Chapter 23

1

ELECTRIC FIELDS

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Lecture 03

2

Electric Field Due To Point Charges

2

Electric Field

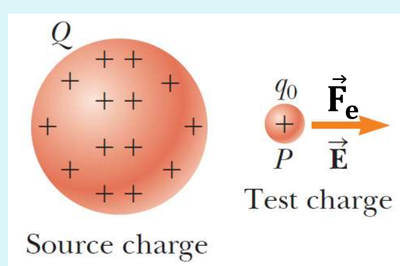
The electric force is a field force.

Field forces can act through space.

The effect is produced even with no physical contact between objects.

Electric Field – Definition

- An electric field is said to exist in the region of space around a charged object.
  - This charged object is the source charge.
- When another charged object, the test charge, enters this electric field, an electric force acts on it.
- The test charge is:
  - small
  - positive



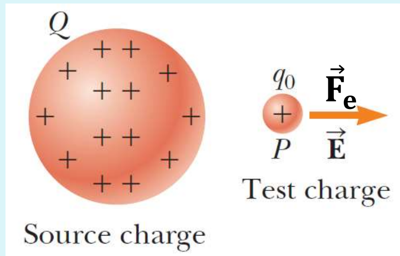
Electric Field – Definition, cont

5

- The electric field vector, $\vec{E}$, at a point in space is **defined as the electric force, $\vec{F}_e$, acting on a positive test charge, q_o,** placed at that point divided by the test charge:

$$\vec{E} = \frac{\vec{F}_e}{q_\circ} \Longleftrightarrow \vec{F}_e = q_\circ \vec{E}$$

- The **direction of E** is that of the force on a positive test charge.
- The SI units of E are N/C.



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Electric Field, Notes

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- The existence of an electric field is a property of the source charge.
  - The presence of the test charge is not necessary for the field to exist.
- The test charge serves as a detector of the field.

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Relationship Between F and E

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$$\vec{F}_e = q_\circ \vec{E}$$

- This is valid for a **point charge** only.
- If q is **positive**, the force and the field are in the **same** direction.
- If q is **negative**, the force and the field are in **opposite** directions.

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More About Electric Field Direction

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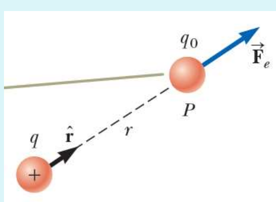
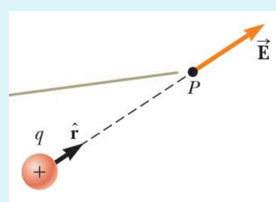


q is positive, the force is directed away from q.



The direction of the field is also away from the positive source charge.

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More About Electric Field Direction

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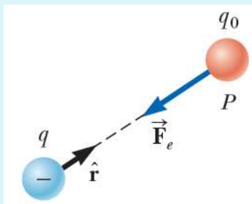
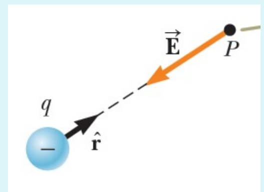


q is negative, the force is directed toward q.



The field is also toward the negative source charge.

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Electric Field Lines, Positive Point Charge

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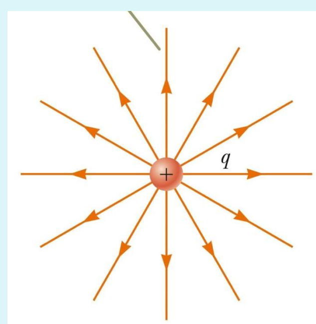
- The field lines radiate outward in all directions.
  - In three dimensions, the distribution is spherical.
- The lines are directed away from the source charge.
  - A positive test charge would be repelled away from the positive source charge.



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Electric Field Lines, Negative Point Charge

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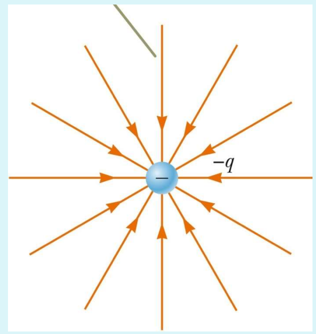
- The field lines radiate inward in all directions.
- The lines are directed toward the source charge.
  - A positive test charge would be attracted toward the negative source charge.



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Electric Field Lines – Rules for Drawing

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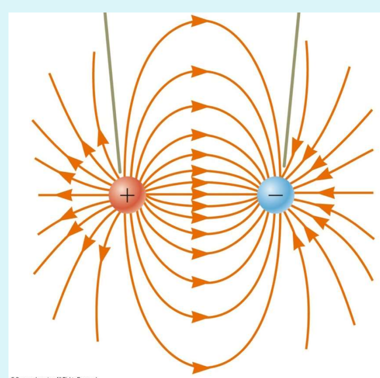
- The direction of the line is that of the force on a positive charge placed in the field.
- The lines must begin on a positive charge and terminate on a negative charge.



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Electric Field Lines – Rules for Drawing

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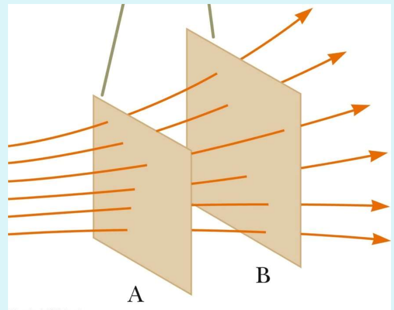
- The number of lines per unit area through a surface perpendicular to the lines is proportional to the magnitude of the electric field in that region.

•The density of lines through surface A is greater than through surface B.

•The magnitude of the electric field is greater on surface A than B.

•The lines at different locations point in different directions.

•This indicates the field is nonuniform.



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Electric Field Lines – Rules for Drawing

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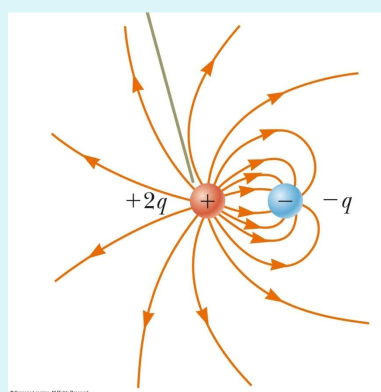
- The number of lines is proportional to the magnitude of the charge.



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Electric Field Lines – Rules for Drawing

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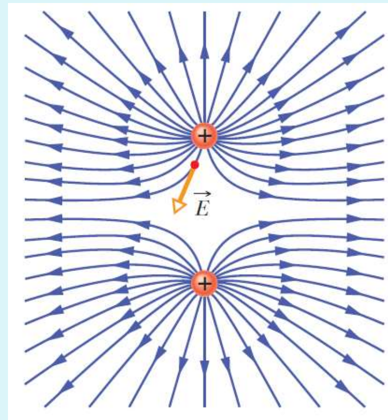
- The electric field vector is tangent to the electric field line at each point.
- No two field lines can cross.
- Remember that field lines are not material objects, they are a pictorial representation used to qualitatively describe the electric field.



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Electric Field Lines – Dipole

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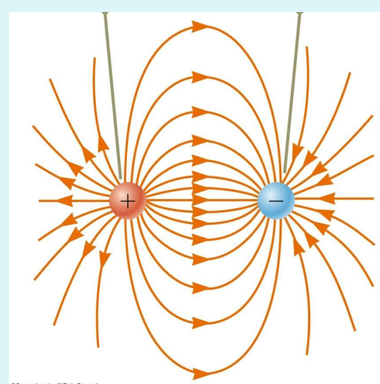
- The charges are equal and opposite.
- The number of field lines leaving the positive charge equals the number of lines terminating on the negative charge.



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Electric Field Lines – Like Charges

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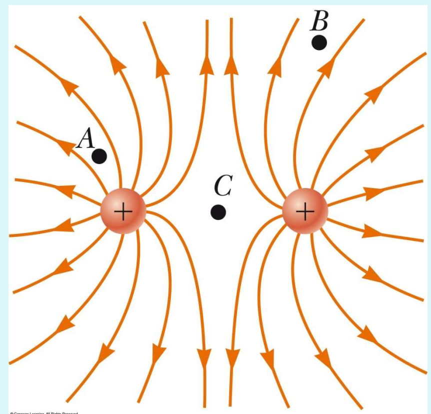
- The charges are equal and positive.
- The same number of lines leave each charge since they are equal in magnitude.
- C is a neutral point:
  - $E_C = 0$
  - $F_C = 0$



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Uniform Electric Field

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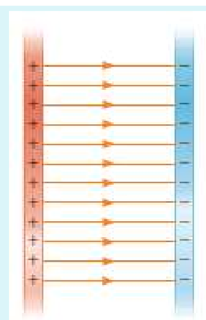
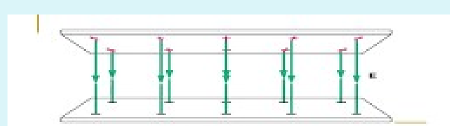
- Constant in magnitude and direction.
- Two infinite planes of charge are parallel to each other, one positively charged and the other negatively charged. The surface charge densities of both planes are of the same magnitude.





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Electric Field, Vector Form (Point Charge)

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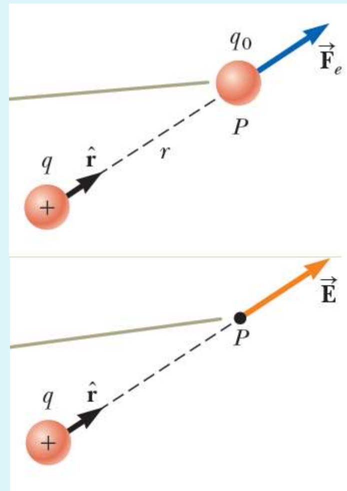
- Remember Coulomb's law, between the source and test charges, can be expressed as

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

- Then, the electric field at (p) will be:

$$\vec{E} = \frac{\vec{F}_e}{q_\circ} = \frac{k_e \frac{|q||q_\circ|}{r^2}}{q_\circ}\hat{r}$$

$$\boxed{\vec{E} = k_e \frac{q}{r^2}\hat{r}}$$



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Electric Fields from Multiple Charges

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- At any point P, the total electric field due to a group of source charges equals the vector sum of the electric fields of all the charges.

$$\vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \cdots$$

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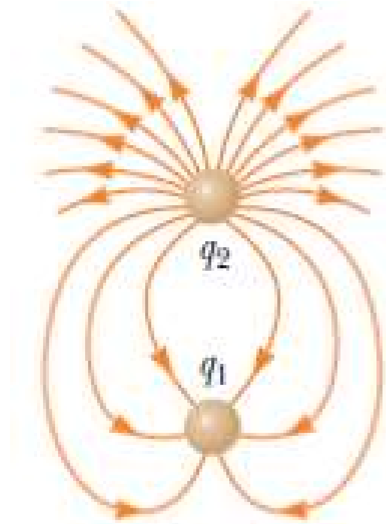
E Lines

Friday, 29 January, 2021 19:58

Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.

R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.
J. Walker, D. Halliday and R. Resnick, *Fundamentals of Physics*, 10th ed., WILEY,2014.
H. D. Young and R. A. Freedman, *University Physics with Modern Physics*, 14th ed., PEARSON, 2016.
H. A. Radi and J. O. Rasmussen, *Principles of Physics For Scientists and Engineers*, 1st ed., SPRINGER, 2013.

The figure shows the electric field lines for two charged particles separated by a small distance. Determine the ratio q_1/q_2.



Field lines emerge from positive charge and enter negative charge. The number of field lines emerging from positive q_2 and entering negative charge q_1 is proportional to their charges:

$$\frac{q_1}{q_2} = \frac{-6}{18} = -\frac{1}{3}$$

A Suspended Water Droplet

Friday, 29 January, 2021 19:54

A water droplet of mass $3 \times 10^{-12}\ kg$ is located in the air near the ground during a stormy day. An atmospheric electric field of magnitude $6 \times 10^{3}\ N/C$ 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?

Solution

The droplet is in equilibrium under the influence of two forces: the gravitational force and the electric force, such that the electric force is directed upward to balance the gravitational force. So,

$$\sum \vec{F}_y = 0 \Rightarrow \vec{F}_e + \vec{F}_g = 0 \Rightarrow F_e - F_g = 0 \Rightarrow qE = mg$$

$$q = \frac{mg}{E} = \frac{3 \times 10^{-12} \times 9.8}{6 \times 10^{3}} = 4.9 \times 10^{-15} C$$

The problem statement claims that the electric field is in the downward direction. Therefore, the charge found above is **negative so that the electric force is in the direction opposite to the electric field**, i.e. $(q = -4.9 \times 10^{-15} C)$

Find the Resultant E

Friday, 29 January, 2021 19:55

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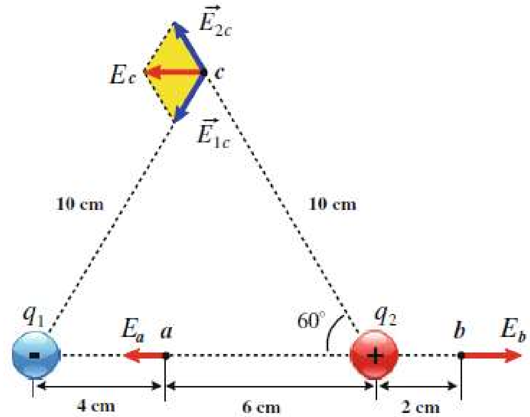
Consider two point charges $q_1 = -24\,nC$ and $q_2 = +24\,nC$ that are $10\,cm$ apart, forming an electric dipole. Calculate the electric field due to the two charges at points a, b and c.



Solution

At point (a), the electric field vector due to the negative charge q_1, is directed toward the left, and its magnitude is:

$$E_{1a} = k\frac{q_1}{r_{1a}^2} = \frac{9\times10^9\times24\times10^{-9}}{0.04^2} = 135\times10^3\ N/C$$

The electric field vector due to the positive charge q_2 is also directed toward the left, and its magnitude is:

$$E_{2a} = k\frac{q_2}{r_{2a}^2} = \frac{9\times10^9\times24\times10^{-9}}{0.06^2} = 60\times10^3\,N/C$$

Then, the resultant electric field at point a is toward the left and its magnitude is:

$$E_a = E_{1a} + E_{2a} = 135\times10^3 + 60\times10^3 = 195\times10^3\,N/C\,(Left)$$

Solution

At point b, the electric field vector due to the negative charge q_1, is directed toward the left, and its magnitude is:

$$E_{1b} = k\frac{q_1}{r_{1b}^2} = \frac{9\times10^9\times24\times10^{-9}}{0.12^2} = 15\times10^3\,N/C$$

In addition, the electric field vector due to the positive charge q_2 is directed toward the right, and its magnitude is:

$$E_{2b} = k\frac{q_2}{r_{2b}^2} = \frac{9\times10^9\times24\times10^{-9}}{0.02^2} = 540\times10^3\,N/C$$

Since $E_{2b} > E_{1b}$, the resultant electric field at point b is toward the right and its magnitude is:

$$E_b = E_{2b} - E_{1b} = 540 \times 10^3 - 15 \times 10^3 = 525 \times 10^3\ N/C\ (Right)$$

Solution

At point c, the magnitudes of the electric field vectors $\vec{E}_{1c}$ and $\vec{E}_{2c}$ established by q_1 and q_2 are the same because $|q_1| = |q_2| = +24nC$ and $r_{1c} = r_{2c} = 10cm$. Thus:

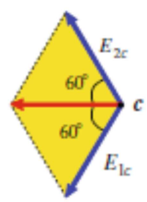
$$E_{1c} = E_{2c} = k\frac{q_1}{r_{1c}^2} = \frac{9 \times 10^9 \times 24 \times 10^{-9}}{0.1^2} = 21.6 \times 10^3\ N/C$$

The triangle formed from q_1, q_2, and point c in the figure is an equilateral triangle of angle $60°$. Hence, from geometry, the **vertical components** of the two vectors $\vec{E}_{1c}$ and $\vec{E}_{2c}$cancel each other. The **horizontal components** are both directed toward the left and add up to give the resultant electric field E_c at point c, see the figure aside. Thus:

$$E_c = E_{1c} \cos 60° + E_{2c} \cos 60° = 2E_{1c} \cos 60°$$

$$= 2 \times 21.6 \times 10^3 \times 0.5 = 21.6 \times 10^3\ N/C\ (Left)$$

$E_c = E_{1c}\cos 60° + E_{2c}\cos 60°$



E Along the Perpendicular Bisector of a Dipole Axis

Friday, 29 January, 2021 19:57

Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.

R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.

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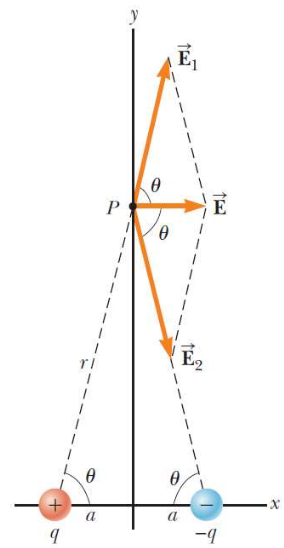

Charges $+q$ and $-q$ are located on the x axis, at distance (a) from the origin as shown.

- Find the components of the net electric field at the point P, which is at position $(0, y)$.
- Find the electric field due to the electric dipole when point P is a distance $(y \gg a)$ from the origin.

Solution

The electric field, due to the dipole at a point P lying a distance y from its center along the central axis perpendicular to the axis of the dipole, has two components:

Because of the symmetry along the y-axis:

$$E_y = 0$$

Along the x-axis, the fields due to the two charges are of the same magnitude and direction; then:

$$E_x = k\frac{q}{r^2}\cos\theta + k\frac{q}{r^2}\cos\theta = 2k\frac{q}{r^2}\cos\theta$$

Where:

$$r^2 = a^2 + y^2\ , \ \cos\theta = \frac{a}{r} = \frac{a}{\sqrt{a^2+y^2}}$$

$$E_x = 2k\frac{q}{a^2+y^2}\frac{a}{\sqrt{a^2+y^2}} = \frac{2kqa}{(a^2+y^2)^{\frac{3}{2}}}$$

If $(y \gg a)$, neglect (a^2) compared with (y^2), and write the electric field as:

$$E_x = \frac{2kqa}{y^3}$$

The magnitude of the electric field created by the dipole varies as $\left(\frac{1}{r^3}\right)$, this variation also is obtained for a distant point along the x axis and for any general distant point.

★ Where Is the Net E Zero?

Friday, 29 January, 2021 19:56

Lecturer: Mustafa Al-Zyout, Philadelphia University, Jordan.

- R. A. Serway and J. W. Jewett, Jr., *Physics for Scientists and Engineers*, 9th Ed., CENGAGE Learning, 2014.
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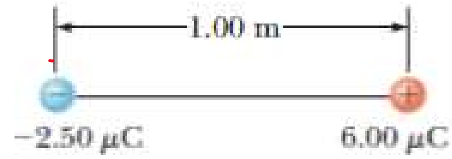
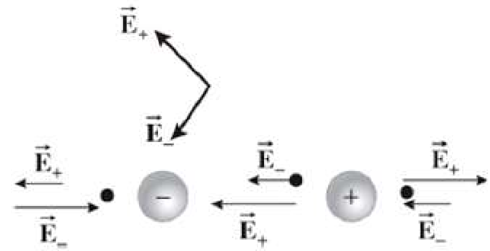
In the figure, determine the point at which the electric field is zero.



Solution:

The field of the positively-charged object is everywhere pointing radially away from its location. The object with negative charge creates everywhere a field pointing toward its different location. These two fields are directed along different lines at any point in the plane except for points along the extended line joining the particles; so the two fields cannot be oppositely directed to add to zero except at some location along this line, which we take as the x axis. Observing the figure shown, we see that at points to the left of the negatively charged object, this particle creates field pointing to the right and the positive object creates field to the left.



At some point along this segment the fields will add to zero. At locations in between the objects, both create fields pointing toward the left, so the total field is not zero. At points to the right of the positive $6\ \mu C$ object, its field is directed to the right and is stronger than the leftward field of the $-2.5\ \mu C$ object, so the two fields cannot be equal in magnitude to add to zero. We have argued that only at a certain point straight to the left of both charges can the fields they separately produce be opposite in direction and equal in strength to add to zero.

Let x represent the distance from the negatively-charged particle to the zero-field point to its left. Then $(1 + x)$ is the distance from the positive particle to this point. Each field is separately described by:

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

so the equality in magnitude required for the two oppositely-directed vector fields to add to zero is described by

$$k\frac{q_-}{x^2} = k\frac{q_+}{(1+x)^2}$$

Eliminate k_e and rearrange the equation:

$$(1+x)^2 q_- = x^2 q_+$$

$$(1 + 2x + x^2)(2.5 \times 10^{-6} C) = x^2(6 \times 10^{-6} C)$$

Reduce the quadratic equation to a simpler form:

$$3.5x^2 - 5x - 2.5 = 0$$

Solve the quadratic equation for the positive root: $x = 1.82m$

So, x = 1.82 m to the left of the negatively-charged object.