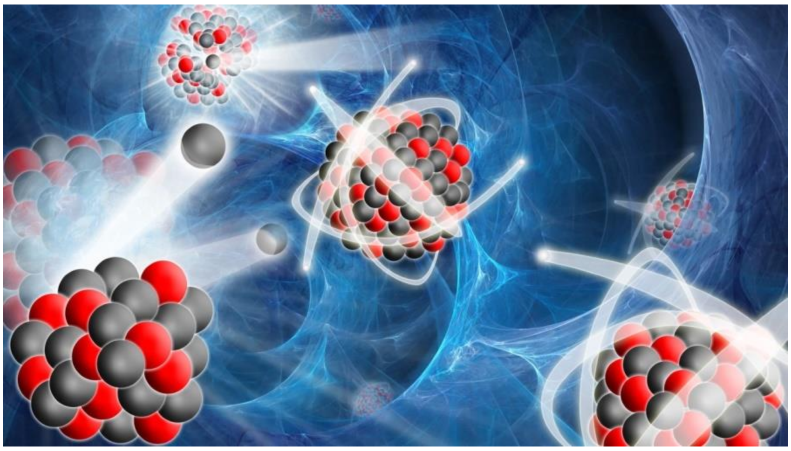
S4 New Curriculum chemistry

Theme: Consumable Chemicals

Chapter 4 – Nucear processes



Nuclear reaction

This is a reaction where rearrangement of protons and neutrons in the nucleus of an atom take place and new element is formed.

Radioactive substances

Radioactive substances contain unstable atomic nuclei that emit radiation as they decay into more stable forms. These materials are used in various fields, including medicine, energy production, and scientific research.

Common Radioactive Elements

- **Uranium (U-238)**: Used in nuclear power plants and weapons.
- **Radium (Ra-226)**: Previously used in luminous paints and medical treatments.
- **Plutonium (Pu-239)**: A key component in nuclear reactors and weapons.
- **Technetium (Tc-99m)**: Widely used in medical imaging.
- **Thorium (Th-232)**: Found in some nuclear reactors and industrial applications.

Uses of Radioactive Substances

- **Medicine**: Radiation therapy for cancer treatment and diagnostic imaging.
- **Energy**: Nuclear power plants generate electricity using radioactive fuel.
- **Industry**: Used in radiography for inspecting materials and structures.
- **Scientific Research**: Helps in studying atomic structures and space exploration.

Dangers of handling radioactive substances

Handling radioactive substances comes with significant risks, requiring strict safety measures to prevent harmful exposure. Here are some key dangers:

- **Radiation Exposure**: Prolonged exposure can lead to radiation sickness, DNA damage, and increased cancer risk.
- **Environmental Contamination**: Improper disposal can pollute water, soil, and air, affecting ecosystems.
- **Health Hazards**: Inhalation or ingestion of radioactive particles can cause internal damage, particularly to organs like the lungs and thyroid.
- **Accidental Spills**: Mishandling can lead to contamination of workspaces, requiring extensive cleanup.
- **Security Risks**: Unauthorized access to radioactive materials can pose threats, including potential misuse.

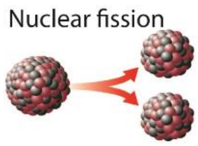
Precautions when handling radioactive substance

Handling radioactive substances requires strict safety measures to minimize exposure and prevent contamination. Here are key precautions:

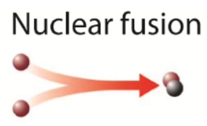
- **Use Protective Gear**: Wear gloves, lab coats, safety glasses, and radiation-resistant clothing to reduce direct exposure.
- **Limit Exposure Time**: Minimize the duration spent near radioactive materials to reduce radiation absorption.
- **Maintain Safe Distance**: Keep as much distance as possible from the radiation source to lower exposure levels.
- **Use Shielding**: Lead, concrete, or specialized barriers help block radiation effectively.
- **Proper Storage**: Store radioactive materials in secure, labeled containers to prevent accidental exposure.
- **Monitor Radiation Levels**: Use dosimeters and radiation detectors to track exposure levels.
- **Follow Disposal Guidelines**: Dispose of radioactive waste according to regulatory standards to prevent environmental contamination.

Types of nuclear decay

(a) **Nuclear Fission**: The splitting of a heavy nucleus into smaller nuclei, releasing a large amount of energy. This process is used in nuclear power plants and atomic bombs.



(b) **Nuclear Fusion**: The combining of two light nuclei to form a heavier nucleus, releasing even more energy than fission. This is the process that powers the Sun and hydrogen bombs.

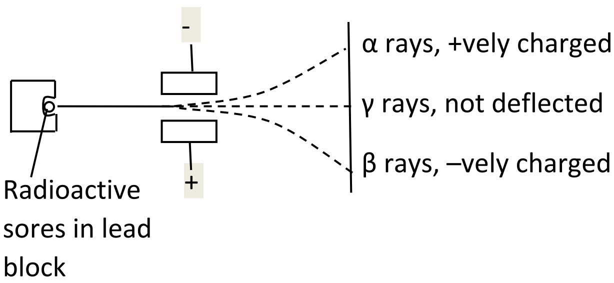


(c) **Nuclear Transmutation**: The conversion of one element into another through nuclear reactions, often used in scientific research and medical applications.

(d) **Radioactive Decay**: The spontaneous transformation of an unstable nucleus into a more stable one, emitting radiation in the form of alpha, beta, or gamma particles.

Properties of radiations

There are three types of radiations given by radioactive substances. They all cause certain substances, such as zinc sulphide, to luminesce, and all ionize gases through which they pass. They differ in their response to an electric field in the manner shown in figure below:



γ-rays

These uncharged rays are similar to X-rays

- they have high penetrating power; being able to pass through 0.1m of metal.
- have negligible weight
- are un deflected by electric field
- ionize gases they pass through

α-rays

- positively charged helium ions
- ionize gases they pass through
- deflected towards negative electric field
- have low penetrating power

β-rays

- negatively charged

- deflected toward positive electric field
- have medium penetrating power
- ionize gases they pass through

Rates of radioactive decay

The rate of radioactive decay describes how quickly unstable atomic nuclei lose energy and transform into more stable forms. This process follows a **first-order reaction**, meaning the decay rate is proportional to the number of radioactive atoms present.

Key concepts in radioactive decay rates

- **Half-Life ($t_{1}/_{2}$)**: The time required for half of a radioactive substance to decay. It remains constant for a given isotope.
- **Decay constant (k)**: A value that represents the probability of decay per unit time.

  k = $\frac{0.693}{t_{1/2}}$

- **Exponential decay formula**: The number of remaining radioactive atoms at time t is given by:

  N = N_0e^{-kt} where N_0 = initial quantity, N is the quantity at time t, k = decay constant

  Or

  $In\frac{N_0}{N} = kt$

Example

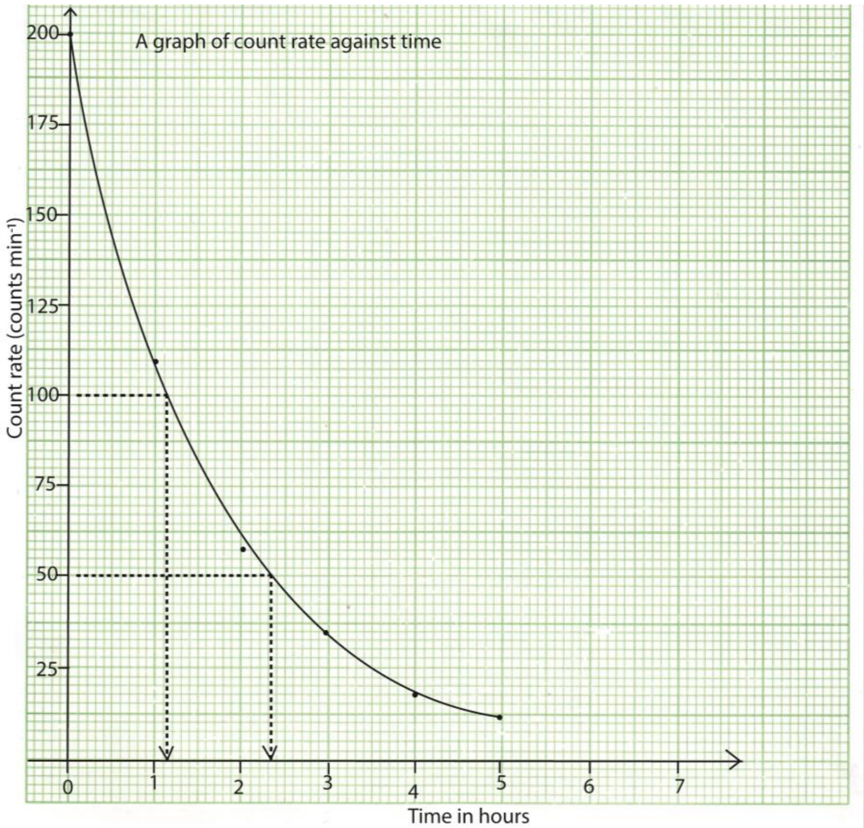
The table below shows the decay data of a certain radioactive substance

Time (hrs)	0	1	2	3	4	5
Count rate (counts min^{-1})	200	110	57	35	20	13

(a) Plot a graph of count rate against time for the substance.
(b) Explain the shape of the graph
(c) Use the graph to determine the half-life of the substance
(d) Calculate the decay constant
(e) Explain why the curve will finally level.

Solution

(a)



(b) This graph sloped down **exponentially**, indicating that the reactant concentration decreases over time.

(c) Time taken for count rate to fall from 200 to 100 = 1.2hour

Time taken for count to fall from 100to 50 = 2.4 – 1.2

= 1.2hour

Hence, half-life = $\frac{1.2+1.2}{2}$ = 1.2 hrs

(c) Decay constant, k = $\frac{0.693}{t_{1/2}} = \frac{0.693}{1.2}$ **= 0.5775 per hour**

(d) Because the reacting particles will get used up.

Environmental Impact

- Nuclear power plants produce minimal greenhouse gas emissions compared to fossil fuels, making them a cleaner energy source.
- Proper containment prevents harmful radiation leaks, but accidents like Chernobyl and Fukushima have shown the risks of uncontrolled emissions.
- Waste disposal remains a challenge, as spent nuclear fuel requires long-term storage to prevent environmental contamination.

Balancing nuclear equations

The sum of protons and the mass number on the either side of the equation should be equal. Deficits are balanced with either α-particle ($_{2}^{4}He$), β-particle ($_{-1}^{0}e$, or $_{-1}^{0}\beta$) or positron($_{+1}^{0}e$) or neutron ($_{0}^{1}n$).

Example

The nucleus of element X reacts with an alpha particle according to the following equation

$_{n}^{m}X + _{2}^{4}He \rightarrow _{21}^{45}Sn + _{0}^{1}n$

Determine the values of m and n.

Solution

m+4 = 45 +1; m = 42

n + 2 = 21 + 0

n = 19

∴ X is potassium, i.e., the number of protons in an atom is characteristic of an element.

Revision question

1. Polonium $_{84}^{216}Po$ undergoes radioactive to give element Y according to the following equation

   $_{84}^{216}Po \rightarrow$ Y +α

(a) Calculate

   (i) atomic number of Y (½ mk)

   (ii) the mass number of Y (½ mk)

(b) Y decays further to form Z as shown by the equation below

   Y → Z + β

Calculate

   (i) the atomic number of Z (½ mk)

   (ii) the mass number of Z (½ mk)

2. The following equation shows part off the radioactive decay of Thorium.

   $_{90}^{234}Th \rightarrow _{91}^{234}Pa$ + ___ → X +α

   (i) Name the particle emitted in the first stage of the reaction (1mk)

   (ii) State the atomic number and the atomic mass of X (1mk)

3. (a) State three properties of beta particles

   (b) complete the following nuclear transformations

   (i) $_{94}^{239}Pu + _{0}^{1}n \rightarrow _{34}^{86}Se + _{60}^{150}Nd$ + _____

   (ii) $_{96}^{235}Cm + _{2}^{4}He \rightarrow$ ______

   (iii) $_{92}^{235}U + _{0}^{1}n \rightarrow _{57}^{148}La$ + _____ + $3_{0}^{1}n$

(c) Francium isotope ($^{223}_{87}Fr$) emits beta particles. the rate of emission reduces from 14.0 to 7.5 counter in 80 second. Calculate the half life of isotopes.

4. (a) $^{234}_{91}\text{Pa} \rightarrow\ ^{234}_{92}\text{U}$ + --------

(b) $^{6}_{3}\text{Li} + ^{1}_{0}\text{n} \rightarrow\ ^{3}_{1}\text{H}$ +---------

(c) $^{107}_{47}\text{Ag} + ^{1}_{0}\text{n} \rightarrow$..................

5. (a) Complete the following equations for the decay of bismuth.

$^{214}_{83}\text{Bi} \rightarrow\ _{-1}^{0}\text{e}$ + --------

(b) The half life of bismuth is 19.7minutes. Determine the time taken for 43% by mass of bismuth to decay.

Solutions to trials of chapter 2

1. (a)(i) atomic mass of Y = 82

(ii) mass number of Y = 212

(b)(i) atomic mass of Z = 83

(ii) mass number of Z = 212

No.2

(i) particle emitted = beta ($_{-1}^{0}\beta$)

(ii) atomic number of X = 89

Mass number of X = 230

No.3

(b)(i) $^{239}_{94}Pu + ^{1}_{0}n \rightarrow\ ^{86}_{34}Se + ^{150}_{60}Nd + \mathbf{4^{1}_{0}n}$

(ii) $^{235}_{96}Cm + ^{4}_{2}He \rightarrow \mathbf{^{239}_{98}Cf}$

(iii) $^{235}_{92}U + ^{1}_{0}n \rightarrow\ ^{148}_{57}La + \mathbf{^{85}_{35}Br} + 3^{1}_{0}n$

(c) From In $\frac{N_0}{N}$ = Kt

K = In $\frac{14}{7.5}$ ÷ 80 = 0.0078s^{-1}

t $_{½}$ = $\frac{In2}{K} = \frac{In2}{0.0078}$ = 88.865s

No. 4

(a) $^{234}_{91}\text{Pa} \rightarrow\ ^{234}_{92}\text{U} + \mathbf{_{-1}^{0}\beta}$

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

(c) $^{107}_{47}\text{Ag} + ^{1}_{0}\text{n} \rightarrow\ ^{108}_{47}Ag$

N0. 5

(a) $^{214}_{83}\text{Bi} \rightarrow {}^{0}_{-1}\text{e} + {}^{\mathbf{214}}_{\mathbf{84}}\mathbf{po}$

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Thanks

Dr. Bbosa Science