Solutions Ch 4·1 and 4·2 Year 11

Answer 1

(3 marks)

The fusion of deuterium and tritium to form helium can be represented by the equation:

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n.$$

If the mass defect for this reaction is 0.0189 u, calculate the energy released, in joules, in one such fusion reaction.

Description		Marks
Mass defect in kg $0.0189 \times 1.66 \times 10^{-27}$ $= 3.137 \times 10^{-29}$ kg	**or** $E = m \times 931$ $= 17.59$ MeV	1
$E = mc^2$ $= 3.137 \times 10^{-29} \times (3 \times 10^8)^2$	$= 17.59 \times 10^6 \times 1.6 \times 10^{-19}$	1
$= 2.82 \times 10^{-12}$	$= 2.82 \times 10^{-12}$	1
	Total	**3**

Answer 2

(4 marks)

State whether each of the following statements is true or false.

	Statement	True or False
A	When a nucleus is unstable it decays to emit alpha, beta and gamma radiation all at the same time.	
B	Ionising radiation causes an atom to lose a proton and thus become charged.	
C	Solar energy is produced by nuclear fusion reactions.	
D	Binding energy is the energy needed to bind atoms to each other.	

	Description	Marks
A	False	1
B	False	1
C	True	1
D	False	1
	Total	**4**

Answer 3

(13 marks)

(a) An isotope of thorium decays to form radium-228 and an alpha particle.

(i) Write the nuclear equation to represent this decay. (2 marks)

Description	Marks
$^{232}_{90}Th \rightarrow ^{228}_{88}Ra + ^{4}_{2}He$	1–2
Total	**2**

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Answer 3 continued

(ii) State the atomic number and mass number of the thorium isotope. (2 marks)

Atomic number: 90

Mass number: 232

Description	Marks
Atomic number = 90	1
Mass number = 232	1
Total	**2**

(b) Radium-228 is an isotope of radium. Define the term 'isotope'. (2 marks)

Description	Marks
Same number of protons	1
Different mass number or number of neutrons	1
Total	**2**

(c) The radium-228 paint on a pilot's instruments had an initial activity of 140 kBq. If the half-life of radium-228 is 5.80 years determine the activity in kBq of the radium on the instruments, 52.2 years later. Show **all** workings. (3 marks)

Description	Marks
Number of half-lives = 52.2 ÷ 5.8 = 9	1
$A = A_0 (0.5)^n$ $= 140 \times (0.5)^9$	1
A = 0.273 kBq	1
Total	**3**

(d) Alpha particles, ${}^4_2\alpha$, are often emitted during the decay of radium. An alpha particle is similar in structure to a helium nucleus. Determine the binding energy, in MeV, of a helium nucleus. Use the information in your **Formulae and Data Booklet**, and show **all** workings.

Description	Marks
Helium nucleus has 2 protons and 2 neutrons $(4 \times 1.67 \times 10^{-27}) - 6.64 \times 10^{-27}$ 4.00×10^{-29}	1–2
$4.00 \times 10^{-29} / 1.66 \times 10^{-27}$ = 0.02410 u	1
0.0241×931 = 22.4	1
Total	**4**

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Answer 4

(7 marks)

Calculate the average binding energy per nucleon (in joules) for carbon-14.

Use the mass of carbon-14 = 2.32478×10^{-26} kg.

Use the **Formulae and Constants sheet** for the masses of the neutron and the proton.

Description	Marks
Theoretical mass = $8 \times 1.68 \times 10^{-27} + 6 \times 1.67 \times 10^{-27}$ $= 2.346 \times 10^{-26}$ kg	1–2
Mass defect = theoretical – actual $= 2.346 \times 10^{-26} - 2.325 \times 10^{-26}$ $= 2.10 \times 10^{-28}$	1–2
Total binding energy = $\Delta mc^2 = 2.10 \times 10^{-28} \times (3.00 \times 10^{8})^2$ $= 1.89 \times 10^{-11}$ J	1–2
Av binding energy/nucleon = total E_b/total nucleons = $1.89 \times 10^{-11}/14$ $= 1.35 \times 10^{-12}$ J	1
	Total 7

Answer 5

(a) Which element listed is considered to be the most stable? (1 mark)

Circle the correct answer: ^{3}He ^{4}He ^{56}Fe ^{235}U

(b) Explain your choice, using information from the graph. (2 marks)

Description	Marks
(a) Fe^{56}	1
(b) Fe^{56} has the highest average binding energy per nucleon	1
The nucleons would require the most energy to break them apart making it more stable	1
	Total 3

Answer 6

(13 marks)

When a uranium-235 nucleus absorbs a neutron, many fission products are possible. One such reaction in a nuclear power plant results in the formation of lanthanum-148 (La), bromine-85 (Br) and neutrons.

(a) Write an equation for this reaction and identify clearly the number of neutrons produced. (2 marks)

Description	Marks
${}^{1}_{0}n + {}^{235}_{92}U \rightarrow {}^{148}_{57}La + {}^{85}_{35}Br + 3\,{}^{1}_{0}n$ + energy	1–2
	Total 2

(b) How do the neutrons released in this reaction differ from those that took part in the initial fission reaction? (1 mark)

Description	Marks
The released neutrons are much more energetic (have more speed).	1
	Total 1

Answer 6 continued

Many of the products of such fission reactions are themselves radioactive but are not able to be used as an energy source for the reactor. This waste is taken from the site and stored permanently in a safe and secure place where its activity can be monitored. The measured activity from some radioactive waste when it was first removed from the reactor was 128 Bq above the background count of 2.00 Bq.

(c) Explain what is meant by the term 'background count' and give an example of a source that contributes to it. (2 marks)

Description	Marks
There are naturally occurring sources of radiation in the environment.	1
e.g. cosmic rays, rocks such as granite, atomic testing, nuclear sources, etc	1
	Total 2

(d) If the average half-life of the waste in part (c) is taken as being 7.00×10^5 years, calculate how long it will take for its activity to reach the same level as the background count. (4 marks)

Description	Marks
$A = A_0(½)^n$; $2 = 128(½)^n$	1
n = 6.0 halflives	1
Age = $n \times t_{½} = 6.0 \times 7x10^5$ yrs	1
= 4.2×10^6 years	1
	Total 4

The safety device worn by an 85.0 kg nuclear power plant worker indicated that they absorbed 24.0 J of energy overall when exposed to this waste fuel during one work period.

(e) Calculate the dose they absorbed. (2 marks)

Description	Marks
Absorbed Dose= E/m = 24 / 85 $\frac{t}{m} = \frac{24}{85}$	1
= 0.282 Gy	1
	Total 2

(f) Determine the dose equivalent for the worker, assuming all of the absorbed radiation is from gamma rays. (2 marks)

Description	Marks
Dose Equivalent = Absorbed Dose × Quality Factor = = 0.282 × 1	1
= 0.282 Sv	1
	Total 2

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Answer 7 **(4 marks)**

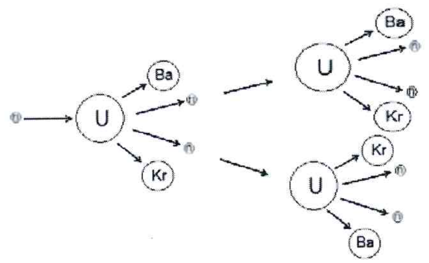
Consider the following nuclear reaction for uranium:

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{143}_{56}\mathrm{Ba} + {}^{91}_{36}\mathrm{Kr} + \ ?\,{}^{1}_{0}\mathrm{n}$$

(a) Determine the number of neutrons released. (1 mark)

Description	Marks
2	1
Total	**1**

(b) Uranium-235 is commonly used to produce a self-sustaining neutron-induced chain reaction. Using U-235 as the example, draw a labelled diagram that illustrates a self-sustaining neutron-induced chain reaction. (3 marks)

Description	Marks
Diagram should contain the following: • A neutron hitting a U-235 atom which splits into daughter products releasing at least 2 neutrons • These two neutrons hit other U-235 atoms releasing daughter products and neutrons • Some appropriate labels  	1–3
Total	**3**