# Mark scheme for Topic 13

**1** **a** The graph on the left.

because the stopping voltage is less. **[2]**

**b** Because the saturation current is the same.

The saturation current is proportional to the total number of electrons emitted and this number is in turn proportional to the flux density of the photons. **[2]**

**c** Intensity is power per unit area and so equals $I = \Phi hf$, where $\Phi$ is the number of photons per second per unit area.

Hence intensity is largest for graph to the right. **[2]**

**d** **i** It takes a different amount of energy to eject an electron depending on where in the metal the electron is/the work function gives the minimum energy required to eject an electron.

And hence there is a range of energies of the emitted electrons. **[2]**

**ii** $\frac{1}{2}mv^2 = hf - \phi \Rightarrow \phi = \frac{hc}{\lambda} - \frac{1}{2}mv^2$

$\phi = \frac{6.63\times10^{-34}\times3\times10^{8}}{4.86\times10^{-7}} - \frac{1}{2}\times9.1\times10^{-31}\times(3.5\times10^{5})^2 = 3.5\times10^{-19}\text{ J} = 2.2\text{ eV}.$ **[2]**

**2** **a** All particles show wavelike behaviour.

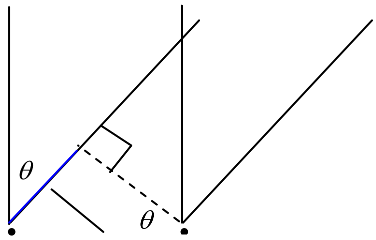
With a wavelength that equals the Planck constant divided by the momentum of the particle. **[2]**

Exam tip: If you use a formula, define the symbols that appear.

**b** $E_K = qV = \frac{p^2}{2m} \Rightarrow p = \sqrt{2mqV} = \sqrt{2\times9.1\times10^{-31}\times1.6\times10^{-19}\times95} = 5.26\times10^{-24}\text{ N s}$

$\lambda = \frac{h}{p} = \frac{6.63\times10^{-34}}{5.26\times10^{-24}} = 1.26\times10^{-10} \approx 1.3\times10^{-10}\text{ m}.$ **[2]**

**c** **i**




**[1]**

**ii** The distance in blue is opposite the angle $\theta$ .

And so from trigonometry equals $d\sin\theta$ . **[1]**

**iii** Strong scattered beam indicates constructive interference.

And so $d\sin\theta=\lambda$.

Hence $\lambda=1.58\times10^{-10}\times\sin 52.9^{\circ}=1.26\times10^{-10}$ m.

In agreement with what is predicted for the wavelength of the electron by de Broglie. **[4]**

Exam tip: You must make a comment like the fourth marking point.

**3** **a** The energies of alpha and gamma particles in radioactive decay are discrete,

indicating that they originate as differences of discrete energy levels. **[2]**

**b** $Q=13.4-4.4=9.0$ MeV **[1]**

**c** **i** With only two particles produced, the energy of each would be a fixed fraction (of the available 9.0 MeV).

With three particles produced the energy of each would depend on the direction each particle moves along.

And so would be variable, just as experiments show. So a third particle must be produced.

**[3]**

**ii** ${}^{12}_{5}\mathrm{B}\rightarrow{}^{12}_{6}\mathrm{C}+{}^{0}_{-1}\mathrm{e}+\bar{\nu}$ . **[1]**

**d** $\frac{hc}{\lambda} = \Delta E = 4.4 \text{ MeV}$

$$\lambda = \frac{hc}{\Delta E} = \frac{6.63\times10^{-34}\times3\times10^{8}}{4.4\times10^{6}\times1.6\times10^{-19}} = 2.8\times10^{-13}\text{ m}$$ **[2]**

**4** **a** The product of the uncertainty in position and the uncertainty in momentum is never less than Planck's constant divided by $4\pi$. **[1]**

**b** **i** $\Delta x \approx 2.9\times10^{-15}\text{ m}$ (accept half this value as well),

and so $\Delta p \geq \frac{h}{4\pi\Delta x} = \frac{6.63\times10^{-34}}{4\pi\times2.9\times10^{-15}} = 1.8\times10^{-20}\text{ N s}$ (accept also double this answer) **[2]**

**ii** From the binding energy curve, the binding energy of carbon 14 is approximately $14\times7.5 = 105\text{ MeV}$.

An electron with a kinetic energy of 100 MeV moving inside the nucleus would therefore rip the nucleus apart. **[2]**

**c** The uncertainty in the position of the electron is of order $\Delta x \approx L$

Hence $\Delta p \geq \frac{h}{4\pi\Delta x} = \frac{h}{4\pi L}$.

The minimum kinetic energy of the electron is therefore $E_{\min} = \frac{\Delta p^2}{2m} = \frac{h^2}{32\pi^2 mL^2}$, i.e. non-zero and of the same order of magnitude as the energy predicted by the electron in the box model. **[3]**

**5** **a** **i** $E_P = \frac{kq^2}{r} = \frac{8.99\times10^{9}\times(1.6\times10^{-19})^2}{2.0\times10^{-15}}$

$E_P = 1.151\times10^{-13} \approx 1.2\times10^{-13}\text{ J}$. **[2]**

**ii** $E_K + E_K = E_P \Rightarrow E_K = \frac{1}{2}E_P = 5.6\times10^{-14}\text{ J}$. **[1]**

**b** **i** $2.1\times10^{-23}T = 5.8\times10^{-14} \Rightarrow T = 2.8\times10^{9}\text{ K}$. **[1]**

**ii** The hydrogen nuclei have a range of kinetic energies.

Even at lower temperatures there are nuclei with sufficiently high kinetic energy to initiate fusion. **[2]**

**c** The energy released is the difference in the binding energies to the right of the reaction minus the binding energies to the left of the reaction.

The binding energy to the right is $2 \times 1.1 = 2.2$ MeV.

All the other particles have zero binding energy and so the energy released is 2.2 MeV. **[3]**

Exam tip: Particles that have no constituents have **zero** binding energy.

**6 a** The probability per unit time that a particular nucleus will decay. **[1]**

Exam tip: You can also define it in terms of the formula for activity.

**b** $A = A_0 e^{-\lambda t}$ and $A = \frac{A_0}{2}$ when $t = T_{1/2}$ leading to $\frac{A_0}{2} = A_0 e^{-\lambda T_{1/2}}$

Cancelling $A_0$ and taking logs gives the result

$\ln 2 = \lambda T_{1/2}$ . **[2]**

**c i** Argon being a gas would escape from the liquid lava. **[1]**

**ii** Number of K-40 atoms after time *t* is $N = N_0 e^{-\lambda t}$ and number of Ar-40 atoms after time *t* is $N = N_0(1 - e^{-\lambda t})$;

Exam tip: The atoms of potassium that decay become nuclei of argon.

and so $\frac{N_0(1-e^{-\lambda t})}{N_0 e^{-\lambda t}} = 0.15$;

$e^{\lambda t} = 1.15$

$t = \frac{\ln(1.15)}{\lambda} = \frac{\ln(1.15)}{\ln 2} \times 1.28 \times 10^9 = 2.6 \times 10^8$ y. **[4]**