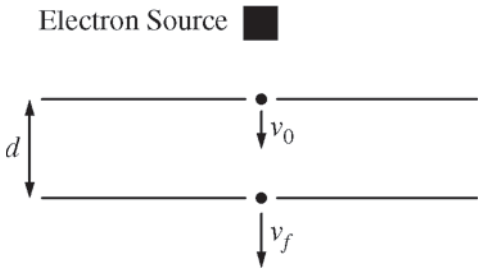


Note: Figure not drawn to scale.

4. (10 points - suggested time 20 minutes)

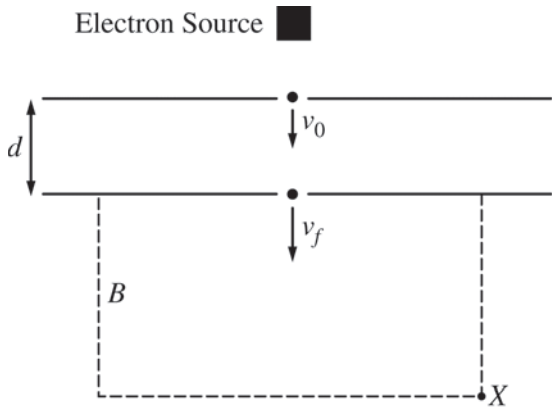
The apparatus shown in the figure above consists of two oppositely charged parallel conducting plates, each with area $A = 0.25\ \text{m}^2$, separated by a distance $d = 0.010\ \text{m}$. Each plate has a hole at its center through which electrons can pass. High velocity electrons produced by an electron source enter the top plate with speed $v_0 = 5.40 \times 10^6\ \text{m/s}$, take $1.49\ \text{ns}$ to travel between the plates, and leave the bottom plate with speed $v_f = 8.02 \times 10^6\ \text{m/s}$.

(a) Which of the plates, top or bottom, is negatively charged? Support your answer with a reference to the direction of the electric field between the plates.

(b) Calculate the magnitude of the electric field between the plates.

(c) Calculate the magnitude of the charge on each plate.

(d) The electrons leave the bottom plate and enter the region inside the dashed box shown below, which contains a uniform magnetic field of magnitude B that is perpendicular to the page. The electrons then leave the magnetic field at point X.



Note: Figure not drawn to scale.

i. On the figure above, sketch the path of the electrons from the bottom plate to point X. Explain why the path has the shape that you sketched.

ii. Indicate whether the magnetic field is directed into the page or out of the page. Briefly explain your choice.

STOP

END OF EXAM

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Question 4

10 points total **Distribution of points**

(a) 2 points

The top plate is negative.
For relating the direction of force or acceleration to the direction of the field 1 point
For relating the direction of the electric field to the sign of the charge on the top plate 1 point
No points are awarded for identifying that the top plate is negative with no attempt to explain why.

(b) 4 points

For using an appropriate kinematic relation to determine the acceleration of the electron while it is between the plates 1 point

$a = (v_f - v_i)/t$

For using Newton's second law to determine an expression for the magnitude of the force needed to give the electron the calculated acceleration 1 point

$F = ma = m(v_f - v_i)/t$

For setting eE equal to the force calculated from Newton's second law 1 point
For correctly manipulating equations to solve for the magnitude of the electric field and arriving at a correct numerical answer with units 1 point

$E = m(v_f - v_i)/et$

$$E = \frac{(9.11 \times 10^{-31}\ \text{kg})(8.02 \times 10^{6}\ \text{m/s} - 5.40 \times 10^{6}\ \text{m/s})}{(1.6 \times 10^{-19}\ \text{C})(1.49 \times 10^{-9}\text{s})} = 10{,}000\ \text{N/C}$$

Alternate Solution *Alternate Points*

For applying conservation of energy for the time the electron is between the plates *1 point*

$\Delta K = \Delta U$

For using the correct relationship between potential energy and potential difference *1 point*

$\Delta U = e\,\Delta V$

$$\frac{1}{2}m_e(v_f^2 - v_i^2) = e\,\Delta V$$

For using the relation between potential difference, electric field, and plate separation *1 point*

$\Delta V = Ed$

$$\frac{1}{2}m_e(v_f^2 - v_i^2) = eEd$$

For correctly manipulating equations to solve for the magnitude of the electric field and arriving at a correct numerical answer with units *1 point*

$E = m_e(v_f^2 - v_i^2)/2ed$

$$E = \frac{(9.11 \times 10^{-31})\left((8.02 \times 10^{6}\ \text{m/s})^2 - (5.40 \times 10^{6}\ \text{m/s})^2\right)}{2(1.6 \times 10^{-19}\ \text{C})(0.010\ \text{m})} = 10{,}000\ \text{N/C}$$

Question 4 (continued)

Distribution of points

(c) 1 point

$E = Q/\varepsilon_0 A$

$Q = \varepsilon_0 AE$

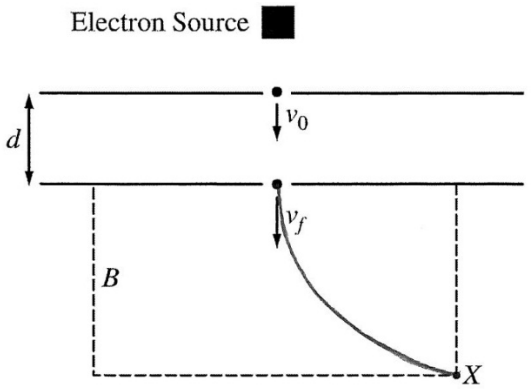
For correct substitution of values into the equation to calculate the magnitude of charge on each parallel plate — 1 point

$Q = \left(8.85 \times 10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2\right)\left(0.25\ \text{m}^2\right)(10{,}000\ \text{N/C})$

$Q = 2.2 \times 10^{-8}\ \text{C}$

(d)

i. 2 points



Note: Figure not drawn to scale.

For drawing a reasonably circular path from the point where the electrons leave the bottom plate to point X — 1 point

Note: There is no penalty for starting the path at the tip of the arrow.

For explaining that the field is always perpendicular to the velocity, so the force is also always perpendicular to the velocity which creates a curved (circular) path — 1 point

ii. 1 point

In order for the electron to reach point X, the magnetic field must exert a centripetal force on the electron toward the top right corner of the dashed box.

For using the right hand rule and reasoning that the force on a negatively charged object is in the opposite direction from the force exerted on a positively charged object (or using the "left hand rule") to conclude that the direction of the magnetic field is directed out of the page — 1 point

Notes:

No points are awarded for identifying that the direction of the magnetic field is out of the page without explaining why.

Credit can be earned for a correct analysis at any individual point on the path.