Welcome to the Physics class

Principles of Physics II

Summer Semester 2023

Prof. Dr. A.F.M. Yusuf Haider (YUH)

Chairperson

Mathematics and Natural Science (MNS)

PHY112	Principles of Physics II	04	Professor Dr. A. F. M. Yusuf Haider	YUH	Sunday Tuesday	12:30 pm	01:50 pm	UB20204
PHY112	Principles of Physics II (Lab)	04	Concerned TAs		Wednesday	08:00 am	011:00 am	UB20204

Introduction and Overview of the course

Go To

(PHY-112 Course Plan Template Summer 2023)

Required Textbook: Fundamentals of Physics.
Authors:
Halliday, Resnick & Walker (10th edition, Extended).

Marks Distribution: The total marks for this course is 100. The marks will be allocated as follows: (It may be changed).

Attendance	Quiz	Lab	Assignments	Midterm	Final
5%	10%	10%	25%	20%	30%

How to get full marks

- **Explain in clear terms,**
- **Draw appropriate diagrams.**
- **Write all the parameter values in the calculation.**
- **Show the important steps in the calculation.**
- **Be particular about the units.**

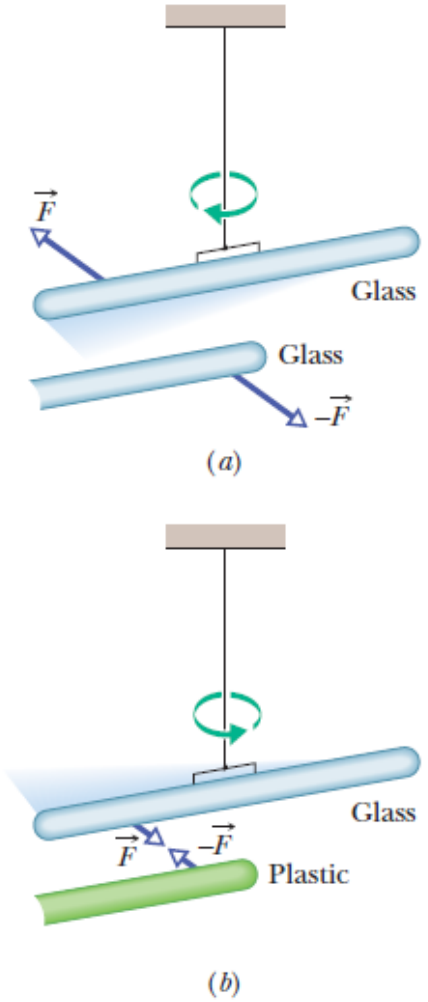
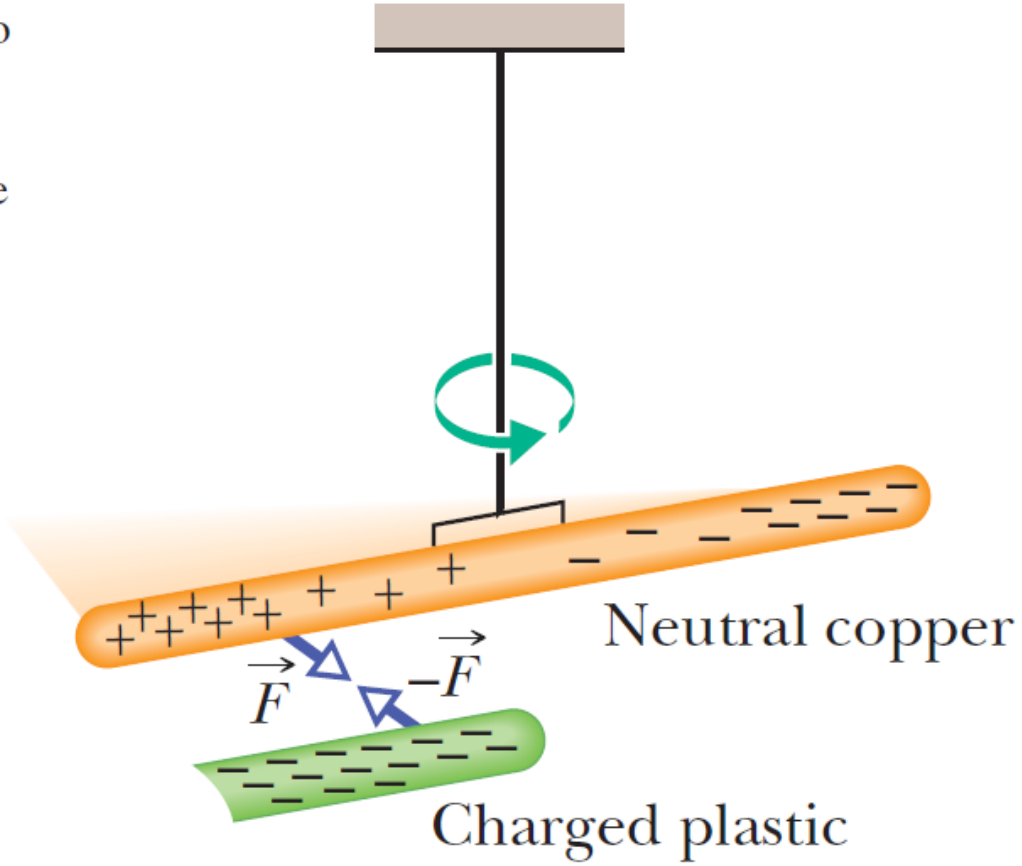


Figure 21-1 (*a*) The two glass rods were each rubbed with a silk cloth and one was suspended by thread. When they are close to each other, they repel each other. (*b*) The plastic rod was rubbed with fur. When brought close to the glass rod, the rods attract each other.

Figure 21-3 A neutral copper rod is electrically isolated from its surroundings by being suspended on a nonconducting thread. Either end of the copper rod will be attracted by a charged rod. Here, conduction electrons in the copper rod are repelled to the far end of that rod by the negative charge on the plastic rod. Then that negative charge attracts the remaining positive charge on the near end of the copper rod, rotating the copper rod to bring that near end closer to the plastic rod.



Particles with the same sign of electrical charge repel each other, and particles with opposite signs attract each other.

Atomic Structure

(1913) Bohr model.

$m_e = 9.11 \times 10^{-31}$ kg

$m_p = 1.674 \times 10^{-27}$ kg

electron charge $e^- = -1.602 \times 10^{-19}$ Coulomb

Proton charge $e^+ = +1.602 \times 10^{-19}$ Coulomb

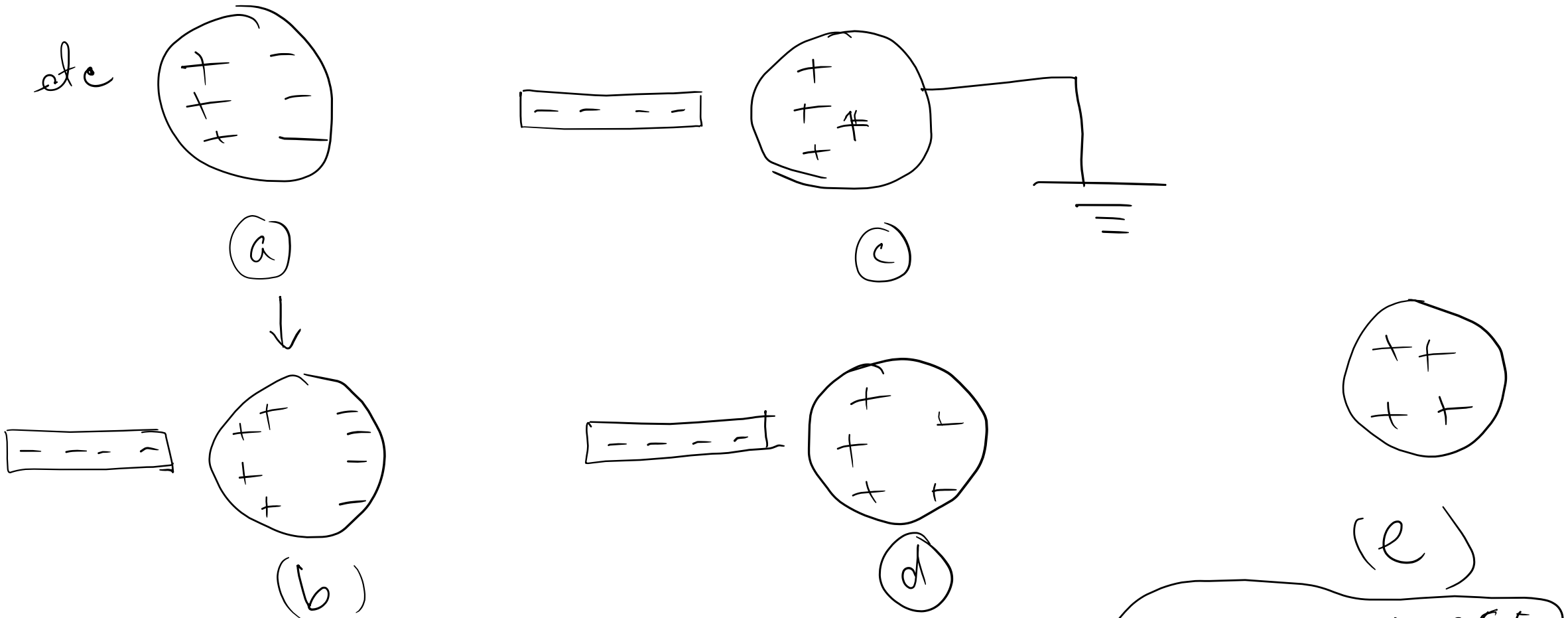
Types of materials → Band gaps

Insulators and Conductors.

Semiconductors; Examples Si (1.17 eV)

Ge (0.67 eV)

Charging a metallic object by induction:



a → b → c → d → e

BOUND CHARGE

Charge Is Quantized

Any positive or negative charge q that can be detected can be written as

$$q = ne, \qquad n = \pm 1, \pm 2, \pm 3, \ldots,$$

in which e, the **elementary charge,** has the approximate value

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

$$i = \frac{dq}{dt} \qquad \text{(electric current).} \qquad 1\ \mathrm{C} = (1\ \mathrm{A})(1\ \mathrm{s}).$$

Charge Is Conserved

$$\underset{92}{{}^{238}\mathrm{U}} \rightarrow \underset{90}{{}^{234}\mathrm{Th}} + \underset{2}{{}^{4}\mathrm{He}},$$

$$\mathrm{e}^- + \mathrm{e}^+ \rightarrow \gamma + \gamma \qquad \text{(annihilation).}$$

$$\gamma \rightarrow \mathrm{e}^- + \mathrm{e}^+ \qquad \text{(pair production).}$$

UNIT VECTORS

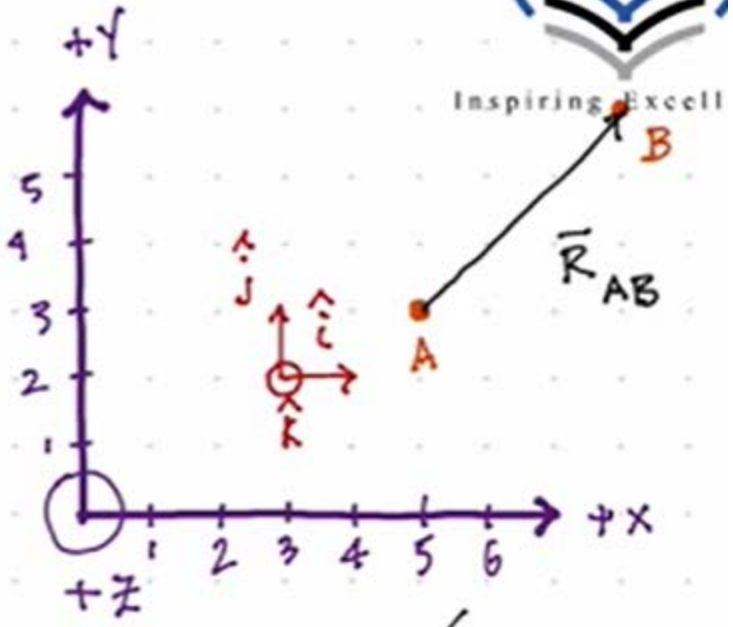
Vectors:

1. Direction
2. Magnitude

$$|\bar{R}_{AB}| = r_{AB}$$

$$\hat{r}_{AB} = \frac{\bar{R}_{AB}}{|\bar{R}_{AB}|} = \frac{\bar{R}_{AB}}{r_{AB}}$$

$$|\hat{r}_{AB}| = \frac{|\bar{R}_{AB}|}{r_{AB}} = 1$$



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Inspiring Excellenc

4

$$|\hat{r}_{AB}| = \sqrt{\left(\frac{4}{5}\right)^2 + \left(\frac{3}{5}\right)^2}$$

$$= \sqrt{\frac{16+9}{25}}$$

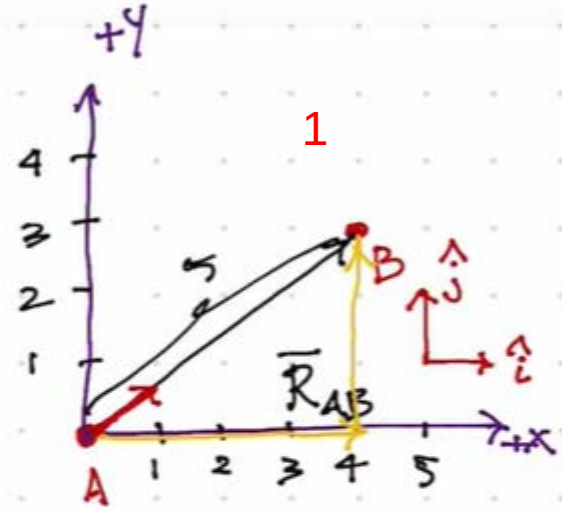
$$= \sqrt{\frac{25}{25}} = 1$$

$$\hat{r}_{AB} = \frac{\bar{R}_{AB}}{r_{AB}}$$

3

$$= \frac{4}{5}\hat{i} + \frac{3}{5}\hat{j}$$

1



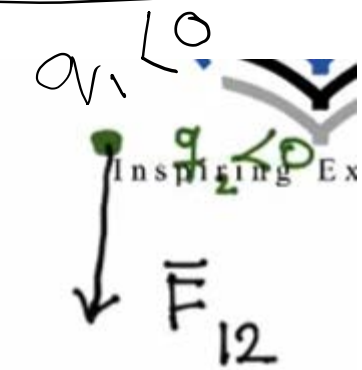
$$\bar{R}_{AB} = 4\hat{i} + 3\hat{j}$$

2

$$r_{AB} = |\bar{R}_{AB}| = \sqrt{4^2 + 3^2}$$

$$= \sqrt{16+9} = \sqrt{25} = 5$$

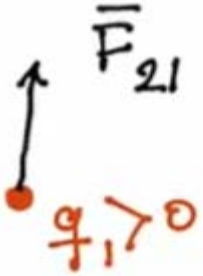
Coulomb's Law

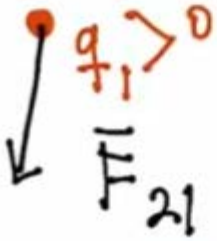


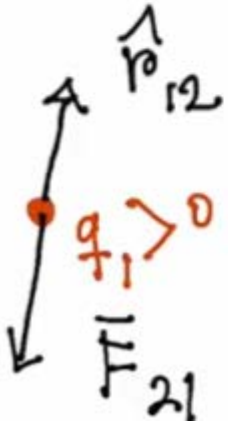
$$\bar{F}_{12} = q_1 q_2 \hat{r}_{12}$$

1. $q_1 q_2 > 0$
2. $q_1 q_2 < 0$

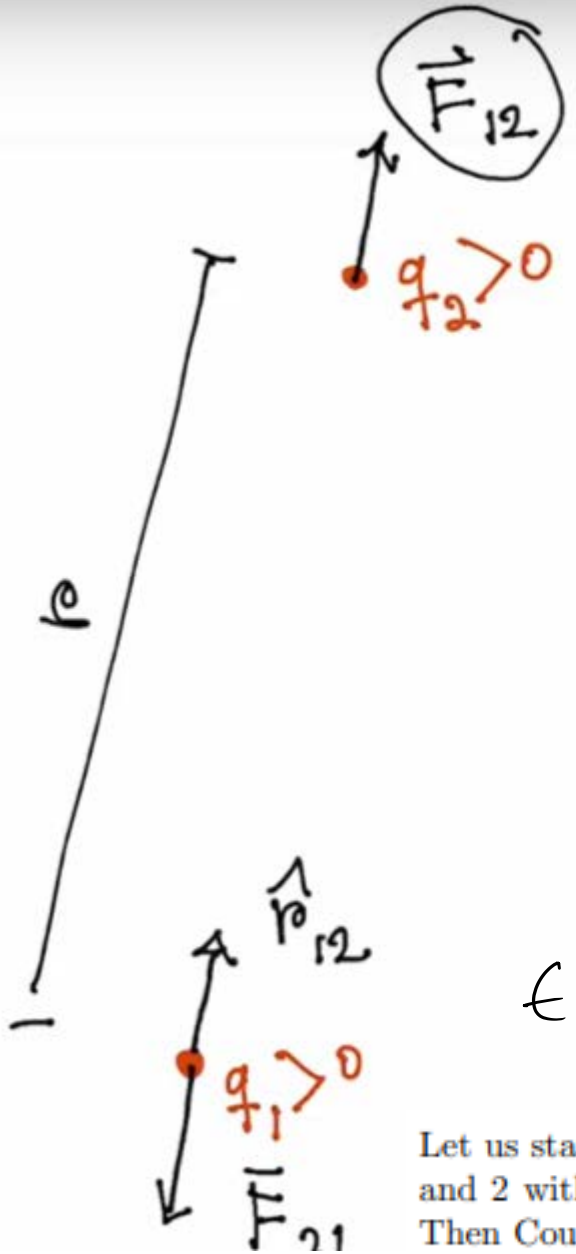
Explain repulsion & attraction







F_{12} = Force on particle 2 due to charge 1.



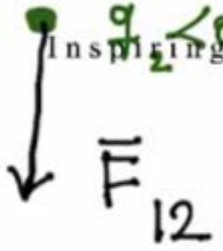
$$\boxed{F_{12} = k\frac{q_1 q_2}{r^2}\hat{r}_{12}}$$

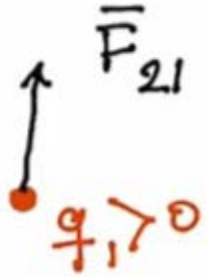
Coulomb's law

$$K = \frac{1}{4\pi\epsilon_0} = 8.98 \times 10^9 \ Nm^2/C^2$$

ϵ_0 = permittivity of free space

$= 8.85 \times 10^{-12} \ C^2/Nm^2$



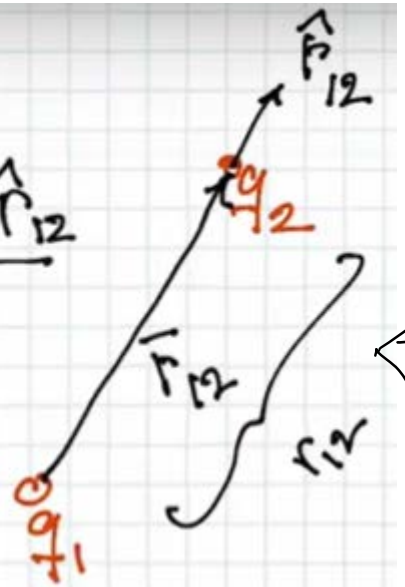


Let us start by considering the force between point-like charges. Consider two point-like objects, labelled 1 and 2 with charges q_1 and q_2 respectively. Then we denote the force on object 2 due to object 1 by $F_{1,2}$. Then Coulomb's law states that this force is given by

$$\mathbf{F}_{1,2} = k\frac{q_1 q_2}{r_{1,2}^2}\hat{\mathbf{r}}_{1,2} \tag{3.2}$$

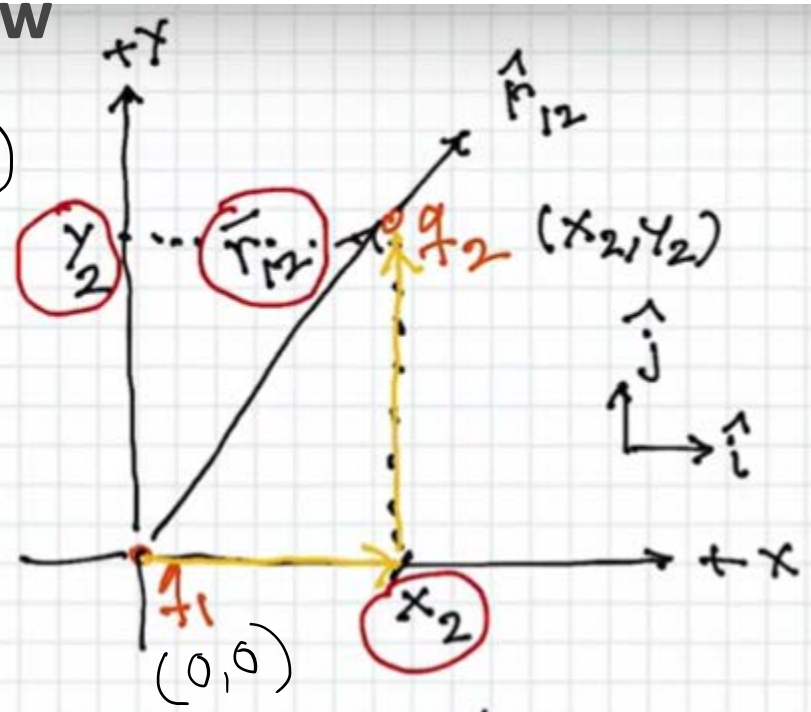
L1V3: Rewriting Coulomb's Law

1. $\bar{F}_{12} = k\dfrac{q_1 q_2 \hat{r}_{12}}{r_{12}^2}$



$$\hat{r}_{12} = \frac{\bar{r}_{12}}{|\bar{r}_{12}|} = \frac{\bar{r}_{12}}{r_{12}}$$

$$\boxed{2.\ \bar{F}_{12} = k\frac{q_1 q_2 \bar{r}_{12}}{r_{12}^3}}$$



$$\bar{r}_{12} = (\hat{i}x_2 + \hat{j}y_2)$$

$$r_{12} = |\bar{r}_{12}| = (x_2^2 + y_2^2)^{1/2}$$

$$\boxed{\bar{F}_{12} = \frac{k q_1 q_2 (\hat{i}x_2 + \hat{j}y_2)}{(x_2^2 + y_2^2)^{3/2}}}$$

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Newton's Law of Gravitation

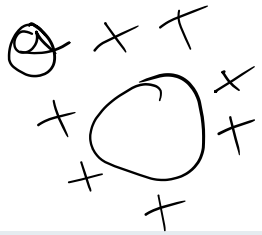
$$\vec{F} = G\frac{m_1 m_2}{r^2}\hat{\mathrm{r}} \qquad \text{(Newton's law)},$$

Both Newton's law of gravitation and Coulombs law of electrostatic force follow inverse square law

Superposition of Fields

$$\vec{F}_{\cancel{1,\mathrm{net}}} = \vec{F}_{\cancel{12}} + \vec{F}_{\cancel{13}} + \vec{F}_{\cancel{14}} + \vec{F}_{\cancel{15}} + \cdots + \vec{F}_{\cancel{1n}},$$

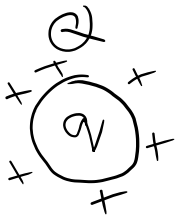
net, 1 21 31 41 51 n1



q

$F \neq 0$

Shell theory 1. A charged particle outside a shell with charge uniformly distributed on its surface is attracted or repelled as if the shell's charge were concentrated as a pt particle at its center.

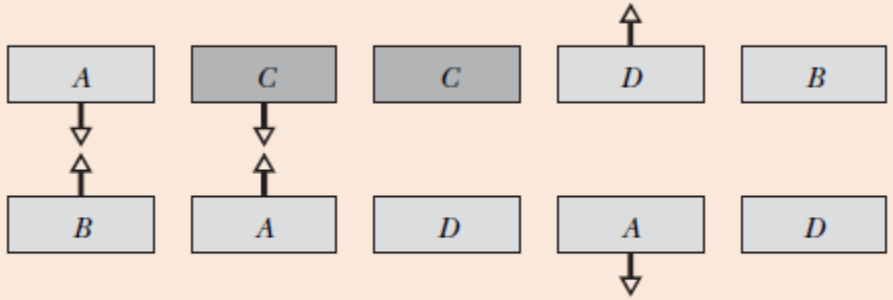


$F = 0$

Shell theory 2. A charged particle inside a shell with charge uniformly distributed on its surface has no net force acting on it due to the shell.

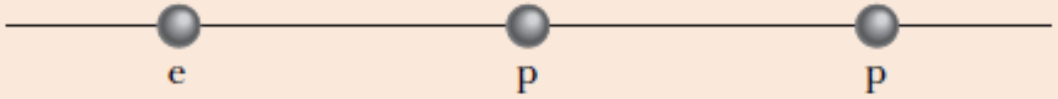
CHECKPOINT 1

The figure shows five pairs of plates: A, B, and D are charged plastic plates and C is an electrically neutral copper plate. The electrostatic forces between the pairs of plates are shown for three of the pairs. For the remaining two pairs, do the plates repel or attract each other?



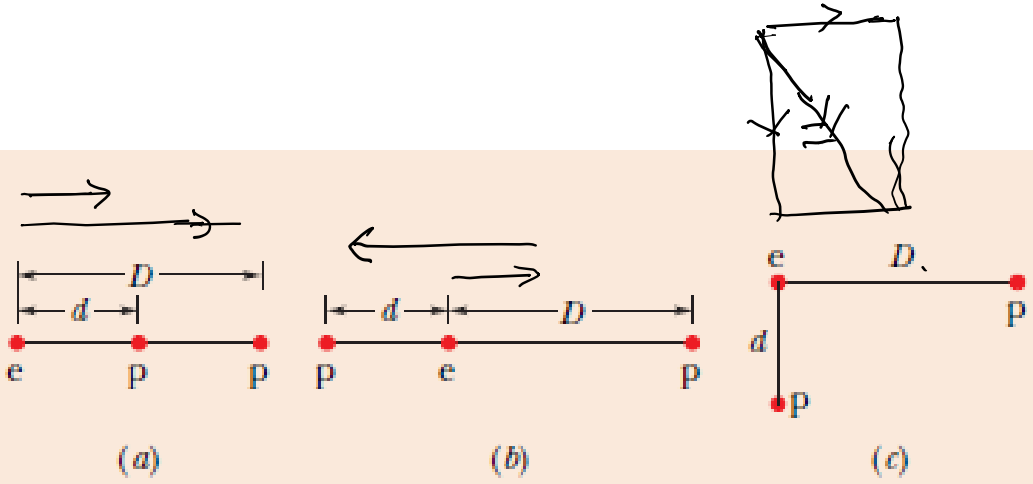
CHECKPOINT 2

The figure shows two protons (symbol p) and one electron (symbol e) on an axis. What is the direction of (a) the electrostatic force on the central proton due to the electron, (b) the electrostatic force on the central proton due to the other proton, and (c) the net electrostatic force on the central proton?



CHECKPOINT 3

The figure here shows three arrangements of an electron e and two protons p. (a) Rank the arrangements according to the magnitude of the net electrostatic force on the electron due to the protons, largest first. (b) In situation *c*, is the angle between the net force on the electron and the line labeled *d* less than or more than 45°?



CHECKPOINT 4

Initially, sphere *A* has a charge of $-50e$ and sphere *B* has a charge of $+20e$. The spheres are made of conducting material and are identical in size. If the spheres then touch, what is the resulting charge on sphere *A*?

Problem 1: Two identical small charged sphere each having a mass of 3.0x10 (-2) kg, hang in equilibrium as shown in figure. The length of each string is 0.15 m and the angle θ is 5.0 degree. Find the magnitude of the charge on each sphere

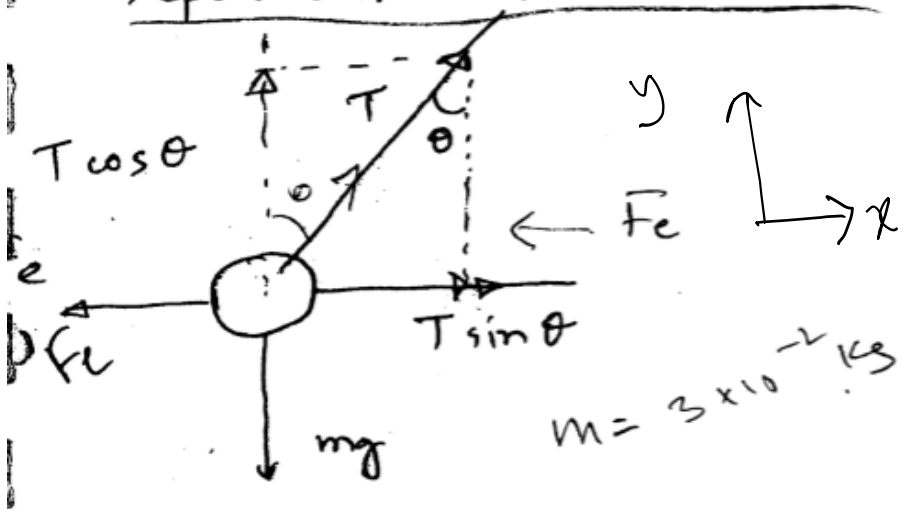
DRAW FIGURE

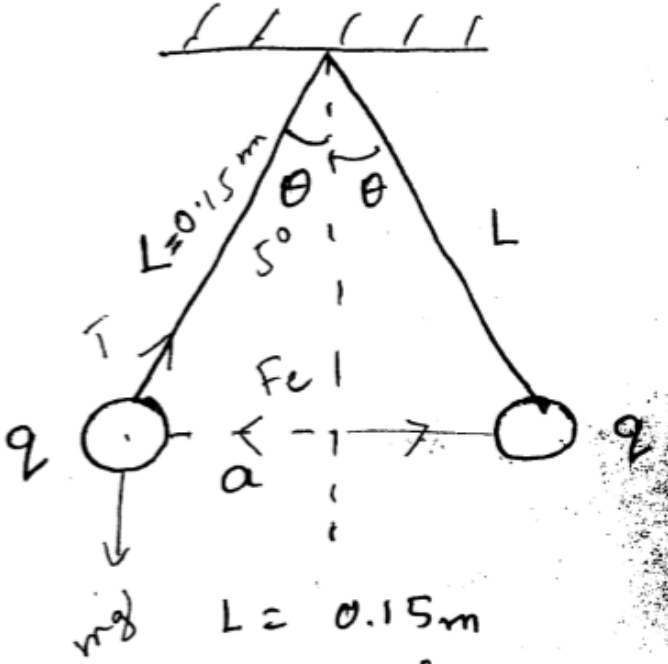
$$\sin\theta = \frac{a}{L} \Rightarrow a = L\sin\theta$$

$$= (0.15\,m)\sin 5.0^\circ$$

$$\underline{a = 0.013\ m}$$

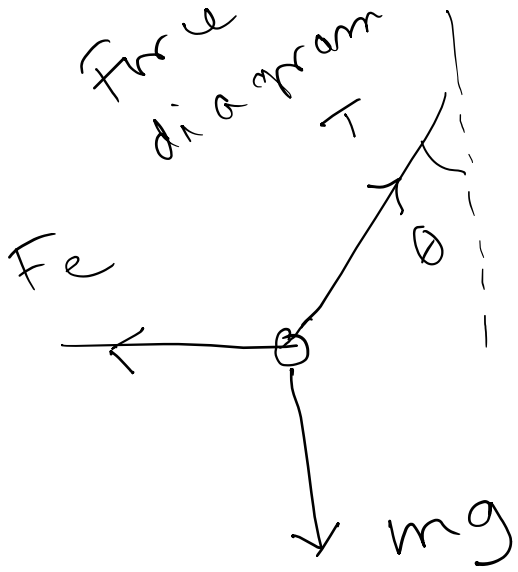
separation $2a = 0.026\ m$





$L = 0.15\,m$

$\theta = 5.0^\circ$



$$\frac{F_e}{mg} = \frac{T\sin\theta}{T\cos\theta} = \tan\theta$$

$$\sum F_x = T\sin\theta - F_e = 0 \qquad (1)$$

$$\sum F_y = T\cos\theta - mg = 0 \qquad (2)$$

$$\left.\begin{aligned} F_e &= T\sin\theta \quad \cdots (3) \\ mg &= T\cos\theta \quad \cdots (4) \end{aligned}\right\}$$

7/10/20.

$$F_e = mg\tan\theta = 3\times10^{-2}\times 10\times\tan 5^\circ$$

$$= 2.6\times10^{-2}\ N$$

$$F_e = \frac{K|q|^2}{r^2} \qquad r = 2a = 0.026\ m$$

$$|q|^2 = \frac{F_e r^2}{K} = \frac{2.6\times10^{-2}\times(0.026\ m)^2}{8.99\times10^9}$$

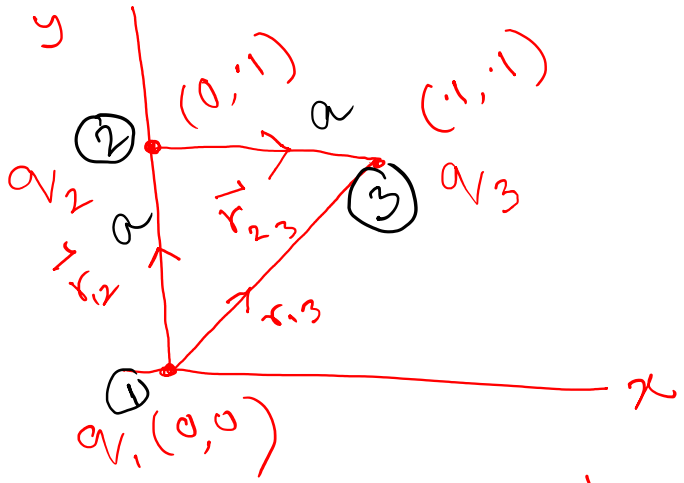
$$= 1.96\times10^{-15} = 19.6\times10^{-16}$$

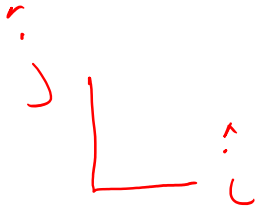
$$\therefore\ |q| = 4.4\times10^{-8}\ C$$

$$q = \pm\ 4.4\times10^{-8}\ C.$$

Problem 2: Consider three point charges at the corners of a right angled triangle as shown in figure, $q1 = q3 = 5.0\ \mu C$, $q2 = -2.0\ \mu C$ and $a = 0.10$ m. Find the resultant force exerted on q3.

DRAW FIGURE





$\vec{r}_{12} = 0\hat{i} + 0.1\hat{j}$

$|\vec{r}_{12}| = \sqrt{0^2 + .1^2} = 0.1\,m$

$r_{13} = 0.1\hat{i} + 0.1\hat{j}$

$|\vec{r}_{13}| = \sqrt{2} \times 0.1\ m$

$a = 0.1\ m$

$q_1 = 5\ \mu C$

$q_2 = -2\ \mu C$

$q_3 = 5\ \mu C$

$\vec{r}_{12} + \vec{r}_{23} = \vec{r}_{13}$

$\vec{r}_{23} = r_{13} - r_{12}$

$= (0.1\hat{i} + 0.1\hat{j}) - (0.0\hat{i} + 0.1\hat{j})$

$= 0.1\hat{i} + 0\hat{j}$

$|r_{23}| = 0.1\ m$

$$\vec{F}_{23} = \frac{k q_2 q_3 \vec{r}_{23}}{|r_{23}|^3} = \frac{8.99\times10^9 \times (-2\times10^{-6}) \times (5\times10^{-6})(0.1\hat{i} + 0\hat{j})}{(0.1)^3} = -9\hat{i}\ N$$

$$\vec{F}_{13} = \frac{k q_1 q_3 \vec{r}_{13}}{|r_{13}|^3} = \frac{8.99\times10^9 \times 5\times10^{-6} \times 5\times10^{-6}(.1\hat{i} + .1\hat{j})}{(\sqrt{2} \times .1)^3} = 7.9(\hat{i} + \hat{j})$$

$$\vec{F}_3 = \vec{F}_{23} + \vec{F}_{13} = (-9\hat{i} + 0\hat{j}) + (7.9\hat{i} + 7.9\hat{j})$$

$$= -1.1\hat{i} + 7.9\hat{j}$$

$$|F_3| = \sqrt{(-1.1)^2 + (7.9)^2} \simeq 8\,N$$

θ is the angle that the force F_3 makes with $+x$ direction.

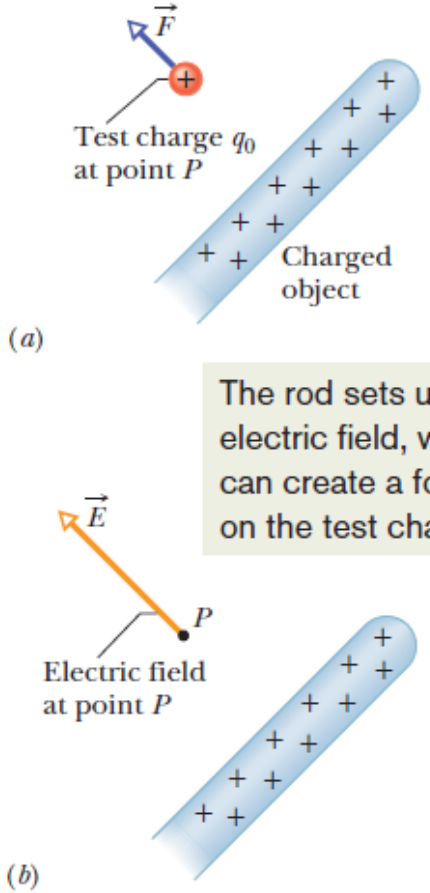
$$\therefore \quad \theta = \tan^{-1}\left(\frac{7.9}{-1.1}\right) = 98^\circ$$

Electric Field

What is a field

Figure 22-1 How does charged particle 2 push on charged particle 1 when they have no contact?

Action at a distance!



The rod sets up an electric field, which can create a force on the test charge.

Figure 22-2 (*a*) A positive test charge q_0 placed at point P near a charged object. An electrostatic force $\vec{F}$ acts on the test charge. (*b*) The electric field $\vec{E}$ at point P produced by the charged object.

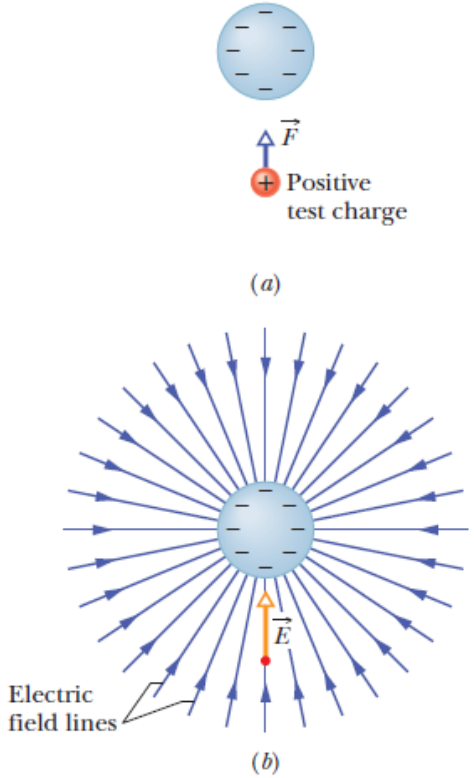
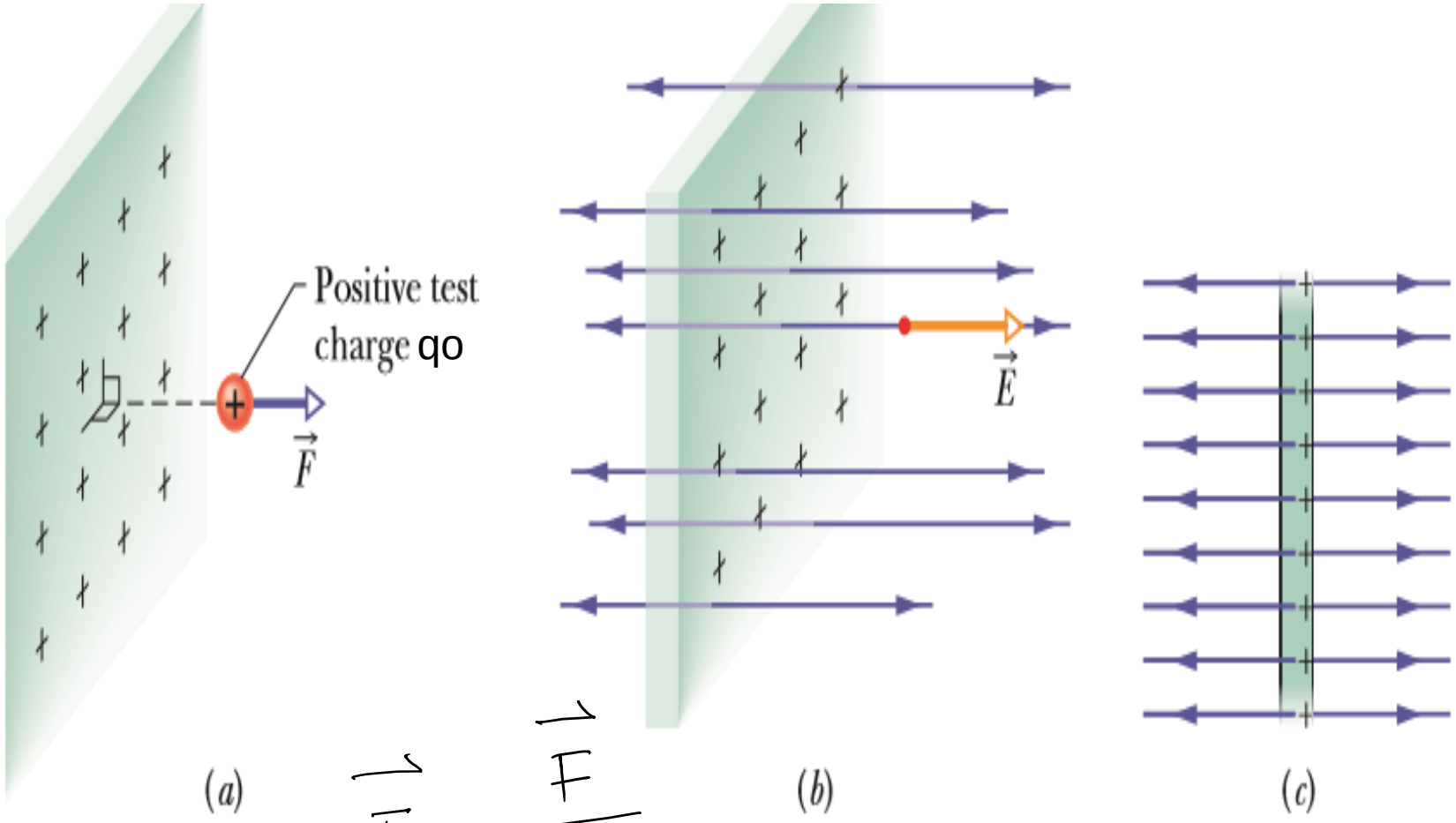


Figure 22-3 (*a*) The electrostatic force $\vec{F}$ acting on a positive test charge near a sphere of uniform negative charge. (*b*) The electric field vector $\vec{E}$ at the location of the test charge, and the electric field lines in the space near the sphere. The field lines extend *toward* the negatively charged sphere. (They originate on distant positive charges.)

Electric field lines extend away from positive charge (where they originate) and toward negative charge (where they terminate).

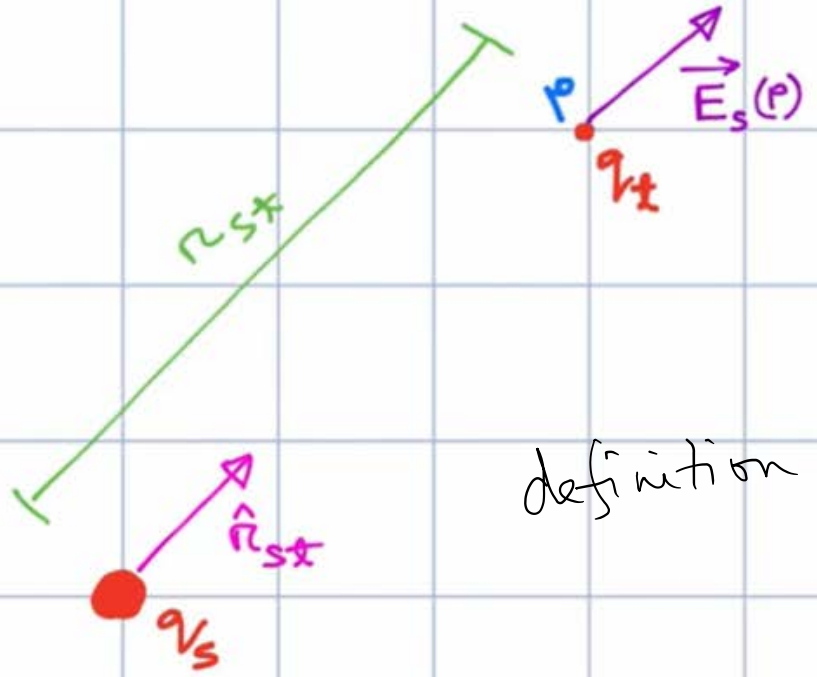
Fig. 22-3 (*a*) The electrostatic force $\vec{F}$ on a positive test charge near a very large, nonconducting sheet with uniformly distributed positive charge on one side. (*b*) The electric field vector $\vec{E}$ at the location of the test charge, and the electric field lines in the space near the sheet. The field lines extend *away from* the positively charged sheet. (*c*) Side view of (*b*).



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

$$\text{unit} = \frac{N}{C}$$

Electric Field of a Positive Point Charge



$$\vec{E}_s(P) = \frac{\vec{F}_{st}(P)}{q_t}$$

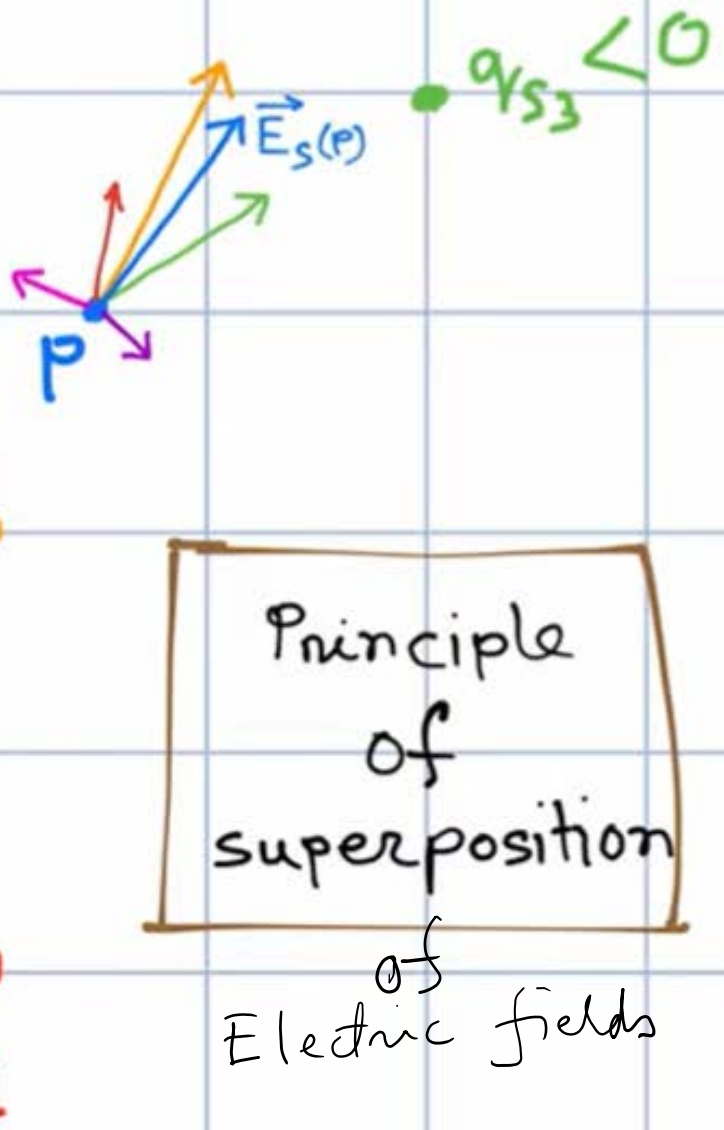
$$= \frac{k\, q_s\, \cancel{q_t}\, \hat{r}_{st}}{r_{st}^2} \times \frac{1}{\cancel{q_t}}$$

definition $\Rightarrow$ $$\boxed{\vec{E}_s(P) = \frac{k\, q_s\, \hat{r}_{st}}{r_{st}^2}}$$

$$\boxed{\vec{F}_{st}(P) = q_t\, \vec{E}_s(P)}$$

$$k = \frac{1}{4\pi\epsilon_0}$$

Inspiring



$$\vec{E}(P) = \vec{E}_{S_1}(P) + \vec{E}_{S_2}(P) + \vec{E}_{S_3}(P) + \vec{E}_{S_4}(P) \cdots + \vec{E}_{S_N}(P)$$

Principle of superposition of Electric fields

Electric field lines

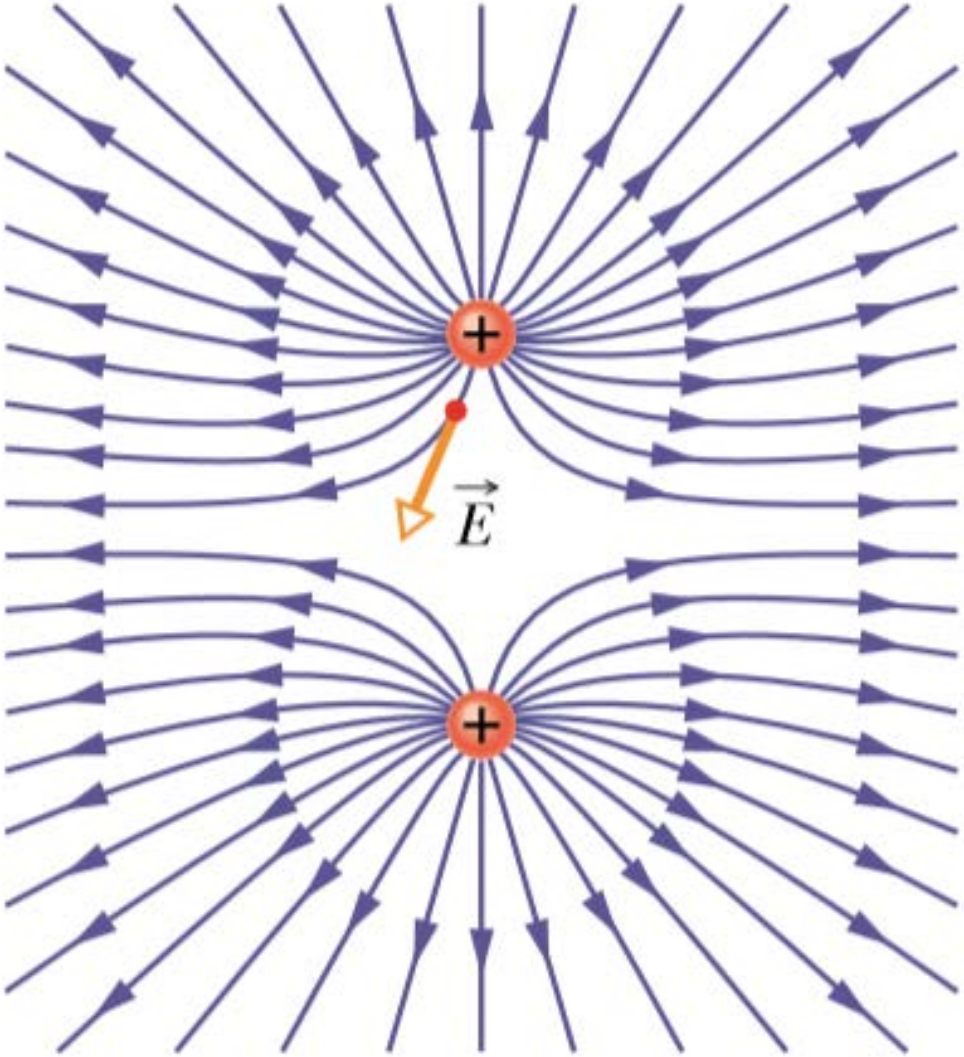
1. Visualization is very important when someone wants to learn physics.
2. Sometimes it might not be accurate but it helps to develop good intuition.
3. We can visualize electric field at all points around a charged object using the simple formula

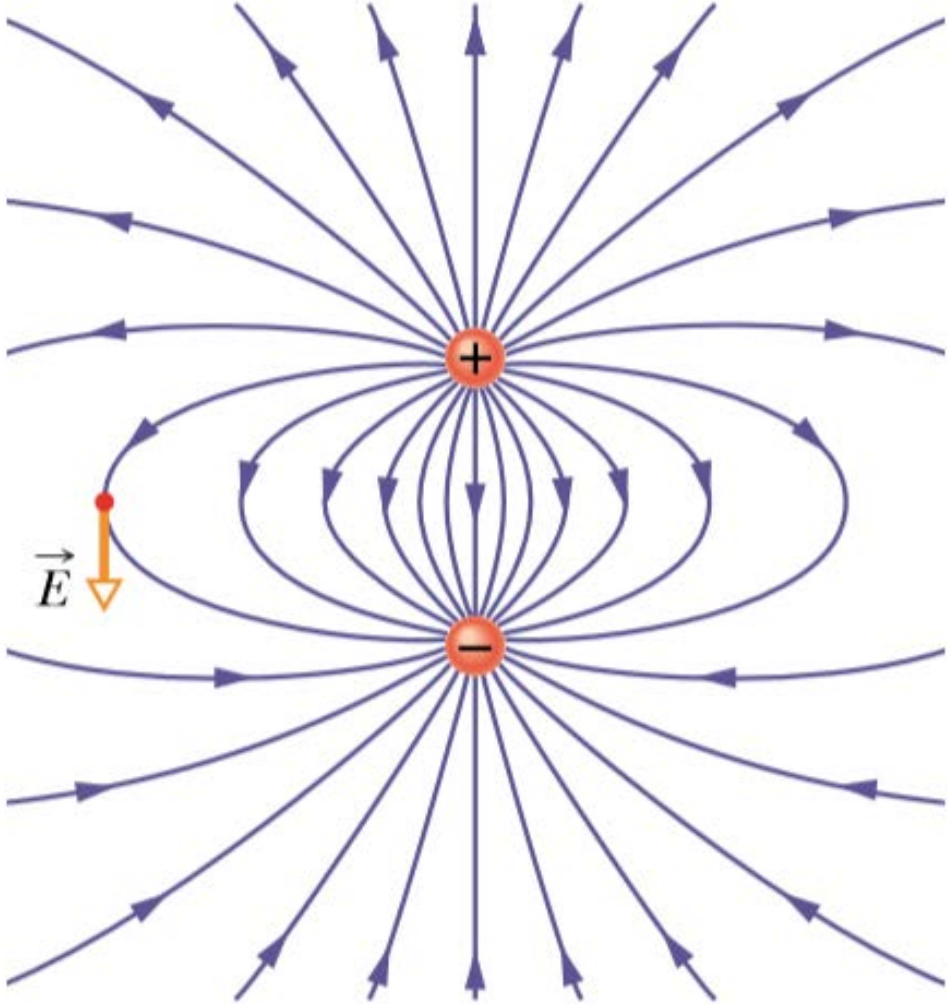
$$\vec{E}_s(p) = k\frac{q_s\hat{r}}{r^2} \tag{1}$$

4. We will see some **patterns** of lines, and we call them electric field lines.
5. Electric field lines do not cross each other (I will explain it later).

E is related to the density of electric field lines

field lines.





(Dipole)

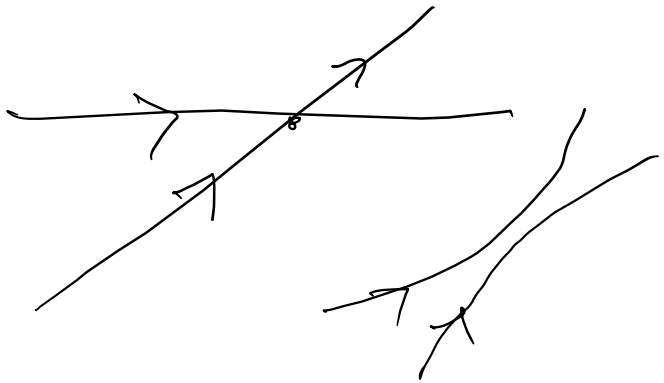
The electric field **E** at a point on the line of force is tangent to the line of force at that point

Why no two field lines never cross each other

1. Say we have two electric field at p, namely $\vec{E}_1(p), \vec{E}_2(p)$.
2. They are vector quantity. So you can add them

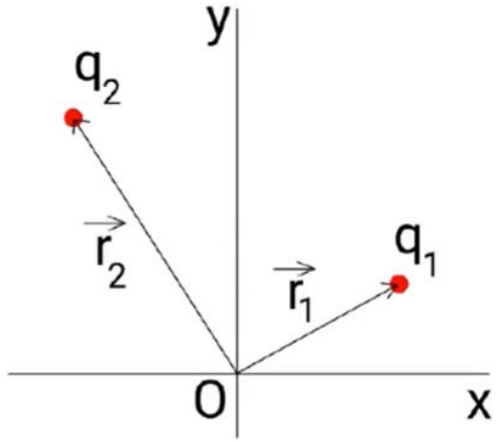
$$\vec{E}(p) = \vec{E}_1(p) + \vec{E}_2(p) \qquad ? \tag{4}$$

3. You get only one net $\vec{E}$ field, not two.
4. Thus whenever you have more than one $\vec{E}$ field at a point, you can always take the vector sum and get the net $\vec{E}$ field. That's why there is no intersection of $\vec{E}$ field.



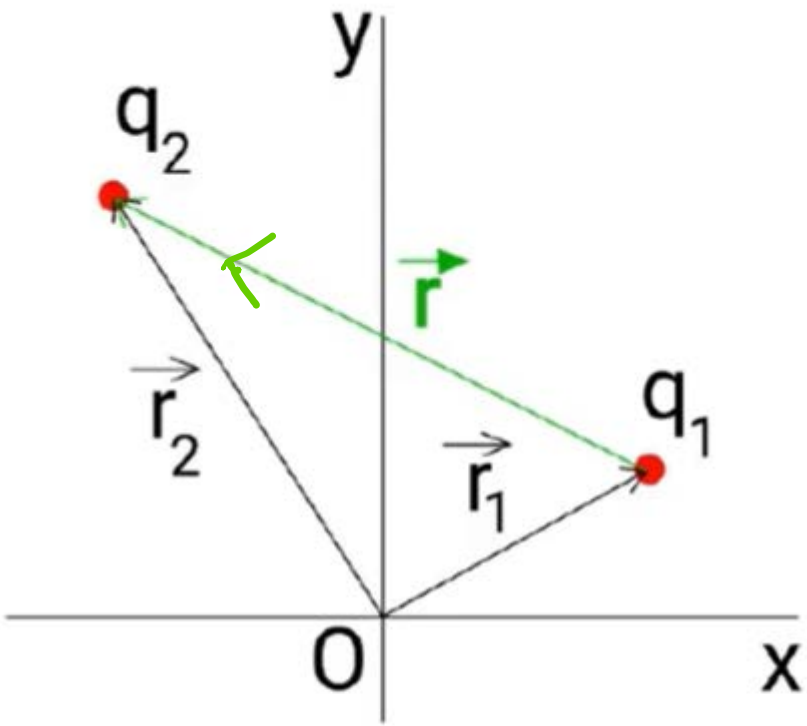
Find the coulomb force on q2 due to q1

Step 1



$$\vec{r_1} = 3\hat{i} + 2\hat{j} \quad (1)$$
$$\vec{r_2} = -3\hat{i} + 5\hat{j} \quad (2)$$

$$q_1 = 5\mu C = 5 \times 10^{-6} C$$
$$q_2 = 10\mu C = 10 \times 10^{-6} C$$



r1+r=r2

$$\vec{r} = \vec{r_2} - \vec{r_1}$$
$$\vec{r} = -6\hat{i} + 3\hat{j}$$

$(-3i+5j)$
$-(3i+2j)$

Now, put the values of r1 and r2

$$\vec{r} = -6\hat{i} + 3\hat{j} \qquad (4)$$

1

and

$$r = |\vec{r}| = \sqrt{(-6)^2 + 3^2} = \sqrt{36+9} = \sqrt{45} = 3\sqrt{5} \qquad (5)$$

$$r^3 = (3\sqrt{5})^3 = 27 \times 5^{3/2} \qquad (6)$$

The Coulomb's Law is

2

$$\vec{F}_{1,2} = k\frac{q_1 q_2}{r^2}\hat{r}_{1,2} \qquad (7)$$

$\vec{F}_{1,2}$ denotes the force on object 2 due to object 1.
$\hat{r}_{1,2}$ denotes the unit vector from 1 to 2.

The Coulomb's Law is

$$\vec{F}_{1,2} = k\frac{q_1 q_2}{r^2}\hat{r}_{1,2} \qquad (8)$$

3

Roughly,

$$\vec{F} = k\frac{q_1 q_2}{r^2}\hat{r} \qquad (9)$$

$$= k\frac{q_1 q_2}{r^3}\vec{r} \qquad (10)$$

Because,

$$\hat{r} = \frac{\vec{r}}{r} \qquad (11)$$

Given,

4

$$q_1 = 5\mu C = 5 \times 10^{-6} C$$

$$q_2 = 10\mu C = 10 \times 10^{-6} C$$

and We calculated

$$\vec{r} = -6\hat{i} + 3\hat{j} \qquad (12)$$

$$r^3 = 27 \times 5^{3/2} \qquad (13)$$

Plugging these into the Coulomb force formula,

$$\vec{F} = k\frac{q_1 q_2 \vec{r}}{r^3} = k\frac{5 \times 10^{-6} \times 10 \times 10^{-6}}{27 \times 5^{3/2}}\vec{r}$$

$$\vec{F} = k\frac{50 \times 10^{-12}}{27 \times 5^{3/2}}\left(-6\hat{i} + 3\hat{j}\right) \qquad (14)$$

Coulomb's constant $k = \frac{1}{4\pi\epsilon_0} = 9 \times 10^9 N \cdot m \cdot C^{-2}$

$$\vec{F} = k\frac{50 \times 10^{-12}}{27 \times 5^{3/2}}\left(-6\hat{i} + 3\hat{j}\right) \quad (15)$$

$$= 9 \times 10^9 \frac{50 \times 10^{-12}}{27 \times 5^{3/2}}\left(-6\hat{i} + 3\hat{j}\right) \quad (16)$$

$$= 1.49071 \times 10^{9-12}\left(-6\hat{i} + 3\hat{j}\right) \quad (17)$$

Therefore,

$$\vec{F} = 1.49071 \times 10^{-3}\left(-6\hat{i} + 3\hat{j}\right) \quad (18)$$

$$\vec{F} = 1.49071 \times 10^{-3}\left(-6\hat{i} + 3\hat{j}\right) \quad (19)$$

Therefore,

$$F_x = -6 \times 1.49071 \times 10^{-3}\text{N} = -8.94427mN$$

$$F_y = 3 \times 1.49071 \times 10^{-3}\text{N} = 4.47214mN$$

$$\vec{E}_{12} = \frac{K q_1}{r_{12}^3}\vec{r}_{12}$$

$$\vec{E}_{21} = \frac{K q_2}{r_{21}^3}\vec{r}_{21}$$

Assignment 1:

1. Find the electric field **E12** at q2 due to q1.
   From the electric field find the force on q2 due to q1.
2. Find the electric field **E21** at q1 due to q2.
   From the electric field find the force on q1 due to q2.

Compare these two forces and comment. Do the forces obey Newton's third law of motion

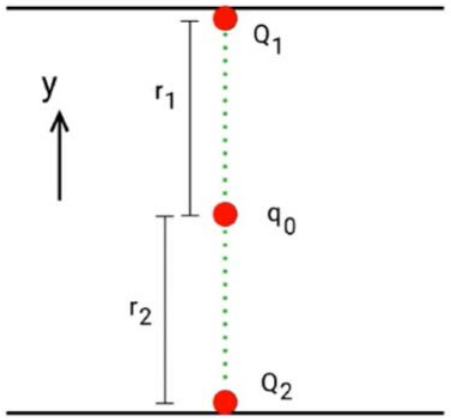


Figure: Test charge in the middle (can move). Other charges are fixed (cannot move).

Find the relation between r1 and r2 when q0 is in equilibrium

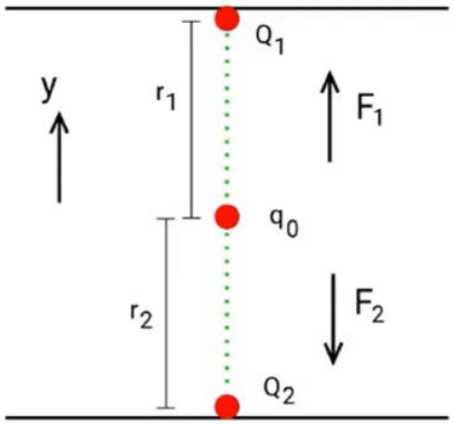


Figure: Test charge in the middle. Forces is along opposite direction when q_0 has $-ve$ charge and Q_1, Q_2 is positive.

Say the charges are,

$$q_0 = -10nC \tag{1}$$

$$Q_1 = Q_2 = 20\mu C \tag{2}$$

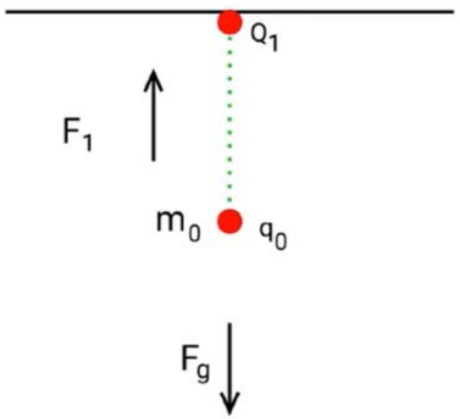
Therefore, intuitively $F_1 = F_2$ in *magnitude*.
Q_1 also feels force due to other two charges q_0, Q_2 and same goes for Q_2.

$$F_1 = F_2 \tag{3}$$

$$k\frac{q_0 Q_1}{r_1^2} = k\frac{q_0 Q_2}{r_2^2} \tag{4}$$

Since $Q_1 = Q_2$ we have $r_1 = r_2$. If r_1 is $1cm$ then r_2 will be $1cm$. A slight deviation from the middle will make q_0 go toward the closer charge due to attractive force.

What if we replace Q_2 from the picture and get **gravity** in the picture



Same as before. but we have to take the mass m_0 of object q_0 into account.

$$F_1 = F_g \tag{15}$$

$$k\frac{q_0 Q_1}{r_1^2} = m_0 g \tag{16}$$

$$\tag{17}$$

Say we want to keep it $r_1 = 1m$ apart in $g = 9.8m/s^2$ gravitational field then

$$k\frac{q_0 Q_1}{r_1^2} = m_0 g \tag{18}$$

$$m_0 = k\frac{q_0 \times Q_1}{g} \tag{19}$$

$$= 9 \times 10^9 \times \frac{q_0 \times Q_1}{9.8} \tag{20}$$

$$\tag{21}$$

~~Let's use $q_0 = Q_1 = 1\mu C$~~

Let's use $q_0 = Q_1 = 1\mu C$

$$m_0 = 9 \times 10^9 \times \frac{10^{-12}}{9.8} \tag{22}$$

$$= 0.918 \times 10^{-3}\text{Kg} \tag{23}$$

$$= 0.918 \text{ gram} \tag{24}$$

Therefore we cannot use an object of arbitrary mass to keep it balanced at $r = 1m$. This can be the other way around. If the mass is given, there is a specific distance where the forces will cancel out giving no **net** force to the test charge q_0.

Problem 3: Two particles are fixed to an x-axis. Particle 1 of charge q1 = 2.1x10 (- 8) C at x = 20 cm and particle 2 of charge q2 = - 4.00q1 at x = 70 cm. At what coordinate on the axis is the net electric field produced by the particles equal to zero?

Draw Diagram

Let at $x = d$ on the x-axis the $\vec{E} = 0$

E due to $q_1 = E_1$ $\quad E_1 = \dfrac{k q_1}{(d-20)^2}$

E " " $q_2 = E_2$ $\quad E_2 = \dfrac{k q_2}{(d-70)^2}$ $\quad E = \dfrac{kq}{r^2}$

$$|E_1| = |E_2|$$

$$\frac{k|q_1|}{(d-20)^2} = \frac{k|q_2|}{(d-70)^2} \Rightarrow \frac{(d-70)^2}{(d-20)^2} = \frac{|q_2|}{|q_1|}$$

or $$\frac{(d-70)^2}{(d-20)^2} = \frac{|-4q_1|}{|q_1|} = 4$$

$$\frac{d-70}{d-20} = \pm 2$$

Considering (+)ve sign

$$\frac{d-70}{d-20} = 2 \qquad d-70 = 2d-40 \Rightarrow d = -30 \text{ cm}$$

Considering (−)ve sign

$$\frac{d-70}{d-20} = -2 \Rightarrow d-70 = -2d+40 \Rightarrow d = 36.66 \text{ cm}$$

This is not possible as at $d = 36.66$ cm although $|E_1| = |E_2|$, they are pointing in the same direction.

So at $x = -30$ cm, the net electric field is zero.