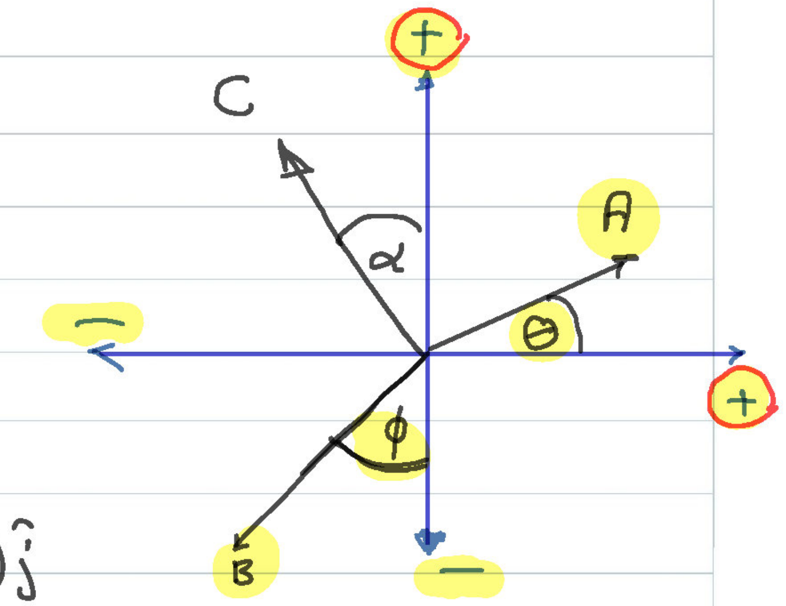
Review :-

Components of Vectors

$$A_x = A\cos\theta$$

$$A_y = A\sin\theta$$

$$\vec{A} = (A_x)\hat{i} + (A_y)\hat{j}$$



$$B_x = -B\sin\phi \qquad C_x = -C\sin\alpha$$

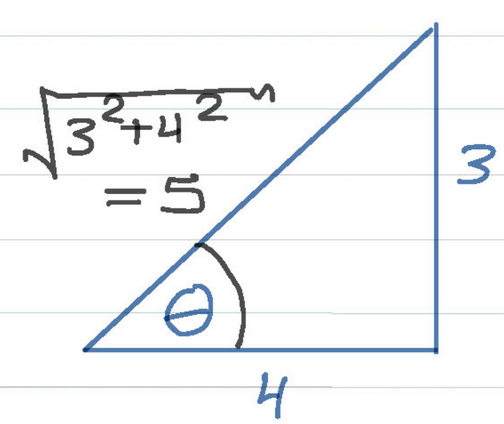
$$B_y = -B\cos\phi \qquad C_y = +C\cos\alpha$$

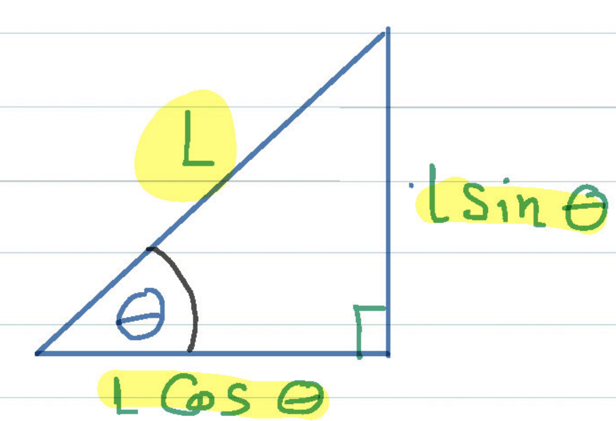
$$\vec{B} = (B_x)\hat{i} + (B_y)\hat{j}$$

$$\sin\theta = 3/5$$

$$\cos\theta = 4/5$$

$$\tan\theta = 3/4$$





* Resultant (SUM) OF Vectors :-

$$\vec{C} = \vec{A} + \vec{B}$$

1. Resolve

2. $\vec{C} = \vec{A} + \vec{B}$

$$= \underbrace{(A_x + B_x)}_{C_x}\hat{i} + \underbrace{(A_y + B_y)}_{C_y}\hat{j}$$

3. $C = \sqrt{C_x^2 + C_y^2}$

4. $\theta = \tan^{-1} C_y/C_x$

Motion with Constant Acceleration

$$a = dv/dt$$

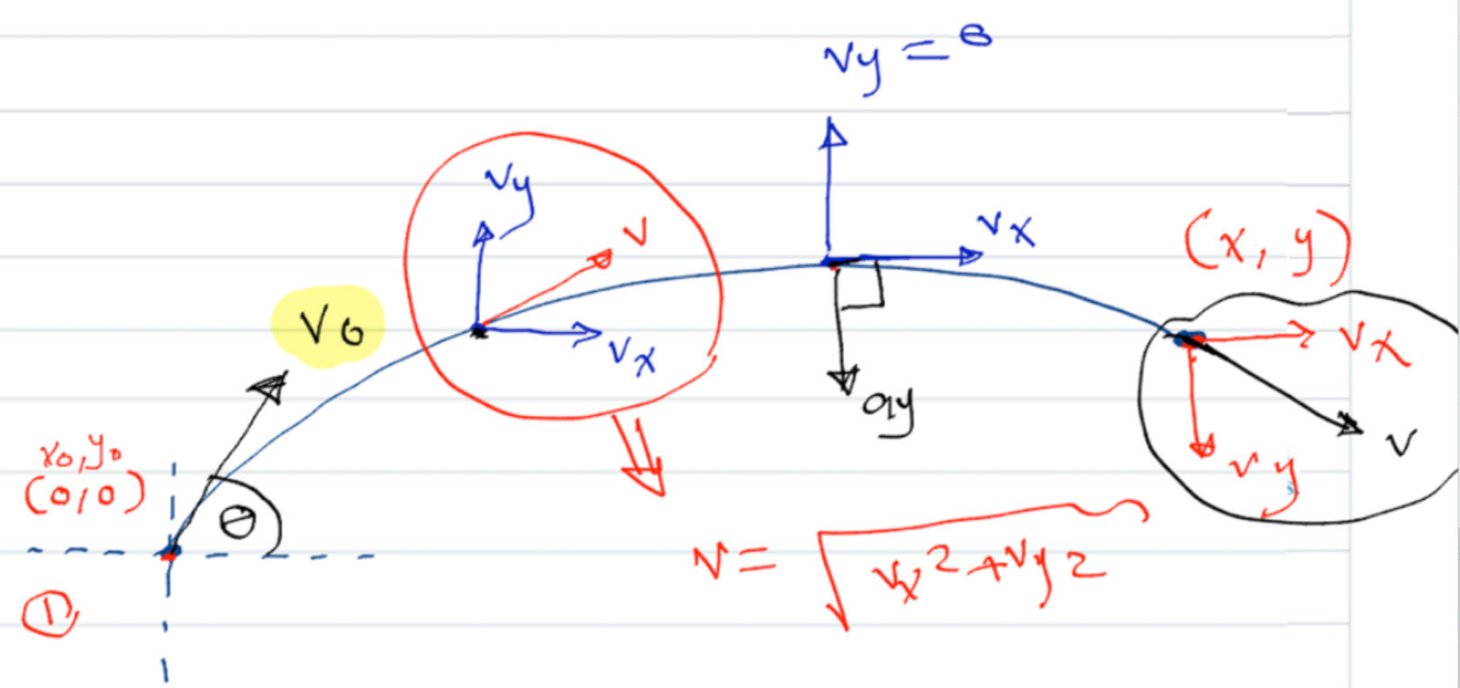
$$v = v_0 + at \quad (\text{No} - x)$$

$$x = x_0 + v_0 t + \tfrac{1}{2}at^2 \quad (\text{No} - v)$$

$$v^2 = v_0^2 + 2a(x - x_0) \quad (\text{No} - t)$$

$$x - x_0 = \left(\frac{v_0 + v}{2}\right)t \quad (\text{No} - a)$$

Projectile Motion



② $V_{ox} = V_o \cos\theta$

$V_{oy} = V_o \sin\theta$

③ Horizontal Motion (x-axis)

→ $a_x = 0$

→ $V_x = V_{ox} =$ Constant

→ $x = x_0 + V_x t$

→ Uniform Motion

④ Vertical Motion :- (y-dir)

→ $a_y = -9.8 \ m/s^2$

→ V_y is Changing

$V_y = V_{oy} + a_y t$

$y = y_0 + V_{oy} t + \frac{1}{2} a_y t^2$

$V_y^2 = V_{oy}^2 + 2a_y (y - y_0)$

$y - y_0 = \left(\frac{V_{oy} + V_y}{2}\right) t$

Newton's First Law

@ Equilibrium
@ rest
@ Moving @ Constant v

$\Sigma F = 0$

1) Resolve

2) $\Sigma F_x = 0 \ \overset{+}{\rightarrow}$ $\quad \Sigma F_y = 0 \ \uparrow +$

Newton's Second Law

$\Sigma F = M a$

$\Rightarrow \Sigma F_x = M a_x \ \overset{+}{\rightarrow}$

$\Rightarrow \Sigma F_y = M a_y \ \uparrow +$

Conservation of Mechanical Energy

→ KE
→ PE

⇓

in Case of Conservation Forces

1) Gravity $\quad U_g = Mgy$

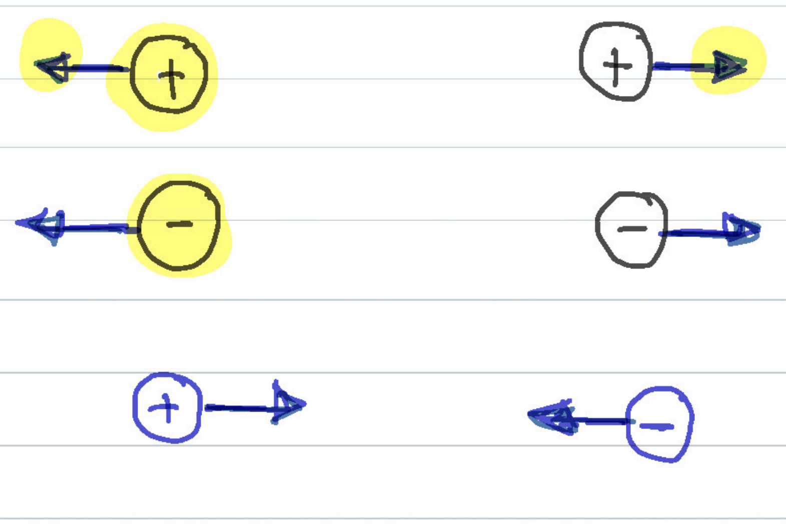
2) Spring $\quad U_e = \frac{1}{2} k x^2$

$K_1 + U_1 = K_2 + U_2$

$\frac{1}{2} M V_1^2 + Mgy_1 = \frac{1}{2} M V_2^2 + Mgy_2$

Chapter 22: Electric Fields

Electric charge :-



repel each other

attract each other

* Charge oF the electron and Proton are equal in magnitude

$|e| = 1.6 * 10^{-19}$ C

Coulomb's Law

to get electric Force between Point charges

Magnitude :-

$$F = \frac{K |q_1| |q_2|}{r^2}$$

$K \Rightarrow$ Coulomb Constant

$$K = \frac{1}{4 \pi \varepsilon_0} = 9 * 10^9 \ N \cdot m^2 / C^2$$

$\varepsilon_0 \Rightarrow$ Permittivity oF Free SPace

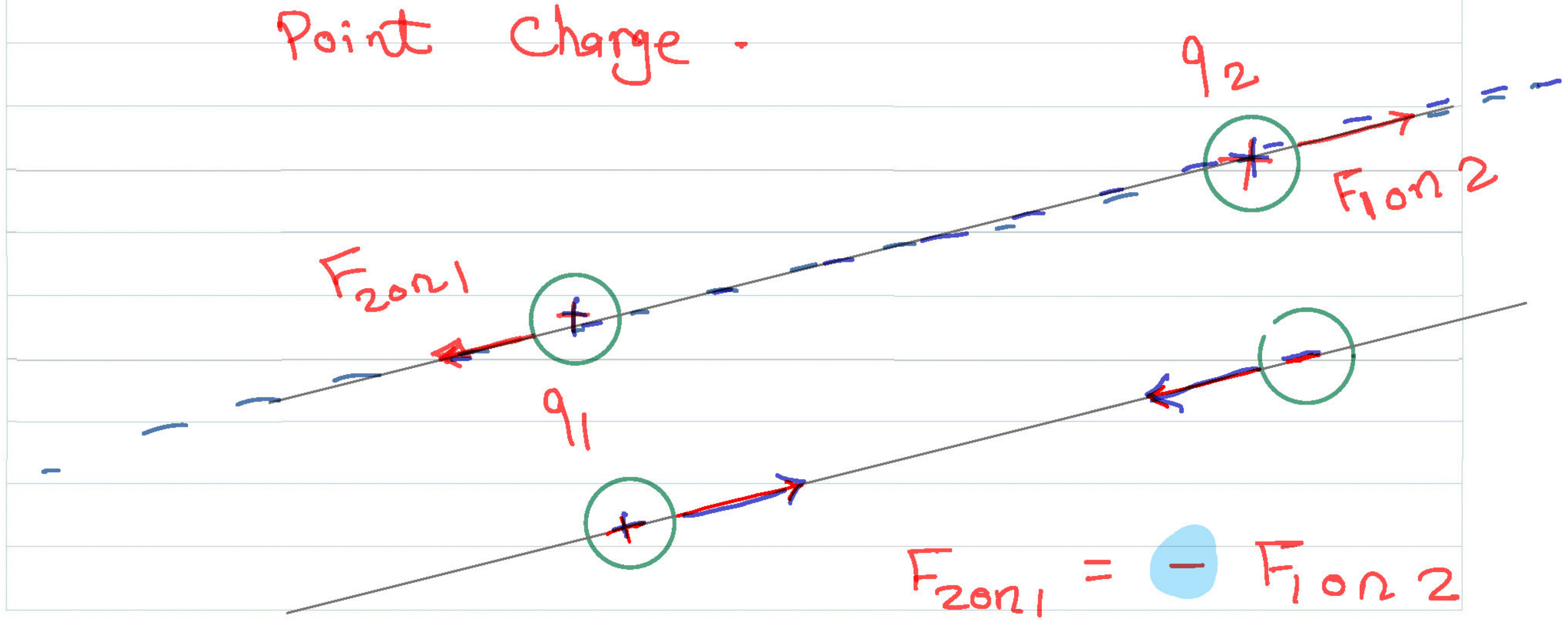
$$= 8.85 * 10^{-12} \ C^2 / N \cdot m^2$$

q_1, q_2 } two point charge (C)

r } distance (m)

Direction :-

Directed along line between two Point Charge.



$F_{2on1} = - F_{1on2}$

gravitational Force :-

$$F_g = \frac{G\, M_1\, M_2}{r^2}$$

$G \rightarrow$ gravitational Constant

$$= 6.67 * 10^{-11} \; N \cdot m^2/kg^2$$

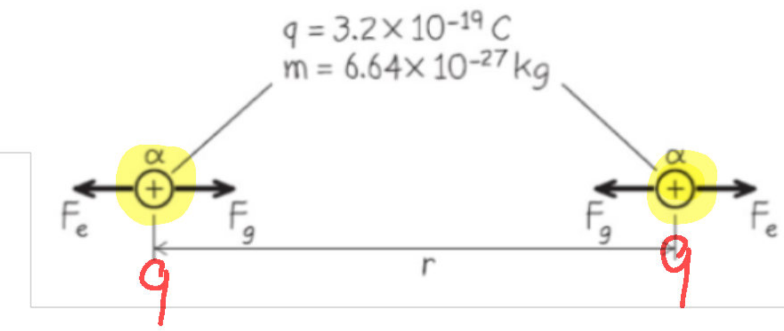
$\left.\begin{matrix} M_1 \\ M_2 \end{matrix}\right\}$ Mass of two charges (kg)

$r \;\}$ Distance (m)

Example 21.1 **Electric force versus gravitational force**

An α particle (the nucleus of a helium atom) has mass $m = 6.64 \times 10^{-27}$ kg and charge $q = +2e = 3.2 \times 10^{-19}$ C. Compare the magnitude of the electric repulsion between two α ("alpha") particles with that of the gravitational attraction between them.

SOLUTION



$$M = 6.64 * 10^{-27} \; kg$$

$$q = 3.2 * 10^{-19}$$

$$F_e = \frac{K q^2}{r^2}$$

$$F_g = \frac{G M^2}{r^2}$$

$$\frac{F_e}{F_g} = \frac{K q^2 \cancel{r^2}}{\cancel{r^2} \cdot G M^2}$$

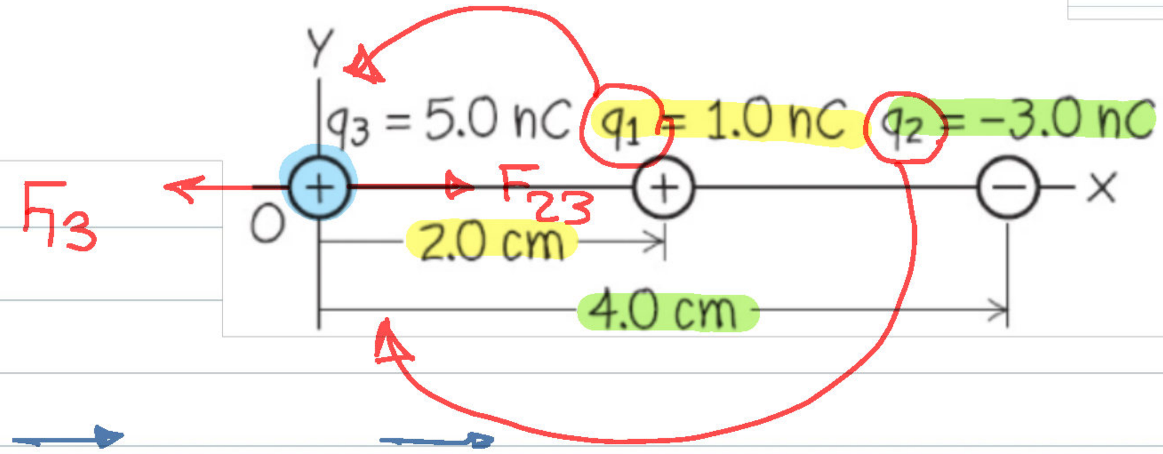
$$= \frac{9 * 10^{9} * (3.2 * 10^{-19})^2}{6.67 * 10^{-11} * (6.64 * 10^{-27})^2}$$

$$= 3.1 * 10^{35}$$

Example 21.3 **Vector addition of electric forces on a line**

Two point charges are located on the x-axis of a coordinate system: $q_1 = 1.0\ \text{nC}$ is at $x = +2.0\ \text{cm}$, and $q_2 = -3.0\ \text{nC}$ is at $x = +4.0\ \text{cm}$. What is the total electric force exerted by q_1 and q_2 on a charge $q_3 = 5.0\ \text{nC}$ at $x = 0$?

SOLUTION



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

$$\vec{F}_{13} = \frac{k\,|q_1|\,|q_3|}{r_{13}^2} = \frac{9*10^9 * 1*10^{-9} * 5*10^{-9}}{(0.02)^2}$$

$$= 1.125 * 10^{-4}\ N$$

$$F_{23} = \frac{k\,|q_2|\,|q_3|}{r_{23}^2}$$

$$= \frac{9*10^9 * 3*10^{-9} * 5 * 10^{-9}}{(0.04)^2}$$

$$= 8.44 * 10^{-5}\ N$$

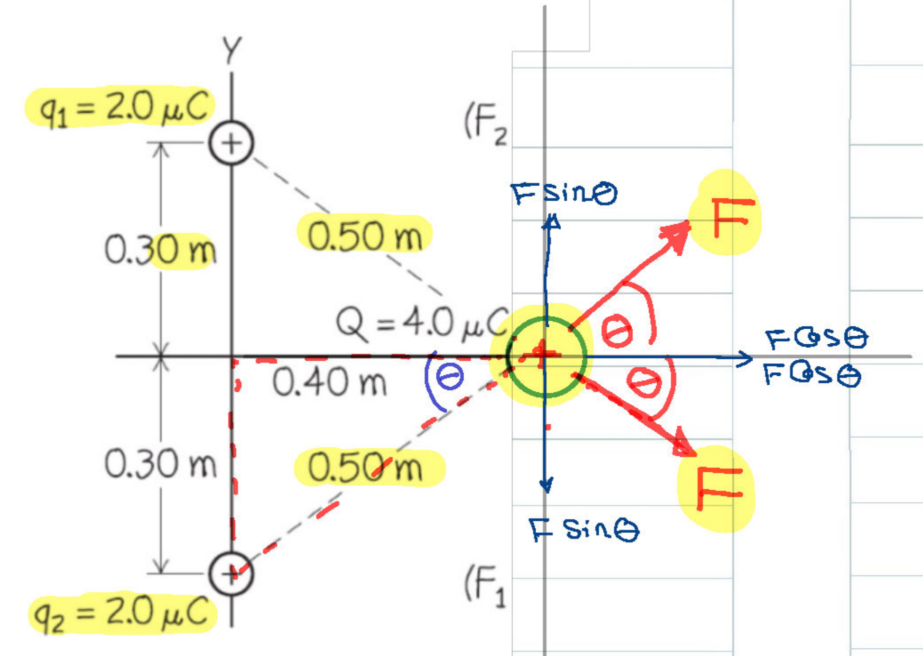
$$\vec{F}_3 = -(1.125 * 10^{-4})\,\hat{i} + (8.44 * 10^{-5})\,\hat{i}$$

$$= (-2.8 * 10^{-5}\ N)\ \hat{i}$$

Example 21.4 **Vector addition of electric forces in a plane**

Two equal positive charges $q_1 = q_2 = 2.0\ \mu C$ are located at $x = 0$, $y = 0.30$ m and $x = 0$, $y = -0.30$ m, respectively. What are the magnitude and direction of the total electric force that q_1 and q_2 exert on a third charge $Q = 4.0\ \mu C$ at $x = 0.40$ m, $y = 0$?

SOLUTION



As $q_1 = q_2$

$r_1 = r_2$

$F_{1 \text{ on } \phi} = F_{2 \text{ on } \phi} = F$

$$F = \frac{K|q_1||\phi|}{r^2}$$

$$= \frac{9*10^9 * 2*10^{-6} * 4*10^{-6}}{(0.5)^2}$$

$= 0.29$ N

$\sin\theta = 0.3/0.5$

$\cos\theta = 0.4/0.5$

to get total electric force :-

1) Resolution

$$\vec{F} = (2F\cos\theta)\hat{i} + (F\sin\theta - \cancel{F\sin\theta})\hat{j}$$

$= 0$

$$\vec{F} = (2 * 0.29 * 0.4/0.5)\hat{i}$$

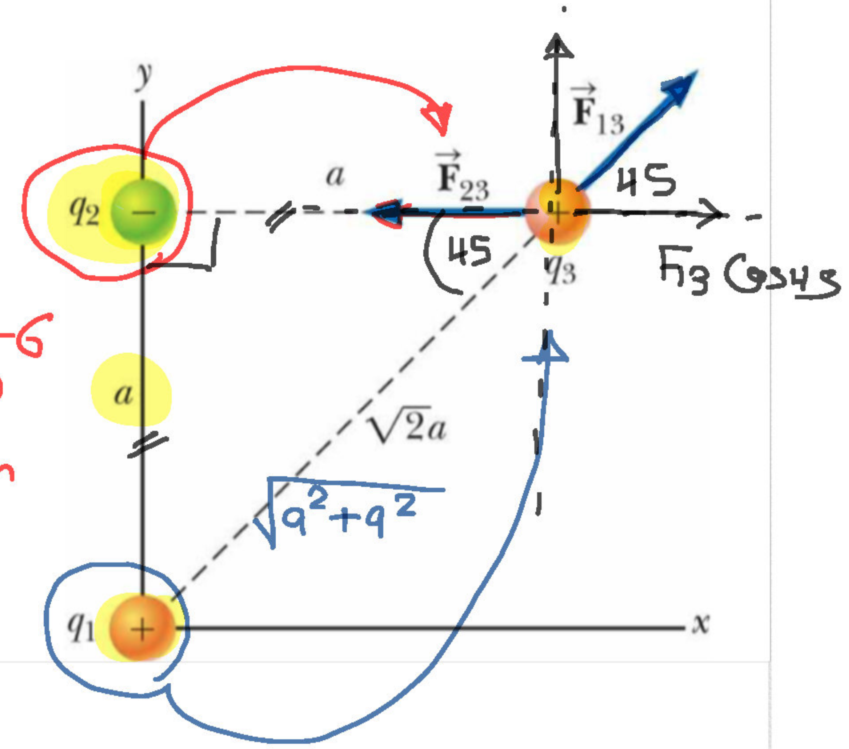
$$= 0.46\ \hat{i}$$

* Magnitude of F = 0.46

directed along + x-axis

Example 22.2:
Find the Resultant Force

Consider three point charges located at the corners of a right triangle as shown in the figure, where $q_1 = q_3 =$ 5.00 μC, $q_2 = -2.00$ μC, and $a = 0.100$ m. Find the resultant force exerted on q_3.



$$F_{23} = \frac{k|q_2||q_3|}{r_{23}^2}$$

$$= \frac{9*10^9 * 2*10^{-6} * 5*10^{-6}}{(0.1)^2}$$

$$= 8.99 \text{ N}$$

$$F_{13} = \frac{k|q_1||q_3|}{r_{13}^2}$$

$$= \frac{9*10^9 * 5*10^{-6} * 5*10^{-6}}{(\sqrt{2} * 0.1)^2}$$

$$= 11.2 \text{ N}$$

$$F_{13x} = 11.2 \cos 45 = 7.94 \text{ N}$$

$$F_{13y} = 11.2 \sin 45 = 7.94 \text{ N}$$

$$\vec{F}_{13} = (7.94)\hat{i} + (7.94)\hat{j}$$

$$\vec{F}_{23} = -(8.99)\hat{i} + (0)\hat{j}$$

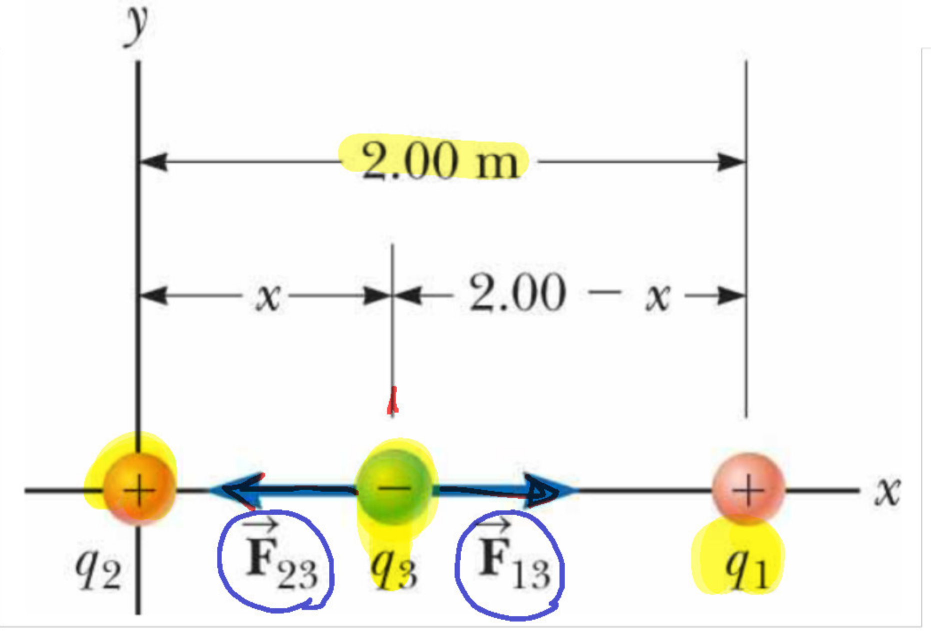
$$\vec{F}_3 = \vec{F}_{13} + \vec{F}_{23}$$

$$= (7.94 - 8.99)\hat{i} + (7.94 + 0)\hat{j}$$

$$\vec{F}_3 = -(1.04)\hat{i} + (7.94)\hat{j}$$

Example 22.3: Where Is the Net Force Zero?

Three point charges lie along the x axis as shown in the figure. 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 net force acting on q_3 is zero. What is the x coordinate of q_3?



$$\vec{\Sigma F_3} = \vec{F}_{23} + \vec{F}_{13} = \text{zero}$$

$$= -\left(\frac{k|q_2||q_3|}{r_{23}^2}\right)\hat{i} + \left(\frac{k|q_1||q_3|}{r_{13}^2}\right)\hat{i} = 0$$

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

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

$$2-x\sqrt{|q_2|} = x\sqrt{|q_1|}$$

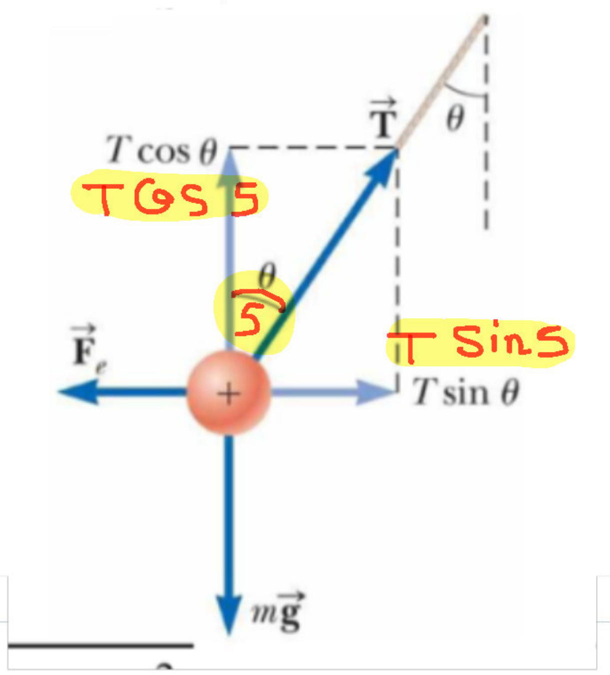
$$x = \frac{2\sqrt{|q_2|}}{\sqrt{|q_2|}+\sqrt{|q_1|}}$$

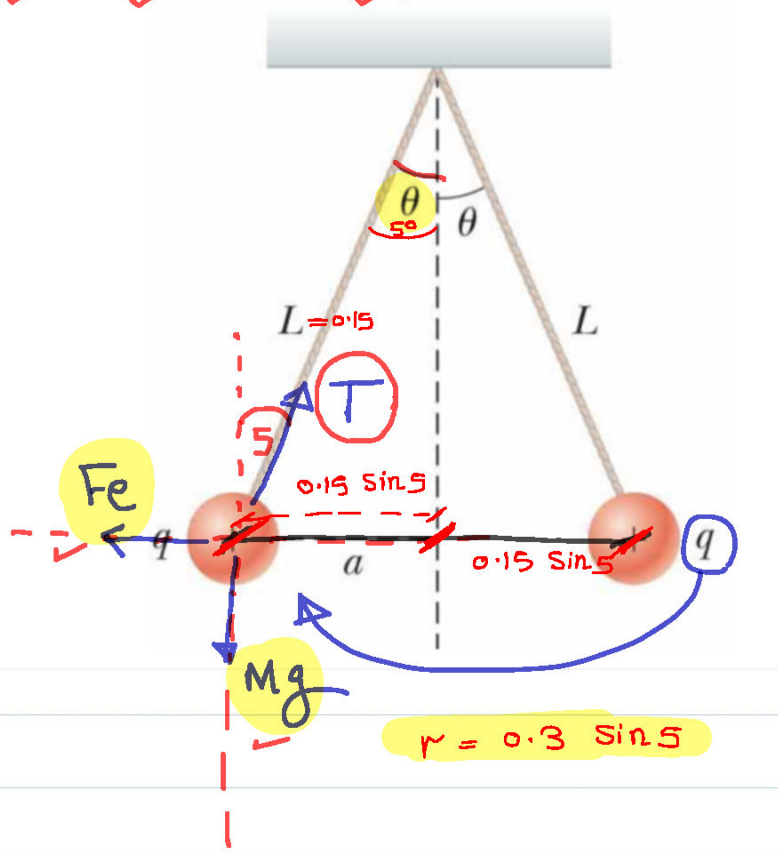
$$= \frac{2 * \sqrt{6 * 10^{-6}}}{\sqrt{6 * 10^{-6}} + \sqrt{15 * 10^{-6}}}$$

$$x = 0.775\ \text{M}$$

Example 22.4:
Find the Charge on the Spheres

Two identical small charged spheres, each having a mass of 3.00×10^{-2} kg, hang in equilibrium as shown in the figure. The length L of each string is 0.150 m, and the angle θ is 5.00°. Find the magnitude of the charge on each sphere.





$\Sigma F_x = 0 \quad \xrightarrow{+}$

$T \sin 5 - F_e = 0 \qquad T = F_e / \sin 5 \Rightarrow (1)$

$\Sigma F_y = 0 \quad \uparrow +$

$T \cos 5 - Mg = 0$

Eq$^{\text{4}}$ (1)

$F_e \dfrac{\cos 5}{\sin 5} = Mg \qquad \to \dfrac{1}{\tan 5}$

$F_e = Mg \tan 5$

$= 3 * 10^{-2} * 9.81 \tan 5$

$= 0.026$ N

$F_e = \dfrac{k q^2}{r^2}$

$q = \sqrt{\dfrac{F_e * r^2}{k}} = \sqrt{\dfrac{0.026 * (0.3 \sin 5)^2}{9 * 10^9}}$

$= 4.42 * 10^{-8}$

② Electric Field :- (vector - Quantity)

* Space around charged body

→ Magnitude :-

$$E = \frac{k|q|}{r^2} \qquad (N/C)$$

→ Direction :-

radially outward radially inward

$$\vec{E} = \frac{\vec{F}}{q_0}$$

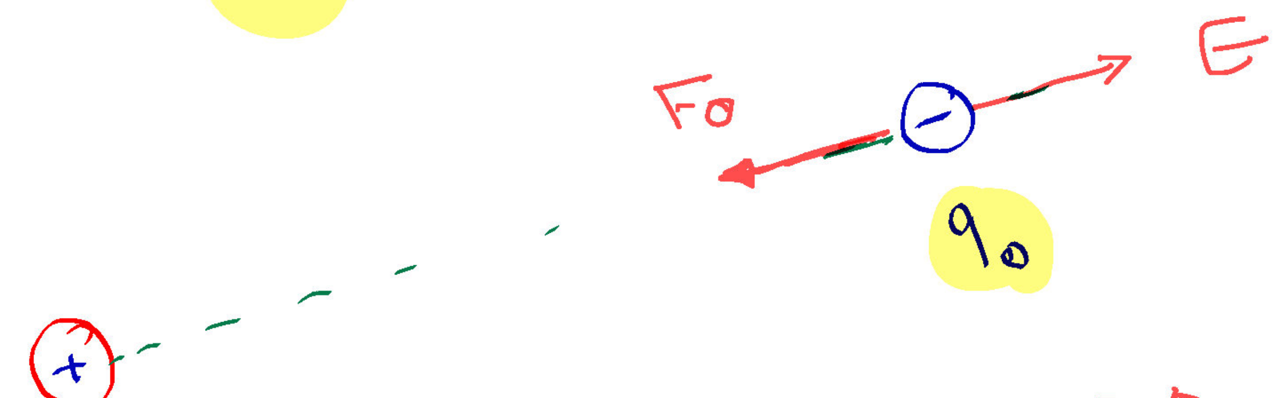
$$F_0 = \frac{k|q||q_0|}{r^2}$$

$$E = \frac{k|q|}{r^2}$$

due to q

$$\vec{F} = q_0 \vec{E}$$

⇒ F_0 on Positive charge q_0 Points in direction of E



q

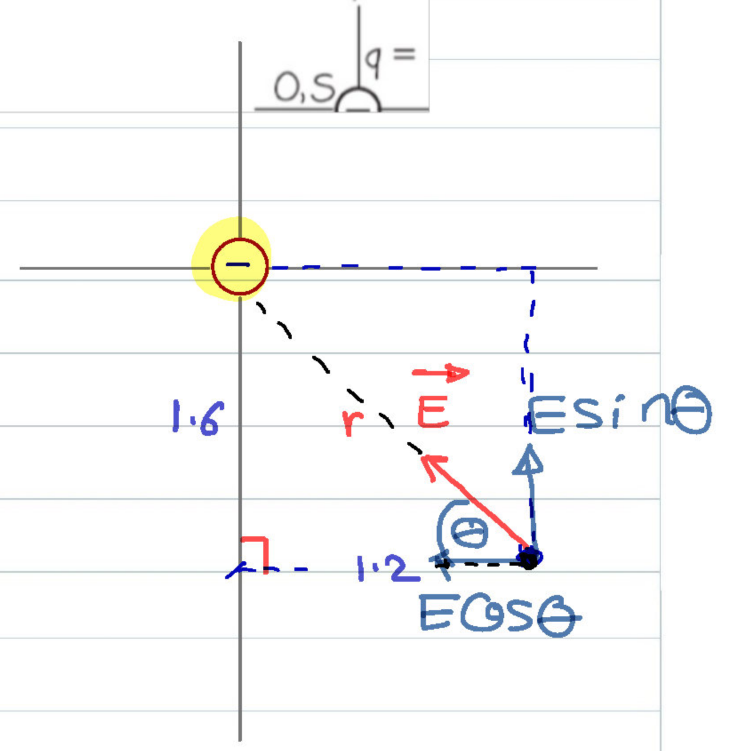
$$\vec{F} = -q_0 \vec{E}$$

⇒ F_0 on Negative charge q_0 Points in opposite direction of E

Example 21.6 **Electric-field vector for a point charge**

A point charge $q = -8.0\ \text{nC}$ is located at the origin. Find the electric-field vector at the field point $x = 1.2$ m, $y = -1.6$ m.

SOLUTION



Magnitude :-

$$E = \frac{k|q|}{r^2}$$

$$= \frac{9*10^{9} * 8*10^{-9}}{(2)^2}$$

$$= 18 \ \text{N/C}$$

$$r = \sqrt{(1.2)^2 + (1.6)^2}$$

$$= 2\ \text{M}$$

$\vec{E}$ in Vector Form :-

$$\sin\theta = \frac{1.6}{2} = 0.8$$

$$\cos\theta = \frac{1.2}{2} = 0.6$$

$$\vec{E} = -(E\cos\theta)\hat{i} + (E\sin\theta)\hat{j}$$

$$= -(18 * 0.6)\hat{i} + (18 * 0.8)\hat{j}$$

$$\vec{E} = -(10.8)\hat{i} + (14.4)\hat{j}$$

Example 22.5:
A Suspended Water Droplet

A water droplet of mass 3.00×10^{-12} kg is located in the air near the ground during a stormy day. An atmospheric electric field of magnitude 6.00×10^3 N/C points vertically downward in the vicinity of the water droplet. The droplet remains suspended at rest in the air. What is the electric charge on the droplet?

$$E = 6 * 10^3 \quad N/C$$

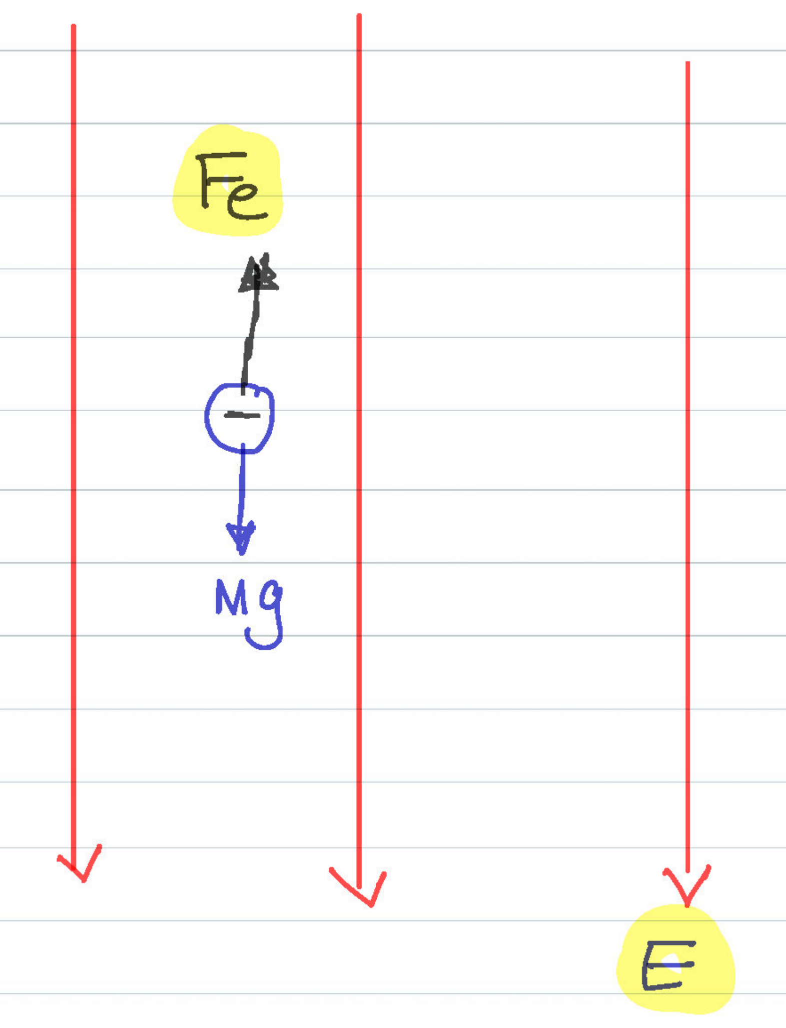
$$\Sigma F_y = 0 \quad \uparrow +$$

$$F_e - F_g = 0 \Rightarrow q(-E) - Mg = 0$$

$$q = \frac{-Mg}{E}$$

$$= \frac{-3 * 10^{-12} * 9.8}{6 * 10^3}$$

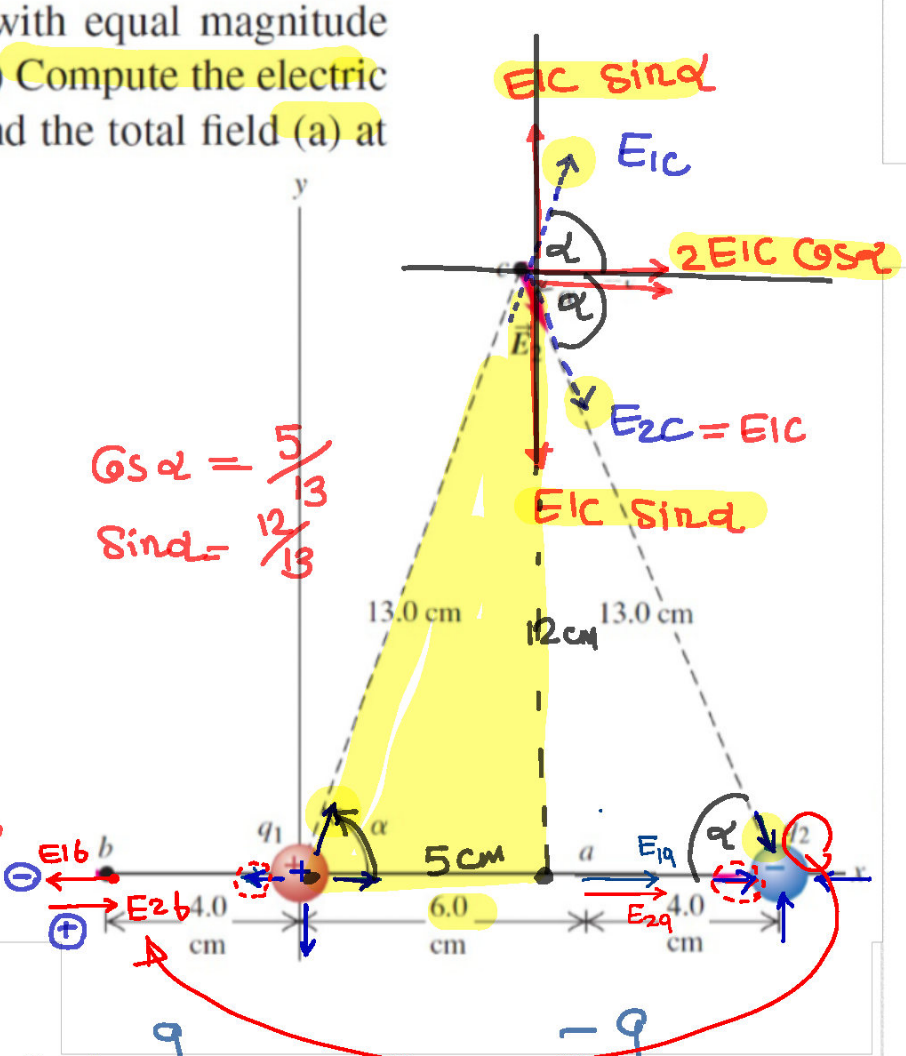
$$= -4.9 * 10^{-15} \quad C$$



Example 21.8 Field of an electric dipole

Point charges $q_1 = +12$ nC and $q_2 = -12$ nC are 0.100 m apart (Fig. 21.22). (Such pairs of point charges with equal magnitude and opposite sign are called *electric dipoles*.) Compute the electric field caused by q_1, the field caused by q_2, and the total field (a) at point a; (b) at point b; and (c) at point c.

SOLUTION



(a)

$$E_{1a} = \frac{k|q_1|}{r_{1a}^2} = \frac{9*10^9 * 12*10^{-9}}{(0.06)^2} = 3*10^4 \ N/C$$

$$E_{2a} = \frac{k|q_2|}{r_{2a}^2} = \frac{9*10^9 * 12*10^{-9}}{(0.04)^2} = 6.8*10^4 \ N/C$$

$$\vec{E}_a = \vec{E}_{1a} + \vec{E}_{2a} = (3*10^4)\hat{i} + (6.8*10^4)\hat{i} = (9.8*10^4)\hat{i}$$

(b)

$$E_{1b} = \frac{k|q_1|}{r_{1b}^2} = \frac{9*10^9 * 12*10^{-9}}{(0.04)^2}$$

$$= 6.8*10^4 \ N/C$$

$$E_{2b} = \frac{k|q_2|}{r_{2b}^2} = \frac{9*10^9 * 12*10^{-9}}{(0.14)^2}$$

$$= 0.55*10^4 \ N/C$$

$$E_b = -(6.8*10^4)\hat{i} + (0.55*10^4)\hat{i}$$

$$= (-6.2*10^4)\hat{i} \quad N/C$$

(c) As $q_1 = q_2$, $r_{1c} = r_{2c}$ } $E_{1c} = E_{2c}$

$$E_{1c} = \frac{k|q_1|}{r_{1c}^2} = \frac{9*10^9 * 12*10^{-9}}{(0.13)^2}$$

$$= 6.39*10^3 \ N/C$$

$$\vec{E}_c = \vec{E}_{1c} + \vec{E}_{2c}$$

$$= (2E_{1c}\cos\alpha)\hat{i} + (\underbrace{\cancel{E_{1c}\sin\alpha - E_{1c}\sin\alpha}}_{=0})\hat{j}$$

$$= (2*6.39*10^3*5/13)\hat{i}$$

$$\vec{E}_c = (4.9*10^3)\hat{i}$$

Review

Coulomb's Law

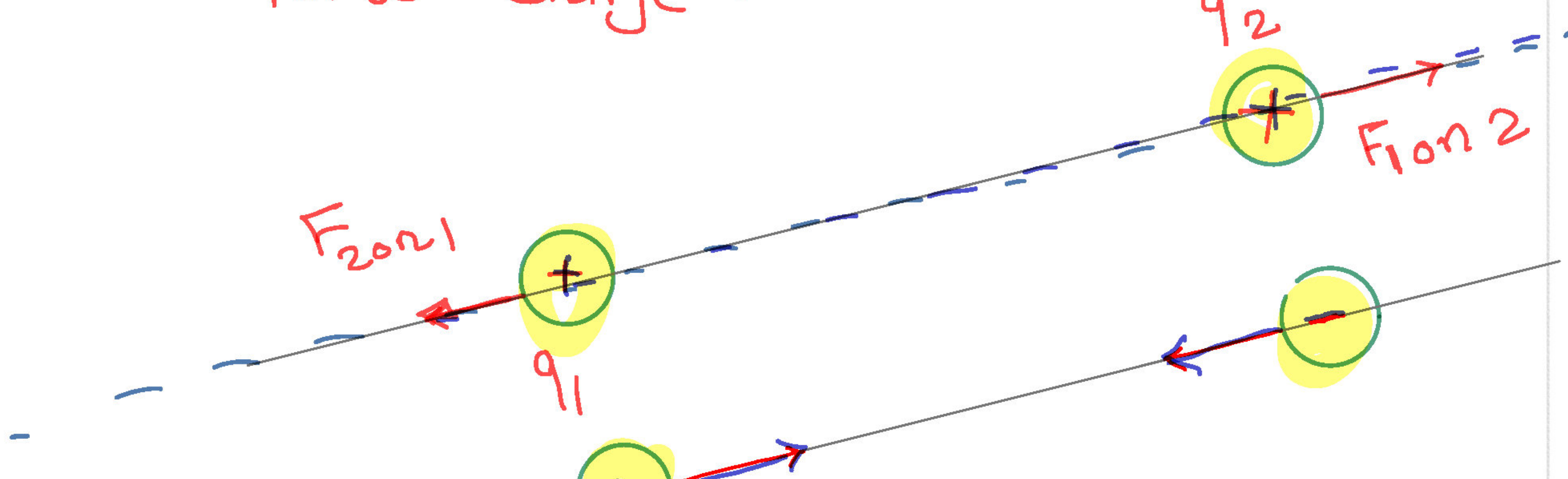
to get electric Force between Point charges

Magnitude :-

$$F = \frac{k\,|q_1|\,|q_2|}{r^2}$$

Direction :-

Directed along line between two Point charge.



$$F_{2 on 1} = - F_{1 on 2}$$

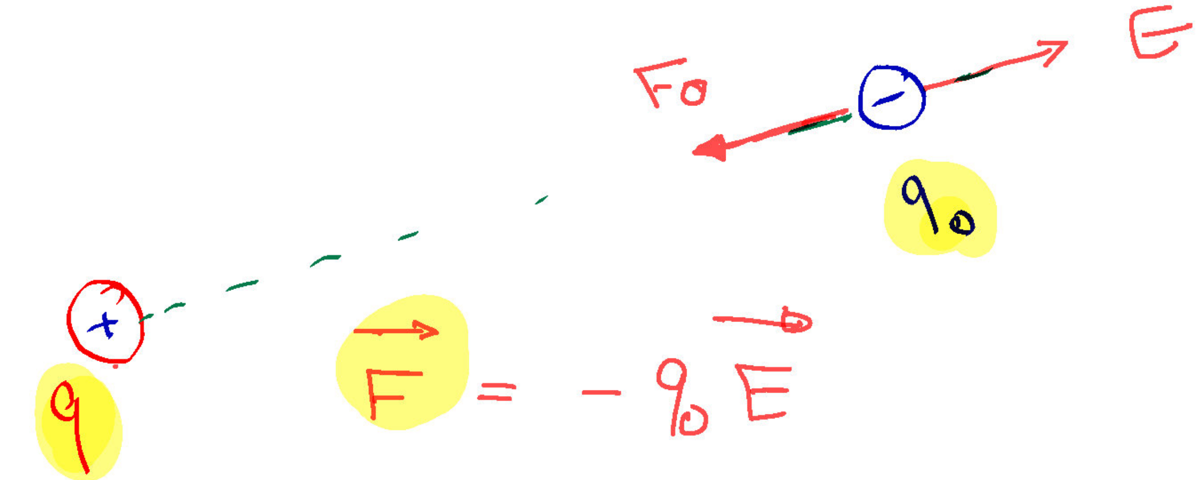
② **Electric Field :-** (vector - Quantity)

* Space around charged body

→ **Magnitude :-**

$$E = \frac{k\,|q|}{r^2} \quad (N/C)$$

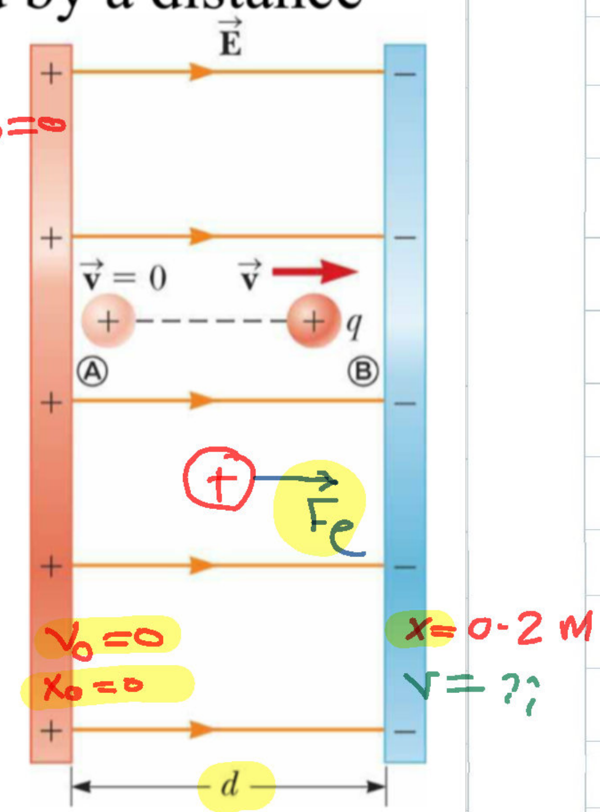
$$\vec{F} = q_o \vec{E}$$



$$\vec{F} = -q_o \vec{E}$$

Example 22.7:
An Accelerating Positive Charge: Two Models

A uniform electric field $\vec{\mathbf{E}}$ is directed along the x axis between parallel plates of charge separated by a distance d as shown in the figure. A positive point charge q of mass m is released from rest at a point A next to the positive plate and accelerates to a point B next to the negative plate.



(A) Find the speed of the particle at B by modeling it as a particle under constant acceleration.

given

$d = 0.2\ M$

$E = 100\ N/C$

$q = 12\ nC$

$M = 6 * 10^{-25}\ kg$

① $F_e = qE = 12 * 10^{-9} * 100$

$= 1.2 * 10^{-6}\ N$

② $\Sigma F = Ma \quad \xrightarrow{+}$

$F_e = Ma \Rightarrow a = F_e / M$

$a = \dfrac{1.2 * 10^{-6}}{6 * 10^{-25}} = 2 * 10^{18}\ M/s$

③ $V^2 = V_0^2 + 2a(x - x_0)$

$V^2 = 0 + 2 * 2 * 10^{18}(0.2 - 0)$

$V = 0.89 * 10^{9}\ M/s$

(B) Find the speed of the particle at B by modeling it as a nonisolated system in terms of energy.

$W = K_2 - K_1$

$F_e * d = \frac{1}{2} M V^2 - \cancel{\frac{1}{2} M V_0^2}$ $= 0$

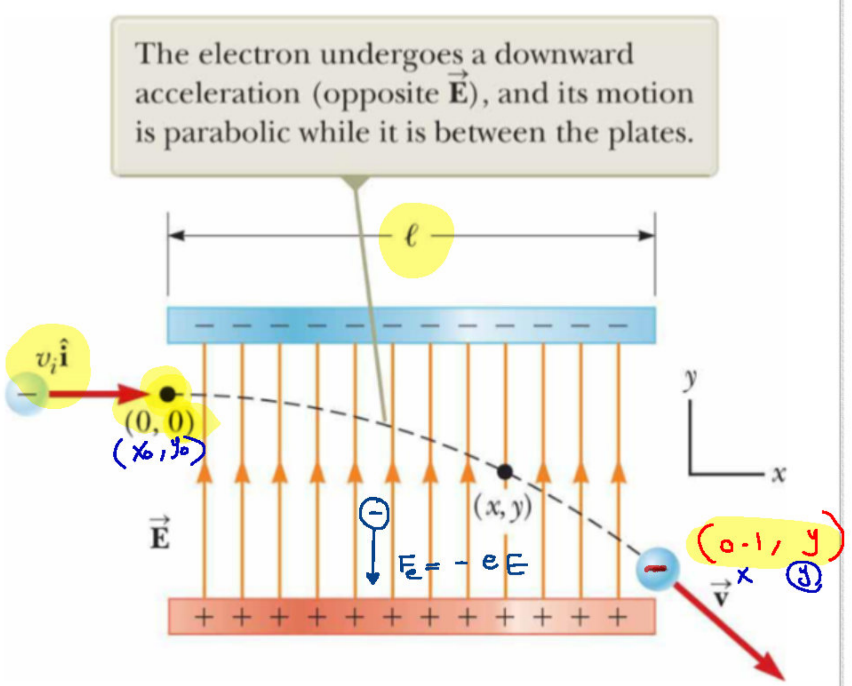
$1.2 * 10^{-6} * 0.2 = \frac{1}{2}(6 * 10^{-25}) V^2$

$V = 0.89 * 10^{9}\ M/s$

Example 22.8: An Accelerated Electron

An electron enters the region of a uniform electric field as shown in the figure, with $v_i = 3.00 \times 10^6$ m/s and E = 200 N/C. The horizontal length of the plates is ℓ = 0.100 m.

(A) Find the acceleration of the electron while it is in the electric field.



$*\ \Sigma F_y = m\, a_y \quad \uparrow +$

$-eE = m\, a_y$

$a_y = \dfrac{-eE}{m}$

$= \dfrac{-1.6 \times 10^{-19} \times 200}{9.11 \times 10^{-31}} = -3.51 \times 10^{13}\ m/s^2$

$*\ a_x = 0$

@ Start Point $\begin{cases} V_{0x} = 3 \times 10^6\ m/s \\ V_{0y} = 0 \end{cases}$

(B) Assuming the electron enters the field at time $t = 0$, find the time at which it leaves the field.

H Z – Motion :–

$a_x = 0$

$V_x = 3 \times 10^6\ m/s$

$x = x_0 + V_x t$

$0.1 = 0 + 3 \times 10^6\, t$

$t = \dfrac{0.1}{3 \times 10^6} = 3.33 \times 10^{-8}\ s$

(C) Assuming the vertical position of the electron as it enters the field is $y_i = 0$, what is its vertical position when it leaves the field? y

⇒ Vertical Motion

$a_y = -3.51 \times 10^{13}\ m/s$

$V_{oy} = 0 \qquad y_0 = 0$

$t = 3.33 \times 10^{-8}\ s$

$y = y_0 + V_{oy} t + \frac{1}{2} a_y t^2$

$y = 0 + \frac{1}{2}(-3.51 \times 10^{13})(3.33 \times 10^{-8})^2$

$= -0.0195\ M = -1.95\ CM$

Quick Quiz 22.1

Three objects are brought close to each other, two at a time. When objects A and B are brought together, they repel. When objects B and C are brought together, they also repel. Which of the following are true?

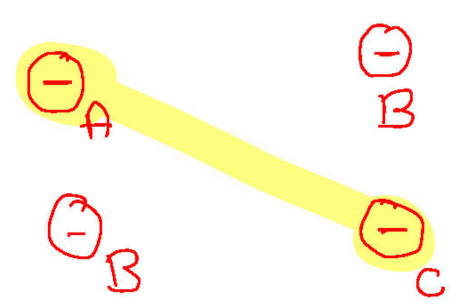
(a) Objects A and C possess charges of the same sign.

(b) Objects A and C possess charges of opposite sign.

(c) All three objects possess charges of the same sign.

(d) One object is neutral.

(e) Additional experiments must be performed to determine the signs of the charges.



Quick Quiz 22.3

Object A has a charge of +2 μC, and object B has a charge of +6 μ C. Which statement is true about the electric forces on the objects?

(a) $\vec{\mathbf{F}}_{AB} = -3\vec{\mathbf{F}}_{BA}$

(b) $\boxed{\vec{\mathbf{F}}_{AB} = -\vec{\mathbf{F}}_{BA}}$

(c) $3\vec{\mathbf{F}}_{AB} = -\vec{\mathbf{F}}_{BA}$

(d) $\vec{\mathbf{F}}_{AB} = 3\vec{\mathbf{F}}_{BA}$

(e) $\vec{\mathbf{F}}_{AB} = \vec{\mathbf{F}}_{BA}$

(f) $3\vec{\mathbf{F}}_{AB} = \vec{\mathbf{F}}_{BA}$

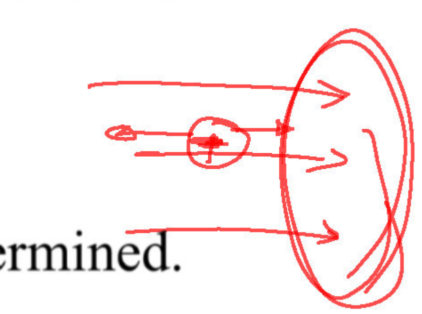
Quick Quiz 22.4

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 $-3\ \mu C$, what happens to the external electric field at P?

(a) It is unaffected.

(b) It reverses direction.

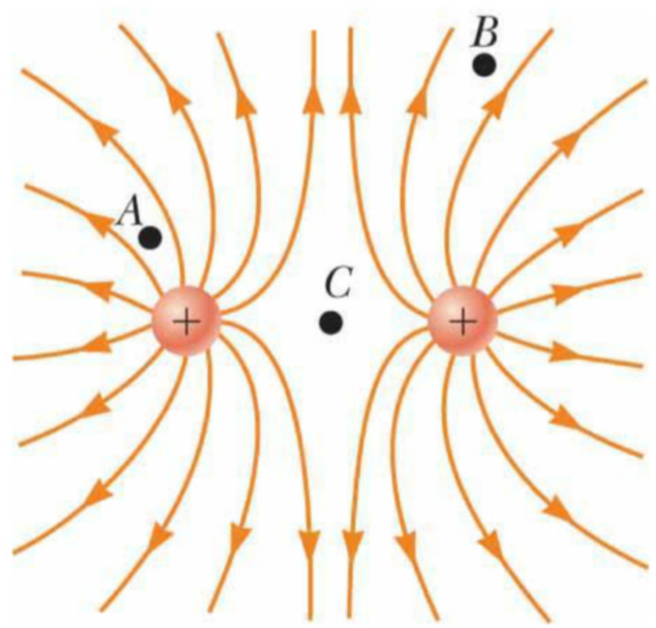
(c) It changes in a way that cannot be determined.



Quick Quiz 22.5

Rank the magnitudes of the electric field at points A, B, and C shown in the figure (greatest magnitude first).

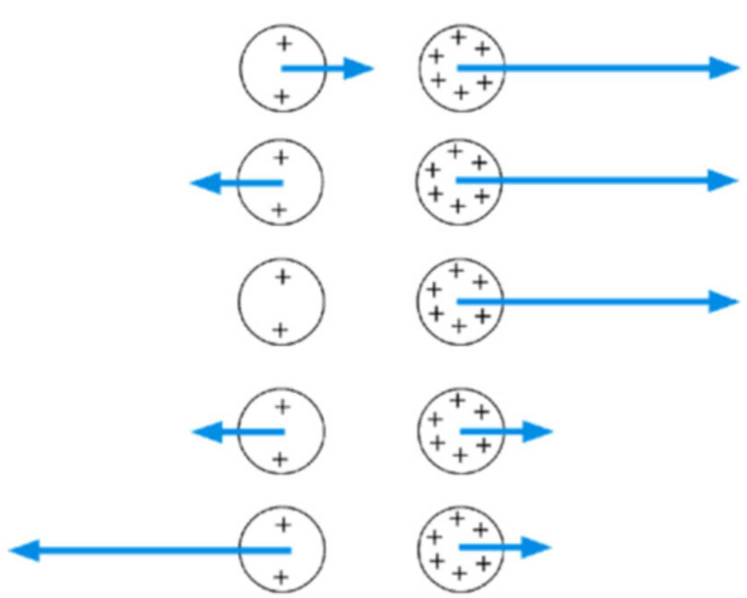
A, B, C



Assessing to Learn

The diagrams below show two uniformly charged spheres. The charge on the right sphere is 3 times as large as the charge on the left sphere. Which force diagram best represents the magnitudes and directions of the electric forces on the two spheres?

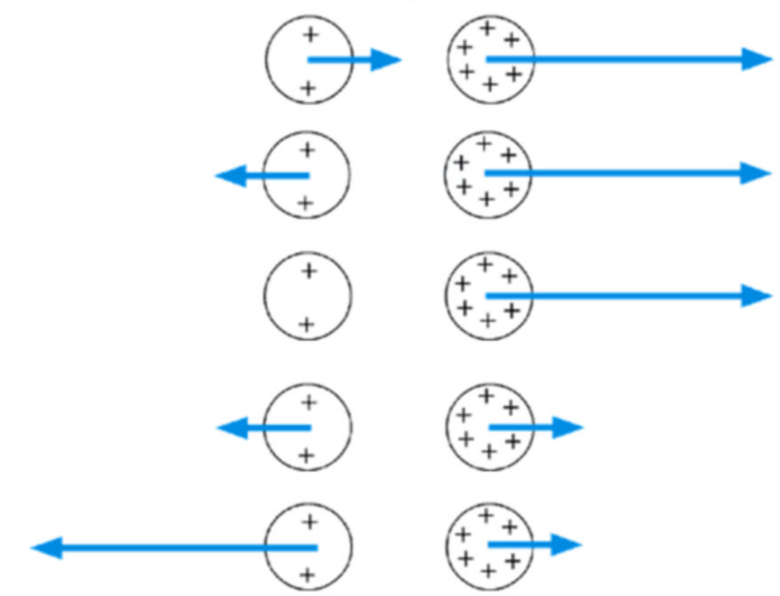
1.
2.
3.
4.
5.



Assessing to Learn

The diagrams below show two uniformly charged spheres. The charge on the right sphere is 3 times as large as the charge on the left sphere. Each arrow represents the electric field at the center of one sphere created by the other. Which choice best represents the magnitudes and directions of the electric field vectors created by one sphere at the location of the other sphere?

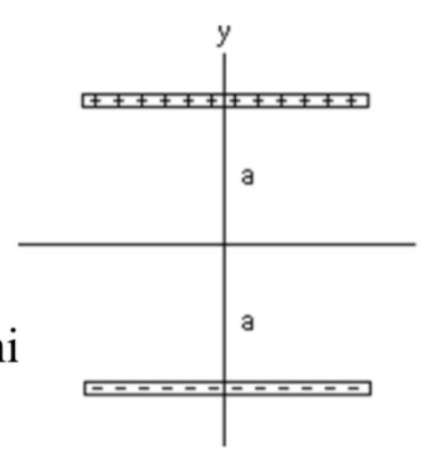
1.
2.
3.
4.
5.



Assessing to Learn

Two uniformly charged rods are positioned horizontally as shown. The top rod is positively charged and the bottom rod is negatively charged. The total electric field at the origin:

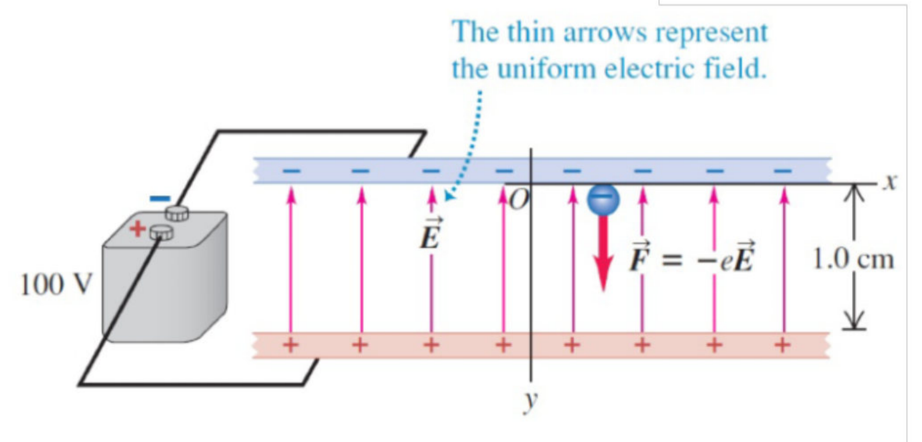
1. is zero.
2. has both a non-zero x component and a non-zero y component.
3. points totally in the $+x$ direction.
4. points totally in the $-x$ direction.
5. points totally in the $+y$ direction
6. points totally in the $-y$ direction.
7. points in a direction impossible to determi without doing a lot of math.



Example 21.7 Electron in a uniform field

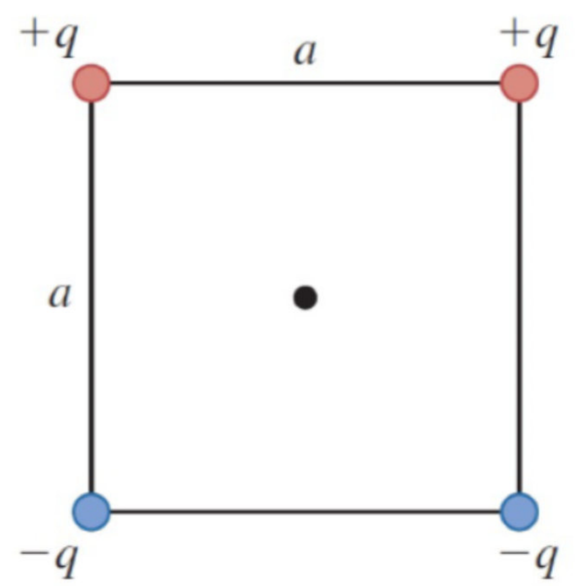
When the terminals of a battery are connected to two parallel conducting plates with a small gap between them, the resulting charges on the plates produce a nearly uniform electric field $\vec{E}$ between the plates. (In the next section we'll see why this is.) If the plates are 1.0 cm apart and are connected to a 100-volt battery as shown in Fig. 21.20, the field is vertically upward and has magnitude $E = 1.00 \times 10^4$ N/C. (a) If an electron (charge $-e = -1.60 \times 10^{-19}$ C, mass $m = 9.11 \times 10^{-31}$ kg) is released from rest at the upper plate, what is its acceleration? (b) What speed and kinetic energy does it acquire while traveling 1.0 cm to the lower plate? (c) How long does it take to travel this distance?

SOLUTION



21.30 •• A point charge is placed at each corner of a square with side length a. The charges all have the same magnitude q. Two of the charges are positive and two are negative, as shown in Fig. E21.30. What is the direction of the net electric field at the center of the square due to the four charges, and what is its magnitude in terms of q and a?

Figure **E21.30**



21.47 • Three negative point charges lie along a line as shown in Fig. E21.47. Find the magnitude and direction of the electric field this combination of charges produces at point P, which lies 6.00 cm from the -2.00-μC charge measured perpendicular to the line connecting the three charges.

Figure **E21.47**