A Level OCR Physics

Chapter 23 Nuclear and particle physics

Q	Answers	Extra information	Marks	AO	Spec reference
1(a)	In path A the alpha particle is directed at the centre of the nucleus, so the electrostatic force is along the same line that the alpha particle is travelling but in the opposite direction, so it stops and goes back out. In path B the force and velocity are not parallel, so the electrostatic force on the alpha particle changes its direction.		1 1	2	6.4.1
(b)	$E_e = \frac{Q_1 Q_2}{4\pi\varepsilon_0 d}$ $5 \times 1.6 \times 10^{-13} = \frac{2 \times 79 \times (1.6 \times 10^{-19})^2}{4\pi \times 8.85 \times 10^{-12} \times d}$ $d = \frac{2 \times 79 \times (1.6 \times 10^{-19})^2}{4\pi \times 8.85 \times 10^{-12} \times 5 \times 1.6 \times 10^{-13}}$ $= 4.55\times10^{-14}$ m $\sim10^{-13}$ m	Use of electric potential energy Answer	1 1	2	6.4.1
(c)	A gold nucleus contains 79 protons and 197 − 79 = 118 neutrons Mass of nucleus = 79 × 1.673×10^{-27} + 118 × 1.675×10^{-27} = 3.298×10^{-25} kg Mass of atom = 3.298×10^{-25} kg + 79 × 9.11×10^{-31} ≈ 3.298×10^{-25} kg Approximate diameter of gold atom = 10^{-10} m. Density = mass/volume $\frac{\rho_{nucleus}}{\rho_{atom}} = \frac{m_{nucleus}}{V_{nucleus}} \frac{V_{atom}}{m_{atom}}$ $= \frac{V_{atom}}{V_{nucleus}} = \frac{\frac{4}{3}\pi r_{atom}^3}{\frac{4}{3}\pi r_{nucleus}^3} = \frac{0.5\times10^{-103}}{9.1\times10^{-143}}$	Use of atomic mass and number to calculate mass of nucleus Either mass of electrons is negligible, or calculation Substitution	1 1 1	3	6.4.1

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	$= 1.66\times10^5$ Or density of nucleus = 1.04×10^{14} kg m^{-3} Density of atom = 6.29×10^8 kg m^{-3}	Answer	1		
(d)	The force on the alpha particle depends on the charges on the nucleus The charge on the alpha particle is the same, but the charge on the nucleus is halved/+40e compared to +79e The alpha particle would be deflected through a smaller angle.		1 1 1	3	6.4.1
(e)	No, nuclear density is approximately constant		1	1	6.4.1
(f)	Scale on x−axis showing 1 fm/square Graph showing repulsive force below about 0.5 fm Attractive force (below axis) peaking at about 1 fm Tending to zero beyond 3 fm As nucleons are pushed together the strong nuclear force maintains their distance.		1 1 1 1	1	6.4.1
2(a)	An isotope has the same number of protons but a different number of neutrons		1	1	6.4.1
(b)	$u \rightarrow d + e^{+} + v_{e}$		1	2	6.4.2
(c)	lepton number: 0 = 0 + (−1) + (+1) charge: +2/3 = +1/3 + (+1) + 0 baryon number: 1/3 = 1/3 + 0 + 0	Numbers consistent with equation All particle numbers must be present in each equation for the mark	1 1 1	2	6.4.2
(d)	energy/momentum		1	1	6.4.2
(e)	The positron and the neutrino They are leptons		1 1	1	6.4.2
(f)	**Level 3 (5–6 marks)** Clear description of the method required along with analysis *The student presents relevant information coherently, employing structure,*	**Indicative scientific points may include:** Method:	6	1	6.4.3

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	style and SP&G to render meaning clear. **Level 2 (3–4 marks)** Partial description of the method or analysis required OR a detailed description of one *The student presents relevant information and in a way which assists the communication of meaning. SP&G are sufficiently accurate not to obscure meaning.* **Level 1 (1–2 marks)** Limited description of the method and analysis *The student presents some relevant information in a simple form. SP&G allow meaning to be derived although errors are sometimes obstructive.* 0 marks No response or no response worthy of credit.	- Measure the background radiation count rate in counts per minute. Repeat and take the average. Set up a source of iodine−124 with a Geiger counter and stop clock/ratemeter. Set it to measure counts per minute. Measure the activity every hour or two hours for at least 10 days. Subtract the background count from all measurements Analysis: - Plot a graph of corrected count rate vs time. Find at least 3 half−lives from the graph. Find the average OR plot a graph of ln (corrected count rate) vs time find half−life from the gradient: half−life = ln2/gradient			
(g)	A down quark decays to an up quark An anti−neutrino is produced		1 1	1	6.4.2
3(a)	Put the source in front of a Geiger counter Place paper between the source and the counter, and the Geiger counter reading will not change Place a sheet of aluminium between the source and the counter, and the Geiger counter reading will not change	Use of paper with effect Use of aluminium with effect	1 1	1	6.4.3

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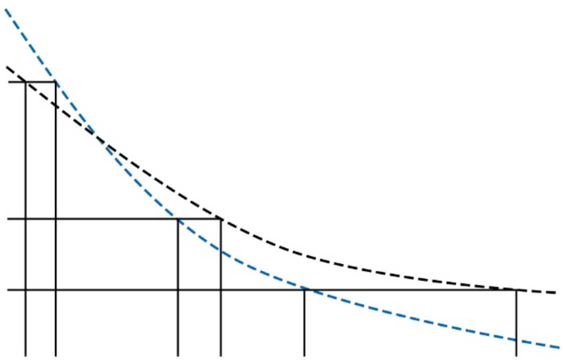
(b)	Place a source far away from the Geiger counter and measure the count rate in Becquerels (counts per second) due to background radiation only Measure the thickness of the paper with a micrometer Place one piece of paper between the source and detector and measure the count rate Keeping the distance between the Geiger counter and the source constant repeat for different thicknesses of paper/numbers of sheets Repeat the whole experiment three times and take an average activity for each distance Subtract the background count from each activity	Measurement of background count Measuring thickness with instrument Repeated measurements of activity at different thicknesses mean taken Subtraction of background count	1 1 1 1 1 1	1	6.4.3
(c)	Either: Estimate uncertainty from limitations of equipment Or use the spread of data for repeat readings		1	1	6.4.3
(d)	 Steep line: 0.31 − 0.09 = 0.22, and 0.56 − 0.31 = 0.25, average 0.24 mm Shallow line: 0.40 − 0.035 = 0.365, and 0.95 − 0.40 = 0.55, average 0.46 mm Average of two readings = (0.24 + 0.46)/2 = 0.35 mm	Lines showing max and min gradients Evidence of lines on graph to find values	1 1	2	6.4.3

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	Half thickness = 0.35 ± 0.11 mm	Values of half thickness for each graph Average value Thickness stated with uncertainty.	1 1 1		
(e)	The energy of alpha particles emitted by a nucleus can vary		1	2	6.4.3
4(a)	Proton – Two up quarks and one down quark or uud Antiproton – Two up antiquarks and one down antiquark or $\overline{uud}$		1 1	1	6.4.2
(b)	The charge on an up quark is +2/3, anti−up is −2/3, on down quark is −1/3, anti−down is +1/3 uud – total charge = +2/3 + +2/3 + −1/3 = +1 $\overline{uud}$ = −2/3 + −2/3 + +1/3 = −1	Charges on quarks 2 equations showing +1 and −1	1 1	2	6.4.2
(c)	Hadrons are subject to the strong and weak nuclear force, but leptons are only subject to the weak nuclear force.	Accept answer in terms of quark and fundamental particle composition	1	1	6.4.2
(d)	$uud + \overline{uud} \rightarrow u\bar{d} + d\bar{u} + u\bar{u}$ $u\bar{d}$ is a π^+ meson $d\bar{u}$ is a π^- meson	Evidence of quarks structure of products from p and anti−p q $\bar{q}$ match each particle	1 1 1	2	6.4.2
(e)	Quarks have a baryon number of +1/3, antiquarks −1/3 $u\bar{u}$ annihilate, total baryon number does not change because the total is zero.		1 1	2	6.4.2
(f)	The neutron is composed of quarks, udd, with charges +2/3, −1/3, −1/3, which add up to zero		1 1	1	6.4.2

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	The antineutron is composed of antiquarks $\overline{u}\overline{d}\overline{d}$, so the charge is −2/3, +1/3, +1/3, which still add up to zero				
5(a)	$\lambda = \ln 2/t_{1/2} = 0.693/1.3\times10^9 \times 3.16\times10^7 = 1.69\times10^{-17}\ s^{-1}$ $A = \lambda N,\ N = A/\lambda$ $N = 0.48/1.69\times10^{-17}\ s^{-1}$ $= 2.84\times10^{16}$ atoms Mass = $40 \times 2.84\times10^{16} / 6.02\times10^{23}$ $= 1.89\times10^{-6}$ g, 1.89 μg	Calculation of decay constant Use of $A = \lambda N$ Answer	1 1 1	2	6.4.3
(b)	$N = N_0 e^{-\lambda t}$ $t = 3.2\times10^9 \times 3.16\times10^7 = 1.01\times10^{17}$ s $N_0 = \frac{N}{e^{-\lambda t}} = \frac{2.79\times10^{16}}{e^{-1.69\times10^{-17}\times1.01\times10^{17}}}$ $= 1.51\times10^{17}$ atoms when the rock formed Atoms of argon = $1.51\times10^{17} - 2.79\times10^{16} = 1.23\times10^{17}$ atoms of argon Mass = $40 \times 1.23\times10^{17} / 6.02\times10^{23}$ $= 8.18\times10^{-6}$g Assuming all the potassium decayed to argon Assuming no argon was lost from the rock	Use of equation to find original number of atoms Subtraction to find atoms of argon and answer One assumption	1 1 1	2	6.4.3
(c)	If the potassium did not all decay to argon there would be less argon that anticipated, and the sample would be deemed to be younger than it actually is	Reasoning for younger	1	3	6.4.3
(d)	If only 0.00535 has decayed that means that the fraction remaining is 1−0.0000535 = 0.999947	Fraction that has decayed Correct use of equation	1 1	3	6.4.3

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	$N = N_0 e^{-\lambda t}$ $t = -\ln\left(\frac{N}{N_0}\right) \times \frac{1}{\lambda}$ $= \ln(0.999947) \times \frac{1}{1.69 \times 10^{-17}}$ $= 3.14\times10^{12}$ s = 99 246 years ~ 100 000 years	Answer	1		
6(a)	The difference is a measure of the energy needed to separate the nucleons that are bound as a result of the strong nuclear force. Deuterium nucleus contains one proton and one neutron $m_{proton} = 1.673\times10^{-17}$ kg $m_{neutron} = 1.675\times10^{-17}$ kg $m_{proton} + m_{neutron} = 3.348\times10^{-17}$ kg mdeuterium = 2.013553 × 1.661×10^{-27} kg = 3.3445×10^{-17} kg Mass difference = 3.5×10^{-30} kg	Must mention strong nuclear force. Use of data Correct calculation of mass difference	1 1 1	2	6.4.4
(b)	Binding energy = mc^2 $= 3.5\times10^{-30} \times (3.00\times10^8)^2$ $= 3.15\times10^{-13}$ J $= 3.15\times10^{-13}/1.6\times10^{-13}$ =1.97 MeV	e.c.f. Answer in J Answer in MeV	 1 1	2	6.4.4
(c)	The binding energy is 3 and 4 times bigger The tritium nucleus has an additional neutron which is attracted to both the other two particles in the nucleus		1 1	3	6.4.4
(d)	The tritium contains one proton and two neutrons, whereas the helium−3 contains one neutron and two protons	Comparison of the nuclei in terms of protons and neutrons	1	3	6.4.4

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	The strong nuclear force is charge independent, so the energy required to separate the nucleons is the same in each nucleus The two protons in the helium−3 nucleus repel each other, so the energy needed to separate them is smaller	Recognition that effect of strong nuclear force is the same Use of Coulomb repulsion	1 1		
(e)	The current is in the direction of the motion of the nuclei Use the direction of the current, the direction of the magnetic field and Fleming's Left Hand Rule to deduce the direction		1 1	1	6.3.1
(f)	$F = Bqv = 3.1 \times 1.6\times10^{-19}$ C $\times 2.1\times10^{6}$ $= 1.04\times10^{-12}$ N $a = F/m = 1.04\times10^{-12}$ N$/3.3445\times10^{-27}$ $= 3.11\times10^{14}$ m s^{-2} $s = ut + \frac{1}{2}at^2 = 0.5 \times 3.11\times10^{14}$ m s$^{-2} \times (24 \times 10^{-9})^2$ $= 0.18$ m		1 1 1	3	6.3.2 3.1.2
7(a)	Alpha particles are absorbed by the skin/would not get through body tissue to be detected outside the body		1	3	6.4.3
(b)	${}^{210}_{86}\text{Ra} \rightarrow {}^{206}_{84}\text{Po} + {}^{4}_{2}\alpha$	Correct symbol for α Correct A and Z in equation	1 1	2	6.4.3
(c)	In alpha decay the neutron number decreases by 2 and the proton number decreases by 2. There are 86 protons in radon−210, and 84 protons in polonium−206 There are 124 neutrons in radon−210, and 122 neutrons in polonium−206 The arrow goes from (86, 124) to (84, 122)	Explanation of what happens in alpha decay Changes to N and Z Description of arrow	1 1 1	2	6.4.3

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	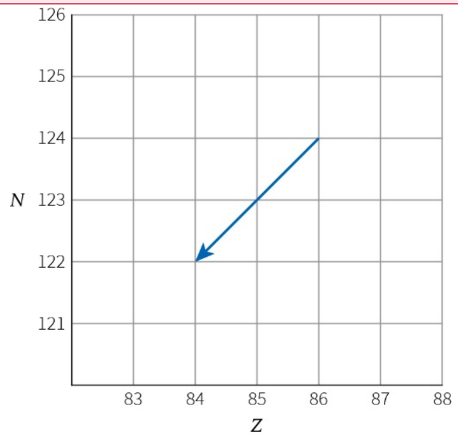	Correct arrow on diagram	1		
(d)	Alpha particle: A = 4, $R = 1.25 \times 10^{-15} \times 4^{\frac{1}{3}}$ $= 1.9(3) \times 10^{-15}$ m Radon: A = 210, $R = 1.25 \times 10^{-15} \times 210^{\frac{1}{3}}$ $= 7.3(9) \times 10^{-15}$ m Despite having a mass that is over 50 times larger, the radon nucleus is less than 4 times larger in terms of radius	Calculations of radii – both correct for the mark Suitable comment	1 1	2	6.4.1
(e)	Assuming $E = ½\, mv^2$ $v = \sqrt{\frac{2E}{m}} = \sqrt{\frac{2 \times 6.4 \times 1.6 \times 10^{-13}}{4 \times 1.661 \times 10^{-27}}}$ $= \sqrt{3.08 \times 10^{14}} = 1.76 \times 10^{7}\,\text{m s}^{-1}$		1 1	2	3.3.2
(f)	Conservation of momentum	Conservation of momentum (explicit or implied)	1	3	3.5.1

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	$0\ \text{kg m s}^{-1} = m_\alpha v_\alpha + m_{Po} v_{Po}$ $v_{Po} = \frac{-m_\alpha v_\alpha}{m_{Po}} = \frac{-4 \times 1.76 \times 10^7\ \text{m s}^{-1}}{206} = -3.4(2) \times 10^5\ \text{m s}^{-1}$	ECF	1		
(g)	The strong nuclear force will act between the constituent parts of the alpha particle and the nucleus/an external force acts		1	3	6.4.1
8(a)	Induced fission requires the absorption of a thermal/slow−moving neutron but spontaneous fission does not		1	1	6.4.4
(b)	Atomic mass increases by one – 239 Atomic number increases by 2 – 94		1 1	2	6.4.3
(c)	One from: Plutonium has a higher probability of fission, so less fuel would be needed to produce the same energy as the energy per fission is about the same The half−life is less so would become less radioactive more quickly There are fewer spontaneous fissions per kilogram, so is less chance of the mass going critical/exploding		1	3	6.4.4
(d)	$\lambda = \ln 2/t_{1/2} = 0.693/87.7 \times 3.16 \times 10^7 = 2.5\times10^{-10}\ \text{s}^{-1}$ One gram of plutonium contains $6 \times 10^{23}/238 = 2.53 \times 10^{21}$ plutonium atoms $A = -\lambda N = 2.5\times10^{-10}\ \text{s}^{-1} \times 2.53 \times 10^{21} = 6.33\times10^{11}$ Bq Energy per second per gram = 6.33×10^{11} Bq × 8.96×10^{-13} J = 0.59 W g^{-1}	Calculation of λ Calculation of activity Answer	1 1 1	3	6.4.3
(e)	Suggestion such as: Electrons are moving faster at one end of the wire, and move towards the lower temperature end and moving charge = current		1	2	4.1.2
(f)	Plutonium−238 decays by alpha decay and it is easy to shield the patient from the radiation using a thin sheet of metal		1	3	6.4.3

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(g)	Power = VI = 1.5 V × 2×10^{-3} A = 3×10^{-3} W Power density = 0.57 W g^{-1} Mass required = 3×10^{-3} / 0.57 W = 5×10^{-3} g Reason – only pulses produced/continuous supply not needed	Power required Answer Reason	1 1 1	4	4.2.5