

Chapter = 20

Nuclear Structure



Q1. Define Binding energy, radioactive element, Radioactivity, ionization, penetrating power.

Binding energy

It is amount of energy required to separate a particle from a system of particles or to disperse all the particles of the system.

Radio-isotope or radioactive element

If an isotope undergoes radioactive decay is called radio-isotope or radioactive element.

Radioactivity

The emission of α , β and γ radiation with the release of energy is known as radioactivity.

IONIZATION

The phenomenon by which radiations split matter into positive and negative ions is called ionization.

PENETRATING POWER

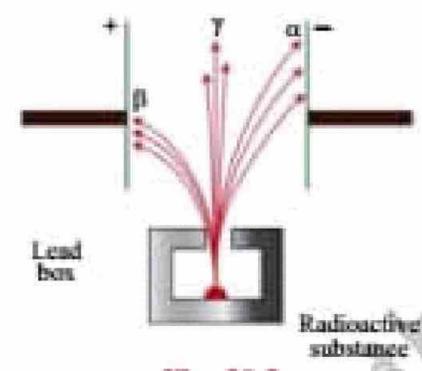
The strength of radiations to penetrate a certain material is called penetrating power.

Q2. Explain the radioactive emission

Nature of radioactive emission

Experiment

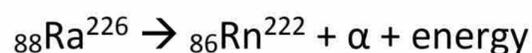
To describe the nature of three types of radiation α , β , and γ , the radioactive source is placed inside the electric field. The radiation emitted from the source breaks down into three components: α and β -radiations bend in the opposite direction in the electric field, while γ -radiation does not change its direction;



Conclusions:

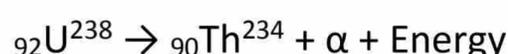
- α deflected towards a negatively charged while the plate is positively charged.
- β deflected towards a positive plate that is negatively charged. It is deflected more in the field, thus, much lighter than a particle.
- γ rays are not deflected by the field and carry no electric charge.

When radium ${}_{88}\text{Ra}^{226}$ decays by alpha emission. The alpha decay leaves the nucleus with 2 protons and two neutrons less than before. So the atomic number drops to 86 and the atomic mass to 222. Radon has the atomic number of 86, so radon is the new element formed. Its decay process can be written as,



Example 2

When radium ${}_{92}\text{U}^{238}$ decays by alpha emission. The alpha decay leaves the nucleus with 2 protons and two neutrons less than before. So the atomic number drops to 90 and the atomic mass to 234. Thorium has the atomic number of 90, so thorium is the new element formed. Its decay process can be written as,



What is beta (β)-decay, give its general equation and example

Beta (β)-decay

In beta decay, the atomic number (Z) of the parent nuclide increases by one, and its atomic mass or nucleon number remains unchanged.

General equation:



Example

When carbon ${}_{6}\text{C}^{14}$ decays by beta emission. The beta decay leaves the nucleus with one more proton and one neutron less than before. So the atomic number increases to 7, and the mass number remains unchanged. Nitrogen has the atomic number of 7, so nitrogen is the new element formed. Its decay process can be written as,

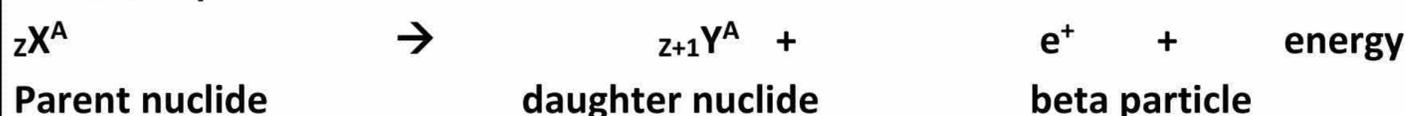


Q6. What do you know about β+ decay

Positron emission or positive beta decay (β+ decay) or Beta (β)+ decay

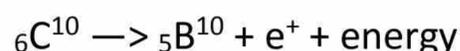
A proton in the parent nucleus decays into a neutron that remains in the daughter nucleus and the nucleus emits a neutrino and a positron, which is a positive particle like an ordinary electron in mass but of opposite charge.

General equation:



Example

When carbon ${}^6\text{C}^{10}$ decays by beta emission. The beta decay leaves the proton with one more neutron and one proton less than before. So the atomic number decreases to 5, and the mass number remains unchanged. Boron has the atomic number of 5, so boron is the new element formed. Its decay process can be written as,



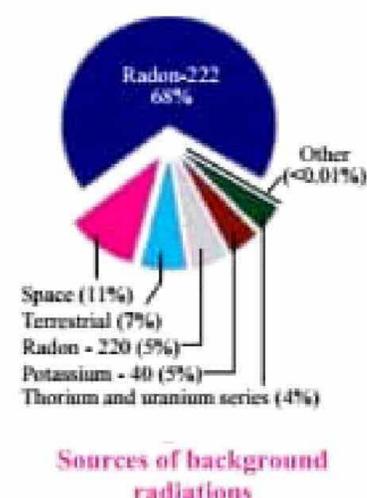
Q7. What is Background radiations. Describe it in detail.

Background radiations

These natural radiations that come from the surroundings are called background radiations.

Sources from which over half of background radiations come

In some areas, over half of these radiations come from radioactive radon ${}^{86}\text{Rn}^{222}$ gas, rocks seeping, and some types of granite.



Manufactured background radiation or man-made radiation

We all receive exposure to man-made radiation or background radiation.

Example

X-rays, radiation used to diagnose diseases and cancer therapy.

Sources

The fallout from nuclear explosives testing and also small amounts of radioactive materials released to the surroundings from coal and nuclear power plants are the sources of man-made radiation or background radiation.

Q8. What is Cosmic radiations?

Cosmic radiations

Our planet Earth is also exposed to radiation from outer space called cosmic radiations.

Composition

Cosmic radiations consist of electrons, protons, alpha particles, and larger nuclei.

Interaction with atmospheric atoms: The cosmic radiation interacts with atoms in the atmosphere to create a shower of radiation. Including X-rays, muons, protons, alpha particles, electrons, and neutrons.

Q9. What is Spontaneous decay?

Spontaneous decay

Spontaneous decay is a process in which environmental factors cannot influence.

Explanation: Radioactive decay takes place naturally (all by itself). The process is unaffected by pressure, temperature, chemical conditions, and other physical conditions.

Q10. What is Random decay?

A random decay is a process in which the exact time of decay of a nucleus cannot be predicted.

Q11. What do you know about Half-life?

Half-life

The half-life of a radioactive isotope is the time taken for half of the nuclei present in any given sample to decay.



Radioactive isotope	Half-life
Boron-12	0.02 second
Radon-220	52 second
Iodine-128	25 minutes
Radon-222	3.8 days
Iridium-192	74 days
Cobalt-60	5.27 year
Strontium-90	28 year
Radium-226	1602 year
Carbon-14	5730 year
Plutonium-239	24400 year
Uranium-235	7.1×10^8 year
Uranium-238	5×10^9 year

Q12. What is Radioactive dating? Give its example.

Radioactive dating

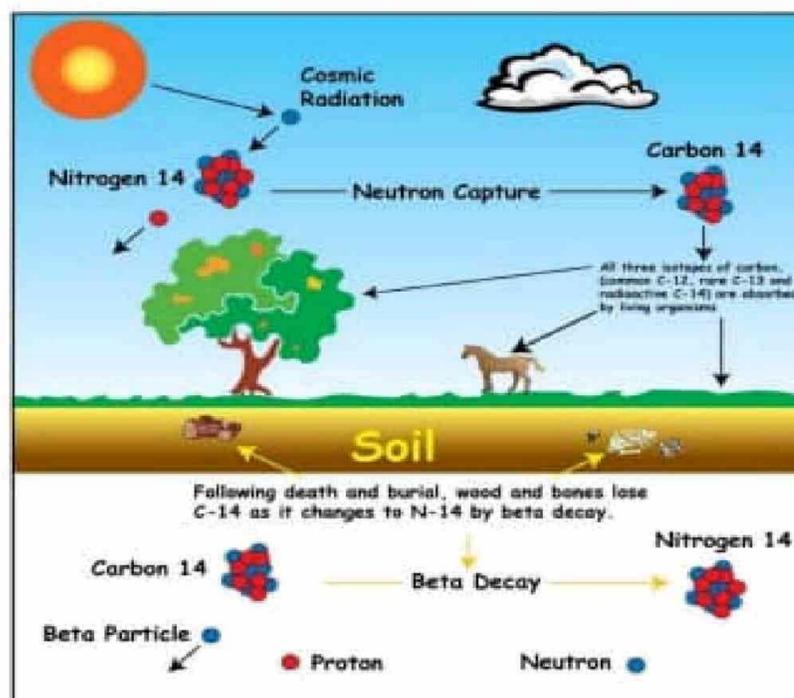
Radioactive dating is a process by which the approximate age of an object is determined by using certain radioactive nuclides.

Example 1

Radioisotope carbon-14 is used to measure the age of organic material. Living plants and animals use carbon dioxide and become slightly radioactive accordingly. While an organism is alive, the amount of carbon-14 remains constant because fresh carbon-14 enters whenever the organism consumes nutrients.

Cycle of Radio Carbon-14

When an organism dies, no more carbon is absorbed, and the radio carbon-14 presents inside the organism starts decaying to nitrogen-14. Since the half-life of carbon-14 is 5730 years, archaeologists can estimate the age of remains by computing the activity of carbon-14 in the live and dead organism.



Example 2

Radioisotope potassium-40 is used for dating rocks to estimate the age of the geological specimen. The unstable K-40 is trapped when molten material cools to form igneous rock. This K-40 decays to the stable argon nuclide Ar-40 with a half-life of $\times 10^8$ years. The age of the rock sample can be estimated by computing the concentrations of K-40 and Ar-40.

Example 3

Uranium-containing materials that have been analyzed by radioactive dating have allowed scientists to determine that the Earth is over 4.5 billion years old.

Q13. What is Radio-isotopes?

Radio-isotopes

A radioisotope is a kind of the same element with different masses. It undergoes decay spontaneously and emits radiation to dissipate excess energy.

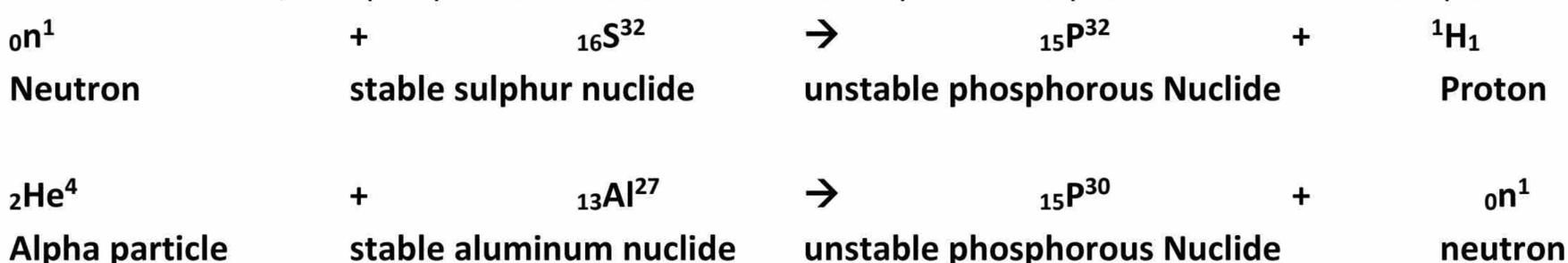
Example:

Naturally occurring radioisotopes

Hydrogen, the lightest element, has three isotopes H^1 , H^2 and H^3 . Only H^3 (tritium) is unstable. However, it is a radioactive isotope and undergoes nuclear decay.

Artificial radioisotopes

The stable and non-radioactive elements can also be transmuted into radioactive elements by exposing them to neutrons, or alpha particles. Here are some examples of the production of radioisotopes:



In these examples, P^{32} and P^{30} produced are artificial radioisotopes.

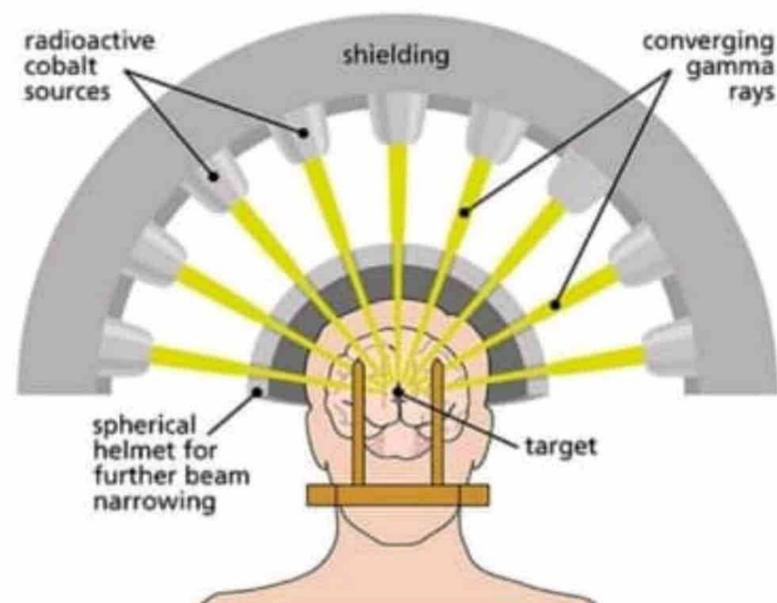
Q14. What are the Applications of radioisotopes in different fields?**medicine, agriculture, and industrial fields**

Radioisotopes are often used in medicine, industry, and agriculture for various beneficial purposes.

In medicine

Radiotracers: Radioisotopes are used as radiotracers in medicine.

For example, a patient drinks a liquid containing radio iodine-131, a gamma emitter, to check thyroid function. Over the next 24 hours, a detector measures the activity of the tracer to find out how quickly it becomes concentrated in the thyroid gland.



For the diagnosis of brain tumors, the phosphorous-32 isotope is used.

Curing various diseases

In nuclear medicines, radioisotopes are used for curing various diseases.

For example, cobalt-60 is a strong gamma emitter. These rays can penetrate in-depth into the body and kill the malignant tumor cells in the patient. Treatment like this is called radiosurgery.

Gamma knife radiosurgery

In Industry:**Radiotracers**

Radioisotopes are used as radiotracers in industry. A small amount of short-lived radioactive substances is used in various processes and scanned the flow rates of various materials, including liquids, powders, and gases, to locate leakages. Radiotracers are also used in the oil and gas industry to detect and estimate the extent of oil fields.

Crack Testing

Gamma rays have high penetrating power, so they can photograph metals to check cracks. A cobalt-60 is a natural gamma rays source and does not need electrical power like an x-ray tube.

In agriculture:

Radiotracers

In agriculture, fertilizer uptake in the plant from root to leaves is traced by adding tracer phosphorus- 32 to the soil water.

Q15. What is Nuclear reactions?

Nuclear reactions

Nuclear reactions are processes in which one or more nuclides are produced from the collisions between two atomic nuclei.

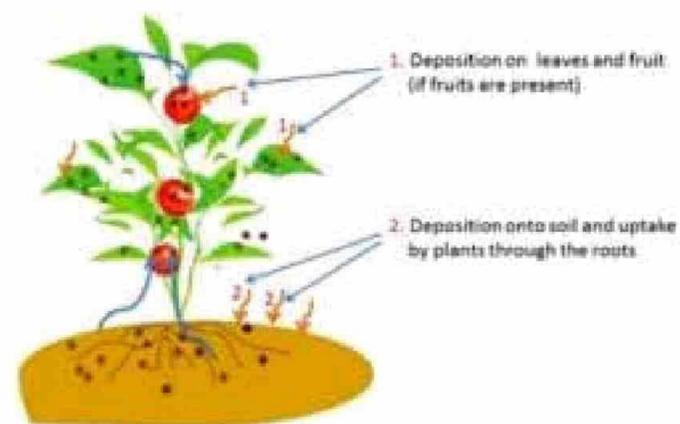


Illustration of radionuclide transfer to plants

Types: Types of nuclear reactions are given below:

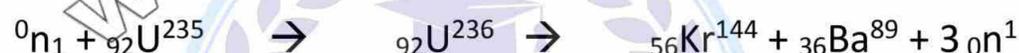
1. Nuclear fission
2. Nuclear fusion

Q16. Describe Nuclear Fission with example.

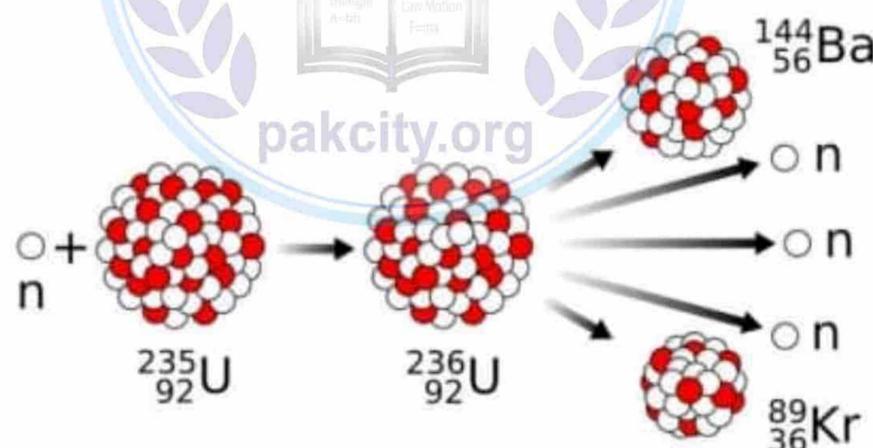
Nuclear fission occurs when a heavy nucleus absorbs a slow-moving neutron and splits or fissions into two smaller nuclei with the release of energy.

Example

When U-235 captures a neutron, an intermediate, highly unstable nucleus, U-236 is formed that disintegrates only for a fraction of a second into two smaller nuclei of nearly equal fragments, Kr-144 and Barium-89, called fission fragments accompanied by two or three neutrons.



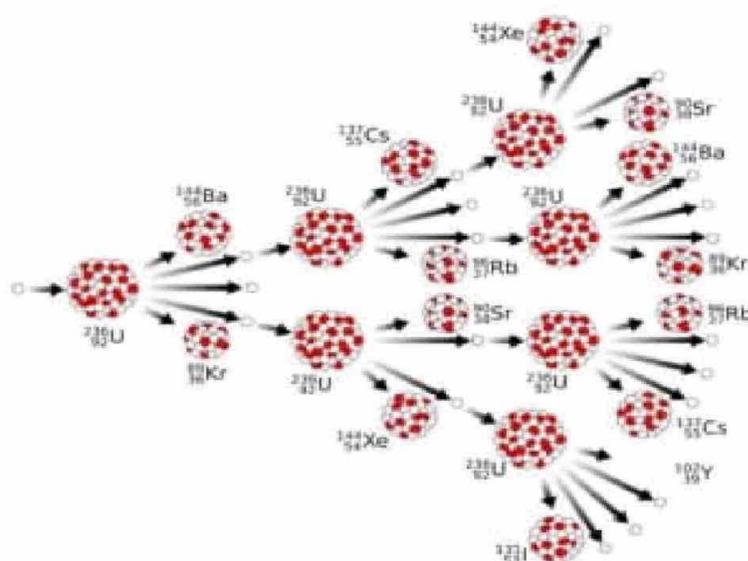
Measurements showed that about 200 MeV of energy is released in each fission event. The following schematic illustration represents the fission of ${}^{92}_{92}\text{U}^{235}$.

**Schematic illustration of nuclear fission**

In nuclear fission, the total mass of the products is less than the original mass of the heavy nucleus that is converted into energy.

Q17. What is Chain reaction? Illustrate it with diagram.

In each nuclear fission, a few neutrons are emitted. These neutrons can, in turn, trigger further nuclei to undergo fission with the possibility of a chain reaction. Computations show that if the chain reaction is not controlled, it will explode, releasing massive energy.



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The fission chain reaction in U-235

This fission chain reaction is controlled in nuclear reactors.

Q18. What is Nuclear Fusion? Also explain with example**Nuclear Fusion**

Nuclear fusion occurs when two light nuclei combine to form a heavier nucleus with the release of energy.

Example

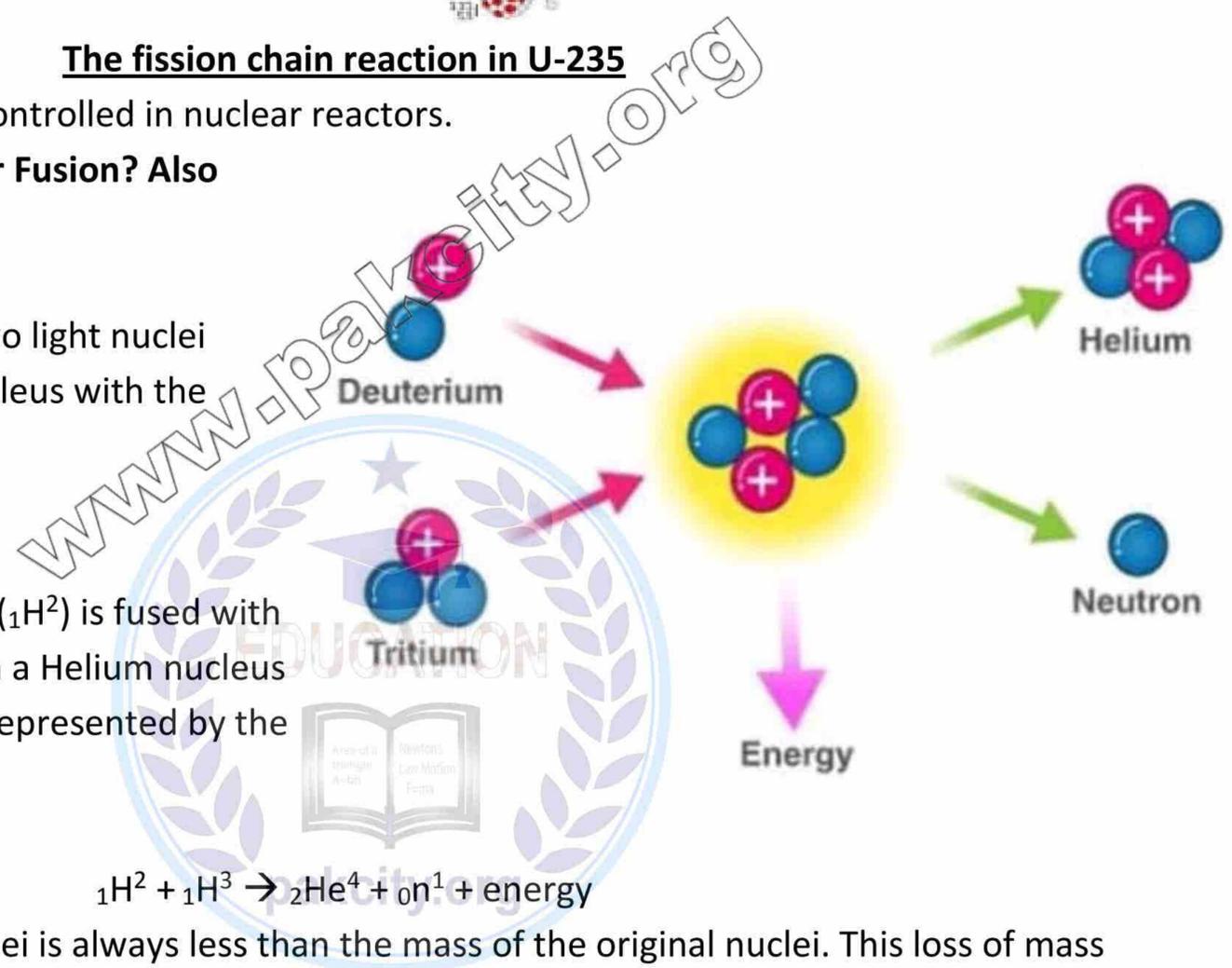
When a nucleus of Deuterium (${}_1\text{H}^2$) is fused with a nucleus of Tritium (${}_1\text{H}^3$), then a Helium nucleus or alpha particle is formed as represented by the equation,



The total mass of the final nuclei is always less than the mass of the original nuclei. This loss of mass produces nuclear energy.

Q19. What are Radiation Hazards? Also give Hazards of particles.**Radiation Hazards**

The prolonged exposure to radioactive radiations (α, β, γ and rays) can produce deep-sided burns, damage to cells or tissues, and the mutations of the cells that can lead to genetic changes. Radioactive exposure can also cause cancerous growth in specific body tissues.

Hazards of α -particles

The danger from α particles because of their lower penetration power is minimal. If sources of α particles are lodged into the body, through the air, or we eat, it can damage our body tissues.

Hazards of β -particles

The β particles are more penetrating and can damage the body surface tissues. Sources of these particles that enter the body can be quite damaging.

Hazards of γ -particles

The γ rays are highly penetrating and the most dangerous of all other radioactive radiations.

Q20. What are the Safety Measures taken for radiations?

Safety Measures

While working in the radiology department in hospitals, nuclear reactors, and research laboratories, should take the following safety measures to avoid any risk of radiation hazards:

1. Keep all radioactive sources at a safe distance from the body.
2. Minimize the time spent near radioactive materials.
3. Wear personal protective equipment, including a laboratory coat, gloves, safety glasses, and close toed shoes.
4. Lapel the dosimeter badge always and monitor regularly.
5. Do not eat, drink, smoke or touch exposed areas of skin while working in a room where radioisotopes are handled.
6. Use tongs to handle radioactive sources.
7. After use, must return the source immediately to its lead boxes.
8. All radioactive sources should be kept in thick lead containers.
9. Dispose of all radioactive waste under permitted regulation or statutory control.

Q21. What is Radiation dosimeter

Radiation dosimeter

Radiation dosimeter is a scientific device that detects, measures and calculates dose uptake of external high energy ionizing beta, gamma, or X-ray radiation.

Section (A) Multiple Choice Questions (MCQs)

1. The α -radiation is
 - (a) A stream of fast-moving electrons.
 - (b) A form of electromagnetic radiation.
 - (c) Highly ionizing than γ -radiation.
 - (d) More penetrating than β -radiation.
2. A radioactive nuclide emits a β -particle. The atomic number (proton number) of the nucleus
 - (a) Stays the same.
 - (b) Increases by 1.
 - (c) Decreases by 2.
 - (d) Decreases by 4.
3. A radioactive element emits a particle from the nucleus of one of its atoms. The particle comprises two protons and two neutrons. The name of this process is called
 - (a) α -emission
 - (b) β -emission
 - (c) γ -emission
 - (d) Nuclear fission

4. A radioactive decay can be represented as shown ${}_{91}\text{Pa}^{233} \rightarrow {}_{92}\text{U}^{233} + \dots$. The emitted particle is a/an
 (a) Gamma-ray. (b) Proton. (c) α -particle. (d) β -particle.
5. The type of radiation that travels in a straight line across an electric field is a/an
 (a) Proton (b) Electron (c) Alpha particle (d) Gamma-ray
6. A powder contains 100mg of a radioactive material that emits α -particles. The half-life of the isotope is five days. The mass of isotope that remains after ten days will be
 (a) 0mg (b) 25mg (c) 50mg (d) 75mg
7. The main source of energy in the stars is.
 (a) Chemical reaction (b) Nuclear fission
 (c) Nuclear fusion (d) Mechanical energy
8. The splitting of a heavy nucleus into smaller nuclei is called
 (a) Fusion (b) Fission (c) Half-life (d) Gamma decay
9. A process in which two light nuclei combine to form a heavier nucleus is called
 (a) Nuclear fusion (b) Nuclear fission (c) Beta-decay (d) Alpha-decay
10. Compared with α -particles and β -particles, γ -rays,
 (a) Are a type of radiation to carry a charge.
 (b) Have the most significant ionizing effect.
 (c) Have the most significant penetrating effect.
 (d) Have the most negligible mass.
11. The severe health hazards caused by radioactive emissions is/are.
 (a) Cancer (b) Genetic change (c) Deep-seated burns (d) All of these
12. Radioactive materials should be handled carefully. Which safety measure does not reduce the risk of using radioactive material?
 (a) Keeping the material a long distance (b) Keeping the material at a low temperature
 (c) Using lead screening (d) Using the material for a short time
13. A scientist experiments using a sealed source that emits β -particles. The range of the β -particles in the air is about 30cm. The precaution that is the most effective to protect the scientist from the radiation is,
 (a) Handling the source with long tongs (b) Keeping the temperature of the source low
 (c) Opening all windows in the laboratory (d) Washing his hands before leaving the laboratory
14. The safest way to dispose of a large quantity of radioactive waste is,
 (a) Burying it in a dry rock deep underground (b) Washing it in the drain
 (c) Burning it on a fire (d) Draining it into the sea

Ans:

1. Highly ionizing than γ -radiation.	2. Increases by 1.	3. α -emission	4. β -particle.	5. Gamma-ray
6. 25mg	7. Nuclear fusion	8. Fission	9. Nuclear fusion	
10. Have the most significant penetrating effect.	11. All of these	12. Keeping the material at a low temperature	13. Handling the source with long tongs	14. Burying it in a dry rock deep underground

Numerical

1. A living plant contains approximately the same isotopic abundance of C-14 as does atmospheric carbon dioxide. The observed rate of decay of C-14 from a living plant is 15.3 disintegrations per minute per gram of carbon. How much disintegration per minute per gram of carbon will be measured from a 12900 year-old sample? (The half-life of C-14 is 5730 years.) (2.2513, 0.21, 3.2)

2. The smallest C-14 activity that can be measured is about 0.20%. If C-14 is used to date an object, the object must have died within how many years? (51374 yr)

3. How long will it take for 25% of the C-14 atoms in a sample of C-14 to decay? (2378 yr)

. The carbon-14 decay rate of a sample obtained from a young tree is 0.296 disintegration per second per gram of the sample. Another wood sample prepared from an object recovered at an archaeological excavation gives a decay rate of 0.109 disintegration per second per gram of the sample. What is the age of the object? (8258 yr)

Worked Example 1 If there are 96 grams of radioactive element Neptunium-240 present, how much Np-240 will remain after 6 hours? (Neptunium-240 has a half-life of 1 hour)

Worked Example 2 A sample of Ac-225 originally contained 8.0×10^{24} nuclei. After 960 hours, how much of the original sample remains un-decayed. The half-life of the isotope is ten days.

Worked Example 3 How long will it take to decay for 36.0 mg of Ra-226 to leave 4.5 mg? The half-life of the isotope is 1600 years.

