Unit 12 · Radioactivity

ANSWER KEY · FOR TEACHERS

Full marks 44

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

1 Key words

K · 3

1. radioisotope → **f.** an isotope with unstable nuclei
2. daughter nucleus → **a.** the nucleus left after the change
3. alpha particle → **d.** 2 protons and 2 neutrons, stuck tightly together
4. beta particle → **e.** a fast electron made when a neutron turns into a proton
5. gamma ray → **g.** an electromagnetic wave with no charge and no mass
6. dosimeter → **b.** a small badge that records the dose received

Each carries 0.5 mark.

2 Label the diagram

U · 3

1. β
2. α
3. γ

Each carries 1 mark.

3 Multiple choice

i. **b.** a helium nucleus — K · 1

An alpha particle is 2 protons and 2 neutrons, which is the nucleus of a helium-4 atom, $^{4}_{2}\mathrm{He}$.

ii. **c.** atomic number goes up by 1 and its mass number stays the same — U · 1

In beta decay a neutron turns into a proton (which stays) and an electron (which leaves). One more proton raises the atomic number by 1; the total of protons and neutrons, the mass number, is unchanged.

iii. **b.** towards the positive plate — U · 1

Beta particles are negatively charged electrons, so they are attracted to the positive plate. Alpha particles, being positive, bend towards the negative plate; gamma rays go straight.

iv. **a.** alpha particles — K · 1

Smoke detectors use americium-241, an alpha source: its alpha particles ionize the air between two plates strongly, and they are stopped by the air and the plastic case, so the detector is safe.

v. **c.** sievert — K · 1

The dose, which combines the energy left in the body with the kind of radiation, is measured in sieverts (Sv), usually in millisieverts or microsieverts. (The becquerel and the curie measure how many nuclei in a source decay each second, not the dose received.)

4 Very short answers

a. MARKING SCHEME — K · 1

✓ Radioactive material gets onto or into something.

b. MARKING SCHEME — K · 1

✓ 1.2 cm.

c. MARKING SCHEME — U · 1

✓ The food does not become radioactive (no radioactive material gets into it).

d. MARKING SCHEME — U · 1

✓ Only its energy (Z and A are unchanged).

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5 Short answers

a. MARKING SCHEME U · 2

- ✓ Each ion a particle makes costs it a little of its energy.
- ✓ Alpha particles ionize so strongly that they use up all their energy within a few centimeters of air, and stop.

b. MARKING SCHEME U · 2

- ✓ Alpha particles are stopped by the dead outer layer of the skin, so they could never reach the tumor.
- ✓ Gamma rays penetrate the body and can be aimed at the tumor from many directions.

c. MARKING SCHEME A · 2

- ✓ Beta: a thin sheet absorbs part of it, more as it gets thicker.
- ✓ Alpha would be stopped completely, and gamma would pass almost unchanged.

d. MARKING SCHEME U · 2

- ✓ Outside: gamma, which passes through skin to every organ.
- ✓ Inside: alpha, which dumps all its energy in a few nearby cells.

6 Long answers

a. ANSWER U · 4

A radioactive source giving out all three radiations is placed in a lead block with a narrow channel, so that a thin beam comes out. The beam passes between two metal plates, one charged positive and one negative, in a vacuum (so the alpha particles are not stopped by air), and falls on a photographic plate or screen beyond.

- One beam bends towards the **negative** plate: it must be **positive**, the alpha particles.
- One beam bends towards the **positive** plate, and spreads out: it must be **negative**, the beta particles.
- One beam goes straight on: it has **no charge**, the gamma rays.

(Diagram: the lead block with the source and channel; the + plate and − plate; the beta beam curving towards +, the alpha beam curving less towards −, the gamma beam straight; the screen, as in the figure in the book.) A magnetic field across the beam shows the same: alpha and beta bend opposite ways, gamma not at all.

MARKING SCHEME

- ✓ A thin beam from a source in a lead block passes between charged plates, in a vacuum (with a labeled diagram).
- ✓ One beam bends towards the negative plate: positive, the alpha particles.
- ✓ One beam bends towards the positive plate: negative, the beta particles.
- ✓ One beam goes straight on: no charge, the gamma rays.

b. ANSWER

Handling:

- Keep the **time** near a source as short as possible.
- Keep the **distance** large: use long tongs or remote handling, never bare hands; the gamma dose falls with the square of the distance.
- Use **shielding**: work behind lead bricks, lead glass or concrete walls.
- Wear gloves, a lab coat and a dosimeter badge; never eat or drink where sources are used; wash and check hands afterwards.

Storing:

- Keep sources in thick lead (or concrete) containers in a locked place, away from people.
- Label every container with the radiation warning sign and what is inside.
- Record every source, where it is and who is responsible, so none is ever lost or thrown away.
- Store radioactive waste shielded until it has decayed; seal long-lived waste in steel and concrete for very long storage; follow the license conditions of the country's regulatory body.

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MARKING SCHEME K · 4

- ✓ Time near a source short, and distance large (tongs or remote handling, never bare hands).
- ✓ Shielding (lead bricks, lead glass, concrete), with gloves, lab coat and dosimeter, and no eating or drinking.
- ✓ Stored in thick lead or concrete containers in a locked place, labeled with the warning sign.
- ✓ Every source recorded; waste kept shielded until it has decayed.

7 Numerical problems

a. **ANSWER** A · 2

i. $^{238}_{92}\mathrm{U} \longrightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He}$ $(238 = 234 + 4;\ 92 = 90 + 2)$

ii. $^{131}_{53}\mathrm{I} \longrightarrow {}^{131}_{54}\mathrm{Xe} + {}^{0}_{-1}\mathrm{e}$ $(131 = 131 + 0;\ 53 = 54 - 1)$

MARKING SCHEME

- ✓ i. Th: A = 234, Z = 90, with the alpha particle.
- ✓ ii. Xe: A = 131, Z = 54, with the beta particle.

b. **ANSWER** A · 3

The mass number falls by $237 - 209 = 28$, so there are $28 \div 4 =$ **7 alpha particles**.
They lower the atomic number by $7 \times 2 = 14$, to $93 - 14 = 79$. Bismuth is 83, so it must rise by $83 - 79 = 4$: **4 beta particles**.
Check: $209 + 28 = 237$; $83 + 14 - 4 = 93$. ✓

MARKING SCHEME

- ✓ $237 - 209 = 28$, so $28 \div 4 = 7$ alpha particles.
- ✓ $93 - 14 = 79$.
- ✓ $83 - 79 = 4$ beta particles.

c. **ANSWER** A · 2

New dose rate $= 36 \div 3^2 = 36 \div 9 = 4\ \mu$Sv per hour.
Dose in 2 hours $= 4 \times 2 = 8\ \mu$Sv.
4 μSv per hour; 8 μSv in 2 hours (instead of 72 μSv had she stayed at 1 m).

MARKING SCHEME

- ✓ $36 \div 3^2 = 4$ μSv per hour.
- ✓ $4 \times 2 = 8$ μSv.

d. **ANSWER** A · 3

Yearly dose $= 2 \times 8 \times 250 = 4{,}000\ \mu$Sv $= 4$ mSv.
4 mSv a year, a fifth of the 20 mSv limit, and less than twice the natural background of about 2.4 mSv a year that everyone receives anyway.

MARKING SCHEME

- ✓ $2 \times 8 \times 250 = 4{,}000$ μSv.
- ✓ 4,000 μSv = 4 mSv.
- ✓ A fifth of the 20 mSv limit.

8 Think

ANSWER HA · 3

Lead doesn't stop gamma rays; it **reduces** them, to half for every 1.2 cm or so (for cobalt-60). One centimeter lets through a little more than half of them, about 56%, so the apron would only roughly halve the dose. A safe level from a strong source needs many centimeters of lead or a meter or more of concrete, together with distance and short times.

MARKING SCHEME

- ✓ Lead doesn't stop gamma rays; it only reduces them.
- ✓ For cobalt-60, each 1.2 cm halves them, so 1 cm lets through a little more than half.
- ✓ So the apron would only roughly halve the dose; a safe level needs many centimeters of lead, with distance and short times.

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9 Activity: Chart of the three radiations (Practical 23)

(not marked)

WHAT STUDENTS SHOULD FIND

Alpha: helium nucleus, +2, about 4 u, stopped by paper or a few cm of air, most ionizing, bends towards the − plate, Z − 2 and A − 4 (a smoke detector: ionizes air strongly, stopped by the case). Beta: fast electron, −1, about 1/1836 u, stopped by a few mm of aluminium, less ionizing, bends towards the + plate, Z + 1 and A the same (a thickness gauge: a thin sheet absorbs part of it). Gamma: electromagnetic wave, no charge or mass, only reduced by thick lead or concrete, least ionizing, not bent, Z and A the same (radiotherapy: reaches a deep tumor). Every ion costs energy, so the radiation that makes most ions stops soonest.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	12	17	12	3	**44**

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