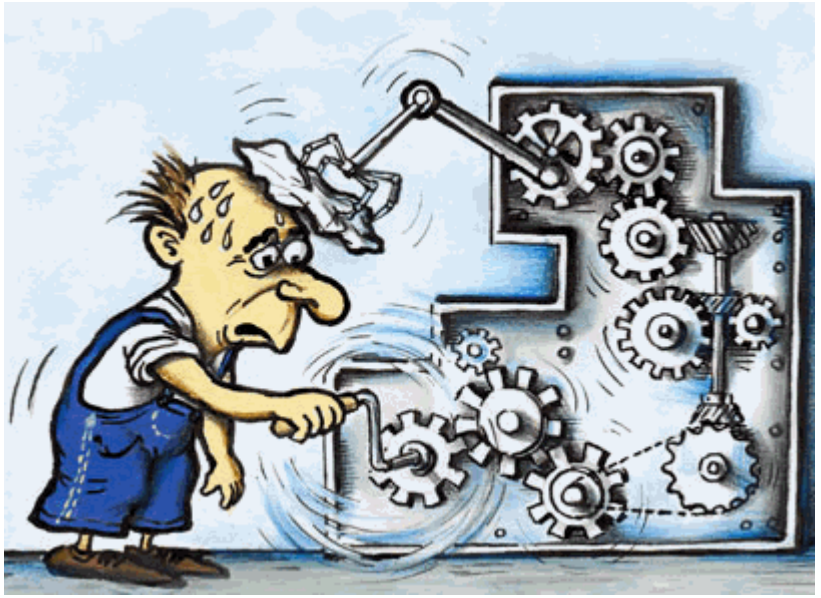
What the matter is?

How the science „works”?

- in material science, in physics, in engineering the definitions can only be accepted if they can be proved
- the method of proving is the: EXPERIMENT
- Conditions and effects:
  - have to be reproducible
  - not disputable (TRUE)



What the matter is?

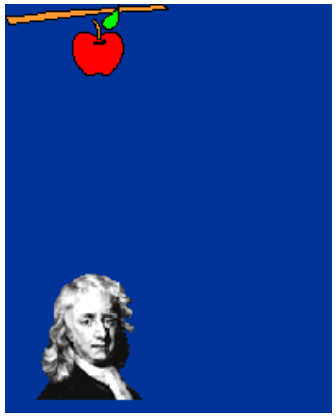
- **Natural sciences: everything that is able to interact with one of the fundamental interactions (forces) or with the combination of these, is MATTER (Manuel Carreira, Spanish physicist and philosopher)**
- The matter:
  - has a place in space
  - has some quantity of energy
  - can interact with physical instruments
  - it constructs the Universe

Fundamental interactions

INTERACTION	CHARACTERISTICS	MEDIATING
GRAVITATIONAL	**acts on all particles having mass**	GRAVITON?
ELECTRO-MAGNETIC	**acts between electrically charged particles**	PHOTON
WEAK	**acts on the atomic scale**	W and Z bosones
STRONG	**acts on quarks**	GLUON

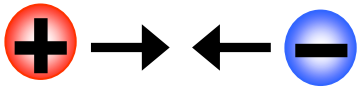
Fundamental interactions

INTERACTION	CHARACTERISTICS	MEDIATING
GRAVITATIONAL	**acts on all particles having mass**, has an infinite range, like electromagnetism but unlike strong and weak interaction, cannot be absorbed, transformed, or shielded against, always attracts and never repels, responsible for the structure of galaxies	GRAVITON?



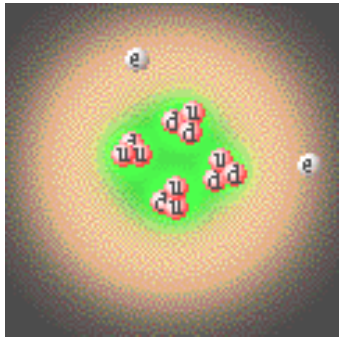
Fundamental interactions

INTERACTION	CHARACTERISTICS	MEDIATING
ELECTRO-MAGNETIC	**acts between electrically charged particles**, is infinite-ranged like gravity, but stronger, describes a number of macroscopic phenomena of everyday experience such as **friction, rainbows, lightning**, and all human-made **devices using electric current**. Determines all macroscopic, and many atomic levels, **properties of the chemical elements**, including all **chemical bonding**.	PHOTON



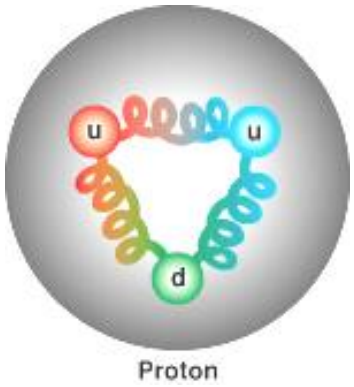
Fundamental interactions

INTERACTION	CHARACTERISTICS	MEDIATING
WEAK	**acts on the atomic scale**, it acts on all the leptons and quarks, is responsible for some nuclear phenomena such as **beta decay, free neutron decay, etc.**	W and Z bosones

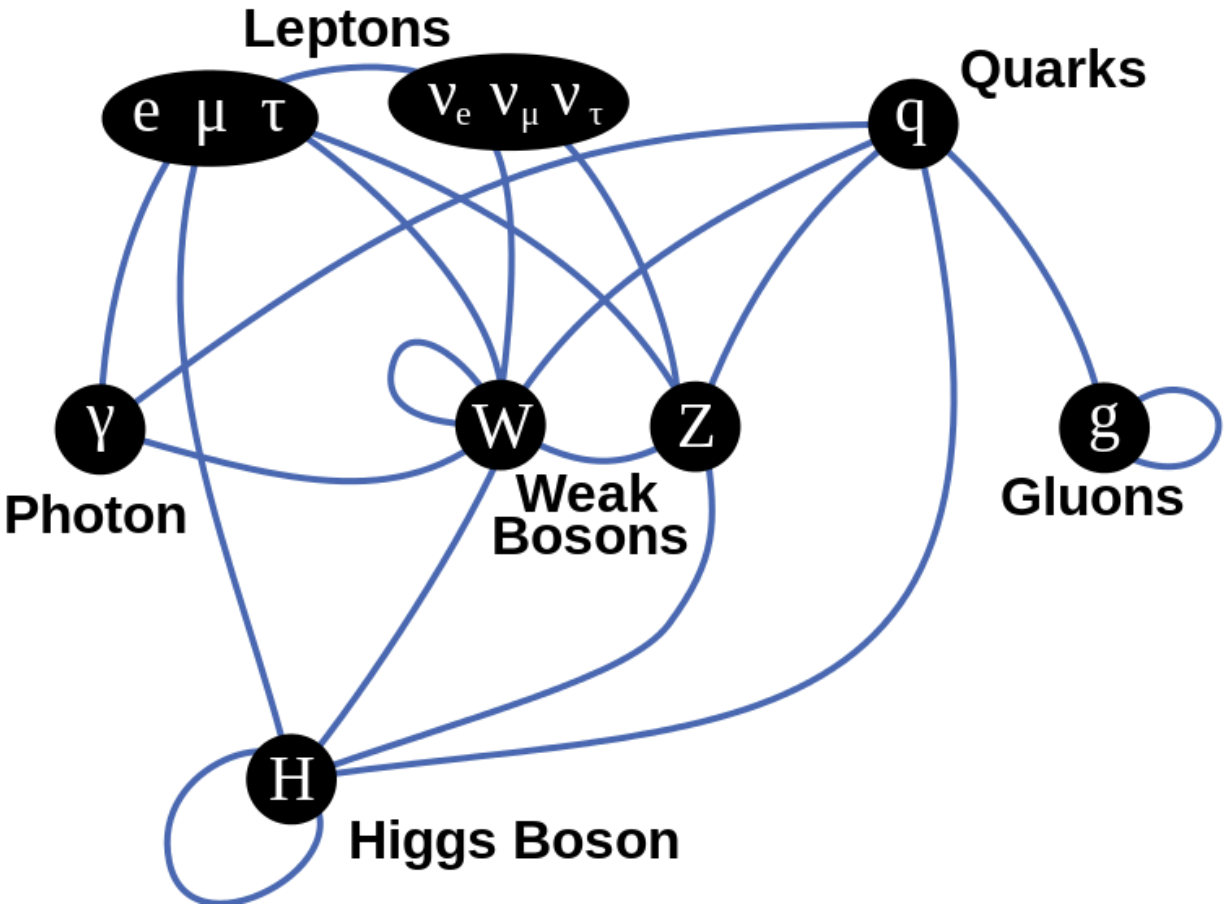


Fundamental interactions

INTERACTION	CHARACTERISTICS	MEDIATING
STRONG	**acts on quarks**, it holds together the nucleons (protons and neutrons), acts on femtometre scale ($1fm=10^{-15}m$)	GLUON



What the matter is?



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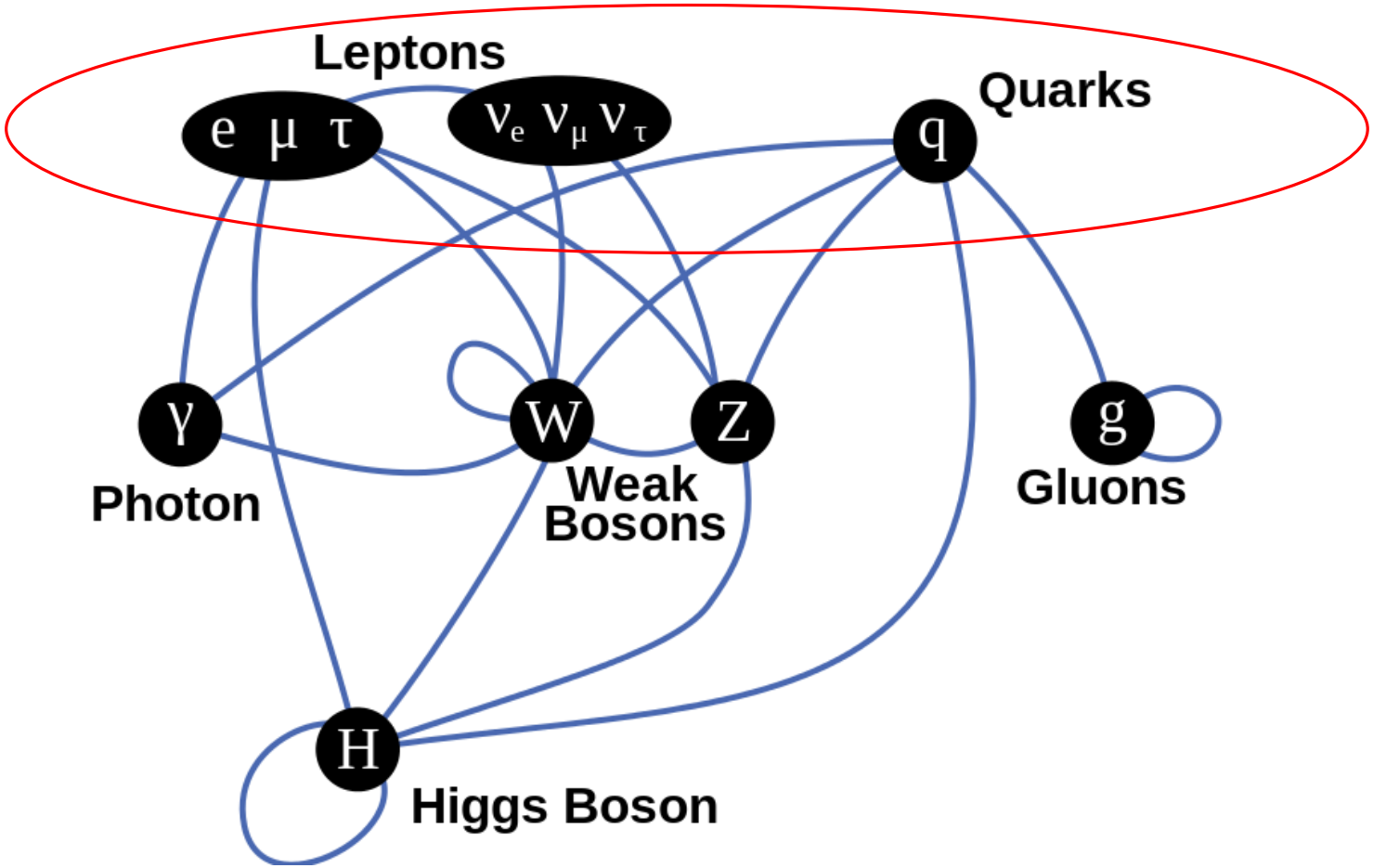

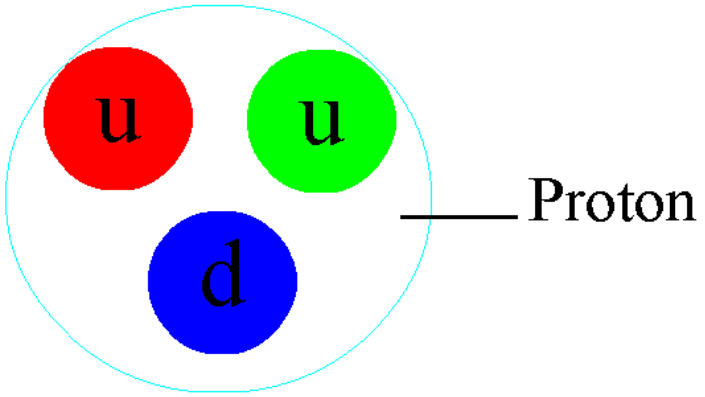
u
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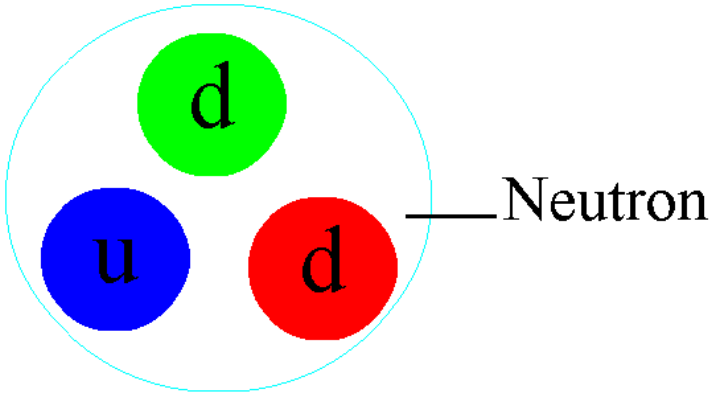
Proton


d
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Neutron

What the matter is?

Higgs bozon – 2012

Peter Higgs

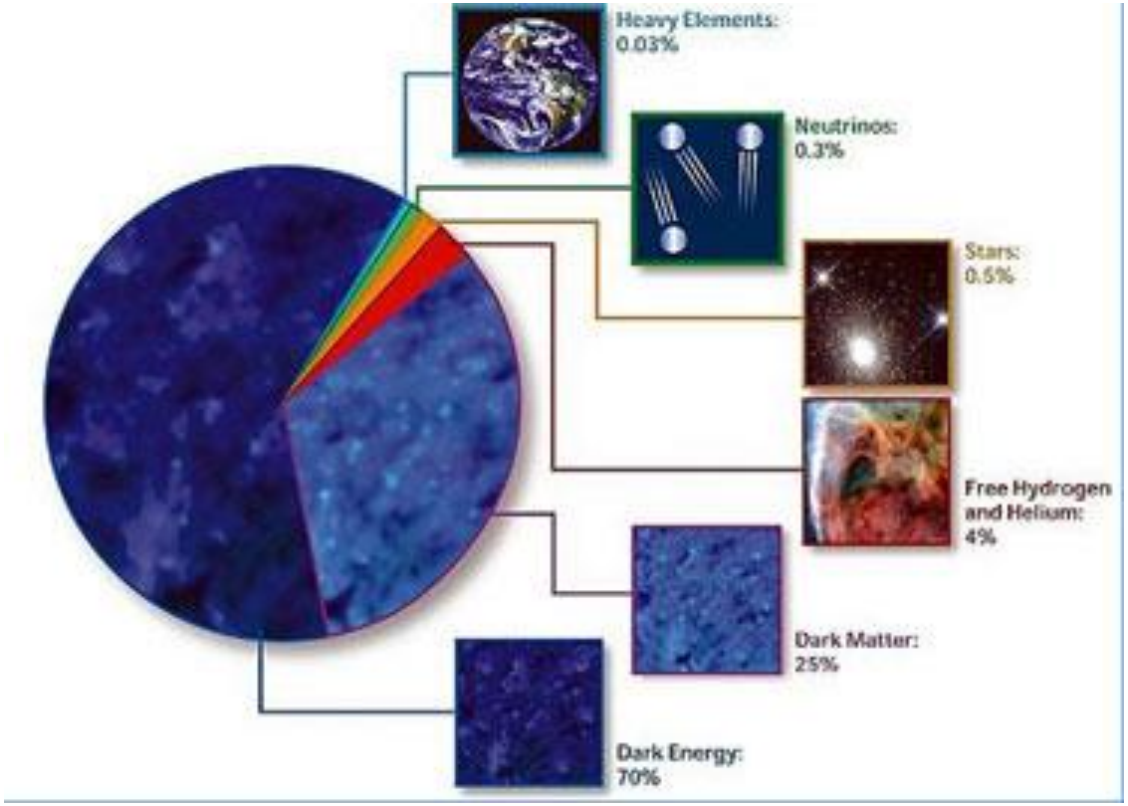
What the matter is?

Higgs space

Higgs bozon

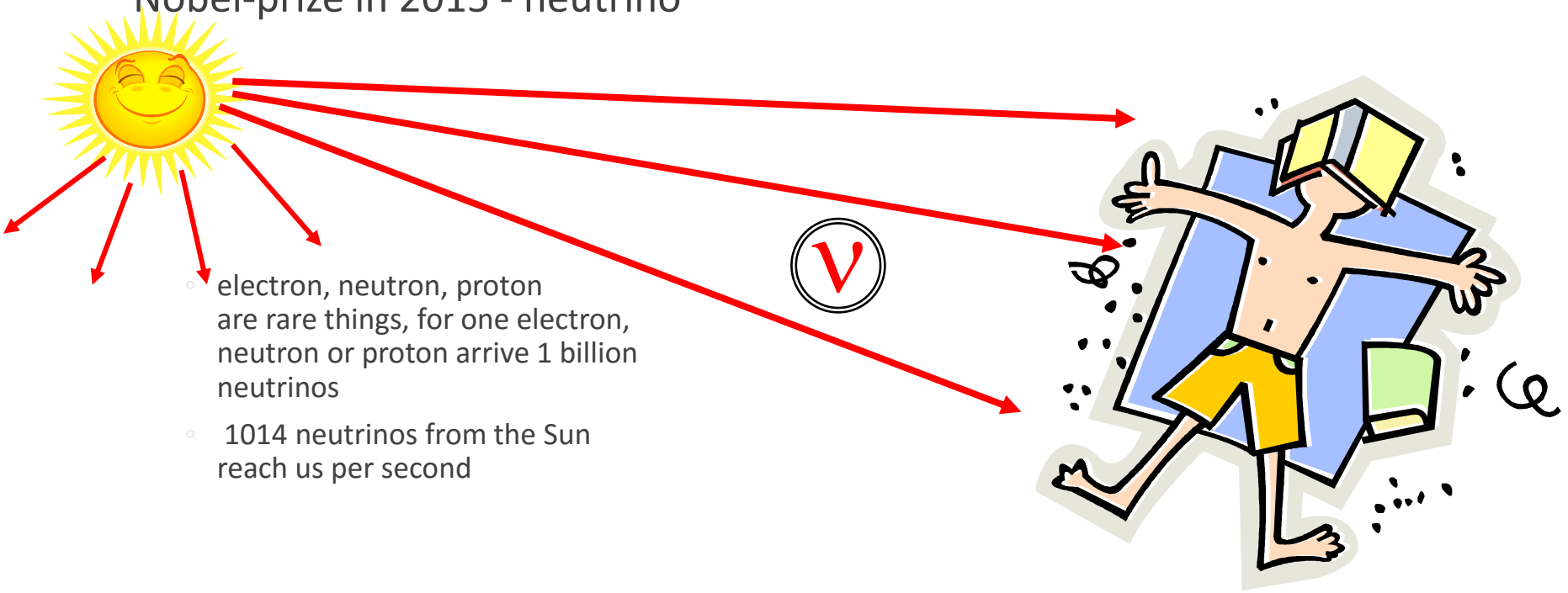
What the matter is?

Dark matter, dark energy

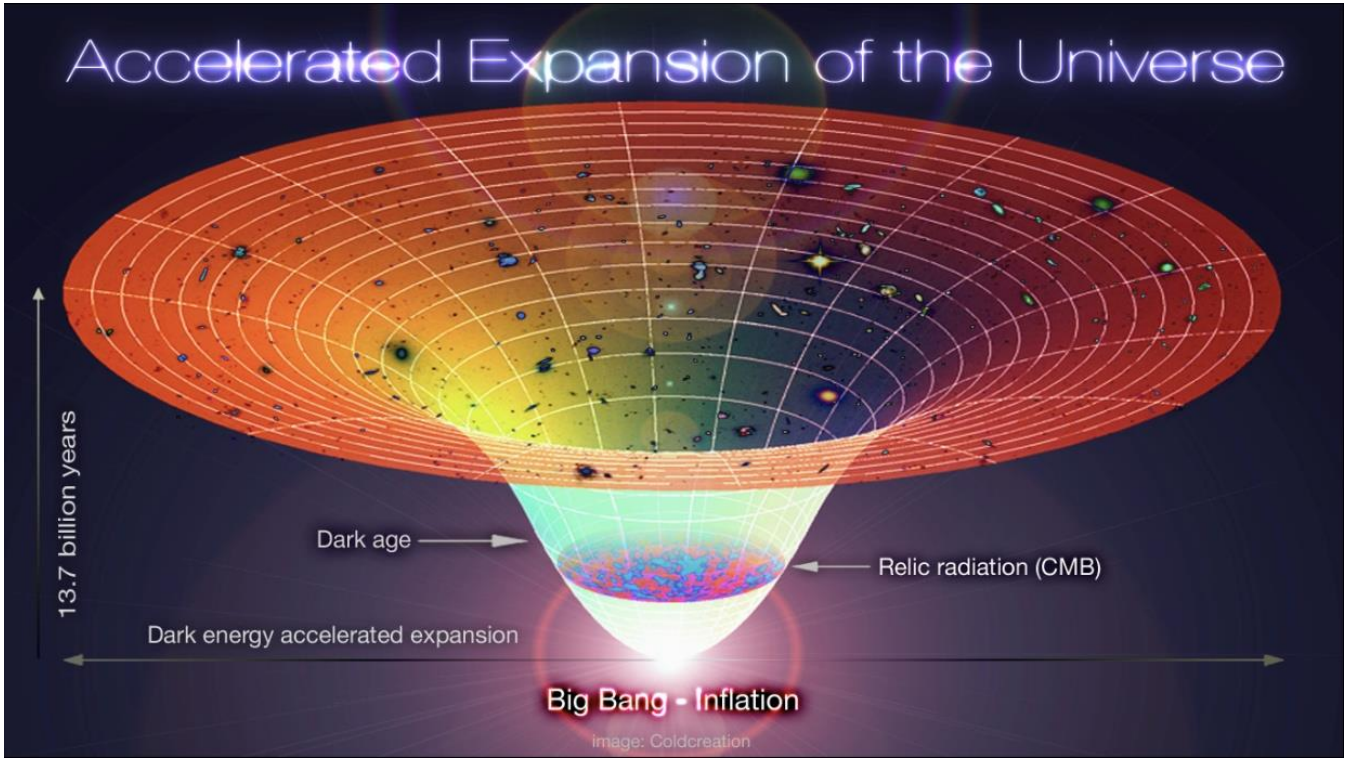


What the matter is?

Nobel-prize in 2015 - neutrino

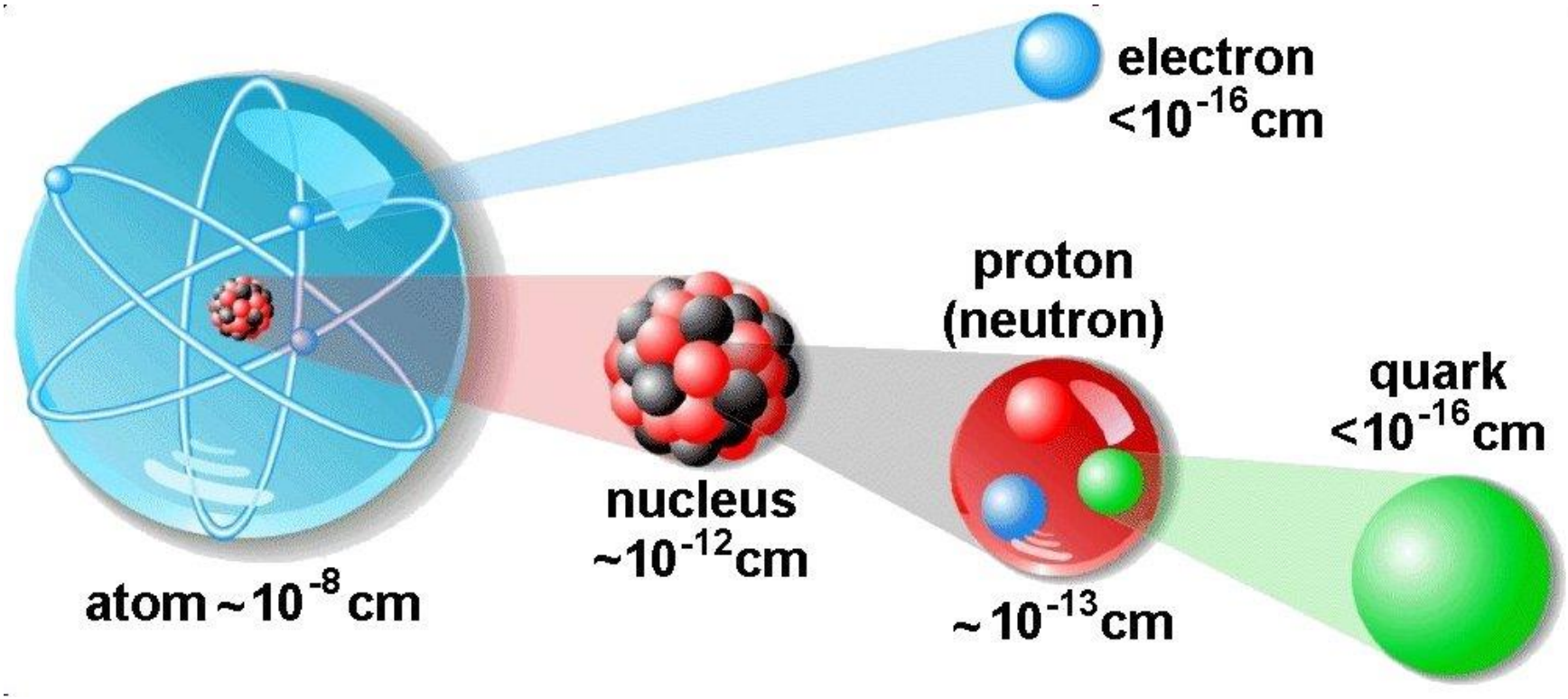


- electron, neutron, proton are rare things, for one electron, neutron or proton arrive 1 billion neutrinos
- 1014 neutrinos from the Sun reach us per second


Accelerated Expansion of the Universe
13.7 billion years
Dark age
Relic radiation (CMB)
Dark energy accelerated expansion
Big Bang - Inflation
image: Coldcreation

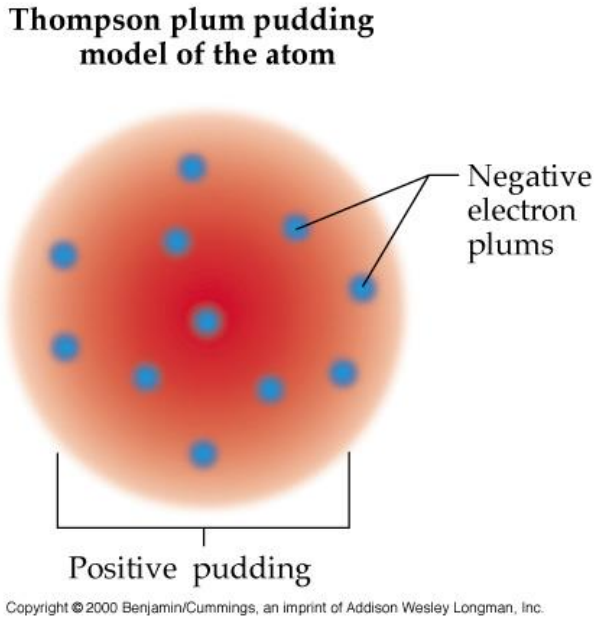
From quarks to atoms

The structure of an atom



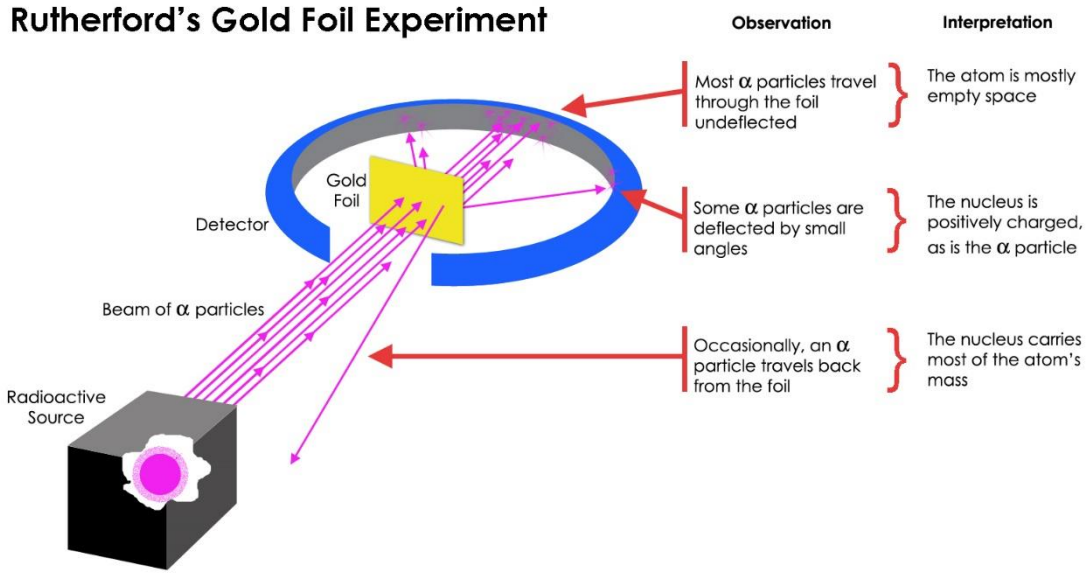
Atomic structure

- **The internal structure of the atom**
  - early 20th century: Ernest Rutherford model
  - **before Rutherford:**
    - "plum-pudding" model
      Joseph John Thomson:
      - electrons: plum with negative charge
      - positively charged pudding
      - negative charge of the electrons exactly balances the total positive charge, therefore
        an atom is electrically neutral



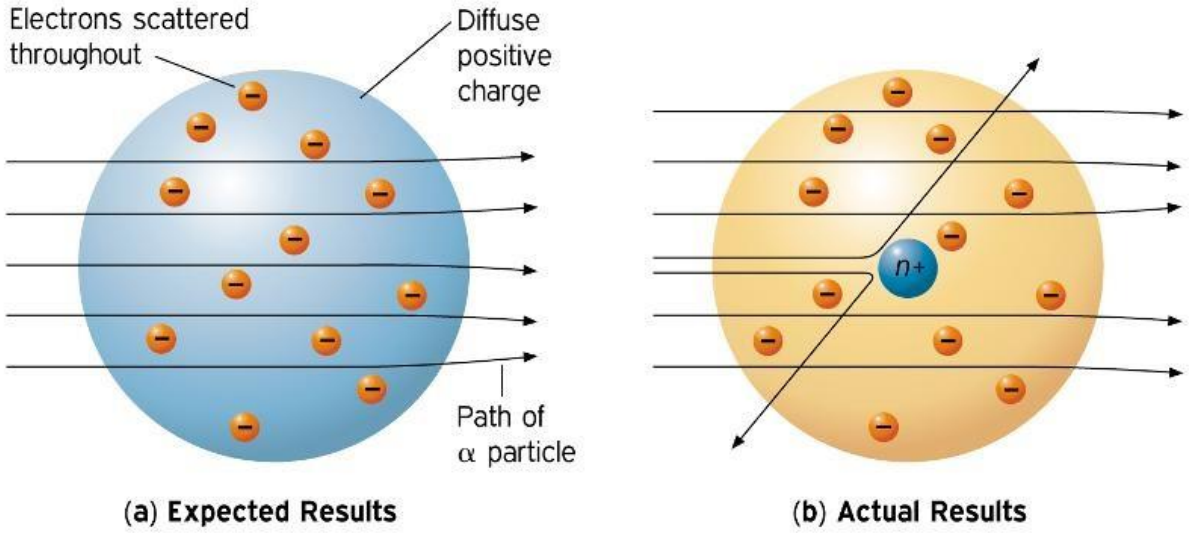
Rutherford experiment

- Rutherford suggested, that the positive charge is concentrated in the center of the atom. The atom consists mainly of empty space, and the positive centre is surrounded by a negative electron cloud
- called planetary model



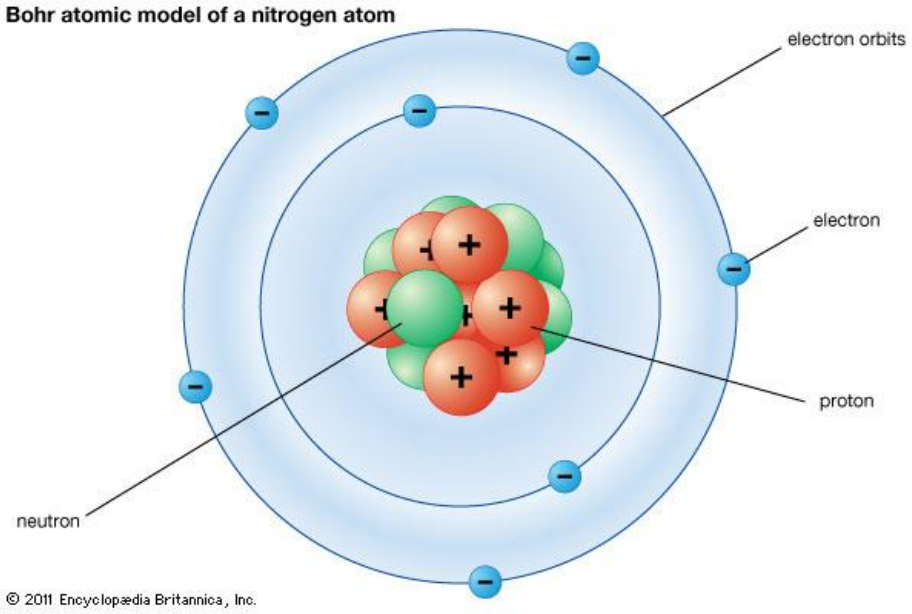
Rutherford model

- Rutherford observed that when a beam of alpha particles (He^{2+}) struck a thin gold foil, some of the particles are deflected backward. Such large deflections were inconsistent with the Thomson model



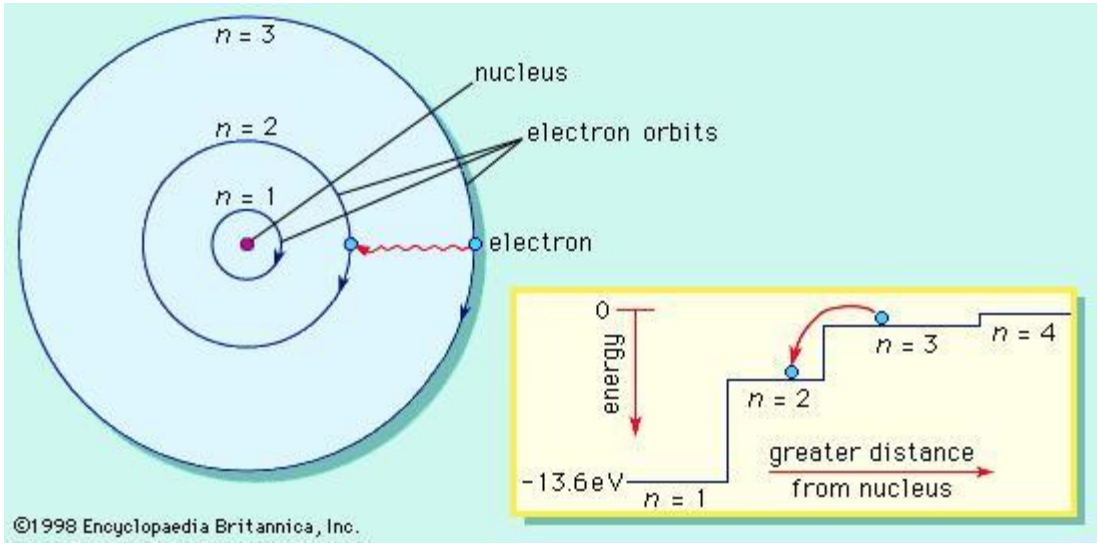
Bohr model

- proposed by Niels Bohr in 1913
- was the first model that incorporated the quantum theory and was the predecessor of quantum mechanical models
- Atoms absorb or emit radiation only when the electrons abruptly jump between allowed, or stationary, states



Bohr model

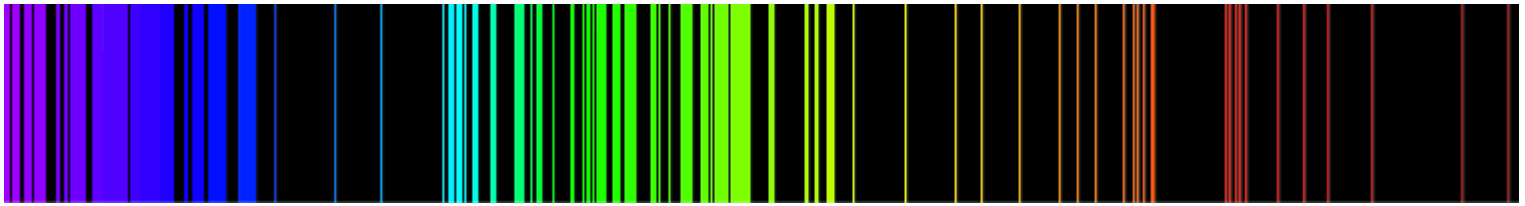
- Bohr made light scattering experiments with different atoms. He realized, that light radiated from hydrogen atoms only when an electron made a transition from an outer orbit to one closer to the nucleus. The energy lost by the electron in the abrupt transition is precisely the same as the energy of the quantum of emitted light



Spectral lines – emission spectrum

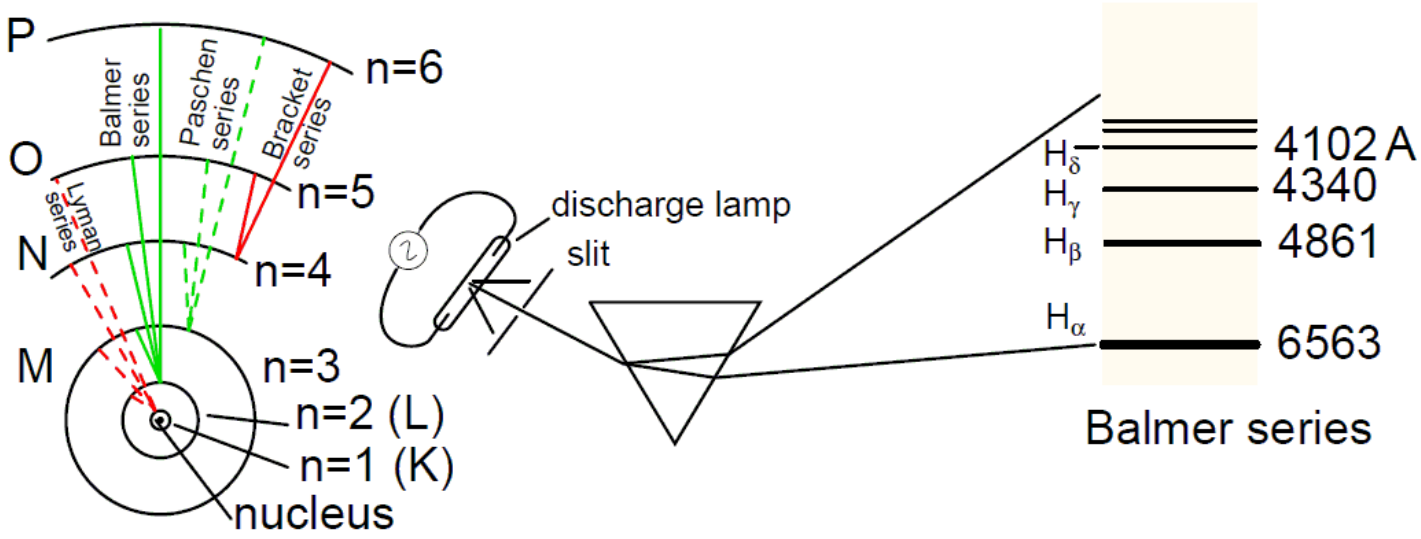
- The **emission spectrum**:
  - transition from a high energy state to a lower energy state
- Each element's emission spectrum is unique.

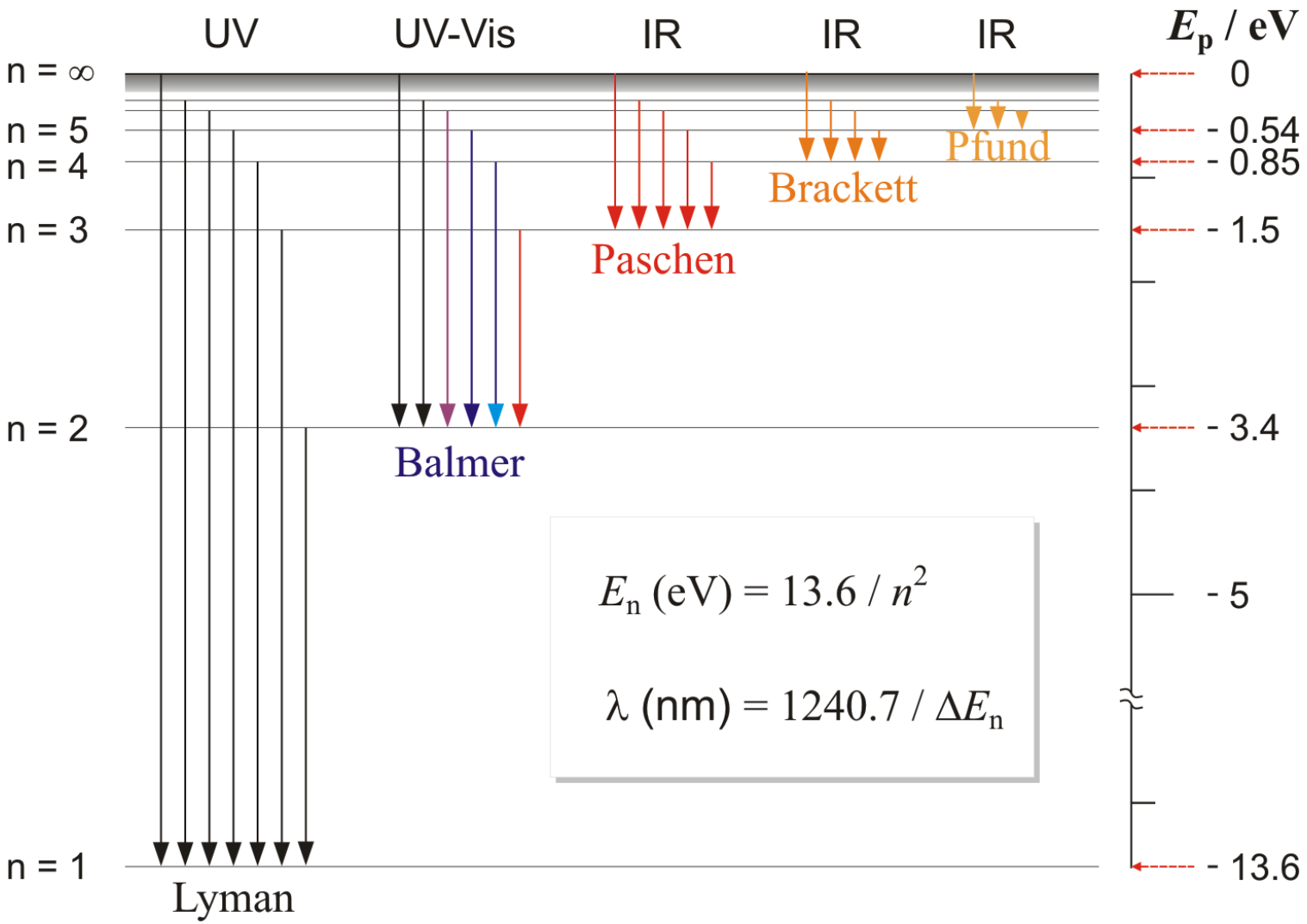
- Hydrogen emission spectrum



- Iron emission spectrum

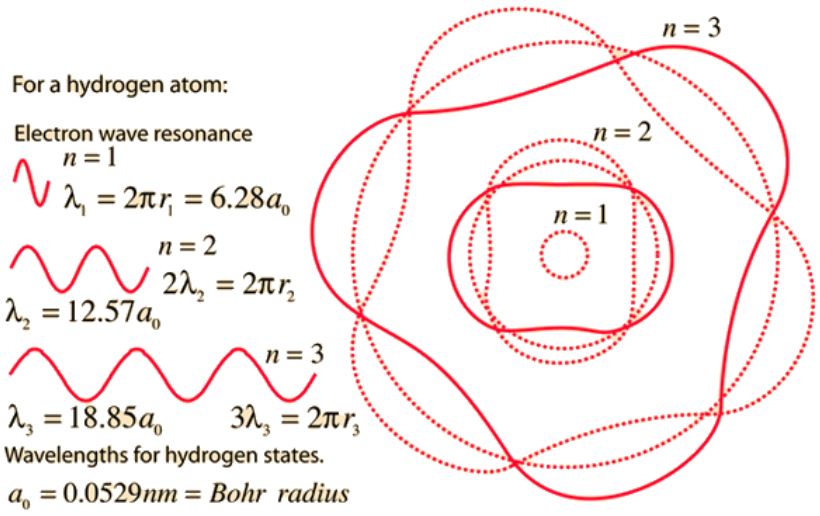
Extended Bohr model




UV
UV-Vis
IR
IR
IR
E_p / eV
n = ∞
n = 5
n = 4
n = 3
n = 2
n = 1
0
- 0.54
- 0.85
- 1.5
- 3.4
- 5
- 13.6
Pfund
Brackett
Paschen
Balmer
Lyman
E_n (eV) = 13.6 / n^2
λ (nm) = 1240.7 / ΔE_n

Quantum mechanical atomic model

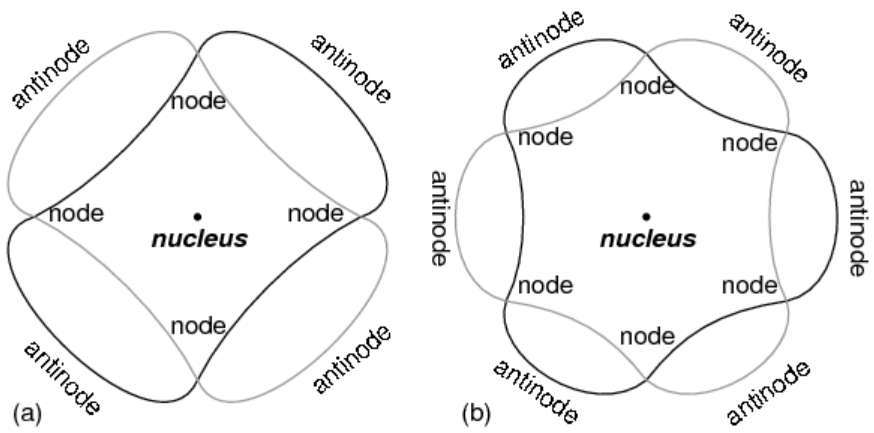
- In this model electrons are **NOT only considered particles**, but also **waves**, which are described by the same mathematical formulae as standing waves
- Electrons occupy orbitals, that are regions in an atom around the nucleus within which an electron with a given energy is most likely to be found
- Permitted electron orbitals (standingwaves) according to de Broglie wave hypothesis



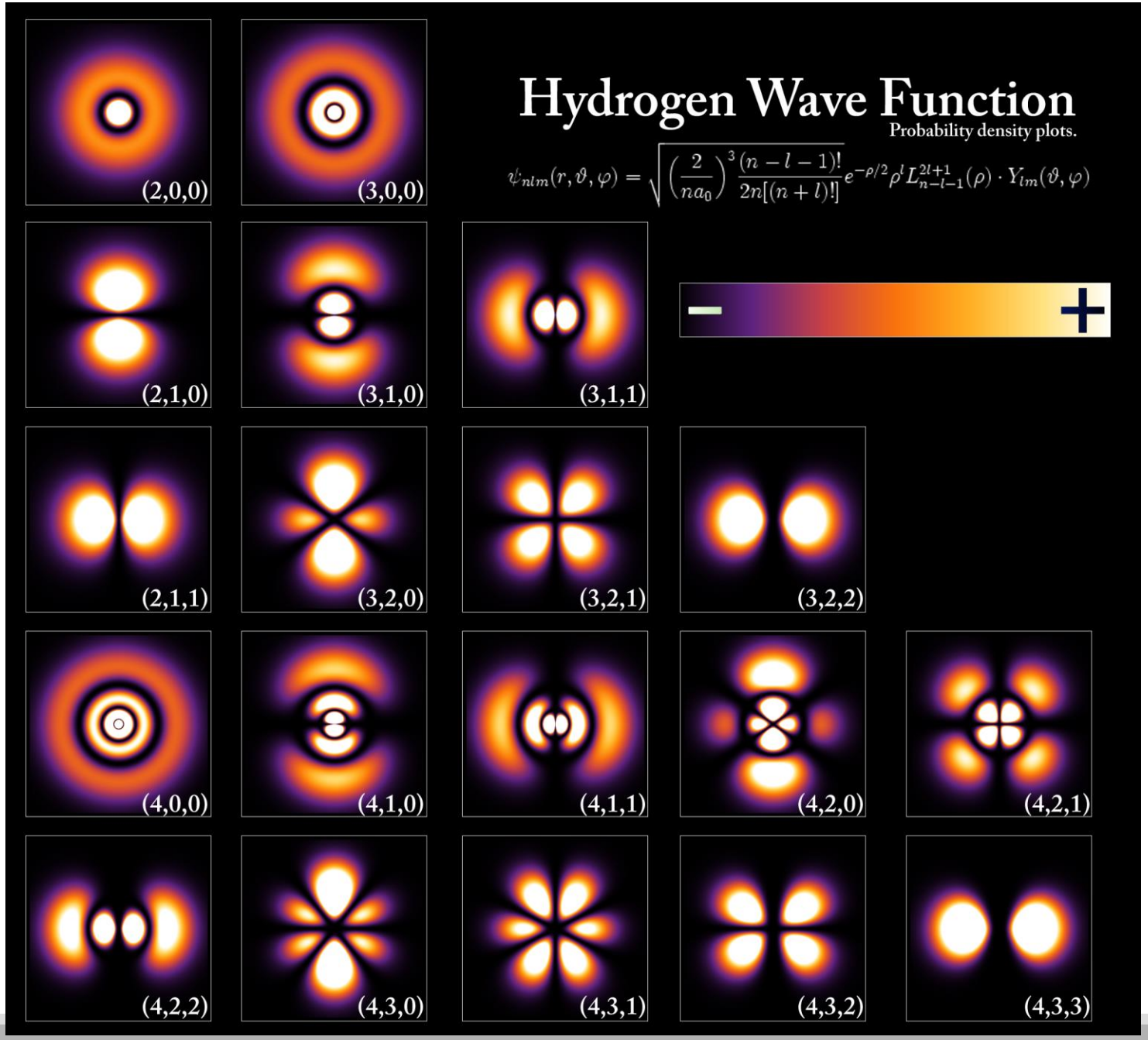
Quantum mechanical atomic model

- Particle (m) – wave (l) duality:

$$\lambda = \frac{h}{p} = \frac{h}{m_0 v}\sqrt{1-\frac{v^2}{c^2}}$$

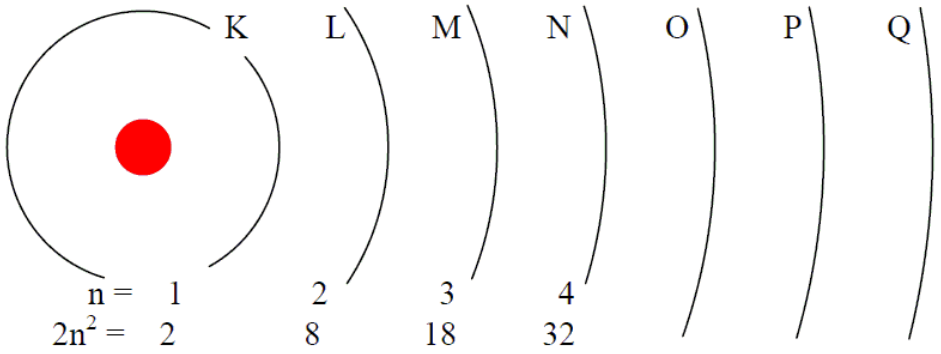


- $h = 6.626 \cdot 10^{-34}$ Js : Planck-constant
- $m_0 = 9.109 \cdot 10^{-31}$ kg : rest mass of the electron


Hydrogen Wave Function
Probability density plots.
$\psi_{nlm}(r,\vartheta,\varphi) = \sqrt{\left(\frac{2}{na_0}\right)^3 \frac{(n-l-1)!}{2n[(n+l)!]}} e^{-\rho/2} \rho^l L_{n-l-1}^{2l+1}(\rho) \cdot Y_{lm}(\vartheta,\varphi)$
−
+
(2,0,0)
(3,0,0)
(2,1,0)
(3,1,0)
(3,1,1)
(2,1,1)
(3,2,0)
(3,2,1)
(3,2,2)
(4,0,0)
(4,1,0)
(4,1,1)
(4,2,0)
(4,2,1)
(4,2,2)
(4,3,0)
(4,3,1)
(4,3,2)
(4,3,3)

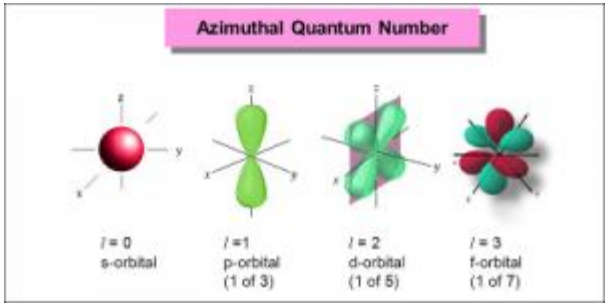
Quantum numbers

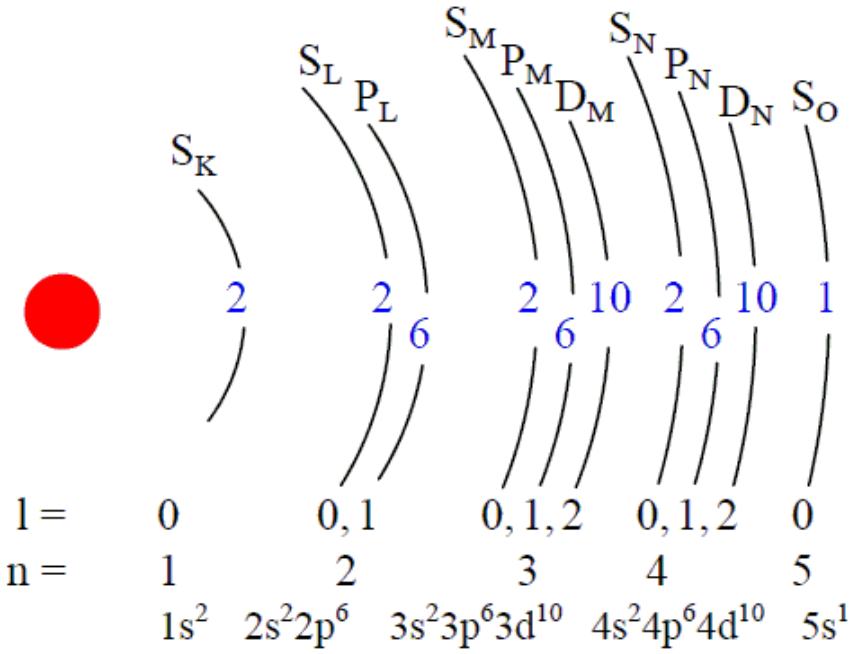
- **Quantum numbers**: specify the posslible location of each electron in an atom. They are the wave equation (Schrödinger-equation) possible solutions
- **Principal quantum number, *n***: – indicates the energy levels of the electrons relative to their distance from the nucleus
  - n=1-7
  - maximum number of electrons in each principal energy level is $2n^2$



Quantum numbers

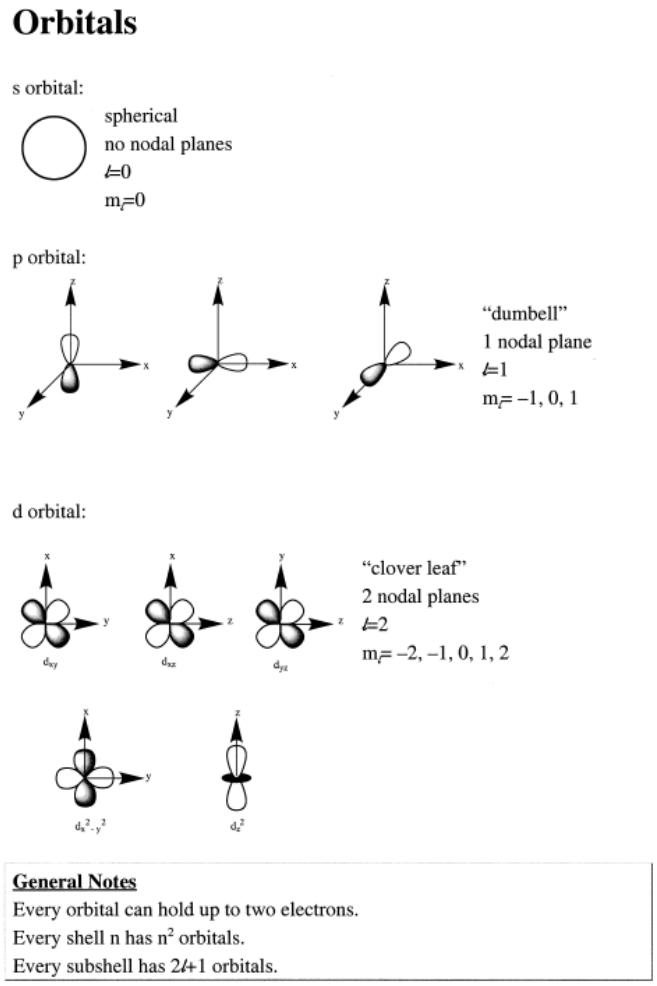
- **Azimuthal quantum number, *l***: – subshell number – specifies the shape of the orbital: l = 0, 1, 2, 3, 4 nodals
- electrons in the principal energy level exist in closely grouped sublevels (subshells)
  - *l* = 0 to (n-1)
  - sublevels are signed by
    - *s (l=0)*
    - *p (l=1)*
    - *d (l=2)*
    - *f (l=3)*





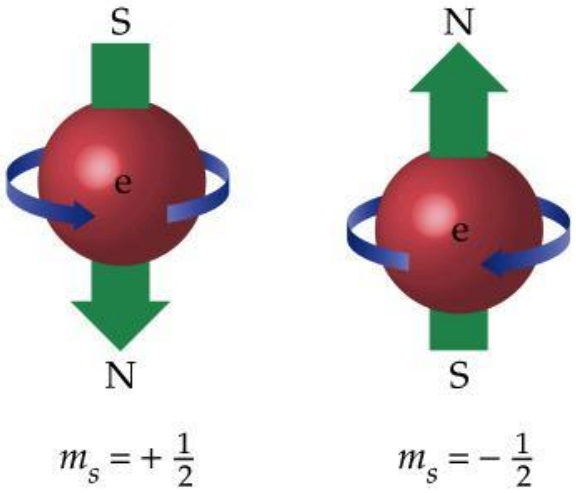
Quantum numbers

- **Magnetic quantum numbers**, **m**: show the specific orientation of the orbitals in space
- m: 0 to ±*l*
- orbitals that differ only in magnetic quantum number are called degenerated
  - s: one (m=0)
  - p: three (m = -1, 0, +1)
  - d: five (m = -2, -1, 0, +1, +2)
  - f: seven (m = -3, -2, -1, 0, +1, +2, +3)

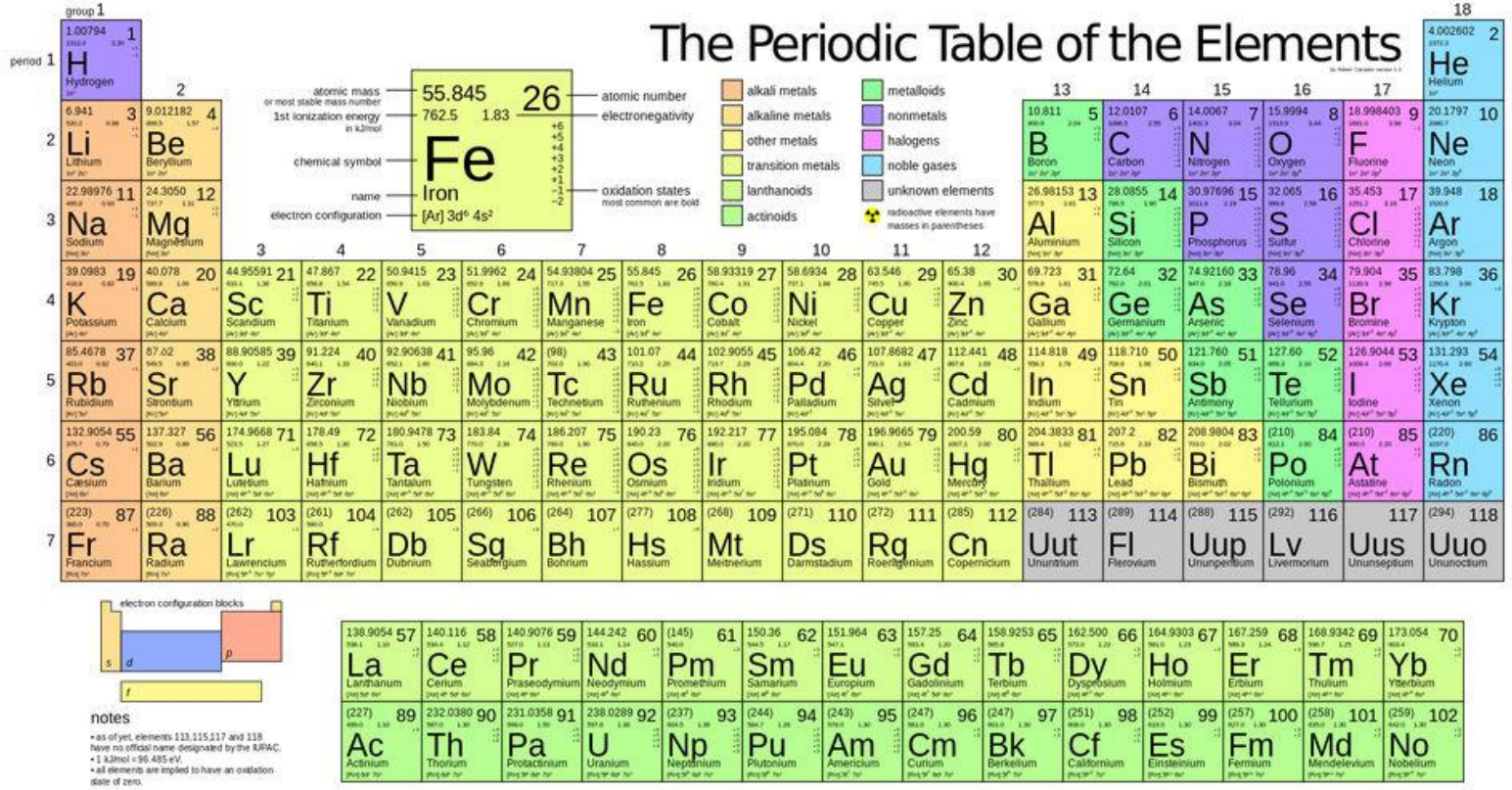


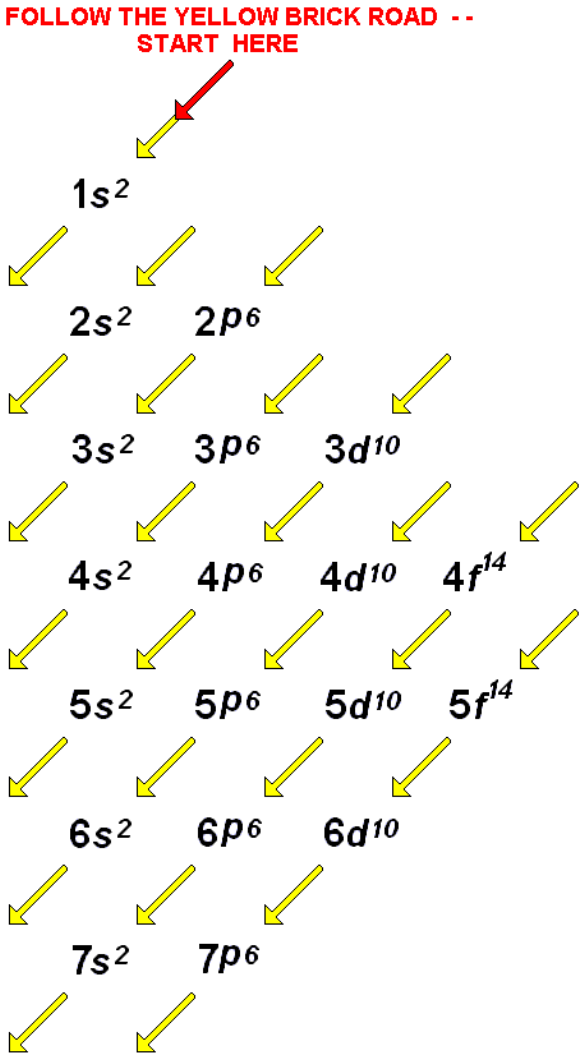
Quantum numbers

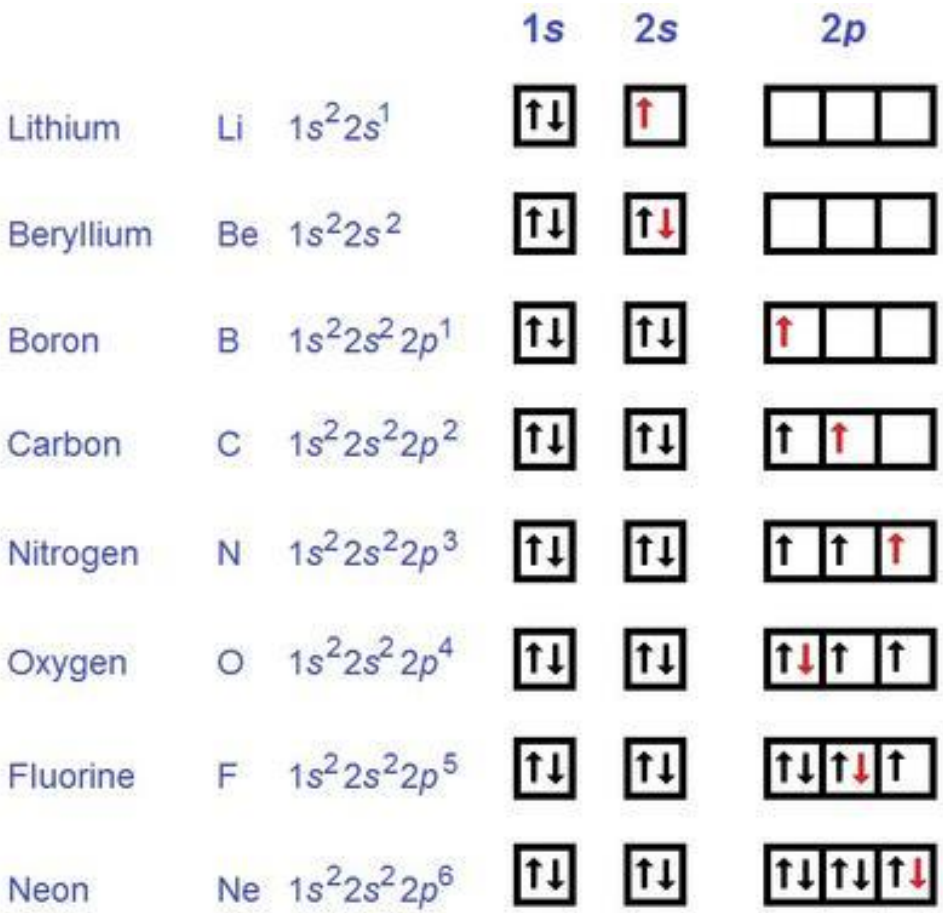
- **Spin quantum number, s**: relates to direction of a spin of an electron
- two possible values of spin: +1/2 and -1/2
- a maximum of two electrons can occupy each orbital.
- if two electrons differ only in their s number are said to be **paired**
- **Pauli's exclusion principle**:
  in an atom no two electrons with the same quantum numbers can exist.
  If this is fulfilled, the atoms will be stable



n	l	m_l	Number of Orbitals	Orbital Name	Number of Electrons	Number of Electrons Per Orbital
1	0	0	1	1s	2	2
2	0 1	0 -1,0,+1	1 3	2s 2p	2 6	2 2
3	0 1 2	0 -1,0,+1 -2,-1,0, +1,+2	1 3 5	3s 3p 3d	2 6 10	2 2 2
4	0 1 2 3	0 -1,0,+1 -2,-1,0,+1,+2 -3,-2,-1,0,+1,+2,+3	1 3 5 7	4s 4p 4d 4f	2 6 10 14	2 2 2 2


The Periodic Table of the Elements
group 1
18
period 1
2
3
4
5
6
7
atomic mass
or most stable mass number
1st ionization energy
in kJ/mol
chemical symbol
name
electron configuration
55.845
762.5
1.83
26
Fe
Iron
[Ar] 3d⁶ 4s²
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
electron configuration blocks
s
d
p
f
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.


FOLLOW THE YELLOW BRICK ROAD - -
START HERE
1s2
2s2 2p6
3s2 3p6 3d10
4s2 4p6 4d10 4f14
5s2 5p6 5d10 5f14
6s2 6p6 6d10
7s2 7p6


1s
2s
2p
Lithium Li $1s^2 2s^1$
Beryllium Be $1s^2 2s^2$
Boron B $1s^2 2s^2 2p^1$
Carbon C $1s^2 2s^2 2p^2$
Nitrogen N $1s^2 2s^2 2p^3$
Oxygen O $1s^2 2s^2 2p^4$
Fluorine F $1s^2 2s^2 2p^5$
Neon Ne $1s^2 2s^2 2p^6$