PhysicsTutor

mh

Capacitor and electron motion

Giambattista 17.63

Problem:

- A tiny hole is made in the center of the plates of a capacitor allowing a beam of electrons to pass through. If 40.0 V are applied across the plates, and electrons enter through the hole of the negative plate with a speed of 2.50×10^6 m/s, what is the speed of the electrons when they emerge out of the hole in the positively charged plate?

Relevant ideas:

Relevant ideas:

- Energy conservation should be used, as we cannot determine the electric field (without knowledge of the plate separation).

$$\frac{1}{2} m v_i^2 + PE_i = \frac{1}{2} m v_f^2 + PE_f$$

$$\therefore \quad \frac{1}{2} m v_f^2 = \frac{1}{2} m v_i^2 + (PE_i - PE_f)$$

Relevant ideas:

- Energy conservation should be used, as we cannot determine the electric field (without knowledge of the plate separation).
- An electron gains an energy of eΔV as it crosses the plate separation. The electric PE is converted into kinetic energy KE.

$$|PE_f - PE_i| = |-e\,\Delta V| = |e\,\Delta V|$$

$q = -e$ for electron

$e = 1.60 \times 10^{-19}$ C

Relevant ideas:

- Energy conservation should be used, as we cannot determine the electric field (without knowledge of the plate separation).
- An electron gains an energy of $e\Delta V$ as it crosses the plate separation. The electric PE is converted into kinetic energy KE.
- Be careful with the sign: the electron is accelerated, as it enters at the negative plate.

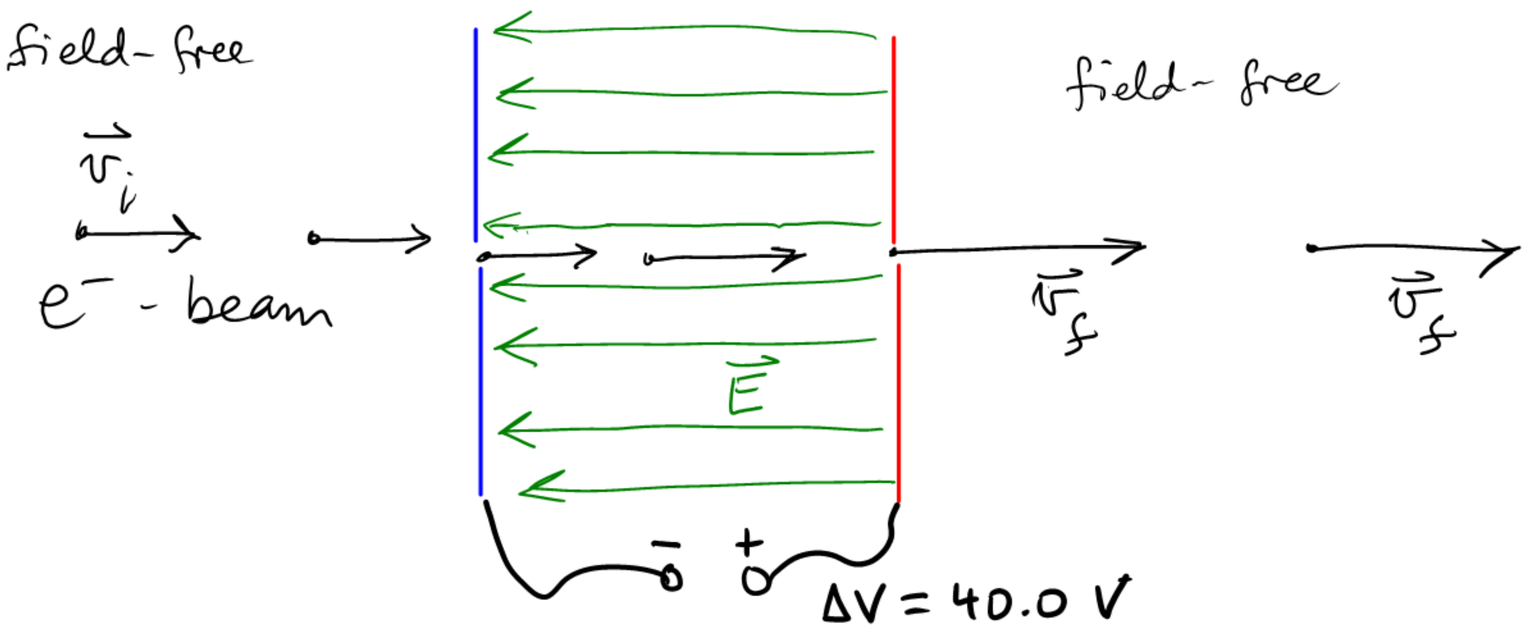
$KE_f > KE_i$

Equations associated with ideas:

$$PE_f - PE_i = q\,\Delta V \qquad KE = \tfrac{1}{2} m v^2$$

$$KE_f + PE_f = KE_i + PE_i$$

conservation of energy



Strategy

Strategy

- Calculate the energy gained by the electron: potential difference times electron charge.

Strategy

- Calculate the energy gained by the electron: potential difference times electron charge.
- Evaluate in SI, calculate the initial kinetic energy from the electron speed and mass, and add to obtain the total energy for the electron at the positive plate.

Strategy

- Calculate the energy gained by the electron: potential difference times electron charge.
- Evaluate in SI, calculate the initial kinetic energy from the electron speed and mass, and add to obtain the total energy for the electron at the positive plate.
- Calculate the final electron speed from the total energy.

Solution

Solution

- $$\Delta PE = q\Delta V = -e\Delta V = -1.60\times 10^{-19}\cdot 40.0\ \overset{As}{\overset{\shortparallel}{C}}V \left\}\begin{array}{l} = Ws \\ = J \end{array}\right.$$

Solution

- $\Delta PE = q\Delta V = -e\Delta V = -1.60\times10^{-19}\cdot 40.0\ \overset{As}{\overset{\shortparallel}{C}}\cdot V \left.\begin{matrix} =Ws \\ =J \end{matrix}\right.$
- $\Delta KE + \Delta PE = 0 \quad \therefore \quad \Delta KE = -\Delta PE = 6.40\times10^{-18}\ J$

Solution

- $\Delta PE = q\Delta V = -e\Delta V = -1.60\times10^{-19}\cdot 40.0\ \overset{As}{\overset{\shortparallel}{C}}V \left.\begin{matrix} =Ws \\ =J \end{matrix}\right\}$
- $\Delta KE + \Delta PE = 0 \therefore \Delta KE = -\Delta PE = 6.40\times10^{-18}\ J$
- $KE_i = \frac{1}{2} m_e v_i^2 = 0.50\cdot 9.11\times10^{-31}\cdot (2.50)^2\times10^{12}\ J = 2.847\times10^{-18} J$

Solution

- $\Delta PE = q\Delta V = -e\Delta V = -1.60\times10^{-19}\cdot 40.0 \overset{\overset{As}{\shortparallel}}{C}V \left.\begin{matrix}\\ \\ \end{matrix}\right\} \begin{matrix}=Ws\\=J\end{matrix}$
- $\Delta KE + \Delta PE = 0 \quad \therefore \quad \Delta KE = -\Delta PE = 6.40\times10^{-18}\,J$
- $KE_i = \frac{1}{2}m_e v_i^2 = 0.50\cdot 9.11\times10^{-31}\cdot(2.50)^2\times10^{12}\,J = 2.847\times10^{-18}\,J$
- $KE_f = 9.247\times10^{-18}\,J \quad \therefore \quad v_f = \sqrt{2m_e^{-1}KE_f} = 4.51\times10^{6}\,\frac{m}{s}$

The electron almost doubles its speed.

Note: given a potential difference, the plate separation, and electric field strength don't matter. For a small separation, i.e., strong field: change in KE happens over a shorter distance.