Chapter 20: Electric Fields and Forces

20.1: Charges and Forces

See the pre-lecture video. We will not be concerned with most of the details of specific friction experiments, but will focus on the broad, general conclusions:

- There are 2 types of charge: Call them “+” and “-“
- Like charges repel
- Opposite charges attract
- Total charge is conserved.

20.2: Charges, Atoms, and Molecules

Read for general perspective.

Charge on an electron: $-e$

Charge on a proton: $-e$

where $e = 1.602176634 \times 10^{19} C$ usually round to

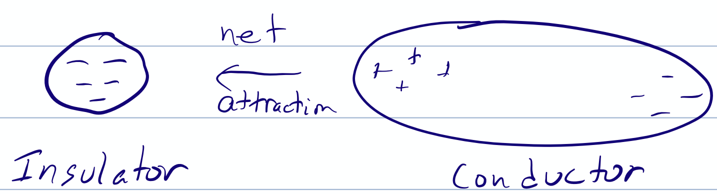
$$e = 1.602 \times 10^{-19} C.$$

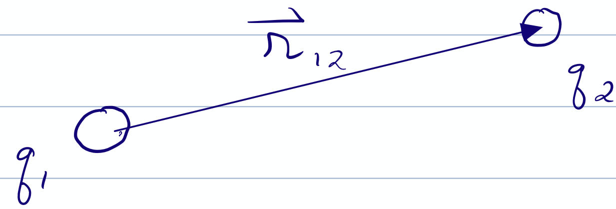
Definition of the Coulomb: $1\ C \simeq 6.2415 \times 10^{18} e$

Common subunits: $1\ \mu C = 10^{-6} C$ $\quad$ $1\ nC = 10^{-9} C$

Typically use q or Q for charge.

Conductor: Charges move easily within a conductor
Insulator: Charges are not free to move within an insulator
Polarization: a separation of positive and negative charge





Let $\vec{F}_{1 \text{ on } 2}$ = force exerted on q_1 by q_2.

Magnitude: $F_{1 \text{ on } 2} = \dfrac{K|q_1||q_2|}{r_{12}^2}$

Direction: attractive, if charges are opposite
repulsive, if charges are same sign.

$K = 8.99 \times 10^9 \, Nm^2/C^2$
(often rounded to $9.0 \times 10^9 \, Nm^2/C^2$).

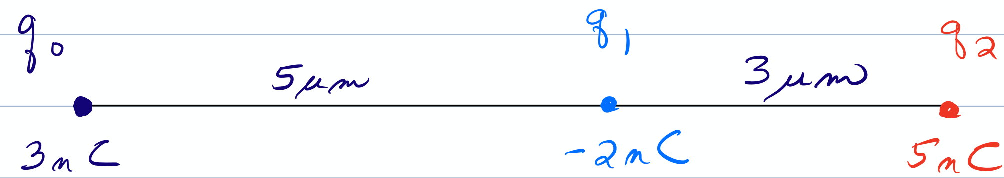
a related constant ϵ_0, given by $\epsilon_0 = 1/4\pi K$

$K = 1/4\pi\epsilon_0$, $\epsilon_0 = 8.854\ 187\ 8128 \times 10^{-12} \dfrac{C^2}{Nm^2}$,

or $\epsilon_0 \approx 8.85 \times 10^{-12} \, C^2/Nm^2$

- Do we really know all those digits? Yes! Electricity and Magnetism have been measured to astonishing precision — much better than gravity!
- Functional form is identical to gravity, except gravity is always attractive.

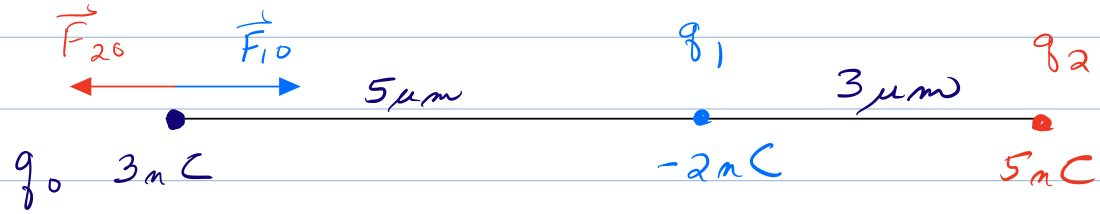
e.g. 3 charges in a line. What is the net force on q_0?



Strategy: Find $\vec{F}_{10}$ and $\vec{F}_{20}$, then add.
For each force, draw direction on diagram and calculate magnitude of the force.
(Poll: direction of $\vec{F}_{10}$? direction of $\vec{F}_{20}$?)
(Force on q_0 due to q_1) (Force on q_0 due to q_2)

Magnitude: $F_{10} = \frac{K|q_1||q_0|}{r_{10}^2}$

$F_{20} = \frac{K|q_2||q_0|}{r_{20}^2}$



magnitude: $F_{10} = \dfrac{\left(9.0\times10^{9}\,\frac{Nm^2}{C^2}\right)\left(2\times10^{-9}\,C\right)\left(3\times10^{-9}\,C\right)}{\left(5\times10^{-6}\,m\right)^2}$

$F_{10} = 2158\,N$

$$F_{20} = \frac{\left(9\times10^{9}\,Nm^2/C^2\right)\left(5\times10^{-9}\,C\right)\left(3\times10^{-9}\,C\right)}{\left(8\times10^{-6}\,m\right)^2}$$

$F_{20} = 2107\,N$

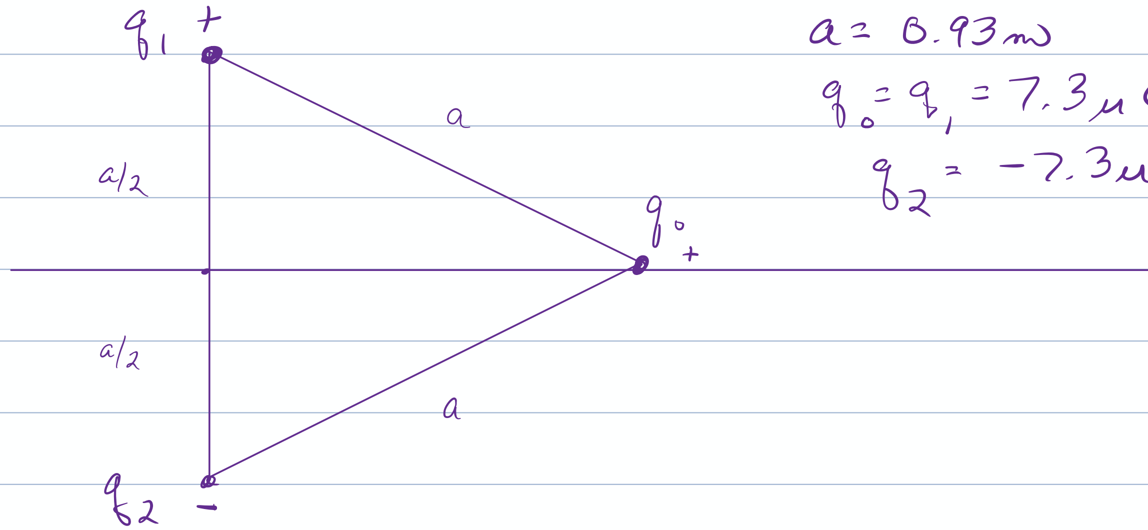
Total Force $F = F_{10} - F_{20} = 2158\,N - 2107\,N$

$F = 51\,N$

direction? To the right.

Assess: The 5nC charge is bigger but also further away. The $1/r^2$ distance factor means the net force is positive.

Vector Example – charged triangle

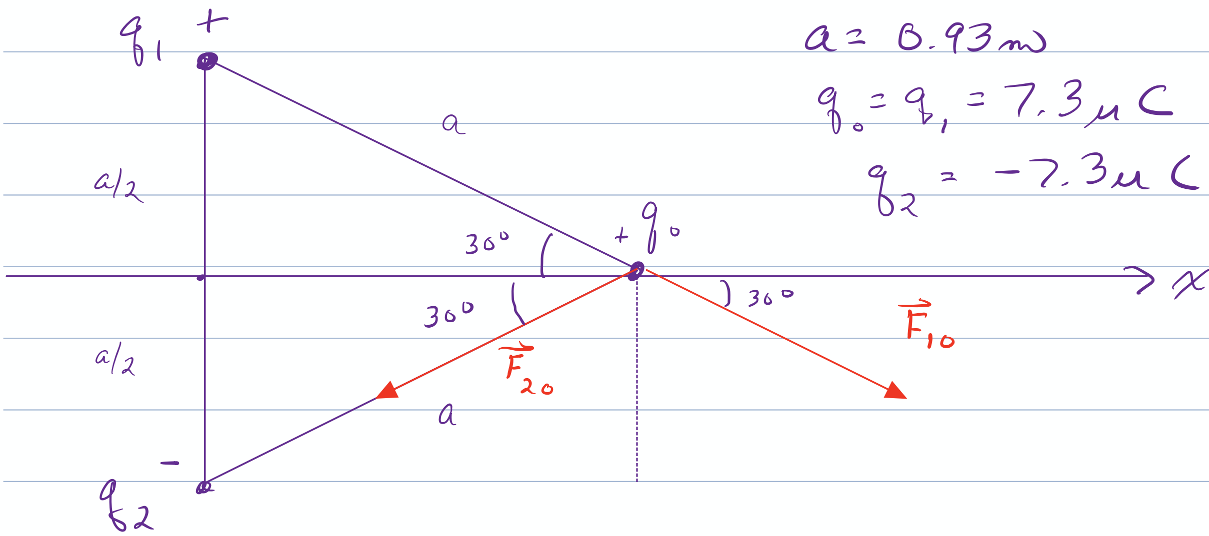


$a = 0.93\,m$

$q_0 = q_1 = 7.3\,\mu C$

$q_2 = -7.3\,\mu C$

What is the net force on q_0 due to the other 2 charges?



$a = 0.93\,m$

$q_0 = q_1 = 7.3\,\mu C$

$q_2 = -7.3\,\mu C$

$$|\vec{F}_{10}| = F_{10} = \frac{k\,|q_1|\,|q_0|}{a^2} = \frac{\left(9\times10^{9}\,\frac{Nm^2}{C^2}\right)\left(7.3\times10^{-6}\,C\right)\left(7.3\times10^{-6}\,C\right)}{(0.93\,m)^2}$$

$$F_{10} = 0.555\,N$$

$$\vec{F}_{10} = 0.555\,N \;@\; -30^\circ$$

NO − sign.

$$|\vec{F}_{20}| = F_{20} = \frac{K|q_2||q_0|}{a^2} = \frac{(9\times10^9 \frac{Nm^2}{C^2})(7.3\times10^{-6}C)(7.3\times10^{-6}C)}{(0.93m)^2}$$

$F_{20} = 0.555\ N$ (could guess from symmetry).

$\vec{F}_{20} = 0.555\ N$ @ $-150°$

What is the net force?

$\vec{F} = \vec{F}_{10} + \vec{F}_{20}$. Add as vectors.

x-components

$$F_x = F_{10,x} + F_{20,x}$$
$$= (0.555\ N)\cos(-30°) + (0.555N)\cos(-150°)$$
$$= 0$$ (obvious from symmetry).

y-components

$$F_y = F_{10,y} + F_{20,y}$$
$$= (0.555N)\sin(-30°) + (0.555N)\sin(-150°)$$
$$F_y = -0.555\ N$$

$$\vec{F} = 0\,\hat{i} - 0.555N\,\hat{j}$$
$$\vec{F} = 0.555\ N \text{ @ } -90°$$

Defer more vector work until we discuss the electric field.