Section 13: Coulomb's Law of Electric Force

Coulomb's Law of Electric Force states:

The electric force between 2 charged objects is

- directly proportional to the product of the charges on the objects and
- inversely proportional to the square of the distance between them.

The direction of the force extends along an imaginary line joining the centers of the two objects and is called **positive** for **repulsion** and **negative** for **attraction**. *

Proportionality statement: $F_e \alpha \frac{q_1 q_2}{r^2}$

Equation: $F_e = k\frac{q_1 q_2}{r^2}$

* $\mu C = \times 10^{-6}\,C$

where q_1 and q_2 – are the charges on the objects in Coulombs (C)
r – is the distance between their centers in meters (m)
k – is the proportionality constant which is 9.0 x 10^9 Nm^2/C^2
F_e – is the electric force in Newtons (N)

Proportionality Exercises:

1 The electrostatic force between two charged objects is 2.5×10^{-4} N. What will be the new force if the distance between them is tripled, one charge is doubled and the other charge is quartered?

$F \propto \frac{q_1 q_2}{r^2} \propto \frac{(2)(\frac{1}{4})}{(3)^2} \propto \frac{\frac{1}{2}}{9} = \frac{1}{18}$

$F_{New} = \frac{1}{18} \times 2.5 \times 10^{-4} N = 1.4 \times 10^{-5} N$

2 The electrostatic force between two point charges is 6.0×10^{-5} N when the separation distance is 0.18 m. What will be the magnitude of the force if the distance changes to

A) 0.36 m B) 0.06 m C) 0.27 m

A) $0.36 \div 0.18 = 2$

$F \propto \frac{1}{r^2} \propto \frac{1}{(2)^2} = \frac{1}{4}$

B) $\frac{0.06m}{0.18m} = \frac{1}{3}$

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

$F \propto \frac{1}{(\frac{1}{3})^2}$

$F \propto 9$

C) $\frac{0.27m}{0.18m} = \frac{3}{2}$

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

$F \propto \frac{1}{(\frac{3}{2})^2}$

$F \propto \frac{1}{9/4}$

$F \propto 4/9$

3 Two identical spheres have charges 3q and 11q respectively. They are a distance "r" apart. If the spheres are allowed to touch and are then separated, what must be their new separation distance if the electrostatic force between them remains unchanged?

Before: $q_1 = 3q$, $q_2 = 11q$, $r = r$

After: $q_1 = 7q$, $q_2 = 7q$, $r = ?$

$F_1 = F_2$

* Key: As the spheres touch, a new charge distribution will be set up. B/c the spheres are identical they will share the chare equally. ($\frac{3q + 11q}{2} = 7q$)

method 1

$\frac{F_2}{F_1} = \frac{\frac{Kq_1q_2}{r_2^2}}{\frac{Kq_1q_2}{r_1^2}}$ b/c $F_2 = F_1$, $\frac{F_2}{F_1} = 1$

$1 = \frac{\frac{(7q)(7q)}{r_2^2}}{\frac{(3q)(11q)}{r_1^2}}$

$\frac{33q^2}{r_1^2} = \frac{49q^2}{r_2^2}$

$33r_2^2 = 49r_1^2$

$r_2^2 = \frac{49}{33} r_1^2$

$F_1 = F_2$

$\frac{Kq_1q_2}{r_1^2} = \frac{Kq_1q_2}{r_2^2}$

$\frac{(3q)(11q)}{r_1^2} = \frac{(7q)(7q)}{r_2^2}$

$\frac{33q^2}{r_1^2} = \frac{49q^2}{r_2^2}$

$33r_2^2 = 49r_1^2$

$r_2^2 = \frac{49}{33} r_1^2$

4 Ball 1 has a charge of 3q while an identical sphere (ball 2) has a charge of –5q. They are held a distance "r" apart and the force of attraction between them is 6.9 x 10^{-14} N. What will be the new force between them if they are allowed to touch and then are moved apart a distance of "r" again?

Before
$q_1 = 3q$
$q_2 = -5q$
$r_1 = r$
$F_1 = -6.9\times10^{-14}$ N

After
$q_1 = -q$
$q_2 = -q$
$r = r$
$F_2 = ?$

(3q)(-5q) → (-2q) → (-1q) (-q)

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

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

* An attractive force is negative.

$r_1 = r_2$

$\frac{kq_1q_2}{F_1} = \frac{kq_1q_2}{F_2}$

$\frac{(3q)(-5q)}{6.9\times10^{-14}N} = \frac{(-q)(-q)}{F_2}$

$\frac{-15q^2}{-6.9\times10^{-14}N} = \frac{q^2}{F_2}$

$-15F_2 = -6.9\times10^{-14}N$

$F_2 = 4.6\times10^{-15}$

Homework: Coulomb's Law of Electric Charge - Questions 1 - 10
Textbook: Questions 46-47 and 49-50 page 582-583

Calculations Involving Coulomb's Law of Electric Force

1 Two point charges q_1 = 5.0 μC and q_2 = 4.0 μC, are 35 cm apart. What is the electrostatic force between them? mc

$q_1 = 5.0\times10^{-6}$ C
$q_2 = 4.0\times10^{-6}$ C
$r = 0.35$ m
$F = ?$

q_1 q_2

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

$F = \frac{(9.0\times10^{9}\frac{Nm^2}{C^2})(5.0\times10^{-6}C)(4.0\times10^{-6}C)}{(0.35m)^2}$

$F = 1.5$ N

* Note the force is positive which means a repelling force. ∴ q_1 will move to the left & q_2 will move to the right.

2 Determine the electric force between 2 point charges of 4.0×10^{-8} C and -8.0×10^{-7} C that are separated by a distance of 3.0 mm.

mc

$r = 3.0 \times 10^{-3}$ m
$= 0.003$ m

q_1 q_2

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

$$F = \frac{(9.0 \times 10^9 \,\frac{Nm^2}{C^2})(4.0 \times 10^{-8}\,C)(-8.0 \times 10^{-7}\,C)}{(0.003m)^2}$$

$F = -32N$

3 Determine the separation distance between $q_1 = 5.0$ μC and $q_2 = -4.0$ μC if the force of attraction is 2.2 N.

$q_1 = 5.0 \times 10^{-6}$ C
$q_2 = -4.0 \times 10^{-6}$ C
$F = -2.2N$
$r = ?$

Force is neg. b/c it is an attractive force

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

$$r = \sqrt{\frac{kq_1q_2}{F}}$$

$$r = \sqrt{\frac{(9.0 \times 10^9\,Nm^2/c^2)(5 \times 10^{-6}\,c)(-4 \times 10^{-6}\,c)}{-2.2N}}$$

$r = 0.29m$

4 The electric force between 2 charged particles is 20.0 N when they are placed a distance of 10.0 cm apart. What would be the distance between these particles is the force is reduced to 16.0 N?

$F_1 = 20N$
$r_1 = 10.0cm$
$= 0.1m$

$F_2 = 16N$
$r_2 = ?$

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

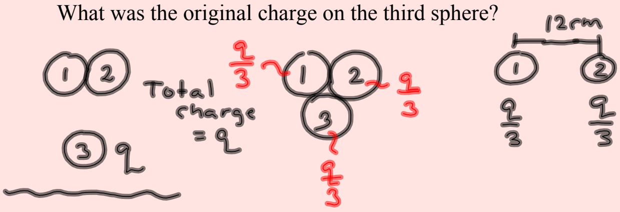
$$\frac{F_1}{F_2} = \frac{r_2^2}{r_1^2}$$

$$\frac{20N}{16N} = \frac{r_2^2}{(0.1)^2}$$

$$r_2^2 = \frac{(20N)(0.1)^2}{16N}$$

$r_2 = 0.11m$

5 Two identical spheres 1 and 2 are neutral and touching each other. A third identical sphere with an unknown amount of charge (q) touches the other two spheres simultaneously and is then removed. The first two spheres are moved 12 cm apart, and the electrostatic force of 6.5×10^{-5} N is measured between them. What was the original charge on the third sphere?



Test

$$\frac{F_{12}}{1} = \frac{kq_1q_2}{r^2}$$

$$\frac{kq_1q_2}{k} = \frac{Fr^2}{k}$$

$$q_1q_2 = \frac{(6.5\times10^{-5}N)(0.12m)^2}{(9.0\times10^{9}Nm^2/c^2)}$$

$$q_1q_2 = 1.04\times10^{-16}c^2$$

$$\left(\frac{q}{3}\right)\left(\frac{q}{3}\right) = 1.04\times10^{-16}c^2$$

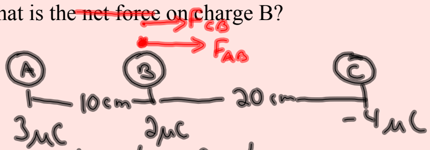
$$\frac{q^2}{9} = 1.04\times10^{-16}c^2$$

$$q = \pm3.1\times10^{-8}c$$

6 Charges A, B, and C lie on a straight line. Charge A is 10.0 cm to the left of charge B and charge C is 20.0 cm to the right of B.

$q_A = 3.0\ \mu C \quad q_B = 2.0\ \mu C \quad q_C = -4.0\ \mu C$

A) What is the ~~net force on~~ charge B?



*Determine direction first.

① $F_{AB} = \frac{kq_Aq_B}{r^2} = \frac{(9\times10^{9}\frac{Nm^2}{c^2})(3\times10^{-6}c)(2\times10^{-6}c)}{(0.10m)^2}$

$= 5.4N$ (+ means repulsion ∴ B moves to the right)

$= 5.4N$ [R]

② $F_{CB} = \frac{(9\times10^{9}Nm^2/c^2)(2\times10^{-6}c)(-4\times10^{-6}c)}{(0.20m)^2}$

$= -1.8N$ [- means attraction, so B is attracted to C so it moves to the right]

$= 1.8N$ [R]

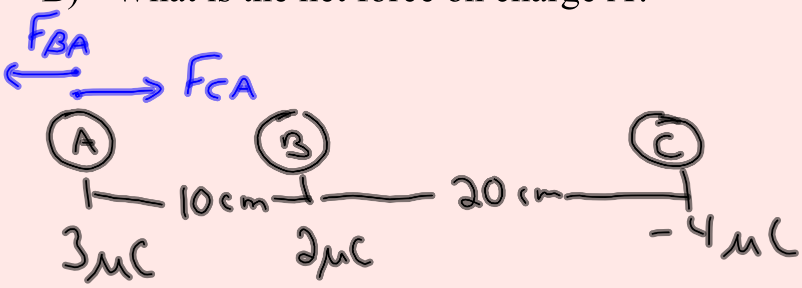
③ $F_{net\,B} = F_{AB} + F_{CB}$

$= 5.4N + 1.8N$

$= 7.2N$

(Note, we did not use $-1.8N$. $-$ means attraction)

B) What is the net force on charge A?



① $F_{BA} = 5.4N$ (A moves left)
$F_{BA} = 5.4N$ [L]

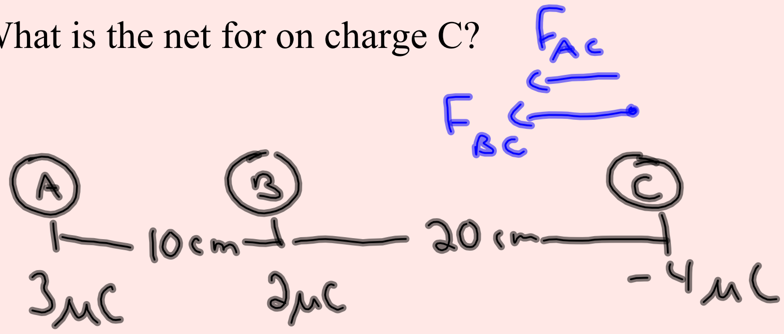
② $F_{CA} = \frac{(9\times10^{9}\,Nm^2/C^2)(-4\times10^{-6}\,C)(3\times10^{-6}\,C)}{(0.30\,m)^2}$

$F_{CA} = -1.2N$ (− means attraction. so A moves to the right.)

$F_{CA} = 1.2N$ [R]

③ $F_{net} = F_{BA} + F_{CA}$
$= 5.4N\,[L] + 1.2N\,[R]$
$= 4.2N\,[L]$

C) What is the net for on charge C?

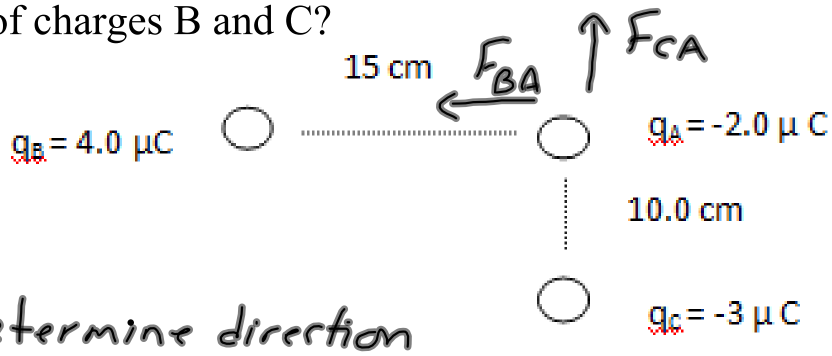


$F_{AC} = -1.2N$
$= 1.2N$ [L]

$F_{BC} = -1.8N$
$= 1.8N$ [L]

$F_{net} = F_{AC} + F_{BC}$
$= 1.2N\,[L] + 1.8N\,[L]$
$= 3.0N\,[L]$

7 Three charged spheres are set on the corners of a right triangle as shown. What is the net force on charge A due to the presence of charges B and C?



Test

*Determine direction first.

$$F_{BA} = \frac{kq_Aq_B}{r^2} \quad \frac{(9\times10^{9}\ Nm^2/C^2)(-2\times10^{-6}\ C)(4\times10^{-6}\ C)}{(0.15\ m)^2}$$

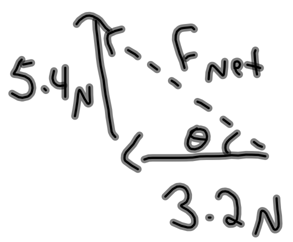
$$= -3.2\ N \text{ (Attractive)}$$

$$F_{BA} = 3.2\ N\ [W]$$

$$F_{CA} = \frac{(9\times10^{-9}\ Nm^2/C^2)(-2\times10^{-6}\ C)(-3\times10^{-6}\ C)}{(0.10\ m)^2}$$

$$= 5.4\ N \text{ [Repelling force]}$$

$$= 5.4\ N\ [N]$$



$$F_{net}^2 = (3.2\ N)^2 + (5.4\ N)^2$$

$$F_{net} = 6.3\ N\ [W\ 59^\circ\ N]$$

$$\tan\theta = \frac{5.4\ N}{3.2\ N}$$

$$\theta = 59^\circ$$

Homework: Worksheet on Coulomb's Law of Electric Force - Questions 11 - 19

Textbook: 49, 51, 52 a, b, c, 53, 55 - page 583

583 Q 46, 47, 50