ELECTRIC FIELD AND APPLICATIONS

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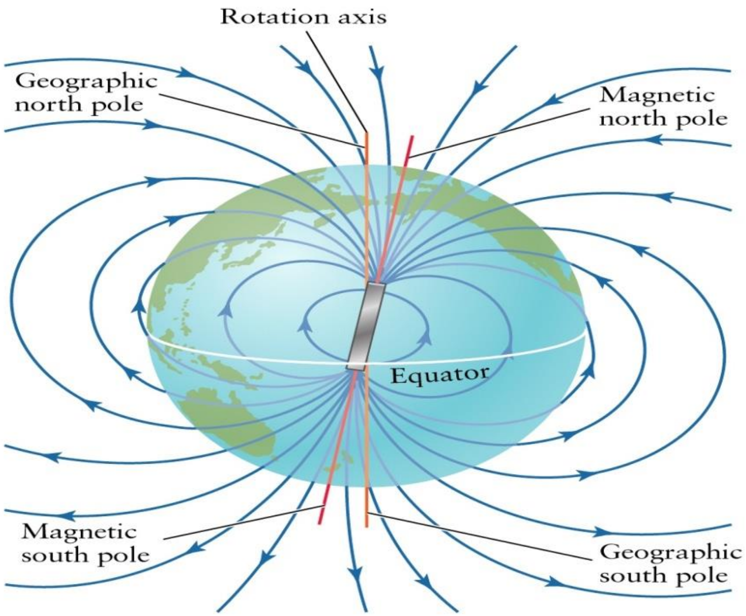
TYPE OF FORCES

Contact forces

- Pushing a car up a hill or kicking a ball or pushing a desk across a room are some of the everyday **examples** where **contact forces** are at work

Field Forces

- **Examples** of **force fields** include magnetic **fields**, gravitational **fields**, and electrical **fields**.



ELECTRIC FIELD

- The concept of a field was developed by Michael Faraday (1791–1867) in the context of electric forces.
- An **electric field is said to exist** in the region of space around a charged object, the **source charge.**
- The presence of the electric field can be detected by placing a **test charge in the field and noting the** electric force on it.
- the electric field vector E at a point in space is defined as the electric force Fe acting on a positive test charge q_0 placed at that point divided by the test charge:

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

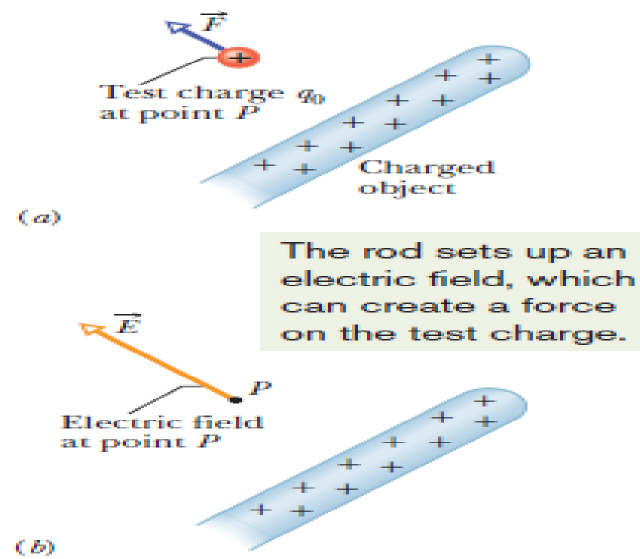
ELECTRIC FIELD

- It's a vector field
- We define the electric field at point *P due to the charged object as*

$$\vec{E} = \frac{\vec{F}}{q_0} \qquad \text{(electric field).}$$

Thus, the magnitude of the electric field $\vec{E}$ at point P is $E = F/q_0$, and the direction of $\vec{E}$ is that of the force $\vec{F}$ that acts on the *positive* test charge. As shown in Fig b

The SI unit for the electric field is the Newton per coulomb (N/C).



PURPOSE OF A TEST CHARGE

- Note that E is the field produced by some charge or charge distribution separate from the test charge—it is not the field produced by the test charge itself.
- Also, note that the existence of an electric field is a property of its source—the presence of the test charge is **not necessary** for the field to exist.
- The test charge serves as a **detector of the electric field.**

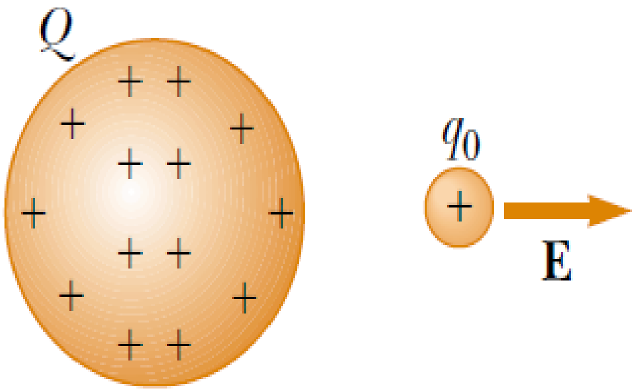


Figure A small positive test charge q_0 placed near an object carrying a much larger positive charge Q experiences an electric field **E** directed as shown.

ELECTRIC FIELD DUE TO A POINT CHARGE

- consider a point charge ***Q*** *as a* **source charge**.
- this charge creates an **electric field** at all points in space surrounding it.
- A **test charge** q is placed at point P, a **distance r** from the **source charge**
- We imagine using the test charge to determine the direction of the electric force and, therefore that of the electric field
- However, the electric field does not depend on the existence of the test charge—it is established solely by the source charge.

Electric Field due to a Point Charge

- According to Coulomb's law, the force exerted by *q on the test* charge is:

$$\vec{F}_e = \frac{1}{4\pi\epsilon_o}\frac{Qq}{r^2}\hat{r}$$

- The electric field at *P, the position* of the test charge, is defined by,

$$\vec{E} = \frac{\vec{F}_e}{q}$$

- Substituting the value of Fe in Electric field equation we will get

$$\vec{E} = \frac{1}{4\pi\epsilon_o}\frac{Qq}{r^2}\hat{r}\left(\frac{1}{q}\right)$$

$$\boxed{\vec{E} = \frac{1}{4\pi\epsilon_o}\frac{Q}{r^2}\hat{r}}$$

Electric field created by source charge Q

TO CALCULATE E-FIELD BY GROUP OF CHARGES

- To calculate the electric field at a point P due to a group of point charges, we first calculate the electric field vectors at P individually using Equation, $\vec{E} = \frac{1}{4\pi\epsilon_o}\frac{Q}{r^2}\hat{r}$ and then add them algebraically (in vector form).

Or in other words….

- ***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.***
- Thus, the electric field at point *P due to a group* of source charges can be expressed as the vector sum,

$$\boxed{\vec{E} = \frac{1}{4\pi\epsilon_o}\sum_{i}^{n}\frac{Q}{{r_i}^2}\hat{r_i}}$$

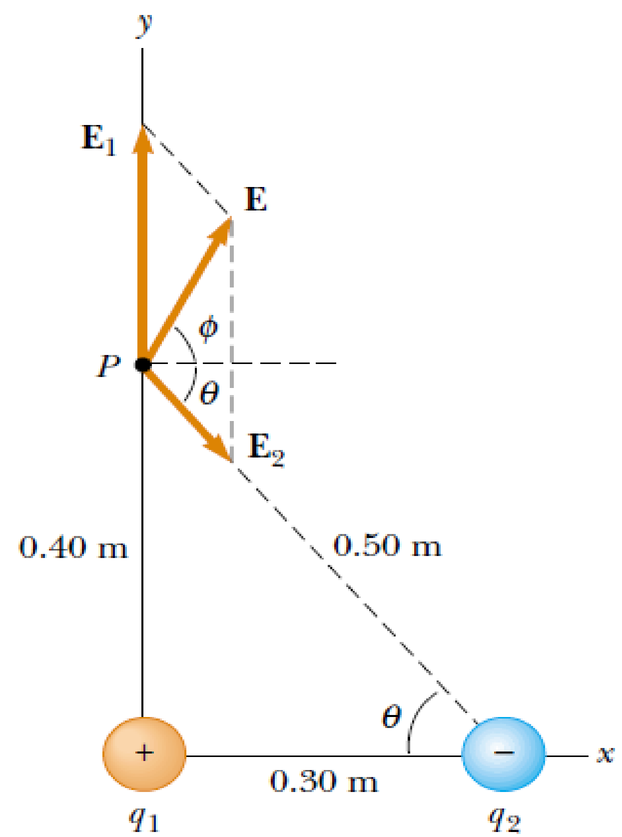
FIELD DUE TO TWO CHARGES (DUE TO POINT CHARGE)

A charge $q_1 = 7.0\ \mu C$ is located at the origin, and a second charge $q_2 = -5.0\ \mu C$ is located on the x axis, 0.30 m from the origin (Fig.) Find the electric field at the point P, which has coordinates (0, 0.40) m.

Solution First, let us find the magnitude of the electric field at P due to each charge. The fields $\mathbf{E}_1$ due to the 7.0-μC charge and $\mathbf{E}_2$ due to the -5.0-μC charge are shown in Their magnitudes are

$$E_1 = k_e \frac{|q_1|}{r_1^2} = (8.99 \times 10^9\ \mathrm{N \cdot m^2/C^2}) \frac{(7.0 \times 10^{-6}\ \mathrm{C})}{(0.40\ \mathrm{m})^2}$$
$$= 3.9 \times 10^5\ \mathrm{N/C}$$

$$E_2 = k_e \frac{|q_2|}{r_2^2} = (8.99 \times 10^9\ \mathrm{N \cdot m^2/C^2}) \frac{(5.0 \times 10^{-6}\ \mathrm{C})}{(0.50\ \mathrm{m})^2}$$
$$= 1.8 \times 10^5\ \mathrm{N/C}$$



The total electric field $\mathbf{E}$ at P equals the vector sum $\mathbf{E}_1 + \mathbf{E}_2$, where $\mathbf{E}_1$ is the field due to the positive charge q_1 and $\mathbf{E}_2$ is the field due to the negative charge q_2.

The vector $\mathbf{E}_2$ has an x component given by

$$E_2 \cos\theta = \tfrac{3}{5} E_2$$

and a negative y component given by

$$-E_2 \sin\theta = -\tfrac{4}{5} E_2$$

Hence, we can express the vectors as

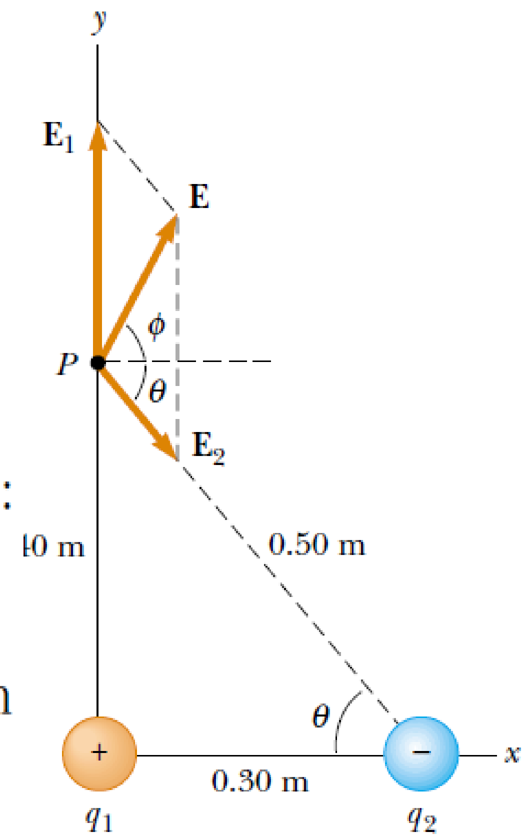
$$\mathbf{E}_1 = 3.9 \times 10^5 \hat{\mathbf{j}} \text{ N/C}$$

$$\mathbf{E}_2 = (1.1 \times 10^5 \hat{\mathbf{i}} - 1.4 \times 10^5 \hat{\mathbf{j}}) \text{ N/C}$$

$$E_1 = 3.9 \times 10^5 \text{ N/C}$$

$$E_2 = 1.8 \times 10^5 \text{ N/C}$$

The vector $\mathbf{E}_1$ has only a y component. coordinates (0, 0.40) m.



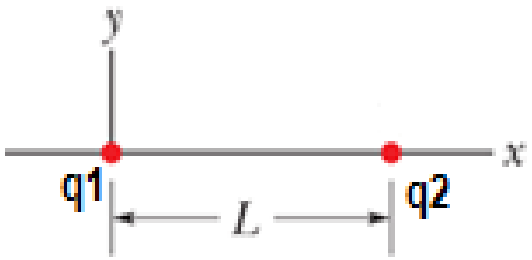
The resultant field $\mathbf{E}$ at P is the superposition of $\mathbf{E}_1$ and $\mathbf{E}_2$:

$$\mathbf{E} = \mathbf{E}_1 + \mathbf{E}_2 = (1.1 \times 10^5 \hat{\mathbf{i}} + 2.5 \times 10^5 \hat{\mathbf{j}}) \text{ N/C}$$

From this result, we find that $\mathbf{E}$ makes an angle ϕ of 66° with the positive x axis and has a magnitude of 2.7×10^5 N/C.

Example:

Particle 1 of charge q_1 = -5q and particle 2 of charge q_2 = +2q are fixed to an x-axis. As a multiple of distance L, at what coordinate on the axis is the net electric field of the particles is zero?



At points left of q1 (on the −x axis) the field point in opposite directions, but there is no possibility of cancellation (zero net field) since **|E1| is everywhere bigger than |E2|** in this region. In the region between the charges.

At points to the right of q2 (where x>L), E1 points leftward and E2 points rightward so the net field in this range is:

Enet=(|E2|−|E1|)i

Although |q1|>q2 there is the possibility of Enet=0 since these points are closer to q2 than to q1.

Thus, we look for the zero net field point in the **x>L** region:

$$|\vec{E}_1| = |\vec{E}_2| \Rightarrow \frac{1}{4\pi\varepsilon_0}\frac{|q_1|}{x^2} = \frac{1}{4\pi\varepsilon_0}\frac{q_2}{(x-L)^2}$$

which leads to

$$\frac{x-L}{x} = \sqrt{\frac{q_2}{|q_1|}}$$

$$= \sqrt{\frac{2}{5}}$$

Thus, we obtain $x = \dfrac{L}{1-\sqrt{2/5}} \approx 2.72\,L.$

Example:

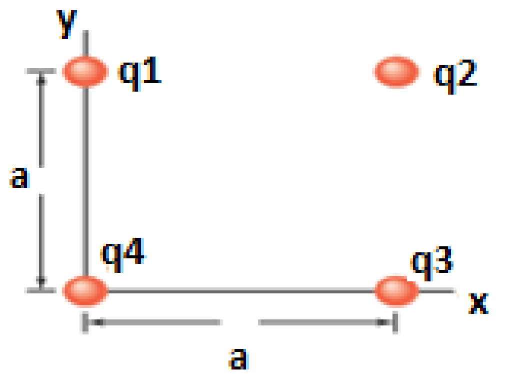
The four particles form a square of edge length a = 5.00 cm and have charges q1 = 10.0 nC, q2 = - 20.0 nC, q3 = 20.0 nC, and q4 = -10.0 nC. In unit vector notation, what net electric field do the particles produce at the square's center?

The x component of the electric field at the center of the square is given by

$$E_x = \frac{1}{4\pi\varepsilon_0}\left[\frac{|q_1|}{(a/\sqrt{2})^2} + \frac{|q_2|}{(a/\sqrt{2})^2} - \frac{|q_3|}{(q/\sqrt{2})^2} - \frac{|q_4|}{(a/\sqrt{2})^2}\right]\cos 45°$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{1}{a^2/2}(|q_1| + |q_2| - |q_3| - |q_4|)\frac{1}{\sqrt{2}}$$

$$= 0.$$



Similarly, the y component of the electric field is

$$E_y = \frac{1}{4\pi\varepsilon_0}\left[-\frac{|q_1|}{(a/\sqrt{2})^2} + \frac{|q_2|}{(a/\sqrt{2})^2} + \frac{|q_3|}{(q/\sqrt{2})^2} - \frac{|q_4|}{(a/\sqrt{2})^2}\right]\cos 45°$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{1}{a^2/2}(-|q_1| + |q_2| + |q_3| - |q_4|)\frac{1}{\sqrt{2}}$$

$$= \frac{(8.99\times 10^9 \mathrm{N.m^2/C^2})(2.0\times 10^{-8}\mathrm{C})}{(0.050\ \mathrm{m})^2/2}\frac{1}{\sqrt{2}} = 1.02\times 10^5 \mathrm{N/C}$$

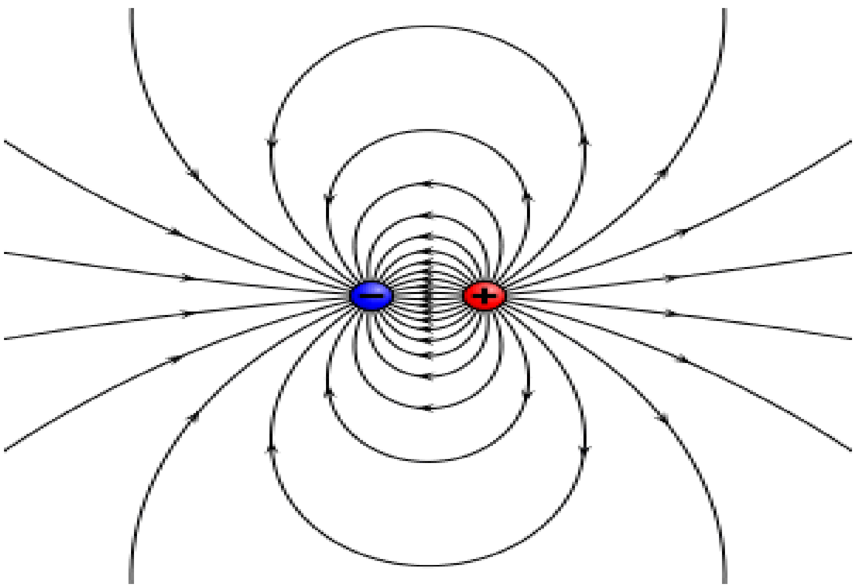
Thus, the electric field at the center of the square is $\vec{E} = E_y\hat{j} = (1.02\times 10^5 \mathrm{N/C})\hat{j}$.

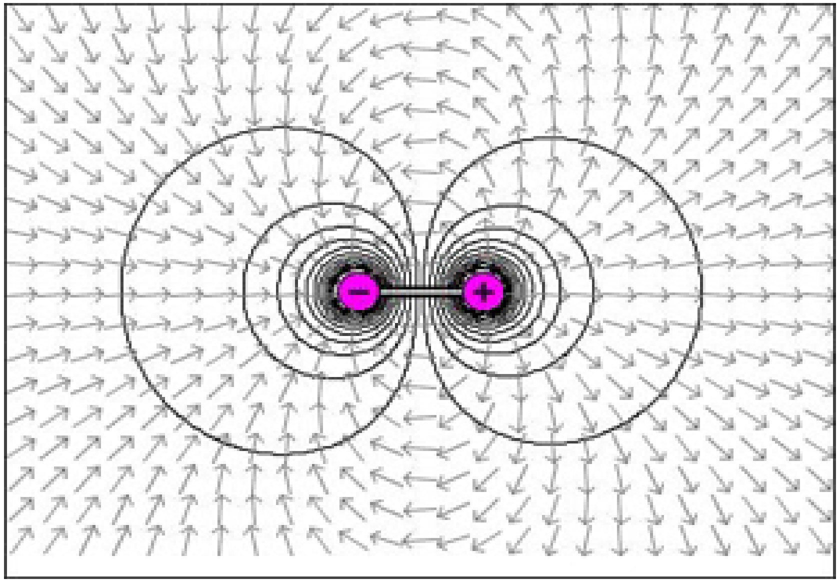
The net electric field is depicted in the figure below (not to scale). The field. pointing to the +y direction, is the vector sum of the electric fields of individual charges.

ELECTRIC DIPOLE & DIPOLE MOMENT

- **Electric Dipole**: Two **equal and opposite** point charges attached at a **fixed distance** is called Electric dipole.
- **Dipole Moment**: when the pair of these charges are placed in electric field they experience a turning effect this turning effect is known as **dipole moment**.

$$\vec{P} = 2ql$$





Electric Field due to Dipole

An **electric dipole** is defined as a positive charge q and a negative charge $-q$ separated by a distance $2a$. For the dipole shown in Figure , find the electric field $\mathbf{E}$ at P due to the dipole, where P is a distance $y \gg a$ from the origin.

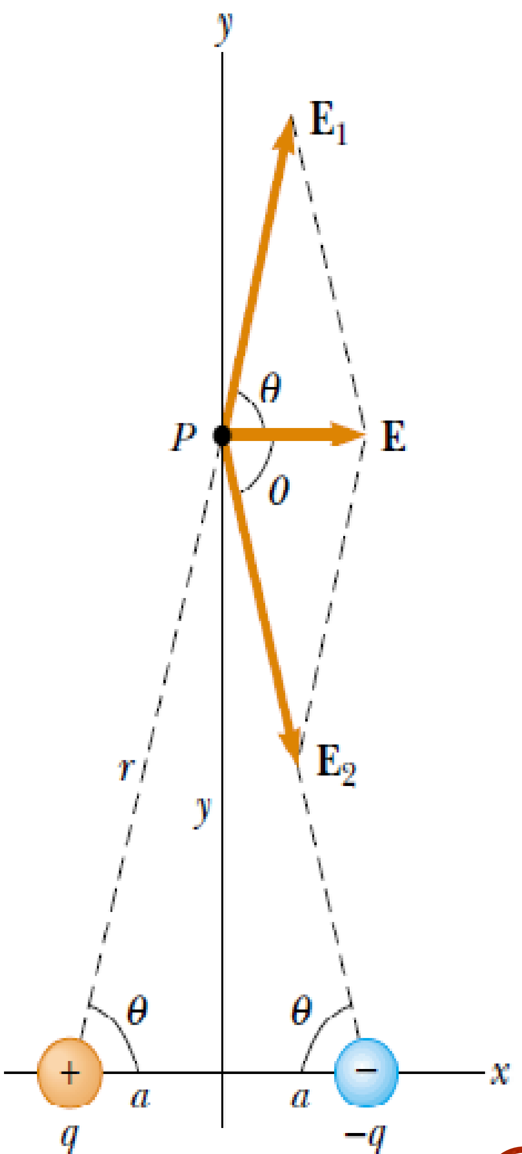


Figure The total electric field $\mathbf{E}$ at P due to two charges of equal magnitude and opposite sign (an electric dipole) equals the vector sum $\mathbf{E}_1 + \mathbf{E}_2$. The field $\mathbf{E}_1$ is due to the positive charge q, and $\mathbf{E}_2$ is the field due to the negative charge $-q$.

Solution At P, the fields $\mathbf{E}_1$ and $\mathbf{E}_2$ due to the two charges are equal in magnitude because P is equidistant from the charges. The total field is $\mathbf{E} = \mathbf{E}_1 + \mathbf{E}_2$, where

$$E_1 = E_2 = k_e \frac{q}{r^2} = k_e \frac{q}{y^2 + a^2}$$

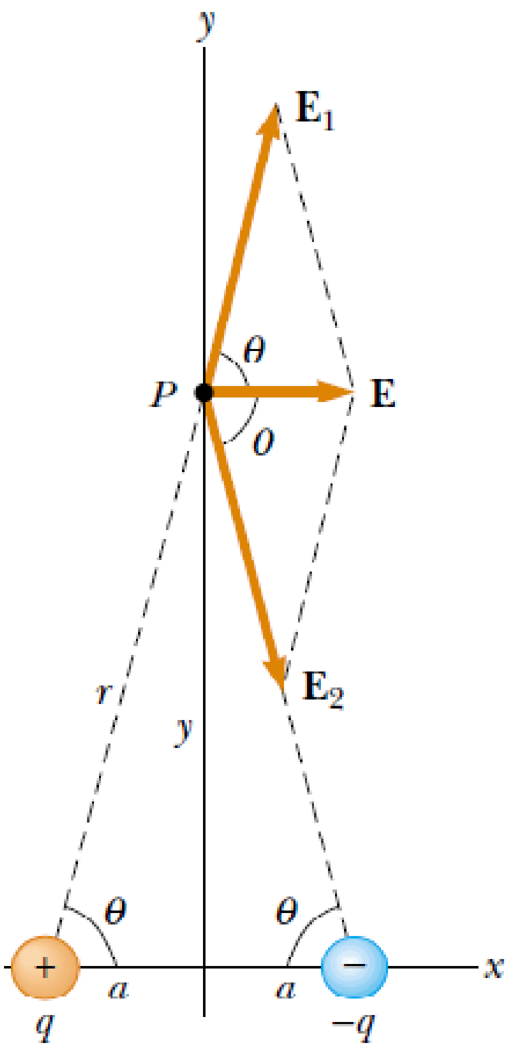
The y components of $\mathbf{E}_1$ and $\mathbf{E}_2$ cancel each other, and the x components are both in the positive x direction and have the same magnitude. Therefore, $\mathbf{E}$ is parallel to the x axis and has a magnitude equal to $2E_1 \cos\theta$. From Figure we see that $\cos\theta = a/r = a/(y^2 + a^2)^{1/2}$. Therefore,

$$E = 2E_1 \cos\theta = 2k_e \frac{q}{(y^2 + a^2)} \frac{a}{(y^2 + a^2)^{1/2}}$$

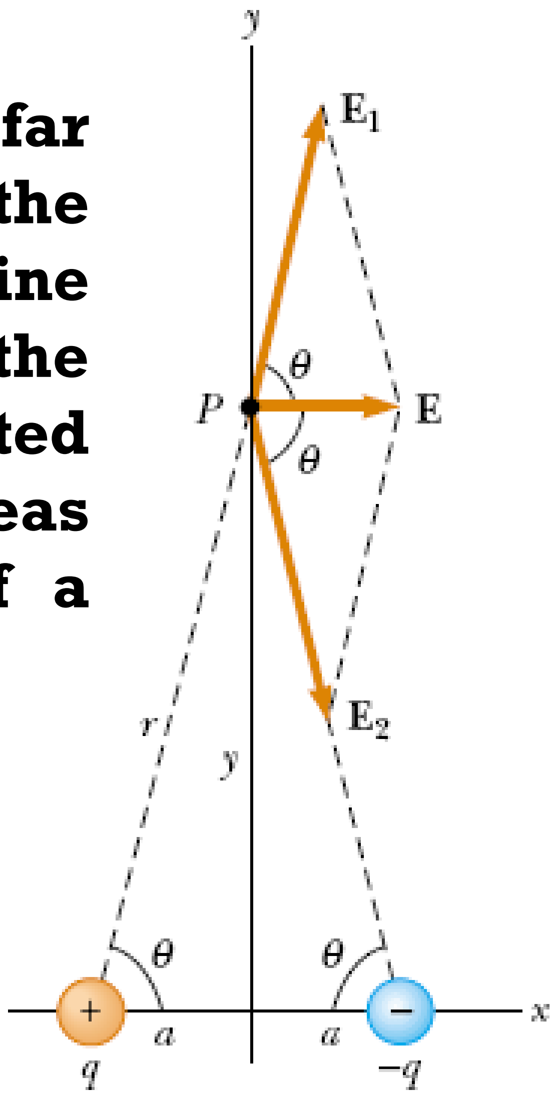
$$= k_e \frac{2qa}{(y^2 + a^2)^{3/2}}$$

Because $y \gg a$, we can neglect a^2 compared to y^2 and write

$$E \approx \boxed{k_e \frac{2qa}{y^3}}$$



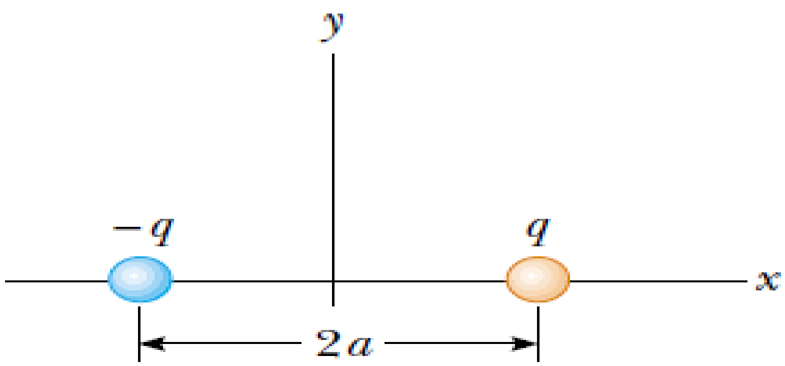
Thus, we see that, at distances far from a dipole but along the perpendicular bisector of the line joining the two charges, the magnitude of the electric field created by the dipole varies as $1/r^3$, whereas the more slowly varying field of a point charge varies as $1/r^2$.



Home Work

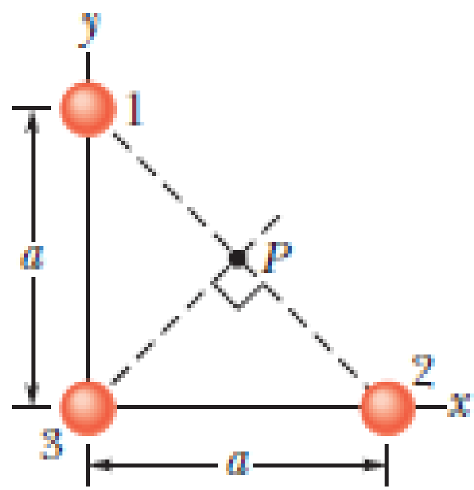
Q 1 Two 2.00-μC point charges are located on the x axis. One is at $x = 1.00$ m, and the other is at $x = -1.00$ m. (a) Determine the electric field on the y axis at $y = 0.500$ m. (b) Calculate the electric force on a -3.00-μC charge placed on the y axis at $y = 0.500$ m.

Q 2 Consider the electric dipole shown in Figure. Show that the electric field at a *distant* point on the $+x$ axis is $E_x \approx 4k_e qa/x^3$.



Figure

Q-3 In Fig, the three particles are fixed in place and have charges q1=q2=+e and q3=+2e. Distance a=6.00μm. What are the magnitude and direction ff net electric field at point P due to particles?



Q-4 A charge q1=7μC is located at the origin and a second charge q2=−5μC is located on the x-axis, 0.30m from the origin. Find the electric field at the point P which has coordinates (0,0.40)m.