



Electromagnetism

Electric Charges and Forces

Concepts: Electric Charges
Insulator, Conductor
Electric Force
Coulomb's Law

Chapter 25: 25.1-4

Fundamental forces

1) Gravity

- the force between masses
- holds planets and stars together, makes things fall, etc...

2) Electromagnetism

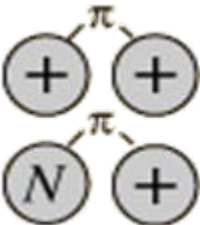
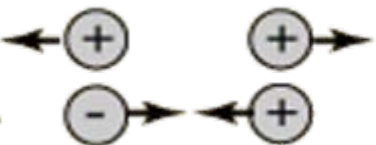

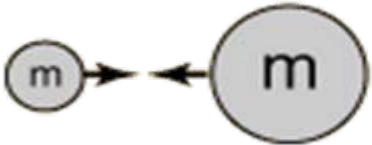
- the force between charges
- responsible for all familiar "everyday" forces (except gravity)

3) "Weak Nuclear Forces"

- changes one flavour of quark into another

4) "Strong Nuclear Forces"

- holds atomic nuclei together

<i>Strong</i>	 <p>Force which holds nucleus together</p>	<p>Strength</p> <p>1</p>	<p>Range (m)</p> <p>10^{-15} (diameter of a medium sized nucleus)</p>	<p>Particle</p> <p>π, others mass > 0.1 GeV</p>
<i>Electro-magnetic</i>		<p>Strength</p> <p>$\frac{1}{137}$</p>	<p>Range (m)</p> <p>Infinite</p>	<p>Particle</p> <p>photon mass = 0 spin = 1</p>
<i>Weak</i>	 <p>neutrino interaction induces beta decay</p>	<p>Strength</p> <p>10^{-5}</p>	<p>Range (m)</p> <p>10^{-17} (0.1% of the diameter of a proton)</p>	<p>Particle</p> <p>Intermediate vector bosons W^+, W^-, Z_0, mass > 80 GeV spin = 1</p>
<i>Gravity</i>		<p>Strength</p> <p>6×10^{-39}</p>	<p>Range (m)</p> <p>Infinite</p>	<p>Particle</p> <p>graviton ? mass = 0 spin = 2</p>

Why "Electromagnetic"??

ELECTROMAGNETISM: the interaction between charges

"*Electric*": refers to stationary charges

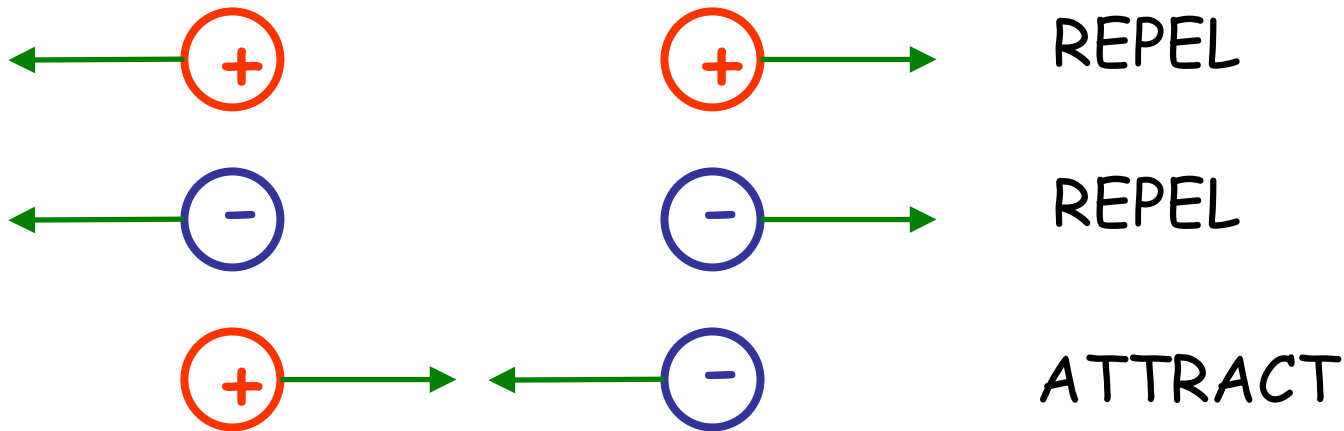
"*Magnetic*": additional interactions among *moving* charges

To a "moving" observer, a "purely electric" field will appear to be a mixture of electric and magnetic interactions.

∴ ⇒ Special Relativity (1905)

Electric Charge

- A scalar quantity, like mass
- Comes in "positive" and "negative" - *unlike mass*



Units: Coulomb, C

"electric charge" on one electron or proton:

$$e = 1.6 \times 10^{-19} C$$

Quick Quiz 32

Two electrons are brought near to one another. Which statement is true?

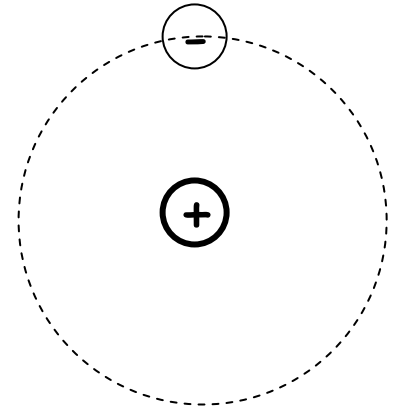
- a) The gravitational force between the electrons is stronger than the electrostatic force between the electrons
- b) The electrons attract each other
- c) Both electrons must have exactly the same charge
- d) The charge on the electrons is 1 Coulomb

Conservation of Charge

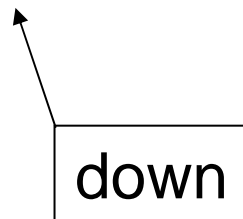
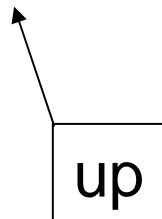
- The net electric charge during any process occurring in a closed system remains constant
- Charge is *conserved* — it is neither created nor destroyed

- Charge is "quantized": appears in nature only in units of "e".*

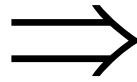
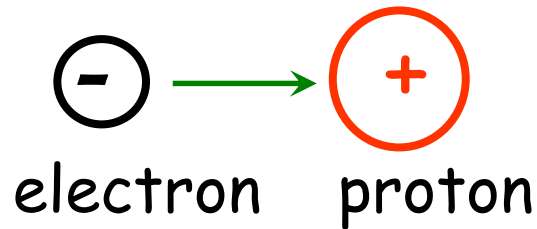
eg:	<u>Particle</u>	<u>Charge</u>
	electron	-e
	proton	+e



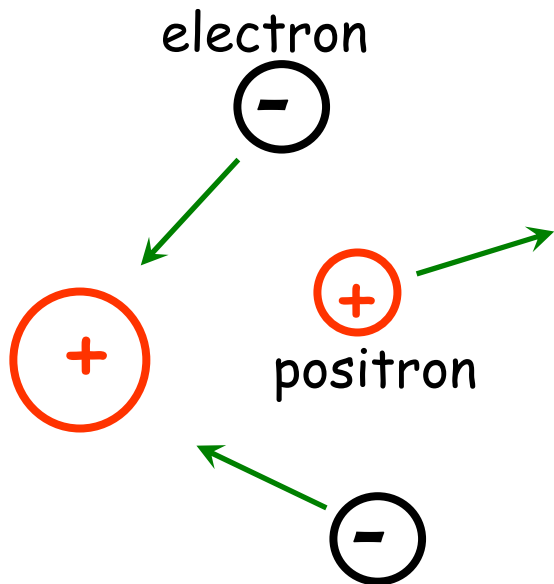
* Except for *quarks*: the sub-sub-atomic particles within protons and neutrons which have $+(2/3)e$ or $-(1/3)e$ charges



Examples using elementary particles



Total charge,
 $(-e) + (+e) = 0$



$$Q_{TOTAL} = (+e) + 2 \cdot (-e) + (+e)$$

proton electrons positron

$$= 0$$

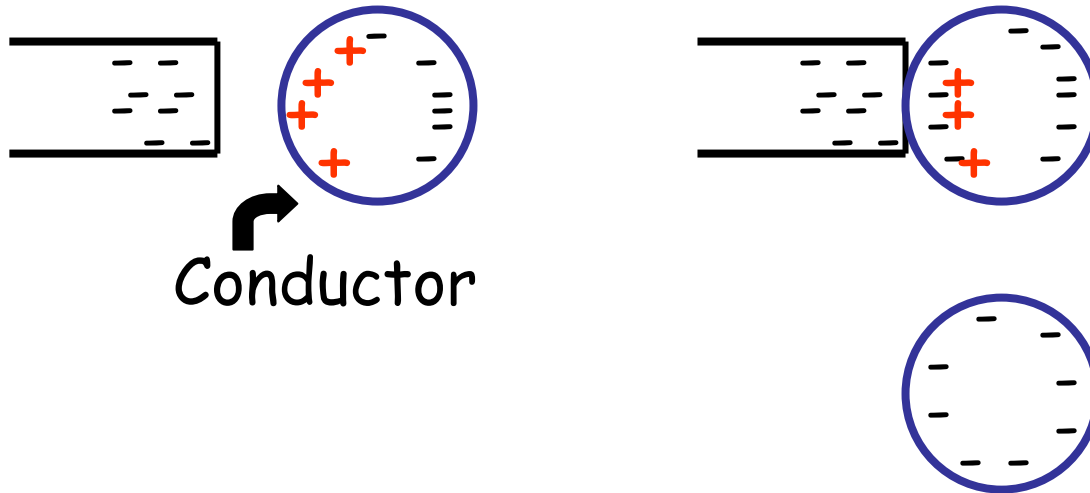
Basic electrical properties of materials:

Insulators: charges do NOT move

Conductors: (some) charges move freely

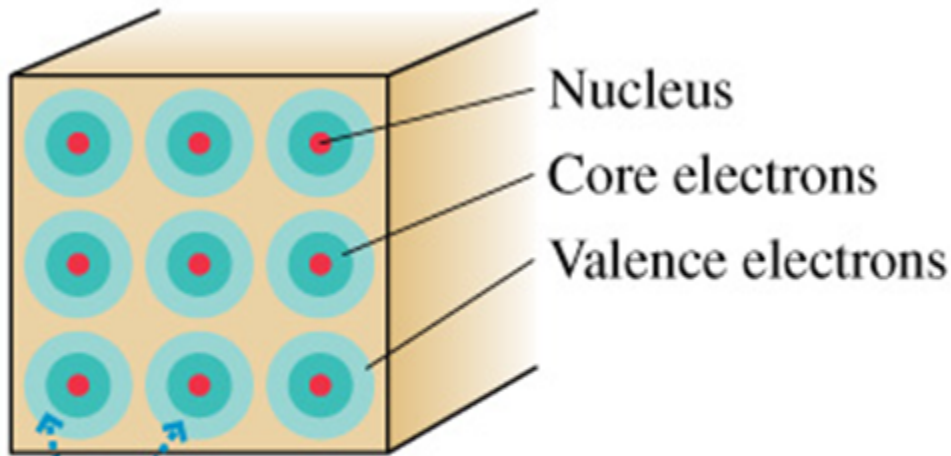


Insulator: charges remain in place



Conductor

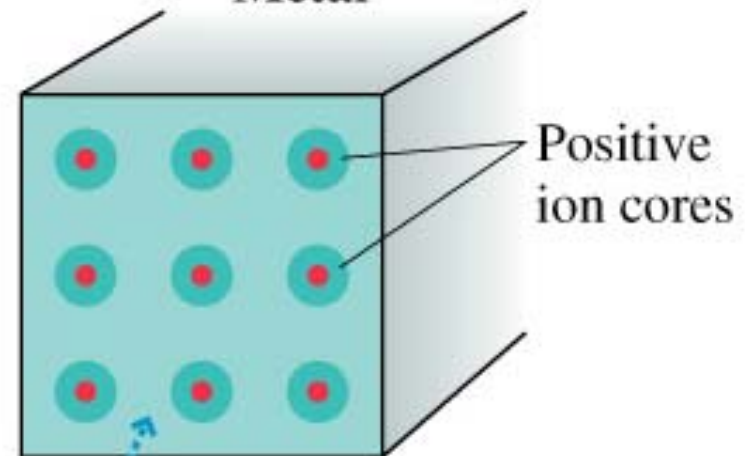
Insulator



Valence electrons
are tightly bound.

immobile charges

Metal



Valence electrons form
a "sea of electrons."

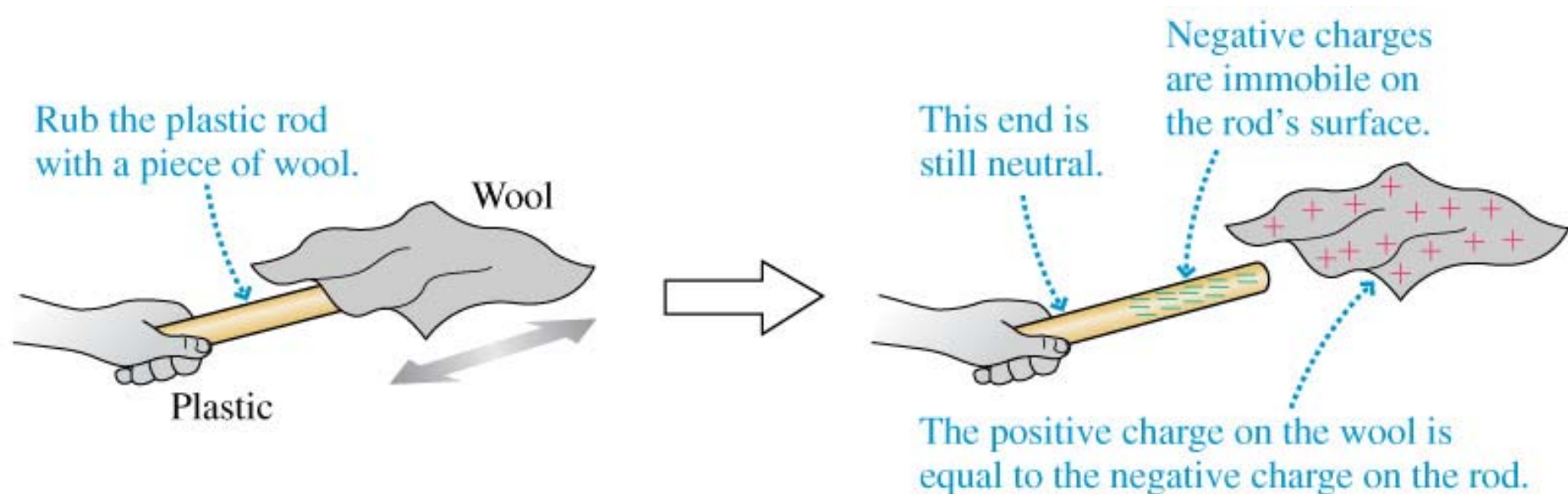
mobile charges

Quick Quiz 33

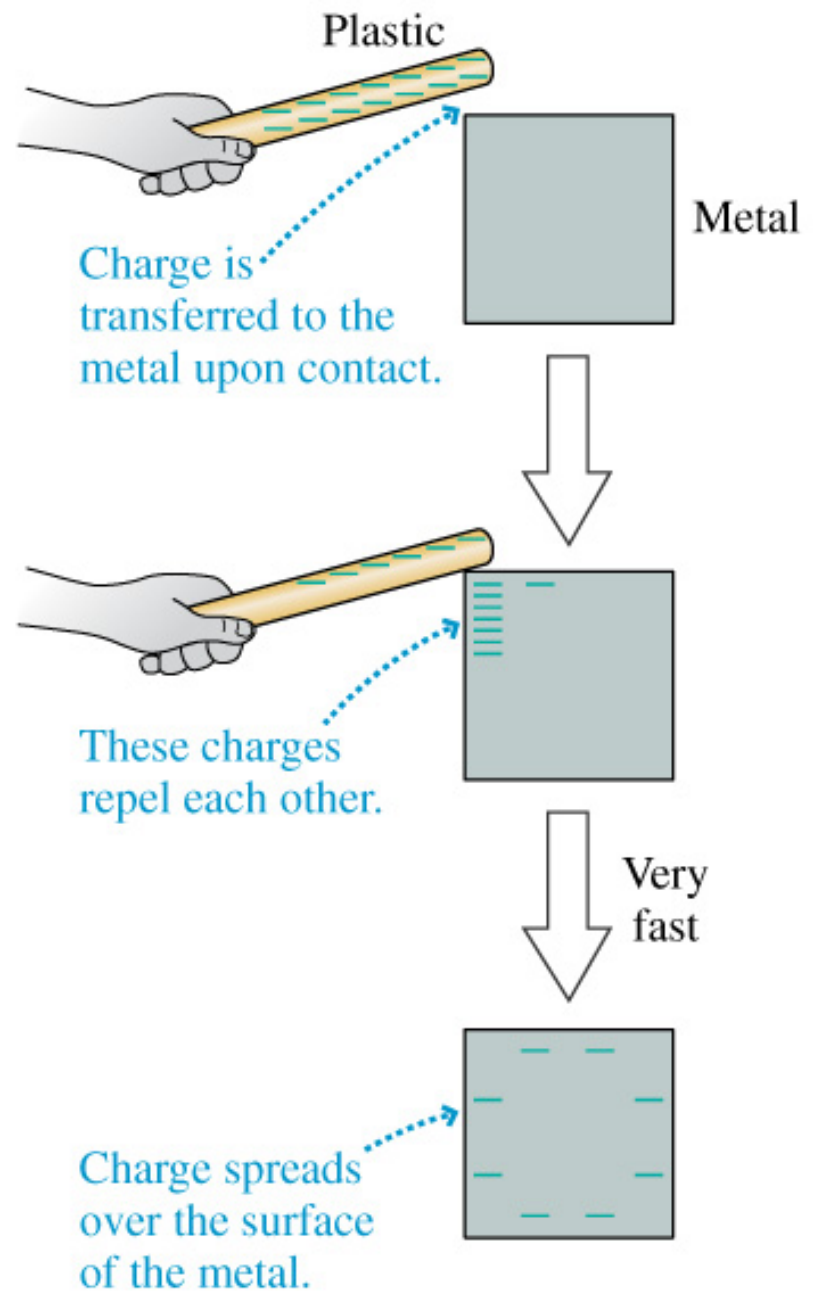
What is the difference between an insulator and a conductor?

- a) An insulator is plastic, a conductor is metal.
- b) A conductor can take excess charge, an insulator can't.
- c) The atoms in a conductor are able to move freely.
- d) The charge carriers in an insulator are not free to move.
- e) More than one answer is correct.

- Plastic is an insulator. We can charge a plastic rod by rubbing it with a piece of wool. Electrons leave the wool and ionize atoms in the plastic. The charges in the plastic don't move around, so the plastic acquires a **static charge**.



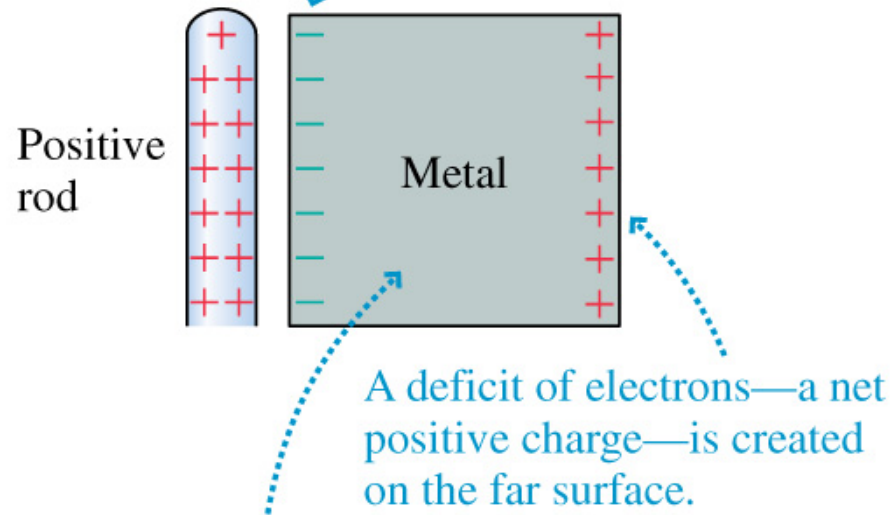
- Most metals are good conductors. If we bring charged plastic close to the metal, it will take the charge from the plastic and spread it around on its **surface**.



- Separation of positive and negative charges in a conductor is called **charge polarization**

– we are giving the object + and – “poles”

The sea of electrons is attracted to the rod and shifts so that there is excess negative charge on the near surface.

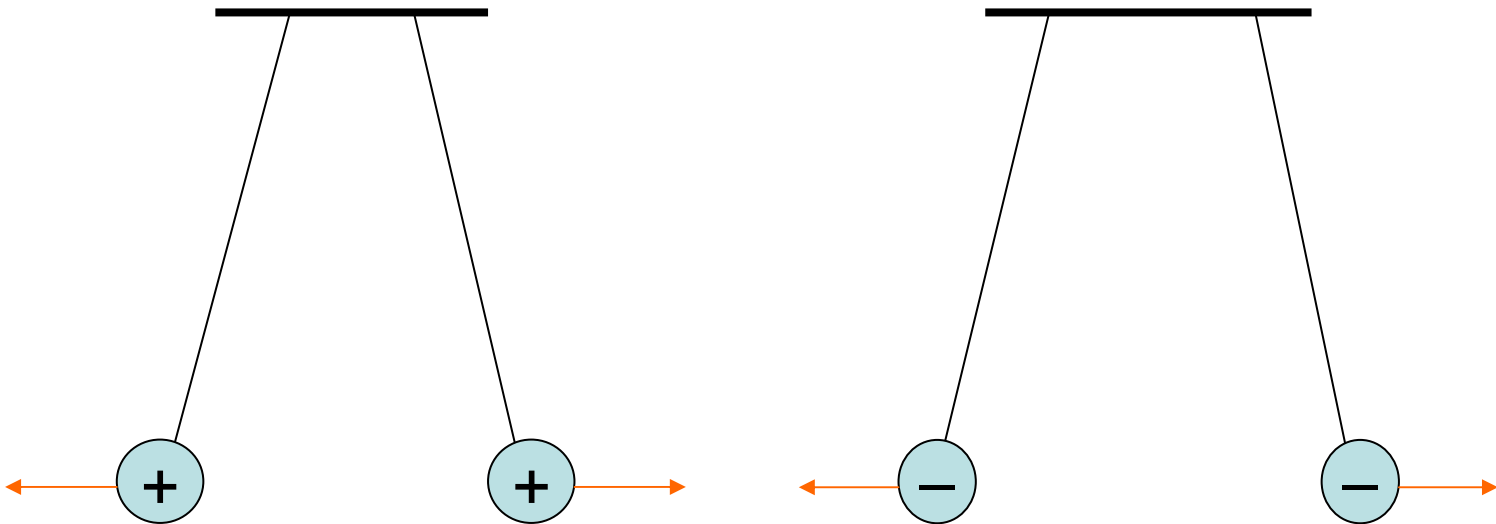


A deficit of electrons—a net positive charge—is created on the far surface.

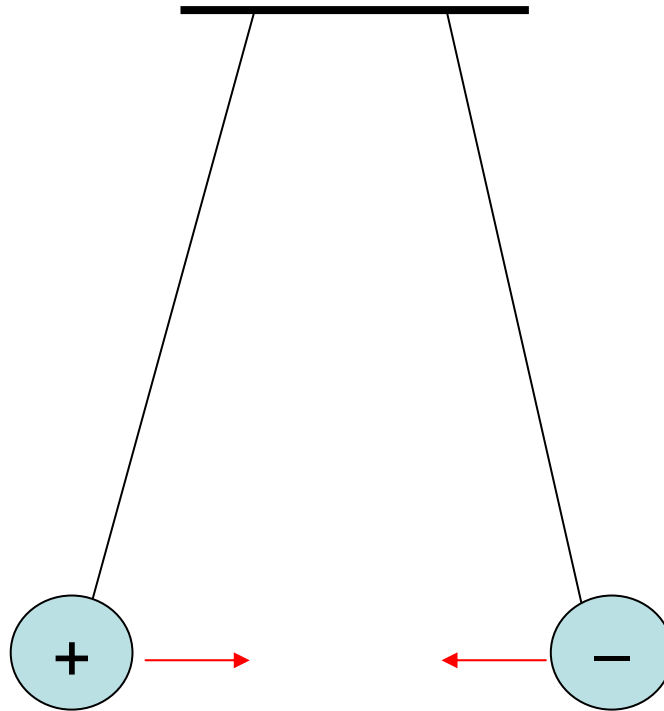
The metal's net charge is still zero, but it has been *polarized* by the charged rod.

Repulsion and Attraction

- Like charges repel one another
 - This means that they must exert forces on one another

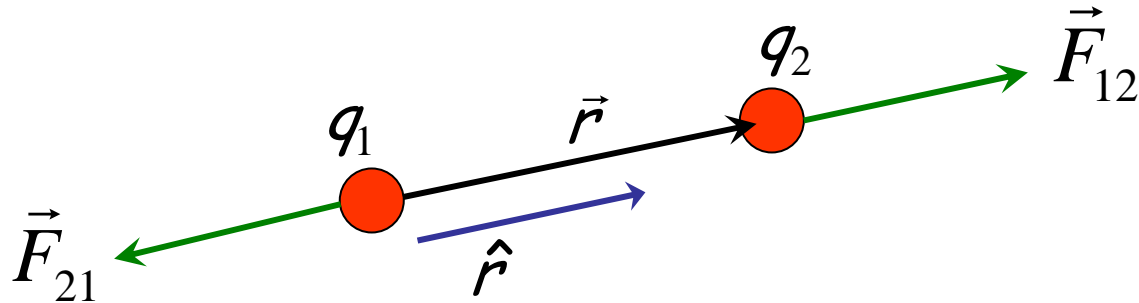


- Opposite charges attract
 - This means that they must exert forces on one another



Coulomb's Law: the basis for everything to come

Charges q_1, q_2 exert forces on each other:



Point charges:

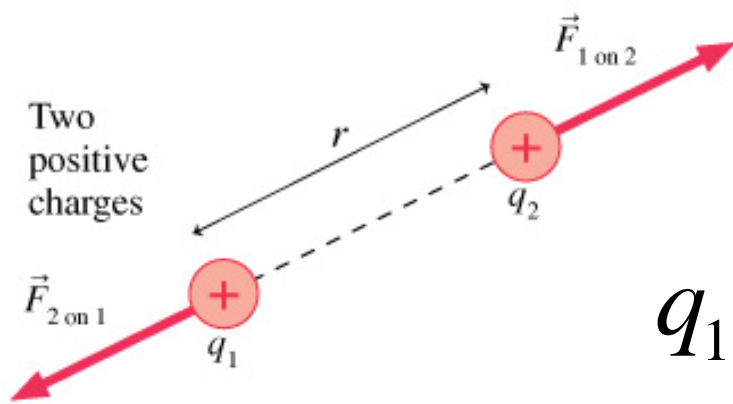
$$\vec{F}_{12} = k_e \frac{q_1 q_2}{r^2} \hat{r} \quad \hat{r} = \frac{\vec{r}}{|\vec{r}|} \text{ (unit vector)}$$

where $k_e = 8.988 \times 10^9 \text{ N m}^2 / \text{C}^2$

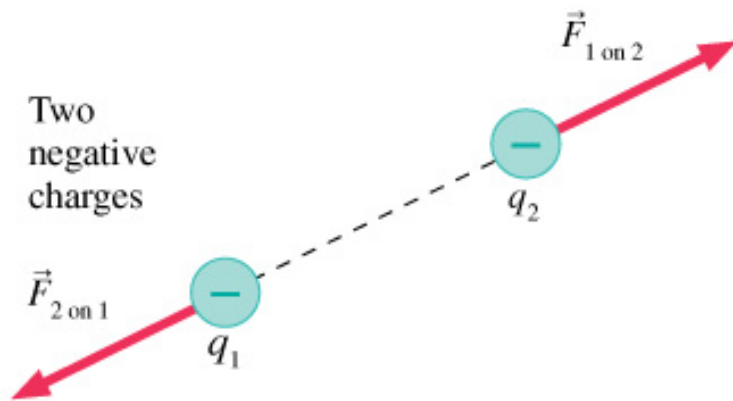
Quick Quiz 34

The unit vector describing the direction of the electrostatic force of charged particle 1 on charged particle 2:

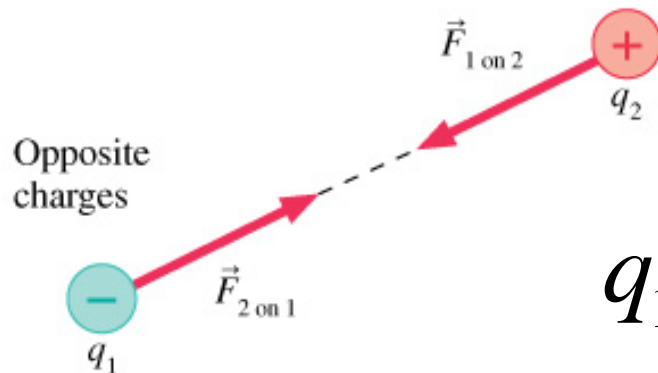
- a) points along a line from particle 1 to particle 2.
- b) points along a line from particle 2 to particle 1.
- c) depends on the whether the charges are like, or unlike.
- d) points in a direction that depends on the superposition of vectors.



$q_1 q_2 > 0 \Rightarrow$ repulsive force



$$\vec{F}_{12} = k_e \frac{q_1 q_2}{r^2} \hat{r}$$



$q_1 q_2 < 0 \Rightarrow$ attractive force

Quick Quiz 35

If $q_1 = +1 \text{ C}$ and $q_2 = +3 \text{ C}$, then:

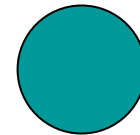
a) $F_{12} = -3 F_{21}$

b) $F_{12} = -F_{21}$

c) $3 F_{12} = -F_{21}$



q_1



q_2

Electric Force and Newton's 3rd Law

- Coulomb's law with vectors:

$$\vec{F}_{12} = k_e \frac{q_1 q_2}{r^2} \hat{r}$$

force exerted by q_1 on q_2

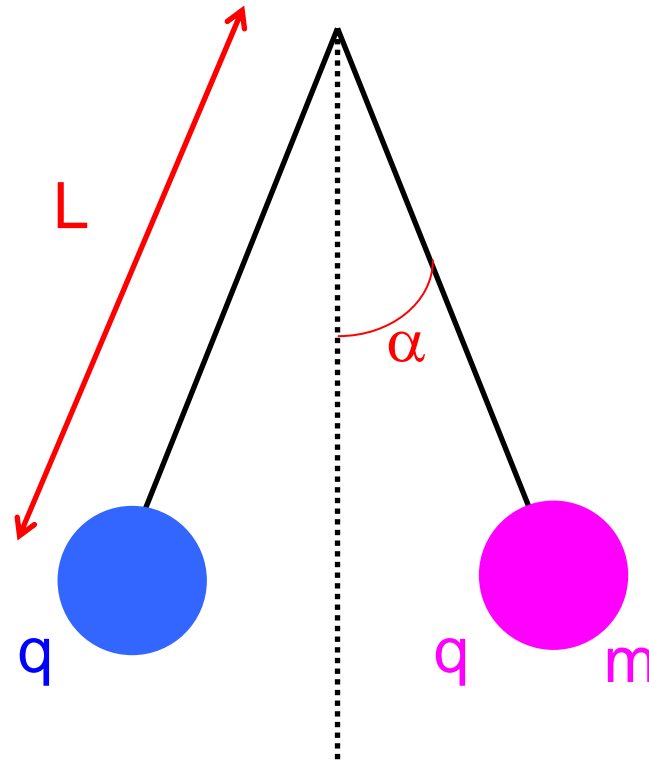
unit vector in direction from q_1 to q_2

- Newton's 3rd law:

$$\vec{F}_{12} = -\vec{F}_{21}$$

Example: Charged Balloons

- Two 1.0 g balloons are each suspended from a 1.0 m long thread. Each thread each makes an angle of 10° with the vertical. What is the charge on each balloon?



Solution

- Draw free body diagram for one of the balloons
- Forces on pink balloon are T , W , F_e

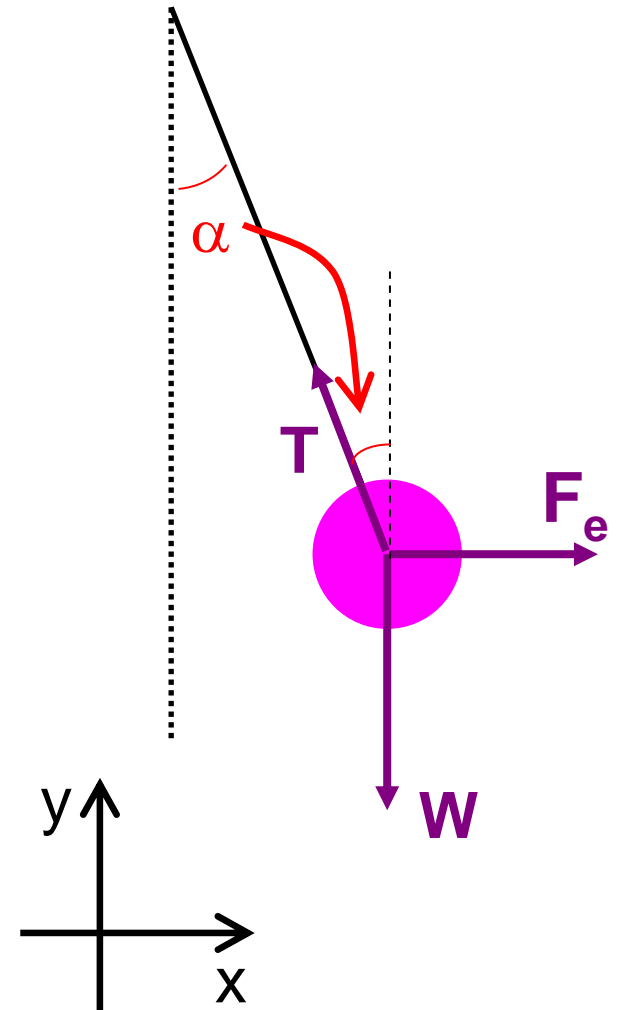
$$\Sigma F_y = T \cos \alpha - W = 0$$

S.E.

$$\longrightarrow T = W / \cos \alpha$$

$$\Sigma F_x = F_e - T \sin \alpha = 0$$

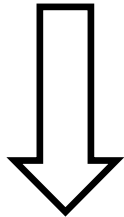
S.E.



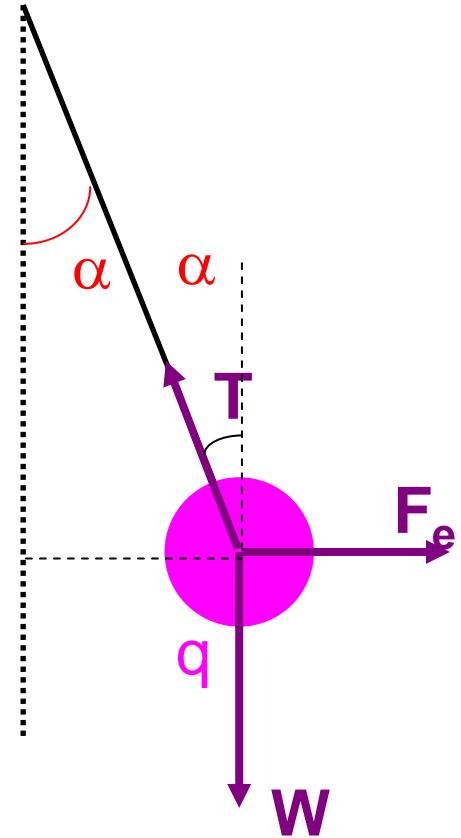
$$\vec{F}_e = k_e \frac{q_1 q_2}{r^2} \hat{r}$$

$$T = \frac{W}{\cos \alpha}$$

$$\Sigma F_x = F_e - T \sin \alpha = 0$$



$$k_e \frac{|q_1||q_2|}{r^2} - \left(\frac{W}{\cos \alpha} \right) \sin \alpha = 0$$



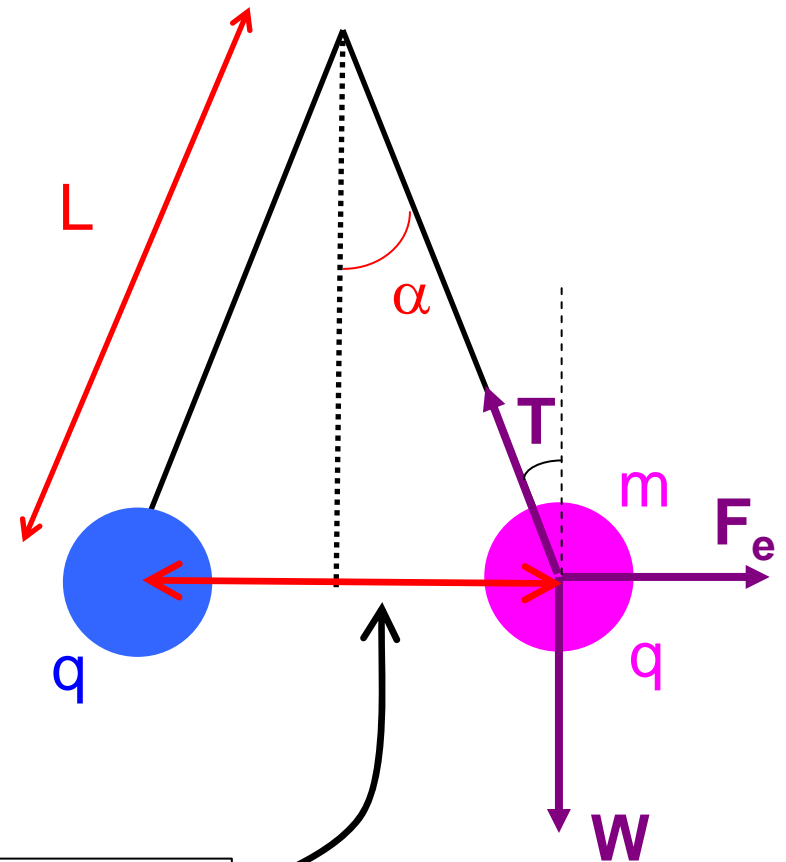
$$k_e \frac{|q_1||q_2|}{r^2} - \frac{W}{\cos \alpha} \sin \alpha = 0$$

$$W = mg \quad ; \quad q_1 = q_2 = q$$

$$k_e \frac{q^2}{(2L \sin \alpha)^2} - mg \tan \alpha = 0$$

$$q = \sqrt{\frac{mg \tan \alpha}{k_e}} (2L \sin \alpha)$$

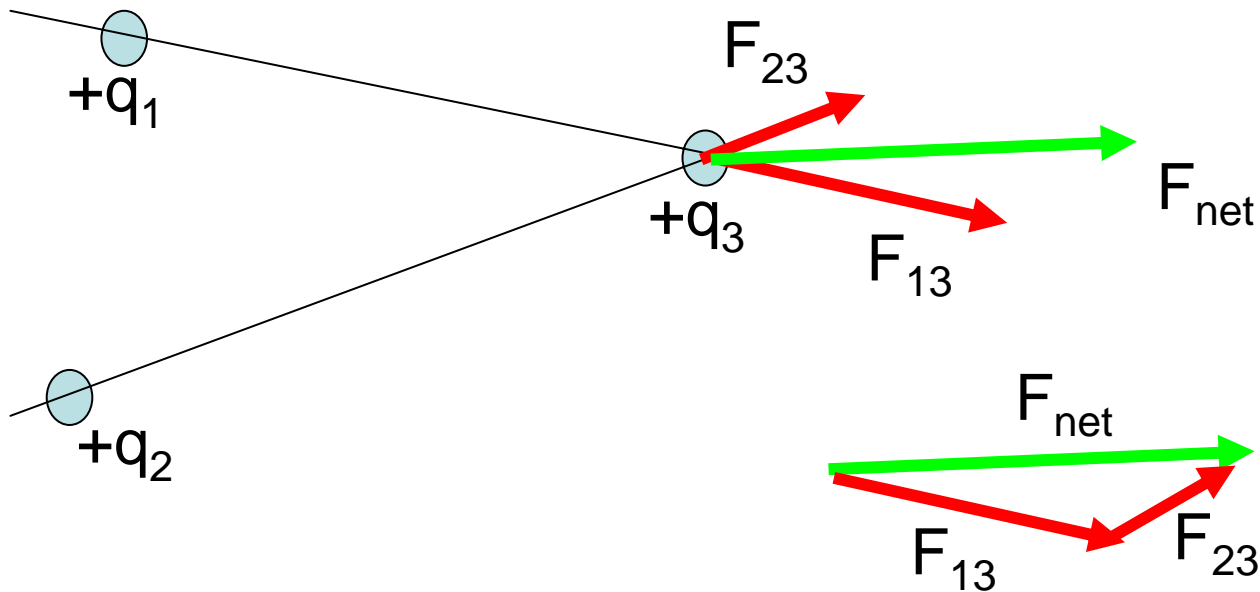
$$= 1.5 \times 10^{-7} \text{ C}$$



$$r = 2 L \sin \alpha$$

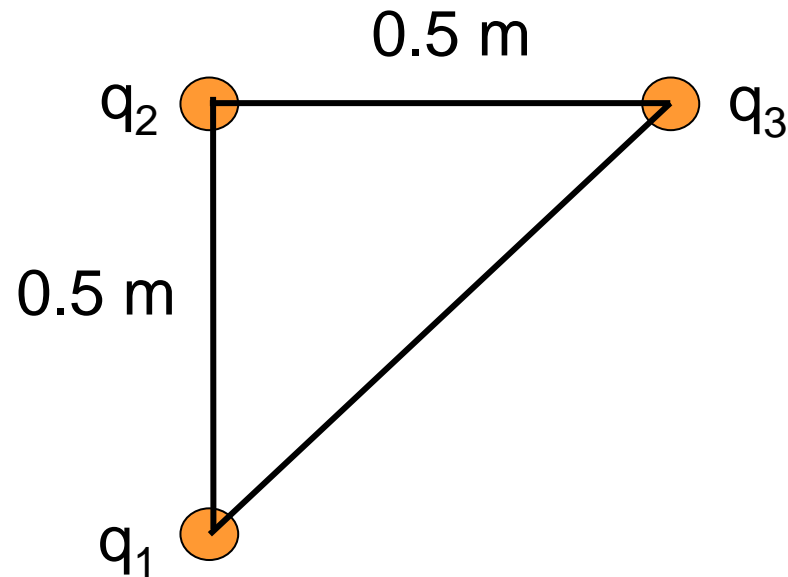
Vector Addition of Electric Forces ("Superposition")

$$\vec{F}_{net} = \vec{F}_{13} + \vec{F}_{23}$$

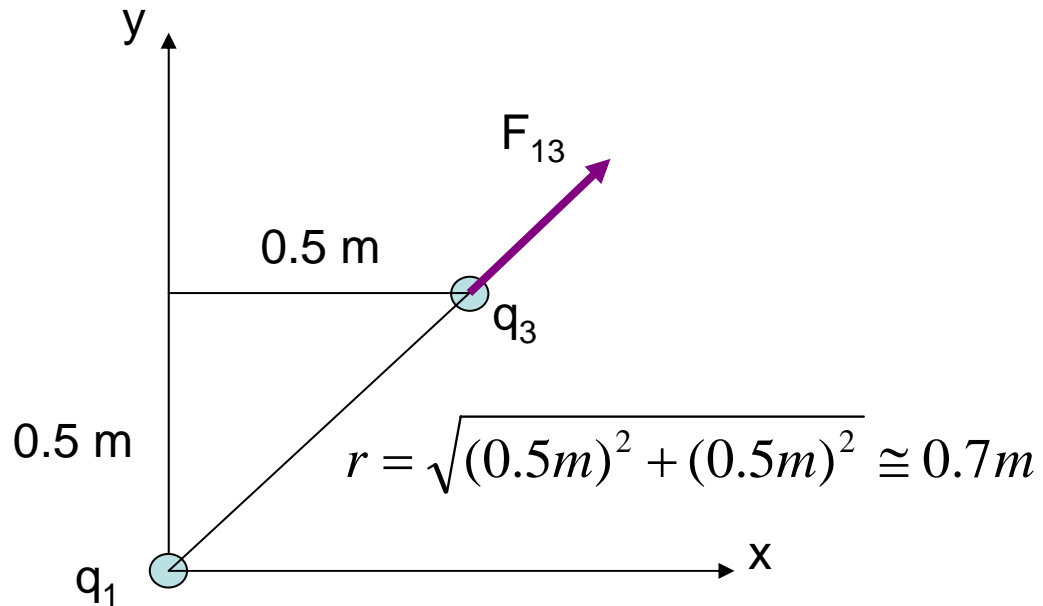


Example: Superposition

- Three charges, each equal to $+2 \mu\text{C}$, are placed at three corners of a square 0.50 m on a side, as shown in the figure below. Find the magnitude and direction of the net force on the charge number 3.

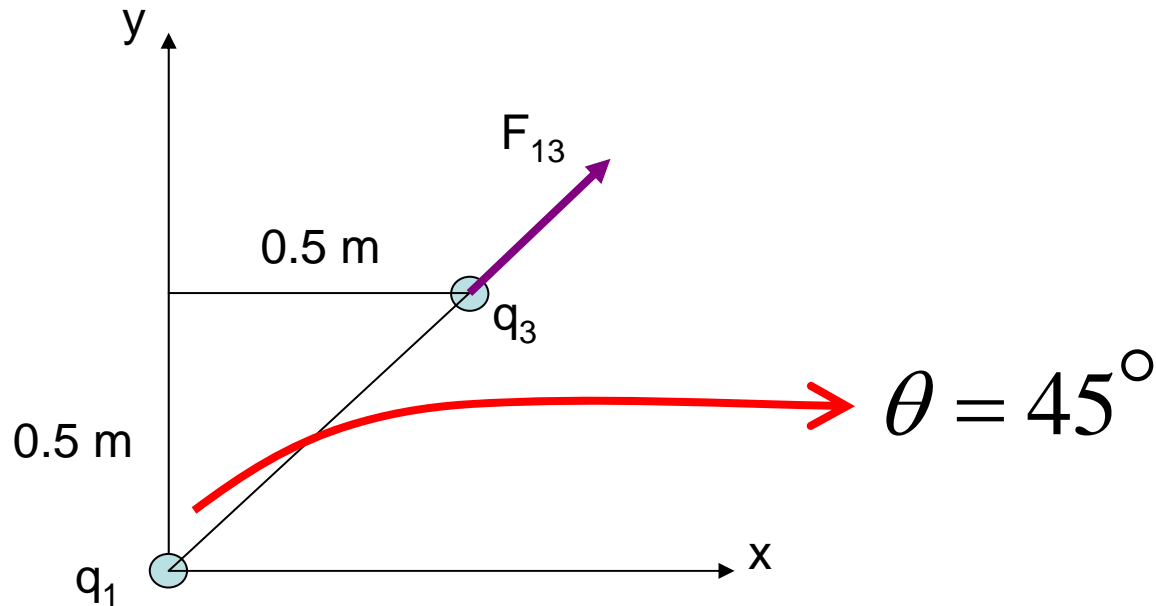


- Step 1: Find F_{13}



$$F_{13} = k_e \frac{q_1 q_3}{r^2} = \frac{(9 \times 10^9 \text{ Nm}^2 / \text{C}^2)(2 \times 10^{-6} \text{ C})^2}{(0.7\text{ m})^2} = 0.07 \text{ N}$$

- Step 2: Find \vec{F}_{13}

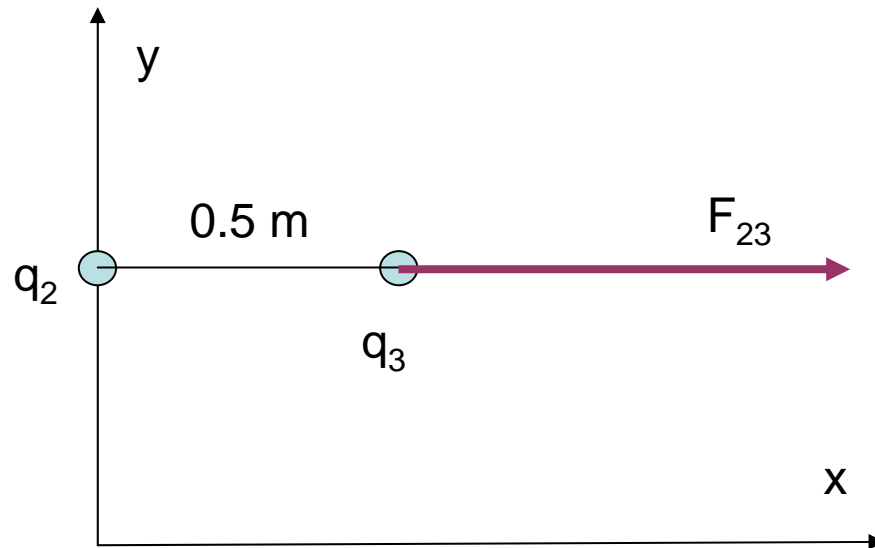


$$\vec{F}_{13} = 0.07 \sin(45^\circ) \hat{i} + 0.07 \cos(45^\circ) \hat{j}$$

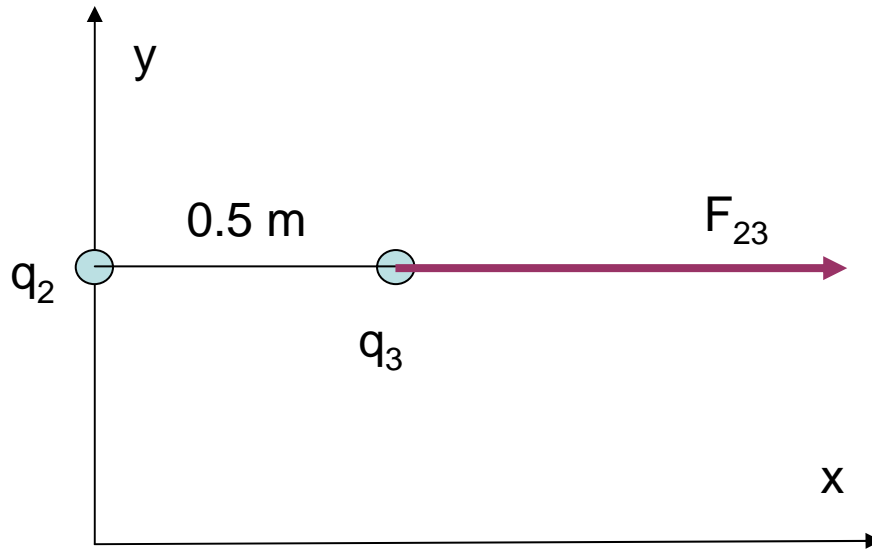
$$\vec{F}_{13} = 0.05 \hat{i} + 0.05 \hat{j} \quad [\text{N}]$$

- Step 3: Find F_{23} :

$$F_{23} = k_e \frac{q_2 q_3}{(0.5m)^2} = 0.14N$$



- Step 4: Find \vec{F}_{23}

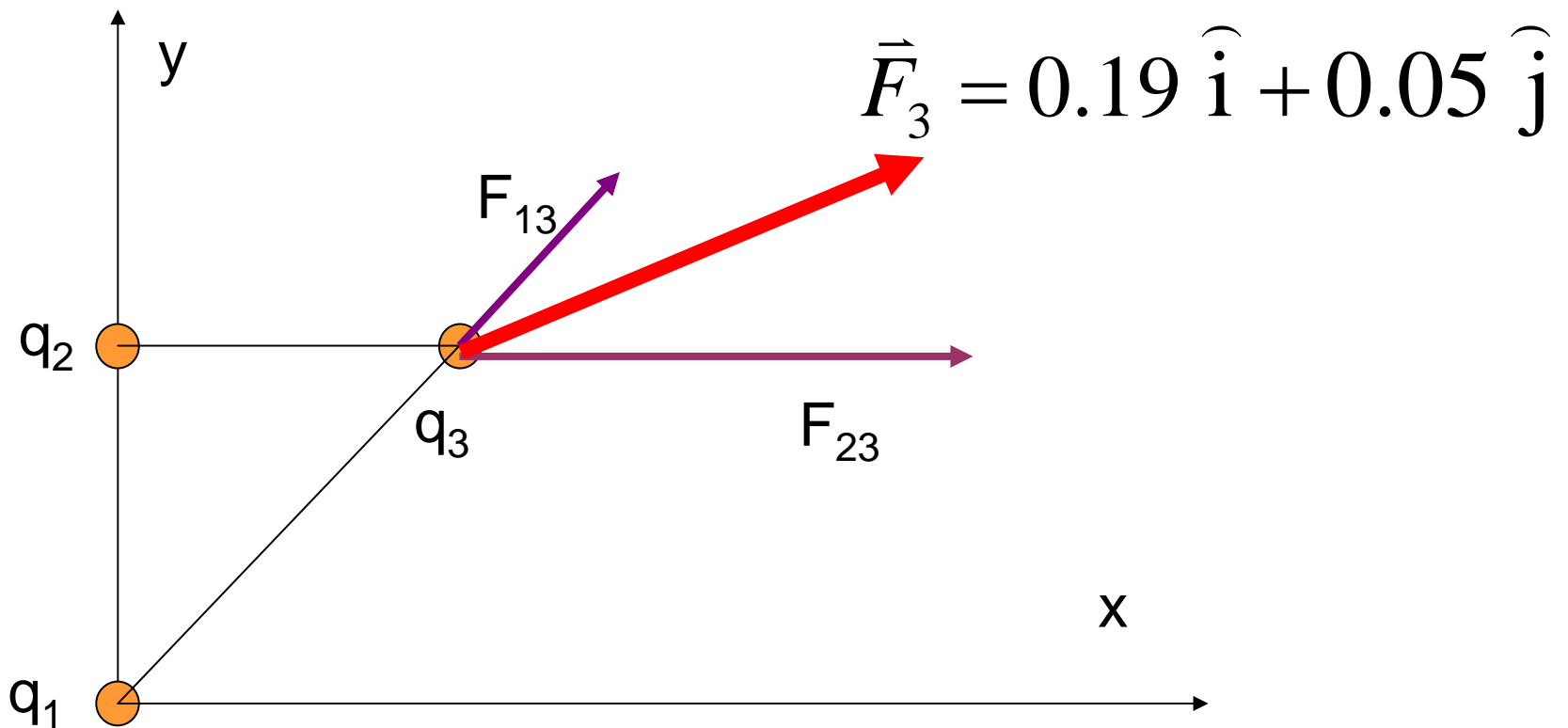


$$\vec{F}_{23} = 0.14 \hat{i} \quad [\text{N}]$$

- Step 5: Add as vectors

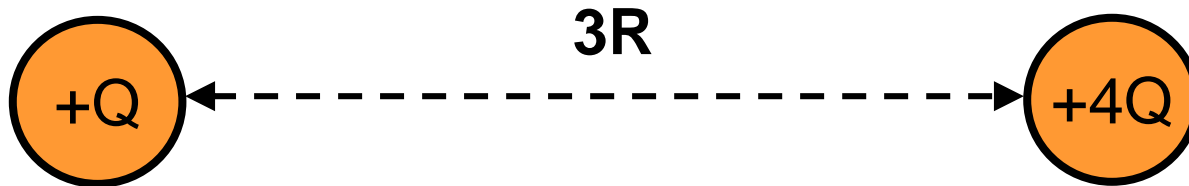
$$\vec{F}_3 = \vec{F}_{13} + \vec{F}_{23}$$

$$\vec{F}_3 = 0.05 \hat{i} + 0.05 \hat{j} + 0.14 \hat{i}$$



Quick Quiz 36

Two balls with charges $+Q$ and $+4Q$ are placed a fixed distance $3R$ apart. Is it possible to place a third charge, Q_0 , on the line between the two charges such that the net force on Q_0 will be zero?



- A. Yes, but only if Q_0 is positive
- B. Yes, but only if Q_0 is negative
- C. Yes, regardless of the sign of Q_0
- D. No

Quick Quiz 37

Which of the arrows best represents the direction of the net force on charge $+Q$ due to the other two charges?

