

Total 40 marks.

Each marking point ends with ✓ and is worth one mark. Words in « » are not needed for the mark. A correct numerical answer with no working is awarded full marks unless the Notes say otherwise. ECF = error carried forward: award the mark if the candidate used their own wrong earlier answer correctly. Do not penalize errors in units or significant figures unless the Notes say so.

Question 1: Alpha particles and a gold foil

Part	Answers	Notes	Total
1(a)	most alpha particles passed through undeflected / with very small deflections ✓ a very small number were deflected through large angles «greater than 90°» ✓		2
1(b)	«most of» the mass of the atom is confined within a very small volume «the nucleus» ✓ «all» the positive charge is confined within this very small volume / electrons orbit the nucleus «far away» ✓	Accept “the atom is mostly empty space” for one mark.	2
1(c)	the electric force on the alpha particle is always small «because the charge is spread out / r is never small» ✓ a large deflection needs a very large force, so the charge must be concentrated in a tiny region ✓		2
1(d)	thin: each alpha particle is scattered by «at most» one nucleus / the alpha particles are not absorbed by the foil ✓ evacuated: the alpha particles are not stopped / scattered by air molecules ✓		2
1(e)	118 ✓		1

Question 2: Energy levels and spectra

Part	Answers	Notes	Total
2(a)	electrons/atoms make transitions from higher to lower energy levels, emitting a photon each time ✓ the energy levels are discrete, so the photon energies ($E = hf = hc/\lambda$) and the wavelengths have only certain values ✓		2
2(b)	$\Delta E = 5.6 \text{ «eV»} = 5.6 \times 1.60 \times 10^{-19} = 8.96 \times 10^{-19} \text{ «J»}$ ✓ $\lambda = hc/\Delta E = 2.2 \times 10^{-7} \text{ «m»}$ ✓		2
2(c)	6 ✓		1
2(d)	E_3 to E_2 «smallest gap, 1.2 eV» ✓ $\lambda = hc/(1.2 \times 1.60 \times 10^{-19}) = 1.0 \times 10^{-6} \text{ «m»}$ ✓		2

2(e)	photons whose energy equals the difference between two energy levels are absorbed ✓ electrons move to higher energy levels «are excited» ✓ the energy is re-emitted in all directions, so these wavelengths are missing / appear as dark lines in the transmitted light ✓		3
2(f)	photon: not absorbed, because no energy gap from E_0 is exactly 4.0 eV «gaps 3.4, 5.6, 6.8 eV» ✓ electron: gives 3.4 eV to the atom « $E_0 \rightarrow E_1$ » and leaves with 0.6 eV ✓		2

Question 3: (HL) Closest approach and the size of a nucleus

Part	Answers	Notes	Total
3(a)	$E_k = k(2e)(47e)/d$ «with $E_k = 5.5 \times 10^6 \times 1.60 \times 10^{-19}$ J» ✓ $d = 2.5 \times 10^{-14}$ «m» ✓	Award [1 max] if the alpha charge is taken as e.	2
3(b)	$R = 1.2 \times 10^{-15} \times 107^{1/3} = 5.7 \times 10^{-15}$ «m» ✓		1
3(c)	the closest approach is much larger than the nuclear radius «about 4 times» ✓ so the strong nuclear force does not act; only the electric force acts «as Rutherford assumed» ✓		2
3(d)	deviations start when the nuclei touch: $d = 5.7 + 1.9 = 7.6 \times 10^{-15}$ «m» ✓ $E = k(2e)(47e)/d = 2.8 \times 10^{-12}$ «J» ≈ 18 «MeV» ✓	Allow ECF from (b). Accept 15–20 MeV.	2
3(e)	mass $\approx Au$ and volume $= (4/3)\pi R^3 = (4/3)\pi R_0^3 A$ ✓ $\rho = 3u/(4\pi R_0^3)$: A cancels, so ρ is the same for all nuclei ✓		2
3(f)	higher energy: the larger charge repels the alpha particles more, so more energy is needed to reach the nucleus ✓		1

Question 4: (HL) The Bohr model of hydrogen

Part	Answers	Notes	Total
4(a)	an orbiting electron accelerates «centripetally», so «by classical physics» it radiates energy ✓ it would therefore spiral into the nucleus / atoms would be unstable ✓ the only orbits where electrons do not radiate are those with $mvr = nh/2\pi$ ✓ so the electrons have discrete energy levels ✓	Award [3 max] for any three points.	3

4(b)	$ke^2/r^2 = mv^2/r$, so $mv^2 = ke^2/r$ ✓ $v = nh/(2\pi mr)$ substituted: $m n^2 h^2 / (4\pi^2 m^2 r^2) = ke^2/r$, giving the result ✓	Do not award MP2 for a bald statement of the answer: some working (cancellation of m or r) must be shown.	2
4(c)	$r = 4 \times 5.3 \times 10^{-11} = 2.1 \times 10^{-10}$ «m» ✓		1
4(d)	$\Delta E = 13.6(1/4 - 1/9) = 1.89$ «eV» = 3.02×10^{-19} «J» ✓ $\lambda = hc/\Delta E = 6.6 \times 10^{-7}$ «m» ✓		2
4(e)	it works only for atoms with one electron / it does not explain why the condition holds / it cannot explain the intensities of the lines ✓		1