

Radioactivity. Nuclear radiations

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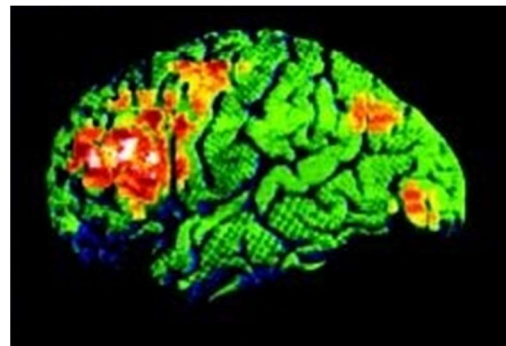
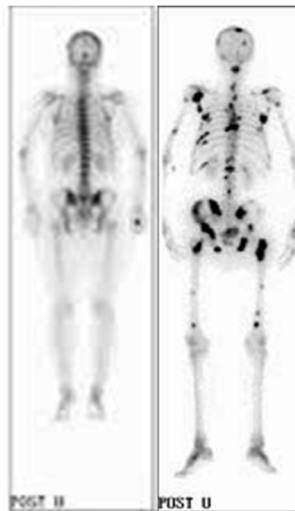
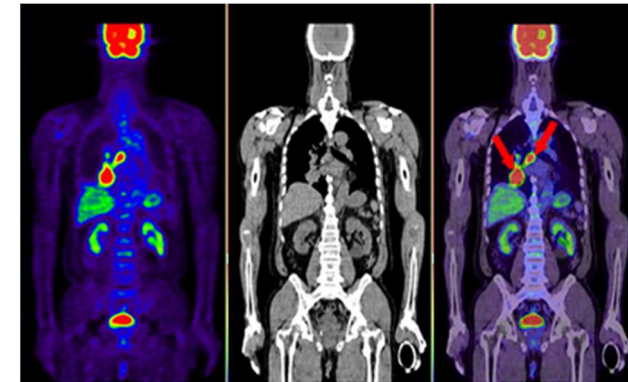
Semmelweis University



What is the relevance of the isotopes in the medicine?

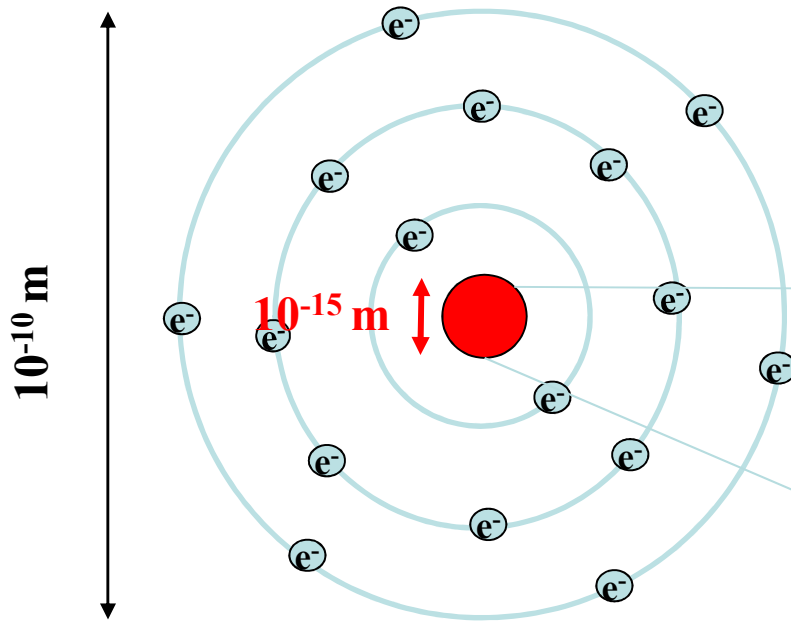
Medical applications of the radioactive isotopes and their radiations

- diagnostics
(isotope diagnostics, molecular imaging)
- therapy (radiation therapy)
- pharmacokinetical investigations

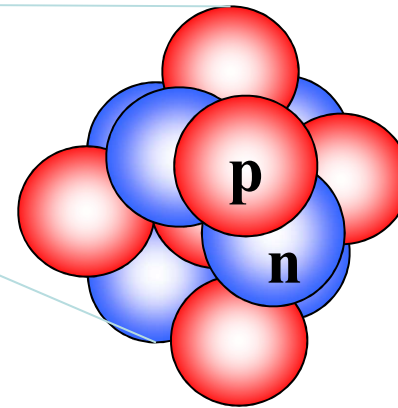


György Hevesy 1885-1966, Nobel prize 1943

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: radioactivity (physics)

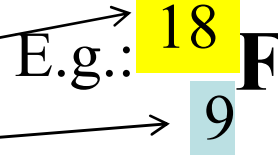
Isotopes of an element :
Identical atomic number (protons)
Different mass number (neutrons)

Stability of the nucleus:
 Coulomb force
 Nuclear force

Diskrete energy levels

Isotopes and decays

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



unstable
(radioactive)



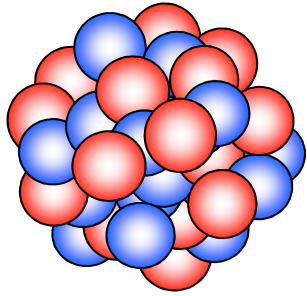
stable



unstable
(radioactive)

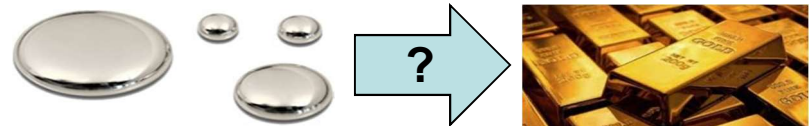
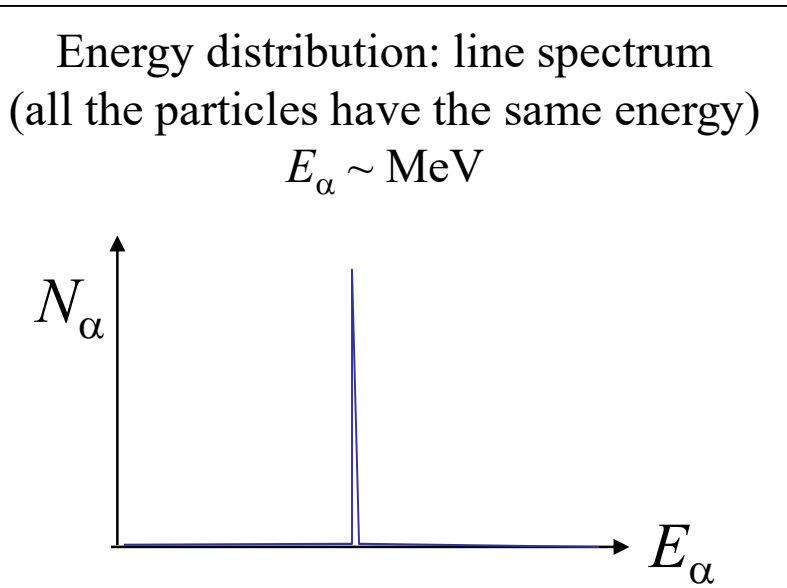
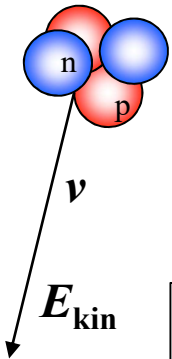
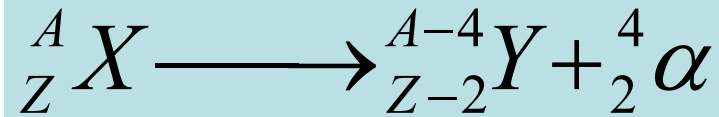
Radioactive decay: transition in the nucleus + radiation

Type of the decay	Emitted particle	Typical occurrence
α - decay	α - particle = ^4_2He nucleus	high mass number
β^- decay: β^+ decay:	β^- particle = electron β^+ particle = positron	neutron surplus proton surplus
Prompt γ emission Isomeric transition	γ -ray	after α or β decay



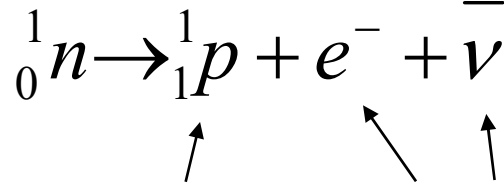
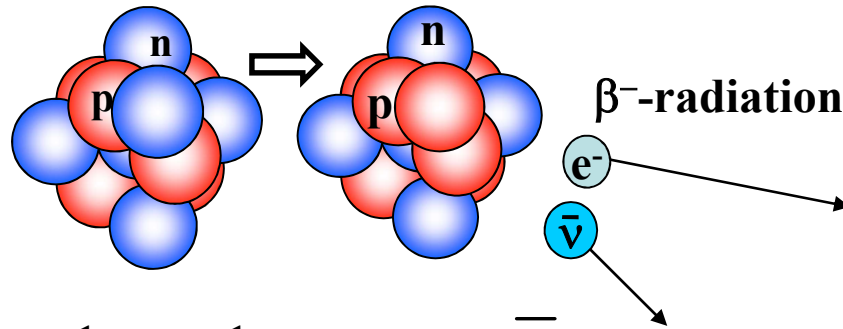
α - decay

an α particle (${}^4\text{He}$ nucleus) will be emitted
typical for the heavy atoms



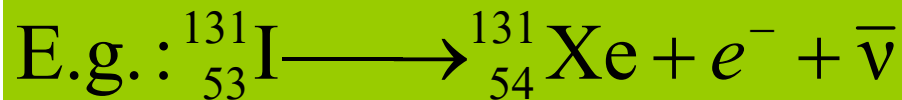
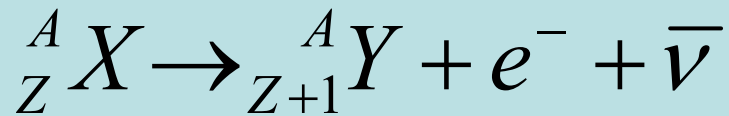
β - decay

β^- - decay (neutron surplus)



remains in
the nucleus

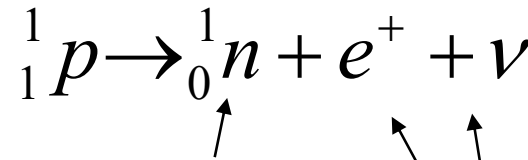
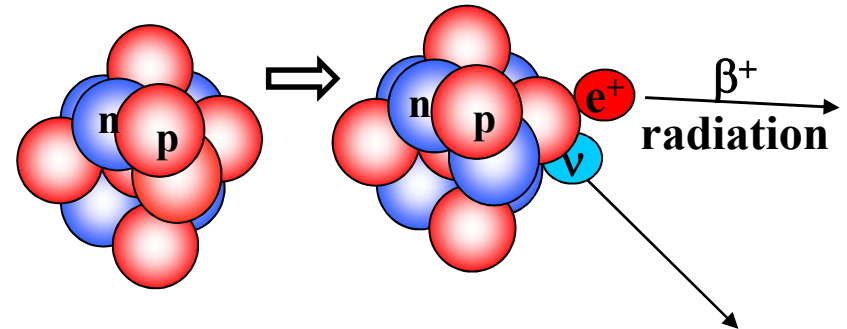
leave the
nucleus



$$\beta^- = e^-$$

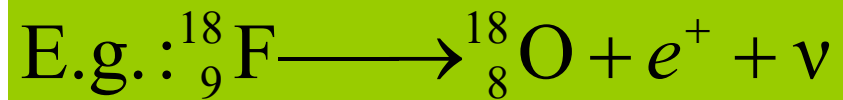
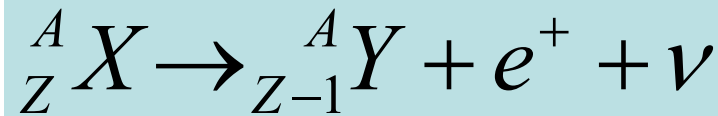
continuous energy spectrum

β^+ - decay (proton surplus)



remains in
the nucleus

leave the
nucleus

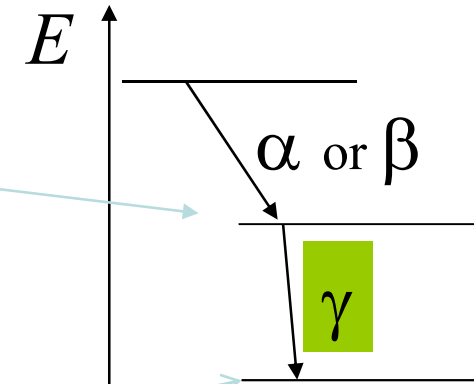
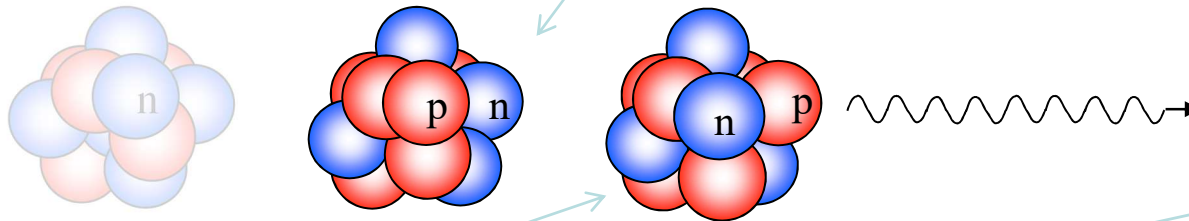


$$\beta^+ = e^+$$

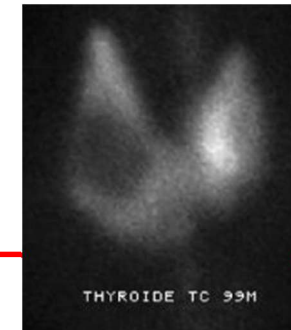
The origin of the γ -ray

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 immediately after the α or β decay.
(within $<10^{-12}$ s)

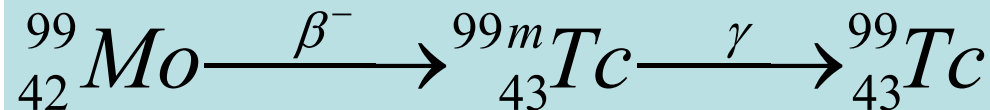
Isomeric transition

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



Characteristics of radioactive decays and of isotopes in general

activity	A	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 = 37 GBq

immeasurably
small

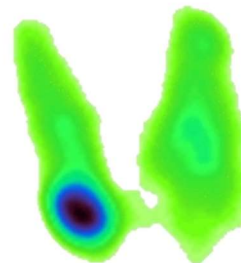
level of natural activity

kBq, MBq, GBq, TBq, PBq

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

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

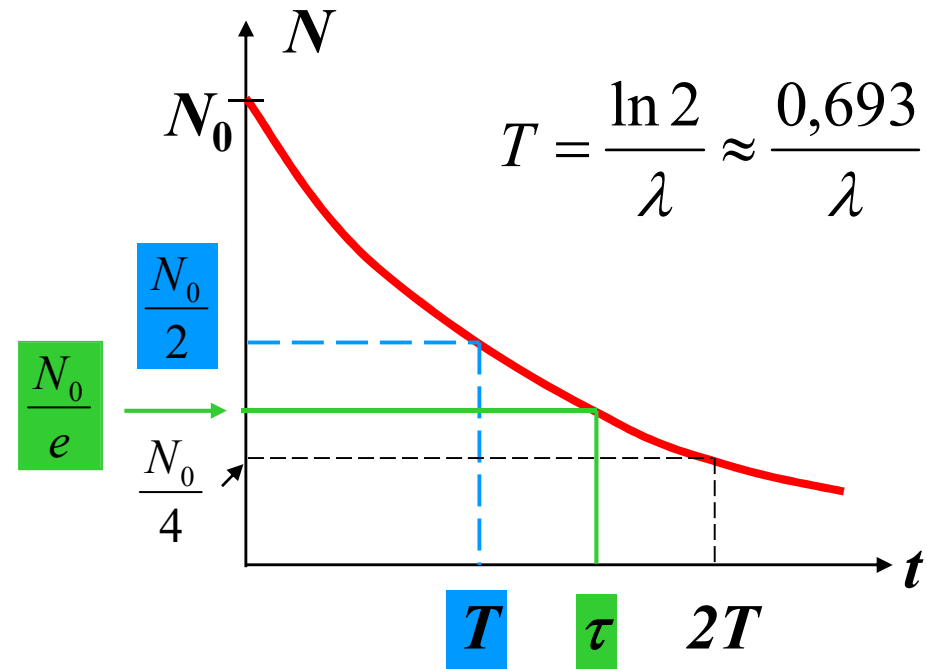
Differential equation

solution:

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

N_0 = number of undecayed atoms at $t=0$

Exponential decrease



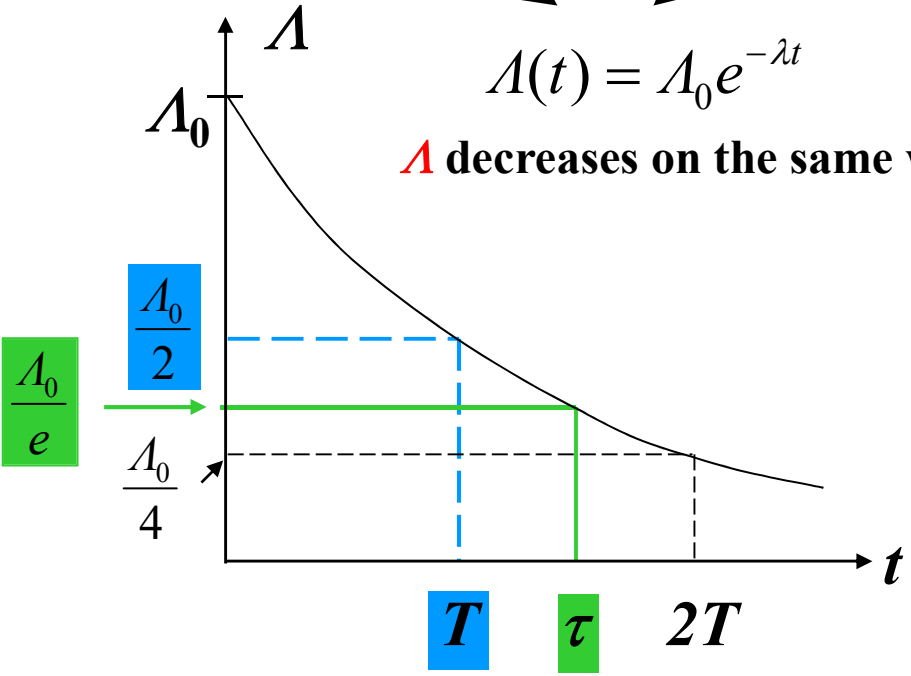
Decrease of the activity as a function of time

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

$$A = \lambda N$$

$$A(t) = A_0 e^{-\lambda t}$$

A 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

^3H 12,3 years

^{60}Co 5,3 years

^{59}Fe 1,5 months

^{56}Cr 1 month (28 d)

^{131}I 8 day

$^{99\text{m}}\text{Tc}$ 6 hours

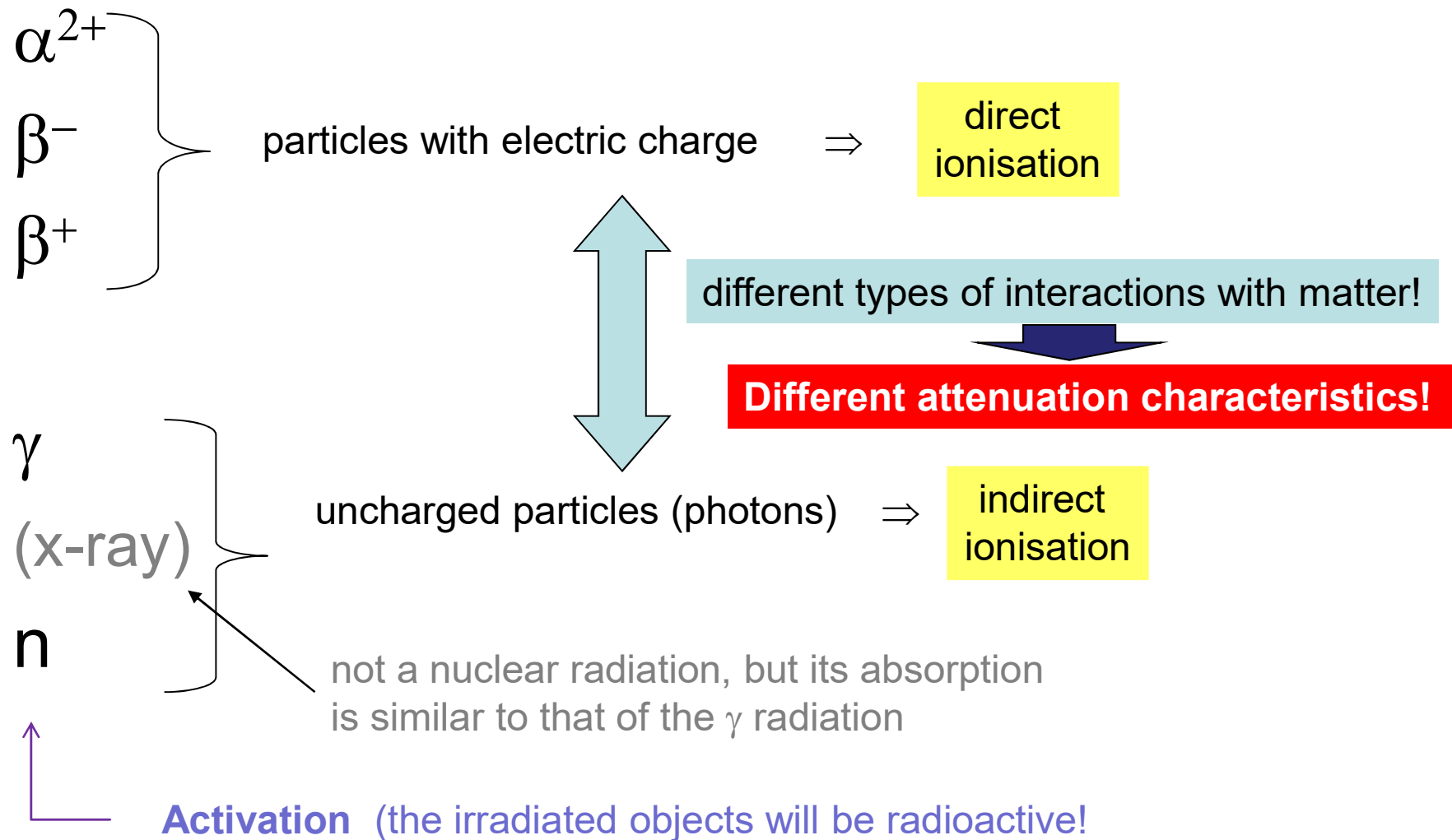
^{18}F 110 minutes

About 10 T is needed to decrease the activity to its 1/1000

e.g. GBq \rightarrow MBq

MBq \rightarrow kBq

Absorption of the nuclear radiation



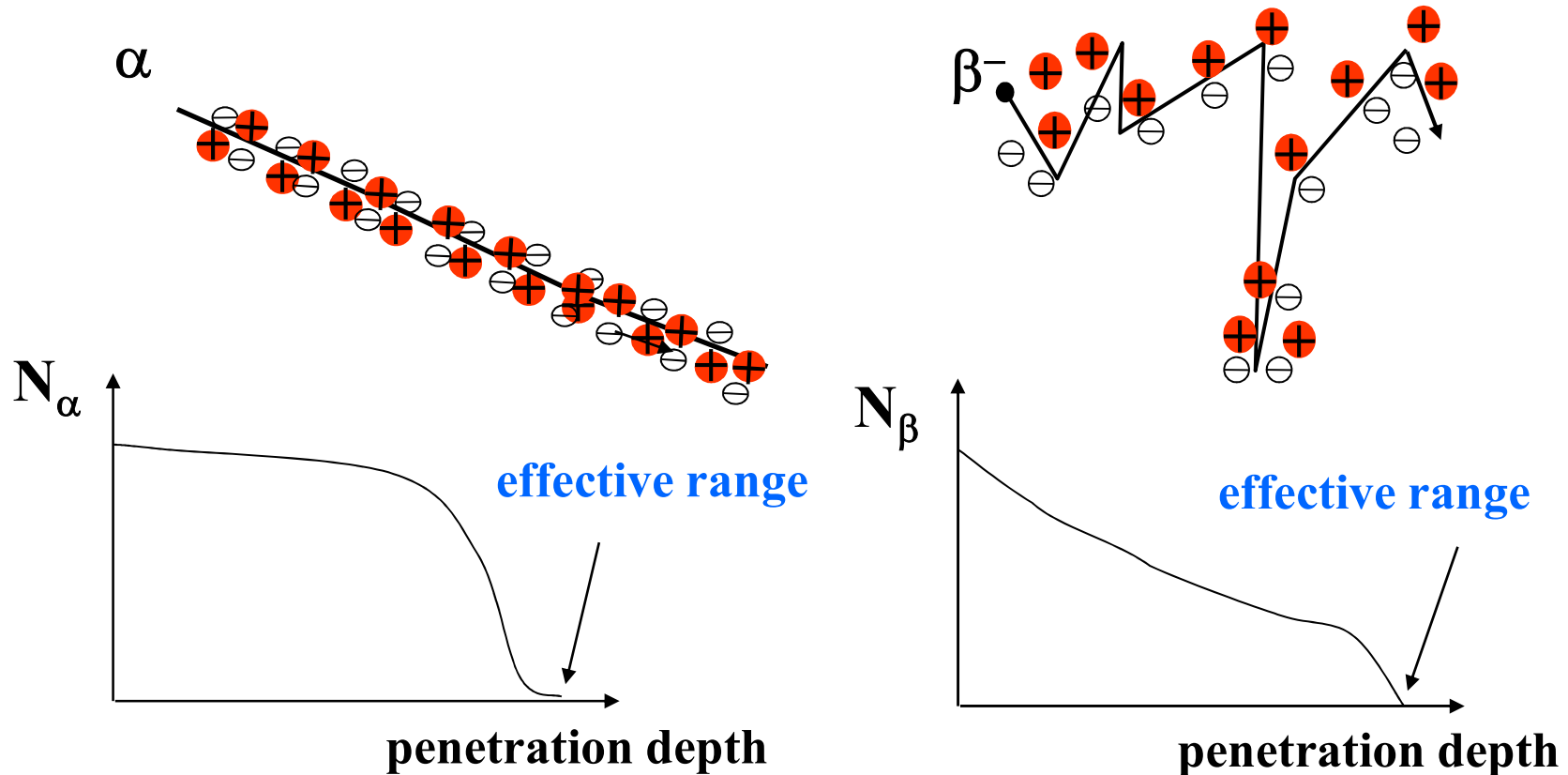
Absorption of the charged particles

Ionizing during the path => continuous decrease of the particle energy

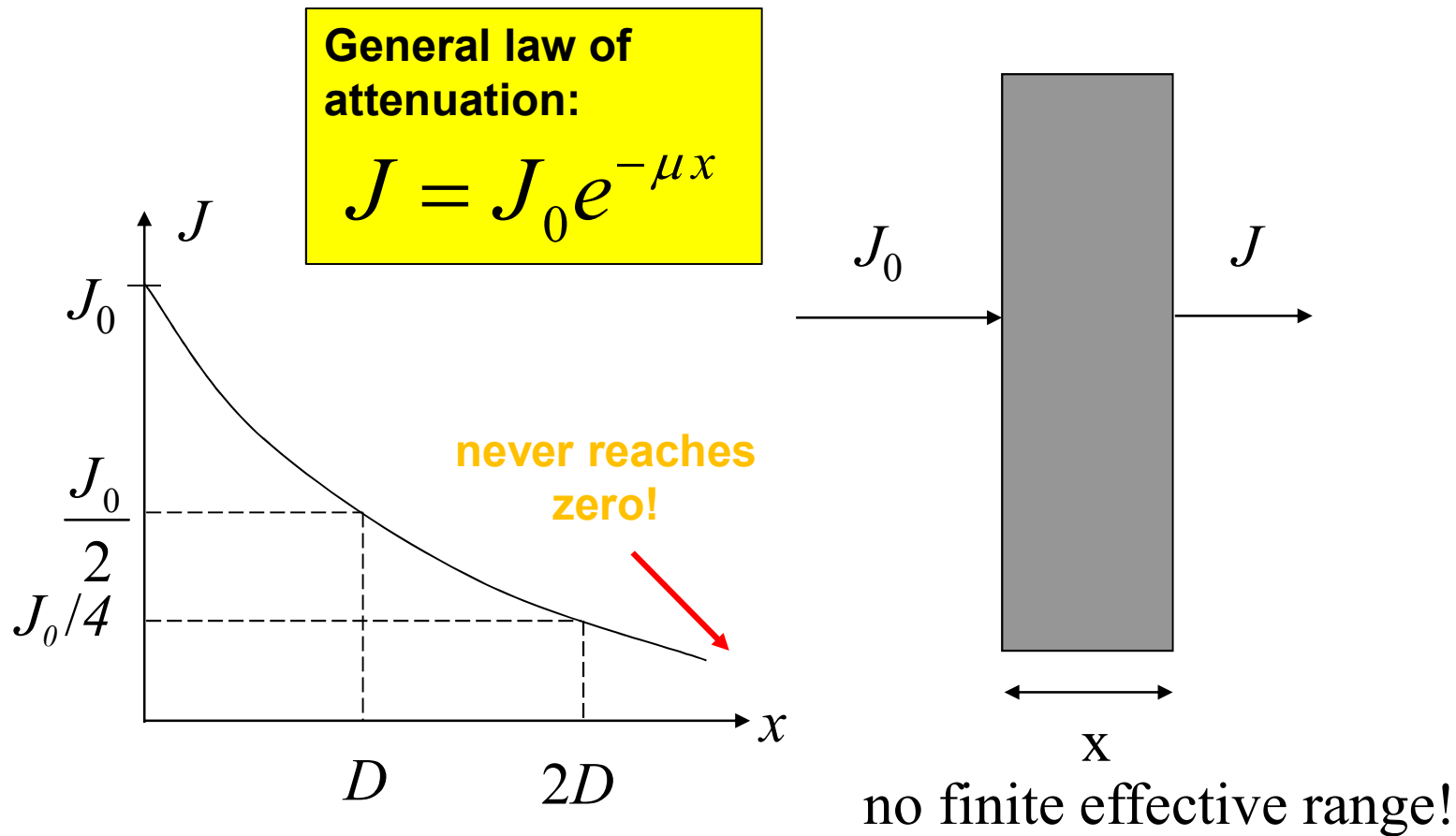
The energy after a given path length decreases to near zero: **effective range!**

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



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