7 Electrons and nuclei

Pages 127–130 Exam practice questions

1 Answer C [Total 1 mark]
2 Answer B [Total 1 mark]
3 Answer B [Total 1 mark]
4 Answer C [Total 1 mark]
5 Answer D [Total 1 mark]
6 Answer A [Total 1 mark]
7 Answer D [Total 1 mark]
8 Answer B [Total 1 mark]
9 a) Answer D [1]
b) Answer A [1]

[Total 2 marks]

10 Your diagram should look like the figure below, with appropriate labelling.

[Total 4 marks]

11

a) \[ \text{EPE} = \frac{\left(9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2}\right) \times \left(2 \times 1.6 \times 10^{-19} \text{ C}\right) \times \left(79 \times 1.6 \times 10^{-19} \text{ C}\right)}{5.0 \times 10^{-14} \text{ m}} \]
\[= 7.3 \times 10^{-13} \text{ J} \] [1]

b) \[ \text{EPE} = \frac{7.3 \times 10^{-13} \text{ J}}{1.6 \times 10^{-19} \text{ J eV}^{-1}} \]
\[= 4.6 \times 10^6 \text{ eV} = 4.6 \text{ MeV} \] [1]

From the principle of conservation of energy, \( \text{EPE} + \text{KE} = \text{constant} \) (here 4.6 MeV). [1]

As the alpha-particle approaches the gold nucleus, the electric field of the nucleus does work on the alpha-particle and slows it down. The KE of the alpha-particle is stored as \( \text{PE} \) in the field. At the point of closest approach, all the KE of the \( \alpha \)-particle will be stored as EPE and so the \( \alpha \)-particle will momentarily come to rest. [1]

As the ‘collision’ is elastic, no KE is lost and so all the EPE is converted back to KE and the \( \alpha \)-particle rebounds with the same KE as it had before the ‘collision’. [1]

[Total 6 marks]
12 The fraction is \[ \left( \frac{r_{\text{atom}}}{r_{\text{nucleus}}} \right)^3 = \left( \frac{10^{-10}}{10^{-14}} \right)^3 = 10^{12} \] [1]

13 The (inward) centripetal force of the proton on the electron is \[ F = \frac{k e e_p}{r^2} = m_e r^2 \omega^2 \] [1]

As \( e_e = e_p = e \),

\[ m_e r^2 \omega^2 = \frac{k e^2}{r^2} \Rightarrow \omega^2 = \frac{(2\pi f)^2}{m_e r^3} \]

\[ f^2 = \frac{k e^2}{4\pi^2 m_e r^3} \Rightarrow f = \frac{1}{2\pi} \sqrt{\frac{(9.0 \times 10^9 \text{ N} \text{ m}^{-2}) \times (1.6 \times 10^{-19} \text{ C})^2}{4\pi^2 \times (9.1 \times 10^{-31} \text{ kg}) \times (5.3 \times 10^{-11} \text{ m})^3}} \] [2]

\[ f = 6.6 \times 10^{15} \text{ Hz} \]

Such a frequency lies in the ultraviolet part of the spectrum. [1]

14 For speeds that are not too high, \( KE = E_k = \frac{1}{2} m v^2 \) [1]

Given that \( r = \frac{p}{Be} \Rightarrow p = Be r = mv \) [1]

From \( E_k = \frac{1}{2} m v^2 \Rightarrow 2mE_k = (mv)^2 = (Be r)^2 \) [1]

This gives \( E_k = \frac{B^2 e^2 r^2}{2m} \) [1]

\[ \Rightarrow E_k \propto r^2 \text{ provided } B, e \text{ and } m \text{ are constant.} \] [1]

15 The maximum field between the tubes is \[ E_{\text{max}} = \frac{V_{\text{max}}}{d} = \frac{200 \times 10^3 \text{ V}}{25 \times 10^{-3} \text{ m}} \] [2]

\[ = 8.0 \times 10^6 \text{ V m}^{-1} \text{ or } 8.0 \text{ MN C}^{-1} \]

\[ \therefore \text{ The mean value of the electric field } = \frac{1}{2} E_{\text{max}} = 4.0 \text{ MN C}^{-1} \] [1]
16 The protons move in circles. When the radius is \( r \), their acceleration is \( \frac{v^2}{r} \).

By Newton’s second law:

\[
\text{Centripetal force} = Bev = \frac{m_p v^2}{r}
\]

\[\Rightarrow v = \frac{Be r}{m_p} \]

But \( \frac{2\pi r}{v} \) is the time \( T \) to complete one revolution at a speed \( v \) is

\[
T = \frac{2\pi r}{v} \Rightarrow \frac{1}{2\pi} = \frac{v}{2\pi m_p} = \frac{Be}{2\pi m_p} \]

[Total 4 marks]

17 The number of ionisations is equal to the area under the graph line, as interpreted by the axes.

For a particle that travels 60 mm in air, as on the graph, this is about 11 large squares.

One square represents 10 mm \( \times \) 2000 ionisations mm\(^{-1} \) = 20 000 ionisations.

Thus 11 squares represents \( 11 \times 20 \ 000 \) ionisations = 220 000 ionisations

As each ionisation requires 30 eV, the initial energy \( E_0 \) of the particle is

\[
E_0 = 30 \text{ eV per ionisation} \times 220 \ 000 \text{ ionisations} = 6.6 \times 10^6 \text{ eV or 6.6 MeV} \]

[Total 5 marks]

18 Each particle has a mass of \( 6.65 \times 10^{-27} \) kg (2 protons plus 2 neutrons).

Resolving vertically, the two momenta are therefore:

up \( (6.65 \times 10^{-27} \text{ kg}) \times (1.23 \times 10^7 \text{ m s}^{-1}) \times \sin 35^\circ = 4.7 \times 10^{-20} \text{ kg m s}^{-1} \)

down \( (6.65 \times 10^{-27} \text{ kg}) \times (0.86 \times 10^7 \text{ m s}^{-1}) \times \sin 55^\circ = 4.7 \times 10^{-20} \text{ kg m s}^{-1} \)

The momenta are equal to when rounded to 2 s.f.

We have to assume that speeds are such that the rest masses still apply.

[Total 6 marks]

19 Their mass increase \( \Delta m \) is given by Einstein’s equation \( \Delta E = c^2 \Delta m \)

For an extra energy of 20 MeV

\[
\Delta E = (20 \times 10^6) \text{ eV} \times (1.60 \times 10^{-19} \text{ J eV}^{-1}) = 3.20 \times 10^{-12} \text{ J} \]

This represents a mass increase of

\[
\frac{\Delta m}{m_0} = \frac{3.20 \times 10^{-12} \text{ J}}{(3.00 \times 10^8 \text{ m s}^{-1})^2} = 3.56 \times 10^{-29} \text{ kg} \]

\[
\frac{\Delta m}{m_0} = 3.56 \times 10^{-29} \text{ kg} \]

\[= 0.021 \text{ or just over 2 %} \]

[Total 5 marks]
Stretch and challenge

20 a) Your diagram should look like the figure below. Note that you must include the direction of the field lines.

The electric fields between the drift tubes accelerate the electrons as they pass in a vacuum between them.

b) i) They are called drift tubes because the electrons do not feel an electric acceleration force as they travel within each tube. Within each tube the velocity of the electrons remains constant.

ii) Once the electrons have reached a speed $> 0.9c$, where $c$ is the speed of light, each addition of a few keV of energy does not noticeably alter their speed. Thus their time in each drift tube remains essentially the same and consequently the length of successive drift tubes does not noticeably alter.

c) Using $\Delta E = \Delta m c^2$

$$\Rightarrow \Delta m = \frac{(8.4 \times 10^9 \text{ V}) \times (1.6 \times 10^{-19} \text{ C})}{(3.0 \times 10^8 \text{ m s}^{-1})^2}$$

$$= 1.5 \times 10^{-26} \text{ kg}$$

This is more than 16 000 times the rest mass, $9.1 \times 10^{-31} \text{ kg}$, of an electron.

d) A volt is a $\text{J C}^{-1}$

Therefore the unit for $\Delta m$ is $\text{J C}^{-1} \times \text{C m}^2\text{s}^{-2}$

But a joule is a $\text{N m} = \text{kg m s}^{-2} \times \text{m} = \text{kg m}^2\text{s}^{-2}$

This gives units for $\Delta m$ as $\frac{\text{kg m}^2\text{s}^{-2} \text{C}^{-1} \times \text{C}}{\text{m}^2\text{s}^{-2}} = \text{kg}$

[Total 16 marks]
21 a) Measured radius of electron’s path:
  At A: 46 mm, at B: 31 mm, at C: 22 mm
  [1]
  As photograph is \( \frac{3}{2} \) scale, the actual radii are \( \frac{3}{2} \times \) measured values
  [1]
  Actual radius of electron’s path at A: 69 mm, at B: 46.5 mm, at C: 33 mm
  [1]

b) In the relationship \( p = Be \), the above numbers represent \( r \).
   Here we have:
   \[ Be = (1.2 \text{ N m}^{-1}) (1.6 \times 10^{-19} \text{ C}) = 1.9 \times 10^{-19} \text{ kg s}^{-1} \]
   [2]
   Therefore the momenta are:
   \[ p_A = 1.3 \times 10^{-20} \text{ kg m s}^{-1}, \quad p_B = 8.9 \times 10^{-21} \text{ kg m s}^{-1}, \quad p_C = 6.3 \times 10^{-21} \text{ kg m s}^{-1} \]
   [2]

c) The speed of the electron is \( 3.0 \times 10^8 \text{ m s}^{-1} \) at each of A, B and C and the mass \( m \) of the electron is \( p/v \) in each case, therefore
   \[ m_A = 4.4 \times 10^{-29} \text{ kg}, \quad m_B = 3.0 \times 10^{-29} \text{ kg}, \quad m_C = 2.1 \times 10^{-29} \text{ kg} \]
   [2]
   (You may get slightly different values due to rounding down.)

d) Each of these masses is much greater than the rest mass, \( 9.1 \times 10^{-31} \text{ kg} \), of the electron. [1]

[Total 11 marks]