Introduction to Electric Fields

How is it that two charged objects interact without contact?

- The source charge somehow alters the space around them. This alteration is the electric field.
- The (ficticious) test charge experiences a force from the field.

This is a hypothesis about electrical interactions.

Regarding the ELECTRIC FIELD:

- The field exists at all points in space, even though diagrams may show only a few illustrative vectors.
- The field at each point in space is a vector. It causes a test charge to experience a force in a particular direction.
- The field is there whether the test charge is there or not. The test charge measures the field, but does not cause the field.

Electric Fields

Recall that we defined the gravitational field on a test mass, m_0, experiencing a gravitational force as:

$$\vec{g} = \frac{\vec{F}}{m_0}$$

Similarly, we define the electric field from the electric force acting on a (+) test charge, q_0, experiencing an electric force as:

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

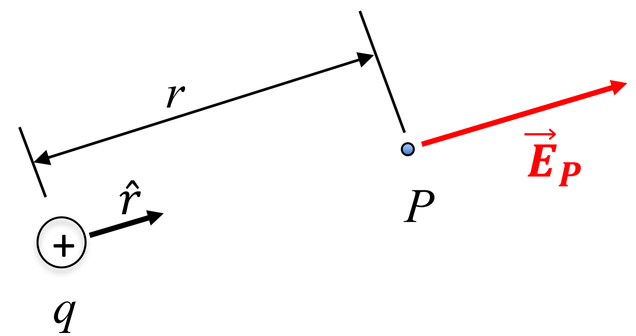
Note that **E** is external to the test charge q_0 (i.e., it is not produced by the test charge).

By assuming that the test charge is (+), the **E** has the same direction as **F**.

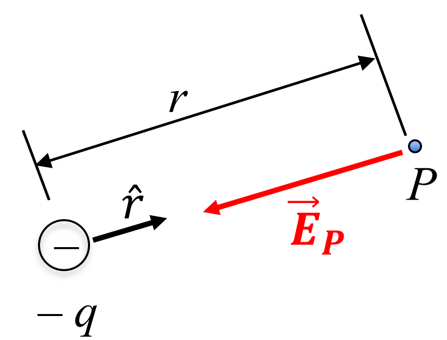
Recall Coulomb's law: $\vec{F} = \frac{kqq_0}{r^2}\hat{r}$.

F is the force between the source point charge q and the test charge q_0, and $\hat{r}$ is the unit vector that is directed from the source charge q to the test charge.

It follow then that $\vec{E} = \frac{kq}{r^2}\hat{r}$



If the source charge is negative, then the **E**-field will be directed directed toward the source charge.

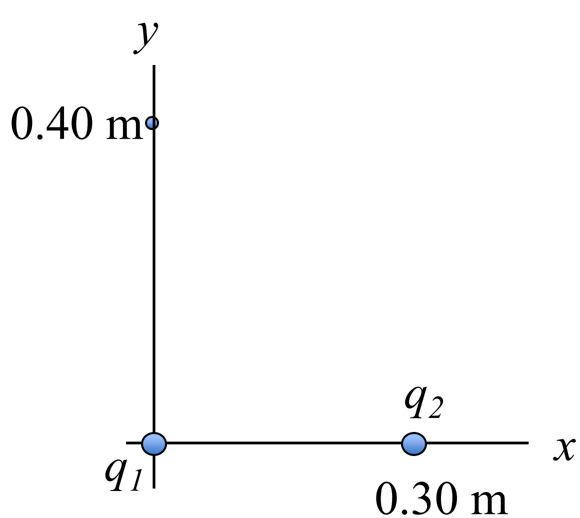


Regarding ELECTRIC FIELD DIAGRAMS:

- Electric field lines begin on + charges (or infinity) and end on – charges (or infinity).
- Electric field lines are drawn symmetrically entering or leaving an isolated point charge.
- The number of electric field lines drawn leaving a + charge or entering a – charge is directly proportional to the magnitude of the charge.
- The density of the electric field lines at any point is proportional to the magnitude of **E** at that point.
- At large distances from a system of charges, the field lines are equally spaced and radial, as if they came from a single point charge equal to the net charge of the system.
- Electric field lines do not cross.

Example #1

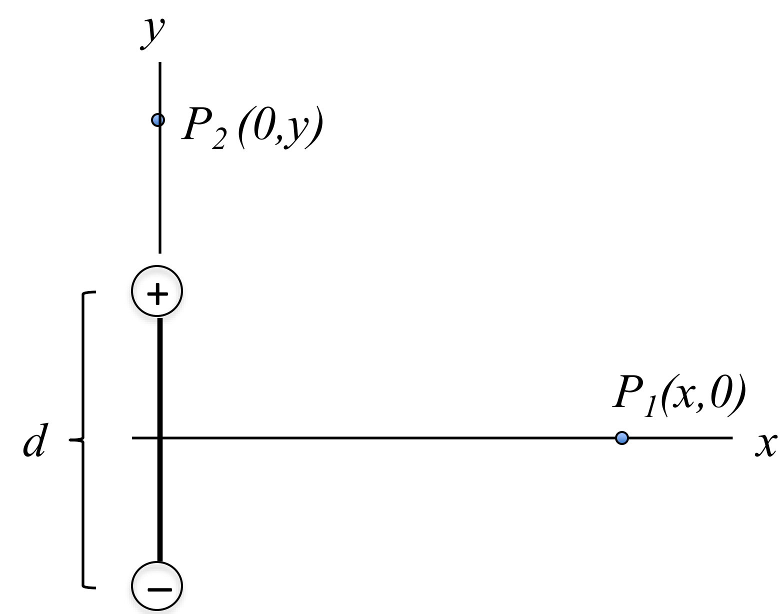
A charge $q_1 = 7.0\ \mu C$ is at the origin and a charge of $q_2 = -5.0\ \mu C$ is on the $+x$-axis 0.30 m from the origin. Calculate the magnitude and direction of the electric field at point $P = (0, 0.40m)$.



Example #2

Consider an electric dipole (two equal but opposite points charges separated by a distance *d*) oriented vertically and centered at the origin.

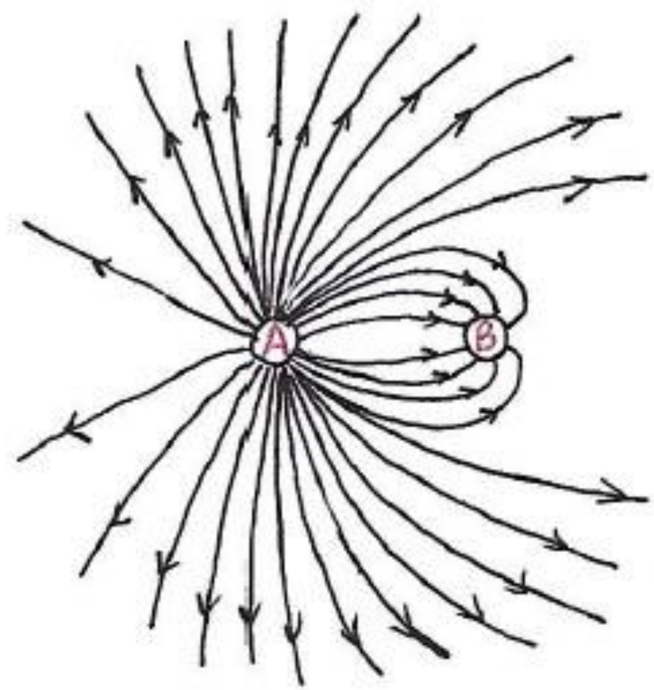
- Determine the **E**-field at any point along the *x*-axis.
- Determine the **E**-field at any point along the *y*-axis.



Example #3

Based on the rules for electric field lines, determine the ratio of the magnitude of charge *A* to charge *B* for the situation shown below.

a) 4:1
b) 3:1
c) 2:1
d) 1:1
e) Not enough info.



Example #4

Based on the rules for electric field lines, determine the ratio of the magnitude of charge *A* to charge *B* for the situation shown below.

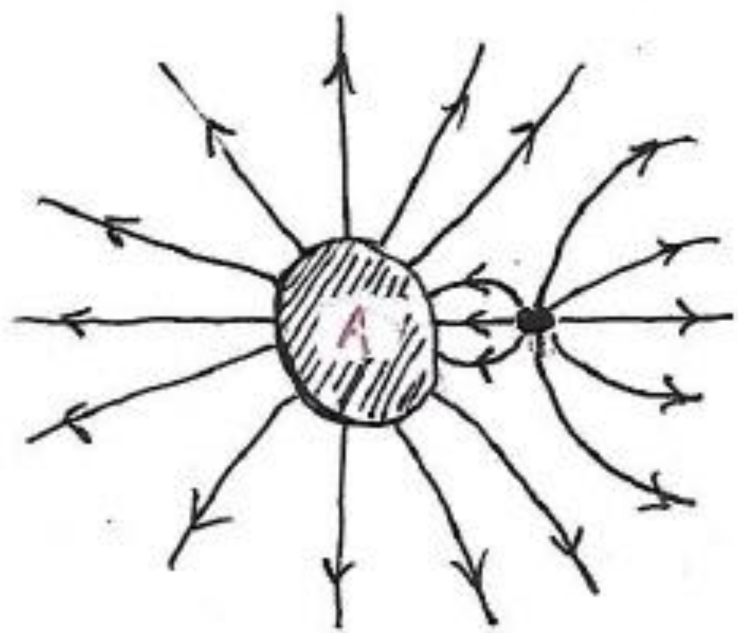
a) 14:5

b) 14:8

c) 11:5

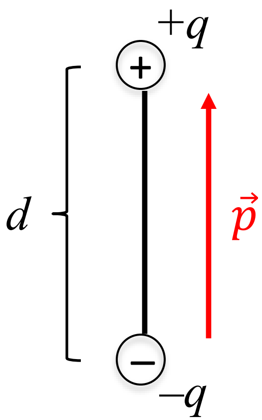
d) 11:8

e) 1:1



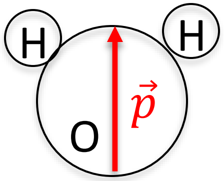
Electric Dipole

Recall an *electric dipole* consists of two equal but opposite points charges separated by a distance d:

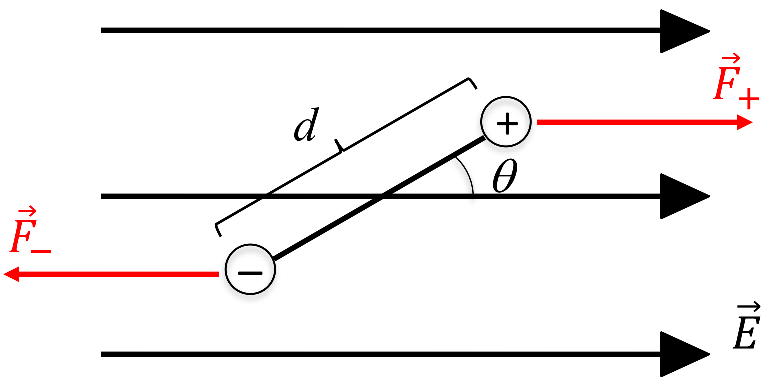


Define electric dipole moment:

$\vec{p} \equiv q\vec{d}$, (directed *from* $-q$ *to* $+q$).

Example: Water molecule: 

Electric Dipole in an (Uniform) **E**-field



$|\vec{F}_+| = |\vec{F}_-| = F$,

$\therefore$ the net force = 0.

However, the net torque $\neq 0$ $\qquad \vec{\tau} = \vec{r} \times \vec{F}$

Arbitrarily choosing to compute $\vec{\tau}$ about $-q$,

$$\sum \vec{\tau}_{q_-} = 0 - Fd\sin\theta = -qEd\sin\theta = -pE\sin\theta$$

Since $\vec{p}$ and $\vec{E}$ are vectors: $\vec{\tau} = \vec{p} \times \vec{E}$

Calculating Potential Energy

$$dW_{field} = -\tau d\theta$$

$$dU = -dW_{field} = \tau d\theta = pE\sin\theta d\theta$$

$$\Delta U = \int_{\theta_i}^{\theta_f} pE\,\sin\theta = -pE\left(\cos\theta_f - \cos\theta_i\right)$$

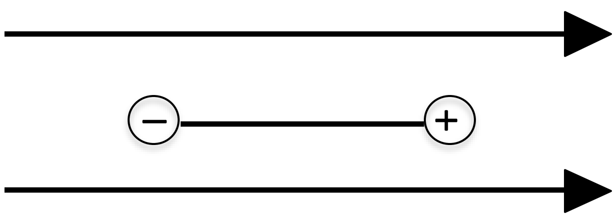
$$= -pE\cos\theta + U_0$$

Take $\theta_i = \frac{\pi}{2}$ rad. Then $U_0 = 0$ at $\theta = \frac{\pi}{2}$ rad.

$$\Delta U = -pE\cos\theta = -\vec{p}\cdot\vec{E}$$

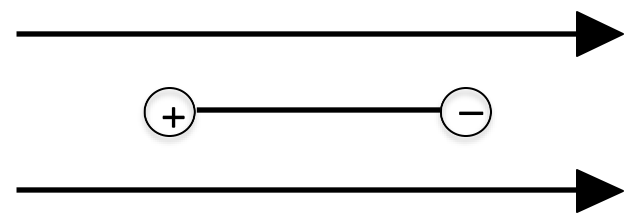
Potential Energy of Electric Dipole in a Uniform E-field

U is least when:



$(U = -pE\cos\theta)$

U is most when:



$(U = +pE\cos\theta)$

U is zero when: