Key Concepts

Chapter 8

$C = \frac{Q}{V}$ (C/V)

$F = ma$ (N: kg·m/s²)

$F = qE$ (N)

$\Delta y = v_{oy}t + \frac{1}{2}a_y t^2$

Capacitance

Kinematics

Electrostatics

Voltage

Electric field

Electric force

$E = \frac{V}{d}$ (V/m) (parallel plate capacitor)

Takeaways

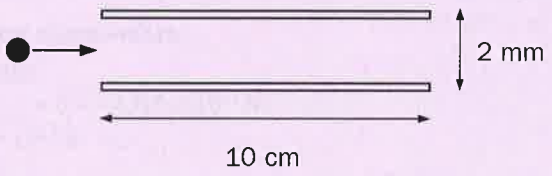
This is a combination between a capacitor problem, an electrostatics problem, and a kinematics problem. Use the properties of capacitors to find the voltage, which leads you to the force and acceleration of the particle. After you have the acceleration, this problem is no different from a standard free-fall or projectile problem.

Things to Watch Out For

There are several equations you must memorize to solve this problem.

Electron Between Charged Plates

A charged particle of mass 1 μg and charge 10 nC with velocity 2,000 m/s enters the center of the gap in a parallel plate capacitor as shown below. The capacitor holds a charge of 2 C and has a capacitance of 5 mF. The plates of the capacitor are 2.0 mm apart and 10 cm long. Will the particle strike one of the plates of the capacitor before it exits the gap?



1) Find the voltage across the capacitor.

The capacitance of a capacitor is related to the charge and voltage across the capacitor by $C = \frac{Q}{V}$. Solve for V.

$$C = \frac{Q}{V} \rightarrow V = \frac{Q}{C} = \frac{2}{5 \times 10^{-3}} = 400 \text{ volts}$$

2) Find the electric field in between the plates.

$$V = Ed \rightarrow E = \frac{V}{d} = \frac{400}{2 \times 10^{-3}} = 200{,}000 \text{ V/m}$$

The magnitude of the electric field inside a parallel plate capacitor is given by the formula $E = \frac{V}{d}$.

3) Find the acceleration of the particle.

$$a = \frac{F}{m}$$

$$F = qE \rightarrow a = \frac{qE}{m} = \frac{(10 \times 10^{-9})(200{,}000)}{1 \times 10^{-9}} = 2{,}000{,}000 \text{ m/s}^2$$

Remember to convert the mass to SI units (kg).

4) Find the time that the particle is between the plates.

Use the standard kinematics formula to find the amount of time it takes the particle to travel the distance across the capacitor. Note that there is no force in the x-direction, so there is no acceleration in the x-direction. Solve for time.

$$\Delta x = v_{ox}t + \frac{1}{2}a_x t^2$$

$$a_x = 0 \rightarrow \Delta x = v_{ox}t$$

$$t = \frac{\Delta x}{v_{ox}} = \frac{0.1}{2{,}000} = 5 \times 10^{-5}\ \text{s}$$

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5) Find the deflection of the particle.

Use the standard kinematics formula to find the movement in the *y*-direction based on the acceleration, time, and initial velocity. Note that initially there is no velocity in the *y*-direction.

$$\Delta y = v_{oy}t + \frac{1}{2}a_y t^2$$

$$v_{oy} = 0 \rightarrow \Delta y = \frac{1}{2}a_y t^2 = \frac{1}{2}(2{,}000{,}000)(5 \times 10^{-5})^2$$

$$= 2.5 \times 10^{-6}\ \text{m} = 2.5\ \text{mm}$$

Since the deflection of the particle (2.5 mm) is greater than the distance between the plates (2.0 mm), the particle will strike one of the plates of the capacitor before it exits the gap.

Similar Questions

1) An electron starts from rest at one plate of a parallel plate capacitor and accelerates to the other plate. The plate separation is 2 mm, and it takes 1 ms for the electron to travel from one side to the other. What is the capacitance of this capacitor if there are 2 C of charge stored on the plates? ($m_e = 9.11 \times 10^{-31}$ kg; $e = 1.6 \times 10^{-19}$ C)
2) An electron is brought to rest by a potential difference of 1 kV. What was the initial velocity of the electron?
3) A proton experiences a force of 10 mN as it travels between the plates of a parallel plate capacitor, parallel to the plates. If the capacitor holds 1 mC of charge and has a potential of 10 V, what is the separation between the plates?