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)

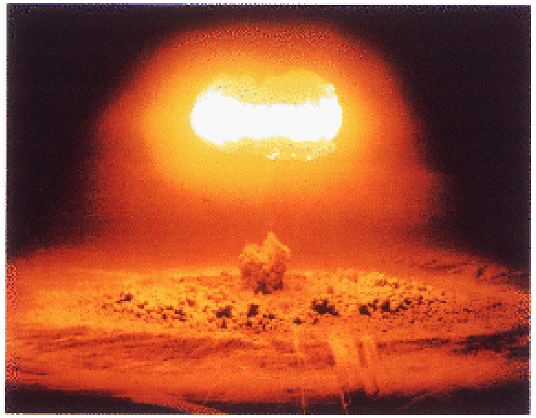
- „force" particles – integer spin – **bosons**
  - **Vector bosons – spin 1**
    - **Foton**
    - **Gluons**
    - **W, Z** (week bosons)
    - **Graviton**
  - **Scalar boson – spin 0**
    - **Higgs boson**
- „matter" particles – non-integer spin (like ½) - **fermions**
  - The elementary particles 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-antiquark))

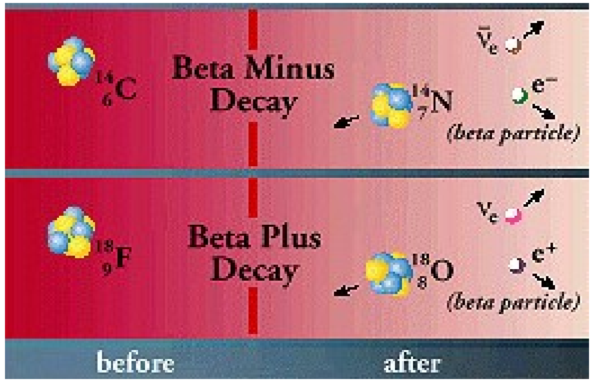
The Four Fundamental Energy / Force Fields

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: $E = h \cdot f = h \cdot c/\lambda$
  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.

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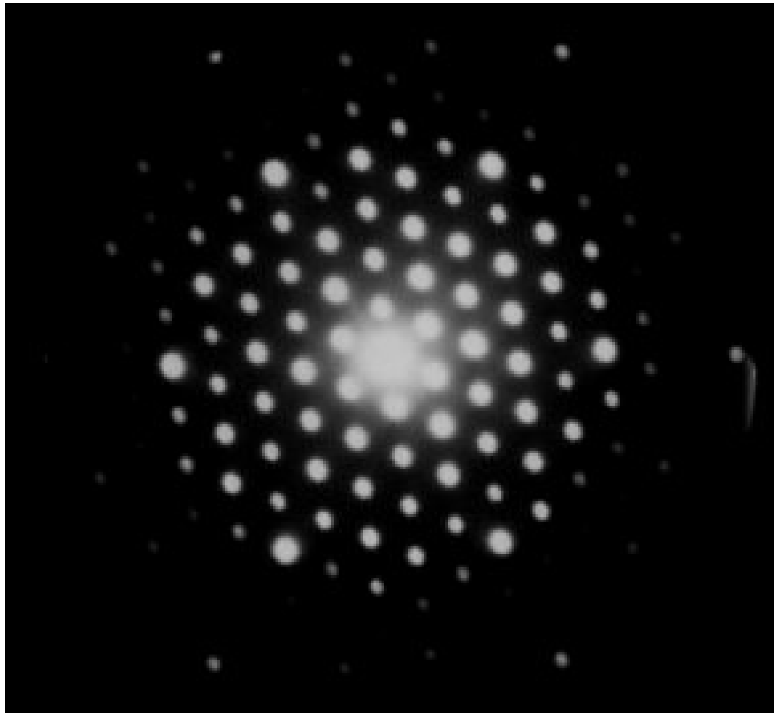
Particles and Field Energy Quanta

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



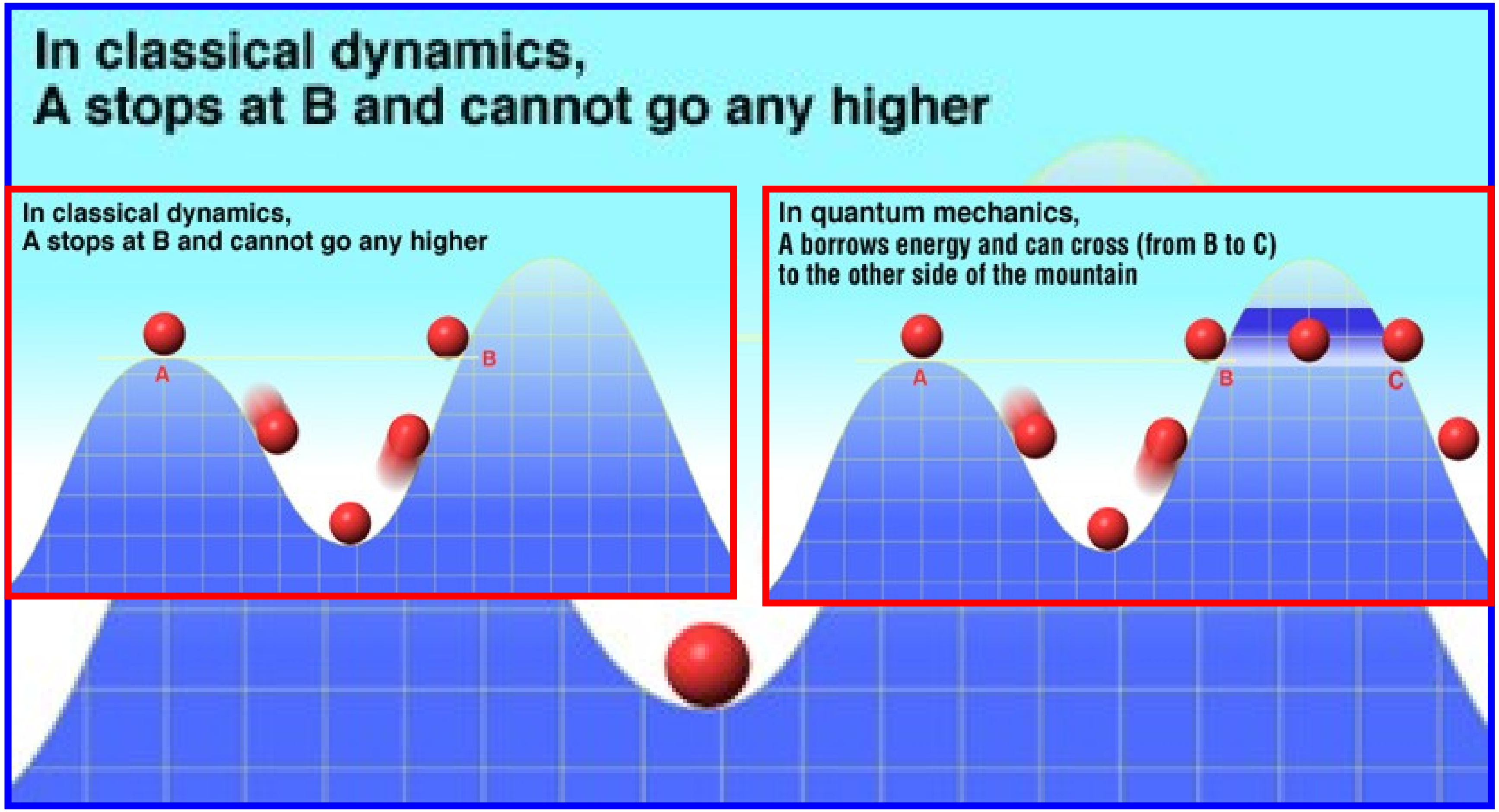
The behaviors of ensembles of a given type of particles obey equations which are similar to wave equations.

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

$$\delta r \cdot \delta p \geq h/4\pi$$
$$\delta E \cdot \delta t \geq h/4\pi$$

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

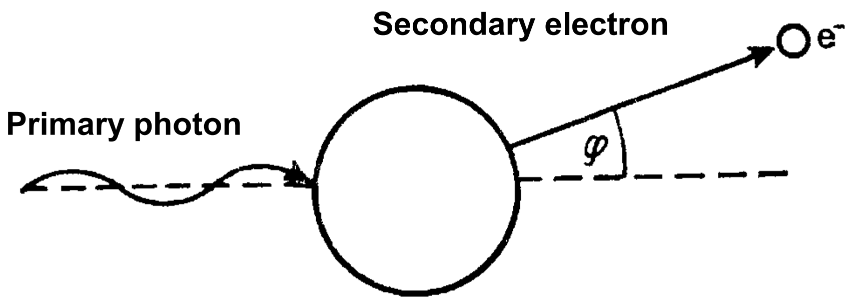
- **Principal n** = 1, 2, 3 …. (K, L, M, ….)
- **Orbital** for each n **l** = 0, 1, 2, …. n – 1 (s, p, d, f …)
- **Magnetic** for each l **m** = 0, 1, 2, … l
- **Spin magnetic** for each m **s** = 1/2

- **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

$$h \cdot f = E_b + ½\, m \cdot\cdot v^2$$

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.

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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 Ångströms (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 $\quad N = A - Z$

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

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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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