Answers to exam-style questions

Topic 12

Where appropriate, 1 ✓ = 1 mark

1 D

2 C

3 C

4 D

5 B

6 B

7 B

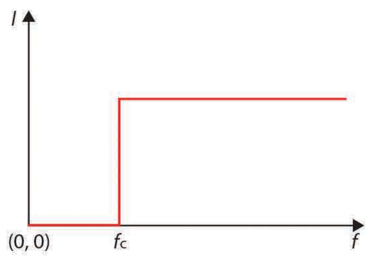
8 A

9 B

10 B

11 a i Photons are the massless particles of light. ✓
Whose energy is given by $E = hf$ where f is the frequency of light and h is Planck's constant. ✓

ii Straight line ✓
Horizontal ✓



iii The photocurrent is the rate of emission of electrons from the photosurface times the electron's charge, $I = eR$ as long as $f > f_c$. ✓
And this is independent of photon frequency or the electron speed. ✓

b i *One of*:
Emission without delay. ✓
Electron energy increases with photon frequency. ✓
Existence of a critical frequency below which no electrons are emitted. ✓

ii *Using the first feature*:
With very weak electromagnetic waves incident on the surface an electron would have to accumulate energy slowly and so would take a long time to leave the metal. ✓
In the photon model of light an electron absorbs all the energy of the photon at once and so there is no delay. ✓
Using the second feature:
The energy of electromagnetic waves does not depend on frequency. ✓
But the energy of a photon increases with frequency. ✓
Using the third feature:
The energy of electromagnetic waves does not depend on frequency. ✓
But the energy of a photon does and if the frequency is low the supplied energy cannot overcome the work function so no electrons are emitted. ✓

c **i** Extending the graph to the vertical intercept gives –3.4 V. ✓
So the work function is 3.4 eV. ✓

ii From $E = hf - \phi$ and $E = eV$ we have that $V = \frac{h}{e}f - \frac{\phi}{e}$ and so the gradient of the graph is the Planck constant divided by e. ✓

The gradient is $\frac{8.0 - 0}{3.0 \times 10^{15} - 0.90 \times 10^{15}} = 3.8 \times 10^{-15}\ \text{V Hz}^{-1}$. ✓

And so $h = 1.6 \times 10^{-19} \times 3.8 \times 10^{-15} = 6.1 \times 10^{-34}\ \text{C V Hz}^{-1} = 6.1 \times 10^{-34}\ \text{J s}$. ✓

iii The threshold frequency is 0.90×10^{15} Hz. ✓

And so the maximum wavelength is $\frac{3.0 \times 10^{8}}{0.90 \times 10^{15}} = 3.3 \times 10^{-7}$ m. ✓

d The energy of the emitted electrons does not depend on intensity. ✓
So the graph will not change. ✓

12 **a** The net force on the electron is the electric force of attraction between the electron and the proton i.e. $\frac{ke^2}{r^2}$. ✓

Equating this with the centripetal force $\frac{mv^2}{r}$ gives the answer. ✓

b The Bohr condition is that $mvr = n\frac{h}{2\pi}$. ✓

Squaring gives $m^2v^2r^2 = n^2\frac{h^2}{4\pi^2}$ and substituting the expression from the previous part leads to

$m^2\frac{ke^2}{mr}r^2 = n^2\frac{h^2}{4\pi^2}$. ✓

Simplifying gives $mke^2r = n^2\frac{h^2}{4\pi^2}$ and the answer. ✓

c The total energy of the electron is $E = \frac{1}{2}mv^2 - \frac{ke^2}{r}$. ✓

Substituting the value for the square of the speed in the first part again gives the answer. ✓

d It signifies that the electron is bound to the proton and cannot escape far away unless sufficient energy is provided to it. ✓

e From $\lambda = \frac{h}{p}$ we find $p = \frac{h}{\lambda}$ and so the Bohr condition becomes $\frac{h}{\lambda}r = n\frac{h}{2\pi}$. ✓

Simplifying gives the answer. ✓

f **i** An electron wave is a wave whose amplitude is related to the probability of finding the electron somewhere in space at a given time. ✓

ii The wave corresponds to $n = 4$. ✓

From **b**, $r = n^2\frac{h^2}{4\pi^2mke^2} = 4 \times \frac{(6.63 \times 10^{-34})^2}{4\pi^2 \times 9.11 \times 10^{-31} \times 8.99 \times 10^{9} \times (1.6 \times 10^{-19})^2}$. ✓

$r = 2.1 \times 10^{-10}$ m. ✓

iii The total energy from **c** is $E = -\frac{ke^2}{2r} = \frac{8.99 \times 10^{9} \times (1.6 \times 10^{-19})^2}{2 \times 2.1 \times 10^{-10}} = 5.5 \times 10^{-19}$ J and this, or more, is what must be supplied. ✓

g The probability wave associated with the electron implies that the electron is not an object that is localised at a particular point at a given time, ✓
but can be thought to be spread out through space like waves do. ✓
The Bohr orbit only gives the average position of the electron. ✓

13 **a** To every particle there corresponds a wave of probability. ✓
With a wavelength that is given by the Planck constant divided by the momentum of the particle. ✓

b **i** $qV = E_K = \frac{p^2}{2m}$ ✓

Hence $p = \sqrt{2mqV}$ and the result follows from $\lambda = \frac{h}{p}$. ✓

ii $\lambda = \frac{h}{\sqrt{2mqV}} = \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 9.11 \times 10^{-31} \times 1.6 \times 10^{-19} \times 120}} = 1.1 \times 10^{-10}$ m ✓

c In a Davisson–Germer type of experiment electrons that have been accelerated are directed at a crystal from which they diffract and interfere. ✓
From the interference pattern the wavelength may be determined. ✓
And this is consistent with the de Broglie formula. ✓

d The de Broglie wavelength of the bullet is $\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}}{0.080 \times 420} \approx 2 \times 10^{-35}$ m. ✓

For diffraction effects to be seen the wavelength must be comparable to the size of the hole. ✓
But 2×10^{-35} m << 5.0 cm. ✓
And so no diffraction will be observed. ✓

14 **a** Tunnelling is a quantum mechanical phenomenon in which particles can be transmitted through energy barriers. ✓
That would classically be impossible due to energy conservation. ✓

b **i** The width is about $2.8 \times 10^{-10} - 1.3 \times 10^{-10} = 1.5 \times 10^{-10}$ m. ✓

ii From the graph the de Broglie wavelength before and after is the same. ✓
And hence the ratio is 1. ✓

iii The wavefunction squared is proportional to the probability of finding a particle somewhere. ✓

And so the transmitted ratio is $\left(\frac{3}{20}\right)^2 \approx 2 \times 10^{-2}$. ✓

c Protons have a higher mass so fewer of them would get transmitted. ✓

15 **a** **i** The electron antineutrino. ✓

ii Electrically neutral. ✓
Very small non-zero mass. ✓

b If no third particle were present in the products of the beta decay the electron would always carry away a fixed proportion of the total energy released. ✓
But experiments show that this is not the case which means a third particle must be sharing in the energy. ✓

c When the tree dies it will no longer absorb C-14 from its surroundings. ✓
The amount of C-14 present when the tree died will then diminish with time because C-14 is unstable and decays into N-14. ✓

d We may ignore C-14 in this part of the calculation since its concentration is so small. ✓

So 15 g correspond to $\frac{15}{12} \times 6.02 \times 10^{23} = 7.525 \times 10^{23} \approx 7.5 \times 10^{23}$ atoms. ✓

e $A = \lambda \times N_{14}$ and so $N_{14} = \frac{A}{\lambda}$ with $\lambda = \frac{\ln 2}{5730 \times 365 \times 24 \times 3600} = 3.8359 \times 10^{-12}\ \text{s}^{-1}$. ✓

$N_{14} = \frac{A}{\lambda} = \frac{1.40}{3.8359 \times 10^{-12}} = 3.6498 \times 10^{11} \approx 3.6 \times 10^{11}$. ✓

Hence $\frac{N_{14}}{N_{12}} = \frac{3.6498 \times 10^{11}}{7.525 \times 10^{23}} = 4.85 \times 10^{-13}$. ✓

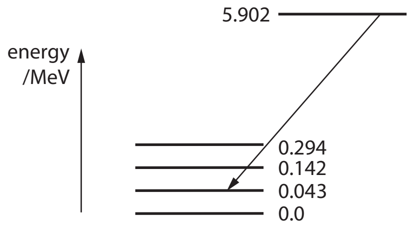
f $\dfrac{N_{14}}{N_{12}} = 4.85 \times 10^{-13} = 1.3 \times 10^{-12} e^{-\lambda t}$ so $e^{-\lambda t} = 0.3731$ ✓

$-\lambda t = \ln 0.3731 \Rightarrow t = -\dfrac{\ln 0.3731}{\lambda}$ ✓

$t = -\dfrac{\ln 0.3731}{3.8359 \times 10^{-12}} = 2.57 \times 10^{11}\ \text{s} \approx 8150$ year ✓

16 a Alpha particle and gamma ray energies in radioactive decay, ✓
are discrete. ✓

b i Correct transition selected. ✓



ii $5.902 - 0.043 = 5.86$ MeV ✓

c i The nuclear force has a short range. ✓
And is practically zero for distances larger than the nuclear radii. ✓

ii It must overcome an energy barrier of height 30 MeV and its total energy is less than this. ✓
Leaving the nucleus would violate energy conservation. ✓

iii Like all particles alpha particles have wavelike properties and are described by quantum mechanical wavefunctions. ✓
Which allow for the tunneling phenomenon in which the wavefunction leaks out into the classically forbidden region. ✓

d The half-life has to do with the tunneling probability, i.e. how long an alpha particle takes to leave the nucleus on the average. ✓
And this tunneling probability is very sensitive to small changes in alpha particle energies. ✓

e The uncertainty in position is of order $\Delta x \approx 10^{-15}$ m. ✓

Hence the uncertainty in momentum is $\Delta p \approx \dfrac{h}{4\pi \Delta x} \approx \dfrac{h}{4\pi \times 10^{-15}} = 5.3 \times 10^{-20}$ N s. ✓

17 a i $\sin\theta = \dfrac{\lambda}{b} \Rightarrow b = \dfrac{\lambda}{\sin\theta}$ ✓

$E_K = \dfrac{p^2}{2m} \Rightarrow p = \sqrt{2E_K m} = \sqrt{2 \times 54 \times 10^6 \times 1.6 \times 10^{-19} \times 1.67 \times 10^{-27}} = 1.7 \times 10^{-19}$ N s ✓

Hence $\lambda = \dfrac{6.63 \times 10^{-34}}{1.7 \times 10^{-19}} = 3.9 \times 10^{-15}$ m and then $b = \dfrac{3.9 \times 10^{-15}}{\sin 15°} = 1.5 \times 10^{-14}$ m. ✓

ii $m \approx A \times 1.661 \times 10^{-27}$ kg. ✓

$V = \dfrac{4\pi}{3}\left(1.2 \times 10^{-15} \times A^{\frac{1}{3}}\right)^3 = 7.24 \times 10^{-45} \times A\ \text{m}^3$. ✓

$\rho = \dfrac{m}{V} = \dfrac{1.661 \times 10^{-27} \times A}{7.24 \times 10^{-45} \times A} = 2.29 \times 10^{17} \approx 2 \times 10^{17}\ \text{kg m}^{-3}$. ✓

b $E = \dfrac{kQq}{d}$ ✓

$d = \dfrac{8.99 \times 10^9 \times 2 \times 82 \times 1.6 \times 10^{-19}}{5.2 \times 10^6}$. ✓

$d = 4.54 \times 10^{-14} \approx 4.5 \times 10^{-14}$ m ✓

c i The only force acting on the alpha particle is the electric force. ✓

ii A sharp decrease in the number of scattered particles at high energies. ✓
As the energy increases the alpha particles approach closer to the nucleus and so the nuclear force acts on them, the nucleus absorbs some thus reducing the number that is being scattered. ✓