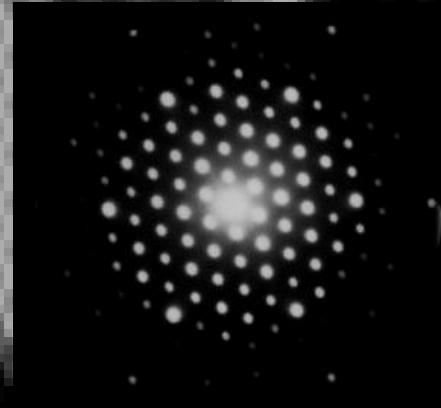
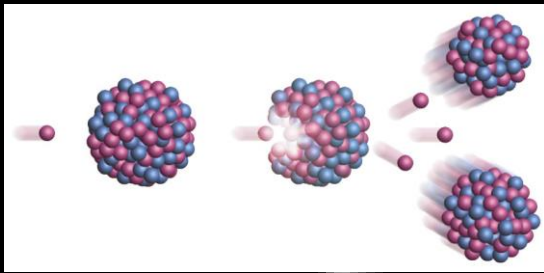


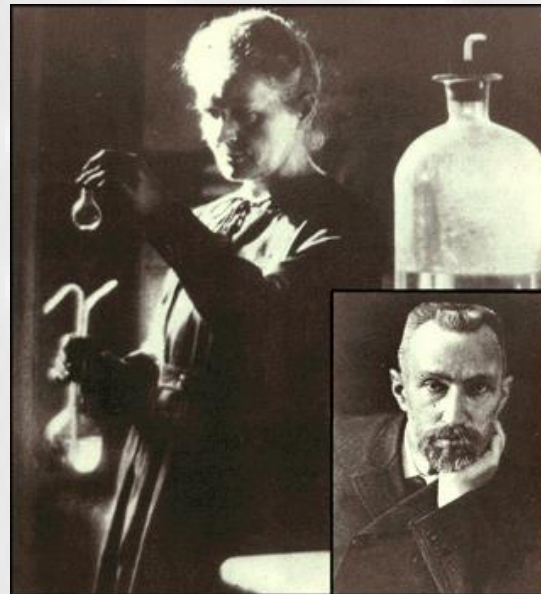
Lectures on Medical Biophysics

Department of Biophysics, Medical Faculty,
Masaryk University in Brno



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Structure of matter

Matter and Energy

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

Elementary Particles of Matter

- The elementary (i.e. having 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)

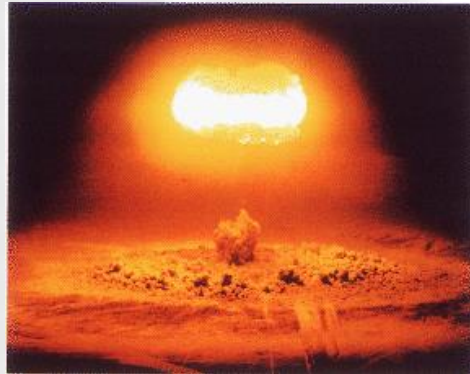
The Four Fundamental Energy / Force Fields



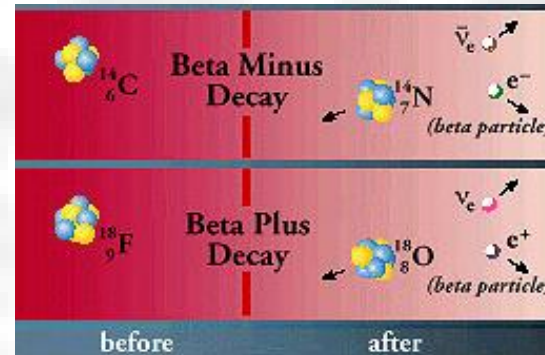
gravitational



electromagnetic



strong



weak

Strong : weak : electromagnetic : gravitational force - $1 : 10^{-5} : 10^{-2} : 10^{-39}$ at interaction distance of about 10^{-24} m; $10^{-7} : \sim 0 : 10^{-9} : 10^{-46}$ at a distance of about 10^{-18} m (1/1000 of atom nucleus dimension). In the distance equal to nucleus dimension goes to zero also strong interaction.

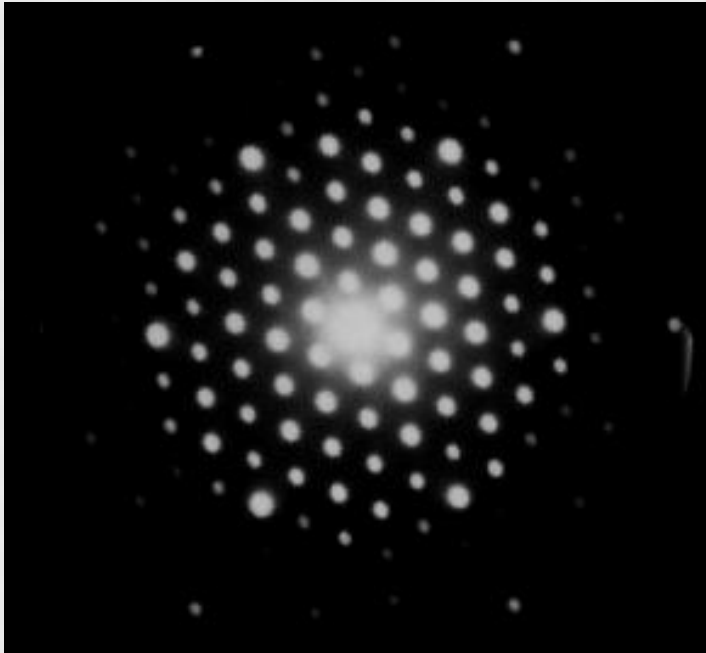
Photons

- Photons - energy quanta of electromagnetic field, zero mass
- Energy of (one) photon: $E = hf = hc/\lambda$
 - h is the Planck constant ($6.62 \cdot 10^{-34}$ J·s),
 - f is the frequency,
 - c is speed of light in vakuum,
 - 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 and positron transform to two gamma photons in the so-called annihilation – 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.

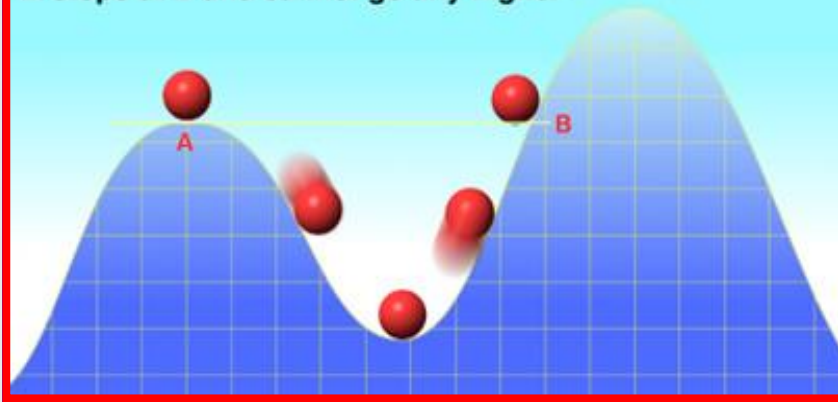
On the left pattern formed on a photographic plate by an ensemble of electrons hitting a crystal lattice. Notice that it is very similar to the diffraction pattern produced by a light wave passed through optical grating.

Quantum Mechanics

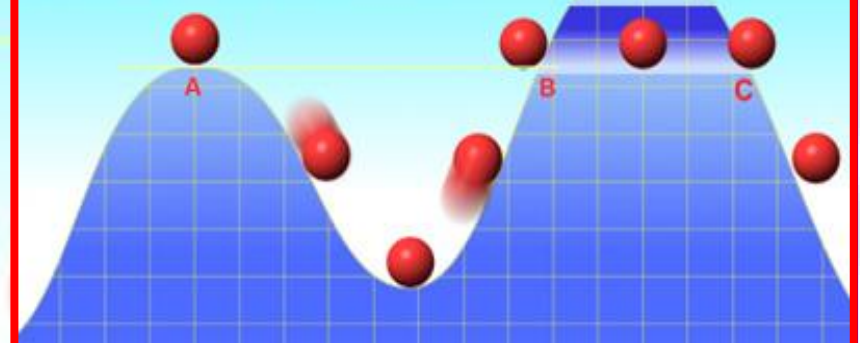
tunnel effect:

**In classical dynamics,
A stops at B and cannot go any higher**

**In classical dynamics,
A stops at B and cannot go any higher**



**In quantum mechanics,
A borrows energy and can cross (from B to C)
to the other side of the mountain**



Quantum Mechanics: Heisenberg uncertainty relations

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

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

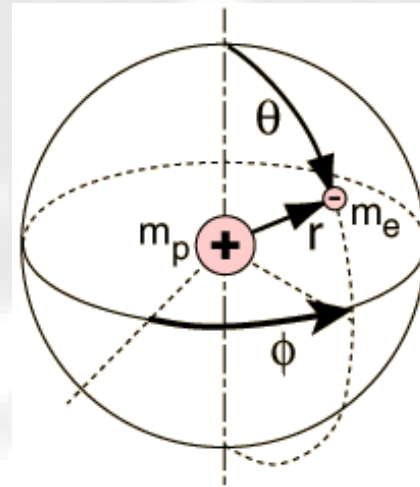
The position r and momentum p of a particle **cannot be simultaneously** measured with independent precision (if the uncertainty of particle position – δr – is made smaller, the uncertainty of particle momentum – δp – automatically increases). The same holds for the simultaneous measurement of energy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

Schrödinger equation (to admire)

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

druhá derivace podle x Schrd. vlnová funkce
 poloha energie potenciální energie

„one-dimensional“ S. equation



Radial co-ordinates of an electron in a hydrogen atom

$$\begin{aligned}
 &-\frac{\hbar^2}{2\mu} \frac{1}{r^2 \sin \theta} \left[\sin \theta \frac{\partial}{\partial r} \left(r^2 \frac{\partial \Psi}{\partial r} \right) + \frac{\partial}{\partial \theta} \left(\sin \theta \frac{\partial \Psi}{\partial \theta} \right) + \frac{1}{\sin \theta} \frac{\partial^2 \Psi}{\partial \phi^2} \right] \\
 &-U(r) \Psi(r, \theta, \phi) = E \Psi(r, \theta, \phi)
 \end{aligned}$$

Ψ - wave function

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

Solution of the Schrödinger Equation

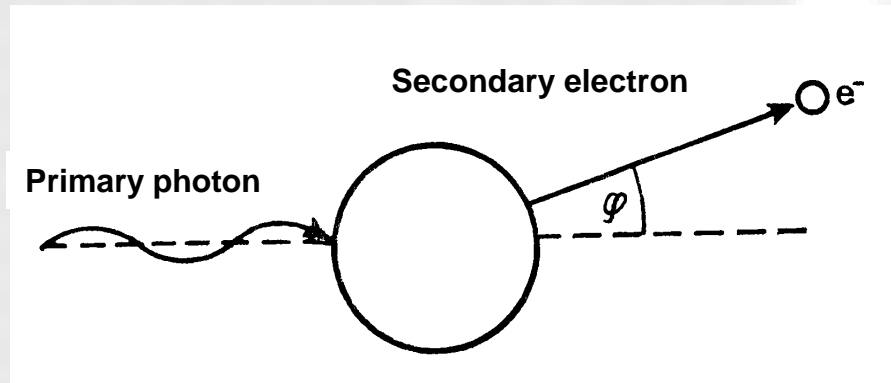
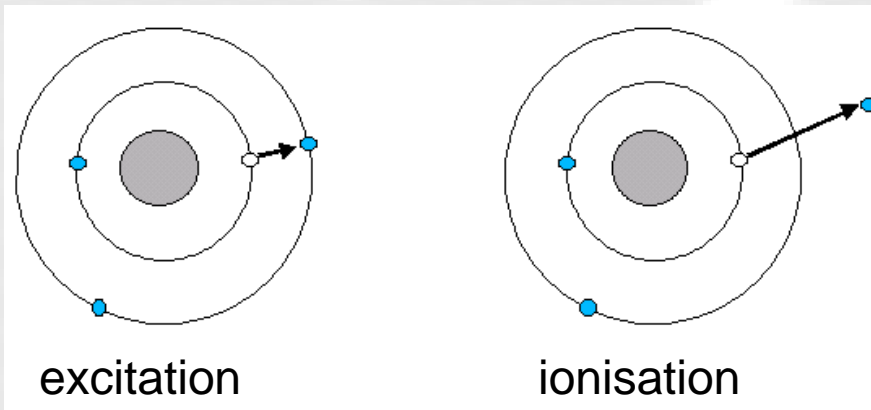
- The solution of the Schrödinger equation for the electron in the hydrogen atom leads to the values of the energies of the orbital electron.
- The solution of the Schrödinger equation often leads to numerical coefficients which determine the possible values of energy. These numerical coefficients are called **quantum numbers**

Quantum numbers for Hydrogen

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

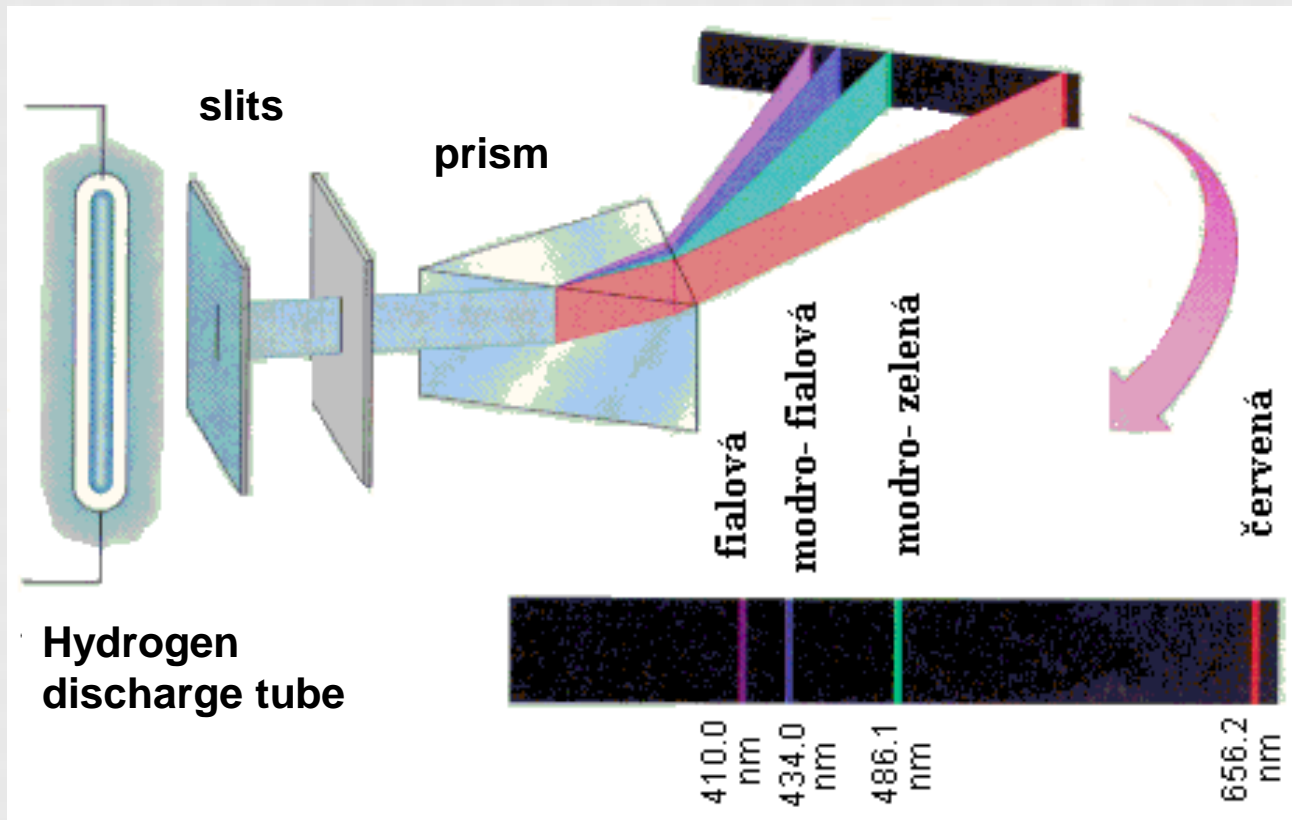
The binding energy of an electron E_b is the energy that would be required to liberate the electron from its atom – depends mainly on the principal quantum number.



Example of ionisation:
photoelectric effect

$$hf = E_b + \frac{1}{2}mv^2$$

Emission Spectra



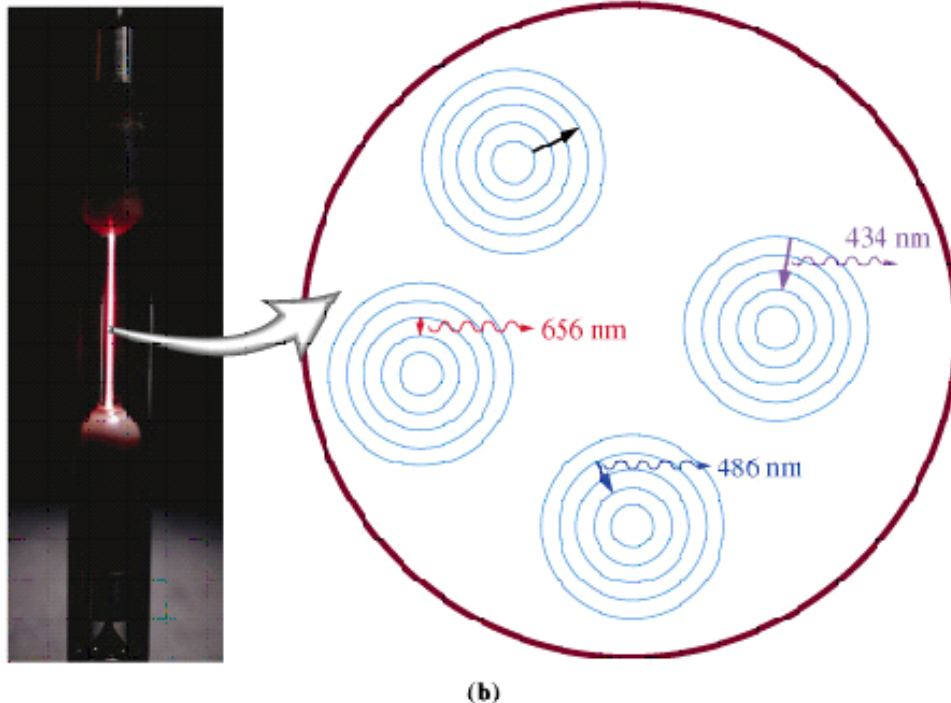
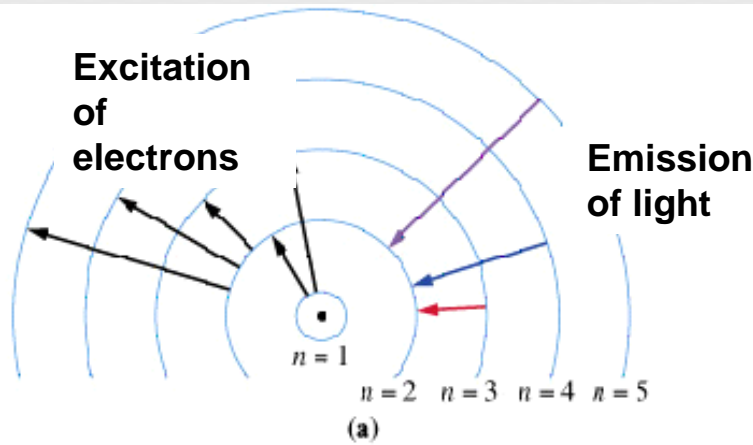
Visible emission spectrum of hydrogen.

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

Hydrogen spectrum again

magenta, cyan
and red line

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

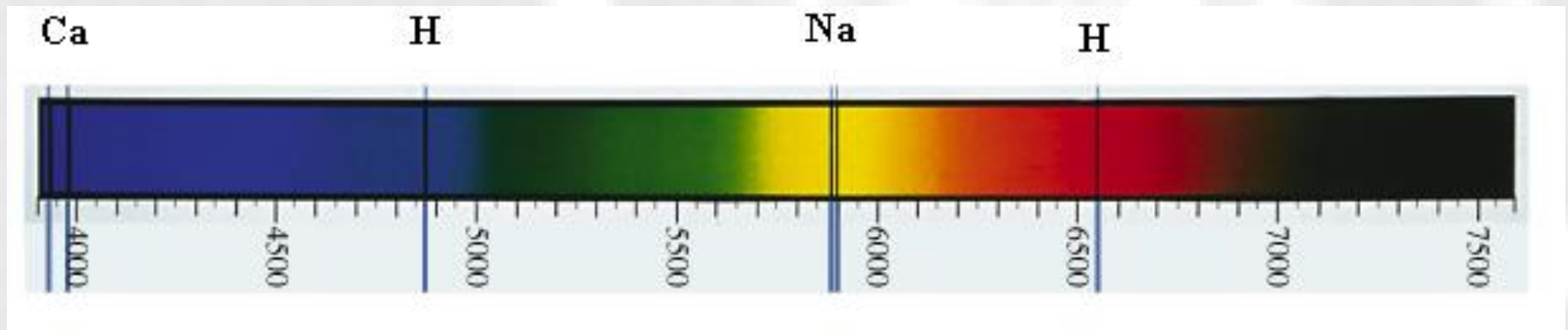


Excitation (absorption) Spectra for Atoms

Absorption lines in visible spectrum of sun light.

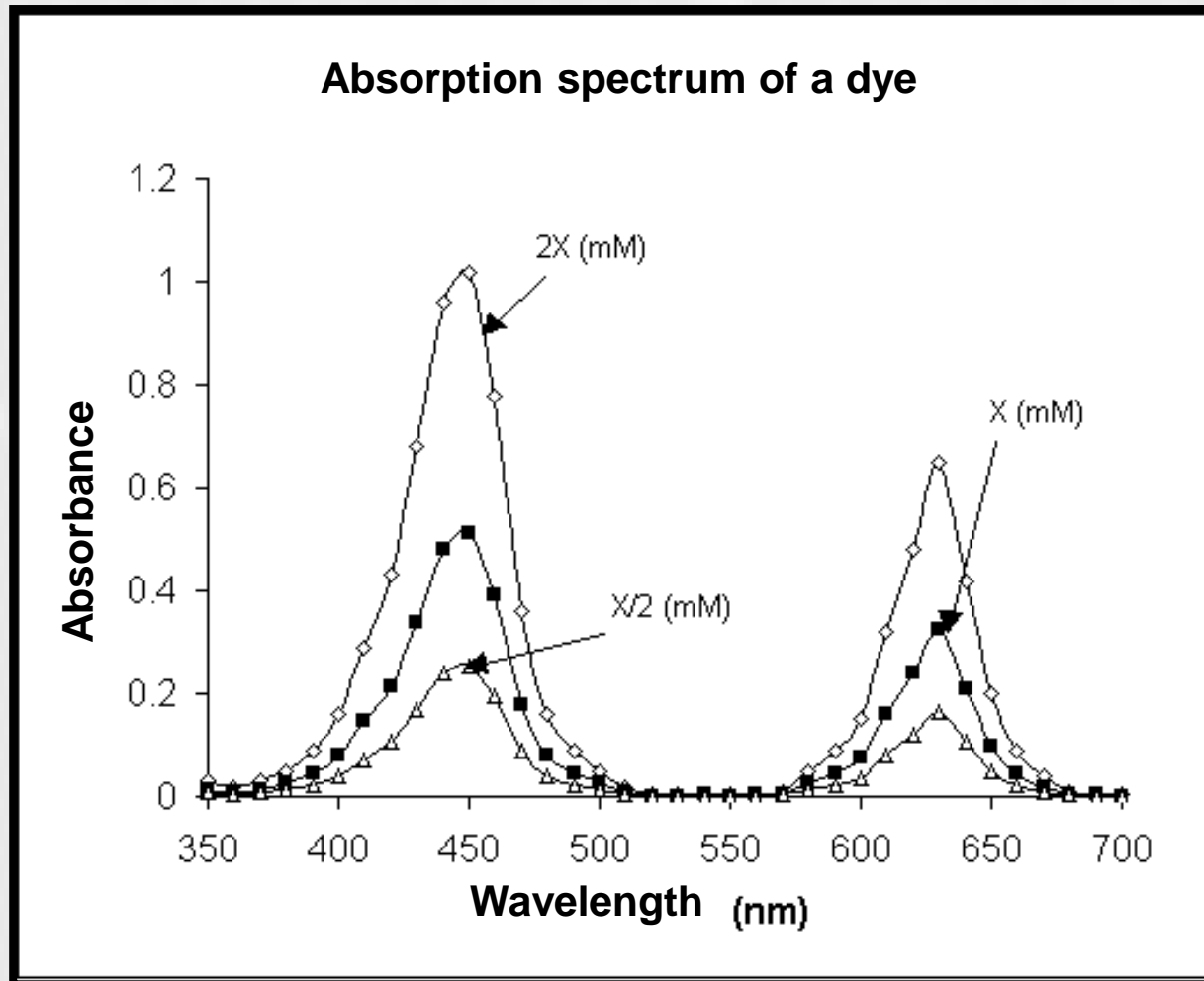
Wavelengths are given in Angströms (\AA) = 0.1 nm

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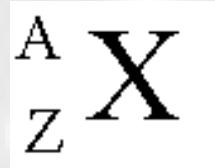
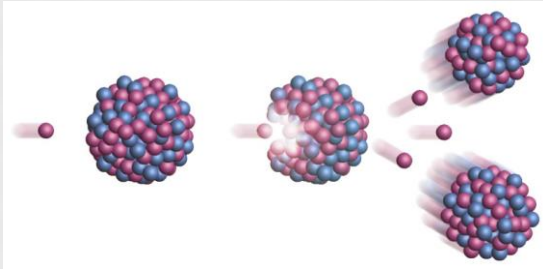


Transitions between discrete energy states of atoms!!

Excitation (Absorption) Spectrum for Molecules



Atom nucleus



Proton (atomic) number – Z

Nucleon (mass) number – A

Neutron number – N $N = A - Z$

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

Electric charge of the nucleus $Q = Z1.602 \cdot 10^{-19}$ C

If relative mass of electron = 1

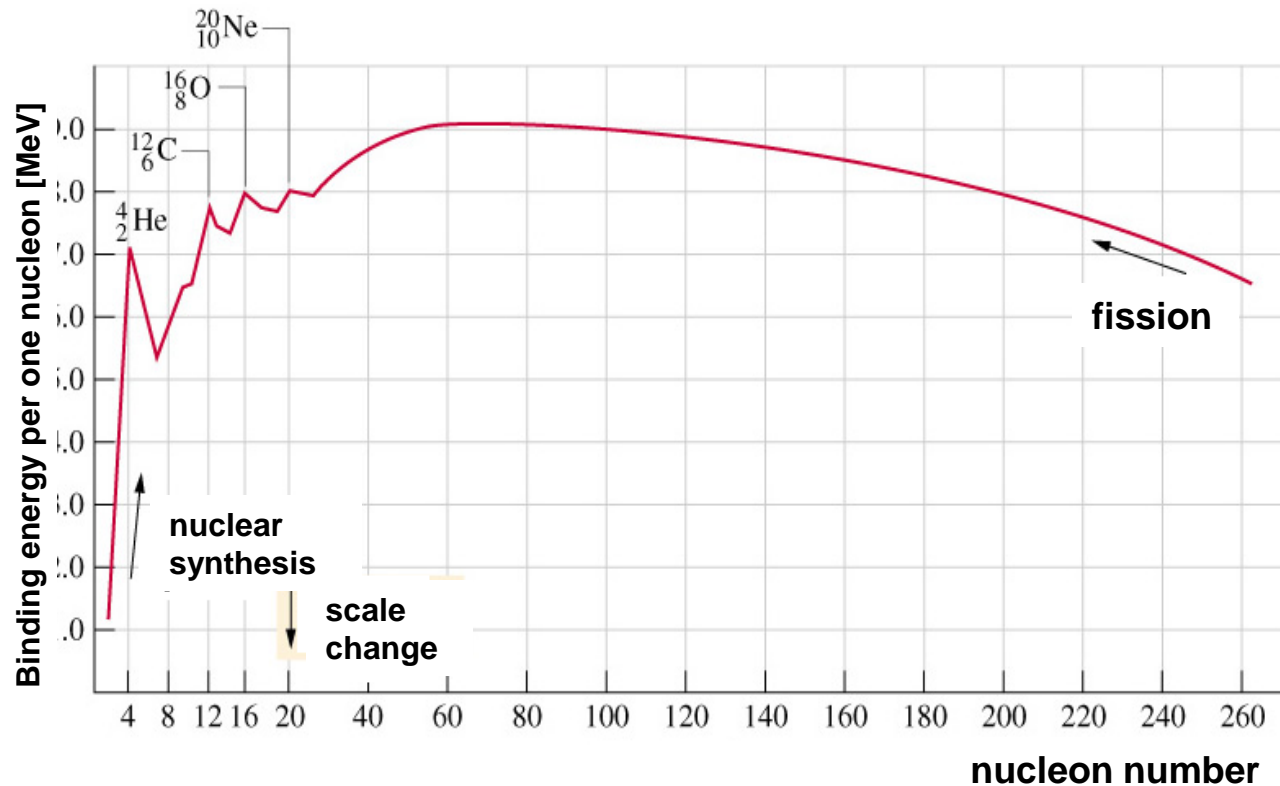
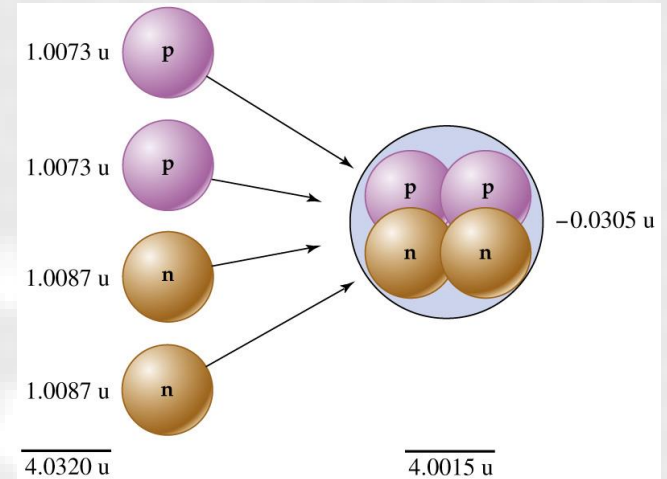
⇒ Relative mass of proton = 1836

⇒ Relative mass of neutron = 1839

Mass defect of nucleus

= measure of nucleus stability:

$$\delta m = (Zm_p + Nm_n) - m_{nuc}$$



Sources:

http://cwx.prenhall.com/bookbind/pubbooks/hilchem3/medialib/media_portfolio/text_images/CH19/FG19_05.JPG

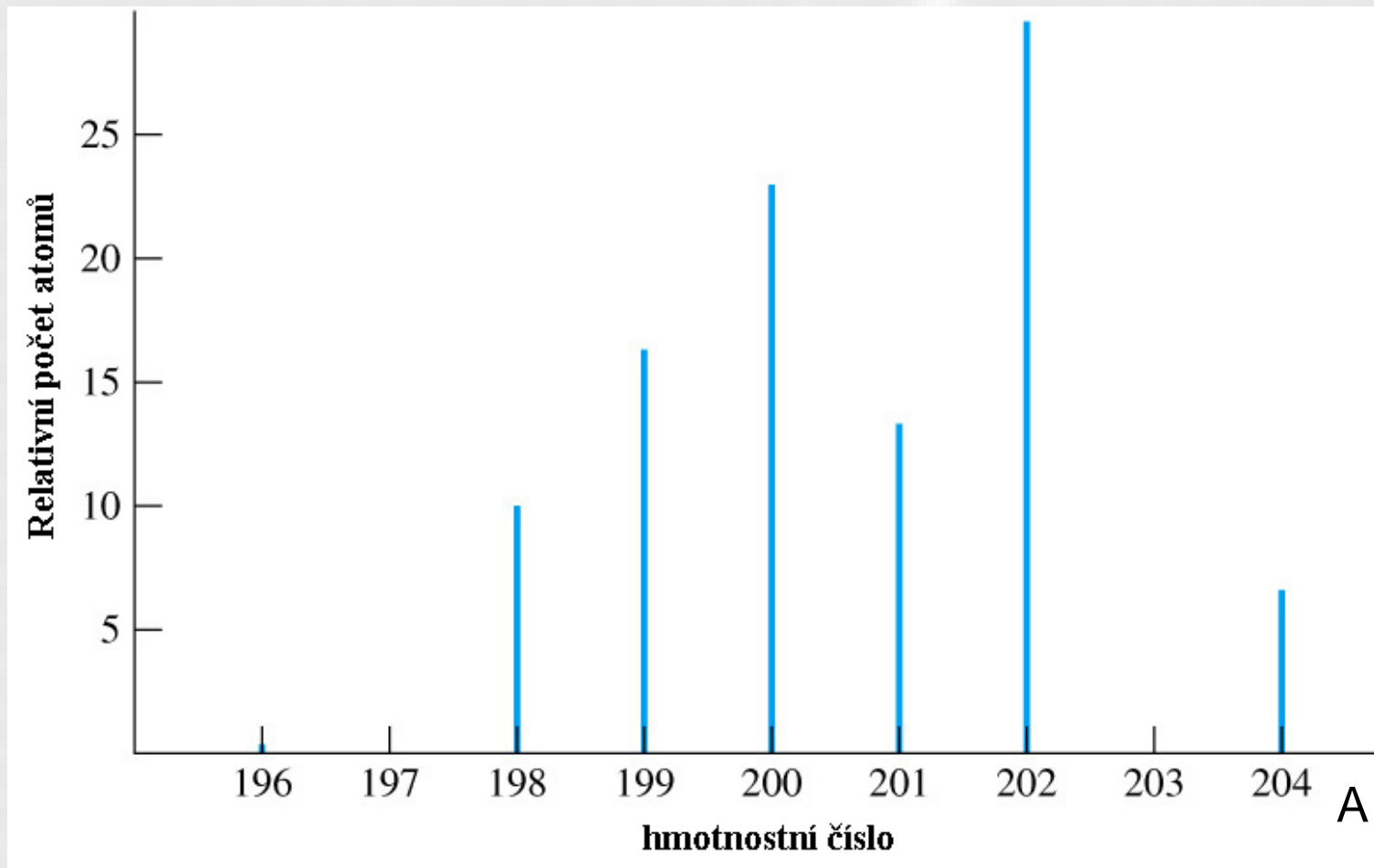
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Nuclides

- **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., $\text{Tc}^{99\text{m}}$ used in gamma camera imaging)

Isotope composition of mercury

% of Hg atoms vs. isotope nucleon number (A)



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 (MRI) in radiology are based on this property.

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