Chapter 19 Electric Charges, Forces, and Fields

19.1 Electric Charges
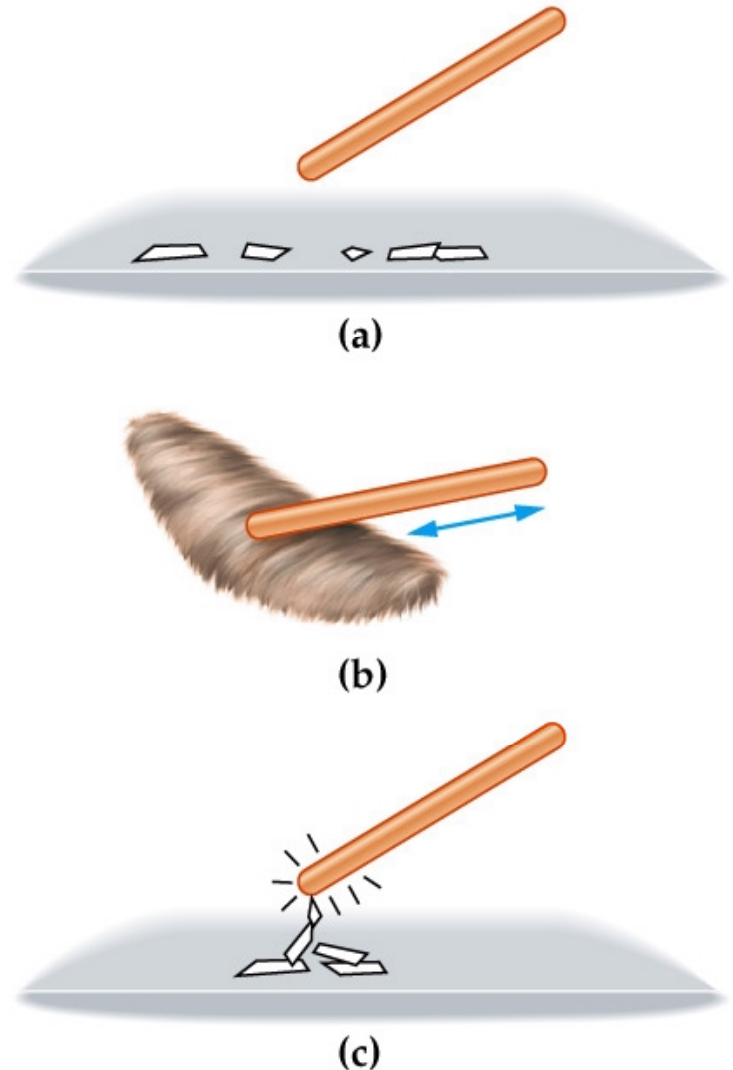
19.2 Insulators and Conductors

19.3 Coulomb's Law

19.4 The Electric Field

19.5 Electric Field Lines

19.6 Shielding and Charging by Induction

Figure 19-1 Charging an amber rod

An uncharged amber rod (a) exerts no force on scraps of paper. When the rod is rubbed against a piece of fur (b) it becomes charged and then attracts the paper (c).


(a)

(b)

(c)

Figure 19–2 Likes repel, opposites attract

A charged amber rod is suspended by a string. According to the convention introduced by Benjamin Franklin, the charge on the amber is designated as negative. (a) When another charged amber rod is brought near the suspended rod it rotates away, indicating a repulsive force between like charges. (b) When a charged glass rod is brought close to the suspended amber rod, the amber rotates toward the glass, indicating an attractive force and the existence of a second type of charge, which we designate as positive.

(a)

(b)
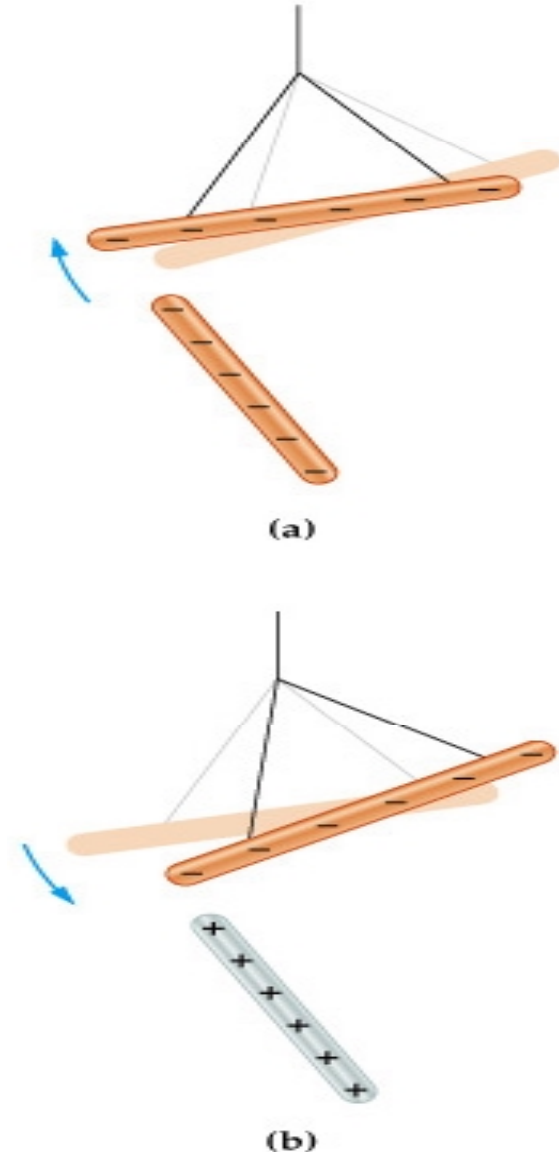
Figure 19−3 The structure of an atom

A crude representation of an atom, showing the positively charged nucleus at its center and the negatively charged electrons orbiting about it. More accurately, the electrons should be thought of as forming a "cloud" of negative charge surrounding the nucleus.
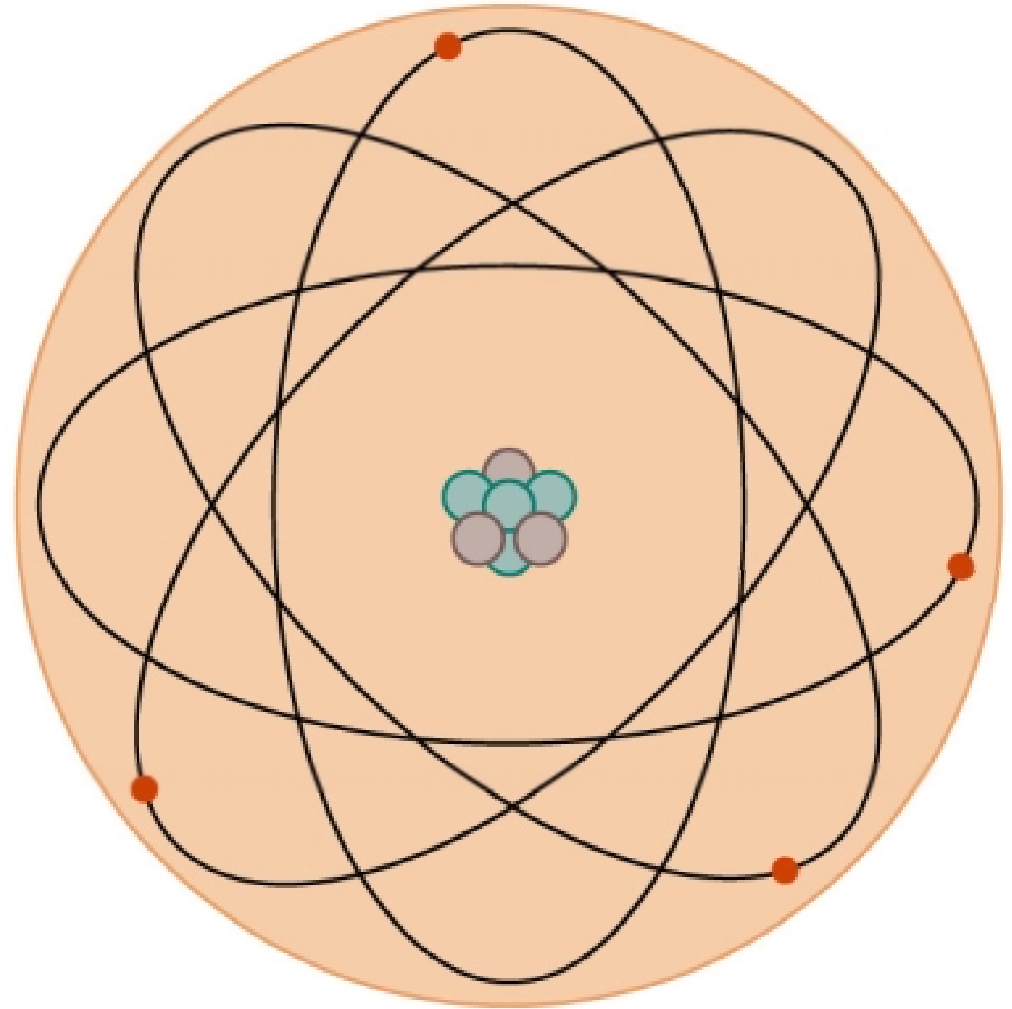
All of these attractive or repulsive ELECTROSTATIC forces are due to electrical charges in the atoms of the materials. Since there are two types of force there must be two types of charge!

Both protons and electrons have the same charge. BUT, It is Positive for the Proton and Negative for the Electron.

Proton charge, $e_p = +1.6 \times 10^{-19}$ C
Electron charge, $e = -1.6 \times 10^{-19}$ C

An atom is **neutral** because # protons = # electrons

Proton mass, $m_p = 1.67 \times 10^{-27}$ kg
Electron mass, $m_e = 9.11 \times 10^{-31}$ kg

Charge is QUANTIZED

Charge on an object, **Q = Ne**

It only exists in discrete units

Charge is CONSERVED

The net charge in a closed system is constant.
It can be moved around, however

Charge is measured in Coulombs

1 C is a lot of charge

$1 \mu C = 10^{-6} C = 0.000001 C$

Problem: Charge is Quantized
A amber rod is rubbed with fur and acquires a charge of –4.8 μC.
A   How many electrons does it gain?
B   Does the fur gain or lose electrons? How many?

Charge is Conserved
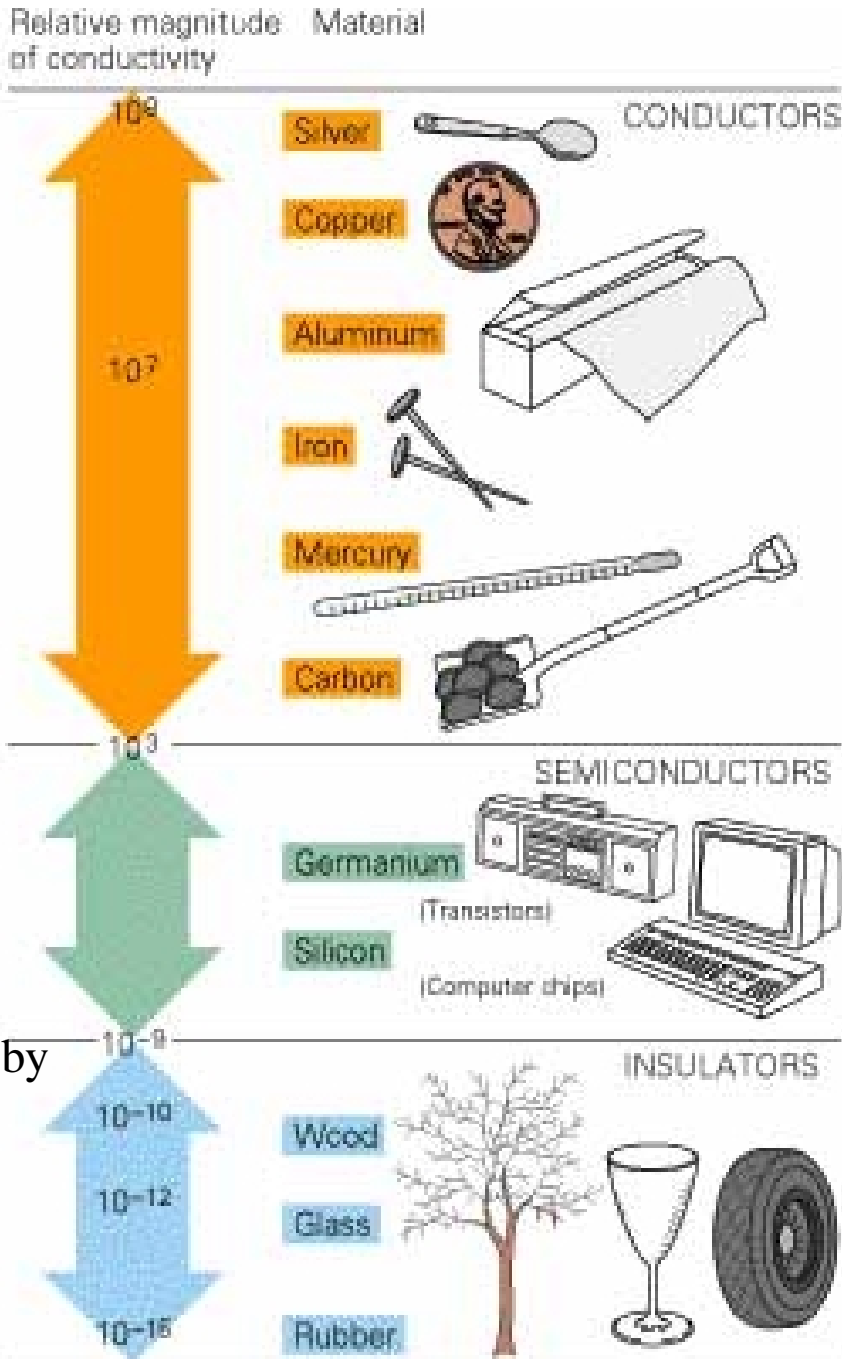A glass rod rubbed with silk acquires a charge of 8×10^{-9} C.
A   What is the charge on the silk?
B   Is the glass rod heavier or lighter after rubbing?
C   Is the silk heavier or lighter after rubbing?

19.2 CONDUCTORS AND INSULATORS

Relative magnitude of conductivity — Material

Relative magnitude of conductivity	Material	
10^9	Silver	CONDUCTORS
	Copper	
10^7	Aluminum	
	Iron	
	Mercury	
10^3	Carbon	
		SEMICONDUCTORS
	Germanium (Transistors)	
	Silicon (Computer chips)	
10^{-9}		INSULATORS
10^{-10}	Wood	
10^{-12}	Glass	
10^{-16}	Rubber	

Charges move easily through them.

Conducts electricity
CONDUCTOR

Can conduct electricity a little
SEMICONDUCTOR

Can charge by rubbing

Do not conduct electricity
INSULATOR

Charges on an insulator DO NOT move through the insulator. Proof:?????
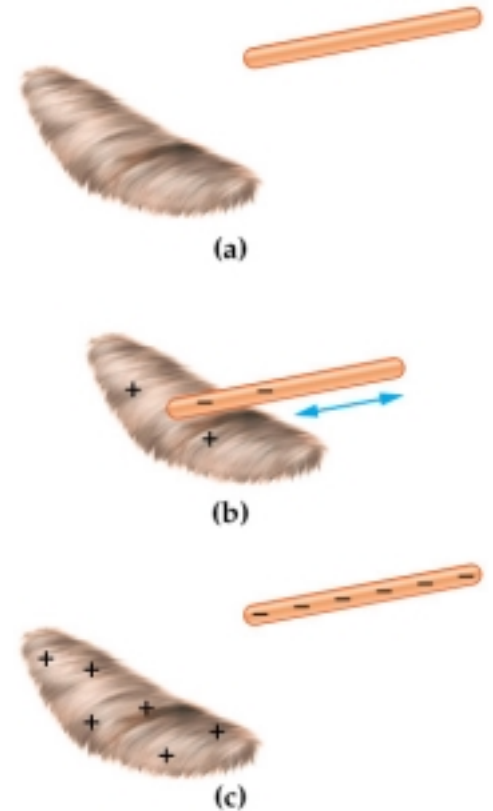
Charging an insulator by rubbing it with another insulator.

ONLY electrons can move between materials.

If an object (insulator) becomes positively charged by rubbing.
It means that it has LOST electrons.
The material used for rubbing has gained electrons.
It is the large amount of energy from the rubbing that removes the
electrons from the insulator.

(a)

(b)

(c)

Figure 19–4 Charge transfer

Initially. an amber rod and a piece of fur are electrically neutral. As they are rubbed together, charge is transferred from one to the other. In the end, the fur and the rod have charges of equal magnitude but opposite sign.

(a)

(b)

(c)
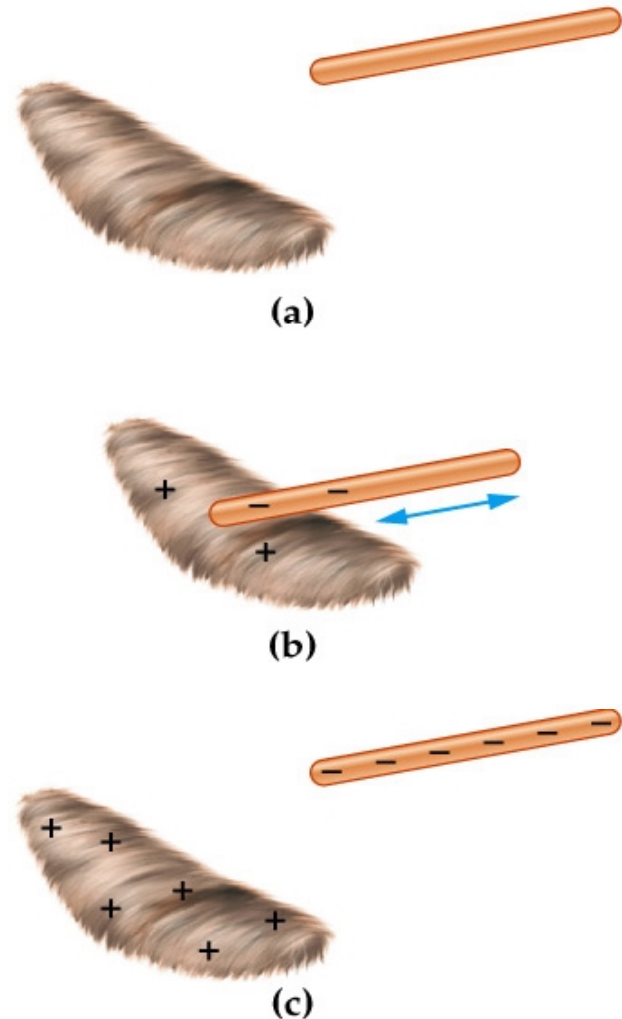
Figure 19–5 Electrical polarization

When a charged rod is far from a neutral object the atoms in the object are undistorted, as in Figure 19–3. As the rod is brought closer, however, the atoms distort, producing an excess of one type of charge on the surface of the object (in this case a negative charge). This induced charge is referred to as a polarization charge. Since the sign of the polarization charge is the opposite of the sign of the charge on the rod, there is an attractive force between the rod and the object.
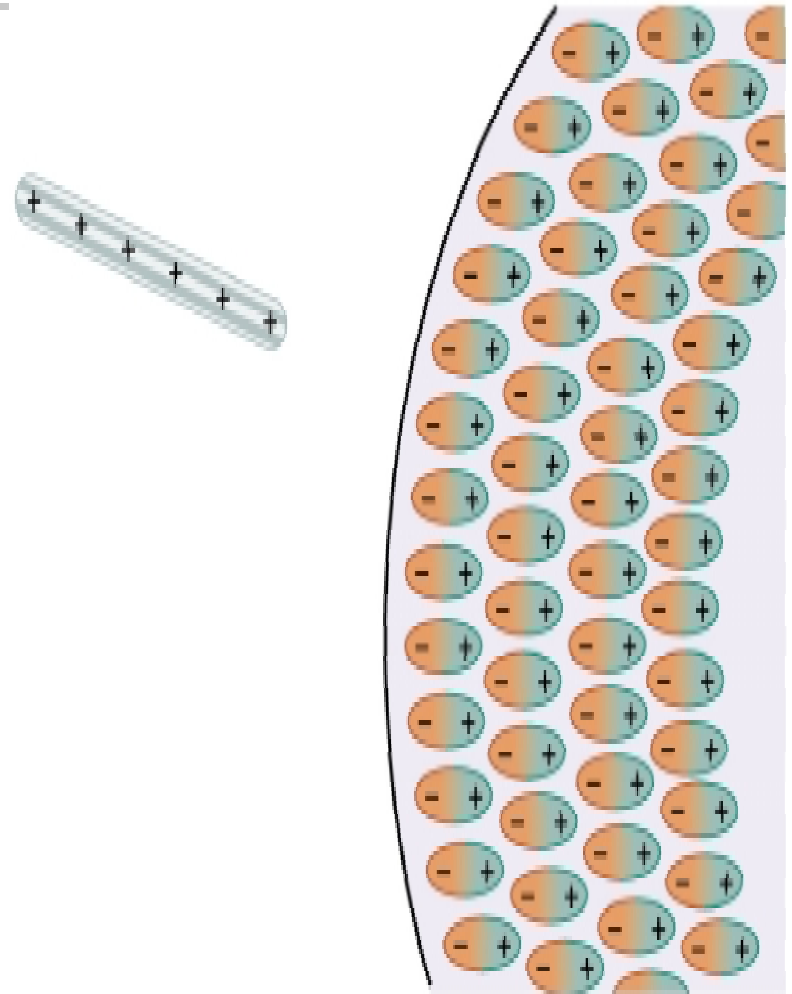
A charged insulator causes an uncharged insulator to become **polarized**.

The atoms in the insulator are neutral but the charges within them can move around.
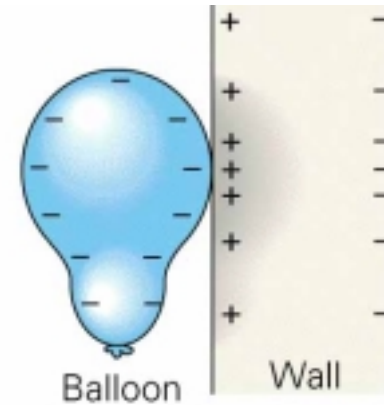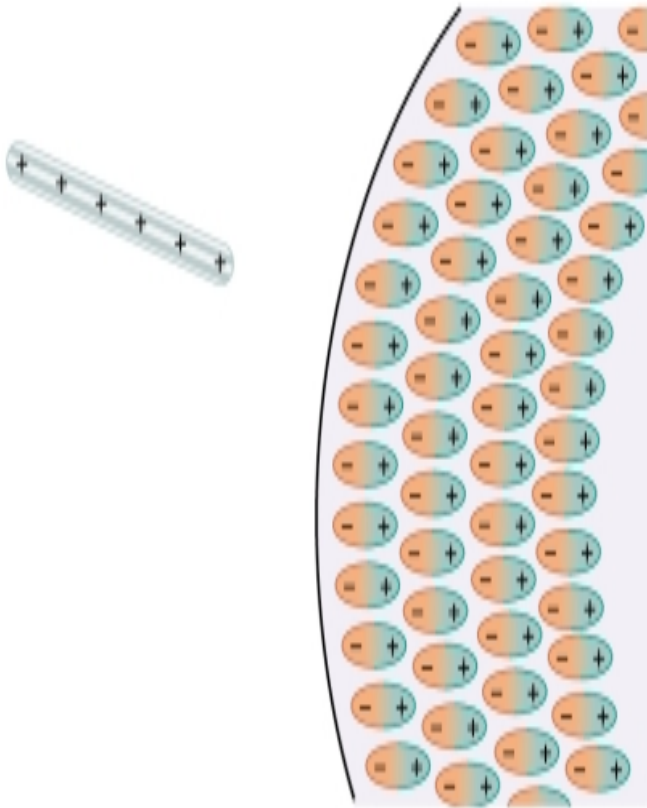
A charged insulator ALWAYS attracts uncharged insulators.
It does not matter if it is positively or negatively charged.

Figure 19–6 Charging a conductor

When an uncharged metal sphere is touched by a charged rod (a) some charge is transferred at the point of contact. Because like charges repel, and charges move freely on a conductor, the transferred charge quickly spreads out and covers the entire surface of the sphere (b).

(a)

(b)
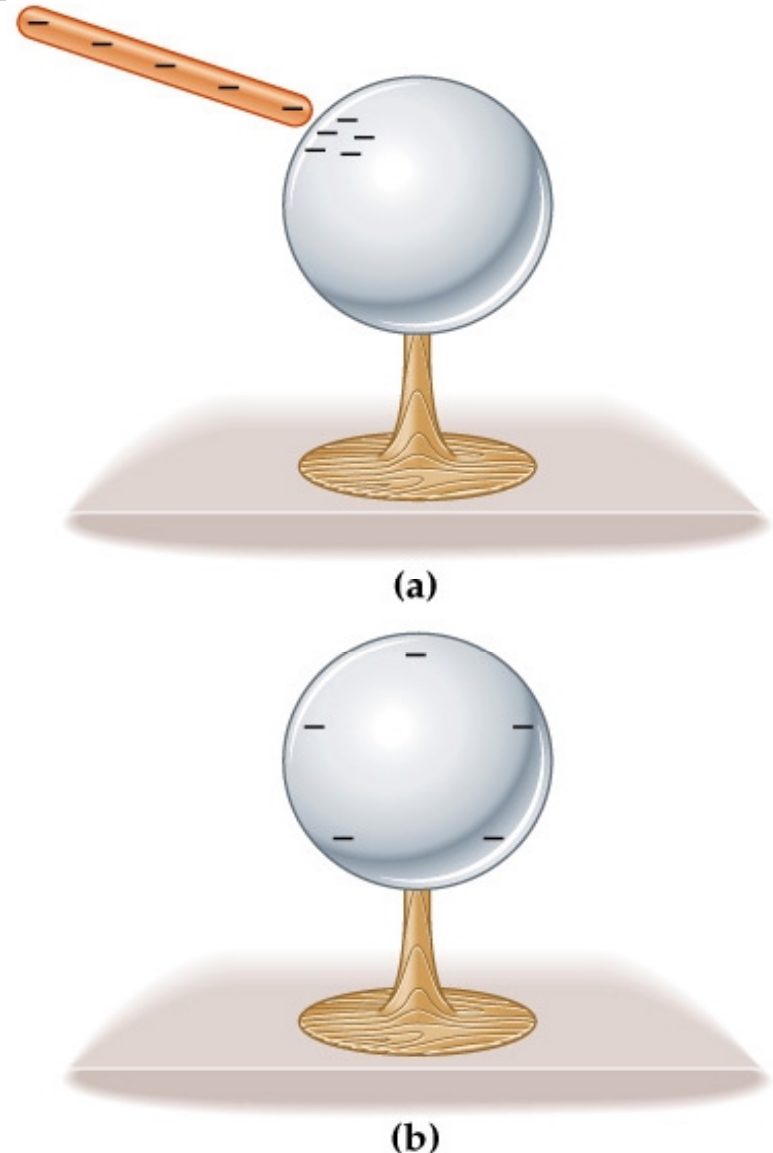
Figure 19–7 Forces between point charges

Notice that in each case the forces exerted on the two charges form an action–reaction pair. Thus, the force that charge 1 exerts on charge 2 is equal and opposite to the force that charge 2 exerts on charge 1.
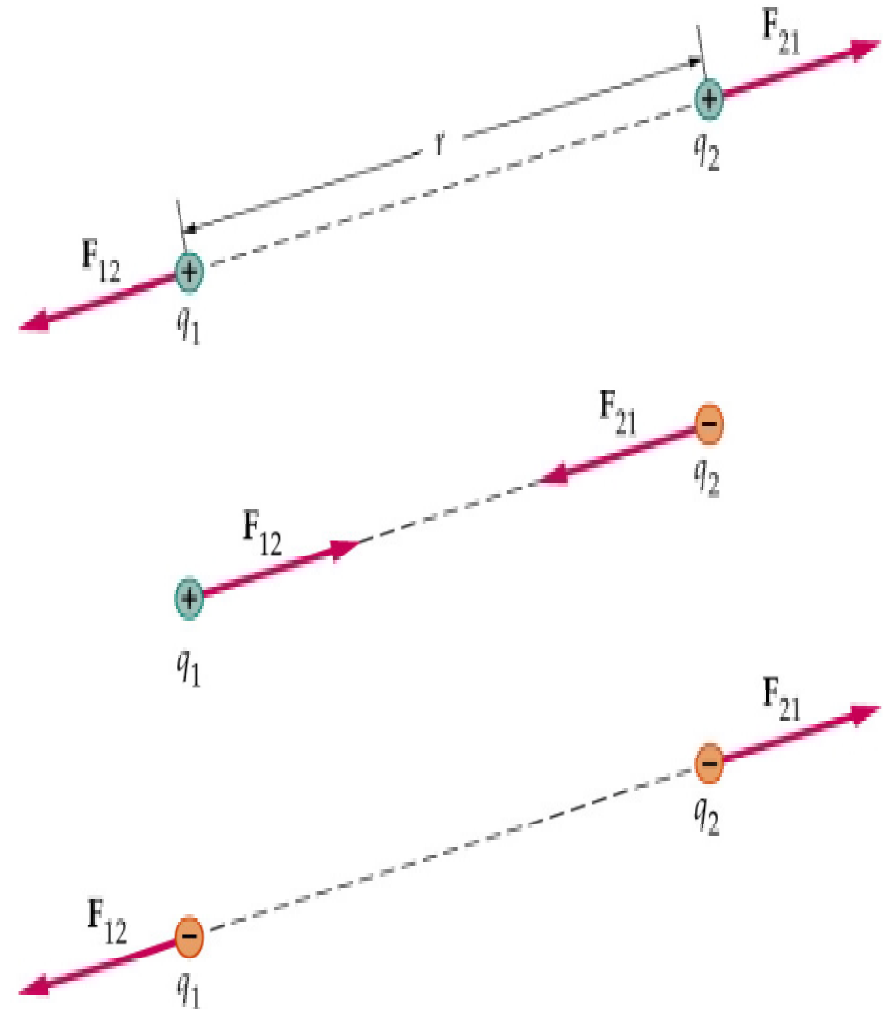
How Big Are The Forces Between Charges?

In 1769, John Robison found that if you double the distance between charges then the force between them is reduced by 4.

In 1785 Coulomb showed:

$$F = \frac{kq_1q_2}{r^2}$$ where $$k = \frac{1}{4\pi\varepsilon_0} = 8.99\text{x}10^9 \frac{Nm^2}{C^2}$$

Force, F is in Newtons, N
Charge is in Coulombs, C
r is in meters, m

$$F_{12} = \frac{kq_1q_2}{r^2}$$ q_1 q_2 $$F_{21} = \frac{kq_1q_2}{r^2}$$

$$|F_{12}| = |F_{21}|$$

Directions are opposite, however.

Do not worry about the sign of the charges when calculating the forces between charges. The direction of the forces on charges follows from the fact that opposite charges attract and like charges repel.

Figure 19–8 Superposition

a) Forces are exerted on charge 1 by the charges 2, 3, and 4. These forces are F_{12}, F_{13}, and F_{14} respectively. (b) The net force acting on charge 1, which we label F_1, is the vector sum of F_{12}, F_{13}, and F_{14}.
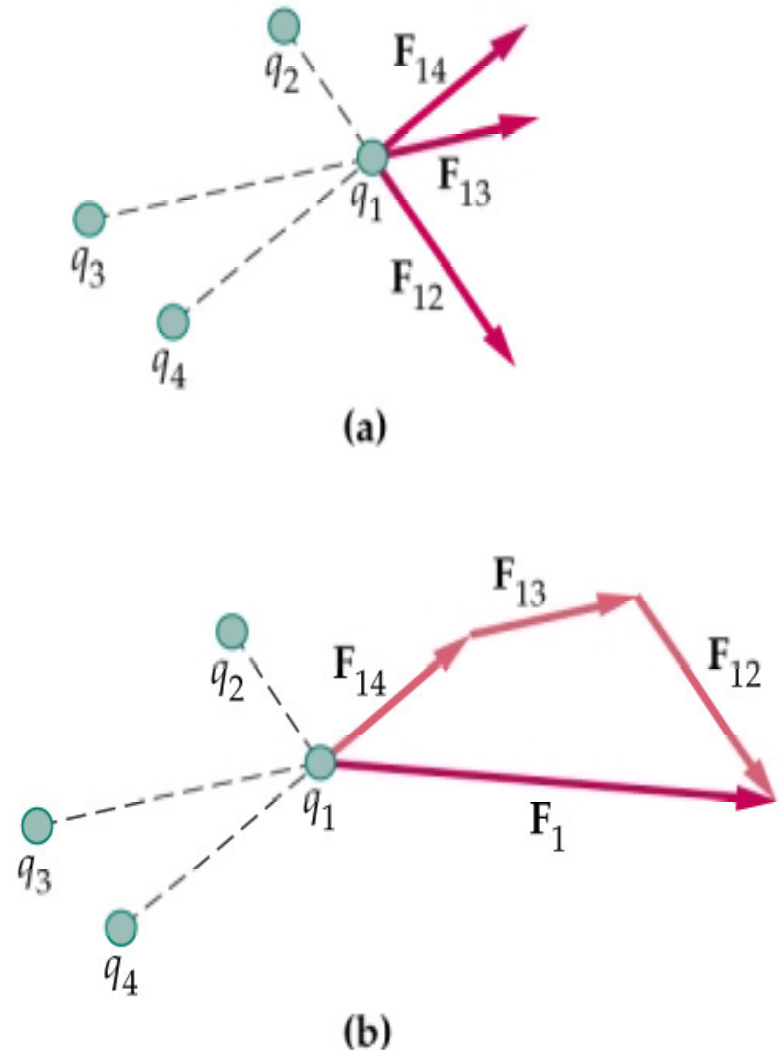
Worked example: Similar to problems 22-23 and 54A.
What is the force (magnitude and direction) on q_3
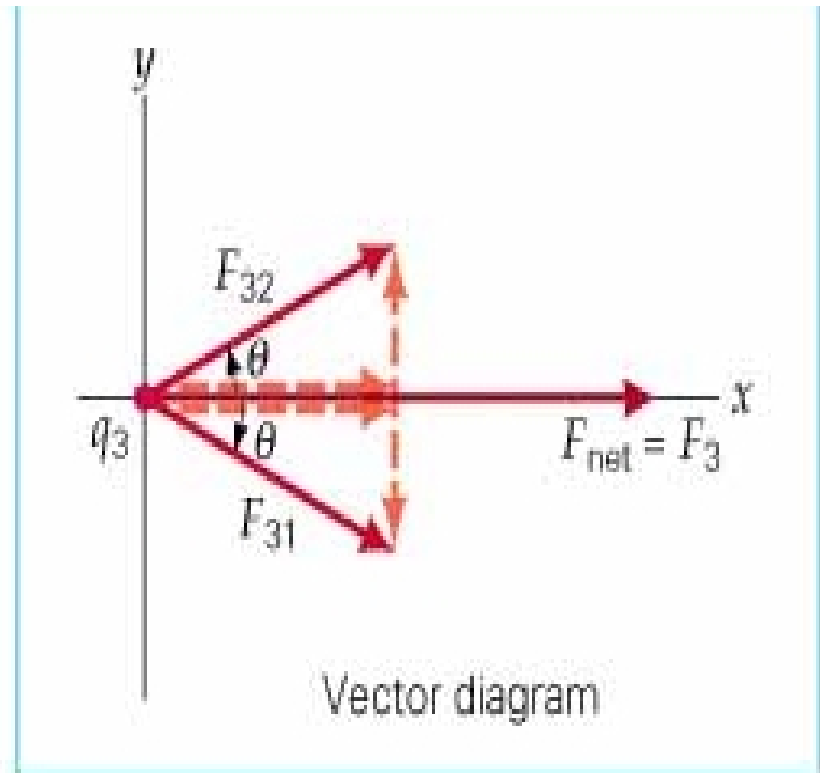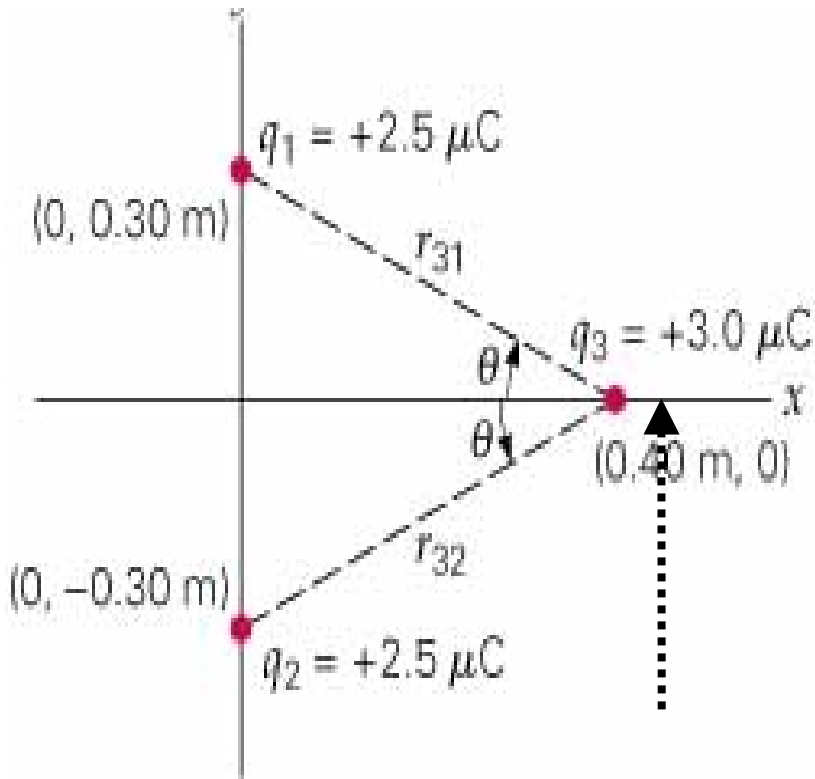
The force is along the line joining the charges.
The direction depends on the sign of the charges.
Two charges will give rise to two forces on q_1.
Remember: Forces add as vectors.

The Electric Field

Electric forces appear to act through empty space. Just like gravitational forces.

A charge in space creates an electric field. Just like the earth creates a gravitational field in the space around it.

A second charge in the vicinity of the first experiences a force because of the electric field. Just like a second mass near the earth experiences a force because of the field of the earth.

The electric field is a vector and points in the direction of the force that a positive "test" charge would feel.

For gravitation we describe how these forces vary in space by using the concept of GRAVITATIONAL FIELD.

For example, the earth produces a gravitational field. A mass, such as the planet Mercury, is attracted to the earth. But the size of this attraction depends on how far Mercury is from earth. The distance between Mercury and earth varies as Mercury moves so the attraction will vary. We say that Mercury experiences a force due to the earths gravitational field.

Figure 19–9 An electrostatic force field

The charge q at the origin of this coordinate system exerts a different force on a given charge at every point in space. Here we show the force vectors associated with q for a grid of points.
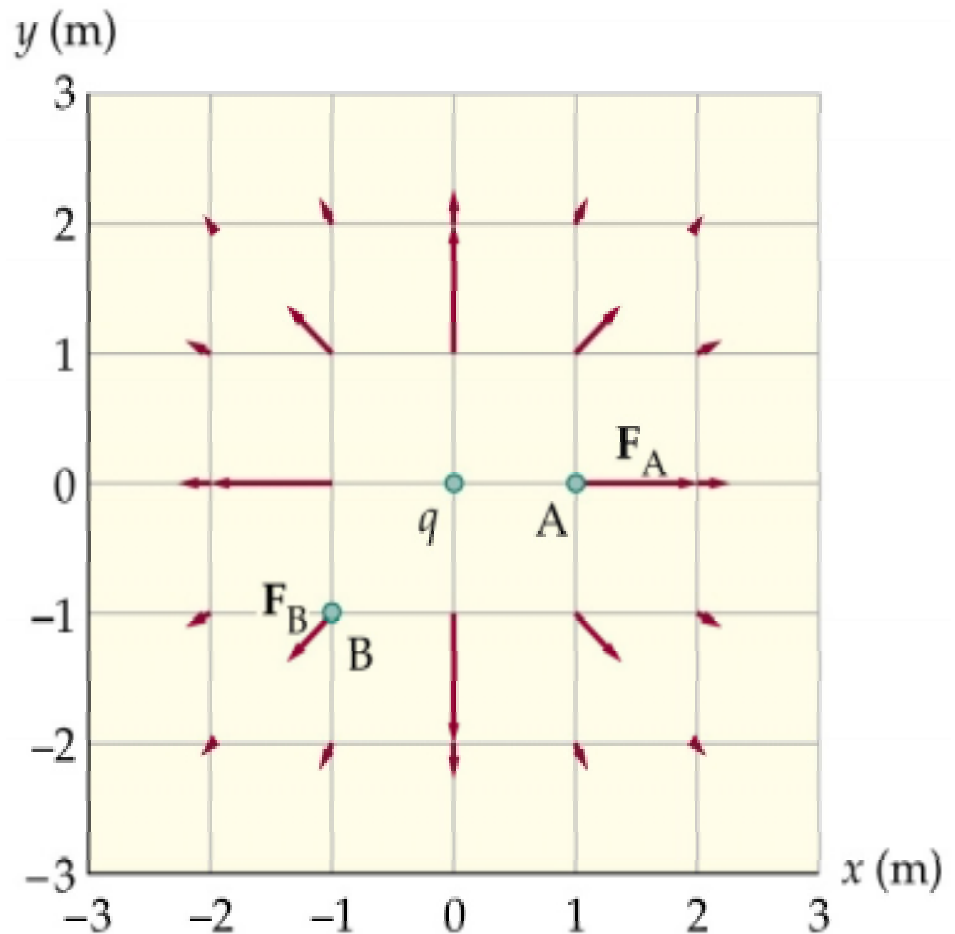
Figure 19–9B The Electric Field

Place test charge, q_0 at various points near the charge q. The force at each point varies in magnitude and direction. The size of the force depends on the size of the test charge, q_0. If we divide this force by q_0 we get the force per unit charge at each point in space. The electric field due to a charge or distribution of charges at some point in space is defined in terms of the force that a test charge (q_0) would experience if it were at that point in space.

$$\mathbf{F}/q_0 = \mathbf{E} \quad \text{equation 19.8}$$
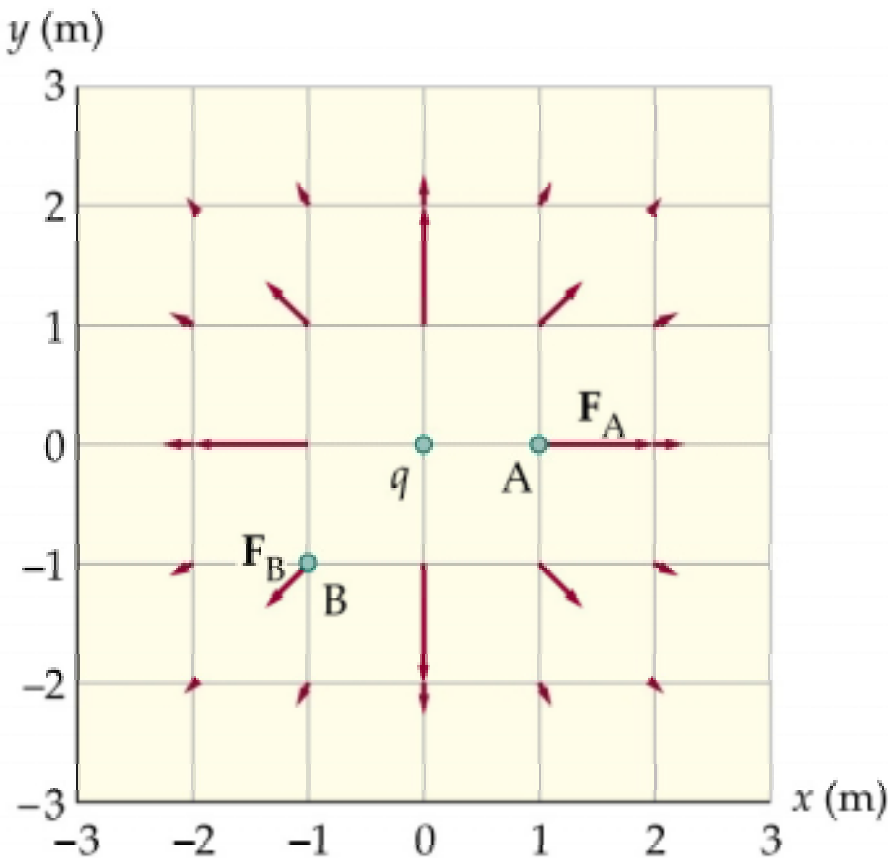
Figure 19–10 The electric field of a point charge

The electric field E due to a positive charge q at the origin is radially outward. Its magnitude is
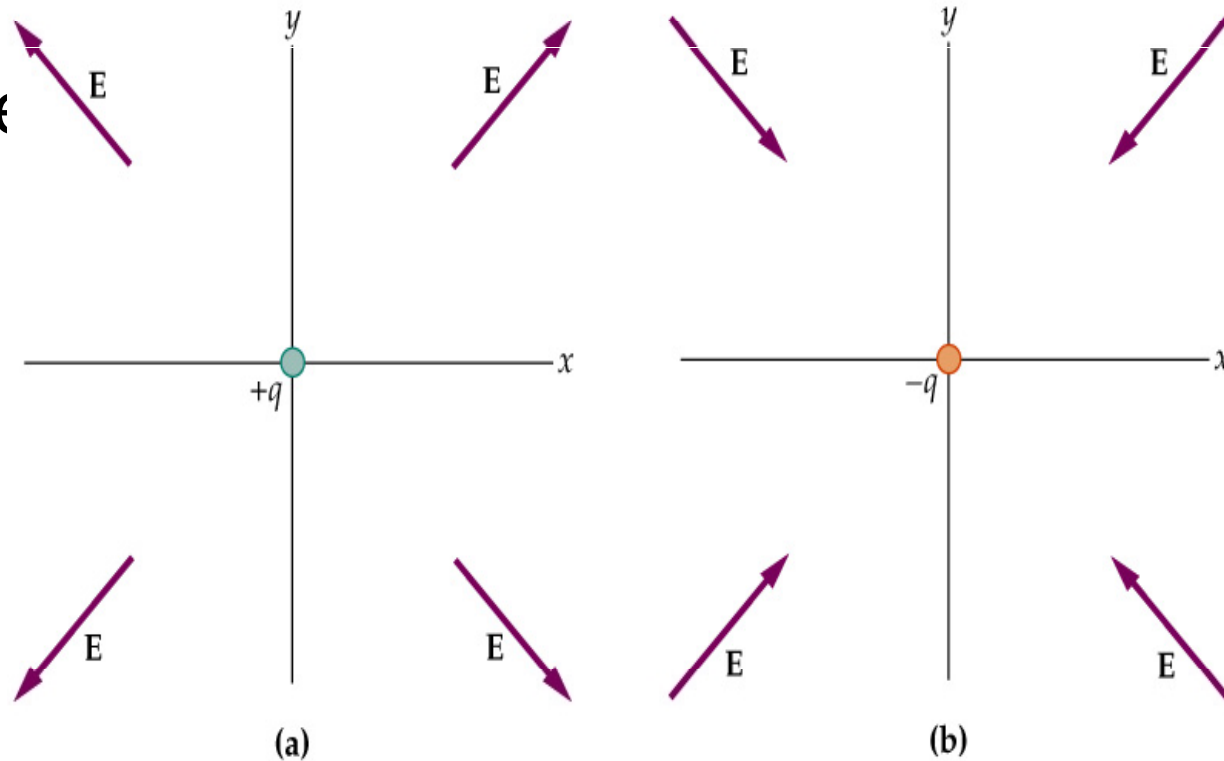
$E = kq /r^2$.

For a point charge,

$E = F/q_0 = kqq_0 /r^2q_0$

$E = kq / r^2$
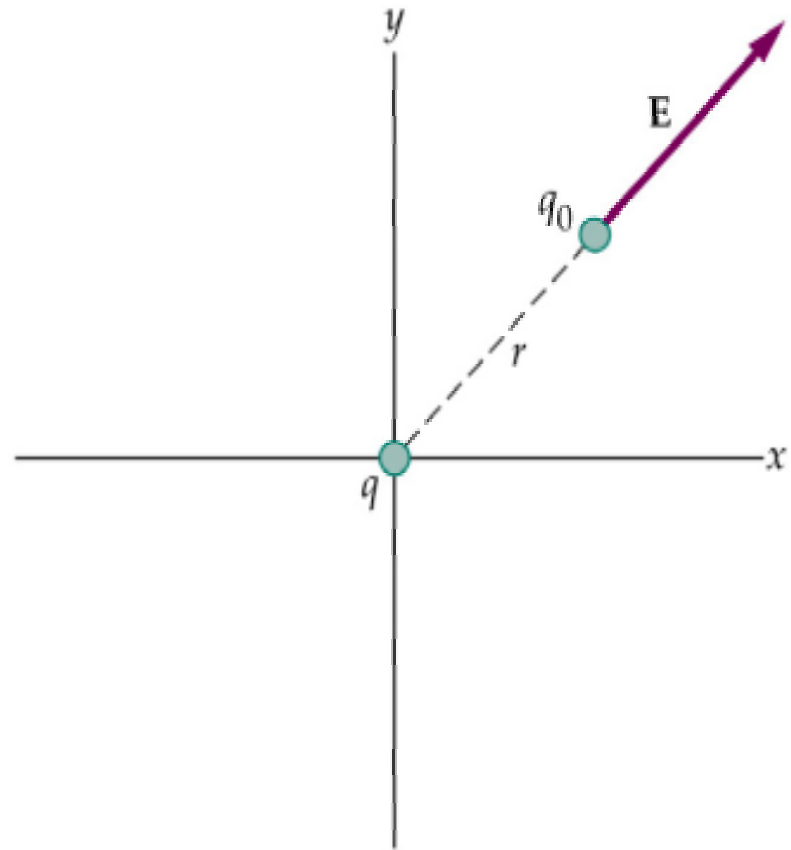
Figure 19–11 The direction of the electric field

(a) The electric field due to a positive charge at the origin points radially outward. (b) If the charge at the origin is negative, the electric field is radially inward.

Figure 19–12 Superposition of the electric field

The net electric field at the point P is the vector sum of the fields due to the charges q_1 and q_2. Note that E_1 and E_2 point away from the charges q_1 and q_2 respectively. This is as expected, since both of these charges are positive.


(c)
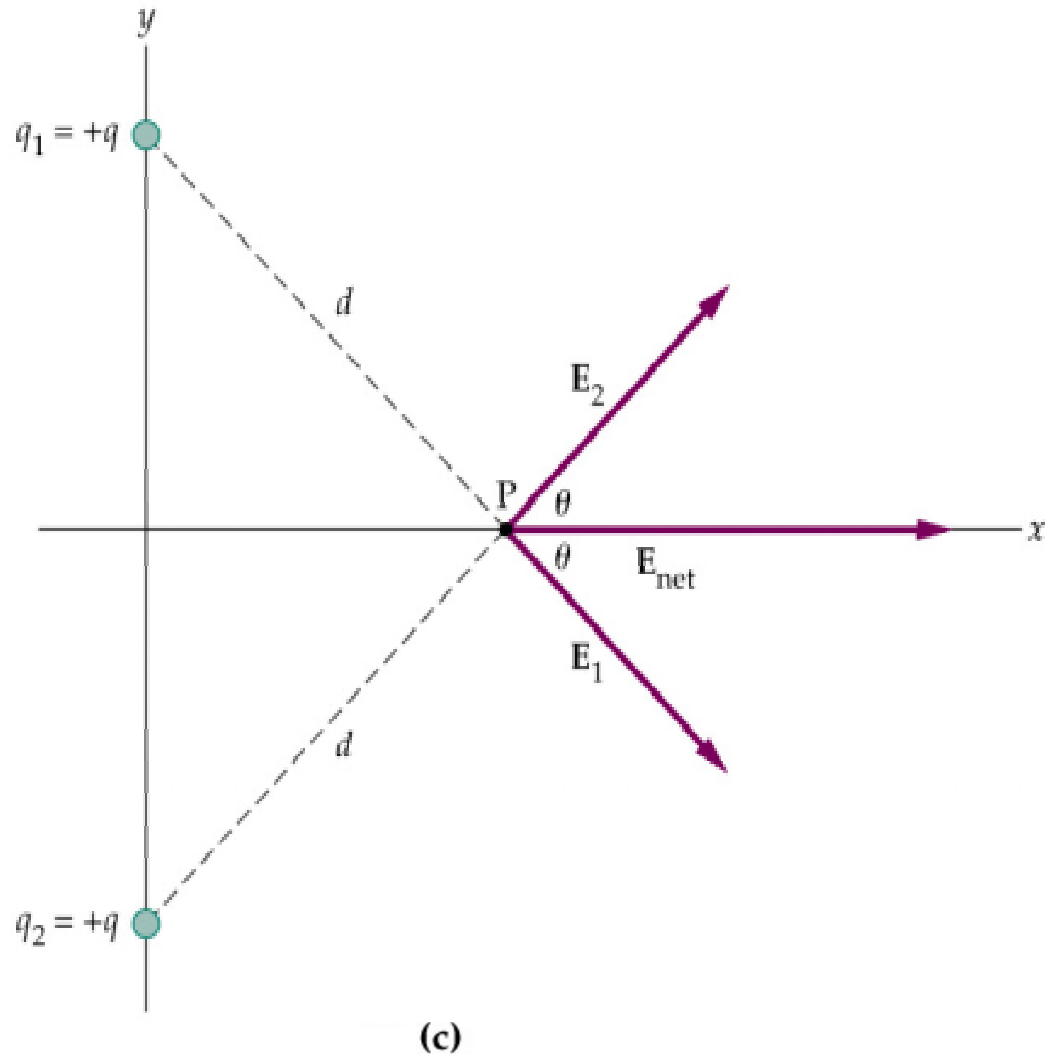
Figure 19–14 Electric field lines for a point charge

(a) Near a positive charge the field lines point radially away from the charge. The lines start on the positive charge and end at infinity. (b) Near a negative charge the field lines point radially inward. They start at infinity and end on a negative charge and are more dense where the field is more intense. Notice that the number of lines drawn for part (b) is twice the number drawn for part (a), a reflection of the relative magnitudes of the charges.
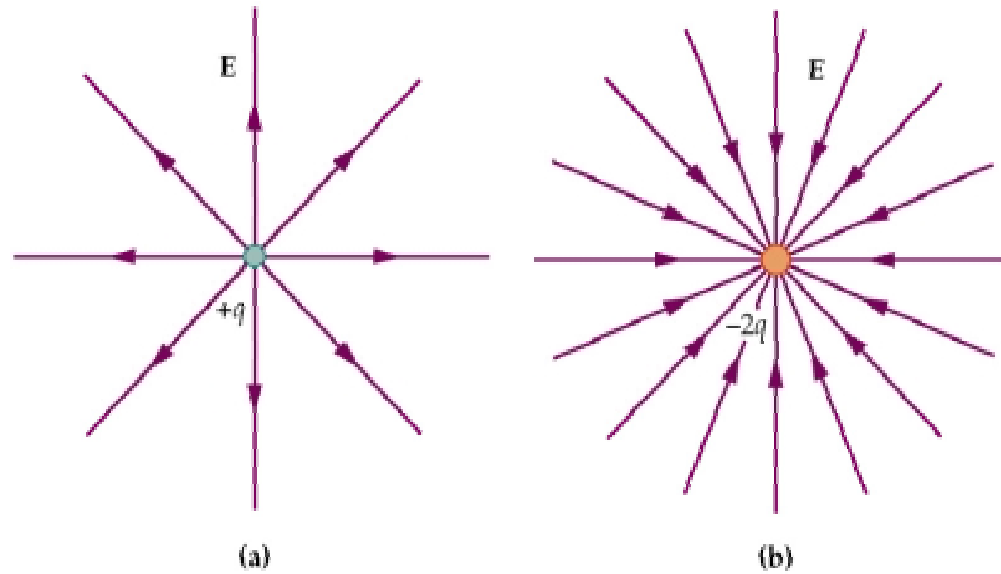
# Figure 19–15 Electric field lines for systems of charges

(a) The electric field lines for a dipole form closed loops that become more widely spaced with distance from the charges. (b) In a system with a net charge, some field lines extend to infinity. If the charges have opposite signs, some field lines start on one charge and terminate on the other charge. (c) All of the field lines in a system with charges of the same sign extend to infinity.
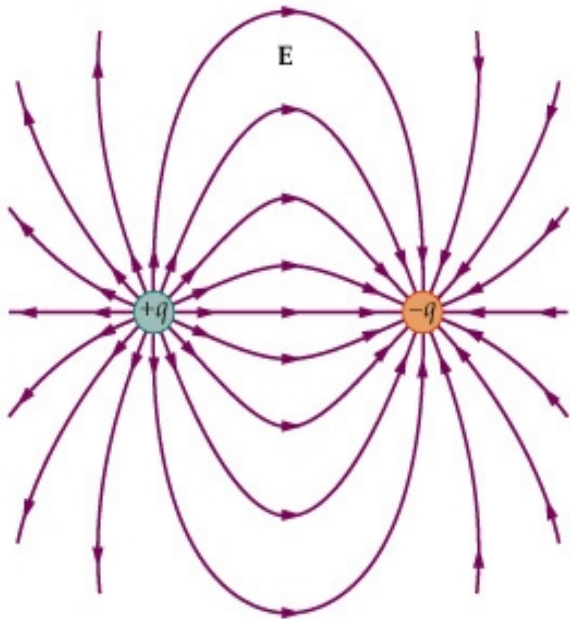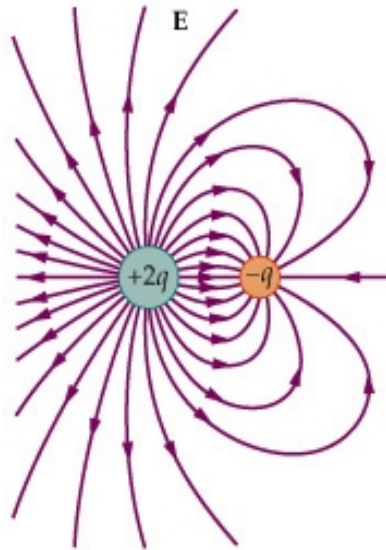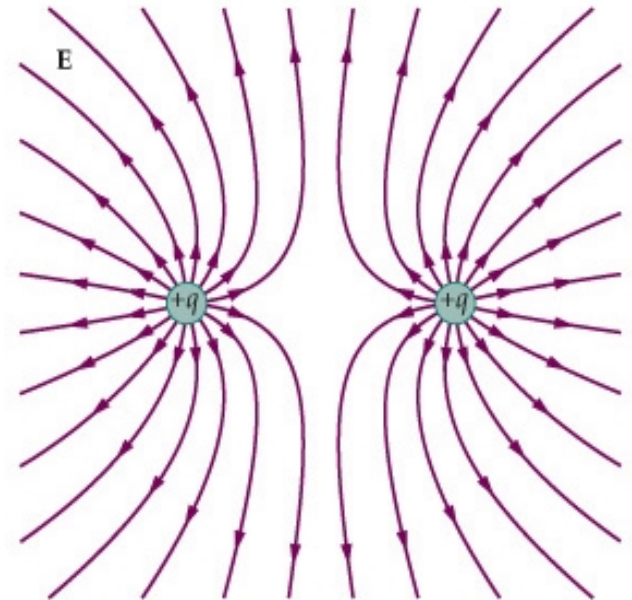

(a) (b) (c)
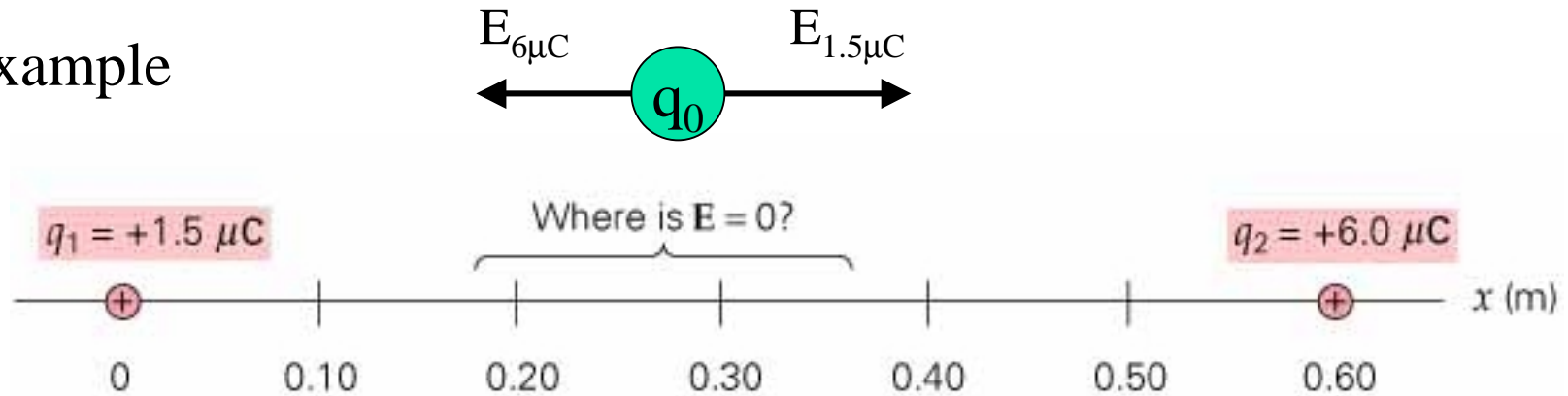
Properties of Electric Field Lines (Lines of force)

1. They do not cross.   WHY?
2. The # of field lines leaving a positive charge equals the # of field lines entering a negative charge.
3. Field lines are usually curved. They are only straight for a point charge or in a parallel plate capacitor.
4. Electric field lines points in the direction of the force that a positive "test" charge would experience.
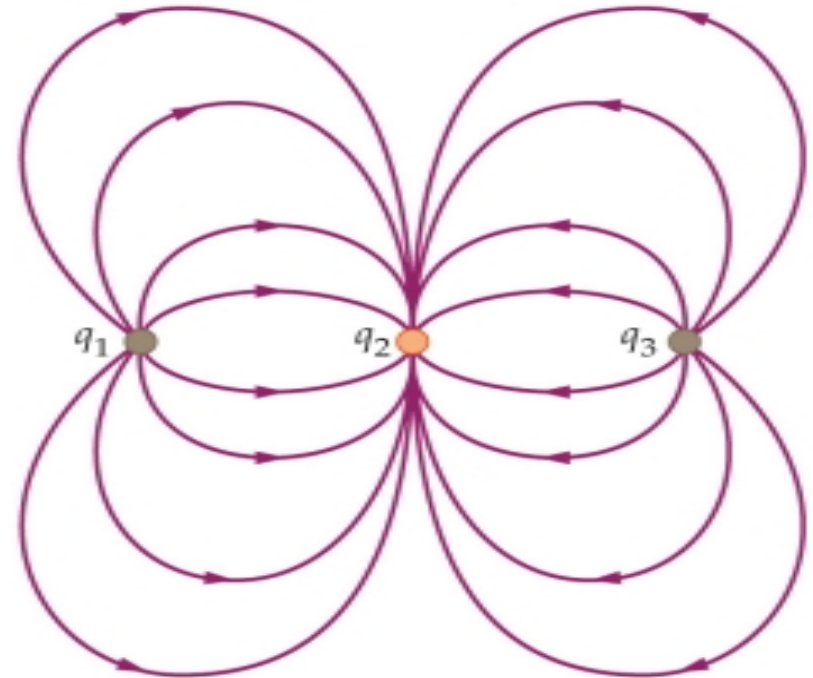
Problem 37:   The electric field lines surrounding three charges is shown. The center charge, q_2=-10 μC. What are the signs of the other two charges. Find q_1 , q_3

Example

$E_{6\mu C}$ $E_{1.5\mu C}$

q_0

$q_1 = +1.5\ \mu C$

Where is $E = 0$?

$q_2 = +6.0\ \mu C$

x (m)

0   0.10   0.20   0.30   0.40   0.50   0.60
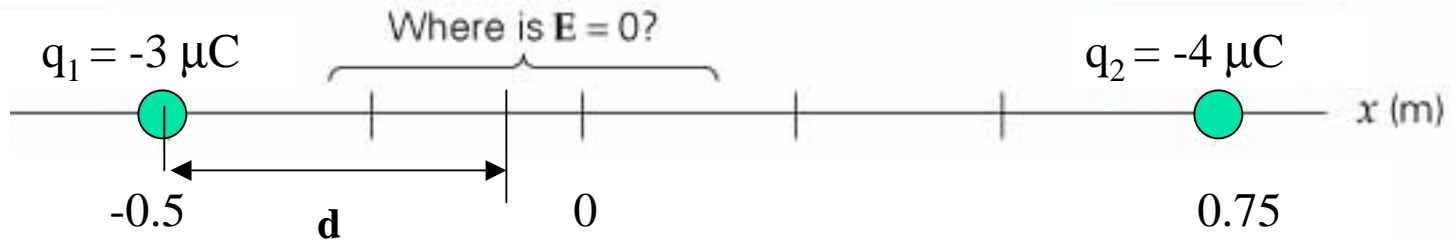
Can $\mathbf{E} = 0$ to the left of q_1?
Can $\mathbf{E} = 0$ to the right of q_2?

If E=0 at some position it means that the force on a positive test charge at that position is zero.
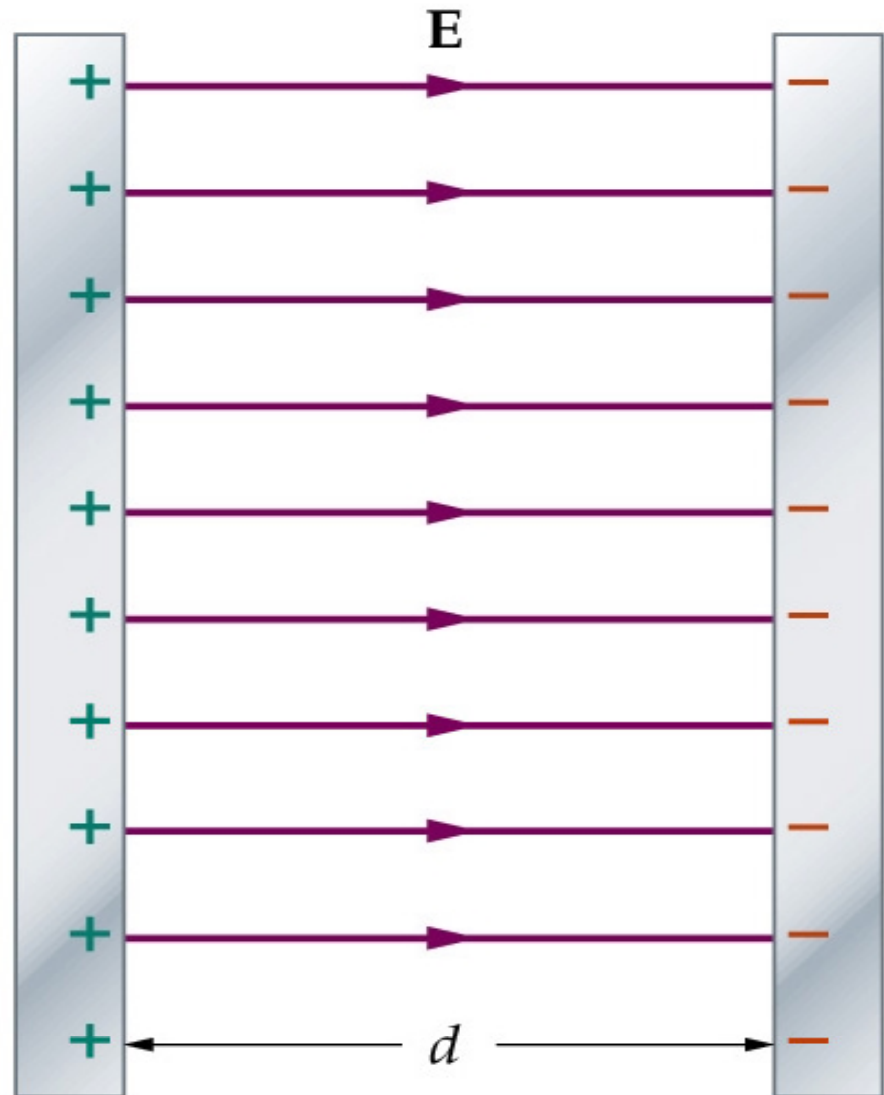
Problem

Two charges, $-3\ \mu C$ and $-4\ \mu C$ are located at (-0.5 m, 0) and (0.75 m, 0), respectively.
(A) Where on the axis is the electric field zero?

$q_1 = -3\ \mu C$

Where is E = 0?

$q_2 = -4\ \mu C$

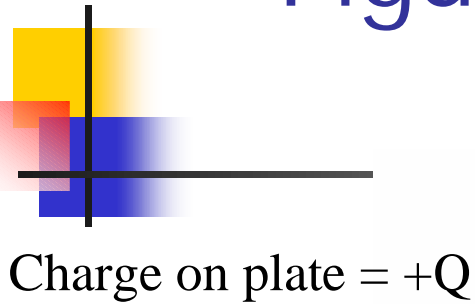x (m)

-0.5   d   0   0.75

Figure 19–17 A parallel-plate capacitor

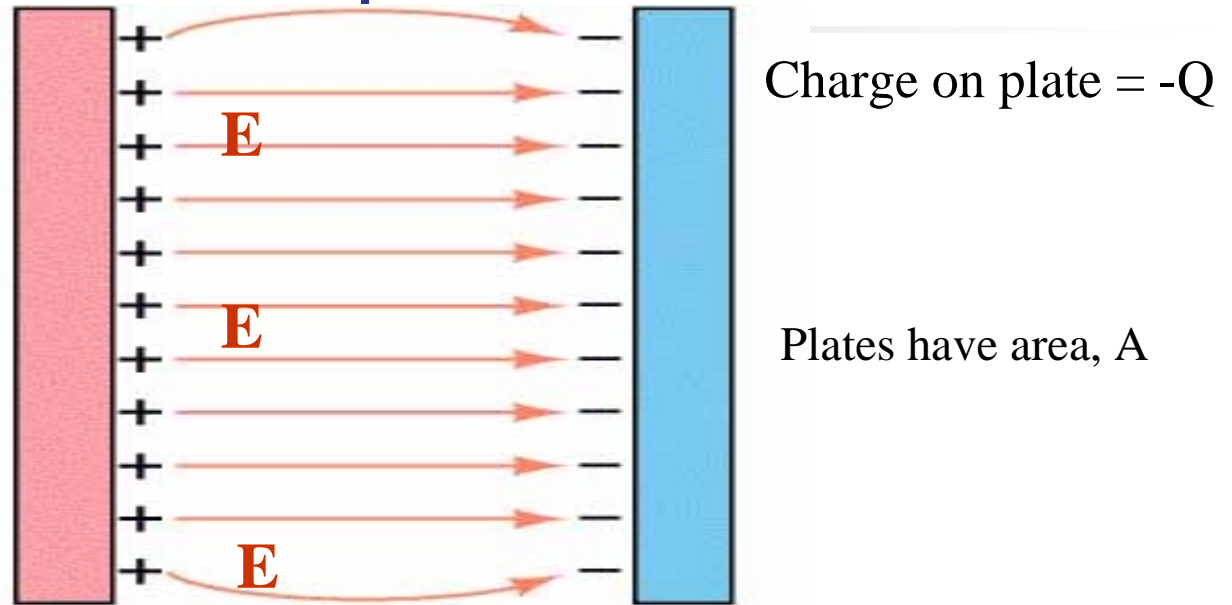In the ideal case, the electric field is uniform between the plates and zero outside.

Figure 19–17b A parallel-plate capacitor

Charge on plate = +Q

Charge on plate = -Q

$$E = Q / \varepsilon_0 A$$
$$= \sigma / \varepsilon_0$$
$$= 4\pi k \, Q / A$$

Plates have area, A

E

E

E

(b) Metal parallel plates

Note
No distance dependence

E is constant between the plates

See page 636

Figure 19–18 Charge distribution on a conducting sphere

a) A charge placed on a conducting sphere distributes itself uniformly on the surface of the sphere; none of the charge is within the volume of the sphere. (b) If the charge were distributed uniformly throughout the volume of a sphere, individual charges, like that at point A, would experience a force due to other charges in the volume. Since charges are free to move in a conductor, they will respond to these forces by moving as far from one another as possible; that is, to the surface of the conductor.
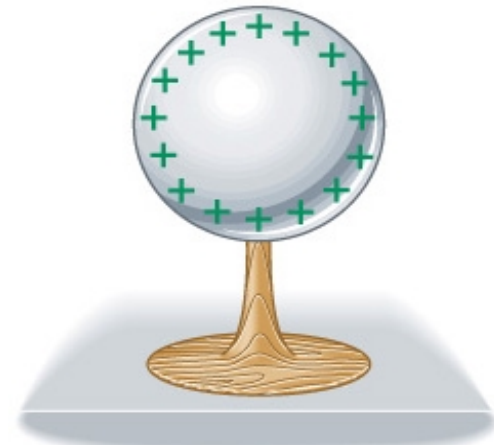
(a)
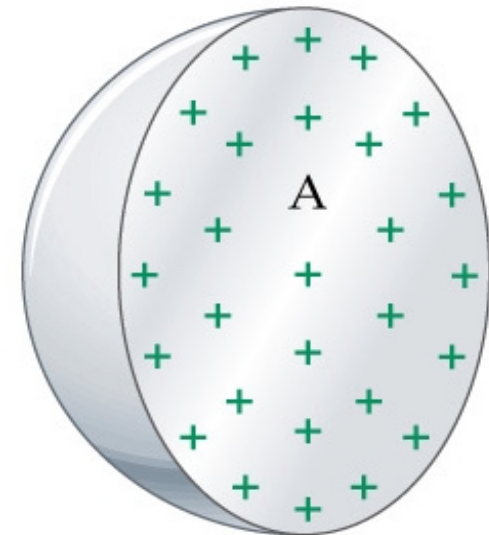
(b)

Figure 19–19 Electric field near a conducting surface

(a) When an uncharged conductor is placed in an electric field, the field induces opposite charges on opposite sides of the conductor. The net charge on the conductor is still zero, however. The induced charges produce a field within the conductor that exactly cancels the external field, leading to E = 0 inside the conductor. This is an example of electrical shielding. (b) Electric field lines meet the surface of a conductor at right angles. That is, electric field lines are ALWAYS perpendicular to the conductor surface.
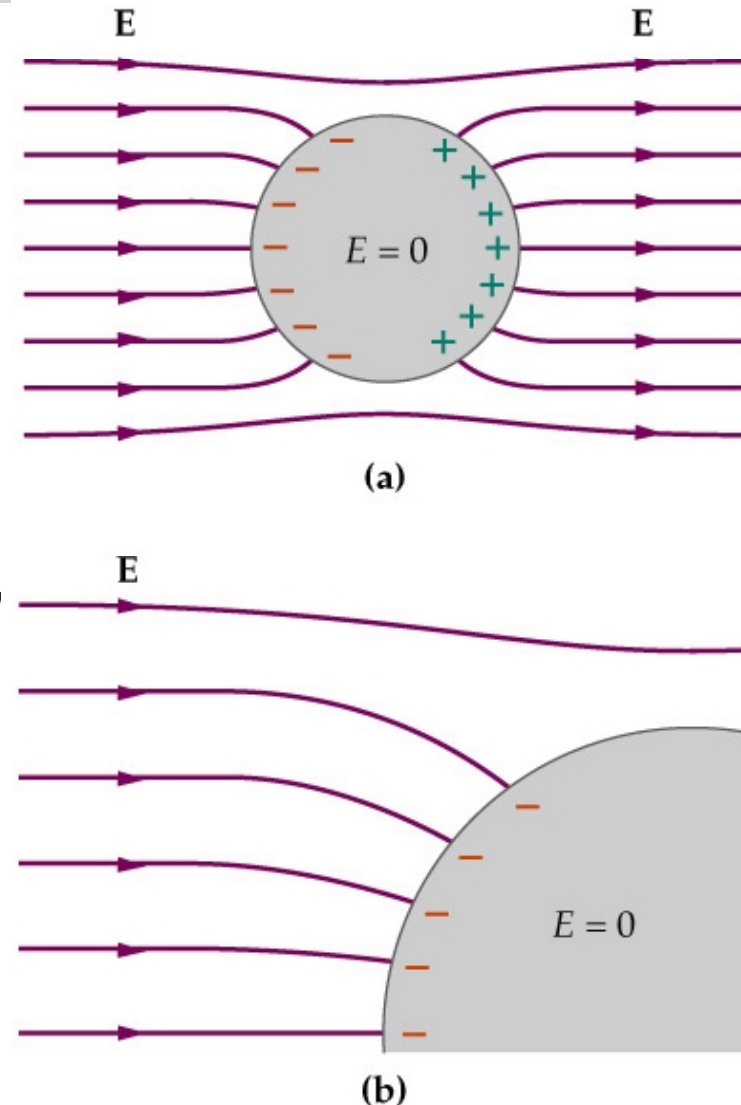
# Figure 19–20 Intense electric field near a sharp point

Electric charges and field lines are more densely packed near a sharp point. This means that the electric field is more intense in such regions as well. (Note that there are no electric charges on the interior surface surrounding the cavity.
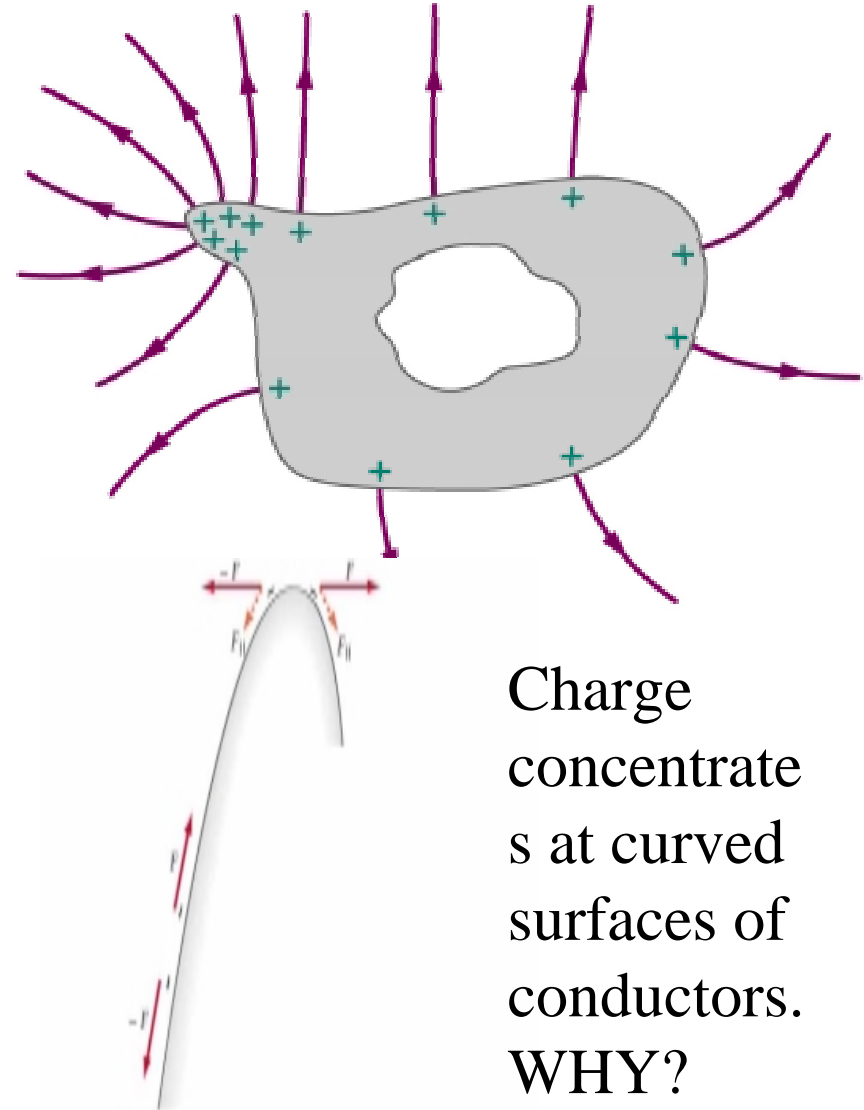
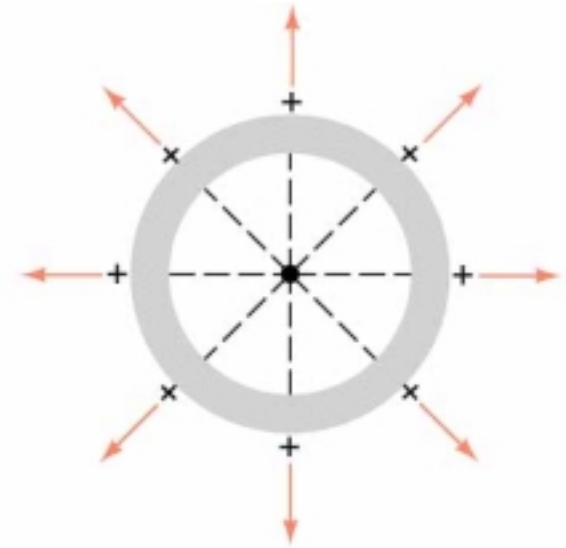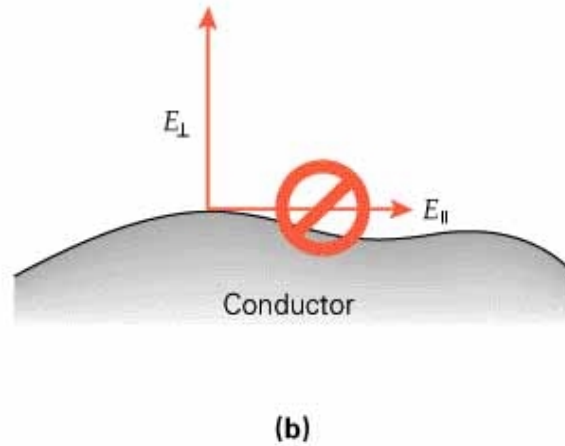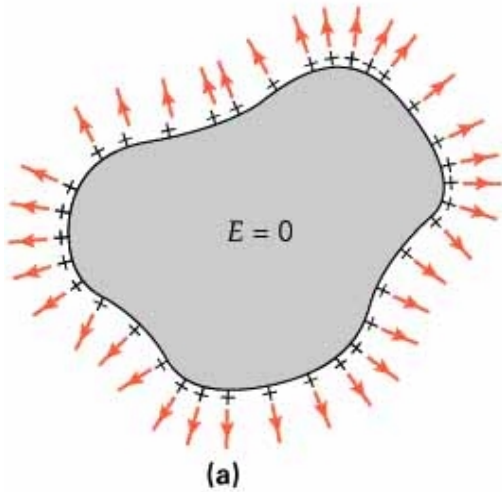Charge concentrates at curved surfaces of conductors. WHY?

Charge concentrates at curved surfaces of conductors.
WHY?
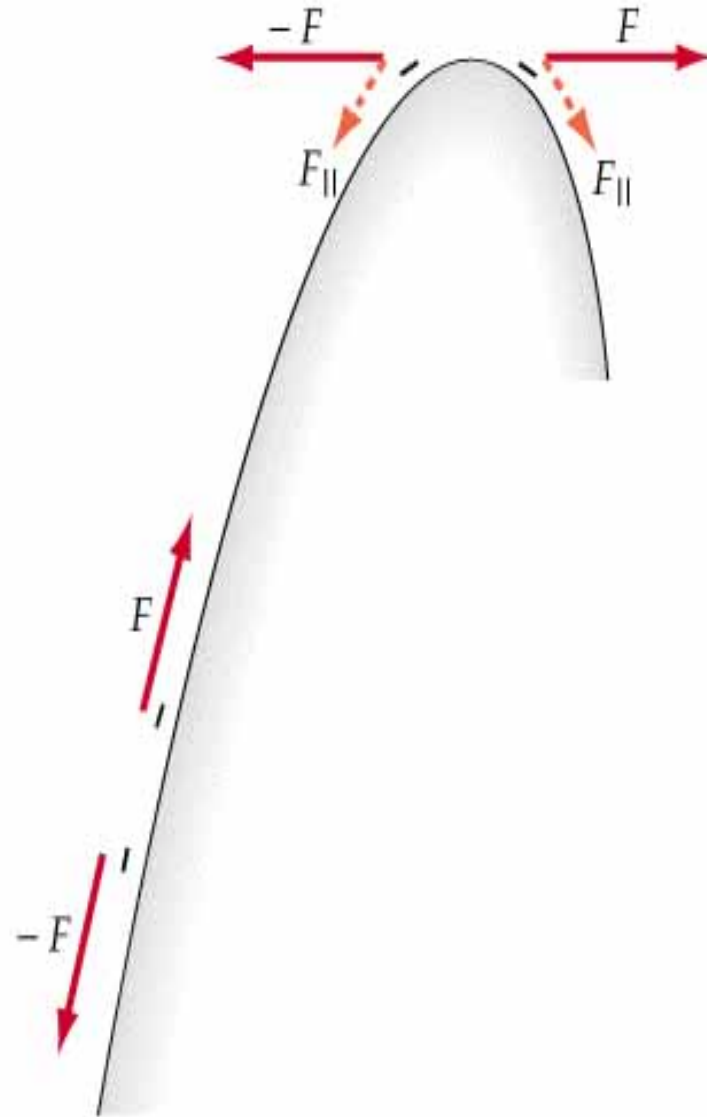
Electric fields do not exist inside conductors, ever. - **Faraday Cage**
Electric field lines are ALWAYS perpendicular to the conductor surface.

$E = 0$

(a)

$E_\perp$

$E_\parallel$

Conductor

(b)

No E-field inside conducting sphere

Is it best to stay in your car or get out of it during a lightning storm?

Figure 19–21 Shielding works in only one direction

A conductor does not shield the external world from charges it encloses. Still, the electric field is zero within the conductor itself.
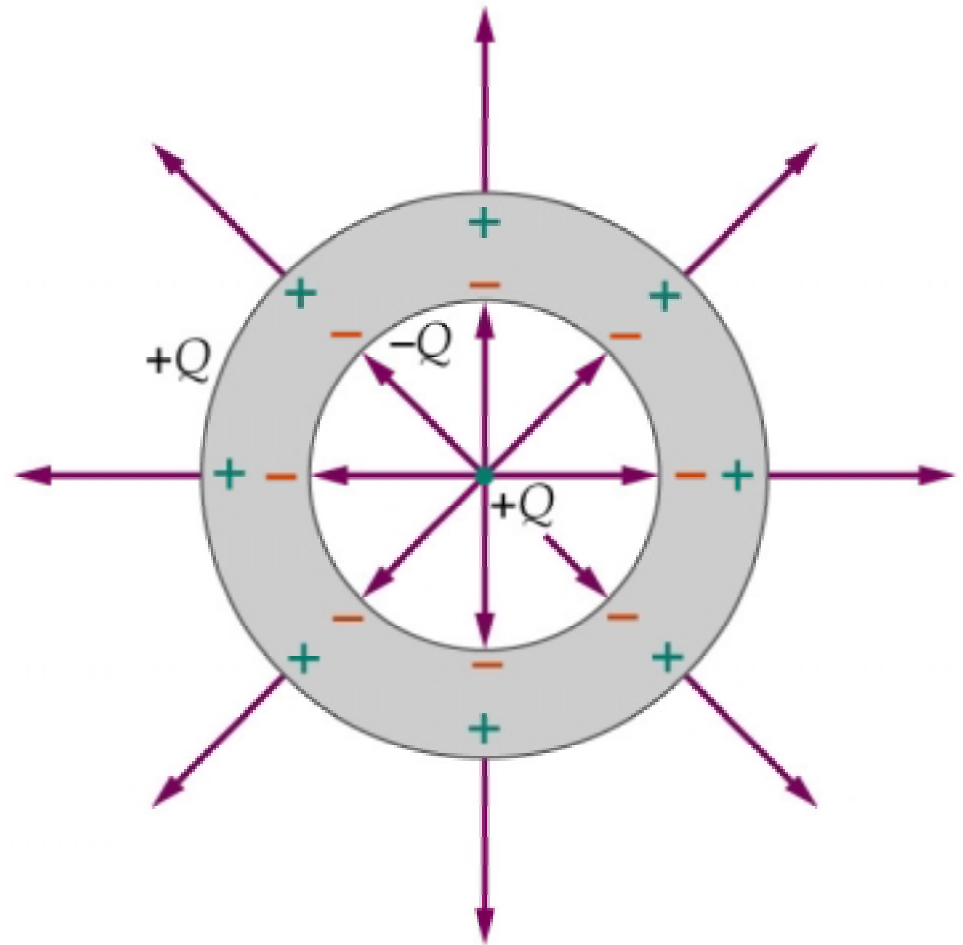
Figure 19-22 Charging by induction

(a) A charged rod induces + and - charges on opposite sides of the conductor. (b) When the conductor is grounded, charges that are repelled by the rod enter the ground. At this point there is a net charge on the conductor. (c) Removing the grounding wire, with the charged rod still in place, traps the net charge on the conductor. (d) The charged rod can now be removed, and the conductor retains a charge that is opposite in sign to that on the charged rod.

(a)

(b)

(c)

(d)