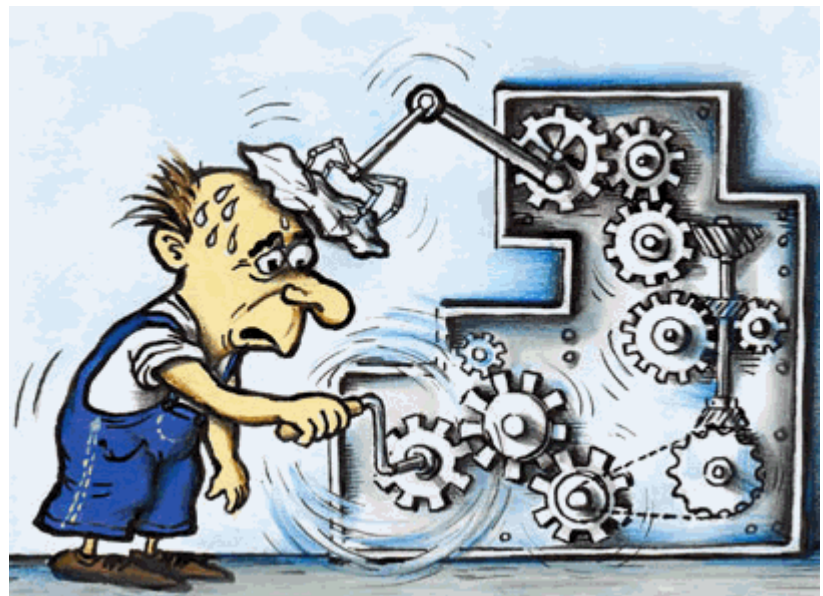


What the
matter is?

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?

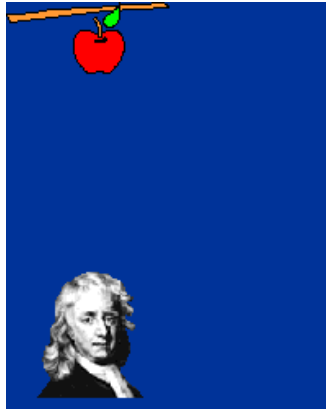
- **Natural sciences:** everything that is able to interact with one of the fundamental interactions (forces) or with the combination of these, is **MATTER** (Manuel Carreira, Spanish physicist and philosopher)
- The matter:
 - has a place in space
 - has some quantity of energy
 - can interact with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

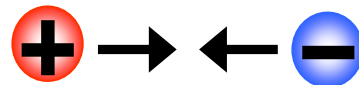
Fundamental interactions

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?



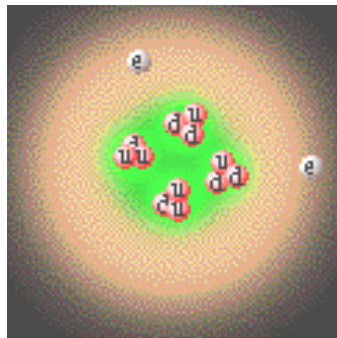
Fundamental interactions

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



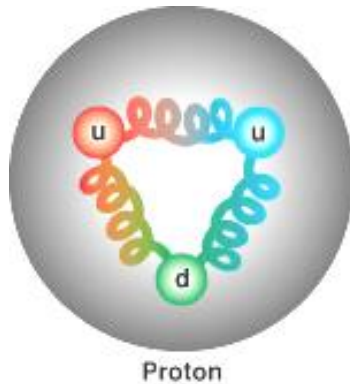
Fundamental interactions

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

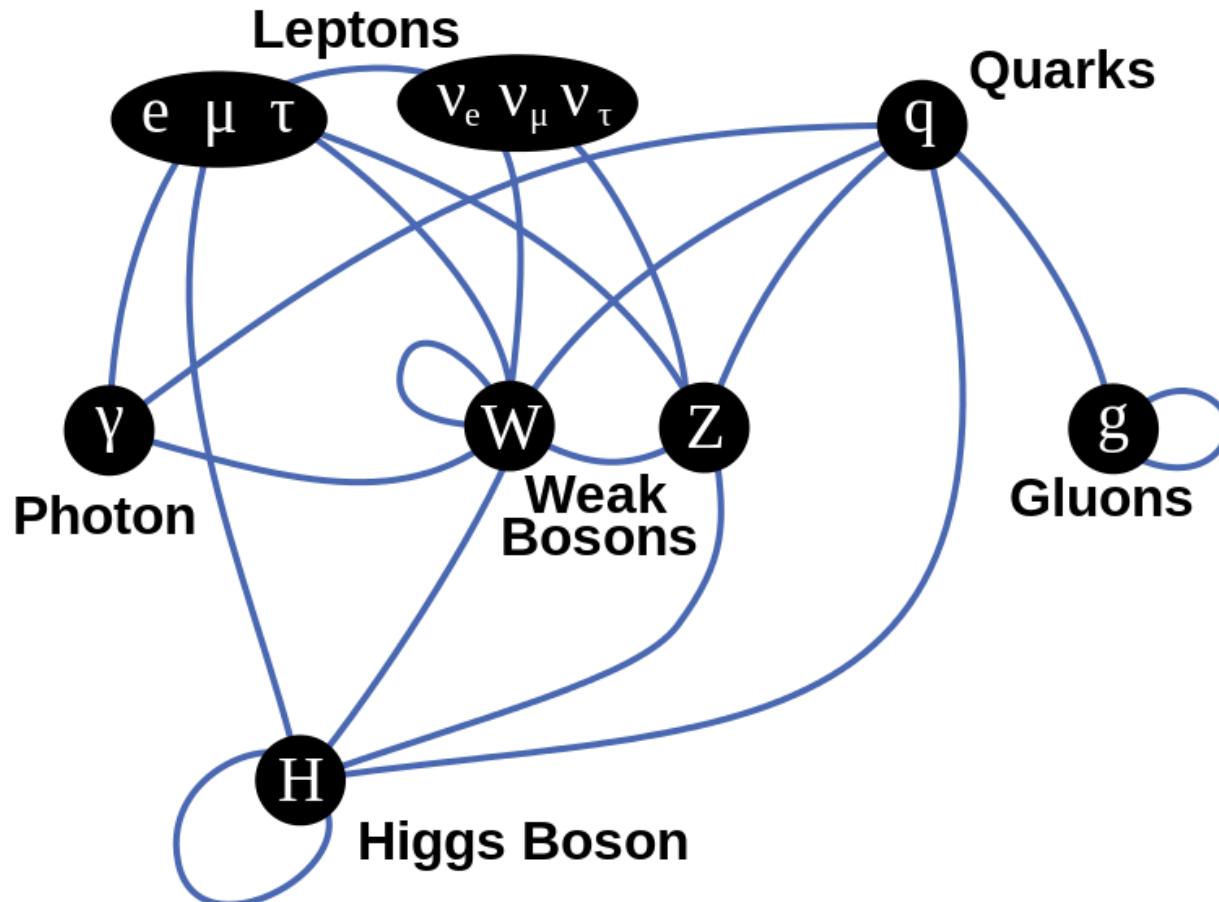


Fundamental interactions

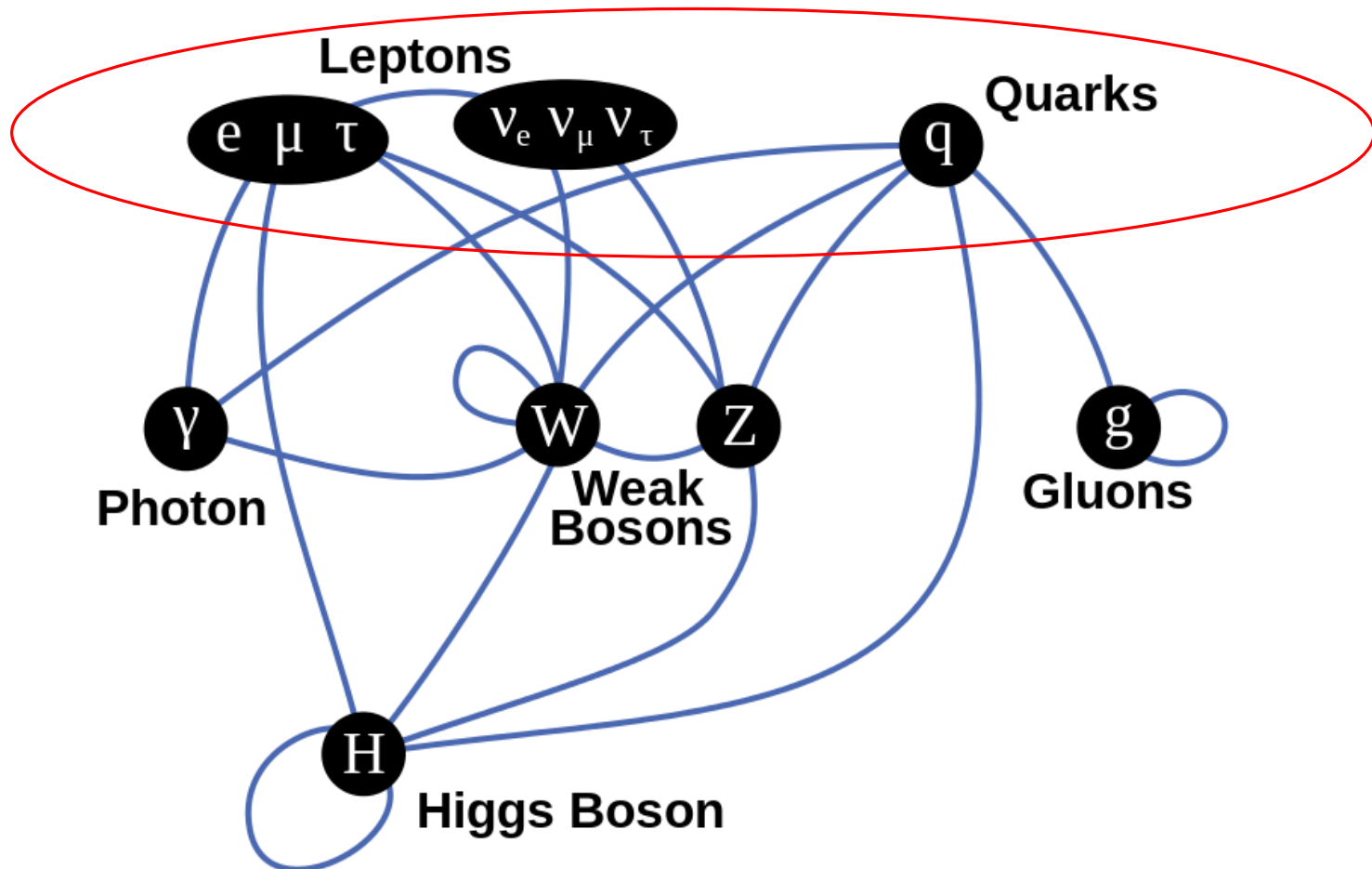
INTERACTION	CHARACTERISTICS	MEDIATING
STRONG	acts on quarks , it holds together the nucleons (protons and neutrons), acts on femtometre scale ($1\text{fm}=10^{-15}\text{m}$)	GLUON

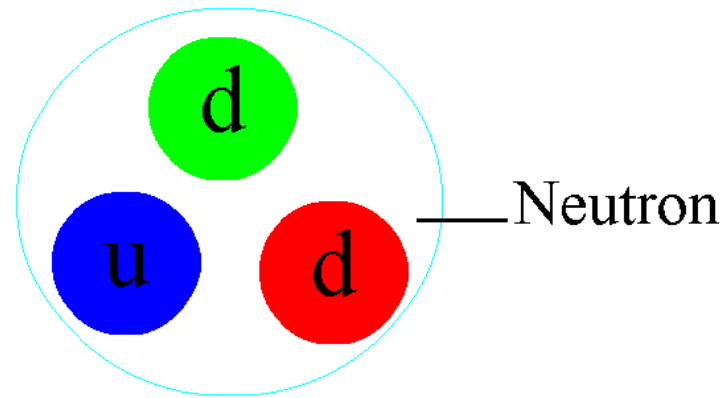
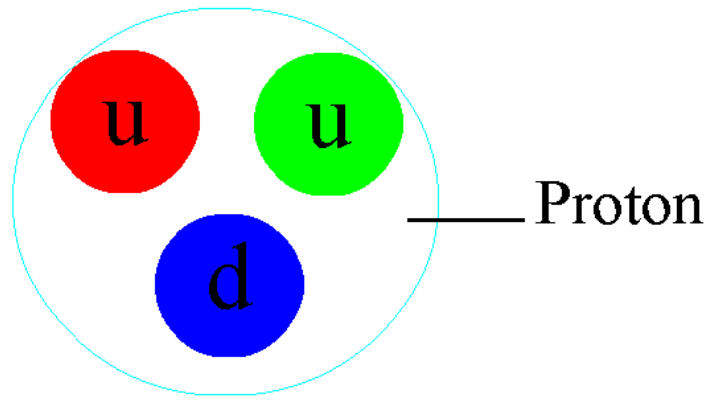


What the matter is?



What the matter is?





What the matter is?

Higgs bozon – 2012

Peter Higgs



What the matter is?

Higgs space

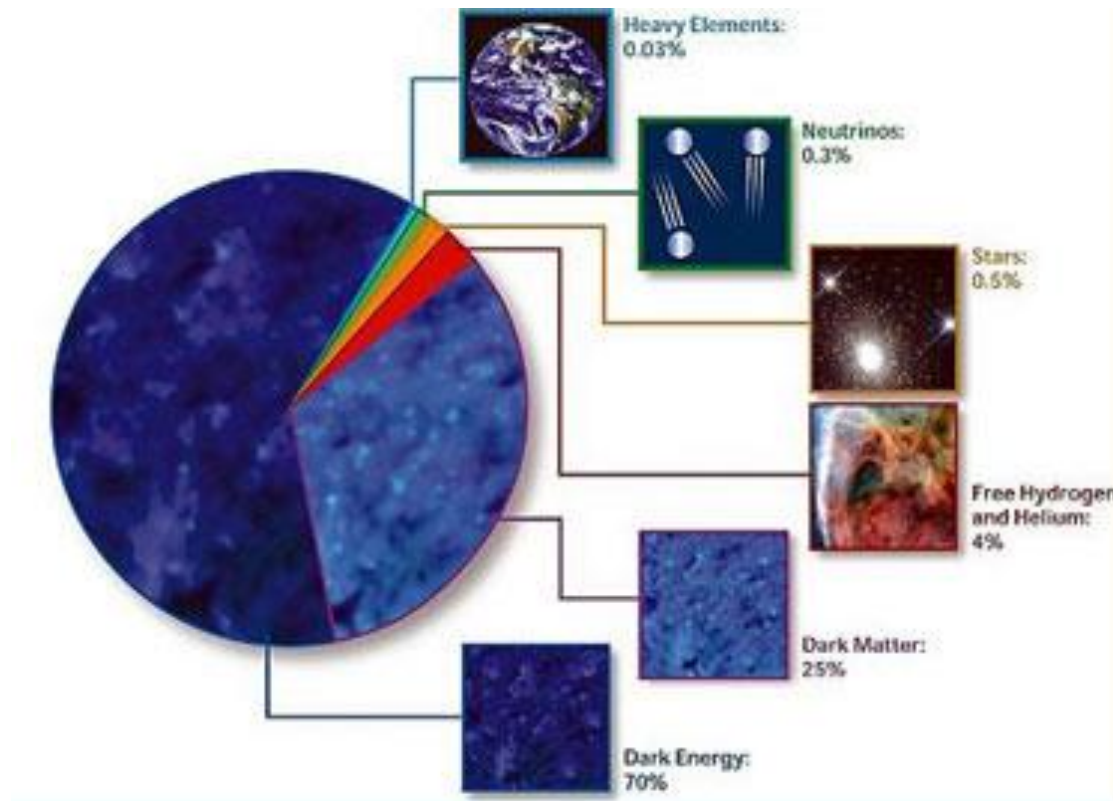


Higgs bozon



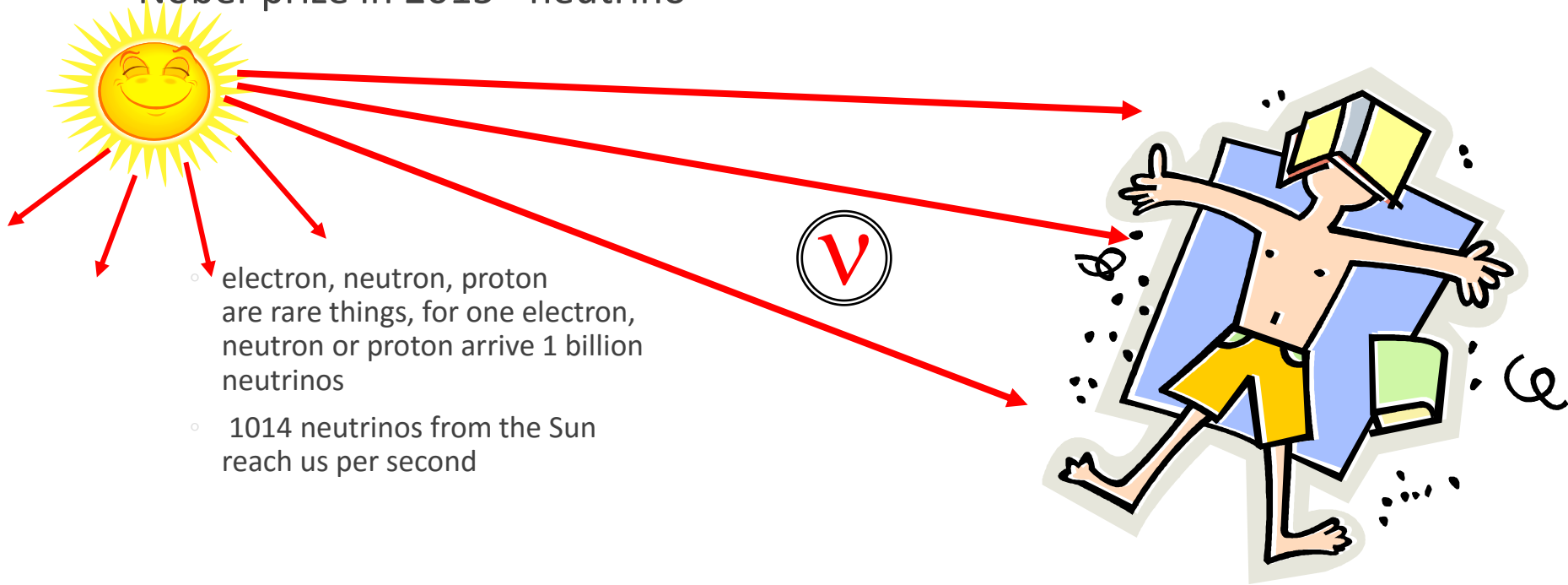
What the matter is?

Dark matter, dark energy



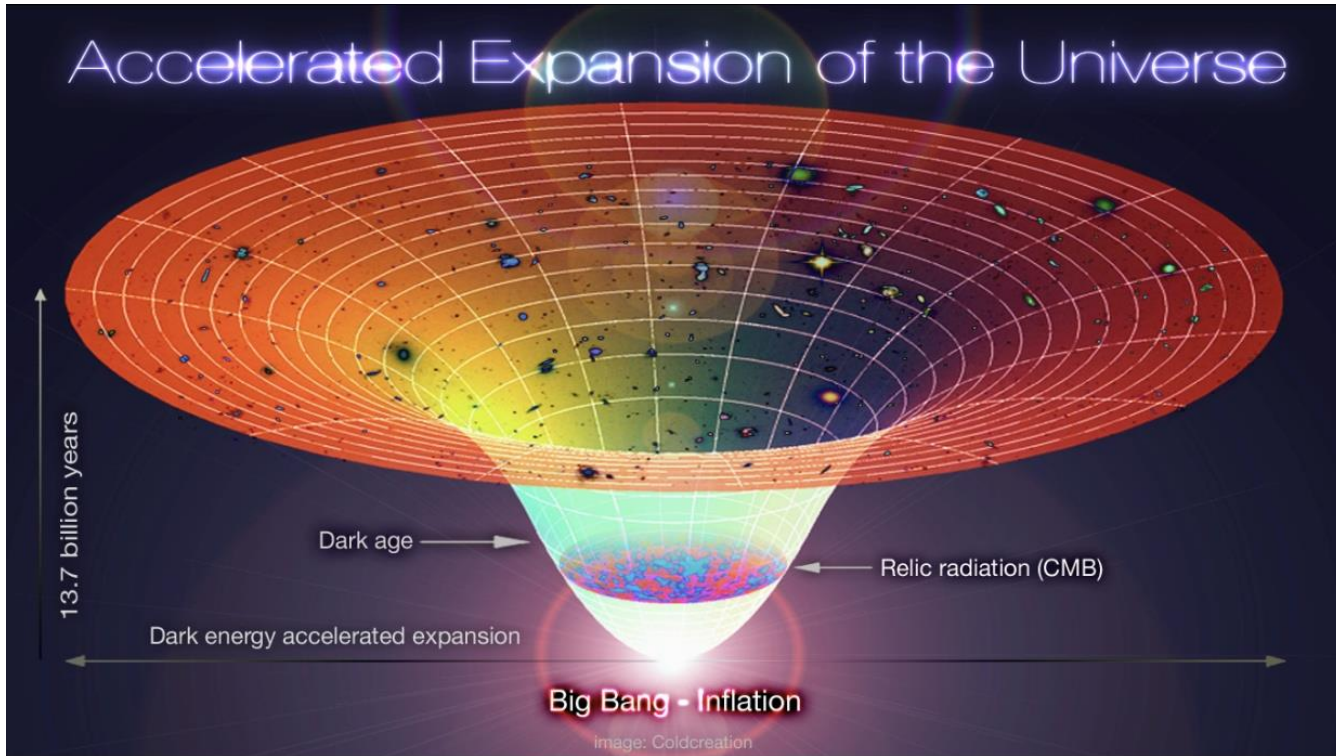
What the matter is?

Nobel-prize in 2015 - neutrino



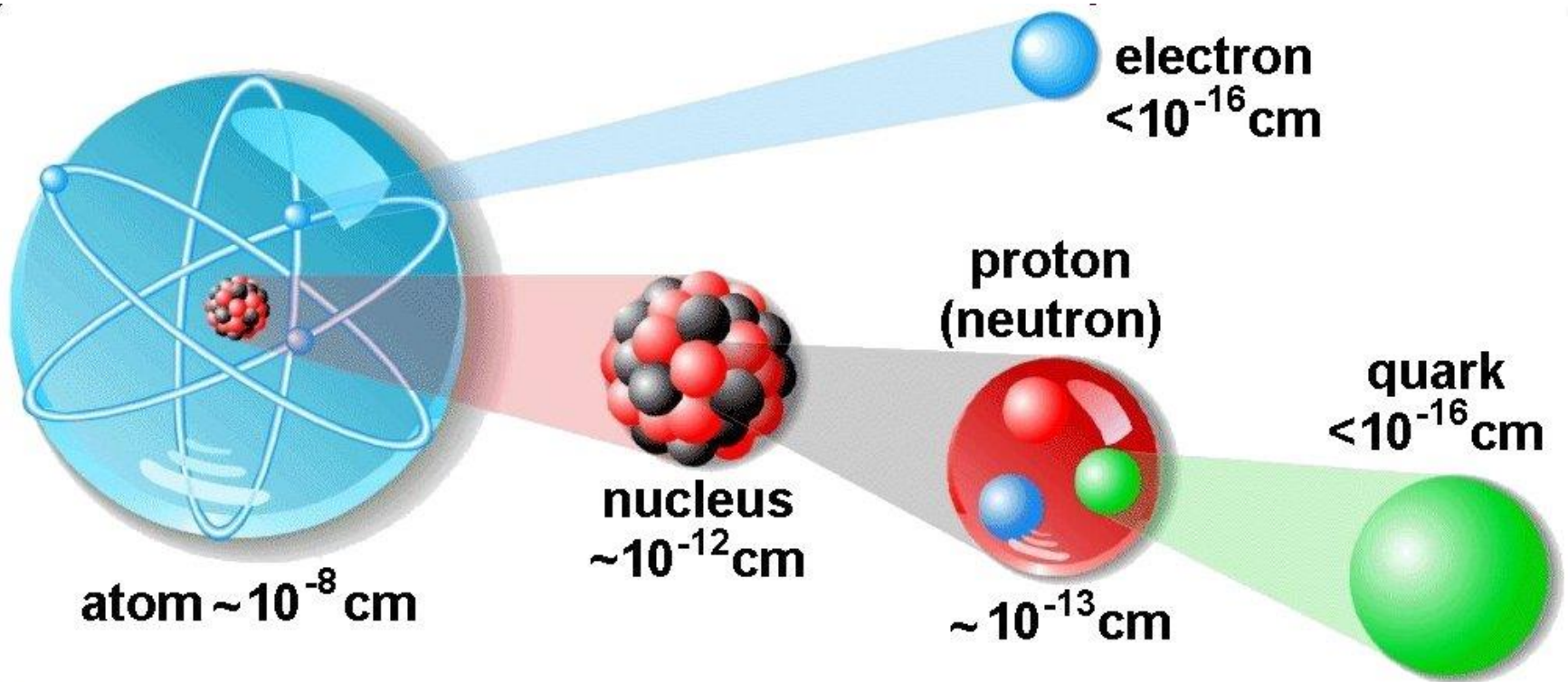
- electron, neutron, proton are rare things, for one electron, neutron or proton arrive 1 billion neutrinos
- 10^{14} neutrinos from the Sun reach us per second

Accelerated Expansion of the Universe



From quarks to atoms

The structure of an atom



Atomic structure

- **The internal structure of the atom**

- early 20th century: Ernest Rutherford model

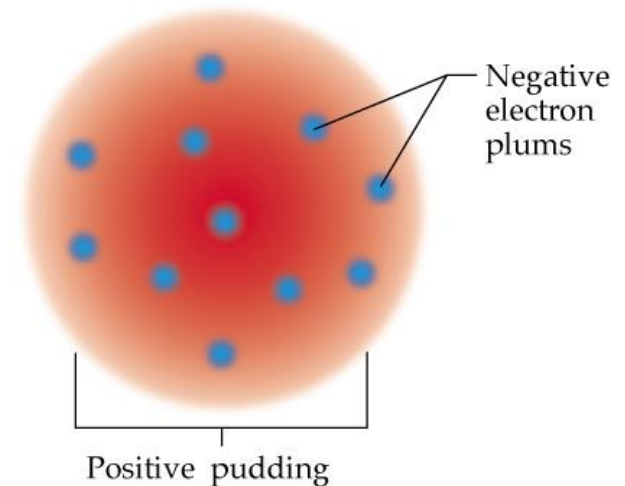
- **before Rutherford:**

- “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**

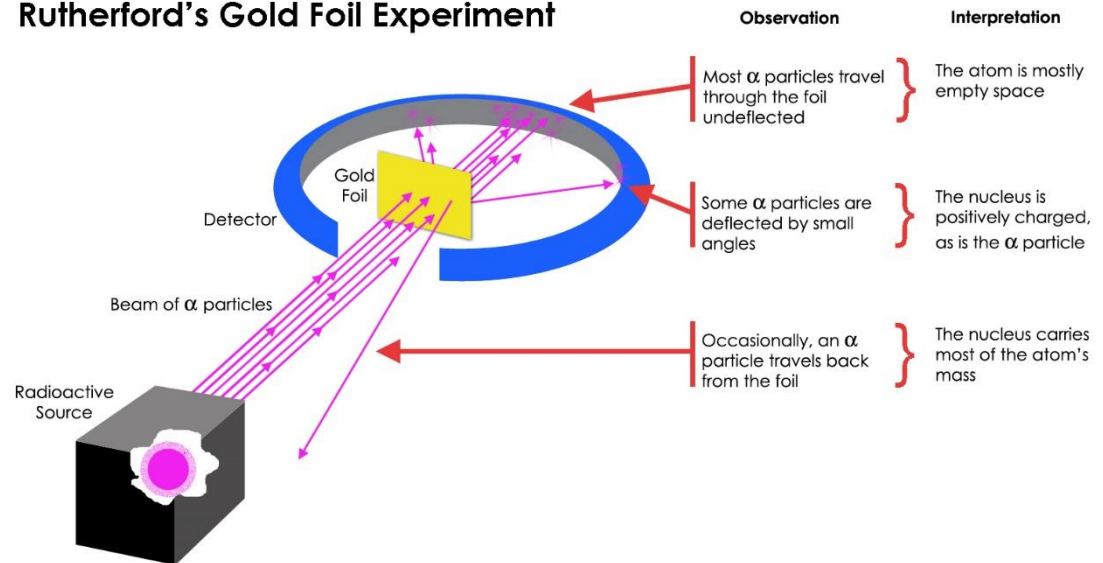
Thompson plum pudding model of the atom



Rutherford experiment

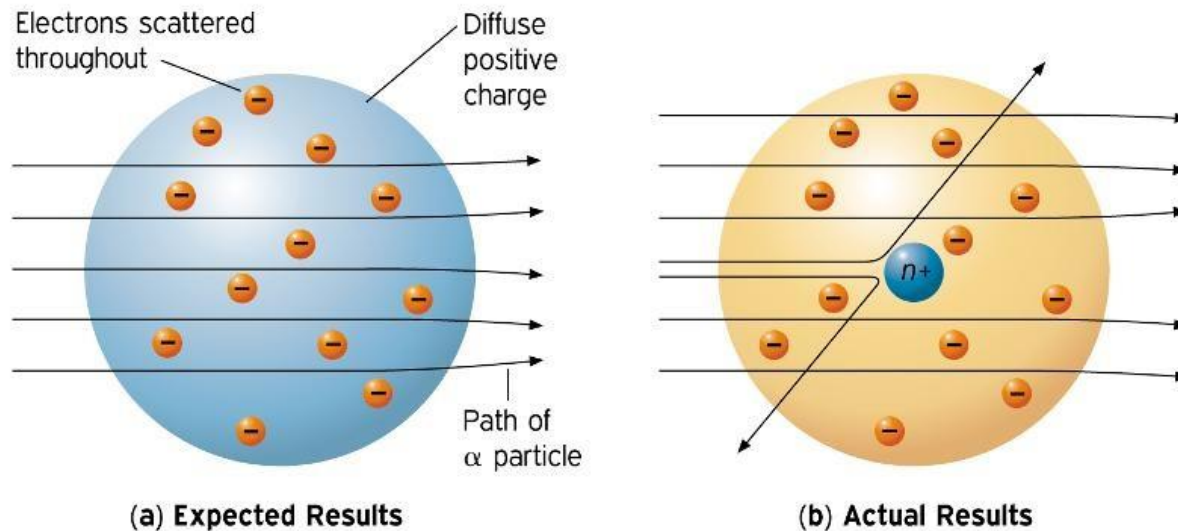
- Rutherford suggested, that the positive charge is concentrated in the center of the atom. The atom consists mainly of empty space, and the positive centre is surrounded by a negative electron cloud
- called planetary model

Rutherford's Gold Foil Experiment



Rutherford model

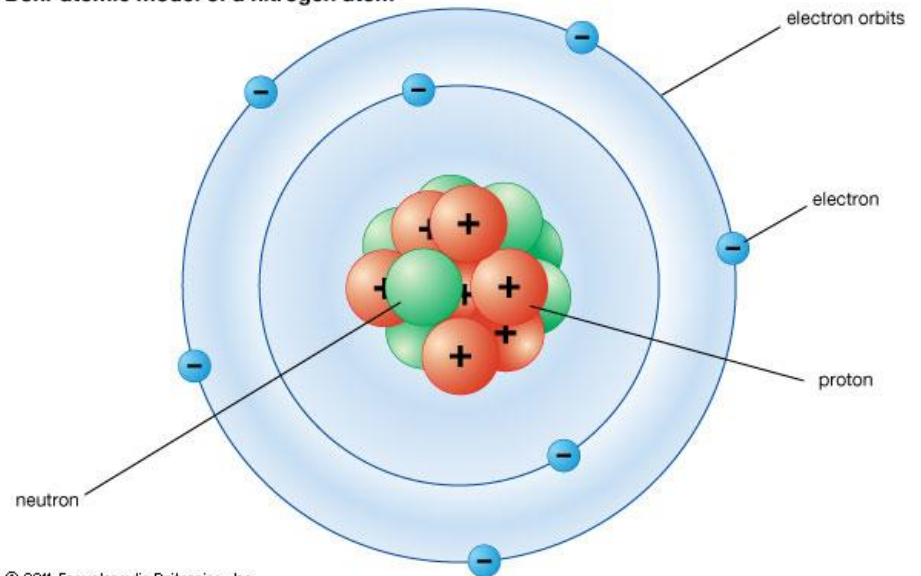
- Rutherford observed that when a beam of alpha particles (He^{2+}) struck a thin gold foil, some of the particles are deflected backward. Such large deflections were inconsistent with the Thomson model



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

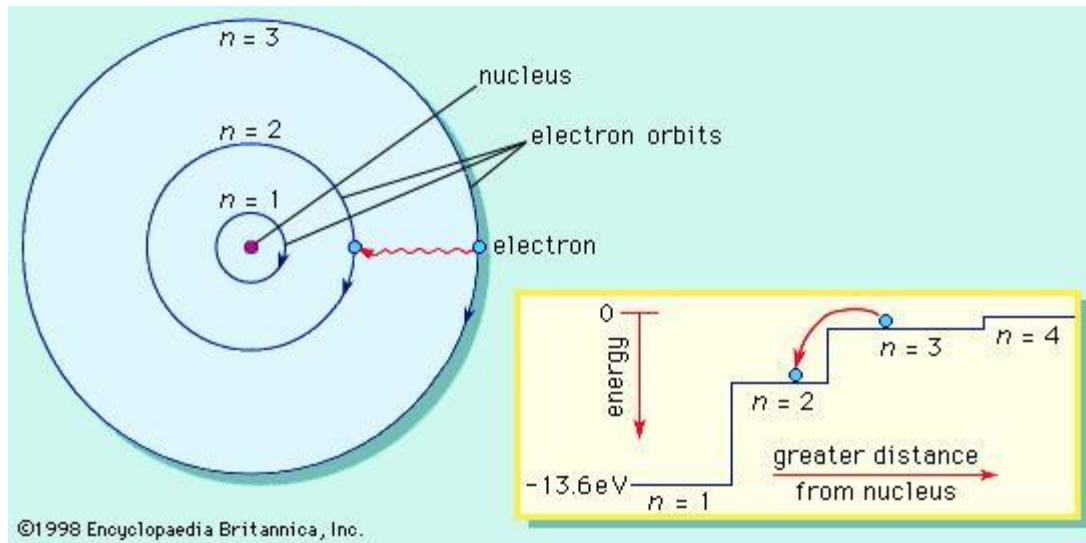
Bohr atomic model of a nitrogen atom



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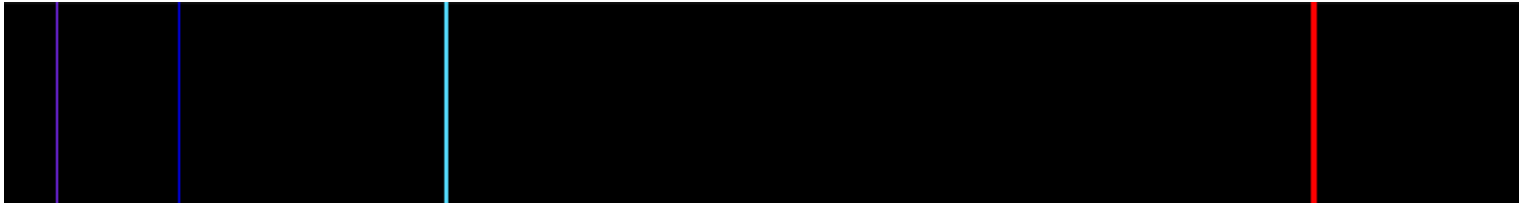
Bohr model

- 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

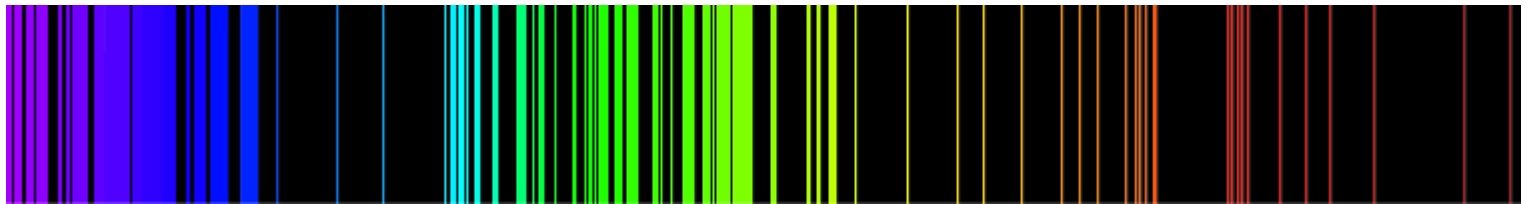


Spectral lines – emission spectrum

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

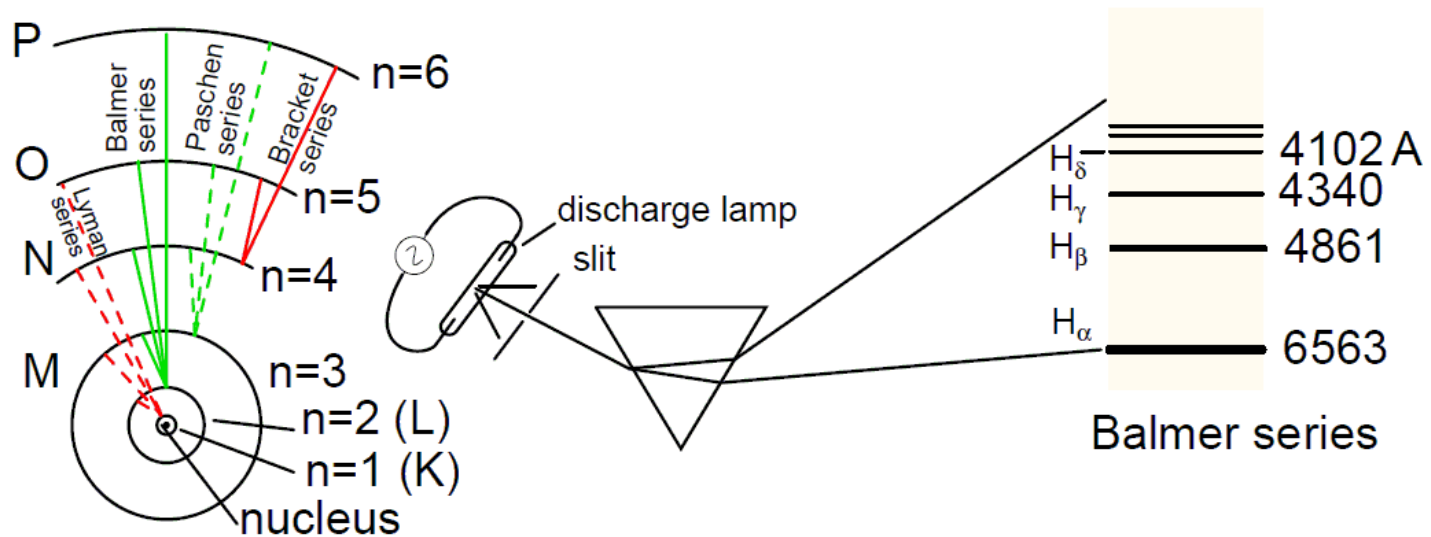


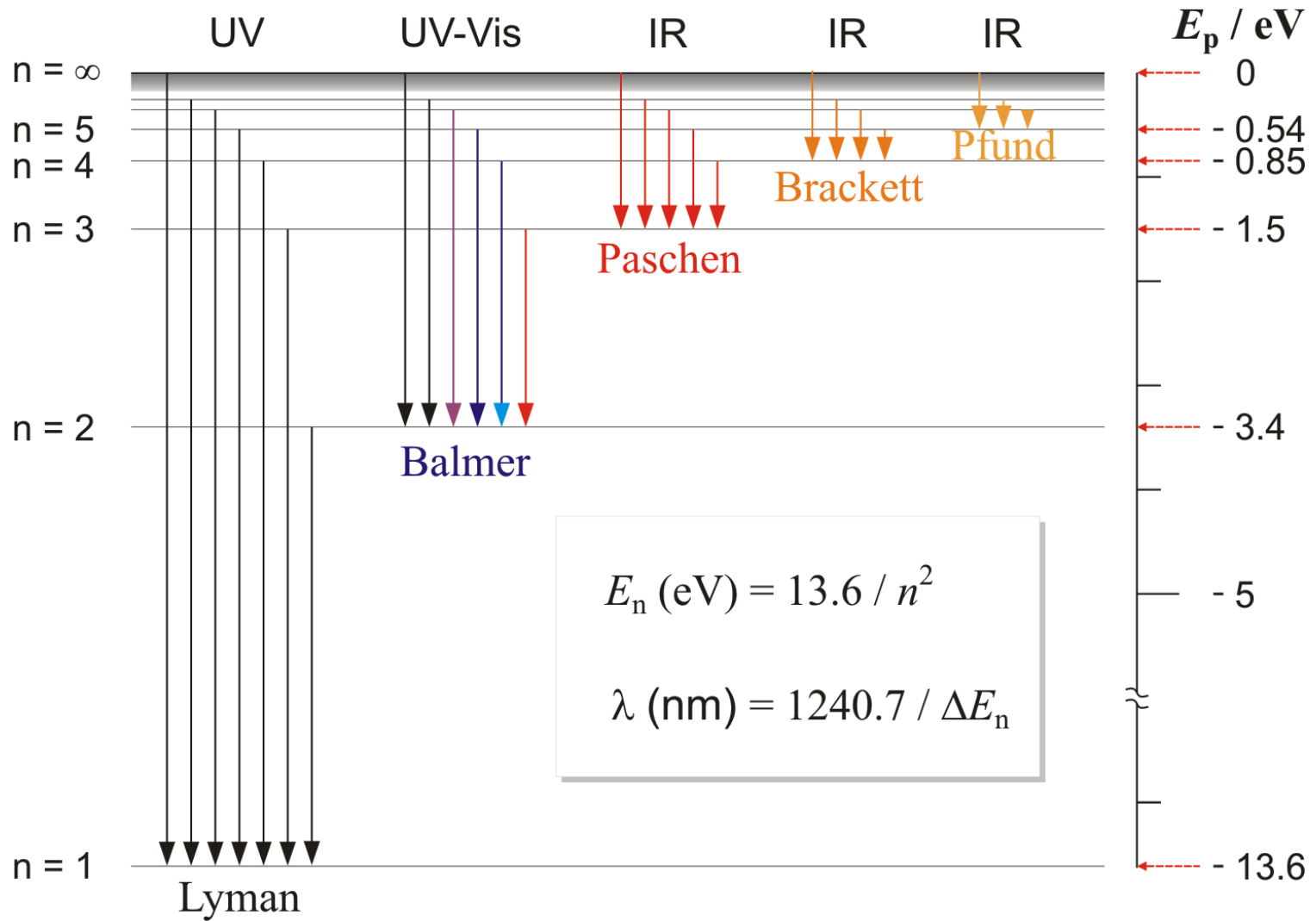
- Hydrogen emission spectrum



- Iron emission spectrum

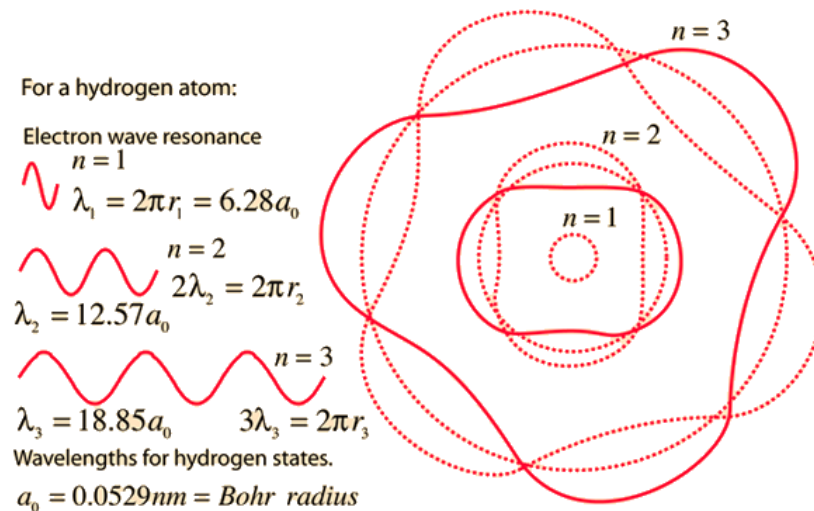
Extended Bohr model





Quantum mechanical atomic model

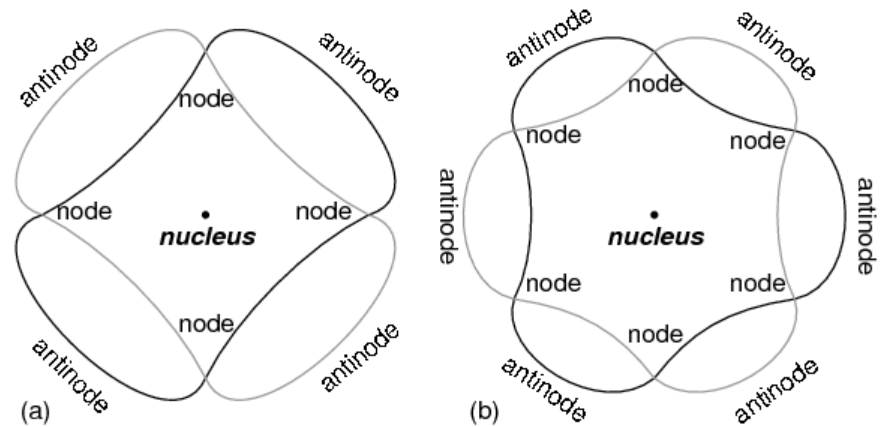
- In this model electrons are **NOT only considered particles**, but also **waves**, which are described by the same mathematical formulae as standing waves
- Electrons occupy orbitals, that are regions in an atom around the nucleus within which an electron with a given energy is most likely to be found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



Quantum mechanical atomic model

- Particle (m) – wave (λ) duality:

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

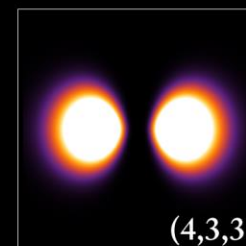
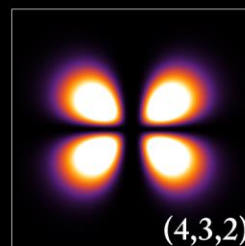
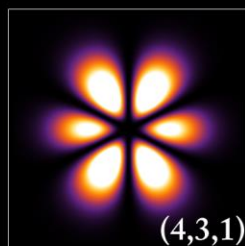
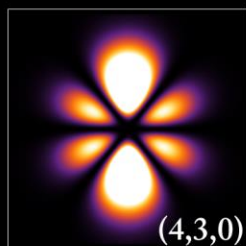
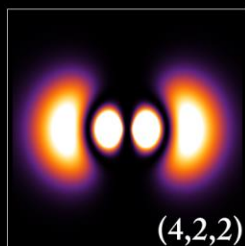
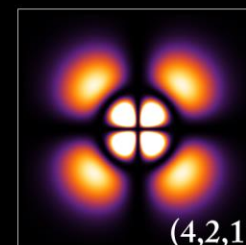
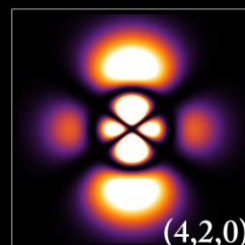
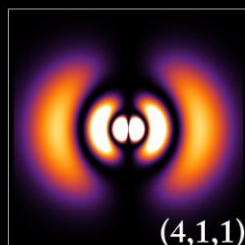
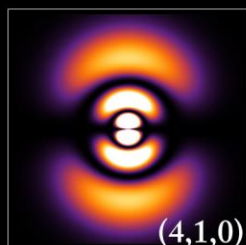
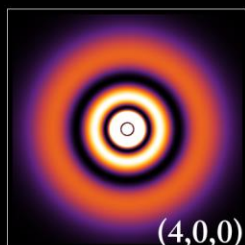
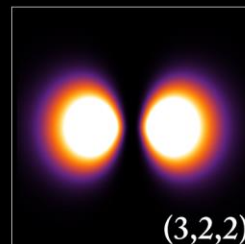
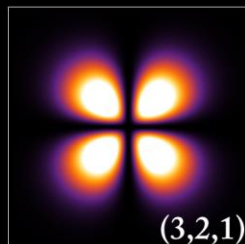
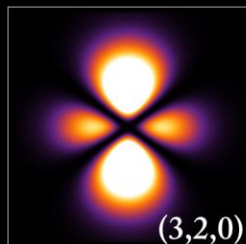
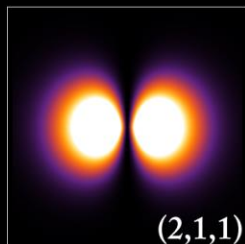
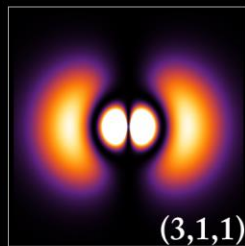
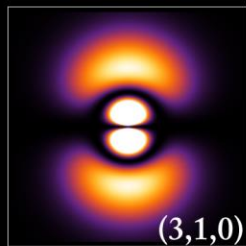
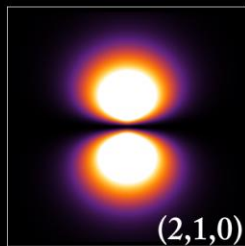
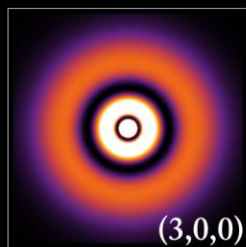
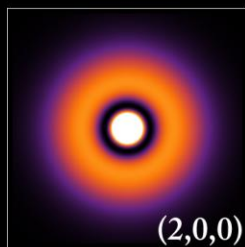


- $h = 6.626 \cdot 10^{-34}$ Js : Planck-constant
- $m_0 = 9.109 \cdot 10^{-31}$ kg : rest mass of the electron

Hydrogen Wave Function

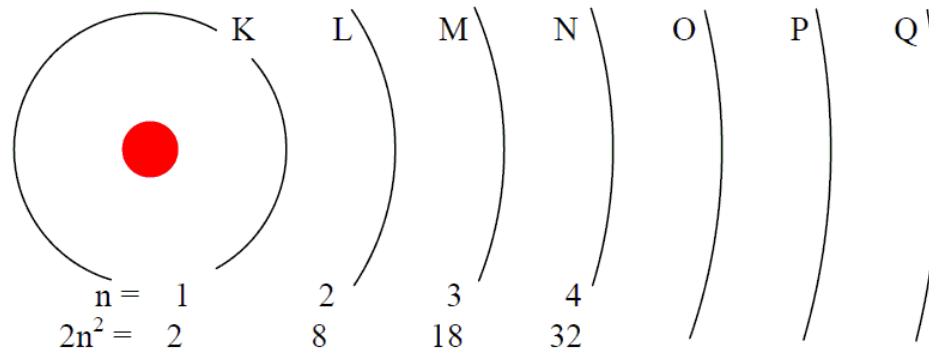
Probability density plots.

$$\psi_{nlm}(r, \vartheta, \varphi) = \sqrt{\left(\frac{2}{na_0}\right)^3 \frac{(n-l-1)!}{2n[(n+l)!]} e^{-\rho/2} \rho^l L_{n-l-1}^{2l+1}(\rho) \cdot Y_{lm}(\vartheta, \varphi)}$$



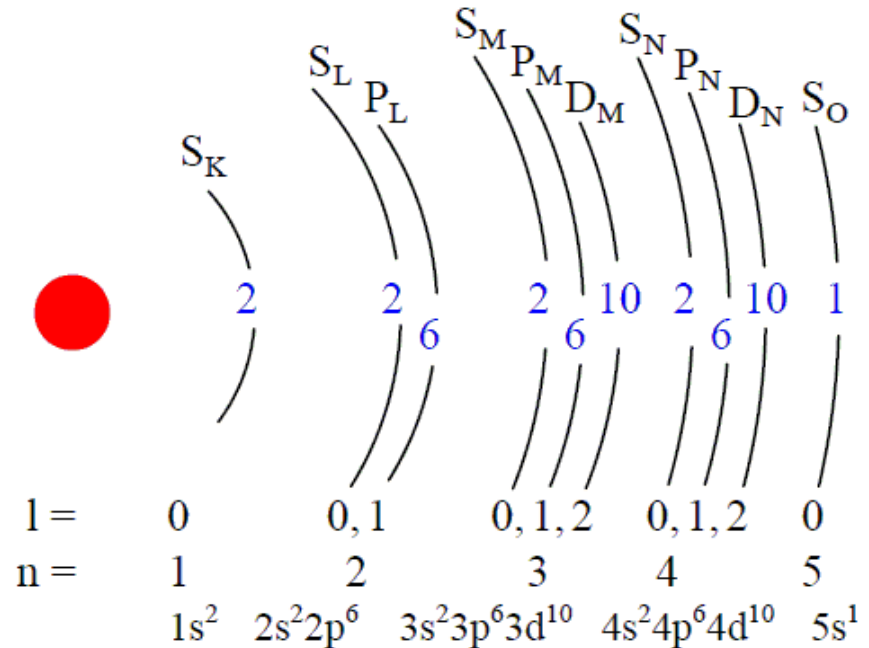
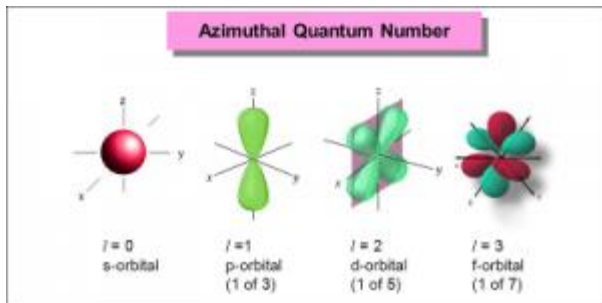
Quantum numbers

- **Quantum numbers:** specify the possible 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 ($l=3$)

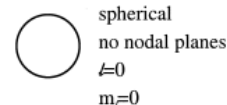


Quantum numbers

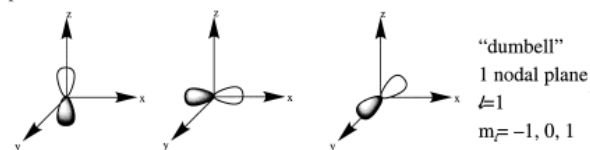
- **Magnetic quantum numbers, m :** show the specific orientation of the orbitals in space
- m : 0 to $\pm l$
- orbitals that differ only in magnetic quantum number are called degenerated
 - s: one ($m=0$)
 - p: three ($m = -1, 0, +1$)
 - d: five ($m = -2, -1, 0, +1, +2$)
 - f: seven ($m = -3, -2, -1,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

Orbitals

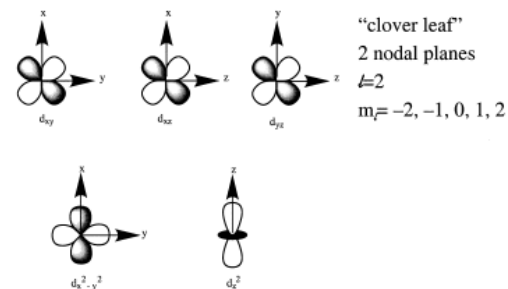
s orbital:



p orbital:



d orbital:



General Notes

Every orbital can hold up to two electrons.
Every shell n has n^2 orbitals.
Every subshell has $2l+1$ orbitals.

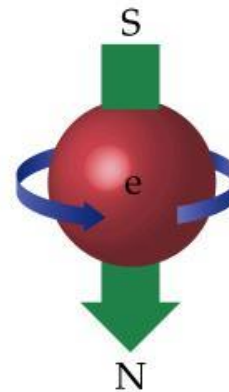
Quantum numbers

- **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**

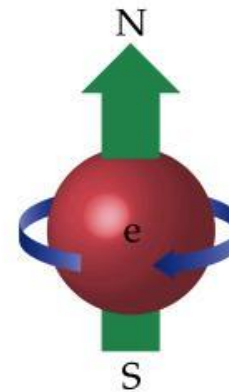
- **Pauli's exclusion principle:**

in an atom no two electrons with the same quantum numbers can exist.

If this is fulfilled, the atoms will be stable



$$m_s = +\frac{1}{2}$$



$$m_s = -\frac{1}{2}$$

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

The Periodic Table of the Elements

group 1																	18	
1																	2	
1	1.00794 H Hydrogen																	4.002602 He Helium
2	6.941 Li Lithium	9.012182 Be Beryllium															20.1797 Ne Neon	
3	22.98976 Na Sodium	24.3050 Mg Magnesium															39.948 Ar Argon	
4	39.0983 K Potassium	40.078 Ca Calcium	44.95591 Sc Scandium	47.867 Ti Titanium	50.9415 V Vanadium	51.9962 Cr Chromium	54.93804 Mn Manganese	55.845 Fe Iron	58.93319 Co Cobalt	58.6934 Ni Nickel	63.546 Cu Copper	65.38 Zn Zinc	69.723 Ga Gallium	72.64 Ge Germanium	74.92160 As Arsenic	78.96 Se Selenium	79.904 Br Bromine	83.798 Kr Krypton
5	85.4678 Rb Rubidium	87.62 Sr Strontium	88.90585 Y Yttrium	91.224 Zr Zirconium	92.90638 Nb Niobium	95.96 Mo Molybdenum	(98) Tc Technetium	101.07 Ru Ruthenium	102.9055 Rh Rhodium	106.42 Pd Palladium	107.8682 Ag Silver	112.414 Cd Cadmium	114.818 In Indium	118.710 Sn Tin	121.760 Sb Antimony	127.60 Te Tellurium	126.9044 I Iodine	131.293 Xe Xenon
6	132.9054 Cs Cesium	137.327 Ba Barium	174.9668 Lu Lutetium	178.49 Hf Hafnium	180.9478 Ta Tantalum	183.84 W Tungsten	186.207 Re Rhenium	190.23 Os Osmium	192.217 Ir Iridium	195.084 Pt Platinum	196.9665 Au Gold	200.59 Hg Mercury	204.3833 Tl Thallium	207.2 Pb Lead	208.9804 Bi Bismuth	(210) Po Polonium	(210) At Astatine	(220) Rn Radon
7	(223) Fr Francium	(226) Ra Radium	(262) Lr Lawrencium	(261) Rf Rutherfordium	(262) Db Dubnium	(266) Sg Seaborgium	(264) Bh Bohrium	(277) Hs Hassium	(268) Mt Meitnerium	(271) Ds Darmstadtium	(272) Rg Roentgenium	(285) Cn Copernicium	(284) Uut Ununtrium	(289) Fl Flerovium	(288) Uup Ununpentium	(292) Lv Livermorium	117 Uus Ununseptium	(294) Uuo Ununoctium

atomic mass
 or most stable mass number
 1st ionization energy
 in kJ/mol

atomic number
 electronegativity

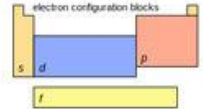
chemical symbol
Fe
 Iron

name
 Iron

electron configuration
 [Ar] 3d⁶ 4s²

oxidation states
 most common are bold
 +6
 +5
 +4
 +3
 +2
 +1
 -1
 -2

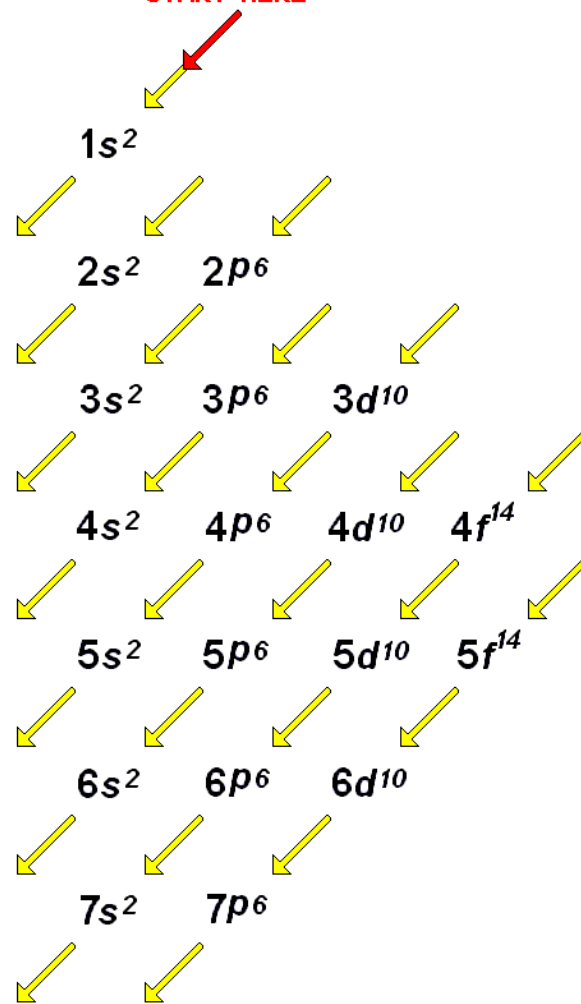
- alkali metals
- alkaline metals
- other metals
- transition metals
- lanthanoids
- actinoids
- metalloids
- nonmetals
- halogens
- noble gases
- unknown elements
- radioactive elements have masses in parentheses



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

138.9054 La Lanthanum	140.116 Ce Cerium	140.9076 Pr Praseodymium	144.242 Nd Neodymium	(145) Pm Promethium	150.36 Sm Samarium	151.964 Eu Europium	157.25 Gd Gadolinium	158.9253 Tb Terbium	162.500 Dy Dysprosium	164.9303 Ho Holmium	167.259 Er Erbium	168.9342 Tm Thulium	173.054 Yb Ytterbium
(227) Ac Actinium	232.0380 Th Thorium	231.0368 Pa Protactinium	238.0289 U Uranium	(237) Np Neptunium	(244) Pu Plutonium	(243) Am Americium	(247) Cm Curium	(247) Bk Berkelium	(251) Cf Californium	(252) Es Einsteinium	(257) Fm Fermium	(258) Md Mendelevium	(259) No Nobelium

**FOLLOW THE YELLOW BRICK ROAD --
START HERE**



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