# Physics for Chemical Engineers

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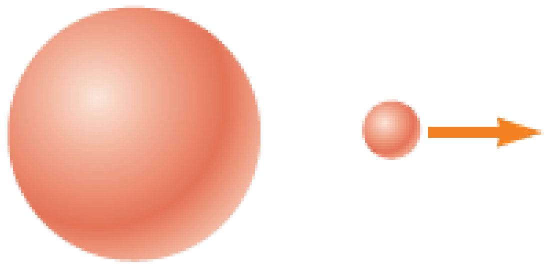
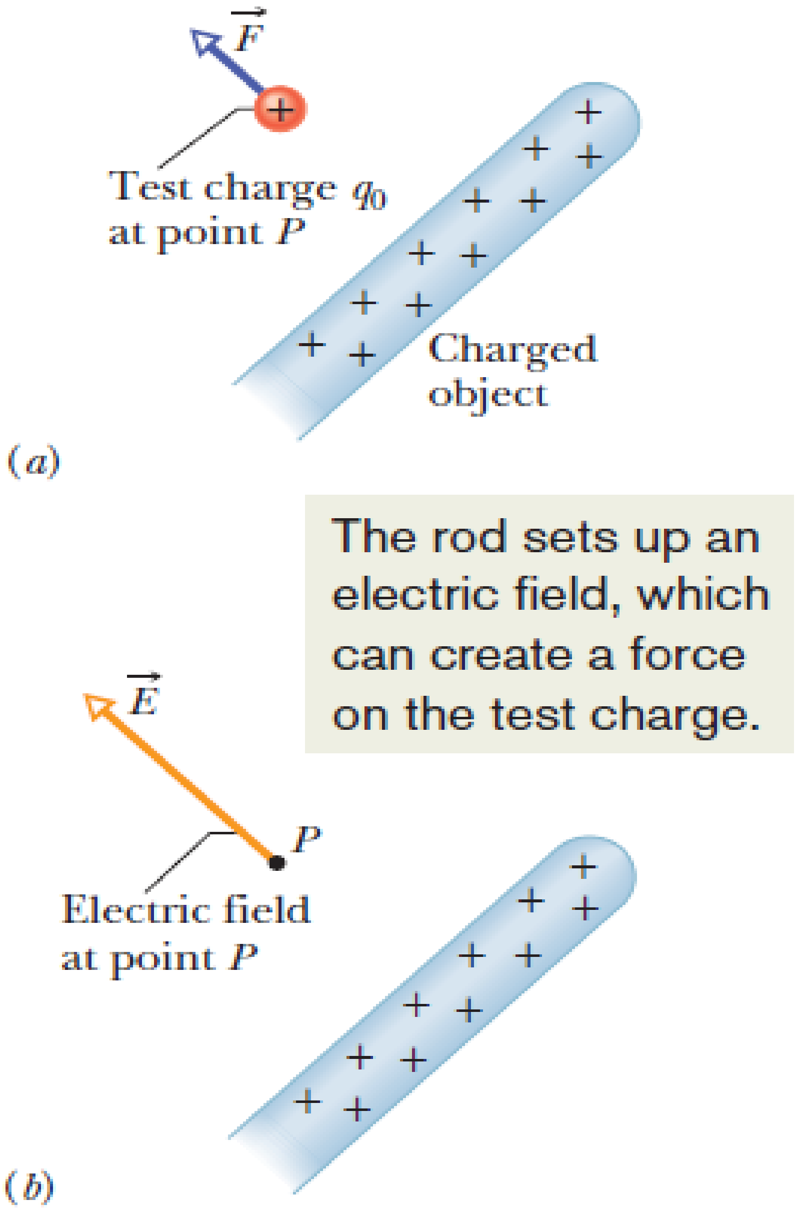
Electric field, electric field lines, electric field due to point and dipole

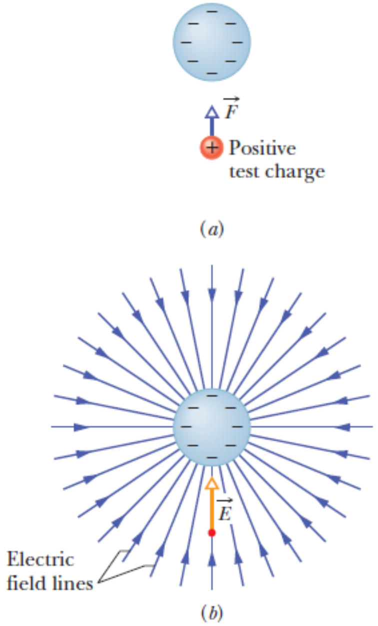
# Electric Field

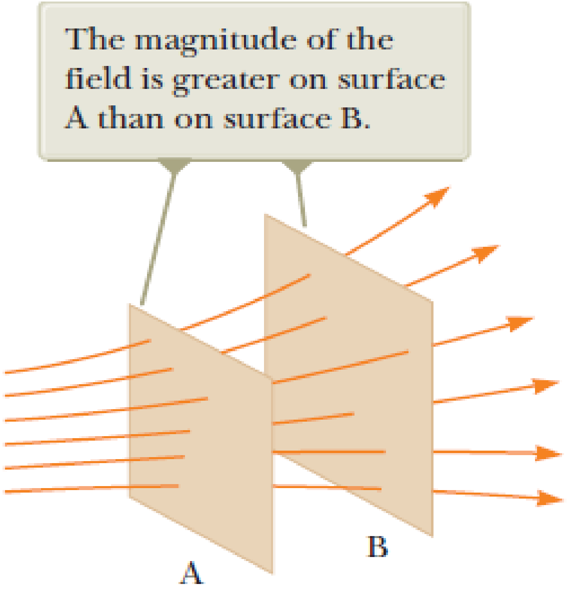
An **electric field** is said to exist in the region of space around a charged object, the **source charge.** The presence of the electric field can be detected by placing a **test charge** in the field and noting the electric force on it

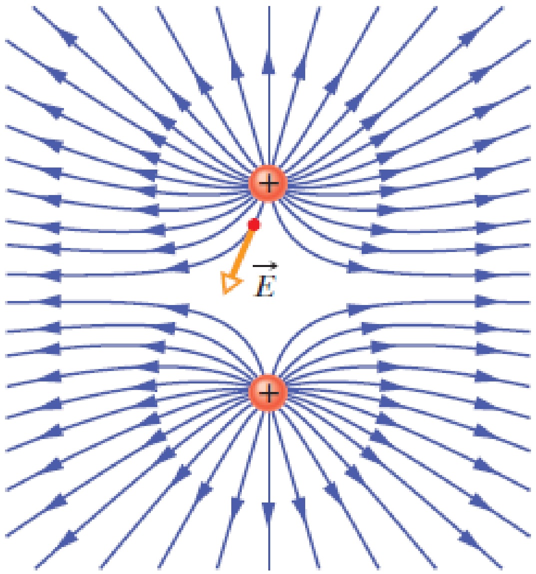


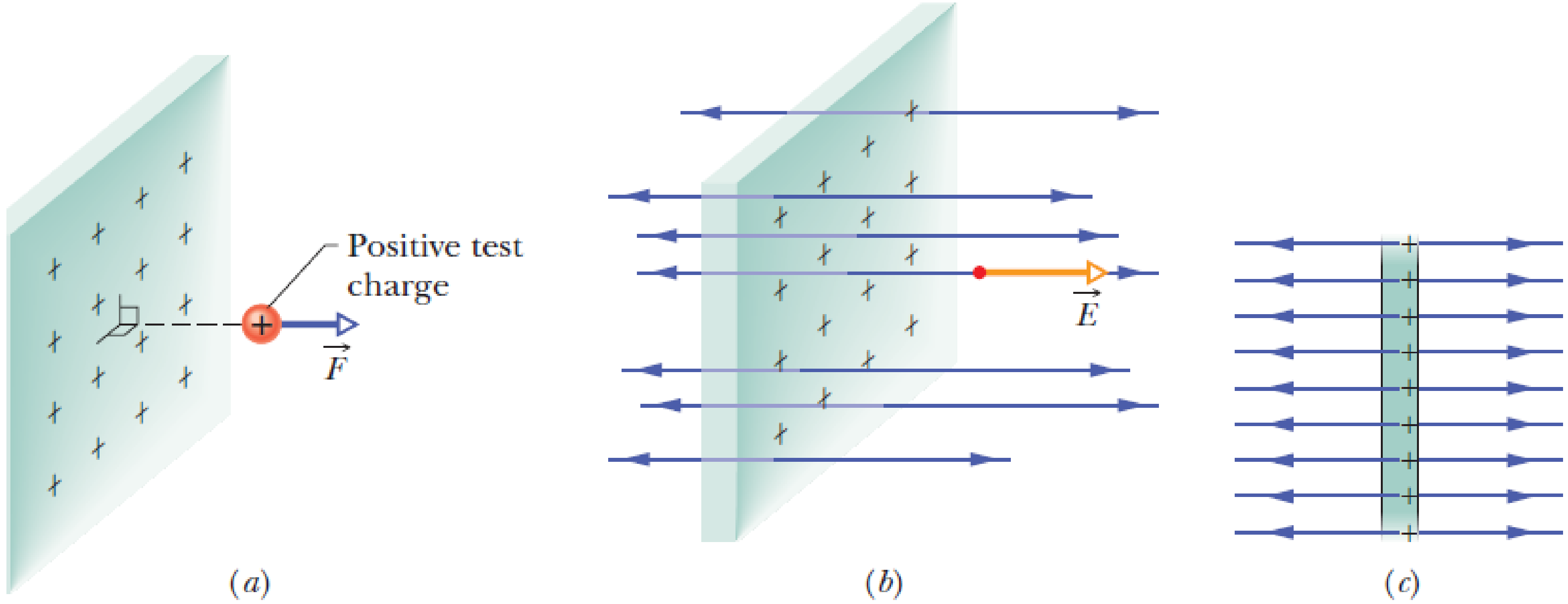
$$\vec{E} = \frac{\vec{F}}{q_0}$$





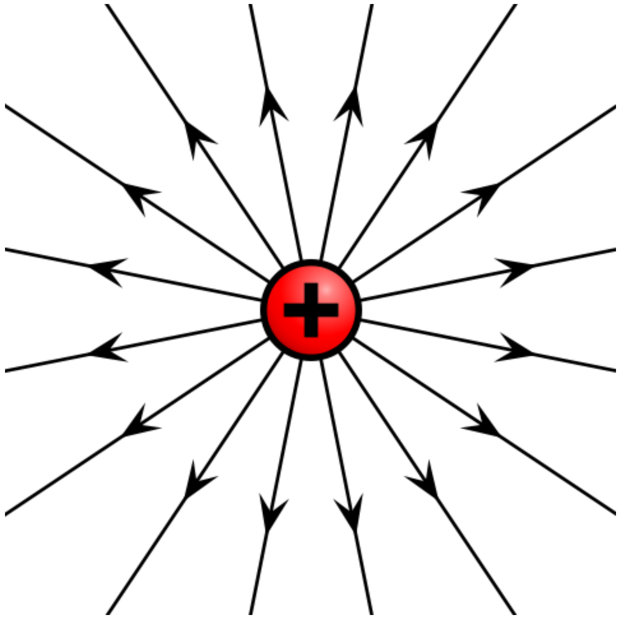

# Electric Field Lines

# The Electric Field Due to a Point Charge

$$\vec{F} = \frac{1}{4\pi\varepsilon_0}\frac{qq_0}{r^2}\hat{\mathrm{r}}$$

$$\vec{E} = \frac{\vec{F}}{q_0} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{\mathrm{r}}$$

$$E = \frac{1}{4\pi\varepsilon_0}\frac{|q|}{r^2}$$

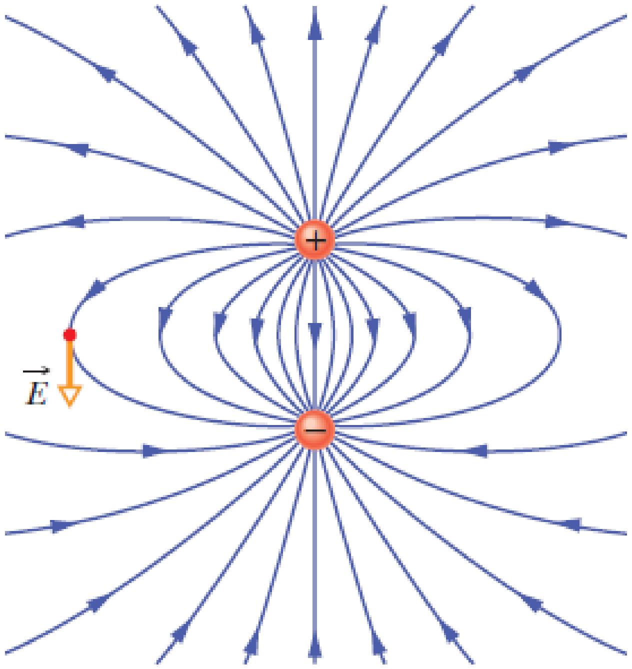


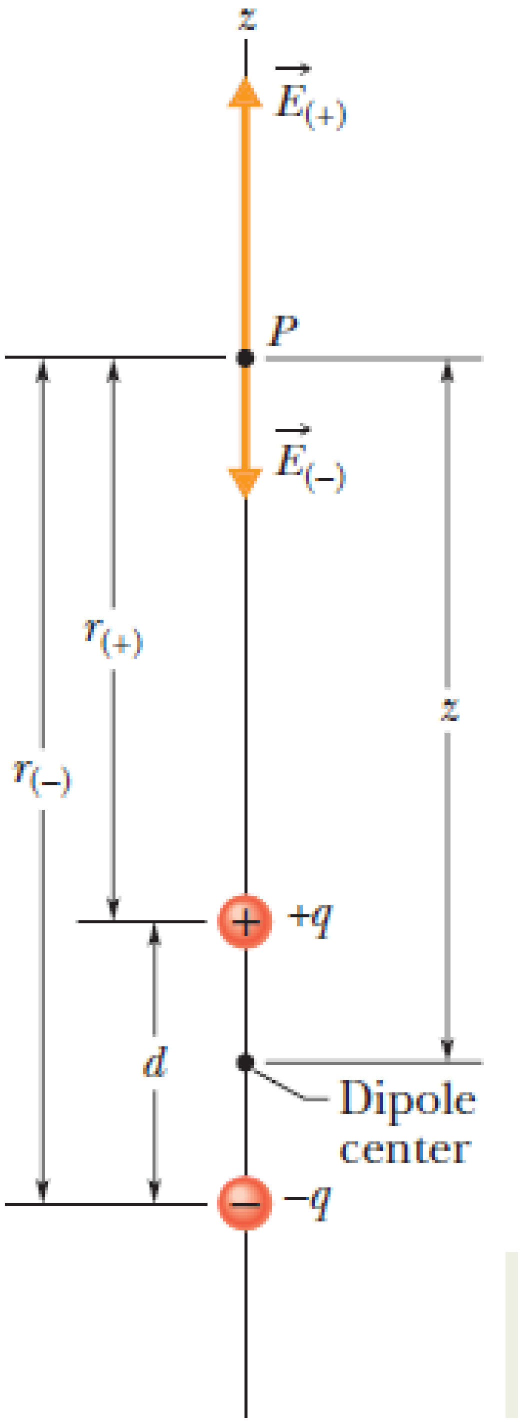
$$\vec{F}_0 = \vec{F}_{01} + \vec{F}_{02} + \cdots + \vec{F}_{0n}.$$

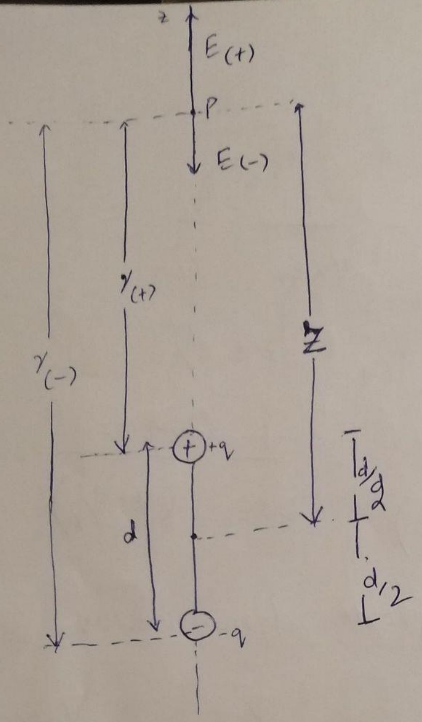
$$\vec{E} = \frac{\vec{F}_0}{q_0} = \frac{\vec{F}_{01}}{q_0} + \frac{\vec{F}_{02}}{q_0} + \cdots + \frac{\vec{F}_{0n}}{q_0}$$

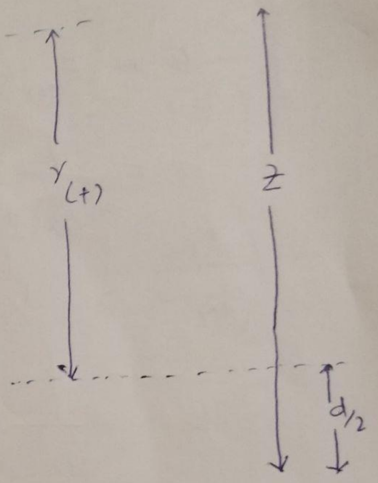
# Electric Field Due to a Dipole

Figure below shows electric field lines for two particles that have the same charge magnitude $q$ but opposite signs, known as dipole.

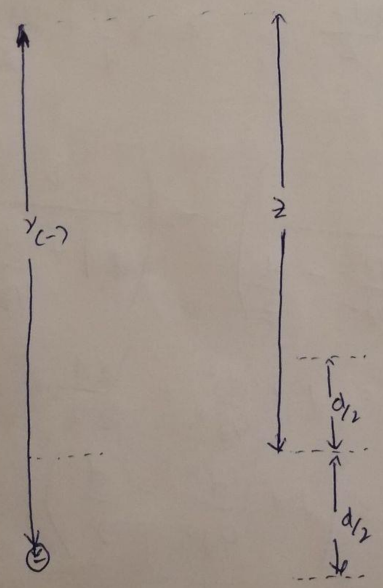





So $r_{(+)} = z - d/2$




So $r_{(-)} = z + \frac{d}{2}$

$$E = E_{(+)} - E_{(-)}$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{q}{r_{(+)}^2} - \frac{1}{4\pi\varepsilon_0}\frac{q}{r_{(-)}^2}$$

$$r_{(+)} = z - d/2 \quad , \quad r_{(-)} = z + d/2$$

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{(z-d/2)^2} - \frac{1}{4\pi\varepsilon_0}\frac{q}{(z+d/2)^2}$$

take $z^2$ common from denominator.

$$E = \frac{1}{4\pi\varepsilon_0}\left(\frac{q}{z^2+\frac{d^2}{4}-\frac{\cancel{2}dz}{\cancel{2}}} - \frac{q}{z^2+\frac{d^2}{4}+\frac{\cancel{2}dz}{\cancel{2}}}\right)$$

$z^2$ common.

$$E = \frac{1}{4\pi\varepsilon_0 z^2}\left(\left(\frac{q}{1+\frac{d^2}{4z^2}-\frac{d}{z}}\right) - \left(\frac{q}{\cancel{z}1+\frac{d^2}{4z^2}+\frac{d}{z}}\right)\right)$$

$$\because \left(1-\frac{d}{2z}\right)^2 = 1+\frac{d^2}{4z^2}-\frac{\cancel{2}d}{\cancel{2}z}$$

$$= \left(1+\frac{d^2}{4z^2}-\frac{d}{z}\right)$$

$$E = \frac{q}{4\pi\varepsilon_0 z^2}\left(\frac{1}{\left(1-\frac{d}{2z}\right)^2} - \frac{1}{\left(1+\frac{d}{2z}\right)^2}\right)$$

$$E = \frac{q}{4\pi\varepsilon_0 z^2}\left(\frac{\left(1+d/2z\right)^2 - \left(1-d/2z\right)^2}{\left(1-\frac{d}{2z}\right)^2\left(1+\frac{d}{2z}\right)^2}\right)$$

$$E = \frac{q}{4\pi\varepsilon_0 z^2}\left(\frac{1+d^2/4z^2 + 2d/2z - \left(1+d^2/4z^2 - 2d/2z\right)}{\left(1+\frac{d^2}{4z^2}-\frac{\cancel{2}d}{\cancel{2}z}\right)\left(1+\frac{d^2}{4z^2}+\frac{\cancel{2}d}{\cancel{2}z}\right)}\right)$$

$$E = \frac{q}{4\pi\varepsilon_0 z^2}\left(\frac{\cancel{1}+\cancel{d^2/4z^2}+\cancel{2}d/\cancel{2}z-\cancel{1}-\cancel{\frac{d^2}{4z^2}}+\cancel{2}d/\cancel{2}z}{1+\frac{d^2}{4z^2}+\cancel{d/z}+\frac{d^2}{4z^2}+\frac{d^4}{16z^4}+\cancel{\frac{d^3}{4z^3}}-\cancel{\frac{d}{z}}-\cancel{\frac{d^3}{4z^3}}-\frac{d^2}{z^2}}\right)$$

$$E = \frac{q}{4\pi\varepsilon_0 z^2}\left(\frac{d/z + d/z}{1+\frac{\cancel{2}^{1}d^2}{{}_{2}\cancel{4}z^2}+\frac{d^4}{16z^4}-\frac{d^2}{z^2}}\right)$$

$$= \frac{q}{4\pi\varepsilon_0 z^2}\left(\frac{2d/z}{1+\frac{d^4}{16z^4}+\frac{d^2}{z^2}\left(\frac{1}{2}-1\right)}\right)$$

$$= q/4\pi\varepsilon_0 z^2\left(\frac{2d/z}{1+d^4/16z^4+d^2/z^2\left(\frac{1-2}{2}\right)}\right)$$

$$= \frac{q}{4\pi\varepsilon_0 z^2}\left(\frac{2d/z}{1+\left(\frac{d^2}{4z^2}\right)^2-\frac{d^2}{(2z)^2}}\right)$$

$$= \frac{q}{2\pi\varepsilon_0 z^3}\left(\frac{d}{\left(1-\left(\frac{d}{2z}\right)^2\right)^2}\right)$$

$$z \gg d \rightarrow 1 \gg \frac{d}{z} \rightarrow 1 \gg \frac{d}{2z}.$$

So $\frac{d}{2z}$ can be neglected.

Now,

$$E = \frac{q}{2\pi\varepsilon_0 z^3}\left(\frac{d}{1-0}\right)$$

$$E = \frac{qd}{2\pi\varepsilon_0 z^3}$$

$P = qd$ is called dipole moment

so

$$E = \frac{P}{2\pi\varepsilon_0 z^3}$$