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Different types of radiation from radioactive substance

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The radiations emitted by radioactive substance are of three types - (i) α-rays, (ii) β-rays (iii) γ-rays.

Nature (i) α-rays consist of nuclei of helium atoms He^4_2 moving with velocities of the order of 10^7 m/sec. They have a positive charge twice in magnitude of the charge of an electron and mass equal to 4 atomic mass unit.

(ii) β-rays consist of electrons moving with a velocity of the order of 1% to 99% of the velocity of light. As these rays consist of electrons, they have a negative charge equal to 1.6×10^{-19} coulomb and the same mass as that of electron.

(iii) γ-rays are electromagnetic waves of very short wave length ranging from ·005 to 0·5 Å.

Properties of α-rays :-

(i) The α-rays are shot out from the radioactive material with large velocities ~~from a given substance~~ ranging from 1.4×10^7 to 1.7×10^7 m/sec.

The velocity of α-rays depends upon the radioactive substance from which they are ejected and from a given substance it is always the same.

(ii) They produce intense ionisation in the gas through which they pass. Their ionisation power is 100 times greater than that of β-rays and 10,000 times greater than that of γ-rays.

(iii) They affect a photographic plate. The effect is, of course, very feeble.

(iv) They produce fluorescence in substance like zinc sulphide. On observing the fluorescence through a low power microscope it is found to consist of successive scintillations produced by the impact of an individual α-particle.

(v) Range of α-particles:- Scintillation from α-particle cease abruptly after it has traversed a certain through matter. The distance that an α-particle can travel in air, at atmospheric pressure is called its range in air. It varies from 2·70 cm for a α-particle given by Uranium to 8·62 cm for those of thorium C. The range of an α-

article depends upon
The radioactive substance from which the rays are given out.
The nature of the medium through which the rays travels.
velocity of emission. The range is proportional to v^3
the number of α-particle in a beam remains constant
up to the end of the range. but their energy goes in decreasing.
Ultimately the α-particles do not have sufficient energy to produce
either scintillations or ionisations.
The ionisation first increases slightly, reaches a maximum
and then suddenly drops almost to zero value. The distance
at which the ionisation drops almost to zero gives the range of
α-particles
(i) The α-rays are scattered when they pass through thin sheets
of mica, gold foil etc. The divergence of α-particle from its
straight line path is 2 to 3 degree. Geiger and Marsden found
that a few particles some times were deflected by more than
90°. This is due to the repulsion betn the α-particles.
(ii) The α-rays deflected by electric and magnetic ~~field~~ field
showing that they are charged particle.
(iii) They produce a heating effect. A quantity of radium
always maintains itself at a temperature higher than that
of the surrounding.
(ix) when exposed to α-rays the body suffers incurable burns.

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α- Decay

Alpha - Emission

Alpha emission:- The nucleus consist of protons and neutrons, collectively known as nucleons. The number of proton is equal to the atomic number Z and the number of neutrons is equal to (A-Z) where A is the mass number. The protons carry a positive charge and there is an electrostatic force of repulsion between them. The total repulsive force in the nucleus is approximately proportional to Z^2. The gravitational force of attraction between the nucleons is very weak. The nuclear attract force between the nucleons is of a very short range and the total binding energy of a nucleus is therefore approximately proportional to its mass number. A.

High energy of α-particles favours emission:-
The α-particle which consist of two protons and two neutrons has a very high binding energy of more than 28 MeV because the α-particle mass is sufficiently smaller than that of its constituent nucleons.
Thus the formation of an α-particle within the nucleus makes available the kinetic energy of the particle must have to escape from the nucleus. The K.E. is known as disintegration energy released in the process of emission of a particle from a heavy nucleus is given by

$$Q = [M_p - (M_d + M_s)]c^2 \quad \text{--- (1)}$$

where M_p is the mass of the parent nucleus, M_d the mass of the daughter of nucleus, and M_2 the mass of the particle emitted. Nuclei which contain 210 or more nucleons are so large that the short range molecular forces that hold them together are hardly able to counterbalance the mutual repulsive force between the protons. The α-decay occur in such a nuclei as a means of increasing their stability by reducing their size and is energitically possible. The α-decay from U^{238}_{92} nucleus is accompanied by a release of 5.4 MeV of energy. This value agree with the values predicted from the nuclear masses involved in the process.

The radio active nuclei whose atomic number Z is greater than 82 (mass number 208) spontaneously disintegrate with parent nucleus decaying into a daughter nucleus have a kinetic energy even if the ~~kinetic energy~~ parent nucleus is at rest, the condition necessary for emission of an α - particle is that the sum of the masses of the daughter nucleus and the α - particle must be less than the mass of the parent nucleus. The decrease in mass appears as the kinetic energy of the α - particle and the daughter nucleus.

proton and He^3_2 emission not possible! - On the other hand release of proton will require 6.1 MeV and that of He^3_2 nucleus 9.6 MeV of energy to be supplied from outside. Hence emission of individual proton or He^3_2 nuclei is not energetically possible.

Condition for α-decay

Whenever an α- particle is emitted by a radioactive nucleus the following conservation law must be obeyed.

(i) Conservation of charge and the number of nucleons:-

In α-decay, as in all nuclear reactions, the total charge and the total number of nucleons must be conserved. If A is a mass number and the Z the atomic number of the parent then $P^A_Z = D^{A-4}_{Z-2} + He^4_2$ where P and D refer to the parent and daughter nuclei. As a ~~example~~ particular example we have the decay of Bismuth 212 in to Thallium 208 according to the reaction.

$$B^{212}_{83} = Tl^{208}_{81} + He^4_2 .$$

It will be seen that the sum of the nucleon numbers on the right (208+4) is equal to the nucleons number on the left (212) and the sum of the units of charge on the right (81+2) is equal to the total charge (83) on the left.

(ii) Conservation of linear momentum:-

The linear momentum must also be conserved in the emission of α-particle. If the parent nucleus of mass M_p is at rest, then initial momentum $=0$

If the daughter nucleus of mass M_d has a velocity V_d and the α-particle of mass m a velocity u, then final momentum $= M_d V_d + mu$.

$$\text{Hence } M_d V_d + mu = 0$$

$$\text{or } mu = -M_d V_d \quad \text{——— (II)}$$

In other words, the daughter nucleus must have a velocity in a direction opposite to that ~~of~~ in which the α-particle is ejected.

(III) Conservation of mass-energy:—

If E is the energy with which the α-particle is ejected and E_d is the K.E of the daughter, then according to the principle of conservation of mass energy

$$M_p c^2 = M_d c^2 + mc^2 + E_d + E \quad \text{——— (III)}$$

we have the K.E or disintigration energy of α-particle is $Q = (M_p - M_d - m)c^2$ ——— (III)a

This can be put in the form

$$Q = E_d + E = \frac{1}{2} M_d V_d^2 + \frac{1}{2} m u^2 \quad \text{——— (IV)}$$

From equn (II) $V_d = \dfrac{-mu}{M_d}$

$$\text{or } (V_d)^2 = \left(\frac{mu}{M_d}\right)^2$$

substituting in (IV) we have

$$Q = \frac{1}{2} mu^2 + \frac{1}{2} mu^2 \left(\frac{m}{M_d}\right)$$

$$= \frac{1}{2} mu^2 \left(1 + \frac{m}{M_d}\right) = E\left(1 + \frac{m}{M_d}\right)$$

As $Q = E\left(1 + \frac{m}{M_d}\right)$, the α-particle energy E is less than the disintegration energy Q.

For example, decay of Bi^{212} in to Thallium 208 with the emission of an α-particle, the K.E of the α-particle $E = 10.54$ MeV, the mass of the daughter nucleus is $212 - 4 = 208$ and mass of α-particle $= 4$.

$$\therefore Q = E\left(1 + \frac{m}{M_d}\right) = 10.54\left(1 + \frac{4}{208}\right) = 10.54 \times \frac{212}{208} = 10.74 \text{ MeV}$$

i.e when Total disintegration energy available is 10.74 MeV, α-particle is emitted with an energy 10.54 MeV. The balance 0.2 MeV becomes the K.E of daughter nucleus.

Energy of α-particle discrete in α-decay :-

The formation of an α-particle within the nucleus makes available the kinetic energy the particle must have to escape from the nucleus. The K.E Q known as the disintegration energy released in the process of emission of an α-particle from a heavy nucleus is given by

$$Q = [M_p - (M_d + M_\alpha)]c^2$$

where M_p is the mass of the parent nucleus, M_d the mass of product or daughter nucleus and M_α the mass of α-particle emitted. Thus if the daughter nucleus does not carry any energy the α-particles has a discrete value of energy as all other factors constant. Even if the daughter nucleus carries some energy the α-particle energy will be less by the same amount but it will still have a discrete value.

Range of α-particle.

The α-particles have the property of ionising a gas. As the α-particles pass through gas, these lose energy by ionising the gas particles and slowed down. This process continues till the energy of the α-particles falls below the ionisation potential of the gas. After this, the α-particle captures two electrons and becomes a neutral helium atom.

The distance the α-particle travels in the gas before its energy falls below the ionisation potential of the gas is called its range in that gas.

The range is usually expressed in cm in air at 76 cm of mercury pressure and 15°C. The range depends upon

i) The initial energy of the α-particle.
ii) The ionisation potential of the gas
iii) Nature and pressure of the gas.

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