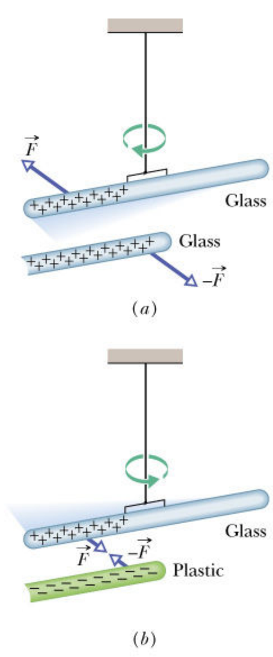
Electricity and Magnetism

Properties of charge, q:

- Types of electric charge
- Forces among two charges (Coulomb's law)
- Charge quantization
- Charge conservation

Concept of an electric field $\vec{E}$

- Calculating the electric field generated by a point charge.
-Using the principle of superposition to determine the electric field created by a collection of point charges as well as continuous charge distributions.
-Once the electric field at a point *P* is known, calculating the electric force on any charge placed at *P*.
-Defining the notion of an "electric dipole." Determining the net force, the net torque, exerted on an electric dipole by a uniform electric field, as well as the dipole potential energy.



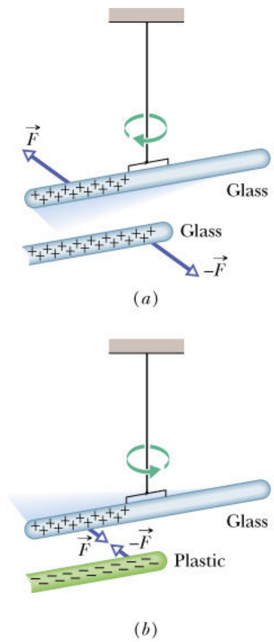
If amber is rubbed on cloth, it attracts objects such as feathers.

Attributed to a new property of matter called 'electric charge' (electron is the Greek name for amber.)

Experiments show that there are two distinct types of electric charge: positive (color code: red) and negative (color code: black). The names "positive" and "negative" were given by Benjamin Franklin.

When we rub a glass rod with $\boxed{}$ the sign on the charge on the glass rod is defined as **positive.**

When we rub a plastic rod with $\boxed{}$ the sign on the charge on the plastic rod is defined as **negative.**

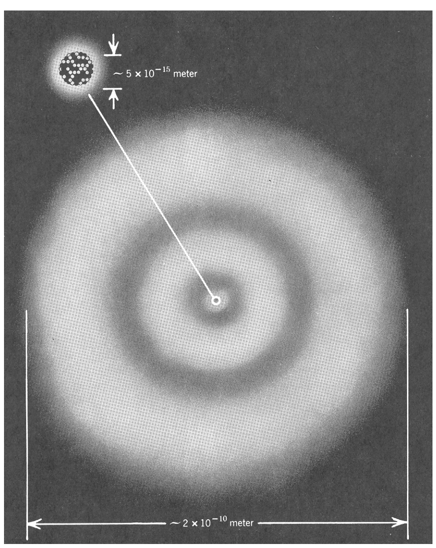


Charges of repel each other.
Charges of attract each other.

Experiments on charged objects showed:

1. Charges of the same type (either both positive or both negative) repel each other (fig. *a*).
2. Charges of opposite type attract each other (fig. *b*).

This force direction allows us to determine the sign of electric charge.



Atoms consist of **electrons** and the **nucleus**. Relative sizes are that of a

Atoms have sizes ~ 5× m.
Nuclei have sizes ~ 5× m.

The nucleus itself consists of two types of particles: **protons** and **neutrons**.

All are fundamental particles: the electrons are **negatively** charged; the protons are **positively** charged; the neutrons are

(18th century) - assumed that electric charge is some type of weightless continuous fluid.

(beginning 20th century) revealed how matter is organized.

Mass and Charge of Atomic Constituents

Neutron (n) : Mass $m = 1.675\times10^{-27}$ kg; Charge $q =$

Proton (p) : Mass $m = 1.673\times10^{-27}$ kg; Charge $q =$

Electron (e) : Mass $m = 9.11\times10^{-31}$ kg; Charge $q =$

Note 1: We use the symbols “-e” and “+e” for the electron and proton charge, respectively. This is known as the **charge.**

Note 2: Atoms are electrically neutral. The number of electrons is equal to the number of protons. This number is known as the (symbol: Z). The chemical properties of atoms are determined **exclusively** by Z.

Note 3: The sum of the number of protons and the number of neutrons is known as the ‘ ’ (symbol: A).

Notation: $^{235}_{92}\mathrm{U}$

$Z = 92$ = number of protons/electrons
$A = 235$ = number of protons + neutrons

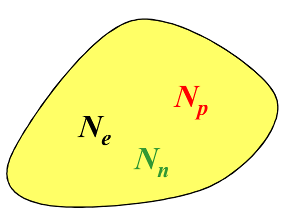
The atomic number Z = 92 defines the nucleus as that of a uranium atom.

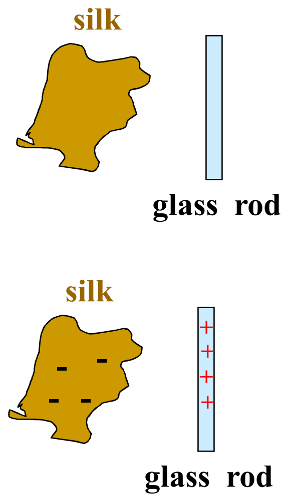
Charge Quantization

Now that we have identified the charge of the atomic constituents (electrons, protons, neutrons), it is clear that the net charge Q_{net} of an object that contains N_e electrons , N_p protons , and N_n neutrons is given by $Q_{\text{net}} = -eN_e + eN_p + 0N_n =$

Here $n =$ and it is an integer. Thus the net charge is **quantized.**

This means that it cannot take any arbitrary value but only values that are multiples of the elementary charge e. The value of e is small and thus in many large-scale phenomena the "graininess" of electric charge is not apparent.





of Charge

Rubbing does not create charge but only transfers it from one body to the other.

Charge can be summarized as follows: In any process the net charge at the beginning equals the net charge at the end of the process.

Net charge before = Net charge after

No exceptions of charge conservation have been found.

For example, charge is conserved in nuclear reactions.

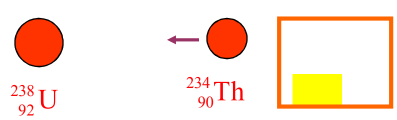
An example is given below:

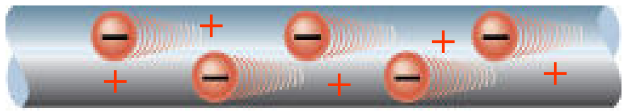
$^{238}_{92}\text{U} \rightarrow$

In this example, a parent nucleus of Uranium-238, which has 92 protons and = 146 neutrons, decays into two products:

i. A daughter Thorium-234 nucleus, which consists of 90 protons and = 144 neutrons

ii. A Helium-4 nucleus, which has 2 protons and 2 neutrons. The net charge before and after the decay remains the same, equal to 92e.





Conductors and Insulators

Conductors are materials that allow charges to move freely through them. Examples are: copper, aluminum, mercury.

Insulators are materials through which charges cannot move freely. Examples are: plastic, rubber, glass, ceramics.

In conductors, one or more of the outermost electrons of the constituent atoms become free and move throughout the solid. These are known as ______. The ______ leave behind positively charged atoms (known as ______). Only the negatively charged electrons are free to move inside a conductor. The positively charged ______ are fixed in place.

Insulators do not have ______

Q. An initially electrically neutral conducting sphere is placed on an insulating stand. A negatively-charged glass rod is brought near, but does not touch the sphere. Without moving the rod, a wire is then attached to the sphere on the opposing side that connects it to earth ground. The rod and wire are then removed simultaneously. What is the final charge on the sphere?

a) negative

b) positive

c) neutral

d) It has a fifty percent chance of having a positive charge and a fifty percent chance of having a negative charge.

Fig. a

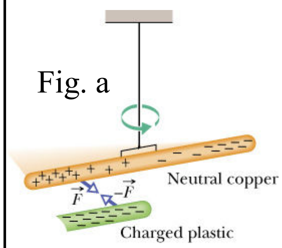
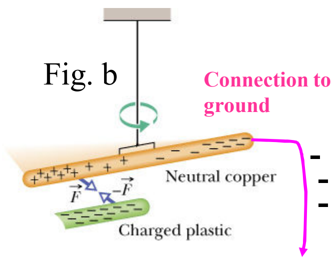


Fig. b



Charging a Conductor by Induction

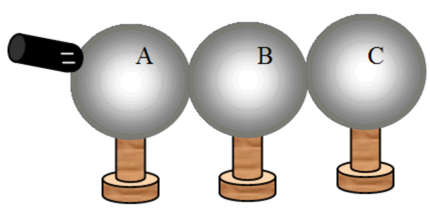
A conductor can be charged using the procedure shown in fig. *a* and fig. *b*. In fig. *a* a conductor is suspended using an insulating thread. The conductor is initially uncharged. We then approach the conductor with a negatively charged rod. The negative charges on the rod are fixed because plastic is an insulator. These repel the conduction electrons of the conductor, which end up at the right end of the rod. The right end of the rod has an electron deficiency and thus becomes positively charged. In fig. *b* we provide a conducting path to ground (e.g., we can touch the conductor). As a result, the electrons escape to the ground. If we remove the path to the ground and the plastic rod, the conductor remains positively charged.

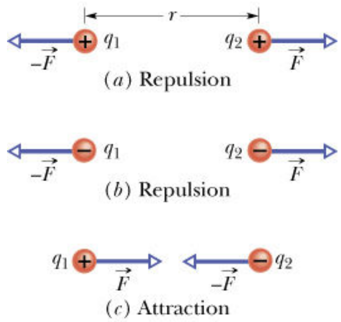
Note 1 : The induced charge on the conductor has the opposite sign of the charge on the rod.

Note 2 : The plastic rod can be used repeatedly.

Q. Three identical conducting spheres on individual insulating stands are initially electrically neutral. The three spheres are arranged so that they are in a line and touching as shown. A negatively-charged conducting rod is brought into contact with sphere A. Subsequently, someone takes sphere C away. Then, someone takes sphere B away. Finally, the rod is taken away. What is the sign of the final charge, if any, of the three spheres?

	A	B	C
a)	+	+	–
b)	+	–	+
c)	+	0	–
d)	–	+	0
e)	–	–	–





$F =$

c.f. $F = G\dfrac{m_1 m_2}{r^2}$

Coulomb's Law

Consider two charges q_1 and q_2 placed at a distance r.
The two charges exert a force on each other that has the following characteristics:

1. The force acts along the two charges.
2. The force is for charges of opposite sign.
The force is for charges of the same sign.
3. The magnitude of the force, known as force, is given by the equation $F =$

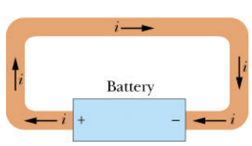
The constant ε_0 is known as the **permittivity constant**
$\varepsilon_0 = 8.85 \times 10^{-12}\ \mathrm{N \cdot m^2/C^2}$.

Units of Charge

The unit of charge in the SI unit system is the "Coulomb" (symbol C).

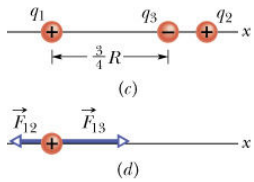
How much weight could a coulomb of charge lift, where separated from it's equal and opposite charge by 1m?

For practical reasons that have to do with the accuracy of the definition, the electric current is used instead. The electric current i in the circuit of the figure is defined by the equation , i.e., the amount of charge that flows through any cross section of the wire per unit time. The unit of current in SI is the ampere (symbol A) and it can be defined very accurately.



(b)

If we solve the equation above for dq we get
Thus if a current $i = 1\mathrm{A}$ flows through the circuit, a charge $q = 1\mathrm{C}$ passes through any cross section of the wire in one second.



Coulomb's Law and the Principle of Superposition

The net electric force exerted by a group of charges is equal to the $\boxed{\quad}$ of the contribution from each charge.

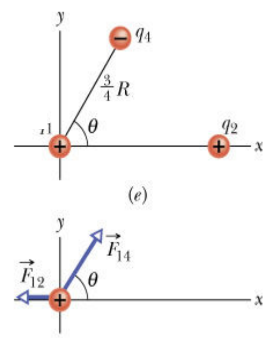
For example, the net force $\vec{F}_1$ exerted on q_1 by q_2 and q_3 is equal to $\vec{F}_1 = \boxed{\quad}$

Here $\vec{F}_{12}$ and $\vec{F}_{13}$ are the forces exerted on q_1 by q_2 and q_3, respectively.

In general, the force exerted on q_1 by n charges is given by the equation

$$\vec{F}_1 = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14} + \ldots + \vec{F}_{1n} = \boxed{\quad}$$

$$\vec{F}_1 = \boxed{\quad}$$



Q. Two objects separated by a distance r are each carrying a charge $-q$. The magnitude of the force exerted on the second object by the first is F. If the first object is removed and replaced with an identical object that carries a charge $+4q$, what is the magnitude of the electric force on the second object?

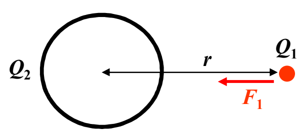
a) $4F$

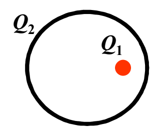
b) $2F$

c) F

d) $F/2$

e) $F/4$

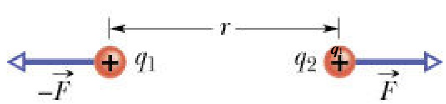




If Q_1 is outside the shell, then the force F_1 exerted by Q_2 is

$F_1 =$. If Q_1 is inside the shell, then the force

Coulomb's law, gives the force between two point charges. The law is written in such a way as to imply that q_2 acts on q_1 at a distance r. "action at a distance – how?"

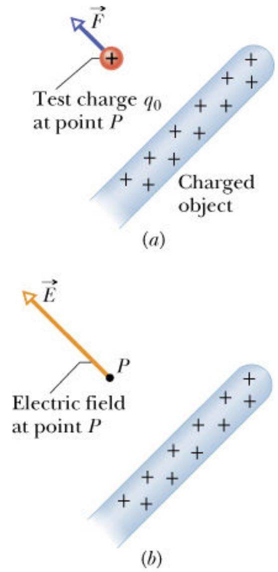


$F =$

Can introduce the new concept of an **electric field** vector as follows: point charge q_1 does not exert a force directly on q_2. Instead, q_1 creates in its vicinity an electric field that exerts a force on q_2 .

charge q_1 $\rightarrow$ **generates** $\rightarrow$ **on q_2**

$\vec{E} = \boxed{\quad}$



Definition of the Electric Field Vector

Consider the positively charged rod shown in the figure. For every point P in the vicinity of the rod we define the electric field vector $\vec{E}$ as follows:

1. We place a $\boxed{\quad}$ at point P.

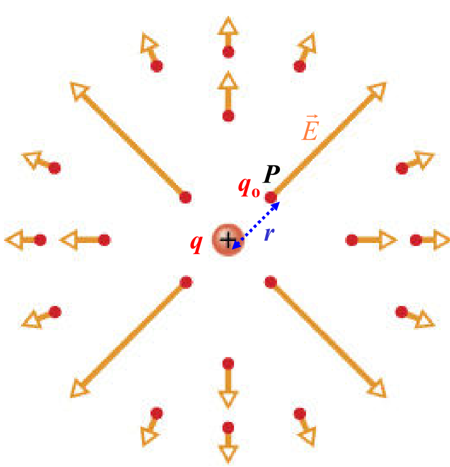
2. We measure the electrostatic force $\vec{F}$ exerted on q_0 by the charged rod.

3. We define the electric field vector $\vec{E}$ at point P as:

$\vec{E} = \boxed{\quad}$ SI Units: N/C

From the definition it follows that $\vec{E}$ is parallel to $\vec{F}$.

Note : We assume that the test charge q_0 is small



Electric Field Generated by a Point Charge

Consider the positive charge q shown in the figure. At point P a distance r from q we place the test charge q_0. The force exerted on q by q_0 is equal to:

$$F = \frac{1}{4\pi\varepsilon_0}\frac{|q||q_0|}{r^2}$$

$$E = \frac{F}{q_0} = \frac{1}{4\pi\varepsilon_0}\frac{|q||q_0|}{q_0 r^2} = \boxed{\quad}$$

$E = \boxed{\quad}$

If q were a negative charge the magnitude of $\vec{E}$ would remain the same. The direction of $\vec{E}$ would point radially $\boxed{\quad}$ instead.

Electric field lines extend away from positive charges (where they originate) and toward negative charges (where they terminate).

Example 1 : Electric field lines of a negative point charge - q :

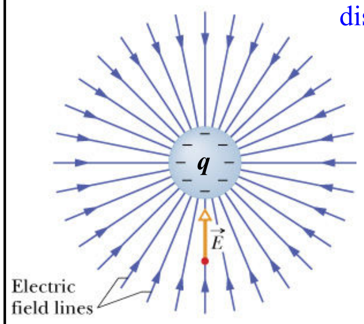
$$\boxed{E = \frac{1}{4\pi\varepsilon_0}\frac{|q|}{r^2}}$$

-The electric field lines point toward the point charge.

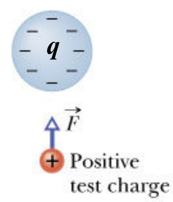
-The direction of the lines gives the direction of $\vec{E}$.

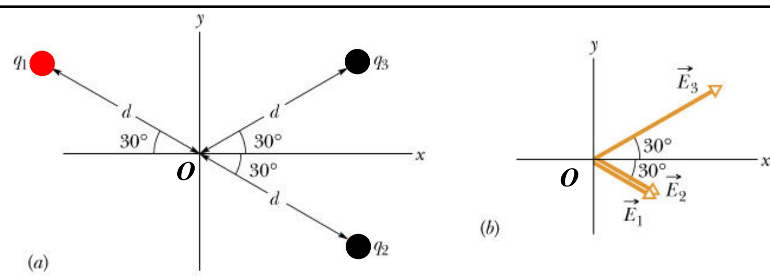
-The density of the lines/unit area increases as the distance from $-q$ decreases.

Note : In the case of a positive point charge the electric field lines have the same form but they point **outward.**



(b)





Electric Field Generated by a Group of Point Charges. Superposition

The net electric electric field $\vec{E}$ generated by a group of point charges is equal to the vector sum of the electric field vectors generated by each charge.

In the example shown in the figure, $\vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3$.

Note: $\vec{E}_1$, $\vec{E}_2$, and $\vec{E}_3$ must be added as vectors:

$E_x = E_{1x} + E_{2x} + E_{3x}$, $E_y = E_{1y} + E_{2y} + E_{3y}$, $E_z = E_{1z} + E_{2z} + E_{3z}$

At a distance of one centimeter from an electron, the electric field strength has a value *E*. At what distance is the electric field strength equal to *E*/2?

a) 0.5 cm

b) 1.4 cm

c) 2.0 cm

d) 3.2 cm

e) 4.0 cm

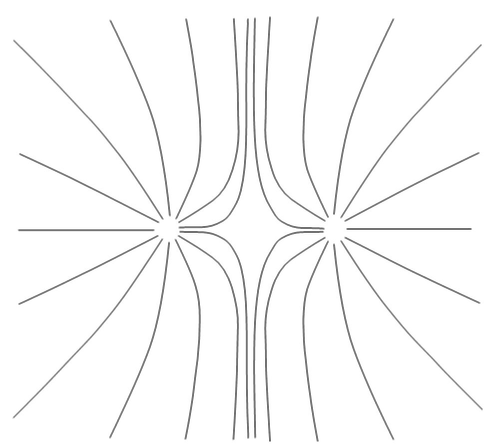
22.4.4. Consider the electric field lines shown in the drawing. Which of the following statements correctly describes this situation?

a) The electric field is due to a positively charged particle.

b) The electric field is due to a negatively charged particle.

c) The electric field is due to a positively charged particle and a negatively charged particle.

d) The electric field is due to particles that are both charged either positively or negatively.

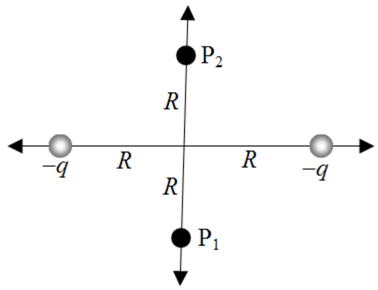


Q. Two negatively-charged objects are located on the x axis, equally distant from the origin as shown. Consider the electric field at the point P_1. How will that electric field change if a third object with a charge $+q$ is placed at point P_2? Note: the point P_2 is the same distance from the origin as the point P_1 and the magnitude of each of the charges is the same.

a) The magnitude of the electric field will decrease by less than 1/5.

b) The magnitude of the electric field will increase by ~ 1/4.

c) The magnitude of the electric field will decrease by ~ 1/2



d) The magnitude of the electric field will increase by ~ 1/2

e) The magnitude of the electric field will increase by 100%.

Q. The drawing shows a hollow conducting sphere with a net positive charge uniformly distributed over its surface. A small negatively-charged object has been brought near the sphere as shown. What is the direction of the electric field at the center of the sphere?

a) There is no electric field at the center of the sphere.

b) to the left

c) to the right

d) upward

e) downward