Topic 1 Electrostatic

ELECTROSTATICS : Study of Electricity in which electric charges are static i.e. not moving, is called electrostatics

- STATIC CLING
- An electrical phenomenon that accompanies dry weather, causes these pieces of papers to stick to one another and to the plastic comb.
- Due to this reason our clothes stick to our body.

- ELECTRIC CHARGE : Electric charge is characteristic developed in particle of material due to which it exert force on other such particles. It automatically accompanies the particle wherever it goes.
- Charge cannot exist without material carrying it
- It is possible to develop the charge by **rubbing two solids having friction.**
- Carrying the charges is called **electrification**.
- Electrification due to friction is called **frictional electricity**.

Since these charges are <u>not flowing</u> it is also called static electricity.

There are two types of charges. +ve and -ve.

- Similar charges repel each other,
- Opposite charges attract each other.

- Benjamin Franklin made this nomenclature of charges being +ve and -ve for mathematical calculations because adding them together cancel each other.
- Any particle has vast amount of charges.
- The number of positive and negative charges are **equal**, hence **matter is basically neutral.**
- Inequality of charges give the material a **<u>net</u>** charge which is equal to the difference of the two type of charges.

<u>Electrostatic series</u> :If two substances are rubbed together the former in series acquires the positive charge and later, the –ve.

(i) Glass (ii) Flannel (iii) Wool (iv) Silk (v) Hard Metal (vi) Hard rubber (vii) Sealing wax (viii) Resin (ix) Sulphur

<u>Electron theory of Electrification</u>

- Nucleus of atom is positively charged.
- The electron revolving around it is negatively charged.
- They are equal in numbers, hence atom is electrically neutral.
- With friction there is transfer of electrons, hence net charge is developed in the particles.

- It also explains that the charges are compulsorily developed in pairs equally . +vein one body and –ve in second.
- It establish **conservation of charges in the universe.**
- The **loss** of **electrons** develops +ve charge. While **excess** of **electrons** develop -ve charge
- A **proton** is 1837 times heavier than electron hence it cannot be transferred. Transferring lighter electron is easier.
- Therefore for electrification of matter, only **electrons** are active and responsible.

<u>Charge and Mass relation</u>

- Charge cannot exist without matter.
- One carrier of charge is electron which has **mass** as well.
- Hence if there is charge transfer, mass is also transferred.
- Logically, negatively charged body is heavier then positively charged body.

<u>Conductors, Insulators and Semiconductors</u>

- Conductors : Material in which electrons can move easily and freely.

Ex. Metals, Tap water, human body.

Brass rod in our hand, if charged by rubbing the charge will move easily to earth. Hence Brass is a conductor.

The flow of this excess charge is called **discharging**

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- **Insulator** : Material in which charge cannot move freely. Ex . Glass, pure water, plastic etc.
- Electrons can be forced to move across an insulator by applying strong force (called electric field.) Then this acts like a conductor.

- **dielectric strength.**

The maximum electric field an insulator can withstand without becoming a conductor is called its dielectric strength.

- **Semiconductor** : is a material which under little stimulation (heat or Elect. Field) converts from insulator to a conductor.

Ex. Silicon, germanium.

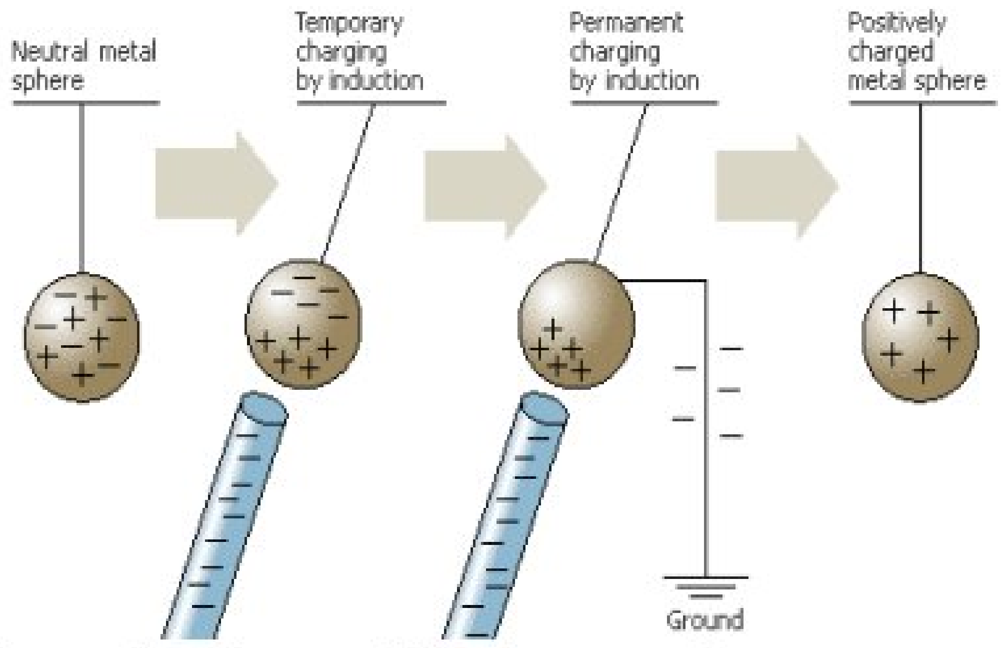
- **Superconductor** : is that material which presents no resistance to the movement of the charge through it.

The resistance is precisely zero.

Electrostatic Induction

- Phenomenon of polarization of charges in a body, when a charged body is present near it, is called electrostatic induction.
- In this process bodies are charged without touching them.

- **Charging by Induction**



A charged object will induce a charge on a nearby conductor. In this example, a negatively charged rod pushes some of the negatively charged electrons to the far side of a nearby copper sphere because like charges repel each other. The positive charges that remain on the near side of the sphere are attracted to the rod.

- If the sphere is grounded so that the electrons can escape altogether, the charge on the sphere will remain if the rod is removed.

Basic properties of Electric charge

- Additivity of Electric charges
- Quantization of Electric charge
- Conservation of Electric Charge

Additivity of Charges...

- Charges can be added by simple rules of algebra. Addition of positive and negative charge makes Zero charge

Quantization of Electric charge

- Principle: **Electric charge is not a continuous quantity, but is an integral multiple of minimum charge (e).**
- Reason of quantization:
- Minimum charge *e* exist on an electron.
- The material which is transferred during electrification is an electron, in integral numbers.
- Hence **charge transferred has to be integral multiple of *e*.**
- Charge on an electron (-e) and charge on a proton (+e) are equal and opposite, and are the **minimum.**

This minimum charge is 1.6×10^{-19} coulomb.

one electron has charge -1.6×10^{-19} C

One proton has charge $+1.6 \times 10^{-19}$ C

- Charge on a body Q is given by

$Q = \pm ne$

Where n is a whole number 1,2,3…..

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

- since e is smallest value of charge, it is called Elementary Charge or Fundamental charge

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- (**Quarks** : In new theories of proton and neutrons, a required constituent particles called Quarks which carry charges ±(1/3)e or ±(2/3)e.
- But because free quarks do not exist and their sum is always an integral number, it does not violet the quantization rules.)

- **Conservation of Charges**
- Like conservation of energy, and Momentum, the electric charges also follow the rules of conservation.

1. Isolated (Individual) Electric charge can neither be created nor destroyed, it can only be transferred.
2. Charges in pair can be created or destroyed.

Example for 1.

At Nuclear level : Decay of U-238

^{238}U $^{234}Th + {}^{4}He$ (Radio active decay)

Atomic number Z of radioactive material U-238 is 92. Hence it has 92 protons hence charge is 92*e*. Thorium has Z= 90, hence charge is 90e, alpha particles have charge 2e. Therefore charges before decay are 92 and after decay are 90+2=92

Example for 2. (a) Annihilation (destruction in pair)
In a nuclear process an electron -e and its antiparticle positron +e undergo annihilation process in which they transform into two gamma rays (high energy light)

$e^- + e^+$ $\gamma + \gamma$

Example for 2 (b):Pair production:
is converse of annihila tion, charge is also conserved when a gamma ray transforms into an electron and a positron

γ $e^- + e^+$ (pair production)

Electric Force - Coulumb's Law

- Coulumb's law in Electrostatics :

Force of Interaction between two stationery point charges is
directly proportional to the product of the charges,
inversely proportional to the square of the distance between them and
acts along the straight line joining the two charges.

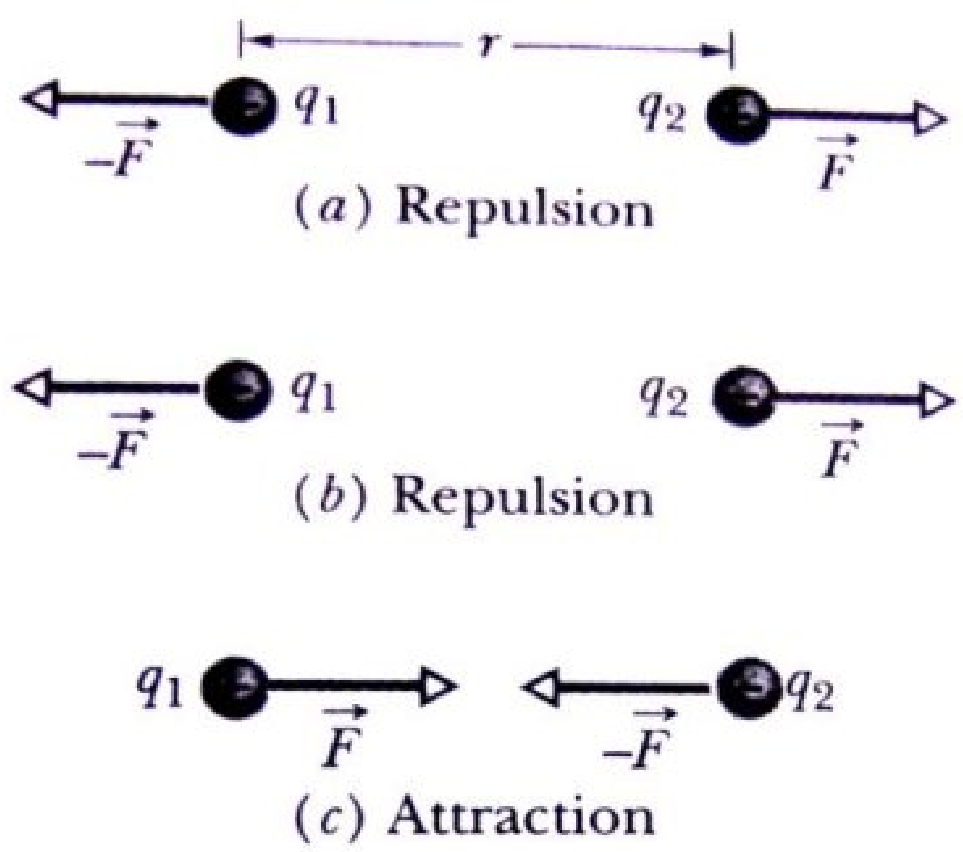

Fig. 22-6 Two charged particles, separated by distance *r*, repel each other if their charges are (*a*) both positive and (*b*) both negative. (*c*) They attract each other if their charges are of opposite signs. In each of the three situations, the force acting on one particle is equal in magnitude to the force acting on the other particle but has the opposite direction.

If two charges q_1 and q_2 are placed at distance r then,

where c is a constant .

c is called Coulomb's constant and its value is

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$$F = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r^2}$$

The value of c depends upon system of units and on the medium between two charges

It is seen experimentally that if two charges of 1 Coulomb each are placed at a distance of 1 meter in air or vacuum, then they attract each other with a force (F) of 9×10^9 Newton.

Accordingly value of c is 9×10^9 Newton x $m^2/coul^2$

e_0 is permittivity of free space or vacuum and its value is $e_0 = 8.85 \times 10^{-12}$ $coul^2$ / N x m^2

If point charges are immersed in a dielectric medium, then e_0 is replaced by e a quantity-characteristic of the matter involved In such case. For vacuum $e = e_0$

$$F = \frac{1}{4\pi\varepsilon} \frac{q_1 q_2}{r^2}$$

Permittivity, Relative Permittivity and Dielectric Constant

Permittivity is a measure of the property of the medium surrounding electric charge which determine the forces between the charges.

Its value is known as Absolute permittivity of that Medium e

More is Permittivity of medium, Less is coulombs Force.

For water, permittivity is 80 times then that of vacuum, hence force between two charges in water will be 1/80 time force in vacuum (or air.)

Relative Permittivity(e_r) : It is a dimension-less characteristic constant, which express absolute permittivity of a medium w.r.t. permittivity of vacuum or air. It is also called

Dielectric constant (K) **$K = e_r = e/e_0$**

- This result leads to the calculation that

$$\varepsilon_r = K = \frac{F \text{ (Force in Vacuum)}}{F' \text{ (Force in Medium)}}$$

$$F = \frac{1}{4\pi\varepsilon} \frac{q_1 q_2}{r^2} = \frac{1}{4\pi}$$

- Unit of charge:- In S.I. System of units, the unit of charge is **Coulomb.**

- **One coulomb** is defined as that charge, which, when placed at a distance of 1 m in air or vacuum from an equal and similar charge, repel it with a force of 9×10^9 Newton
- Charge on one electron is 1.6019×10^{-19} coul. Hence
- One coulomb is equivalent to a charge of 6.243 x 10^{18} electrons

Is electric charge a fundamental quantity?

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- No, In S.I. System, the fundamental quantity is **Electric current** and its unit is Ampere. Therefore coulomb is defined in it's terms as under:
- Coulomb is that quantity of charge which passes across any section of a conductor per second when current of one ampere flows through it, i.e.
- 1 coulomb=1 Ampere x 1 sec

In **cgs electrostatic** system, the unit of charge is called as STATECOULUMB or esu of charge.

- In this system electrostatic constant c=1 for

vacuum or air,

One stat coulomb is defined that amount of charge which when placed at a distance of 1 cm in air from an equal and similar charge repel it with a force of one dyne.

In **cgs electromagnetic** system, the unit of charge is called ABCOULOMB or emu of charge

1 Coulomb = 3 x 10^9 statcoulomb

= 1/10 abcoulomb

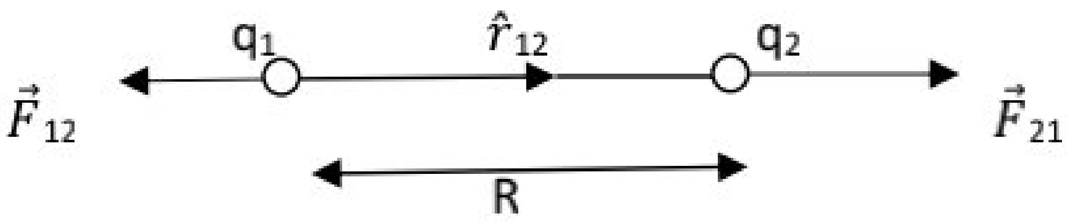
\ 1 emu = 3×10^{10} esu of charge

<u>Vector form of Coulumbs' Law</u>

Equation of Coulumbs force showing magnitude as well as direction is called Vector form of coulumbs' law.

If $\hat{r}_{12}$ is unit vector pointing from q_1 to q_2, then as per diagram $\hat{r}_{12}$ and $\vec{F}_{21}$ will be in the same direction, then

$\vec{F}_{21} = \frac{1}{4\pi\varepsilon_0} \frac{q_1q_2}{r^2} \hat{r}_{12}$ (vector equation)........ 1.



Similarily $\vec{F}_{12} = \frac{1}{4\pi\varepsilon_0} \frac{q_1q_2}{r^2} \hat{r}_{21}$ 2

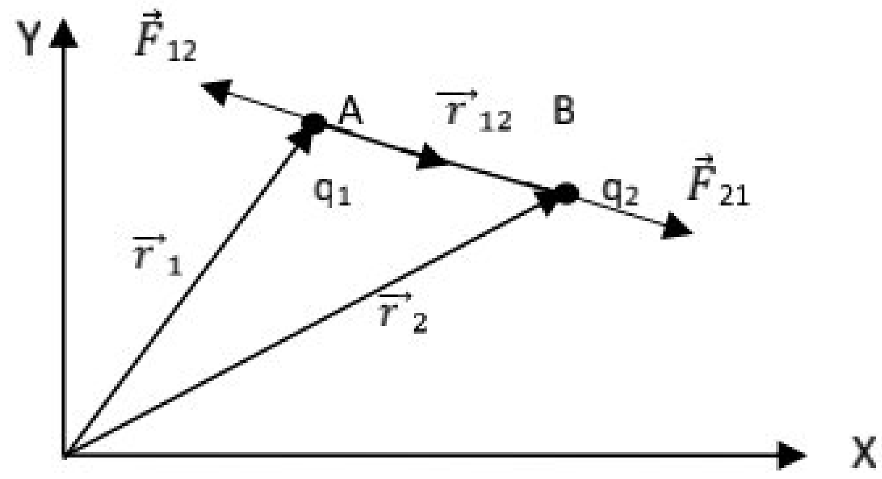
Since $\hat{r}_{21}$ = - $\hat{r}_{12}$ $\therefore$ $\vec{F}_{21}$ = - $\vec{F}_{12}$

Electrostatic Force between two point charges in terms of their position vectors.

(i).Let there be two point charges q1 and q2 at points A & B in vacume. With reference to an origin O let their position vectors be $\vec{r}_1$ (OA) and $\vec{r}_2$ (OB). Then AB=$\vec{r}_{12}$. According to triangle law of vectors :

$\vec{r}_1 + \vec{r}_{12} = \vec{r}_2$ $\therefore$ $\vec{r}_{12} = \vec{r}_2 - \vec{r}_1$ and

$\vec{r}_{21} = \vec{r}_1 - \vec{r}_2$



(ii) According to Coulomb's law, the Force $\vec{F}_{12}$ exerted on q_1 by q_2 is given by : $\vec{F}_{12} = \frac{1}{4\pi\varepsilon_0} \frac{q_1q_2}{|\vec{r}_{21}|^2} \hat{r}_{21}$ where $\hat{r}_{21}$ is a unit vector pointing from q_2 to q_1 . We know that $\hat{r}_{21} = \frac{\vec{r}_{21}}{|\vec{r}_{21}|} = \frac{(\vec{r}_1 - \vec{r}_2)}{|\vec{r}_1 - \vec{r}_2|}$

Hence, general Vector forms of Coulumb's equation is

$\vec{F}_{21} = \frac{1}{4\pi\varepsilon_0} \frac{q_1q_2}{|\vec{r}_1 - \vec{r}_2|^2}\overrightarrow{(r_1 - r_2)}$ and

$\vec{F}_{12} = \frac{1}{4\pi\varepsilon_0} \frac{q_1q_2}{|\vec{r}_2 - \vec{r}_1|^2}\overrightarrow{(r_2 - r_1)}$

Comparison of Electrostatic and Gravitational Force

1. <u>Identical Properties</u> :
   - Both the forces are central forces, i.e., they act along the line joining the centers of two charged bodies.
   - Both the forces obey inverse square law, F$\propto \frac{1}{r^2}$
   - Both are conservative forces, i.e. the work done by them is independent of the path followed.
   - Both the forces are effective even in free space.
2. <u>Non identical properties</u> :
   a. Gravitational forces are always attractive in nature while electrostatic forces may be attractive or repulsive.
   b. Gravitational constant of proportionality does not depend upon medium, the electrical constant of proportionality depends upon medium.
   c. Electrostatic forces are extremely large as compared to gravitational forces

Qn. Compare electrostatic and gravitational force between one electron and one proton system.

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Ans : $F_e = \frac{1}{4\pi\varepsilon_0}\frac{e.e}{r^2} = 9x10^9\frac{(1.6x10^{-19})^2}{r^2}$ Newton

$F_g = G\frac{me\ x\ mp}{xr^2} = 6.67x10^{-11}\frac{(9.1\ x\ 10^{-31})\ x\ (1.67\ x\ 10^{-27})}{r^2}$ Newton

$F_e / F_g = 2.26 \times 10^{39}$

Principle of Superposition of Charges :

If a number of Forces F_{11}, F_{12}, F_{13},......F_{1n} are acting on a single charge q_1 then charge will experience force F_1 equal to vector sum of all these forces .

$F_1 = F_{11} + F_{12} + F_{13} + ... + F_{1n}$

The vector sum is obtained as usual by parallelogram law of vectors.

All electrostatics is basically about Coulomb's Law and Principle of superposition.

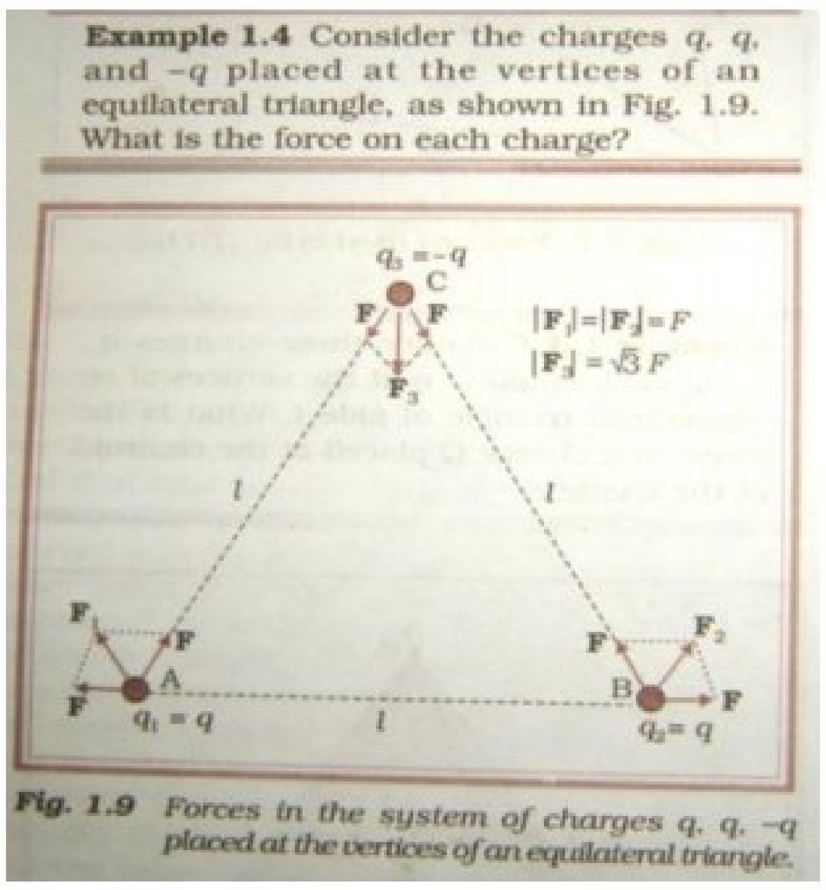

Example 1.4 Consider the charges q, q, and −q placed at the vertices of an equilateral triangle, as shown in Fig. 1.9. What is the force on each charge?

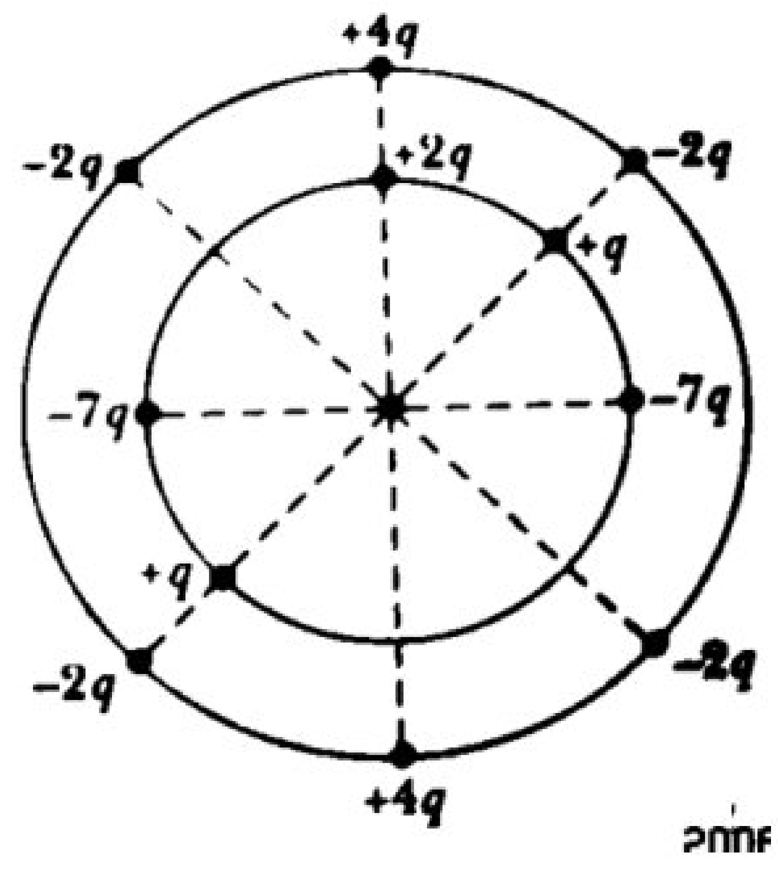
Fig. 1.9 Forces in the system of charges q, q, −q placed at the vertices of an equilateral triangle.

NUMERICALS FOR PRACTICE

1.How many electrons must be removed from the sphere to give it a charge of +2 μC . Is there any change in the mass when it is given this positive charge. How much is this change?

2. Two identical charged copper spheres A and B have their centers separated by a distance of 50 cm. A third sphere of same size but uncharged is brought in contact with the first, then brought in contact with the second and finally removed from both. What is the new force of repulsion between A and B?

3. A central particle of charge −q is surrounded by two circular rings of charged particles, of radii r and R, such that R > r. What are the magnitude and direction of the net electrostatic force on the central particle due to other particles.



4.-Three equal charges each of 2.0 x 10-6 are fixed at three corners of an equilateral triangle of side 5 cm. Find the coulomb force experienced by one of the charges due to other two.

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-3q

6. A charge q is placed at the center of the line joining two equal charges Q. Show that the system of three charges will be in equilibrium if q = Q/4.

7. Two particles having charges 8q and −2q are fixed at a distance L. where, in the line joining the two charges, a proton be placed so that it is in equilibrium (the net force is zero). Is that equilibrium stable or unstable?

8. What are the horizontal and vertical components of the net electrostatic force on the charged particle in the lower left corner of the square if $q = 1.0 \times 10^7$C and a = 5.0 cm?