PRESTON
MANOR

A Level Physics Exam Packs

Radioactivity

Name:

Form:

Question	Mark

6 **(a)** A sample of a radioactive isotope contains 4.5×10^{23} active undecayed nuclei. The half-life of the isotope is 12 hours. Calculate

(i) the initial activity of the sample

activity = ... s^{-1} **[2]**

(ii) the number of active nuclei of the isotope remaining after 36 hours

number = ... **[1]**

(iii) the number of active nuclei of the isotope remaining after 50 hours.

number = ... **[2]**

(b) Explain why the activity of a radioactive material is a major factor when considering the safety precautions in the disposal of nuclear waste.

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.... **[2]**

[Total: 7]

Question			Expected Answers	Marks	Additional Guidance
6	a	(i)	$A = \lambda N_0 = 4.5 \times 10^{23} \times 0.693 / (12 \times 3600)$ $= 7.22 \times 10^{18}$ (s^{-1})	C1 A1	allow one mark if the 12 hours is not converted into seconds. Answer is 2.6×10^{22} Allow one mark if the 12 hours is converted into minutes Answer 4.33×10^{20}
		(ii)	3 half lives $N = 5.6 \times 10^{22}$	A1	
		(iii)	$N = N_0 e^{-\lambda t}$ $= 4.5 \times 10^{23} \times e^{-(0.693 \times 50/12)}$ or use of 2^n $= 2.5 \times 10^{22}$	C1 A1	use of 2^n 50/12 half lives
	b		material with large λ / short half life have initial high activity hence precautions needed <u>for initial period</u> of disposal OR material with small λ / long half life activity will last for a long period hence need for long term disposal MAX 2	(B1) (B1) (B1) (B1) B2	
			Total	[7]	

10 **(a)** Describe what is meant by the **spontaneous** and **random** nature of radioactive decay of unstable nuclei.

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.... **[2]**

(b) Define the *decay constant*.

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.... **[2]**

(c) Explain the technique of radioactive carbon-dating.

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.... **[4]**

(d) The activity of a sample of living wood was measured over a period of time and averaged to give 0.249 Bq. The same mass of a sample of dead wood was measured in the same way and the activity was 0.194 Bq. The half-life of carbon-14 is 5570 years.

(i) Calculate

1 the decay constant in y^{-1} for the carbon-14 isotope

decay constant = ... y^{-1} **[1]**

2 the age of the sample of dead wood in years.

age = ... y **[2]**

(ii) Suggest why the activity was measured over a long time period and then averaged.

....

.... **[1]**

(iii) Explain why the method of carbon-dating is not appropriate for samples that are greater than 10^5 years old.

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.... **[1]**

[Total: 13]

END OF QUESTION PAPER

Question			Expected Answer	Mark	Additional Guidance
10	(a)		**Spontaneous**: the decay cannot be induced / occurs without external influence **Random**: cannot predict when / which (nucleus) will decay next	B1 B1	
	(b)		The probability of decay of a <u>nucleus</u> <u>per</u> unit time	M1 A1	**Allow**: $\lambda = A / N$ (Any subject) C1 A = activity and N = number of <u>nuclei</u> A1
	(c)		Living plants / animals absorb carbon(-14) Once dead, the plant does not take in any more carbon(-14) The fraction of C-14 to C-12 (nuclei) or number of C-14 (nuclei) or activity of C-14 (nuclei) measured in dead <u>and</u> living (sample) $x = x_0 e^{-\lambda t}$ used with data above to estimate the age	B1 B1 M1 A1	
	(d)	(i)1	$\lambda = \ln 2 / T_{1/2}$ decay constant = 1.24×10^{-4} (y^{-1})	B1	
		(i)2	$A = A_0 e^{-\lambda t}$ $0.194 = 0.249 \times e^{-(1.24\times10^{-4}\times t)}$ $\ln(0.194/0.249) = -1.24\times10^{-4} t$ time = 2.0×10^3 (y)	C1 A1	
		(ii)	The activity is (very) small / decay is random	B1	
		(iii)	Activity so low that it cannot be differentiated from the background	B1	
			Total	13	

7 There are two types of beta decay, beta-plus and beta-minus. An isotope of carbon ${}^{15}_{6}C$ decays by beta emission into an isotope of nitrogen ${}^{15}_{7}N$. An isotope of phosphorus ${}^{30}_{15}P$ decays by beta emission into an isotope of silicon ${}^{30}_{14}Si$.

(a) Complete the following decay equations for the carbon and phosphorus isotopes.

(i) carbon decay

$${}^{15}_{6}C \rightarrow {}^{\cdots}_{\cdots}e + {}^{\cdots}_{\cdots}N + \ldots\ldots$$

(ii) phosphorus decay

$${}^{30}_{15}P \rightarrow {}^{\cdots}_{\cdots}e + {}^{\cdots}_{\cdots}Si + \ldots\ldots$$

[3]

(b) State the two beta decays in terms of a quark model of the nucleons.

(i) beta-plus decay

(ii) beta-minus decay

[2]

(c) Name the force responsible for beta decay.

.... **[1]**

[Total: 6]

Question			Expected Answers	Marks	Additional Guidance
7	a	(i)	e: 0 and −1 N: 15 and 7 + (antineutrino)	B1	
		(ii)	e: 0 and +1 Si: 30 and 14 + (neutrino) correct 'neutrino' <u>in each case</u>	B1 B1	Allow 1 for +1 Correct symbols required for the neutrinos: ν and (Allow ν_e and ($_e$
	b	(i)	uud → udd	B1	Allow u → d
		(ii)	udd → uud	B1	Allow d → u
	c		weak(nuclear force)	B1	
			Total	**[6]**	

5 The radioactive nucleus of plutonium ($^{238}_{94}Pu$) decays by emitting an alpha particle ($^{4}_{2}He$) of kinetic energy 5.6MeV with a half-life of 88 years. The plutonium nucleus decays into an isotope of uranium.

(a) State the number of neutrons in the **uranium** isotope.

.... **[1]**

(b) The mass of an alpha particle is 6.65×10^{-27} kg.

(i) Show that the kinetic energy of the alpha particle is about 9×10^{-13} J.

[1]

(ii) Calculate the speed of the alpha particle.

speed = ... $m\,s^{-1}$ **[2]**

(c) In a space probe, a source containing plutonium-238 nuclei is used to generate 62W for the onboard electronics.

(i) Use your answer to **(b)(i)** to show that the initial activity of the sample of plutonium-238 is about 7×10^{13} Bq.

[1]

(ii) Calculate the decay constant of the plutonium-238 nucleus.

1 year = 3.16×10^7 s

decay constant = ... s^{-1} **[2]**

(iii) The molar mass of plutonium-238 is 0.24 kg. Calculate

1 the number of plutonium-238 nuclei in the source

number of nuclei = ... **[2]**

2 the mass of plutonium in the source.

mass = ... kg **[1]**

[Total: 10]

Question			Answer	Marks	Guidance
5	(a)		no: of neutrons = 142	B1	
	(b)	(i)	(5.6 MeV =) 5.6 × $\underline{10^6}$ × $\underline{1.6 \times 10^{-19}}$ energy = 8.96 × 10^{-13} (J)	M1 A0	**Allow**: 5.6 × $\underline{1.6 \times 10^{-13}}$
		(ii)	$\frac{1}{2} \times 6.65 \times 10^{-27} \times v^2 = 8.96 \times 10^{-13}$ $v = \sqrt{\frac{2 \times 8.96 \times 10^{-13}}{6.65 \times 10^{-27}}}$ speed = 1.6 × 10^7 (m s^{-1})	C1 A1	Answer to 3 sf is 1.64 × 10^7 (m s^{-1}) **Note**: The answer is 1.65 × 10^7 (m s^{-1}) if 9 × 10^{-13} (J) is used
	(c)	(i)	activity = $\frac{62}{8.96 \times 10^{-13}}$ activity = 6.92 × 10^{13} (Bq)	C1 A0	**Allow**: activity = $\frac{62}{9 \times 10^{-13}}$ (= 6.89 × 10^{13} Bq) Possible ecf from **(b)(i)**
		(ii)	$\lambda = \frac{0.693}{T}$ $\lambda = \frac{0.693}{88 \times 3.16 \times 10^7}$ decay constant = 2.49 × 10^{-10} (s^{-1}) or 2.5 × 10^{-10} (s^{-1})	C1 A1	**Note**: ln2 = 0.693 **Allow**: 1 mark for using 88 years and getting an answer of 7.9 × 10^{-3}
		(iii)	**1** $A = \lambda N$ $N = \frac{6.92 \times 10^{13}}{2.49 \times 10^{-10}}$ number =2.78 × 10^{23} or 2.8 × 10^{23} **2** mass = $\frac{2.78 \times 10^{23}}{6.02 \times 10^{23}} \times 0.24$ mass = 0.11 (kg)	C1 A1 B1	Possible ecf from **(c)(ii)** **Note**: '7 × 10^{13}/2.5 × 10^{-10} = 2.8 × 10^{23}' Possible ecf for mass from incorrect value for number of nuclei
			Total	**10**	

5 The isotopes of carbon-14 ($^{14}_{6}C$) and carbon-15 ($^{15}_{6}C$) are beta-minus emitters. The table in Fig. 5.1 shows the maximum kinetic energy of each electron emitted and the half-life of the isotope.

isotope	maximum kinetic energy / MeV	half-life
$^{14}_{6}C$	0.16	5560 years
$^{15}_{6}C$	9.8	2.3 s

Fig. 5.1

(a) State one property common to all isotopes of an element.

....

.... **[1]**

(b) The neutrons and protons inside each isotope experience fundamental forces. Name the two fundamental forces experienced by both neutrons and protons.

1. ....

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

(c) An isotope of carbon-15 decays into an isotope of nitrogen (N).

(i) Complete the nuclear reaction below.

$$^{15}_{6}C \rightarrow \,^{\cdots\cdots}_{\cdots\cdots}N + \,^{0}_{-1}e + \bar{\nu}$$

[1]

(ii) Use the quark model to state the changes taking place within the nucleus of the carbon-15 atom.

....

.... **[1]**

(d) (i) Estimate the maximum speed of an electron from the nucleus of carbon-14.

speed = ... $m\,s^{-1}$ **[2]**

(ii) Suggest why the actual speed of the electron is much less than your answer in **(i)**.

....

.... **[1]**

(e) **(i)** Calculate the decay constant λ in s^{-1} of carbon-14.

λ = ... s^{-1} **[2]**

(ii) The molar mass of carbon-14 is $14\,g\,mol^{-1}$. Show that 1.0 mg of carbon-14 has 4.3×10^{19} nuclei.

[1]

(iii) Calculate the activity of the 1.0 mg mass of carbon-14.

activity = ...Bq **[2]**

(f) The isotope of carbon-14 is very useful in determining the age of a relic (e.g. ancient wooden axe) using a technique known as carbon-dating.
Describe carbon-dating and explain one of its major limitations.

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.... **[4]**

[Total: 17]

6 **(a)** Explain the term *binding energy* of a nucleus.

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.... **[2]**

(b) Nuclear fusion takes place in the core of the Sun. One of the simplest fusion reactions is shown below.

$${}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{4}_{2}He$$

(i) The binding energy per nucleon of ${}^{2}_{1}H$ is 1.8×10^{-13} J and the binding energy per nucleon of ${}^{4}_{2}He$ is 1.1×10^{-12} J. Show that the energy released in the reaction is 3.7×10^{-12} J.

[2]

Question			Answers	Marks	Guidance
5	(a)		Same charge / number of protons	B1	**Not**: 'same chemical property'
	(b)		strong (nuclear force / interaction) gravitational (force)	B1 B1	 **Allow**: 'gravity'
	(c)	(i)	$^{15}_{7}\text{N}$	B1	
		(ii)	(u d d) → (u u d)	B1	**Allow**: *One down quark becomes up quark* or d → u (+ electron + antineutrino)
	(d)	(i)	0.16 MeV = 0.16 × 10^6 × 1.6 × 10^{-19} $\frac{1}{2} \times 9.11 \times 10^{-31} \times v^2 = 2.56 \times 10^{-14}$ speed = 2.4 × 10^8 (m s^{-1}) or 2.37 × 10^8 (m s^{-1})	C1 A1	 **Allow**: 1 mark for using 9.8 MeV; answer is equal to 1.86 × 10^9 (m s^{-1})
		(ii)	The mass of the electron increases / greater than 'rest mass'	B1	
	(e)	(i)	$\lambda = 0.693/T$ $\lambda = 0.693/(5560 \times 3.16 \times 10^7)$ λ = 3.9 × 10^{-12} (s^{-1}) or 3.94 × 10^{-12} (s^{-1})	 C1 A1	 **Allow**: 1 mark for 1.25 × 10^{-4} (if 5560 y used)
		(ii)	number = $\frac{1.0 \times 10^{-3}}{14} \times 6.02 \times 10^{23}$ number = 4.3 × 10^{19}	M1 A0	**Note**: This step must be seen to score 1 mark
		(iii)	activity = λN activity = 3.94 × 10^{-12} × 4.3 × 10^{19} activity = 1.7 × 10^8 (Bq) or 1.69 × 10^8 (Bq)	 C1 A1	 Possible ecf from **(e)(i)** and **(e)(ii)**

Question			Answers	Marks	Guidance
	(f)		Any **three** from: 1. Plants / living things take in carbon(-dioxide) or plants / living things stop taking in carbon after death 2. The ratio of carbon-14 to carbon-12 (nuclei) for the relic sample is determined 3. The current ratio of carbon-14 to carbon-12 nuclei is determined 4. The age of the relic is found using '$x = x_0 e^{-\lambda t}$'	B1×3	**Must use ticks on Scoris to show where the marks are awarded**
			Limitation: The ratio of carbon-14 to carbon-12 is assumed to be constant / count(-rate) from relic may be comparable to background count(-rate)	B1	**Allow**: Any other valid comment for the limitation
			Total	**17**	

5 Fluorodeoxyglucose (FDG) is a radiopharmaceutical used for PET scans. It contains radioactive fluorine-18, which is a positron-emitter with a half-life of 6.6×10^3 s.
A patient is injected with FDG which has an initial activity of 250 MBq.

(a) Calculate the decay constant of fluorine-18.

decay constant = ... s^{-1} **[2]**

(b) Show that the initial number of fluorine-18 nuclei in the FDG is about 2×10^{12}.

[1]

(c) About 9.9% of the mass of FDG is fluorine-18. Use your answer in **(b)** to determine the initial mass of FDG given to the patient. The molar mass of fluorine-18 is $0.018\,kg\,mol^{-1}$.

mass = ... kg **[3]**

(d) A typical PET scan takes 20 minutes. Determine the activity of FDG in the patient after this time.

activity = ... MBq **[2]**

(e) Positron emission tomography (PET) can be used to locate an area of increased activity within the brain. Describe the principles of PET.

In your answer you should make clear how the position of increased activity is located.

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.... **[4]**

[Total: 12]

Question			Answer	Marks	Guidance
5	(a)		$\lambda = \frac{0.693}{6.6\times10^3}$ or $\lambda = \frac{\ln 2}{6.6\times10^3}$ decay constant = 1.1×10^{-4} (s^{-1})	C1 A1	**Note**: Answer to 3sf is 1.05×10^{-4} (s^{-1})
	(b)		$A = \lambda N$ $N = \frac{250\times10^6}{1.05\times10^{-4}}$ number = 2.38×10^{12} or 2.4×10^{12}	C1 A0	Possible ecf from **(a)** **Allow** full credit for bald 2.4×10^{12}
	(c)		mass of F-18 = $\frac{2.38\times10^{12}}{6.02\times10^{23}}\times0.018$ (= 7.116×10^{-14} kg) mass of FDG= $7.116\times10^{-14}/0.099$ mass of FDG = 7.2×10^{-13} (kg)	C1 C1 A1	Possible ecf from **(b)** **Allow** full credit for using 2×10^{12}; answer is 6.04×10^{-13} (kg)
	(d)		$A = 250 \times e^{-(1.05\times10^{-4}\times20\times60)}$ activity = 220 (MBq)	C1 A1	Possible ecf from **(a)** **Allow**: 1 mark for 249 (MBq); factor of 60 omitted
	(e)		(FDG/positron-emitting substance is injected into the patient) Any <u>three</u> from: 1. Annihilation of electron and positron 2. Positron-electron annihilation produces <u>two</u> gamma photons 3. The gamma photons travels in opposite directions 4. The patient is surrounded by (a ring of) gamma detectors 5. A 3-D image is created (using the detector-signals with the aid of computer software) **QWC**: The arrival times / delay times of the photons (at diametrically opposite detectors) are used to pinpoint areas of increased activity (AW)	B1 × 3 B1	**Allow**: rays / waves instead of photons in 2 and 3
			Total	**12**	

10 **(a)** State the *cosmological principle*.

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.... **[2]**

(b) State some of the properties of the microwave background radiation observed from the Earth. Discuss how the background microwave radiation is linked to the big bang model of the universe.

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.... **[3]**

(c) Calculate the age of our universe in years based on a critical density of the universe of $9.7 \times 10^{-27}\,\mathrm{kg\,m^{-3}}$.

age = ... y **[3]**

[Total: 8]

END OF QUESTION PAPER

Question			Answers	Marks	Guidance
10	(a)		The universe is homogeneous. and isotropic (on a large scale).	B1 B1	
	(b)		The intensity of the microwaves is the same in all directions.	B1	**Allow** the microwave (background radiation) is isotropic.
			These microwaves correspond to a temperature of 2.7 K or The temperature of the universe is 2.7 K.	B1	**Allow** 3 K
			The expansion of the universe following the big bang led to cooling and hence we observe microwaves rather than short wavelength e.m. waves / gamma waves.	B1	**Allow** - The short e.m. / gamma waves during the early stages of the universe have been 'stretched out' / 'red-shifted' to microwaves by the expansion.
	(c)		$(\rho = \frac{3H_0^2}{8\pi G})$ $H_0 = \sqrt{\frac{8\pi \times 6.67 \times 10^{-11} \times 9.7 \times 10^{-27}}{3}}$ $H_0 = 2.328 \times 10^{-18}$ (s^{-1})	C1	**Allow** any subject
			(age = $1/H_0$) age = $\frac{1}{2.328 \times 10^{-18}}$ or age = 4.3×10^{17} (s)	C1	
			age = 1.4×10^{10} (y)	A1	Answer to 3 sf is 1.36×10^{10} (y)
			Total	**8**	

4 **(a)** In the core of a nuclear reactor, one of the many fission reactions of the uranium-235 nucleus is shown below.

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{140}_{54}Xe + ^{94}_{38}Sr + 2^{1}_{0}n$$

(i) State **one** quantity that is conserved in this fission reaction.

.... [1]

(ii) Fig. 4.1 illustrates this fission reaction.

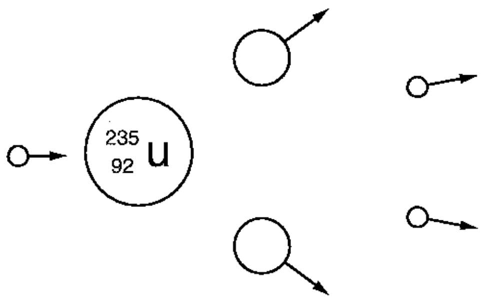

Fig. 4.1

Label all the particles in Fig. 4.1 and extend the diagram to show how a chain reaction might develop. **[2]**

(b) Fusion of hydrogen nuclei is the source of energy in most stars. A typical reaction is shown below.

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

The $^{2}_{1}H$ nuclei repel each other. Fusion requires the $^{2}_{1}H$ nuclei to get very close and this usually occurs at very high temperatures, typically 10^9 K.

(i) Use the data below to calculate the energy released in the fusion reaction above.

mass of ${}^{2}_{1}H$ nucleus = 3.343×10^{-27} kg

mass of ${}^{3}_{2}He$ nucleus = 5.006×10^{-27} kg

mass of ${}^{1}_{0}n$ = 1.675×10^{-27} kg

energy = ... J **[3]**

(ii) State in what form the energy in **(b)(i)** is released.

.... **[1]**

(iii) The ${}^{2}_{1}H$ nuclei in stars can be modelled as an ideal gas. Calculate the mean kinetic energy of the ${}^{2}_{1}H$ nuclei at 10^{9} K.

energy = ... J **[2]**

(iv) Suggest why some fusion can occur at a temperature as low as 10^{7} K.

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.... **[1]**

[Total: 10]

Question			Answer	Marks	Guidance
4	(a)	(i)	momentum / mass-energy / charge / proton number / baryon number / nucleon number	B1	**Not**: 'energy' on its own
		(ii)	Some basic labelling of neutron(s), Xe and Sr Correct extension of diagram showing at least one of the neutrons interacting with U-235 nucleus and producing neutron(s) and 'fragments'	B1 B1	
	(b)	(i)	initial $m = 6.686 \times 10^{-27}$ (kg) or final $m = 6.681 \times 10^{-27}$ (kg) or $\Delta m = 0.005 \times 10^{-27}$ (kg) $\Delta E = 0.005 \times 10^{-27} \times (3.0 \times 10^{8})^{2}$ energy = 4.5×10^{-13} (J)	C1 C1 A1	
		(ii)	kinetic (energy)	B1	**Not**: heat / sound **Allow**: (gamma) photons / EM radiation
		(iii)	KE = $\frac{3}{2}kT$ KE = $\frac{3}{2} \times 1.38 \times 10^{-23} \times 10^{9}$ KE = 2.1×10^{-14} (J)	C1 A1	**Allow**: 1 sf answer or 10^{-14} (J) because the temperature is given as 10^{9} K
		(iv)	Some nuclei will have KE greater than the mean KE (and hence cause fusion) (AW)	B1	
			Total	**10**	

3 **(a)** State, with a reason, whether or not protons and neutrons are fundamental particles.

....

.... **[1]**

(b) State **two** fundamental particles that can be classified as leptons.

.... **[1]**

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

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

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

$$^{40}_{19}K \rightarrow \,^{\cdots\cdots}_{\cdots\cdots}Ca \;+\; \cdots\cdots \;+\; \cdots\cdots$$ **[2]**

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

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.... **[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 kg mol^{-1}.

Calculate the activity from this banana.

activity = ... Bq **[3]**

Question			Answer	Marks	Guidance
3	(a)		They are not fundamental particles because they consist of quarks	B1	**Not**: They can be sub-divided
	(b)		Any two from: electron / positron / neutrino / antineutrino	B1	**Allow**: muon / tau
	(c)	(i)	${}^{40}_{20}Ca$ ${}^{0}_{-1}e + \bar{\nu}_{(e)}$ or electron + (electron) antineutrino	B1 B1	 **Allow**: ${}^{0}_{-1}\beta$ but not β^- or e^- for the electron
		(ii)	There is a decrease in mass Energy (released) given by $(\Delta)E = (\Delta)mc^2$ **or** Binding energy increases Energy (released) is the difference between the binding energies (of Ca and K nuclei)	M1 A1 M1 A1	 **Ignore** Δm being referred to as the 'mass defect' **Allow**: binding energy per nucleon increases
		(iii)	$\lambda = \frac{0.693}{4.2\times10^{16}}$ / $N = \frac{0.012}{100}\times\frac{4.5\times10^{-4}}{0.040}\times6.02\times10^{23}$ $A = 1.65\times10^{-17}\times8.127\times10^{17}$ activity = 13 (Bq)	C1 C1 A1	**Allow**: 1 mark for either $\lambda = 1.65\times10^{-17}$ s^{-1} or $N = 8.127\times10^{17}$ **Note**: Answer to 3 sf is 13.4 (Bq) **Note**: 1.3×10^3 (Bq) scores 2 marks; division by 100 omitted
			Total	**9**	