Detection and measurement of different type of isotopes used in biology

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Unit 3- Radiolabeling techniques

Detection and measurement of different types of radioisotopes used in biology, incorporation of radioisotopes in biological tissues and cells, molecular imaging of radioactive material, safety guidelines.

Atom ?

- An atom is fundamental piece of matter. An atom itself is made up of three tiny kinds of particles called subatomic particles: protons, neutrons and electrons..
- The protons and neutrons make up the center of the atom called the nucleus.
- The electrons fly around above the nucleus in a small cloud.
- Protons are positively charged while electrons are negatively charged sub atomic particles.
- The number of protons present in the nucleus is known as the atomic number (Z)
- Neutrons are uncharged particles with a mass approximately equal to that of a proton.
- The sum of the protons (z)and neutrons(N) in a given nucleus is the mass number (A)

$$A=Z+N$$

Isotopes

- ✓ Atoms of a given element with different mass numbers (i.e. different numbers of neutrons) are called isotopes.
- ✓ Different isotopes of the same element have the same number of protons in their atomic nuclei but differing numbers of neutrons.
- ✓ A nuclear species is represented by a subscript number for the atomic number, and a superscript number for the mass number (atomic weight) followed by the symbol of element.

  $^{16}{}_{8}O$ (8= atomic number of oxygen atom, 16= atomic mass or mass number of oxygen atom)

- ✓ The number of isotopes of a given element varies: there are three isotopes of hydrogen ($^{1}{}_{1}H$, $^{2}{}_{1}H$, $^{3}{}_{1}H$), seven of carbon ($^{10}{}_{6}C$- $^{16}{}_{6}C$) etc.

Stability of isotopes

- Ratio of neutron and proton determine the stability of isotopes.
- For stable isotopes N/Z ratio will be 1.1-1.55
- Isotopes for elements with low atomic numbers tend to have an equal number of neutrons and protons in nucleus.
- Isotopes for elements with high atomic numbers requires more neutrons.
- Unstable isotopes called radioisotopes and they tend to be stable by radioactive decay.

Radioisotopes

- ✓ Radioisotopes are radioactive isotopes of an element. They can also be defined as atoms that contain an unstable combination of neutrons and protons, or excess energy in their nucleus.

- ✓ The radioactive isotopes or radioisotopes , are isotopes of an element having an unstable nucleus that decays (emitting alpha, beta, gamma rays) until stability is reached.

- ✓ The stable end product is a nonradioactive isotopes of another element.

- ✓ More than 3000 radioisotopes are known, of which only about 84 are seen in nature.

Alpha, beta and gamma radiation

- Alpha radiation is heavy charged particle and more toxic than other forms of radiation. It is non penetrating.
- Beta radiation is light charged particle and its toxicity is same as electromagnetic radiation per unit of energy. Its penetration potential varies with source.
- Gamma radiation is an electromagnetic radiation and it is highly penetrating.

Types of radioactive decay

- **Negatron emission Or Negatively charged beta particles (β^-)**
- **Positron emission Or Positively charged beta particles (β^+)**
- **$\alpha-$ particle Emission Or Helium nucleus (^4_2He)**
- **γ-rays emission**

Effects of decay on radioisotopes

- Emission of negatron results in loss of a neutron and gain of a proton so the mass number remain constant.

$$^{12}_{6}C \longrightarrow {}^{14}_{7}N + \beta^{-}$$

- $^{14}_{6}C$ which decaying negatron is an isotope which frequently used in biological work.
- $^{14}_{6}C$ and $^{3}_{1}H$ used to label any organic compound; ^{35}S used to label methionine(for protein synthesis), ^{32}P and ^{33}P used for nucleic acid labelling.
- Emission of positron results in loss of a proton from nucleus and gain of neutron so the mass number remain unchanged.

$$^{22}_{11}Na \longrightarrow {}^{22}_{10}Ne + \beta^{+}$$

- Positron emitters can be detected by same instruments used to detect γ-radiation. They are used in biological sciences to spectacular effect in brain scanning with the technique PET scanning used to identify active and inactive areas of the brain.

- Emission of alpha particles results in a considerable lightening of the nucleus , a decrease in atomic number of 2 and a decrease in the mass number of 4. isotopes that decay by alpha emission are not frequently encountered in biological work although they can be found in instruments such as scintillation counters and smoke alarm. Alpha emitters are extremely toxic if ingested , due to the large mss and the ionising power of the alpha particles.

$$^{226}_{88}Ra \longrightarrow {}^{4}_{2}He^{2+} + {}^{222}_{86}Rn \longrightarrow \longrightarrow \longrightarrow {}^{206}_{82}Pb$$

- In some cases alpha and beta particle emission also give rise to γ – rays (electromagnetic radiation similar to, but with a shorter wavelength than , X-rays). The radiation from ^{60}Co will penetrate 15 cm of steel. The toxicity of γ – radiation is similar to that of X-rays.

- $$^{131}_{53}I \longrightarrow {}^{131}_{54}Xe + \beta^{-} + \gamma$$

Decay energy

- Decay energy of α particle is falling in the range 4.0-8.0 MeV(Million or mega electron volts)
- Decay energy of β and γ– emitters is < 3.0 MeV
- Decay energy directly related to penetration power and potential of toxicity.
- 1eV(electron volt)=1.6X 10^9 J (jule)

Rate of decay

- Decay of radioactive element measured as disintegrations per minute(d.p.m.). It is a spontaneous process and it occurs at a rate characteristic of the source, defined by the rate constant(λ).

- Rate constant or decay constant (the fraction of an radioisotope decaying in unit time) is not affected by temperature or pressure because decay of radioisotopes are nuclear event.

The number of atoms disintegrating at any time is proportional to the number of atoms of the isotopes present at that time (t).

The graph of radioactivity against time shows a curve , called an exponential decay curve.

$$\ln N_t/N_o = -\lambda t$$

Unit of radioactivity

- In SI system becquerel(Bq) is the unit of radioactivity.
- It is defined as one disintegration per second.
- Curie (Ci) is another most popular frequently used unit of radioactivity.
- This is defined as the quantity of radioactive material in which the number of nuclear disintegrations per second is the same as that in 1gm of radium, namely 3.7×10^{10} (37 GBq)

Because Curie (Ci) is larger unit so in the case of biological system millicurie (mCi)and microcurie (μCi) are used.

Bq and Ci refers to the actual disintegrations occur in sample while counts per second (c.p.s.) are referred to detected decays.

Half-life

The rate at which a radioactive isotope decays is measured in half-life. The term half-life is defined as the time it takes for one-half of the atoms of radioactive material to disintegrate. In other word we can say that Half-life is the time required for a quantity to reduce to half of its initial value.

Half-life is denoted by $\mathbf{t_{1/2}}$ symbol.

Decay can be described by any of the following formula

$$N(t)= N_0 (1/2)^{t/ t_{1/2}}$$

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

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

$N (t)$= Remaining quantity after a time t

N_0 = Initial quantity

$t_{1/2}$ = Half- life of the decaying time

τ= a positive number called the mean life time of the decaying quantity

λ= a positive number called the decay constant

If number of half life is ‘n’ then remaining fraction will be **$1/2^n$** and remaining percentage of radioactive material will be **$100/2^n$.**

The three parameters $t_{1/2}$, λ and τ all are directly related in the following way

$$t_{1/2} = \ln(2)/\lambda = \tau \ln(2)$$

Where In(2) is the natural logarithm of 2 (approximately 0.693)

The value of $t_{1/2}$ vary widely from over 10^{19} years for lead (^{204}Pb) to 3x 10^{-7} second for polonium (^{212}Po)

Radioactive isotopes and their half-life

^{60}Co – 5.20 years

^{131}I -8.04 days

^{125}I -59.6 days

^{35}S – 87.4 days

^{133}Xe- 5.245 days

^{32}P-14.3 days

^{33}P-25.4 days

^{3}H-12.3 days

^{14}C -5370 years

^{11}C-20.4 min

^{18}F-110 min

^{235}U -4.5X$\mathbf{10^{9}}$ **Years**

^{59}Fe-44.5 days

^{99m}Tc- 66 hours

Thank you