Unit 21 · Nuclear Chemistry and Applications of Radioactivity

ANSWER KEY · FOR TEACHERS

Full marks 36

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

1 Key words

U · 3

i. ✓ **True**

ii. ✗ **False**: One D–T fusion gives 17.6 MeV and one fission about 200 MeV; fusion gives more energy only per kilogram of fuel.

iii. ✓ **True**

iv. ✗ **False**: It was the first artificial transmutation, but oxygen-17 is stable, so nothing radioactive is made.

v. ✗ **False**: It dates only things that were once alive, up to about 50,000 years old; rocks are dated by uranium-238 and lead-206.

vi. ✓ **True**

Each carries 0.5 mark.

2 Label the diagram

A · 2

1. slow neutron absorbed
2. ^{240}Pu
3. 3n
4. ^{97}Zr

Each carries 0.5 mark.

3 Multiple choice

i. **b.** 0 and +1 — K · 1

In β^- decay a neutron becomes a proton and an electron leaves: the number of nucleons stays the same and the atomic number rises by one.

ii. **c.** A = 206, Z = 82 — A · 1

An α particle carries away 4 from the mass number and 2 from the atomic number: $210 - 4 = 206$ and $84 - 2 = 82$, which is lead-206.

iii. **c.** 2 Ci — U · 1

1 Ci = 3.7×10^{10} Bq, so $7.4 \times 10^{10} \div 3.7 \times 10^{10} = 2$ Ci.

iv. **c.** boron or cadmium — K · 1

Boron and cadmium absorb neutrons, so each fission causes on average only one more. Water or graphite is the moderator, which slows the neutrons.

v. **c.** positrons — K · 1

PET is positron emission tomography: fluorine-18, oxygen-15 and nitrogen-13 give out positrons, $^{0}_{+1}$e.

4 Short answers

a. MARKING SCHEME — A · 2

✓ $^{27}_{13}\text{Al} + {}^{4}_{2}\text{He} \rightarrow {}^{30}_{15}\text{P} + {}^{1}_{0}\text{n}$ (top 31 = 31, bottom 15 = 15).

✓ $^{30}_{15}\text{P} \rightarrow {}^{30}_{14}\text{Si} + {}^{0}_{+1}\text{e}$ (top 30 = 30, bottom 15 = 14 + 1).

b. MARKING SCHEME — U · 2

✓ Controlled: each fission causes on average exactly one more, so the reaction goes on at a steady rate (control rods absorb the extra neutrons), as in a nuclear power reactor.

✓ Uncontrolled: each fission causes more than one more, the fissions multiply in millionths of a second and the energy comes out all at once, as in a fission (atomic) bomb.

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c. MARKING SCHEME U · 2

- ✓ The thyroid takes up iodine, so the iodine-131 collects in the gland and treats it from inside.
- ✓ Its β particles kill the cells around it, while its γ rays escape the body and can be counted from outside (half-life 8.0 days).

d. MARKING SCHEME U · 2

- ✓ An α particle is a helium nucleus, charge +2, mass 4 u; a γ ray is electromagnetic radiation, with no charge and no mass.
- ✓ α ionizes most and is stopped by a sheet of paper; γ ionizes least and is reduced only by thick lead or concrete (any correct second difference: speed, deflection in a field).

e. MARKING SCHEME U · 3

- ✓ An americium-241 source ionizes the air between two plates, and a small current flows.
- ✓ Smoke soaks up the ions, the current falls and the alarm sounds.
- ✓ α particles are stopped by the case, so none reach the people in the house.

5 Long answer

ANSWER U · 4

Nuclear fission is the splitting of a heavy nucleus into two lighter nuclei, with the release of a large amount of energy (about 200 MeV for each uranium-235 nucleus) and radiation.

$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{141}_{56}\mathrm{Ba} + {}^{92}_{36}\mathrm{Kr} + 3\,{}^{1}_{0}\mathrm{n}$

Each fission gives out two or three neutrons, and each of them can split another uranium-235 nucleus: one fission leads to two, then four, then eight, a chain reaction.

Advantages: very little carbon dioxide; a small amount of fuel gives a very large amount of energy; steady power day and night. Disadvantages: an accident can cause long-term harm (Chernobyl, Fukushima); the radioactive waste must be kept safe for thousands of years; stations are costly; the fuel can be misused for weapons.

MARKING SCHEME

- ✓ The definition of nuclear fission.
- ✓ The balanced equation (236 = 141 + 92 + 3; 92 = 56 + 36).
- ✓ The chain reaction: the neutrons released split more nuclei.
- ✓ Two advantages and two disadvantages.

6 Numerical problems

a. ANSWER A · 4

i. $t = \frac{t_{1/2}}{\log 2} \log \frac{N_0}{N} = \frac{5730}{0.3010} \log \frac{15.3}{9.6} = 19\,040 \times 0.2024 \approx$ **3,850 years**.

ii. One more half-life halves it: 9.6 ÷ 2 = **4.8 counts per minute per gram**.

iii. After about 50,000 years too little carbon-14 is left to measure; 200,000 years is about 35 half-lives.

MARKING SCHEME

- ✓ The formula with $N_0/N = 15.3/9.6$.
- ✓ About 3,850 years.
- ✓ 4.8 counts per minute per gram.
- ✓ Too little carbon-14 is left after about 50,000 years.

b. ANSWER A · 4

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

ii. 60 h ÷ 15.0 h = 4 half-lives: $8.0 \times 10^6 \div 2^4 =$ **5.0×10^5 Bq**.

iii. $8.0 \times 10^6 \div 3.7 \times 10^{10} =$ **2.2×10^{-4} Ci** (0.22 mCi).

iv. $t = \frac{15.0}{0.3010} \log 100 = 49.8 \times 2 \approx$ **100 hours** (about four days).

MARKING SCHEME

- ✓ The balanced equation (24 = 24 + 0; 11 = 12 − 1).
- ✓ 5.0×10^5 Bq after four half-lives.
- ✓ 2.2×10^{-4} Ci.
- ✓ About 100 hours.

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7 Think

ANSWER HA · 3

The energy per kilogram depends on the energy per reaction divided by the mass of the nuclei that react. A fission uses a uranium-235 nucleus and a neutron, 236 u: $200 \div 236 \approx 0.85$ MeV for each unit of mass. A D–T fusion uses nuclei of only $2 + 3 = 5$ u: $17.6 \div 5 \approx 3.5$ MeV for each unit of mass. So a kilogram of D–T fuel holds about 47 times as many reacting pairs as a kilogram of uranium-235 holds nuclei, and gives about $3.5 \div 0.85 \approx 4$ times as much energy.

MARKING SCHEME

- ✓ Energy per kilogram is energy per reaction over the mass that reacts.
- ✓ Fission about 0.85 MeV per u ($200 \div 236$); fusion about 3.5 MeV per u ($17.6 \div 5$).
- ✓ The ratio is about 4: fusion's nuclei are so light that far more of them react in a kilogram.

8 Activity: Half-lives with coins

(not marked)

WHAT STUDENTS SHOULD FIND

About half the coins go at each throw: roughly 64, 32, 16, 8, 4, 2, 1, so one throw is one half-life. The graph is the same falling curve as any radioactive decay (first order): the same fraction goes in each equal time, whatever the number left. No one can say which coin will go next, only how many on average, just as no one can say when a particular nucleus will decay.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	3	17	13	3	**36**

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