ELECTRIC DIPOLES

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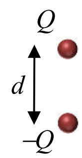
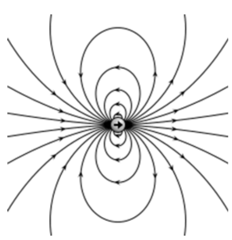
Electric Dipole

An electric dipole is formed when two point charges of equal magnitude but opposite sign are separated by a small distance.





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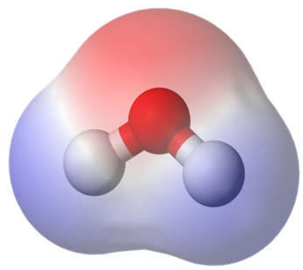
Why Dipoles?

- Nature likes to make dipoles!



- A molecule of water is polar.

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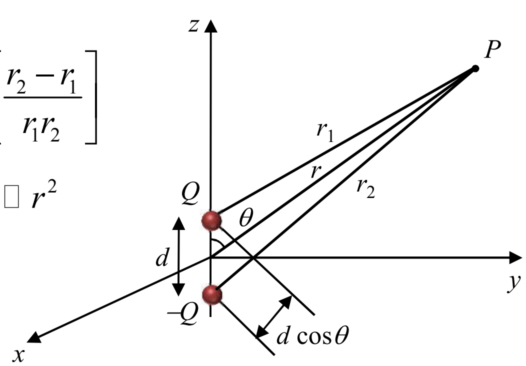
Dipole Potential

The potential at P is

$$V = \frac{Q}{4\pi\varepsilon_0}\left[\frac{1}{r_1} - \frac{1}{r_2}\right] = \frac{Q}{4\pi\varepsilon_0}\left[\frac{r_2 - r_1}{r_1 r_2}\right]$$

$$r \gg d,\ r_2 - r_1 \approx d\cos\theta,\ r_2 r_1 \approx r^2$$

$$V = \frac{Q}{4\pi\varepsilon_0}\frac{d\cos\theta}{r^2}$$



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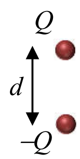
Dipole Moment

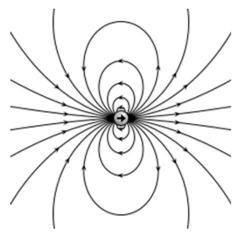
- A measure of the charge system's overall polarity.

$$\vec{p} = Q\vec{d}$$

where $\vec{d} = d\,\hat{a}_z$

$\vec{p}$ is directed from $-Q$ to $+Q$.





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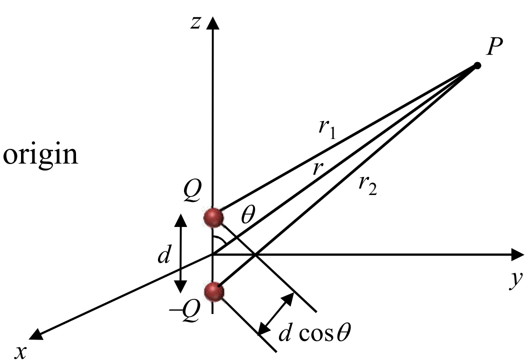
Dipole Potential

$$\vec{p} = Q\vec{d}$$

$$V = \frac{\vec{p}\cdot\hat{a}_r}{4\pi\varepsilon_0 r^2}$$

If dipole center is not at the origin

$$V = \frac{\vec{p}\cdot\left(\vec{r}-\vec{r}'\right)}{4\pi\varepsilon_0\,|\,\vec{r}-\vec{r}'\,|^3}$$



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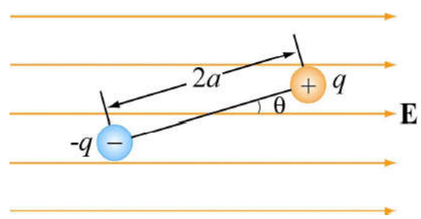
Dipole in Uniform Electric Field

$\vec{\mathrm{E}} = E\,\hat{\mathrm{a}}_y$

$\vec{\mathrm{p}} = 2qa\left(\cos\theta\,\hat{\mathrm{a}}_y + \sin\theta\,\hat{\mathrm{a}}_z\right)$



Total net force:

$\vec{\mathrm{F}}_{\mathrm{net}} = \vec{\mathrm{F}}_+ + \vec{\mathrm{F}}_- = q\vec{\mathrm{E}} + (-q)\vec{\mathrm{E}} = 0$

Torque on dipole: $\vec{\tau} = \vec{\mathrm{r}} \times \vec{\mathrm{F}} = \vec{\mathrm{p}} \times \vec{\mathrm{E}}$

$\vec{\tau} = rF\sin\theta = (2a)(qE)\sin\theta = pE\sin\theta$

$\vec{\mathrm{p}}$ tends to align with the electric field.

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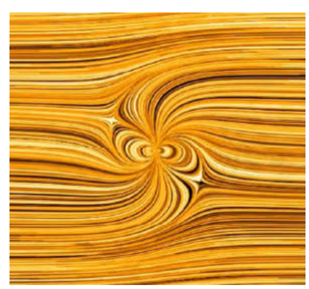
Dipole in Uniform Electric Field

Total Field = Dipole + Background

- Field lines transmit tension.
- Connection between dipole field and constant field "pulls" dipole into alignment.



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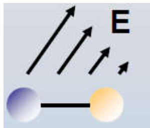
Concept Question: Dipole in Non-Uniform Field



Due to the electric field this dipole will feel:

1. Force but no torque
2. No force but a torque
3. Both a force and a torque
4. Neither a force nor a torque.

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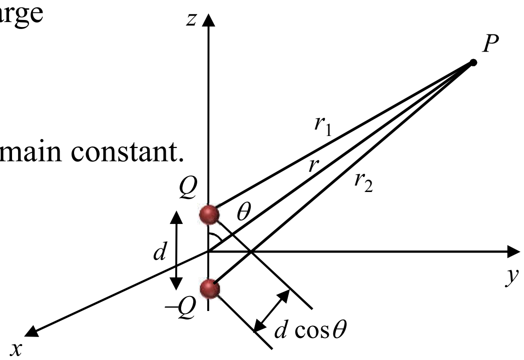
Concept Question: Dipole Field

As you move to larger distances *r* away from a dipole, the electric field will fall-off as:

1. $1/r^2$, just like a point charge
2. More rapidly than $1/r^2$
3. More slowly than $1/r^2$
4. The electric field will remain constant.



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