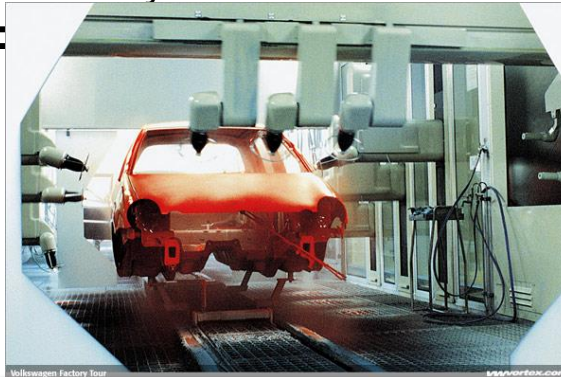


# PHY132 Introduction to Physics II

## Class 10 – Outline:

- Finishing off chapter 26
- Electric Field of:
  - Continuous Charge Distribution
  - Rings, Planes and Spheres
  - Parallel Plate Capacitor



**Volkswagen Factory Tour:** Ionized paint droplets are transferred in an electrostatic field to the body, and adheres to the metal in an even coat.

- Motion of a Charged Particle in an Electric Field
- Motion of a Dipole in an Electric Field

Image from [http://www.vvortex.com/artman/publish/vortex\\_news/article\\_329.shtml?page=4](http://www.vvortex.com/artman/publish/vortex_news/article_329.shtml?page=4)

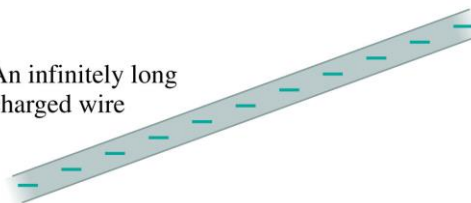
## Electric Field Models

- Most of this chapter will be concerned with the *sources* of the electric field.
- We can understand the essential physics on the basis of simplified *models* of the sources of electric field.
- The drawings show models of a positive point charge and an infinitely long negative wire.
- We also will consider an infinitely wide charged plane and a charged sphere.

A point charge



An infinitely long charged wire

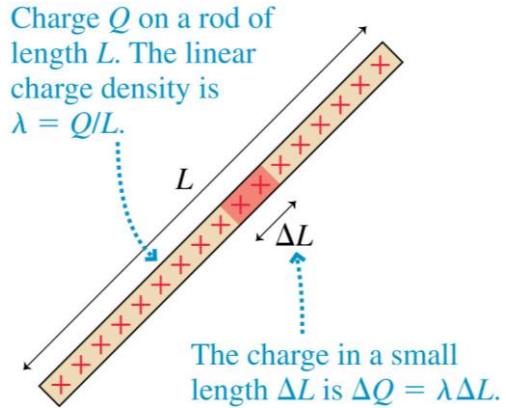


## Continuous Charge Distributions

The linear charge density of an object of length  $L$  and charge  $Q$  is defined as

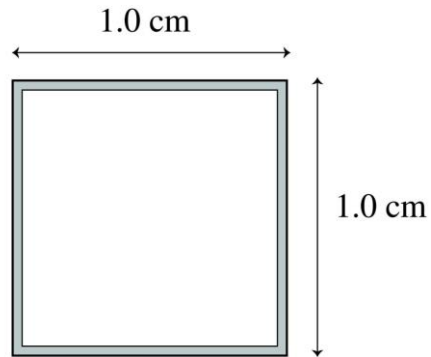
$$\lambda = \frac{Q}{L}$$

Linear charge density, which has units of C/m, is the amount of charge *per meter* of length.



If 8 nC of charge are placed on the square loop of wire, the linear charge density will be

- A. 800 nC/m.
- B. 400 nC/m.
- C. 200 nC/m.
- D. 8 nC/m.
- E. 2 nC/m.

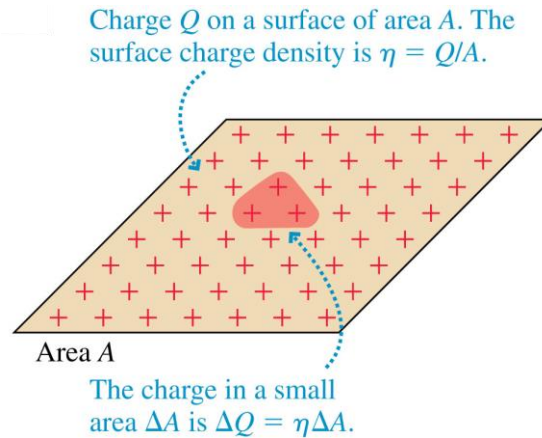


## Continuous Charge Distributions

The surface charge density of a two-dimensional distribution of charge across a surface of area  $A$  is defined as:

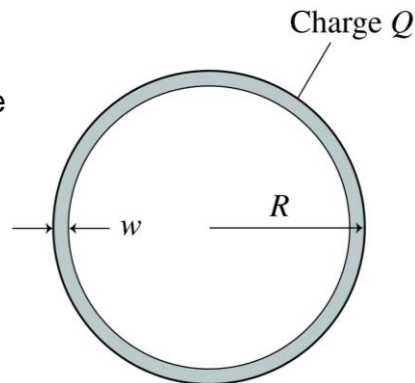
$$\eta = \frac{Q}{A}$$

Surface charge density, with units  $\text{C}/\text{m}^2$ , is the amount of charge *per square meter*.



A flat circular ring is made from a very thin sheet of metal. Charge  $Q$  is uniformly distributed over the ring. Assuming  $w \ll R$ , the surface charge density  $\eta$  on the top side, facing out of the page, is

- A.  $Q/2\pi R w$ .
- B.  $Q/4\pi R w$ .
- C.  $Q/\pi R^2$ .
- D.  $Q/2\pi R^2$ .
- E.  $Q/\pi R w$ .



## The Electric Field of a Finite Line of Charge

Total charge  $Q$

$L$

$r$

What is the electric field at this point?

The linear charge density is  $\lambda = Q/L$ .

The electric field strength at a radial distance  $r$  in the plane that bisects a rod of length  $L$  with total charge  $Q$ :

$$E_{\text{rod}} = \frac{1}{4\pi\epsilon_0} \frac{|Q|}{r \sqrt{r^2 + (L/2)^2}}$$

## An Infinite Line of Charge

The field points straight away from the line at all points.

Infinite line of charge

The field strength decreases with distance.

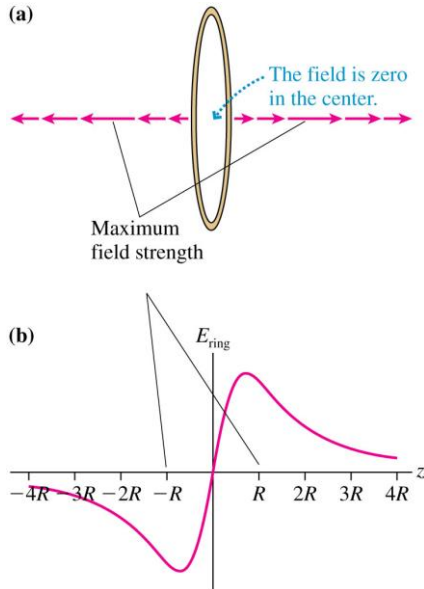
The electric field of a thin, uniformly charged rod may be written:

$$E_{\text{rod}} = \frac{1}{4\pi\epsilon_0} \frac{2|\lambda|}{r} \frac{1}{\sqrt{1 + 4r^2/L^2}}$$

If we now let  $L \rightarrow \infty$ , the last term becomes simply 1 and we're left with:

$$E_{\text{line}} = \frac{1}{4\pi\epsilon_0} \frac{2|\lambda|}{r}$$

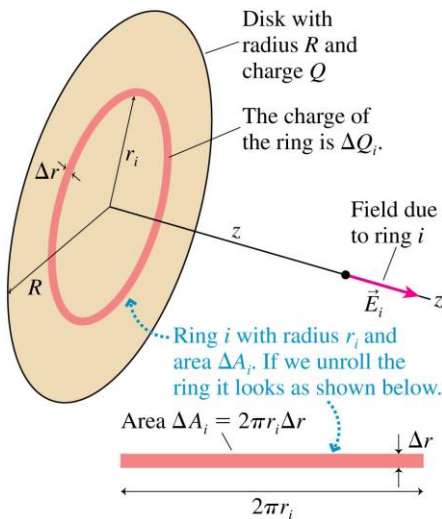
## A Ring of Charge



- Consider the on-axis electric field of a positively charged ring of radius  $R$ .
- Define the  $z$ -axis to be the axis of the ring.
- The electric field on the  $z$ -axis points away from the center of the ring, increasing in strength until reaching a maximum when  $|z| \approx R$ , then decreasing:

$$(E_{\text{ring}})_z = \frac{1}{4\pi\epsilon_0} \frac{zQ}{(z^2 + R^2)^{3/2}}$$

## A Disk of Charge



- Consider the on-axis electric field of a positively charged disk of radius  $R$ .
- Define the  $z$ -axis to be the axis of the disk.
- The electric field on the  $z$ -axis points away from the center of the disk, with magnitude:

$$(E_{\text{disk}})_z = \frac{\eta}{2\epsilon_0} \left[ 1 - \frac{1}{\sqrt{1 + R^2/z^2}} \right]$$

## A Plane of Charge

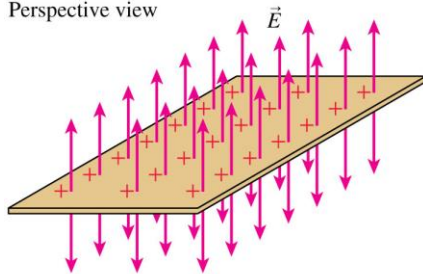
- The electric field of a plane of charge is found from the on-axis field of a charged disk by letting the radius  $R \rightarrow \infty$ .
- The electric field of an infinite plane of charge with surface charge density  $\eta$  is:

$$E_{\text{plane}} = \frac{\eta}{2\epsilon_0} = \text{constant}$$

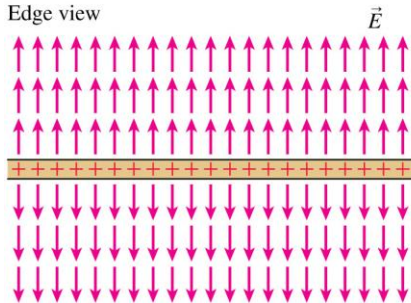
- For a positively charged plane, with  $\eta > 0$ , the electric field points *away from* the plane on both sides of the plane.
- For a negatively charged plane, with  $\eta < 0$ , the electric field points *towards* the plane on both sides of the plane.

## A Plane of Charge

Perspective view

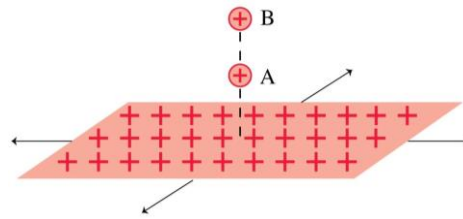


Edge view



$$(E_{\text{plane}})_z = \begin{cases} +\frac{\eta}{2\epsilon_0} & z > 0 \\ -\frac{\eta}{2\epsilon_0} & z < 0 \end{cases}$$

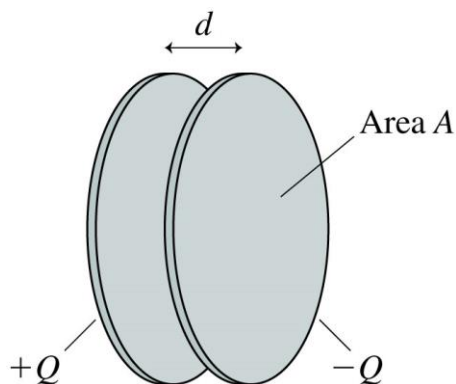
Two protons, A and B, are next to an infinite plane of positive charge. Proton B is twice as far from the plane as proton A. Which proton has the larger acceleration?



- A. Proton A.
- B. Proton B.
- C. Both have the same acceleration.

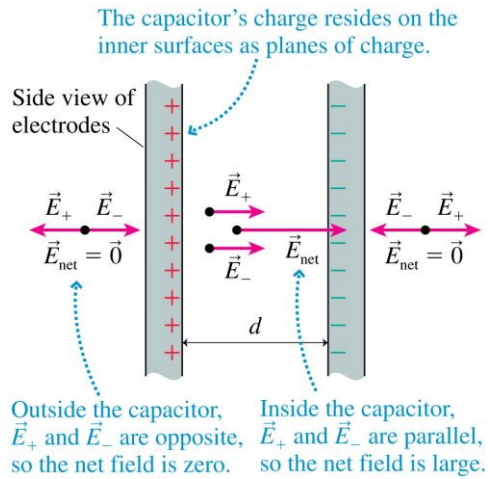
## The Parallel-Plate Capacitor

- The figure shows two electrodes, one with charge  $+Q$  and the other with  $-Q$  placed face-to-face a distance  $d$  apart.
- This arrangement of two electrodes, charged equally but oppositely, is called a **parallel-plate capacitor**.
- Capacitors play important roles in many electric circuits.



## The Parallel-Plate Capacitor

- The figure shows two capacitor plates, seen from the side.
- Because opposite charges attract, all of the charge is on the *inner* surfaces of the two plates.
- Inside the capacitor, the net field points toward the negative plate.
- Outside the capacitor, the net field is zero.



## The Parallel-Plate Capacitor

The electric field inside a capacitor is

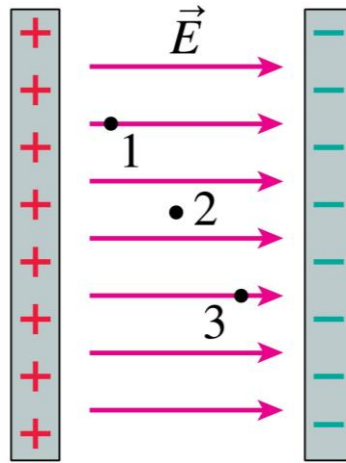
$$\begin{aligned}\vec{E}_{\text{capacitor}} &= \vec{E}_+ + \vec{E}_- = \left( \frac{\eta}{\epsilon_0}, \text{ from positive to negative} \right) \\ &= \left( \frac{Q}{\epsilon_0 A}, \text{ from positive to negative} \right)\end{aligned}$$

where  $A$  is the surface area of each electrode. Outside the capacitor plates, where  $E_+$  and  $E_-$  have equal magnitudes but *opposite* directions, the electric field is zero.



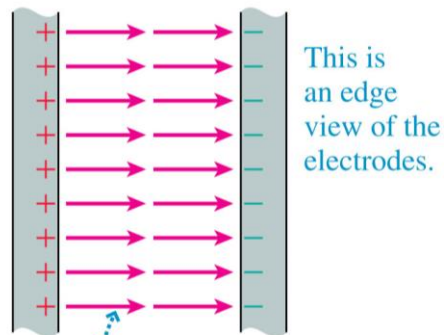
Three points inside a parallel-plate capacitor are marked. Which is true?

- A.  $E_1 > E_2 > E_3$
- B.  $E_1 < E_2 < E_3$
- C.  $E_1 = E_2 = E_3$
- D.  $E_1 = E_3 > E_2$



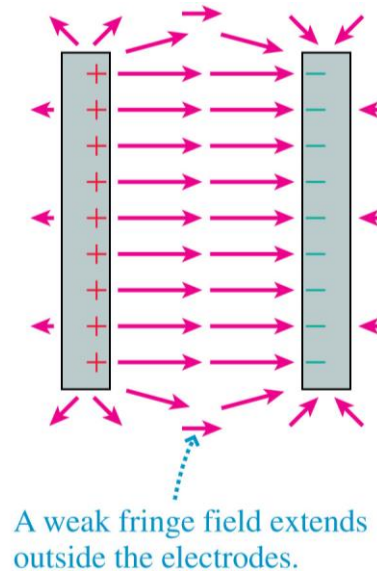
## The Ideal Capacitor

- The figure shows the electric field of an ideal parallel-plate capacitor constructed from two infinite charged planes
- The ideal capacitor is a good approximation as long as the electrode separation  $d$  is much smaller than the electrodes' size.

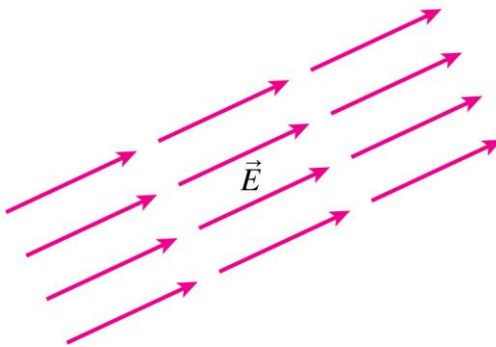


## A Real Capacitor

- Outside a real capacitor and near its edges, the electric field is affected by a complicated but weak **fringe field**.
- We will keep things simple by always assuming the plates are very close together and using  $E = \eta/\epsilon_0$  for the magnitude of the field inside a parallel-plate capacitor.



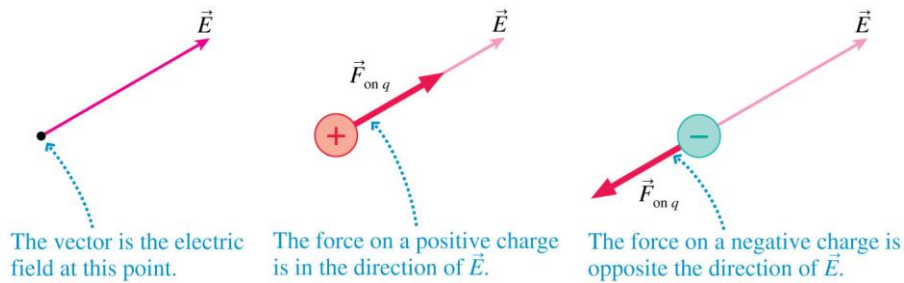
## Uniform Electric Fields



- The figure shows an electric field that is the *same*—in strength and direction—at every point in a region of space.
- This is called a **uniform electric field**.
- The easiest way to produce a uniform electric field is with a parallel-plate capacitor.

## Motion of a Charged Particle in an Electric Field

- Consider a particle of charge  $q$  and mass  $m$  at a point where an electric field  $\vec{E}$  has been produced by *other* charges, the source charges.
- The electric field exerts a force  $\vec{F}_{\text{on } q} = q\vec{E}$ .



## Motion of a Charged Particle in an Electric Field

- The electric field exerts a force  $\vec{F}_{\text{on } q} = q\vec{E}$  on a charged particle.
- If this is the only force acting on  $q$ , it causes the charged particle to accelerate with

$$\vec{a} = \frac{\vec{F}_{\text{on } q}}{m} = \frac{q}{m} \vec{E}$$

- In a uniform field, the acceleration is constant:

$$a = \frac{qE}{m} = \text{constant}$$

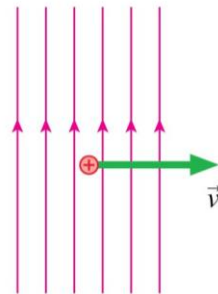
## Motion of a Charged Particle in an Electric Field



- “DNA fingerprints” are measured with the technique of *gel electrophoresis*.
- A solution of negatively charged DNA fragments migrate through the gel when placed in a uniform electric field.
- Because the gel exerts a drag force, the fragments move at a terminal speed inversely proportional to their size.

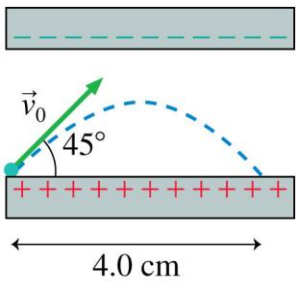
A proton is moving to the right in a vertical electric field. A very short time later, the proton's velocity is

- A.
- B.
- C.
- D.
- E.

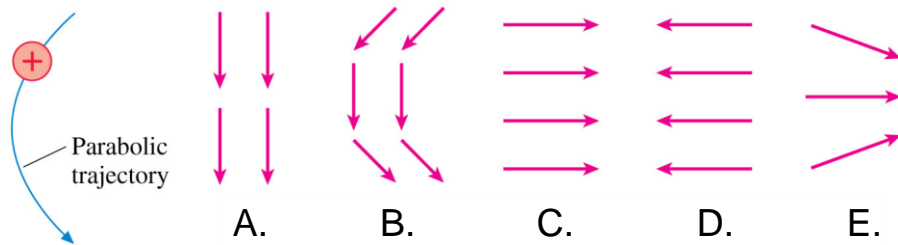


Problem 26.50

An electron is launched at a  $45^\circ$  angle at a speed of  $5 \times 10^6$  m/s from the positive plate of the parallel plate capacitor shown. The electron lands 4 cm away. What is the electric field strength inside the capacitor?

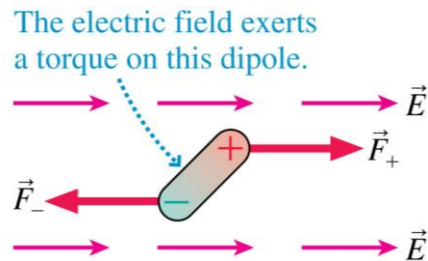


Which electric field is responsible for the proton's trajectory?



## Dipoles in a Uniform Electric Field

- The figure shows an electric dipole placed in a *uniform* external electric field.
- The net force on the dipole is zero.
- The electric field exerts a *torque* on the dipole which causes it to *rotate*.

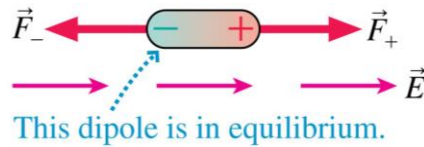


## Dipoles in a Uniform Electric Field

- The figure shows an electric dipole placed in a *uniform* external electric field.

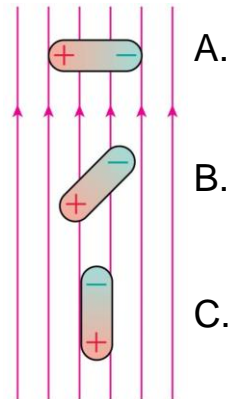
- The torque causes the dipole to rotate until it is aligned with the electric field, as shown.

- Notice that the positive end of the dipole is in the direction in which  $\vec{E}$  points.



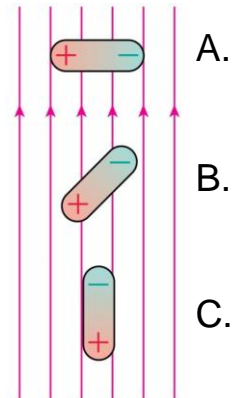
Which dipole experiences no net force in the electric field?

- A. Dipole A.
- B. Dipole B.
- C. Dipole C.
- D. Both dipoles A and C.
- E. All three dipoles.

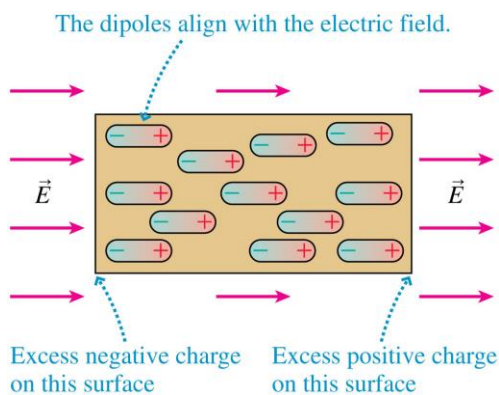


Which dipole experiences no net torque in the electric field?

- A. Dipole A.
- B. Dipole B.
- C. Dipole C.
- D. Both dipoles A and C.
- E. All three dipoles.



## Dipoles in a Uniform Electric Field



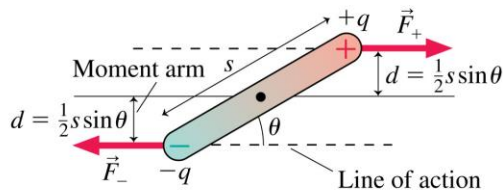
- The figure shows a sample of permanent dipoles, such as water molecules, in an external electric field.
- All the dipoles rotate until they are aligned with the electric field.
- This is the mechanism by which the sample becomes *polarized*.



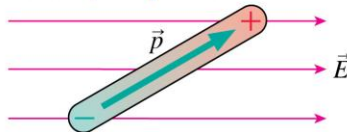
## The Torque on a Dipole

The torque on a dipole placed in a uniform external electric field is

$$\tau = 2 \times dF_+ = 2\left(\frac{1}{2}s \sin \theta\right)(qE) = pE \sin \theta$$

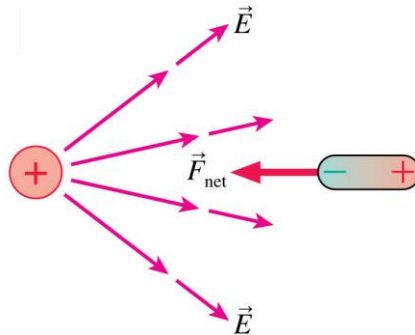


In terms of vectors,  $\vec{\tau} = \vec{p} \times \vec{E}$ .



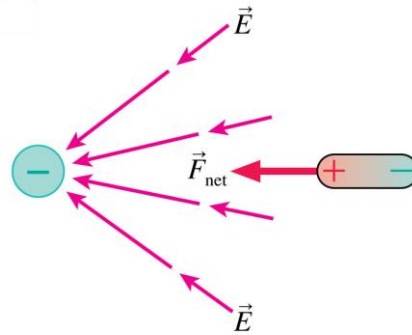
## Dipoles in a Nonuniform Electric Field

- Suppose that a dipole is placed in a nonuniform electric field, such as the field of a positive point charge.
- The first response of the dipole is to rotate until it is aligned with the field.
- Once the dipole is aligned, the leftward attractive force on its negative end is slightly stronger than the rightward repulsive force on its positive end.
- This causes a net force to the *left*, toward the point charge.



## Dipoles in a Nonuniform Electric Field

- A dipole near a negative point charge is also attracted toward the point charge.
- The net force on a dipole is toward the direction of the strongest field.
- Because field strength increases as you get closer to any finite-sized charged object, we can conclude that **a dipole will experience a net force toward any charged object.**



## Before Class 11 on Monday

- Complete Problem Set 4 on MasteringPhysics due Sunday at 11:59pm on Ch. 26.
- Please read Knight Pgs. 810-818: Ch. 28, sections 28.1-28.3
- Please do the short pre-class quiz on MasteringPhysics by Sunday night.
- Something to think about: If a fixed charge repels a moving charge, does it do **work** on the charge? Does this increase the **energy** of the system?