Particles/photons

I.		II.	III.
a	b		
p	e^+	n	γ
α	e^-		X

Partners

1. Electromagnetic field
2. Electron
3. Field of the nucleus
4. Nucleus

	Effect on	
Mechanism	**radiation**	**matter**
A) Absorption	ΔI	E_{kin}, E^*
B) Coherent scattering (only the direction is altered))	ΔI	-
C) Incoherent scattering (also exchange of *E*)	ΔI, ΔE	
elastic (no excitation)		E_{kin}
inelastic		E_{kin}, E^*

1. Ionizing radiations

The first step of the ionizing radiation in the matter:

1. Neutral excitation

A + radiation → A^* + radiation'

2. External ionization

A + radiation → $A^+ + e^-$ + radiation'

A_2 + radiation → $A^+ + A^-$ + radiation'

A_2 + radiation → $A_2^+ + e^-$ + radiation'

A_2 + radiation → $2\,A\cdot$ + radiation'

3. Internal ionization

A + radiation → $A^{*+} + e^-$ + radiation'

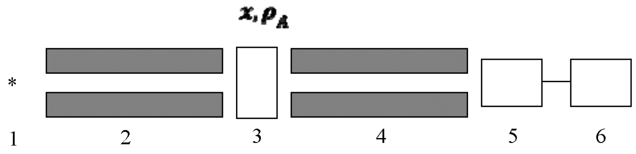
$A^{*+} \rightarrow A^+ + X_{char}$

$A^{*+} \rightarrow A^{2+} + e^-_{Auger}$

4. Bremsstrahlung (breaking radiation)

A + radiation $^{\pm}$ → $A + X_b$ + radiation $^{\pm}$'

Quantitative description of the interaction



$$\nu = \sigma n x \rho_A$$

cross section

$$-dn = \sigma(E) n \rho_A dx$$

$$n = n_0 e^{-\sigma(E)\rho_A x}$$

$$I = \frac{n}{t}$$

$$I = I_0 e^{-\mu x}$$

linear absorption coefficient

$$I = I_0 e^{-\mu x} = I_0 e^{-\frac{\mu}{\rho} x \cdot \rho} = I_0 e^{-\mu_m d}$$

mass absorption coefficient

$$x_{1/2} = \frac{\ln 2}{\mu} \qquad d_{1/2} = \frac{\ln 2}{\mu_m}$$

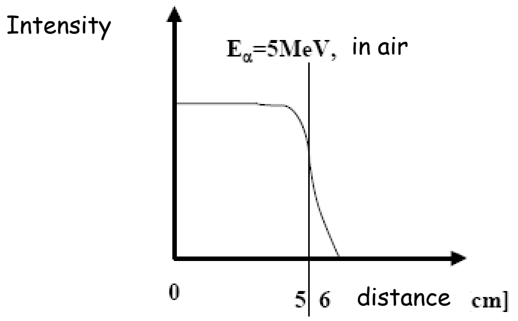
α-radiation

Heavy, charged, high energy

With electrons: **incoherent scattering**
ionisation and excitation (50-50 %)
E and direction of the alpha particles is modified

With the nucleus: **Rutherford-scattering**
nuclear reaction (see later)

! Bremsstrahlung (continuous energy gamma radiation)!



β-radiation

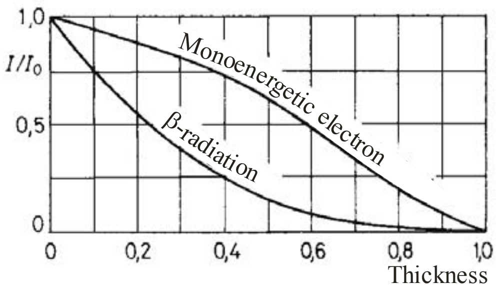
small, charged, limited energy

With electron: **incoherent scattering**
ionisation (external and internal)
excitation
E and the direction of the radiation changes

$$\frac{\left(\frac{dE}{dx}\right)_r}{\left(\frac{dE}{dx}\right)_{ion}} = \frac{EZ}{800}$$

With the field of the nucleus: **incoherent scattering**

! Bremsstrahlung !



$$I = I_0 e^{-\mu' x} = I_0 e^{-\mu d}$$

Linear/mass absorption coefficient

Calculate the activity of 1 kg KCl. 0.012 % of the K atoms is radioactive ^{40}K. The half life of ^{40}K is $1.13 \cdot 10^9$ years.

We prepared a ^{35}S labelled protein at 12:00, 10 September 2014. The half life of the pure β^- emitter is 88 days. This sample was measured at noon on 26 September and the intensity was found 7000 imp/s. The overall effieciency of the measurement was 22 %. Calculate the activity of the sample in the time of synthesis.

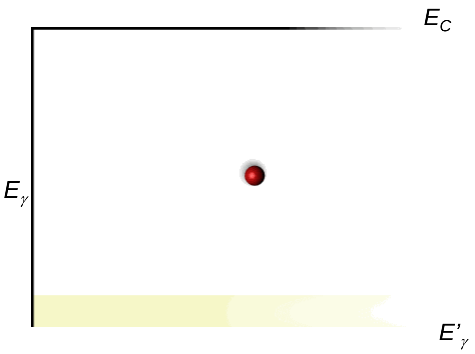
The linear absorption coefficient of gamma radiation of 660 keV in aluminum is 3,4 cm^{-1}. Calculate the half thickness. How efficiently will attenuate this radiation an 10 cm aluminum wall ?

γ-radiation

electromagnetic radiation

1. Compton-scattering

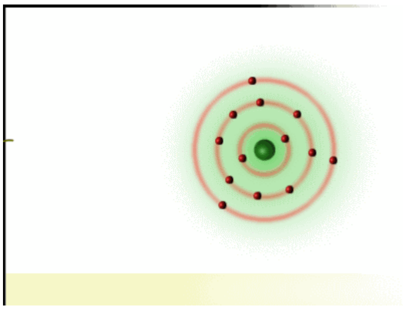
Elastic collision of the photon with an electron



$$\mu_C = \frac{\mu'_C}{\rho} = \sigma_C \frac{\rho_A}{\rho} = \sigma_C \frac{N_A Z}{A}$$

$$\sigma_C = \sigma_s + \sigma_a$$

2. Photoelectric effect



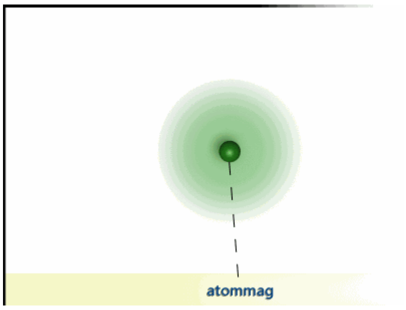
$$A + \gamma \longrightarrow A^{*+} + e^-_{\mathrm{f}}$$

$$\begin{tikzcd} A^{*+} \arrow[r] \arrow[dr] & A^{+} + X_{\mathrm{k}} \\ & A^{2+} + e^-_{\mathrm{A}} \end{tikzcd}$$

$$\sigma_{\mathrm{f}} \approx \mathrm{konst.}\, \frac{Z^{n}}{(h\nu)^3}$$

$n(E)$=4 - 5

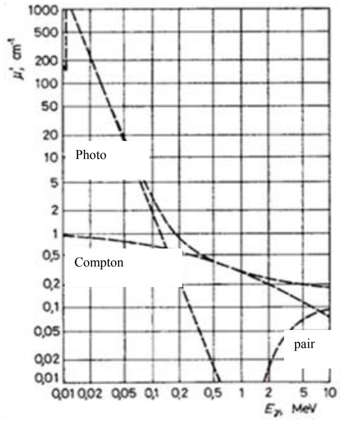
3. Pair production

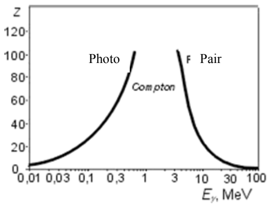


$$\sigma_{\mathrm{p}} = K(E_{\gamma} - 1{,}02)^{2{,}2} Z^2$$

$$I = I_0 e^{-\mu d} = I_0 e^{-(\mu_C + \mu_f + \mu_p)d}$$

Germanium





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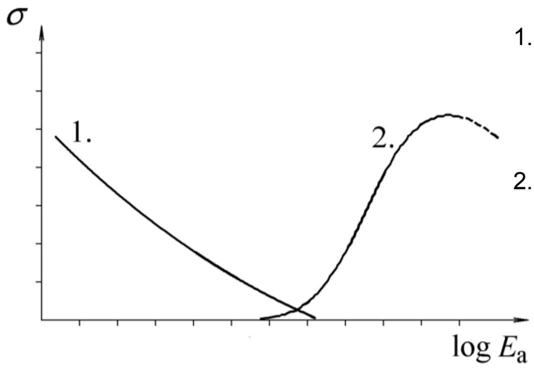
2. Nuclear reactions

Cross section (~probability)

Conventional equation

$$\begin{array}{lcl} {}^{10}\mathrm{B} + \alpha \rightarrow & & \rightarrow {}^{10}\mathrm{B} + \alpha \\ & {}^{14}\mathrm{N}^{*} & \rightarrow {}^{13}\mathrm{C} + \mathrm{p} \\ {}^{12}\mathrm{C} + \mathrm{d} \rightarrow & & \rightarrow {}^{13}\mathrm{N} + \mathrm{n} \end{array}$$

Transition state



1.
(n,γ)
(n,f) ^{233}U, ^{235}U, ^{239}Pu, ^{241}Pu
^{10}B(n,α)
^{6}Li(n,α)

2.
(γ,n)
(n,2n)
(n,α)
(p,)
(d,)

Tunnel effect

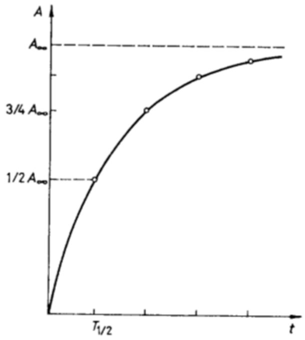
Kinetics of the nuclear reactions

$$\frac{dN^*}{dt} = \sigma_a N \phi - \lambda N^*$$

$$N^* = N^*_\infty \left[1 - \exp(-\lambda t)\right]$$

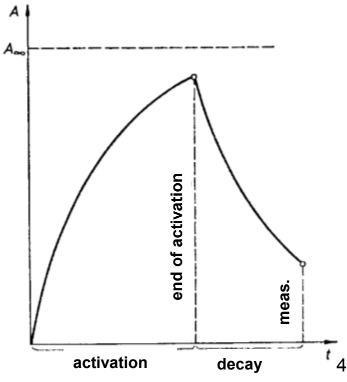
$$A = A_\infty \left[1 - \exp(-\lambda t)\right]$$

$$A_\infty = \lambda N^*_\infty = \phi \sigma_a N$$



$$A' = \lambda N^* =$$

$$= A_\infty \left[1 - \exp(-\lambda t)\right] \exp\left(-\lambda t_h\right)$$



We intend to obtain ^{65}Ni with neutron irradiation. Therefore, we expose 1 g of Ni (with a ^{64}Ni content of 91 %) to neutrons with a flux $\Phi=10^{12}$ 1/cm^{2}s. Thre cross section σ of the

$$^{64}\mathrm{Ni}(n,\gamma)^{65}\mathrm{Ni}$$

reaction is $1.55\cdot10^{-28}$ m^2. The half-life of ^{65}Ni is 2.52 h.

i) How long should the irradtiation last if we want to reach 80 % of the saturation activity?

ii) Estimate the ratio of the ^{64}Ni/^{65}Ni isotopes in the sample after being „cooled" for the same period as the activation lasted.