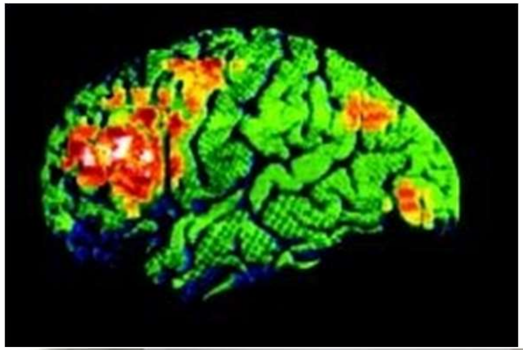
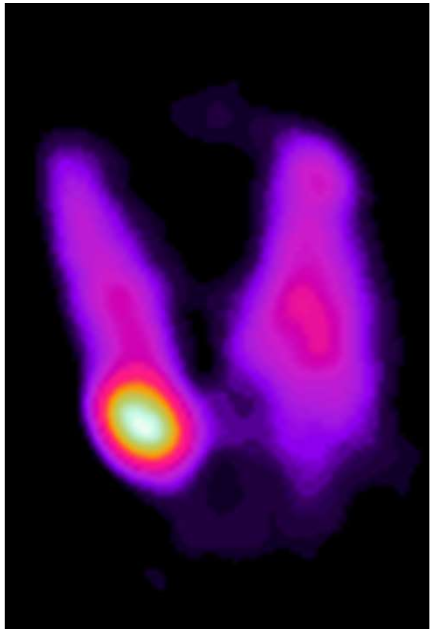
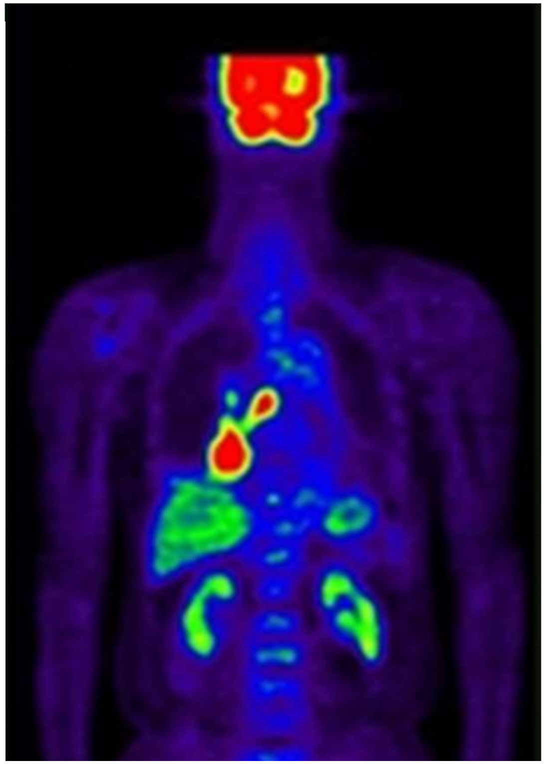
The atomic nucleus.
Radioactivity. Nuclear radiations

László Smeller



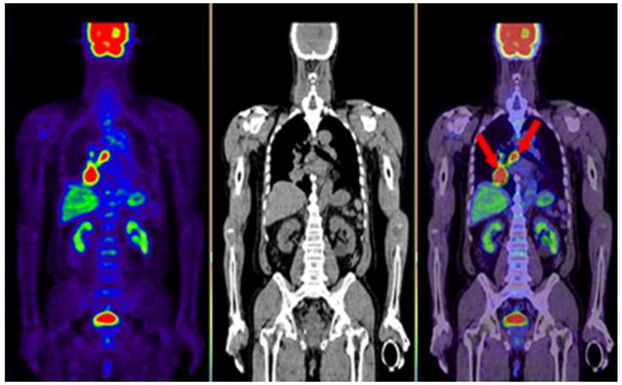


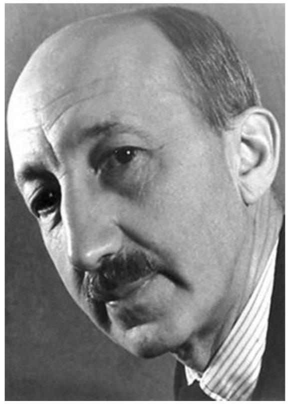


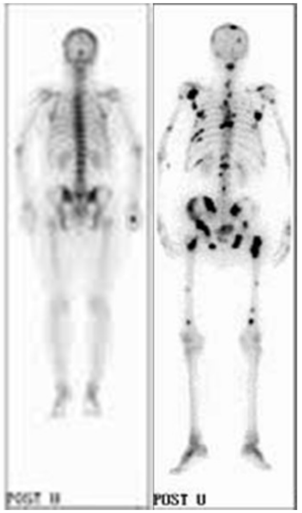
What is the relevance of the isotopes in the medicine?

Medical applications of the radioaktive isotopes and their radiations

- diagnostics
  (isotope diagnistics, molecular imaging)
- therapy (radiation therapy)
- phamacokinetical investigations

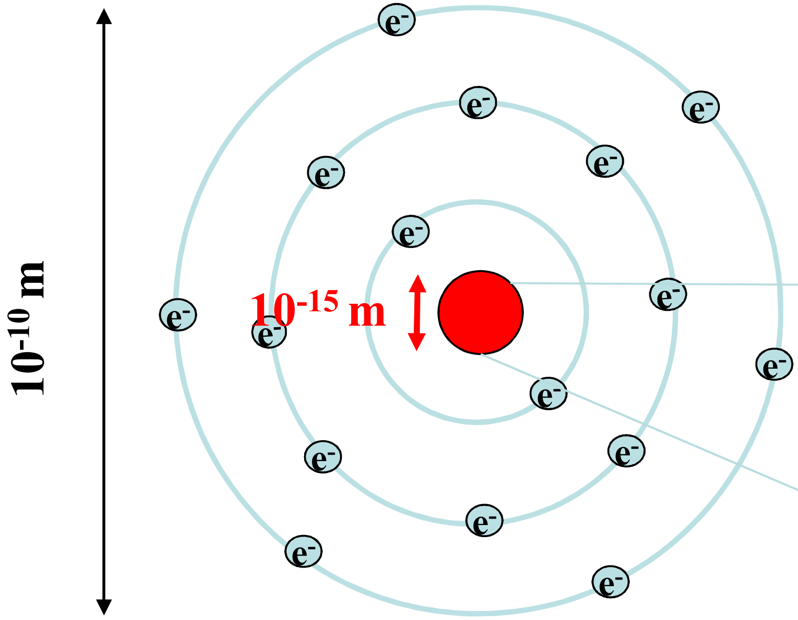






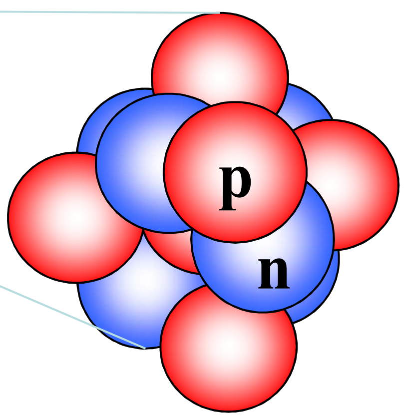
György Hevesy 1885-1966, Nobel prize 1943

The atom, and its nucleus



A (mass number) = number of protons
+ number of neutrons

Z (atomic number) = number of protons



e.g.: $^{99}_{43}Tc$

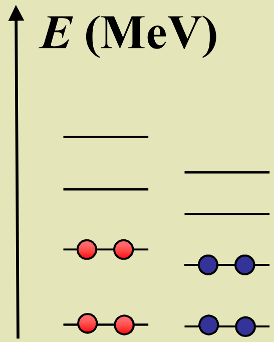
99 nucleons,
43 protons and
99-43=56 neutrons

Electron shell: chemistry
Nucleus: radioaktivity (physics)

Isotopes of an element :
Identical atomic number (protons)
Different mass number (neutrons)

Stability of the nucleus:
Coulomb force
Nuclear force

Diskrete energy levels



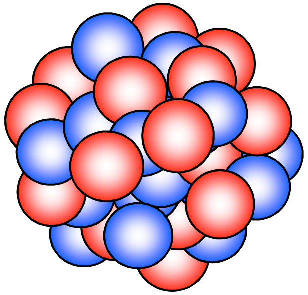
Isotopes and decays

Isotopes of an element :
Identical atomic number (protons)
Different mass number (neutrons)

E.g.: $^{18}_{9}\mathbf{F}$ unstable (radioactive) $^{19}_{9}\mathbf{F}$ stable $^{20}_{9}\mathbf{F}$ unstable (radioactive)

Decay: transition in the nucleus + radiation

Type of the decay	Emitted particle	Typical occurence
α - decay	α - particle = $^{4}_{2}$He nucleus	high mass number
β^- decay: β^+ decay:	β^- particle = electron β^+ particle = positron	neutron surplus proton surplus
Prompt γ emission Isomeric transiton	γ-ray	after α or β decay

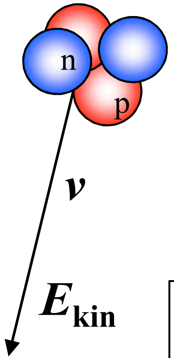


α - decay

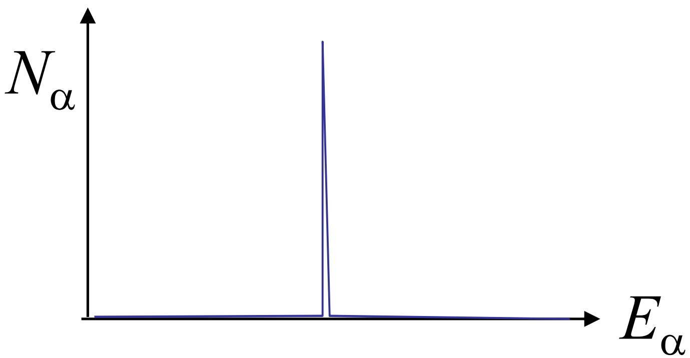
an α particle (^4He nucleus) will be emitted
typical for the heavy atoms

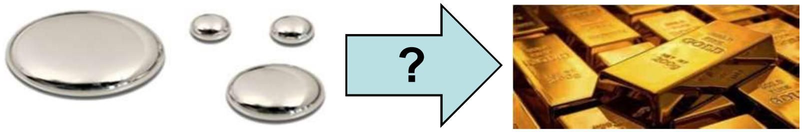
$$ {}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}\alpha $$

e.g. $$ {}^{226}_{88}\mathrm{Ra} \longrightarrow {}^{222}_{86}\mathrm{Rn} + {}^{4}_{2}\alpha $$



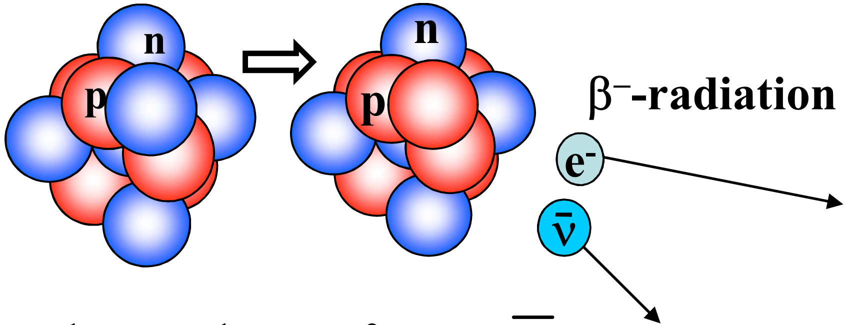
Energy distribution: line spectrum
(all the particles have the same enrgy)
$E_\alpha \sim$ MeV





β - decay

β⁻ – decay (neutron surplus)



$$ {}^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}\beta + \overline{\nu} $$

remains in the nucleus (${}^{1}_{1}p$)

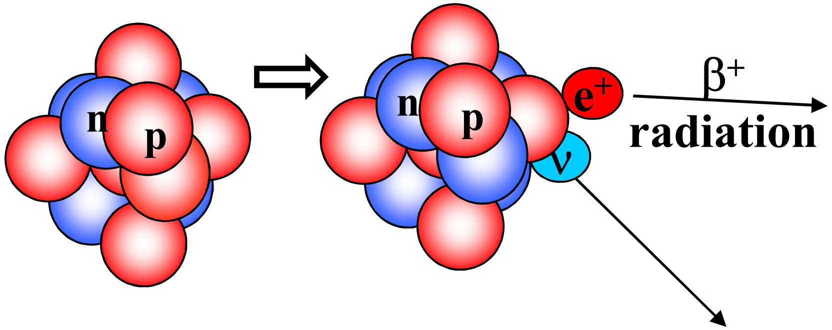
leave the nucleus (${}^{0}_{-1}\beta$, $\overline{\nu}$)

$$ {}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}\beta + \overline{\nu} $$

$$ \text{E.g.}: {}^{131}_{53}\text{I} \longrightarrow {}^{131}_{54}\text{Xe} + {}^{0}_{-1}\beta + \overline{\nu} $$

$$ \beta^{-} = {}^{0}_{-1}\beta = e^{-} $$

β⁺ - decay (proton surplus)



$$ {}^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{0}_{+1}\beta + \nu $$

remains in the nucleus (${}^{1}_{0}n$)

leave the nucleus (${}^{0}_{+1}\beta$, ν)

$$ {}^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + {}^{0}_{+1}\beta + \nu $$

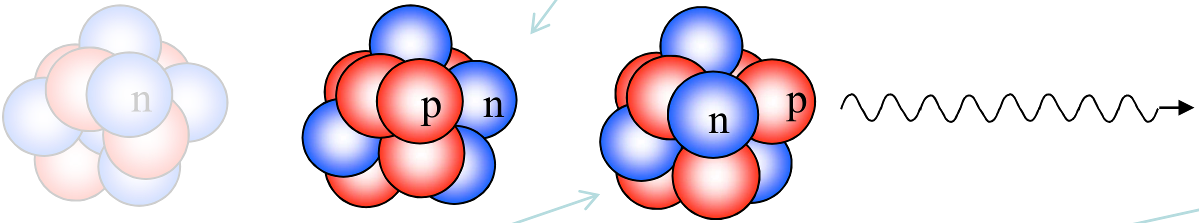
$$ \text{E.g.}: {}^{18}_{9}\text{F} \longrightarrow {}^{18}_{8}\text{O} + {}^{0}_{+1}\beta + \nu $$

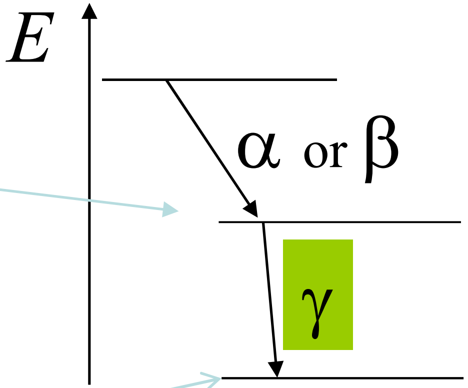
$$ \beta^{+} = {}^{0}_{+1}\beta = e^{+} $$

continous energy spectrum

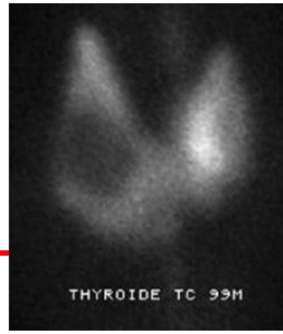
The origin of the γ-ray

After an α or β decay the nucleus might have an energetically unfavoured arrangement of nucleons. (excited state)





The surplus energy will be emitted in form of γ radiation
Number of protons and neutrons remains unchanged. Line spectrum.



Prompt γ radiation

In most of the cases the γ emission occurs immedately after the α or β decay. (within $<10^{-12}$ s)

Isomeric transition

In some rare cases the excited state of the daughter nucleus is metastable, the γ-radiation will be emitted by minutes or hours later.
The β and γ emissions are separated in time e.g.: ^{99m}Tc

Isotope with solely γ-emission!

=> Ideal for isotope diagnostics

$$^{99}_{42}Mo \xrightarrow{\beta^-} {}^{99m}_{43}Tc \xrightarrow{\gamma} {}^{99}_{43}Tc$$

Characteristics of radioactive decays and of isotopes in general

activity	Λ	characterizes the source
half life time	T or $T_{1/2}$	characterizes the speed of the decay*
particle type	α, β, γ	(see above)
particle energy	E	characterizes the radiation*

*depends on the type of the isotope

Activity (Λ)

$$\Lambda = \left| \frac{\Delta N}{\Delta t} \right|$$

$N =$ Number of undecayed atoms
t = time
$-\Delta N$ = Number of decays during Δt time

Activity= number of decay events in a unit time

unit: becquerel Bq
1 Bq= 1 decay/sec

old unit: Ci=37GBq

immeasurably small

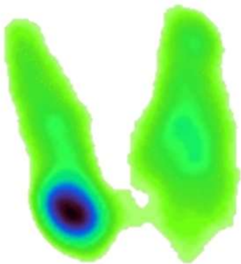
kBq, MBq, GBq, TBq, PBq

level of natural activity

in vivo diagn.

work carefully with it!

activity used in radiotherapy



Law of radioactive decay

$\Delta N \sim N$

N: Number of undecayed nuclei

($-\Delta N$ = Number of decays during Δt time)

λ: decay constant (probability of the decay [1/s])

$1/\lambda=\tau$ average lifetime

$$\frac{\Delta N}{\Delta t} = -\lambda N$$

Differential equation

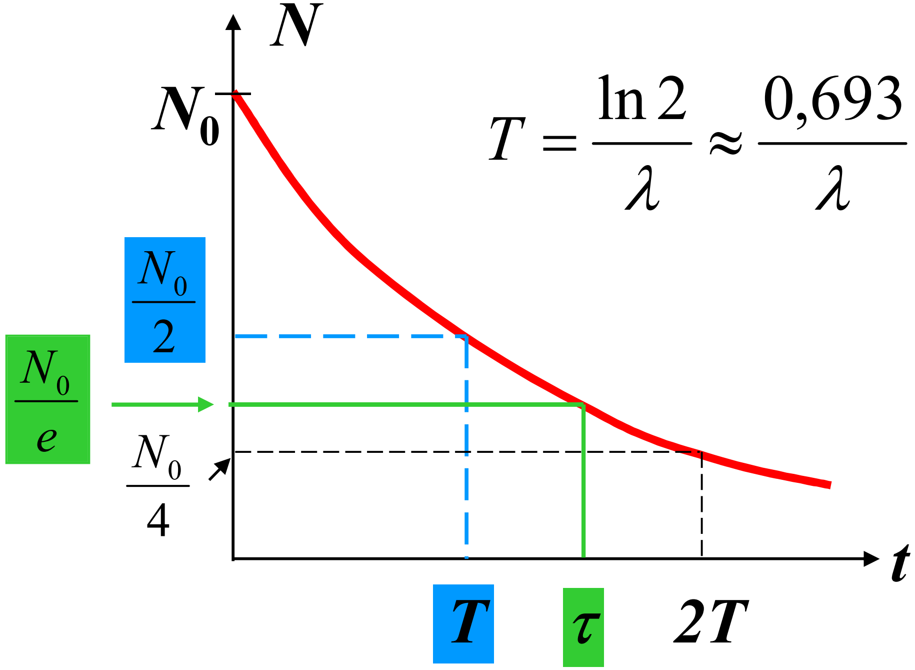
solution:

$$N(t) = N_0 e^{-\lambda t}$$

N_0 = number of undecayed atoms at t=0

Exponential decrease

$$T = \frac{\ln 2}{\lambda} \approx \frac{0{,}693}{\lambda}$$



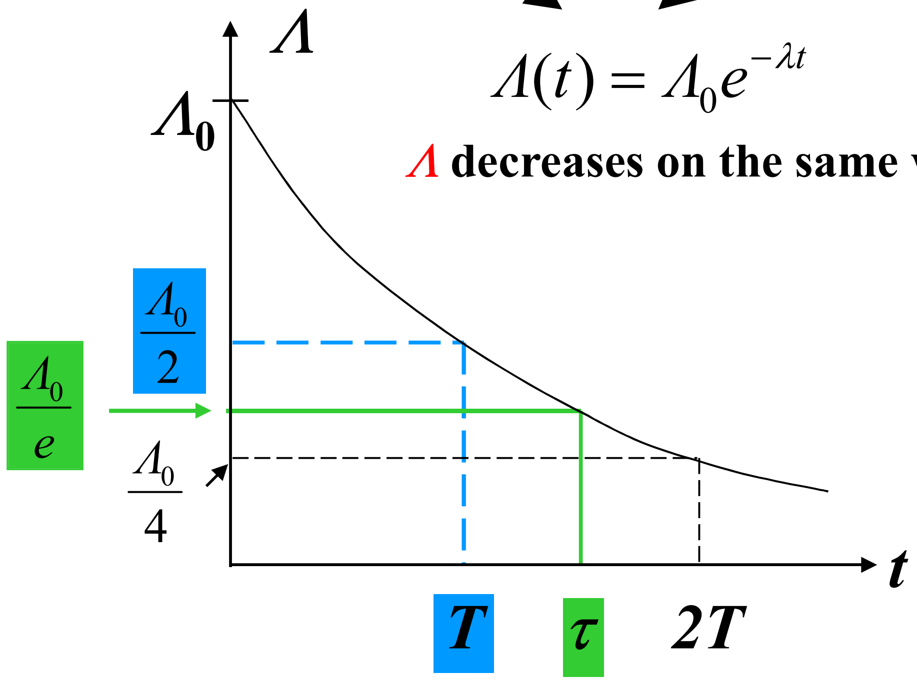
Decrease of the activity as a function of time

$$\Lambda = \left|\frac{\Delta N}{\Delta t}\right| \qquad \frac{\Delta N}{\Delta t} = -\lambda N \qquad N(t) = N_0 e^{-\lambda t}$$

$$\Lambda = \lambda N$$

$$\Lambda(t) = \Lambda_0 e^{-\lambda t}$$

Λ decreases on the same way as N!



Some examples for T :

^{40}K	$1,3 \cdot 10^9$ years
^{14}C	5736 years
^{137}Cs	30 years
^{3}H	12,3 years
^{60}Co	5,3 years
^{59}Fe	1,5 months
^{56}Cr	1 month (28 d)
^{131}I	8 day
^{99m}Tc	6 hours
^{18}F	110 minutes

About 10 T is needed to decrease the activity to its 1/1000
e.g. GBq → MBq
MBq → kBq

Absorption of the nuclear radiation

α^{2+}, β^{-}, β^{+} — particles with electric charge ⇒ direct ionisation

different types of interactions with matter!

Different attenuation characteristics!

γ, (x-ray), n — uncharged particles ⇒ indirect ionisation

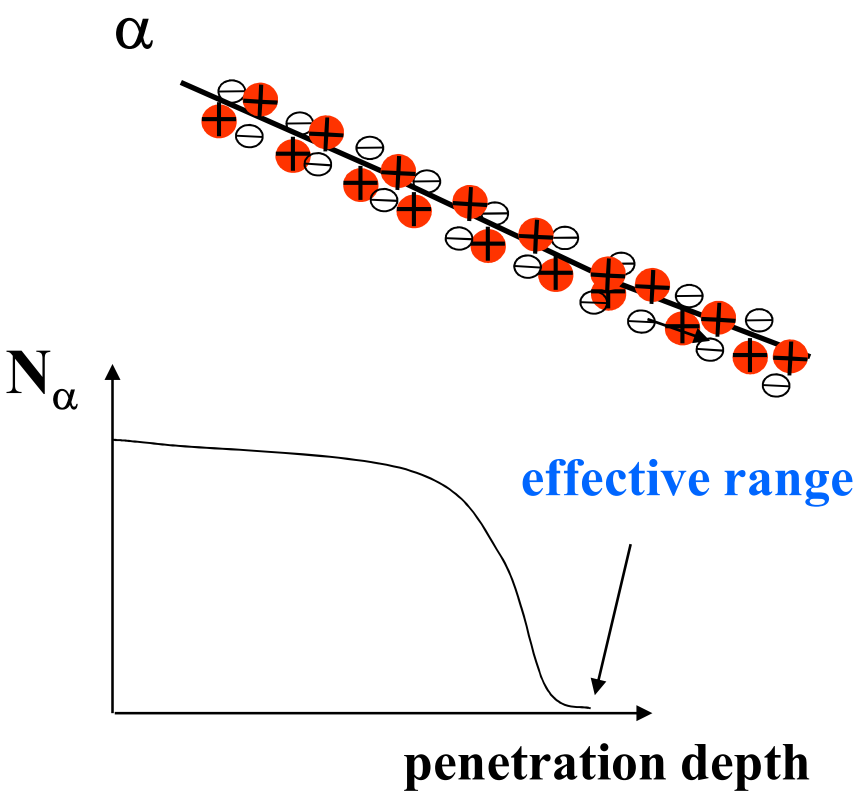
(x-ray): not a nuclear radiation, but its absorption is similar to that of the γ radiation

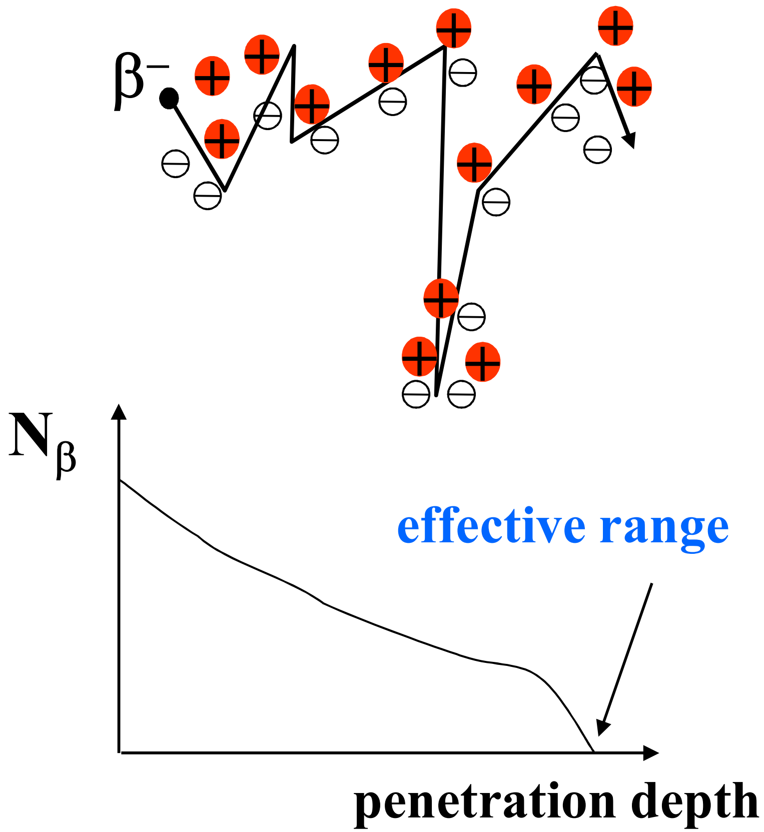
n: **Activation** (the irradiated objects will be radioactive!

Absorption of the charged particles

Ionizing during the path => continuous decrease of the particle energy
The energy after a given path length decreases to near zero: effective range!

- α–radiation: ***few cm*** in air, ***10-100 μm*** in tissue
- β–radiation: ***few m*** in air, ***few cm*** in tissue

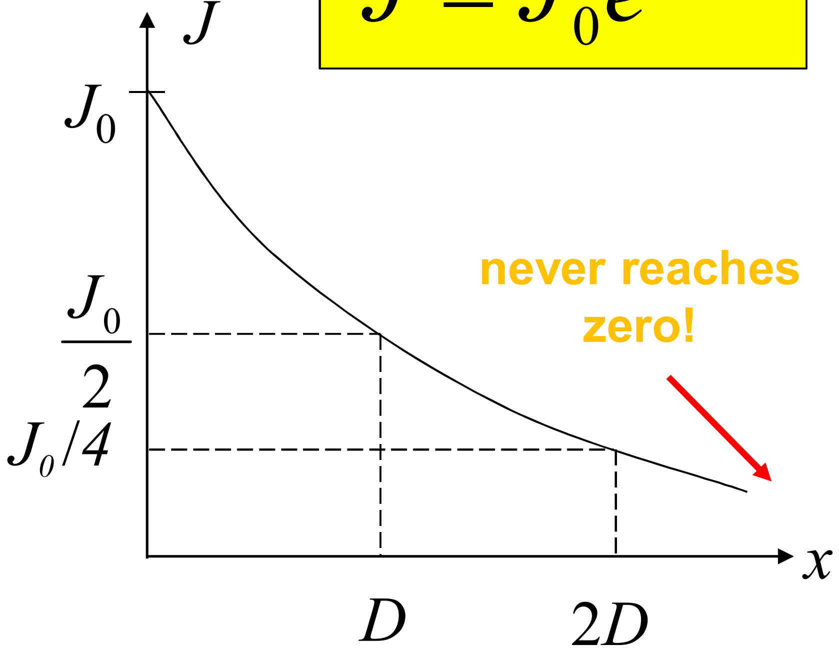


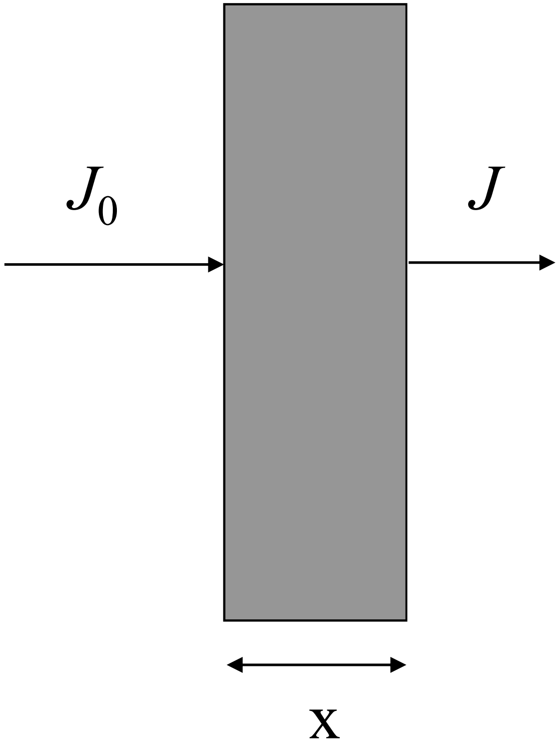


Attenuation of the γ–radiation and x-ray

General law of attenuation:

$$J = J_0 e^{-\mu x}$$





no finite effective range!

few rules of thumb: $x_{1/10}$=3,32 D $x_{1/1000}$=10 D