Neap

Diagnostic Topic Test 2023

VCE Physics Units 1&2

Suggested Solutions

Test 3: How is energy from the nucleus utilised?

- Radiation from the nucleus
- Nuclear energy

SECTION A – MULTIPLE-CHOICE QUESTIONS

Question 1 B

B is not a correct statement and is therefore the required response. Microwaves do not carry sufficient energy to be classified as ionising radiation.

A is a correct statement and therefore not the required response. Ionising radiation carries sufficient energy to strip electrons from atoms and create free radicals.

C is a correct statement and therefore not the required response. X-rays carry sufficient energy to be classified as ionising radiation.

D is a correct statement and therefore not the required response. Ionising radiation has the potential to create free radicals. These can alter the structure of DNA within living cells and lead to genetic mutations.

Question 2 A

A is correct. Unstable nuclei seek stability by undergoing radioactive decay, which results in the emission of radiation.

B is incorrect. The rate of decay of a nucleus does not determine whether it is radioactive or not. Any nucleus that decays will emit radiation and therefore be considered radioactive.

C is incorrect. The transfer of electrons, such as in chemical reactions, does not result in the emission of radiation.

D is incorrect. Internal energy describes the kinetic and potential energy of particles within a thermodynamic system; it does not relate to the nuclear stability of individual nuclei.

Question 3 C

$$\begin{aligned}\text{absorbed dose} &= \frac{E}{m}\\ &= \frac{0.04}{50\times10^{-3}}\\ &= 0.80\text{ Gy}\end{aligned}$$

$$\begin{aligned}\text{equivalent dose} &= \text{absorbed dose}\times\text{quality factor}\\ &= 0.80\times20\\ &= 16\text{ Sv}\end{aligned}$$

Question 4 B

Reading from the graph, the mass of radon-222 decreases by half from 10 g to 5 g over the first 3.5 days.

Question 5 B

Reading from the graph, at t = 10 days, the mass of radon-222 remaining is 1.5 g.

Question 6 D

From the graph, ${}^{226}_{88}\text{Ra}\rightarrow{}^{222}_{86}\text{Rn}+{}^{4}_{2}\text{X}+\text{energy}.$ This implies that X is an alpha particle; therefore, ${}^{226}_{88}\text{Ra}\rightarrow{}^{222}_{86}\text{Rn}+{}^{4}_{2}\alpha+\text{energy}.$

Question 7 B

B is correct and **D** is incorrect. Once Rosemary eats the oyster, the alpha particles are able to hit sensitive tissues in her gullet and stomach; hence, it is internal exposure.

A and **C** are incorrect. Alpha radiation has a high ionising ability but poor penetration, so it is not an external exposure problem. For example, Rosemary is not exposed to radiation from the oysters when they are sitting on her plate as alpha particles can only travel a few centimetres in air.

Question 8 A

A is correct. The absorption of a neutron by a nucleus can upset the ratio of protons to neutrons that is required for the atom to be stable. Thus, the atom becomes an unstable radioisotope.

B and **C** are incorrect. Natural radioisotopes are produced in stars, in supernovae or by bombardment with cosmic rays.

D is incorrect. The absorption of an electron by an atom will not upset the ratio of protons to neutrons required for the atom to be stable and thus will not affect the atom's nuclear stability.

Question 9 D

D is correct. A sphere has the smallest surface area to volume ratio of any shape. Decreasing the surface area of a fissile sample decreases the amount of neutron escape, thus decreasing the critical mass.

A and **C** are incorrect. The shape of a sample does not affect its density.

B is incorrect. A sphere has the smallest surface area to volume ratio of any shape, not the largest.

Question 10 C

C is correct. Australia already mines and transports large quantities of uranium as an economically viable industry. Whether or not Australia has this capability would therefore not be a matter of debate.

A is incorrect. Australia does not presently store and dispose large volumes of nuclear waste. Whether this capability could be developed safely and in an economically viable manner is a matter of ongoing debate.

B and **D** are incorrect. The up-front cost and time required to build a nuclear power plant is considerably higher than other alternatives. Whether this time and cost is worth the benefits provided by nuclear power is a matter of ongoing debate.

SECTION B

Question 1 (4 marks)

a. *Any one of:*

- The half-life of plutonium-239 is the time it takes for half of a sample of plutonium-239 to decay via radioactive decay.
- The half-life of plutonium-239 is the time in which every plutonium-239 nuclei in a sample has a 50% chance of decaying.

2 marks

1 mark for indicating that half-life is a measure of time.
1 mark for explaining the half-life of plutonium-239.

b. $\frac{72\,300}{24\,100} = 3$ half-lives — 1 mark

Thus, there are three transitions: 200 g $\rightarrow$ 100 g $\rightarrow$ 50 g $\rightarrow$ 25 g.

There will be 25 g of plutonium-239. — 1 mark

Question 2 (6 marks)

a. ${}^{99}_{43}\text{Tc}^{*} \rightarrow \mathbf{{}^{99}_{43}Tc} + \mathbf{{}^{0}_{0}\gamma}$

2 marks

1 mark for each correct product.
*Note: * indicates an excited nucleus.*

b. $\frac{12.02}{6.01} = 2$ half-lives — 1 mark

The fraction remaining after 2 half-lives is:

$\left(\frac{1}{2}\right)^{2} = \frac{1}{4}$ of the original amount — 1 mark

c. After each half-life, the amount of remaining technetium-99m will decrease by half.

$1 \rightarrow \frac{1}{2} \rightarrow \frac{1}{4} \rightarrow \frac{1}{8}$

Therefore, it will take 3 half-lives to decrease to $\frac{1}{8}$ of the original amount. — 1 mark

Each half-life is 6.01 hours; therefore:

$3 \times 6.01 = 18.03$

≈ 18 h — 1 mark

Question 3 (8 marks)

a.

Radiation characteristic	Radiation symbol
The radiation has very high penetration.	γ
The radiation is always positively charged.	α
The radiation is part of the electromagnetic spectrum.	γ

2 marks

Note: Award 1 mark only for 2 correct symbols.

b. $^{137}_{55}\text{Cs} \rightarrow {}^{137}_{56}\text{Ba} + {}^{0}_{-1}\beta^{-} + \overline{v} + \text{energy}$

2 marks

1 mark for $^{137}_{56}\text{Ba} + {}^{0}_{-1}\beta^{-}$.

1 mark for $\overline{v}$ + energy.

c. Gamma rays have very high penetration and are therefore highly suitable for radiation treatments of cancers inside the brain. 1 mark

Any one of:

- Alpha and beta particles have poor penetration characteristics and are therefore unsuitable for use in radiation treatment for cancers inside the brain.
- Gamma radiation has a lower ionising ability than alpha or beta radiation and is therefore less harmful to living tissue in the brain.

1 mark

d. Caesium-137 is highly active and has a relatively long half-life (30.23 years). 1 mark

When decommissioned after a period (for example, after twenty years' service in a hospital), it will still be very active. 1 mark

Note: For the activity of a sample to decrease to an acceptably safe level, it must be stored properly for a period of approximately 10 half-lives or approximately 300 years.

Question 4 (7 marks)

a. binding energy of the helium-4 nucleus = 28.295674

Binding energy of the two helium-3 nuclei:

$2 \times 7.718058 = 15.436116$ 1 mark

The difference in binding energies is given by:

$28.295674 - 15.436116 = 12.859558$

$\approx 12.86 \text{ MeV}$ 1 mark

b. Mass of reactant nuclei:

$2 \times 5.022664 \times 10^{-27} = 1.0045328 \times 10^{-26}$ 1 mark

Mass of product nuclei:

$6.665892 \times 10^{-27} + 2 \times 1.678256 \times 10^{-27} = 1.0022404 \times 10^{-26}$ 1 mark

Mass defect:

$1.0045328 \times 10^{-26} - 1.0022404 \times 10^{-26} = 2.2924 \times 10^{-29} \text{ kg}$

Note: Deduct a maximum of 1 mark if the final calculation for mass defect is not shown.

c. $E = mc^2$

$= (2.2924 \times 10^{-29})(2.997924 \times 10^{8})^2$

$= 2.0603 \times 10^{-12} \text{ J}$ 1 mark

$\dfrac{2.0603 \times 10^{-12}}{1.602176 \times 10^{-19}} = 1.2861 \times 10^{7} \text{ eV}$ 1 mark

$\dfrac{1.2861 \times 10^{7}}{10^{6}} = 12.86 \text{ MeV}$ 1 mark