Al- Mustaqbal University

College of Science

Medical Physics Department

Fourth Stage

جامـــــعـة المـــسـتـقـبـل
AL MUSTAQBAL UNIVERSITY

Ionizing Radiation Detection

Lecture Two: Laws of Radioactivity

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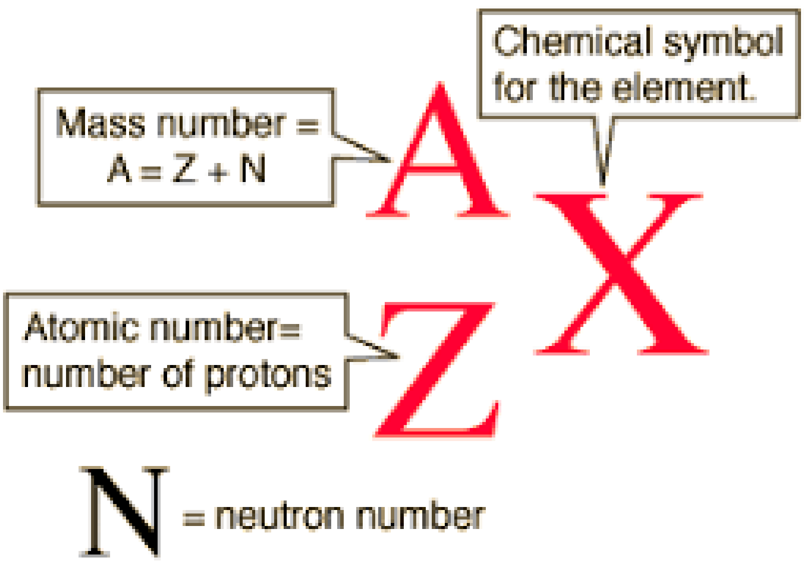
Review of Atomic Terms:

- Nucleons – particles found in the nucleus of an atom which are neutrons and protons.
- Atomic Number (Z) – number of protons in the nucleus.
- Neutron Number (N) – number of neutrons in the nucleus.
- Mass Number (A) – sum of the number of protons and neutrons.
- Isotopes – atoms with identical atomic numbers but different mass numbers $^{1}_{1}H_{0}$, $^{2}_{1}H_{1}$, $^{3}_{1}H_{2}$
- Isotones: atoms with identical neutrons numbers $^{64}_{28}Ni_{36}$, $^{65}_{29}Cu_{36}$
- Isobars: atoms with identical mass numbers $^{14}_{7}N_{7}$, $^{14}_{6}C_{8}$
- Symbol of nuclei $^{A}_{Z}X_{N}$
- Stability condition of nucleus N / Z = 1; N = Z, while non-stable is N / Z > 1; N > Z.



Laws of radioactivity:

Radioactive decay: The activity of a radioactive sample diminishes over time with the gradual disappearance of the unstable nuclei it contains. There is an equal probability for all nuclei of a radioactive element to decay.

The rate of spontaneous disintegration of a radioactive element is proportional to the number of nuclei present at that time.

$$dN/dt \propto N \qquad (1)$$

N: number of unstable atoms present at time t.

Removing proportionality sign, we get

$$dN/dt = -\lambda N \qquad (2)$$

λ: decay constant of the element.

Negative sign indicates that as t increases N decreases. Rewriting Eq. (2) as

$$dN/N = -\lambda dt \qquad (3)$$

Integrating both sides, we have:

$$\int_{No}^{N} \frac{dN}{N} = -\lambda \int_{o}^{t} dt$$

$$\ln \frac{N}{No} = -\lambda\, t$$

$$N = No\, e^{-\lambda\, t} \qquad (4)$$

The exponential nature of this equation shows that it takes an infinite time for the whole of the radioactive material to disintegrate.

$$A = -dN/dt = \lambda N \qquad (5)$$

Substituting for N from Eq. (4)

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

$$A = \lambda\, N_0\, e^{-\lambda t}$$

Substituting $A_0 = \lambda\, N_0$

$$A = A_0\, e^{-\lambda t} \text{ Activity Law} \qquad (6)$$

The exponential factor shows that the activity is decreasing in the same fashion as N.

The half-life ($t_{1/2}$) is defined as the time elapsed when the radioactive nuclei are reduced to one half of its original value, where if ($t = t_{1/2}$ so that $N = N_o/2$):

$$t_{1/2} = \frac{\ln 2}{\lambda} \qquad (7)$$

Units of radioactivity measurement:

1- Becquerel (Bq) is the number of disintegrations per second of the radioactive nuclei within it. The unit of activity is the Becquerel (symbol Bq).

1 Bq = 1 disintegration per second.

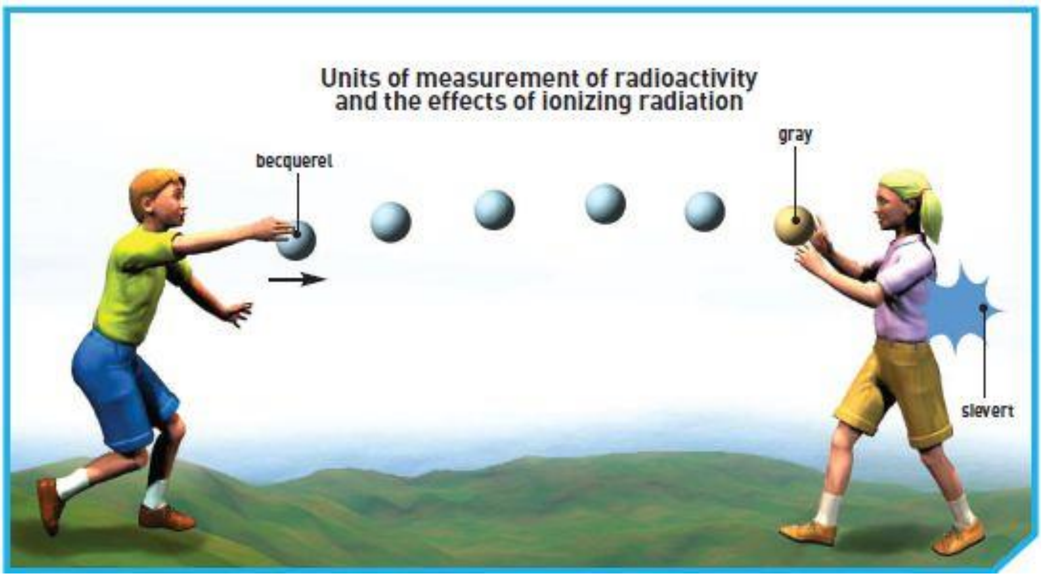
This is a very small unit, so the activity of radioactive sources is more often expressed in multiples of the Becquerel such as: kilobecquerel (kBq) = 1000 Bq

2- Curie (Ci): Is the old unit to measurement the radioactivity. The curie was defined as the activity of 1 gram of radium ^{226}Ra, a natural element found in the earth with uranium. This unit is much larger than the Becquerel because, in one gram of radium, 37 billion disintegrations per second are produced so that:

1 curie = 3.7×10^{10} Bq.

3- Gray (Gy) this unit is used to measure the quantity of radiation absorbed by an organism or object exposed to radiation (the absorbed dose). The gray replaced the rad in 1986. Where 1 Gray = 100 rad.

4- Sievert (Sv) The biological effects of radiation on an organism subject to exposure (depending on its nature and the organs exposed) are measured in Sievert, and are generally expressed as an "equivalent dose" and "effective dose". 1 Sv = 100 rem.



Example: Find the activity of (1 g) of radium, ^{226}Ra, whose mass number is 226 and $t_{1/2}$= 1620 year.

Solution:

$$A = \lambda N$$

$$t_{1/2} = \frac{\ln 2}{\lambda}$$

$$\lambda = \frac{\ln 2}{t1/2}$$

$$\lambda = \frac{0.693}{1620 \times 365.25 \times 24 \times 60 \times 60 \text{ sec}}$$

$$\lambda = 1.36 \times 10^{-11} \text{ s}^{-1}$$

$$N = \frac{m\,(g) \times An}{A} = \frac{1 \times 6.02 \times 10^{23}}{226} = 2.66 \times 10^{21} \text{ nuclei}$$

$$A = 1.36 \times 10^{-11} \times 2.66 \times 10^{21}$$

$$A = 3.7 \times 10^{10} \text{ Bq}$$

Example: Calculate the activity of (1 mg) of radon gas ^{222}Rn, whose mass number is 222 and half-life to decay 3.8 day.

Example: The half-life of ^{30}P is 2.5 minutes if a sample of ^{30}P has 4.8×10^{19} nuclei present initially, what time does it takes for the number of ^{30}P nuclei to decrease to the value 1.2×10^{18} nuclei?

Example: Calculate the activity of ^{137}Cs after: (a) 2 years, (b) 15 years, (c) 30 years; if its activity at production was (10 μCi) and the half – life of ^{137}Cs is (30 years)?

Decay modes:

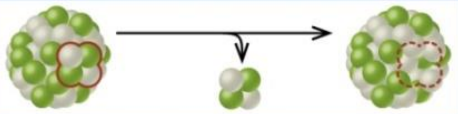
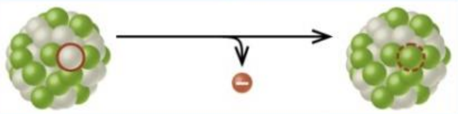
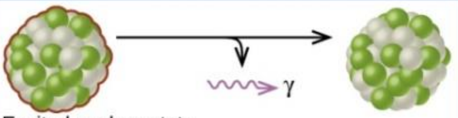
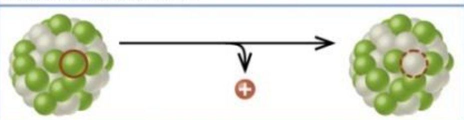
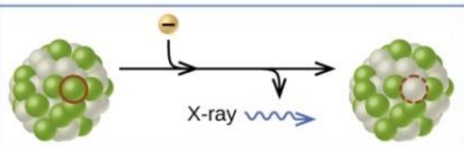
The simplest form of radioactive decay involves a radioactive parent nucleus P decaying with decay constant λ_P into a stable or unstable daughter nucleus D.

Radioactive decay results in the emission of either:

- Alpha particle (α)
- Beta particle (β)
- Gamma ray (γ)

Table 1 Radioactive Decay

Decay	Transformation	Example
Alpha decay	${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$	${}^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$
Beta decay	${}^{A}_{Z}X \rightarrow {}_{Z+1}{}^{A}Y + e^-$	${}^{14}_{6}C \rightarrow {}^{14}_{7}N + e^-$
Positron emission	${}^{A}_{Z}X \rightarrow {}_{Z-1}{}^{A}Y + e^+$	${}^{64}_{29}Cu \rightarrow {}^{64}_{28}Ni + e^+$
Electron capture	${}^{A}_{Z}X + e^- \rightarrow {}_{Z-1}{}^{A}Y$	${}^{64}_{29}Cu + e^- \rightarrow {}^{64}_{28}Ni$
Gamma decay	${}^{A}_{Z}X^* \rightarrow {}^{A}_{Z}X + \gamma$	${}^{87}_{38}Sr^* \rightarrow {}^{87}_{38}Sr + \gamma$

Type	Nuclear equation	Representation	Change in mass/atomic numbers
Alpha decay	${}^{A}_{Z}X \quad {}^{4}_{2}He + {}^{A-4}_{Z-2}Y$		A: decrease by 4 Z: decrease by 2
Beta decay	${}^{A}_{Z}X \quad {}^{0}_{-1}e + {}_{Z+1}{}^{A}Y$		A: unchanged Z: increase by 1
Gamma decay	${}^{A}_{Z}X \quad {}^{0}_{0}\gamma + {}^{A}_{Z}Y$		A: unchanged Z: unchanged
Positron emission	${}^{A}_{Z}X \quad {}^{0}_{+1}e + {}_{Y-1}{}^{A}Y$		A: unchanged Z: decrease by 1
Electron capture	${}^{A}_{Z}X \quad {}^{0}_{-1}e + {}_{Y-1}{}^{A}Y$		A: unchanged Z: decrease by 1