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
(i.e. having - probably - no internal structure)

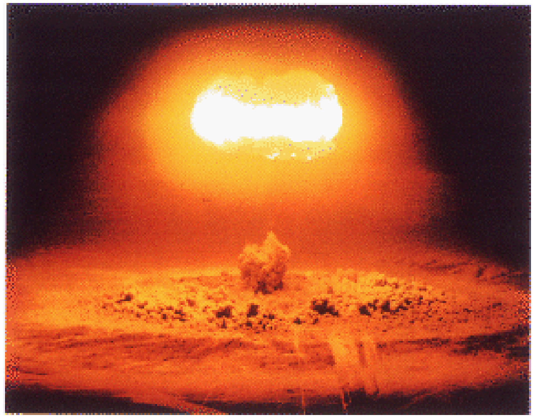
- „force“ particles – integer spin – **bosons**
  - **Vector bosons – spin 1**
    - **Foton**
    - **Gluons**
    - **W, Z** (week bosons)
    - **Graviton**
  - **Scalar boson – spin 0**
    - **Higgs boson**
- „matter“ particles – noninteger (odd) spin - **fermions**
  - The elementary particles 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

- **Composite particles**
  - **Hadrons** – heavy particles formed of quarks - **baryons (fermions - proton** (u, u, d), **neutron** (d, d, u)**) mezons** (bosons (quark-antiqvark))

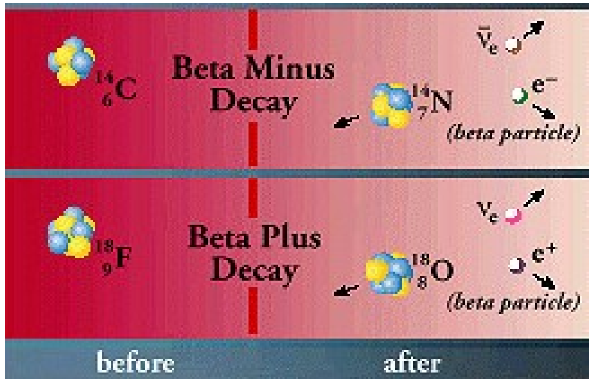
The Four Fundamental Energy / Force Fields

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} : ~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

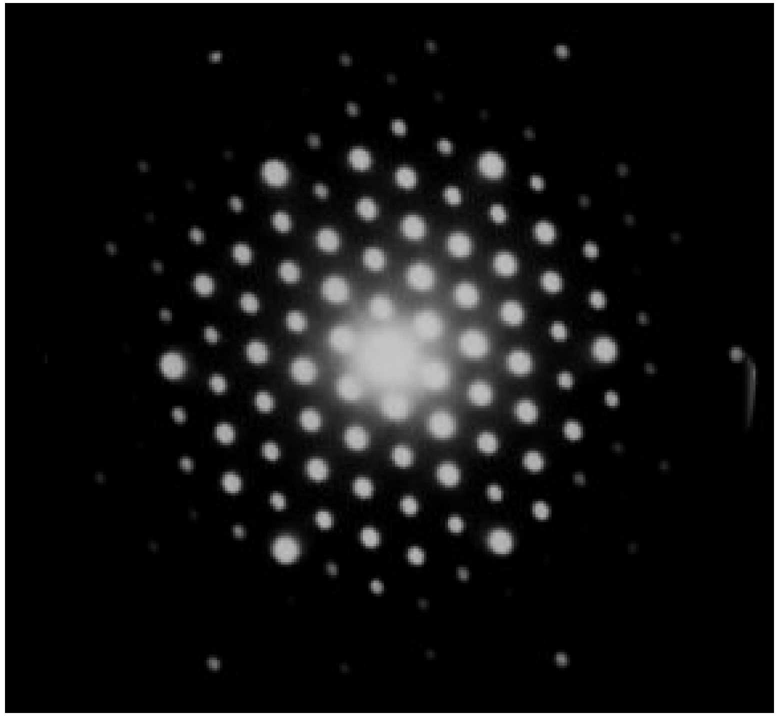
- Photons - energy quanta of electromagnetic field, zero mass

- 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 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 and positron transform to two gamma photons in the so-called annihilation – this is used in PET imaging).

Quantum Mechanics



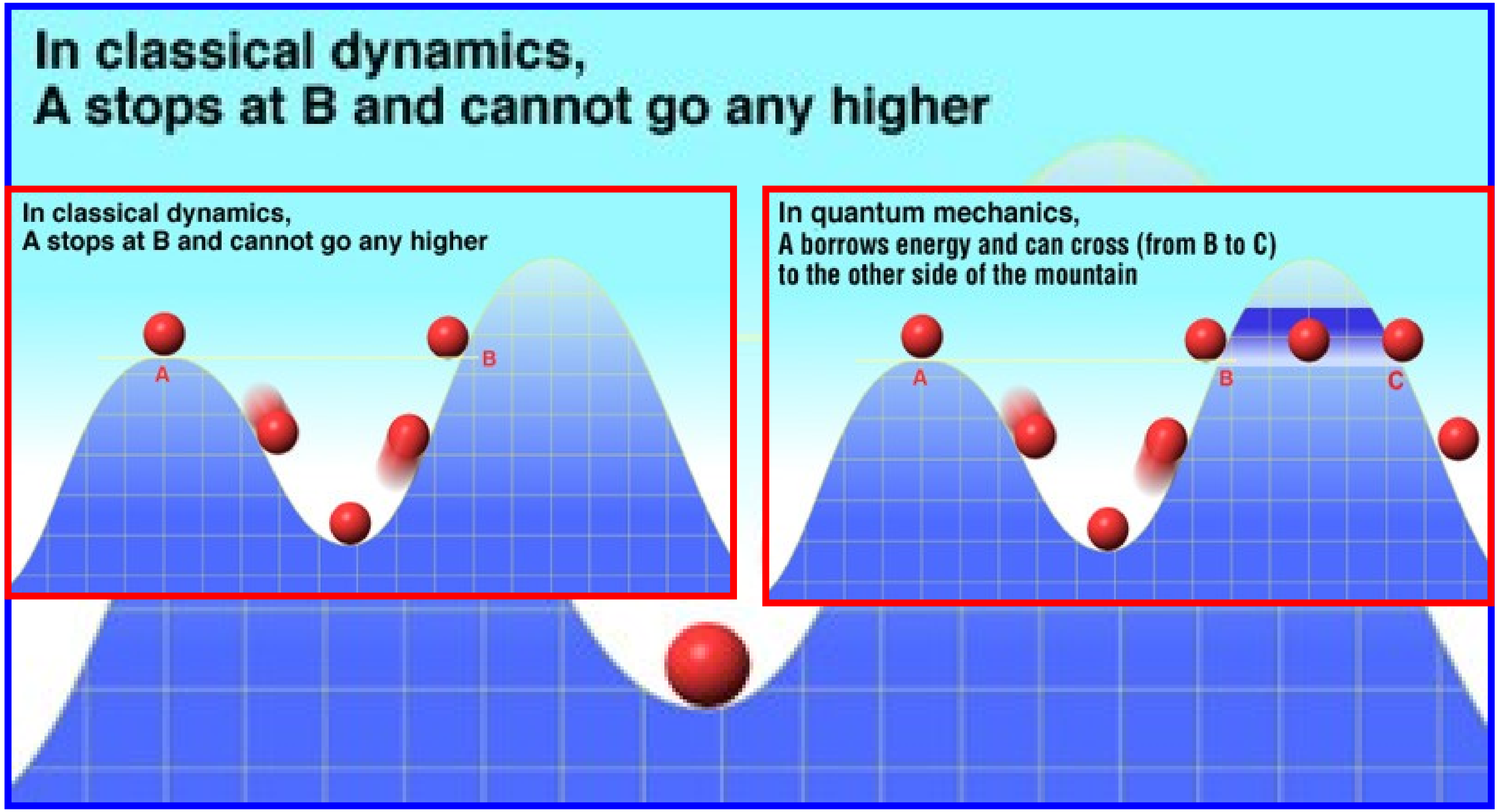
The behaviors of ensembles of a given type of particle obey equations which are similar to wave equations.

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.

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

Quantum Mechanics

tunnel effect:



Quantum Mechanics: Heisenberg uncertainty relations

$$\delta r \cdot \delta p \geq h/2\pi$$
$$\delta E \cdot \delta t \geq h/2\pi$$

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. h is the Planck constant.

Schrödinger equation

(to admire ☺)

second derivative

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

position

energy potential energy

„one-dimensional“ S. equation

Radial co-ordinates of an electron in a hydrogen atom

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

Ψ - wave function

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

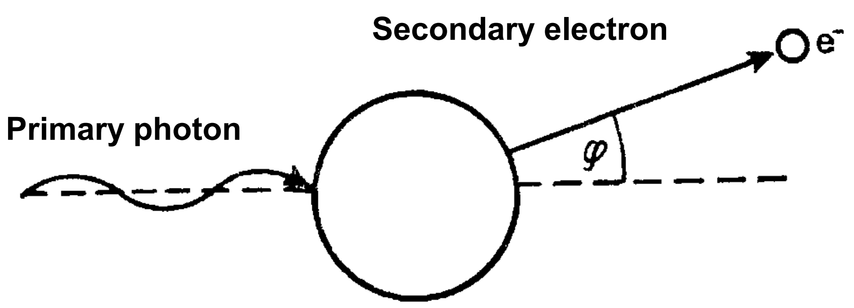
- **Principal n** = 1, 2, 3 …. (K, L, M, ….)
- **Orbital** for each n **l** = 0, 1, 2, …. n – 1 (s, p, d, f …)
- **Magnetic** for each l **m** = 0, 1, 2, … l
- **Spin magnetic** for each m **s** = 1/2

- **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.

excitation ionisation



Example of ionisation:
photoelectric effect

$$h \cdot f = E_b + \tfrac{1}{2}\, m \cdot \cdot v^2$$

Emission Spectra

slits

prism

Hydrogen
discharge tube

Visible emission spectrum of **hydrogen**.

modro- = bluish
Learn the Czech names of colours ☺

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

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

Excitation
of
electrons

Emission
of light

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 of atoms!!

Excitation (Absorption) Spectrum for Molecules

Absorption spectrum of a dye

Absorbance

Wavelength

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

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 $Q = Z 1.602 \cdot 10^{-19}$ 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:

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

Sources:

http://cwx.prenhall.com/bookbind/pubbooks/hillchem3/medialib/media_portfolio/text_images/CH19/FG19_05.JPG

http://cwx.prenhall.com/bookbind/pubbooks/hillchem3/medialib/media_portfolio/text_images/CH19/FG19_06.JPG

Binding energy per one nucleon [MeV]

fission

nuclear synthesis

scale change

nucleon number

$E = \delta m.c^2$

This formula allows to calculate amount of energy liberated during the synthesis of the nucleus.

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 Hg atoms vs. isotope nucleon number (A)

Percentage of atoms

A

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 (MRI) in radiology are based on this property.

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