EDEXCEL A LEVEL PHYSICS · TOPIC 11

Nuclear Radiation

FREE Online Physics A Level Course

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Name _____ **Date** _____

TIME ALLOWED	TOTAL MARKS	YOU WILL NEED
90 minutes	76	a calculator, a ruler and a black or blue pen

Instructions

- Answer **all** questions in the spaces provided.
- Question 1 is multiple choice: tick **one** box for each part.
- Show your working in calculations, and include units where appropriate.
- Use 1 MeV = 1.60×10^{-13} J.

Information

- The marks for each question are shown in brackets: use them as a guide to how long to spend.
- This test covers Edexcel A Level Physics Topic 11, Nuclear Radiation (spec points 164–173).
- In the question marked with an asterisk (*), marks are awarded for structuring your answer logically.

Your score

Question	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Total	%
Out of	10	2	9	4	7	13	6	9	16	**76**	100
Your mark											

Marking your test The full mark scheme is at the back of this booklet. Try every question first, then mark your answers in a different colour.

1 Question 1

Multiple choice | 10 marks

For each part, put a tick (✓) in **one** box. Each part is worth 1 mark.

(a) A number of conditions must be met for the fusion of hydrogen nuclei to occur. Which condition, in a sample of hydrogen, is **not** necessary for nuclear fusion?

Tick (✓) **one** box.

- **A** very high density ☐
- **B** very high mass ☐
- **C** very high pressure ☐
- **D** very high temperature ☐

(1)

(b) The fuel used in a nuclear fission reactor is uranium. Which of the following is required for fission to proceed?

Tick (✓) **one** box.

- **A** Neutrons must be removed from the reactor core. ☐
- **B** The reactor core must be very hot. ☐
- **C** The uranium nuclei must absorb neutrons. ☐
- **D** The uranium nuclei must absorb protons. ☐

(1)

(c) A radioactive sample is a beta emitter. Beta particles are able to pass through

Tick (✓) **one** box.

- **A** air only. ☐
- **B** thick card. ☐
- **C** 1 cm of aluminium. ☐
- **D** 1 mm of lead. ☐

(1)

(d) A radioactive source is placed a few cm from a detector. The count rate does not change when a thin aluminium foil is placed between them, but falls to the background rate when a 0.5 cm aluminium plate is used. The source must be emitting

Tick (✓) **one** box.

- **A** alpha and beta radiation. ☐
- **B** beta and gamma radiation. ☐
- **C** beta radiation only. ☐
- **D** gamma radiation only. ☐

(1)

(e) Which row correctly compares the range of β particles, and the number of ion pairs per centimetre they produce, with α particles of the same energy?

Tick (✓) **one** box.

- **A** Range: greater · Ion pairs per cm: greater ☐
- **B** Range: smaller · Ion pairs per cm: greater ☐
- **C** Range: greater · Ion pairs per cm: smaller ☐
- **D** Range: smaller · Ion pairs per cm: smaller ☐

(1)

(f) Radiation beam therapy can kill cancerous cells. One treatment for brain tumours directs many narrow beams of radiation from different directions onto the cancerous cells. Which is the most suitable radiation to use?

Tick (✓) **one** box.

- **A** alpha radiation, because it is very ionising ☐
- **B** alpha radiation, because it is high energy ☐
- **C** gamma radiation, because it is very penetrating ☐
- **D** gamma radiation, because it has a very short wavelength ☐

(1)

(g) In an experiment to measure the activity of a radioactive source, the measured activity should always be corrected by

Tick (✓) **one** box.

- **A** adding the background count. ☐
- **B** adding the background count rate. ☐
- **C** subtracting the background count. ☐
- **D** subtracting the background count rate. ☐

(1)

(h) A student uses a Geiger counter to measure the counts per minute from a weak radioactive source. To determine the background count rate, the best procedure is to measure the count for

Tick (✓) **one** box.

A	1 minute before the source is in position. ☐	**B**	1 minute with the source in position. ☐
C	10 minutes before the source is in position. ☐	**D**	10 minutes with the source in position. ☐

(1)

(i) Radioactive decay is described as spontaneous. In this context, spontaneous means

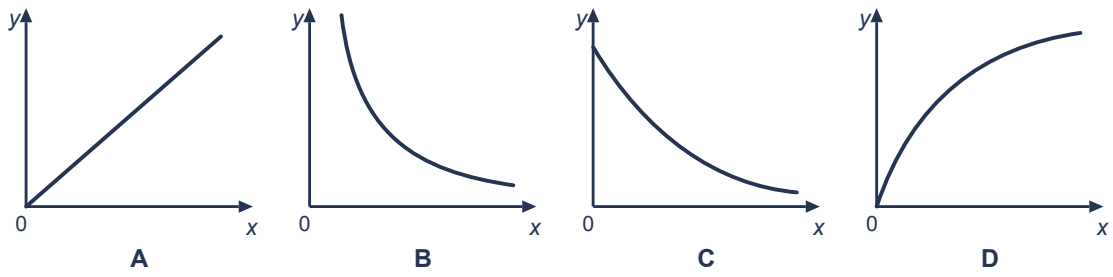
Tick (✓) **one** box.

A	nothing can influence the decay. ☐	**B**	the decay is random. ☐
C	the decay can be predicted. ☐	**D**	the decay is exponential. ☐

(1)

(j) A sample of a radioactive isotope decays to a stable isotope. Which graph shows how the number of daughter nuclei (y) varies with time (x)?

Sketch graphs



Tick (✓) **one** box.

A	☐	**B**	☐	**C**	☐	**D**	☐

(1)

Total for this question: 10 marks

2 Question 2 — 2 marks

State what is meant by binding energy.

(2)

Total for this question: 2 marks

3 Question 3 — 9 marks

(a) In 1939 Hans Bethe published a paper describing the fusion processes in stars. In the proton–proton cycle, hydrogen is converted to helium in stages. The nuclear equation below represents one of the stages.

$$^{7}_{3}\text{Li} + \text{.....X} \rightarrow 2 \times {}^{4}_{2}\text{He}$$

(a) (i) Complete the equation and identify X.

X is = _____

(2)

(ii) Calculate, in joules, the energy released in this stage of the cycle.

	Mass / MeV/c^2
proton	938.3
neutron	939.6
helium nucleus	3727.4
lithium nucleus	6533.8

Energy = _____ **J**

(3)

(b) In 1967 Bethe received a Nobel Prize for his work on fusion in stars. Explain why sustainable fusion has not yet been achieved for the generation of electrical power.

(4)

Total for this question: 9 marks

4 Question 4

4 marks

In 2012, building began on the International Thermonuclear Experimental Reactor (ITER) in France: a fusion reactor.

(a) Describe the process of nuclear fusion.

(2)

(b) Explain why the fusion of hydrogen nuclei should release energy.

(2)

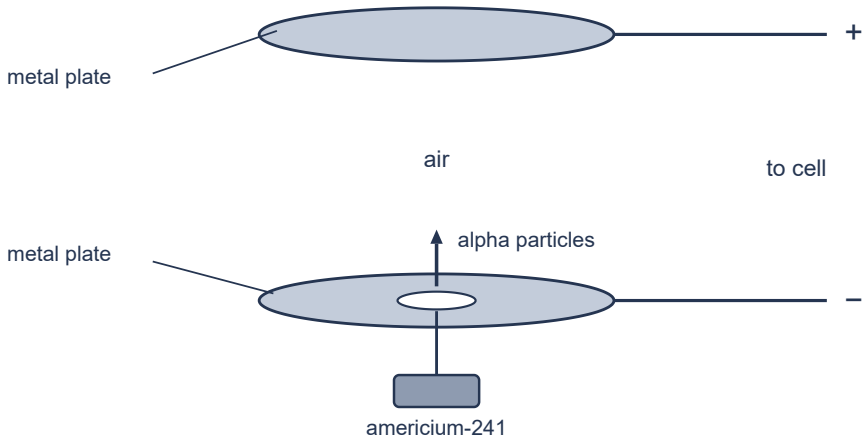
Total for this question: 4 marks

5 Question 5

7 marks

Some smoke detectors contain americium-241, whose nuclei decay by emitting an alpha particle. A small amount of americium makes the air between two metal plates conduct.

Part of a smoke detector



(a) (i) Explain why a stream of alpha particles causes charge to flow between the metal plates.

(2)

(ii) Suggest how smoke particles entering the space between the plates cause the current to decrease.

(1)

(b) **(i)** The decay of americium-241 is said to be random and spontaneous. State what is meant by random and by spontaneous.

Random

Spontaneous

(2)

(ii) Complete the equation for the alpha decay of americium-241.

$$___{95}Am \rightarrow ___^{237}Np + {}^{4}_{2}\alpha$$

(2)

Total for this question: 7 marks

6 Question 6

13 marks

Positron emission tomography (PET) is a medical imaging technique. Pairs of gamma rays, produced when positrons from a radioisotope annihilate with electrons, are detected to form the image.

Radioisotopes used in PET have short half-lives, such as carbon-11. Carbon-11 has a half-life of 1220 s and decays by positron emission to stable boron-11. Positrons are the antiparticles of electrons.

(a) Explain what is meant by a radioactive atom.

(2)

(b) Complete the equation for the decay of carbon-11.

$${}^{11}_{6}C \rightarrow ___B + ___e^{+} + {}^{0}_{0}\nu_e$$

(2)

(c) Calculate the energy, in joules, released in the positron decay of one carbon-11 nucleus.

	Mass / MeV/c^2
positron	0.511
carbon-11 nucleus	10 253.6
boron-11 nucleus	10 252.2

Energy = _____ **J**

(3)

(d) Explain why carbon-11 is a relatively safe radioisotope to use within the body.

(2)

(e) A patient was injected with a compound containing carbon-11 with an activity of 1.58×10^6 Bq. The sample was prepared 3600 s before it was given to the patient. Calculate the activity of the sample when it was prepared.

Activity when prepared = _____ **Bq**

(4)

Total for this question: 13 marks

7 Question 7

6 marks

Technetium-99m is an unstable isotope that decays by emitting γ radiation. Its half-life is 2.16×10^4 s.

(a) State what is meant by half-life.

(1)

(b) A sample containing 7.30×10^{19} nuclei of technetium-99m is prepared for a medical application.

(b) (i) Show that the activity of the sample when it is prepared is about 2.3×10^{15} Bq.

(3)

(ii) Calculate the activity of the sample 1 day after it was prepared. 1 day = 86 400 s.

Activity after 1 day = _____ **Bq**

(2)

Total for this question: 6 marks

8 Question 8

9 marks

In March 2011, radioactive material was released from the Fukushima nuclear power plant. A month later, seaweed near Long Beach, California was found to be contaminated with iodine-131, a β emitter. One sample had an activity of 2.5 Bq per gram of dry seaweed.

(a) State what is meant by the activity of a radioactive source.

(1)

(b) A Geiger counter measures the count from a sample of seaweed over 10 minutes. The corrected readings are shown.

Corrected count 1	Corrected count 2	Corrected count 3	Corrected count rate / Bq
3820	3830	3825	6.38

(b) (i) State why the readings from the Geiger counter have to be corrected.

(1)

(ii) Explain why the count is repeated.

(2)

(iii) The measurements are repeated with the same sample 30 days later. Calculate the new corrected count rate. Half-life of iodine-131 = 8.0 days.

New corrected count rate = _____ **Bq**

(3)

(iv) There is a moderate risk to the public from iodine-131 building up in the seaweed. Explain why.

(2)

Total for this question: 9 marks

9 Question 9

16 marks

Carbon-12 is the stable isotope of carbon. Carbon-14, formed in the upper atmosphere, is radioactive and decays randomly by emitting β^- particles.

(a) Carbon-14 forms when a nitrogen nucleus absorbs a neutron. Complete the nuclear equation and identify the particle X.

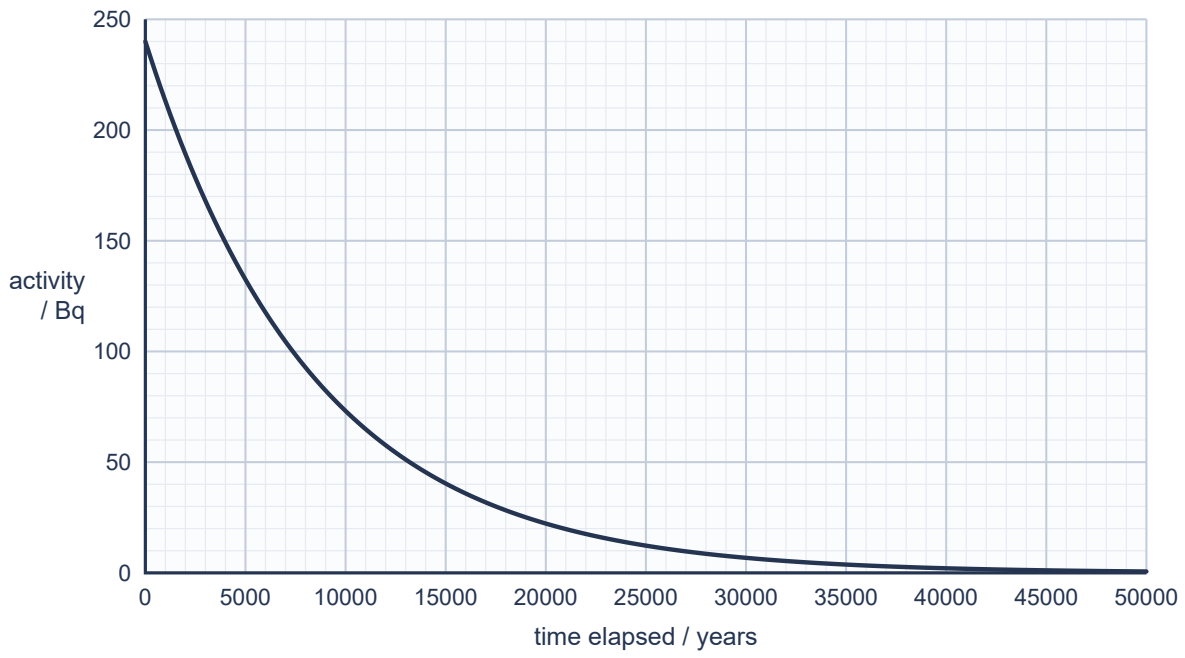
$$____n + {}^{14}_{7}N \rightarrow {}^{14}_{6}C + ____X$$

X is = _____

(3)

(b) While an organism is alive, the ratio of carbon-14 to carbon-12 in it stays the same. After it dies the ratio falls, so ancient objects can be dated. An activity–time graph for carbon-14 is shown.

Activity of carbon-14



Use the graph to show that the half-life of carbon-14 is about 6000 years.

(2)

(c) A sample from an ancient wooden object gives a corrected count rate of 10.9 Bq. A sample of the same mass from living wood gives 29.6 Bq.

(c) (i) State why the count rates have to be corrected.

(1)

(ii) State one procedure that would make these count rates more accurate.

(1)

(iii) Calculate the age of the object. Assume the half-life of carbon-14 is 6000 years.

Age of the object = _____ **years**

(3)

(d) A news report claims that a dinosaur skull has been found that is 68 million years old. Explain why carbon-14 dating could not have been used to find the age of this skull.

(2)

***(e)** A website includes this statement about heavy nuclei:

> Particles in the nucleus are held together by a force scientists call nuclear binding energy. It is possible to overcome the binding energy in some large atoms, such as uranium atoms, causing the atoms to undergo fission.

Comment on this statement.

Spelling of technical terms must be correct and your answer organised in a logical sequence.

(4)

Total for this question: 16 marks

END OF TEST

Now mark your answers using the mark scheme that follows.

MARK SCHEME

Nuclear Radiation · Topic Test

[1] in the Mark column means one mark for that line.

accept / allow notes (gold) are other answers that also score.

reject / do not accept notes (red) are answers that do not.

1 Question 1 — mark scheme

Multiple choice · 10 marks

PART	ANSWER	MARK
(a)	**B** very high mass *Temperature gives the nuclei enough energy to overcome the repulsion; density (pressure) makes collisions frequent. The sample's total mass doesn't matter.*	1
(b)	**C** the uranium nuclei must absorb neutrons	1
(c)	**B** thick card *Beta is stopped by a few mm of aluminium, so not C or D.*	1
(d)	**C** beta radiation only *No drop with thin foil: no alpha. Back to background with 0.5 cm aluminium: no gamma.*	1
(e)	**C** greater range, fewer ion pairs per cm *Beta is less ionising, so it loses its energy more slowly and travels further.*	1
(f)	**C** gamma, because it is very penetrating	1
(g)	**D** subtracting the background count rate	1
(h)	**C** 10 minutes before the source is in position *A long count reduces the effect of randomness; with the source there you'd measure the source too.*	1
(i)	**A** nothing can influence the decay	1
(j)	**D** KEY EQUATION $N_{daughter} = N_0(1 - e^{-\lambda t})$ starts at zero, grows, levels off	1

Total: 10 marks

2 Question 2 — mark scheme

2 marks

PART	ANSWER	MARK
	The energy equivalent to the mass deficit KEY EQUATION $\Delta E = c^2 \Delta m$	1

	Released when nucleons bind together to form a nucleus *accept (PWK definition): the energy required to completely separate a nucleus into its individual protons and neutrons*	1

Total: 2 marks

3 Question 3 — mark scheme — 9 marks

PART	ANSWER	MARK
(a)(i)	$^{7}_{3}\text{Li} + {}^{1}_{1}\text{X} \rightarrow 2 \times {}^{4}_{2}\text{He}$ *top and bottom numbers both needed for this mark*	1
	X is a proton *accept hydrogen / H* *reject deuterium: the numbers show A = 1*	1
(ii)	Attempt at the mass difference KEY EQUATION $\Delta E = c^2 \Delta m$ in MeV/c^2, Δm gives ΔE in MeV directly	1
	Use of 1 MeV = 1.60×10^{-13} J	1
	$\Delta E = 2.77 \times 10^{-12}$ J *6533.8 + 938.3 − 2 × 3727.4 = 17.3 MeV; 17.3 × 1.60 × 10^{-13} = 2.77 × 10^{-12} J*	1
(b)	**Max 4** of:	
	Extremely high temperature and density are needed	1
	High temperature because the nuclei need high energy to overcome the electrostatic repulsion	1
	Because the nuclei must come very close (close enough for the strong force to act)	1
	Very high density is needed for a sufficient collision rate	1
	These extreme conditions are very hard to contain *reject cost or other non-physics reasons*	(1)

Total: 9 marks

4 Question 4 — mark scheme — 4 marks

PART	ANSWER	MARK
(a)	(Small mass) nuclei come very close together **or** the strong force acts on the nuclei	1
	The nuclei join to form a more massive nucleus *reject atoms or particles: it is nuclei that fuse*	1

(b)	The mass of the fused nucleus is less than the total mass of the fusing nuclei KEY EQUATION $\Delta E = c^2\Delta m$	1
	The mass deficit is released as energy ($\Delta E = c^2\Delta m$) **or** the binding energy per nucleon is greater in the fused nucleus	1

Total: 4 marks

5 Question 5 — mark scheme — 7 marks

PART	ANSWER	MARK
(a)(i)	Alpha particles ionise the air (strip electrons from air molecules)	1
	The ions / electrons move in the electric field between the plates	1
(ii)	Smoke particles capture the electrons/ions **or** alpha particles collide with smoke, so there is less ionisation	1
(b)(i)	Random: we cannot predict which nucleus will decay next or when a particular nucleus will decay *reject atom / particle: it's nuclei that decay*	1
	Spontaneous: the decay is not affected by external factors (such as temperature, pressure)	1
(ii)	${}^{241}_{95}\text{Am} \rightarrow {}^{237}_{93}\text{Np} + {}^{4}_{2}\alpha$ *top line: 241*	1
	Bottom line: 93	1

Total: 7 marks

6 Question 6 — mark scheme — 13 marks

PART	ANSWER	MARK
(a)	A radioactive atom has an unstable nucleus…	1
	…which emits α, β or γ radiation (at least one named)	1
(b)	${}^{11}_{6}\text{C} \rightarrow {}^{11}_{5}\text{B} + {}^{0}_{1}\text{e}^{+} + {}^{0}_{0}\nu_e$ *top line correct: 11 and 0*	1
	Bottom line correct: 5 and 1 *(the positron has charge +1)*	1
(c)	Attempt at the mass difference KEY EQUATION $\Delta E = c^2\Delta m$	1

	Attempt at converting MeV to J	1
	$\Delta E = 1.4 \times 10^{-13}$ J *10 253.6 − 10 252.2 − 0.511 = 0.889 MeV; × 1.6 × 10⁻¹³ = 1.42 × 10⁻¹³ J*	1
(d)	It won't produce radiation for long, because carbon-11 has a short half-life	1
	Positrons are not very ionising **or** boron is safe in small amounts	1
(e)	Use of $\lambda t_{½} = \ln 2$ ($\lambda = 5.68 \times 10^{-4}$ s^{-1}) KEY EQUATION $\lambda t_{½} = \ln 2$ KEY EQUATION $A = A_0 e^{-\lambda t}$	1
	Use of $A = A_0 e^{-\lambda t}$	1
	$A = 1.58 \times 10^6$ Bq used as the activity **now** (not A_0)	1
	$A_0 = 1.2 \times 10^7$ Bq *$1.58 \times 10^6 = A_0\, e^{-5.68 \times 10^{-4} \times 3600}$, so $A_0 = 1.58 \times 10^6 \times 7.73 = 1.22 \times 10^7$ Bq*	1

Total: 13 marks

7 Question 7 — mark scheme — 6 marks

PART	ANSWER	MARK
(a)	The average time taken for the number of undecayed nuclei (or the activity) to halve *reject "half the mass"*	1
(b)(i)	Use of $\lambda t_{½} = \ln 2$ ($\lambda = 3.21 \times 10^{-5}$ s^{-1}) KEY EQUATION $A = \lambda N$	1
	Use of $A = \lambda N$ ($dN/dt = -\lambda N$)	1
	$A = 2.34 \times 10^{15}$ Bq *$3.21 \times 10^{-5} \times 7.30 \times 10^{19}$. A "show that" needs 3 significant figures.*	1
(ii)	Use of $A = A_0 e^{-\lambda t}$ **or** 1 day = 4 half-lives KEY EQUATION $A = A_0 e^{-\lambda t}$	1

	$A = 1.5 \times 10^{14}$ Bq *$2.34 \times 10^{15} \div 2^4 = 1.46 \times 10^{14}$ Bq; 1.4 × 10^{14} Bq if 2.3×10^{15} was used* *a unit is needed*	1

Total: 6 marks

8 Question 8 — mark scheme — 9 marks

PART	ANSWER	MARK
(a)	The number of nuclei that decay per second (the rate of decay of nuclei) *reject "sample", "particle" or "substance" decaying*	1
(b)(i)	Background radiation increases the recorded count, so it must be subtracted *do not accept just "to correct for background radiation"*	1
(ii)	Radioactive decay is random, so a count over a fixed time varies	1
	Repeating lets a mean (average) be calculated	1
(iii)	Use of $\lambda = \ln 2 \div t_{½}$ (0.0866 day^{-1}) KEY EQUATION $A = A_0 e^{-\lambda t}$	1
	Use of $A = A_0 e^{-\lambda t}$ *allow 2.5 Bq for A_0 here; allow $A = A_0(½)^{t/t_{½}}$*	1
	$A = 0.47$ Bq *$6.38 \times e^{-0.0866 \times 30} = 6.38 \times 0.074 = 0.47$ Bq*	1
(iv)	People must be close to / eat the seaweed for any risk **or** β is moderately ionising **or** β can enter the body through the skin	1
	The half-life is short: after a month or so the activity is negligible	1

Total: 9 marks

9 Question 9 — mark scheme — 16 marks

PART	ANSWER	MARK
(a)	${}^{1}_{0}n + {}^{14}_{7}N \rightarrow {}^{14}_{6}C + {}^{1}_{1}X$ *top line correct: 1 and 1*	1
	Bottom line correct: 0 and 1	1
	X is a proton	1

(b)	Reads activity–time pairs for at least 2 half-lives and finds the mean **or** uses $A = A_0e^{-\lambda t}$ with graph values KEY EQUATION $\lambda t_{½} = \ln 2$	1
	$t_{½}$ matches their graph readings *e.g. 240 Bq at 0 and 30 Bq at 17 500 years: 3 half-lives, so $t_{½}$ = 5833 years*	1
(c)(i)	Background radiation increases the recorded count rate, so it has to be subtracted	1
(ii)	Record the count for a longer time **or** repeat and find an average	1
(iii)	Use of $\lambda t_{½} = \ln 2$ (1.16×10^{-4} year^{-1}) KEY EQUATION $A = A_0\, e^{-\lambda t}$	1
	Use of $A = A_0e^{-\lambda t}$	1
	t = 8650 years *accept 8600–8700 years. $10.9 = 29.6\, e^{-1.16 \times 10^{-4} t}$ so $t = \ln(29.6 \div 10.9) \div 1.16 \times 10^{-4}$*	1
(d)	The time is far too long compared with the half-life (too many half-lives have passed)	1
	So the activity would be too small to measure **or** the skull would have almost no carbon left	1
***(e)**	Binding energy is the energy released when a nucleus forms **or** the energy needed to separate it into its nucleons *QWC: technical terms spelt correctly, answer in a logical sequence*	1
	Binding energy is not a force (it is the strong force that holds the nucleons together)	1
	Atoms do not undergo fission: nuclei do	1
	Fission is when a large mass nucleus splits into smaller mass nuclei	1

Total: 16 marks

END OF MARK SCHEME