Four Fundamental Forces of Nature:

Strong Nuclear Force

Electromagnetic Force

Weak Nuclear Force

Gravity

In order of decreasing strength

Magnetic Forces
Forces from moving charges on other moving charges

Electrostatic Forces
Forces between charges

ELECTRIC CHARGE

- Two types of charge (vs. one kind of mass)
- Only a single mobile kind of charge -- the negative electron.
- Things become charged due to an excess or a deficit of electrons.
- Neutral objects have no charge because they have equal numbers of negative electrons and positive protons.
- The charge of an electron = -1.6×10^{-19} Coulombs (C)
- The charge of a proton = $+1.6 \times 10^{-19}$ C
- For the purposes of this class, this is the smallest unit of charge that we normally consider.

Parallels Between Gravity & the Electrostatic Force

GRAVITY	ELECTROSTATIC FORCE
A very weak attractive force	Stronger force - can attract or repel
Effective between large masses over large distances	Acts over smaller distances
Described by Newton's Law of Universal Gravitation:	Described by Coulomb's Law:
$F = G\frac{m_1 m_2}{r^2}$	$F = k\frac{Q_1 Q_2}{r^2}$
$G = 6.67 \times 10^{-11}\ N\frac{m^2}{kg^2}$	$k = 9.0 \times 10^9\ \frac{N \cdot m^2}{C^2}$
	k = COULOMB'S CONSTANT
	Q_1 = CHARGE 1 (COULOMBS)
	Q_2 = CHARGE 2 (COULOMBS)
	r = DISTANCE BETWEEN CHARGES (METERS)

Coulomb's Law describes the force between charges **IN A VACUUM**.

If charges are within other materials, the equation must be modified:

$$F = \frac{k}{K} \frac{Q_1 Q_2}{r^2}$$

K = THE DIELECTRIC CONSTANT OF THE MATERIAL THE CHARGES ARE IN

K = 1.0 FOR A VACUUM
$\approx$ 1.0 FOR AIR
= 7.0 FOR MICA
= 80 FOR WATER

WHEN Q_1 & Q_2 ARE IN A MATERIAL OTHER THAN AIR, USE THE APPROPRIATE VALUE FOR K

Coulomb's Constant "k" is often written as:

$$k = \frac{1}{4\pi\varepsilon_0}$$

ε_0 = THE PERMITTIVITY OF FREE SPACE

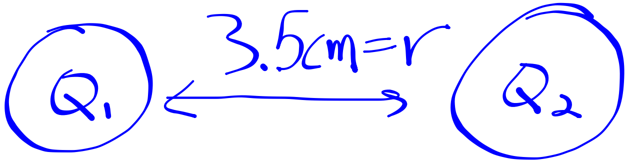
$$= 8.85 \times 10^{-12} \frac{C^2}{N \cdot m^2}$$

WHEN NOT IN A VACUUM, OR FREE SPACE, ε_0 MUST BE MODIFIED TO THE VALUE FOR THAT MATERIAL.

$$\varepsilon_{\text{MATERIAL}} = K\varepsilon_0$$

This is a second way of thinking about the purpose of the dielectric constant introduced on the previous slide.

EXAMPLE 1: What is the force between a 1.6×10^{-7} C charge and a 1.3×10^{-6} C charge separated by 3.5 cm?



$Q_1 = +1.6\times10^{-7}\ C$

$Q_2 = +1.3\times10^{-6}\ C$

$r = 3.5cm = 0.035m$

$$F = k\frac{Q_1Q_2}{r^2} = 1.53\,N$$

(repulsive)

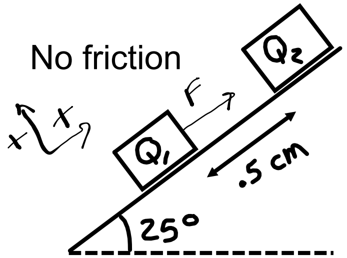
EXAMPLE 1: What is the force between a 1.6×10^{-7} C charge and a 1.3×10^{-6} C charge separated by 3.5 cm?

$$F = k\frac{Q_1Q_2}{r^2}$$

$$= \left(9.0\times10^{9}\ \frac{N\cdot \cancel{m^2}}{\cancel{C^2}}\right)\frac{(1.6\times10^{-7}\ \cancel{C})(1.3\times10^{-6}\ \cancel{C})}{(.035\ \cancel{m})^2}$$

$$= \boxed{1.53\ N\ \text{REPULSIVE}}$$

EXAMPLE 2: What is the charge on Q_2 to keep Q_1 (1.7×10^{-5} C) from sliding down the incline? Assume Q_2 is held in place and cannot move, and that Q_1 has a mass of 1.6 grams.

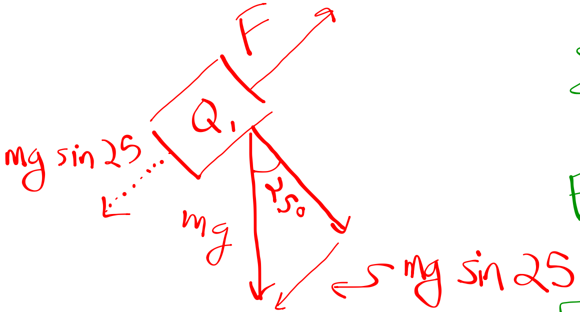


$Q_1 = 1.7\times10^{-5}$ C

$Q_2 = ?$ (must be negative)

$r = 0.5\text{cm} = 0.005\text{ m}$

$m = 1.6\text{g} = 0.0016\text{ kg}$



$\Sigma F = m\cancel{a} \; 0$

$\Sigma F = 0$

$F + mg\sin 25 = 0$

$\boxed{F} + \underline{mg\sin 25}$

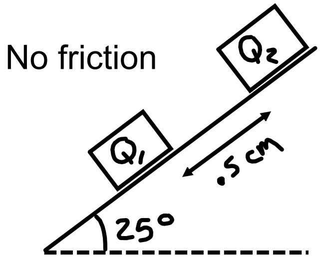
$F = \dfrac{kQ_1Q_2}{r^2}$

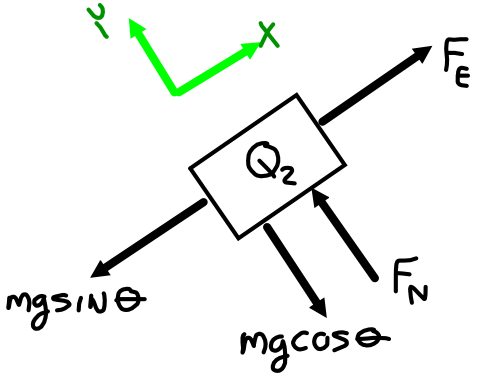
$$mg\sin 25 = \frac{kQ_1Q_2}{r^2}$$

$$Q_2 = \underbrace{\frac{(mg\sin 25)r^2}{kQ_1}}$$

make it negative
(create an attractive
force between Q_1/Q_2)

EXAMPLE 2: What is the charge on Q_2 to keep Q_1 (1.7×10^{-5} C) from sliding down the incline? Assume Q_2 is held in place and cannot move, and that Q_1 has a mass of 1.6 grams.





$$\Sigma F_x = m\cancel{a_x}^{\,0}$$

$$F_E - mg\sin\theta = 0$$

$$k\frac{Q_1Q_2}{r^2} - mg\sin\theta = 0$$

$$k\frac{Q_1Q_2}{r^2} = mg\sin\theta$$

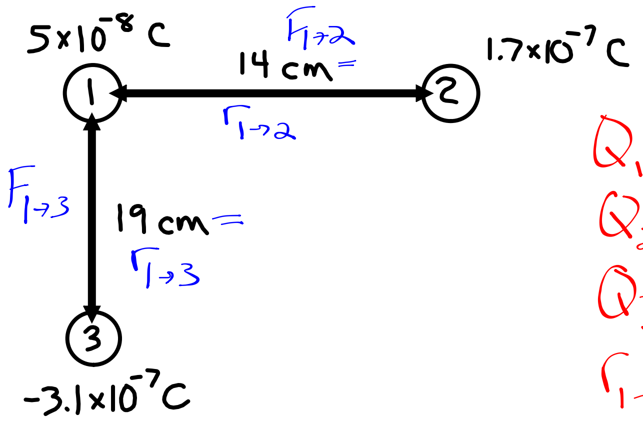
$$Q_2 = \frac{r^2 mg\sin\theta}{kQ_1} = \frac{(.005)^2(.0016)(9.8)\sin 25}{(9\times10^9)(1.7\times10^{-5})}$$

$$= 1.08\times10^{-12}\ C$$

$$\therefore \boxed{Q_2 = -1.08\times10^{-12}\ C}$$

MUST BE NEGATIVE SO Q_1 & Q_2 REPEL

EXAMPLE 3: Determine the net force on Charge 1.



$Q_1 = 5\times10^{-8}\,C$

$Q_2 = 1.7\times10^{-7}\,C$

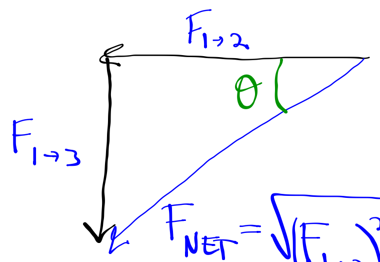
$Q_3 = -3.1\times10^{-7}\,C$

$r_{1\to2} = 14\,cm = 0.14\,m$

$r_{1\to3} = 19\,cm = 0.19\,m$

$$F_{1\to2} = k\frac{Q_1 Q_2}{(r_{1\to2})^2}$$

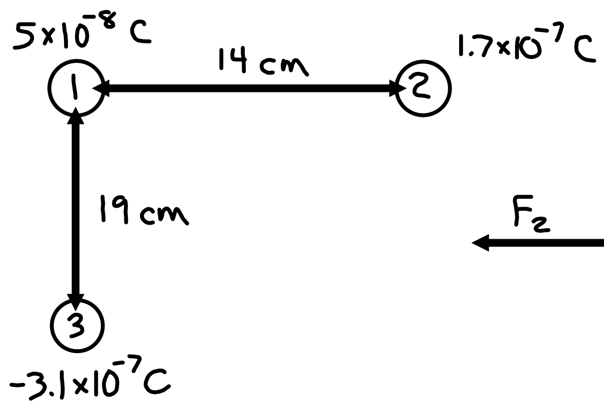
$$F_{1\to3} = k\frac{Q_1 Q_3}{(r_{1\to3})^2}$$

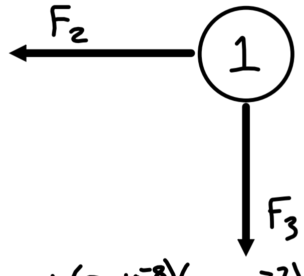


$$F_{NET} = \sqrt{(F_{1\to2})^2 + (F_{1\to3})^2}$$

$$\theta = \tan^{-1}\frac{F_{1\to3}}{F_{1\to2}}$$

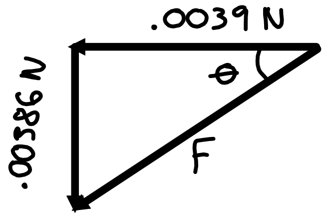
EXAMPLE 3: Determine the net force on Charge 1.





$$F_2 = (9\times10^9)\frac{(5\times10^{-8})(1.7\times10^{-7})}{(.14)^2} = .0039\text{ N}$$

$$F_3 = (9\times10^9)\frac{(5\times10^{-8})(3.1\times10^{-7})}{(.19)^2} = .00386\text{ N}$$



$$F = \sqrt{(.0039)^2 + (.00386)^2} = \boxed{.00549\text{ N}}$$

$$\theta = \tan^{-1}\left(\frac{.00386}{.0039}\right) = \boxed{44.7^\circ \text{ As Shown}}$$

Note that the negative sign for Q3 WAS NOT inserted into the equation. Instead, it was accounted for in the FBD. When dealing with forces, this is generally the best approach.

Later in the unit, there will be cases where we have to insert negative signs, but lets wait until we get there. At that time, we'll be dealing with something other than forces.