# 5.2 Radioactivity

Name: _____ Class: _____ Date: _____ **Total: 37 marks**

## 0 Vocabulary

| Word | Example |
|---|---|
| **radiation** /ˌreɪdɪ'eɪʃn/<br>辐射 | **Radiation** from the source can damage cells.<br>辐射源发出的**辐射**可能损伤细胞。 |
| **background radiation**<br>背景辐射 /'bækgraʊnd ˌreɪdɪ'eɪʃn/ | **Background radiation** comes from rocks and space.<br>**背景辐射**来自岩石和太空。 |
| **radon** /'reɪdɒn/<br>氡 | **Radon** is a radioactive gas that can collect in basements.<br>**氡**是一种放射性气体，可能聚集在地下室里。 |
| **cosmic rays** /'kɒzmɪk reɪz/<br>宇宙射线 | **Cosmic rays** come from space.<br>**宇宙射线**来自太空。 |
| **counter** /'kaʊntə/<br>计数器 | The **counter** goes up by 1 each time.<br>**计数器**每次增加 1。 |
| **corrected** /kə'rektɪd/<br>修正 | Subtract the background to get the **corrected** count.<br>减去背景计数，得到**修正**后的计数。 |
| **ionising** /'aɪənaɪzɪŋ/<br>电离 | Alpha radiation is very **ionising**.<br>$\alpha$ 辐射的**电离**能力很强。 |
| **aluminium** /ˌæljʊ'mɪnɪəm/<br>铝 | **Aluminium** is light and does not rust.<br>**铝**很轻，而且不会生锈。 |
| **electromagnetic wave**<br>电磁波 /ɪˌlektrəʊməg'netɪk weɪv/ | Light is an **electromagnetic wave**.<br>光是**电磁波**。 |
| **lead** /liːd/<br>铅 | **Lead** forms at the cathode when molten lead bromide is electrolysed.<br>电解熔融溴化铅时，阴极产生**铅**。 |
| **penetrating** /'penɪtreɪtɪŋ/<br>穿透 | Gamma rays are very **penetrating**.<br>伽马射线的**穿透**能力很强。 |
| **absorbed** /əb'sɔːbd/<br>吸收 | Alpha particles are **absorbed** by paper.<br>$\alpha$ 粒子会被纸**吸收**。 |



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| Word | Example |
|---|---|
| **beta particle** /'biːtə 'paːtɪkl/<br>$\beta$ 粒子 | A **beta particle** is a fast electron.<br>$\beta$ **粒子**是高速运动的电子。 |
| **kinetic energy**<br>动能 /kɪ'netɪk 'enədʒi/ | A fast car has a lot of **kinetic energy**.<br>一辆快速行驶的汽车具有很大的**动能**。 |
| **sample** /'sæmpl/<br>样品 | Hold the **sample** close to the detector.<br>将**样品**靠近探测器。 |
| **half-life** /haːf laɪf/<br>半衰期 | After one **half-life**, half the nuclei have decayed.<br>经过一个**半衰期**后，一半的原子核已经衰变。 |
| **smoke alarm** /sməʊk ə'laːm/<br>烟雾报警器 | A **smoke alarm** uses a tiny alpha source.<br>**烟雾报警器**使用一个微小的 $\alpha$ 放射源。 |
| **medical tracer**<br>医用示踪剂 /'medɪkl 'treɪsə/ | A **medical tracer** shows how blood moves in the body.<br>**医用示踪剂**可以显示血液在体内如何流动。 |
| **cancer** /'kænsə/<br>癌症 | Smoking can cause **cancer**.<br>吸烟可能导致**癌症**。 |
| **living cells** /'lɪvɪŋ selz/<br>细胞 | Radiation can damage **living cells**.<br>辐射会损伤活**细胞**。 |
| **mutation** /mjuː'teɪʃn/<br>突变 | A **mutation** is a change in the DNA.<br>**突变**是 DNA 发生的改变。 |
| **dose** /dəʊs/<br>剂量 | Workers wear badges to measure their radiation **dose**.<br>工作人员佩戴剂量徽章来测量所受的辐射**剂量**。 |
| **exposure** /ek'spəʊʒə/<br>照射 | Keep your **exposure** to radiation short.<br>尽量缩短受到辐射**照射**的时间。 |
| **shielding** /'ʃiːldɪŋ/<br>屏蔽 | Lead **shielding** protects staff from gamma rays.<br>铅制**屏蔽**层保护工作人员免受伽马射线的伤害。 |

## 1 Key knowledge and worked examples

### ■ Background radiation and the corrected count rate

Some radiation is always present: **radon** 氡 gas in the air (usually the largest source), rocks and buildings, food and drink, and **cosmic rays** 宇宙射线 from space. Radiation is measured with a detector joined to a **counter** 计数器, and the **count rate** 计数率 is the counts each second or minute.

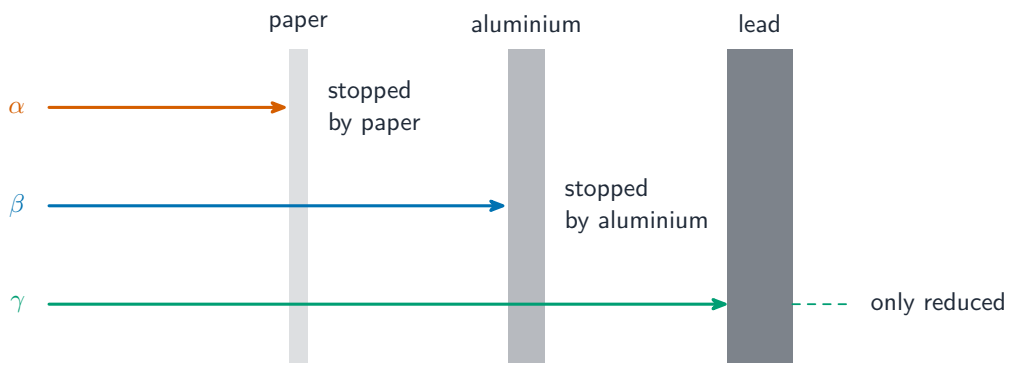
Always measure the background first, with the source removed, and subtract it:

$$\text{corrected count rate} = \text{measured count rate} - \text{background count rate}$$

**Worked example 1.** A detector next to a source reads 250 counts/min. With the source removed it reads 30 counts/min. Corrected: $250 - 30 = 220$ counts/min.

## The three radiations

| Type | What it is | Charge | Ionising | Stopped by |
|---|---|---|---|---|
| alpha ($\alpha$) | a helium nucleus, 2 protons + 2 neutrons | $+2$ | strongest | a sheet of paper, a few cm of air |
| beta ($\beta$) | a fast electron from the nucleus | $-1$ | medium | a few mm of **aluminium** 铝 |
| gamma ($\gamma$) | a high-energy electromagnetic wave | 0 | weakest | thick **lead** 铅 or concrete (only reduced) |




*Alpha is the most ionising but the least penetrating; gamma is the opposite*

Explain the ionising order from **charge** and **kinetic energy**: an alpha particle carries a charge of $+2$ and is heavy and slow, so it passes close to many atoms and pulls strongly on their electrons, ionising a great deal and losing its energy in a short distance. A beta particle has a smaller charge ($-1$) and moves much faster, so it interacts with each atom for less time and ionises less. Gamma has no charge at all, so it ionises least and travels furthest.

Because alpha and beta are charged, an electric or a magnetic field deflects them in **opposite** directions, and the much lighter beta is deflected more. Gamma is not deflected.

## Decay equations

In every decay the nucleon numbers balance and the proton numbers balance.

**Alpha decay** loses 2 protons and 2 neutrons, so $A$ falls by 4 and $Z$ by 2:


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$$^{226}_{88}\mathrm{Ra} \rightarrow\ ^{222}_{86}\mathrm{Rn} +^{4}_{2}\alpha$$

**Beta decay**: inside the nucleus a neutron changes into a proton and an electron, and the electron leaves as the beta particle. So $A$ is unchanged and $Z$ rises by 1:

$$^{24}_{11}\mathrm{Na} \rightarrow\ ^{24}_{12}\mathrm{Mg} +^{0}_{-1}\beta$$

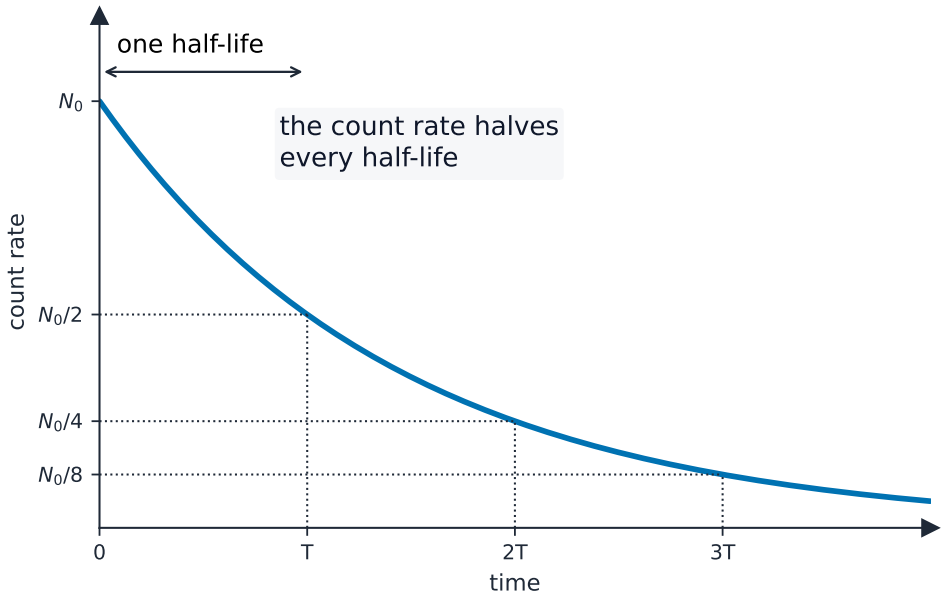
**Gamma emission** changes neither number: the nucleus only loses energy.

**Worked example 2.** $^{241}_{95}\mathrm{Am}$ decays by alpha emission to an isotope of neptunium. Nucleon number: $241 - 4 = 237$. Proton number: $95 - 2 = 93$. So

$$^{241}_{95}\mathrm{Am} \rightarrow\ ^{237}_{93}\mathrm{Np} +^{4}_{2}\alpha$$

## Half-life

The **half-life** is the time for half the unstable nuclei in a sample to decay. After each half-life the number left, and the corrected count rate, falls to half. Count the halvings rather than dividing the total time.




*Each half-life the count rate halves:* $N_0 \rightarrow N_0/2 \rightarrow N_0/4 \rightarrow N_0/8$

**Worked example 3.** A source falls from 800 to 100 counts/min and its half-life is 5 days. The halvings are $800 \rightarrow 400 \rightarrow 200 \rightarrow 100$, which is 3 half-lives, so the time is $3 \times 5 = 15$ days.

**Worked example 4 (mass decayed).** A source contains 25 $\mu$g of an isotope whose half-life is 29 years. Find the mass that decays in 87 years.

1. Number of half-lives: $87 \div 29 = 3$.
2. Fraction left: $\left(\frac{1}{2}\right)^3 = \frac{1}{8}$, so the mass left is $25 \div 8 = 3.1$ $\mu$g.

3. The question asks for the mass that **decayed**: $25 - 3.1 = 22$ $\mu$g.

Read a half-life off a graph by taking any starting value, finding half of it, and reading the time between them. Subtract the background from every reading first.

### ■ Choosing an isotope, and safety

The job decides the radiation and the half-life:

- **smoke alarm**: an alpha source with a long half-life. Alpha ionises the air between two plates so a small current flows; smoke particles absorb the alpha and the current drops. Alpha is safe outside the alarm because paper (or a few centimetres of air) stops it, and the long half-life means the alarm lasts for years.
- **thickness gauge** for paper or foil: a beta source, because the amount getting through changes with the thickness (alpha would all be stopped, gamma would all pass).
- **medical tracer**: a gamma emitter with a short half-life, so the radiation escapes the body to a detector and the activity soon falls to a safe level.
- **sterilising** equipment or food, and treating tumours: gamma, because it penetrates the sealed package or the body.

Ionising radiation damages **living cells** 细胞: it can kill cells, cause **mutations** 突变 in the genes, and cause cancer. To keep the **dose** 剂量 low: reduce the **exposure** 照射 time, increase the distance from the source, and use **shielding** 屏蔽 such as lead. Handle sources with tongs, never with bare hands; point them away from people; store them in a lead-lined box.

## 2 Practice

**2.1** State what material stops beta radiation. [1]

beta radiation

**2.2** Name two sources of background radiation. [2]

background radiation

**2.3** A detector reads 250 counts/min; the background is 30 counts/min. Find the corrected count rate. [2]

reading: 250 counts/min

background: 30 counts/min

**2.4** State the nature and the charge of an alpha particle and of a beta particle. [2]

$\alpha$ particle

$\beta$ particle

**2.5** Complete this decay equation, giving both numbers for the new nucleus: $^{210}_{84}\text{Po} \rightarrow {}^{?}_{?}\text{Pb} + {}^{4}_{2}\alpha$. [2]

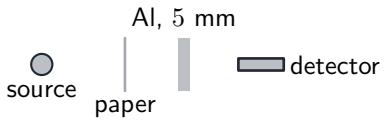



**2.6** State two precautions a scientist should take when working with a radioactive source to lower the dose received. [2]

radioactive source

## 3 Exam-style questions

**3.1** A source of radiation is placed near a detector. A sheet of paper between them makes no difference to the count rate, but a 5 mm sheet of aluminium reduces it almost to the background level. Which radiation is the source emitting? [1]




☐ **A** alpha only
**B** beta only
**C** gamma only
**D** alpha and gamma

**3.2** A nucleus emits a beta particle. Which row is correct? [1]

$\beta$ emission

☐ **A** nucleon number unchanged, proton number +1
**B** nucleon number unchanged, proton number −1
**C** nucleon number −4, proton number −2
**D** nucleon number −1, proton number unchanged



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**3.3** A student investigates a radioactive source. Before using it she records a count rate of 24 counts/min with the source in its lead box. With the source in place the detector reads 824 counts/min.

(a) Explain why she measured the count rate before bringing out the source, and calculate the corrected count rate. [3]




(b) The corrected count rate falls to 100 counts/min after 12 hours. Determine the half-life of the source. [3]

(c) The source emits beta particles. Describe what happens inside a nucleus when a beta particle is emitted. [2]

**3.4** A smoke alarm contains a small americium-241 source, which decays by alpha emission to an isotope of neptunium (Np).

(a) Complete the nuclide equation: $^{241}_{95}\mathrm{Am} \rightarrow \ \ldots\ldots \mathrm{Np} + \ldots\ldots \alpha$. [3]




(b) Describe how the alpha particles ionise the air inside the alarm. [3]



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(c) Suggest and explain one reason why the alarm uses an alpha emitter rather than a gamma emitter. [2]

(d) The half-life of americium-241 is 432 years. Explain why this long half-life is an advantage for a smoke alarm. [1]

**3.5** A hospital uses a gamma-emitting isotope with a half-life of 6 hours as a medical tracer.

(a) Explain why a gamma emitter, and not an alpha emitter, is used inside the body. [2]

$\gamma$ emitter $t_{1/2} = 6$ h

(b) A sample contains 80 $\mu$g of the isotope. Calculate the mass that has decayed after 24 hours. [3]

(c) State two effects that ionising radiation can have on living cells. [2]



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## Solutions

Each answer shows the steps, then the **result**.

**2.1**

- a few millimetres of aluminium

**2.2**

- any two of: radon gas in the air; rocks and buildings; food and drink; cosmic rays from space

**2.3**

- corrected $= 250 - 30$
- 220 **counts/min**

**2.4**

- alpha: a helium nucleus (2 protons and 2 neutrons), charge $+2$
- beta: a fast-moving electron, charge $-1$

**2.5**

- nucleon number $210 - 4 = 206$
- proton number $84 - 2 = 82 \Rightarrow {}^{206}_{82}\mathrm{Pb}$

**2.6**

- any two: reduce the time spent near the source; stand further away, handling it with tongs; work behind lead shielding; store it in a lead-lined box when not in use

**3.1 B**

- paper stops alpha, so there is no alpha; aluminium stops beta and would not stop gamma, so the source emits beta only
- **A** and **D** would have been blocked by the paper; **C** would still pass through the aluminium

**3.2 A**

- a neutron becomes a proton, so the proton number rises by one while the total number of nucleons is unchanged
- **C** describes alpha decay

**3.3**

(a) the reading with the source shut away is the background radiation, which is always present and must be subtracted so the count rate is due to the source alone

- corrected $= 824 - 24 =$ **800** counts/min



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(b) 800 → 400 → 200 → 100 is 3 half-lives

- half-life = 12 ÷ 3 = **4** hours

(c) a neutron in the nucleus changes into a proton

- and an electron, which is emitted as the beta particle

**3.4**

(a) $^{237}_{93}\text{Np}$ and $^{4}_{2}\alpha$

(b) the alpha particles are emitted from the americium

- and collide with (or pass close to) molecules in the air between the plates
- knocking electrons out of them so the air contains ions and conducts

(c) any one, with its explanation: alpha is easily absorbed by smoke particles, so the current drops as soon as smoke enters, while gamma would pass straight through and the alarm would not respond; alpha is much more ionising, so it makes the air conduct well enough to give a steady current; alpha has a very short range and is stopped by the plastic case, so it is far less harmful to people in the house than gamma would be

(d) the activity stays almost constant for the whole life of the alarm, so it does not need replacing

**3.5**

(a) gamma is the most penetrating, so it passes out of the body to the detector outside

- alpha would be absorbed within a few centimetres of tissue, giving a large dose to the patient and no signal outside

(b) 24 ÷ 6 = 4 half-lives

- mass left = 80 ÷ $2^4$ = 80 ÷ 16 = 5.0 $\mu$g
- mass decayed = 80 − 5.0 = **75** $\mu$g

(c) any two of: cell death; mutation of the genes; cancer



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