01 - CONSERVATION AND QUANTIZATION OF CHARGE

Electric charge, like mass, is one ot the fundarnental attributes of the particle of which the matter is made of.

Charge is the intrinsic property of certain fundamental particles (such as, electron, proton) by virtue of which they interact with the other similar fundamental particles.

The apparatus used to detect charge is known as an electroscope, most commonly being a gold leaf electroscope (GLE).

UNIT OF CHARGE :

SI unit : ampere-second also known as coulomb (C).

C.G.S. unit : e.s.u (electrostatic unit) or stat coulomb.

$1C = 2.998 \times 10^9$ esu $\approx 3 \times 10^9$ esu

Dimension : [AT]

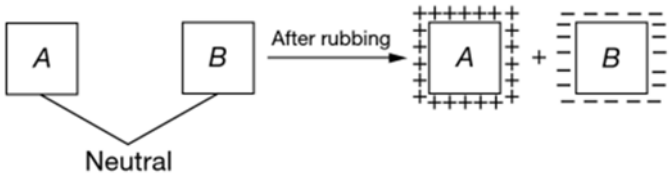
TYPES OF CHARGE :

Positive Charge : Positive charge is produced by removal of electrons from a neutral body. That is positive charge means deficiency (or lack) of electrons in a neutral body.

Negative Charge : Negative charge is produced by giving electrons to a neutral body. That is negative charge means excess (or gain) of electrons on a neutral body.

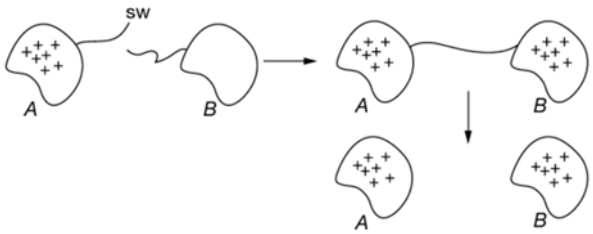
DIFFERENT WAYS OF CHARGING A BODY :

1. Charging by Friction (by rubbing)



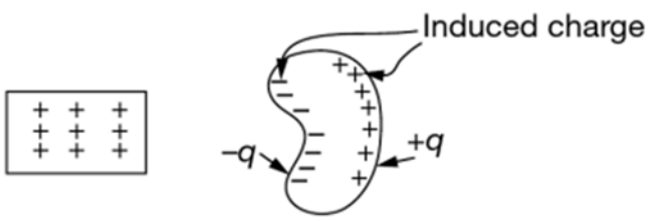
When two bodies are rubbed together, electrons are transferred from one body to the other making one body positively charged and the other negatively charged.

2. Charging by Conduction (by touch without rubbing)



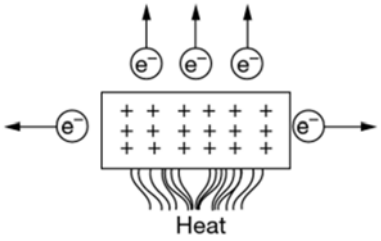
When two conductors, one charged and other uncharged bring in contact, the same type of charge will appear on both the conductors. Charge on any conductor is proportional to its size.

3. Charging by Induction (without touch)



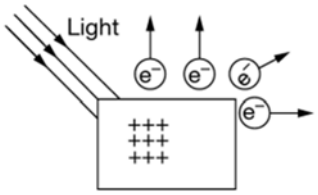
Induction is a process by which a charged body can be used to charge neutral bodies without touching them or losing its own charge. If a charged body is brought near a neutral body, the charged body attracts opposite charge and repels similar charge present on the neutral body.

4. Charging by Thermionic Emission



When the metal is heated at a high temperature then some electrons of metals are ejected and the metal gets ionized. It becomes positively charged.

5. Charging by Photoelectric Effect



When light of sufficiently high frequency is incident on metal surface then some electrons come out and metal gets ionized.

PROPERTIES OF ELECTRIC CHARGE

1. Charge is a scalar quantity : It represents excess or deficiency of electrons.

2. Repulsion and Attraction : It has been found experimentally that like charges repel while unlike charges attract. i.e., there is repulsion between two positive charges and between two negative charges; while there is attraction between a positive and a negative charge.

3. Charge is Additive : Total charge on an isolated system is equal to the algebraic sum of charges on individual bodies of system. This is called additive property of charges. If a system contains three charges, q_1, q_2, $-q_3$ then total charge on system, $Q = q_1 + q_2 - q_3$.

4. Charge is always associated with mass : Charge cannot exist without mass though mass can exist without charge. So the presence of charge itself is a convincing proof of existence of mass. In charging, the mass of a body changes.

When body is given positive charge, its mass decreases.

When body is given negative charge, its mass increases.

5. Charge is quantised : The quantization of electric charge is the property by virtue of which all free charges are integral multiple of a basic unit of charge represented by e.

Thus charge q of a body is always given by q = ne , n = positive integer or negative integer

The quantum of charge is the charge that an electron or proton carries.

Note : Charge on a proton = (-) charge on an electron = $1.6\ 10^{-19}$ C

6. Charge is conserved : In an isolated system, total charge does not change with time, though individual charge may change i.e. charge can neither be created nor destroyed. Conservation of charge is also found to hold good in all types of reactions either chemical (atomic) or nuclear. No exceptions to the rule have ever been found.

7. Charge is invariant :

Charge is independent of frame of reference. i.e. charge on a body does not change whatever be its speed.

$q_{rest} = q_{motion}$

Accelerated charge radiates energy.

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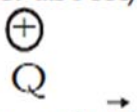
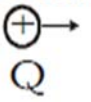
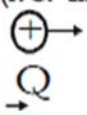
$v = 0$ (i.e. at rest)	$v =$ constant	$v \neq$ constant (i.e. time varying)
		
Q	Q	Q
produces only $\vec{E}$ (electric field)	produces both $\vec{E}$ and $\vec{B}$ (magnetic field) but no radiation	produces $\vec{E}$, $\vec{B}$ and radiates energy

DIFFERENCE BETWEEN CHARGE AND MASS

	Charge		Mass
1.	Electric charge can be positive or negative.	**1.**	Mass of body is always positive.
2.	Charge is conserved.	**2.**	Mass is not conserved as it can be converted into energy and vice versa by $E = mc^2$.
3.	Charge is quantized.	**3.**	Quantization of mass is yet to be established.
4.	Charge is relativistically invariant, i.e., $q_{rest} = q_{motion}$.	**4.**	Mass is relativistically variant. Mass in motion $m = \frac{m_0}{\sqrt{1 - v^2/c^2}}$, where m_0 is rest mass object.
5.	Force between charges may be attractive or repulsive.	**5.**	Force between masses always be attractive.

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SAMPLE EXERCISE

1. Can 8.6 x 10^{-19} Coulomb of charge be given to a conductor? Explain. [ISC 2006]

Sol.

$$n = \frac{q}{e} = \frac{8.6\ x\ 10^{-19}}{1.6\ x\ 10^{-19}} = 5.375$$

which is not an integer, hence violating quantization of charge.
So, a charge of 8.6 x 10^{-19} C cannot be given to a conductor

2. A glass rod is rubbed with a silk cloth. The glass rod acquires a charge of +19.2 x 10^{-19} C.
1. **Find the number of electrons lost by glass rod.**
2. **Find the negative charge acquired by silk.**
3. **Is there transfer of mass from glass to silk?**

Given, m_e = 9 x 10^{-31} kg.

Sol.

1. Number of electrons lost by glass rod is

$$n = \frac{q}{e} = \frac{19.2 \times 10^{-19}}{1.6 \times 10^{-19}} = 12$$

2. Charge on silk = -19.2×10^{-19} C

3. Since an electron has a finite mass ($m_e = 9 \times 10^{-31}$ kg), there will be transfer of mass from glass rod to silk cloth. Mass transferred = $12 \times (9 \times 10^{-31}) = 1.08 \times 10^{-29}$ kg

3. A body has a positive charge of 8 x 10^{-19} C. It has : [ISC 2012]

(a) an excess of 5 electrons
(b) a deficiency of 5 electrons
(c) an excess of 8 electrons
(d) a deficiency of 8 electrons

Sol.

$$n = \frac{q}{e} = \frac{8\ x\ 10^{-19}}{1.6\ x\ 10^{-19}} = 5$$

Since the body has positive charge, it has deficiency of 5 electrons.

Hence, (b)

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4. Objects A, B and C are three identical, insulated, spherical conductors.
Originally, A and B have charges of +3 mC, whereas C has a charge Of -6 mC.
Object A and C are allowed to touch, then they are moved apart.
Objects B and C are allowed to touch before they are moved apart.
i. If objects A and B are now held near each other, they
a. attract b. repel c. have no effect on each other.
ii. If instead objects A and C are held near each other, they will
a. attract b. repel c. have no effect on each other

Sol.

Initially, A (+3 mC) B (+3 mC) C (−6 mC)

- When the objects A and C are allowed to touch and then moved apart:

A C ⟺ A C

$[(+3\ \text{mC}+(-6\ \text{mC})=-3\ \text{mC})]$ $-\frac{3}{2}$ mC $-\frac{3}{2}$ mC

- When the objects B and C are allowed to touch and then moved apart:

B C ⟺ B C

$\left[(+3\ \text{mC})+\left(-\frac{3}{2}\ \text{mC}\right)=+\frac{3}{2}\ \text{mC}\right]$ $+\frac{3}{4}$ mC $+\frac{3}{4}$ mC

i.a. Hence, if A and B are now held near each other, they will attract each other.

ii.a. If A and C are now held near each other, they will also attract each other.

5. An electron at rest has a charge of 1.6 X 10^{-19} C. It starts moving with a velocity v = c/2, where c is the speed of light, then the new charge on it is:

(A) 1.6×10^{-19} Coulomb

(B) $1.6\times10^{-19}\sqrt{1-\left(\frac{1}{2}\right)^2}$ Coulomb

(C) $1.6\times10^{-19}\sqrt{\left(\frac{2}{1}\right)^2-1}$ Coulomb

(D) $\frac{1.6\times10^{-19}}{\sqrt{1-\left(\frac{1}{2}\right)^2}}$ Coulomb

Sol.

Charge is invariant, hence does not change with speed.

$q_{rest} = q_{motion}$

Hence, it will remain **1.6 x 10^{-19} C**

ASSIGNMENT

1. One quantum of charge should be at least being equal to the charge in coulomb:
   (a) 1.6×10^{-17} (b) 1.6×10^{-19} (c) 1.6×10^{-10} (d) 4.8×10^{-10}
2. A stationary electric charge produces:
   (a) Only electric fields
   (b) Only magnetic field
   (c) Both electric as magnetic field
   (d) Neither electric nor magnetic field
3. An accelerated or decelerated charge produces:
   (a) Electric field only
   (b) Magnetic field only
   (c) Localized electric and magnetic fields
   (d) Electric and magnetic fields that are radiated
4. When a piece of polythene is rubbed with wool, a charge of -2×10^{-7} C is developed on polythene. What is the amount of mass, which is transferred to polythene.
5. A particle has charge of $+10^{-12}$ C.
   a. Does it contain more or less number of electrons as compared with the neutral state?
   b. Calculate the number of electrons transferred to provide this charge.
6. How many electrons would have to be removed from a coin to leave it with a charge of $+1.0 \times 10^{-7}$ C?
7. What is the total charge in coulombs of 75.0 kg of electrons ?
8. An isolated metallic sphere is given a negative charge. Will its mass increase, decrease or remain same ?
9. Which of the following charge is not possible
   (a) 1.6×10^{-18} C
   (b) 1.6×10^{-19} C
   (c) 1.6×10^{-20} C
   (d) None of these
10. Number of electrons in one coulomb of charge will be
    (a) 5.46×10^{29}
    (b) 6.25×10^{18}
    (c) 1.6×10^{19}
    (d) 9×10^{11}
11. If 10^9 electrons move out of a body to another body every second, how much time is required to get a total charge of 1 C on the other body ?
12. Consider a neutral conducting sphere. A positive point charge is placed outside the sphere. The net charge on the sphere is then,
    (a) negative and distributed uniformly over the surface of the sphere
    (b) negative and appears only at the point on the sphere closest to the point charge
    (c) negative and distributed non-uniformly over the entire surface of the sphere
    (d) zero.
13. Five balls numbered 1 to 5 are suspended using separate threads. Pair (1 ,2), (2,4) and (4, 1) show electrostatic attraction, while pair (2,3) and (4,5) show repulsion. Therefore "ball 1" must be
    (a) Positively charged
    (b) Negatively charged
    (c) Neutral
    (d) Made of metal

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ANSWER KEY :

1. b
2. a
3. d
4. 11.38×10^{-19} kg
5. (a) Since the particle has positive charge, it has deficiency of electrons, so it has less number of electrons compared to the neutral state.
   (b) 6.25×10^{6}
6. 6.25×10^{11}
7. -1.32×10^{13} C
8. increase
9. c
10. b
11. 198 years
12. d
13. c

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