Coulomb's Law

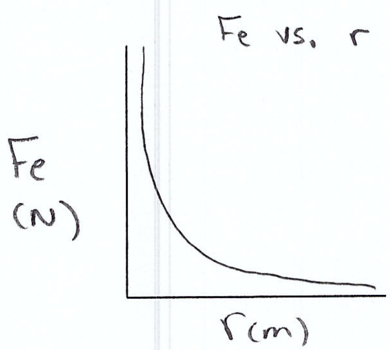
- Coulomb's law describes the electrostatic forces between two charged objects in relationship to the distance between the two charges:

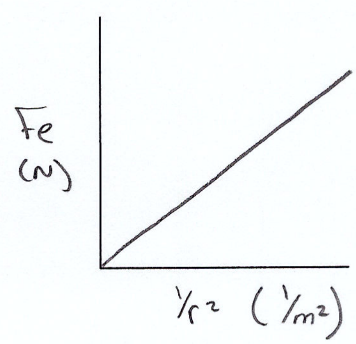
$$\vec{F_e} = \frac{kq_1q_2}{r^2}$$

where F is the electrostatic force (N)
k is Coulomb's constant (8.99×10^9 $N \cdot m^2/C^2$)
q is charge in coulombs (C)
r is the distance separating the two charges (m)

* • When using Coulomb's law, use absolute values. To determine the direction of the force, you need to apply the principles of electrostatic repulsion & attraction.

* • From the equation, we can see that an inverse square relationship exists between the electrostatic force and the separation distance
  - This relationship between electrostatic force and separation distance can be represented graphically





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

∴ inversely squared related

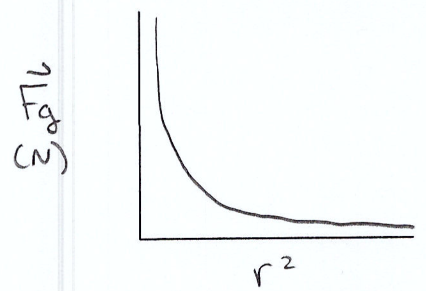
$$y = m\,x + b$$
$$\downarrow \quad \downarrow \quad \downarrow \quad \downarrow$$
$$F_e = kq_1q_2\left(\frac{1}{r^2}\right) + 0$$

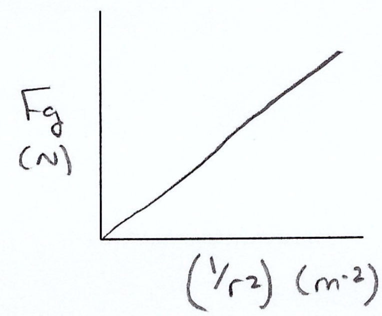
- Coulomb's law is very similar to the Newton's universal law of gravitation

$$\vec{F_g} = \frac{Gm_1m_2}{r^2}$$

where F is the attractive force (N) between two masses
G is the gravitational constant (6.67×10^{-11} $N \cdot m^2/kg^2$)
m is mass of each object (kg)
r is the separation distance between the two masses (m)

- Coulomb's law describes how the *repulsive and attractive force* between two *charges* depends on the separation distance
- Newton's universal law of gravitation describes how the *attractive* force between two *masses* depends on the separation distance
- Newton's universal law of gravitation also exhibits the inverse square relationship between force and separation distance, which can be represented graphically





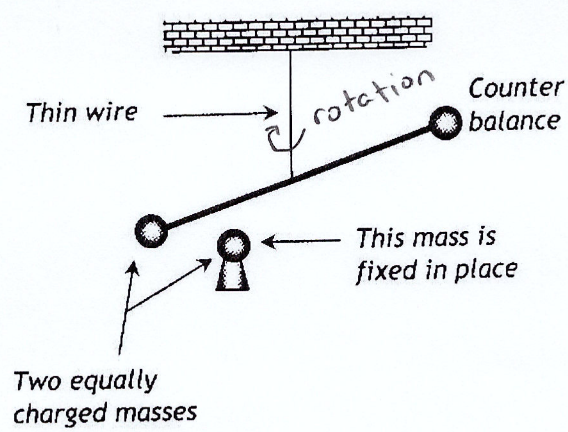
$F_g \propto \frac{1}{r^2}$

∴ inversely squared related

$y = m x + b$

$F_g = Gm_1 m_2 \left(\frac{1}{r^2}\right) + 0$

- Coulomb used a torsion balance apparatus (similar to Cavendish's apparatus for studying gravitational forces) to study the relationship between electrostatic force and the separation distance between charges.
  - Two identical masses are charged by contact (ie. each mass will have identical charges)
  - The charged mass that is free to move will be repelled. This causes the torsion balance to twist, which was measured using the angle of rotation.



- The variables in Coulomb's torsion balance apparatus can be identified as:

Manipulated: separation distance of charges

Responding: electric force (ie. rotation of torsion balance)

Controlled: Charges.

- Common charges on subatomic particles

Particle	Symbol	Charge (C)
electron	e^-	$-1e = -1.6 \times 10^{-19}$ C
proton	p^+	$+1e = 1.6 \times 10^{-19}$ C
alpha particle	α	$+2e = 3.2 \times 10^{-19}$ C

on data sheet!

EXAMPLES:

1. Two point charges produce a force of 2.2×10^{-3} N on each other. Calculate the magnitude of the electrostatic force if the separation distance was doubled and each charge was tripled.

Original

$F_e = 2.2 \times 10^{-3}$ N

q_1

q_2

r

$\therefore F_e = \frac{k q_1 q_2}{r^2} = 2.2 \times 10^{-3}$ N

Modified

$F_e' = ?$

$q_1' = 3q_1$

$q_2' = 3q_2$

$r' = 2r$

$$F_e' = \frac{k(3q_1)(3q_2)}{(2r)^2}$$

$$F_e' = \left(\frac{9}{4}\right)\underbrace{\frac{k q_1 q_2}{r^2}}_{F_e = 2.2 \times 10^{-3} N}$$

$$F_e' = (9/4)(2.2 \times 10^{-3} N)$$

$$F_e' = 4.95 \times 10^{-3} N$$

$$\boxed{F_e' = 5.0 \times 10^{-3} N}$$

2. Two identical objects each have a mass of 2.00kg. These two masses are placed 2.50cm apart from each other. If two charges, each having a charge of 2.0×10^{-6}C were to experience the same magnitude of force as the two masses, at what distance would the two charges need to be placed from each other?

$m = 2.00\,kg$

$d = 2.50\,cm \times \left(\frac{10^{-2}\,m}{1\,cm}\right)$

$d = 0.0250\,m$

$q = 2.0 \times 10^{-6}\,C$

$d = ?$

$F_e = \frac{k q_1 q_2}{r^2}$ (2)

↓

$F_g = \frac{G m_1 m_2}{r^2}$ (1)

(1) $F_g = \frac{G m_1 m_2}{r^2} = \frac{(6.67 \times 10^{-11})(2.00\,kg)(2.00\,kg)}{(0.0250\,m)^2}$

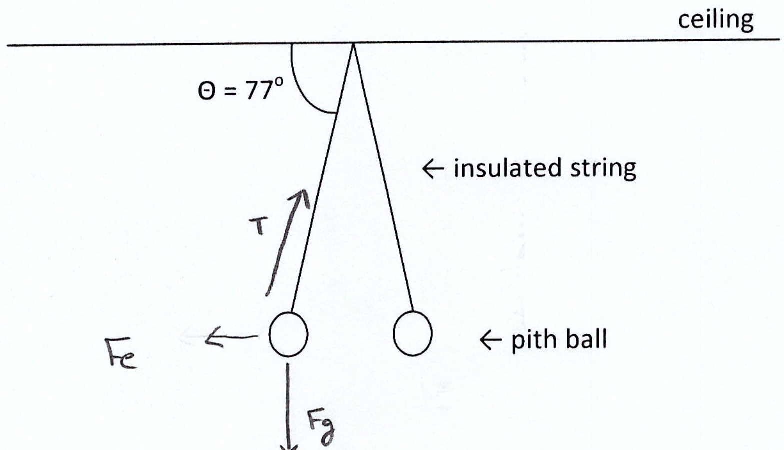
$F_g = 4.2688 \times 10^{-7}\,N$

(2) $F_e = \frac{k q_1 q_2}{r^2} \Rightarrow r = \sqrt{\frac{k q_1 q_2}{F_e}}$

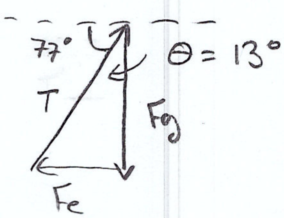
$r = \sqrt{\frac{(8.99 \times 10^{9})(2.0 \times 10^{-6}\,C)^2}{4.2688 \times 10^{-7}\,N}} = 290.239\ldots\,m$

$\boxed{r = 2.9 \times 10^{2}\,m}$

3. Two identical pith balls hanging on insulated strings where charged by contact. The two pith balls repel each other as shown in the diagram below.



The pith balls have a mass of 50.0g each. If the angle measured from the ceiling to the string of one of the pith balls is 77°, what is the magnitude of the electric force exerted on one of the pith balls?



$F_g = mg = (0.050\,kg)(9.81\,m/s^2) = 0.4905\,N$

$\tan\theta = \frac{opp}{adj.}$

$\tan(13°) = \frac{F_e}{F_g}$

$F_e = \tan(13°)\,F_g = \tan(13°)(0.4905\,N)$

$F_e = 0.1132...\,N$

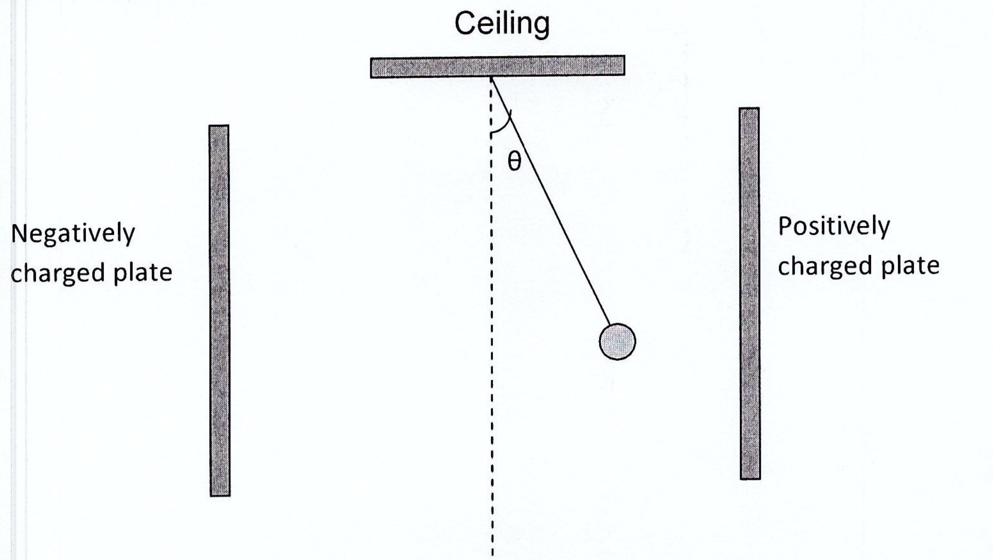
$F_e = 0.11N$

Now try pg. 87# 2, 3, 5-7, 10, 12-14 & Practice Problem

Practice Problem

Use the following information to answer then next two questions.

A negatively charge, graphite-coated sphere is suspended from the ceiling on an insulating string in the region between oppositely charged parallel plates. The charge sphere experiences an electrical force of 8.4×10^{-5}N.



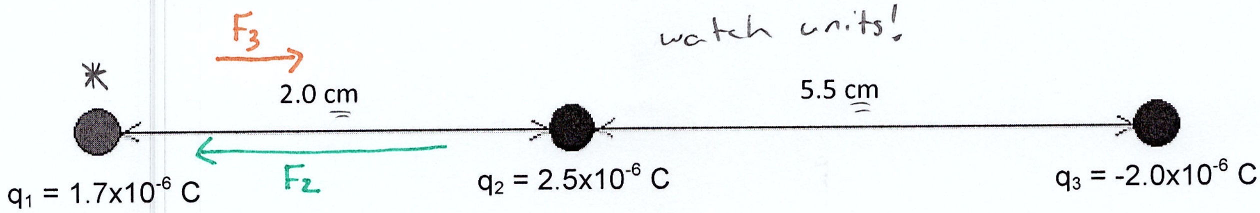
1. One way to give the graphite-coated sphere a negative charge is to touch it with a negative rod. This process is called charging by conduction / contact.

2. If the measured angle (θ) is 4.0°, what is the mass (in grams) of the graphite-coated sphere? **[0.122 g]**

- To determine the direction of the force exerted by two charged objects, it is important to keep in mind electrostatic repulsion and attraction (ie. similar charges repel and opposite charges attract).

EXAMPLES:

1. A charge (q_1) is placed 2.0cm from a second charge (q_2), and the second charge (q_2) is placed 5.5cm from a third charge (q_3) as shown in the diagram.



Calculate the net electric force on the 1.7×10^{-6}C charge.

$$F_2 = \frac{kq_1q_2}{r^2} = \frac{(8.99\times10^9)(1.7\times10^{-6}C)(2.5\times10^{-6}C)}{(0.020m)^2}$$

$$F_2 = -95.51875\ N$$

$$F_3 = \frac{kq_1q_3}{r^2} = \frac{(8.99\times10^9)(1.7\times10^{-6}C)(2.0\times10^{-6}C)}{(0.020m + 0.055m)^2}$$

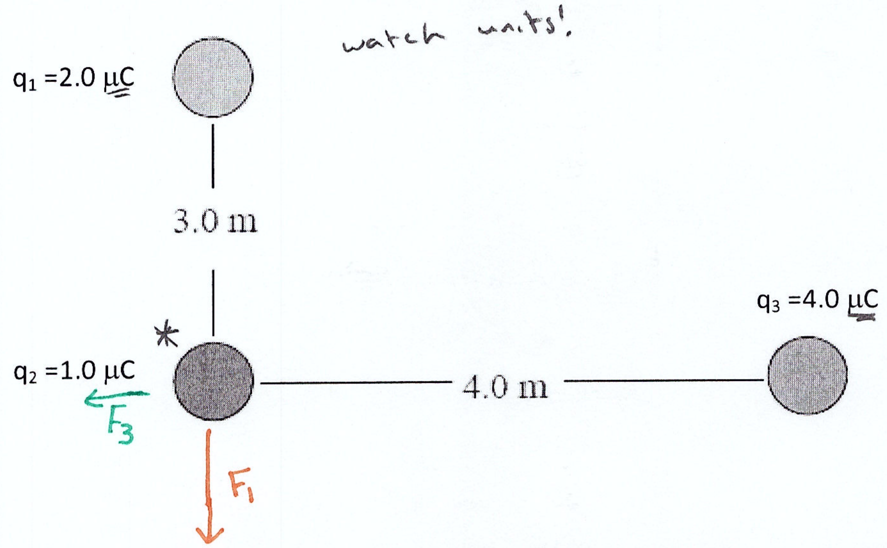
$$F_3 = 5.4339\bar{5}N$$

$$F_{net} = F_2 + F_3 = (-95.51875N) + 5.433\bar{95}\ N$$

$$F_{net} = -90.08479...\ N$$

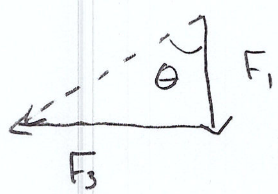
$$\boxed{F_{net} = 90\ N,\ left}$$

2. Three charges are arranged as the following diagram shows. Determine the force on q_2.



$$F_1 = \frac{kq_1q_2}{r^2} = \frac{(8.99\times10^9)(1.0\times10^{-6}C)(2.0\times10^{-6}C)}{(3.0m)^2} = 1.99\bar{7}\times10^{-3}N, \text{ south}$$

$$F_3 = \frac{kq_2q_3}{r^2} = \frac{(8.99\times10^9)(1.0\times10^{-6}C)(4.0\times10^{-6}C)}{(4.0m)^2} = 2.2475\ldots\times10^{-3}N, \text{ west}$$



$$a^2 + b^2 = c^2$$

$$\sqrt{(1.99\bar{7}\times10^{-3}N)^2 + (2.2475\ldots\times10^{-3}N)^2} = F_{net}$$

$$F_{net} = 3.007\ldots\times10^{-3}N$$

$$\theta = \tan^{-1}\left(\frac{F_3}{F_1}\right)$$

$$\theta = \tan^{-1}\left(\frac{2.2475\ldots\times10^{-3}}{1.99\bar{7}\times10^{-3}}\right)$$

$$\theta = 48.366\ldots^\circ$$

$\therefore$ $F_{net} = 3.0\times10^{-3}N$, 48° W of S

or

42° S of W

*****Now try pg. 92 # 15, 16, 18-20*****