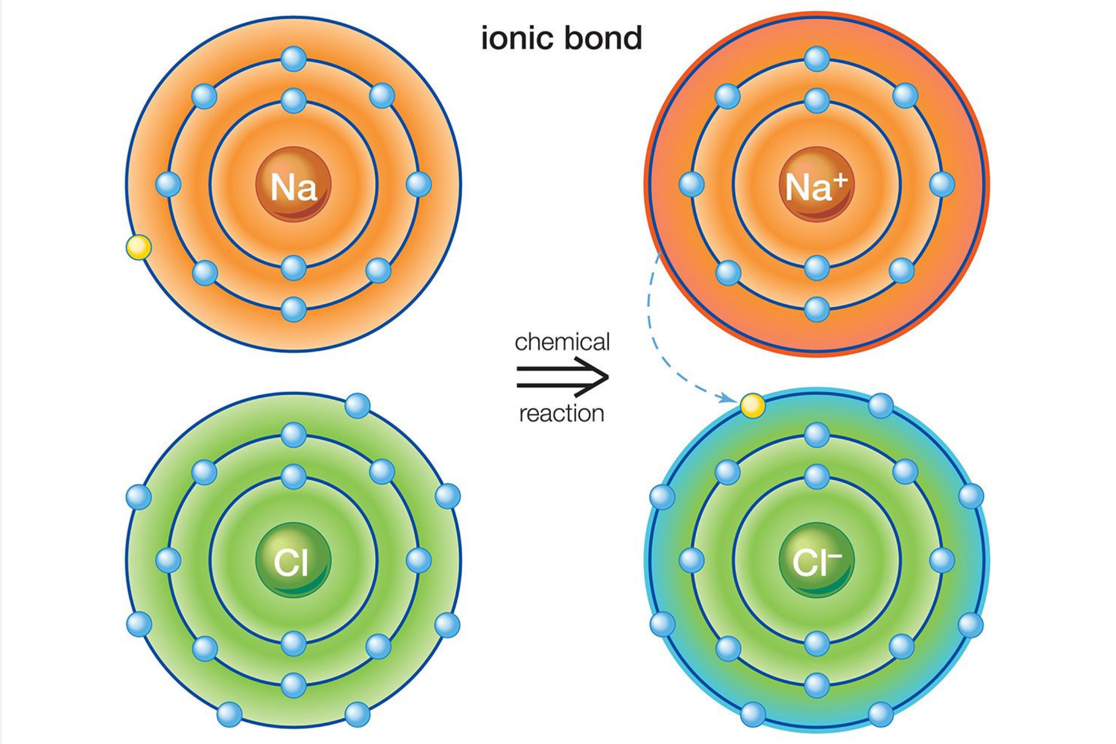






Primary chemical bonds





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

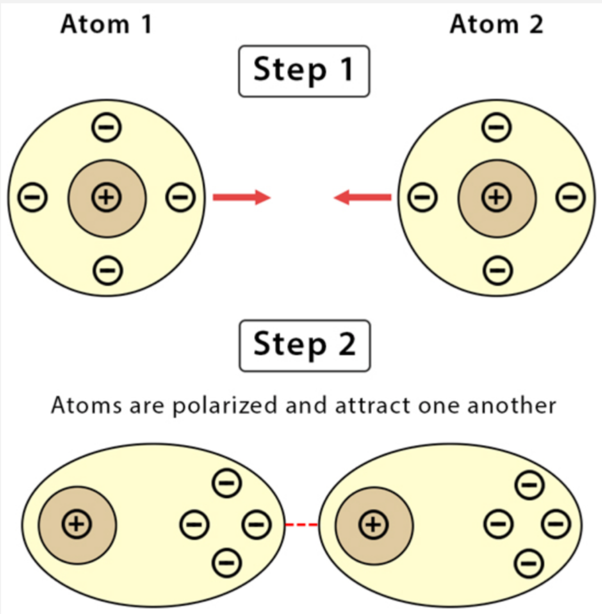
Ionic bond: if there is a great difference in eletronegativity of the atoms (*e.g.* NaCl).

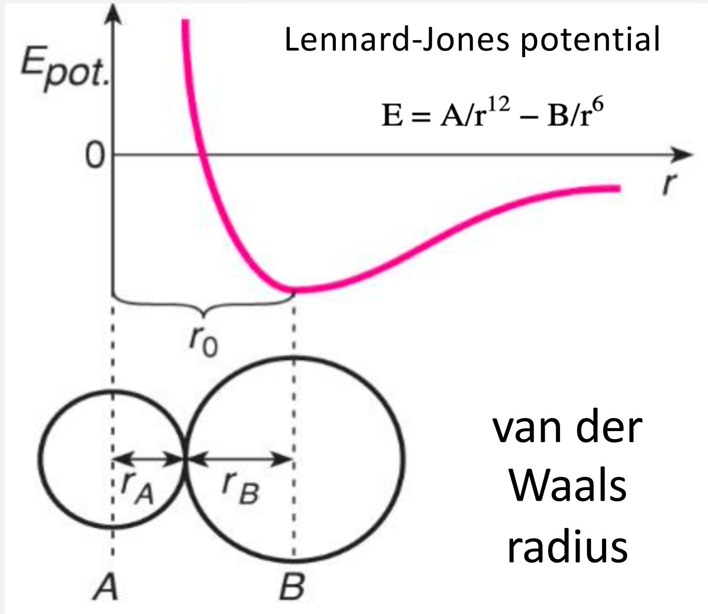
Metallic bond: there is an ordered, periodic lattice of the positive ions. The electrons are delocalized, stabilizing the whole structure.

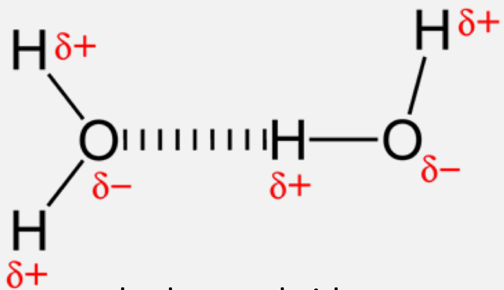
Secondary interactions

dipole-dipole, van der Waals, H-bridge, hydrophobic

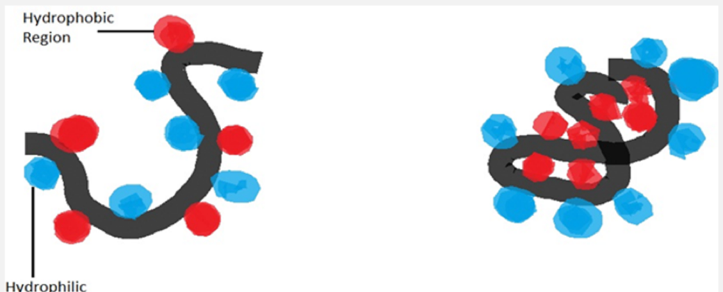
weaker by one-two orders of magnitude







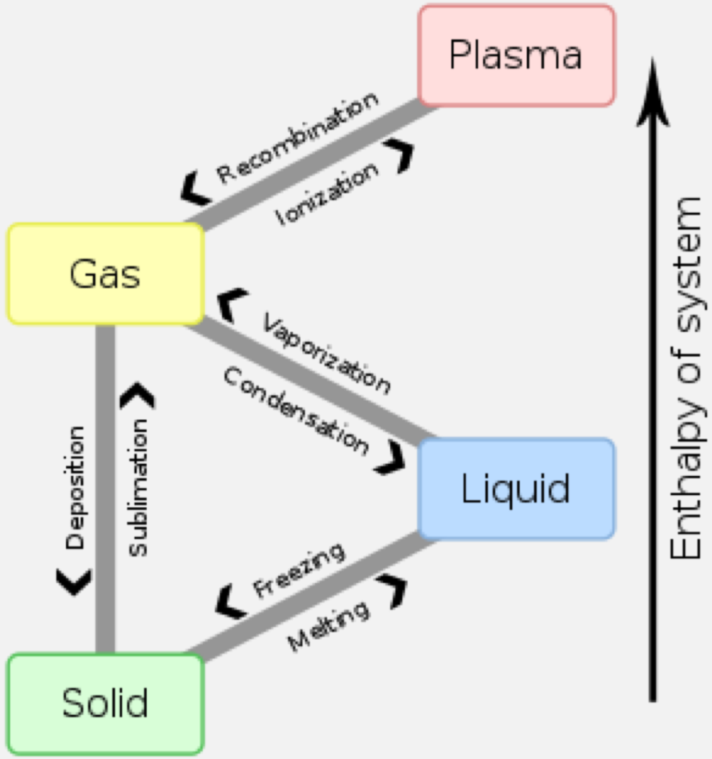
hydrogen-bridge



Hydrophobic core by exclusion of water.

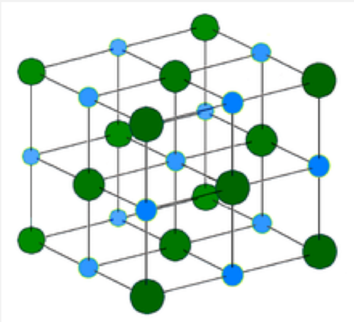
Phases of matter

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.

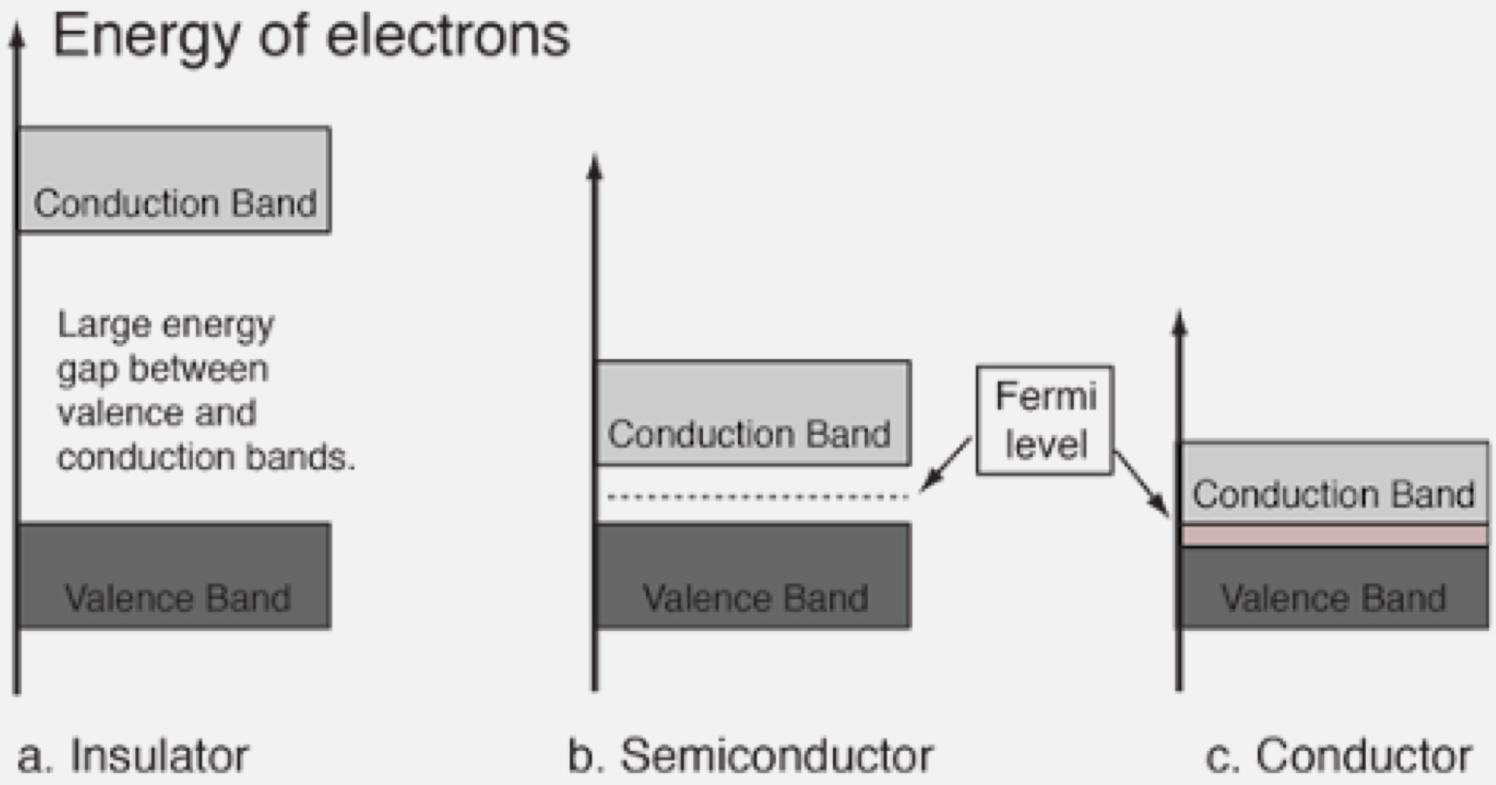


Liquids: there are only short-range order which is dynamic in nature. Particles can roll on each other. A liquid is a nearly incompressible fluid that conforms to the shape of its container but retains a constant volume independent of the pressure. Liquids are usually isotropic.

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



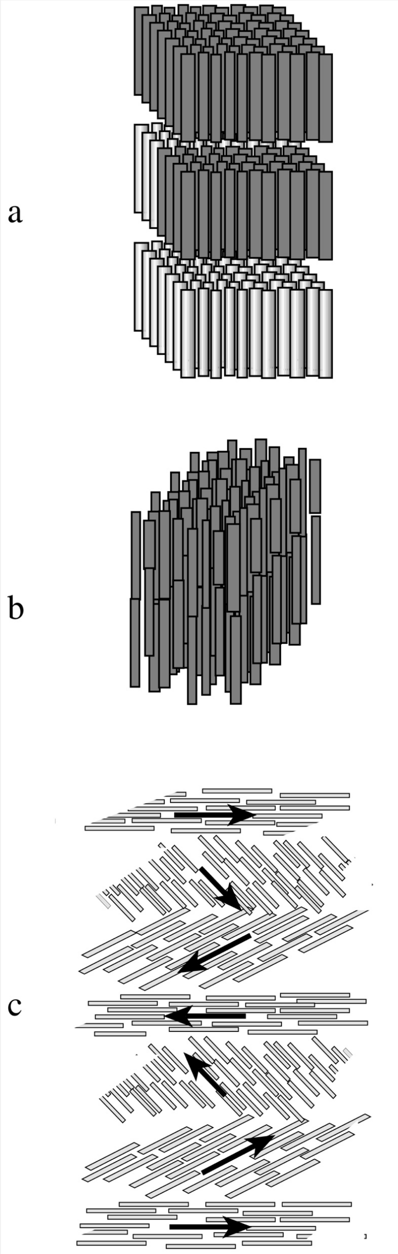
Band structures of crystals



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 absorbe 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).

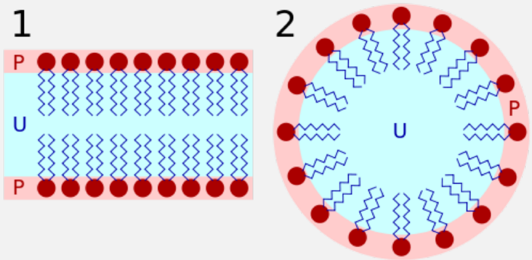
a) smectic phase: both ordering are present

b) nematic phase: only the orientational ordering is present

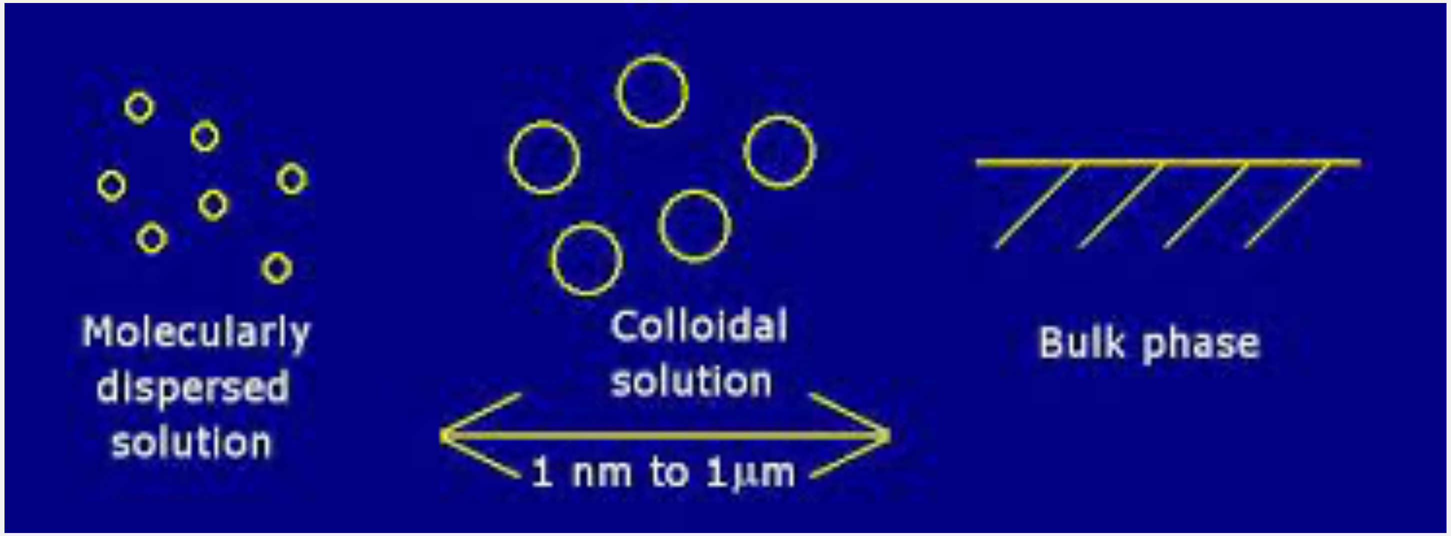
c) cholesteric or twisted nematic phase: a chiral order can be observed due to a fixed angle rotation of asymmetric molecules in the adjacent layers

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

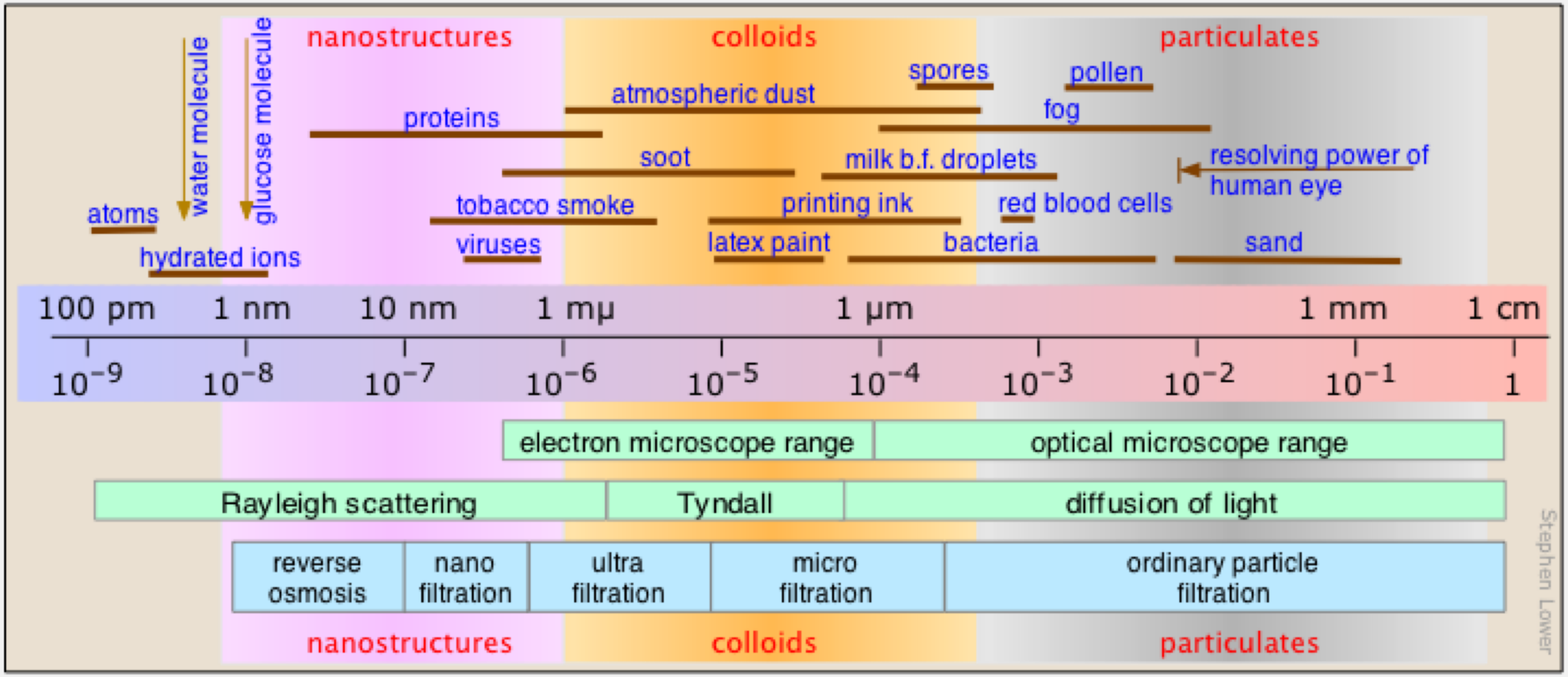


homogeneous *colloid* *heterogeneous*

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.

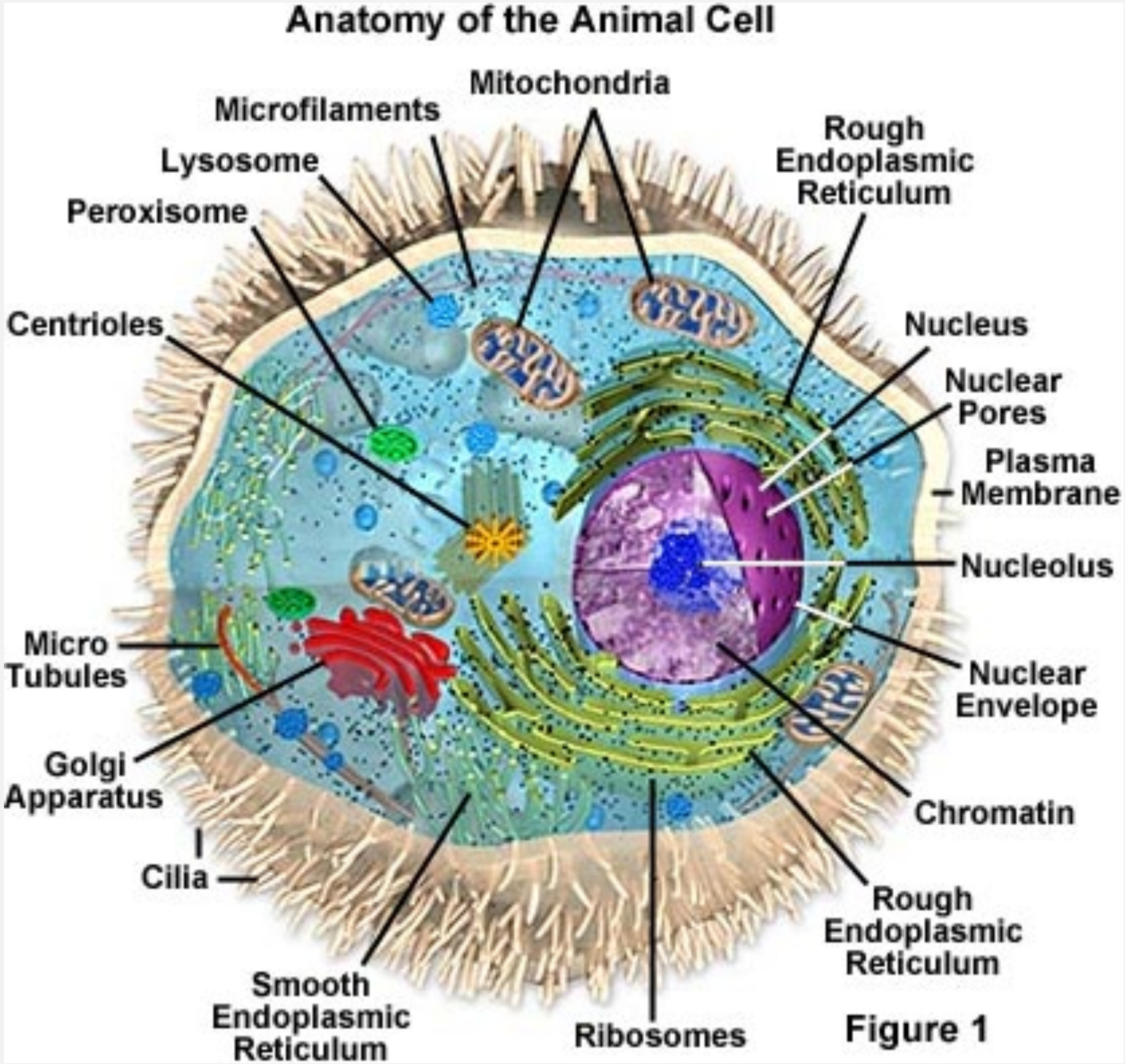
A colloid consists of two distinct phases, a continuous phase (the dispersion medium) and a particulate phase, where the particles generally have dimensions ranging between 2 and 200 nm. The two phases can be liquid-in-liquid (milk), solid-in-liquid (paint), liquid-in-gas (aerosol) and other combinations.

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 christals

colloids

Related chapters in

Damjanovich, Fidy, Szöllősi: Medical Biophysics

I. chapter

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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
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