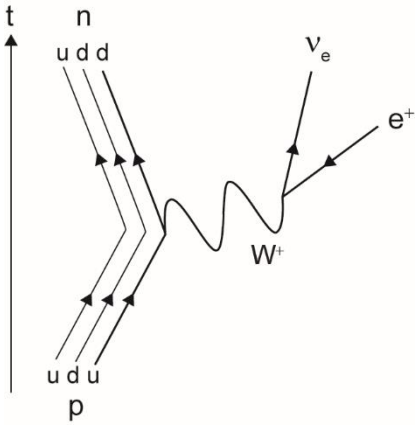
| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| **2.** | **a** | **i** | read off between 17 and 19 **«**deg**»** ✓<br>correct use of $d = \frac{\lambda}{sin\theta} = 7.8 \times 10^{-15}$ **«**m**»** ✓<br>so radius $= \frac{7.8}{2}$ **«**fm**»** $= 3.9$ **«**fm**»** ✓ | *Award ecf for wrong angle in MP1.*<br>*Answer for MP3 must show at least 2 sf.* | **3** |
| **2.** | **a** | **ii** | $R_{Th} = R_{Si}(\frac{A_{Th}}{A_{Si}})^{\frac{1}{3}}$ or substitution ✓<br>7.4 **«**fm**»** ✓ | | **2** |
| **2.** | **a** | **iii** | electron wavelength shorter than alpha particles (thus increased resolution)<br>***OR***<br>electron is not subject to strong nuclear force ✓ | | **1** |
| **2.** | **a** | **iv** | nuclear forces act ✓<br>nuclear recoil occurs ✓<br>significant penetration into nucleus / probing internal structure of individual nucleons ✓<br>incident particles are relativistic ✓ | | **2 max** |

*(continued…)*

*(Question 2 continued)*

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| **2.** | **b** | **i** | ${}^{30}_{15}\text{P} \rightarrow \left({}^{30}_{14}\text{Si}\right)$ ✓<br>$+{}^{0}_{+1}\text{e} + \nu_e$ ✓ | | **2** |
| **2.** | **b** | **ii** |  <br><br>correct change of either u to d ✓<br>$W^+$ shown ✓<br>correct arrow directions for positron and electron neutrino ✓ | | **3** |
| **2.** | **b** | **iii** | quarks cannot be directly observed as free particles/must remain bound to other quarks/quarks cannot be isolated ✓<br>because energy given to nucleon creates other particles rather than freeing quarks/***OWTTE*** ✓ | | **2** |

*(continued…)*

*(Question 2 continued)*

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| **2.** | **c** | | models need testing/new information may change models/new technology may bring new information/Models can be revised/***OWTTE*** ✓ | | **1** |

| | | | | | |
|---|---|---|---|---|---|
| **3.** | **a** | | two waves superpose/mention of superposition/mention of **«**constructive**»** interference ✓<br>they arrive in phase/there is a path length difference of an integer number of wavelengths ✓ | | **2** |
| **3.** | **b** | | path difference = 0.062 **«**m**»**✓<br>so wavelength = 0.031 **«**m**»**✓<br>frequency = $9.7 \times 10^9$ **«**Hz**»**✓ | *Award **[2 max]** for $4.8 \times 10^9$ Hz.* | **3** |
| **3.** | **c** | | intensity is modulated by a single slit diffraction envelope ***OR*** intensity varies with distance ***OR*** points are different distances from the slits ✓ | | **1** |

*(continued…)*

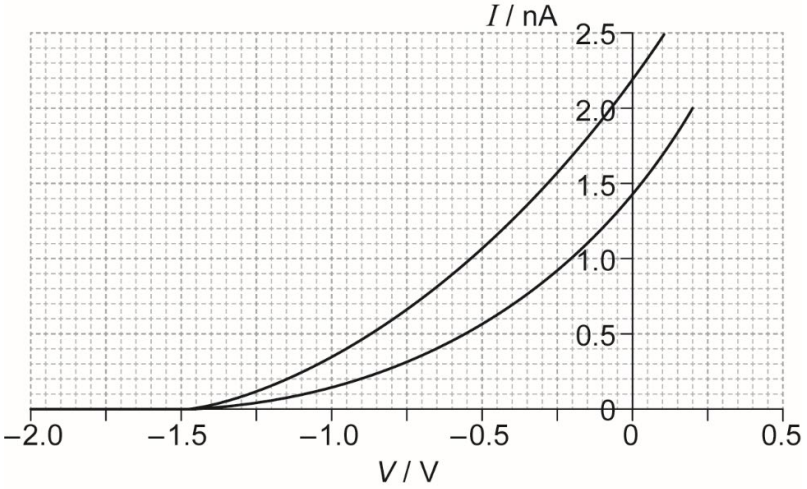
*(Question 8 continued)*

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| **8.** | **b** | **i** | with $n = 3$, $v = \text{«}\sqrt{\frac{2\times 8.99\times 10^{9}\times(1.6\times 10^{-19})^{2}}{9.11\times 10^{-31}\times 9\times 2.7\times 10^{-11}}} = \text{»}\ 1.44\times 10^{6}\ \text{«m s}^{-1}\text{»}$ ✓<br><br>$\lambda = \frac{6.63\times 10^{-34}}{9.11\times 10^{-31}\times 1.44\times 10^{6}}$ ***OR*** $\lambda = 5.05\times 10^{-10}\ \text{«m»}$ ✓ | | **2** |
| **8.** | **b** | **ii** | $\frac{2\pi r}{\lambda} = \text{«}\frac{2\pi\times 9\times 2.7\times 10^{-11}}{5.1\times 10^{-10}} = 2.99\text{»} \cong 3$ ✓ | *Allow ECF from (b)(i)* | **1** |
| **8.** | **c** | | reference to fixed orbits/specific radii ***OR*** quantized angular momentum in Bohr model ✓<br>electron described by a wavefunction/as a wave in Schrödinger model ***OR*** as particle in Bohr model ✓<br>reference to **«**same**»** energy levels in both models ✓<br>reference to **«**relationship between wavefunction and**»** probability **«**of finding an electron in a point**»** in Schrödinger model ✓ | | **3 max** |

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| 11. | a | i | «low intensity light would» transfer energy to the electron at a low rate/slowly ✓<br>time would be required for the electron «to absorb the required energy» to escape/be emitted ✓ | *OWTTE* | **2** |
| 11. | a | ii | «in the photon theory of light» the electron interacts with a single photon ✓<br>and absorbs all the energy ***OR*** and can leave the metal immediately ✓ | *Reference to photon-electron collision scores MP1* | **2** |
| 11. | b | i | $\phi = \frac{hc}{\lambda} - E_{\text{K}}$ ✓<br>$E_{\text{K}} = 1.5$ «eV» ✓<br>$\phi =$ «$\frac{1.24 \times 10^{-6}}{480 \times 10^{-9}} - 1.5 =$» 1.1 «eV» ✓ | *Allow reading from the graph of $E_k$=1.4 leading to an answer of 1.2 «eV».* | **3** |

*(continued…)*

*(Question 11 continued)*

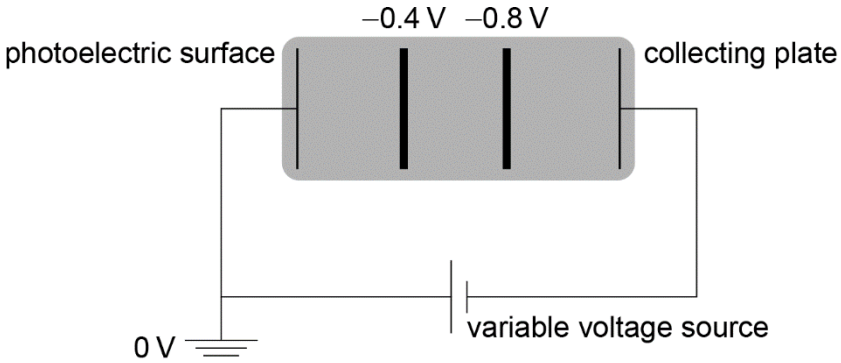
| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| **11.** | **b** | **ii** | similar curve lower than original ✓<br>with same horizontal intercept ✓<br>  | | **2** |

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| **11.** | **a** | | «de Broglie's hypothesis states that the» electron is represented by a wave ✓<br>therefore it cannot be localized/it is spread out/it does not have a definite position ✓ | *Award MP1 for any mention of wavelike property of an electron.* | **2** |
| **11.** | **b** | **i** | «$d\sin\theta = \lambda \Rightarrow$» $d = \frac{1.6\times10^{-15}}{\sin17^{\circ}} / 5.47\times10^{-15}$ «m» ✓<br>$R = \frac{d}{2} \approx 2.7 / 2.8\times10^{-15}$ «m» ✓ | | **2** |
| **11.** | **b** | **ii** | this implies that the nucleons are very tightly packed/that there is very little space in between the nucleons ✓<br>because the nuclear force is stronger than the electrostatic force ✓ | | **2** |
| **11.** | **c** | **i** | number of nuclei is $\frac{28\times10^{-3}}{64}\times6.02\times10^{23} / 2.63\times10^{20}$ ✓<br>$A =$ «$\lambda N = 2.63\times10^{20}\times\frac{5.5\times10^{-2}}{3600}$» $= 4.0\times10^{15}$ «Bq» ✓ | | **2** |
| **11.** | **c** | **ii** | $\frac{1}{3} = e^{-\lambda t}$ ✓<br>$t = 20$ «hr» ✓ | | **2** |

| | | | | | |
|---|---|---|---|---|---|
| **8.** | **a** | | $E_1 = -13.6$ **«**eV**»** $E_2 = -\frac{13.6}{4} = -3.4$ **«**eV**»** ✓<br>energy of photon is difference $E_2 - E_1 = 10.2$ **«**$\approx 10$ eV**»** ✓ | *Must see at least 10.2 eV.* | **2** |
| **8.** | **b** | **i** | $10 - 5.1 = 4.9$ **«**eV**»** ✓<br>$4.9 \times 1.6 \times 10^{-19} = 7.8 \times 10^{-19}$ **«**J**»** ✓ | *Allow* 5.1 *if* 10.2 *is used to give* $8.2 \times 10^{-19}$ **«**J**»**. | **2** |
| **8.** | **b** | **ii** | EPE produced by battery ✓<br>exceeds maximum KE of electrons / electrons don't have enough KE ✓ | *For first mark, accept explanation in terms of electric potential energy difference of electrons between surface and plate.* | **2** |
| **8.** | **b** | **iii** | $4.9$ **«**V**»** ✓ | *Allow 5.1 if 10.2 is used in (b)(i).*<br>*Ignore sign on answer.* | **1** |

*(continued…)*

*(Question 8 continued)*

| | | | | | |
|---|---|---|---|---|---|
| **8.** | **c** | **i** | two equally spaced vertical lines (judge by eye) at approximately 1/3 and 2/3✓<br>labelled correctly ✓<br>  | | **2** |
| **8.** | **c** | **ii** | kinetic energy at collecting plate $= 0.9$ «eV» ✓<br>speed $= \text{«}\sqrt{\frac{2\times 0.9\times 1.6\times 10^{-19}}{9.11\times 10^{-31}}}\text{»} = 5.6\times 10^{5}$ «$\text{ms}^{-1}$» ✓ | *Allow ECF from MP1* | **2** |

*(Question 8 continued)*

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| **8.** | **d** | | the base of the thundercloud must be parallel to the Earth surface<br>***OR***<br>the base of the thundercloud must be flat<br>***OR***<br>the base of the cloud must be very long **«**compared with the distance from the surface**»** ✓ | | **1** |

| | | | | | |
|---|---|---|---|---|---|
| **9.** | **a** | | **«**most of**»** the mass of the atom is confined within a very small volume/nucleus ✓<br>**«**all**»** the positive charge is confined within a very small volume/nucleus ✓<br>electrons orbit the nucleus **«**in circular orbits**»** ✓ | | **2 max** |
| **9.** | **b** | | the electrons accelerate and so radiate energy ✓<br>they would therefore spiral into the nucleus/atoms would be unstable ✓<br>electrons have discrete/only certain energy levels ✓<br>the only orbits where electrons do not radiate are those that satisfy the Bohr condition **«**$mvr = n\frac{h}{2\pi}$**»** ✓ | | **3 max** |

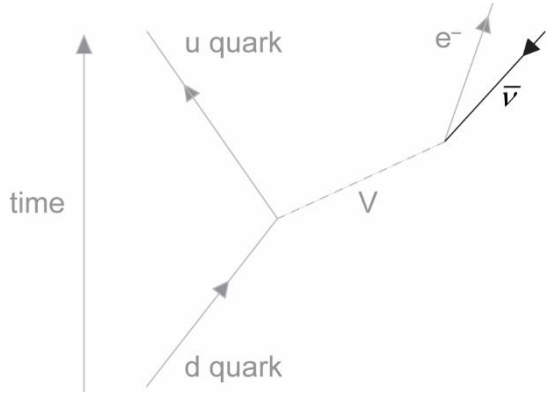
*(continued…)*

*(Question 9 continued)*

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| **9.** | **c** | **i** | $\frac{m_e v^2}{r} = \frac{ke^2}{r^2}$<br>***OR***<br>$\text{KE} = \frac{1}{2}\text{PE}$ hence $\frac{1}{2}m_e v^2 = \frac{1}{2}\frac{ke^2}{r}$ ✓<br>**«**solving for $v$ to get answer**»** | *Answer given – look for correct working* | **1** |
| **9.** | **c** | **ii** | combining $v = \sqrt{\frac{ke^2}{m_e r}}$ with $m_e vr = \frac{h}{2\pi}$ using correct substitution ✓<br>**«***eg* $m_e{}^2 \frac{ke^2}{m_e r}\ r^2 = \frac{h^2}{4\pi^2}$**»**<br>correct algebraic manipulation to gain the answer ✓ | *Answer given – look for correct working*<br>*Do not allow a bald statement of the answer for MP2. Some further working eg cancellation of m or r must be shown* | **2** |
| **9.** | **c** | **iii** | **«**$r = \frac{(6.63\times10^{-34})^2}{4\pi^2\times8.99\times10^9\times9.11\times10^{-31}\times(1.6\times10^{-19})^2}$**»**<br>$r = 5.3\times10^{-11}$ **«**m**»** ✓ | | **1** |
| **9.** | **d** | **i** | the energy released is $3.54 - 0.48 = 3.06$ **«**MeV**»** ✓<br>this is shared by the electron and the antineutrino ✓<br>so the electron's energy varies from 0 to 3.06 **«**MeV**»** ✓ | | **3** |
| **9.** | **d** | **ii** | the palladium nucleus emits the photon when it decays into the ground state **«**from the excited state**»** ✓ | | **1** |

*(continued…)*

*(Question 9 continued)*

| Question | | | Answers | Notes | Total |
|---|---|---|---|---|---|
| **9.** | **d** | **iii** | Photon energy<br>$E = 0.48 \times 10^{6} \times 1.6 \times 10^{-19} = «7.68 \times 10^{-14} J»$ ✓<br>$\lambda = « \frac{hc}{E} = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{7.68 \times 10^{-14}} = » 2.6 \times 10^{-12}$ «m» ✓ | *Award **[2]** for a bald correct answer*<br>*Allow ECF from incorrect energy* | **2** |
| **9.** | **e** | **i** | line <u>with arrow</u> as shown labelled anti-neutrino/$\bar{\nu}$ ✓ | *Correct direction of the "arrow" is essential*<br>*The line drawn must be "upwards" from the vertex in the time direction i.e. above the horizontal*<br>*eg*:<br>  | **1** |
| **9.** | **e** | **ii** | $V = W^{-}$ ✓ | | **1** |