University of Anbar
College of Engineering
Dept. of Electrical Engineering

Electric physics II

Electric charge

By

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1.The electric charge

- Empirically it was known since ancient times that if amber is rubbed on fur, it acquires the property of attracting light objects such as feathers.
- This phenomenon was attributed to a new property of matter called "electric charge".
- electron is the Greek name for amber because of its electrostatic properties and whilst analyzing elementary charge for the first time.
- More experiments show that they are two distinct type of electric charge: positive (color code: red), and negative (color code: black). The names "positive" and "negative" were given by Benjamin Franklin.

The electric charge on

(1) a glass rod rubbed with silk is positive.

(2) an amber (plastic) rod rubbed with fur is negative.

((Note))

Rubber rubbed with cat fur: rubber becomes negative, while the fur becomes positive.

Amber rod (-)
Plastic rod (-)
Rubber (-)
Glass rod (+)

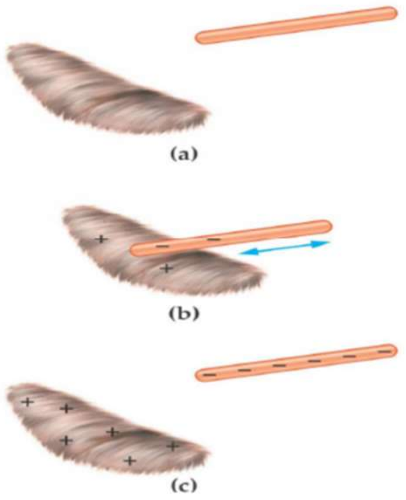
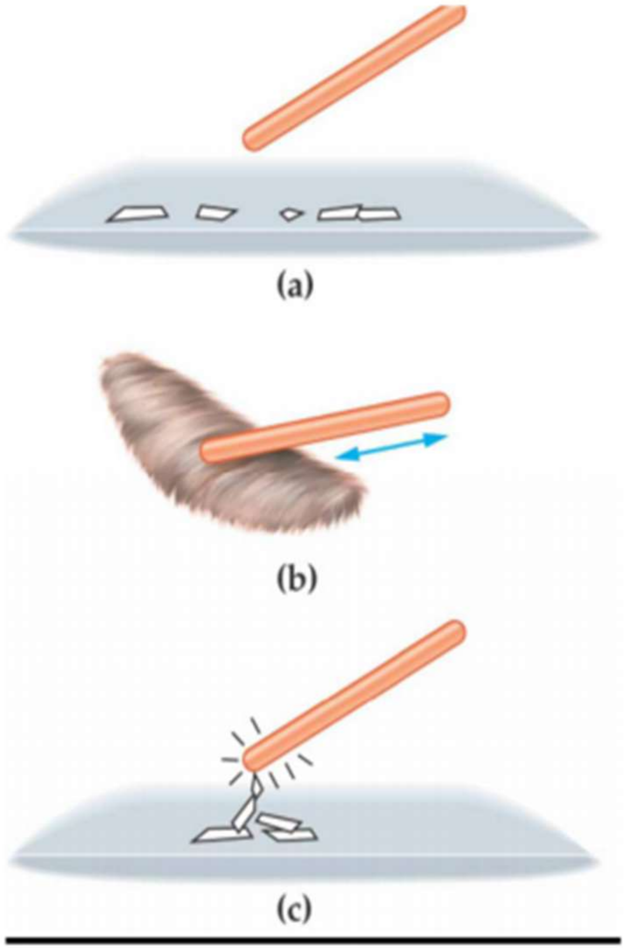


Fig. Plastic rod rubbed with fur



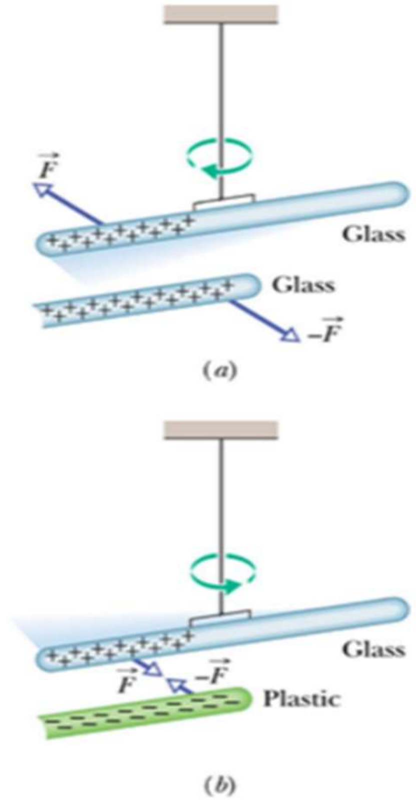
(a) Uncharged amber rod exerts no force on papers
(b) Amber rod is rubbed against a dry cloth (a fur)
(c) Amber rod becomes charged and attracts the papers.

Further experiments on charged objects showed that as :

1. Charges of the same type (either both positive or both negative) repel each other as in fig a.

2. Charges of opposite type on the other hand attract each other as in fig b.

3. The force direction allows us to determine the sign of an unknown electric charge



2.Charge is quantized

- The experiments strongly suggested that the electric charge, q, is said to be quantized. q is the standard symbol used for charge as a variable. Electric charge exists as discrete packets The SI Unit of charge is the coulomb (c).
- The charge of the electron:
- q= n e
- where n is an integer(no. of electron or proton), and e is the fundamental unit of charge.
- e = 1.602176487 x $10^{-1}\ C$
- For electron q = -e
- For proton q = +e
- For neutron q = 0

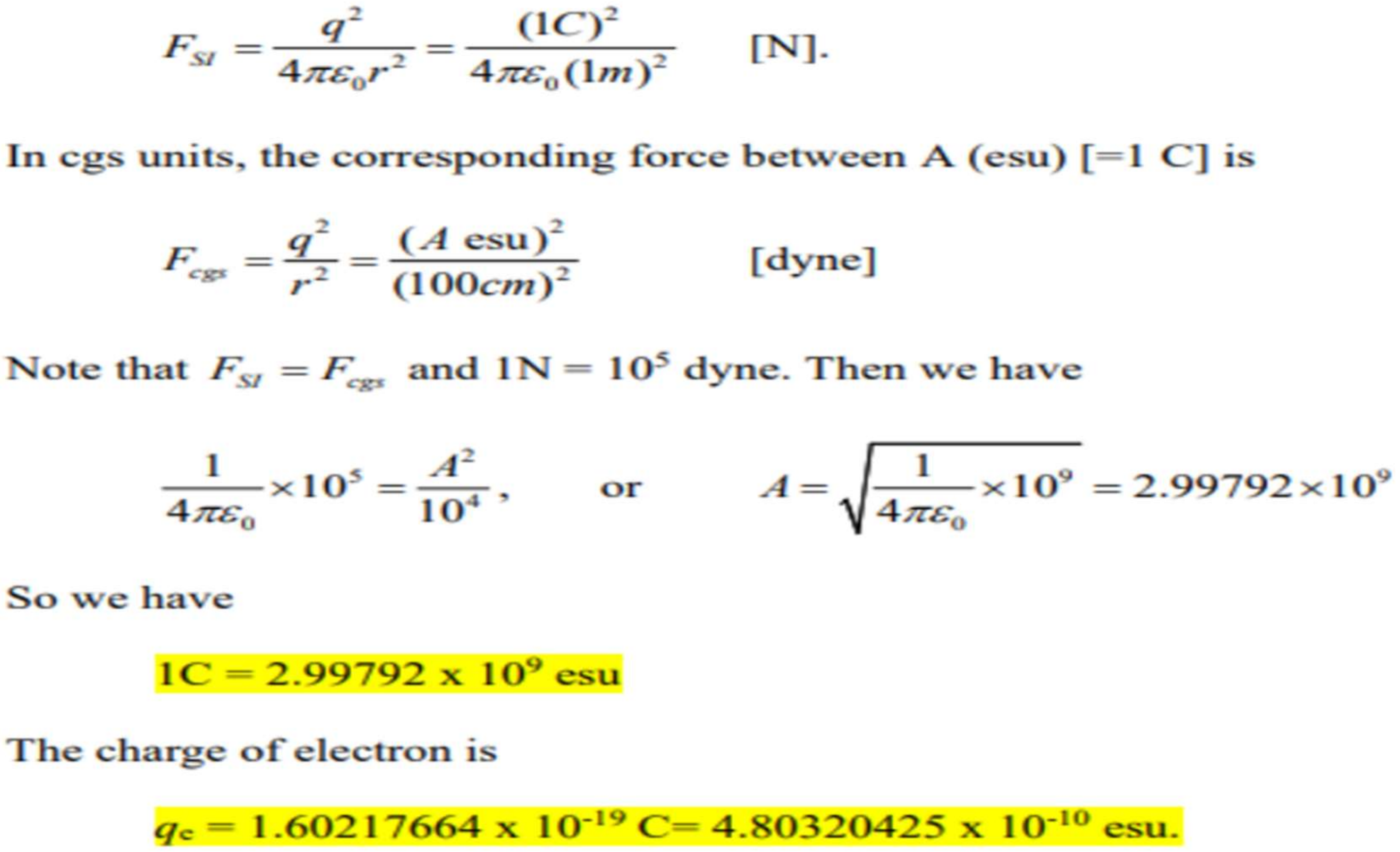
- How many electrons are there to form 1 C?

$$n=\frac{q}{e} = \frac{1\ c}{e} = \frac{1}{1.602*10^{-19}} = 6.24 * 10^{18}$$

- 1 μC = 10^{-6} C (μ: micro)
- 1 nC = 10^{-9} C (n: nano)
- 1 pC = 10^{-12} C (p: pico)
- 1 fC = 10^{-1} C (f: femto)
- 1 aC = 10^{-18} C (a: atto)

- ((Note)) Relation between 1 C (SI units) and 1 esu (cgs gaussian unit of charge, electrostatic unit)

We consider a force between two charges with q = 1c, The separation between two charges is r = 1 m.



$$F_{SI} = \frac{q^2}{4\pi\varepsilon_0 r^2} = \frac{(1C)^2}{4\pi\varepsilon_0 (1m)^2} \qquad [\mathrm{N}].$$

In cgs units, the corresponding force between A (esu) [=1 C] is

$$F_{cgs} = \frac{q^2}{r^2} = \frac{(A\ \mathrm{esu})^2}{(100cm)^2} \qquad [\mathrm{dyne}]$$

Note that $F_{SI} = F_{cgs}$ and 1N = 10^5 dyne. Then we have

$$\frac{1}{4\pi\varepsilon_0}\times 10^5 = \frac{A^2}{10^4}, \qquad \text{or} \qquad A = \sqrt{\frac{1}{4\pi\varepsilon_0}\times 10^9} = 2.99792\times 10^9$$

So we have

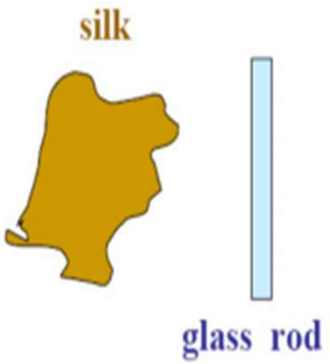
1C = 2.99792 x 10^9 esu

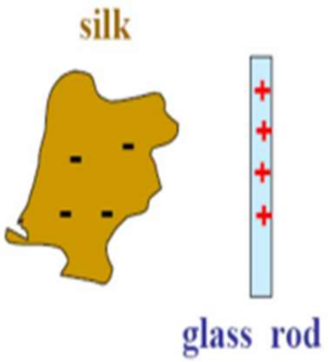
The charge of electron is

q_e = 1.60217664 x 10^{-19} C= 4.80320425 x 10^{-10} esu.

3. Charge is conserved

- Consider a glass rod and a piece of silk cloth (both uncharged) shown in the upper figure.
- If we rub the glass rod with the silk cloth we know that positive charge appears on the rod (see the figure).
- At the same time an equal amount of negative charge appears on the silk cloth
- so that the net rod-cloth charge is actually zero. This suggests that rubbing does not create charge but only transfers it from one body to the other.
- Charge conservation can be summarized as follows: In any process the charge at the beginning equals the charge at the end of the process.
- The total electric charge in an isolated system, that is, the algebraic sum of the positive and negative charge present at any time, never change.



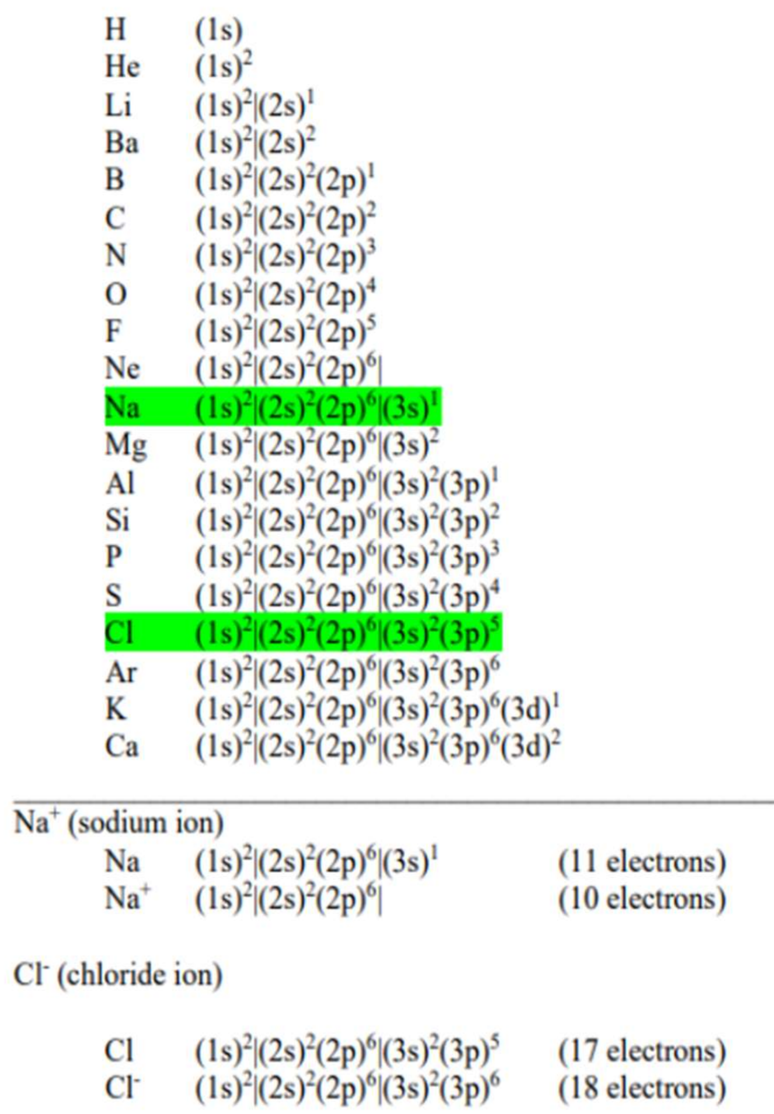


Some concepts

Due to the movement of electrons, charge is transferred from one object to another.

Positive ion: the atom that loses an electron is said to be a positive ion;

Negative ion: the atom that receives an extra electron is said to be a negative ion.



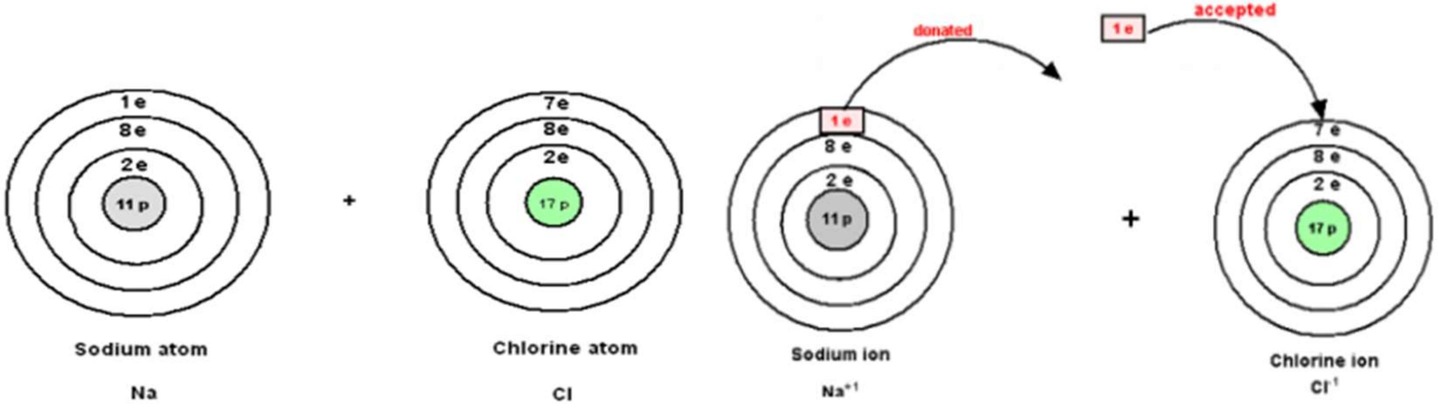
H	(1s)
He	$(1s)^2$
Li	$(1s)^2\|(2s)^1$
Ba	$(1s)^2\|(2s)^2$
B	$(1s)^2\|(2s)^2(2p)^1$
C	$(1s)^2\|(2s)^2(2p)^2$
N	$(1s)^2\|(2s)^2(2p)^3$
O	$(1s)^2\|(2s)^2(2p)^4$
F	$(1s)^2\|(2s)^2(2p)^5$
Ne	$(1s)^2\|(2s)^2(2p)^6\|$
Na	$(1s)^2\|(2s)^2(2p)^6\|(3s)^1$
Mg	$(1s)^2\|(2s)^2(2p)^6\|(3s)^2$
Al	$(1s)^2\|(2s)^2(2p)^6\|(3s)^2(3p)^1$
Si	$(1s)^2\|(2s)^2(2p)^6\|(3s)^2(3p)^2$
P	$(1s)^2\|(2s)^2(2p)^6\|(3s)^2(3p)^3$
S	$(1s)^2\|(2s)^2(2p)^6\|(3s)^2(3p)^4$
Cl	$(1s)^2\|(2s)^2(2p)^6\|(3s)^2(3p)^5$
Ar	$(1s)^2\|(2s)^2(2p)^6\|(3s)^2(3p)^6$
K	$(1s)^2\|(2s)^2(2p)^6\|(3s)^2(3p)^6(3d)^1$
Ca	$(1s)^2\|(2s)^2(2p)^6\|(3s)^2(3p)^6(3d)^2$

Na^+ (sodium ion)

Na	$(1s)^2\|(2s)^2(2p)^6\|(3s)^1$	(11 electrons)
Na^+	$(1s)^2\|(2s)^2(2p)^6\|$	(10 electrons)

Cl^- (chloride ion)

Cl	$(1s)^2\|(2s)^2(2p)^6\|(3s)^2(3p)^5$	(17 electrons)
Cl^-	$(1s)^2\|(2s)^2(2p)^6\|(3s)^2(3p)^6$	(18 electrons)



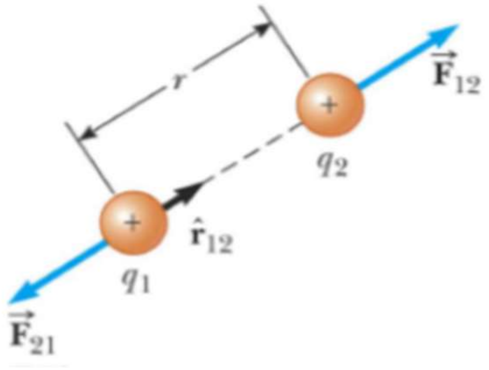
4.Coulomb’s law

- Charles-Augustin de Coulomb was a French physicist. He is best known for developing Coulomb's law

- Coulomb's law which is the definition of the electrostatic force of attraction and repulsion.
- coulomb’s law state that :”Two stationary electric charges repel or attract one another with a force proportional to the product of the magnitude of the charges and inversely proportional to the square of the distance between them”.

$$f_{1,2} = \frac{k_e\, q_1\, q_2}{r^2} e_{1,2}$$

Coulomb's law



Here q1 and q2 are numbers (scalars) giving the magnitude and sign of the respective charges, e is the unit vector in the direction from charge 1 to charge 2, and F12 is the force acting on charge 2.

Note that

F 21= - F12

The constant of proportionality (ke) is written as

$k_e = \frac{1}{2\pi\varepsilon_0}$=$c^2 \times 10^{-7}$=8.98755*$10^9$ N m^2 / c^2(or Vm/c) where c is the speed of light,

$$c = 2.99792458 \text{ x } 10^8 \text{ m/s}$$

Note that ε_0 is the permittivity of free space and μ_0 is the permeability of free space,

$$\varepsilon_0 = 8.8541878176 \times 10^{-12} \frac{C^2}{Nm^2}$$

$$\mu_0 = 4\pi \times 10^{-7} \text{ (N/A}^2\text{)}$$

The coulomb is an extremely large unit. The force between two charges of 1 C each a distance of 1 m apart is

$$F = \frac{1}{4\pi\varepsilon_0} \frac{1C \times 1C}{1m^2} = 8.98755 \times 10^9 N$$

((**Note**)) It is easy for you to memorize the value of k_e.

$$k_e = 9 \times 10^9 \text{ N m}^2\text{/C}^2 \text{ (or V m/C)}$$

((Note))

$$\frac{Nm^2}{C^2} = \frac{Nm}{C}\frac{m}{C} = \frac{J}{C}\frac{m}{C} = \frac{VAs}{As}\frac{m}{C} = \frac{Vm}{C}$$

Nm = J, $C = A\,s$

$W = VA$ $J = W\,s = VAs$

where

J (Joule), A (Ampere), V (Volt), C (Coulomb),
s (second), N (Neuton), and W (Watt).

((**Note**))

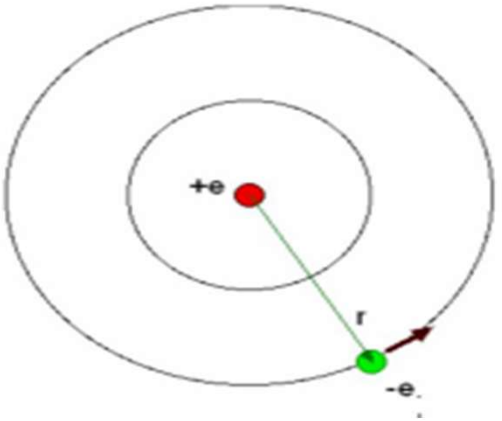
The SI unit of charge is coulomb. The coulomb unit is derived from the SI unit A (Ampere) for the electric current *i*. The current *i* is the rate d*q*/d*t* at which the amount of charge (d*q*) moves past a point or through a region in time d*t* (second).

$$i = \frac{dq}{dt}.$$

This relation implies that.

1C = (1A)(1s)

5.Bohr model



- consider the Bohr model shown in this figure.
- The system consists of a proton and an electron.
- These two particles are coupled with an attractive Coulomb interaction.
- The electrical force between the electron (charge q1 = -e) and proton (charge q2 = +e) is found from Coulomb's law,
- $f_e = \frac{k_e\, q_1\, q_2}{r_B^2} = 8.19 \times 10^{-8}\, N$

where $e = 1.602176487 \times 10^{-19}$ C and r_B is the Bohr radius given by

$$r_B = 5.2917720859 \times 10^{-11}\ (\mathrm{m}) = 0.52917720859\ \text{Å}.$$

This can be compared with the gravitational force between the electron and proton

$$F_g = \frac{G m_e m_p}{{r_B}^2} = 3.63153\text{x}10^{-47}\ \text{N}$$

What is the angular frequency ω for electrons rotating the circular orbit?

$$F_e = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{{r_B}^2} = m\frac{v^2}{r_B} = m r_B \omega^2$$

$$\omega = \sqrt{\frac{1}{4\pi\varepsilon_0}\frac{e^2}{m{r_B}^3}} = 4.13414\times10^{16}\ \text{rad/s}$$

where m is the mass of electron, $m = 9.1093821545 \times 10^{-31}$ kg.

The period is

$$T = \frac{2\pi}{\omega} = 1.51983\times10^{-16} s$$

((Note))

An important difference between the electric force and the gravitational force is that the gravitational force is always attractive, while the electric force can be repulsive, or attractive, depending on the charges of the particles.

6.Conductors and insulators

(a) Conductors

A conductor is a material that permits the motion of electric charge through its volume. Examples of conductors are copper, aluminum and iron. An electric charge placed on the end of a conductor will spread out over the entire conductor until an equilibrium distribution is established.

(b) Insulators

Electric charge placed on an insulator stays in place: an insulator (like glass, rubber and mylar) does not permit the motion of electric charge.

(c) Superconductors

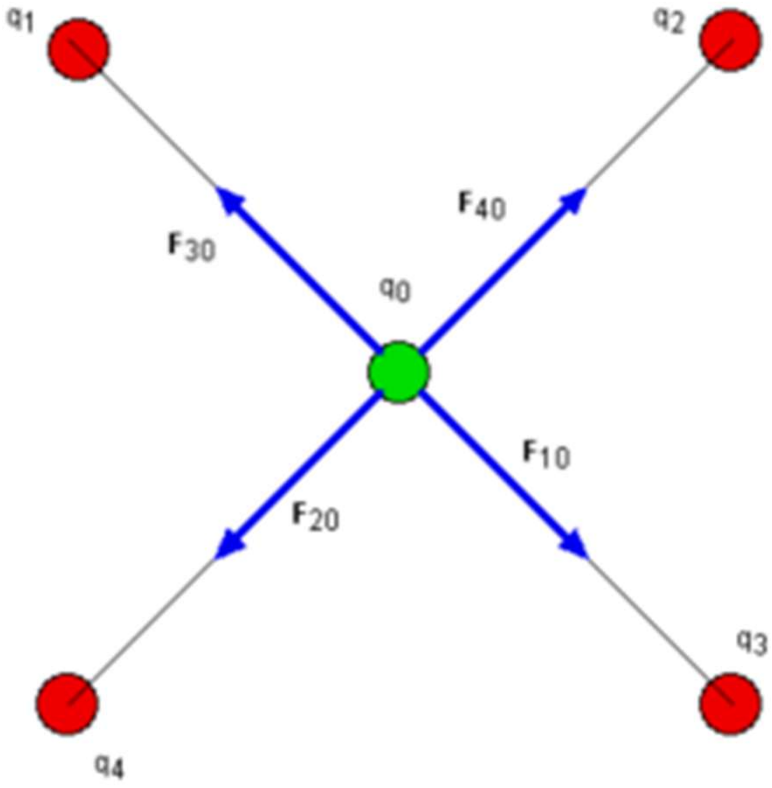
Superconductors are materials that are perfect conductors, allowing charge to move without any hindrance

7. Principle superposition

- When there are more than two charges present we must supplement the Coulomb’s law with one other fact of nature. This fact is called “the principle of superposition.”
- .
- principle of superposition state that The force on any charge is the vector sum of the Coulomb forces(electrostatic force) from each of the other charges. This fact is called “the principle of superposition.”
- If we combine the Coulomb’s law and the principle of superposition, That is all there is to electrostatics.

Suppose we have some arrangement of charges q1, q2, q3, …, qN, fixed in space. From the principle of superposition, the resultant force on the charge q0 is expressed by

$$\boldsymbol{F}_0 = \sum_{j=1}^{N} \boldsymbol{F}_{j0} = \sum_{j=1}^{N} \frac{1}{4\pi\varepsilon_0}\frac{q_0 q_j}{r_{j0}^{2}}\boldsymbol{e}_{j0}$$

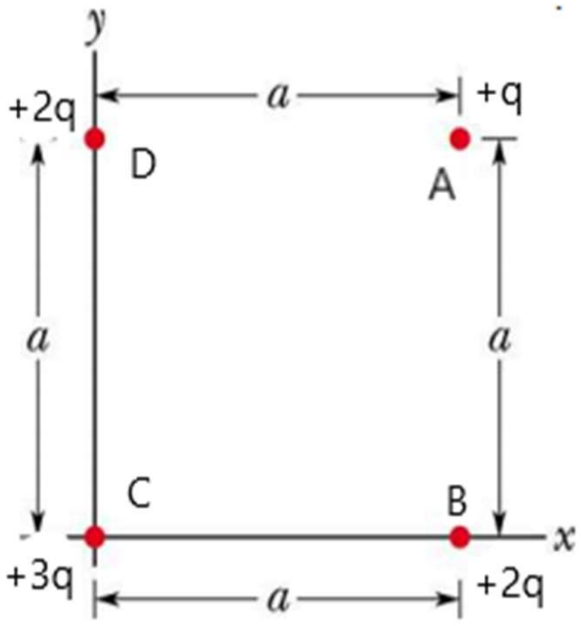


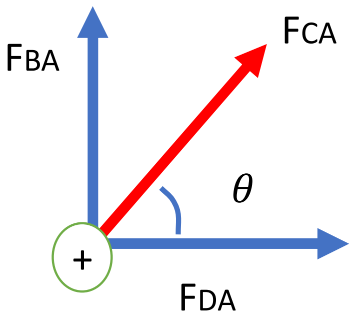
The resultant force F_0 on the charge q_0 is given by

$F_0 = F_{10} + F_{20} + F_{30} + F_{40}$

Example :1

Four point charge at the corners of a square of side (a) shown in fig . Determine the magnitude and direction of the resultant electric force on q in symbolic form q, ke, a ?





Free body diagram (F.B.D) for force on charge A

Solution

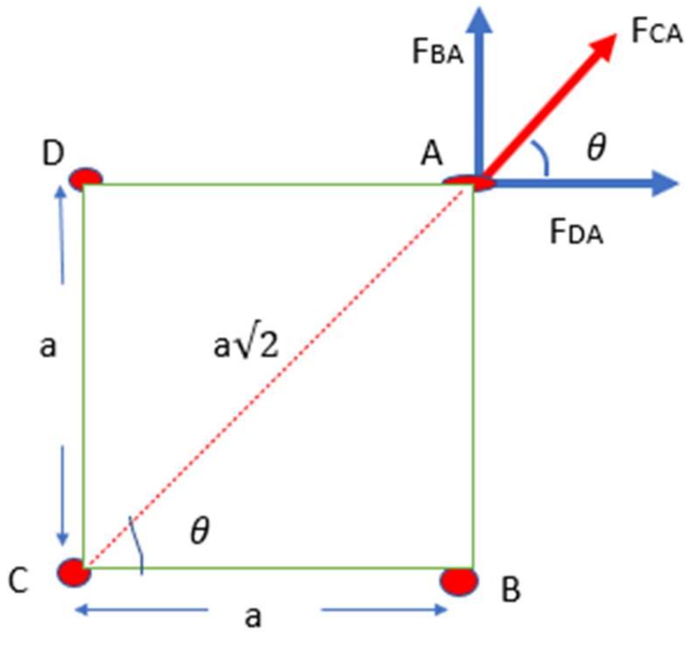


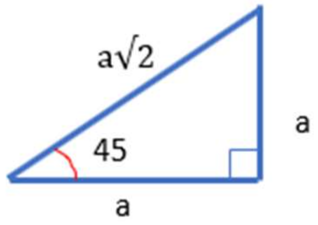
Fig 1.1

As shown in fig 1.1.

1- The force FBA is the force acting from charge B to charge A and the direction of this force upward because the charge(+ A) move away from charge (+B) because of the repel.

2- The force FDA is the force acting from charge D to charge A and the direction of this force to the right because the charge(+ A) move away from charge (+D) because of the repel.

3- The force FcA is the force acting from charge c to charge A and the direction of this force diagonal component in the north east because the charge(+ A) move away from charge (+c) because of the repel. And this force make an angle 45 deg. Because of the symmetry as shown below



- By applying Coulombe's law to find the net electrostatic force

$$f_{1,2} = \frac{k_e\, q_1\, q_2}{r^2}$$

Forces	x – direction	Y- direction
FBA	0	$\frac{k(2q)(q)}{a^2}$
FDA	$\frac{k(2q)(q)}{a^2}$	0
FCA	$\frac{k(3q)(q)}{(a\sqrt{2})^2}$ cos 45	$\frac{k(3q)(q)}{(a\sqrt{2})^2}$ cos 45

The resultant electrostatic force in x-direction (FNX)= $\frac{k(2q)(q)}{a^2} + \frac{k(3q)(q)}{(a\sqrt{2})^2}$ cos 45

The resultant electrostatic force in Y-direction (FNY)= $\frac{k(2q)(q)}{a^2} + \frac{k(3q)(q)}{(a\sqrt{2})^2}$ cos 45

Then find the resultant electrostatic force in q is FN=$\sqrt{F_{NX}^2 + F_{NY}^2}$

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