

GCSE / IGCSE Physics – Radioactivity and Space

GCSE/IGCSE (Edexcel/AQA/Cambridge) · Total marks: 37 · Answers on the last page

This worksheet covers atomic structure, radioactive decay, half-life, and the solar system and stars. A calculator is allowed throughout; use $g = 9.81 \text{ m s}^{-2}$ where needed and take the speed of light as $3.0 \times 10^8 \text{ m s}^{-1}$.

Section A – Atomic Structure and Radioactive Decay (Non-calculator)

1. An atom of the isotope carbon-14 is represented as ${}^{14}_6\text{C}$.
 - (a) State the number of protons, neutrons and electrons in a neutral atom of carbon-14.
 - (b) Define the term isotope. [3]
2. Radium-226 (${}^{226}_{88}\text{Ra}$) decays by alpha emission to form radon (Rn).
 - (a) Write a balanced nuclear equation for this decay.
 - (b) Explain why the mass number and atomic number must both balance in the equation. [3]
3. Carbon-14 decays by beta-minus emission to form nitrogen-14.
 - (a) Write a balanced nuclear equation for this decay, including the beta particle as ${}^0_{-1}\beta$.
 - (b) State what happens inside the nucleus during beta-minus decay. [3]
4. Compare alpha, beta and gamma radiation in terms of:
 - (a) their penetrating power through materials,
 - (b) their relative ionising power. [4]

Section B – Half-life and Uses of Radioactive Sources (Calculator allowed)

5. A radioactive source has an initial activity of 640 Bq. The activity falls to 80 Bq.
 - (a) State the meaning of the term half-life.
 - (b) If the half-life of the source is 6 hours, calculate the total time taken for the activity to fall from 640 Bq to 80 Bq. [4]
6. Carbon-14 has a half-life of 5730 years. A bone sample is found to contain $\frac{1}{8}$ of the activity per gram of carbon found in a living organism. Estimate the age of the bone. [3]
7. A radioactive tracer is injected into a patient to monitor the function of an organ using an external detector.

Explain why an isotope chosen for this purpose should be a gamma emitter with a short half-life. [3]
8. Explain, in terms of ionisation, how ionising radiation can damage living cells, and state one precaution a radiographer should take to reduce their own exposure to radiation. [3]

Section C – The Solar System and Stars (Calculator allowed)

9. The planets orbit the Sun in almost circular paths.

Explain, in terms of forces, why the planets do not travel off in a straight line into space. [2]
10. Light from the Sun reaches the Earth after travelling a distance of $1.5 \times 10^{11} \text{ m}$. Taking the speed of light as $3.0 \times 10^8 \text{ m s}^{-1}$, calculate the time taken, in minutes, for light to travel from the Sun to the Earth. [3]

11. Describe the life cycle of a star with a similar mass to the Sun, from its formation to its final stable state. [3]
12. Astronomers observe that light from distant galaxies is red-shifted, and that more distant galaxies show a greater red-shift.
 - (a) State what is meant by red-shift.
 - (b) Explain how these observations provide evidence for the Big Bang theory. [3]

Answers

Check your working against these. If an answer does not match, try the question again before looking for the method.

- Protons = 6, neutrons = $14 - 6 = 8$, electrons = 6.
 - Isotopes are atoms of the same element (same number of protons) with different numbers of neutrons (different mass number).
- ${}_{88}^{226}\text{Ra} \rightarrow {}_{86}^{222}\text{Rn} + {}_2^4\text{He}$
 - Mass number (nucleons) and charge (protons) are conserved in nuclear reactions, so the sums of the top numbers and the sums of the bottom numbers must be equal on each side.
- ${}_{6}^{14}\text{C} \rightarrow {}_{7}^{14}\text{N} + {}_{-1}^0\beta$
 - A neutron in the nucleus changes into a proton and an electron (beta particle), and the electron is emitted from the nucleus.
- Alpha: stopped by paper/a few cm of air. Beta: stopped by a few mm of aluminium. Gamma: only greatly reduced by thick lead or many metres of concrete; most penetrating.
 - Alpha is the most strongly ionising (large, slow, charged), beta is weakly ionising, gamma is the most weakly ionising (penetrating power and ionising power are inversely related).
- Half-life is the time taken for the activity (or number of undecayed nuclei) of a radioactive sample to halve.
 - $640 \rightarrow 320 \rightarrow 160 \rightarrow 80$ is 3 half-lives, so time = $3 \times 6 = 18$ hours.
- $\frac{1}{8} = \left(\frac{1}{2}\right)^3$, so 3 half-lives have passed: age = $3 \times 5730 = 17190$ years (approximately 1.7×10^4 years).
- Gamma radiation is used because it penetrates body tissue and can be detected outside the body, and (unlike alpha) causes little ionising damage to the patient's cells as it passes through. A short half-life means the source decays away quickly, so the patient's radiation dose does not remain high for long after the test.
- Ionising radiation removes electrons from atoms/molecules in cells, which can damage or mutate DNA; this can kill cells or cause cells to divide uncontrollably (cancer). Precaution: stand behind a lead screen / operate equipment remotely / keep as far from the source as possible / limit exposure time (any one).
- The gravitational force of attraction between the Sun and each planet acts towards the Sun, providing the centripetal force needed to keep the planet moving in a circular orbit.
- $$t = \frac{d}{v} = \frac{1.5 \times 10^{11}}{3.0 \times 10^8} = 500 \text{ s} = \frac{500}{60} \approx 8.3 \text{ minutes.}$$
- A nebula (cloud of dust and gas) contracts under gravity to form a protostar, which becomes a stable main sequence star (fusing hydrogen into helium) for most of its life. When hydrogen runs low it expands into a red giant, then the outer layers drift away as a planetary nebula, leaving behind a white dwarf, which cools and fades.
- Red-shift is the increase in the observed wavelength of light from a source (shift towards the red end of the spectrum), caused by the source moving away from the observer.
 - Since all distant galaxies are red-shifted, they must all be moving away from us; more distant galaxies have greater red-shift, so they are moving away faster — this shows the universe is expanding, which supports the idea that it began from a single very small, hot, dense point (the Big Bang).

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