PHY- 104 ELECTRICITY & MAGNETISM

Credit Hours: Four (3)

Course instructor:

Dr. Fareesa Tahir

PHY- 104 ELECTRICITY & MAGNETISM

Credit Hours: Four (4)

Electrostatics: Electric Charge; Conductors and Insulators; Coulomb's Law; Electric Fields due to a Point Charge and an Electric Dipole; Electric Field due to Charge Distribution; Electric Dipole in an Electric Field; Electric Flux; Gauss' Law and its Applications in Planar; Spherical and Cylindrical Symmetry

Electric Potential: Equipotential Surfaces; Potential due to a Point Charge and a Group of Point Charges; Potential due to an Electric Dipole; Potential due to Charge Distribution; Relation between Electric Field and Electric Potential Energy

Capacitors and Capacitance: Parallel Plate; Cylindrical and Spherical capacitors; Capacitors in Series and Parallel; Energy Stored in an Electric Field; Dielectrics and Gauss' Law

DC Circuits: Electric Current and Current Density; Resistance and Resistivity; Ohm's Law; Power in Electric Circuits; Semiconductors and Superconductors; Work; Energy and EMF; Resistances in Series and Parallel; Single and Multi-loop Circuits; Kirchhoff's Rules; RC Circuits; Charging and Discharging of a Capacitor

Magnetic Field and Magnetic Force: Sources of Magnetic Field; Magnetic Force on a Moving Charge; Crossed Electric and Magnetic Fields and their Applications; Hall Effect; Magnetic Force on a Current Carrying Wire; Torque on a Current Loop; Magnetic Dipole Moment; Magnetic Field Due to a Current; Force between two Parallel Currents; Biot-Savart Law: Magnetic Field due to a Current, Long Straight Wire, Solenoids and Toroids, Ampere's Law; A Current-carrying Coil as a Magnetic Dipole; Inductance; Faraday's Law of Induction; Lenz's Law; Induction and Energy Transfer; Induced Electric Fields; Inductors and Inductance; Self Inductance; RL Circuits; Energy Stored in a Magnetic Field; Energy Density; Mutual Induction **Alternating Fields and Currents:** LC Oscillations; Damped Oscillations in an RLC circuit; Alternating Currents; Forced Oscillations; Resistive, Capacitive, and Inductive Loads; RLC series Circuit; Power in AC Circuits; Transformers;

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Gauss' Law for Magnetism; Induced Magnetic Fields; Displacement Current; Spin & Orbital Magnetic Dipole Moment; Diamagnetism; Paramagnetism; Ferromagnetism and Hysteresis.

Electrostatics: Electric Charge; Conductors and Insulators; Coulomb's Law; Electric Fields due to a Point Charge and an Electric Dipole; Electric Field due to Charge Distribution; Electric Dipole in an Electric Field; Electric Flux; Gauss' Law and its Applications in Planar; Spherical and Cylindrical Symmetry

Electric Potential: Equipotential Surfaces; Potential due to a Point Charge and a Group of Point Charges; Potential due to an Electric Dipole; Potential due to Charge Distribution; Relation between Electric Field and Electric Potential Energy

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Recommended Text Books:

1. D. Halliday, R. Resnick and J. Walker, "Fundamentals of Physics", John Wiley & Sons, 9th ed. (2010).
2. R. A. Serway and J. W. Jewett, "Physics for Scientists and Engineers", Golden Sunburst Series, 8th ed., (2010).
3. R. A. Freedman, H. D. Young, and A. L. Ford (Sears and Zeemansky), "University Physics with Modern Physics", Addison-Wesley-Longman, 13th International ed., (2010).

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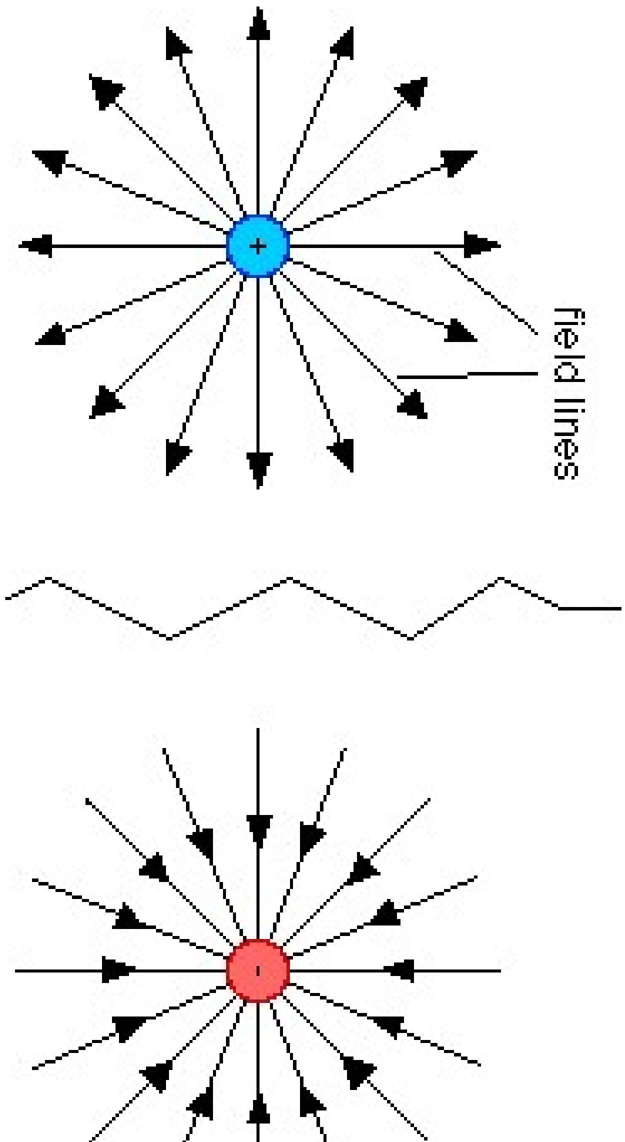
4. F. J Keller, W. E. Gettys and M. J. Skove, “Physics: Classical and Modern", McGraw Hill, 2nd ed., (1992).
5. D. C. Giancoli, “Physics for Scientists and Engineers, with Modern Physics”, Addison-Wesley, 4th ed., (2008).

PHY- 104 ELECTRICITY & MAGNETISM

Credit Hours: Four (4)

Chapter 1: Electrostatics



PHY- 104 ELECTRICITY & MAGNETISM

Credit Hours: Four (4)

Electric Charge; Conductors and Insulators; Coulomb’s Law;

Electric Fields due to a Point Charge and an Electric Dipole;

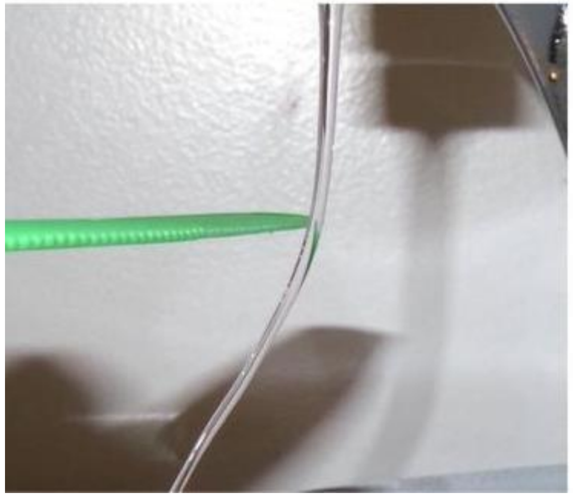
Electric Field due to Charge Distribution; Electric Dipole in an Electric Field;

Electric Flux; Gauss’ Law and its Applications in Planar;

Spherical and Cylindrical Symmetry

Electric Charge Electric Charge is the property of subatomic particles that causes it to experience a force when placed in an electric and magnetic field.

Mathematically



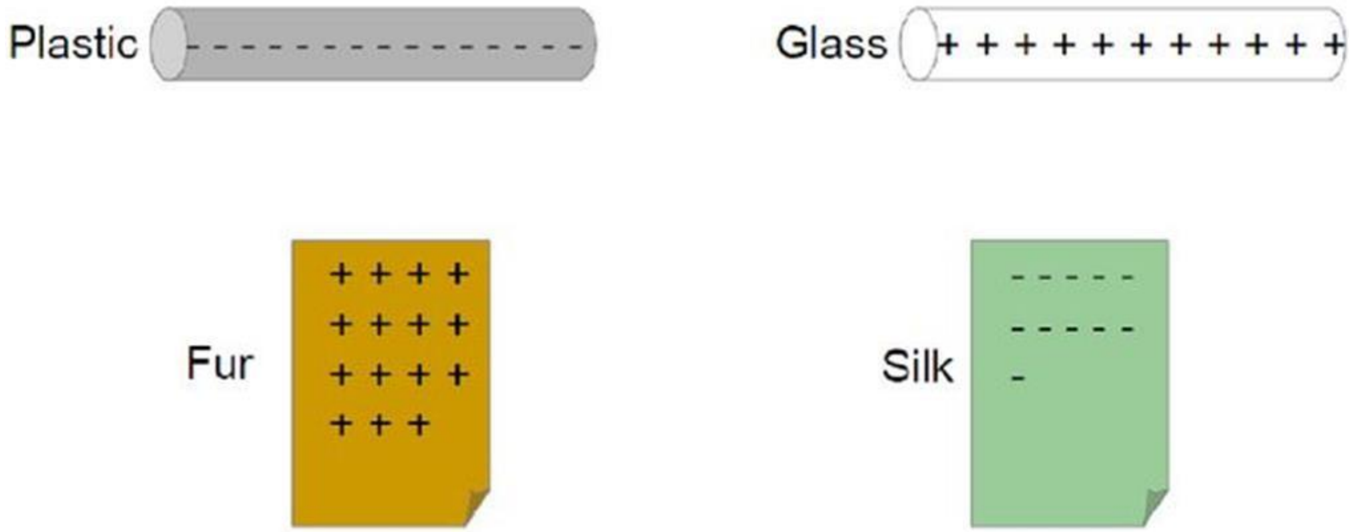
$$q = \int_{t_i}^{t_f} I \cdot dt$$

Electric Charge

Three major ways to create charges onto materials

Tribology/Rubbing

- Tribology/Rubbing (only works for insulators)
- Contact (Works for both insulators and conductors)
- Induction (Only work for conductors)



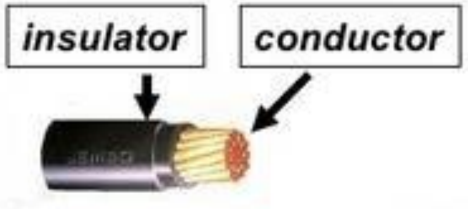
Different materials have different electron affinity

Conductors and Insulators

Conductors

Any material that allows electric current to pass through it

•copper



•any metal

•aluminum

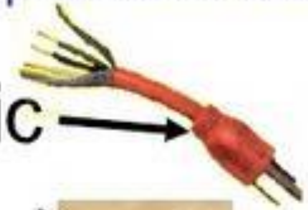
•steel

Insulators

Any material that does not allow electric current to pass through it

•like the protective coating on wires

•plastic



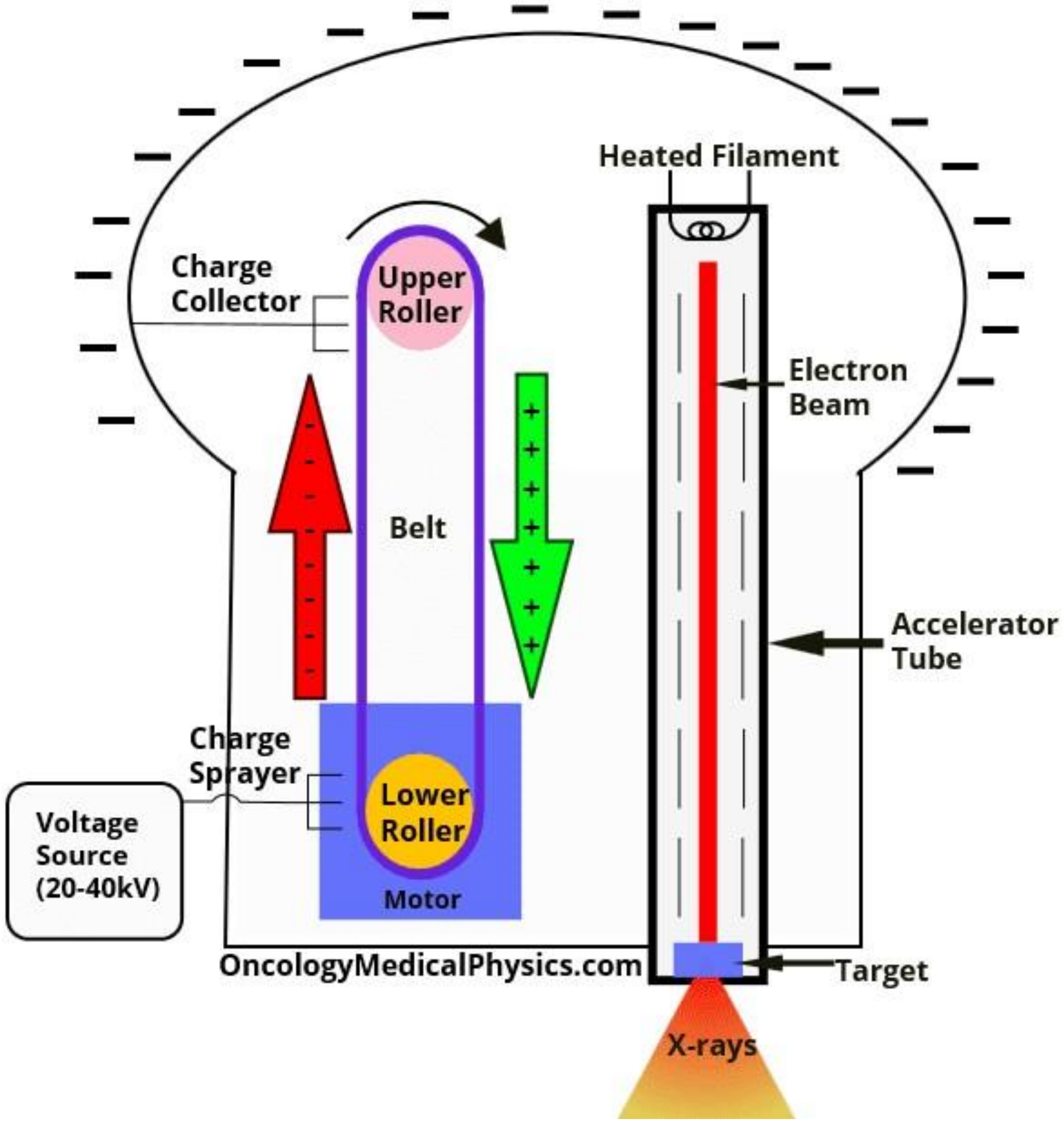
•cloth

•rubber

•wood

•glass

Van de Graaff Generator

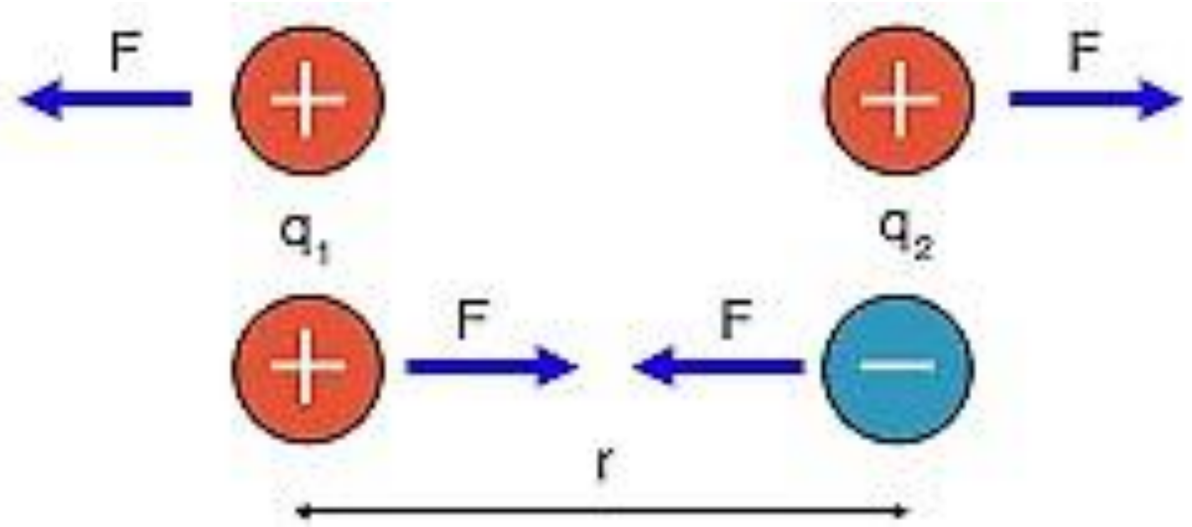


Coulomb's Law

In the year 1786, **Coulomb** deduced the expression for the force between two **stationary point** charges in vacuum or free space. Consider two point charges $\mathbf{q_1}$ and $\mathbf{q_2}$ at rest in vacuum, and separated by a distance of **r**, then

$$\boxed{F = k\frac{q_1 q_2}{r^2}}$$

Inverse Square Law



k = Coulomb's Constant = $9.0\text{x}10^9$ Nm^2/C^2

q_1 = Point charge -1

q_2 = Point charge - 2

r = the distance between the two charges

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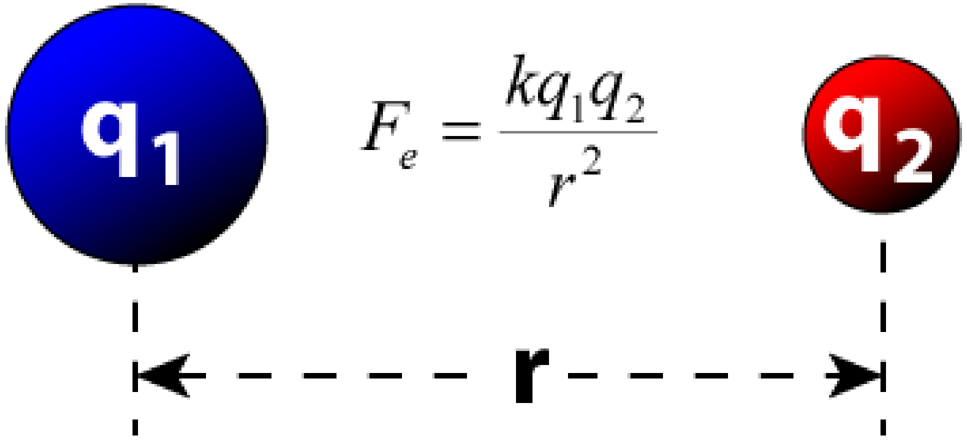
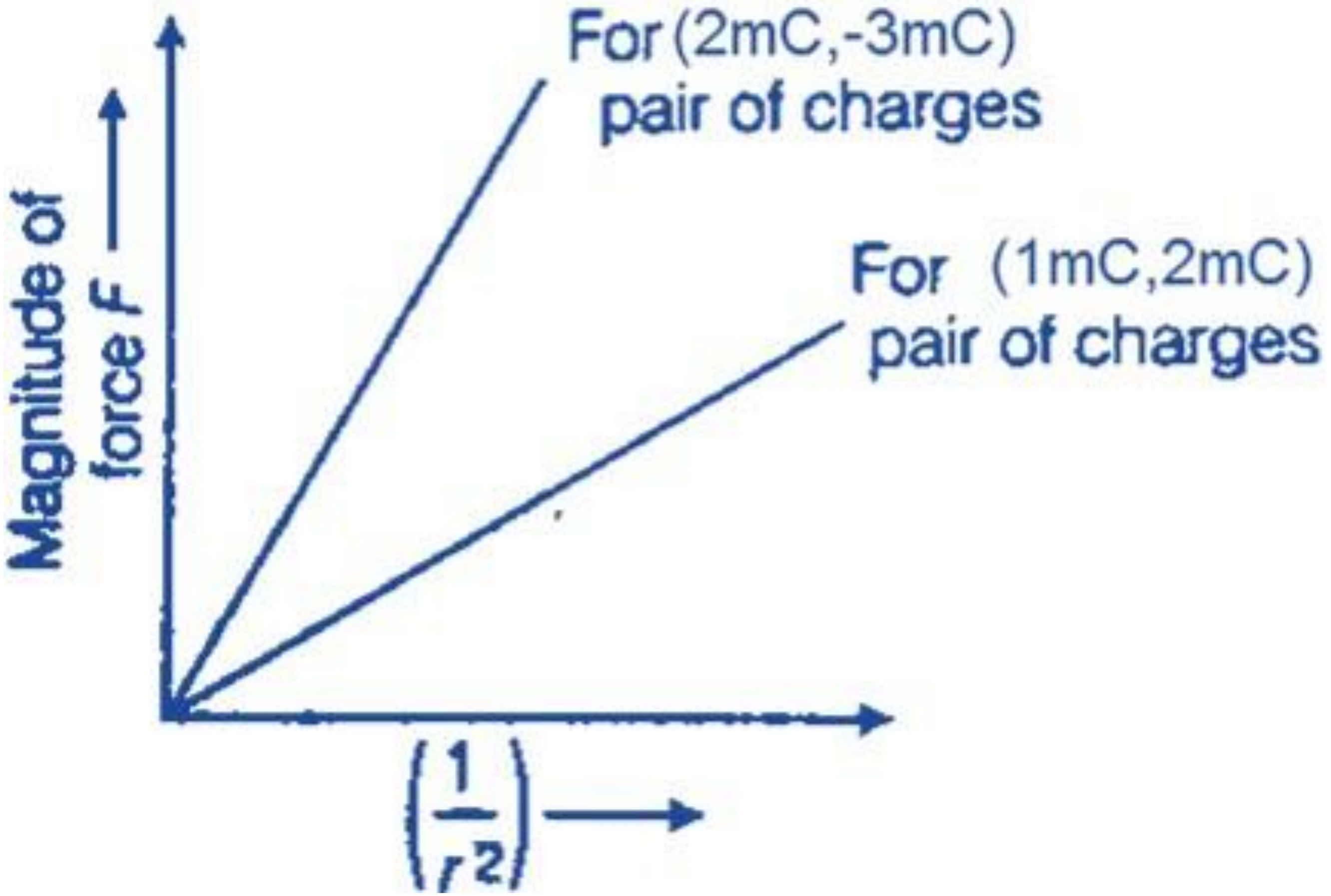
Chapter 1: Electrostatics

Coulomb's Law



$$F_e = \frac{kq_1q_2}{r^2}$$



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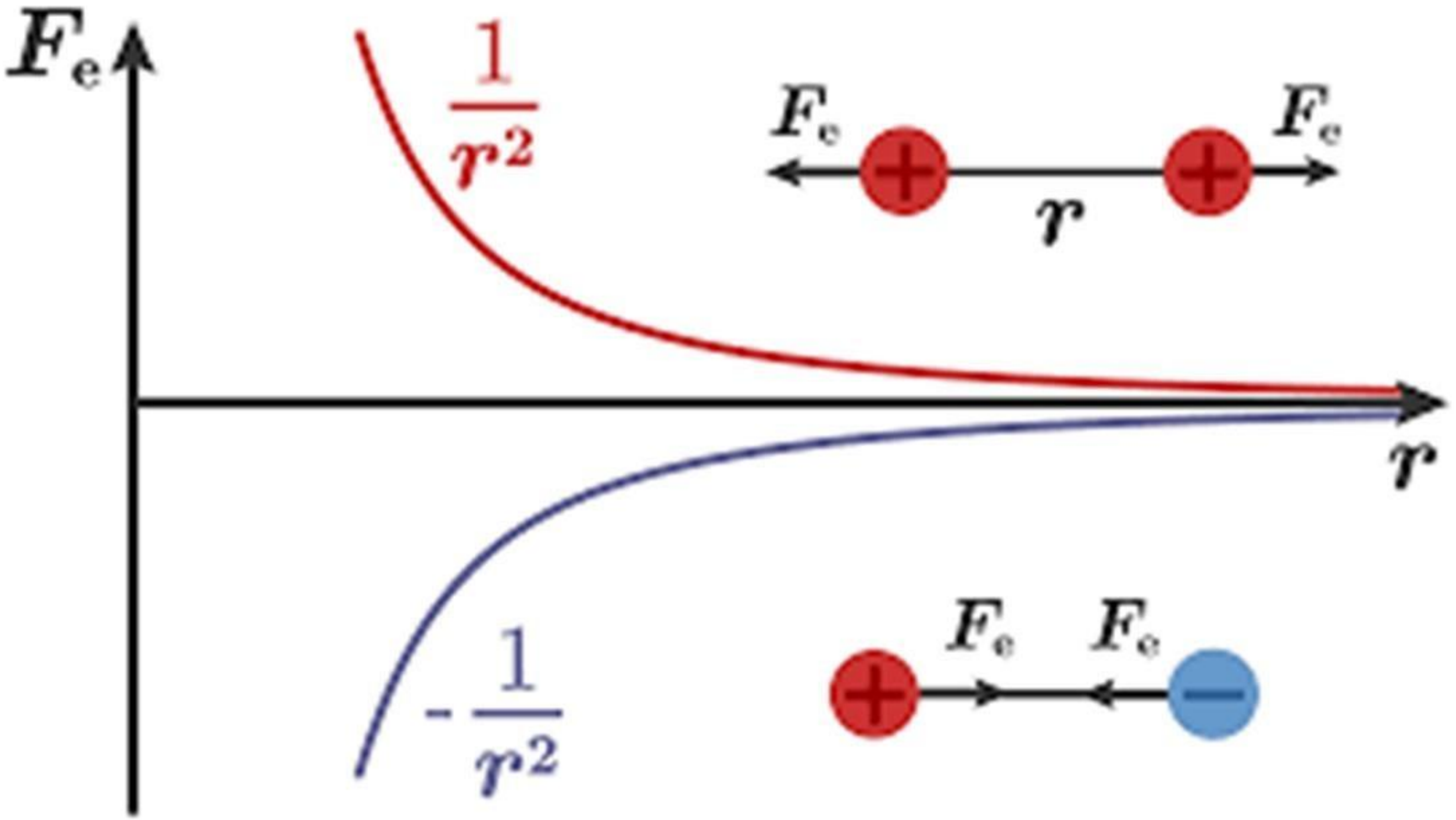

F_e
$\frac{1}{r^2}$
F_e
F_e
r
r
$-\frac{1}{r^2}$
F_e
F_e

Coulomb's Law

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

Inverse Square Law

where ε_0 is the permittivity of a vacuum.

The value of ε_0 is 8.85×10^{-12} Farads/meter, and for a vacuum, K = 1.

For air, K = 1.00059, or nearly unity.

For vacuum $$F_v = \frac{1}{4\pi\varepsilon_o}\frac{q_1 q_2}{r^2}$$

For medium $$F_m = \frac{1}{4\pi\varepsilon_o\varepsilon_r}\frac{q_1 q_2}{r^2}$$

$$\boxed{\therefore \frac{F_m}{F_v} = \varepsilon_r}$$

Coulomb's Law

EXAMPLE

Calculate the **electrostatic force** and **gravitational force** between the **proton** and the **electron** in a **hydrogen atom**. They are separated by a distance of 5.3×10^{-11} m. The magnitude of charges on the electron and proton are 1.6×10^{-19} C. Mass of the electron is $m_e = 9.1 \times 10^{-31}$ kg and mass of proton is $m_p = 1.6 \times 10^{-27}$ kg.

Coulomb's Law

EXAMPLE

Calculate the electrostatic force and gravitational force between the proton and the electron in a hydrogen atom. They are separated by a distance of 5.3×10^{-11} m. The magnitude of charges on the electron and proton are 1.6×10^{-19} C. Mass of the electron is $m_e = 9.1 \times 10^{-31}$ kg and mass of proton is $m_p = 1.6 \times 10^{-27}$ kg.

Solution

The proton and the electron attract each other. The magnitude of the electrostatic force between these two particles is given by

$$F_e = \frac{ke^2}{r^2} = \frac{9\times10^9 \times \left(1.6\times10^{-19}\right)^2}{\left(5.3\times10^{-11}\right)^2}$$

$$= \frac{9\times2.56}{28.09}\times10^{-7} = 8.2 \times 10^{-8}\text{ N}$$

Coulomb's Law

EXAMPLE

Calculate the electrostatic force and gravitational force between the proton and the electron in a hydrogen atom. They are separated by a distance of 5.3×10^{-11} m. The magnitude of charges on the electron and proton are 1.6×10^{-19} C. Mass of the electron is $m_e = 9.1 \times 10^{-31}$ kg and mass of proton is $m_p = 1.6 \times 10^{-27}$ kg.

Solution

The gravitational force between the proton and the electron is attractive. The magnitude of the gravitational force between these particles is

$$F_G = \frac{Gm_e m_p}{r^2}$$

$$= \frac{6.67\times10^{-11}\times9.1\times10^{-31}\times1.6\times10^{-27}}{\left(5.3\times10^{-11}\right)^2}$$

$$= \frac{97.11}{28.09}\times10^{-47} = 3.4 \text{ x } 10^{-47} \text{ N}$$

The ratio of the two forces $\frac{F_e}{F_G} = \frac{8.2\times10^{-8}}{3.4\times10^{-47}}$

$= 2.41 \times 10^{39}$

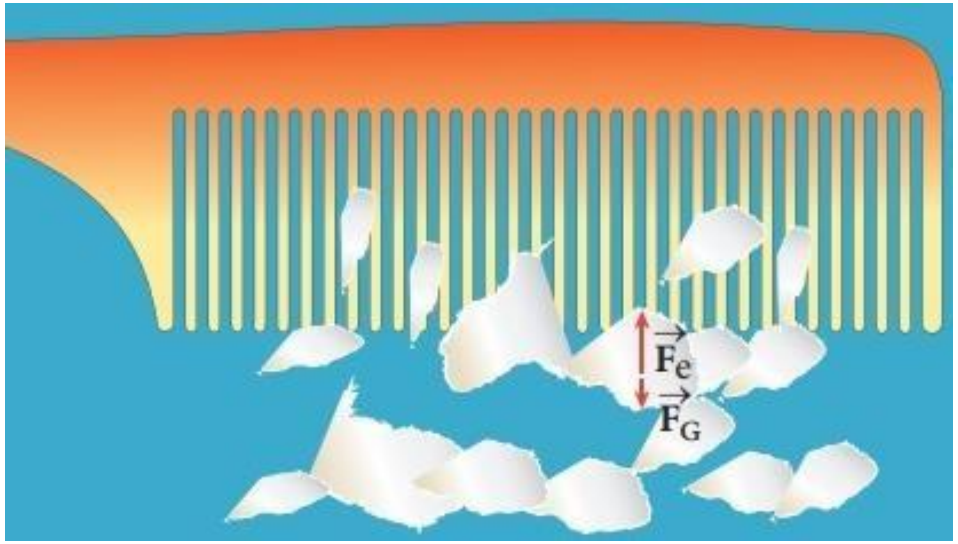
Note that $\boxed{F_e \approx 10^{39} F_G}$

Coulomb's Law

EXAMPLE

$$\boxed{F_e \approx 10^{39} F_G}$$

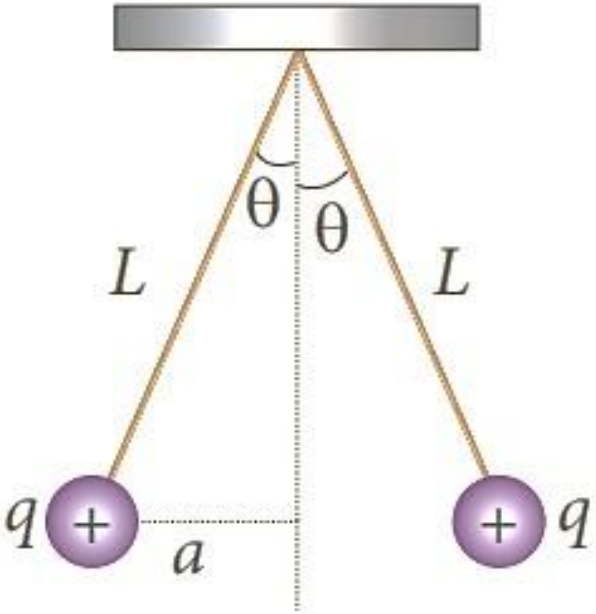
The electrostatic force between a **proton and an electron is enormously greater** than the gravitational force between them. Thus the gravitational force is negligible when compared with the electrostatic force in many situations such as for small size objects and in the atomic domain. **This is the reason that a charged comb attracts an uncharged piece of paper with greater force even though the piece of paper is attracted downward by the Earth.**



Coulomb's Law

EXAMPLE

Two identical equally charged spheres (each having mass **1mg**), are hanging in equilibrium as shown in the figure. The length of each string is **10cm** and the angle **θ** is **7°** with the vertical. **Calculate the magnitude of the charge in each sphere**. (consider **g=10ms^{-2}**)



PHY- 104 ELECTRICITY & MAGNETISM

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Chapter 1: Electrostatics

Coulomb's Law

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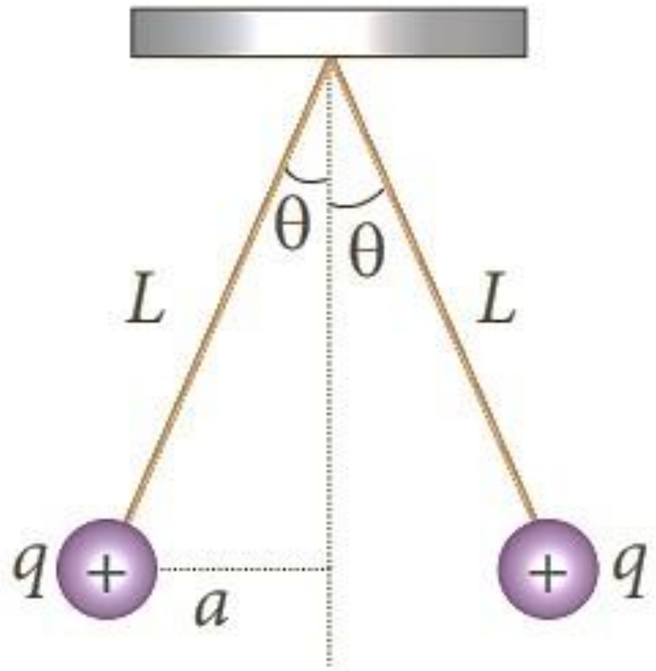
Solution

- **If the two spheres are neutral, the angle between them will be 0° when hanged vertically.**



Coulomb's Law

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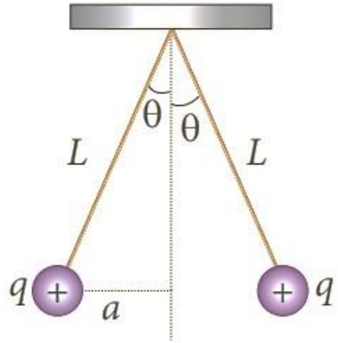
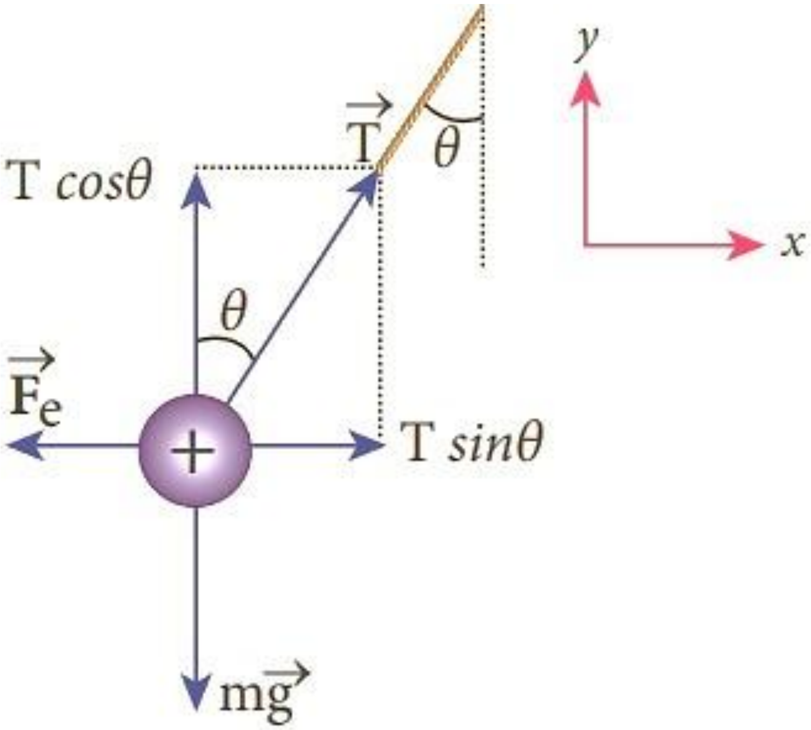


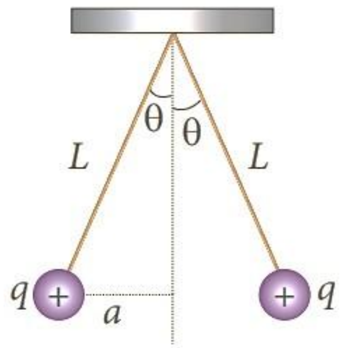
Solution

- If the two spheres are neutral, the angle between them will be 0° when hanged vertically.

- Since they are positively charged spheres, there will be a repulsive force between them and they will be at equilibrium with each other at an angle of 7° with the vertical.



The free body diagram.



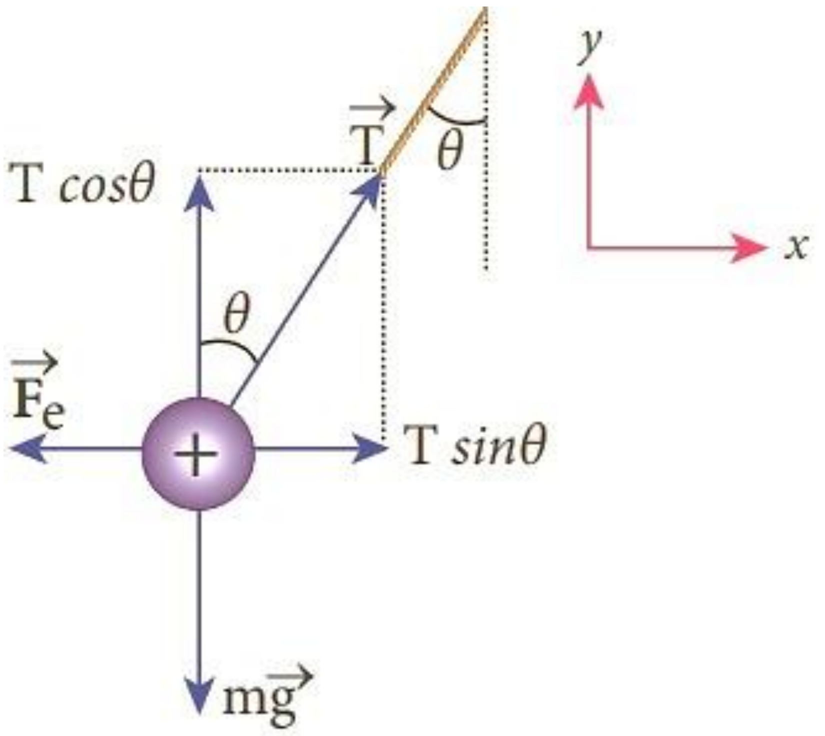
Coulomb's Law

Two identical equally charged spheres (each having mass **1mg**), are hanging in equilibrium as shown in the figure. The length of each string is **10cm** and the angle **θ** is **7°** with the vertical. Calculate the magnitude of the charge in each sphere. (consider $\mathbf{g=10ms^{-2}}$)

Solution

- **If the two spheres are neutral, the angle between them will be 0° when hanged vertically.**

- Since they are positively charged spheres, **there will be a repulsive force between them and they will be at equilibrium with each other at an angle of 7° with the vertical.**
- **At equilibrium**, **each charge experiences zero net force in each direction.** We can draw a free body diagram for one of the charged spheres and apply **Newton's second law** for both vertical and horizontal directions.



The free body diagram.

Coulomb's Law

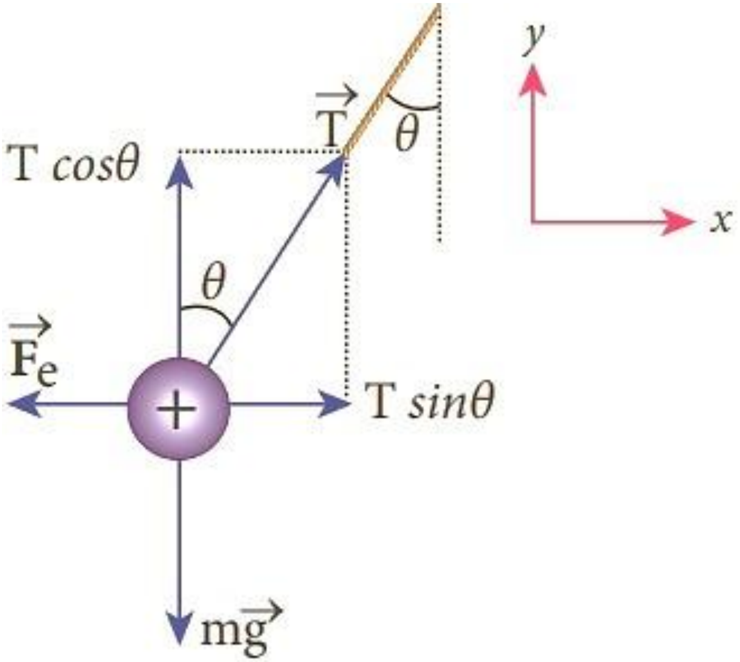
Solution

In the **x-direction**, the acceleration of the charged sphere is zero.

Using Newton's second law $\left(\vec{F}_{tot} = m\vec{a}\right)$, we have

$$T\sin\theta\hat{i} - F_e\hat{i} = 0$$

$$T\sin\theta = F_e \qquad (1)$$



The free body diagram is shown below.

Here **T** is the tension acting on the charge due to the string and $\mathbf{F_e}$ is the electrostatic force between the two charges.

Coulomb's Law

Solution

$$T\sin\theta = F_e \qquad (1)$$

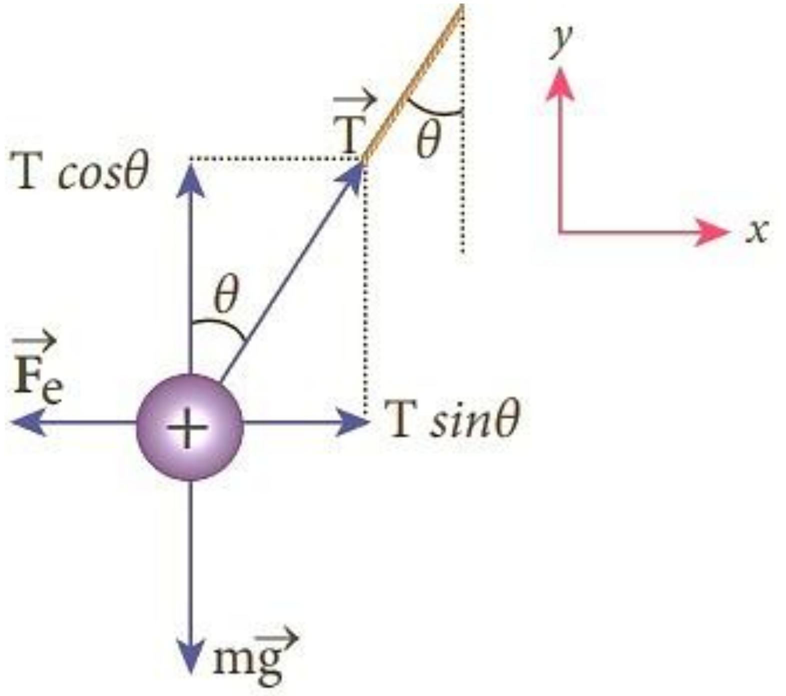
In the y-direction also, the net acceleration experienced by the charge is zero.

By dividing equation (1) by equation (2),

$$\tan\theta = \frac{F_e}{mg} \qquad (3)$$

$$T\cos\theta\,\hat{j} - mg\,\hat{j} = 0$$

Therefore, $T\cos\theta = mg$. (2)



The free body diagram is shown below.

Coulomb's Law

Solution

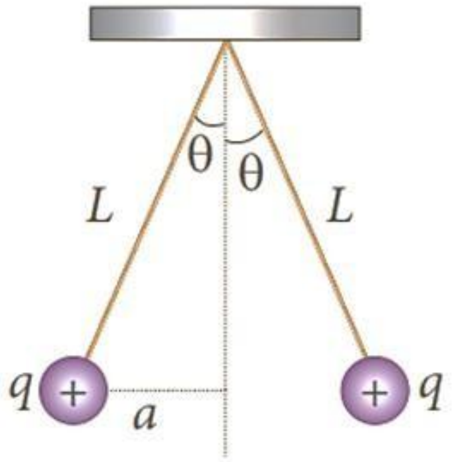
$$\tan\theta = \frac{F_e}{mg} \qquad (3)$$

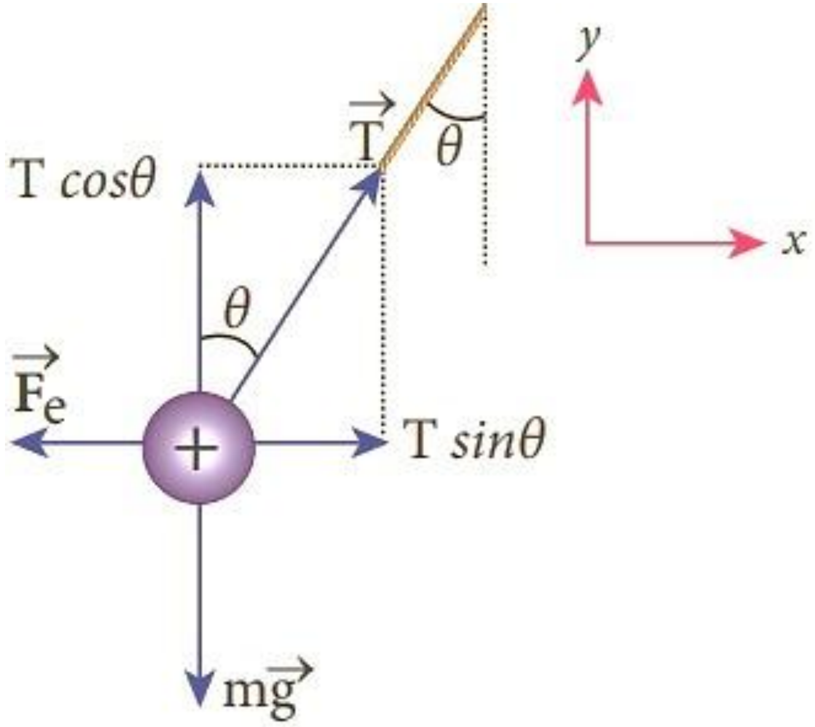
Since they are equally charged, the magnitude of the electrostatic force is

$$F_e = k\frac{q^2}{r^2} \text{ where } k = \frac{1}{4\pi\varepsilon_0}$$

Here r = 2a = 2Lsinθ. By substituting these values in equation (3),

$$\tan\theta = k\frac{q^2}{mg(2L\sin\theta)^2} \qquad (4)$$





The

free body diagram is shown below.

Coulomb's Law

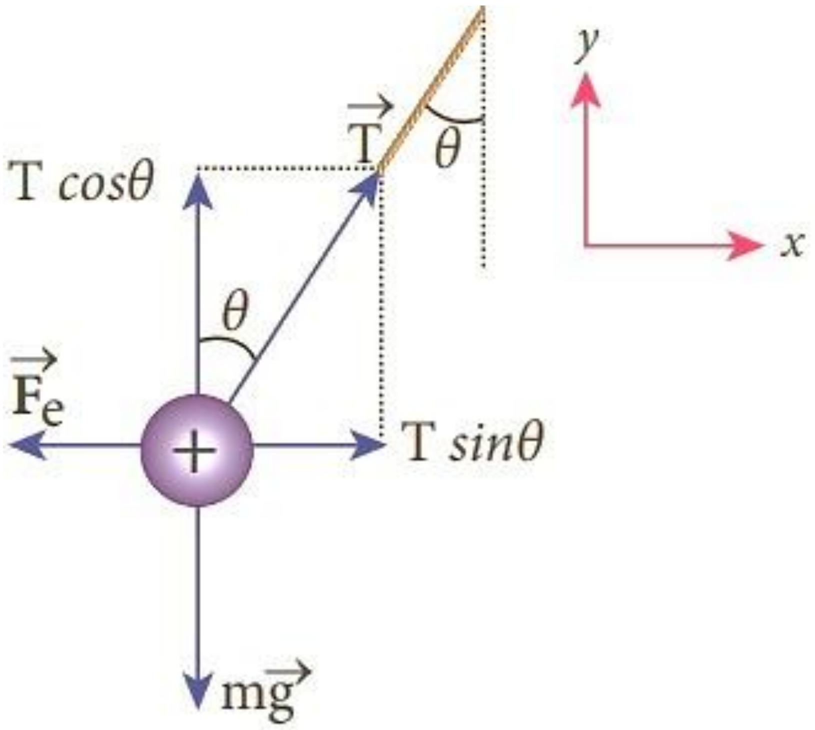
$$\tan\theta = k\frac{q^2}{mg(2L\sin\theta)^2} \qquad (4)$$

Rearranging the equation (4) to get q

$$\boxed{q = 2L\sin\theta\sqrt{\frac{mg\tan\theta}{k}}}$$

$$= 2\times0.1\times\sin7^\circ\times\sqrt{\frac{10^{-3}\times10\times\tan7^\circ}{9\times10^9}}$$

$$\boxed{q = 8.9 \times 10^{-9}\ \text{C} = 8.9\ \text{nC}}$$

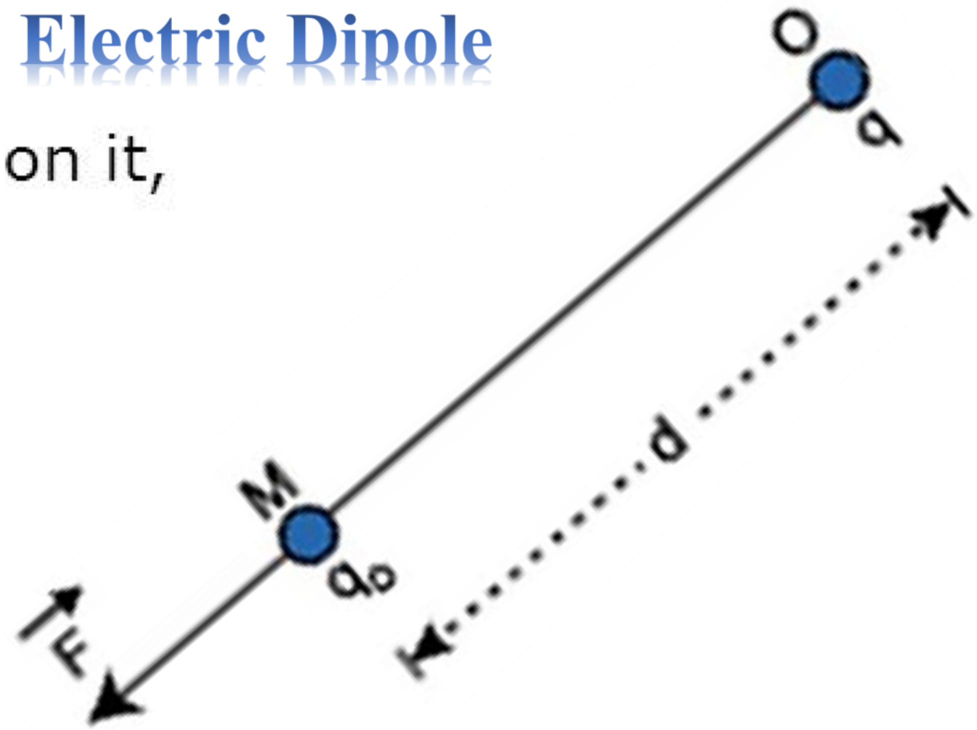


The free body diagram is shown below.

Electric Fields due to a Point Charge and an Electric Dipole

The test charge q_0 is placed at M. The force on it,

$$\boxed{\vec{F} = \frac{1}{4\pi\varepsilon_0}\frac{q q_0}{d^3}\vec{d}}$$



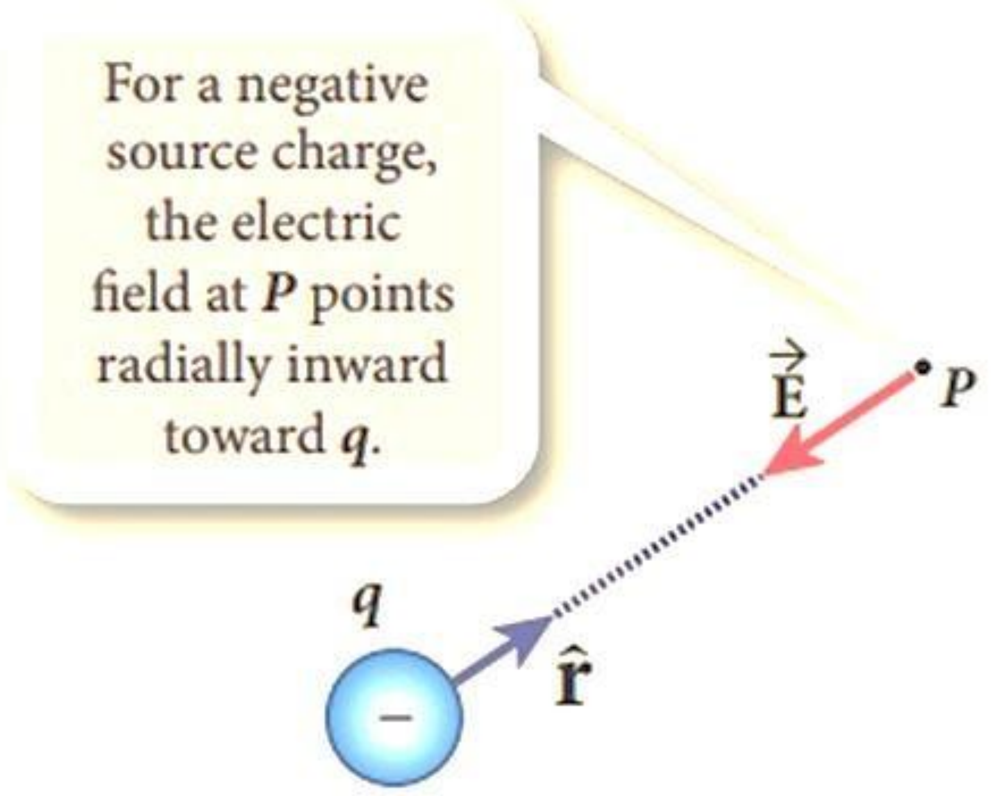
Electric field strength at M,

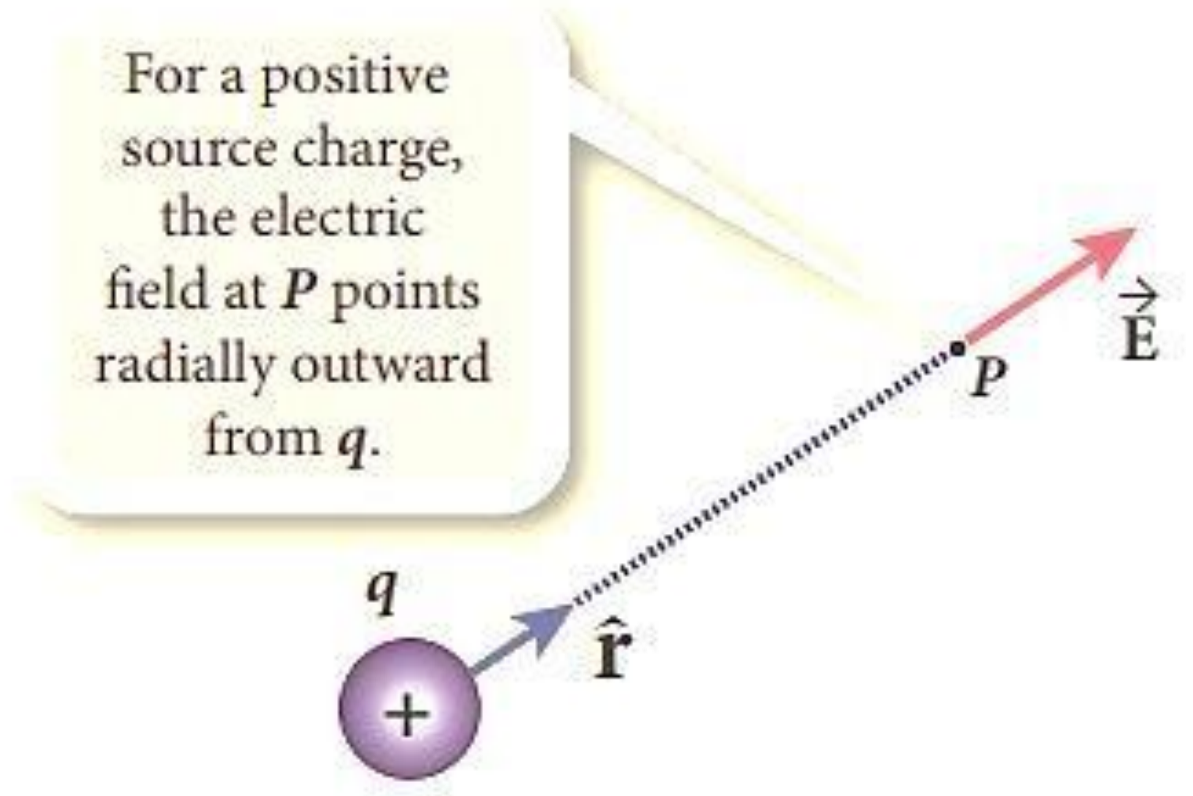
$$\vec{E} = \frac{\vec{F}}{q_0} = \frac{1}{4\pi\varepsilon_0}\frac{q}{d^3}\vec{d}$$

Or

The direction of electric filed is away

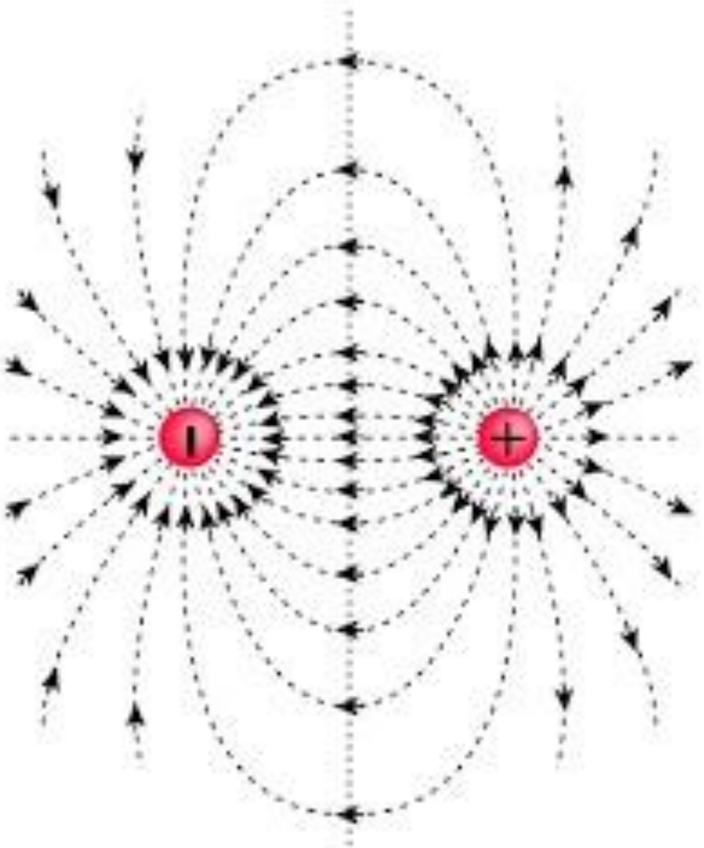
Electric Fields due to a Point Charge and an Electric Dipole

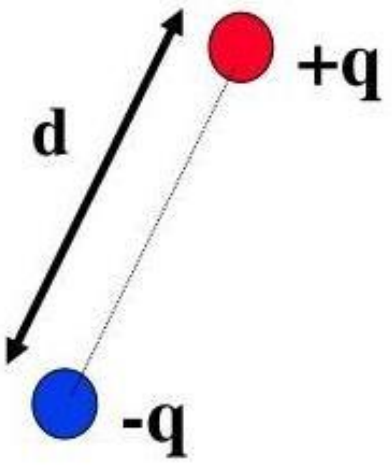




Electric Fields due to a Point Charge and an Electric Dipole

An ***electric dipole*** is defined as a couple of opposite charges “q” and “–q” separated by a distance “d”.





An electric dipole consists of two equal and opposite charges (**q** and **-q**) separated a distance **d.**

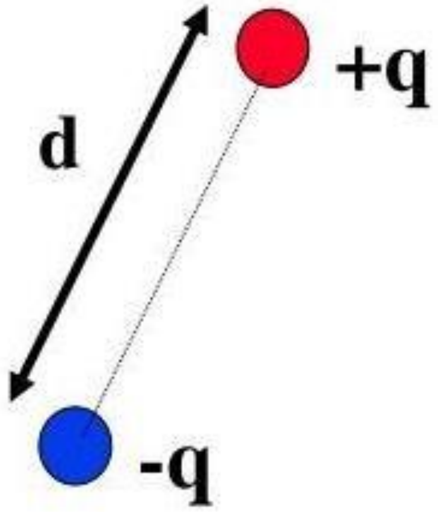
Electric Fields due to a Point Charge and an Electric Dipole

An ***electric dipole*** is defined as a couple of opposite charges “q” and “–q” separated by a distance “d”.

We define the **Dipole Moment** **p**

p → magnitude = **qd**,

p → direction = from -q to +q

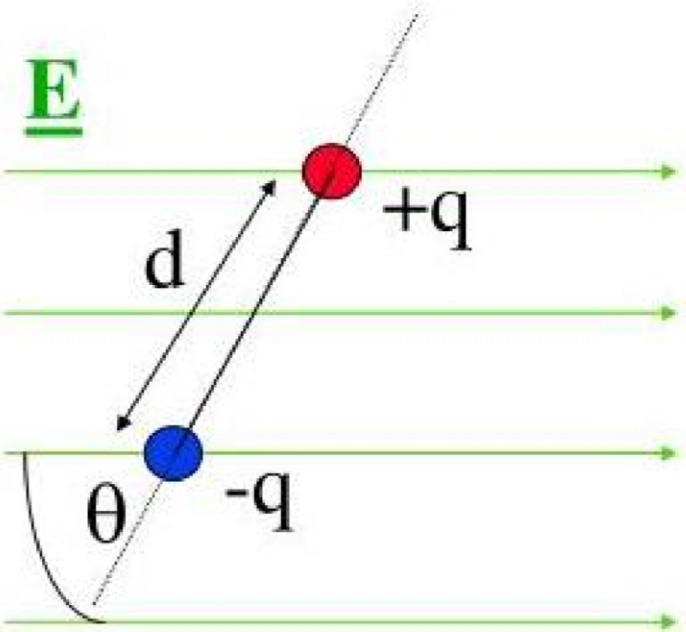


An electric dipole consists of two equal and opposite charges (**q** and **-q**) separated a distance **d.**

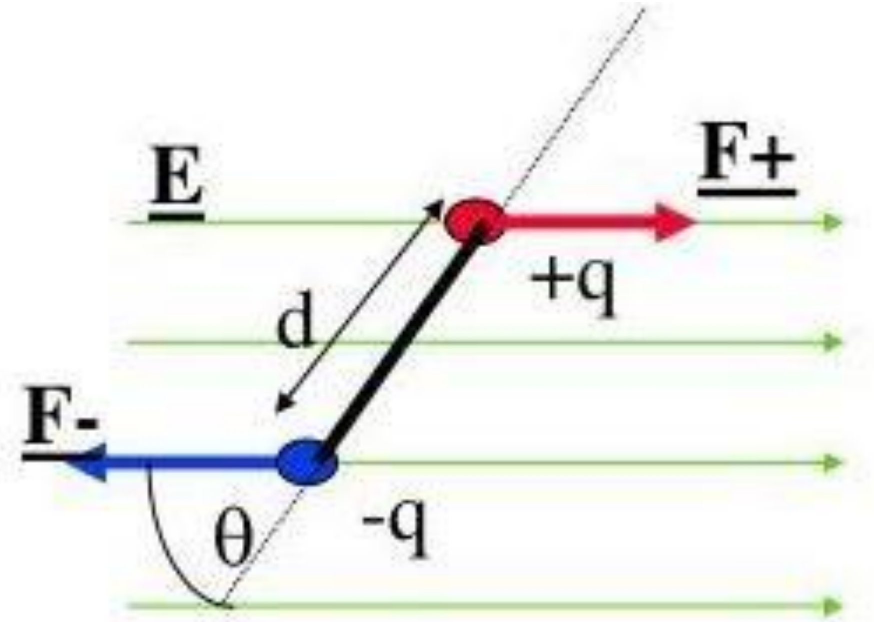
Electric Fields due to a Point Charge and an Electric Dipole

Suppose the dipole is placed in a uniform electric field (i.e., $\underline{\mathbf{E}}$ is the same everywhere in space).

Will the dipole move ??

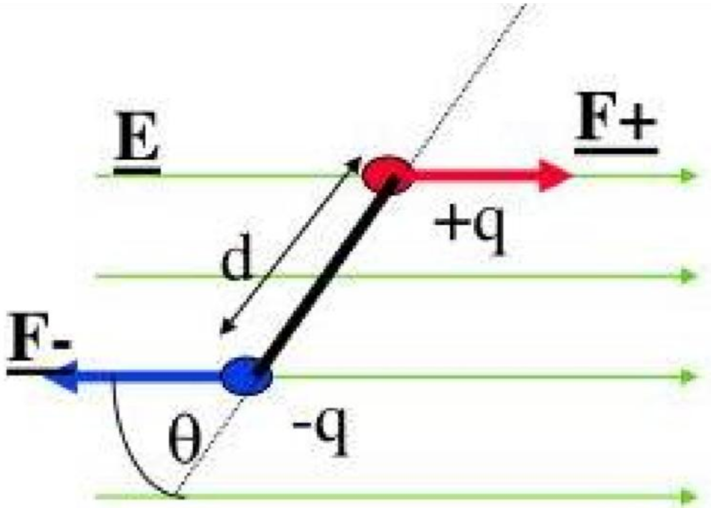


Electric Fields due to a Point Charge and an Electric Dipole



What is the total force acting on the dipole?

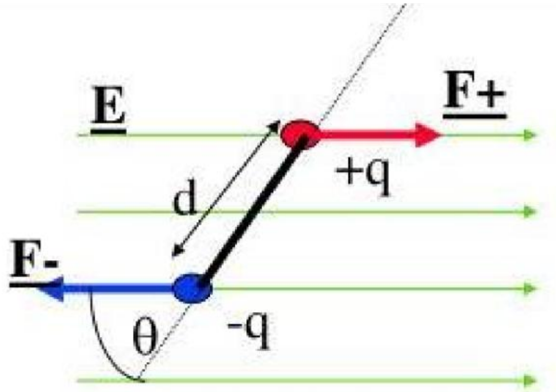
Electric Fields due to a Point Charge and an Electric Dipole



What is the total force acting on the dipole?

Zero, because the force on the two charges cancel: both have magnitude qE. The center of mass does not accelerate.

Electric Fields due to a Point Charge and an Electric Dipole



What is the total force acting on the dipole?

Zero, because the force on the two charges cancel: both have magnitude qE. The center of mass does not accelerate.

But the charges start to move. Why?

Electric Fields due to a Point Charge and an Electric Dipole

But the charges start to move. Why?

There's a torque because the forces aren't colinear and aren't acting exactly at the center of mass.

Chapter 1: Electrostatics

Electric Fields due to a Point Charge and an Electric Dipole

But the charges start to move. Why?

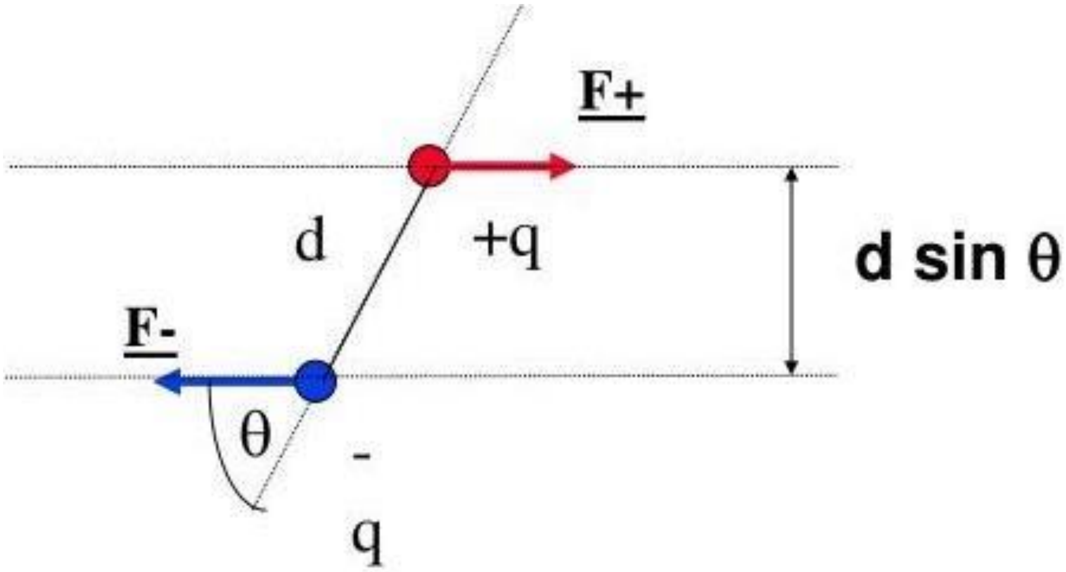
There's a torque because the forces aren't colinear and aren't acting exactly at the center of mass.

The torque is:

τ = (magnitude of force) (moment arm)

$\tau = (2qE)(d \sin \theta/2) = qE\, d\sin\theta$

and the direction of $\underline{\tau}$ is (in this case) into the page



$2r = d\sin\theta$

PHY- 104 ELECTRICITY & MAGNETISM

Credit Hours: Four (4)

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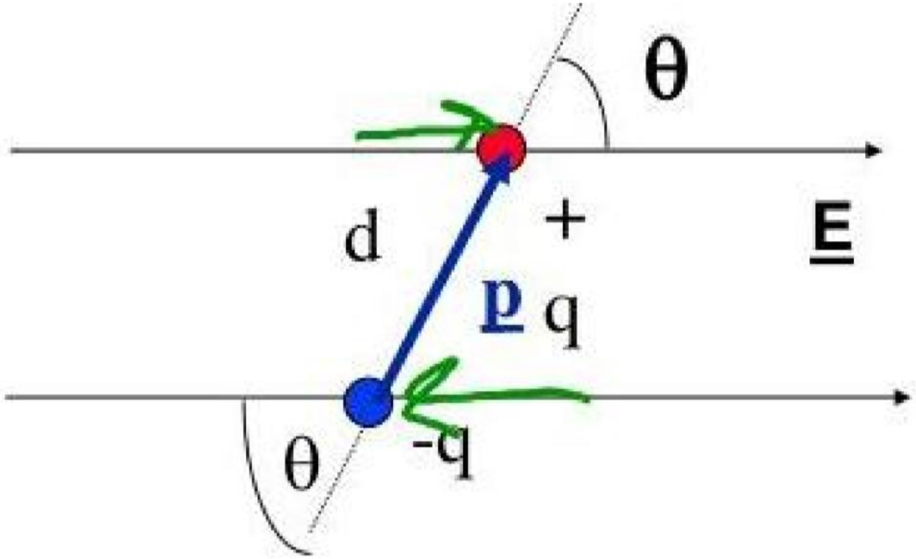
Chapter 1: Electrostatics

Electric Fields due to a Point Charge and an Electric Dipole

$$\tau = \text{(magnitude of force) (moment arm)}$$

$$\tau = (2qE)(d \sin \theta/2) = qE\, d\sin\theta$$

but we have defined : $\mathbf{p} = q\, d$



Then the torque can be written as:

$$\tau = qE\, d\sin\theta$$

$$\boxed{\tau = \boldsymbol{p}E\sin\theta} \text{ or } \boxed{\vec{\tau} = \vec{p} \times \vec{E}}$$

ELECTRICITY & MAGNETISM

Chapter 1: Electrostatics

Calculate E as a function of p, x,and d

$$\boldsymbol{E_x = \square \frac{kq}{r^2}}$$

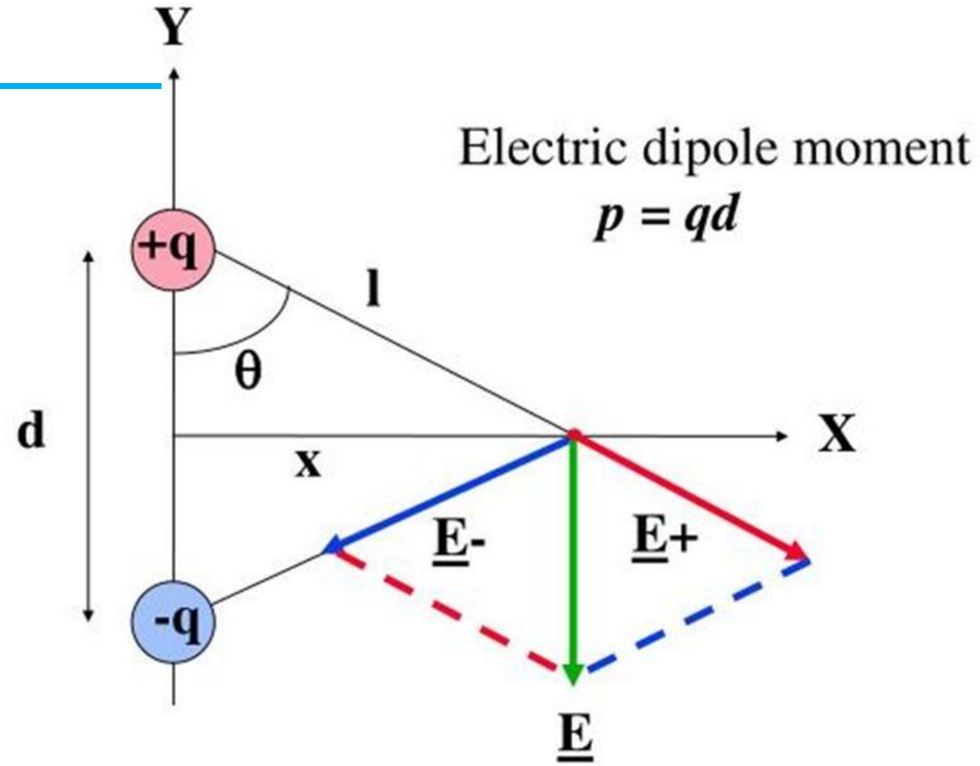
$$l = \sqrt{(\frac{d}{2})^2 + x^2}$$

$$\boxed{E = \frac{2kq\cos\theta}{\left(\frac{d}{2}\right)^2 + x^2\ 2}}$$

Field Due to an Electric Dipole

at a point x straight out from its midpoint

$kqcos\theta$ $kqcos\theta$



You should be able to find E at different points around a dipole where symmetry simplifies the problem

$$E_x = \overline{(\cancel{d}2+x2} + (d)2+x2$$

$)$

$2 \qquad 2$

Electric field due to dipole charge.