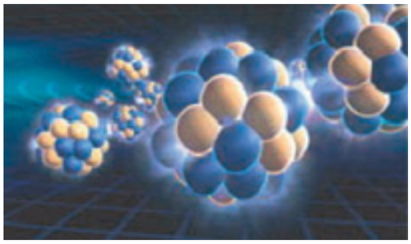


9

NUCLEAR ENERGY

Radioactivity

Changes in the nucleus

OBJECTIVES

At the end of the topic, students should be able to:

- describe the structure of the nucleus and explain isotopes;
- identify the radiations from radioactive substances using their characteristics;
- explain half-life and decay constant and solve simple problems involving half-life of radioactive substances;
- distinguish between natural and artificial radioactivity;
- state some uses of radioactive substances;
- determine the products of radioactive decay.

The Nucleus

An atom has three basic particles, the **electron,** the **proton** and the **neutron.** Protons and neutrons form the central core called **nucleus.** The mass of the entire atom is concentrated in the nucleus. The nucleus is very small; it is about 10^{-15} m in diameter.

The proton is positively charged with a mass of 1.67 Ã— 10^{-27} kg. The neutron has no charge; its mass is nearly the same as the mass of proton.

The proton number (Z): the proton number formerly called **atomic number** is the total number of protons in the nucleus of an atom. Proton number (Z) determines the position of an element in the periodic table and their chemical properties.

The nucleon number (A): the nucleon number formerly called mass number is the total number of protons and neutrons in the nucleus of an atom. The mass of the whole atom depends on its mass number since the mass of the electron is negligible.

Nuclide: an atom with the proton number and the nucleon number specified is a **nuclide.** A nuclide is represented by:

$$^{A}_{Z}X$$

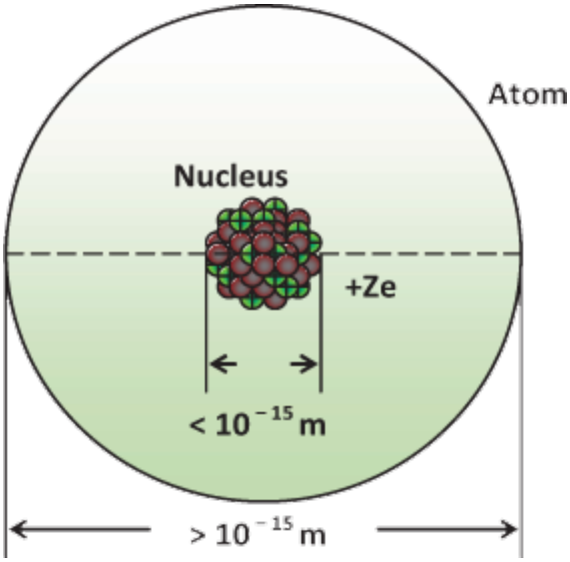


Figure 9.1 : An atom showing the size of nucleus

X = chemical symbol of the element
A = nucleon (mass) number
Z = proton (atomic) number.
Some examples of nuclide include:

$^{1}_{1}H,\ ^{4}_{2}He,\ ^{7}_{3}Li,\ ^{16}_{8}O,\ ^{23}_{11}Na,$

$^{35}_{17}Cl,\ ^{235}_{95}U, etc$

Isotopes

Isotopes are nuclides of the same element. They have the same proton number but different nucleon number (i.e. *isotopes differ in the number of neutrons in the nucleus of the element).* The total number of neutrons in the nucleus of an element is given by:

$$n = A - Z$$

Isotopes of the same element have the same chemical properties since they have the same number of protons. Examples of isotopes are:

- Isotopes of hydrogen

  (i)Hydrogen – 1 $^{1}_{1}H$ (very abundant)

  (ii)Hydrogen – 2 or Deuterium $^{2}_{1}H$

  (iii)Hydrogen – 3 or Tritium $^{3}_{1}H$ (radioactive)

- Isotopes of carbon:

  (i)Carbon – 12 $^{12}_{6}C$ (very abundant)

  (ii)Carbon – 13 $^{13}_{6}C$

  (iii)Carbon – 14 $^{14}_{6}C$ (radioactive)

- Isotopes of chlorine:

    (i)Chlorine – 35 $^{35}_{17}Cl$ (very abundant)

    (ii)Chlorine – 37 $^{37}_{17}Cl$

- Isotopes of uranium:

    (i)Uranium – 235 $^{235}_{92}U$ (scarce)

    (ii)Uranium – 238 $^{238}_{92}U$

Changes in the nucleus

Radioactivity deals with changes in the nucleus of an atom. Henri Becquerel discovered radioactivity in 1896. Radiations emitted by uranium compound blackened a photographic plate used to wrap it. Ernest Rutherford called these radiations **alpha** (Î±), **beta** (Î²) and **gamma** (Î³).

Radioactivity is the spontaneous disintegration of radioactive nuclide with the emission of alpha (Î±), beta (Î²) and gamma (Î³) radiations

Radioactive nuclide (element)

A nuclide, which disintegrates naturally on its own to produce a new element, is a radioactive element. Radioactive elements are heavy and unstable. This is because they contain many protons, therefore, the repulsive force among the protons makes it easy for the nuclide to disintegrate (breakdown) spontaneously.

Examples of radioactive elements are uranium, radium, radon, thorium, polonium etc. All radioactive elements have proton number greater than 82.

Properties of radioactive radiations

1.The effect of electric and magnetic field on

(i) Alpha (Î±) **particles**

Electric and magnetic fields deflect alpha particles slightly. In the electric field, Î± -particles are deflected a little towards the negative plate. This suggests that Î± - particles are **heavy particles carrying positive charges.** In a magnetic field, Î± - particles Î³ are deflected a little towards the S- Pole.

(ii) **Beta** (Î²) **particles**

Beta particles deflect strongly towards the positive plate in an electric field. They are **light particles with negative charges.** In the magnetic field, Î² – particles are deflected towards the N-Pole of a magnet.

(iii) **Gamma** (Î³) **rays**

Electric and magnetic fields do not deflect gamma rays and **therefore they are not particles but electromagnetic waves.**

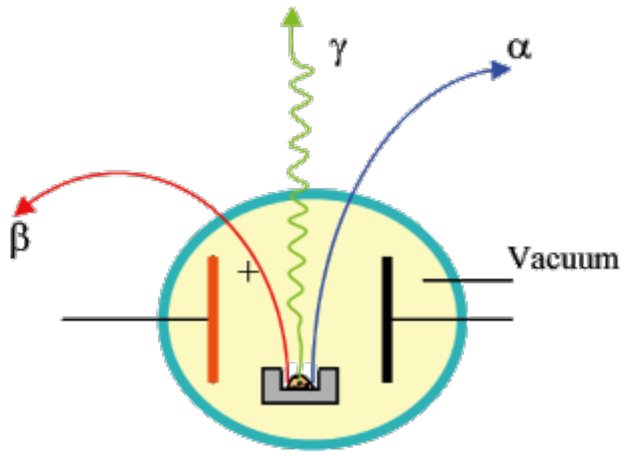


Figure 9.2

2. Ability to penetrate matter

Rutherford showed that these radiations have different energies and penetrate matter depending on their energy.

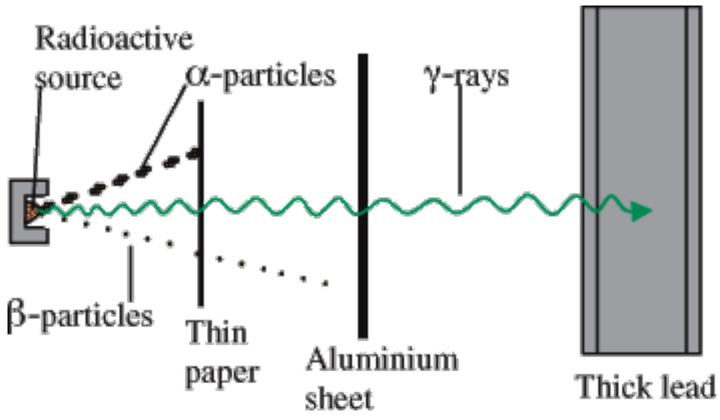


Figure 9.3

3. Ability to ionize gas (air)

A particle has the ability to knock out electrons from gas atoms because of its momentum (mass). This is called **ionization.** Some of the radioactive radiation can ionize gas molecules.

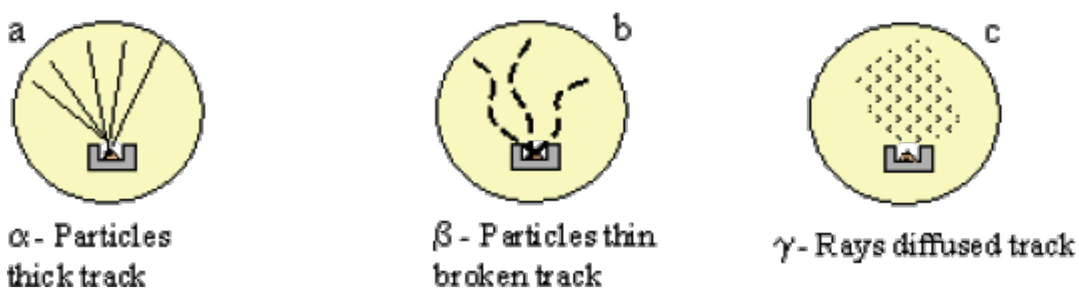


Figure 9.4 : Cloud tracks

(i) Alpha (Î±) particles

Alpha particles are stopped by a thin paper. They have low penetrating power. In air, alpha particles have short range (6 cm) before they are absorbed.

(ii) **Beta (Î²) particles**

Beta particles pass through paper with ease but aluminium sheet (about 5 mm) absorbs it. Hence Beta particles are stopped by aluminium sheet.

(iii) **Gamma (Î³) rays**

Gamma rays penetrate most materials but is absorbed by thick lead or concrete block.

(iv) **Beta (Î²) particles**

Beta particles, when passed through a bubble chamber, produce thin broken lines as a bubble tracks. This shows that Î² - particles are light particles with great ionization power.

(v) **Gamma (Î³) rays**

Gamma rays produce a highly diffused cloud tracks. They are electromagnetic radiation with no ionization ability.

(vi) Alpha (Î±) particles

Alpha particles can ionize air molecules. Their ionization ability is high. If Î± - particles are passed through a bubble chamber, a thick track is produced as shown in figure 9.4a. The tracks are thick straight lines showing that Î± - particles are heavy particles.

Summary

		α - particles	β - particles	γ - particles
1.	Effect of electric field	Deflected towards the – ve plate	Deflected towards the + ve plate	Not affected by electric field
2.	Effect of magnetic field	Deflected towards the S-Pole	Deflected towards the N-Pole	Not affected by magnetic field
3.	Nature of charge	Positively charged	Negatively charge	Neutral
4.	Mass	Massive particle	Small particle	No mass
5.	Mass	Possess high momentum	Low momentum	No momentum
6.	Momentum	Low penetrating power	High penetrating power	Very high penetrating power
7.	Penetrating power	High ionizing power	Low ionizing powe	No ionizing power
8.	Ionization power Nature of particle	Helium nucleus	High energy (fas moving) electrons	Electromagnetic radiation of short wavelength

Radioactive Decay

Radioactive nuclides are unstable. They tend to become stable by giving out radioactive particles spontaneously. If this happens, the nuclide is said to decay.

Radioactive decay is the spontaneous disintegration of radioactive nuclide until a stable nuclide is formed.

The decay process will continue until a new element, which is stable, is formed. Examples of radioactive decay or series are

$$^{234}_{92}U \rightarrow {}^{230}_{90}Th + {}^{4}_{2}He(\alpha) + \Delta E$$
$$^{230}_{90}Th \rightarrow {}^{226}_{88}Ra + {}^{4}_{2}He(\alpha) + \Delta E$$
$$^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}He(\alpha) + \Delta E$$
$$^{222}_{86}Rn \rightarrow {}^{198}_{84}Po + {}^{4}_{2}He(\alpha) + \Delta E$$

- Decay by ejecting Î± - particles

When a nuclide decays by giving out Î± - particles, a new element is produced. The nucleon (mass) number of the element produced is four less than the nucleon number of the original (parent) nuclide. The proton (atomic) number of the new element is decreased by two. The new element formed is displaced two places to the left of the original element in the periodic table.

$$^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He + \Delta E$$
$$^{234}_{92}U \rightarrow {}^{230}_{90}Th + {}^{4}_{2}He(\alpha) + \Delta E$$

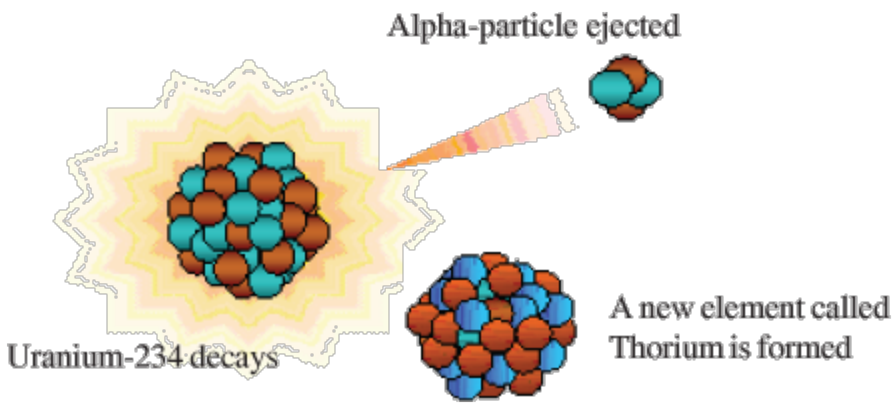


Diagram illustrating decay by emission of alpha- particle

Decay by ejecting Î² – particles:

When an atom decays by Î² – particles emissions, a new element is produced. The proton number (Z) of the element formed is increased by one but the nucleon number (A) remains the same.

$$^{A}_{Z}X \rightarrow {}_{Z+1}^{A}Y + {}^{0}_{-1}\beta + \Delta E$$
$$^{24}_{11}Na \rightarrow {}^{24}_{12}Mg + {}^{0}_{-1}\beta + \Delta Ea$$

A nuclide can decay by ejecting Î± - particles or Î² – particles to form new elements.

Decay by emission of Î³ – rays does not produce new elements. It only changes energy state of the nuclide. The new element is produced. The position of the element in the periodic table is one place to the right of the original element.

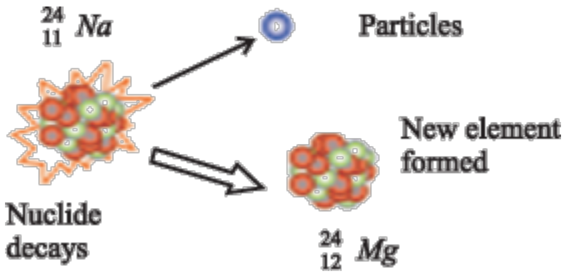
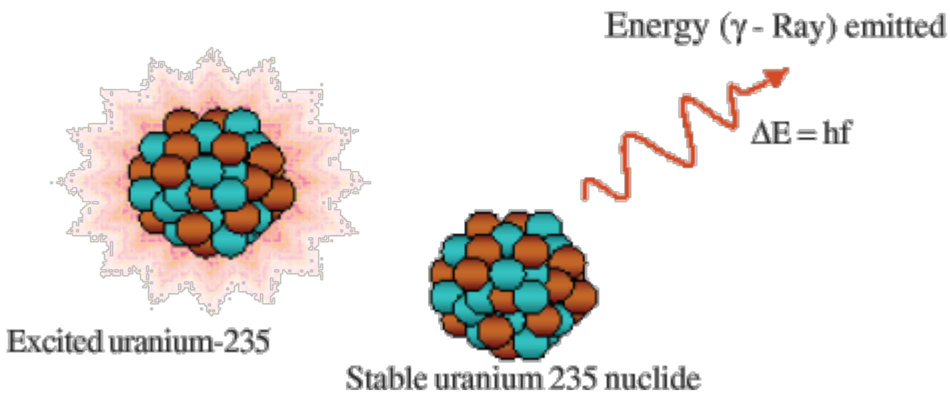


Diagram illustrating decay by beta particle emission

Gamma - emission

The emission of Î³ – radiations does not produce new elements. It only changes the energy state of the nuclide.

$${}^{A}_{Z}X^{*} \rightarrow {}^{A}_{Z}X + \Delta E$$



Half-life

Half-life is the time it takes half of the original number of atoms in a given sample of radioactive element to decay.

Half-life of an element determines its stability. Stable elements have long half-life; this is why they exist naturally. Elements with short half-life are unstable and decay to form stable ones. An element with half-life of 5 seconds will have half of its atom decaying after 5 seconds leaving behind only half. If the number of atoms at the beginning is N, $\frac{N}{2}$ atoms will decay, leaving behind $\frac{N}{2}$ atoms. In the next 5 seconds or 10 seconds later, only $\frac{N}{4}$ atoms remain while $\frac{3N}{4}$ atoms decay.

Decay curve

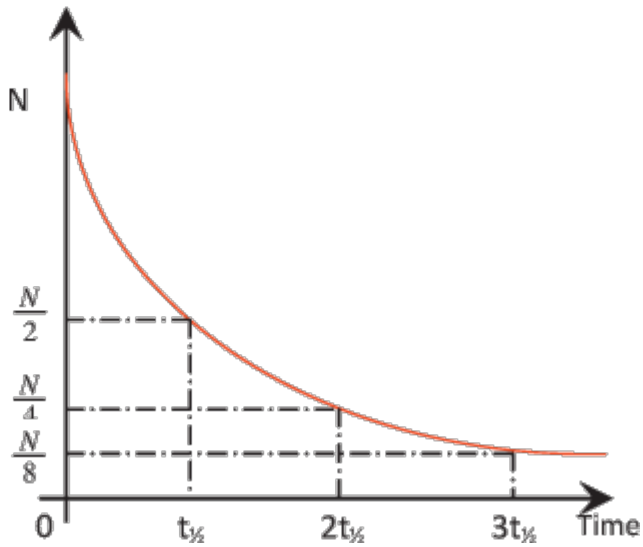


Figure 9.5

Figure 9.5 is a decay curve of a radioactive element. The curve is an exponential curve showing the number of atoms decaying per seconds or activity (R). The rate of decay or activity is proportional to the number of atoms (N) present at the beginning. The unit of activity is Becquerel (Bq).

Rate of decay â^ Number of atoms at the beginning

$$-\frac{dN}{dt} \alpha N$$

$$-\frac{dN}{dt} \alpha N$$

The constant Î» is the **disintegrating or decay constant** of the radioactive element. The unit of decay constant is per second (s^{-1}).

Disintegrating or decay constant is the ratio of the number of atoms decaying per second to the number of atoms present at the beginning.

$$t_{1/2} = \frac{I_n 2}{\lambda} = \frac{0.693}{\lambda}$$

The decay constant is related to half-life of a radioactive element by:

$$t_{1/2} = \frac{I_n 2}{\lambda} = \frac{0.693}{\lambda}$$

The number of atoms decayed in a given time (t) is given by:

$$N_t = Ne^{-\lambda t}$$

N = number of atoms present at the beginning
N_t = number of atoms that decayed in a time t
Î» = disintegrating or decay constant
t = time in seconds.

Worked examples

1. The half-life of a radioactive element is 3 seconds. If there are 15,000 atoms at the beginning, calculate the:
   (a)decay constant of the element;
   (b)the number of atoms remaining after 6 s;
   (c)fraction of the atoms that decayed after 6 s.

Solution

(a) $$\lambda = \frac{0.693}{t_{1/2}} = \frac{0.693}{3} = 0.231\ s^{-1}$$

At $t_0 = 0$ N = 15,000 atoms.

At $t_0 = 3$ $\frac{N}{2} = \frac{15,000}{2} = 7500\ atoms$

(b) At $t_0 = 6$ $\frac{N}{4} = \frac{7500}{2} = 3750\ atoms$

(c)Fraction of atoms that have decayed $= \dfrac{N - \frac{N}{4}}{N} = \dfrac{3N}{4N} = \dfrac{3}{4}$

Or

Number of atoms that decayed

= 15000 – 3750

= 11250 atoms.

Fraction of atoms that decayed $= \dfrac{11250}{15000} = \dfrac{3}{4}$

2. The half-life of an element is 1690 years. What is the decay constant of the element?

Solution

Half-life = $1690 \times 365 \times 24 \times 3600 = 5.33 \times 10^{10}$

$$\lambda = \frac{0.693}{t_{1/2}} = \frac{0.693}{5.33 \times 10^{10}} = 1.3 \times 10^{-11}\ s^{-1}$$

Splitting the atom

An element can be artificially converted to other elements by changing the structure of the nucleus. This is done by hitting or bombarding the nucleus of the atom with high-energy particles. Splitting of an atom by bombarding it with high-energy particles is called **atomic smashing or transmutation.**

Ernest Rutherford was the first man to split the nucleus of an atom and change an element from one form to another form. He used high energy Î± - particles to bombard (hit) nitrogen nuclide inside an evacuated chamber and discovered that the nitrogen nuclide changed into an isotope of oxygen and a proton.

Collision of Î± - particles with nitrogen nuclides to produce isotopes of oxygen nuclide and hydrogen (proton) is represented by the equation:

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

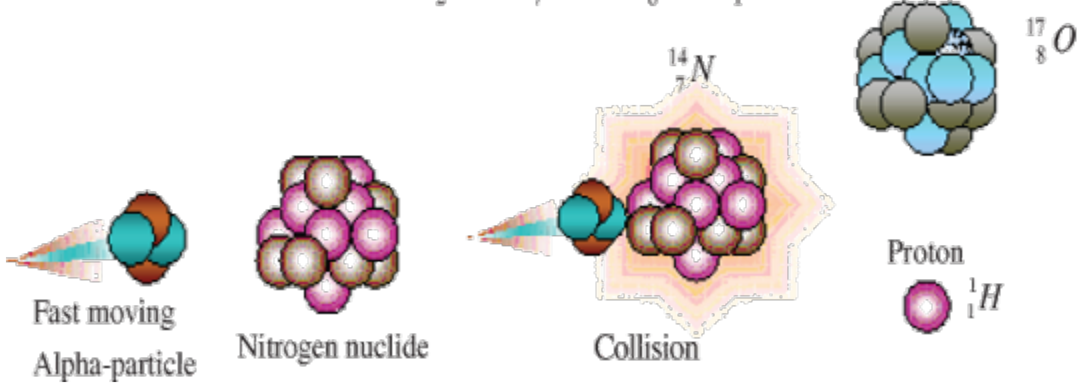
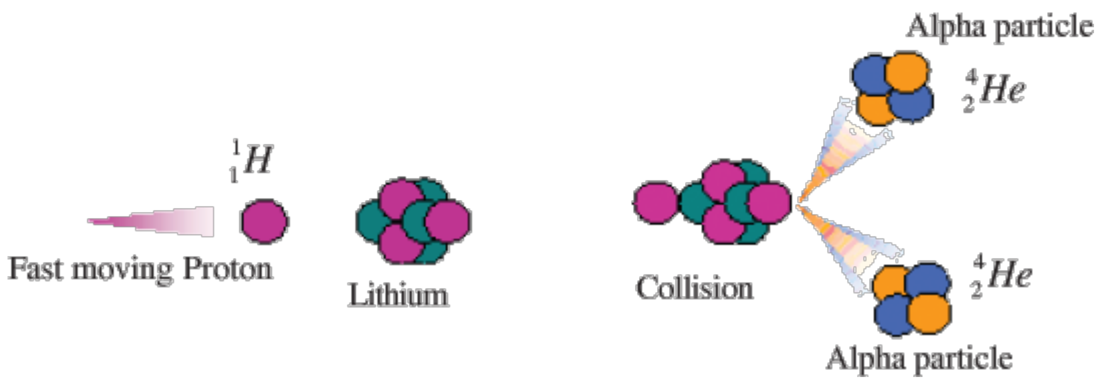


Figure 9.6 : Transmutation of nitrogen nuclide to oxygen nuclide by Î± - particle bombardment.

John Crockcroft and ETS Walton in 1932 designed and built the first particle accelerator to smash atoms. They used the particle accelerator to accelerate protons to high energy before using them to bombard (hit) lithium nuclide. Two Î± - particles are produced from the collision of high-energy protons with Lithium nuclide.

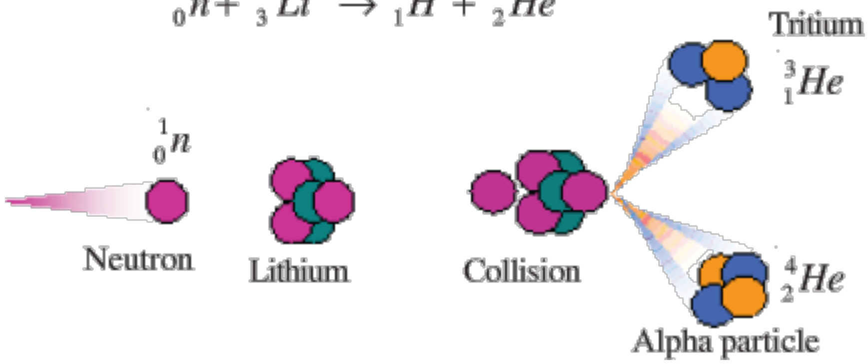
The equation of lithium disintegration by Î± - particle is given by:

$$ {}^{1}_{1}H + {}^{7}_{3}Li \rightarrow {}^{4}_{2}He + {}^{4}_{2}He $$



A neutron can also split a nucleus. Neutrons are not charged particles; therefore, they penetrate and smash the nucleus better than proton or *Î±* - particles. This is because neutrons as neutral particles are not deflected by the positively charged nucleus. Transmutation by neutron bombardment is represented by the equation below.

$$ {}_{0}^{1}n + {}_{3}^{6}Li \rightarrow {}_{1}^{3}H + {}_{2}^{4}He $$



The tritium nuclide decays by ejecting a Î² – particle to form an isotope of helium $({}_{2}^{3}He)$ which is more stable.

$$ {}_{1}^{3}H \rightarrow {}_{2}^{3}He + {}_{-1}^{0}\beta $$

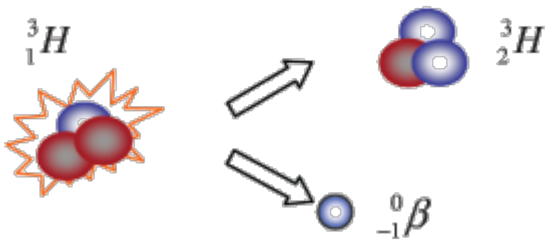


Figure 9.7 : Transmutations by neutron bombardment

Useful application of radioactivity

Radioactive substances are harmful, yet they have many useful applications in industries, agriculture and medicine. Some uses of radioactivity are:

1. Radioactive tracers:

The path of a substance through a system can be traced by adding a radioactive isotope to it. This is used in the industries, agriculture and medicine.

(i) **Industry:** radioactive tracers are used in the industries to locate leakages in underground pipes carrying oil or water. A small quantity of radioactive isotope is added to the substance and its path traced with GM-tube. The point where the count rate is high is likely to be where the pipe is broken. It is also used to detect wears in moving parts of engines.

(ii) **Agriculture:** radioactive tracer is used in agriculture to monitor the passage of water through the plant.

(iii) **Medicine:** radioactive tracers are used in medicine to locate brain tumours or blocked kidney. A small quantity of iodine is given to the patient and its path in the body traced with GM-tube to the place the tumour or blocked kidney is.

2. Sterilisation

(i) **Medicine:** Large dose of radiation can kill living cells. This is used in hospitals to kill germs in medical or surgical instruments and blanket.

(ii) **Agriculture:** Bacteria, moulds and yeasts, which grow on food items, cause food decay. When this food items are exposed to Î³ – radiations, these organisms are killed; therefore perishable food stay longer than usual.

3. Treatment of cancer and malignant growth in the body:

Radioactive radiations are used instead of X-rays in killing cancer growth (cells) and malignant growth like tumour in the body.

4. Detection of cracks or flaws

(i)Industry: Radioactive radiations are used to detect cracks or flaws hidden in welded joints, engine blocks and body of aeroplane.

(ii)Medicine: Radioactive radiations are used to detect broken bones and metal objects hidden in the body.

5. Thickness gauge

Radioactive radiations are used in the industries to control quality of product produced by a factory. The thickness of metal sheets, papers and nylon bags can be checked using a source of Î²-radiations on one side and a GM-tube on the opposite side. If the thickness of the metal sheet is increased, the count rate of GM-tube decreases and the machine is automatically adjusted.

6. Carbon-14 dating

Carbon-14, an isotope of carbon is radioactive. Plants take in small dose of carbon-14 from carbon (IV) oxide. Animals get carbon-14 from plants. When these plants and animals die, they cannot take in carbon-14 again. They already absorbed carbon-14 before their death decays slowly. The half-life of carbon-14 is about 5700 years; therefore, the ratio of carbon-14 remaining in dead plant and animal to the carbon-14 in living ones is used to estimate the age of the plant or animal from the time they died.

Health hazard of Radioactivity

Overdose of radioactive radiations is harmful. The dangers of overexposure to radiations are:

(a)Overexposure to Î± - particles can cause serious skin burn and destroy tissues and organs in the body.

(b)Î²-radiations and Î³ – radiations if absorbed in large dose can affect chromosomes or damage the human genes. This may cause abnormal cell growth and leukaemia.

(c)Overexposure to radioactive radiations may cause serious ill health or death.

Saftey Precaution

Radioactive radiations are very dangerous and must be handled with great care. Workers handling radioactive materials are safe-guarded from unnecessary absorption of radiations. The following precautions should be observed when working in an environment with high radiation risk.

(a)Thick lead or concrete blocks should be used to shield workers working with radioactive materials from the harmful radiation effects.

(b)Radiological workers should wear film sensitive to radiations as badges. This is developed and checked regularly to find how much radiation they have absorbed.

(c)The dose of radiation absorbed by a patient should be controlled.

Summary

- **Nucleus:** It forms the central core of atom; it consists of protons and neutrons. The mass of the entire atom is concentrated inside the nucleus. The nucleus is very small; it is about 10^{-15} m in diameter.
- **The proton number (Z):** The proton number or the atomic number is the total number of protons in the nucleus of an atom.
- **The nucleon number (A):** The nucleon number or the mass number is the total number of protons and neutrons in the nucleus of an atom.
- **Nuclide:** An atom with the proton number and the nucleon number specified is called a nuclide.
- **Isotopes:** They are nuclides of the same element. They have the same proton number but different nucleon number (i.e. isotopes differ in the number of neutrons in the nucleus of the element.
- **Radioactivity:** This is the spontaneous disintegration of radioactive nuclide with the emission of alpha (Î±), beta (Î²) and gamma (Î³) radiations.
- Radioactive element is a nuclide, which disintegrates naturally on its own to produce a new element.
- **Radioactive decay:** This is the spontaneous disintegration of radioactive nuclide until a stable nuclide is formed.
- **Half-life:** This is the time it takes half of the original number of atoms in a given sample of radioactive element to decay.
- **Disintegrating or decay constant:** This is the ratio of the number of atoms decaying per second to the number of atoms present at the beginning.
- **Transmutation or atomic smashing:** This is the splitting of an atom by bombarding it with high-energy particles.

Practice Questions 9

1. (a) Name the particles inside the nucleus of an atom.

   (b) What is a nuclide? The nuclide of an element is given by

$$^{23}_{11}Na$$

   (i) What is the nucleon number and proton number?

   (ii) How many neutrons are present in an atom of the element?

   (iii) How many electrons are present in an atom of the element?

2. (a) Explain the terms *nucleon (mass) number* and *proton (atomic) number.*

   (b) What is an isotope? Explain why isotopes of the same element have the same chemical properties.

3. (a) Define radioactivity.

   (b) Describe the changes that will occur when a radioactive nuclide disintegrates by emitting

      (i) alpha particles;

      (ii) beta particles;

      (iii) gamma radiations.

   (c) Part of the uranium decay series is given as

$$^{234}_{90}Th \rightarrow {}^{234}_{91}Pa \rightarrow {}^{234}_{92}U \rightarrow {}^{230}_{90}Th$$

      (i) identify the particles emitted in each stage;

      (ii) give one word which describes the first and the last elements.

4. (a) Name three types of radiations that may be emitted by a radioactive source.

   (b) List these radiations in the order of

      (i) increasing order of penetrating power;

      (ii) increasing order of ionizing power.

   (c) Which of these radiations

      (i) travels through space at the highest speed?

      (ii) is not deflected by both electric and magnetic fields?

      (iii) is similar to X-rays?

5. (a) What is meant by radioactive decay?

   (b) $^{14}_{6}C$ is an **isotope** of carbon with a **half-life** of 6000 years and short **decay constant.**

      (i) Explain the terms highlighted.

      (ii) Calculate the decay constant of $^{14}_{6}C$.

6. (a) State;

      (i) four uses of radioactive element;

      (ii) two health hazards of radioactive radiations;

      (iii) two precautions to be observed by workers handling radioactive substances;

   (b) State three particles that may be used as bullets to split a nucleus.

   (c) $^{1}_{0}n + {}^{6}_{3}Li \rightarrow {}^{3}_{1}H + {}^{4}_{2}He$

$$^{234}_{92}U \rightarrow ^{230}_{90}Th + ^{4}_{2}He$$

Study the equations above; state the difference between the equations.

7. (a) Stronium-90 is a **Î²-emitter.** Explain what is meant by **Î²**-emitter.

   (b) State what will happen if a narrow beam of radiation from Stronium-90 is:

   (i) passed through an electric field;

   (ii) passed through a cloud chamber;

   (c) State four properties of the radiation from Stronium-90.

NUCLEAR REACTION

OBJECTIVES

At the end of the topic, students should be able to:

→explain nuclear energy and state its advantages;
→explain nuclear fission, chain reaction and nuclear fusion;
→describe nuclear reactor and atomic bomb;
→state the uses of nuclear reactions.

Nuclear energy

Changes in the structure of the nucleus always release energy. ***The energy released when the nucleus of an atom splits or fuses together is called nuclear energy.*** The source of nuclear energy according to Einstein mass-energy relation is the loss or gain in mass due to changes in the nucleus of an atom.

Advantages of nuclear energy

(a)A kilogram of radioactive element produces more energy than the energy released per kilogram during a chemical reaction.

(b)Nuclear energy is a clean source of energy.

(c)Nuclear reactions do not form acid rain like the burning of coal and petroleum.

Disadvantages of nuclear energy

(a)It produces harmful radioactive materials or radiations, which contaminate plants, animals and water.

(b)The radioactive waste materials are dangerous and must be disposed properly.

(c)There is high risk of accidents in the nuclear power stations.

Nuclear fission

Nuclear fission is the splitting of a nucleus when another particle hits it. If a slow moving neutron hits uranium nucleus, it splits into nearly two equal parts. This is called **nuclear fission**. Otto Hahn was the first man to split uranium nucleus by hitting it with neutron. Three facts about nuclear fission reaction are:

- it is an induced nuclear reaction. It occurs when a slow moving neutron hits a radioactive element.
- the bombarded nucleus splits into two nearly equal parts.

energy and more neutrons are produced.

Nuclear fission is splitting of radioactive nuclide into two nearly equal parts when it is bombarded by slow moving neutrons; energy and more neutrons are released in the process.

Nuclear fission reaction is represented by the nuclear equation below.

$$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n + \Delta E$$

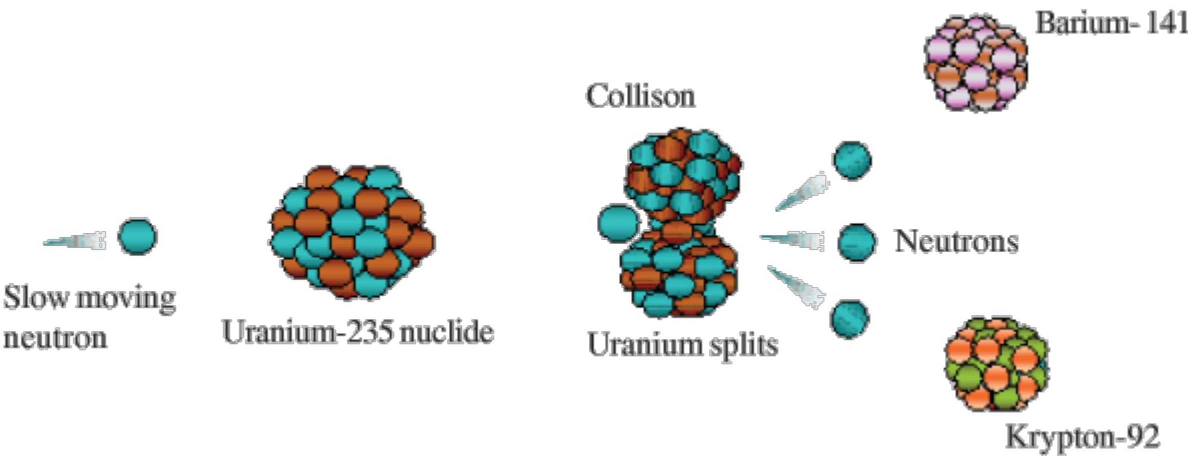


Figure 9.8 : Nuclear fission of uranium nucleus by slow moving neutron

New elements barium- 141 and krypton-92 are produced with large amount of energy and three neutrons released.

Chain reaction

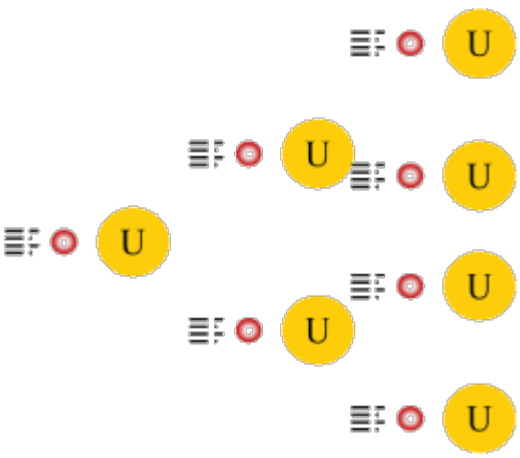


Figure 9.9 : Chain reaction

Splitting of uranium nucleus releases more neutrons. If these neutrons are guided to hit other uranium nuclei and splits them up, the number of neutrons available for fission reaction increases. The continuous splitting of uranium nuclei will lead to a self-sustaining nuclear reaction called **chain reaction.**

Chain reaction is a continuous splitting of uranium nuclei leading to a self-sustaining nuclear reaction.

Great amount of energy is released during chain reaction that it becomes difficult to control the reaction.

Critical mass

The chance of a neutron hitting and splitting a nucleus depends on the number of uranium nuclei or mass of uranium present. If the mass of uranium present is sufficient to enable each neutron hit a nucleus, chain reaction is induced and sustained. The minimum mass needed to induce and maintain a chain reaction is called **critical mass.**

Critical mass is the minimum mass of radioactive element needed to induce and sustain a chain reaction.

Chain reaction is induced and sustained in a nuclear reactor if:

- the mass of radioactive element present is greater than its critical.
- the number of neutrons hitting and splitting a radioactive nuclide is greater than the number of neutrons lost during the same period.
- only pure radioactive element (uranium-235) is used.

Nuclear reactor

Erinco Fermi built the first nuclear reactor in 1942 where chain reaction is controlled. The energy released by the fission of uranium fuel can be used for peaceful purpose like the production of electricity.

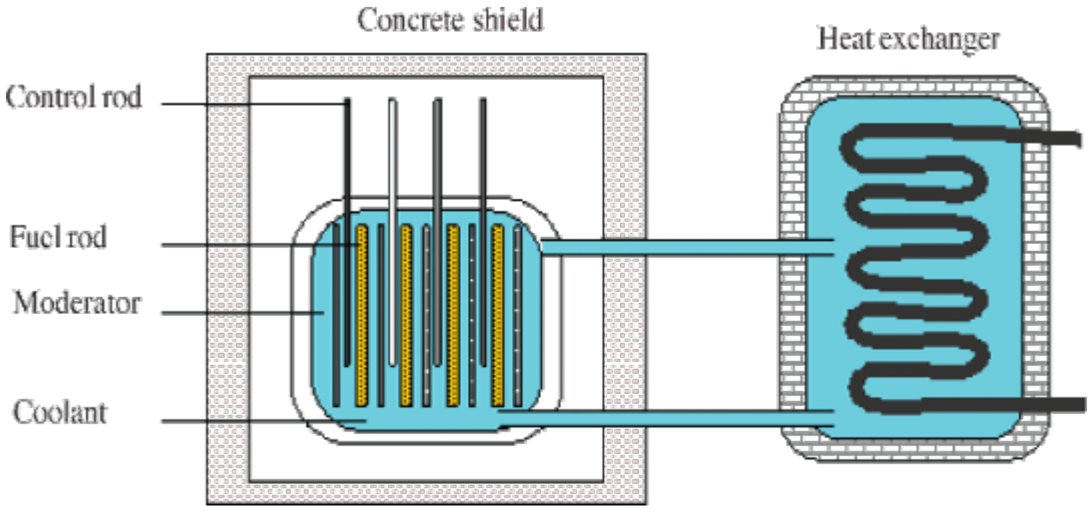


Figure 9.10 : Cross section of a nuclear reactor

Modern nuclear reactors have the following important parts:

- the fuel rods;
- the moderator;
- the control rods;
- the heat exchanger and the coolant.

(i)Fuel rods: reactors use enriched uranium nuclide embedded on rods as fuel. The fuel rods are well spaced in the core of the reactor.

(ii)Moderator: the moderator is used to slow down fast moving neutrons to help them induce nuclear fission. Fast moving neutrons lose their kinetic energy to the moderator when they collide with it. **Graphite** (**carbon)** and **heavy water** (D_2O) are substances used as moderators.

(iii) Control rods: Boron and **cadmium** rods are used as control rods to absorb neutrons. They regulate the rate of fission reaction by absorbing neutrons. To stop the fission reaction completely, the control rods are lowered into the core of the reactor, neutrons are absorbed and the reaction is stopped.

(iv) Coolant: coolants are fluid circulated in the core of the reactor to extract heat produced by fission of uranium. **Pressurized water or carbon (IV) oxide** is used as coolant to extract heat energy and transfer it to the heat exchanger.

(v)Heat exchanger: heat energy extracted by the coolant is used to boil water circulating in the heat exchanger and convert it to steam. The steam power is used to drive an alternator to produce electricity.

Nuclear fusion

When two light nuclides moving at high speed collide, they will join or fuse together. This is called **nuclear fusion** reaction.

Nuclear fusion is the joining of two light nuclides to form a heavier nuclide and in the process energy is released.

Nuclear fusion reaction is represented by the equation below.

$$ {}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + {}^{1}_{0}n + 3.3\,MeV $$

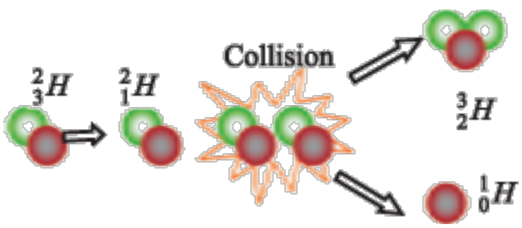


Figure 9.11 : Fusion of two deuterium nuclides

Two deuterium nuclides fused together to form an isotope of helium and a neutron is released. The energy released in fusion reaction is far greater than the energy released in fission reaction. The energy produced is due to small change in mass. The energy produced per kilogram in nuclear fusion reaction is more than the energy released per kilogram in nuclear fission reaction.

Advantages of fusion over fission reaction

- The total energy per kilogram released in a fusion reaction is more than the total energy per kilogram released in fission reaction.
- The by-products of fusion reaction are not harmful while the by-products of fission reaction are harmful.
- The raw materials for fusion reaction $\left({}^{2}_{1}H\right)$ and $\left({}^{3}_{1}H\right)$ are abundantly available and cheap. The raw materials for fission reaction (uranium) is very scarce and expensive.
- Despite these advantages of fusion over fission reaction, fusion reaction is not used to generate electricity for the following reasons:
- Two deuterium nuclides must be heated to high temperature (over 100 million oC) before

they will fuse together. This high temperature is difficult to reach.

- The material to withstand high temperature needed to initiate fusion reaction has not being discovered. All known material will vaporize before reaching this high temperature.
- The technology to control such high temperature has not been fully developed. Scientists are still working on how to contain the high-energy particles in a magnetic field.

Nigerian nuclear energy programme

The increasing demand for electricity and the energy and electricity crisis in the country has led to the formation of Nigerian Nuclear Regulatory Authority (NNRA). Nigeriaâ€™s development of nuclear energy is for electricity generation. It is also for development of agriculture, health, industry, science and technology. The first research reactor was commissioned at Ahmadu Bello University in 2004. It is a 30 kW Chinese Miniature Neutron Source. Another was set up at Abuja. In May 2007, two technical committees were set up to construct the countryâ€™s first nuclear power plant. The nuclear programme is to be supervised by the International Atomic Energy Agency (IAEA) and the United Nations nuclear regulatory body (UNNRB). The problem facing the development of nuclear energy in Nigeria is lack of work force to manage the nuclear power plant when it is fully constructed.

Nuclear energy calculations

Energy is released in chemical reactions to produce a chemical change. In the same way, all nuclear reactions produce changes in the nucleus of an atom releasing nuclear energy. Splitting a nuclide or fusing two or more nuclides releases energy. The aim of this section is to calculate the energy released when particles of a nucleus are separated or fused together.

Binding energy

The molecules of ice are fused together by energy known as **latent heat.** To melt a block of ice, energy is supplied to it. The energy supplied to the ice to melt it is equal to the energy binding its molecules together as ice.

In addition, we can separate the protons and neutrons in the nucleus of an atom by giving them enough energy. This energy is equal to the energy absorbed by the protons and neutrons to fuse or join together to form a nucleus.

Binding energy of a nucleus is the energy absorbed by a stable nucleus to separate its particles (protons and neutrons).

Or

Binding energy of a nucleus is the energy released to join or fuse together the particles (protons and neutrons) of a nucleus.

Mass defect

When the particles of a nucleus are separated, it was discovered that combined mass of the protons and neutrons when added together is more than the mass of the nucleus as a unit. The difference in mass is called the **mass defect.** If the protons and neutrons fuse together, a small mass is lost in forming the nucleus. When a nucleus splits, a small mass is gained in separating the protons and neutrons.

Mass defect is the gain or loss in mass produced when the protons and neutrons in the nucleus are separated or fused together.

Mass defect = Sum of masses of protons and neutrons – Mass of the nucleus

$$\Delta m = \Sigma(m_p + m_n) - m$$

Einstein Mass-energy relation

Mass and energy are related. When the energy of a body changes by a small amount (Î”E), it gains or loses small amount of mass (mass defect = Î”m). Einstein showed that mass and energy are related by the equation:

$$E = mc^2$$

E = energy, m = mass defect and c = speed of light.

The equation above is used to calculate the energy released in a nuclear reaction or the binding energy of a nucleus. Nuclear reactions like fission, fusion and radioactive decay lead to changes in the structure of the nucleus, therefore, energy is released.

Atomic mass unit

The mass of proton is about 1.67 Ã— 10^{-27}kg and the mass of neutron is nearly the same as the mass of proton. These masses are very small; therefore, it is more convenient to measure the masses of protons, neutrons and electrons in atomic mass unit (u).

1u = 1.66 Ã— 10^{-27} Kg.

The atomic mass unit (u) is 1/12 th of the mass of carbon-12 atom.

Table 9.1 gives the atomic mass unit (u) of some particles/nuclei.

Particles/nuclei	Atomic mass unit (u)
Proton (^1_1H)	1.00728
Neutron	1.00867
Electron	0.000549
Deuterium	2.01355
Tritium	3.01550
α - Particles	4.00150
Helium	3.01603
Helium	4.00260
Uranium	235.044

Table 9.1 : Particle and their atomic mass units

Electron-volt

The electron-volt (eV) is the unit of energy for atomic particles.

Electron-volt (eV) is the energy gained by an electron of charge (e = 1.6Ê^{1}10^{-19}C) if it is accelerated by a p.d. of 1 volt.

leV = 1.6 Ã— 10^{-19} J

The energy released when a mass of 1u is converted to energy is equivalent to 931 MeV or 931million eV.

1u = 931MeV

= 931 Ã— 10^{6} Ã— 1.6 Ã— 10^{-19}

= 1.49 Ã— 10^{-10}J

Worked examples

1.Calculate the mass defect and the binding energy of an Î± - particle when the particles of the nucleus are fully separated.

Mass of proton = 1.6735 Ã— 10^{-27} Kg

Mass of neutron = 1.6750 Ã— 10^{-27} Kg

Mass of Î± - particles = 6.6460 Ã— 10^{-27}Kg

Speed of light = 3.0 Ã— 10^{8} m s^{-1}.

Solution

Î”m = Î£(m_p + m_n) – m

= 2 Ã— 1.6735 Ã— 10^{-27}+ 2 Ã— 1.675 Ã— 10^{-27} – 6.646 Ã— 10^{-27}

= 6.697 Ã— 10^{-27} – 6.646 Ã— 10^{-27}

= 0.051 Ã— 10^{-27} Kg.

E= mc^2

= 0.051x10^{-27}x (3.0 Ã— 10^{8})^2

E = 4.59 Ã— 10^{-12} J

2.What is the energy released when the particles of uranium-235 are separated?

Mass of uranium = 235.0440u

Mass of proton = 1.0073u

Mass of neutron = 1.0087u

1u = 931 MeV

1eV = 1.6 Ã— 10^{-19} J.

Solution

Î”m = Î£(m_p + m_n) – m

= (92 Ã— 1.0073 + 143 Ã— 1.0087) – 235.0440

= 236.9157 – 235.0440

= 1.8717u

1u = 931 MeV

âˆ´ 1.8717u = 1.8717 Ã— 931 MeV

= 1742.5527 MeV

1eV = 1.6 Ã— 10^{-19}J

âˆ´ 1742.5527 MeV =

1742.5527 Ã— 10^{6} Ã— 1.6 Ã— 10^{-19} = 2.788 Ã— 10^{-10} J.

3.The nuclear reaction, which converts nitrogen into oxygen, is represented by the equation;

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

Calculate the energy released Q.

${}_{7}^{14}N = 23.2521 \times 10^{-27}$ Kg

${}_{8}^{17}O = 28.2271 \times 10^{-27}$ Kg

${}_{1}^{1}H = 1.6735 \times 10^{-27}$ Kg

${}_{2}^{4}He = 6.6463 \times 10^{-27}$ Kg

Solution

Total mass of reactant = mass of Nitrogen + mass of helium

= (23.2521 Ã— 10^{-27} + 6.6463 Ã— 10^{-27})

= 29.8984 Ã— 10^{-27} Kg.

Total mass of product = mass of oxygen + mass of proton

= (28.2271 Ã— 10^{-27} + 1.6735 Ã— 10^{-27})

= 29.9006 Ã— 10^{-27} kg.

(Î”m) = 29.9006 Ã— 10^{-27} - 29.8984 Ã— 10^{-27}

= 0.0022 Ã— 10^{-27} kg.

Binding energy (E) = mc^2

= 0.0022 Ã— 10^{-27} Ã— (3.0 Ã— 10^{8})^2

= 1.98 Ã— 10^{-13} J.

4. The fusion of deuterium and tritium to form a helium atom is given as:

$${}_{1}^{3}H + {}_{1}^{2}H = {}_{2}^{4}He + {}_{0}^{1}n + Q$$

Calculate the energy (Q) released during the fusion reaction.

Mass of deuterium = 2.01355u

Mass of tritium = 3.01550u

Mass of helium = 4.00260u

Mass of neutron = 1.00867u.

1u = 931 MeV

1eV = 1.6 Ã— 10^{-19} J

Solution

Î”m = (3.01550 + 2.01355) – (4.00260 + 1.00867)

Î”m = 5.02905 – 5.01127

Î”m = 0.01778u

1u = 931 MeV

Q = 0.01778 Ã— 931 MeV

= 16.6 MeV.

Summary

- Nuclear energy is released anytime a change occurs in the structure of the nucleus. The energy released when the nucleus of an atom splits or fuses together is called nuclear energy.
- Nuclear fission is splitting of radioactive nuclide into two nearly equal parts when it

is bombarded by slow moving neutrons; energy and more neutrons are released in the process.

- Chain reaction is a continuous splitting of uranium nuclei leading to a self-sustaining nuclear reaction.
- Critical mass is the minimum mass of radioactive element needed to induce and sustain a chain reaction.
- Nuclear fusion is the joining of two light nuclides to form a heavier nuclide and in the process energy is released.
- Binding energy of a nucleus is the energy absorbed by a stable nucleus to separate its particles (protons and neutrons). Binding energy of a nucleus is the energy released to join or fuse together the particles (protons and neutrons) of a nucleus.
- Mass defect is the gain or loss in mass produced when the protons and neutrons in the nucleus are separated or fused together.
- Einstein showed that mass and energy are related by the equation: $E = mc^2$.
- The atomic mass unit (u) is $\frac{1}{12}th$ of the mass of carbon-12 atom.

Electron-volt (eV) is the energy gained by an electron of charge (e = 1.6 Ã— 10^{-19}C) if it is accelerated by a p.d. of 1 volt.

1eV = 1.6 Ã— 10^{-19} J

Practice Questions 9b

1. (a) State **three** advantages and **two** disadvantages of nuclear energy.

   (b) State three characteristics of nuclear reaction.

2. (a) Explain the terms *nuclear fusion reaction* and *nuclear fission reaction.*

   (b) State **three** advantages of nuclear fusion over nuclear fission as a potential source of energy.

   (c) State **two** reasons why nuclear fusion reaction is used to produce energy on earth.

3. (a) Explain the terms: *atomic number, mass number, isotopes* and *nuclear binding energy.*

   (b) The fusion of two deuterium nuclei is represented by the nuclear equation

   $${}^{2}_{1}H + {}^{2}_{1}H = {}^{4}_{2}He$$

   Calculate the **mass defect** and **binding energy.**

   [${}^{2}_{1}H = 2.01419u$, ${}^{4}_{2}He = 4.00277u$

   lu = 1.49 Ã— 10^{-10} *J*]

4. (a) Define nuclear fission. What is source of energy released in a fission reaction?

   (b) Explain the terms **chain reaction** and **critical mass.** What are the conditions to be fulfilled to sustain chain reaction.

(c) How is chain reaction controlled in nuclear reactor?

5. (a) Describe the structure of a nuclear reactor and state the functions of the: **moderators, control rods** and **coolant.**

   (b) Name **two** materials that can be used as:

   (i) moderators; (ii) control rods; (iii) coolants.

   (c) What is the energy equivalent of the following masses in atomic mass unit (u)? $^{4}_{2}He = 4.0017u$ *and* $^{1}_{1}H = 1.0073;$

   1u =1.49 Ã— 10 $^{-10}$ J

6. Study the following equations representing nuclear reactions.

   (i) $^{1}_{0}n + ^{235}_{92}U \rightarrow ^{141}_{56}Ba + ^{p}_{q}Kr + 3\,^{1}_{0}n$

   (ii) $^{226}_{88}Ra \rightarrow ^{222}_{86}Rn + ^{r}_{S}X$

   (ii) $^{3}_{1}H + ^{2}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{u}Y$

   (a) Identify each reaction above and state the reaction which will lead to a chain reaction.

   (b) What do the letters p, q, r, s, t and u represent? Identify the particles X and Y.

   (c) State **two** differences between the nuclear reactions (i) and (iii).

7 (a). What is **mass defect** and **binding energy?**

   (b). The mass of neutral nitrogen $(^{14}_{7}N)$ atom is 14.0031u; mass proton $(^{1}_{1}H)$ is 1.0073u and the mass neutron $(^{1}_{0}n)$ is 1.0087u, find the mass defect and binding energy of the nitrogen atom. [1u =1.49 Ã— 10 $^{-10}$ J]

Past questions

1. How many alpha particles are emitted in the radioactive decay of?
   $^{238}_{92}U \rightarrow ^{230}_{90}Th + ^{4}_{2}He + ^{0}_{-1}\beta + \Delta E$

   A. 2

   B. 3

   C. 6

   D. 12

WASSCE

2. Which of the following is not applicable in explaining nuclear fusion?

   A. The nuclei must overcome the electrical repulsion of their positive charges.

   B. For fusion to occur, the nuclei must come together to within range of the nuclear force.

C. The electrostatic potential energy of the nuclei represents the initial kinetic energy which the fusion nuclei must have.

D. The energy required for fusion to occur could be obtained at standard temperature and pressure.

WASSCE

3. Which of the following statements is **not** true of the isotopes of an element? They

A. are atoms of the same element.

B. have the same chemical properties.

C. have the same atomic number.

D. have the same mass number.

WASSCE

4. A radioactive element has a decay constant of 0.077 s^{-1}, calculate its half-life.

A. 12.5 s.

B. 9.0 s

C. 5.1 s

D. 0.5 s

WASSCE

5. Nuclear fission is preferred to nuclear fusion in the generation of energy because

A. very high temperatures are required for fusion.

B. the raw materials for fusion are not easily obtained.

C. energy obtained from fusion is relatively smaller.

D. the by-product of fusion are very dangerous.

WASSCE

6. Which of the following reactions represent nuclear fusion?

A. ${}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + {}^{1}_{0}n$

B. ${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{145}_{56}Ba + {}^{90}_{36}Kr + 2\,{}^{1}_{0}n$

C. ${}^{2234}_{90}Th \rightarrow {}^{0}_{-1}n + {}^{234}_{91}Pa$

D. ${}^{238}_{92}U \rightarrow {}^{4}_{2}He + {}^{214}_{90}Th$

WASSCE

7. A sheet of paper is placed in the path of a beam of radiations from the radioactive source. Which of the following radiations will pass through the paper?

I. Gamma rays

II. Beta rays

III. Alpha particles

A. I only

B. II only

C. III only

D. I and II only

E. I, II and III.

WASSCE /NECO

8. In 90 seconds, the mass of a radioactive element reduces to 1/16 th of its original value. Determine the half-life of the element.

A. 15.0 s

B. 18.0 s

C. 22.5 s

D. 30.0 s

E. 45.5 s

NECO

9. If a radioactive atom emits a beta particle, the mass number of the atom

A. decreases by one.

B. decreases by four.

C. increases by one.

D. increases by four.

E. remains the same.

WASSCE / NECO

10. $^{226}_{88}Ra \rightarrow ^{222}_{86}Rn + X + Energy$

The equation above represents a nuclear decay of radium isotope. What is X?

A. Alpha particle.

B. Beta particle.

C. Gamma ray.

D. Neutron.

E. X-ray.

NECO

11. The count rate of a radioactive material is 800 count/minute. If the half-life of the material is 4 days, what would the count rate be 16 days later?

A. 100 count/minute.

B. 50 count/minute.

C. 25 count/minute.

D. 200 count/minute.

JAMB

12. When a nucleus is formed by bringing protons and neutrons together, the actual mass of the formed nucleus is less than the sum of the masses of the constituent protons and neutrons. The energy equivalent of this mass difference is the

A. binding energy.

B. lost energy.

C. stability energy.

D. work function.

JAMB

13. Which of the following particles are used to initiate artificial nuclear disintegration?

I Alpha particles

II Neutron

III Proton

IV Deuteron

A. I, II, and IV only.

B. II, III and IV only.

C. I, III, and IV only.

D. I, II, III and IV.

WASSCE

14. The count rate of a radioactive substance diminishes from 600 to 150 in 60 s. What is its half-life?

A. 60 s.

B. 45 s

C. 30 s.

D. 15 s.

WASSCE

15. The mass defect in a fission process is 0.10%. Calculate the energy that can be obtained from the fission of 1g of a material. [c=3.0 Ã— 10^8m s^{-1}]

A. 3.0 Ã— 10^6 J

B. 8.2 Ã— 10^8 J

C. 9.0 Ã— 10^{10} J

D. 9.0 Ã— 10^{13} J

WASSCE

16. Which of the following materials is used to cause fission in an atomic reactor?

A. Alpha particles

B. Beta particles

C. Electrons

D. Neutrons

WASSCE

17. Which of the following materials is used to control the neutron production in a reactor?

A. Boron rods.

B. Concrete shield.

C. Graphite rods.

D. Uranium rods.

WASSCE

18. A nuclide X is produced by bombarding a nitrogen (N) nucleus with an alpha (Î±) particle with the release of heavy hydrogen (D) as shown by the following nuclear equation.

$$\alpha + {}^{14}_{7}N \rightarrow {}^{p}_{q}X + {}^{2}_{1}D$$

Determine the values of *p* and *q* in the equation.

A. 12 and 6

B. 14 and 7

C. 16 and 8

D. 19 and 8

WASSCE

19. A proton of mass 1.6726 Ã— 10 $^{-27}$ Kg fuses with a neutron of mass1.6744x 10^{-27} Kg to form deuteron of mass 3.3442 Ã— 10^{-27} Kg. Calculate the energy due to the nuclear fusion process. [c = 3.0 Ã— 10^{8} m s^{-1}]

A. 2.52 Ã— 10^{14} J

B. 8.40 Ã— 10^{14} J

C. 2.52 Ã— 10^{-13} J

D. 1.80 Ã— 10^{-21} J

WASSCE

20. What is the decay constant of a radioactive element whose half-life is 3 seconds?

A. 0.132 s^{-1}

B. 0.231 s^{-1}

C. 0.347 s^{-1}

D. 0.693 s^{-1}

E. 0.924 s^{-1}

WAEC

21. Which of the following is a pair of isotopes?

A. ${}^{35}_{18}Ar \, and \, {}^{35}_{16}S$

B. ${}^{35}_{17}Cl \, and \, {}^{37}_{17}Cl$

C. ${}^{15}_{7}N \, and \, {}^{16}_{8}O$

D. ${}^{30}_{14}Si \; and \; {}^{30}_{15}P$

E. ${}^{24}_{12}Mg \; and \; {}^{24}_{11}Na$

WAEC

22. (a) When nitrogen (atomic mass = 14, atomic number = 7) is bombarded with neutrons, the collisions results in disintegration in which alpha particles are produced. Represent this transmutation in a symbolic equation.

(b) (i) How does a radioactive atom differs from a stable one?

(ii) Explain half-life.

(iii) A sample of radioactive material has a half-life of 35 days. Calculate the fraction of the original quantity that will remain after 105 days.

WASSCE

23. (a). Explain:

(i) nuclear fission;

(ii) nuclear fusion.

(b) (i) State **three** applications of atomic energy.

(ii) Define half-life.

(iii) Give the expression of that relates half-life (T) and the decay constant (Î») of a radioactive material.

(c) A radioactive element X with atomic number 88 and mass number 226 emits in succession

(i) an alpha particle;

(ii) a beta particle;

(iii) gamma radiation.

Explain, using equations where necessary, the changes that take place in the atomic structure of the element at each stage.

WASSCE

24. (a) Briefly explain what would happen to a stable element if it is bombarded by Î±-particles.

(b) Explain how the bombardment of uranium with neutrons could lead to nuclear chain reaction and hence nuclear explosion.

(c) State three characteristics of nuclear activity.

(d) State **three** applications of atomic energy.

WAEC

25. (a) Explain the terms isotopes and half-life.

(b) Distinguish between natural and artificial radioactivity.

WASSCE

26. (a) Explain

(i) nuclear fission;

(ii) nuclear fusion.

(b) State **three** advantages of fusion over fission in the generation of power.

(c) Calculate, in joules, the binding energy for ${}^{59}_{27}Co$

Atomic mass of ${}^{59}_{27}Co$ = 58.9332u
Atomic mass of proton = 1.00783u
Atomic mass of neutron = 1.00867u
Unified atomic mass unit (u) = 931 MeV
1eV = 1.6 Ã— 10 – 19 J

WASSCE

27. A possible fusion reaction is

$${}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{1}He + {}^{1}_{1}H + Q$$

Where Q is the energy released as a result of the reaction. If Q = 4.03 MeV, calculate the atomic mass of He in atomic mass units.

[${}^{2}_{1}H = 2.01410u$; ${}^{1}_{1}H = 1.00783u$

1u = 931 MeV]

WASSCE

28. (a) State **three** types of radiation emitted from a radioactive substance and compare their properties under the following headings:

(i) Penetrating power;

(ii) Ionizing ability;

(iii) Magnitude and direction of deflection under the influence of a magnetic field.

(b) (i) Explain the term **binding energy.**

(ii) Calculate, in joules, the binding energy for ${}^{7}_{3}Li$.

Atomic mass of ${}^{7}_{3}Li$ = 7.01600u
Atomic mass of proton = 1.00783u
Atomic mass of neutron = 1.00867u
Unified atomic mass unit (u) = 931 MeV 1eV = 1.6 Ã— 10^{-19} J

NECO

29. (a) Explain how the bombardment of uranium with neutrons could be to nuclear fission chain reaction.

(b) State **three** characteristics of nuclear activity.

(c) Uranium $({}^{235}_{92}U)$, is an alpha-emitter and decays to thorium (Th) which in turn decays by beta-emission with a small **decay constant** to an isotope of protactinium (Pa). The protactinium isotope finally decays by beta – emission to an element Y. Define the term decay constant and write down the decay equations for uranium as stated above.

WAEC / WASSCE

30. (a) <u>Carbon-fourteen</u> is a <u>radioactive isotope</u> of carbon. Explain the underlined words.

(b) What is meant by half-life?

(c) A specimen of an element X of mass 1g was left for 2 weeks and then analysed. It was then found to contain only 0.25 g of X, the other 0.75 g being a different element. Calculate the half-life of X.

WAEC

31. (a) State **two** (i) differences between *nuclear fusion* and *nuclear fission;* (ii) peaceful uses of atomic energy.

(b) (i) Explain *chain reaction.*

(ii) State:

(I) **one** condition necessary for chain reaction to occur.

(II) **two** components in a nuclear reactor used to control chain reaction.

(c) (i) A nuclear reaction is given by

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

What type of nuclear reaction is it?

(ii) The isotope of a nuclide has a half life of 5.40 Ã— 10^3 s. Calculate its decay constant.

WASSCE

32. (a) Define with respect to a radioactive isotope:

(i) *half-life;*

(ii) *decay constant.*

(b) Write the equation relating half life and decay constant.

(c) (i) Explain the terms *mass defect and binding energy.*

(ii) Write an equation to show the relationship between mass defect and binding energy of a nucleus.

(d) A nuclide of mass 39.964001u decays to a nuclide of mass 39.962582 u.

(i) Write the equation which describes the decay of atom into atom.

(ii) Identify the particles emitted by the decaying nucleus.

(iii) Calculate the energy released from the nucleus during the decay.
[1 u = 1.6604 Ã— 10^{-27} kg, c = 3.00 Ã— 10^{8} m s^{-1}]

WASSCE

33. (a) (i) Explain the terms *radioactivity* and *half-life.*

(ii) Name **two** radioactive substances.

(iii) State **two** applications of radioactive isotopes.

(b) A radioactive element X with proton number Z and nucleon number A emits an alpha particle:

(i) determine the proton number and nucleon number of the new element Y formed.

(ii) write the equation for the emission of a beta particle from element Y.

(c) The equation below represents a nuclear reaction

If 10g of Uranium – 235 is used, calculate the energy, E released in joules.

NECO