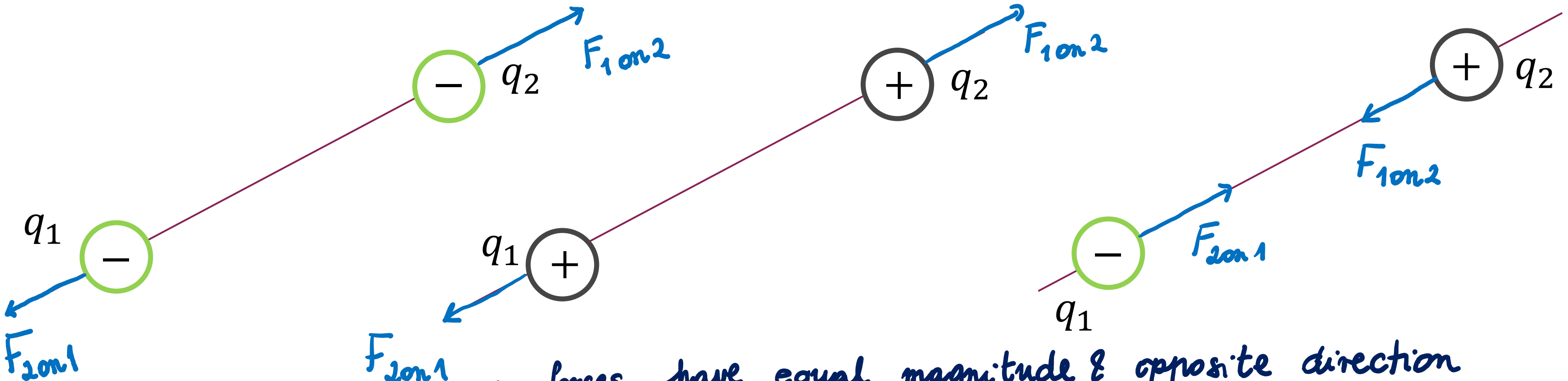
CHAPTER 17: ELECTRIC CHARGE, FORCE, AND ENERGY

LAST CLASS:

If two charged particles are brought near each other, they exert a force on the other.



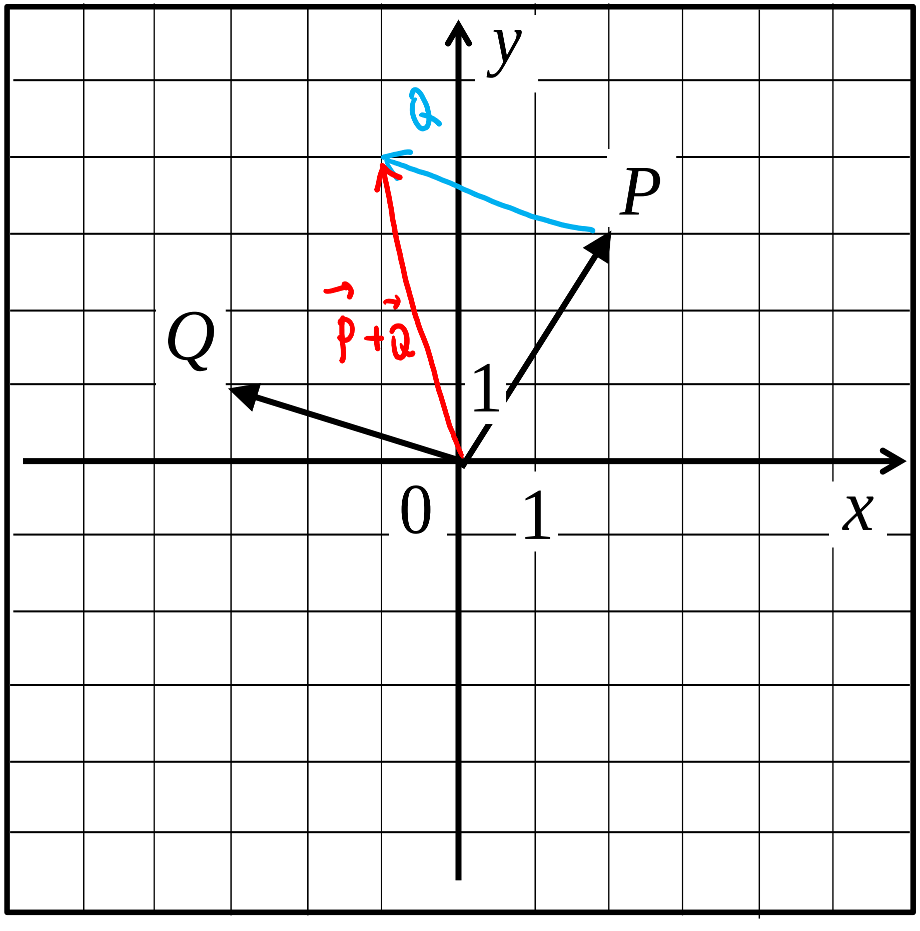
- forces have equal magnitude & opposite direction (ACTION - REACTION)
- forces ALWAYS act along the line connecting charges

If the particles have **opposite** signs of charge, they attract each other..

If the particles have **the same** sign of charge, they repeal each other.

The force of repulsion or attraction due too the charge properties of objects is called an **electrostatic force.**

The equation giving the force for charged *particles* is called **Coulomb's Law**



y
Q
P
$\vec{P}+\vec{Q}$
Q
1
0
1
x

17.4 Coulomb's Force

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Charge values

Unit vector along the line connecting the charges, pointing from the agent to the object

$$\vec{F} = k_e \frac{q_1 q_2}{r^2} \hat{r}$$

Distance between the charges

Coulomb's constant $k_e = 8.99 \times 10^9 \frac{\mathrm{N \cdot m^2}}{\mathrm{C^2}}$

$$k_e = 8.99 \times 10^9 \frac{\mathrm{N \cdot m^2}}{\mathrm{C^2}} = \frac{1}{4\pi\varepsilon_0}$$

where $\varepsilon_0 = 8.85 \times 10^{-12} \frac{\mathrm{C^2}}{\mathrm{N \cdot m^2}}$

17.4 Coulomb's Force

As we can figure out the direction of the force from the sign of the charges and their interactions with each other, we will determine the magnitude of the electric force using equation:

Absolute values of the charges

$$|\vec{F}_e| = k_e \frac{|q_1||q_2|}{r^2}$$

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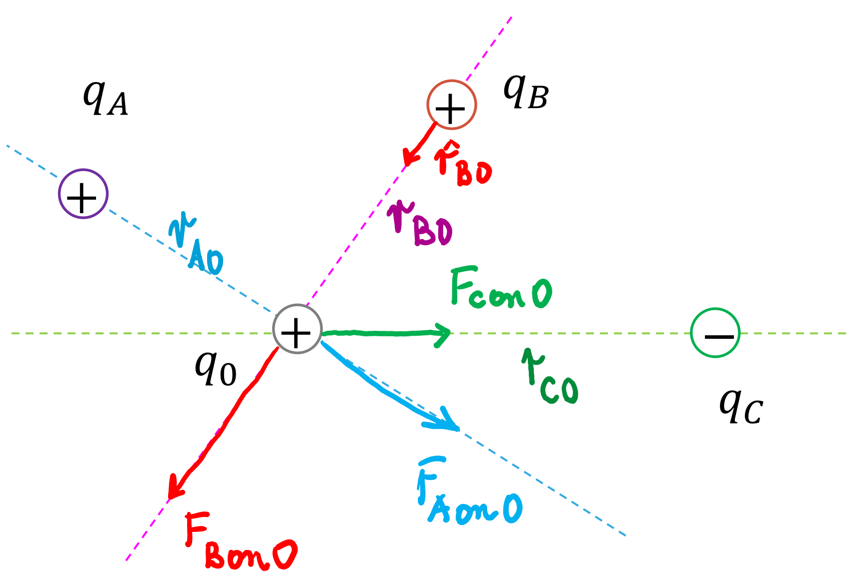
It is a force, therefore it is a vector and we will always treat it as such. We will just use different methods (understanding of the system and empirical equation) to determine direction and magnitude, respectively.

From Newton's Third Law: $\vec{F}_{1on2} = -\vec{F}_{2on1}$

Direction of the Force

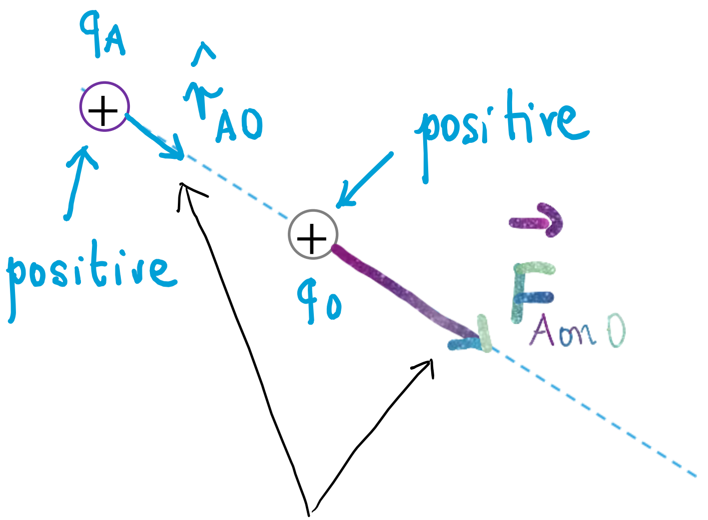


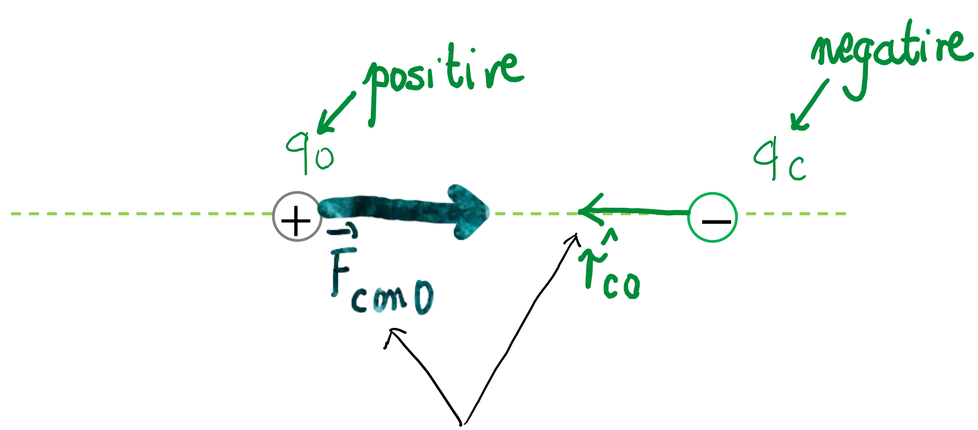
$$\left|F_{A\,on\,O}\right| = \frac{k_e |q_A||q_0|}{r_{AO}^2}$$

$$\vec{F}_{A\,on\,O} = \frac{k_e\, q_A\, q_0}{r_{AO}^2}\,\hat{r}_{AO}$$

$$\left|F_{B\,on\,O}\right| = \frac{k_e |q_B||q_0|}{r_{BO}^2} \rightarrow \vec{F}_{B\,on\,O} = \frac{k_e q_B q_0}{r_{BO}^2}\,\hat{r}_{BO}$$

$$\left|F_{C\,on\,O}\right| = \frac{k_e |q_C||q_0|}{r_{CO}^2} \rightarrow \vec{F}_{C\,on\,O} = \frac{k_e q_C q_0}{r_{CO}^2}\,\hat{r}_{CO}$$





SUMMARY:

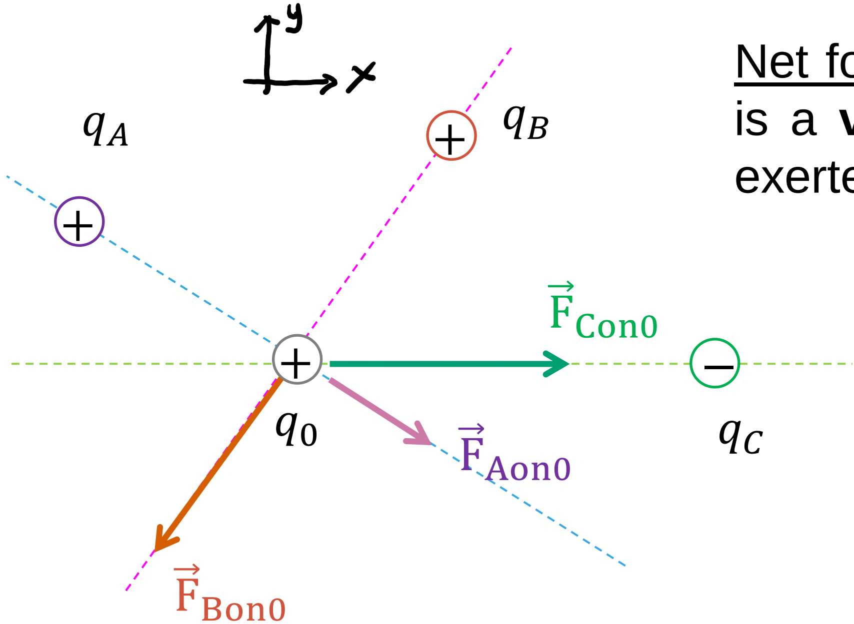
- there is a force between two charged objects:

$$F_{e12} = \frac{k_e|q_1||q_2|}{r^2}$$ ← calculate magnitude

1 on 2

← deduce direction!

PRINCIPLE OF SUPERPOSITION



Net force on a charge due to surrounding charges is a **vector sum** of all the forces on that charge exerted by the other charges.

Each charge exerts force on charge q_0. The magnitude of each force can be calculated as

$$F_{ion} = k_e \frac{|q_i||q_0|}{r_{i0}^2}$$

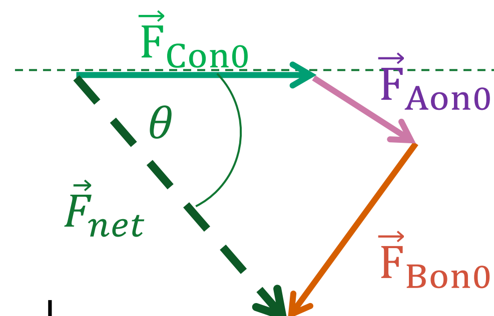
The direction of **each** force is deduced by looking at the geometry of the charge arrangement.

Resultant force:

$$\vec{F}_{net} = \vec{F}_{Aon0} + \vec{F}_{Bon0} + \vec{F}_{Con0}$$

$$F_{net,x} = F_{Aon0,x} + F_{Bon0,x} + F_{Con0,x}$$

$$F_{net,y} = F_{Aon0,y} + F_{Bon0,y} + F_{Con0,y}$$

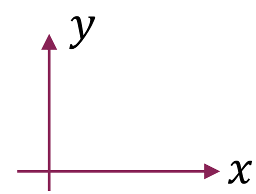


$$F_{net} = \sqrt{F_{net,x}^2 + F_{net,y}^2}$$

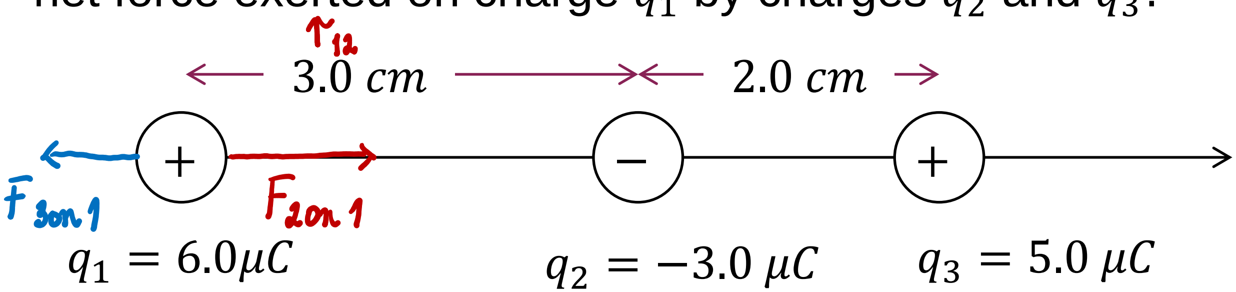
$$\theta = \frac{|F_{net,y}|}{|F_{net,x}|}$$

Example 17B

$k_e = 8.99 \times 10^9 \ \frac{Nm^2}{C^2}$



Three charges are placed along the *x* axis, as shown in the picture. Determine the net force exerted on charge q_1 by charges q_2 and q_3?



$r_{12} = 3.0\ cm$
$= 0.03 m$

$$F_{2on1} = \frac{k_e |q_1||q_2|}{r_{12}^2} = \frac{\left(8.99\times 10^9 \ \frac{Nm^2}{C^2}\right)\left(6.0\times 10^{-6} C\right)\left(3.0\times 10^{-6}\right)}{(0.03 m)^2} = 180 N$$

$\vec{F}_{2on1} = +180 N \quad +x \text{ dir}$

$$F_{3on1} = \frac{k_e |q_1||q_3|}{r_{13}^2} = \frac{\left(8.99\times 10^9 \ \frac{Nm^2}{C^2}\right)\left(6.0\times 10^{-6} C\right)\left(5.0\times 10^{-6}\right)}{(0.05)^2} = 108 N$$

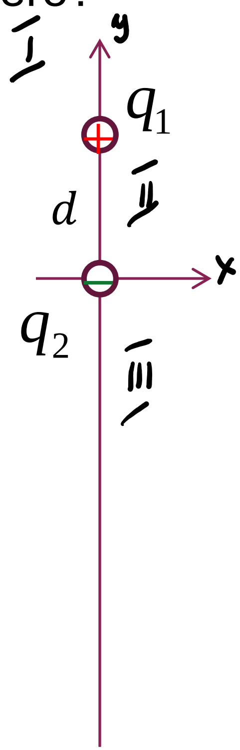
$\vec{F}_{3on1} = -108N$ in x dir
or $108N$ in $-x$ dir

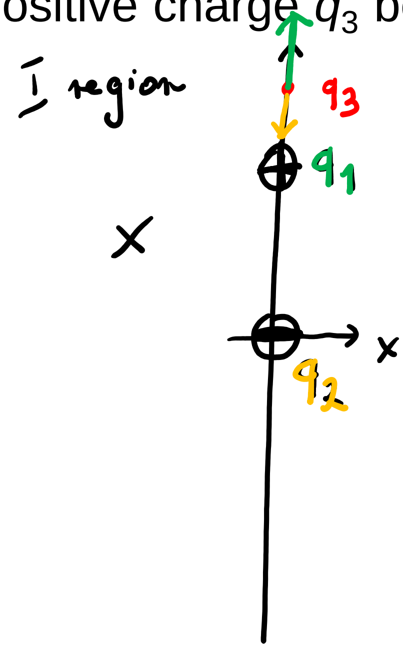
$$\vec{F}_{net} = \vec{F}_{2on1} + \vec{F}_{3on1} = 72 N$$

Example 17c

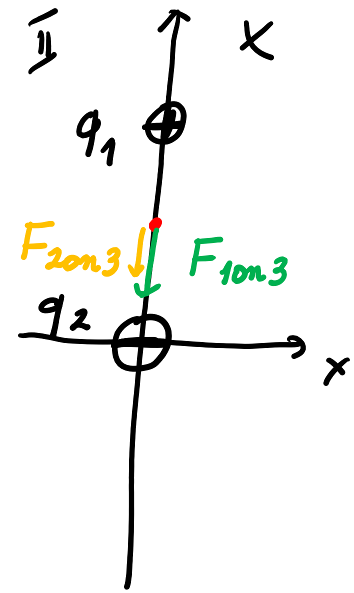
Two charged particles lie along axis y as shown in the picture. The particle with charge $q_1 = 20.0\ \mu\text{C}$ is at $y = 1.00$ cm and particle with charge $q_2 = -\ 10.0\ \mu\text{C}$ is at origin.

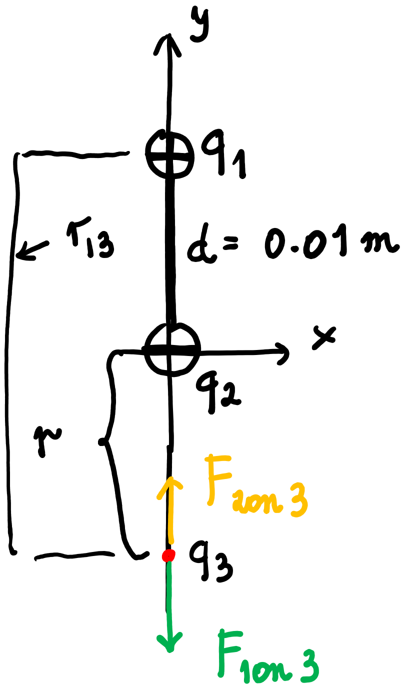
Where on y axis should a positive charge q_3 be placed such that resultant force on it is zero?





$F_{1on3} > F_{2on3}$





$$F_{2on3} = F_{1on3}$$

$$\frac{\cancel{k_e}\,|q_2|\,\cancel{|q_3|}}{r^2} = \frac{\cancel{k_e}\,|q_1|\,\cancel{|q_3|}}{(d+r)^2}$$

$$\boxed{\frac{\sqrt{|q_2|}}{r} = \frac{\sqrt{|q_1|}}{d+r}} \rightarrow \frac{\sqrt{|q_1|}}{\sqrt{|q_2|}} = \frac{d+r}{r}$$

$$\sqrt{|q_1|}\cdot r = \sqrt{|q_2|}\,(d+r) = \sqrt{|q_2|}\cdot d + \sqrt{|q_2|}\,r$$

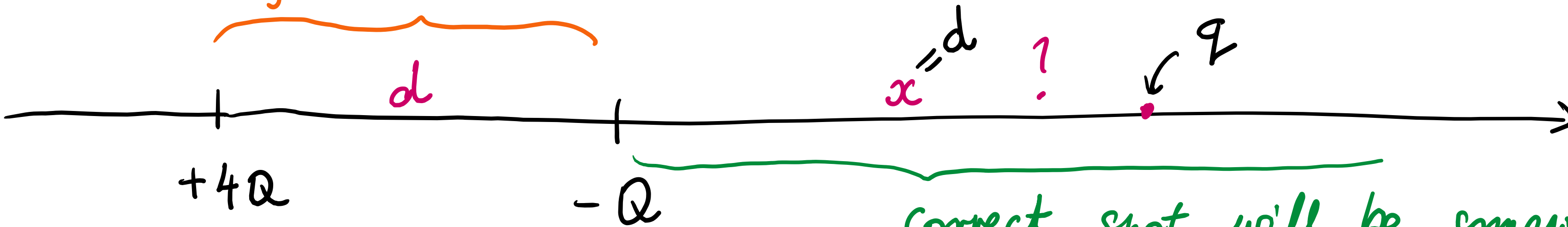
$$\sqrt{|q_1|}\cdot r - \sqrt{|q_2|}\,r = \sqrt{|q_2|}\cdot d$$

$$r = \frac{\sqrt{|q_2|}\cdot d}{\sqrt{|q_1|} - \sqrt{|q_2|}} = \frac{\sqrt{10\times 10^{-6}}\cdot 0.01}{\sqrt{20\times 10^{-6}} - \sqrt{10\times 10^{-6}}}$$

$$r = 0.0241\,m$$

Scenario #1: Opposite charges

forces in the same direction



Correct spot will be somewhere on the outside, closer to smaller charge

$$\frac{\cancel{k_e}|4Q|\cdot|q|}{(d+x)^2} = \frac{\cancel{k_e}(Q)|q|}{x^2}$$

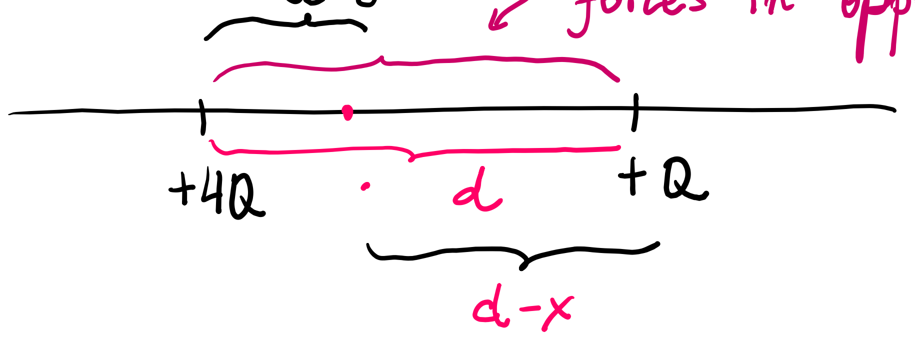
$$\frac{4Q}{(d+x)^2} = \frac{Q}{x^2} \rightarrow \frac{4Q}{Q} = \frac{(d+x)^2}{x^2}$$

ratio of distances squared

ratio of charges

$$\left(\frac{d+x}{x}\right)^2 = 4 \rightarrow \frac{d+x}{x} = 2 \rightarrow 2x = d+x \rightarrow x = d$$

Scenario #2 : same sign



forces in opposite direction so somewhere here

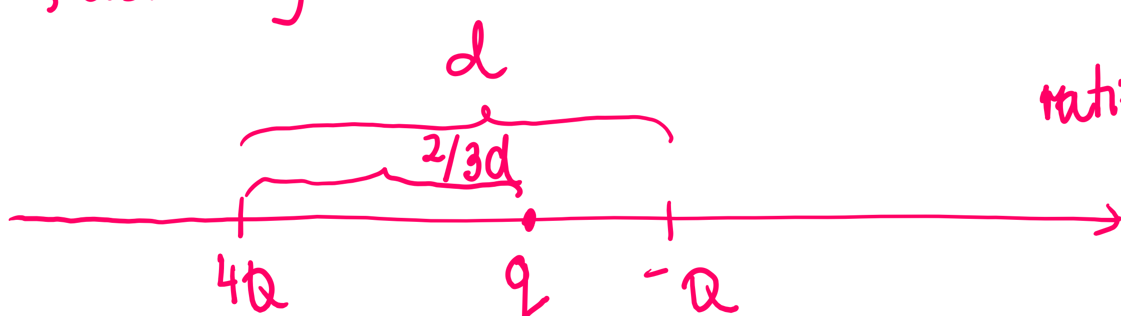
$$\frac{k_e 4Q q}{x^2} = \frac{k_e Q q}{(d-x)^2} \rightarrow \frac{4Q}{Q} = \frac{x^2}{(d-x)^2}$$

$$2 = \frac{x}{d-x} \rightarrow 2d - 2x = x$$

$$3x = 2d$$

$$x = \frac{2}{3}d$$

So, actually



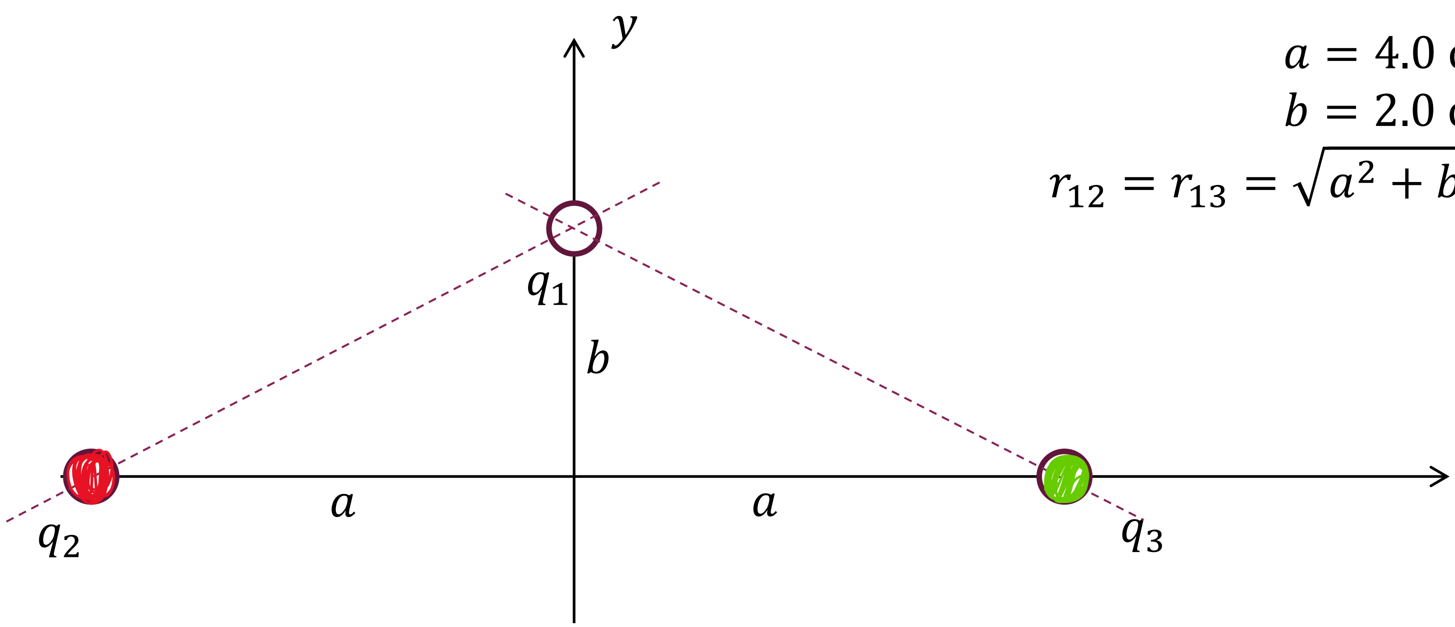
ratio: $x = \frac{2}{3}d$

$d - x = \frac{1}{3}d$

HOMEWORK: Draw $F_{2\,on\,1}$ & $F_{3\,on\,1}$. Calculate magnitudes

EXAMPLE 17D

Find the electric force exerted on a charge q_1 = -1.0 μC located at P_1 =(0,2) cm by two charges: q_2=2.0μC and q_3=-3.0 μC located at P_2 =(-4,0) cm and P_3 =(4,0) cm, respectively



$$a = 4.0 \text{ cm}$$
$$b = 2.0 \text{ cm}$$
$$r_{12} = r_{13} = \sqrt{a^2 + b^2} = 0.0447 \text{ m}$$