The Radioactivity

Introduction:

In the nature, there are some elements which have their nuclei stable (high binding energy per nucleon) and others which have their nuclei unstable (low binding energy per nucleon).

Unstable nuclei are said to be: Radioactive, they disintegrate to give rise to new stable nuclei.

The disintegration of nucleus can occur spontaneously (this is natural radioactivity) or it can be caused (this is artificial radioactivity).

I. Natural radioactivity

The lightest unstable nuclei emit e^- or β^- particles however heavy nuclei can emit e^- or α particles (helium nucleus).

α and β emissions are often accompanied by an emission of very energetic photons called gamma radiation.

1) Emission α

Heavy nuclides are radioactive and have a low average binding energy, any process which transforms such nuclides into lighter nuclides with strong binding energy will be favored, this is the case of α decay.

Example :

Thorium ^{232}Th is an α particle emitter.

$$^{232}Th \longrightarrow {}^{4}He + {}^{228}Ra$$

2) Emission β

When the N/Z ratio is too high, nuclides emit electrons.

How do we accept that a nucleus composed of protons and neutrons emits electrons?

$$^{1}_{0}n \rightarrow {}^{0}_{-1}e + {}^{1}_{1}p$$

Example :

$$^{14}_{6}C \rightarrow {}^{0}_{-1}e + {}^{14}_{7}N$$

3) Radiation ɣ

The ejection of α and β particles is accompanied by strong internal excitation of the nucleus which results in the emission of very energetic electromagnetic radiation (short wavelength $\lambda<1A$).

II. Nuclear reactions and artificial radioactivity

Artificial nuclear reactions are divided into three types:

Transmutations, fissions and fusions.

The production of these reactions depends on:

The nature of the bombarded core, the nature of the projectile and the energy of the projectile.

1) Nuclear transmutation

These reactions produce nuclides with a mass number equal to or close to that which served as the target.

The nuclides formed are stable or radioactive.

Example :

$$^{14}_{7}N + {}^{4}_{2}He \rightarrow {}^{17}_{8}O + {}^{1}_{1}H$$

$$^{27}_{13}Al + {}^{4}_{2}He \rightarrow {}^{30}_{15}P + {}^{1}_{0}n$$

$$^{6}_{3}Li + {}^{2}_{1}H \rightarrow {}^{7}_{3}Li + {}^{1}_{1}H$$

$$^{23}_{11}Na + 11H \rightarrow {}^{23}_{12}Mg + {}^{1}_{0}n$$

Abbreviated Notation:

$^{14}N(\alpha,p)^{17}O$, $^{27}Al(\alpha,n)^{30}P$, ……………. Etc.

2) Nuclear fission

The produced nuclei (72<A<162) are much lighter than the target nuclei which have a high mass number A > 200

Example: Bombing of uranium

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{143}_{56}Ba + ^{90}_{36}Kr + 3^{1}_{0}n$$

Noticed:

The bombardment of uranium $^{235}_{92}U$ can give rise to other forms of nuclides.

Fission reactions release considerable energy compared to transmutation reactions.

3) Nuclear fusions

In fusion reactions, light nuclei come together to form heavier nuclei.

Example :

$$^{2}_{1}H + ^{3}_{1}H \longrightarrow ^{4}_{2}He + ^{1}_{0}n$$

III. Law of radioactive decay

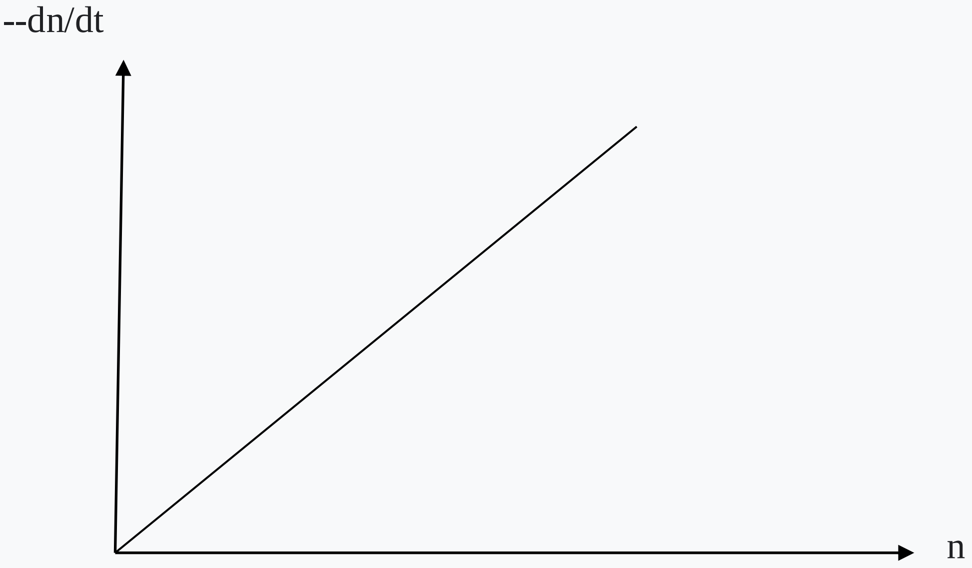
Either disintegration: A $\longrightarrow$ B where B is not radioactive.

Experimentally, we can count the number of particles emitted per unit of time.

This number is equal to: -dn/dt where dn: represents the variation in the number of radioactive nuclei A during the time dt.

Since this is a decrease, dn is negative.

n designates the number of unstable nuclei present in the sample at time t.



$-dn/dt = \lambda . n$ (λ is a constant) (linear function)

The law of decay of the number of nuclei of A as a function of time is obtained by integrating the 1st order differential equation.

$-dn/dt = \lambda . n \longrightarrow -dn/n = \lambda . dt$ hence $\int_{t=0}^{t} -dn/n = \lambda \int_{t=0}^{t} dt$

Which gives: $-\mathrm{Ln}(n)\Big|_{t=0}^{t} = \lambda . t\Big|_{t=0}^{t}$

When t=0 we have $n=n_0$ and the number of unstable nuclei at time t there are n unstable nuclei in the sample studied, so we will have:

$-(\mathrm{Ln}(n)-\mathrm{Ln}(n_0)) = \lambda .(t-0) \rightarrow -(\mathrm{Ln}(n/n_0)) = \lambda . t \longrightarrow n/n_0 = e^{-\lambda t}$

Hence**:** $\mathbf{n(t) = n_0\, e^{-\lambda t}}$ the decay law

The period

Definition: the period is the time after which 50% of the nuclei in the sample have disintegrated.

Notation: We note the period T or t1/2

At half time $t_{1/2}$, $n(t_{1/2)=}n_0$ /2 then $n(t_{1/2}) = n_0 /2 = n_0 e^{-\lambda\, t1/2}$

Hence: **$\lambda = Ln(2)/t_{1/2}$**

IV. Applications

Radioactivity has a very broad field of application; it can be used in various fields.

It can be used: for the dating of archaeological pieces, dating of rocks, in medicine and biology as it can be used for the production of energy (for civil and military reasons).

Among these applications we are interested in the dating of archaeological pieces.

Dating of archaeological pieces

Cosmic neutrons constantly bombard atmospheric nitrogen and transform it into ^{14}C according to the nuclear reaction:

$$^{14}_{7}N + ^{1}_{0}n \longrightarrow ^{14}_{6}C + ^{1}_{1}H$$

The ^{14}C oxidizes to CO_2 and will be absorbed by plants which are in turn consumed by animals.

In a living organism the absorption of ^{14}C and its β-decay are naturally balanced. The activity of ^{14}C is constant and equal to 15.3 des/min.

When life ceases there is no supply of ^{14}C and activity decreases.

The decay period of ^{14}C is 5668 years, so by measuring the activity of ancient objects: pieces of wood, bones, etc., we can determine their age.