14. Electric fields and magnetic fields have different effects on the motion of charged particles.
A positive ion enters a uniform electric field E. The velocity of the ion is perpendicular to the electric field, as shown in Diagram A below.
A positive ion enters a uniform magnetic field B. The velocity of the ion is perpendicular to the magnetic field, as shown in Diagram B below.

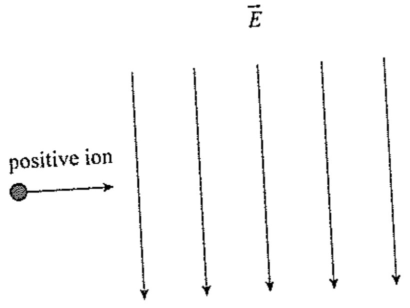


Diagram A

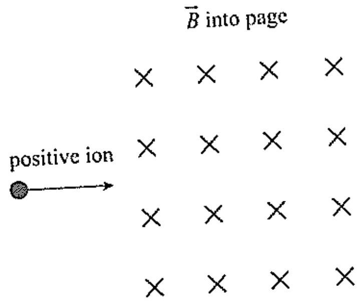
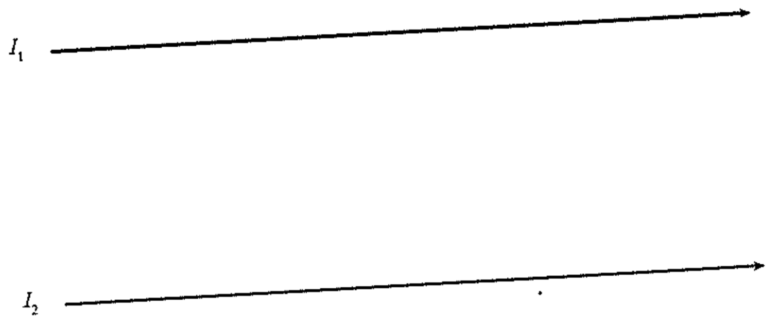


Diagram B

Compare the paths taken by the positive ion in the electric field in Diagram A and in the magnetic field in Diagram B. *Ignore the effects of gravity and air resistance.*

(8 marks)
(adapted from 2009 Q27)

15. The diagram below shows two parallel conductors. The conductors carry currents I1 and I2 in the directions shown.



Each conductor is within the magnetic field created by the other conductor. Determine, giving reasons, whether the two conductors attract or repel each other.

(3 marks)
(2012 Q10)

16. *Science as a Human Endeavour question*
In Australia, radioisotopes that have an excess of neutrons are generally produced in a nuclear reactor, whereas radioisotopes with an excess of protons are generally produced in cyclotrons.
ANSTO operates the only nuclear reactor in Australia as well as the Australian Synchrotron and a research cyclotron. However, the necessity of a nuclear reactor in Australia has been debated, with some people suggesting that cyclotrons can provide all the required radioisotopes.
Discuss the influence of social considerations and public debate on the acceptance and use of scientific knowledge.

(4 marks)

Subtopic 2.5: Electromagnetic Induction – Questions

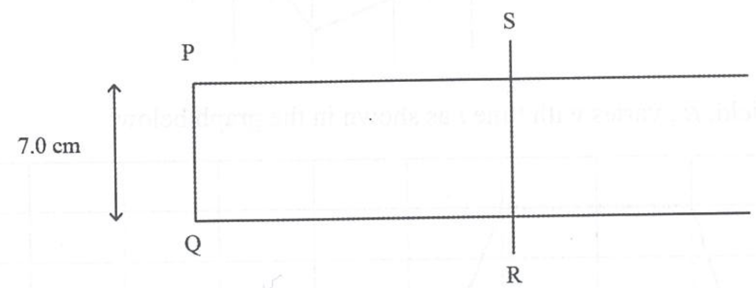
1. Describe two ways of increasing the magnetic flux inside a single loop of current-carrying wire. (2 marks)

2. A single loop of wire with a radius of 3.0 cm is placed at a point in the Earth's magnetic field where the magnetic field strength is 1.2×10^{-4} T. Determine the magnetic flux in the loop if:
   (a) the loop is in a plane perpendicular to the magnetic field lines. (3 marks)
   (b) the loop is in a plane parallel to the magnetic field lines. (1 mark)

3. (a) Explain what is meant by electromagnetic induction. (2 marks)
   (b) State the laws used to determine the magnitude and direction of the induced emf. (2 marks)
   (c) The magnetic field perpendicular to a rectangular loop of wire 30.0 cm × 50.0 cm is increased uniformly from 0.0 to 3.0 T in 2.0 s. The magnetic field is held constant for 1.0 s and then decreased uniformly to 0.0 T in 1.0 s.
      (i) Determine the induced emf in each time interval. (6 marks)
      (ii) Draw a graph of emf (vertical axis) versus time (horizontal axis) (4 marks)
   (adapted from 1989 Q6)

4. (a) State Lenz's law. (1 mark)
   (b) Use Lenz's law to explain the force experienced by:
      (i) the north pole of a magnet when it is pushed towards a coil of wire that is part of a complete circuit. (3 marks)
      (ii) the north pole of a magnet when it is pulled away from a coil of wire that is part of a complete circuit. (3 marks)

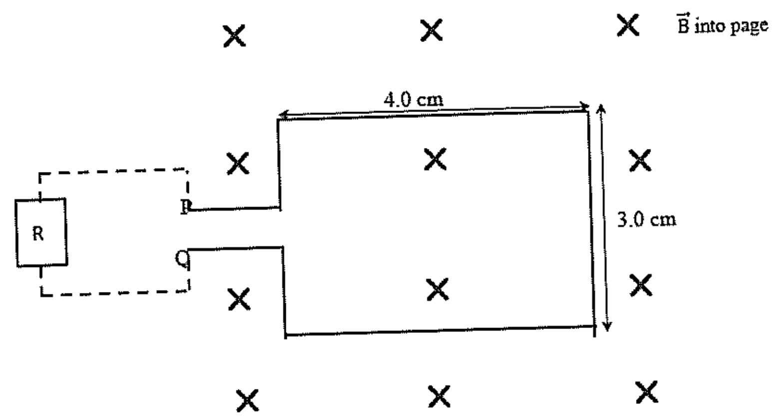
5. Two parallel conducting rails 7.0 cm apart are joined by a conducting wire PQ. A conducting bar RS can slide on the rails, making electrical contact, as shown in the diagram below. A magnetic field of magnitude 0.40 T acts perpendicularly into the plane of the page throughout the region of the conductors. The bar RS moves to the right at 2.0 cm s^{-1}.



   (a) Calculate the magnitude of the induced emf in the loop PQRS. (3 marks)
   (b) Determine the direction of the current in the loop. Justify your answer. (3 marks)

TOPIC 2

6. A rectangular wire frame, 3.0 cm × 4.0 cm, is placed in a uniform magnetic field, directed into the page, as shown in the diagram below:



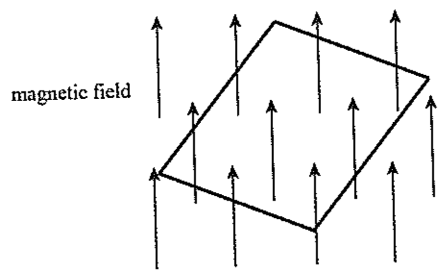
$\vec{B}$ is increased uniformly from 0.050 T to 0.150 T in 2.0 s.

(a) Calculate the magnitude of the emf induced between points P and Q. (3 marks)

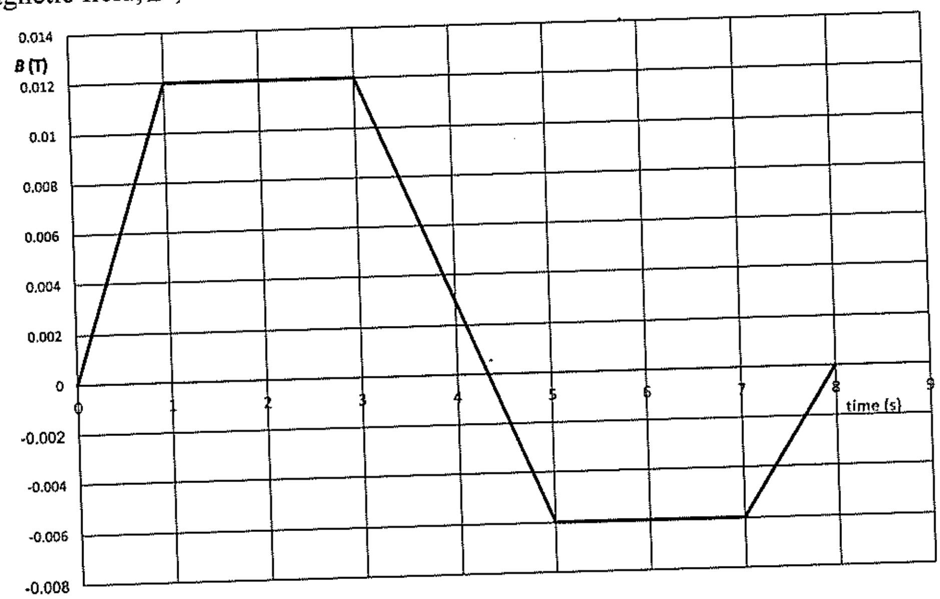
(b) P and Q are then connected via the resistor R. State whether the current passes through R from P to Q or from Q to P. Justify your answer. (3 marks)

(1991 Q1(f))

7. A square loop of wire enclosing an area of 2.5×10^{-3} m^2 is placed perpendicular to a uniform magnetic field, as shown in the diagram below:



The magnetic field, $\bar{B}$, varies with time t as shown in the graph below:



Calculate the emf for each section of the graph above and draw a graph that shows the variation of emf with time. Indicate a change in the direction of the emf by a change in the sign of emf.

(8 marks)

8. A wire coil with 25 loops of area 3.0×10^{-4} m^2 is held between the poles of a magnet, as shown in the diagrams below. The magnetic field strength is 1.0×10^{-2} T and can be assumed to be uniform.
The loop is initially in the position shown in Diagram 1. The loop is then rotated through 90° to the position shown in Diagram 2 in 0.20 s.

Diagram 1

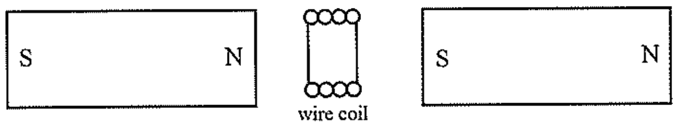
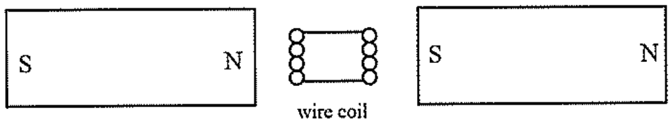


Diagram 2



Calculate the magnitude of the average induced *emf* in the coil during the rotation. (3 marks)

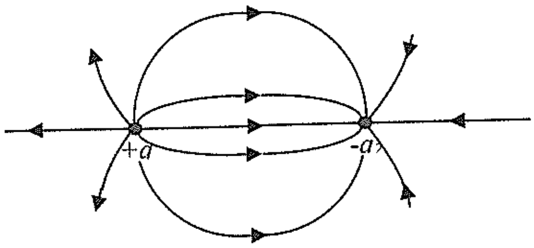
9. A transformer reduces a voltage of 220 V down to 6 V. The transformer has 30 turns in the output coil. Calculate the number of turns in the input coil.

TOPIC 2: ELECTRICITY AND MAGNETISM SOLUTIONS

Solutions are not the official set of solutions used by the examiners of the SACE Board of South Australia

Subtopic 2.1: Electric Fields – Solutions

1 (a)



(b)

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2} = 9.0\times10^9 \frac{(2.0\times10^{-6})(2.0\times10^{-6})}{(0.3)^2}$$

$$= 0.4\,N$$

Directed along line connecting the charges towards q_2.

2 The electric field between the plates is uniform, so the field at B and C are the same. The electric field is zero at point A.

3 (a)

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2} = 9.0\times10^9 \frac{4.0\times10^{-6}\times2.5\times10^{-6}}{(0.015)^2}$$

$F = 400$ N towards the right

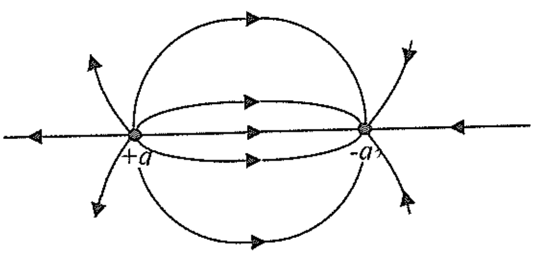
(b) The forces between each of q_1 and q_3, and q_2 and q_3 are attractive as they have opposite charges. For the net force to be zero, the individual forces need to act in opposite directions. The only location where this condition is fulfilled is to the left of q_2.

4

$$F = \frac{1}{4\pi\varepsilon_o}\frac{q_1 q_2}{r^2} = 9.0\times10^9 \frac{(3.4\times10^{-9})(3.4\times10^{-9})}{(3.2\times10^{-2})^2}$$

$$F = 1.0\times10^{-4}\ N$$

5 (a)



(b)

$r = 12\,\text{cm} = 0.12\,\text{m}$

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2} = 9.0\times10^9 \frac{q^2}{r^2}\ (q_1 = q_2 = q)$$

$$q = \sqrt{\frac{Fr^2}{9.0\times10^9}} = \sqrt{\frac{2.09\times10^2(0.12^2)}{9.0\times10^9}} = 1.83\times10^{-5}\ \text{C}$$

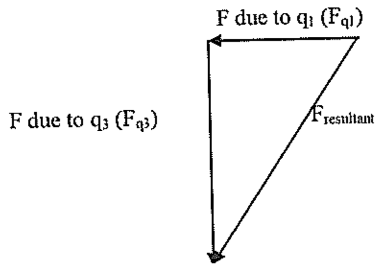
(c) (i)

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_2 q_3}{r^2}$$

$$= 9.0\times10^9 \frac{(1.8287\times10^{-5})(1.20\times10^{-5})}{(0.05)^2}$$

$$= 790\,\text{N}$$

(ii)



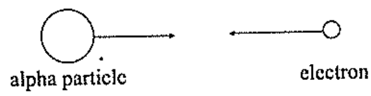
(iii)

$$F = \sqrt{F_{12}{}^2 + F_{12}{}^2} = \sqrt{209^2 + 790^2} = 817\ N$$

6

$$E = \frac{1}{4\pi\varepsilon_o}\frac{q}{r^2} = 9.0\times10^9 \frac{1.60\times10^{-19}}{(5.29\times10^{-11})^2} = 5.15\times10^{-11}\ NC^{-1}$$

7 (a)

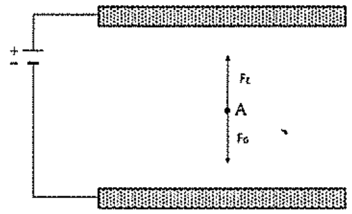


Vectors equal in magnitude, opposite in direction

(b) electron

According to Newton's 2[nd] law, the acceleration is inversely proportional to the mass for constant force. As the electron has the much smaller mass, it will have a much greater acceleration.

8 (a)



(b) Since the mass remains stationary,

$$F_E = F_G \Rightarrow qE = mg \therefore q = \frac{mg}{E}$$

$$q = \frac{4.90\times10^{-14}\times9.80}{1.00\times10^{6}} = 4.80\times10^{-19}\text{ C}$$

$q = ne$ where n is the number of excess electrons

$$n = \frac{q}{e} = \frac{4.80\times10^{-19}}{1.60\times10^{-19}} = 3$$

9 (a)

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$$

$$= (9.0\times10^{9})\frac{3.20\times10^{-19}}{\left(2.64\times10^{-11}\right)^2} = 4.13\times10^{12}\text{ NC}^{-1}$$

(b)

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$$

$$= (9.0\times10^{9})\frac{1.60\times10^{-19}}{\left(5.28\times10^{-11}\right)^2} = 5.17\times10^{11}\text{ NC}^{-1}$$

$$\sum E = (4.13 - 0.517)\times10^{12}\text{ NC}^{-1}$$

Directed left

10 (a)

$$E_1 = \frac{1}{4\pi\varepsilon_0}\frac{q_1}{d^2}$$

(b)

$$E_1 = E_2 \Rightarrow \frac{1}{4\pi\varepsilon_0}\frac{q_1}{d^2} = \frac{1}{4\pi\varepsilon_0}\frac{q_1}{(2d)^2}$$

$$\therefore 4q_1 = q_2 \Rightarrow q_1 : q_2 = 1:4$$

11 (a) (i)

$$F = \frac{1}{4\pi\varepsilon_o}\frac{q_1 q_3}{r^2}$$

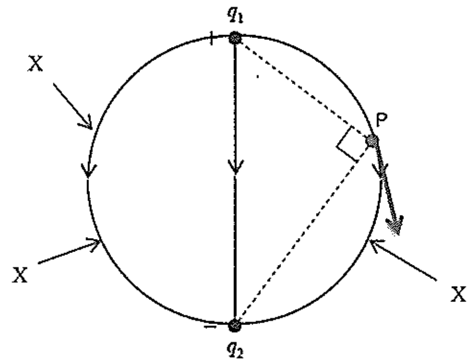
$$F = (9.0\times10^{9})\frac{(2.56\times10^{-6})(1.25\times10^{-6})}{(0.030)^2} = 32.0\ N$$

(ii) As $q_2 = q_1$ and q_3 is unchanged, $F \propto \frac{1}{r^2}$

and

$$F_2 = \frac{r_1^2}{r_2^2}F_1 = \frac{(0.030)^2}{(0.040)^2}\times32.0 = 18.0\ N$$

(b) (i), (ii) and (iii)



12

$$\bar{F}_{CA} = -\bar{F}_{CB}\text{ and } F \propto \frac{q}{r^2}$$

$$\frac{q_A}{r_{CA}^2} = \frac{q_B}{r_{CB}^2} \Rightarrow \frac{q_B}{q_A} = \frac{r_{CB}^2}{r_{CA}^2} = \frac{(2r_{CA})^2}{r_{CA}^2} = 4$$

13 (a) X

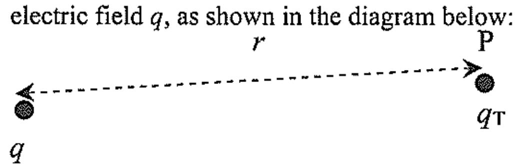
(b)

$$\bar{E}_1 = -\bar{E}_2\text{ and } E \propto \frac{q}{r^2}$$

$$\frac{q_1}{r_1^2} = \frac{q_2}{r_2^2} \Rightarrow \frac{1}{r_1^2} = \frac{4}{r_2^2} \rightarrow r_2 = \pm 2r_1$$

So for $r_2 = 2\,r_1$, position must be 50 cm to the left of q_1

14 (a) Consider a small positive test charge q_T placed at point P a distance r from the source of an electric field q, as shown in the diagram below:

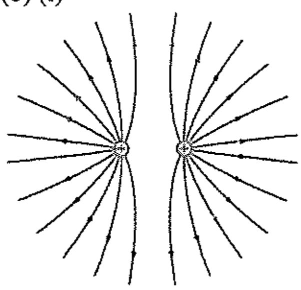


From Coulomb's law, the force on charge q_T is given by

$$F = \frac{1}{4\pi\varepsilon_0}\frac{qq_T}{r^2}\text{ and } E = \frac{F}{q_T}$$

$$\Rightarrow E = \frac{\frac{1}{4\pi\varepsilon_0}\frac{qq_T}{r^2}}{q_T} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$$

(b) (i)



TOPIC 2 SOLUTIONS

(ii)

$$E_1 = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2} = (9.0\times10^9)\frac{2.50\times10^{-6}}{(0.050)^2} = 9.0\times10^6 \text{ NC}^{-1}$$

along line towards P from q_1

$$E_2 = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2} = (9.0\times10^9)\frac{2.50\times10^{-6}}{(0.12)^2} = 1.56\times10^6 \ NC^{-1}$$

along line towards P from q_2

$$\sum E = \sqrt{E_1^2 + E_2^2} = \sqrt{(9.0\times10^6)^2 + (1.56\times10^6)_2^{\,2}}$$

$$\sum E = 9.1\times10^6 \ NC^{-1}$$

15 (a)

$$F = \frac{1}{4\pi\varepsilon_o}\frac{q_{elec}q}{r^2} \Rightarrow q = \frac{Fr^2}{\left(\frac{1}{4\pi\varepsilon_o}\right)q_{elec}}$$

$$q = \frac{(1.7\times10^{-10})(2.0\times10^{-9})^2}{(9.0\times10^9)(1.6\times10^{-19})} = 4.7\times10^{-19} \ C$$

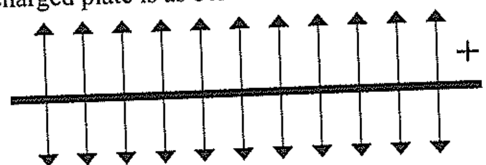
Since the force is repulsive, point q must be negative

(b)

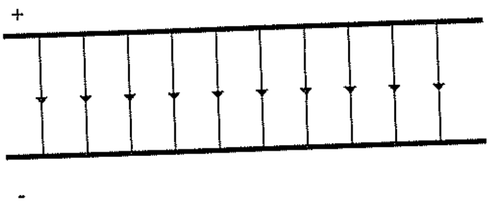
$$F \propto \frac{1}{r^2} \therefore r \rightarrow \times2 \Rightarrow F \rightarrow \times\frac{1}{2^2} \rightarrow \times\frac{1}{4}$$

$$F = \frac{1}{4}(1.7\times10^{-10}) = 4.3\times10^{-11} \ N$$

16 The electric field of an infinitely long positively charged plate is as below:

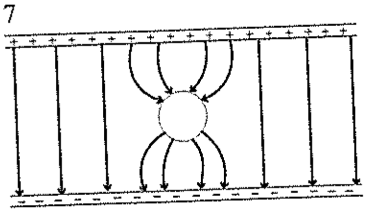


The field is uniform (equal strength no matter how far from the charged plate, as shown by the equally spaced parallel field lines).
For a negatively charged infinitely long plate with the same amount of charge, the field is similar, with the direction of the field opposite to above
When the two plates are placed parallel to each other, the uniform but opposite fields of the positive and negative plates cancel above and below the plates.

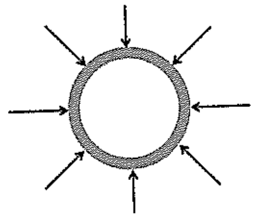


TOPIC 2 SOLUTIONS

17



18



19 (a)

(b) The weight is equal in magnitude to the electric force.

$$qE = mg \therefore q = \frac{mg}{E}$$

$$q = \frac{1.960\times10^{-15}\times9.80}{6.00\times10^4} = 3.2\times10^{-19} \text{ C}$$

20

- Coulomb's law also states that the force is inversely proportional to the square of the distance between the charges; i.e. $F \propto \frac{q}{r^2}$
- the ratio of the radii of the two states is approximately four as shown by the calculation:
  $\frac{r_2}{r_1} = \frac{0.212}{0.0526} = 4 \ (4.03)$
- because the force is inversely proportional to the square of the radius (for constant charge), the force F_1 on the electron in the $n = 1$ state is approximately sixteen times larger than the force F_2 on the electron in the $n = 2$ state, as shown by the calculation
  $\frac{F_1}{F_2} = \frac{r_2^2}{r_1^2} = \frac{(4r_1)^2}{r_1^2} = 16$

21 Two marks are allocated for a description of how scientific advances often influence other areas of science and technology, another mark is allocated for use of the context in the question.

The student *could* discuss how an understanding of a range of science disciplines such as electric fields in physics and cell structure in biology can lead to the development of an effective new technology with wide-ranging benefits. For example, the use of PEF in food preservation may significantly increase the sale of food products due to the longer shelf-life of visually appealing and tasty foods. Other responses could also achieve full marks.

Subtopic 2.2: Motion of Charged Particles in Electric Fields – Solutions

1 (a) The force on the electron is perpendicular to its velocity, so it acts to change the electron's direction, but not its speed. The force remains constant in magnitude and acts to cause centripetal acceleration.

(b) (i) The mass undergoes centripetal acceleration due to the magnetic force $F_B = qvB$.

Therefore,

$$F_B = F_C \Rightarrow qvB = ma = \frac{mv^2}{r}$$

$$qB = \frac{mv}{r} \Rightarrow r = \frac{mv}{qB}$$

(ii)

$$r = \frac{mv}{qB} \Rightarrow mv = rqB \therefore p = rqB$$

$$p = (1.46\times10^{-4})(1.60\times10^{-19})(2.31) = 5.40\times10^{-23}\ kgms^{-1}$$

(c) $p = \frac{h}{\lambda} \Rightarrow \lambda = \frac{h}{p} = \frac{6.63\times10^{-34}}{5.40\times10^{-23}} = 1.23\times10^{-11}\ m$

2 (a) $E = \frac{\Delta V}{d} = \frac{2.00\times10^{3}}{2.00\times10^{-3}} = 1.0\times10^{6}\ \text{Vm}^{-1}$

(b) $\Delta V = Ed = 1.00\times10^{6} \times 1.00\times10^{-5} = 10.0$ V

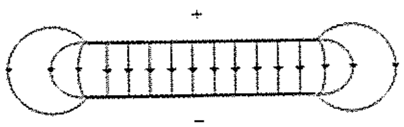
$W = q\Delta V = 1.60\times10^{-19} \times 10$

$= 1.60\times10^{-18}$ J

3

$$a = \frac{F}{m} = \frac{qE}{m} = \frac{1.60\times10^{-19}\times500}{9.11\times10^{-31}} = 8.78\times10^{13}\ \text{ms}^{-2}\ \text{left}$$

4 (a)



(b) (i) vertically up the page

(ii) The only force on the electron between the plates is the upwards electric force. This force is always perpendicular to the horizontal component of the electron's velocity so the horizontal velocity is constant. There is a constant acceleration upwards as the electric force is always parallel to the vertical component of the motion. Hence the shape of the path is parabolic towards the positive plate.

5 (a) $E = \frac{\Delta V}{d} = \frac{2500}{0.050} = 5.0\times10^{4}\ \text{Vm}^{-1}$

(b) Gain in kinetic energy
= work done by electric field

$= q\Delta v$

$= 1.6\times10^{-19}\times2500$

$= 4.0\times10^{-16}$ J

(c) Kinetic energy increases as the direction of the field is away from the positive plate and is the direction of the force on a positive charge. Hence the force is parallel to the motion and increases the speed and kinetic energy.

6 (a) $E = \frac{\Delta V}{d} = \frac{1250}{0.010} = 1.25\times10^{5}\ \text{Vm}^{-1}$

(b)

$$a = \frac{F}{m} = \frac{qE}{m} = \frac{1.60\times10^{-19}\times1.25\times10^{5}}{1.673\times10^{-27}} = 1.2\times10^{13}\ \text{ms}^{-2}$$

7 (a) $d = 4.0\ cm = 4.0\times10^{-2}\ m$

$$F = Eq \ and \ E = \frac{\Delta V}{d} \Rightarrow F = \frac{q\Delta V}{d}$$

$$a = \frac{F}{m} = \frac{q\Delta V}{md} = \frac{(1.60\times10^{-19})(3200)}{(9.11\times10^{-31})(4.0\times10^{-2})} = 1.4\times10^{16}$$

(b)

$$v^2 = v_o^{\ 2} + 2as \Rightarrow s = \frac{v^2 - v_o^{\ 2}}{2a}$$

$$s = \frac{0^2 - (2.8\times10^{7})^2}{2(-1.4\times10^{16})} = 0.0279\ m$$

Minimum distance from plate:

$0.04 - 0.0279 = 0.012$ m

8 (a) The path followed by the electron is parabolic and towards the positive plate (upwards). This is because the electric force acting on it is constant in magnitude and direction (towards the positive plate), as the electric field between the plates is uniform and directed towards the negative plate (downwards) and the electron being a negative charge experiences a force in the opposite direction. This force causes the vertical velocity to change; whilst its horizontal velocity remains constant, thus causing the parabolic motion.

(b)

$$a = \frac{F}{m} = \frac{qE}{m} = \frac{q\Delta V}{md}$$

$$a = \frac{1.60\times10^{-19}\times150}{9.11\times10^{-31}\times0.050} = 5.3\times10^{14}\ \text{ms}^{-2}$$