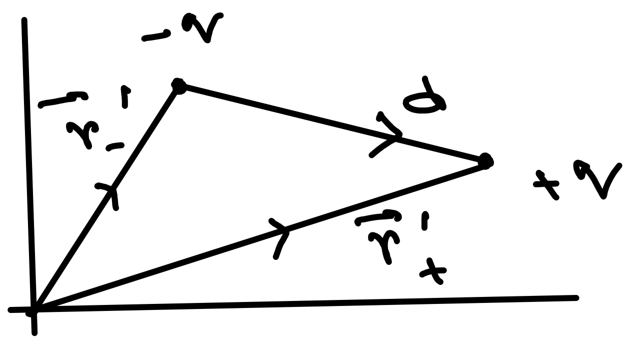
EPHY105L-15 6.12.21

Electric Dipole (contd.)



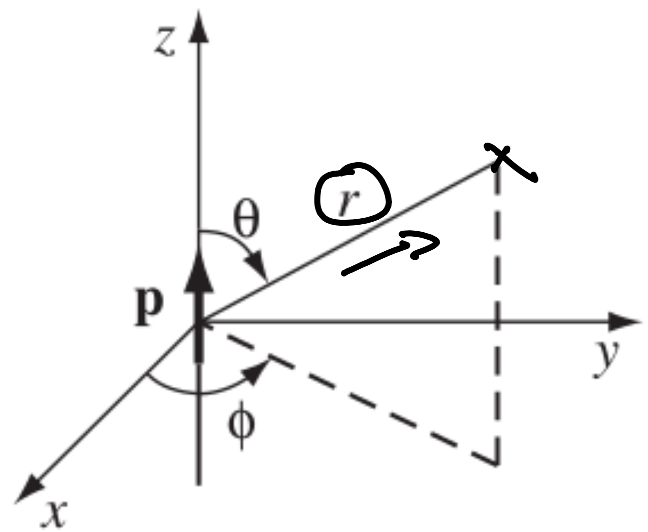
→ Physical charges with equal and opposite charges $\pm q$, dipole moment, $\vec{p} = q(\vec{r}'_+ - \vec{r}'_-)$
$= q\vec{d}$

→ valid for the condition, $r \gg d$.

Dipole approximation ≡ for a perfect dipole, $d \to 0 \Rightarrow$ then q simultaneously has to increase, $q \to \infty$.

⊛ A physical dipole becomes a pure dipole in the limit $d \to 0$ & $q \to \infty$ with the product $p = qd$ kept fixed and finite.

Electric field due to a dipole



$\vec{p}$ is sitting at the origin and points in z-direc^n.

$$V_{dip}(r,\theta) = \frac{\hat{r}\cdot\vec{p}}{4\pi\epsilon_0 r^2}$$

$$\vec{E} = -\vec{\nabla} V \qquad = \frac{p\cos\theta}{4\pi\epsilon_0 r^2}$$

To get the electric field,

$$E_r = -\frac{\partial V}{\partial r} = \frac{2p\cos\theta}{4\pi\epsilon_0 r^3}$$

$$E_\theta = -\frac{1}{r}\frac{\partial V}{\partial \theta} = \frac{p\sin\theta}{4\pi\epsilon_0 r^3}$$

$$E_\phi = -\frac{1}{r\sin\theta}\frac{\partial V}{\partial \phi} = 0$$

Then, the electric field is given by

$$\vec{E}_{dip.}(r, \theta) = \frac{p}{4\pi\epsilon_0 r^3}\left(2\cos\theta\,\hat{r} + \sin\theta\,\hat{\theta}\right)$$

(*) We can rewrite it as

$$\vec{E}_{dip.}(\vec{r}) = \frac{1}{4\pi\epsilon_0 r^3}\left[3(\vec{p}\cdot\hat{r})\hat{r} - \vec{p}\right]$$

$$\vec{p} = \underbrace{(\vec{p}\cdot\hat{r})}\hat{r} + \underbrace{(\vec{p}\cdot\hat{\theta})}\hat{\theta} \qquad \left[\vec{p} = p\,\hat{z}\right.$$

$$= p\cos\theta\,\hat{r} - p\sin\theta\,\hat{\theta}$$

[the unit vector,

$$\hat{\theta} = \cos\theta\cos\phi\,\hat{x} + \cos\theta\sin\phi\,\hat{y} \underbrace{- \sin\theta\,\hat{z}}$$]

Now, $3(\vec{p}\cdot\hat{r})\hat{r} - \vec{p}$

$= 3p\cos\theta\,\hat{r} - p\cos\theta\,\hat{r} + p\sin\theta\,\hat{\theta}$

$= 2p\cos\theta\,\hat{r} + p\sin\theta\,\hat{\theta}$

(*) Electric field due to a dipole falls off $\sim \frac{1}{r^3}$

Electric field due to a monopole falls off $\sim \frac{1}{r^2}$

(*) The expression is valid for ideal dipoles and physical dipoles under approximation, $r \gg d$.

Dielectrics

Unlike conductors, in a dielectric material, electrons cannot move about freely. They can move about a bit within the atoms and (or) molecules.

$\Rightarrow$ if their movement is absolutely restricted $\equiv$ Insulators (small dielectric constants)

$\Rightarrow$ if the charged particles can move a little bit $\equiv$ Dielectrics (larger dielectric constants)

(*) Material is made up of neutral atoms (non-polar molecules) $\rightarrow$ in an external electric field → tiny dipoles are induced pointing in the same direcn as the field.

⊗ If material is made of polar molecules → permanent dipoles in the system → external electric field exerts a torque on them → aligns them along the direcn. of the electric field.

→ Net effect is a lot of tiny dipoles pointing along the direcn. of the field

⇒ <u>Polarisation</u>.