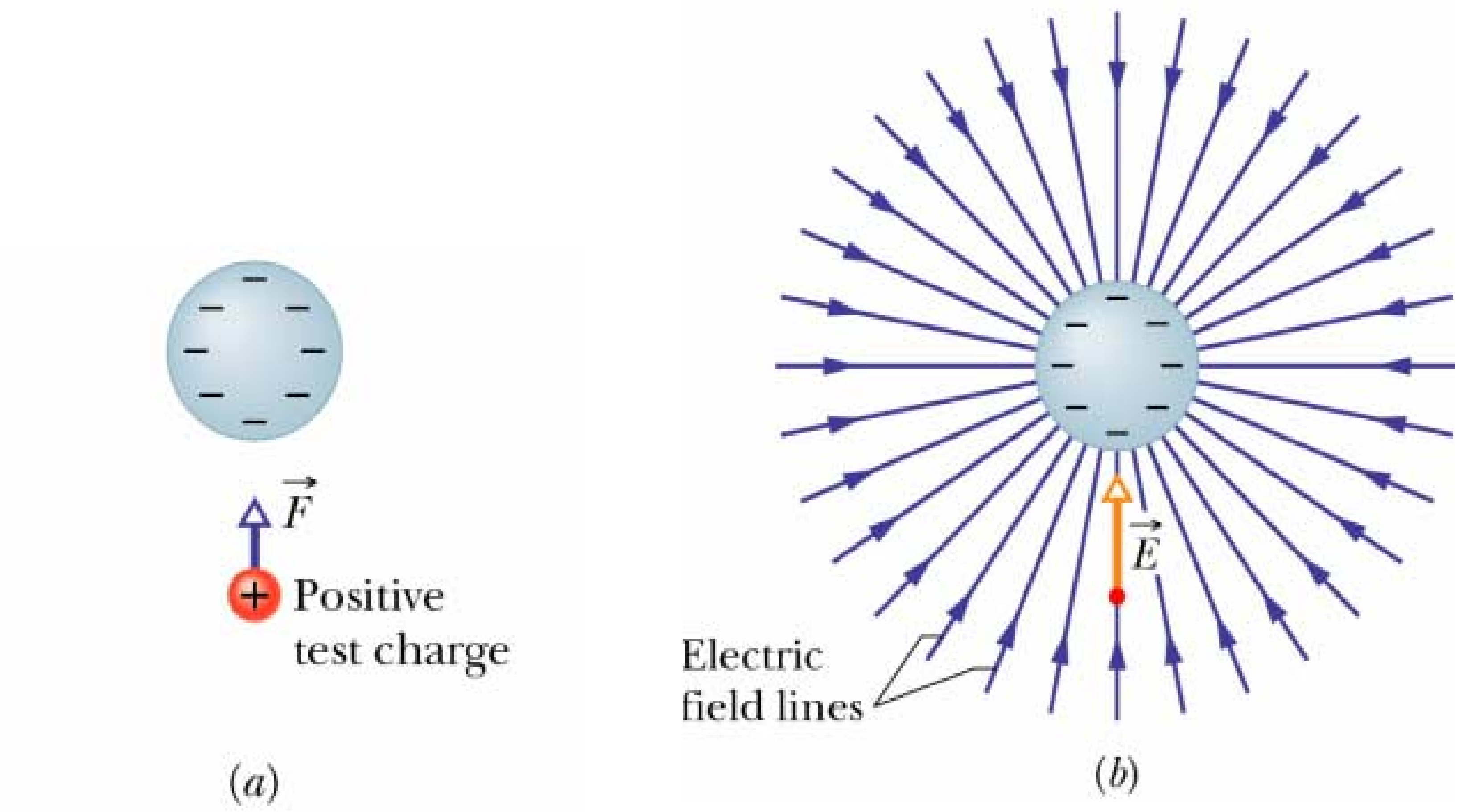
September 2nd

Electric Fields – Chapter 23

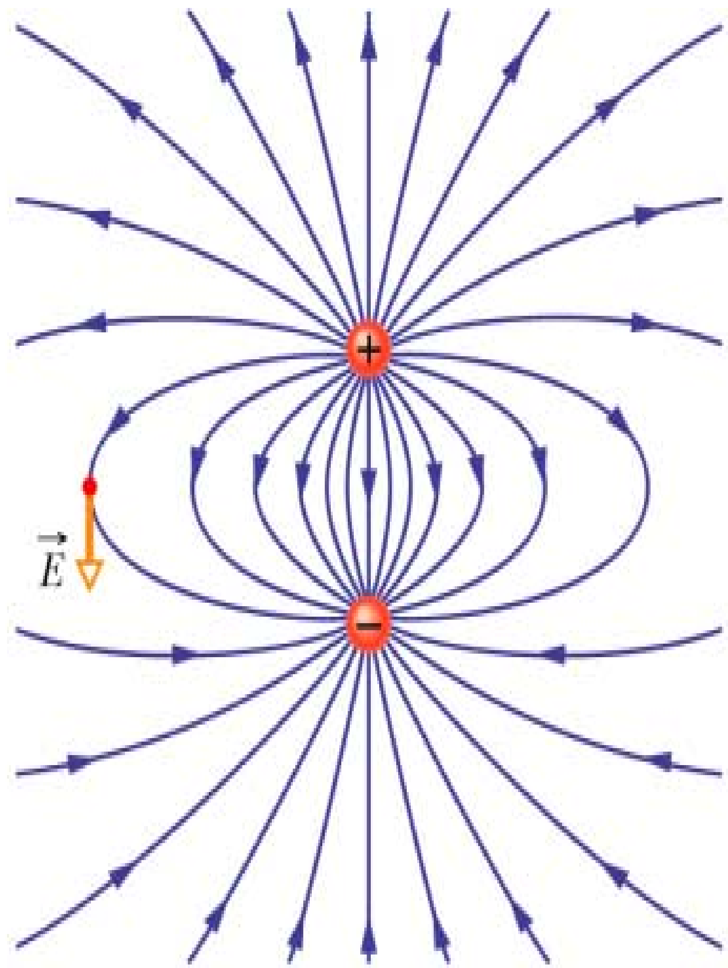
Electric Field

- How does a charge, q_1, exert a force on another charge, q_2, when the charges don't touch?
- The charge, q_1, sets up an electric field in its surrounding space
- This electric field has both magnitude and direction which determine the magnitude and direction of the force acting on q_2


$\vec{F}$
Positive
test charge
(a)
$\vec{E}$
Electric
field lines
(b)

Electric Field

- Electric field lines:
  - Point away from positive and towards negative
  - Tangent to the field line is the direction of the *E* field at that point
  - # lines is proportional to magnitude of the charge



Electric Field

- Electric field lines:

  - Close to a point charge are radial in direction
  - Do not intersect in a charge-free region
  - Begin and end on charges (charge may be at "infinity")
  - Do not begin or end in a charge-free region

Electric Field

- Electric field, *E*, is the force per unit positive test charge

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

- For a point charge

$$F = k\frac{|q_0||q|}{r^2}$$

so

$$E = k\frac{|q|}{r^2}$$

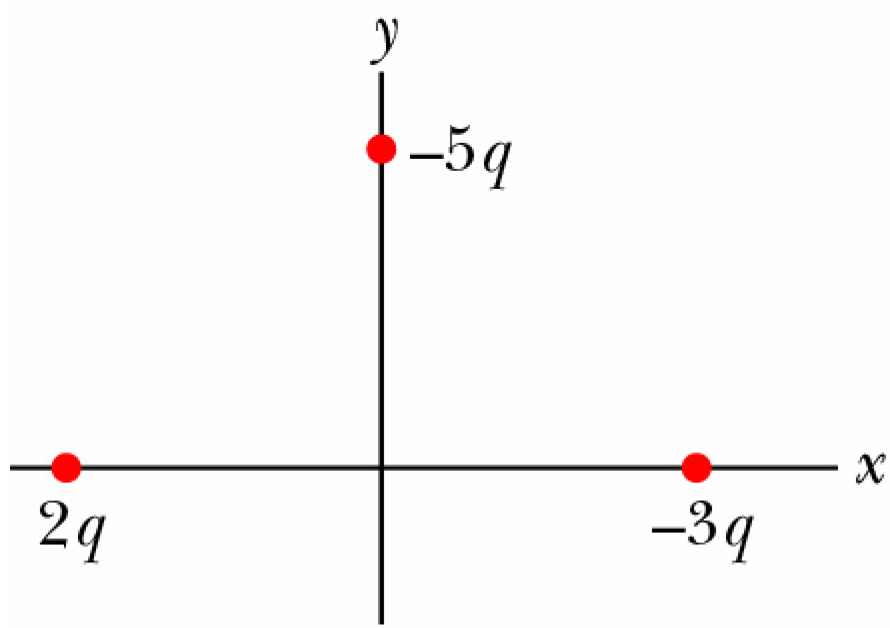
Electric Field

- Direction of *E* = direction of *F* (for positive charge)

- *E* points towards a negative point charge and away from a positive point charge

- Superposition of electric fields

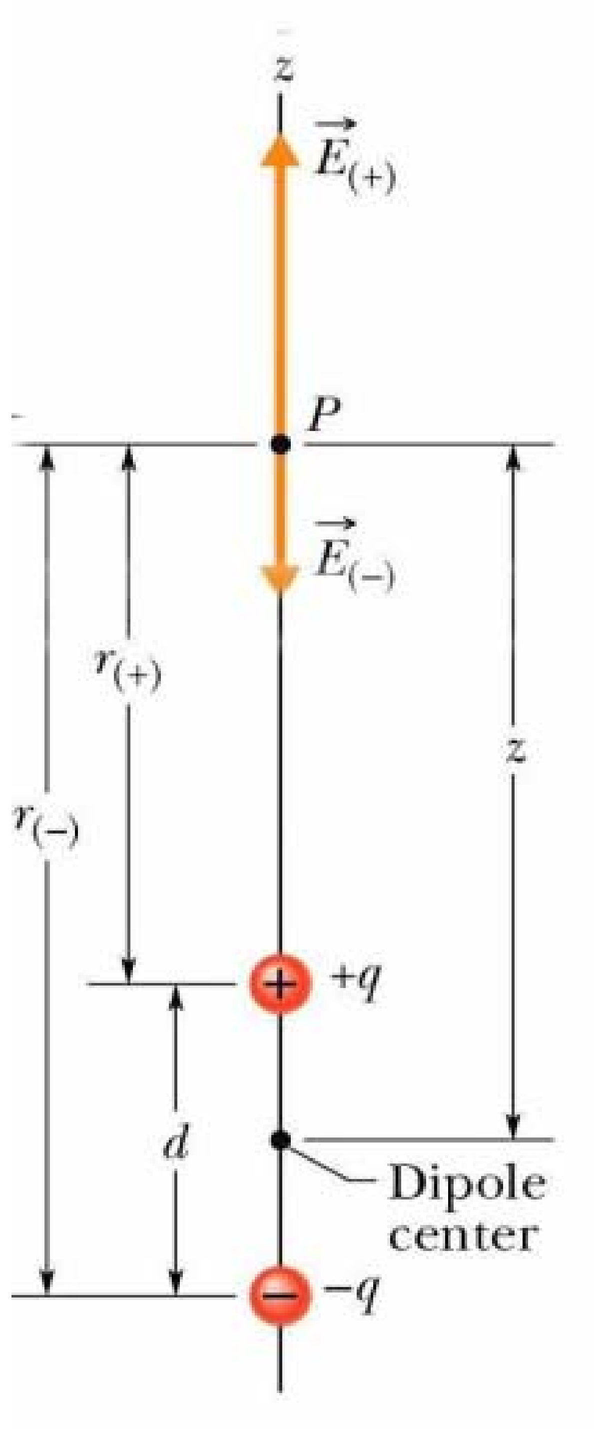
$$\vec{E} = \vec{E}_1 + \vec{E}_2 + \ldots + \vec{E}_n$$



(a)

Electric Dipole

- Electric dipole – two equal magnitude, opposite charged particles separated by distance d
- What's the electric field at point P due to the dipole?



- E is on z-axis so

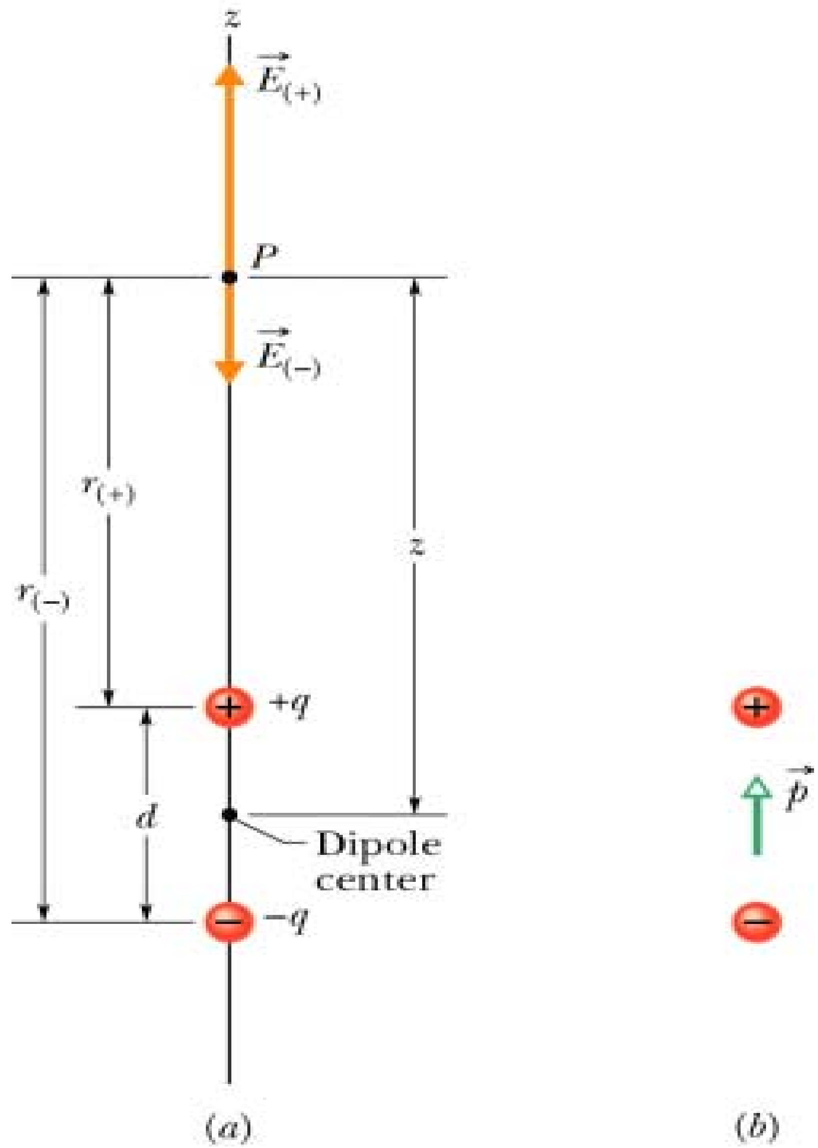
$$E = E_z = E_+ - E_-$$

- giving

$$E = k\frac{q}{r_+^2} - k\frac{q}{r_-^2}$$

- where

$$r_+ = z - \frac{d}{2} \qquad r_- = z + \frac{d}{2}$$



- Substituting and rearranging gives

$$E = \frac{kq}{z^2}\left[\left(1 - \frac{d}{2z}\right)^{-2} - \left(1 + \frac{d}{2z}\right)^{-2}\right]$$

- Assuming z>>d then expand using binomial theorem ignoring higher order terms d/z<<1

$$E = \frac{kq}{z^2}\left[\left(1 + \frac{d}{z} + \ldots\right) - \left(1 - \frac{d}{z} + \ldots\right)\right]$$

Electric Dipole

- Approximate *E* field for a dipole is

$$E = \frac{2\,kqd}{z^3}$$

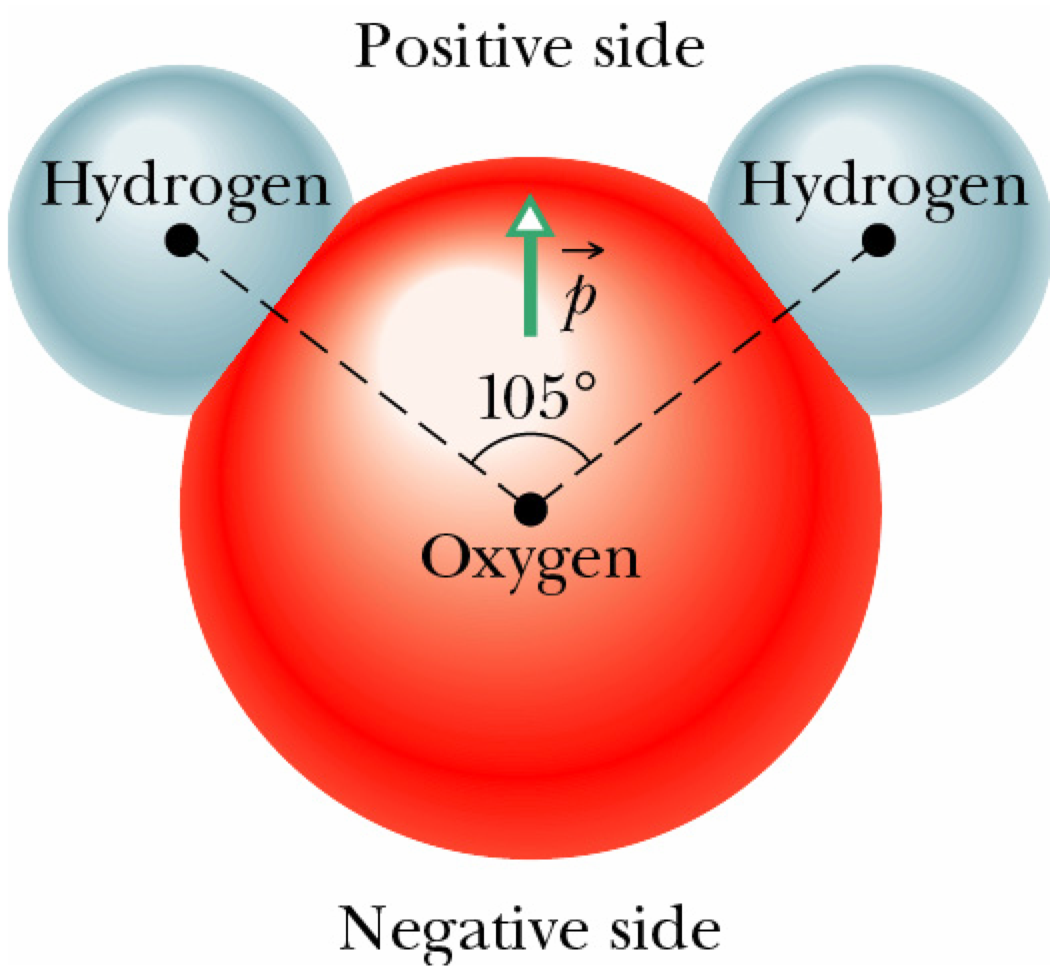
- Define electric dipole moment, *p* as,

$$\vec{p} = q\,\vec{d}$$

- The direction of *p* and *d* is from the negative to positive

- E field along dipole axis at large distances (z>>d) is

$$E = \frac{2kp}{z^3}$$


Positive side
Hydrogen
Hydrogen
$\vec{p}$
105°
Oxygen
Negative side

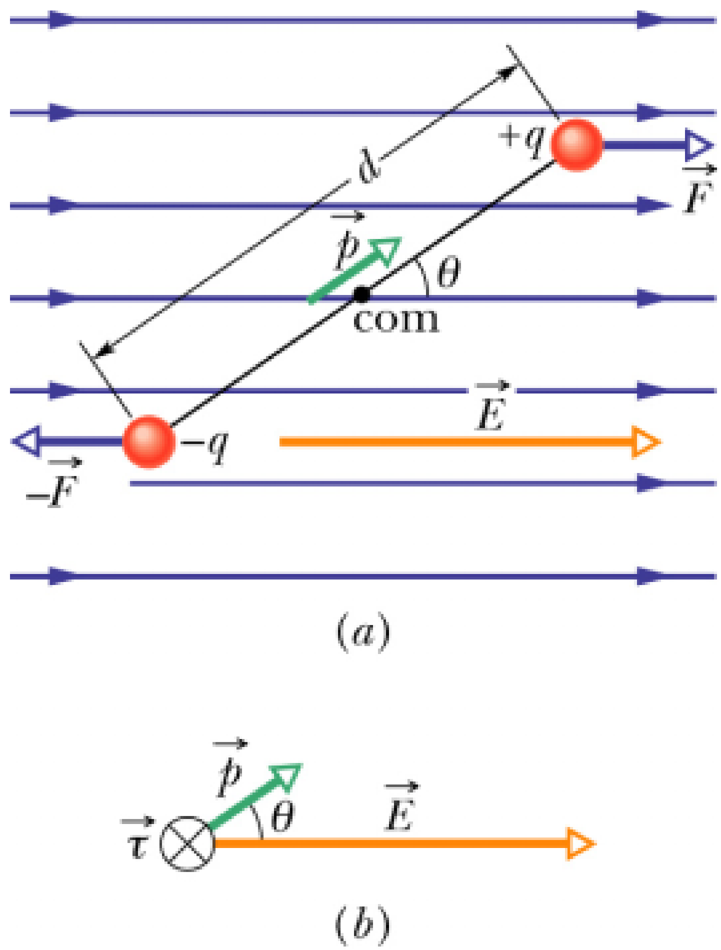
Electric Field

- If a charge q is placed in an electric field, then there is a force given by:

$$\vec{F} = q\,\vec{E}$$

Electric Dipole

- What happens when a dipole is put in an electric field? (com = center of mass)
- Net force, from uniform *E*, is zero
- But force on charged ends produces a net torque about its center of mass



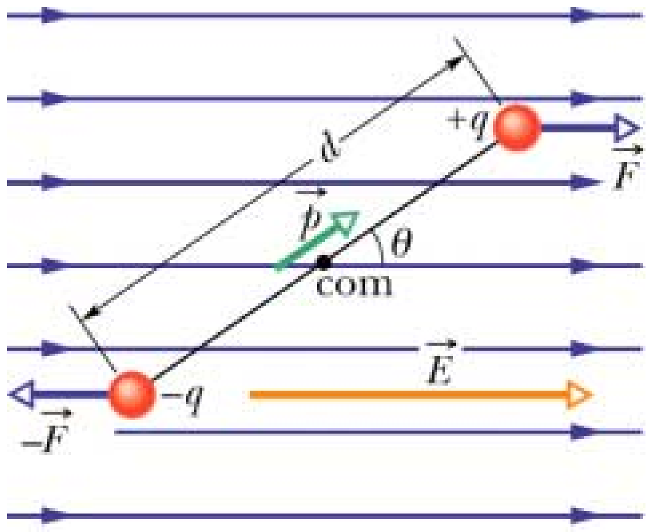
Electric Dipole

- Definition of torque

$$\vec{\tau} = \vec{r} \times \vec{F} = rF\sin\phi$$

- For dipole rewrite it as

$$\tau = xF\sin\theta + (d-x)F\sin\theta$$
$$= d\,F\sin\theta = (qd)(F/q)\sin\theta$$



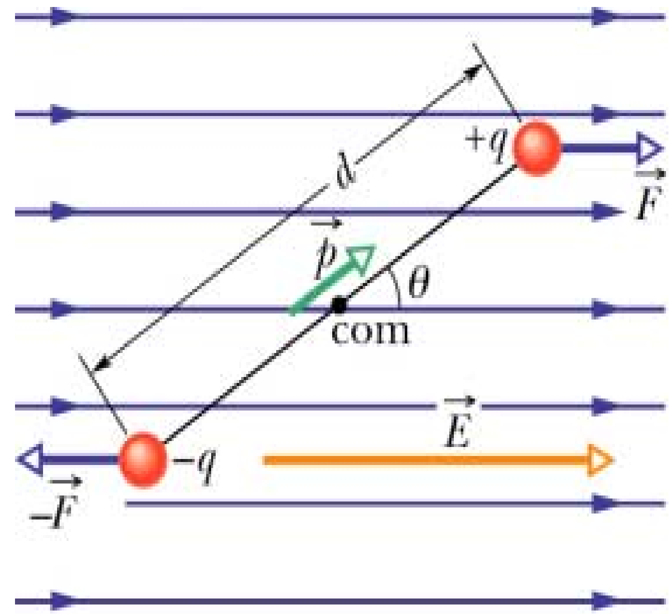
(a)

$$\text{Thus:} \quad \vec{\tau} = \vec{p} \times \vec{E}$$

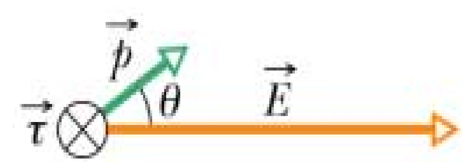
(b)

Electric Dipole

- Torque acting on a dipole tends to rotate *p* into the direction of *E*
- Associate potential energy, *U*, with the orientation of an electric dipole in an *E* field
- Dipole has least *U* when *p* is lined up with *E*



(a)



(b)

Electric Dipole

- Remember $$U = -W = -\int_{90}^{\theta} \tau \, d\theta = \int_{90}^{\theta} pE \sin\theta \, d\theta$$
- Potential energy of a dipole

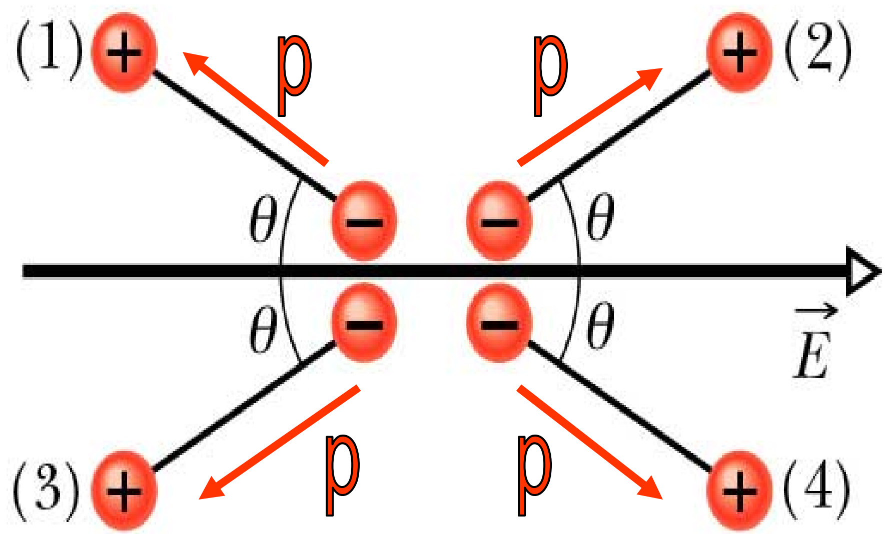
$$U = -pE\cos\theta = -\vec{p} \bullet \vec{E}$$

- *U* is least (greatest) when p and E are in same (opposite) directions

Checkpoint #5

- Rank a) magnitude of torque and b) U, greatest to least

$$\vec{\tau} = \vec{p} \times \vec{E} = pE\sin\theta$$



- a) Magnitudes are same

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

- U greatest at θ=180
- b) 1 & 3 tie, then 2 &4