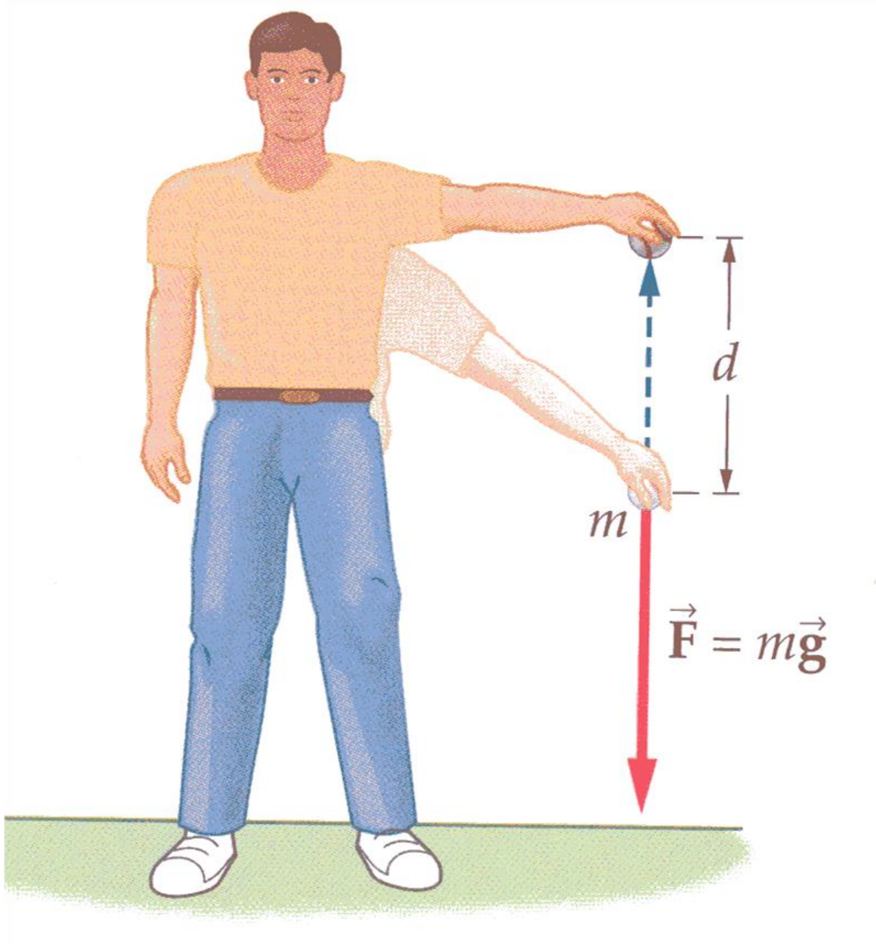
Electric Potential Energy

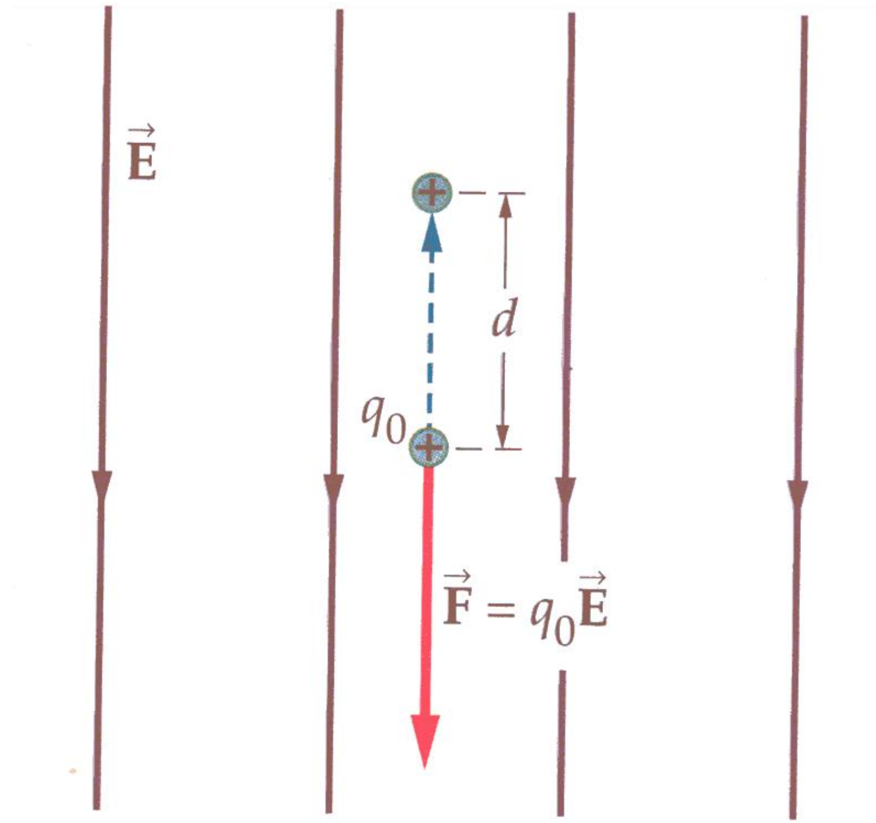
- the electric potential energy of two charges depends on the distance between the charges

- when two like charges are an infinite distance apart, the potential energy is zero

- An increase in potential energy requires a force to do work in a direction opposite to the force of the field on the object



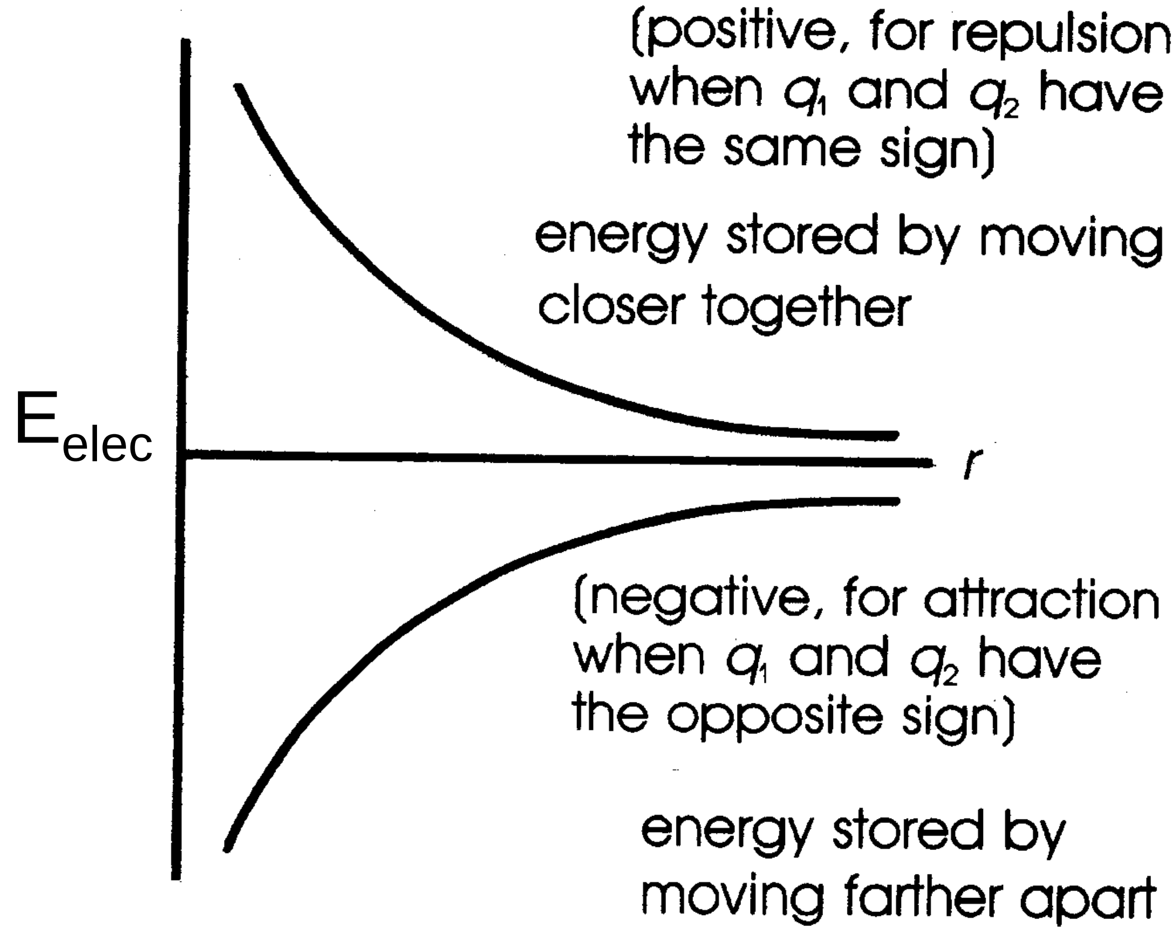
Work must be done to lift an object up against the force of gravity



Work must be done to move a charge against the electric force

- Potential energy can be negative meaning the charges are attracted to each other

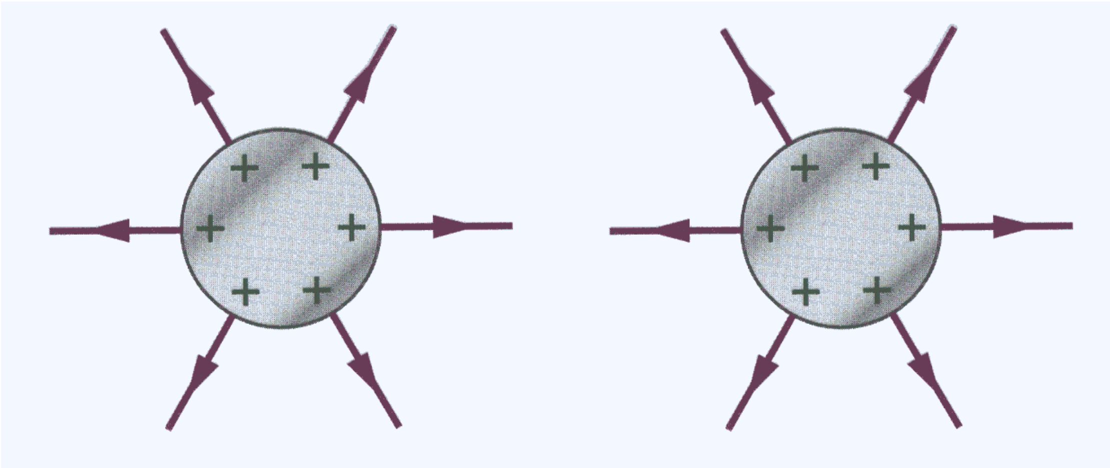
- If E_p is negative, a particle is in a “bound state”



Electric Potential

- Electric potential is the electric potential energy **per unit charge** (J/C)

- electric potential is purely location dependent.



High electric potential: close together

low electric potential between the charges when far apart

Electric potential difference

- The **electric potential difference** (ΔV) is the work done per unit charge as a charge is moved between two points in an electric field.

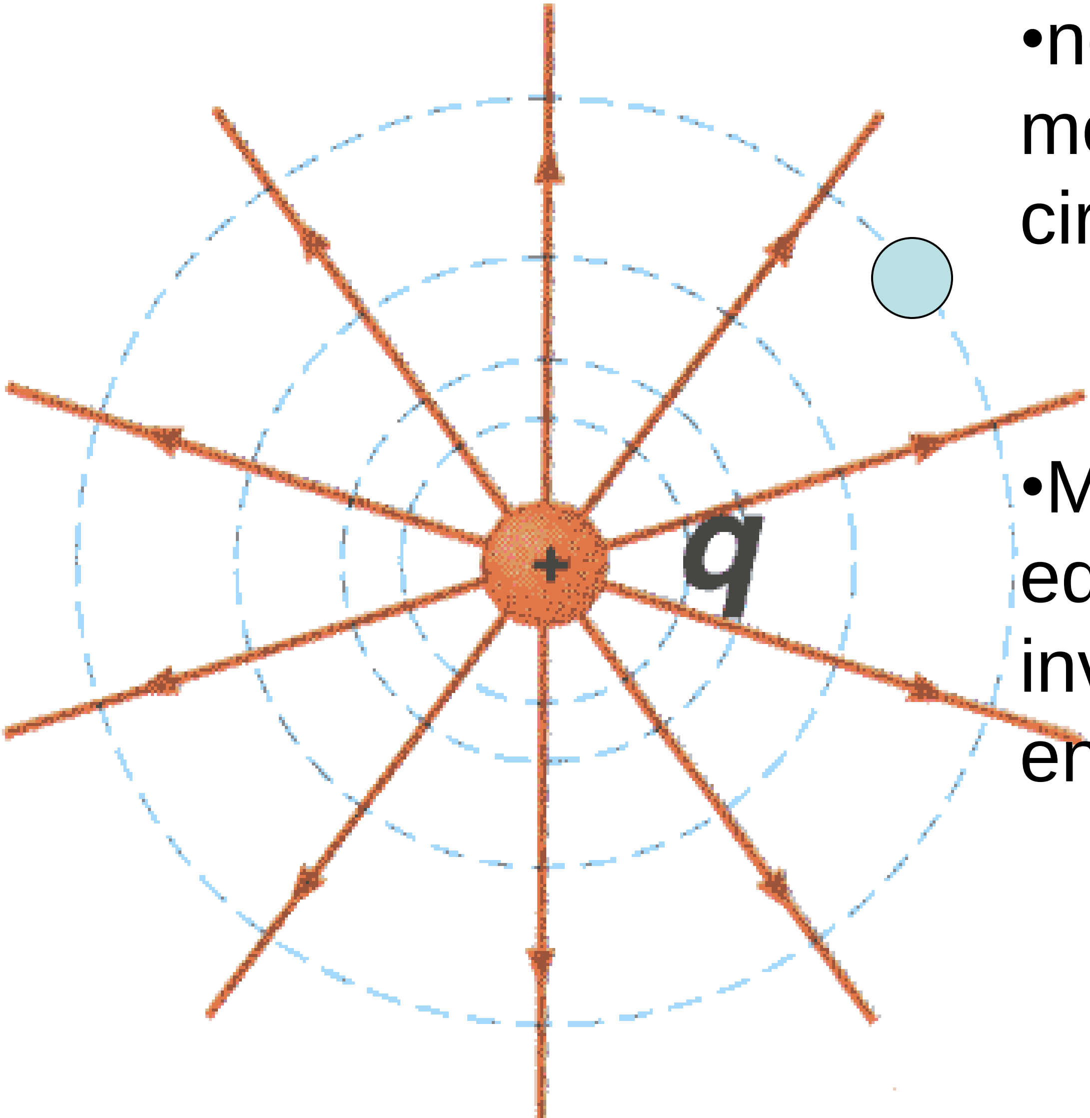
- Don't confuse ΔE with electric field strength!

$$\Delta V = \frac{\Delta E}{q}$$

$$Volt = \frac{Joule}{Coulomb}$$

- a volt is the potential difference necessary to change the energy of 1 C of charge by 1 J in moving the charge between two points

Equipotential lines



- no work is done to move the charge in a circle around **q**
- Moving along an equipotential line involves no change in energy

Batteries

- when a battery is connected to a wire, an electric field is created between the ends of the wire
- the electric field exerts a force on the mobile electrons and an electric current flows in the wire as long as the battery remains connected

- electric current (I) is the amount of charge passing a reference point per second, measured in amperes (A = C/s)

- Current is **NOT** the speed of the charges!

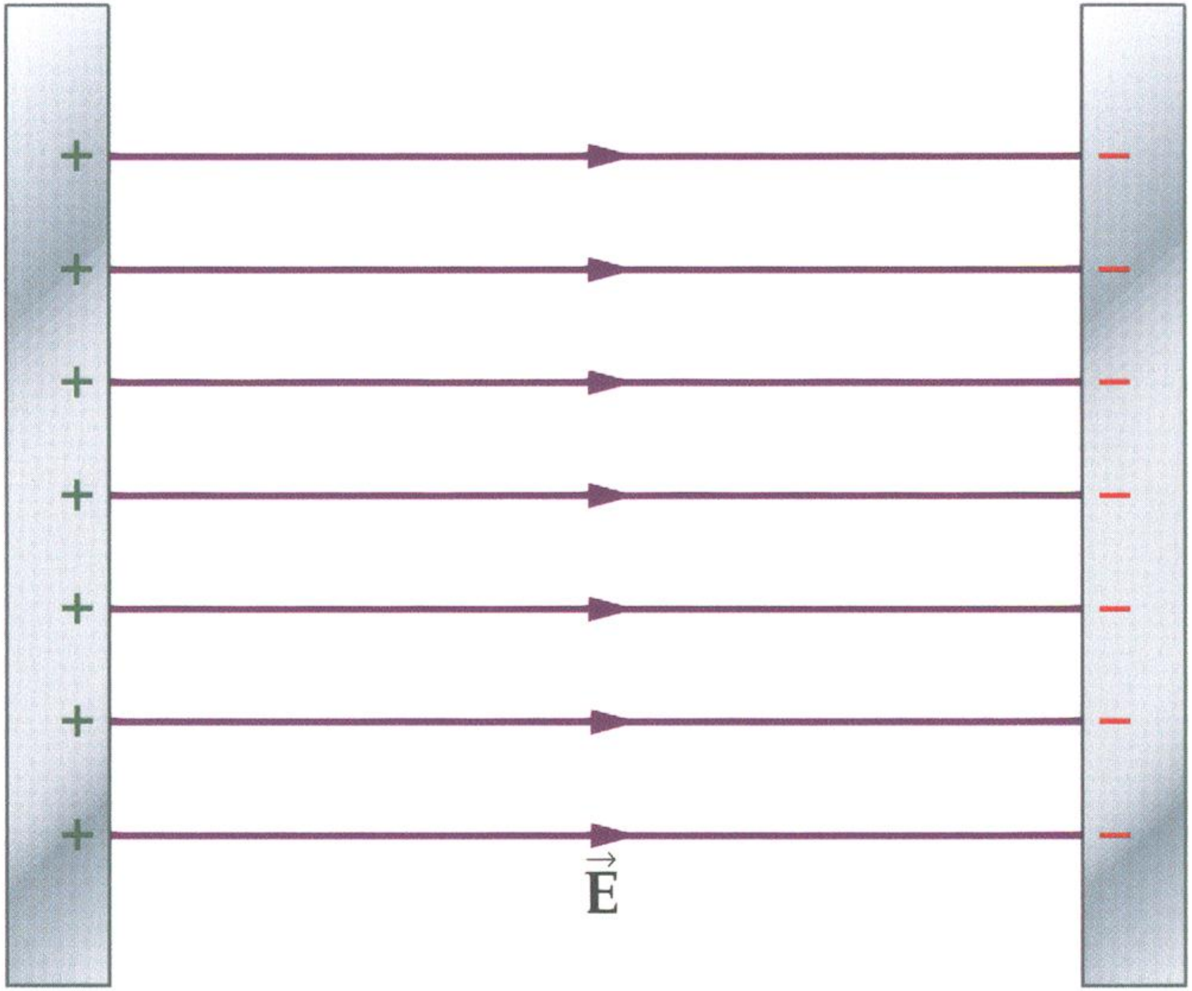
$$I = \frac{q}{t}$$

Uniform Electric Fields

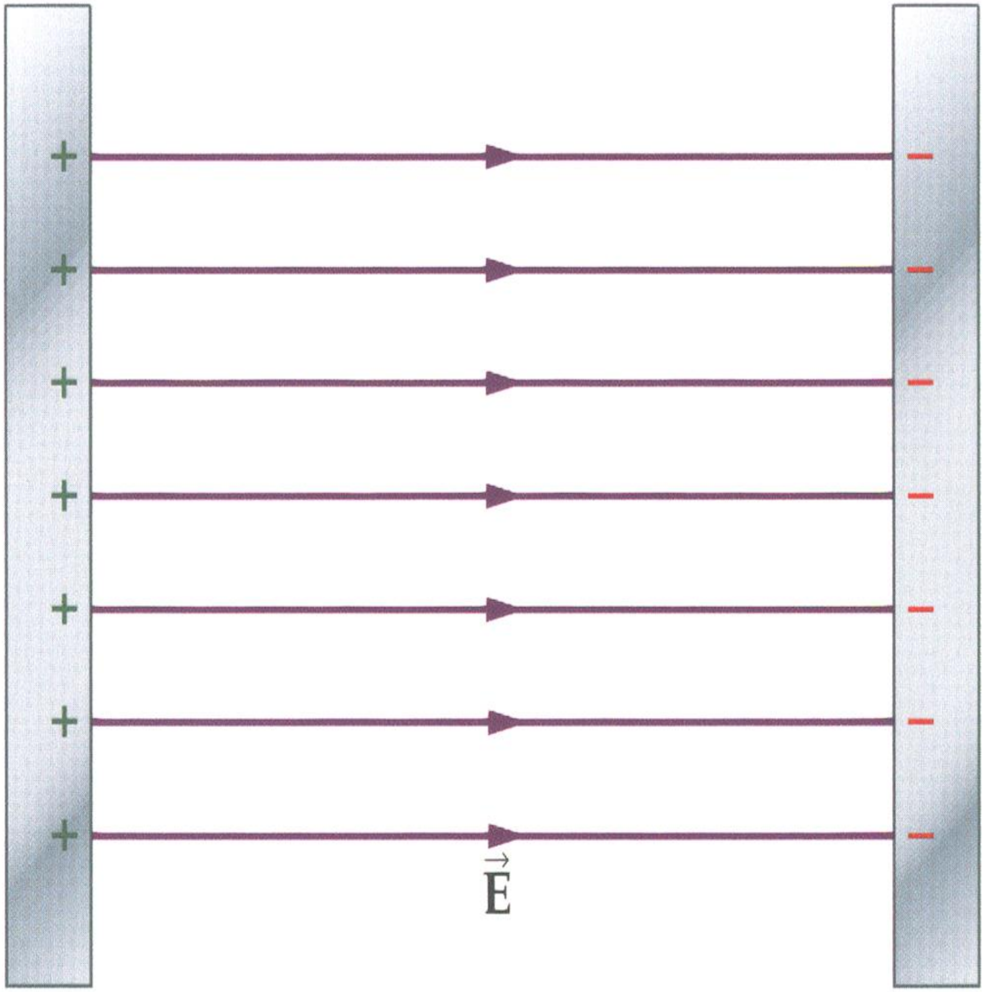
- If two parallel conducting plates are connected to a battery, each plate will have an equal but opposite charge and an electric field will exist between the plates

- electric field strength between the plates is uniform

Uniform Field

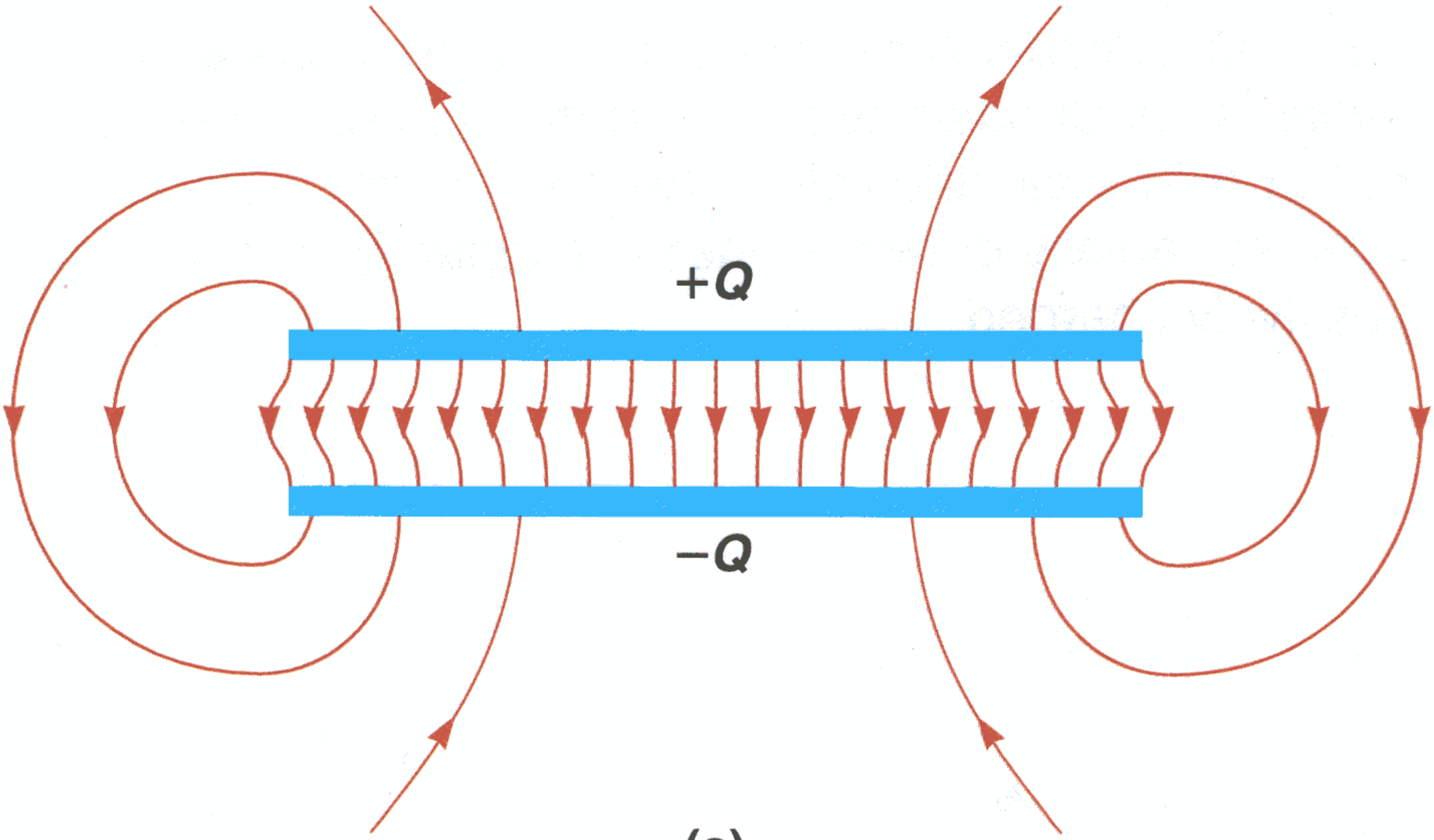


A charge will experience the same force at every point in an uniform field

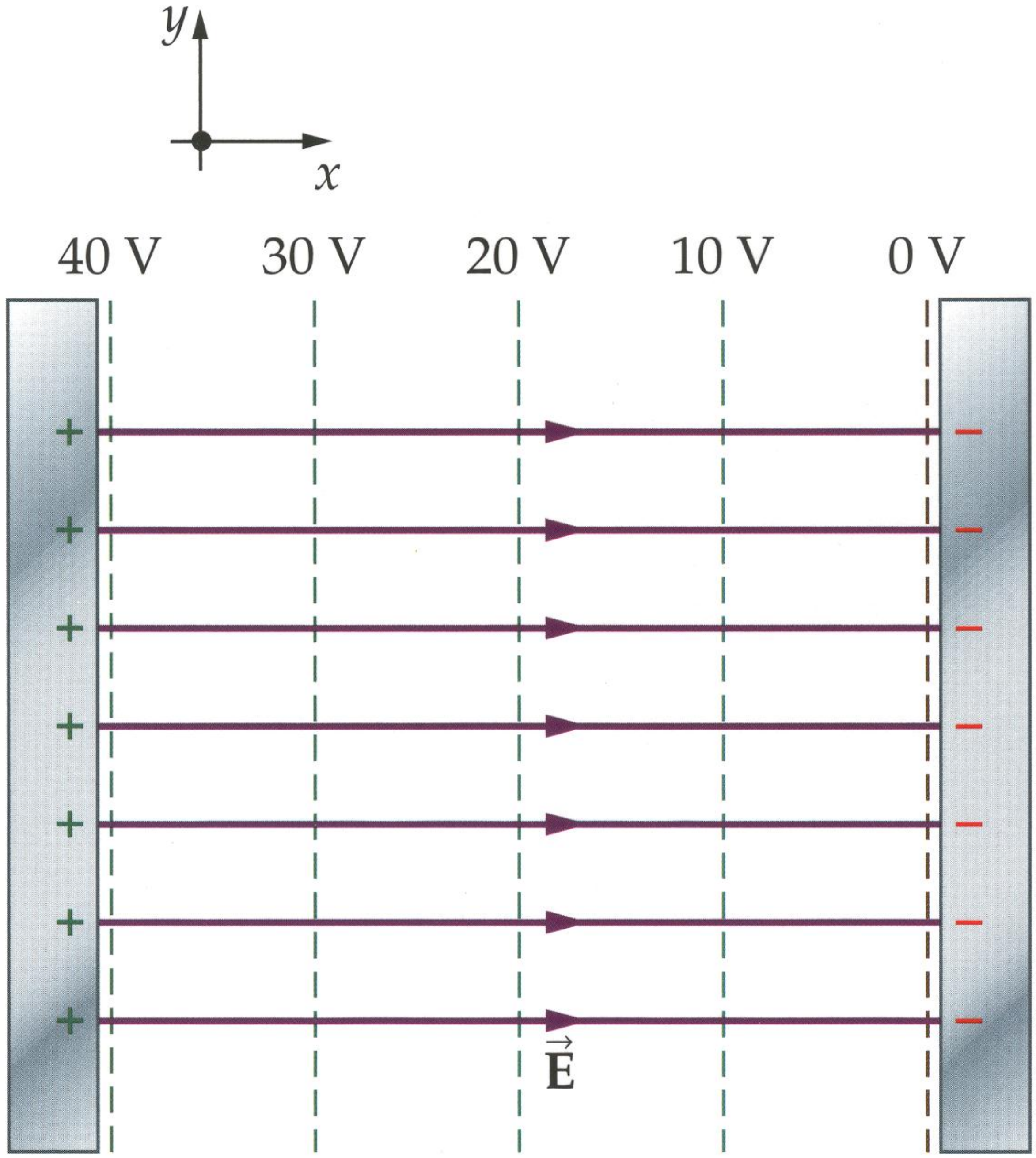


- The field is uniform because as the distance from 1 plate increases, the distance to the other plate decreases

Actual field is not uniform near edges

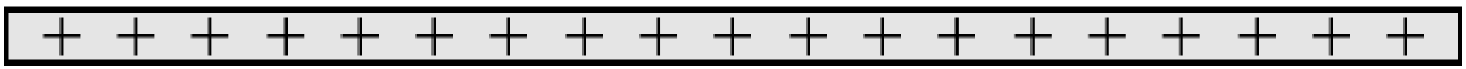


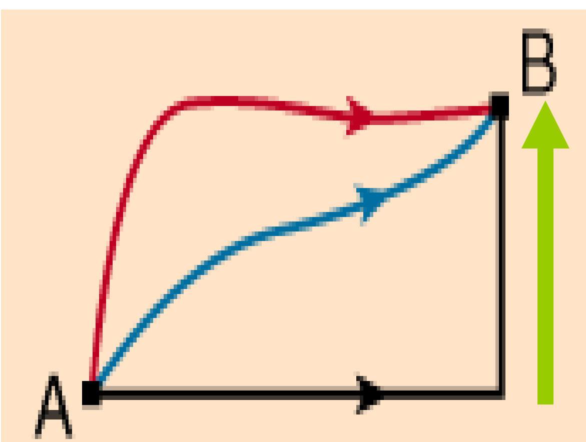
(a)



The potential difference measured from the + plate decreases towards the - plate

- the electric force is **conservative**, the amount of work done to move a charge depends only on the potential difference between the 2 points in the field





•All paths between A and B require the same amount of work

•No work is done to move a charge parallel to the plates (parallel to equipotential lines)

- the electric field strength will depend on the distance between the plates and the voltage of the battery

$$\left|\vec{E}\right| = \frac{\Delta V}{\Delta d}$$

$\left|\vec{E}\right| =$ magnitude of field strength

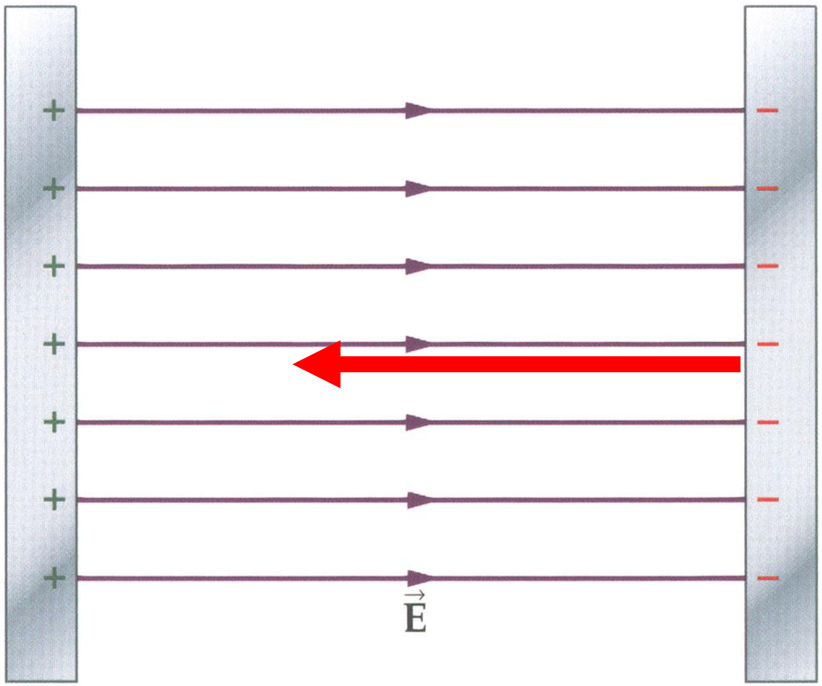
in $\frac{\text{V}}{\text{m}}$

Unit Analysis

$$\frac{V}{m} = \frac{J}{C \bullet m} = \frac{N \bullet m}{C \bullet m} = \frac{N}{C}$$

Example

- An electron is placed in an uniform electric field. It is released from the – plate and accelerates to the + plate. If its initial speed is 0 m/s and the potential difference is 150 V, determine the final speed of the electron.



Solution

$$\Delta V = \frac{\Delta E}{q}$$

$$\Delta E = \frac{1}{2} m v^2$$

$$\Delta E = \Delta V q$$

$$v = \sqrt{\frac{2\Delta E}{m}}$$

$$\Delta E = 150V\left(1.60 \times 10^{-19} C\right)$$

$$= 2.40 \times 10^{-17} J$$

$v = 7.26 \times 10^6$ m/s

Solution Pt 2

- The distance between the plates doesn't matter

- The final speed depends only on the potential difference and the particle's mass and charge

$$\Delta V = \frac{\Delta E}{q}$$

$$\Delta E = \Delta V q$$

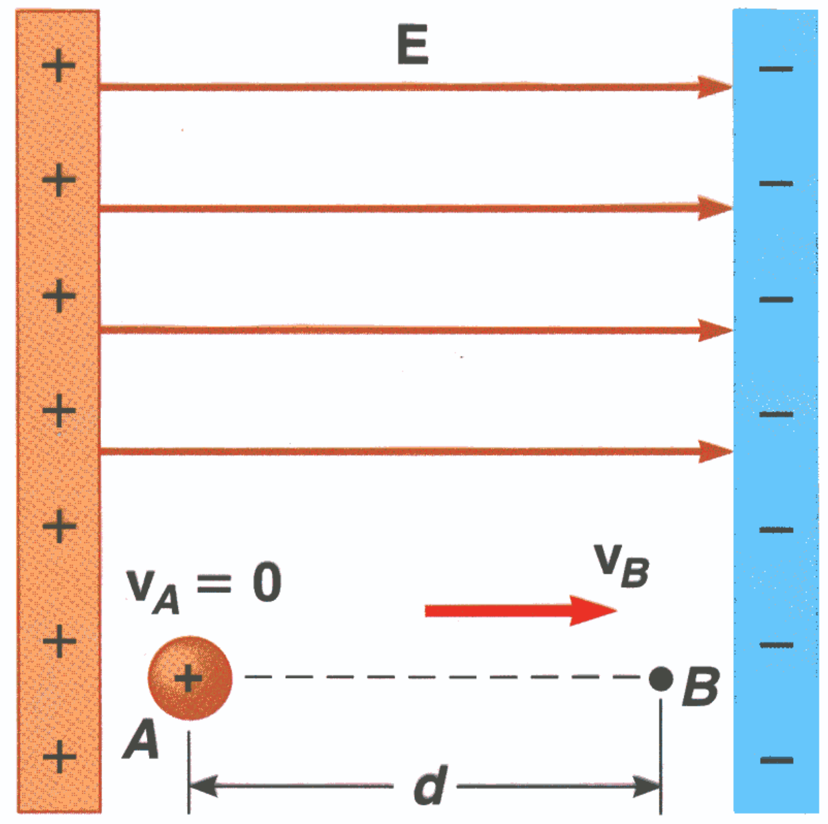
$$\text{and } \Delta \text{E=E}_{\text{kf}} - E_{ki} = \frac{1}{2} m \text{v}^2 - 0$$

$$\frac{1}{2} m \text{v}^2 = \Delta V q$$

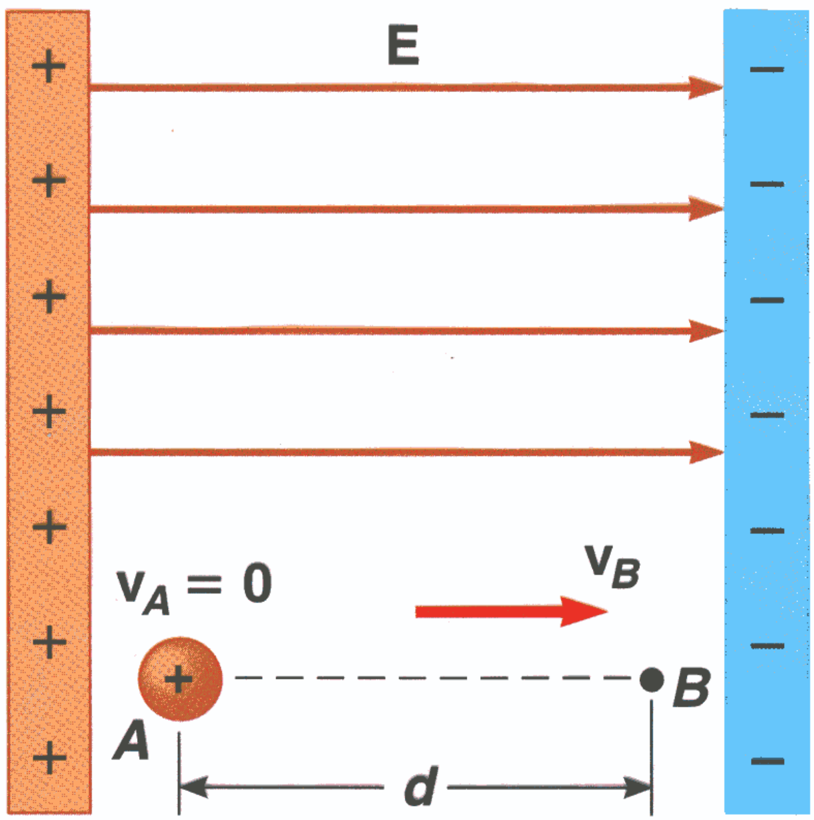
$$\text{v=}\sqrt{\frac{2\Delta V q}{m}}$$

Example

- A proton is released from rest in a uniform electric field of 8.0 x 10^4 V/m. The proton is displaced 0.50 m in the direction of the electric field. Determine the potential difference between its initial and final positions.



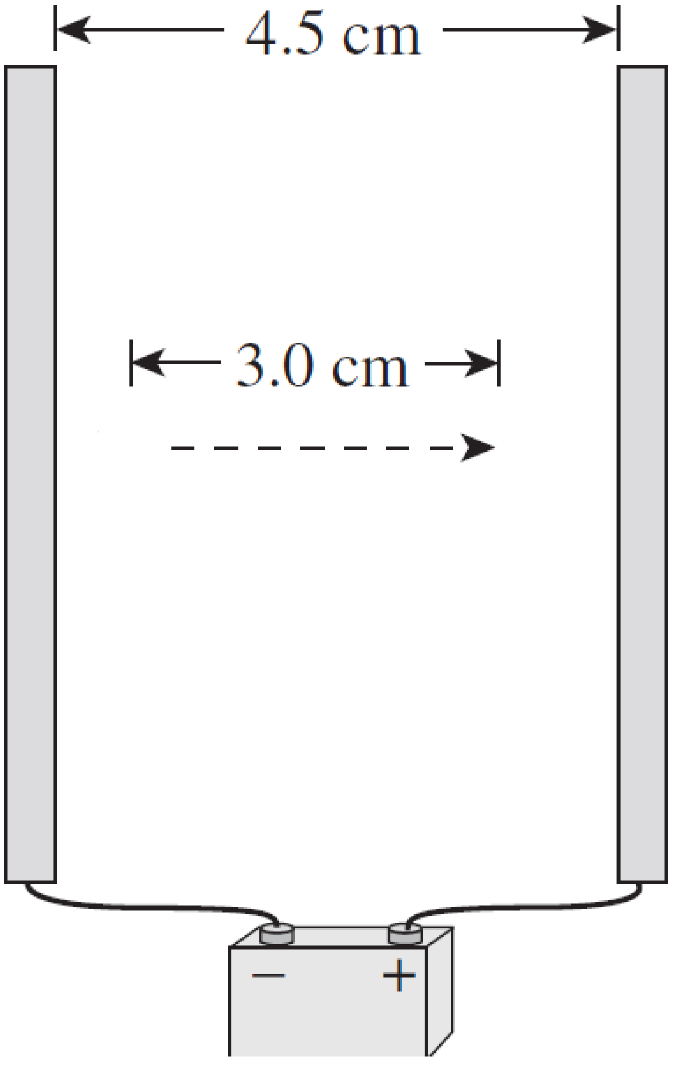
Solution



$$\left|\vec{E}\right| = \frac{\Delta V}{\Delta d}$$

$$\Delta V = \left|\vec{E}\right| \Delta d$$

Example



- Two parallel plates are 4.5 cm apart and connected to a 60 V power supply.

- Determine the potential difference between two points 3.0 cm apart

- $\Delta V = 40$ V

Example

- Two parallel plates are 3.00 cm apart and have a potential difference of 7.10×10^3 V between them. If an object having a surplus of 7 electrons is placed in the field, what is the magnitude of the electric force acting on it?

Solution

q = 7 x 1.60 x 10^{-19} C

$$\left|\vec{E}\right| = \frac{\Delta V}{\Delta d}$$

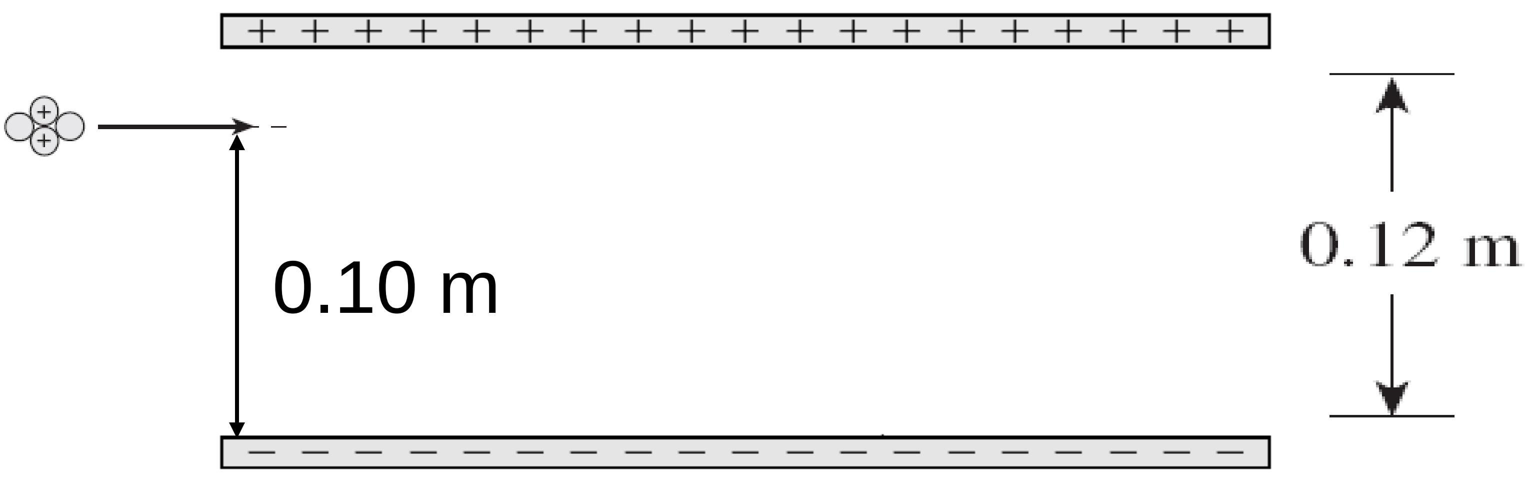
$$\left|\vec{E}\right| = \frac{\left|\vec{F}_e\right|}{q}$$

F_e =2.65 x 10^{-13} N

$$\frac{\Delta V}{\Delta d} = \frac{\left|\vec{F}_e\right|}{q}$$

Example

- Two plates are connected to a potential difference of 250 V and are 0.12 m apart. An alpha particle is fired at right angles to the electric field at 3.8 x 10^4 m/s. Where does the alpha particle hit the negative plate?



Solution

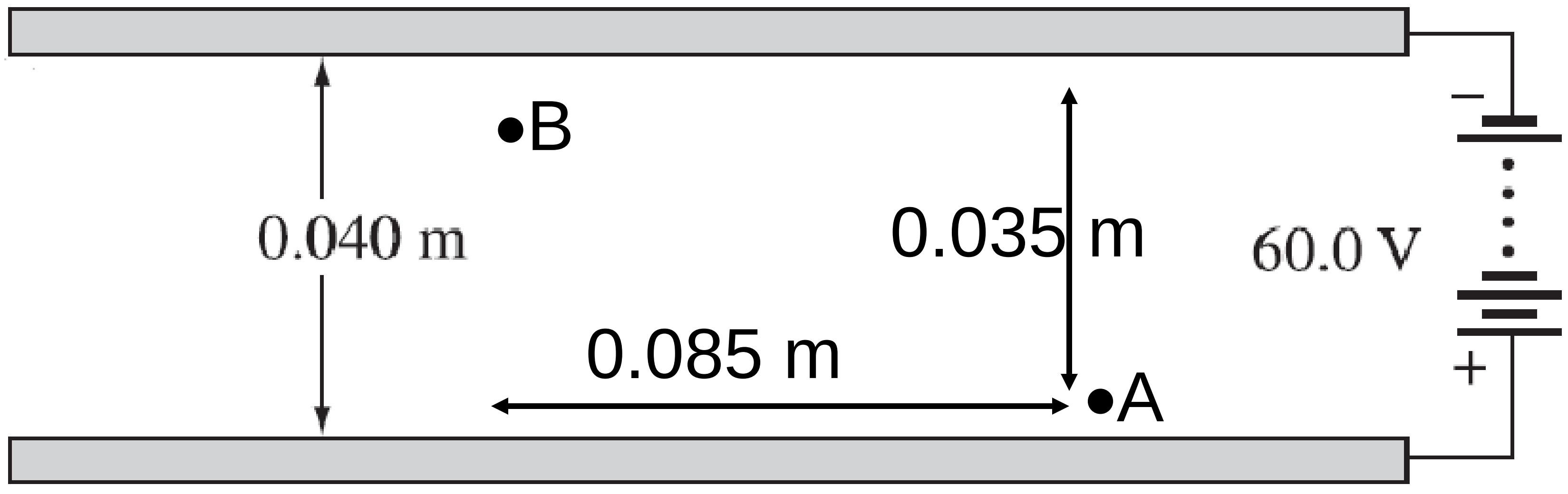
- Determine net force acting on alpha particle (ignore gravity) Unbalanced forces in y-direction
- $F = 6.6667 \times 10^{-16}$ N
- Determine acceleration of alpha particle
- $a = 1.0025 \times 10^{11}$ m/s^2

Solution

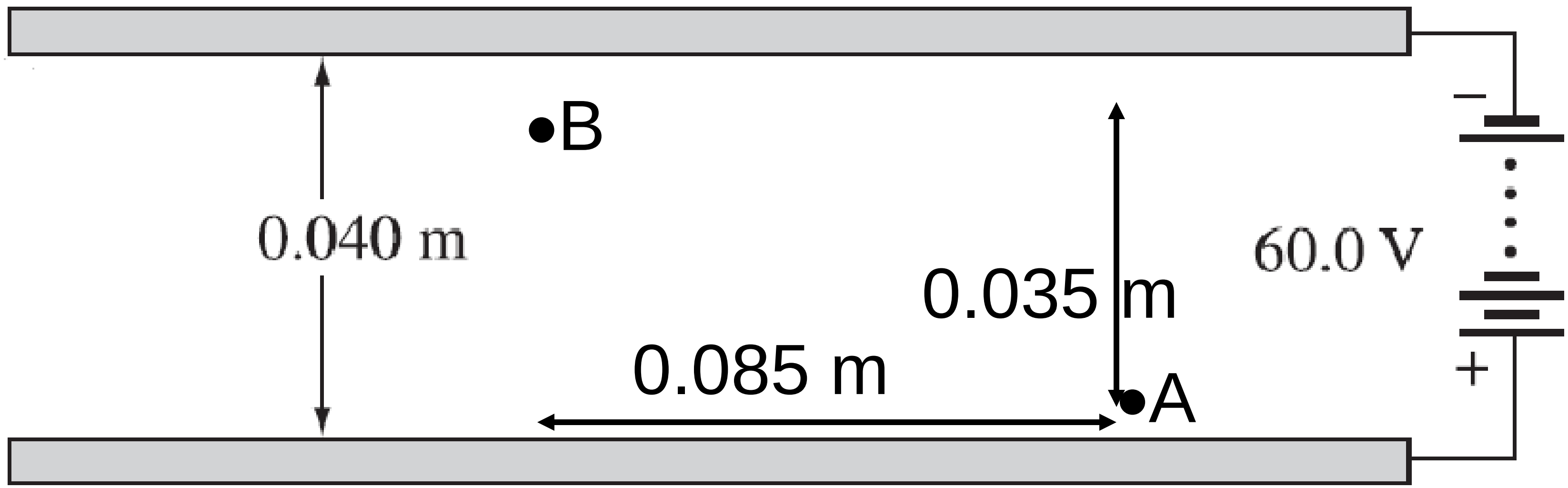
- Find time to hit – plate using $d=v_it + ½ at^2$ ($v_i = 0$ towards - plate)
- $t = 1.41244 \times 10^{-6}$ s
- Balanced forces (Uniform motion) parallel to plates
- d = vt = 0.054 m from the left edge

Example

- Determine the work done to move an electron from A to B



Solution



$$\left|\vec{E}\right| = \frac{\Delta V}{\Delta d}$$

$$\left|\vec{E}\right| = 1500V/m$$

$$\left|\vec{E}\right| = \frac{\left|\vec{F}_e\right|}{q}$$

No work is done on the charge to move it ⊥ to the field

$$1500 \quad V/m = \frac{\left|\vec{F}_e\right|}{q}$$

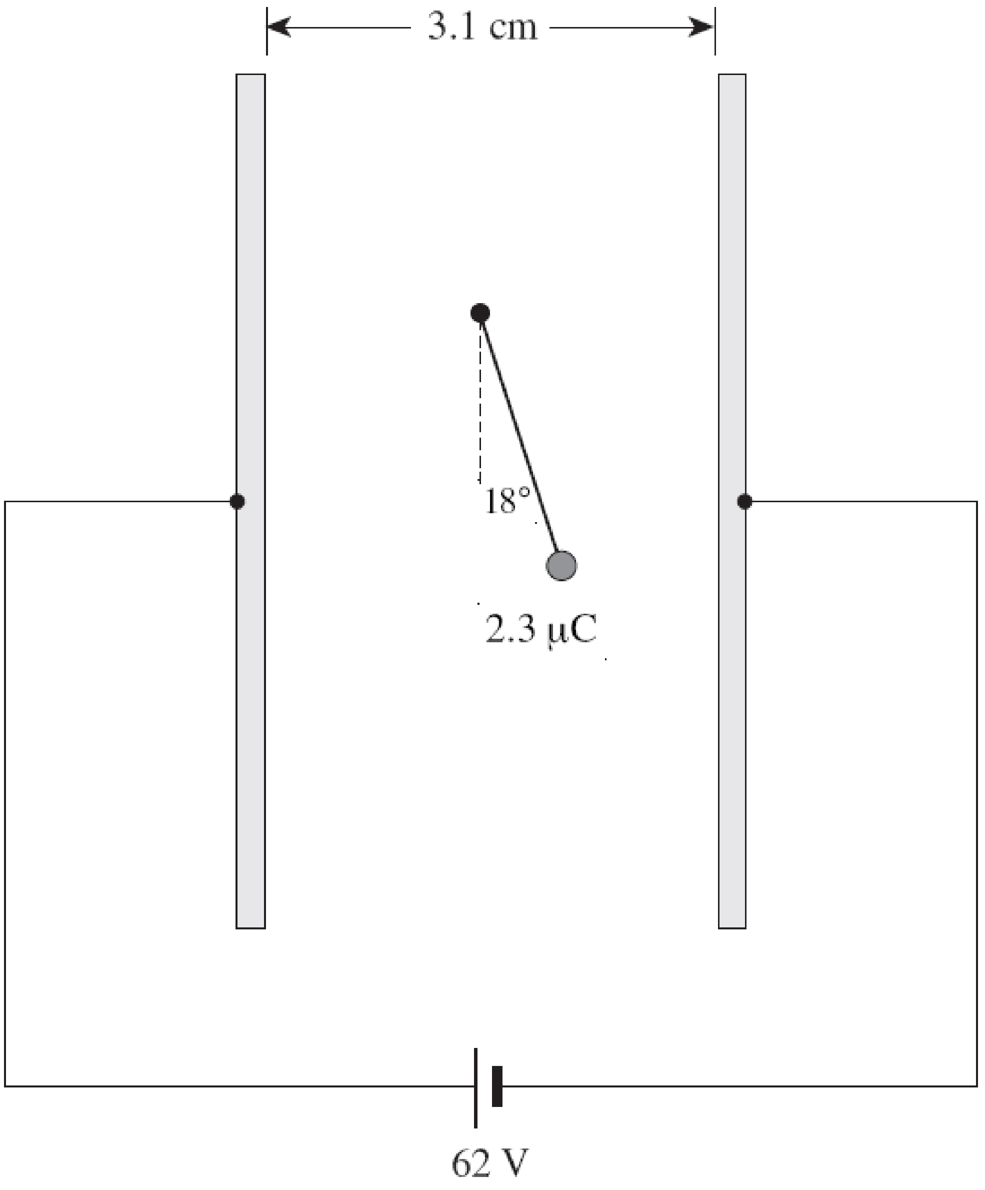
W = ΔE

W = Fd cosθ

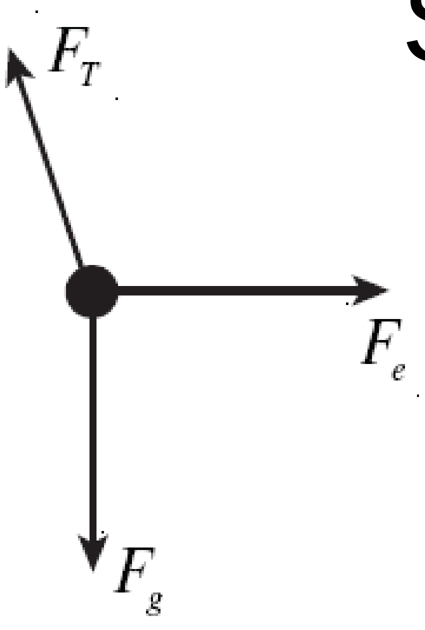
W = 8.4 x 10^{-18} J

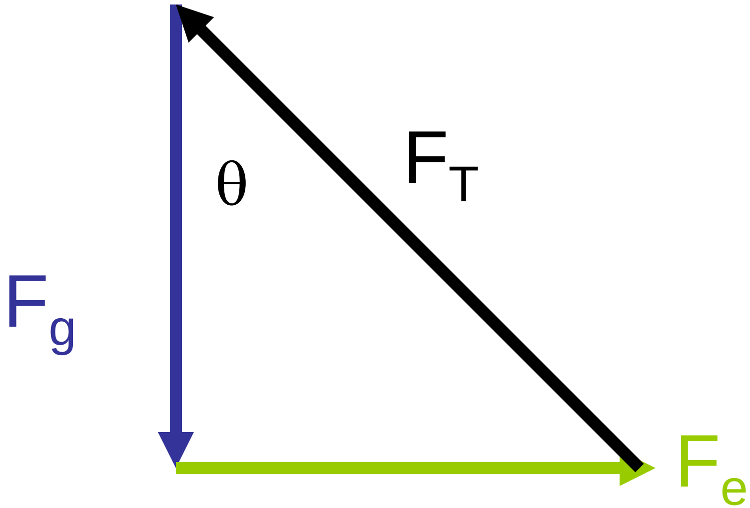
Example

- A small sphere with a charge of magnitude 2.3 μC is suspended from a thread hanging between two charged plates as shown. What is the mass of the small sphere?



Solution: FBD!





$$\tan\theta = F_e / F_g$$

$$F_g = F_e / \tan\theta$$

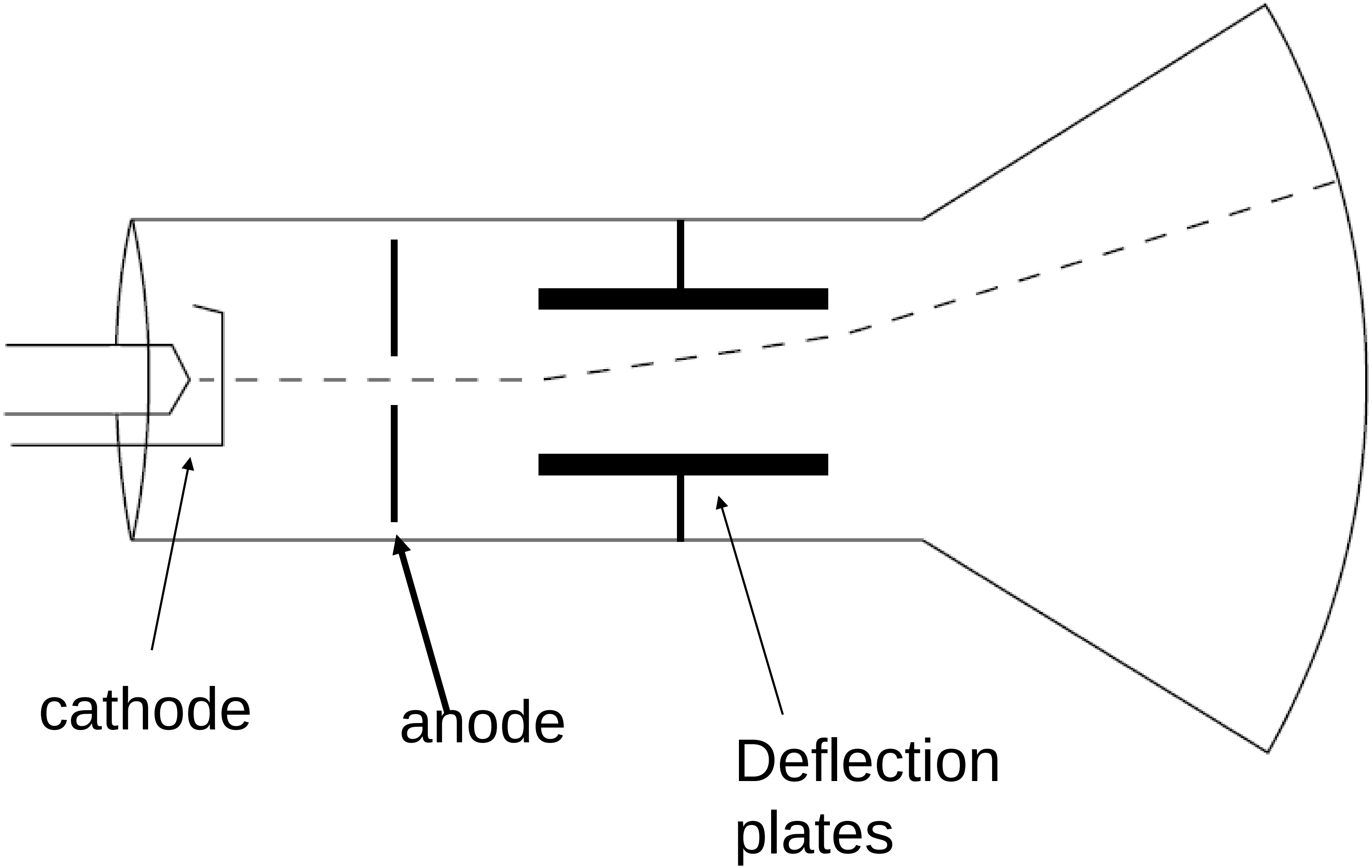
$$mg = qE / \tan\theta$$

$$mg = \frac{q \times V/d}{\tan\theta}$$

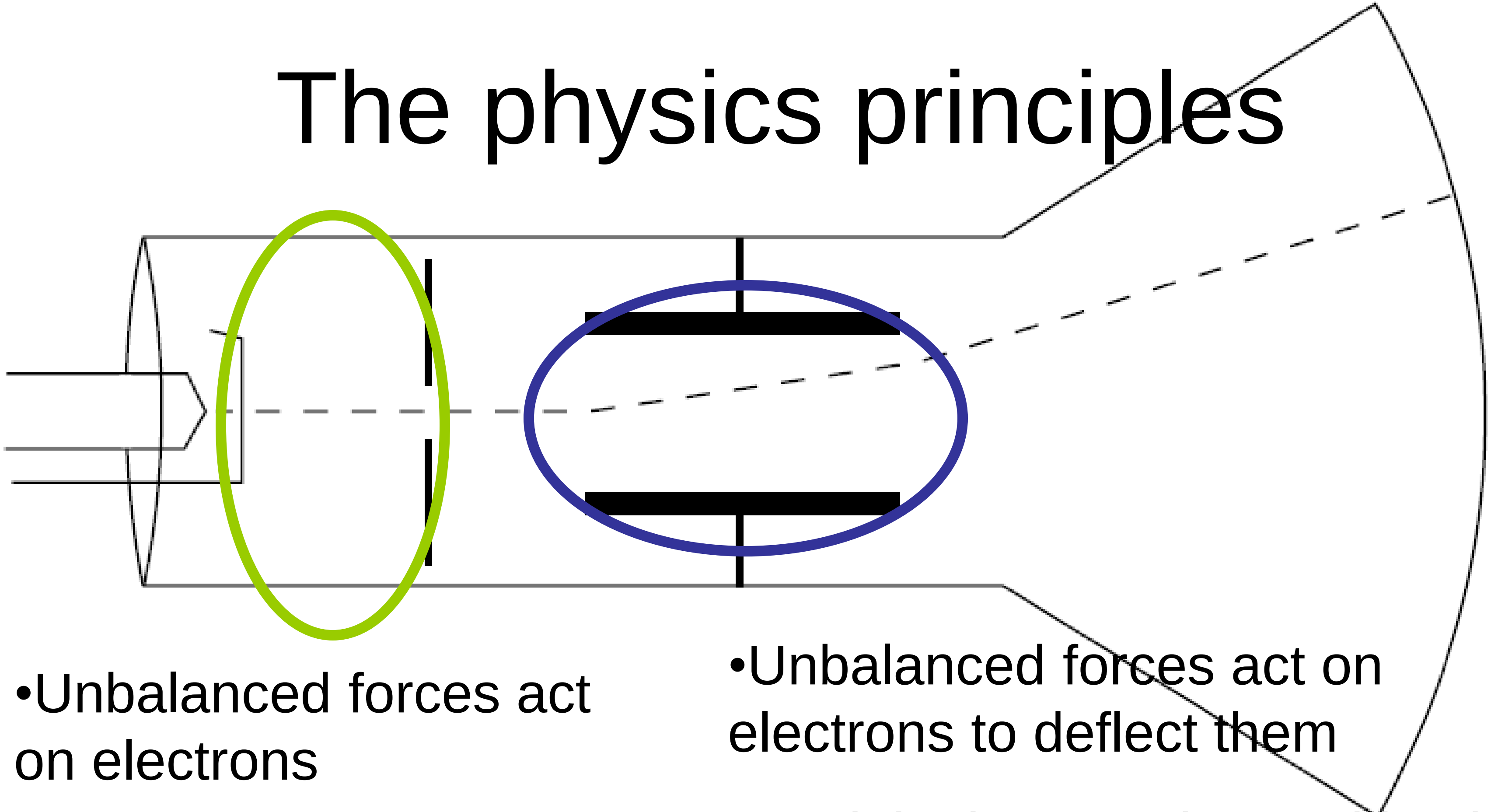
$m = 1.4 \times 10^{-3}$ kg

Cathode Ray Tube

- uses electric fields between parallel plates to accelerate electron beams
- electric field is caused by a very high potential difference between the two plates
- cathode is heated to make the electrons easier to pull off


cathode
anode
Deflection
plates

The physics principles



- Unbalanced forces act on electrons
- Work is done to change kinetic energy of electrons, W = ΔE

- Unbalanced forces act on electrons to deflect them
- Work is done to change kinetic energy of electrons, W = ΔE

Millikan’s oil drop experiment

- developed an experiment to determine the elementary charge

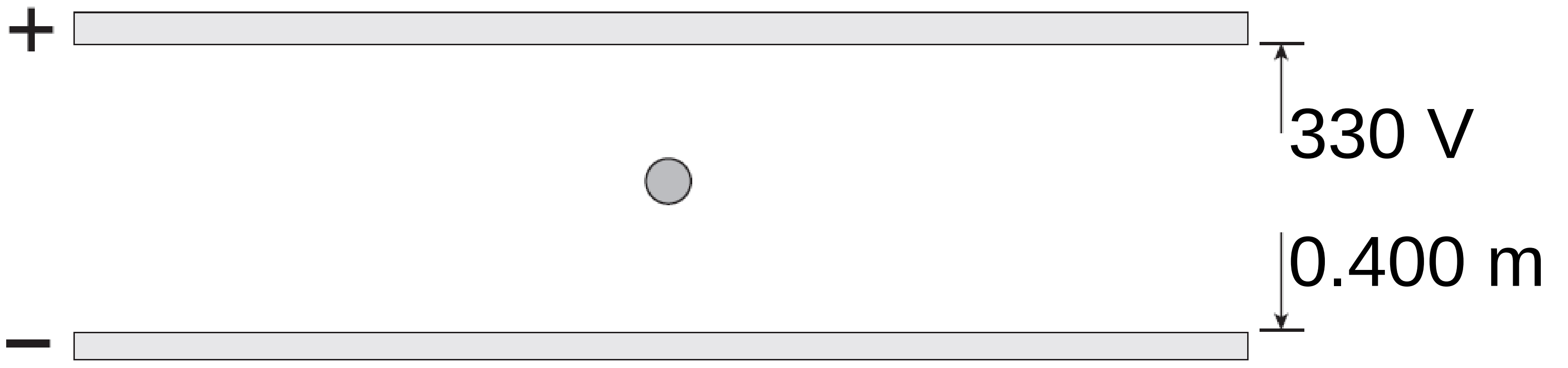
- injected charged oil drops into a vertical uniform electric field and balanced the electric and gravitational forces on the drops

- experiments showed that there was a smallest value of charge possible

- all the oil drops had whole number multiples of this smallest value

- charge is quantized

Example



- A 2.33×10^{-14} kg oil drop is moving vertically down at a uniform speed in a vertical electric field as shown. Determine the magnitude and sign of the charge on the drop & how many electrons were added or removed from the oil drop.

Solution

- for vertical uniform motion, balanced forces must act on drop: $F_g = F_e$

$$mg = \vec{E}\,q$$

$$q = \frac{mg}{\vec{E}}$$

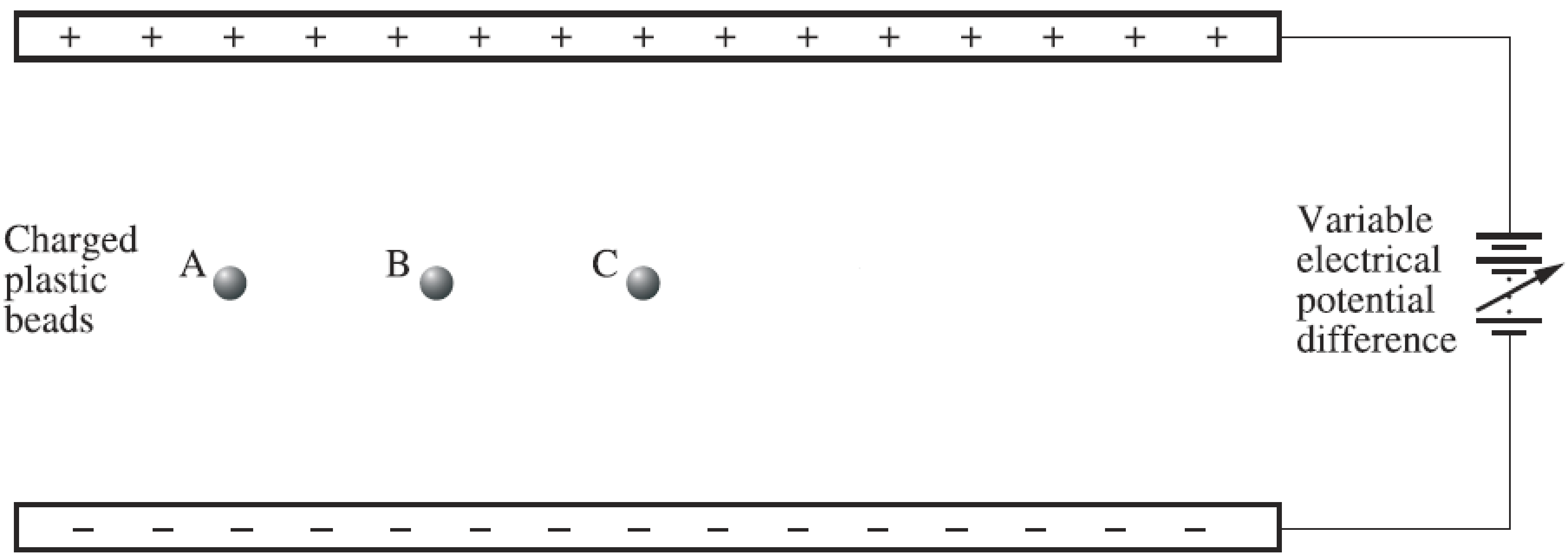
$$\vec{E} = \frac{V}{d} = \frac{330V}{0.400m} = 825N/C$$

$$q = \frac{2.33\times10^{-14}kg\left(9.81m/s^2\right)}{825N/C} = 2.77058\times10^{-16}C$$

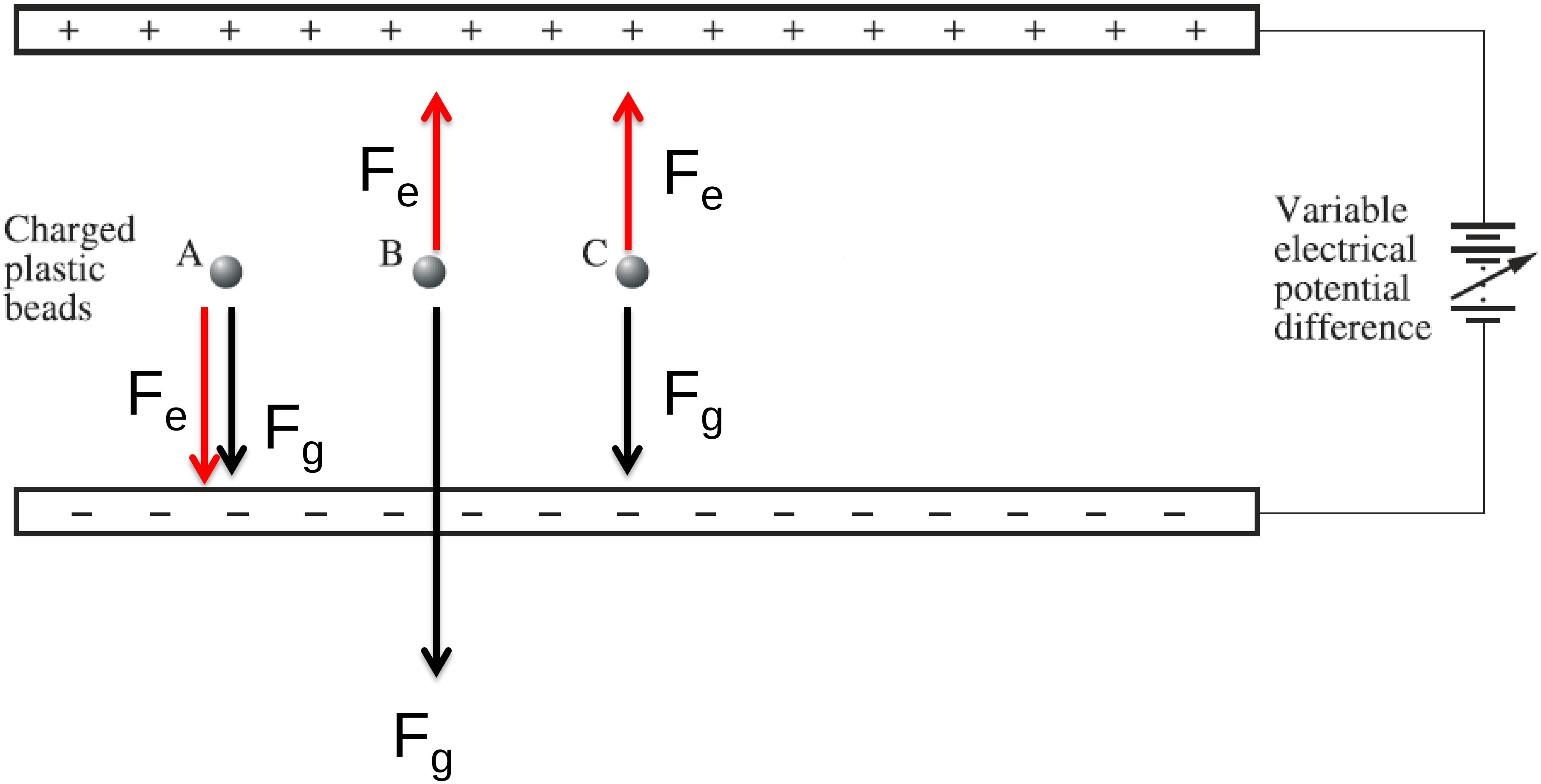
- The oil drop is negative since it must be attracted to the positive plate above it in order to balance the downward force of gravity. 1732 electrons were added.

Three charged beads are placed between two horizontal charged plates.

- A: charge +Q, mass m
- B: charge –Q, mass 2m
- C: charge -Q, mass m and is suspended
  Describe the motion of beads A and B



Free Body Diagram



Things to keep in mind:

- Direction of electric field is the direction a positive particle would move if placed in the field.

- $\vec{E} = \dfrac{\vec{F}_e}{q}$ applies to **any charge** placed in

  any external electric field (the field will exert a force on the charge)

- $|\vec{E}| = \frac{kq}{r^2}$ determines the electric field strength at a distance from a known point charge

- $\left|\vec{E}\right| = \frac{V}{d}$ is for the electric field between 2 parallel plates ONLY