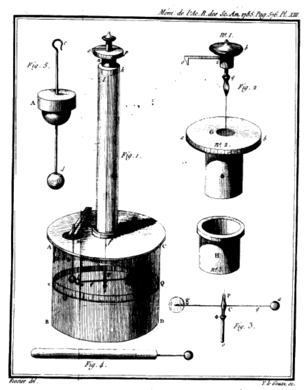
Coulomb’s Law

- An electric charge exerts a force on other electric charges
- Charles Coulomb used a torsion balance in the 1780s to investigate the factors that affect the magnitude this force



- Coulomb reasoned that:
  - If a charged sphere is place in contact with an uncharged sphere, the charge is distributed equally between them
  - Induced charges presented some difficulty, but he was able to argue that the force was directly proportional to the charges
  - If the distance increased, the force decreased by the square of the distance

Coulomb's Law

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

- $k = 8.99\text{x}10^9\ \text{Nm}^2\text{C}^{-2}$
- q_1 and q_2 are the charges measured in coulombs (C)
- r is the distance between the charges (m)

Coulomb's Law (alternate)

$$F = \frac{q_1 q_2}{4\pi\varepsilon_0 r^2}$$

- ε_0 is called the permitivity of free space
- $\varepsilon_0 = 8.85 \times 10^{-12}\ C^2N^{-1}m^{-2}$

Note

- Coulomb's law applies to objects whose size is much smaller than the distance between them
- In other words, they can be considered as point charges

Example

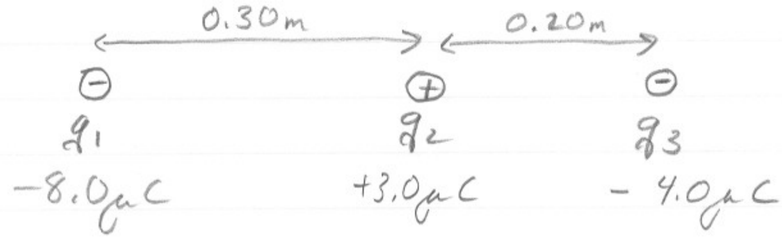
- A hydrogen atom has a proton at its center and an electron “orbiting” at a distance of 0.53x10-10 m. Determine the magnitude of the force on the electron.

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

$$F = (8.99\text{x}10^9\ \text{Nm}^2\text{C}^{-2})\frac{(1.6\text{x}10^{-19}\ \text{C})(1.6\text{x}10^{-19}\ \text{C})}{(0.53\text{x}10^{-10}\ \text{m})^2}$$

$$F = 8.2\text{x}10^{-8}\ \text{N}$$

ex 2



Determine the force on q_3.

$\vec{F} = \vec{F}_{31} + \vec{F}_{32}$ $\qquad F = k\dfrac{q_1 q_2}{r^2}$

$$F_{31} = \frac{(9.0\times10^{9}\, N\cdot m^2 C^{-2})(4.0\times10^{-6} C)(8.0\times10^{-6} C)}{(.50 m)^2}$$

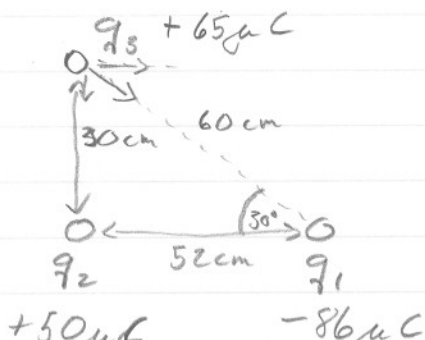
$= 1.2 N$ (repels)

$$F_{32} = \frac{(9.0\times10^{9}\, N\cdot m^2 C^{-2})(4.0\times10^{-6} C)(3.0\times10^{-6} C)}{(0.20 m)^2}$$

$= 2.7 N$ (attracts)

$F = -F_{32} + F_{31} = -2.7N + 1.2N = \underline{-1.5 N}$

ex 3



Determine the force on q_3.

F_{31} has 2 components x, y

$$F_{31x} = \frac{(8.99\times10^{9}\, N\cdot m^2 C^{-2})(65\times10^{-6} C)(86\times10^{-6} C)}{(0.60 m)^2}\cos 30° = 120N$$

$$F_{31y} = -\frac{(8.99\times10^{9}\,Nm^{2}C^{-2})(65\times10^{-6}C)(86\times10^{-6}C)}{(0.60\,m)^{2}}\sin 30^\circ = -70N$$

(force is pointing down)

F_{32} only has a y component

$$F_{32} = \frac{(8.99\times10^{9}\,Nm^{2}C^{-2})(65\times10^{-6}C)(50\times10^{-6}C)}{(0.30\,m)^{2}} = 325N$$

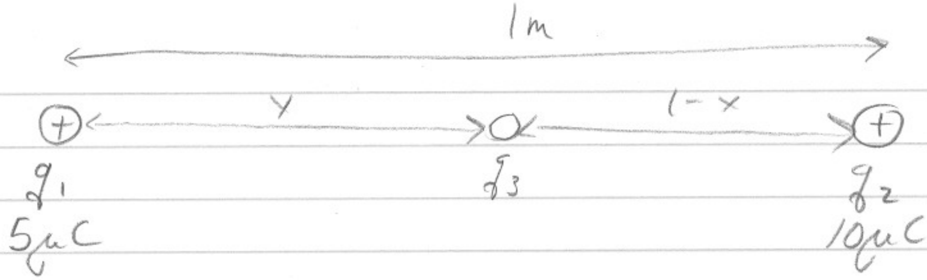
(force points up)

$$F_x = F_{31x} = 120N$$

$$F_y = F_{31y} + F_{32} = -70N + 330N = 260N$$

$$F = \sqrt{F_x^{2} + F_y^{2}} = \sqrt{(120N)^{2} + (260N)^{2}} = \underline{290N}$$

angle $\tan\theta = \frac{F_y}{F_x}$ $\theta = \tan^{-1}\left(\frac{260N}{120N}\right) = \underline{65^\circ}$



Where can a third charge be placed such that it experiences no net force?

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

$$F_{31} = F_{32}$$

$$\frac{k(5\times10^{-6}\,C)\,q_3}{x^2} = \frac{k(10\times10^{-6}\,C)\,q_3}{(1-x)^2}$$

$$(5\times10^{-6}\,C)(1-x)^2 = (10\times10^{-6}\,C)\,x^2$$

$$(5\times10^{-6}\,C)(1-2x+x^2) = (10\times10^{-6}\,C)\,x^2$$

$$5\times10^{-6} - 10\times10^{-6}x + 5\times10^{-6}x^2 = 10\times10^{-6}x^2$$

$$5x^2 + 10x - 5 = 0$$

$$5(x^2 + 2x - 1) = 0$$

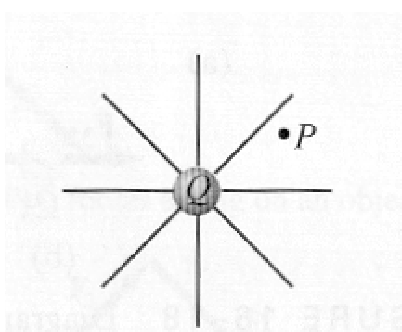
$$x = \frac{-2 \pm \sqrt{2^2 - 4(1)(-1)}}{2(1)} = \frac{-2 \pm \sqrt{8}}{2}$$

$$x = .41,\ \cancel{-2.41}\ m$$

q_3 is 0.41 m to the right of q_1
(0.59 m to the left of q_2)

Electric Field

- The area around a charge or arrangement of charges is said to contain an electric field
- We can investigate the strength of the electric field by measuring the force on a a small **positive** test charge



What's a test charge?

- A test charge is a charge that is so small that the force it exerts does not significantly alter the distribution of charges that create the field being measured

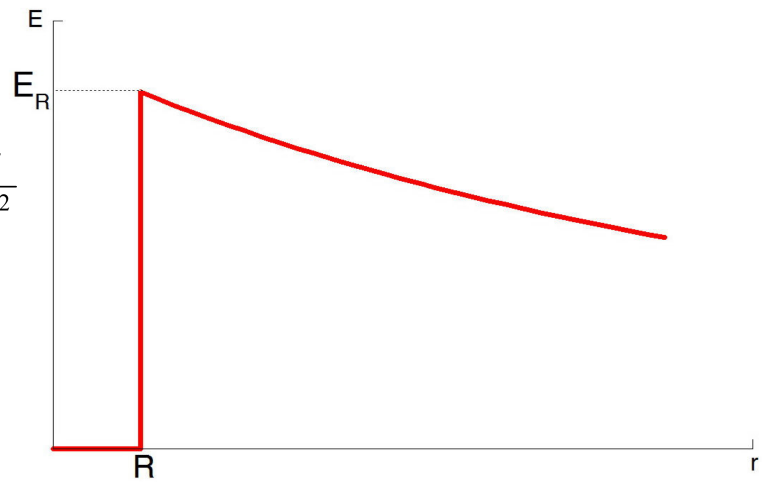
- We define the electric field as the force per unit charge experienced by a small positive test charge q:

$$E = \frac{F}{q}$$

- Electric field is a vector
- The electric field points in the same direction as the force a positive charge would experience
- Measured in NC^{-1}

- In electrostatics, the electric field is zero inside any conducting body

$$E_R = k\frac{q}{R^2}$$

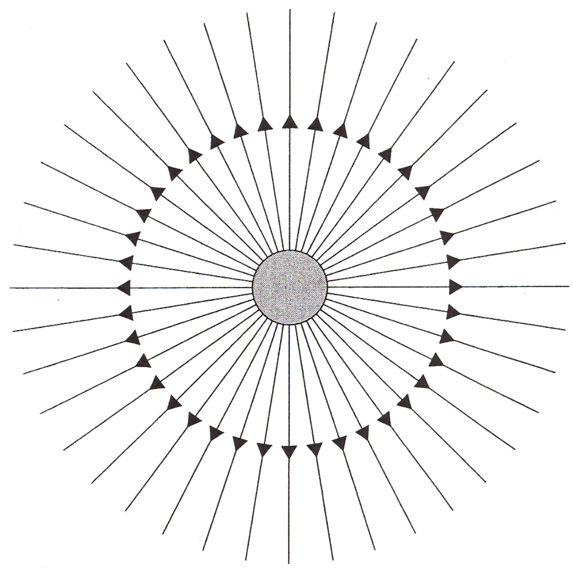


- Electrostatics deals with situations in which electric charge does not move
- If an electric field existed inside a conductor it would for charges to move

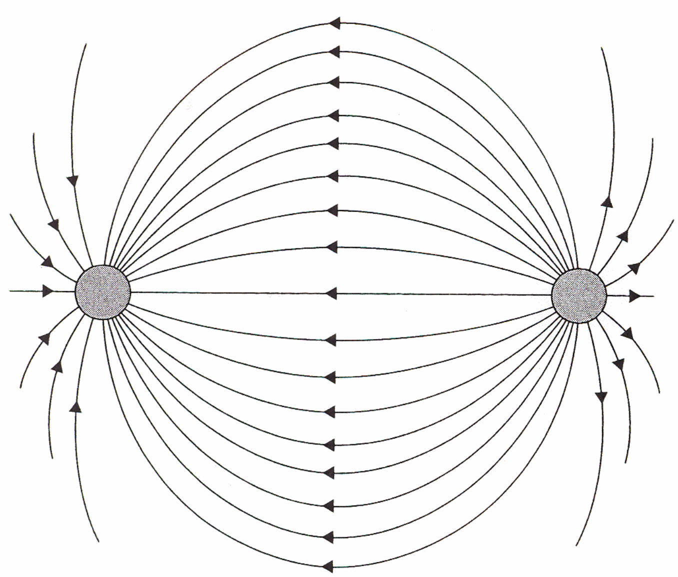
Electric Field Lines

- Electric field lines are imaginary lines (curved or straight) where the tangent to the field line at a point gives the direction of the electric field
- A single positive charge creates an electric field that is directed radially out of the charge, thus the electric field lines are straight lines coming radially out of the charge
- For a negative charge, the lines are directed into the charge

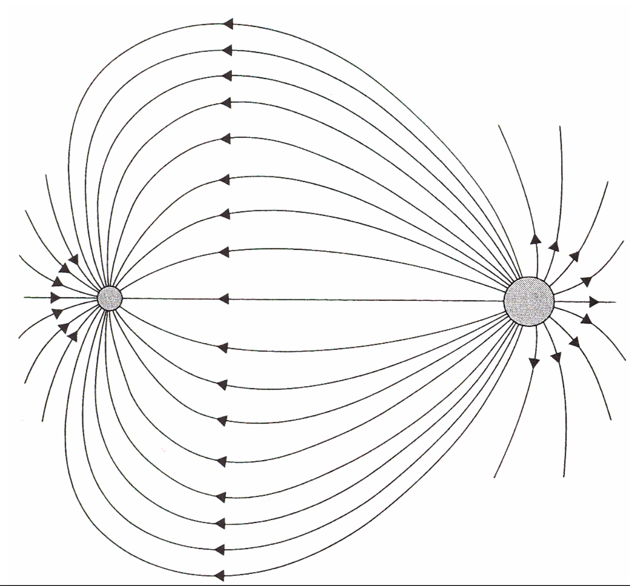
Single point or spherical charge



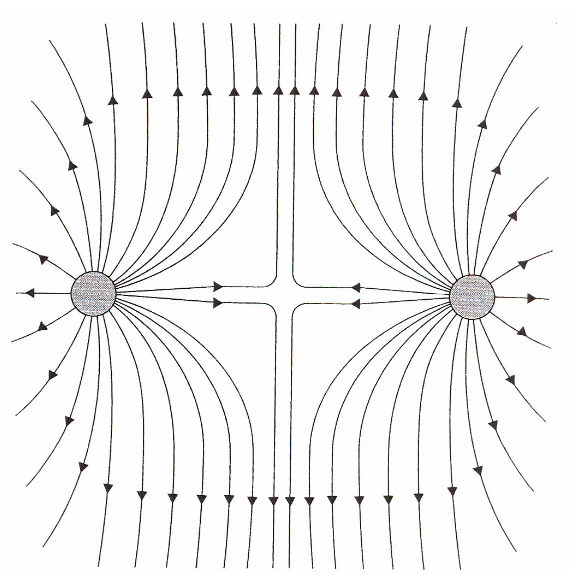
Two equal and opposite charges



Two opposite and unequal charges



Two equal positive charges



Uniform Field

- A uniform field is one that has constant magnitude and direction
- Such a field is generated between two oppositely charged parallel plates
- Near the edges of the plates the field lines are curved, indicating the field is no longer uniform there
- This **edge effect** is minimized when the length of the plates is long compared with their separation

Two long parallel charged plates