

Mixed Exam Questions – Set 10

1.

This question is about the radioisotope americium-241 used in smoke detectors. Fig. 6.1 shows a cross-section through a simplified smoke detector mounted on the ceiling.

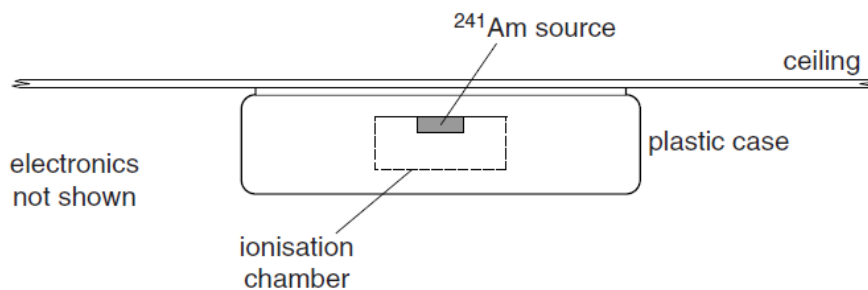
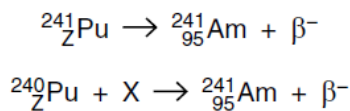


Fig. 6.1

The alpha particles emitted by the americium ionise the air inside the ionisation chamber maintaining a small current in a circuit including the ionisation chamber in series. When smoke enters the chamber the ions are absorbed and the current falls, causing the alarm to sound.

- (a) Americium-241 occurs naturally from the decay of plutonium-241 by beta minus emission, or is made artificially by the bombardment of plutonium-240 inside a nuclear reactor. The nuclear equations for each of these processes are shown below with letters substituted for some of the symbols.



Write down

- (i) the numerical value of the letter Z [1]
 - (ii) what Z represents [1]
 - (iii) the correct name of particle X. [1]
- (b) A typical smoke detector contains 2.5×10^{-10} kg of americium-241.
- (i) Show that the source contains about 6×10^{14} nuclei of americium-241.

[2]

- (ii) The half-life of americium-241 is 480 years. Show that its decay constant is about $4.6 \times 10^{-11} \text{ s}^{-1}$.

$$1 \text{ year} = 3.15 \times 10^7 \text{ s}$$

[1]

- (iii) Calculate the activity of the americium-241 in the smoke detector. Give a suitable unit with your answer.

activity = unit [3]

- (iv) Estimate the time it takes for the activity to fall by one percent.

time = s [3]

- (c) Nuclei of americium-241 decay by alpha particle emission. Suggest

- (i) why the americium is not a hazard when it is inside the detector

.....
..... [1]

- (ii) how a small speck of the source could be hazardous if it came out of the plastic case.

.....
.....
..... [2]

2.

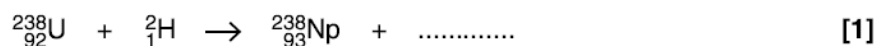
The space probe, Curiosity, roaming on the surface of Mars, is powered by a radioisotope thermoelectric generator (RTG). The generator transforms thermal energy into electrical energy. The thermal energy comes from the radioactive decay of plutonium-238. Fig. 5.1 shows an image of Curiosity.



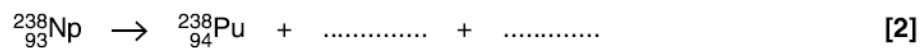
Fig. 5.1

(a) The plutonium-238 (${}^{238}_{94}\text{Pu}$) isotope can be artificially produced by bombarding uranium-238 (${}^{238}_{92}\text{U}$) with deuterium (${}^2_1\text{H}$). This produces an intermediate isotope of neptunium-238 (${}^{238}_{93}\text{Np}$) and neutrons. The isotope of ${}^{238}_{93}\text{Np}$ then decays by beta-minus emission to form plutonium-238.

(i) Complete the following reaction.



(ii) Complete the following decay equation for ${}^{238}_{93}\text{Np}$.



(b) Plutonium-238 is an alpha-emitter with a half-life of 88 years. The kinetic energy produced during each decay is 9.0×10^{-13} J. The RTG on Curiosity produces 120 W of electrical power from 2000 W of thermal power.

(i) Calculate the mass of plutonium-238 on board Curiosity.

molar mass of plutonium-238 = $0.238 \text{ kg mol}^{-1}$

mass = kg [4]

(ii) Calculate the output electrical energy in kWh from the RTG in a day.

energy = kWh [2]

3.

(a) Explain what is meant by the *binding energy* of a nucleus.

.....
..... [1]

(b) The fusion of protons occurs in a star when the temperature within the core is greater than about 10^7 K. It takes the fusion of 4 protons to form a helium-4 (${}^4_2\text{He}$) nucleus. In this process, known as the proton–proton cycle, energy is released.

The net energy released in producing a single helium-4 nucleus is 4.53×10^{-12} J.
Calculate the binding energy per nucleon of the helium-4 nucleus.

binding energy per nucleon = J [1]

(c) The fusion of helium nuclei to make heavier elements occurs in red giants at temperatures above 10^8 K.

Explain why fusion of helium requires higher temperatures than the fusion of hydrogen (protons).

.....
.....
..... [2]

(d) Estimate the mean speed of helium nuclei at a temperature of 10^8 K.

mass of helium nucleus = 6.6×10^{-27} kg

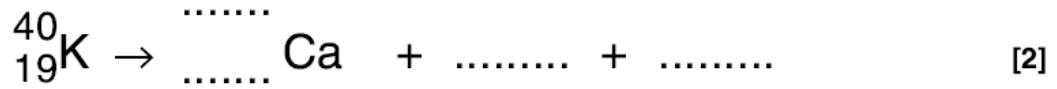
speed = ms^{-1} [2]

4.

Some fruits, such as bananas, are naturally radioactive because they contain the unstable isotope of potassium-40 (${}^{40}_{19}\text{K}$).

(i) The isotope of potassium-40 is a beta-minus emitter.

Complete the following decay equation for ${}^{40}_{19}\text{K}$.



(ii) Explain why energy is released when a single nucleus of potassium-40 decays.

.....
.....
.....
.....
..... [2]

(iii) A banana contains 4.5×10^{-4} kg of potassium. About 0.012% of the mass of potassium in the banana has the unstable isotope of potassium-40. This isotope of potassium-40 has a half-life of 4.2×10^{16} s. The molar mass of potassium-40 is $0.040 \text{ kg mol}^{-1}$.

Calculate the activity from this banana.

activity = Bq [3]