Electrostatic Forces and Fields

Conductors, Insulators, and Induced Charges

Fundamental unit of charge is the Coulomb (C)

-electron charge is -1.60 x 10^{-19} C

-proton charge is +1.60 x 10^{-19} C

Conductors permit easy movement of charge.

Insulators do not.

Charges can be transferred to materials as well as be induced within the material.

The Electrostatic Force

Force between stationary electric charges

Force can be attractive or repulsive

-Like charges repel (+,+) or (-,-)

-Unlike charges attract (+,-) or (-,+)

Coulomb's Law

$$F = \frac{1}{4\pi\varepsilon_o}\left|\frac{q_1 q_2}{r^2}\right|$$

$$k = \frac{1}{4\pi\varepsilon_o} = 9.0 \text{ x } 10^9 \ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}$$

where:

F - Electrostatic Force between q_1 and q_2 (N)

ε_o - Permittivity of free space (8.85 x 10^{-12} $C^2/N\cdot m^2$)

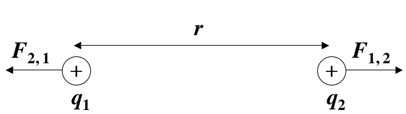
r - Distance between q_1 and q_2 (m)

q_i - Electrostatic charge on object i (C)

Coulomb's Law

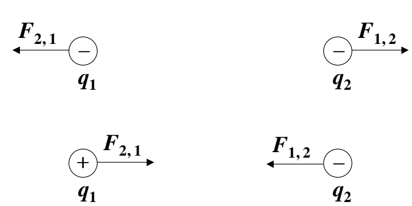
$$F = k\left|\frac{q_1 q_2}{r^2}\right|$$

Both charges experience the same force.



$F_{i,j}$ is the force that charge i exerts on charge j.

Coulomb's Law



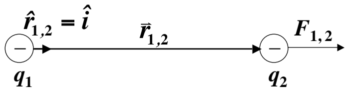
The forces are vectors and

$$\bar{F}_{i,j} = -\bar{F}_{j,i}$$

Coulomb's Law (Vector Form)

$$\vec{F}_{1,2} = \frac{1}{4\pi\varepsilon_o}\frac{q_1 q_2}{r^2}\hat{r}$$

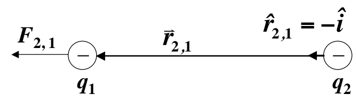
where $\hat{r}$ is a unit vector directed from q_1 to q_2



Coulomb's Law (Vector Form)

$$\vec{F}_{2,1} = \frac{1}{4\pi\varepsilon_o}\frac{q_2 q_1}{r^2}\hat{r}$$

where $\hat{r}$ is a unit vector directed from q_2 to q_1



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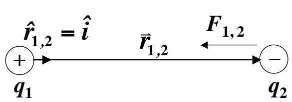

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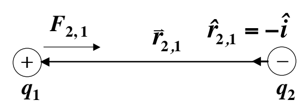
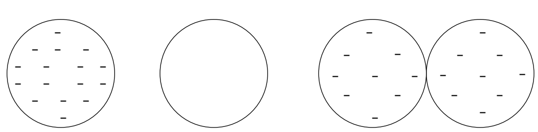


Charging by Conduction

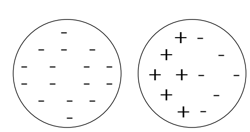
If a negatively-charged conductor is brought into contact with a neutral conductor, electrons are transferred to the neutral conductor and it becomes *charged by conduction*.



Charged Conductor **Neutral Conductor** **Charging by Conduction**

Induction

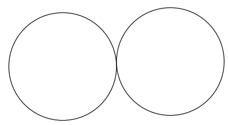
If a negatively-charged object is brought near a neutral conductor the mobile electrons in the conductor will be repelled, leaving behind positively charged nuclei.



Charged Object **Neutral Conductor**

Charging Conductors by Induction

Charge separation can be used to charge an object without touching it.



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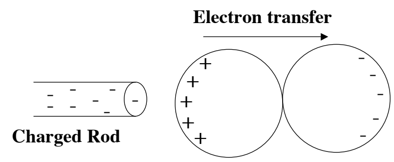
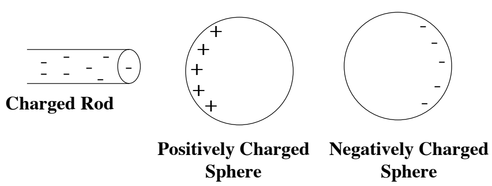


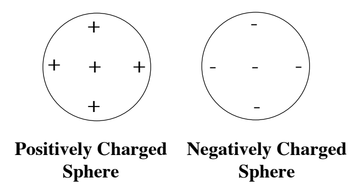
Charging Conductors by Induction

If the spheres are separated while the rod is nearby, each sphere will have an equal and opposite charge.



Charging Conductors by Induction

After removing the charged rod:



This process is called *charging by induction*.

Electric Field

- **An electric field extends outward from a charged object and permeates all of space.**
- **The electric field at some point near a charged object is defined to be the electrostatic force per unit charge acting on the charge placed at that point.**
- **The electric field is a vector field and the direction of electric field is that of the electrostatic force acting on the positive test charge.**

Electric Field

$$\vec{E} = \frac{\vec{F}}{q_o}$$

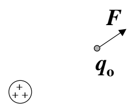
where:

E - Electric Field acting on test charge q_o (N/C)

F - Electrostatic force acting on charge q_o (N)

q_o - magnitude of the test charge (C)

Electric Field



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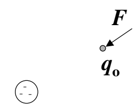
Electric Field



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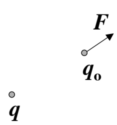
Electric Field



$$F = \frac{1}{4\pi\varepsilon_o}\frac{qq_o}{r^2}$$

$$E = \frac{F}{q_o} = \frac{\frac{1}{4\pi\varepsilon_o}\frac{qq_o}{r^2}}{q_o} = \frac{1}{4\pi\varepsilon_o}\frac{q}{r^2}$$

Electric Field due to a Point Charge

$$\vec{E} = \frac{1}{4\pi\varepsilon_o}\frac{q}{r^2}\hat{r}$$

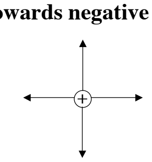
$\hat{r}$ is a unit vector that points along the line from source point to field point.

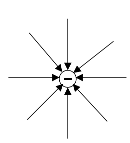
For a system of point charges the electric field can be found by summing up the individual contributions.

Field Lines

Field lines provide a graphical representation of electric fields.

- **At any point on a field line, the tangent to the line is the direction of the electric field at that point**
- **Where the lines are closer together, *E* is larger**
- **Field lines point away from positive charges and towards negative charges**





Electric Field due to Charge Distributions

When charge is distributed over a line, a surface, or through a volume we often speak of

linear charge density λ (C/m)
surface charge density σ (C/m^2)
volume charge density ρ (C/m^3)

$$d\vec{E} = \frac{1}{4\pi\varepsilon_o}\frac{dq}{r^2}\hat{r}$$

Electric Field due to Charge Distributions

$$d\vec{E} = \frac{1}{4\pi\varepsilon_o}\frac{dq}{r^2}\hat{r}$$

$$\int d\vec{E} = \int \frac{1}{4\pi\varepsilon_o}\frac{dq}{r^2}\hat{r}$$

$$\vec{E} = \int \frac{1}{4\pi\varepsilon_o}\frac{dq}{r^2}\hat{r}$$

Electric Field due to Charge Distributions

Since the electric field is a vector the *x* and *y* components must be treated separately.

$$dE_x = dE\cos\theta \qquad dE_y = dE\sin\theta$$

Electric Field due to Charge Distributions

For a total charge *Q* uniformly distributed over a length *L*

$$\lambda = \frac{Q}{L}$$

For linear charge distributions (line charges)

$$dq = \lambda d\ell$$

Electric Field due to Charge Distributions

For uniform charge distributions along the *x*-axis

$$dq = \lambda dx$$

For uniform charge distributions along the *y*-axis

$$dq = \lambda dy$$

For circular uniform charge distributions radius *R*

$$dq = \lambda ds = \lambda R d\theta$$

Electric Field due to Charge Distributions

For a uniformly charged surface total charge *Q* and area *A*

$$\sigma = \frac{Q}{A}$$

For surface charge distributions (charged plates)

$$dq = \sigma dA$$

Electric Field due to Charge Distributions

For a uniformly charged volume total charge *Q* and volume *V*

$$\rho = \frac{Q}{V}$$

For volume charge distributions (charged solids)

$$dq = \rho dV$$