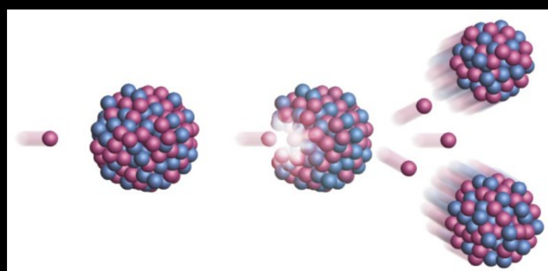
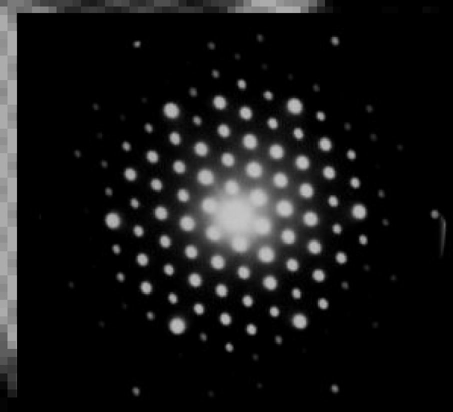
Lectures on Medical Biophysics

Dept. Biophysics Medical faculty,
Masaryk University in Brno





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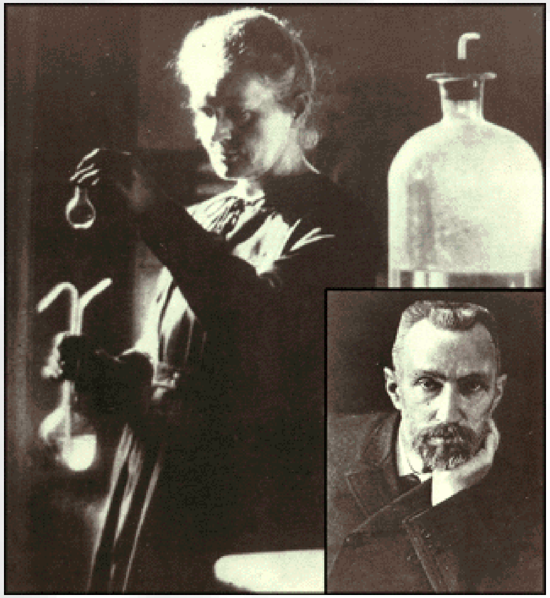


Structure of matter

http://www.accessexcellence.org/AE/AEC/CC/historical_background.html

Matter and Energy

- Everything is made up of particles of matter and fields of energy / force, which means that the fundamental structural elements of the organic and inorganic world are identical.
- Living matter differs from non-living matter only by its much higher level of organisation.

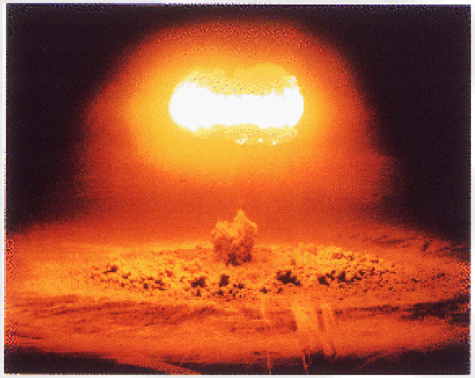
Elementary Particles of Matter

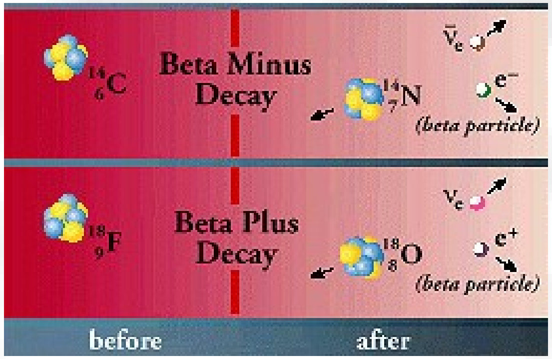
- The elementary (i.e, have no internal structure) particles of matter are **leptons** and **quarks**
- **Leptons** – electrons, muons, neutrinos and their anti-particles – light particles without internal structure
- **Quarks** (u, c, t, d, s, b) – heavier particles without internal structure
- **Hadrons** – heavy particles formed of quarks e.g., **proton** (u, u, d), **neutron** (d, d, u)

The Four Fundamental Energy / Force Fields


gravitational


electromagnetic


strong



weak

Strong : weak : electromagnetic : gravitational = 10^{40} : 10^{15} : 10^3 : 1 (for interaction distance of 10^{-15} m, i.e. approx. the diameter of atom nucleus)

Photons

- Photons - energy quanta of electromagnetic field, zero mass

- Energy of (one) photon: $E = h.f = h.c/\lambda$

  h is the Planck constant (6.62×10^{-34} J.s),

  f is the frequency,

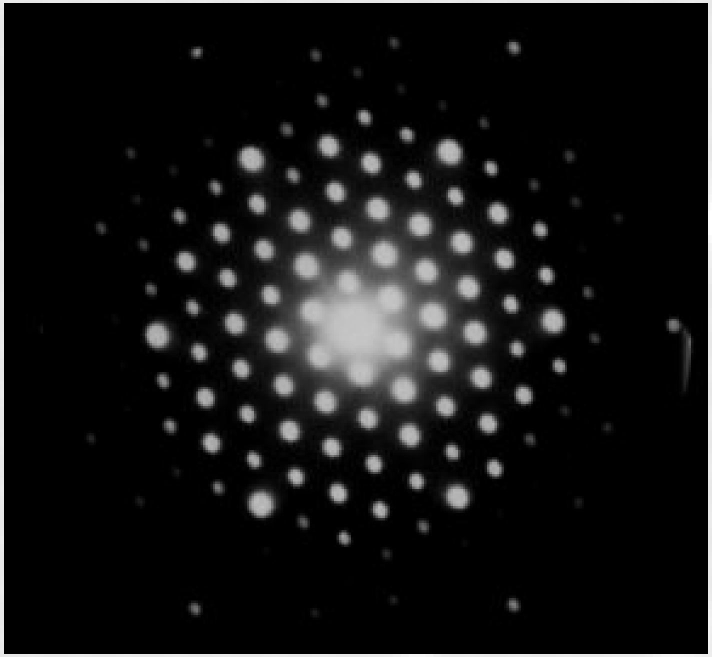
  c is speed of light in vacuum

  λ is the wavelength

Particles and Field Energy Quanta

particles of matter and field energy quanta are capable of mutual transformation (e.g., an electron-positron pair transform to two gamma photons – this is used in PET imaging)

Quantum Mechanics



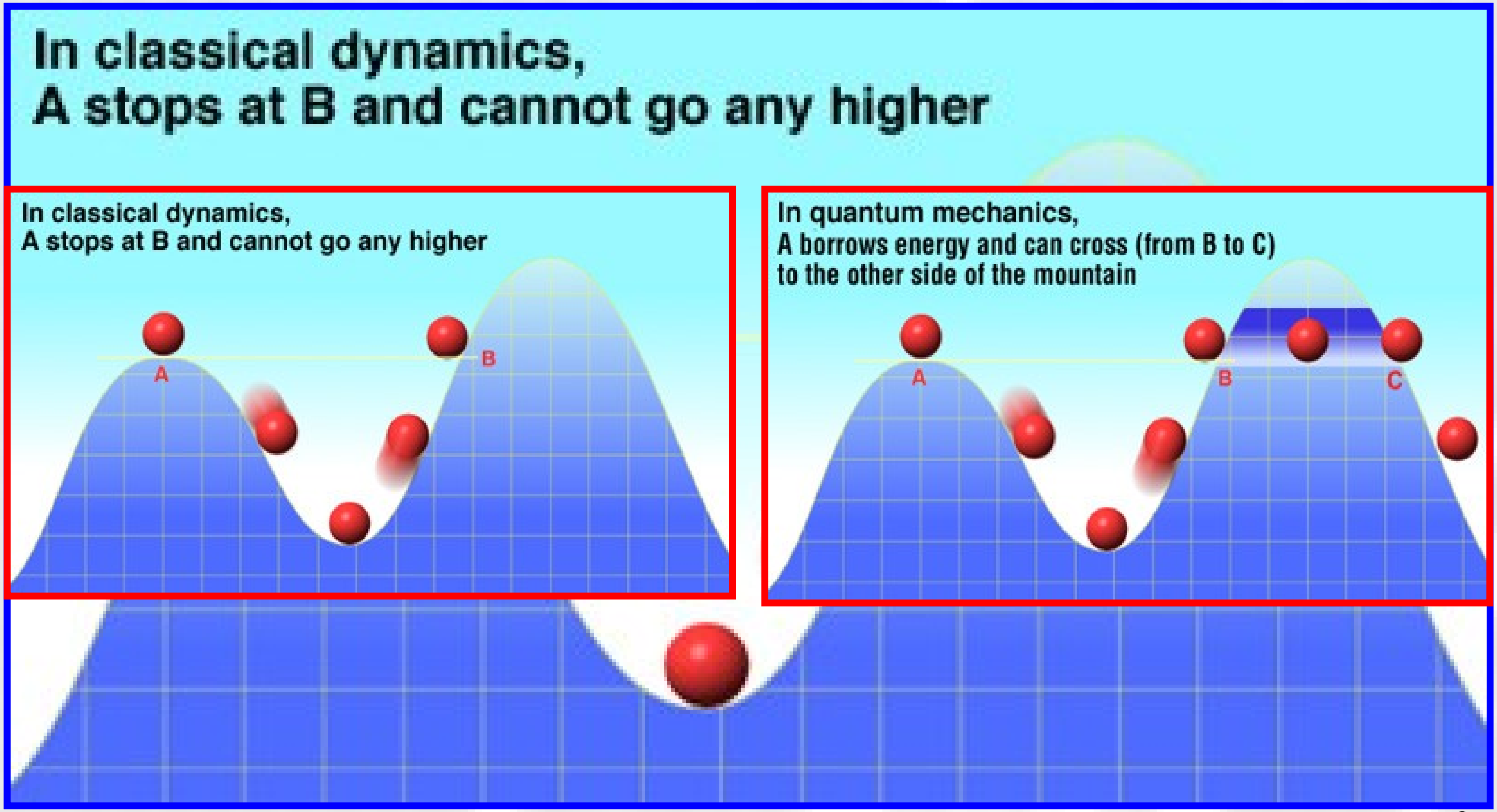
The behaviors of ensembles of a given type of particle obey equations which are similar to wave equations.

On the left pattern formed on a photographic plate by an ensemble of electrons hitting a crystal lattice. Notice that it is very similar to the diffraction pattern produced by a light wave passed through optical grating.

(http://www.matter.org.uk/diffraction/electron/electron_diffraction.htm)

Quantum Mechanics

tunnel effect:



Quantum Mechanics: Heisenberg uncertainty relations

$$\delta r . \delta p \geq h/2\pi$$

$$\delta E . \delta t \geq h/2\pi$$

The position *r* and momentum *p* of a particle cannot be *simultaneously* measured with independent precision (if the uncertainty of particle position – δr – is made smaller, the uncertainty of particle momentum – δp – automatically increases). The same holds for the simultaneous measurement of energy change δE and the time δt necessary for this change.

Schrödinger equation
(to admire)

druhá derivace podle x

Schrd. vlnová funkce

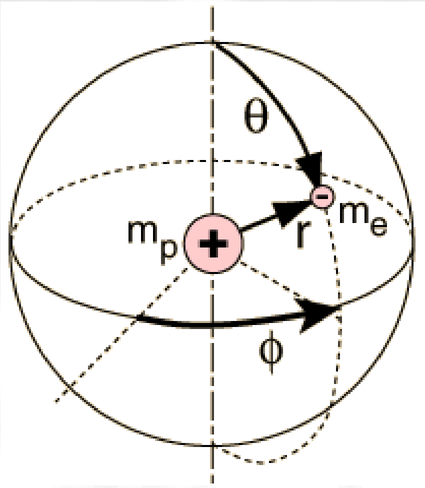
$$\frac{\partial^2 \psi}{\partial x^2} + \frac{8\pi^2 m}{h^2}(E - V)\psi = 0$$

poloha

energie

potenciální energie

„one-dimensional“ S. equation



Radial co-ordinates of an electron in a hydrogen atom

Ψ - wave function

$$\frac{-\hbar^2}{2\mu}\frac{1}{r^2 \sin\theta}\left[\sin\theta\frac{\partial}{\partial r}\left(r^2\frac{\partial \Psi}{\partial r}\right) + \frac{\partial}{\partial \theta}\left(\sin\theta\frac{\partial \Psi}{\partial \theta}\right) + \frac{1}{\sin\theta}\frac{\partial^2 \Psi}{\partial \phi^2}\right]$$

$$-U(r)\Psi(r,\theta,\phi) = E\,\Psi(r,\theta,\phi)$$

S. equation for the **electron** in the **hydrogen** atom

according http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/hydsch.html

Solution of the Schrödinger Equation

- The solution of the Schrödinger equation for the electron in the hydrogen atom leads to the values of the energies of the orbital electron.

- The solution of the Schrödinger equation often leads to numerical coefficients which determine the possible values of energy. These numerical coefficients are called **quantum numbers**

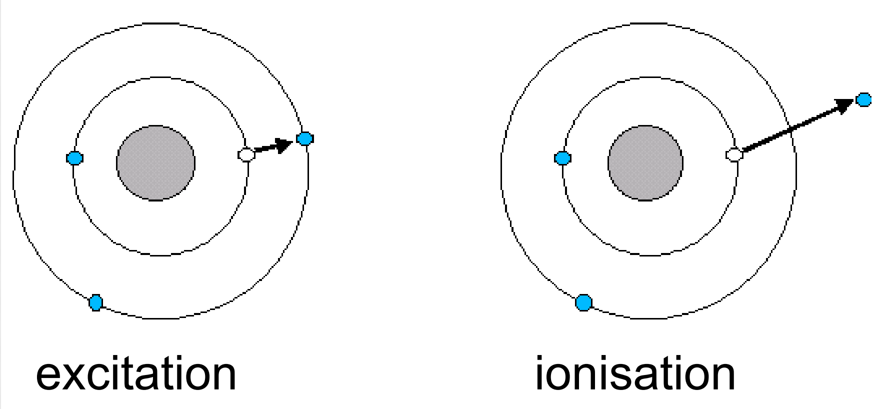
Quantum numbers for Hydrogen

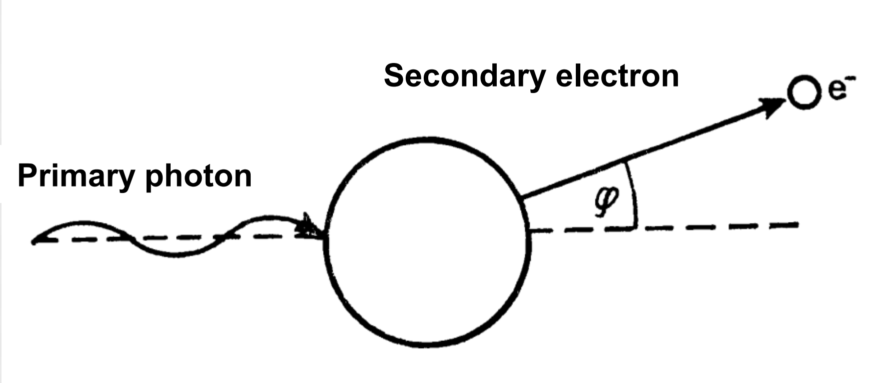
- **Principal n** = 1, 2, 3 …. (K, L, M, ….)
- **Orbital** for each n **l** = 0, 1, 2, …. n – 1 (s, p, d, f …)
- **Magnetic** for each l **m** = 0, 1, 2, … l
- **Spin magnetic** for each m **s** = 1/2

- **Pauli exclusion principle** – in one atomic electron shell there cannot be present two or more electrons with the same set of quantum numbers.

Ionisation of Atoms

The binding energy of an electron E_b is the energy that would be required to liberate the electron from its atom – depends mainly on the principal quantum number.

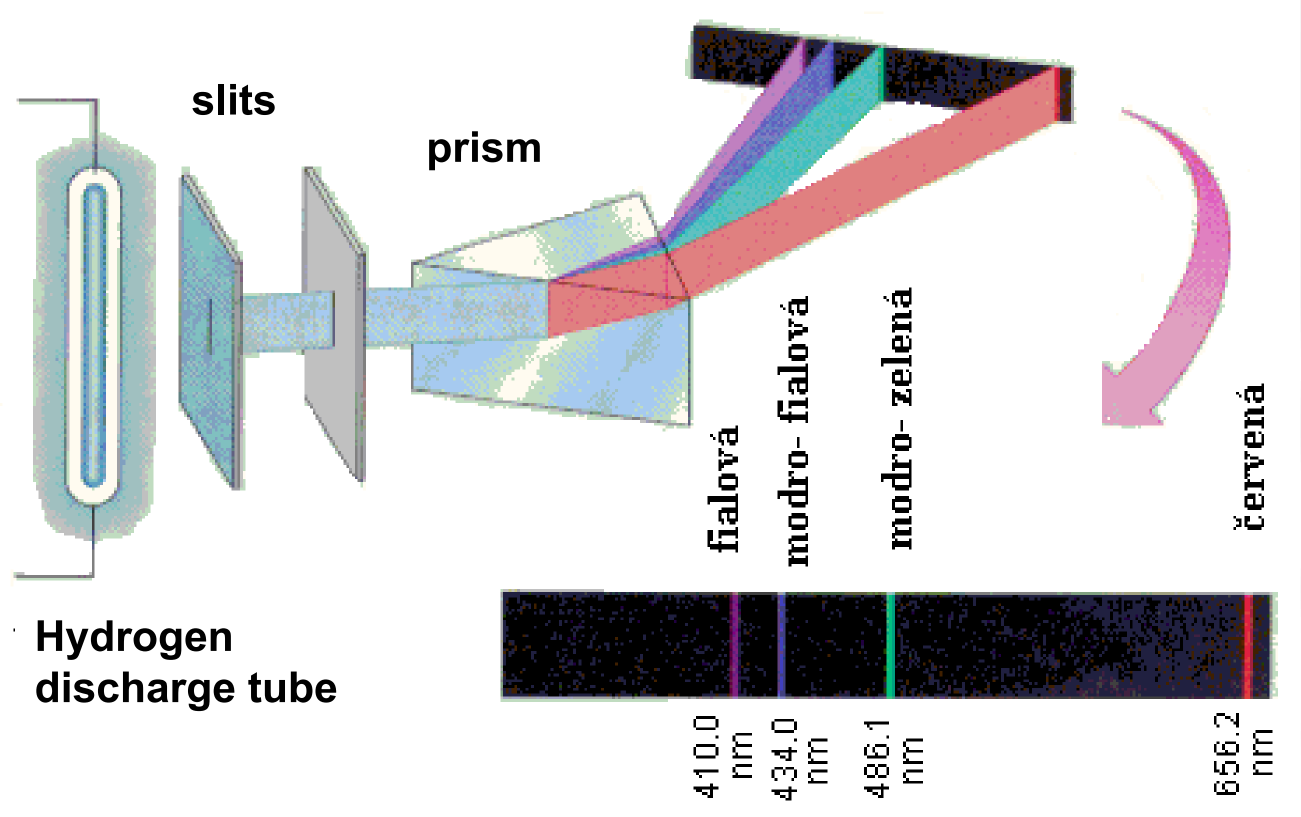




Example of ionisation: photoelectric effect

$h.f = E_b + m.v^2/2$

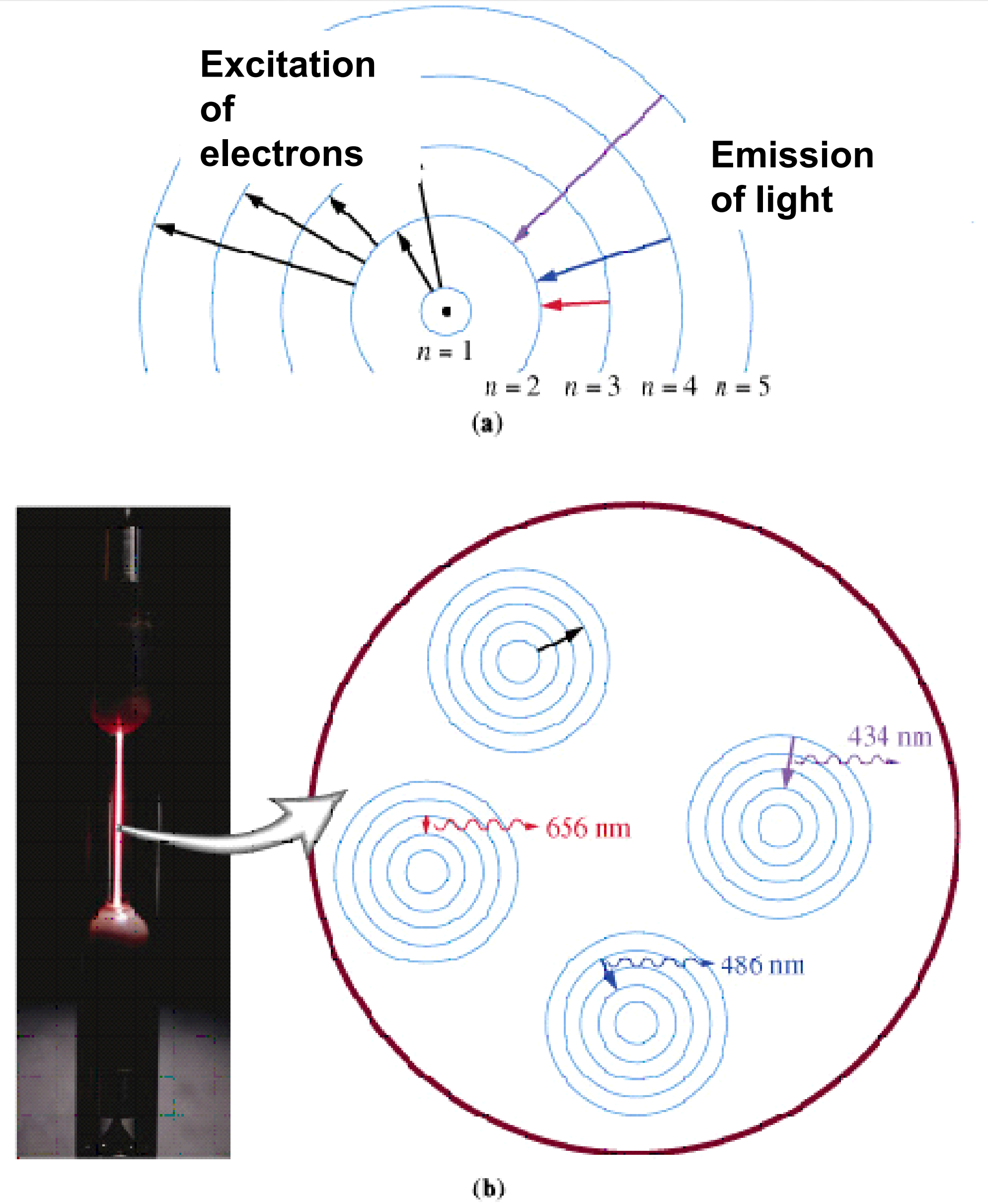
Emission Spectra



Visible emission spectrum of **hydrogen**.

Dexcitations between discrete energy levels result in emitted photons with only certain energies, i.e. radiation of certain frequencies / wavelengths.

http://chemed.chem.purdue.edu/genchem/topicreview/bp/ch6/bohr.html



Hydrogen spectrum again

magenta, cyan and red line

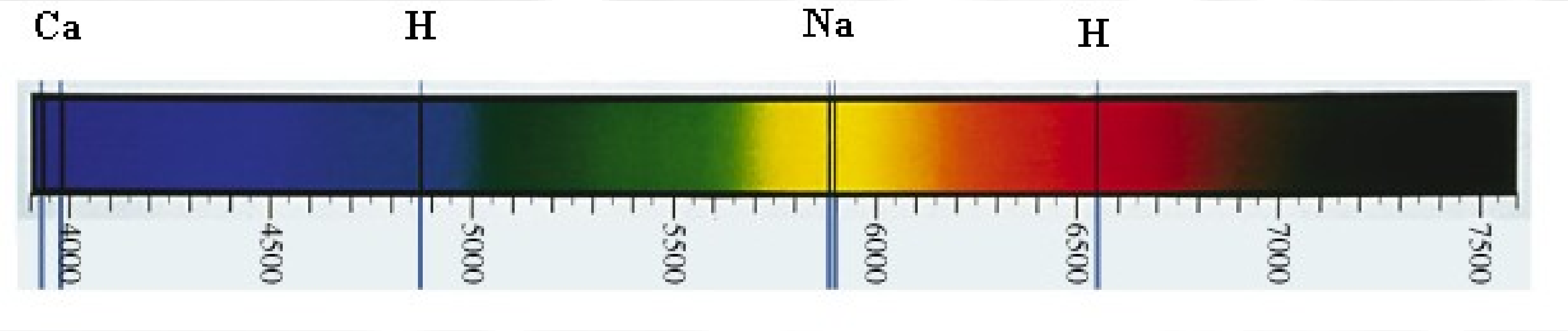
according http://cwx.prenhall.com/bookbind/pubbooks/hillchem3/medialib/media_portfolio/text_images/CH07/FG07_19.JPG

Excitation (absorption) Spectra for Atoms

Absorption lines in visible spectrum of sun light.

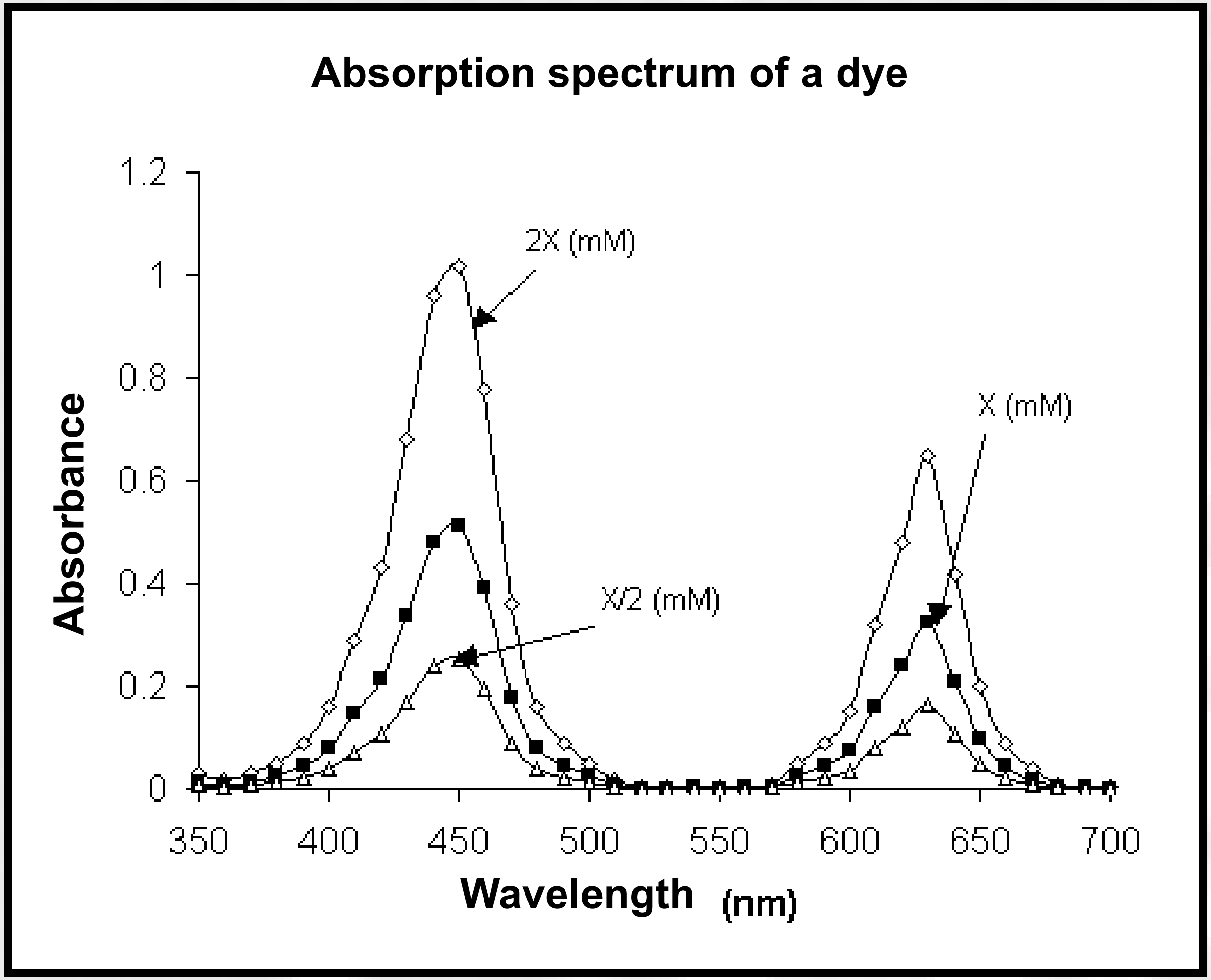
Wavelengths are given in Angströms (Å) = 0.1 nm

http://cwx.prenhall.com/bookbind/pubbooks/hillchem3/medialib/media_portfolio/07.html



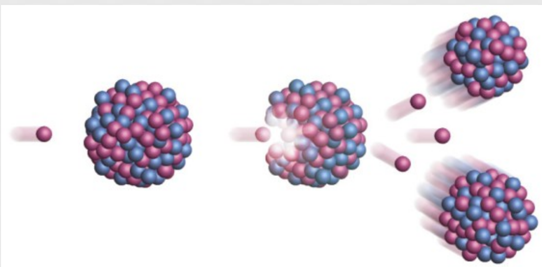
Transitions between discrete energy states!!

Excitation (Absorption) Spectrum for Molecules



According: http://www.biochem.usyd.edu.au/~gareth/BCHM2001/pracposters/dyeZ.htm

Atom nucleus



$${}^{A}_{Z}X$$

Proton (atomic) number – Z

Nucleon (mass) number – A

Neutron number – N $N = A - Z$

Atomic mass unit u = 1.66×10^{-27} kg, i.e. the 1/12 of the carbon C-12 atom mass

Electric charge of the nucleus $Q = Z \times 1.602 \times 10^{-19}$ C

If relative mass of electron = 1

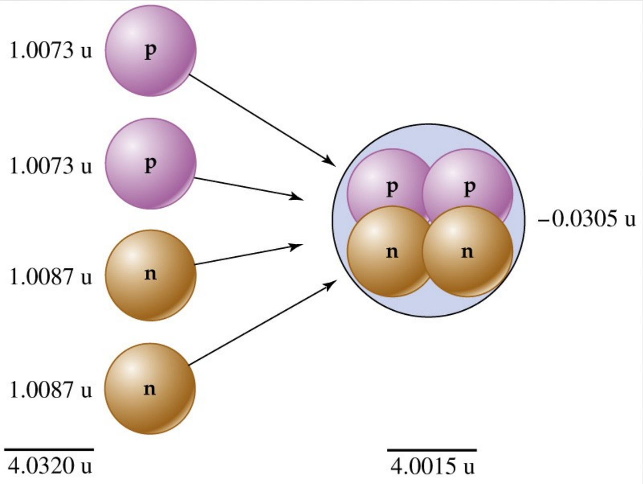
$\Rightarrow$ Relative mass of proton = 1836

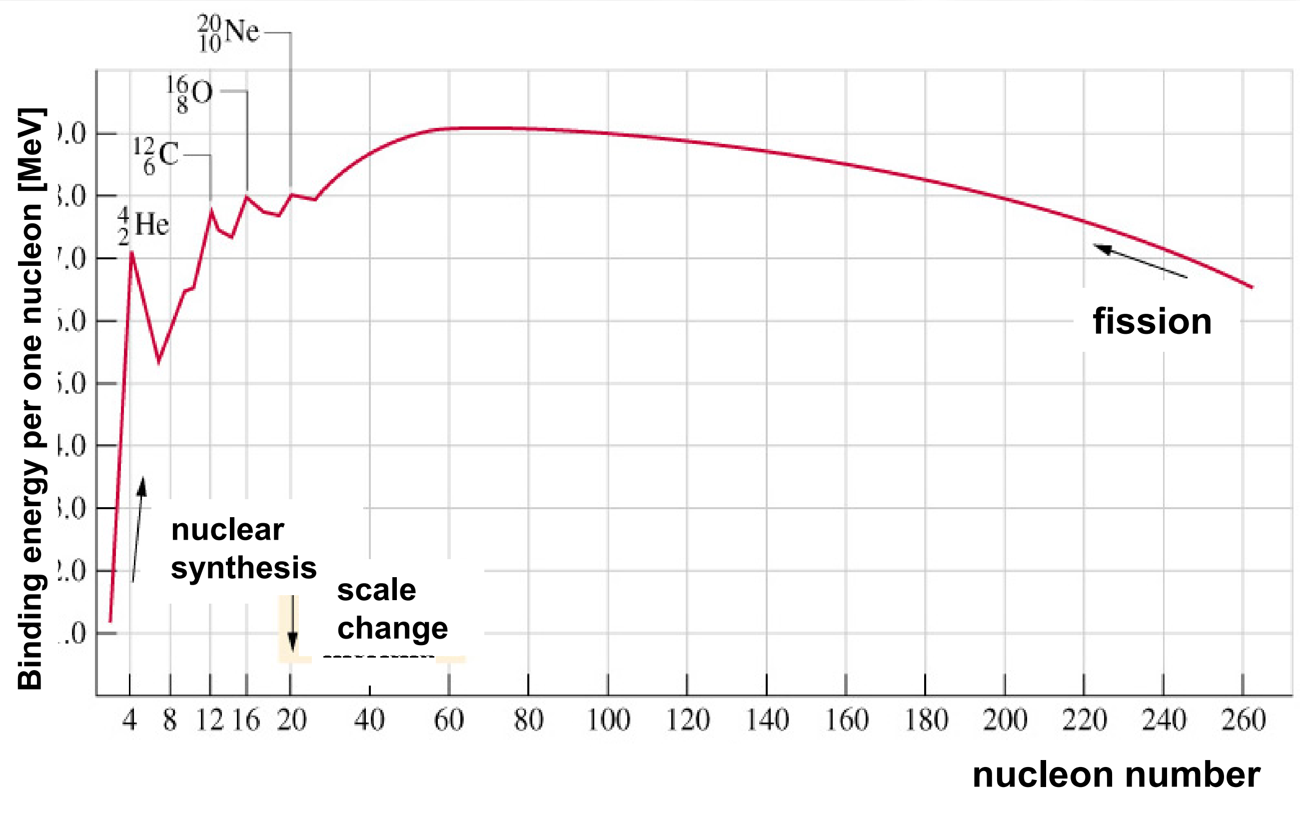
$\Rightarrow$ Relative mass of neutron = 1839

Mass defect of nucleus

= measure of nucleus stability:

$$\delta m = (Z.m_p + N.m_n) - m_j$$





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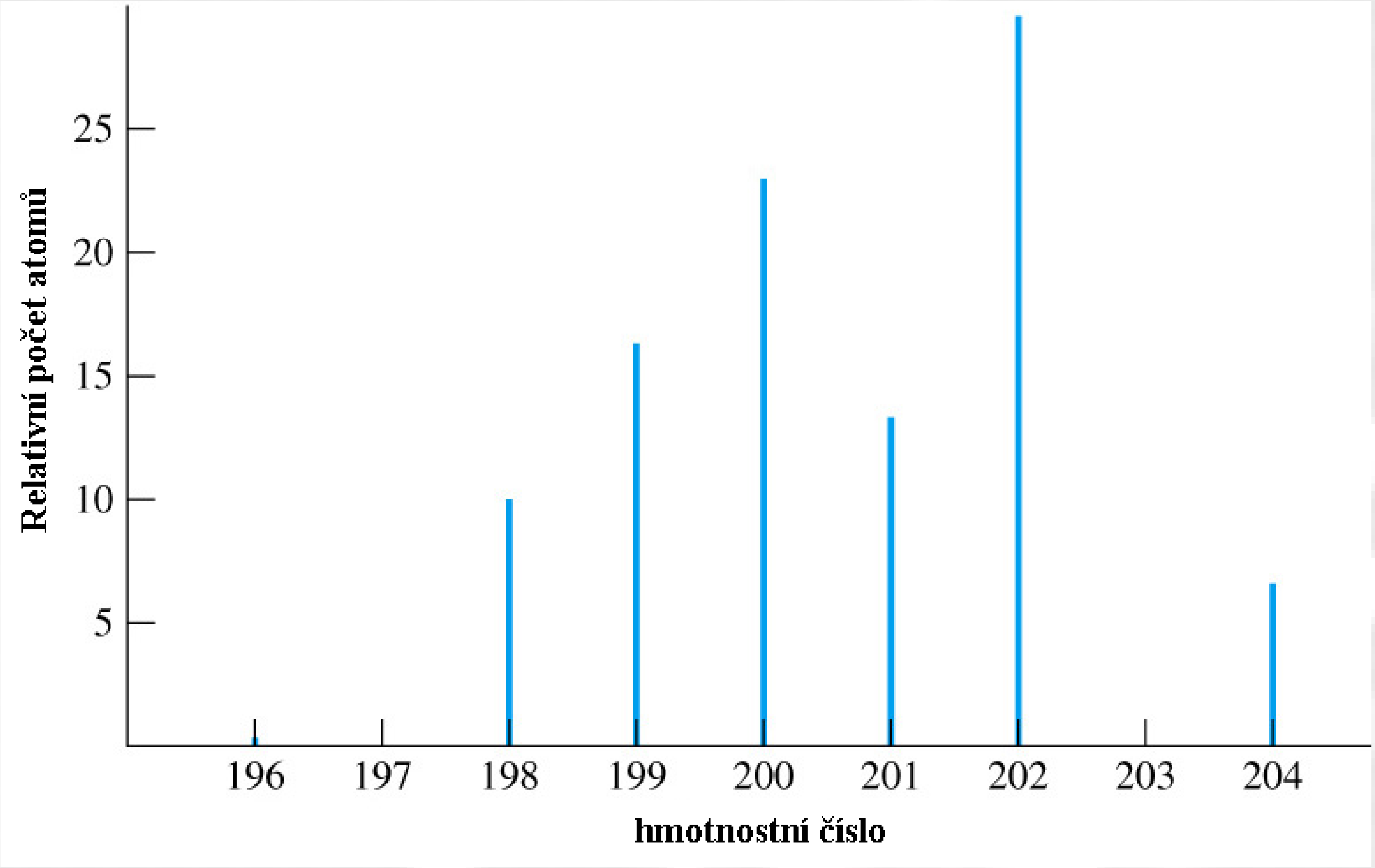
Nuclides

- **nuclide** - a nucleus with a given A, Z and energy
- **Isotopes** - nuclides with same Z but different A
- **Isobars** – nuclides with same A but different Z
- **Isomers** – nuclides with same Z and A, but different energy (e.g., Tc^{99m} used in gamma camera imaging)

Isotope composition of mercury
% of atoms vs. isotope nucleon number



According to:
http://cwx.prenhall.com/bookbind/pubbooks/hillchem3/medialib/media_portfolio/text_images/CH07/FG07_08.JPG

What else is necessary to know?

- **Radionuclides** – nuclides capable of radioactive decay

- **Nuclear spin:**

  Nuclei have a property called spin. If the value of the spin is not zero the nuclei have a magnetic moment i.e, they behave like small magnets - NMR – nuclear magnetic resonance spectroscopy and magnetic resonance imaging in radiology are based on this property.

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Last revision: March 2008

Last revision: March 2008