Question			Answer	Marks	Guidance
1	(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)	$^{40}_{20}\text{Ca}$ $^{0}_{-1}\text{e} + \bar{\nu}_{(e)}$ 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 $\lambda = 1.65 \times 10^{-17}$ s^{-1} or $N = 8.127 \times 10^{17}$ **Note**: Answer to 3 sf is 13.4 (Bq) **Note**: 1.3×10^3 (Bq) scores 2 marks; division by 100 omitted
			Total	**9**	

Question			Answer	Marks	Guidance
2	**(a)**		Observations: 1. Most of the alpha particles went straight / un-deflected through (the atom(s) / foil) (AW) 2. (Some of the) alpha particles were scattered / repelled / deflected through large angles (AW) Conclusions (QWC mark): • 1 showed that most of the atom is empty space **and** • 2 showed the existence of small / dense / positive nucleus	M1 M1 A1	**Not** 'reflected' **Allow**: The QWC mark even if 'alpha reflected at large angles' is mentioned in 2
	(b)	**(i)**	The aluminium nucleus has velocity / accelerates / moves to the right There is a repulsive force on the (aluminium) nucleus (to the right) / According to conservation of momentum the (aluminium) nucleus must move (to the right)	B1 B1	**Allow**: Moves away from the alpha particle
		(ii)	$8.0\times10^{6}\times1.6\times10^{-19}=\frac{1}{2}\times6.6\times10^{-27}\times v^{2}$ (Any subject) speed = 2.0×10^{7} (m s^{-1})	C1 A1	**Note**: Answer to 3 sf is 1.97×10^{7} (m s^{-1}) **Allow** 1 sf answer 2×10^{7} (m s^{-1})
		(iii)	Q = 13e or q = 2e or $F=\dfrac{Qq}{4\pi\varepsilon_0 r^2}$ $270=\dfrac{13\times1.6\times10^{-19}\times2\times1.6\times10^{-19}}{4\pi\times8.85\times10^{-12}\times r^{2}}$ (Any subject) distance = 4.7×10^{-15} (m)	C1 C1 A1	**Allow**: $F=k\dfrac{Qq}{r^2}$, where $k = 9\times10^{9}$ **Note**: No credit for using Q and q as 13 and 2

Question			Answer	Marks	Guidance
		(iv)	The strong force is <u>attractive</u> Correct explanation of size / direction of resultant force	M1 A1	**Allow**: The strong force is <u>repulsive</u> M1 Correct explanation of size / direction of resultant force A1
			Total	**12**	

Question			Answer	Marks	Guidance
3	**(a)**		The (minimum) energy needed to separate / remove all the nucleons / protons <u>and</u> neutrons (to infinity)	B1	**Allow**: The energy released when (stationary) nucleons combine to form the nucleus **Allow**: The (minimum) energy required to break the nucleus into its (separate) nucleons **Allow**: binding energy = mass <u>defect</u> × speed of light^2 **Allow**: 'Work (done)' in place of 'energy'
	(b)		BE per nucleon = $4.53 \times 10^{-12}/4$ BE per nucleon = 1.13×10^{-12} (J)	B1	**Allow** 2 sf answer of 1.1×10^{-12} (J)
	(c)		The helium nucleus has greater charge / The helium nucleus experience greater repulsive force Helium nuclei need to get <u>close</u> together (for the strong force to initiate fusion)	B1 B1	
	(d)		($\frac{1}{2} m v^2 = \frac{3}{2} kT$) $\frac{1}{2} \times 6.6 \times 10^{-27} \times v^2 = \frac{3}{2} \times 1.38 \times 10^{-23} \times 10^8$ speed = 7.9×10^5 (m s^{-1})	C1 A1	**Allow**: KE ≈ kT; this gives an answer of 6.47×10^5 (m s^{-1})
			Total	**6**	

Question			Answers	Marks	Guidance
4	(a)	(i)	One proton / (same) charge / (same) element <u>and</u> (same) chemical property / one electron	B1	**Allow** (same) number of protons. **Allow** (same) number of electrons.
		(ii)	mass of nucleus < (total) mass of nucleons	B1	
			Energy must be supplied to the nucleus to free the nucleons / energy released when nucleons combine (to form the nucleus).	B1	**Allow** nucleus has binding energy.
			$(\Delta)E = (\Delta)mc^2$ and $(\Delta)E$ is the (binding) energy and $(\Delta)m$ is the mass defect or the difference in mass.	B1	
	(b)	(i)	${}^{1}_{0}\text{n} \rightarrow {}^{1}_{1}\text{p} + {}^{0}_{-1}\text{e} + \bar{\nu}_{(\text{e})}$	B1,B1	**Allow** proton or ${}^{1}_{1}\text{H}$ or H^{+} or p <u>and</u> (electron) antineutrino.
		(ii)	(Average) time taken for half of the neutrons (in a sample) to decay.	B1	**Note**: Must have reference to 'half' and 'neutron<u>s</u>' **Allow** 'the time taken for the activity of neutron<u>s</u> to halve'.
	(c)	(i)	$F = \dfrac{1.6\times10^{-19}\times1.6\times10^{-19}}{4\pi\varepsilon_0\times(10^{-14})^2}$	C1	**Not** $Q = q = 1$
			force = 2.3 (N)	A1	
		(ii)	$E = 7.0\times10^{4}\times1.6\times10^{-19}$ (= 1.12×10^{-14} J)	C1	
			($E = \frac{3}{2}kT$); $7.0\times10^{4}\times1.6\times10^{-19} = \frac{3}{2}\times1.38\times10^{-23}\times T$	C1	**Allow** any subject. Also, allow $E \approx kT$ since it is an estimate.
			temperature = 5.4×10^{8} (K)	A1	**Allow** 1 sf answer.
		(iii)	Some nuclei will be travelling faster / have greater (kinetic) energy (to overcome electrostatic repulsion and hence cause fusion).	B1	**Allow** the pressures are high (enough to cause fusion). **Not** 'nuclei get close enough'.
		(iv)	($\Delta E = \Delta mc^2$); $18 \times 10^{6} \times 1.6 \times 10^{-19} = \Delta m \times (3.0 \times 10^{8})^2$	C1	**Allow** any subject
			change in mass = 3.2×10^{-29} (kg)	A1	**Allow** a maximum of 1 mark for 18MeV ± 70 keV.
		(v)	Helium (nucleus) has greater charge / more protons.	B1	
			The (electrostatic) <u>repulsive</u> force (between the deuterium and helium nuclei) is greater (hence smaller chance of fusion).	B1	Do **not** award this mark if 'helium nuclei are moving slower' is also given as the reason for smaller probability for fusion.
			Total	**17**	