WJEC EDUQAS A-LEVEL PHYSICS · COMPONENT 3

PHYSICS



EXAM QUESTION PACK

3.6 NUCLEAR DECAY

SCORE	PERCENTAGE
/93	%

STEMUP

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#1

A tritium nucleus decays into helium-3 as follows:

$$^{3}_{1}\mathrm{H} \longrightarrow {}^{3}_{2}\mathrm{He} + \mathrm{e}^{-} + \bar{\nu}_{\mathrm{e}}$$

$$\left[\begin{array}{ll} \text{mass of } {}^{3}_{1}\mathrm{H} = 3.01550\,\mathrm{u} & \text{mass of } {}^{3}_{2}\mathrm{He} = 3.01493\,\mathrm{u} \\ m_{\mathrm{e}} = 0.00055\,\mathrm{u} & \text{mass of } \bar{\nu}_{\mathrm{e}} = 0.00000\,\mathrm{u} \\ & 1\,\mathrm{u} = 931\,\mathrm{MeV} \end{array}\right]$$

(a) Calculate the energy released in the decay of tritium. [3]

(b) The mass of a proton is 1.00728 u and the mass of a neutron is 1.00866 u.

(i) Calculate the binding energy per nucleon of a tritium nucleus. [3]

(ii) The binding energy per nucleon of a helium-3 nucleus (i.e. 2.6 MeV/nucleon) is slightly lower than the answer to *(b)*(i). How does this show that binding energy per nucleon is not the only measure of stability? [3]

Question taken from Eduqas examination paper 842103, June 2017

#2

4. *(a)* It is possible to distinguish between α, β and γ radiation by their different absorption properties. Explain briefly **one other method** of differentiating between α, β and γ radiation. [3]

Space for diagram

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(b) The half-life of beryllium-7 is 53.1 days. The initial count rate with a beryllium-7 source in position is measured as 3.50 counts per second (cps) and this dropped to 1.50 cps after 84 days.

(i) Show that this final count rate is approximately 0.33 cps higher than would be expected from beryllium alone (approximately 1.17 cps). [3]

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(ii) The discrepancy between the measured count of 1.50 cps and the expected count of 1.17 cps is due to background radiation. Given that the background count rate is a constant 0.50 cps, determine whether the final measured count rate of 1.50 cps is exactly as expected. [4]

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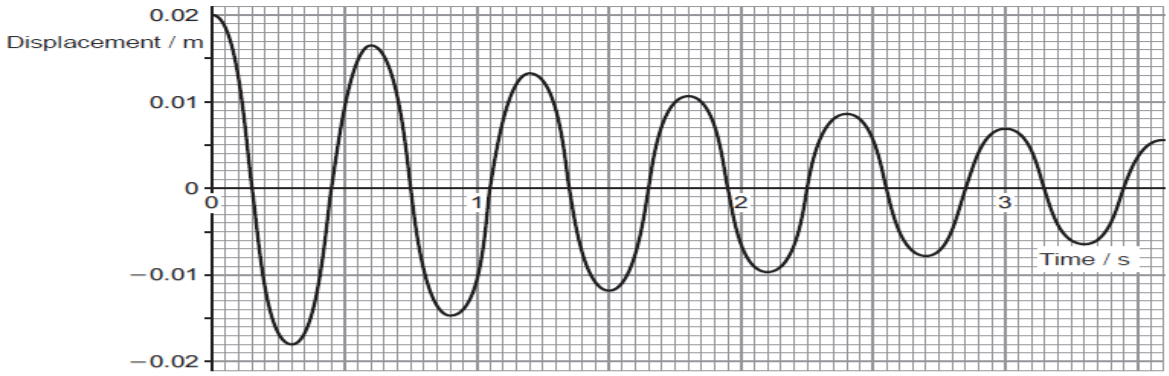
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Question taken from Eduqas examination paper 842103, June 2019

#3

A metal sphere of mass 0.200 kg, hanging from a light spring of stiffness k = 22.0 N m^{-1}, is set oscillating up and down about its equilibrium position. A datalogger records the sphere's position and plots the graph shown below.



(a) State what feature of the graph shows that the sphere's oscillations are damped and identify the force responsible for this feature. [2]

(b) Evaluate whether or not ordinary simple harmonic motion theory predicts the actual periodic time as shown on the graph convincingly. [4]

(c) **Mark with a small circle** the point on the graph where the sphere's speed is the greatest. Use shm theory to calculate a value for this speed **and** explain whether this value is likely to be too high or too low. [4]

(d) The amplitude, A, (in m) of the oscillations at time t is given by the equation:

$$A = 0.020\, e^{-\lambda t}$$

Determine the value of λ. [2]

Question taken from Eduqas examination paper 842101, June 2017

#4

6. *(a)* A radioactive isotope of thorium decays to a stable lead nucleus ($^{208}_{82}Pb$) via 6 alpha decays and 4 beta decays. Complete the equation below. [2]

$$\text{.....}Th \longrightarrow {}^{208}_{82}Pb + 6\ \text{.....}He + 4\ \text{.....}e^{-}$$

(b) The half-life of the thorium nucleus is 14.1×10^{9} years. Calculate the activity of 5.0×10^{-3} kg of the radioactive thorium (the mass of the thorium atom is approximately 3.9×10^{-25} kg). [5]

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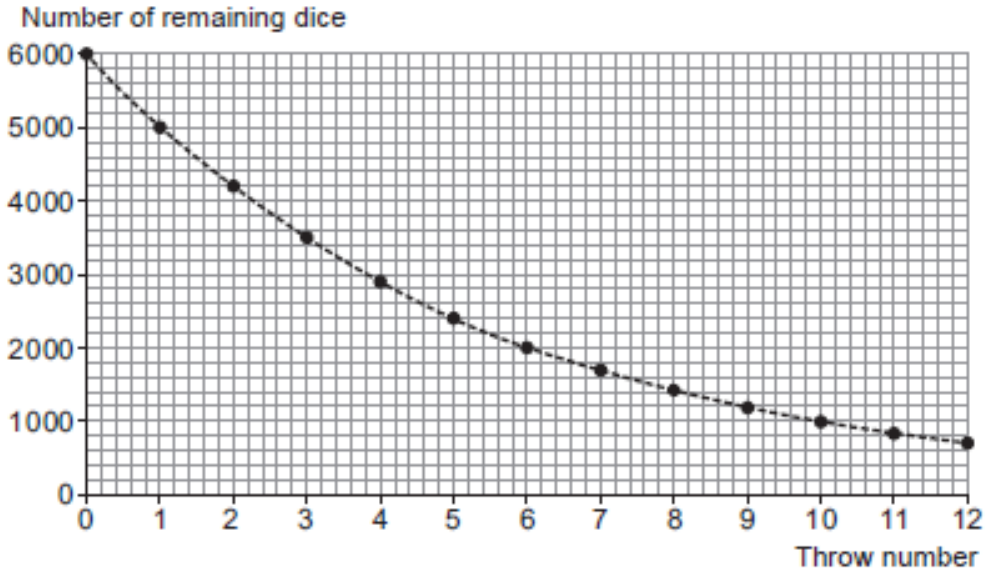
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(c) In order to model nuclear decay, 6000 dice are thrown multiple times. All the dice are thrown initially and all dice landing with the number 1 facing upwards are removed. The remaining dice are then thrown and the procedure repeated. The number of remaining dice is recorded each time as well as the number of dice removed (the decay count). The results are recorded in a table and plotted.



Throw number	Number of remaining dice	Number of dice removed
0	6000	
1	4991	1009
2	4200	791
3	3504	696
4	2871	633
5	2391	480
6	2046	345
7	1707	339
8	1435	272
9	1224	211
10	1018	206
11	858	160
12	725	133

Graph 1



(i) Use the data to deduce whether or not the number of remaining dice decreases exponentially. [4]

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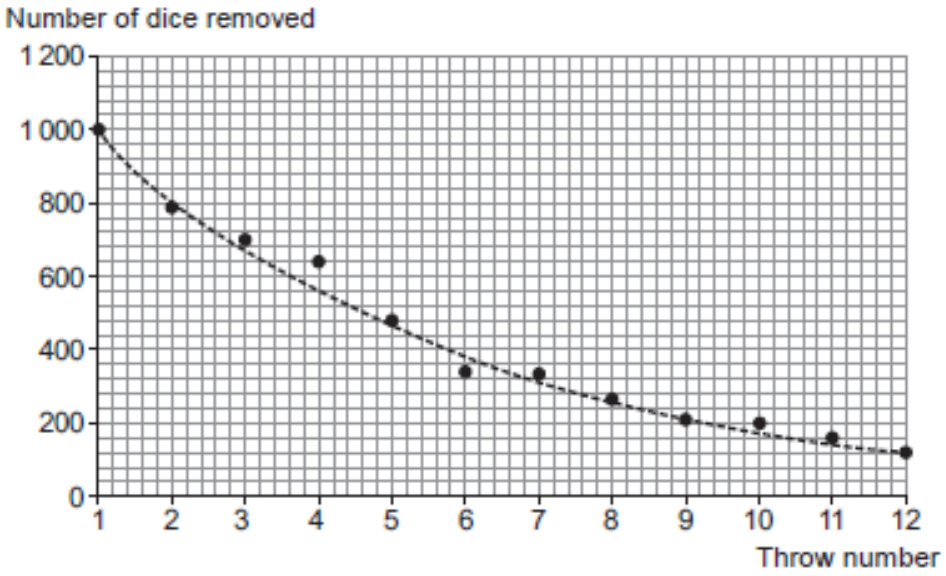
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A graph is also plotted of the number of dice removed against the throw number (Graph 2).

Graph 2



(ii) Suggest why there is more scatter in Graph 2 than Graph 1. [2]

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Question taken from Eduqas examination paper 842103, June 2018

#5

(a) The bismuth isotope ($^{209}_{83}$Bi) decays by alpha decay to an isotope of thallium (Tl). Fill in the missing numbers for this decay. [2]

$$^{209}_{83}\text{Bi} \longrightarrow \text{.....} \text{Tl} + \text{.....} \text{He}$$

(b) Determine whether or not a kinetic energy of 3.6 MeV for the alpha particle in the above reaction is consistent with the data in the table below (you may assume that the kinetic energies of the bismuth and thallium nuclei are negligible). [5]

Nuclear mass of thallium isotope	204.9300 u
Nuclear mass of alpha particle	4.0015 u
Binding energy per nucleon of $^{209}_{83}$Bi nucleus	7.87 MeV / nucleon
Mass of proton, m_p	1.0073 u
Mass of neutron, m_n	1.0087 u
Energy equivalent of 1 u	931 MeV

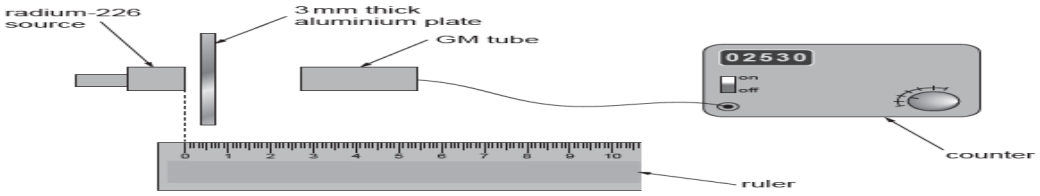
(c) (i) The half-life of $^{209}_{83}$Bi is 1.9×10^{19} year. Calculate the activity of 1.00 gram of $^{209}_{83}$Bi. [4]

(ii) Determine the number of nuclei in 1.00 gram of $^{209}_{83}$Bi which will decay in 5 years. [2]

Question taken from Eduqas examination paper 842103, November 2020

#6

Bronwen carries out an experiment to investigate the relationship between count rate and distance from a gamma emitting radioactive source (radium-226).

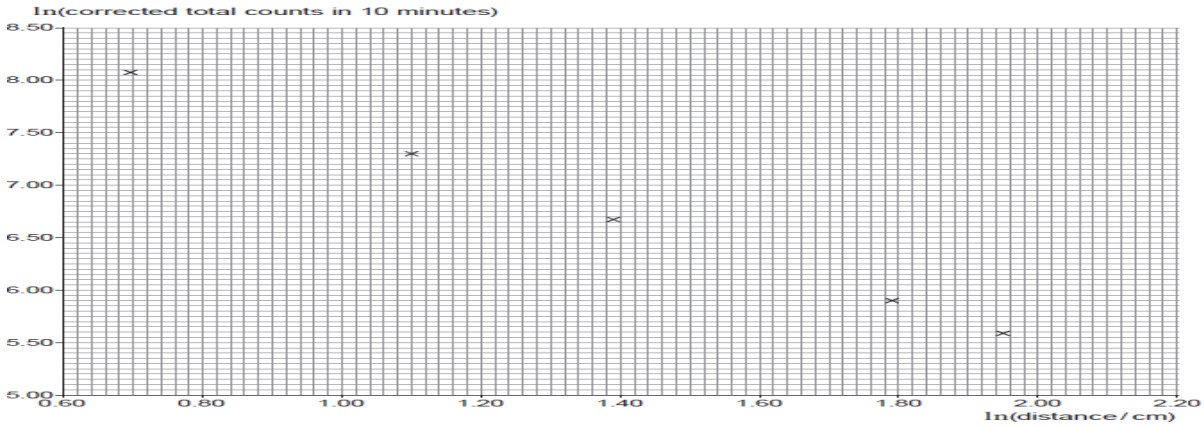


Her results are shown in the table.

Distance / cm	Total counts in 10 minutes	ln(distance / cm)	ln(corrected total counts in 10 minutes) **{corrected for background radiation}**
2.0	3 466	0.69	8.08
3.0	1 697	1.10	7.28
4.0	1 028	1.39	6.67
5.0	762	.....	.....
6.0	609	1.79	5.91
7.0	507	1.95	5.59
8.0	447	.....	.....

(a) (i) The **background radiation is 0.40 counts per second. Complete the table.** [3]
Space for calculations.

(ii) **Complete the graph** by plotting the two missing data points. [1]



(iii) Draw a line of best fit and calculate its gradient. [3]

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(iv) Theory suggests that:

$$\text{count rate} \propto \frac{1}{\text{distance}^2}$$

I. Show that the gradient of the graph should be −2. [2]

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II. Explain to what extent the results obtained in this experiment agree with theory. [3]

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(b) Radium-226 also emits other radiation. Suggest a reason for using a 3 mm aluminium plate between the source and the GM tube. [1]

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(c) In 1896, G. Brandes reported that large intensities of high energy X-rays produced a "blue-grey" glow within the eye. This was later confirmed by Willhelm Röntgen and other scientists. The mechanism for this "blue-grey" glow is still not fully understood. Discuss the ethics of reproducing this experiment to understand it better. [3]

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Question taken from Eduqas examination paper 842103, November 2020

#7

(a) A carbon-14 nucleus decays as shown:

$$^{14}_{6}C \longrightarrow {}^{14}_{7}N + e^{-} + \bar{\nu}_e$$

(i) Show how charge, baryon number and lepton number are conserved in this decay. [3]

(ii) Give two reasons why this must be a weak nuclear force interaction. [2]

(b) The decay constant of carbon-14 is $3.83 \times 10^{-12}\ s^{-1}$.

(i) Calculate its half-life in years. [3]

(ii) The natural ratio of carbon-14 to carbon-12 is 1.00×10^{-12} i.e.

$$\frac{\text{number of } ^{14}_{6}C \text{ nuclei}}{\text{number of } ^{12}_{6}C \text{ nuclei}} = 1.00 \times 10^{-12}$$

Calculate the activity of 12 g of naturally occurring carbon. [3]

(iii) In an old tree found preserved in a peat bog in Ireland, much of the carbon-14 has decayed but the carbon-12 all remains. The ratio of carbon-14 to carbon-12 in this old tree has dropped to 0.34×10^{-12}. Calculate the age of the old tree. [3]

(c) Carbon-11 ($^{11}_{6}C$) is proton rich and undergoes positron decay to a stable isotope of boron (B). Complete the following decay equation for carbon-11. Space is provided should you require analysis of lepton number, baryon number and charge. [3]

$$^{11}_{6}C \longrightarrow$$

(d) On the 14 March 2013, the discovery of the Higgs boson was first announced by CERN. Some physicists were convinced that they had discovered the Higgs boson, others believed that there are many different types of Higgs bosons while others claim that this was just another particle and not the Higgs boson. Explain how it may or may not be decided which, if any, of these claims is correct. [3]

Question taken from Eduqas examination paper 842103, June 2017

Marking Scheme

#1

Question			Marking details	Marks available AO1	AO2	AO3	Total	Maths	Prac
	(a)		LHS – RHS (3.0155 – 3.01493 – 0.00055 i.e. standard knowledge of conservation of mass-energy (1) ×931 or equivalent (× c^2) (1) 0.0186 [MeV] (2.98 × 10^{-15} [J]) (1)	1	1 1		3	2	
	(b)	(i)	Mass of p + 2n (3.0246u) - 3.0155 (1) Dividing by 3 **and** ×931 (or equivalent) (1) Answer = 2.82 [MeV / nucleon] (4.52 × 10^{-13} [J/nucleon]) (1)		3		3	2	
		(ii)	Tritium decays to helium-3 **or** helium has a better proton/neutron ratio **or** proton has a smaller mass than neutron (1) And emits energy **or** products have lower mass **or** helium more stable (1) You would expect the products to have a greater BE/N **or** contrary to what you would expect (1)			3	3		
			Question total	**1**	**5**	**3**	**9**	**4**	**0**

#2

Question			Marking details	Marks available AO1	AO2	AO3	Total	Maths	Prac
4	(a)		Diagram of radiation in *B*-field or *E*-field (or description) [1] α, β deviate in opposite directions [1] α, β and γ radiation all go correct directions [1]	1	1 1		3		
	(b)	(i)	Decay constant obtained 1.51 × 10^{-7} [s^{-1}] or 0.013 [day^{-1}] or 1.58$T_{½}$ [1] $3.5e^{-0.013 \times 84}$ or equivalent e.g. $2^{1.58}$ [1] Answer = 1.169 [cps] (no more required) [1]		3		3	3	
		(ii)	Subtracting background radiation from initial (3 cps) [1] Calculating correct cps after 84 days (i.e. 1.002 cps) [1] Adding background radiation (i.e. 1.502) [1] Valid conclusion: close to expected or okay / due to randomness and low numbers **ecf** [1]			4	4	2	
			Question 4 total	**1**	**5**	**4**	**10**	**5**	**0**

#3

Question			Marking details	Marks available AO1	AO2	AO3	Total	Maths	Prac
	(a)		Falling amplitude (1) [Air] resistance **or** dissipative forces **or** equivalent (1)	2			2		
	(b)		$T = 2\pi\sqrt{\frac{0.200}{22.0}}$ [s] (1) = 0.599 [s] (1) T read from graph = 0.60 [s] (1) Prediction convincing [no significant difference] (1)			4	4	2	
	(c)		Point at 0.15 s marked – no tolerance (first displacement zero) (1) $v_{max} = 0.020 \times \frac{2\pi}{0.60}$ [m s^{-1}] (1) = 0.21 m s^{-1} **UNIT** (1) Too large owing to energy dissipation in first quarter cycle (1) **Accept** less detailed reason, such as 'because of damping' **Alternative for last 3 marks:** $v_{max} = 0.018 \times \frac{2\pi}{0.60}$ [m s^{-1}] (1) = 0.19 m s^{-1} **UNIT** (1) Too small because amplitude has fallen or equivalent (1) **Alternative for last 3 marks (mean found):** $v_{max} = 0.019 \times \frac{2\pi}{0.60}$ [m s^{-1}] (2) = 0.20 m s^{-1} **UNIT** (1) no comment required	1	1 1 1		4	2	
	(d)		Data from one maximum or minimum on the graph (other than at t = 0) substituted into the given equation or equivalent accept slips (1) λ = 0.35 [s^{-1}] [±0.03 s^{-1}] (1)		2		2	1	
			Question total	**3**	**5**	**4**	**12**	**5**	**0**

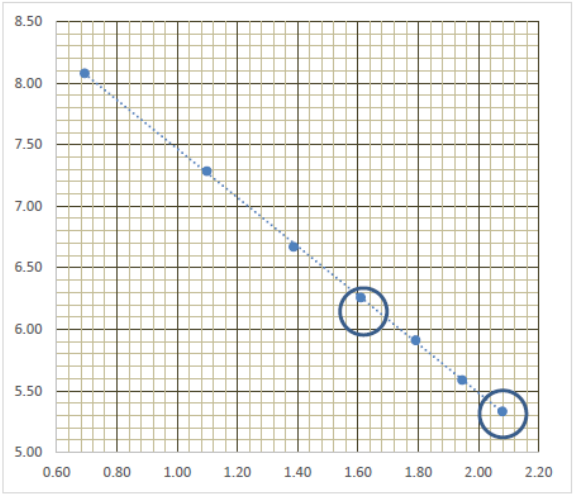
#4

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
6	*(a)*		N.B. no marks for beta and alpha Answer = 232 (1) Answer = 90 (1)		2		2		
	(b)		Conversion to second ($\times 10^9 \times 365 \times 24 \times 3600$) [$4.4\times10^{17}$] (1) Use of decay constant = $\frac{0.693}{\text{half-life}}$ [1.6×10^{-18} s^{-1}] (1) $N = \frac{5.0 \times 10^{-3}\ kg}{3.9 \times 10^{-25}\ kg}$ [allow $\frac{5\times10^{-3}}{232\times1.66\times10^{-27}}$] (1) Use of $A = \lambda \times N$ (1) Answer = 20 kBq ((**unit**)) (1) [accept s^{-1} for Bq] [Accept: correct answer in other units, e.g. 1.7×10^9 day^{-1} If not in Bq and no unit 3max]	1 1	1 1 1		5	4	
	(c)	(i)	**Either** Half-life around 3.8 throws (or get λ from equation or check that decreased by a sixth once) (1) 2× half-lives around 7.8 throws (or calculate another point using λ or check that decreased by a sixth again) (1) Expected activity as one sixth checked e.g. $\frac{6\,000}{6} \approx 1\,009$ (or check that reduced by a sixth for 3rd occasion) (1) Considered conclusion - all is about right (1) Or Exp decay if same interval → same fractional change (1) Calculation of fractional change for a given throw interval (1) Calculation of fractional change for two further same throw intervals (1) Conclusion: about right (1) Or Calculate λ 3 times using three different point → conclusion NB conclusion only after legitimate work			4	4	3	4
		(ii)	Smaller numbers involved (1) More [%] random error expected (1)			2	2		2
			Question 6 total	**2**	**5**	**6**	**13**	**7**	**6**

#5

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
	(a)		4,2 for helium (1) 205, 81 for thalium (1)	1	1		2		
	(b)		**Binding energy method:** BE of Bi = 7.87 × 209 (=1 644.83) (1) Correct method for working out mass defect of He or Tl (1) Conversion of mass defect to energy i.e. ×931 **or** $E = mc^2$ (1) Values correct for BE 28.40 and 1 620.03 (1) Final answer = 3.6 MeV (1) **Alternative:** Calculating mass of 83p and 126n (=210.7021 u) (1) BE of Bi = 7.87 × 209 (=1 644.83) (1) Subtracting mass defect for Bi mass (=208.9354 u) (1) LHS mass - RHS mass (=0.0039 u) (1) Final answer = 3.63 MeV (1)			5	5	4	
	(c)	(i)	Sub into half-life = $\frac{0.693}{\lambda}$ (gives 1.16×10^{-27}) (1) Number of mol = $\frac{1}{209}$ **OR** mass of 1 atom = $209 \times 1.66 \times 10^{-27}$ (1) Number of nuclei/atoms = 2.88×10^{21} (1) Answer = 3.3×10^{-8} Bq (1) **unit mark**	1	1 1 1		4	4	
		(ii)	3.3×10^{-8} **ecf** × 5 × 365 × 24 × 3 600 OR $N = N_0 e^{-\lambda t}$ used (1) Answer = 525 (1)		2		2	2	
			Question total	**2**	**6**	**5**	**13**	**10**	**0**

#6

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
	(a)		1.61 and 2.08 for ln distance (1) 600 × 0.4 seen (or 240 counts or implied) (1) ln(corrected) answers = 6.26 and 5.33 (implies previous) (1)		3		3	2	3
	(b)		 One mark each for the circled points plotted correctly		1		1	1	1
	(c)		Line of best fit as shown above (1) Correct method for gradient (1) Gradient = -1.98 (allow ± 0.05) (1)		3		3	3	3
	(d)		Taking logs correctly e.g. $\log C = \log k - 2 \times \log d$ (1) Comparison with $y = mx + c$ **OR** gradient clearly identified (1)		2		2	2	2
	(e)		Gradient agrees well with inverse square law (1) Points are close to line of best fit (1) Line of best fit is straight (1)			3	3		3
	(f)		Absorbs other radiation	1			1		1
	(g)		Ionising (1) Kills cells / causes cancer / DNA damage / causes cataracts etc. (1) Hence unethical & linked to risk (1)			3	3		
			Question total	**1**	**9**	**6**	**16**	**8**	**13**

#7

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
	(a)	(i)	Charge: 6 = 7 -1 + 0 **or** 0 = 1 - 1 + 0 **or** $-\frac{1}{3}=\frac{2}{3}-1+0$ (1) Baryon number: 14 = 14 + 0 + 0 **or** 1 = 1 + 0 + 0 **or** $\frac{1}{3}=\frac{1}{3}+0+0$ **or** 42 = 42 + 0 + 0 (1) Lepton number: 0 = 0 + 1 – 1 **or** 6 = 6 + 1 – 1 (1)		3		3		
		(ii)	Change of quark flavour [from d to u] (1) Neutrino involved accept symbol (1) Accept long half-life		2		2		
	(b)	(i)	Use of the equation $T_{\frac{1}{2}}=\frac{\ln 2}{\lambda}$ (1) $T_{\frac{1}{2}} = 1.81 \times 10^{11}$ [s] (1) 5 730 [year] (1)	1	1 1		3	3	
		(ii)	Use of the equation $A = \lambda N$ (1) Method for obtaining N correct ($6.02 \times 10^{23} \times 1 \times 10^{-12}$) (1) Answer = 2.30 Bq **unit mark** (1)	1	1 1		3	3	
		(iii)	$0.34 \times 10^{-12} = 1 \times 10^{-12} e^{-\lambda t}$ i.e. substitution or into $\frac{1}{2^n}$ (1) Taking logs correctly e.g. $\log A = \log A_0 - \lambda t$ (1) 2.82×10^{11} [s] or 8 900 [year] (1)	1	1 1		3	3	
	(c)		11, 5 for boron (1) Positron symbol correct e.g. e+ or beta + (1) Neutrino symbol correct (ν_e) but accept ν (1) Any fourth particle added lose 1 mark		1	1 1	3		
	(d)		**Any 3 × (1) from:** • cannot tell who is correct or words to that effect • further experiments or research must be carried out • experiments at higher (collision) energies (to find other particles) / bigger or better colliders • time/history will (probably) show who was correct • further theory / theoretical research • reference to the Higgs behaving as expected or not as expected • those who claim not should suggest an alternative • Higgs thought to be detected with 5σ [confidence] **Don't accept** any reference to charge or baryon number or lepton number conservation			3	3		
			Question total	**3**	**12**	**5**	**20**	**9**	**0**