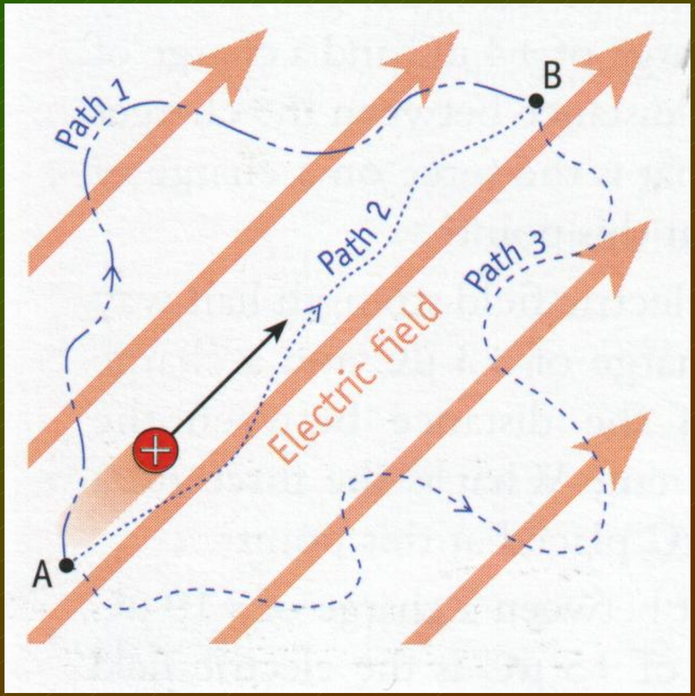
Chapter 20

Potential Difference

Capacitance

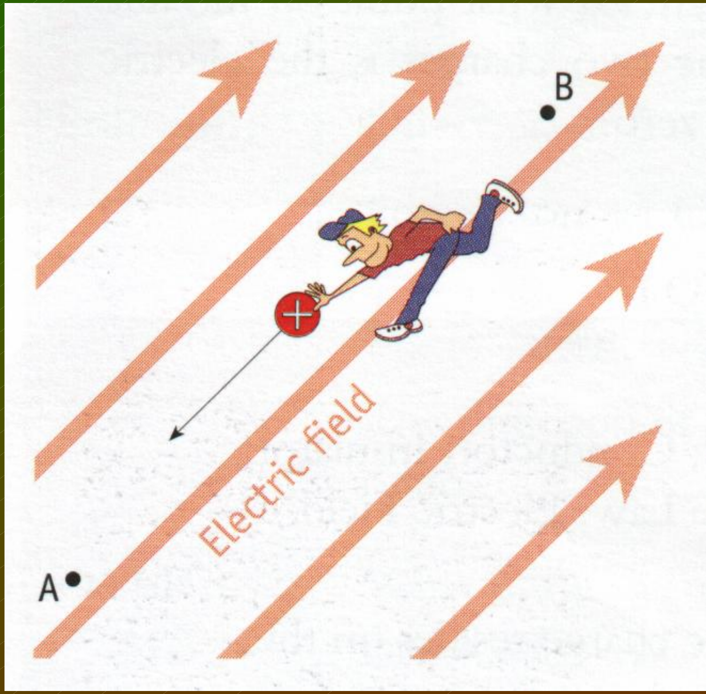
Potential Difference



- Electric field will move the charge from A to B
- Work is done by electric field on the charge
- Electric potential energy is lost by charge
- Potential difference between A and B

Gravity: ***mgh***

Potential Difference



- Charge must be pushed …
- Work is done against the electric field
- Electric potential energy is gained by the charge

Potential Difference (pd)

Voltage

Scalar

Work done
to move 1 C
from one point to another

$$V = \frac{W}{Q}$$

Unit: Volt (V)

$\equiv$ J C^{-1}

Definition of the Volt: 1 V = *pd* between two points
if 1 J of work is done
when moving 1 C from …

Measuring Potential Difference

- Voltmeter (Moving coil)
- Voltmeter (Digital)
- GLE …

  Cap to one point, case to other point

  The divergence of the leaves is a measure of pd between the two points.

Zero Potential

The Earth

Potential of a Point

The *pd* between the point and the Earth

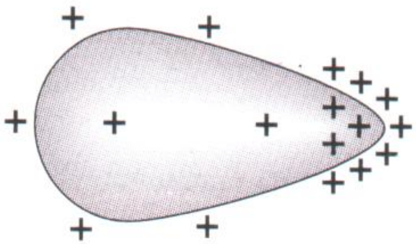
More charge on a body

➔ Greater potential

All points on a charged conductor have the same potential

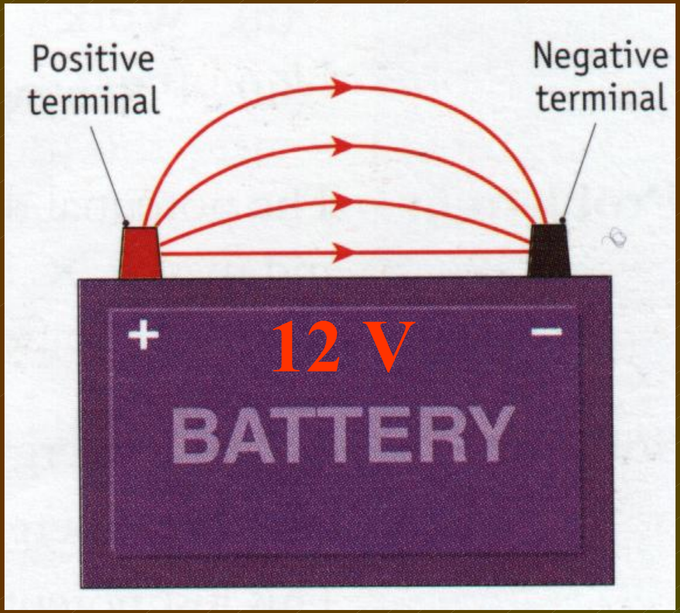
Example

Same potential for all points



pd

makes electric charge move



Electric Current is a flow of electric charge

Problem 3 The pd between two points is 100 kV.

Find the work done when a charge of 3 μC is moved from one point to the other.

$$V = \frac{W}{Q}$$

→ $W = QV$

→ $W = (3 \times 10^{-6})(100 \times 10^{3})$

→ $W = 0.3$ J

Problem 4 Two oppositely charged plates are 3 cm apart. There is a uniform electric field of strength 2×10^3 N C^{-1} between them.

(i) What is the force on +1 C placed between the plates?

(ii) Find the work done in bringing a charge of 1 C from one plate to the other.

(iii) What is the pd between the plates?

(i) $$E = \frac{F}{Q} \Rightarrow F = EQ = (2 \times 10^3)(1) = 2 \times 10^3 \text{ N}$$

Problem 4 Two oppositely charged plates are 3 cm apart. There is a uniform electric field of strength 2×10^3 N C^{-1} between them.

(i) What is the force on +1 C placed between the plates?

(ii) Find the work done in bringing a charge of 1 C from one plate to the other.

(iii) What is the pd between the plates?

(ii) Work = force x displacement

$$= (2 \times 10^3)(3 \times 10^{-2})$$

$$= 60 \text{ J}$$

Problem 4 Two oppositely charged plates are 3 cm apart. There is a uniform electric field of strength 2 x 10^3 N C^{-1} between them.

(i) What is the force on +1 C placed between the plates?

(ii) Find the work done in bringing a charge of 1 C from one plate to the other.

(iii) What is the pd between the plates?

(iii) Pd = work done in moving 1 C …

= 60 V

Problem 6 The pd between two points is 2000 V. An electron (of charge 1.6×10^{-19} C and mass 9.1×10^{-31} kg) is released at one of the points and moves towards the other under the action of the electric field. Find its speed when it arrives at the second point.

Work done by field on electron

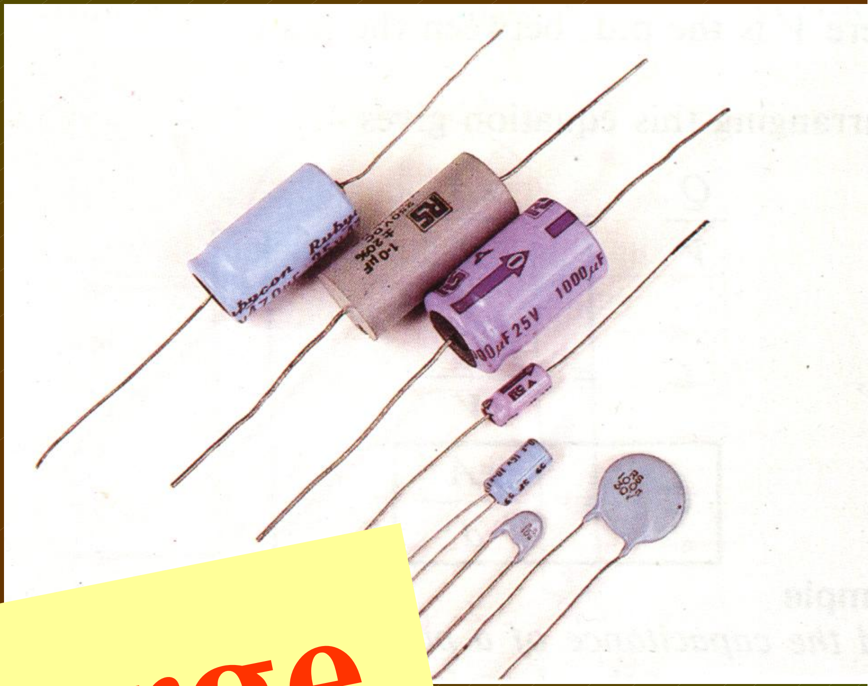
= Kinetic energy gained by electron

$QV = \frac{1}{2} mv^2$

$(1.6 \times 10^{-19})(2000) = \frac{1}{2} (9.1 \times 10^{-31}) v^2$

$v = 2.7 \times 10^7 \text{ m s}^{-1}$

Capacitors
- Capacitance



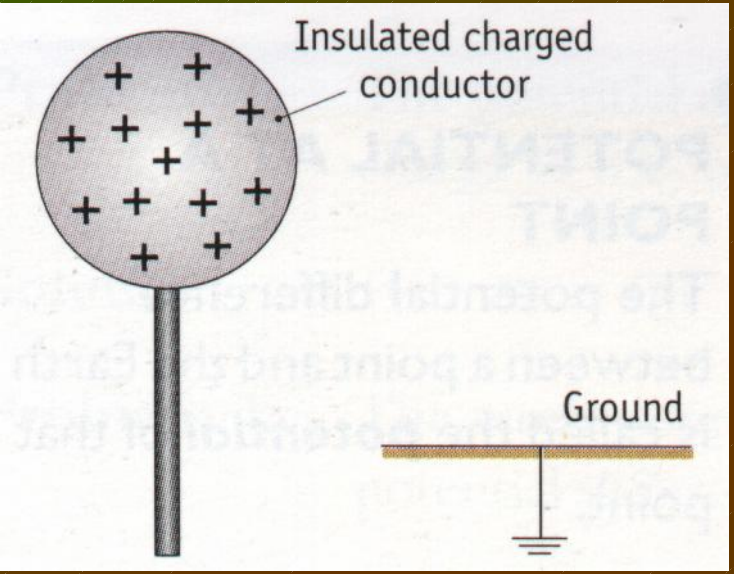
Store charge

Capacitance

As *Q* is added

V increases

Why?



$Q \propto V$

$Q = CV$

C = capacitance

Capacitance

Definition

$$C = \frac{Q}{V}$$

Unit of C **Farad (F)**

1 F = ??

1 F = capacitance if adding 1 C … raises the potential by 1 V

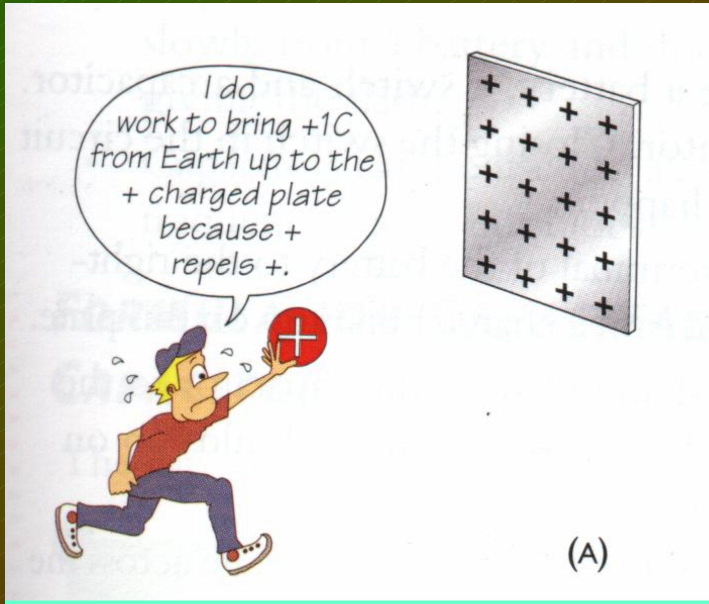
Practical Units Of Capacitance

μF	nF	pF
micro	nano	pico
10^{-6}	10^{-9}	10^{-12}

Problem 8 A conductor has a potential of 6 V when a charge of 6 μC is placed on it. What is its capacitance?

$$C = \frac{Q}{V} = \frac{6 \times 10^{-6}}{6} = 1 \times 10^{-6}\ \text{F} = 1\ \mu\text{F}$$

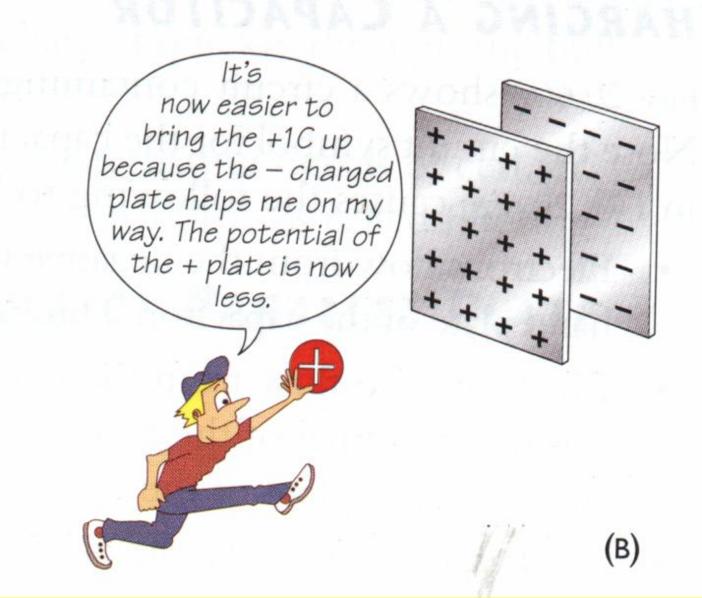
Why is the capacitance of a charged conductor increased by bringing an oppositely charged conductor near to it?



Work needed ..

➔ V (as $V = W/Q$)

➔ C

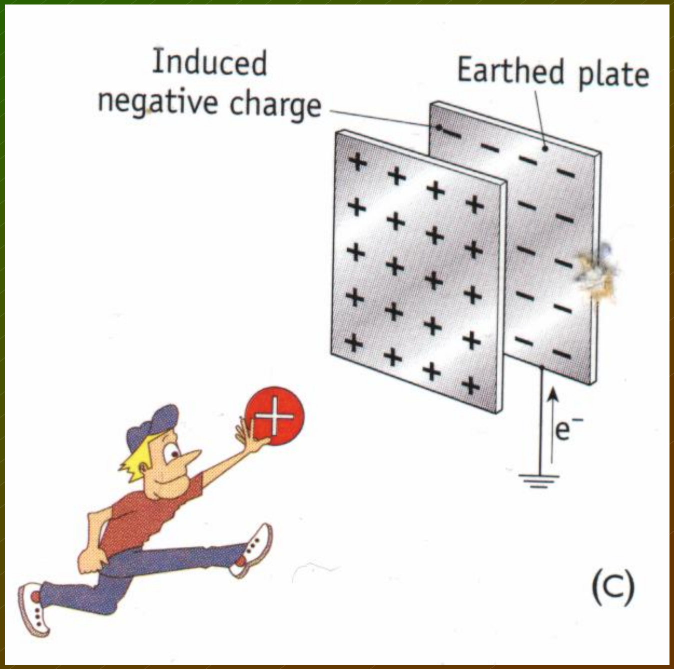


Less work needed

➔ Smaller V (as $V = W/Q$)

➔ Bigger C (as $C = Q/V$)

or Use an earthed conductor instead of oppositely charged conductor



Induced negative charge

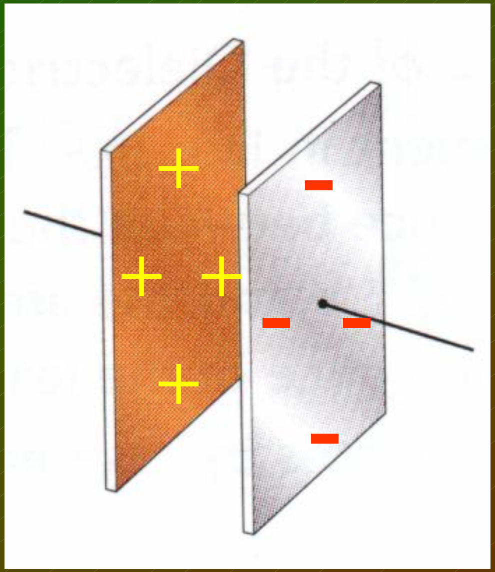
➔ **Same as …**

Less work needed

➔ **Smaller V** (as $V = W/Q$)

➔ **Bigger C** (as $C = Q/V$)

Parallel Plate Capacitor

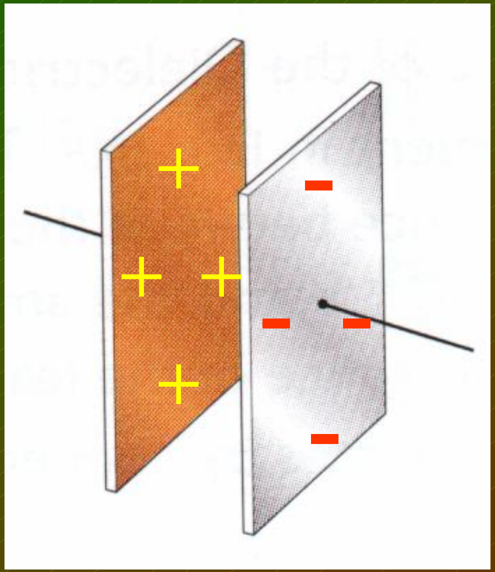


$$C = \frac{Q}{V}$$

2 metal plates

Insulator (dielectric)

Parallel Plate Capacitor



2 metal plates

Insulator (dielectric)

$$C = \frac{Q}{V}$$

$$C = \frac{A\varepsilon}{d}$$

A = common area of plates

d = distance between plates

ε = permittivity of dielectric

Problem 11 The area of overlap of the plates of an air spaced capacitor is 20 cm^2. The distance between the plates is 1 mm.

(i) Given $\varepsilon_o = 8.9 \times 10^{-12}$ F m^{-1}, find the capacitance.

(ii) If the space between the plates is now filled with mica of relative permittivity 7 calculate the capacitance.

(i) $$C = \frac{A\varepsilon}{d} = \frac{(20 x 10^{-4})(8.9 x 10^{-12})}{(1 x 10^{-3})} = 1.78 x 10^{-11} \text{ F}$$

Problem 11 The area of overlap of the plates of an air spaced capacitor is 20 cm^2. The distance between the plates is 1 mm.

(i) Given $\varepsilon_0 = 8.9 \times 10^{-12}$ F m^{-1}, find the capacitance.

(ii) If the space between the plates is now filled with mica of relative permittivity 7, calculate the capacitance.

(ii) $\varepsilon = \varepsilon_0 \times 7 = (8.9 \times 10^{-12}) \times 7 = 6.23 \times 10^{-11}$ F m^{-1}

$$C = \frac{A\varepsilon}{d} = \frac{(20 x 10^{-4})(6.23 x 10^{-11})}{(1 x 10^{-3})} = 1.25 x 10^{-10} \text{ F}$$

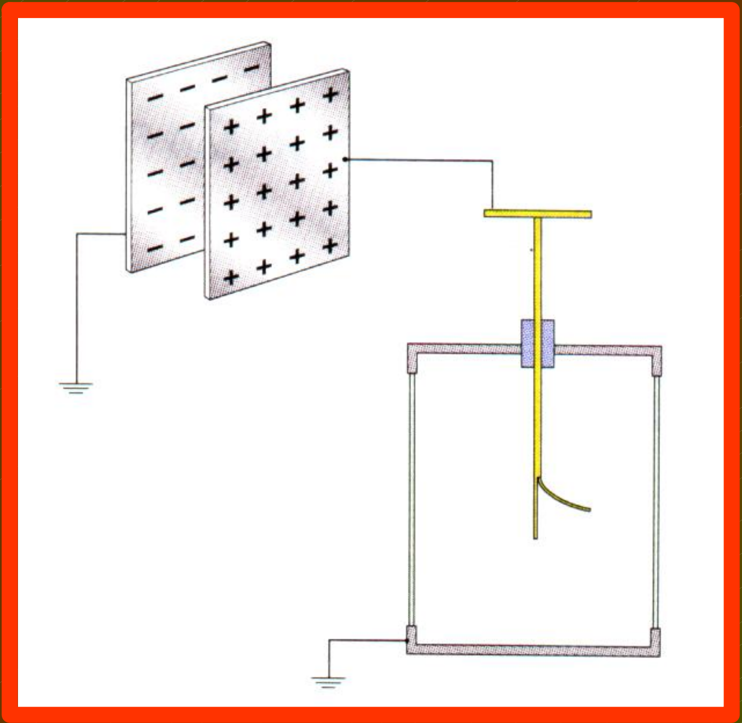
Problem 13 Show that the unit of permittivity is F m^{-1}.

$$C = \frac{A\varepsilon}{d} \Rightarrow \varepsilon = \frac{Cd}{A}$$

$$\Rightarrow \text{Units of } \varepsilon = \frac{\text{F m}}{\text{m}^2}$$

F m^{-1}

Demo $C = A\varepsilon/d$



$C = Q/V$

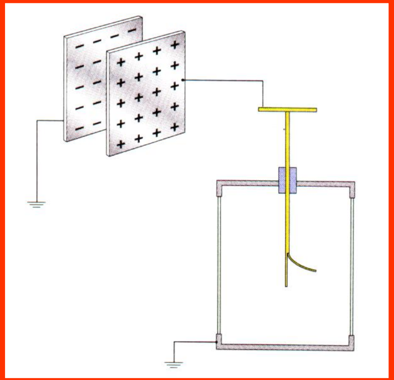
$C \propto 1/V$ (since Q is constant)

GLE measures V

∴ Greater divergence → Greater V → Smaller C

Demo $C = A\varepsilon/d$

$C \propto A$



Charge the capacitor …

Reduce *A* (keeping *d* constant) …

Leaves rise ➔ *V* increases

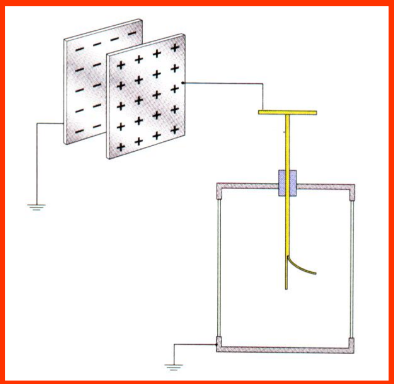
➔ *C* decreases

As *A* decreases *C* decreases

➔ $C \propto A$

Demo $C = A\varepsilon/d$

$C \propto 1/d$



Charge the capacitor …

Reduce *d* (keeping *A* constant) …

Leaves fall ➔ *V* decreases

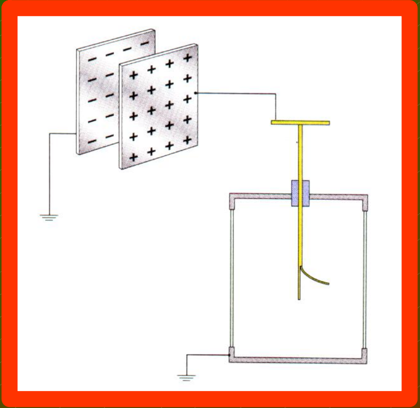
➔ *C* increases

As *d* decreases *C* increases

➔ $C \propto 1/d$

Demo $C = A\varepsilon/d$

$C \propto \varepsilon$



Charge the capacitor …

Increase ε **(add plastic insulator)**

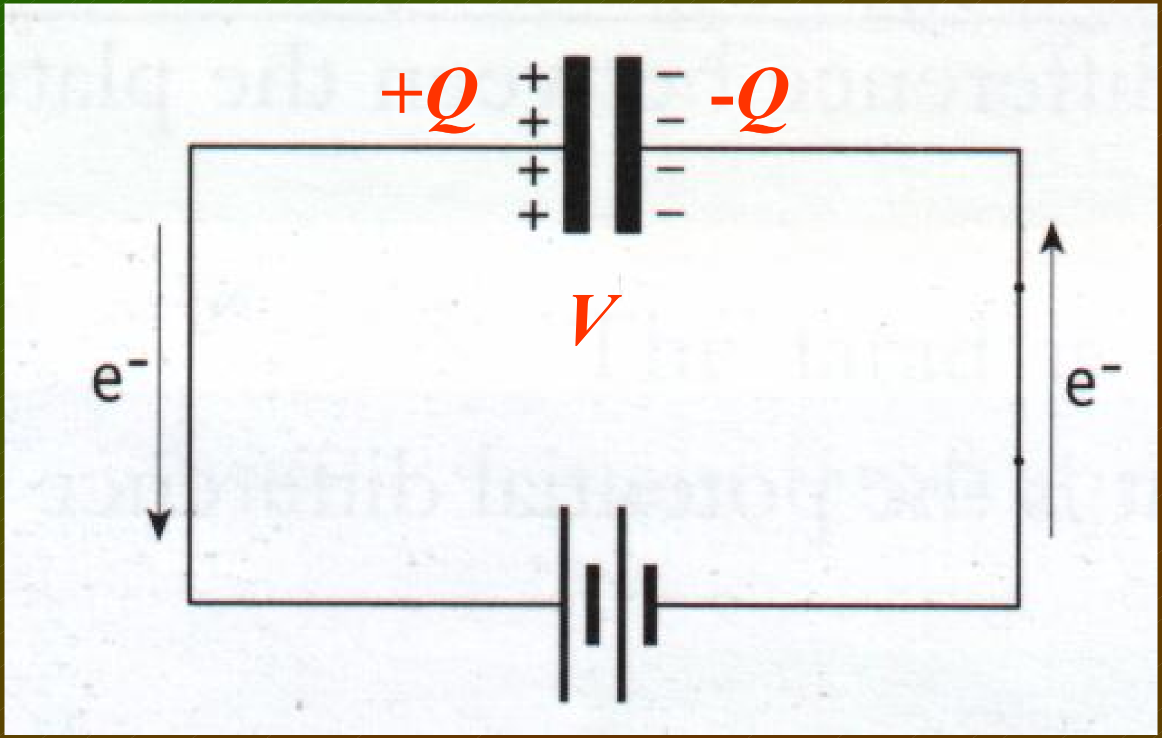
Leaves fall → V decreases

→ C increases

As ε increases C increases

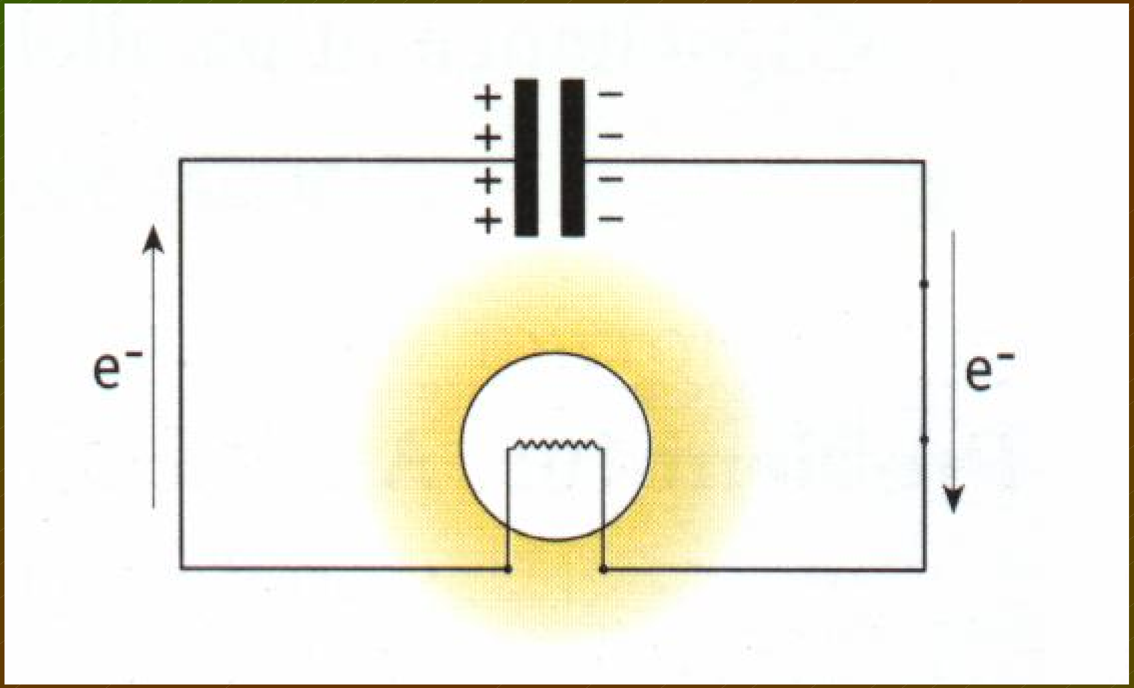
→ $C \propto \varepsilon$

Charging A Capacitor



$$C = \frac{Q}{V}$$

Discharging A Capacitor

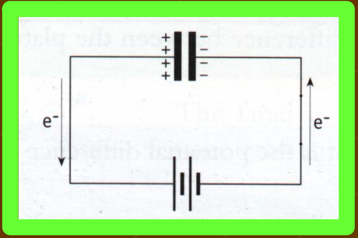


Demo A Charged Capacitor Stores Energy

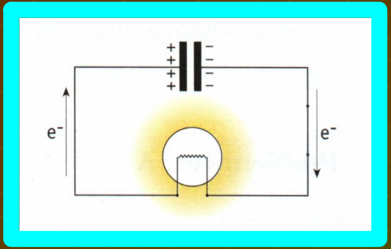
Apparatus Capacitor Battery Bulb

Procedure

1. Charge the capacitor
   by connecting it to the battery.



2. Discharge the capacitor
   by connecting it to the bulb.



Observation

The bulb flashes.

Conclusion

A charged capacitor stores energy.

or d.c. motor

Energy Stored In A Charged Capacitor

$$W = \tfrac{1}{2} CV^2$$ ***

Also
$$W = \frac{1}{2}\frac{Q^2}{C}$$

Problem 14 A capacitor of capacitance 2 μF is charged to a potential difference of 200 V. Find the energy stored in it.

$$W = \tfrac{1}{2} CV^2$$

$$= \tfrac{1}{2} (2 \times 10^{-6})(200)^2$$

$$= 0.04 \text{ J}$$

Problem 15 A capacitor of capacitance 0.47 μF carries a charge of 2.0 μC. Calculate, (i) the *pd* between the plates, (ii) the energy stored.

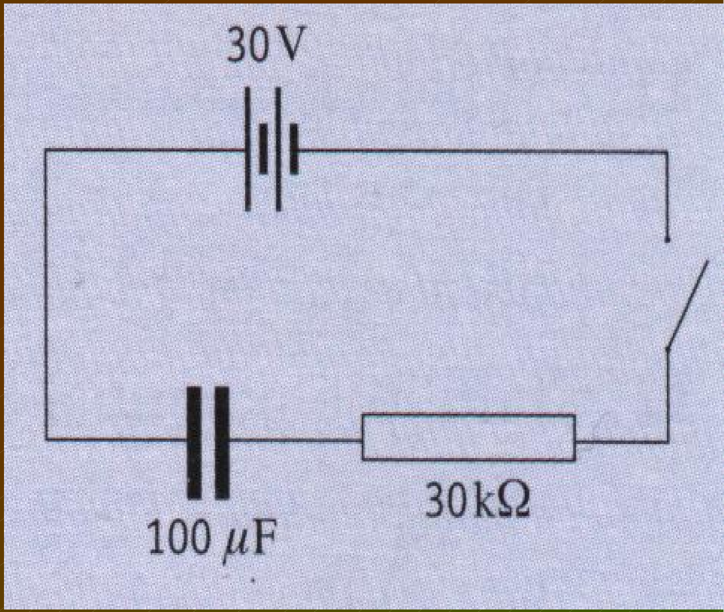
(i) $C = Q/V$ → $V = Q/C$ $= (2.0 \times 10^{-6}) / (0.47 \times 10^{-6})$

$= 4.26$ V

(ii) $W = \frac{1}{2} CV^2$ $= \frac{1}{2} (0.47 \times 10^{-6})(4.26)^2$

$= 4.26 \times 10^{-6}$ J

Problem 17 When the switch is closed, the current flowing at a particular instant is 0.5 mA. Find, (i) the *pd* across the capacitor at this instant, (ii) the charge on the capacitor at this instant.



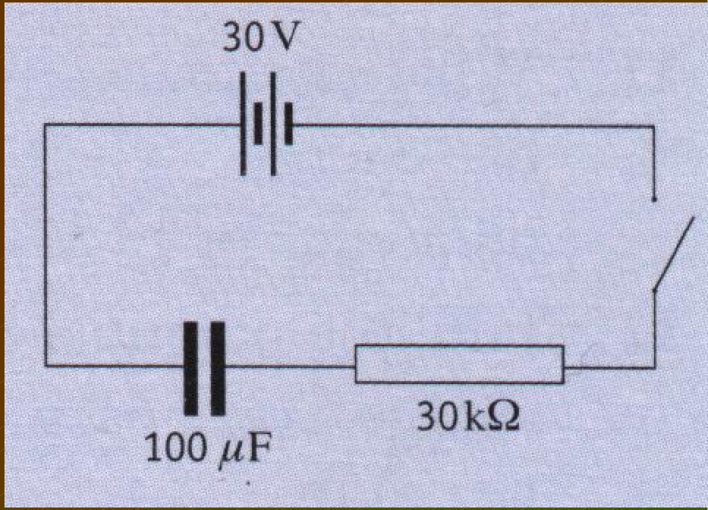
(i) *Pd* across resistor $= V = IR$

$= (0.5 \times 10^{-3})(30 \times 10^{3})$ $= 15$ V

→ *Pd* across capacitor

$= (30 - 15) = 15$ V

Problem 17 When the switch is closed, the current flowing at a particular instant is 0.5 mA. Find, (i) the *pd* across the capacitor at this instant, (ii) the charge on the capacitor at this instant.



(ii) Charge on capacitor

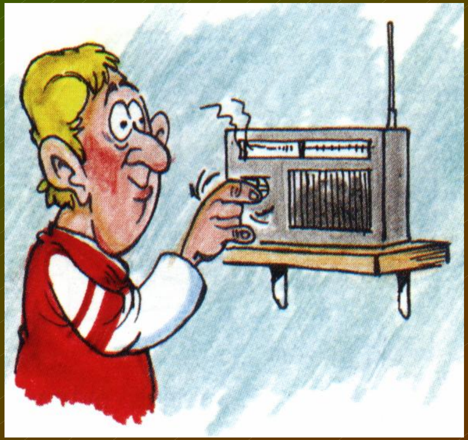
$= Q = CV$

$= (100 \times 10^{-6})(15)$

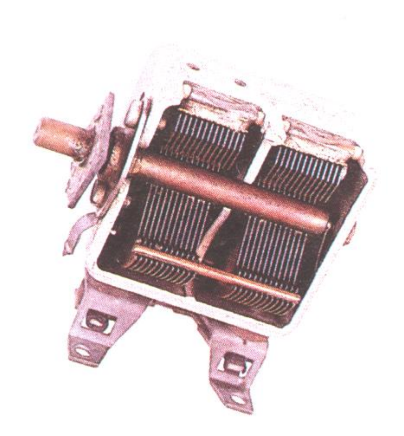
$= 1.5 \times 10^{-3}$ C

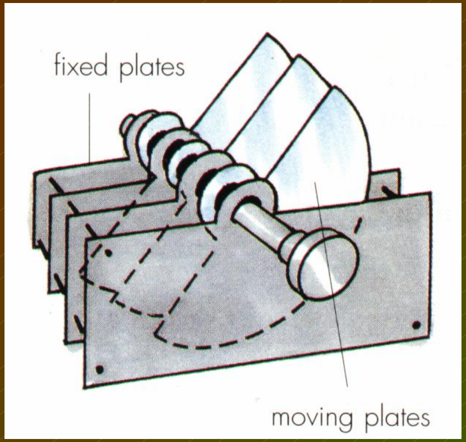
Common Uses Of Capacitors

Tune a radio



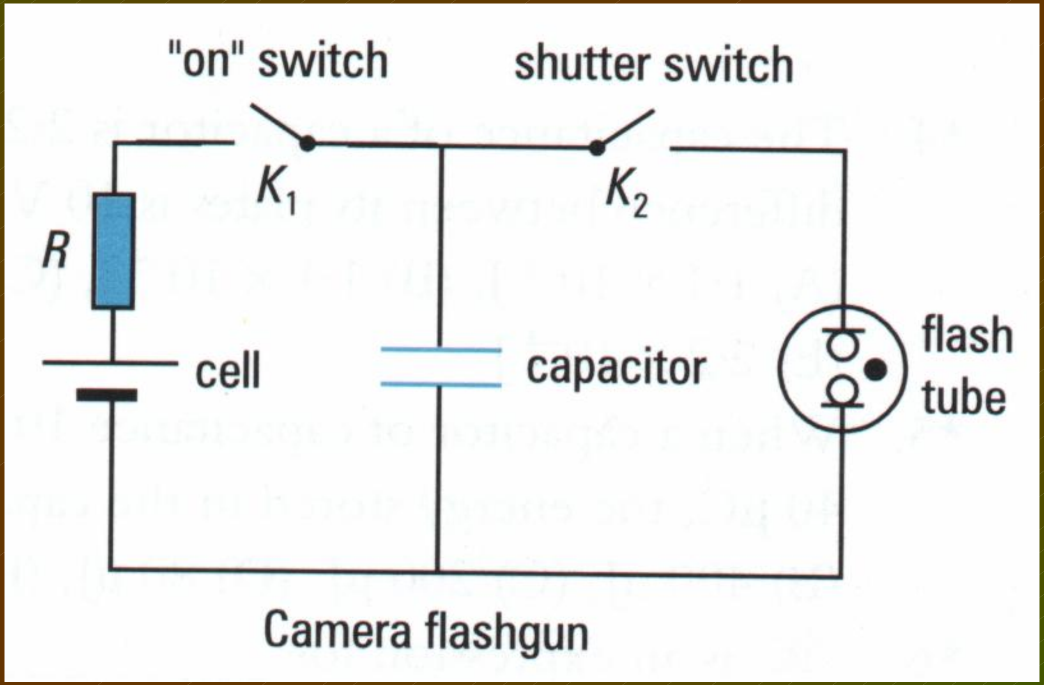
Variable capacitor





Common Uses Of Capacitors

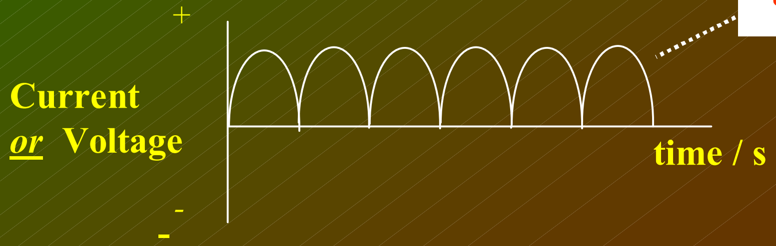
Camera flash



Common Uses Of Capacitors

Smoothing

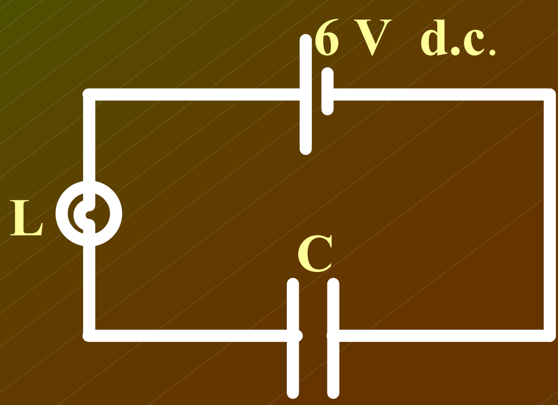
Converting this to this

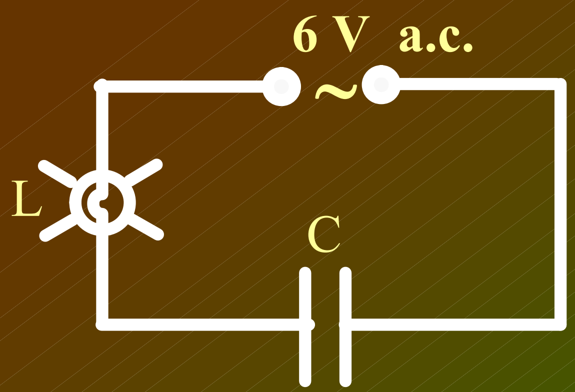


Common Uses Of Capacitors

Separate a.c. from d.c.

Capacitor "conducts" a.c. and blocks d.c.





Common Uses Of Capacitors

- **Tune a radio** (variable capacitor)
- **Camera flash**
- **Smoothing** (Smooth out variations in d.c. current)
- **Separate a.c. from d.c.** (Conduct a.c. but not d.c.)
- **Filtering** (removing unwanted a.c. frequencies)

Chapter 21