Physics 1B
Electricity & Magnetism

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1/12/12

Outline of Today

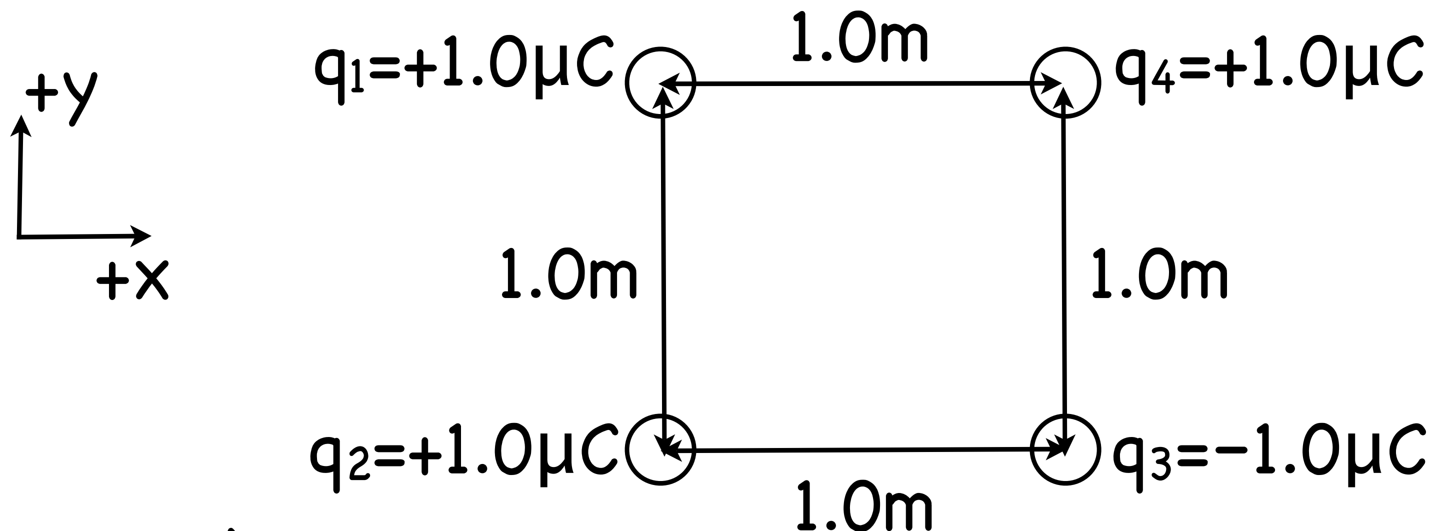
- Finish discussion of Chapter 19

Two Dimensional Electric Force Problem

4 charges in a square -> 2-dimensional problem

4 charges in a square (I)

- Calculate the net electric force (direction and magnitude) on the upper left particle (q_1) in the figure below due to the other three charges.



- Answer
- First, you must define a coordinate system.
- Let's choose up as the +y direction and to the right as the +x direction.

4 charges in a square (II)

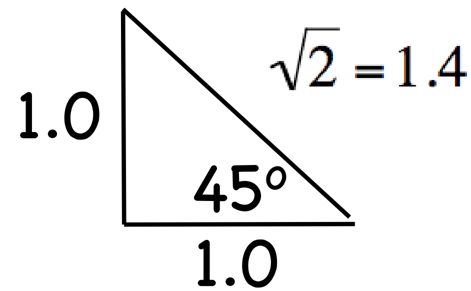
Next, let's list the quantities that we know:

$q_1 = q_2 = q_4 = +1.0\times10^{-6}$Coul

$q_3 = -1.0\times10^{-6}$Coul

$r_{12} = r_{14} = 1.0$m

$r_{13} = 1.4$m



Let's calculate each force separately. First, let's start with the force between particles 1 and 2 (note: 1 and 4 have the same values).

$$F_{12} = k_e \frac{|q_1||q_2|}{r_{12}^2} = F_{14}$$

$$F_{12} = F_{14} = \left(8.99\times10^9\ {}^{\mathrm{N\cdot m^2}}/_{\mathrm{C^2}}\right)\frac{|+1.0\times10^{-6}\mathrm{C}||+1.0\times10^{-6}\mathrm{C}|}{(1.0\mathrm{m})^2} = 9.0\times10^{-3}\mathrm{N}$$

4 charges in a square (III)

Next, let's calculate the force between particles 1 and 3.

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

$$F_{13} = \left(8.99 \times 10^9 \, {}^{\mathrm{N \cdot m^2}}\!/\!{}_{\mathrm{C^2}}\right) \frac{|+1.0 \times 10^{-6}\mathrm{C}||-1.0 \times 10^{-6}\mathrm{C}|}{(1.4\mathrm{m})^2} = 4.5 \times 10^{-3}\mathrm{N}$$

We have the magnitudes, now we need to find the directions for all three forces.

What direction will F_{12} point?

It is repulsive, so in the +y direction.

What direction will F_{14} point?

It is also repulsive, so in the −x direction.

4 charges in a square (III)

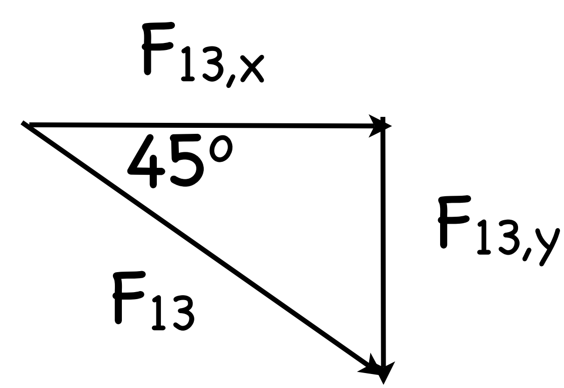
What direction will F_{13} point?

It is attractive, so 45° below the +x axis.

In order to combine these forces we should break them up into components (F_{12} and F_{14} already done).

$$F_{13,x} = F_{13}\cos 45° = 4.5\times10^{-3}\text{N}\left(\frac{\sqrt{2}}{2}\right) = 3.2\times10^{-3}\text{N}$$

$$F_{13,y} = F_{13}\sin 45° = 4.5\times10^{-3}\text{N}\left(\frac{\sqrt{2}}{2}\right) = 3.2\times10^{-3}\text{N}$$



F_{13} will have a component of 3.2×10^{-3}N in the +x direction and a component of 3.2×10^{-3}N in the –y direction.

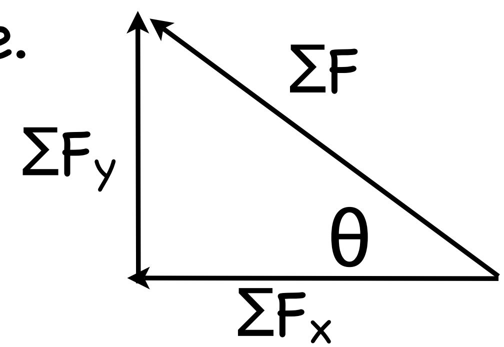
4 charges in a square (III)

Next, we should combine like components to find the net electric force in the x and y directions:

$\Sigma F_x = F_{13,x} + F_{14,x} = 3.2\times10^{-3}\text{N} - 9.0\times10^{-3}\text{N} = -5.8\times10^{-3}\text{N}$

$\Sigma F_y = F_{13,y} + F_{12,y} = -3.2\times10^{-3}\text{N} + 9.0\times10^{-3}\text{N} = +5.8\times10^{-3}\text{N}$

We would like the direction and magnitude.



$$\sum F = \sqrt{F_x^2 + F_y^2}$$

$$\sum F = \sqrt{\left(-5.8\times10^{-3}\text{N}\right)^2 + \left(5.8\times10^{-3}\text{N}\right)^2} = 8.2\times10^{-2}\text{N}$$

$$\tan\theta = \frac{F_y}{F_x} \qquad \theta = \tan^{-1}\left(\frac{5.8\times10^{-3}\text{N}}{5.8\times10^{-3}\text{N}}\right) = \tan^{-1}(1.0) = 45°$$

<- above −x axis

Definition of Electric Field

- We know that the electric force between two charges depends on both charges.
- Now imagine having only a single charge.
  - We call this charge the "source charge"
- The electric field that the source charge creates is given by the force a test charge experiences, divided by the test charge.

Same in equations
(for a point charge)

- Force: $$F(q_0) = q_0 k_e \frac{q_s}{r^2}$$

- E field: $$E = k_e \frac{q_s}{r^2}$$

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

Recap:

- This is a two-step process:

Source charge q [Coul] $\xrightarrow{\text{creates}}$ E field [N/Coul] $\xrightarrow{\text{exerts force on}}$ Test charge q_0 [Coul]

- The electric field can point in towards q OR away from q (depending on the sign of the source charge).

- The electric force can point along the electric field OR opposite the electric field (depending on the sign of the test charge).

Electric Field

- The electric field is a vector
  - It has both a magnitude and a direction
- The SI units for E is [Newton/Coulomb]
- If q_0 is negative then F and E point in opposite directions.

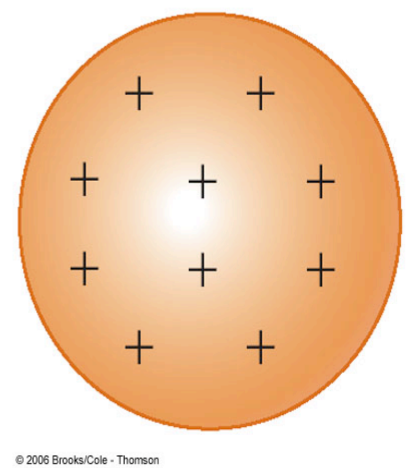
$$\vec{F}_{elec} = q_o \vec{E}$$

- A charge never feels it's own field (Newton's 3rd law)
- The direction of the E field from a point charge depends on the sign of the source charge.

Convention of E field direction

- For a positive point charge we get the following electric field at point P:

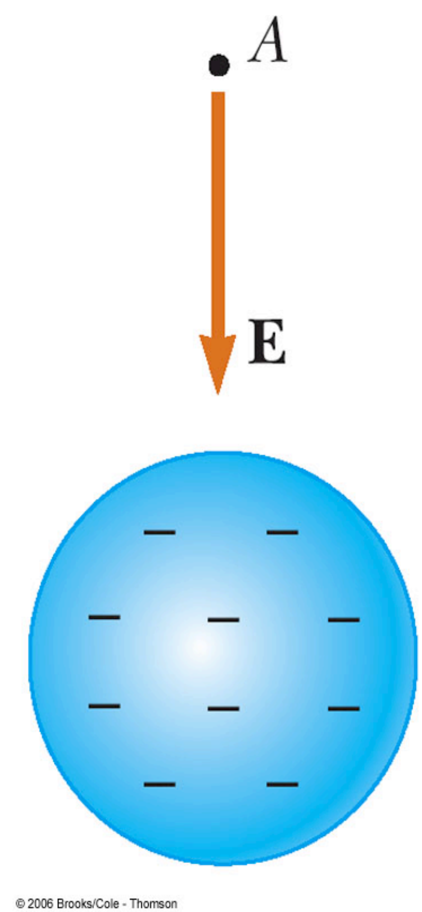
- The electric field produced by a positive charge is directed away from the source charge.
- A positive test charge would be repelled from the positive source charge.



The electric field is essentially the direction the electric force would act if a positive **test** charge of magnitude 1 Coulomb were placed there.

Convention of E field direction

For a negative point charge we get the following electric field at point A:



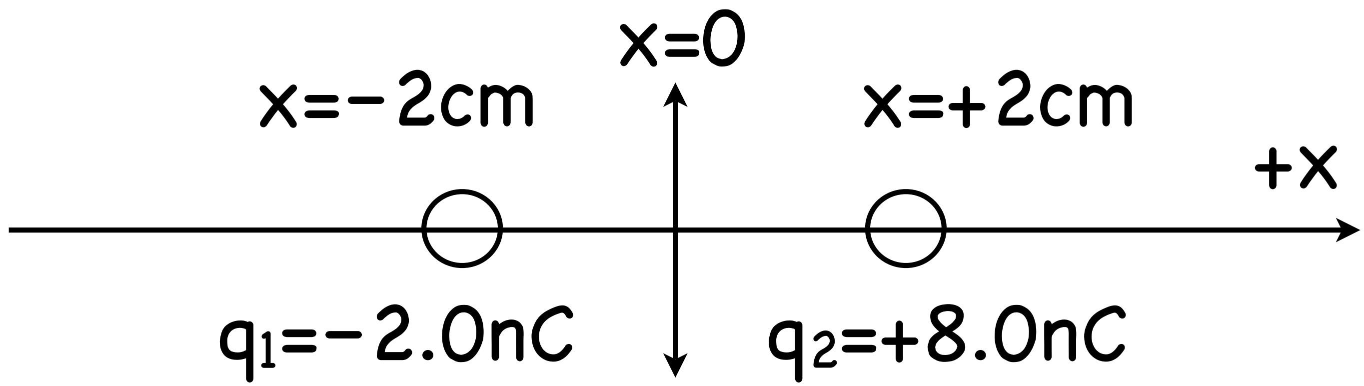
The electric field produced by a negative charge is directed toward the source charge.

A positive test charge would be attracted to the negative source charge.

Please note that the electric field exists whether or not there is a test charge present.

Example Problem:

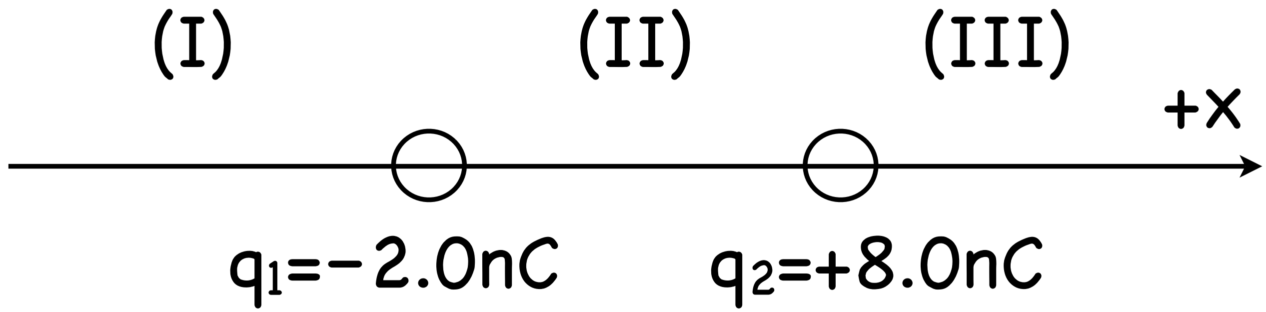
- Charged particles of −2.0nC and +8.0nC are located at x = −2.0cm and x = +2.0cm, respectively. At what point on the x-axis is the electric field equal to zero?



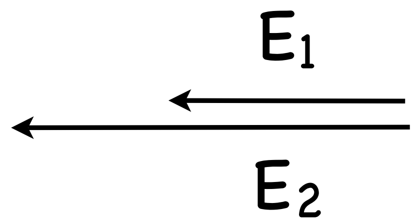
Answer

The coordinate system is already defined for you.

Let's divide the diagram into three distinct regions.

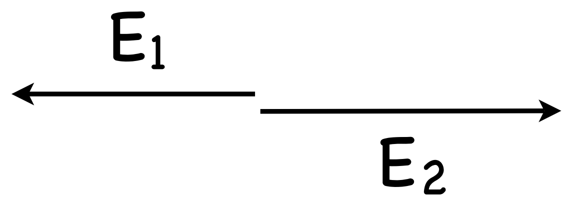


- In region (II), what direction will E_1 and E_2 be?



- Can E_1 and E_2 ever add to zero in region (II)?
- No, so the point cannot be located there.

In region (III), what direction will E_1 and E_2 be?

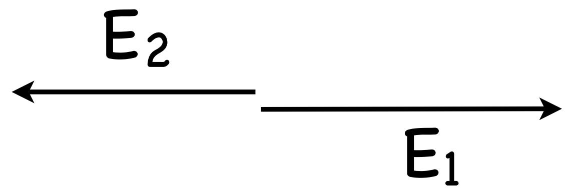


- In region (III), can E_1 and E_2 ever be equal in magnitude?

$$E_{\text{point charge}} = k_e \frac{q}{r^2}$$

- E_2 will always be greater in magnitude since it has a larger charge ($q_2 > q_1$) and will always have a smaller separation distance ($r_2 < r_1$).
- Can E_1 and E_2 ever add to zero in region (III)?
- No, so the point cannot be located there.

In region (I), what direction will E_1 and E_2 be?



In region (I), can E_1 and E_2 ever be equal in magnitude?

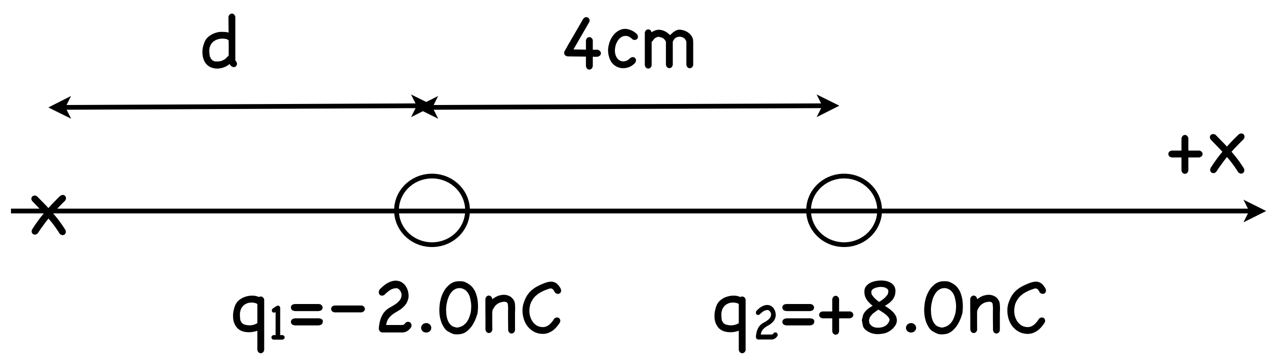
$$E_{\text{point charge}} = k_e \frac{q}{r^2}$$

E_2 will have a larger charge ($q_2 > q_1$) but E_1 will have a smaller separation distance ($r_2 > r_1$).

Can E_1 and E_2 ever add to zero in region (I)?

Yes, so the point can be located there.

So, if the point exists where $E_{tot} = 0$, it must be to the left of the charges.



Next, let's list the quantities that we know:

$q_1 = -2.0\times10^{-9}$Coul

$q_2 = +8.0\times10^{-9}$Coul

$r_1 = d$

$r_2 = d + 0.04$m

Note: we could not have completed this step without knowing what region we were in.

At this point the electric field vectors must have equal magnitude.

$$E_1 = E_2$$

$$k_e \frac{|q_1|}{r_1^2} = k_e \frac{|q_2|}{r_2^2} \qquad \frac{|q_1|}{r_1^2} = \frac{|q_2|}{r_2^2}$$

$$\frac{|-2.0\times 10^{-9}\mathrm{C}|}{d^2} = \frac{|+8.0\times 10^{-9}\mathrm{C}|}{(d+0.04\mathrm{m})^2}$$

$$(d+0.04\mathrm{m})^2 = 4d^2$$

$$(d + 0.04\mathrm{m}) = 2d$$

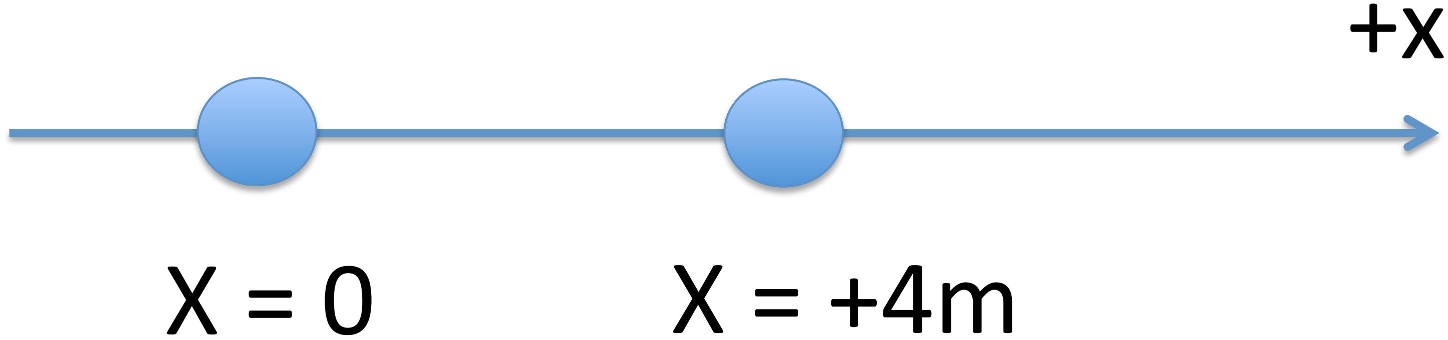
$$d = 0.04\mathrm{m}$$

Since the −2.0nC charge is at x = −2.0cm, this means that the distance d is taken from that location.

The position on the x-axis will correspond to:

x = -0.060m or -6.0cm

Symmetry and intuition
Both charges are the same



- Where on x is the E field E = 0 ?

a) X = 0
b) X = 1m
c) X = 2m
d) X = 3m
e) X = -2m
f) X = 6m

For Next Time (FNT)

- Start reading chapter 20
- Finish working on the homework for chapter 19.