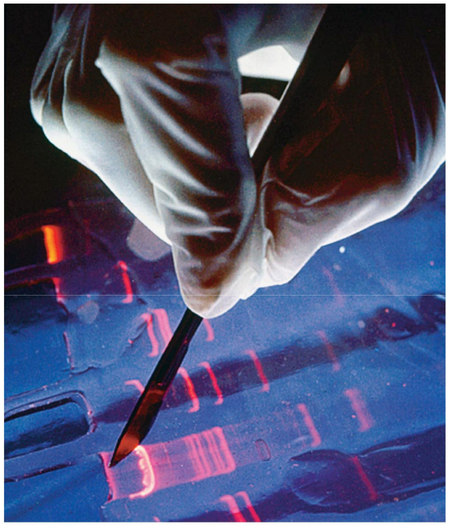
Chapter 20
Electric Forces and Fields

Topics:

- Electric charge
- Forces between charged objects
- The field model and the electric field
- Forces and torques on charged objects in electric fields



Sample question:

In electrophoresis, what force causes DNA fragments to migrate through the gel? How can an investigator adjust the migration rate?

Reading Quiz

1. A negatively charged rod is brought near a neutral metal sphere. Which of the following is true?
   A. There is an attractive force between the rod and sphere.
   B. There is a repulsive force between the rod and sphere.
   C. There is no electric force between the rod and sphere.

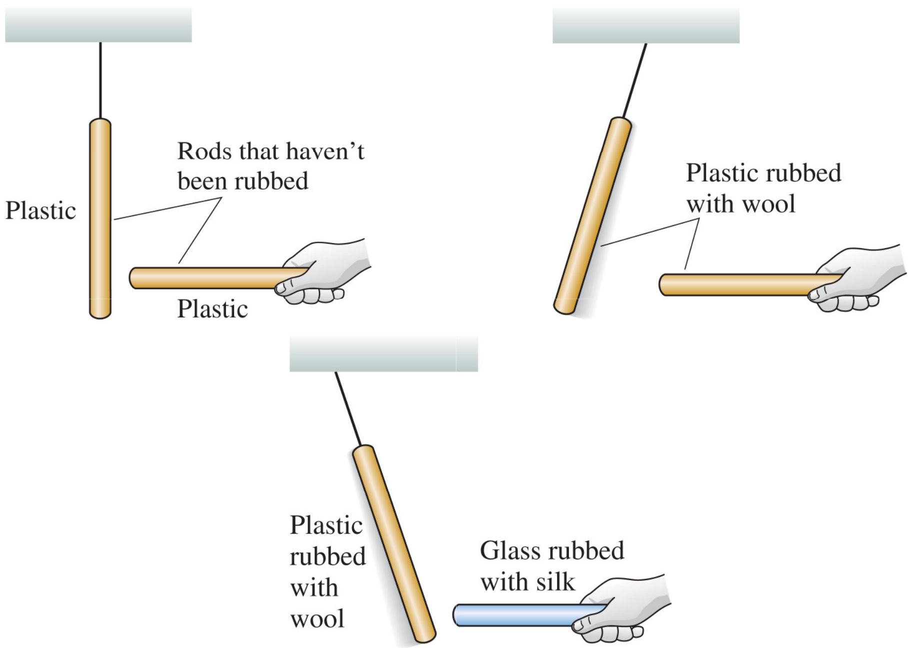
Reading Quiz

2. The field inside a charged parallel-plate capacitor is
   A. zero
   B. uniform
   C. parallel to the plates

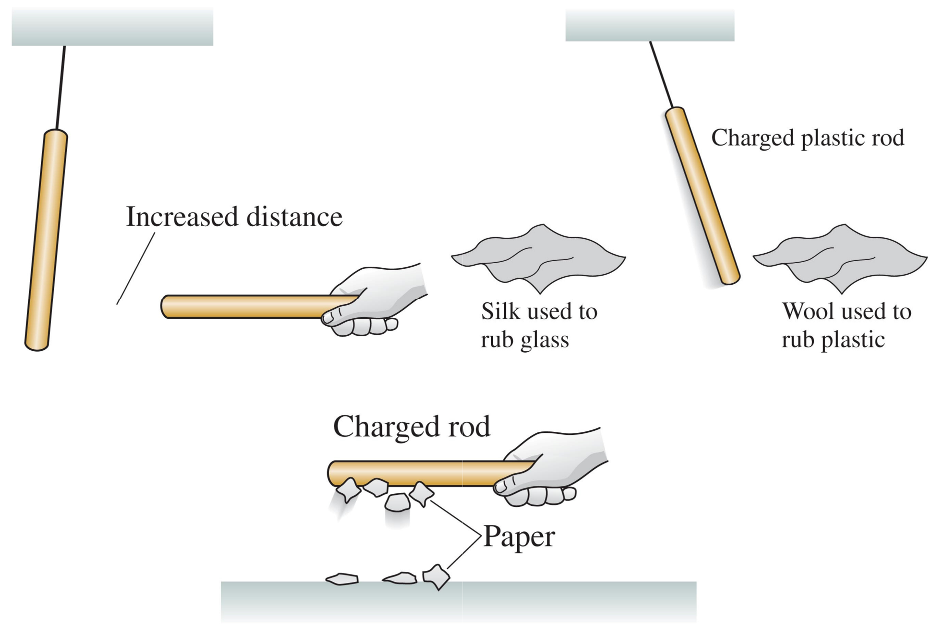
Reading Quiz

3. The electric field inside a metallic conductor is
   A. positive
   B. negative
   C. zero

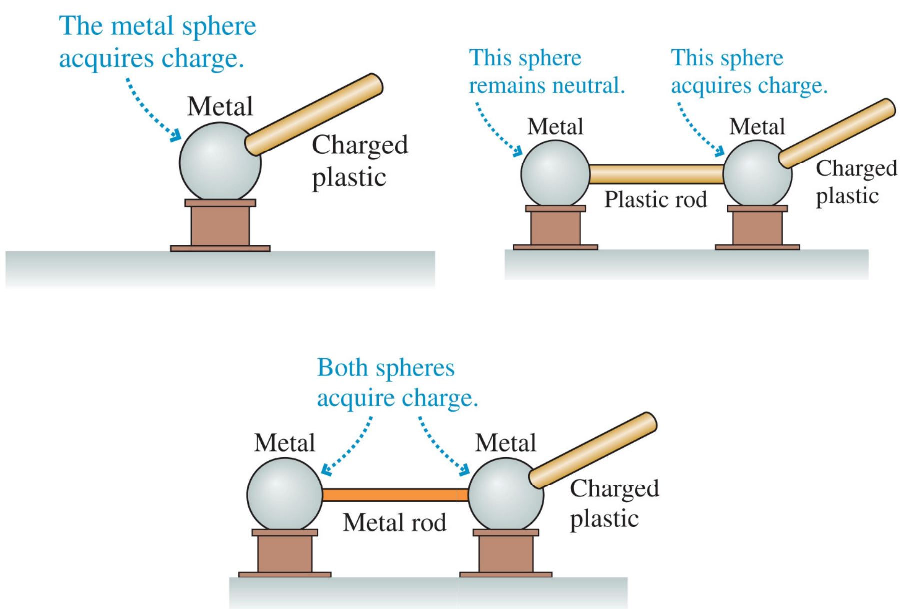
Electric Charges and Forces, Part I



Electric Charges and Forces, Part II



Electric Charges and Forces, Part III



The Charge Model

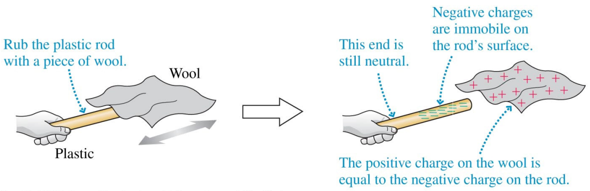
Charge model, part I The basic postulates of our model are:

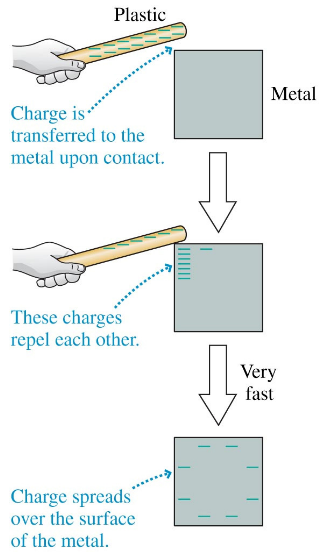
1. Frictional forces, such as rubbing, add something called **charge** to an object or remove it from the object. The process itself is called *charging*. More vigorous rubbing produces a larger quantity of charge.
2. There are two kinds of charge, positive and negative.
3. Two **like charges** (positive/positive or negative/negative) exert repulsive forces on each other. Two **opposite charges** (positive/negative), exert attractive forces on each other.
4. The force between two charges is a long-range force. The magnitude of the force increases as the quantity of charge increases and decreases as the distance between the charges increases.
5. *Neutral* objects have an *equal mixture* of positive and negative charge. The rubbing process somehow manages to separate the two.

Charge model, part II

6. There are two types of materials. Conductors are materials through or along which charge easily moves. Insulators are materials on or in which charges remain fixed in place.
7. Charge can be transferred from one object to another by contact.
8. Charge is conserved; it cannot be created or destroyed.

Visualizing Charge



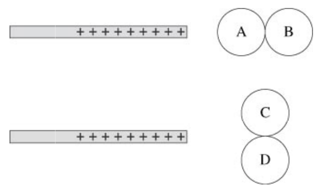


- Charges on an insulator do not move.
- Charges on a conductor adjust until there is no net force on any charge. We call this **electrostatic equilibrium**.

Checking Understanding

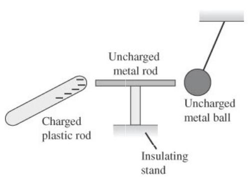
Two spheres are touching each other. A charged rod is brought near. The spheres are then separated, and the rod is taken away. In the first case, the spheres are aligned with the rod, in the second case, they are perpendicular. After the charged rod is removed, which of the spheres is:

i) Positive
ii) Negative
iii) Neutral



Examples

If a charged plastic rod is brought near an uncharged metal rod on an insulating stand, an uncharged metal ball near the other end of the metal rod is attracted to this end of the rod. Explain the motions of charges that give rise to this force.



Describe a procedure by which you could give two identical metal spheres exactly equal charges.
Describe a procedure by which you could give two identical metal spheres charges of opposite sign but exactly equal magnitude.

Coulomb's Law

Coulomb's law

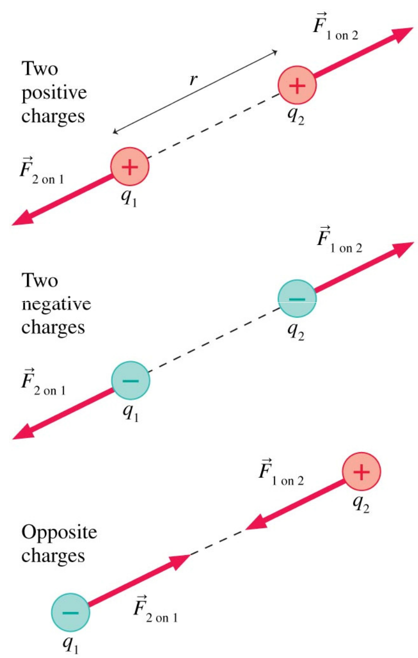
Magnitude: If two charged particles having charges q_1 and q_2 are a distance r apart, the particles exert forces on each other of magnitude

$$F_{1\text{ on }2} = F_{2\text{ on }1} = \frac{K|q_1||q_2|}{r^2} \qquad (20.1)$$

where the charges are in coulombs (C), and $K = 8.99 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2$ is called the **electrostatic constant.** These forces are an action/reaction pair, equal in magnitude and opposite in direction.

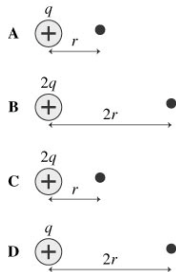
Direction: The forces are directed along the line joining the two particles. The forces are *repulsive* for two like charges and *attractive* for two opposite charges.

It is customary to round K to $9.0 \times 10^9\ \text{N} \cdot \text{m}^2/\text{C}^2$ for all but extremely precise calculations, and we will do so.



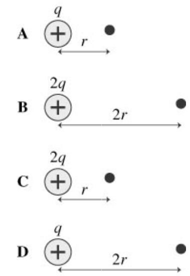
Checking Understanding

A small, positive charge is placed at the black dot.
In which case is the force on the small, positive charge the largest?



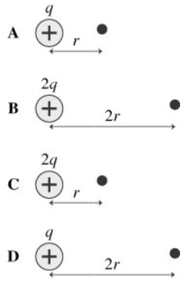
Checking Understanding

A small, positive charge is placed at the black dot.
In which case is the force on the small, positive charge the smallest?



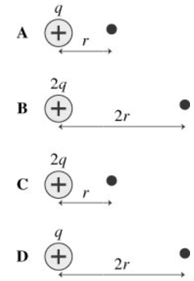
Checking Understanding

All charges in the diagrams below are of equal magnitude. In each case, a small, positive charge is placed at the black dot. In which cases is the force on this charge to the right?



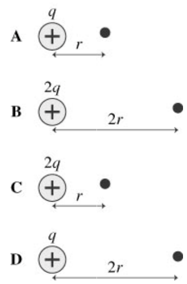
Checking Understanding

All charges in the diagrams below are of equal magnitude. In each case, a small, positive charge is placed at the black dot. In which cases is the force on this charge to the left?



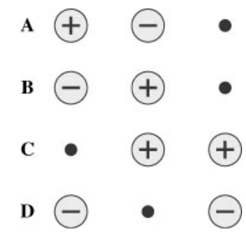
Checking Understanding

All charges in the diagrams below are of equal magnitude. In each case, a small, positive charge is placed at the black dot. In which case is the force on this charge zero?



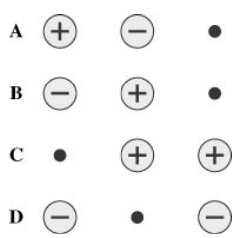
Checking Understanding

All charges in the diagrams below are of equal magnitude. In each case, a small, positive charge is placed at the black dot.
In which case is the force on the small, positive charge the largest?



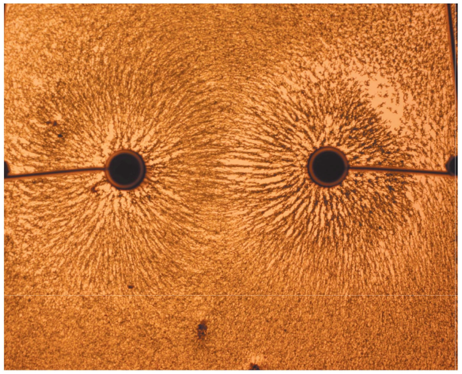
Checking Understanding

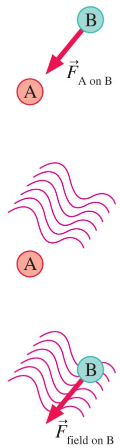
All charges in the diagrams below are of equal magnitude. In each case, a small, positive charge is placed at the black dot.
In which case is the force on the small, positive charge the smallest?



Two 0.10 g honeybees each acquire a charge of +23 pC as they fly back to their hive. As they approach the hive entrance, they are 1.0 cm apart. What is the magnitude of the repulsive force between the two bees? How does this force compare with their weight?

The Electric Field





In the force model, A exerts a force directly on B.

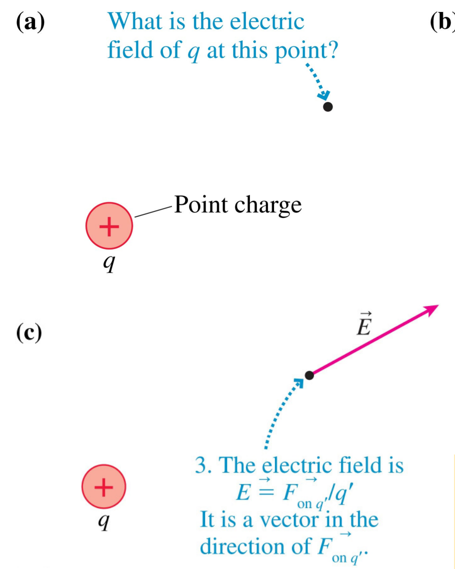
In the field model, A alters the space around it. (The wavy lines are poetic license. We don't know what the alteration looks like.)

Particle B then responds to the altered space. The altered space is the agent that exerts the force on B.

$$\vec{E} \text{ at } (x, y, z) = \frac{\vec{F}_{\text{on } q} \text{ at } (x, y, z)}{q} \qquad (20.3)$$

Electric field at a point defined by the force on charge q

The Electric Field of a Point Charge

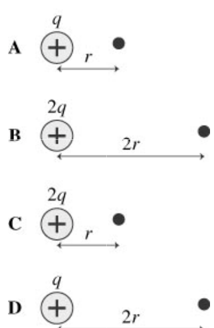


$$\vec{E} = \left(\frac{K|q|}{r^2}, \begin{bmatrix} \text{away from } q \text{ if } q > 0 \\ \text{toward } q \text{ if } q < 0 \end{bmatrix}\right)$$

Electric field of point charge q at a distance r

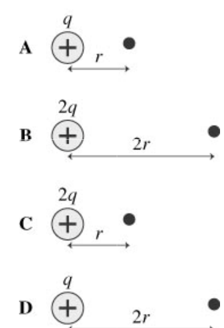
Checking Understanding

Positive charges create an electric field in the space around them. In which case is the field at the black dot the smallest?



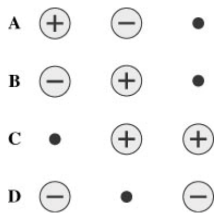
Checking Understanding

Positive charges create an electric field in the space around them In which case is the field at the black dot the largest?



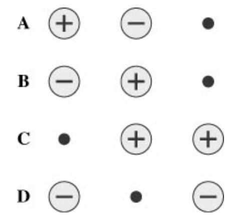
Checking Understanding

All charges in the diagram below are of equal magnitude. In each of the four cases below, two charges lie along a line, and we consider the electric field due to these two charges at a point along this line represented by the black dot. In which of the cases below is the field to the right?



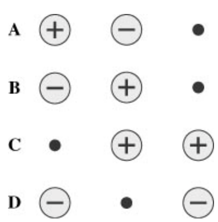
Checking Understanding

All charges in the diagram below are of equal magnitude. In each of the four cases below, two charges lie along a line, and we consider the electric field due to these two charges at a point along this line represented by the black dot. In which of the case below is the field to the left?



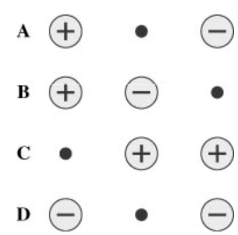
Checking Understanding

All charges in the diagram below are of equal magnitude. In each of the four cases below, two charges lie along a line, and we consider the electric field due to these two charges at a point along this line represented by the black dot. In which of the case below is the field zero?



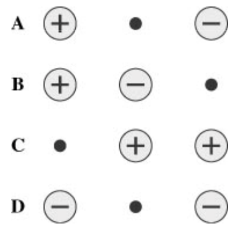
Checking Understanding

All charges in the diagram below are of equal magnitude. In each of the four cases below, two charges lie along a line, and we consider the electric field due to these two charges at a point along this line represented by the black dot. In which case is the magnitude of the field at the black dot the largest?

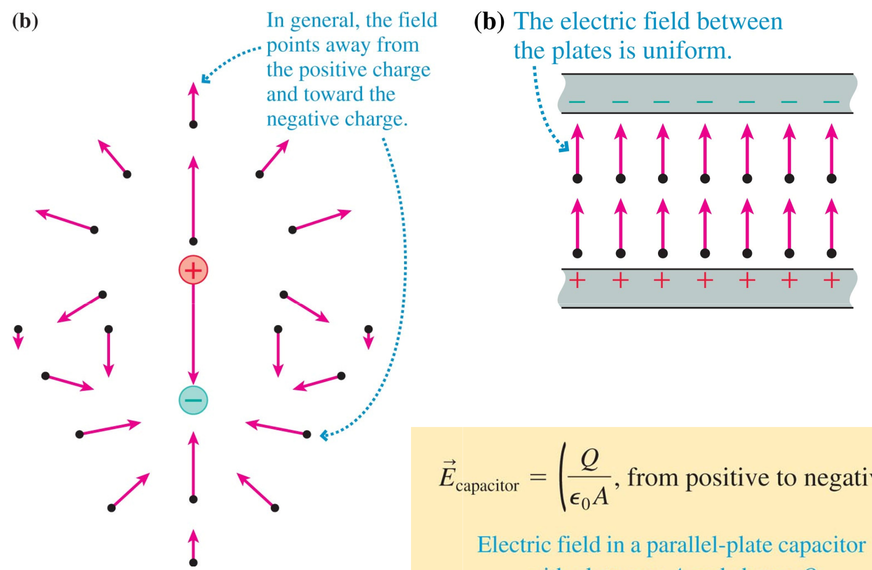


Checking Understanding

All charges in the diagram below are of equal magnitude. In each of the four cases below, two charges lie along a line, and we consider the electric field due to these two charges at a point along this line represented by the black dot. In which case is the magnitude of the field at the black dot the smallest?



Dipole and Uniform Electric Fields

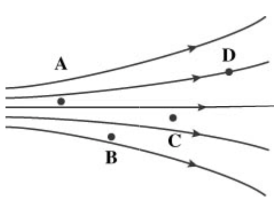


$$\vec{E}_{\text{capacitor}} = \left(\frac{Q}{\epsilon_0 A}, \text{ from positive to negative}\right)$$

Electric field in a parallel-plate capacitor with plate area A and charge Q

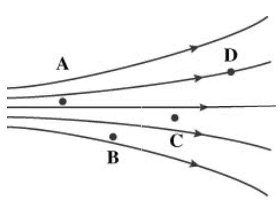
Checking Understanding

A set of electric field lines is directed as below. At which of the noted points is the magnitude of the field the greatest?



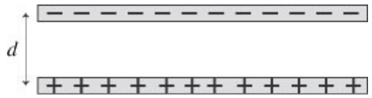
Checking Understanding

A set of electric field lines is directed as below. At which of the noted points is the magnitude of the field the smallest?



Checking Understanding

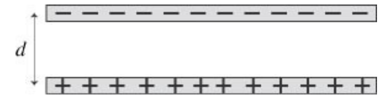
Two parallel plates have charges of equal magnitude but opposite sign. What change could be made to increase the field strength between the plates?



A. increase the magnitude of the charge on both plates
B. decrease the magnitude of the charge on both plates
C. increase the distance between the plates
D. decrease the distance between the plates
E. increase the area of the plates (while keeping the magnitude of the charges the same)
F. decrease the area of the plates (while keeping the magnitude of the charges the same)

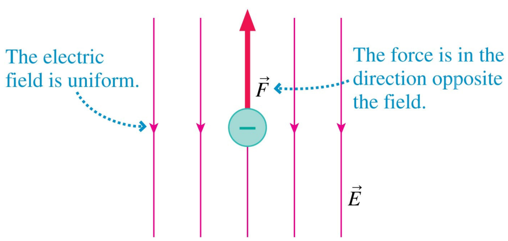
Checking Understanding

Two parallel plates have charges of equal magnitude but opposite sign. What change could be made to decrease the field strength between the plates?



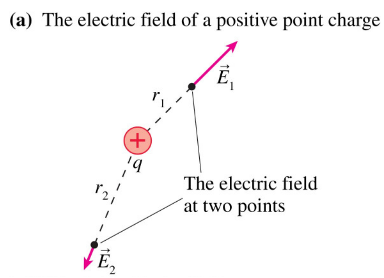
A. increase the magnitude of the charge on both plates
B. decrease the magnitude of the charge on both plates
C. increase the distance between the plates
D. decrease the distance between the plates
E. increase the area of the plates (while keeping the magnitude of the charges the same)
F. decrease the area of the plates (while keeping the magnitude of the charges the same)

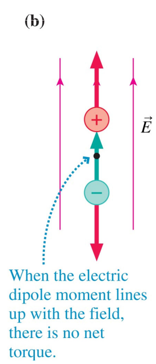
Forces and Torques on Charges in Electric Fields



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

Force on a charge due to an electric field

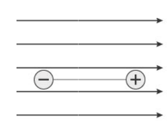




Checking Understanding

A dipole is held motionless in a uniform electric field. For the situation below, when the dipole is released, which of the following describes the subsequent motion?

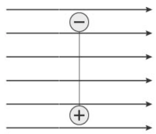
A. The dipole moves to the right.
B. The dipole moves to the left.
C. The dipole rotates clockwise.
D. The dipole rotates counterclockwise.
E. The dipole remains motionless.



Checking Understanding

A dipole is held motionless in a uniform electric field. For the situation below, when the dipole is released, which of the following describes the subsequent motion?

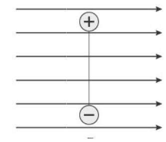
A. The dipole moves to the right.
B. The dipole moves to the left.
C. The dipole rotates clockwise.
D. The dipole rotates counterclockwise.
E. The dipole remains motionless.



Checking Understanding

A dipole is held motionless in a uniform electric field. For the situation below, when the dipole is released, which of the following describes the subsequent motion?

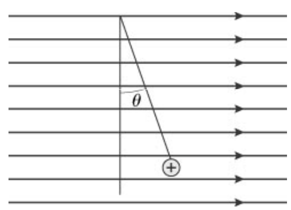
A. The dipole moves to the right.
B. The dipole moves to the left.
C. The dipole rotates clockwise.
D. The dipole rotates counterclockwise.
E. The dipole remains motionless.



Additional Clicker Questions

A small sphere is suspended from a string in a uniform electric field. Several different cases of sphere mass and sphere charge are presented in the following table. In which case is the angle at which the sphere hangs the largest?

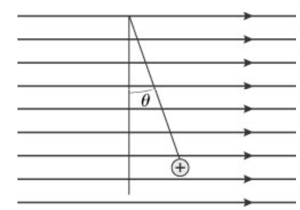
	Sphere mass (g)	Sphere charge (nC)
A.	2.0	4.0
B.	3.0	4.0
C.	2.0	6.0
D.	3.0	8.0
E.	4.0	9.0



Additional Clicker Questions

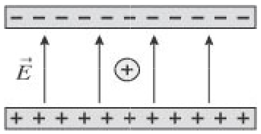
A small sphere is suspended from a string in a uniform electric field. Several different cases of sphere mass and sphere charge are presented in the following table. In which case is the angle at which the sphere hangs the smallest?

	Sphere mass (g)	Sphere charge (nC)
A.	2.0	4.0
B.	3.0	4.0
C.	2.0	6.0
D.	3.0	8.0
E.	4.0	9.0

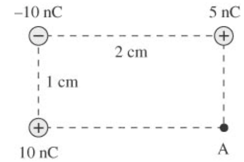


Additional Examples

1. A positively charged particle is motionless in the center of a capacitor. Describe the subsequent motion of the charged particle.



2. Determine the magnitude and the direction of the electric field at point A.



3. Determine the individual forces and the net force on charge B for each of the following cases.