PHYS 111
1^{ST} semester 1439-1440

Dr. Nadyah Alanazi

Lecture 5

23.3 Coulomb's Law

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

- Double one of the charges
  - force doubles
- Change sign of one of the charges
  - force changes direction
- Change sign of *both* charges
  - force stays the same
- Double the distance between charges
  - force four times weaker
- Double both charges
  - force four times stronger

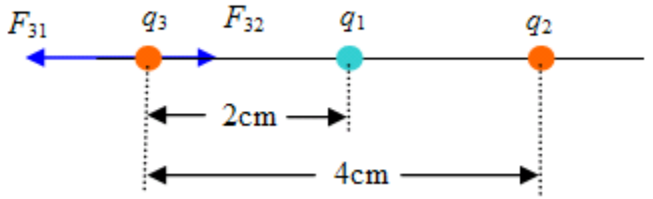
23.3 Coulomb's Law

Quick Quiz 23.4 Object A has a charge of $+2\ \mu C$, and object B has a charge of $+6\ \mu C$. Which statement is true about the electric forces on the objects? (a) $F_{AB} = -3F_{BA}$ (b) $F_{AB} = -F_{BA}$ (c) $3F_{AB} = -F_{BA}$ (d) $F_{AB} = 3F_{BA}$ (e) $F_{AB} = F_{BA}$ (f) $3F_{AB} = F_{BA}$

Quick Quiz 23.5 Object A has a charge of $+2\ \mu C$, and object B has a charge of $+6\ \mu C$. Which statement is true about the electric forces on the objects? (a) $\mathbf{F}_{AB} = -3\mathbf{F}_{BA}$ (b) $\mathbf{F}_{AB} = -\mathbf{F}_{BA}$ (c) $3\mathbf{F}_{AB} = -\mathbf{F}_{BA}$ (d) $\mathbf{F}_{AB} = 3\mathbf{F}_{BA}$ (e) $\mathbf{F}_{AB} = \mathbf{F}_{BA}$ (f) $3\mathbf{F}_{AB} = \mathbf{F}_{BA}$

Example

- Two charges are located on the positive x-axis of a coordinate system, as shown in the figure. Charge q_1=2nC is 2cm from the origin, and charge q_2=-3nC is 4cm from the origin. What is the total force exerted by these two charges on a charge q_3=5nC located at the origin?



$$F_{31} = \frac{(9\times10^{9})(2\times10^{-9})(5\times10^{-9})}{(0.02)^2} = 2.25\times10^{-4}\,N$$

$$F_{32} = \frac{(9\times10^{9})(3\times10^{-9})(5\times10^{-9})}{(0.04)^2} = 0.84\times10^{-4}\,N$$

$$F_3 = F_{32} - F_{31}$$

$$\therefore F_3 = 0.84\times10^{-4} - 2.25\times10^{-4} = -1.41\times10^{-4}\,N$$

Example 23.3 **Where Is the Resultant Force Zero?**

Three point charges lie along the x axis as shown in Figure 23.9. The positive charge $q_1 = 15.0\ \mu C$ is at $x = 2.00$ m, the positive charge $q_2 = 6.00\ \mu C$ is at the origin, and the resultant force acting on q_3 is zero. What is the x coordinate of q_3?

Solution Because q_3 is negative and q_1 and q_2 are positive, the forces $\mathbf{F}_{13}$ and $\mathbf{F}_{23}$ are both attractive, as indicated in Figure 23.9. From Coulomb's law, $\mathbf{F}_{13}$ and $\mathbf{F}_{23}$ have magnitudes

$$F_{13} = k_e \frac{|q_1||q_3|}{(2.00 - x)^2} \qquad F_{23} = k_e \frac{|q_2||q_3|}{x^2}$$

For the resultant force on q_3 to be zero, $\mathbf{F}_{23}$ must be equal in magnitude and opposite in direction to $\mathbf{F}_{13}$. Setting the magnitudes of the two forces equal, we have

$$k_e \frac{|q_2||q_3|}{x^2} = k_e \frac{|q_1||q_3|}{(2.00 - x)^2}$$

Noting that k_e and $|q_3|$ are common to both sides and so can be dropped, we solve for x and find that

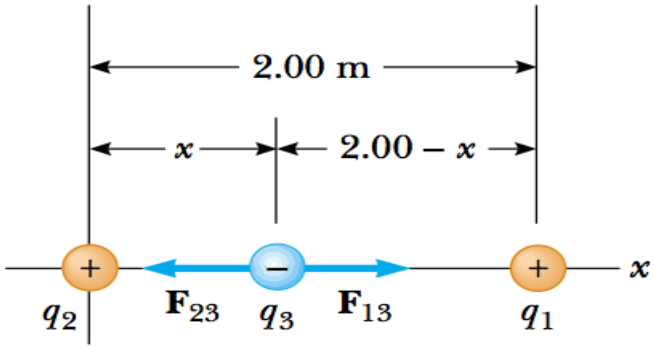
$$(2.00 - x)^2 |q_2| = x^2 |q_1|$$

$$(4.00 - 4.00x + x^2)(6.00 \times 10^{-6}\ \text{C}) = x^2(15.0 \times 10^{-6}\ \text{C})$$

This can be reduced to the following quadratic equation:

$$3.00x^2 + 8.00x - 8.00 = 0$$

Solving this quadratic equation for x, we find that the positive root is $x =$ 0.775 m.



23.4 The Electric Field

- $$\mathbf{E} = k_e \frac{q}{r^2} \hat{\mathbf{r}}$$

Quick Quiz 23.6 A test charge of $+3\ \mu C$ is at a point P where an external electric field is directed to the right and has a magnitude of 4×10^6 N/C. If the test charge is replaced with another test charge of $-3\ \mu C$, the external electric field at P (a) is unaffected (b) reverses direction (c) changes in a way that cannot be determined

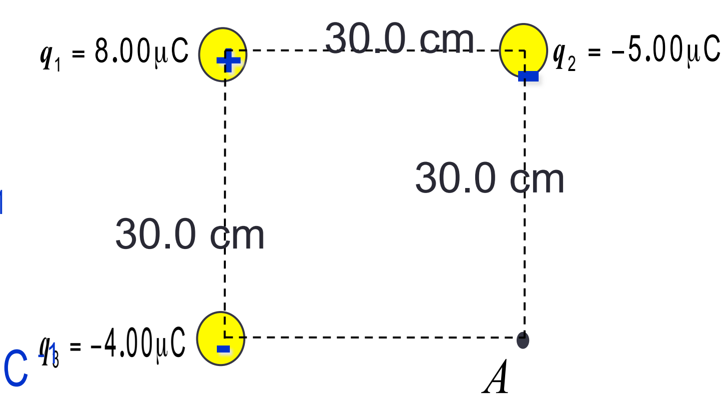
Example

- Three charges are placed on three corners of a square, as shown in the figure. Each side of the square is 30.0 cm. Calculate the electric field strength at point A. What would be the force on a 6.00 μC charge placed at the point A?

$$E_{A1} = \frac{kq_1}{r_1^2} = \frac{(9.0\times10^9)(8.00\times10^{-6})}{(42.4\times10^{-2})^2} = 4.00\times10^5 \text{ N C}^{-1}$$

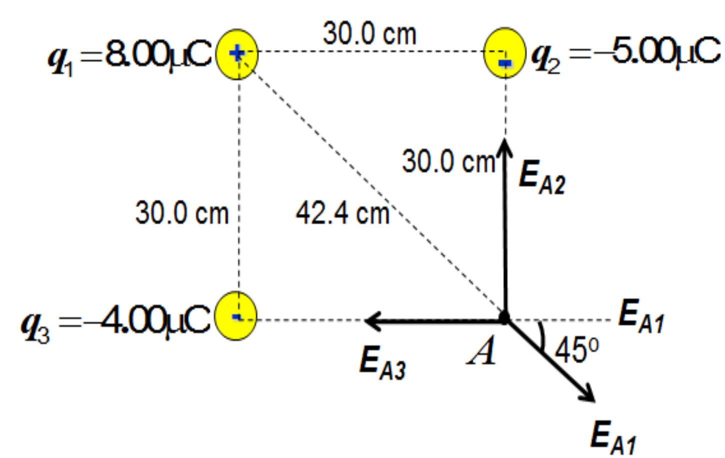
$$E_{A2} = \frac{kq_2}{r_2^2} = \frac{(9.0\times10^9)(5.00\times10^{-6})}{(30.0\times10^{-2})^2} = 5.00\times10^5 \text{ N C}^{-1}$$

$$E_{A3} = \frac{kq_3}{r_3^2} = \frac{(9.0\times10^9)(4.00\times10^{-6})}{(30.0\times10^{-2})^2} = 4.00\times10^5 \text{ N C}^{-1}$$



$$\sum E_{AX} = E_{A1}\cos 45^o - E_{A3}$$
$$= -1.17\times10^5 \text{N/C}$$

$$\sum E_{AY} = E_{A2} - E_{A1}\sin 45^o$$
$$= 2.17\times10^5 \text{N/C}$$



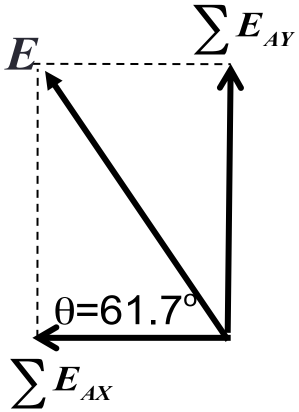
Example

- $$E = \sqrt{\sum E_{AX}{}^2 + \sum E_{AY}{}^2}$$

$$E = 2.46 \times 10^5 \text{ N/C}$$

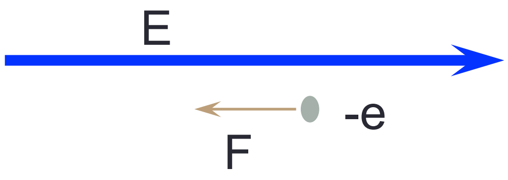
$$\tan\theta = \frac{\sum E_{AY}}{\sum E_{AX}}$$

$$\theta = 61.7°$$



23.7 Motion of Charged Particles in a Uniform Electric Field

- **Example:** Determine the final velocity and kinetic energy of an electron released from rest in the presence of a uniform electric field of 300 N/C in the x direction after a period of 0.5 ms.



$$\vec{F} = q\vec{E} = -eE\hat{i}$$

$$\vec{F} = -\left(1.60\times10^{-19}C\right)\left(300\frac{N}{C}\right)\hat{i}$$

$$\vec{F} = -\left(4.80\times10^{-17}N\right)\hat{i}$$

$$\vec{a} = \frac{\vec{F}}{m} = \frac{-\left(4.80\times10^{-17}N\right)\hat{i}}{9.11\times10^{-31}kg} = -\left(5.3\times10^{+13}\frac{m}{s^2}\right)\hat{i}$$

$$\vec{v} = \vec{v}_o + \vec{a}t$$

$$\vec{v} = 0 - \left(5.3\times10^{+13}\frac{m}{s^2}\hat{i}\right)\left(0.5\times10^{-3}s\right)$$

$$\boxed{\vec{v} = -2.6\times10^{10}\frac{m}{s}\hat{i}}$$

$$K = \frac{1}{2}mv^2 \quad K = \frac{1}{2}\left(9.11\times10^{-31}kg\right)\left(-2.6\times10^{10}\frac{m}{s}\right)^2$$

$$\boxed{K = 3.16\times10^{-10}J}$$