4) Interactions between Radiation and Matter (1)

Interactions between radiation and matter are the fundament for any use of (and any damages due to) radioactivity

undesired interactions ⇒ **damages**
desired interactions ⇒ **applications**
measurements

Dominating process ⇒ **Ionisation**

Most measuring procedures for nuclear radiation follows general procedures for the detection of **ionising radiation**

Ionisation due to different particles

Energy of the particles in MeV	Ion pairs / cm		
	α-particles	protons	ß-particles
1	60 000	8 000	50
10	16 000	1 000	45

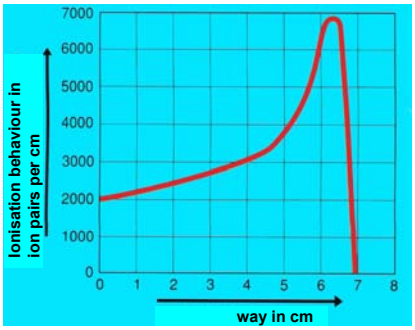
α-radiation is a strongly ionising radiation

4) Interactions between Radiation and Matter (2)

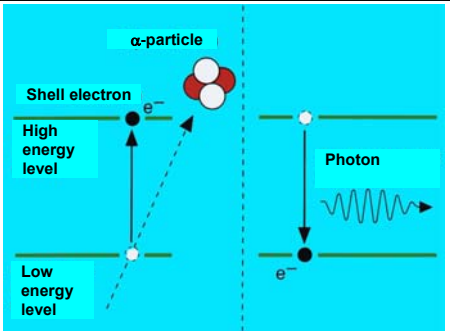
Interactions between α radiation and matter

Strongly ionising radiation: strong interactions, short range

Ion pair formation along the way of an α-particle



Photon emission as a consequence of α-radiation



Finally formation of helium atoms by capturing of electrons

$He^{2+} + 2\ e^- \rightarrow He$

4) Interactions between Radiation and Matter (3)

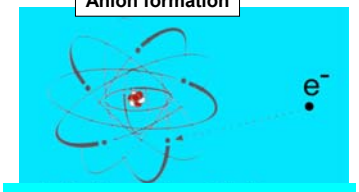
Interactions between ß radiation and matter

Weakly ionising radiation:
- Ionisation potential is by a factor 100 -1000 lower than that of α-radiation
- final stage of interactions is anion formation or reaction with a cation
- Different mechanisms are possible

Energy loss by scattering

- scattering of a ß-particle from its way
- probability of this process increases with the decrease of the energy of the particle

Anion formation



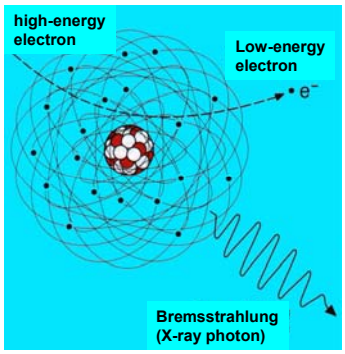
Capturing of an low-energy ß-particle by the electron shell of an atom (anion formation)

4) Interactions between Radiation and Matter (4)

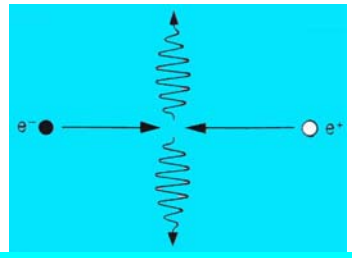
Interactions between ß radiation and matter

Weakly ionising radiation:
- Ionisation potential is by a factor 100 -1000 lower than that of α-radiation
- final stage of interactions is anion formation or reaction with a cation
- Different mechanisms are possible

Energy loss by interactions with electron shells (bremsstrahlung)



Annihilisation of a positron



Formation of two γ-quants in an exact 180° angle

4) Interactions between Radiation and Matter (5)

Interactions between γ radiation and matter

Three certain mechanisms

Photo-Effect

- Interaction between γ - quants and electrons of the inner shells
- emission of a photoelectron (ionisation)
- Electron gap is filled by an outer-sphere electron (X-ray fluorescence)
- dominates with low photon energies
- „absorption“ of the γ -quants

Compton Effect

- Interaction between γ -quants and electrons of the outer electron shells (Compton electrons)
- emission of a Compton electron (ionisation)
- dominates with medium photon energies
- γ -quants lose energy (shift to longer wavelengths)

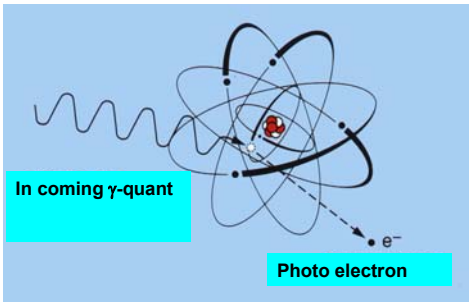
Pair Formation

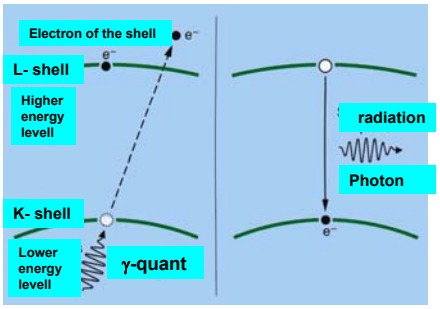
- Interaction between γ - quants and the electric field of a nucleus
- formation of an electron and a positron
- minimum energy is required
- dominates with high photon energies

4) Interactions between Radiation and Matter (6)

Interactions between γ - radiation and matter
Photo effect

- Interaction between γ - quants and electrons of the inner shells
- emission of a photoelectron (ionisation)
- Electron gap is filled by an outer-sphere electron (X-ray fluorescence, secondary radiation)
- dominates with low photon energies
- „absorption“ of the γ -quants

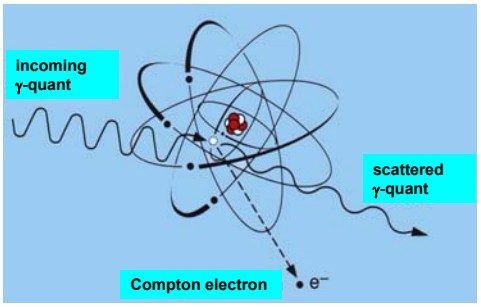




4) Interactions between Radiation and Matter (7)

Interactions between γ - radiation and matter
Compton effect

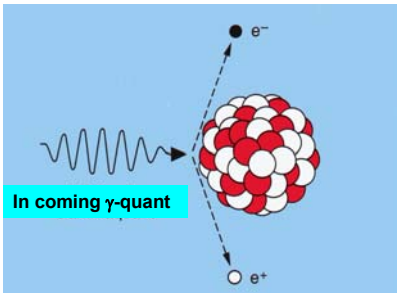
- Interaction between γ -quants and electrons of the outer electron shells (Compton electrons)
- emission of a Compton electron (ionisation)
- dominates with medium photon energies
- γ -quants lose energy (shift to longer wavelengths)
- resulting quant can undergo more Compton reaction or finally photo reactions



4) Interactions between Radiation and Matter (8)

Interactions between γ - radiation and matter
Pair formation

- Interaction between γ -quants and the electric field of a nucleus
- formation of an electron and a positron
- minimum energy is required
- produced positron immediately reacts with an electron (formation of two γ -quants)
- dominates with high photon energies



- minimum energy: **1,022 MeV**

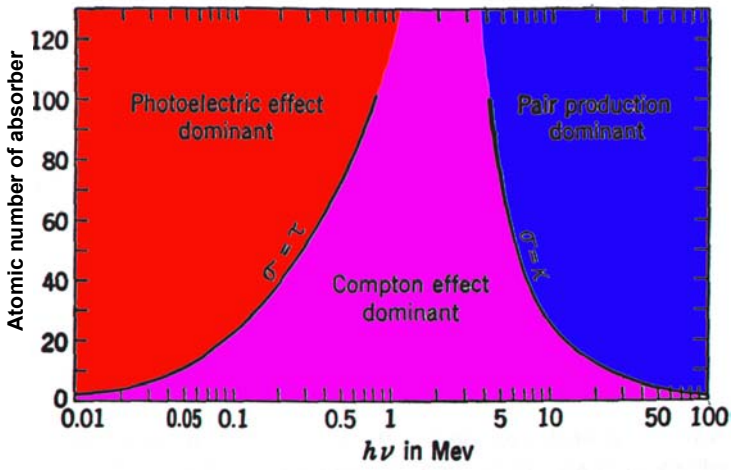
$$E = m c^2$$

- must be high enough to yield the masses for one e^+ and one e^-
- excess energy is kinetic energy of the products

4) Interactions between Radiation and Matter (9)

Interactions between γ - radiation and matter

Occurrence of the three mechanisms of interaction

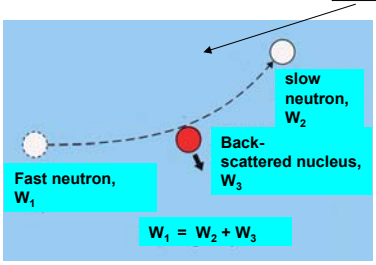


4) Interactions between Radiation and Matter (10)

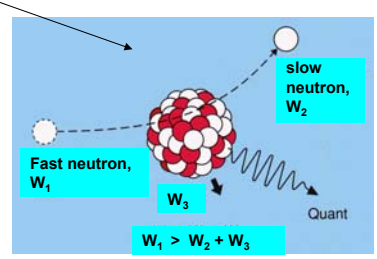
Interactions between neutrons and matter

- Neutrons have no charge and therefore don't interact with the electron shells of atoms (no direct ionisation)
- Interactions between neutrons and matter originate from interactions with nuclei (only secondary ionisation processes)
- main mechanisms: **elastic and inelastic impacts**, **neutron capturing**

Elastic and inelastic impacts



Energy range: 10 keV - 1 MeV



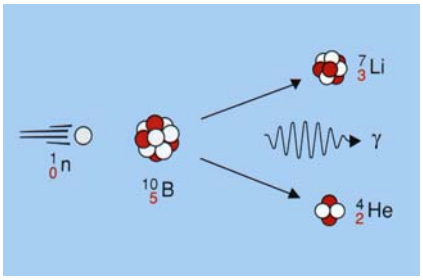
Energy range: 1 - 10 MeV
- emission of excess energy as γ -quants

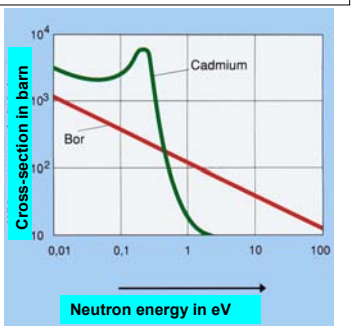
4) Interactions between Radiation and Matter (11)

Interactions between neutrons and matter

Neutron capturing

- nuclear reaction
- in most cases unstable nuclides are formed which undergo secondary radioactive decay (e.g. ß- or γ -decay)





Cross section is a measure for the probability of a nuclear reaction (barn = $10^{-23}m^2$)

4) Interactions between Radiation and Matter (12)

Interactions between neutrons and matter

Summary

Universal behaviour $\Rightarrow$ **Ionisation**

Direcly ionising radiation:
- α-radiation (high density of ionisation, low range)
- β-radiation (medium density of ionisation, medium range)

Indirectly ionising radiation:
- γ-radiation
  - (Photo effect $E_e = E_\gamma$)
  - (Compton effect $E_e < E_\gamma$)
  - (Pair formation $E_\gamma > 1$ MeV)
- Neutron radiation (secondary α-, β- and/or γ-radiation)

Universal principle for the measurement of nuclear radiation

$\Rightarrow$ **measurement of the ionisation**