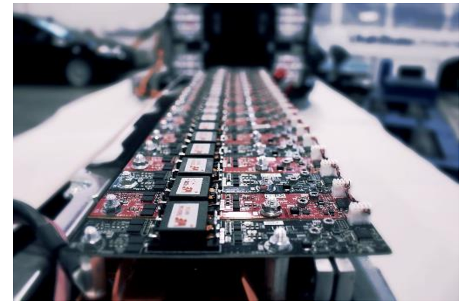
SASTRA
ENGINEERING · MANAGEMENT · LAW · SCIENCES · HUMANITIES · EDUCATION
DEEMED TO BE UNIVERSITY
(U/S 3 OF THE UGC ACT, 1956)
THINK MERIT | THINK TRANSPARENCY | THINK SASTRA

Unit - I
1.6 Electrostatics

Dr.Santhosh.T.K.

Battery Management Systems

- Comprises purpose-built electronics plus custom designed algorithms (computer methods)



- Example: If a PbA battery is not maintained at a high state-of-charge, lead sulphate deposits on both electrodes will begin to form hard crystals, which cannot be reconverted by a standard fixed-voltage (13.6 V) battery charger.

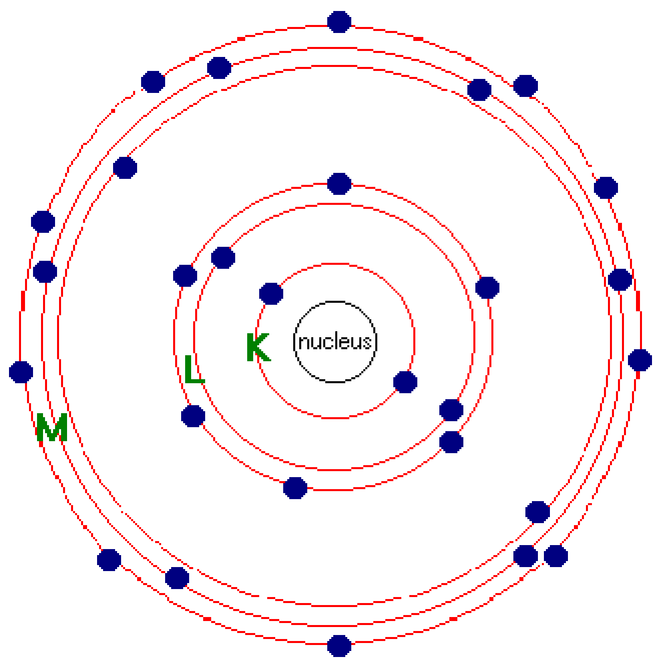
Syllabus

UNIT – I **10 Periods**

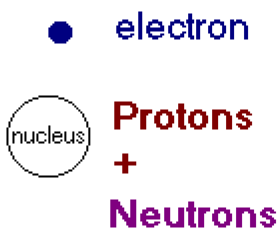
Introduction and Basic Concepts: Concept of Potential difference, voltage, current - Fundamental linear passive and active elements to their functional current-voltage relation - Terminology and symbols in order to describe electric networks - Concept of work, power, energy and conversion of energy- Principle of batteries and application.

Principles of Electrostatics: Electrostatic field - electric field intensity - electric field strength - absolute permittivity - relative permittivity - capacitor composite – dielectric capacitors - capacitors in series & parallel - energy stored in capacitors - charging and discharging of capacitors.

What makes a good conductor?



Nickel Atom



SHELL	Sub shell	Max # of electrons
K	s	2
L	s	2
	p	6
M	s	2
	p	6
	d	10

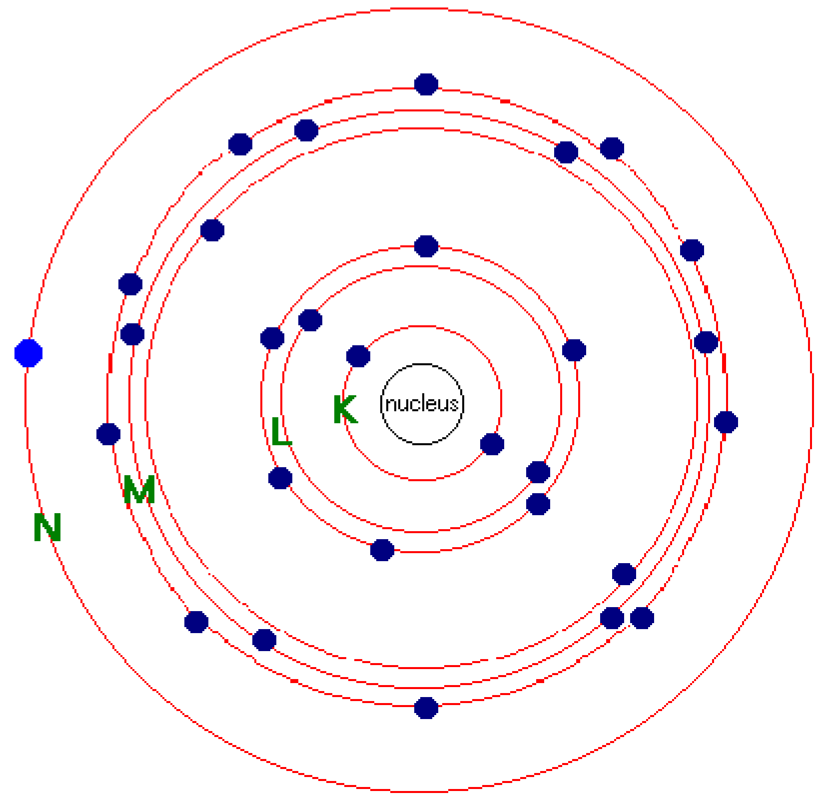
What makes a good conductor?

Copper atom

29 Protons

29 Electrons

29 Neutrons



Definition

- The branch of engineering which deals with the flow of electrons (i.e. electric current) is called current electricity
- Charges (i.e. electrons) do not move but remain static or stationary on the bodies
- The branch of engineering which deals with charges at **rest** is called electrostatics.

Electric Charge

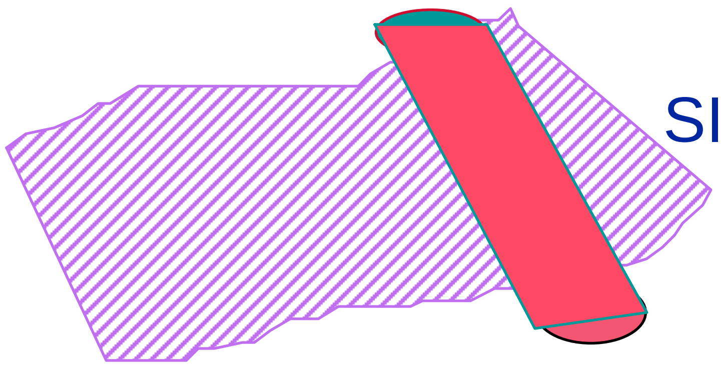
Let's introduce some definitions before we continue:

to quantify "electric charge" we label the amount of charge on a body as: q

$$\boxed{q = \text{quantity of electric charge}}$$

We can have $-q$ (negative charge)
or $+q$ (positive charge)

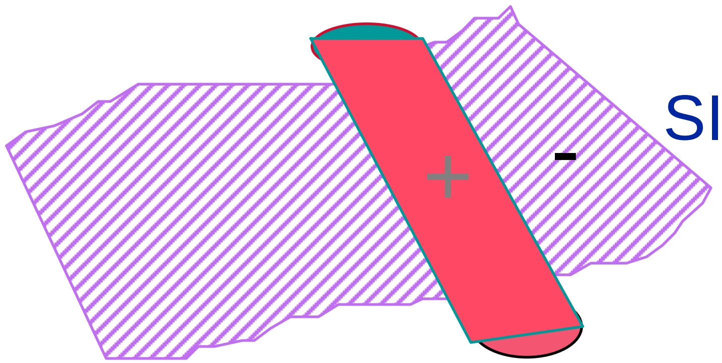
The Transfer of Charge



Some materials attract electrons more than others.

Electric Charge

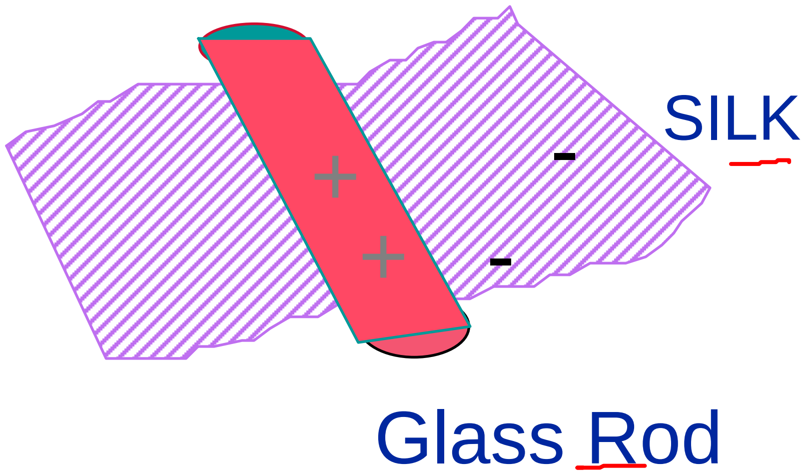
The Transfer of Charge



As the glass rod is rubbed against silk, electrons are pulled off the glass onto the silk.

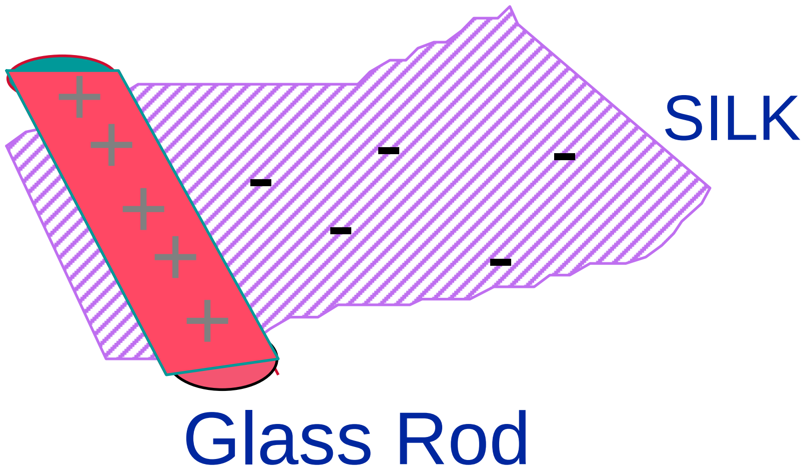
Electric Charge

The Transfer of Charge



Usually matter is charge neutral, because the number of electrons and protons are equal. But here the silk has an excess of electrons and the rod a deficit.

The Transfer of Charge



Glass and silk are insulators:
charges stuck on them stay put.

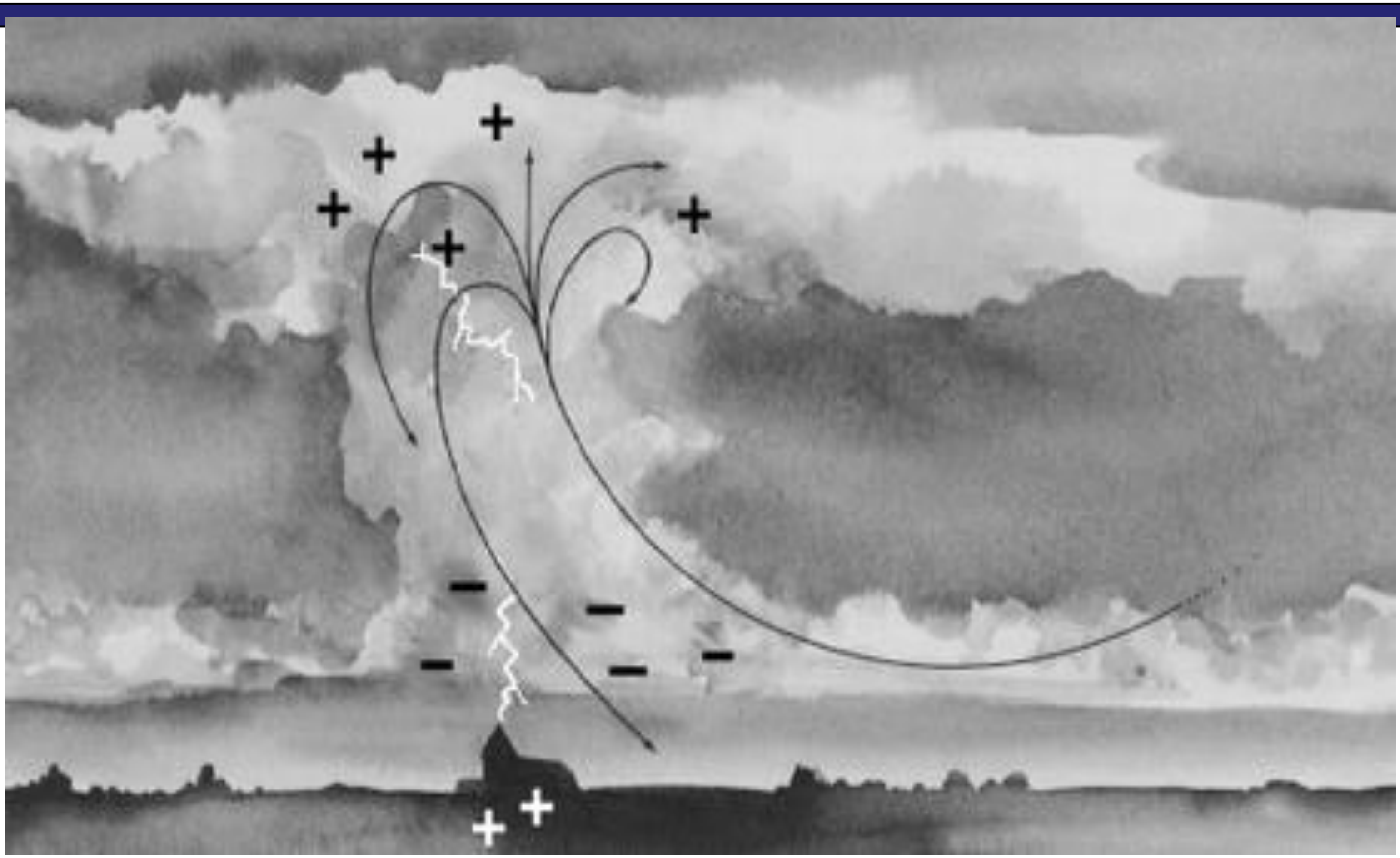
Charge is Quantized

q = multiple of an elementary charge e:

$e = 1.6 \times 10^{-19}$ Coulombs

	Charge	Mass	Diameter
electron	- e	1	0
proton	+e	1836	$\sim 10^{-15}$m
neutron	0	1839	$\sim 10^{-15}$m
positron	+e	1	0

(Protons and neutrons are made up of quarks, whose charge is quantized in multiples of e/3. Quarks can't be isolated.)



Typical current in a lightning bolt is 40,000 Amperes (that's about 40,000 Coulombs per second) with a voltage of up to 100,000,000 volts.

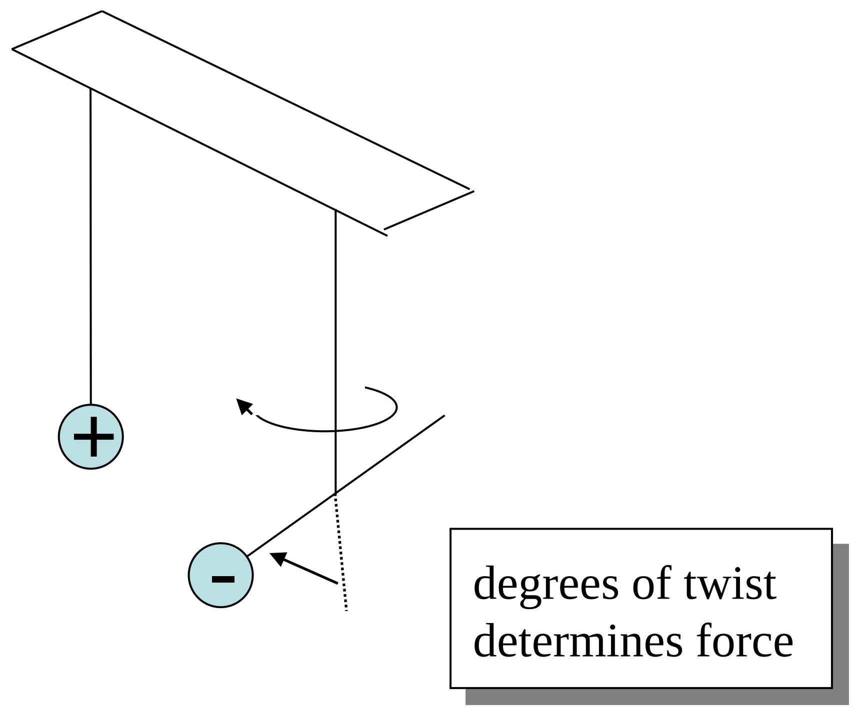
Some Important Applications

- Electrostatic generators for X-ray
- Spray of paints, powder
- Fly ash capture
- Development of lightning rod
- Capacitor
- Insulation design to avoid sparks in HV circuits

Coulomb’s Experiment

quantifies the attractive and repulsive behavior we observe in electrostatics

Coulomb used a torsion balance (similar to the one Cavendish used to determine the gravitational constant)



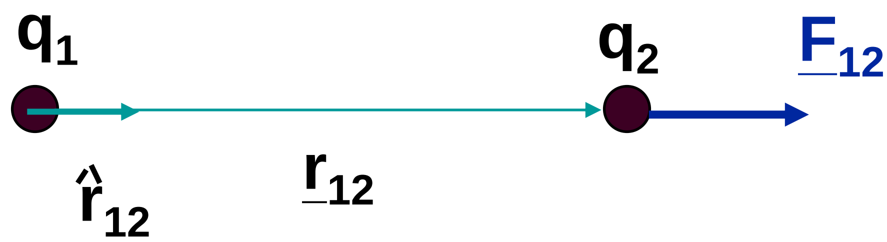
Coulomb's First Law

Like charges repel each other while unlike charges attract each other.

Coulomb’s Second Law

- The force between two point charges is directly proportional to the product of their magnitudes and inversely proportional to the square of distance between their centres.
- Charged bodies approximate to ***point charges*** if they are small compared to the distance between them.

Coulomb's Law (combined)



$$\overrightarrow{F_{12}} = \frac{k q_1 q_2}{d^2} \times \hat{d}$$

Force on 2 due to 1

$k = (4\pi\varepsilon_0)^{-1} = 9.0 \times 10^9 \ \mathrm{Nm^2/C^2}$

ε_0 = permitivity of free space

$= 8.854 \times 10^{-12} \ \mathrm{C^2/Nm^2}$ (F/m)

Coulomb's law describes the interaction between bodies due to their charges

Coulomb

- One coulomb is that *charge which when placed in air at a distance of one metre from an equal and similar charge repels it with a force of* $9 \times 10^9\ N$
- Coulomb is very large unit of charge in the study of electrostatics
- Practical units : pico-coulomb (pC) and micro-coulomb (μC)

Relative Permittivity

- If the space between the charges is another material or air, the law may be written

$$\overrightarrow{F_{12}} = \frac{1}{4\pi\varepsilon_0\varepsilon_r}\frac{q_1q_2}{d^2} \times \hat{d}$$

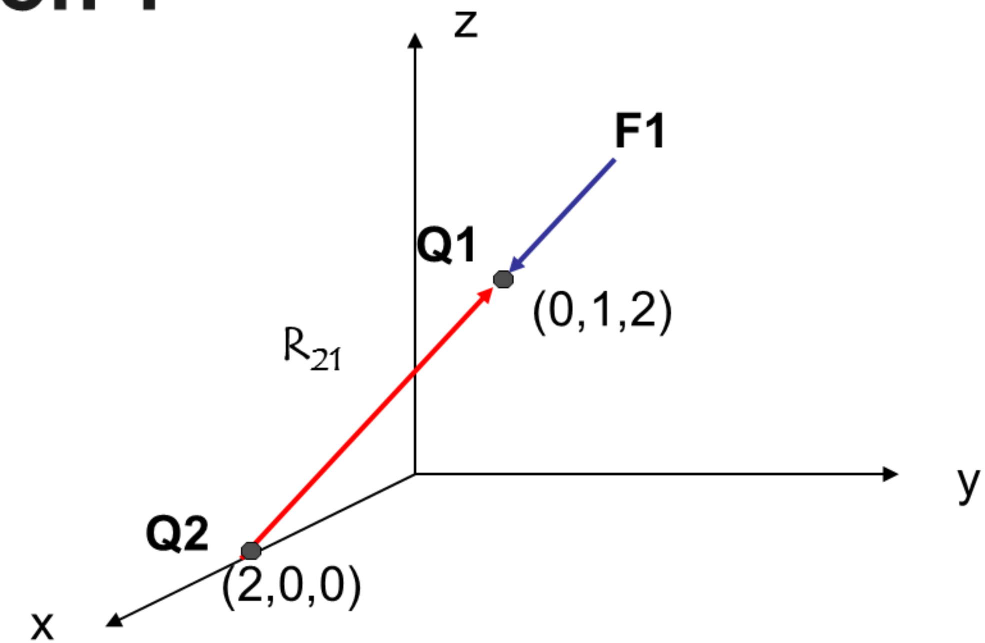
where

$\mathcal{E}_r$ = relative permittivity of material.

Example 1

Find the force on charge Q1, 20 μC, due to charge Q2, -300 μC, where Q1 is at (0,1,2)m and Q2 at (2,0,0)m

Solution 1



Solution 1 (cont'd)

- Because 1C is a rather large unit, charges are often given in microcoulombs (μC), nanocoulombs (nC) and picocoulombs (pC).

Referring to figure,

$R_{21}=-2a_x+a_y+2a_z$

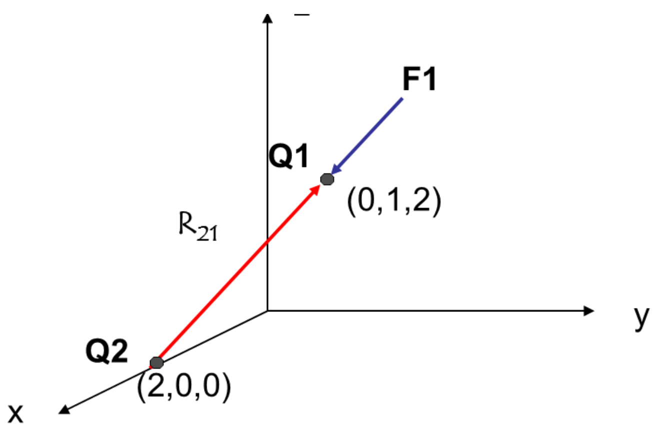
$R=3$

$a_{21}=1/3(-2a_x+a_y+2a_z)$

$$\text{using Coulmb's Law equation; } F_{12}=\frac{Q_1Q_2}{4\pi\varepsilon_0|R_{12}|^2}a_{12}$$

$$F_{21}=\frac{(20\times10^{-6})(-300\times10^{-6})}{4\pi(8.854\times10^{-12})(3)^2}\left(\frac{-2a_x+a_y+2a_z}{3}\right)$$

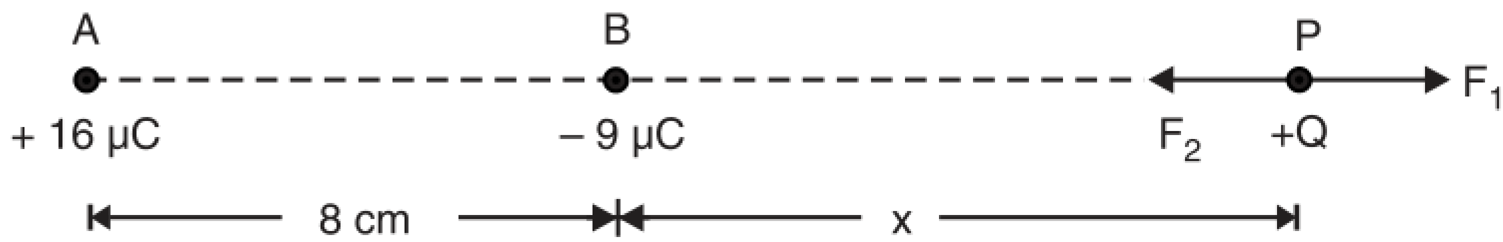
$$=6\left(\frac{2a_x-a_y-2a_z}{3}\right)N$$



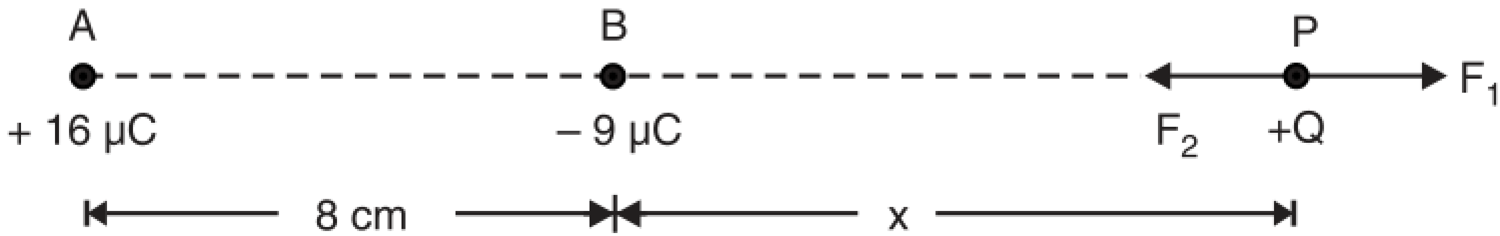
The force magnitude is 6N and the direction is such that Q_1 is attracted to Q_2 (unlike charges attract)

Example 2

- Two point charges of +16 μC and −9 μC are 8 cm apart in air. Where can a third charge be located so that no net electrostatic force acts on it ?



Solution



Force at P due to charge + 16 μC at A is

$$F_1 = k\frac{16\times10^{-6}\times Q}{(x+0.08)^2} \quad \text{along } AP$$

Force at P due to charge −9 μC at B is

$$F_2 = k\frac{9\times10^{-6}\times Q}{x^2} \quad \text{along } PB$$

For zero electrostatic force at P, $F_1 = F_2$.

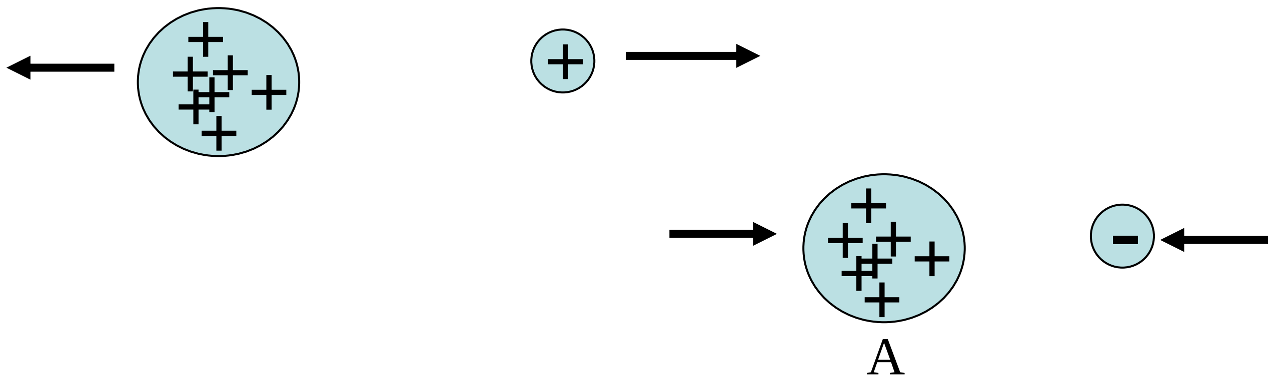
$$\therefore \quad k\frac{16\times10^{-6}\times Q}{(x+0.08)^2} = k\frac{9\times10^{-6}\times Q}{x^2}$$

$$\text{or} \quad \frac{16}{(x+0.08)^2} = \frac{9}{x^2} \quad \text{or} \quad \frac{4}{x+0.08} = \frac{3}{x}$$

$$\therefore \quad x = 0.24 \text{ m} = \mathbf{24\ cm}$$

The Electric Field

Between two charged bodies there is a force, F, of attraction or repulsion:

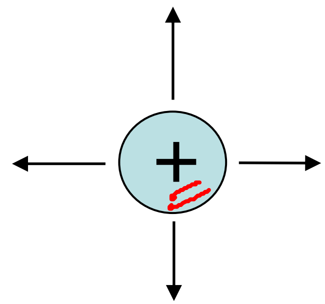


We don't understand why; we can only say this is what happens.

We can think of a charged body as *changing the nature of the space surrounding it*.

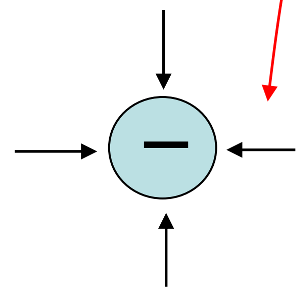
Direction of the Electric Field

Outward (away) from a positive charge



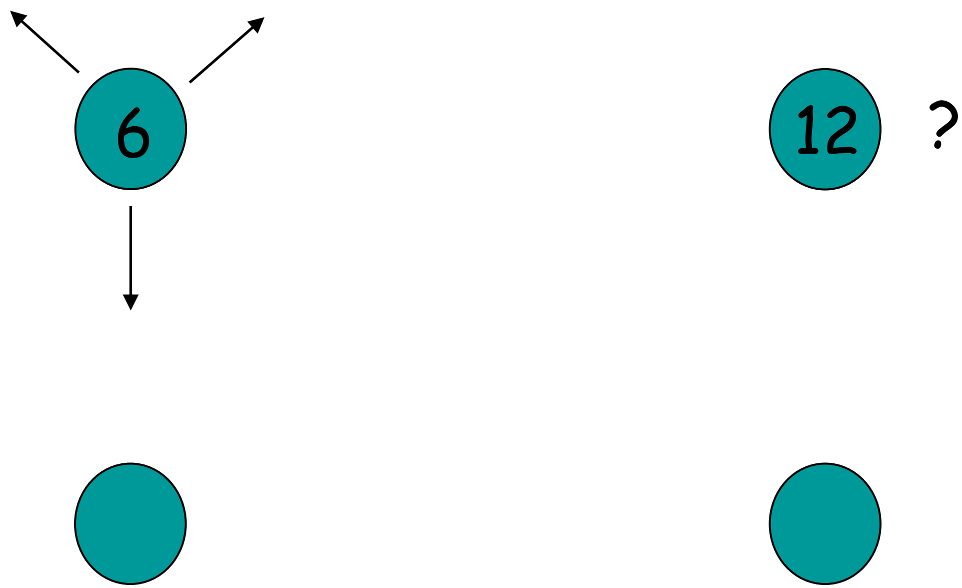
These are called "field arrows"

Inward (towards) a negative charge



Direction of the Electric Field

We draw the number of arrows proportional to the charge…more charge, more arrows. Say the charges are in "μCoulombs" (that's micro-coulombs, or 10^{-6} Coulombs)



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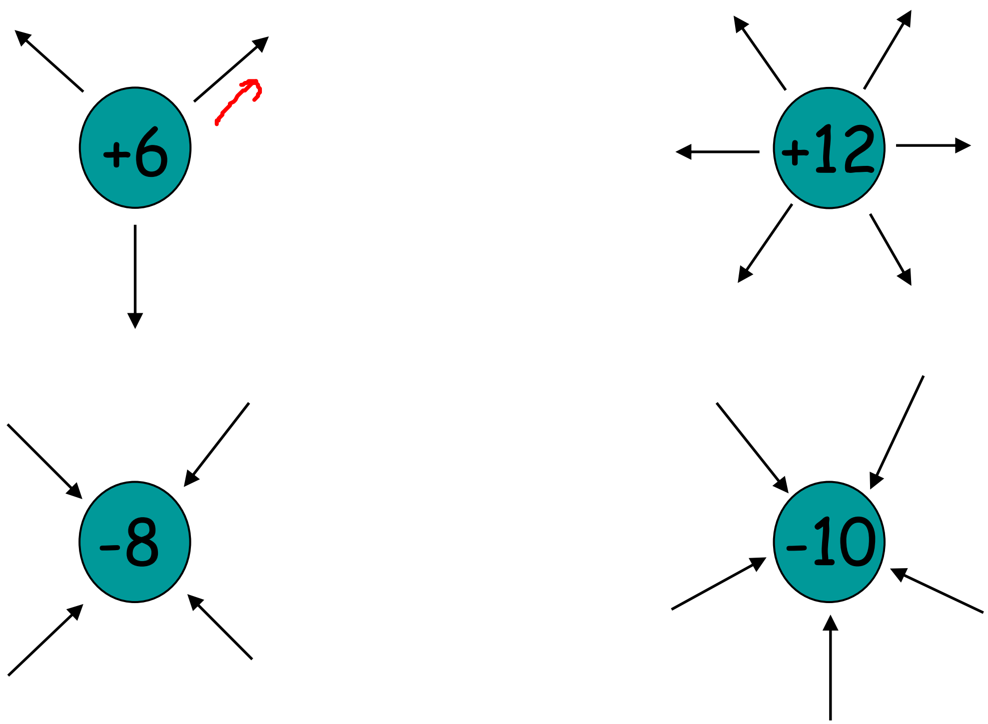
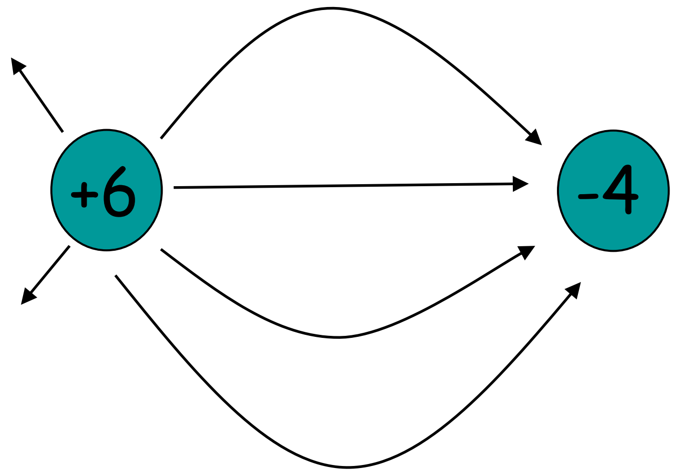


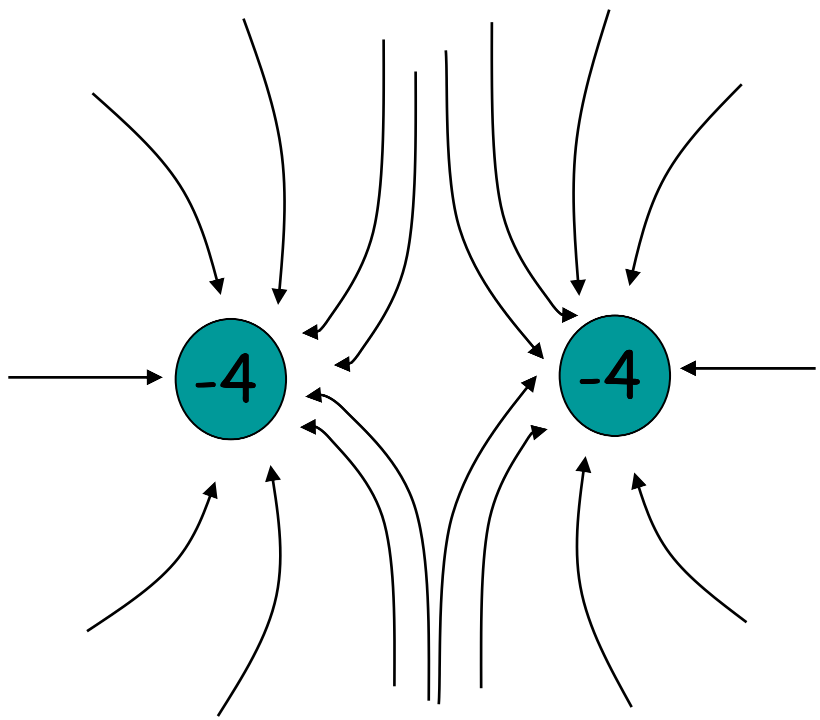
Direction of the Electric Field

When charges get near each other, these fields interact

For unlike charges, the arrows go from the positive charge to the negative charge:



For like particles the arrows are repelled:



The field arrows never cross in either case

Electric Field Intensity

If Q_1 is fixed to be at origin, a second charge Q_2 will have force acting on Q_1 and can be calculated using Coulomb's Law. We also could calculate the force vector that would act on Q_2 at every point in space to generate a *field* of such predicted force values.

Electric Field Intensity (Cont'd)

It becomes convenient to define electric field intensity $\mathbf{E}_1$ or force per unit charge as:

$$\mathbf{E}_1 = \frac{\mathbf{F}_{12}}{Q_2}$$

This field from charge Q_1 fixed at origin results from the force vector $\mathbf{F}_{12}$ for any arbitrarily chosen value of Q_2

Electric Field Intensity (Cont'd)

Coulomb's law can be rewritten as

$$\boxed{\mathbf{E} = \frac{Q}{4\pi\varepsilon_0 |\mathbf{R}|^2} \mathbf{a}_R}$$

to find the **electric field intensity** at any point in space resulting from a fixed charge Q.

Example 3

Two equal and opposite charges of magnitude 2×10^{-7} C are placed 15cm apart. (i) What is the magnitude and direction of electric intensity (E) at a point mid-way between thecharges? (ii) What force would act on a proton (charge = $+1 \cdot 6 \times 10^{-19}$ C) placed there ?

Solution:

Let M be the mid-point i.e. AM = MB = 0·075 m.

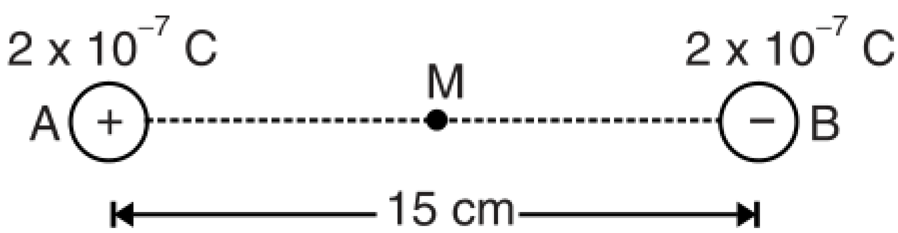


Fig. 5.12

$\therefore$ Electric intensity at M due to charge $+ 2 \times 10^{-7}$ C is

$$E_1 = 9 \times 10^9 \times \frac{2 \times 10^{-7}}{(0.075)^2} = 0.32 \times 10^6 \text{ N/C } along\ AM$$

Electric intensity at M due to charge -2×10^{-7}C is

$$E_2 = 9 \times 10^9 \times \frac{2 \times 10^{-7}}{(0.075)^2} = 0.32 \times 10^6 \text{ N/C } along\ MB$$

$\therefore$ Resultant intensity at point M is

$$E = 0{\cdot}32 \times 10^6 + 0{\cdot}32 \times 10^6 = \mathbf{0{\cdot}64 \times 10^6 \text{ N/C}}\ along\ AB$$

$$F = E\,Q = (0{\cdot}64 \times 10^6) \times (1{\cdot}6 \times 10^{-19}) = \mathbf{1{\cdot}024 \times 10^{-13} \text{ N}}\ along\ AB$$

Summary

Electrostatics

- → charge
- → coulomb's
  - → 1 →
  - → 2 → force
    - → Intensity