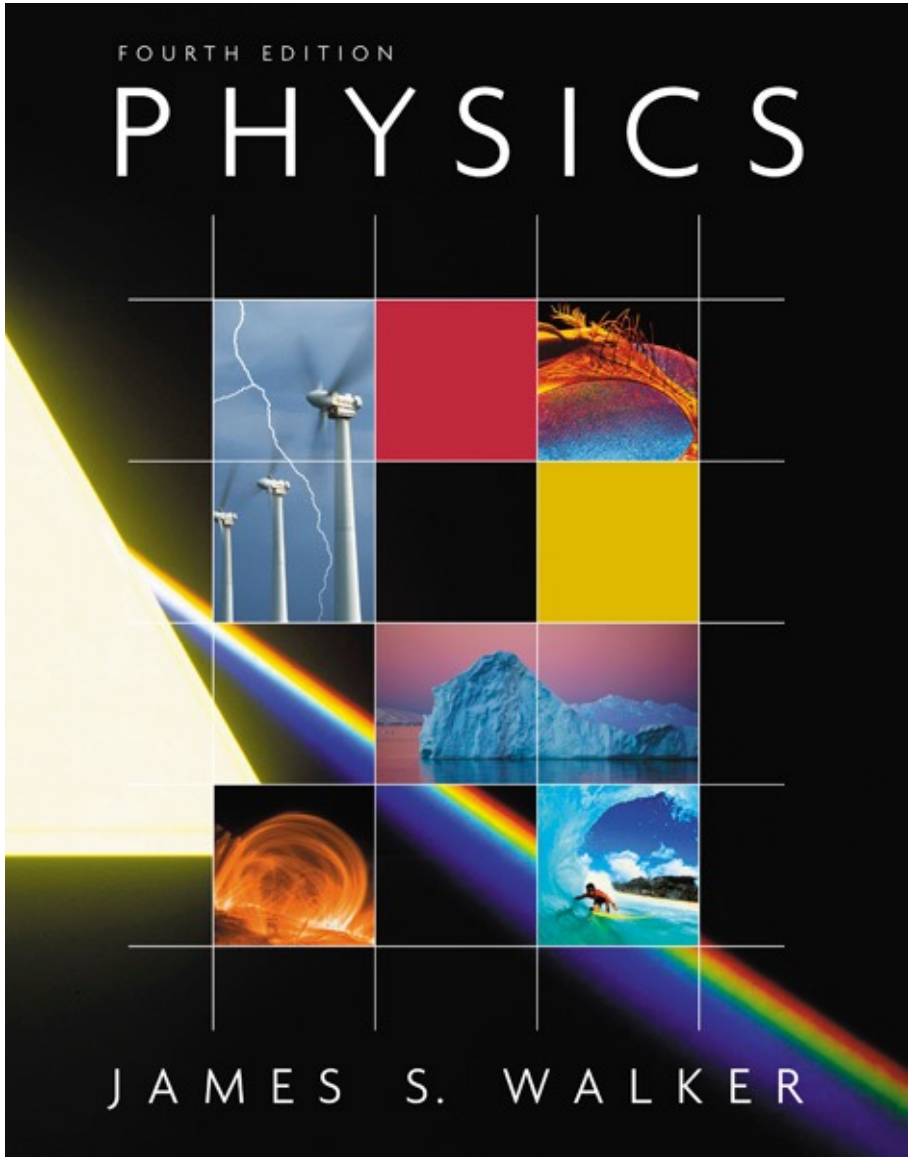


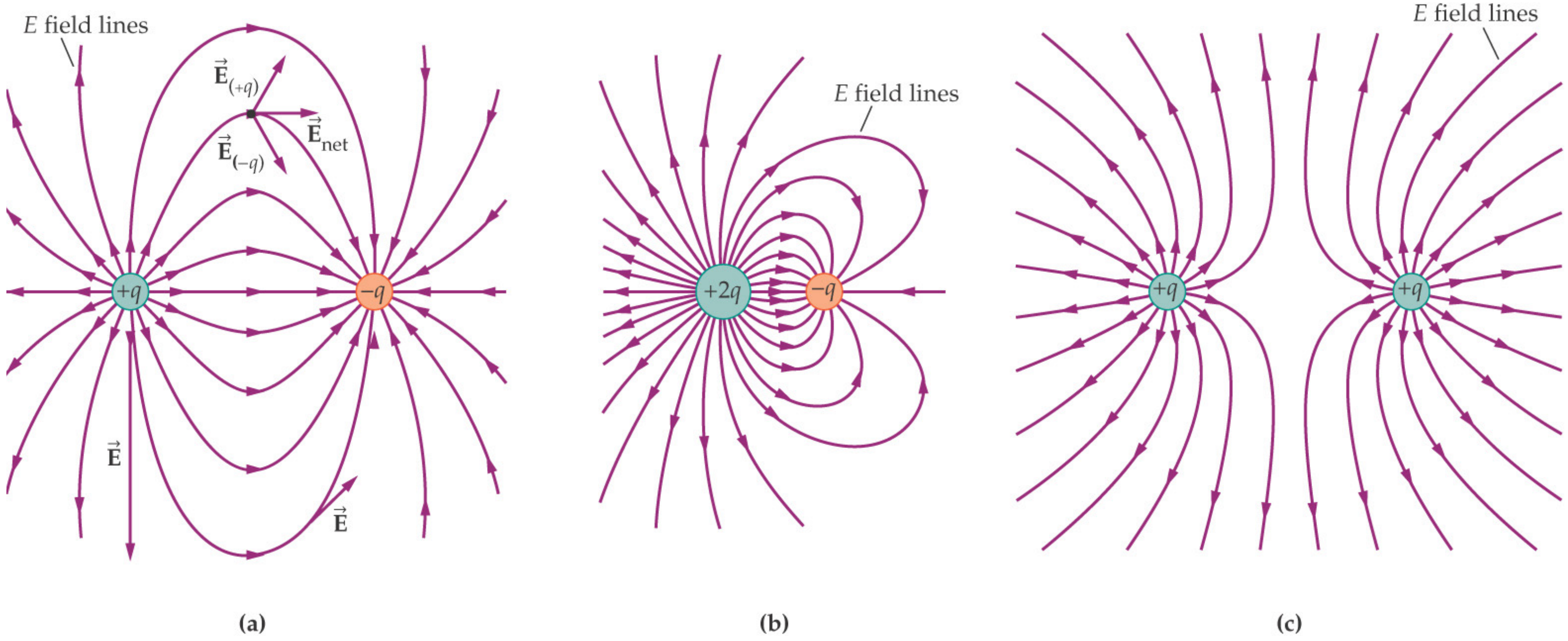
Chapter 19

Physics, 4th Edition

James S. Walker

Chapter 19

Electric Charges, Forces, and Fields



Units of Chapter 19

19.1 Electric Charge

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

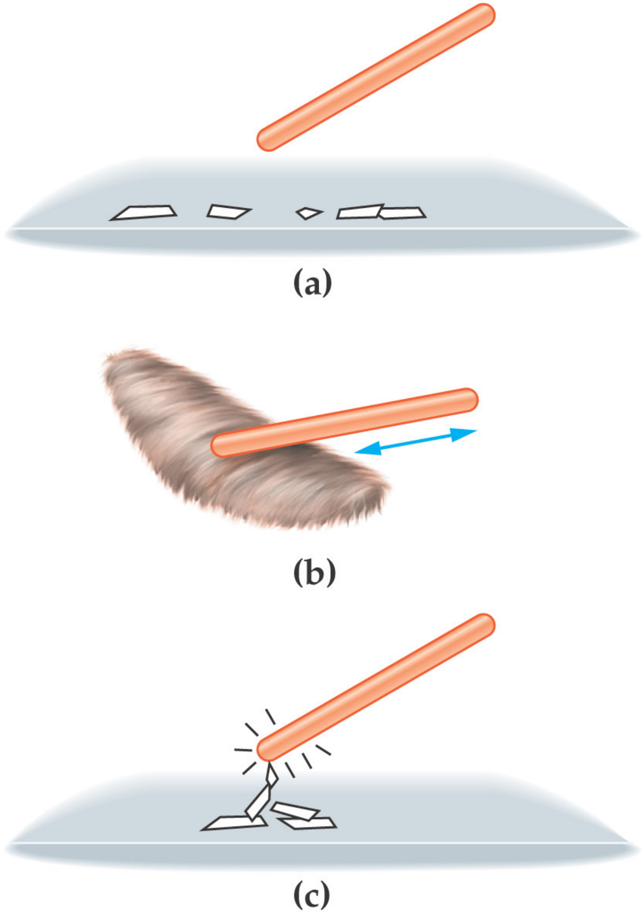
19.7 Electric Flux and Gauss’s Law

19.1 Electric Charge

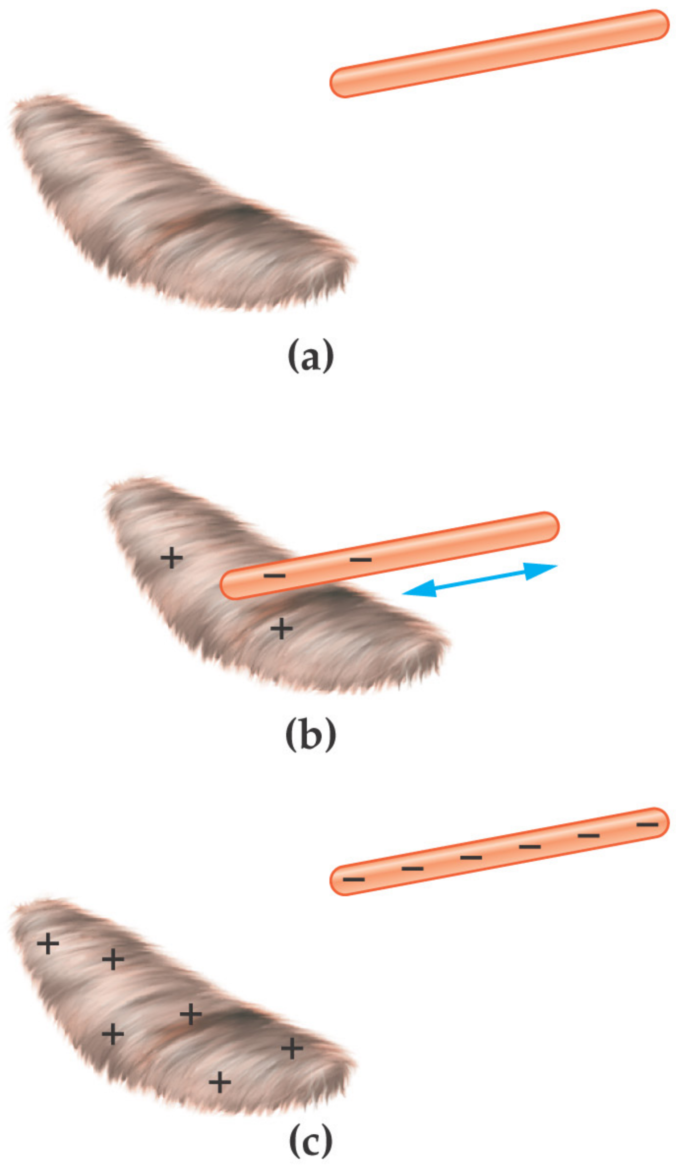
- We are all made up of electric charges.
- Every atom in every human body contains both positive and negative charges.

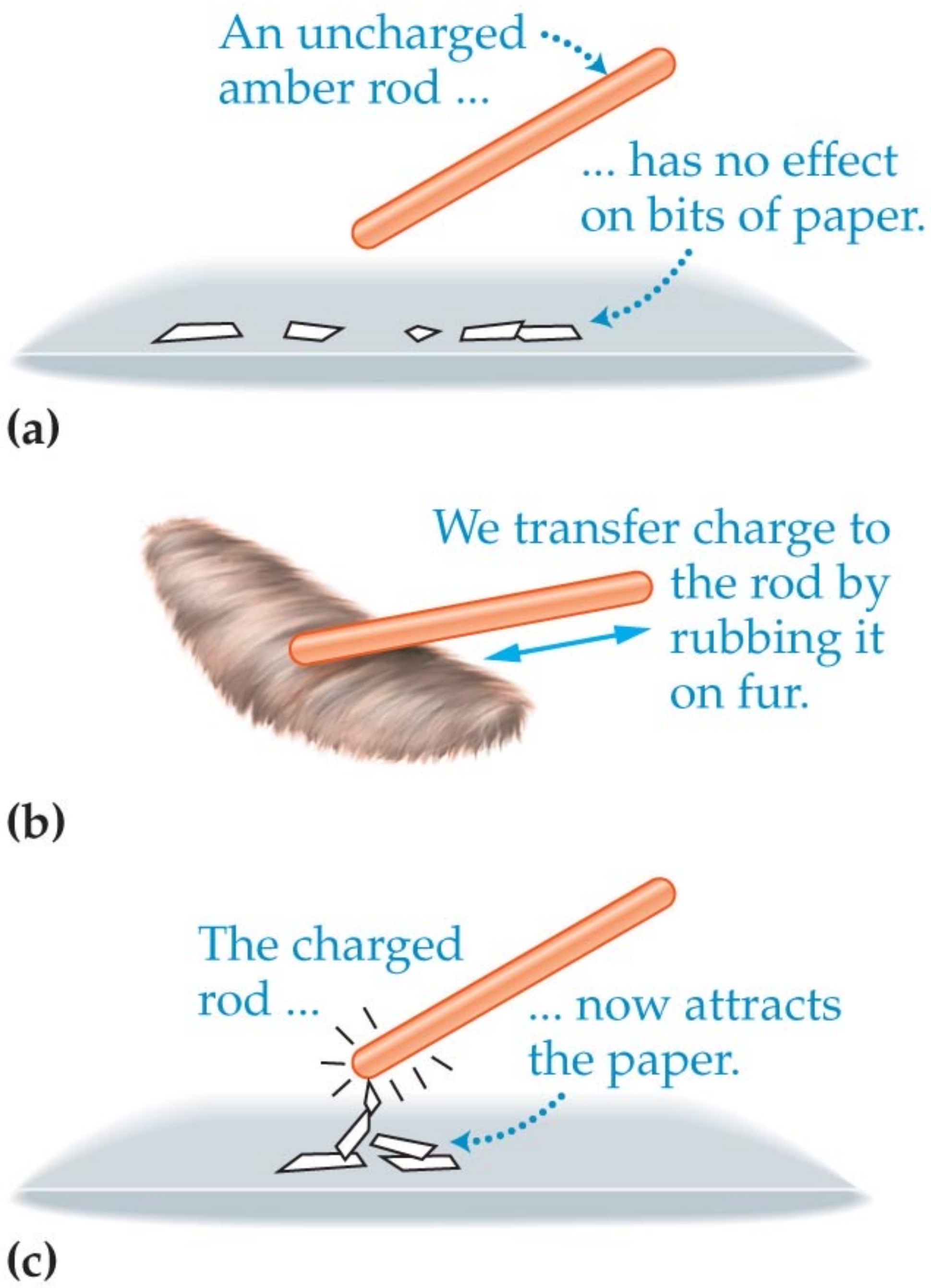
The effect of electric charge were first observed as ***static electricity***

After being rubbed on a piece of fur, an amber rod acquires a charge and can attract small objects (Why?)



When an amber rod is rubbed with fur, some of the electrons on the atoms in the fur are transferred to the amber.




An uncharged amber rod ...
... has no effect on bits of paper.
(a)
We transfer charge to the rod by rubbing it on fur.
(b)
The charged rod ...
... now attracts the paper.
(c)

Remarks

1. The amber rod is not unique in its ability to ***become charged*** .

Other materials can behave in such way as well.

2. If ***glass is rubbed*** with a piece of ***silk***, it too can attract small objects

(**the glass rod will become charged**)

3. They have noticed that, when suspending the ***amber and the glass*** rods they tend to ***get closer*** to each other, in other words, ***attract*** each other.

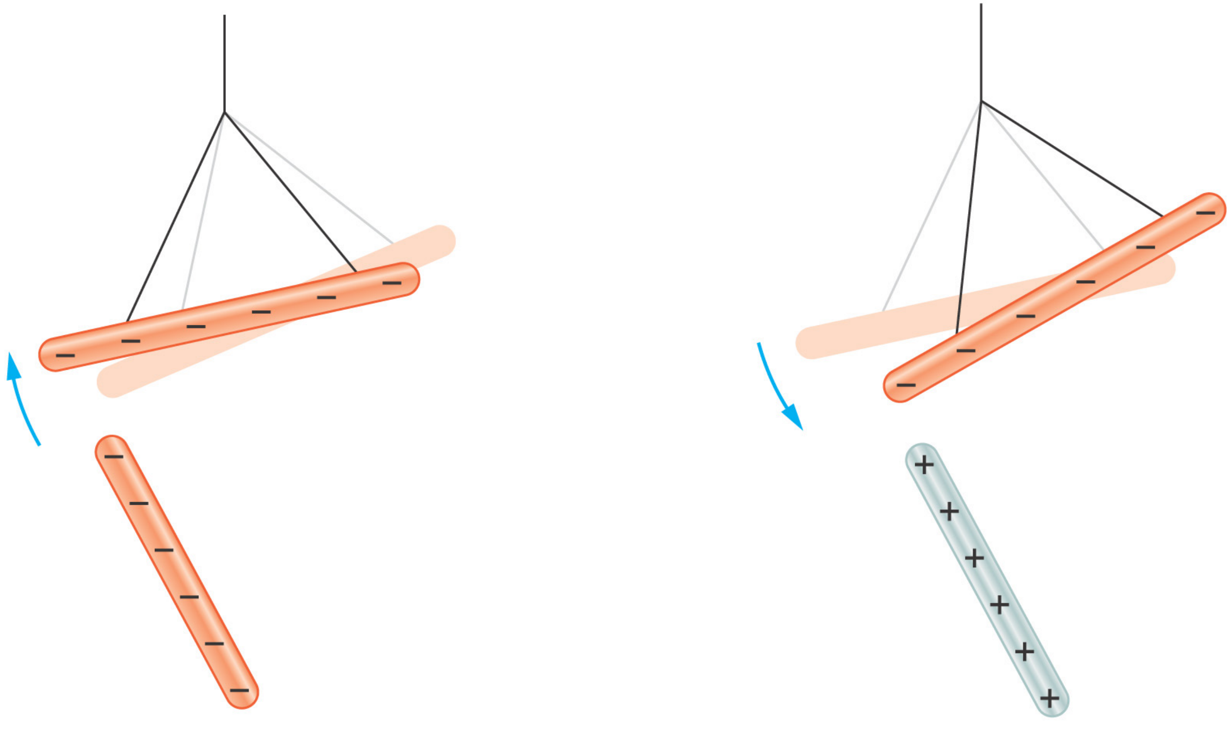
4. The above note implies that, the two rods (the glass and the amber) are both charged, still, ***they are not totally alike***.

General properties of charged objects

1. Two rods with opposite charges will attract each other. (**Fig. a**)

2. Two rods with the same charges will repel each other. (**Fig. b**)

Question: why the amber rod became negatively charged while the glass rod became positively charged?



(a)

(b)

The table on the right presents the relative charging due to rubbing (Triboelectric: electric charge generated by friction)*, where:*

- *The more + associated with the material, the more readily it gives up electrons and becomes positively charged.*
- *The more - for a material, the more readily it acquires electrons.*

TABLE 19–1 Triboelectric Charging

Material	Relative charging with rubbing
Rabbit fur	++++++
Glass	+++++
Human hair	++++
Nylon	+++
Silk	++
Paper	+
Cotton	–
Wood	– –
Amber	– – –
Rubber	– – – –
PVC	– – – – –
Teflon	– – – – – –

Continue…

3. All electrons have exactly the same charge, the charge of the electron is defined as:

$$e = -1.6 \times 10^{-19} \text{ Coulomb (C)}$$

4. The charge of the proton (in the atomic nucleus) has the same magnitude but the opposite sign.

5. A more common unit of charge is the micro coulomb (μc)

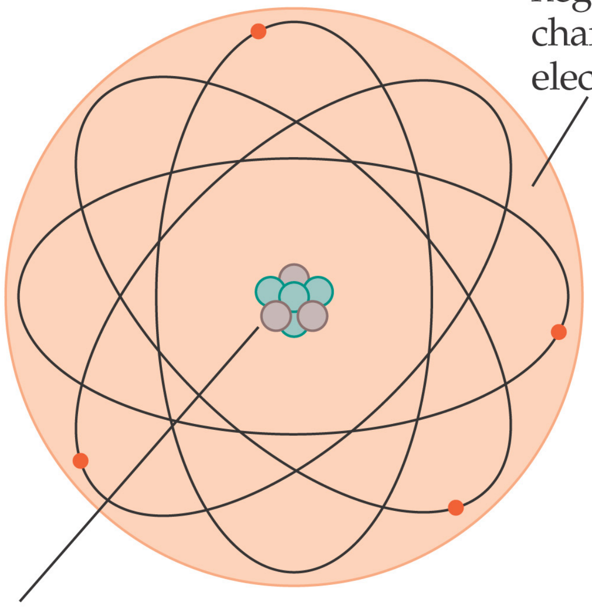
$$1\ \mu c = 10^{-6}\ C$$

Continue …

6. The electrons in an atom are in a cloud surrounding the nucleus and can be separated from the atom with relative ease.

7. The total electric charges of the universe is constant, no physical process can result upon the increase or decrease in the total amount of electric Charge .

(**ELECTRIC CHARGE IS CONSERVED**)



CHECKPOINT PAGE 738:

Is the mass of the amber rod after charging with fur:

a) Greater than its mass before charging
b) Less than its mass before charging
c) The same as its mass before charging

Answer: a)

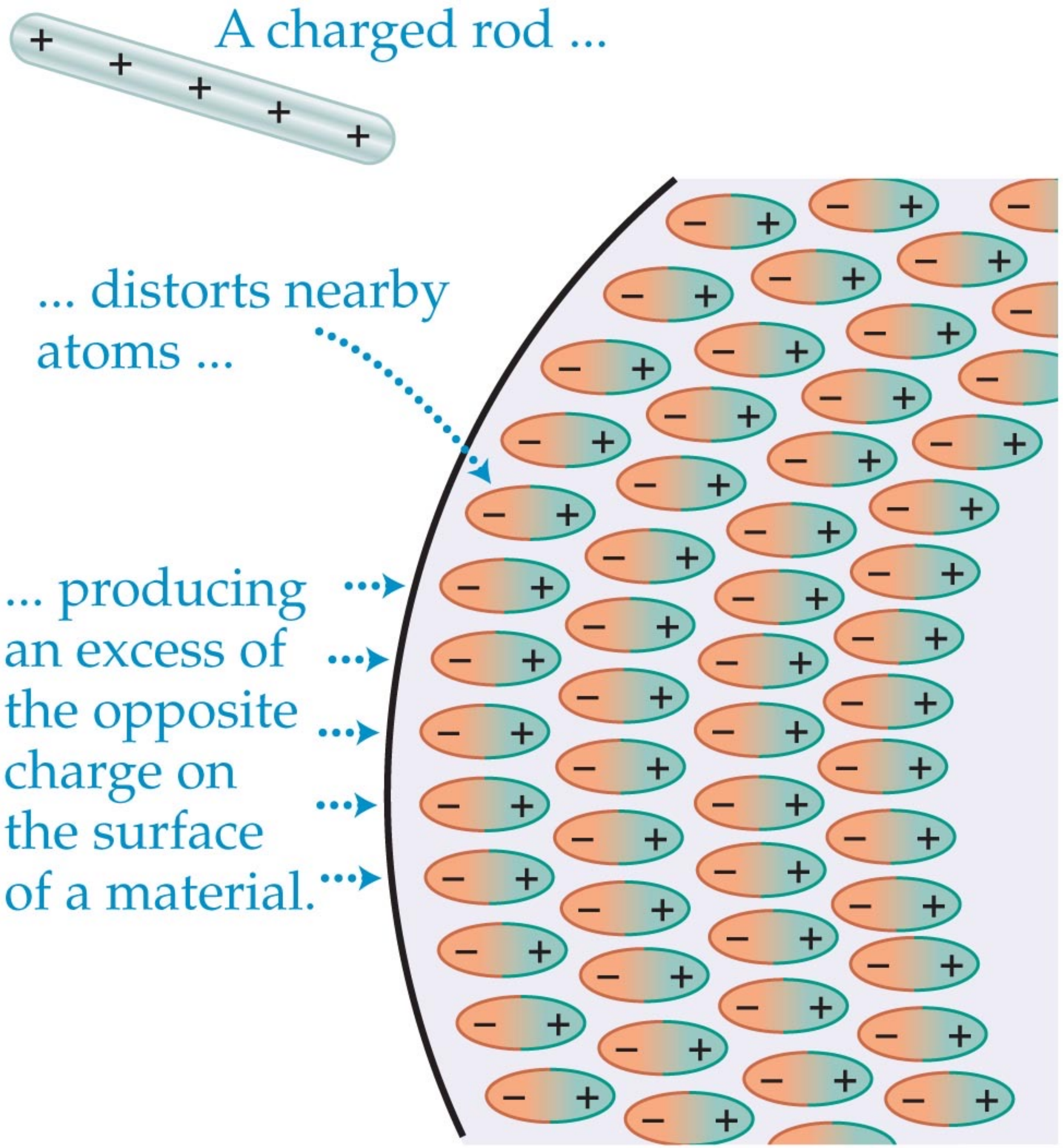
Note: the charged amber rod **has acquired electrons** from the fur, each electron has a small, but nonzero mass, and so, the mass of the amber rod increases ($m_e = 9.1 \times 10^{-31}$ kg)

- ***POLARIZATION (Induced Charge)***

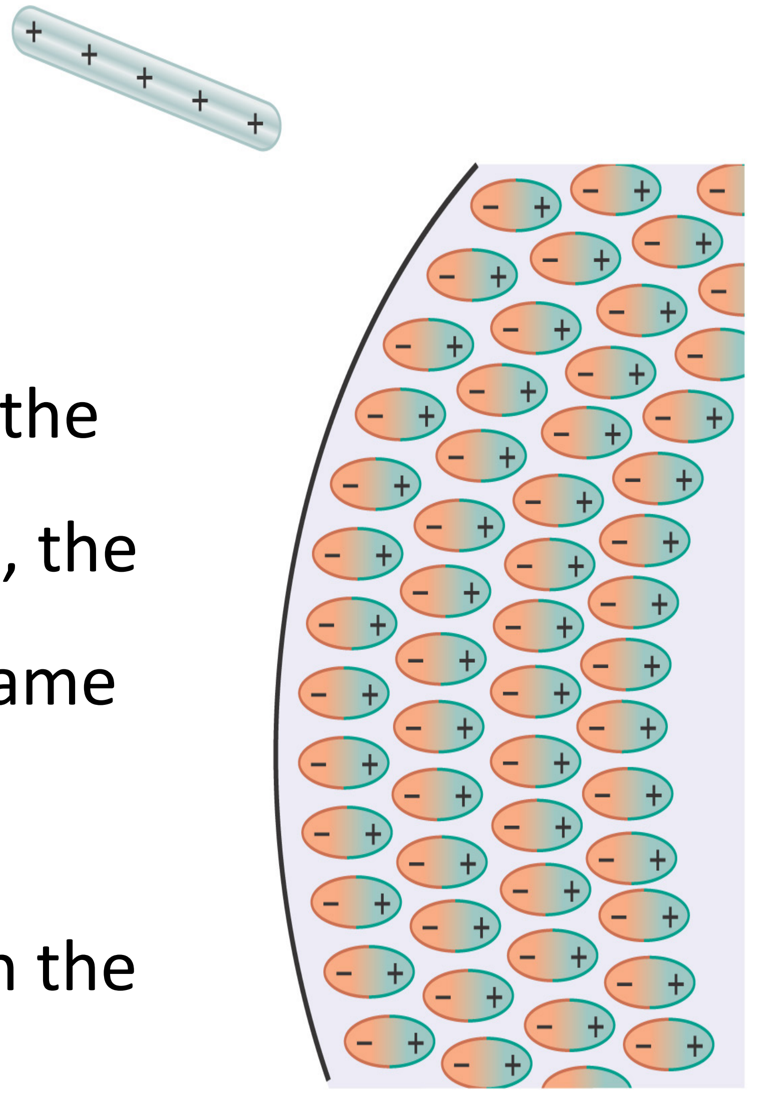
- ***Question:*** Is it possible for a charged rod to attract small objects that have ***ZERO net charge*** ?

- ***Answer:*** yes, just like when the amber rod attracted the small pieces of paper, and the glass rod attracts small objects.

  And this mechanism is called ***POLARIZATION***.


A charged rod ...
... distorts nearby atoms ...
... producing an excess of the opposite charge on the surface of a material.

Properties of polarized a material



1. The net charge on it is zero.

2. Due to the charged rod, the atoms near the surface of the polarized material will be distorted (will elongate), where, the opposite charge will rotate toward the surface, and the same charge will be repelled away from it.

3. As a result of step 2, a net opposite charge develops on the surface near the charged rod.

4. This net opposite charge is called: ***induced polarized charge***

19.2 Insulators and Conductors

Definition

1. Insulators:

- Insulators are materials, in which charges are not free to move.
- Most insulators are nonmetallic substances.

Example: when rubbing the amber rod, the rubbed side becomes charged, whereas the other end remains neutral.

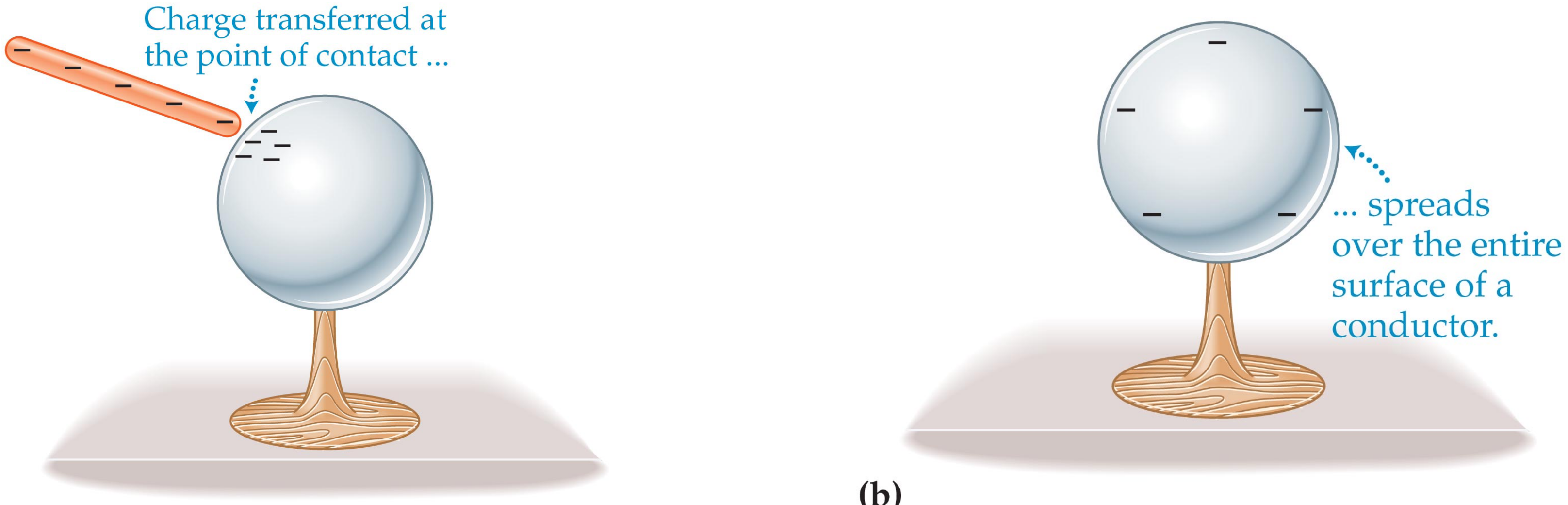
Definition

2. Conductors:

- Materials that allow the charges to move about more or less freely.

  (look at the figure)

- Most conductors are metals.



(a) © 2010 Pearson Education, Inc.

(b) © 2010 Pearson Education, Inc.

- In the previous figure, an uncharged metal sphere is placed in an insulating base.

- A charged rod is brought into contact with the sphere.

- Some charges will be transferred to the sphere at point of contact.

- Since the metal is a good conductor of electricity, the charges will be evenly distributed **over the whole surface of the sphere**.

19.3 Coulomb's Law

Coulomb's law gives the ***electrostatic force*** between two-point ***charges*** (***at rest***):

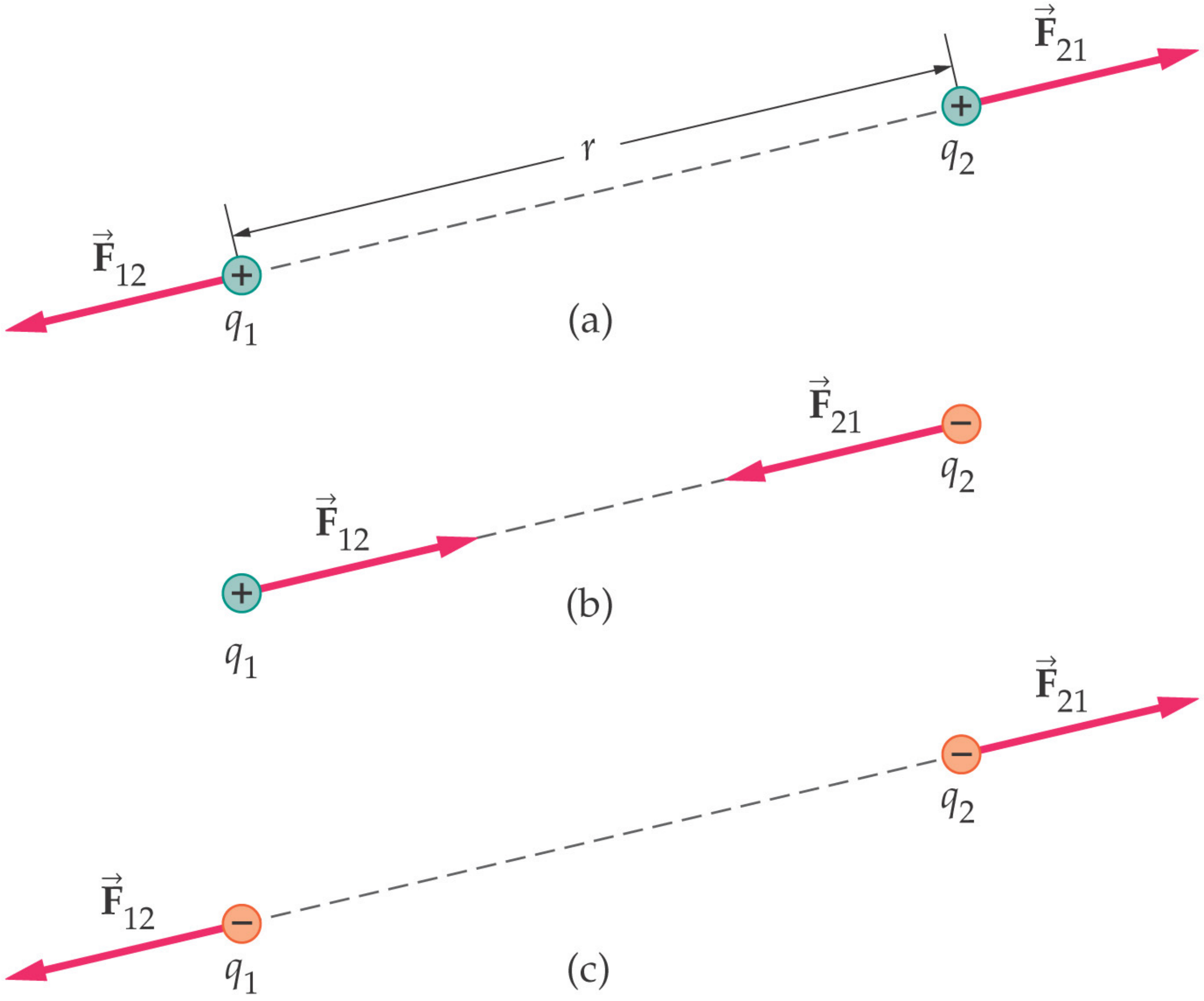
$$F = k\frac{|q_1||q_2|}{r^2}$$

SI unit: newton, N

$$k = 8.99 \times 10^9\ \mathrm{N \cdot m^2/C^2}$$

- ✓ **F** is along the line connecting the charges
- ✓ **F** is attractive if the charges are opposite (Fig. b)
- ✓ **F** is repulsive if the charges are alike (Figs. a and c)

The forces on the two charges are action-reaction forces



Exercise 2 (page 742)

Find the electric force between two (1 C) charges separated by 1 m.

Answer:

$F = k\, q_1 \times q_2 / r^2$

$= (8.99 \times 10^9) \times (1) \times (1)/(1)^2$

$= 8.99 \times 10^9$ N

Exercise 20 (page 766)

Two point-charges $q_1 = + 3.13 \times 10^{-6}$ C and $q_2 = - 4.47 \times 10^{-6}$C, are separated by a distance of 25.5 cm.

1) Find the magnitude of the electrostatic force experienced by the positive charge

2) Is the magnitude of the force experienced by the negative charge greater than, less than, or the same as that experienced by the positive charge? Explain.

Exercise 18 (page 766)

The attractive electrostatic force between the point charges $q_1 = 8.44 \times 10^{-6}$ C and (Q) has the magnitude of (0.975 N)

When the separation between the charges is (1.31 m), find the sign and the magnitude of the charge (Q)

Superposition of forces

- When a charge experiences forces due to two or more other charges, the net force on it is simply the vector sum of the forces taken individually.

- In other words, Coulomb's law helps us to calculate the force between several charges. We calculate the forces one at a time and ADD them **AS VECTORS**.

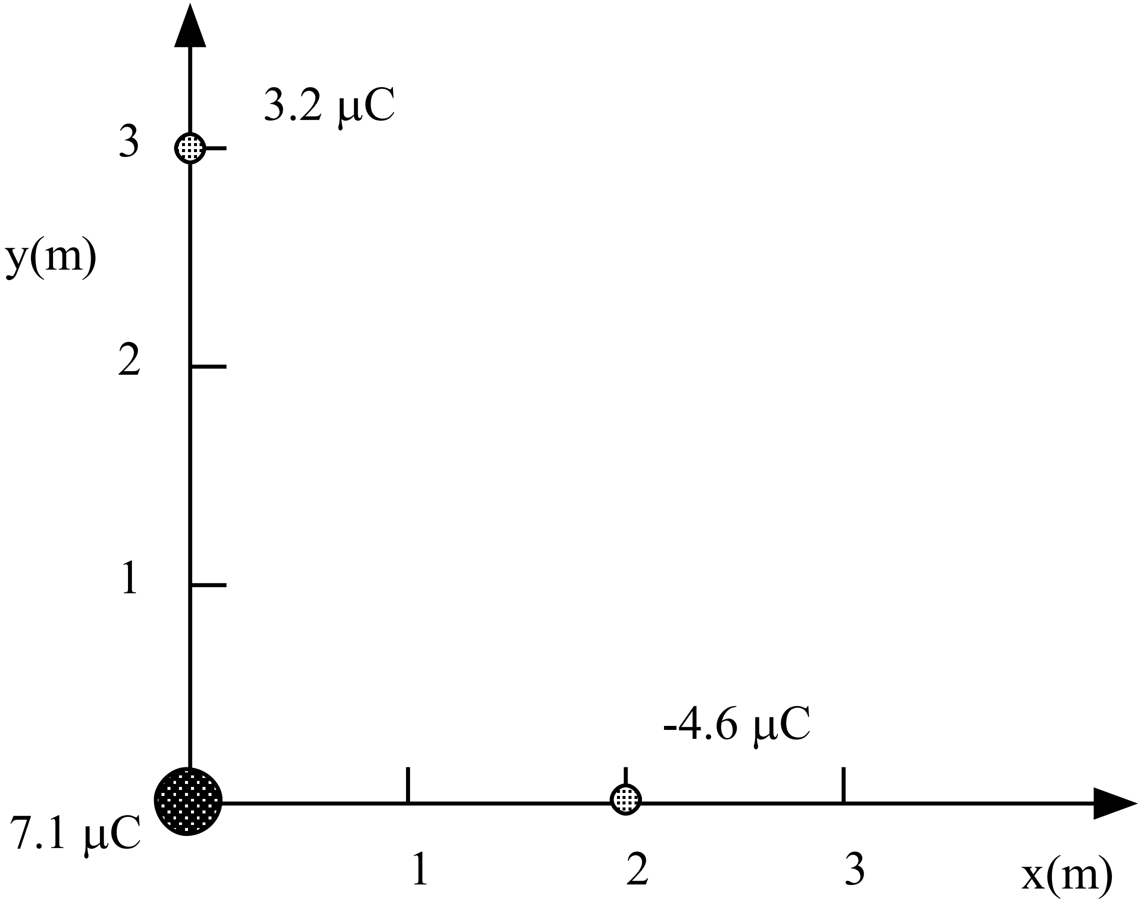
Example 2 (page 743)

A charge q_1 = - 5.4 µC is at the origin and a charge q_2 = -2.2 µC is set on the x axis at a distance x = 1 m.

Find the net force acting on a charge q_3 = +1.6 µC located at a distance x= 0.75 m.

Example

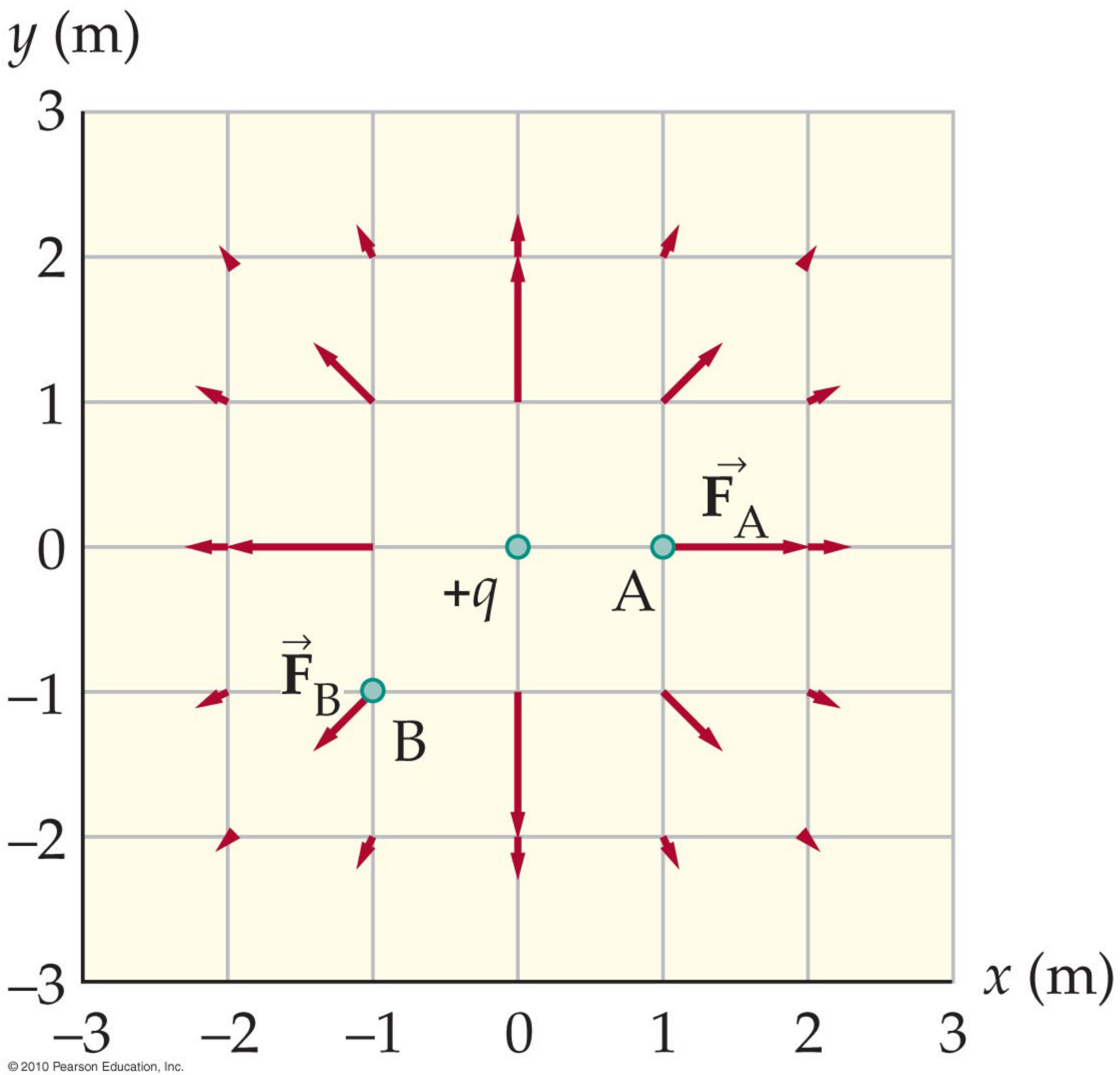
In the figure below, find the magnitude and direction of the net force on the charge located at the origin



19.4 The Electric Field

DEFINITION: What is an electric field?

It is the amount of electrical force associated with a charge q , exerted on a (positive test charge q_0) placed at certain place .



Definition

The mathematical notation of the electric field:

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

SI unit: N/C

Here,

- q_0 is a "test charge" – it serves to allow the electric force to be measured, and it's always assumed to be positive.
- The electric field is a vector quantity, and has the same direction as the electrical force

From the previous relation we say that:

- $\vec{E} = k\ |q|\ /\ r^{\,2}$

(the magnitude of the electric field due to the point charge q)

- The direction of the electric field at any position is <u>toward the Negative charge</u>, and <u>away from the Positive charge.</u>

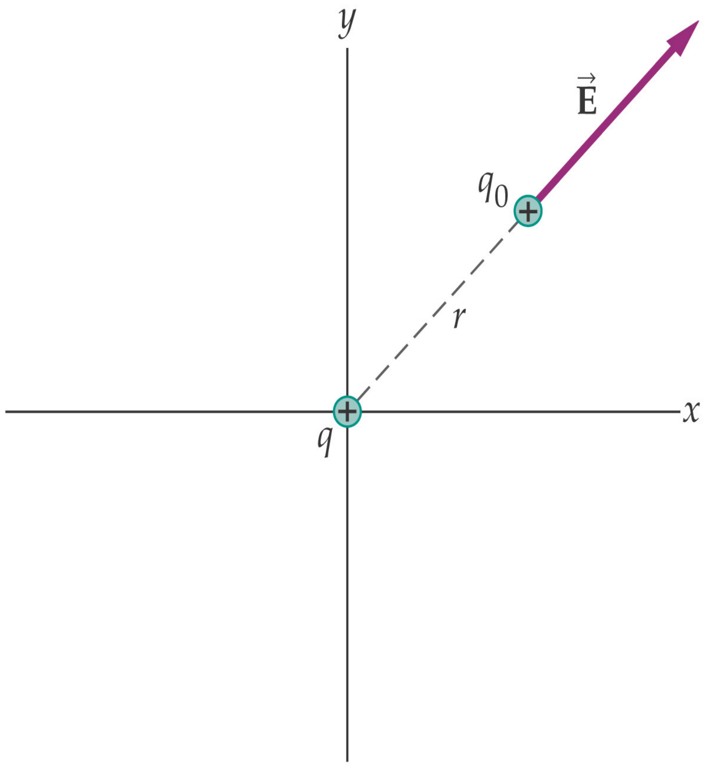
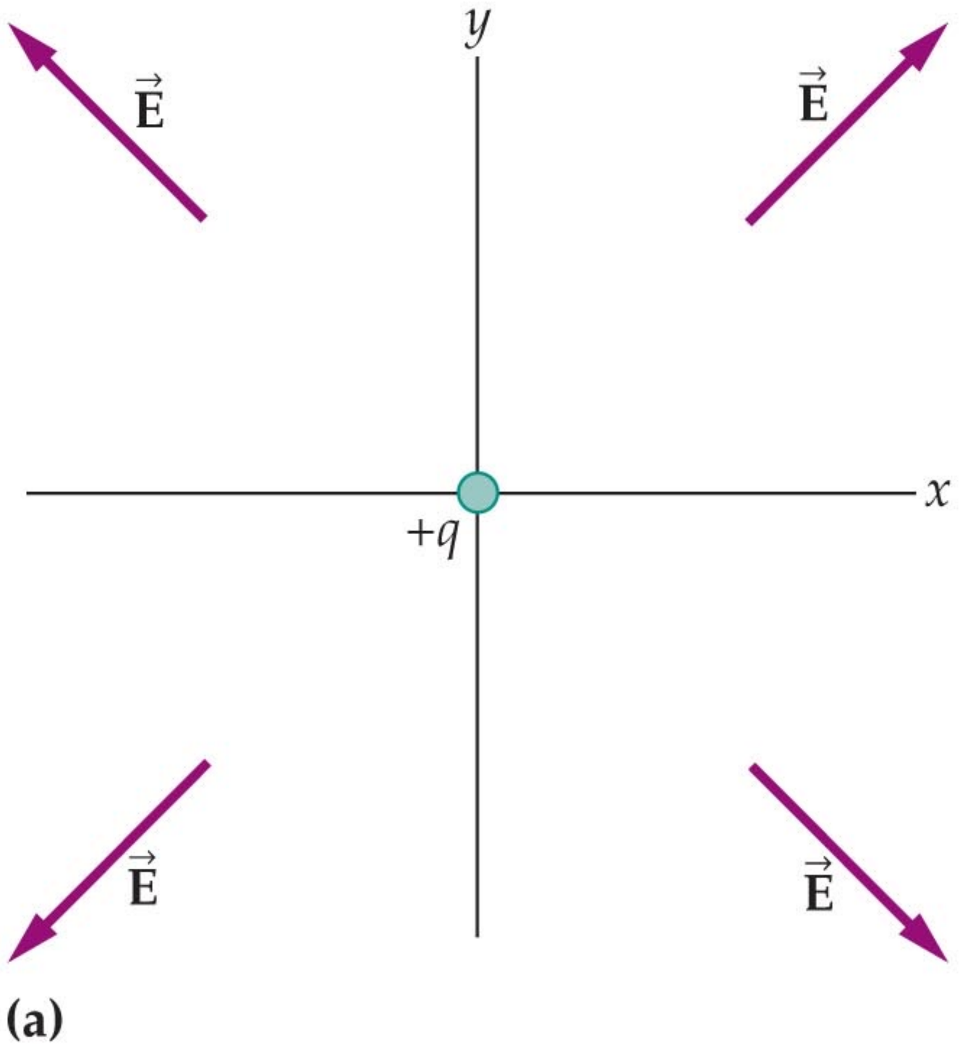


Figure 19-11



Exercise 43 (page 768)

What is the magnitude of the electric field produced by a charge of magnitude (7.5 μC) at a distance of :

a) 1.00 m

b) 2.00 m

c) What happened to the electric field when we double the distance?

Exercise 45 (page 768)

Two point=charges lie along the x-axis. A charge of + 6.2 μC is at the origin and a charge of -9.5 μC is placed at a distance x = 10.0 cm.

What is the net electric field at:

a) x = - 4.0 cm

b) x = + 4.0 cm

Exercise

A charge of 25 nC is placed on the x-axis at x= 7 m and a charge of -75 nC is placed on the y-axis at y= 3 m. What is the magnitude and direction of the net electric field produced at the point x= 4m?

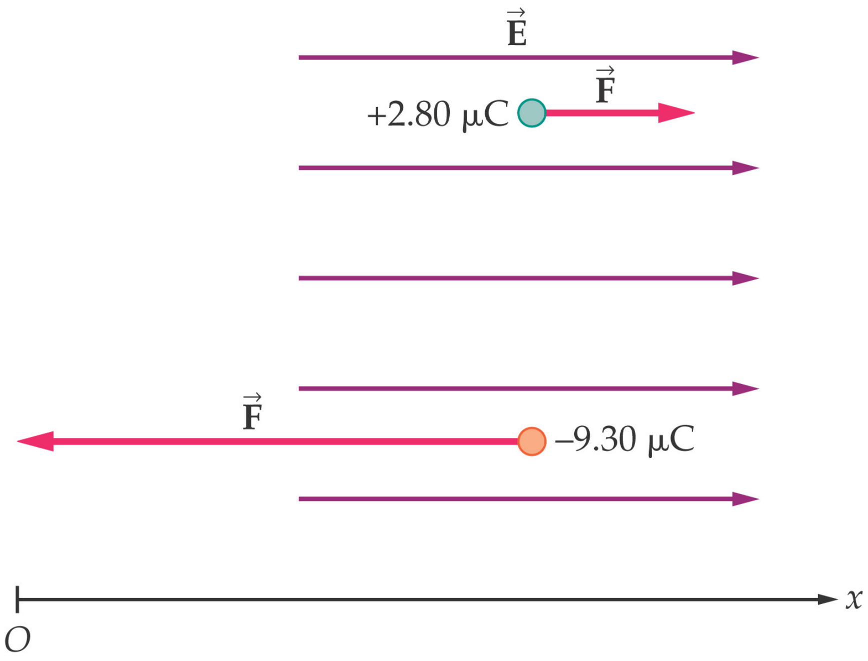
If we know the electric field, we can calculate the force on any charge:

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

The **direction of the force** depends on the **sign of the charge**:

1. Same direction of the field for a positive charge

2. Opposite to the field for a negative charge



Exercise 44 (page 768)

A (+5.0 μC) charge experiences a (0.44 N) force in the positive y-direction. If this charge is replaced with a (-2.7 μC) charge. What force will it experience?

Solution:

- Find the electric field:

$$E = F/q = 0.44 / (5x10^{-6}) = 8.8 \times 10^{4}\ \hat{j}\ N/C$$

- Now, the force on the second charge is:

$$F = q\,E = (-\,2.7 \times 10^{-6}) \times (8.8 \times 10^{4}) = 23.8 \times 10^{-2} = 0.24\ (-\,\hat{j})\ N/C$$

** The **field is exactly the same** at that point **regardless** of

1) **The sign** or

2) Magnitude of **the charge** that is located there.

Exercise 49 (page 768) (H.W.)

Two point-charges of equal magnitudes are (7.5 cm) apart. At the midpoint of the line connecting them, their combined electric field has a magnitude of (45 N/C).

Find the magnitude of the charges.

Solution

The charges must have **opposite signs,** or their electric fields would cancel out at the point midway between them.

- $\mathbf{E}_{tot} = E_{q1} + E_{q2} = 2\,E_q = 45$ (but remember that electric fields are vectors)
- $22.5 = k\,|q| / (3.75 \times 10^{-2})^2$

Then,

$|q| = 3.52 \times 10^{-12}$ C

19.5 Electric Field Lines

Electric field lines are a convenient way of visualizing the electric field.

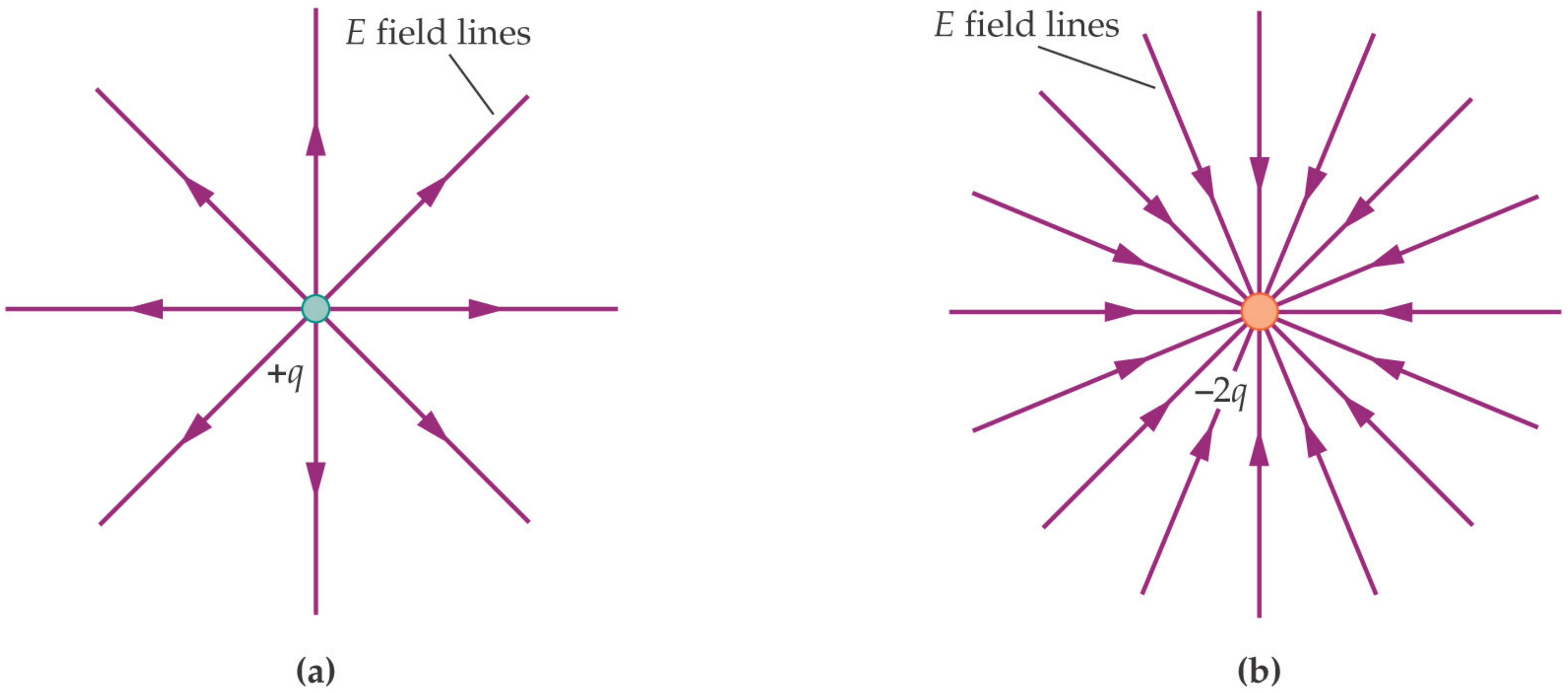
1. Point in the direction of the electric field vector $\vec{E}$ at every point

2. Start at positive charges or infinity

3. End at negative charges or infinity

4. Are denser where the field is stronger

The charge on the right is twice the magnitude of the charge on the left (and opposite in sign), so there are twice as many field lines, and they point towards the charge rather than away from it.



Conceptual Checkpoint 19-5

CONCEPTUAL CHECKPOINT 19–5 INTERSECT OR NOT?

Which of the following statements is correct: Electric field lines **(a)** can or **(b)** cannot intersect?

REASONING AND DISCUSSION

By definition, electric field lines are always tangent to the electric field. Since the electric force, and hence the electric field, can point in only one direction at any given location, it follows that field lines cannot intersect. If they did, the field at the intersection point would have two conflicting directions.

ANSWER

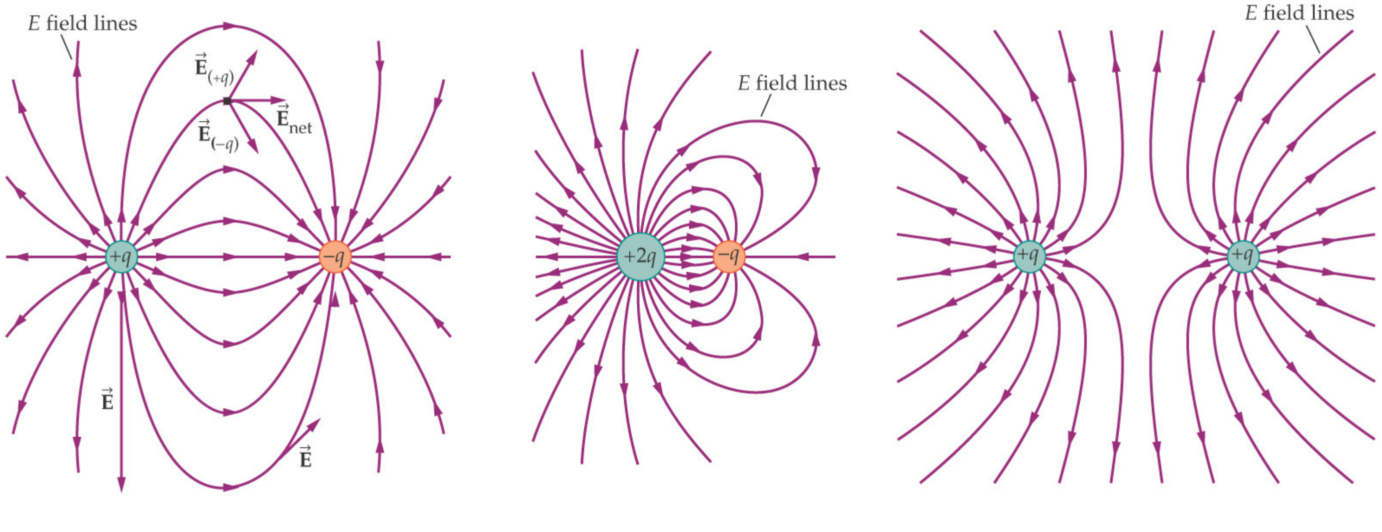
Answer:

Electric field lines can't intersect, because if they do, the electric field will have two directions at this point, which is not possible.

Combinations of Charges

1. While the lines are less dense where the field is weaker, the field is not necessarily zero where there are no lines.

2. There is only one **point** within the figures below where the **field is zero**- can you find it?



(a) (b) (c)

The (**+q**)/(**-q**) charge combination is known as

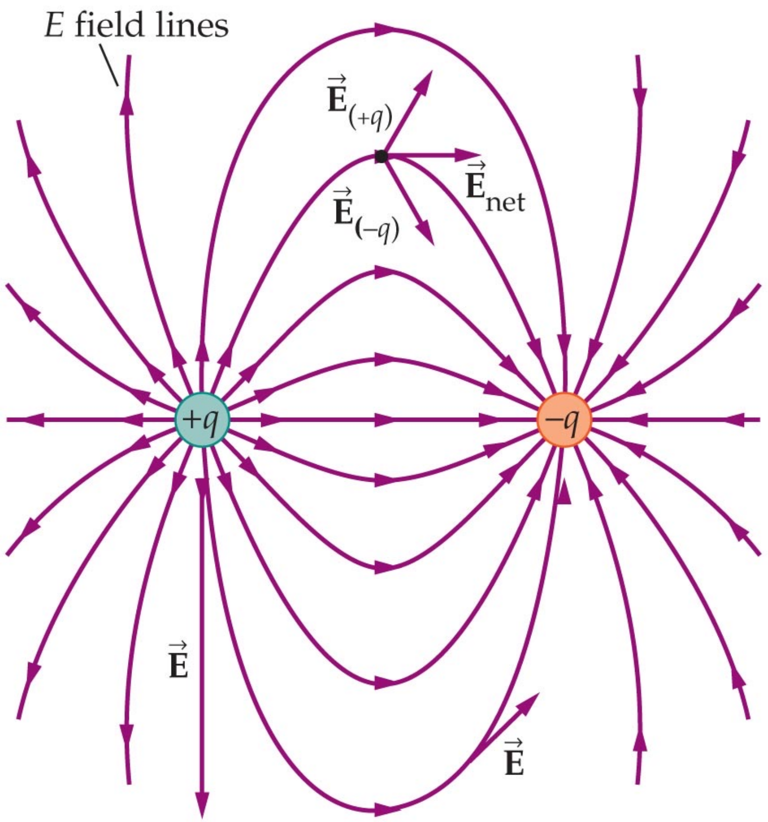
(**electric dipole**):

1. The total charge of the dipole is zero

2. The electric field of the dipole won't vanish

because the charges are separated

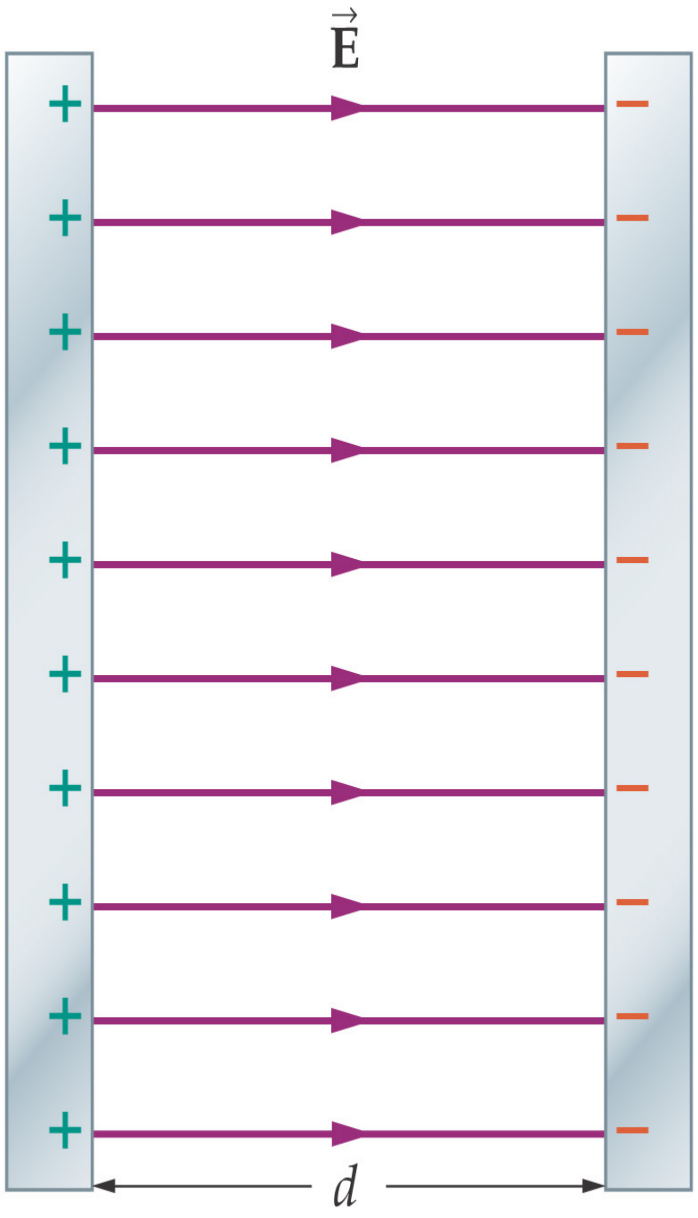
3. Electric field lines form loops



(a)

A parallel-plate capacitor consists of two conducting plates with equal and opposite charges. The electric field between the plates:

1. Uniform (constant) in both magnitude and direction
2. The direction of the field is perpendicular (Normal) to the plates
3. The magnitude of the field is independent of the distance from the plate
4. The field =0 outside the plates



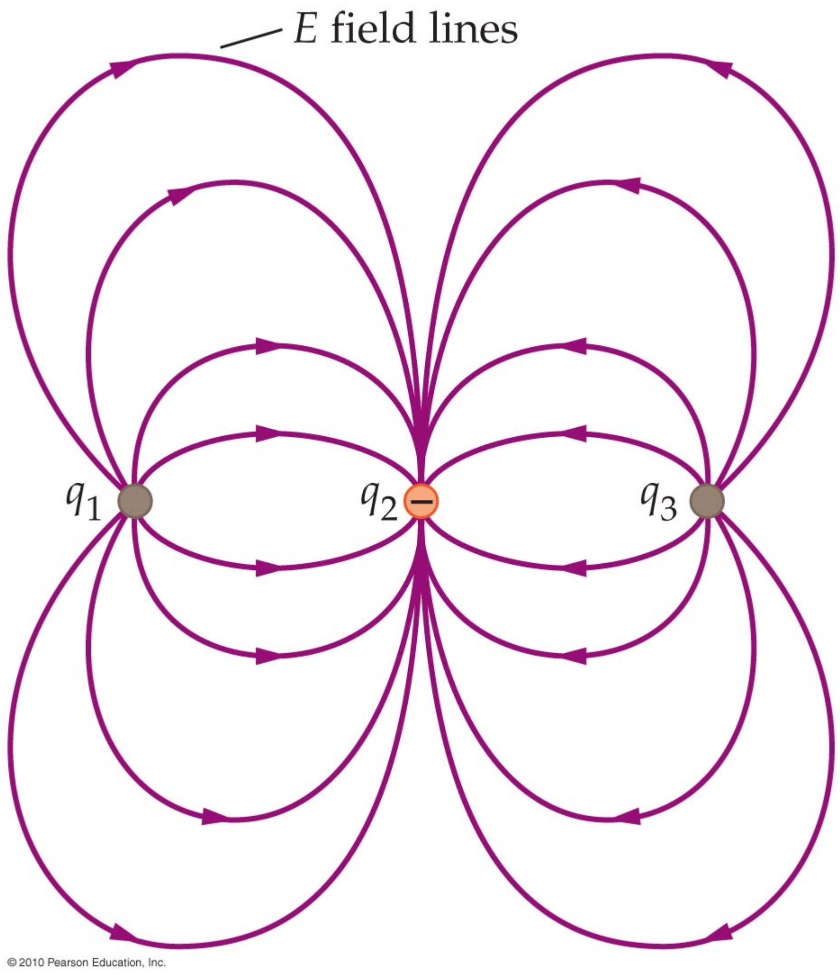
Exercise 53 (page 768)

The electric field lines surrounding three Charges are shown in the figure. The center Charge is q_2 = -10.0 μc

a) What is the sign of q_1 and q_3?

b) Find q_1

c) Find q_3



(a) The electric field lines begin at q_1 and q_3 and end at q_2. The rules of drawing electric field lines indicate that the charges q_1 and q_3 **must be positive**.

(b) The charge q_1 has 8 lines leaving it but q_2 has 16 lines entering it. Because 8 is half of 16, and since the number of lines entering or leaving a charge is proportional to the magnitude of the charge, the magnitude of q_1 is **one-half of q_2** **(+5 μC)**

(c) By the same reasoning of part **(b)**, the magnitude of q_3 is **(+5 μC)**

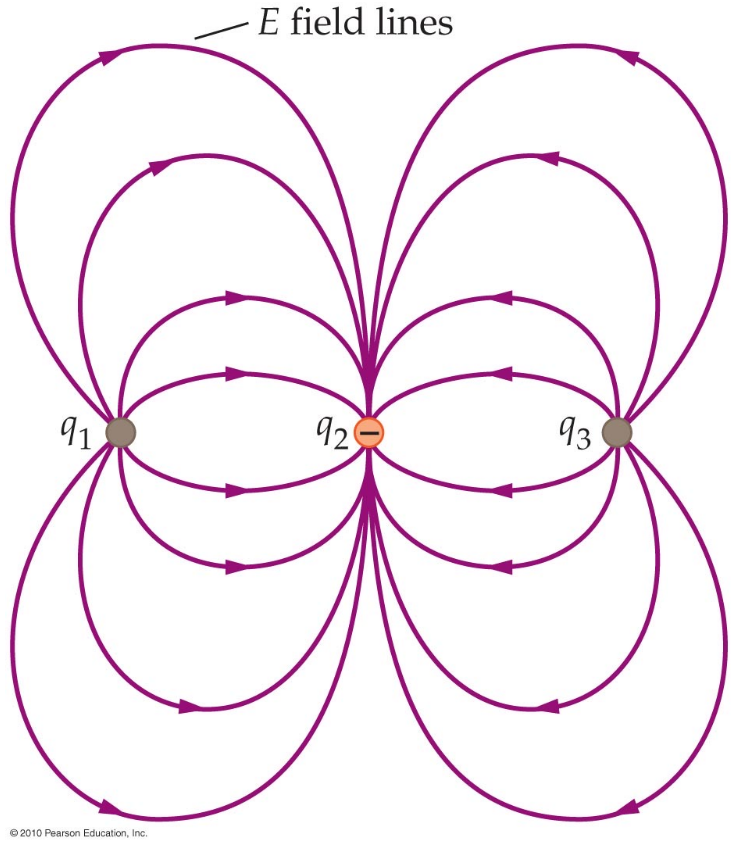
Note: When drawn correctly, an electric field diagram can reveal a wealth of information in a concise approach.

Exercise 56 (page 768)

Referring to the same figure in the previous exercise (53, page 768), suppose q_2 is not known. Instead, it is given that:

$$q_1 + q_2 = -2.5\ \mu C$$

Find q_1 , q_2 , and q_3 .



Answer:

The number of electric field lines **entering q_2** is double the number of electric field lines **leaving q_1 and q_3**, and so:

$$q_2 = -2\, q_1$$

and:

$$q_1 = q_3$$

then:

$q_1 + (-2\, q_1) = -2.5\ \mu C$ and so $-q_1 = -2.5\ \mu C$ and so **$q_1 = 2.5\ \mu C = q_3$**

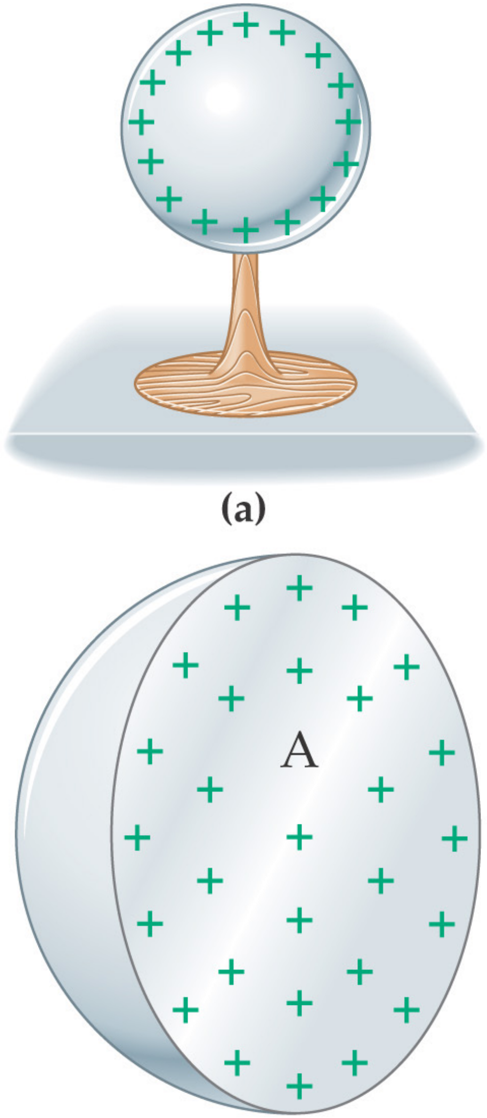
$q_2 = -2 \times q_1 = -5\ \mu C$

19.6 Shielding and Charging by Induction

Question: For a charged sphere of conductor, the **charge will spread uniformly on the exterior surface**, **NOT** **throughout the volume of the sphere**, why? Fig. a

Answer: Since excess charge on a conductor is free to move, the charges will move so that **they are as far apart as possible (repulsive electrostatic forces).** This means that excess charge on a conductor resides on its surface. Fig. b

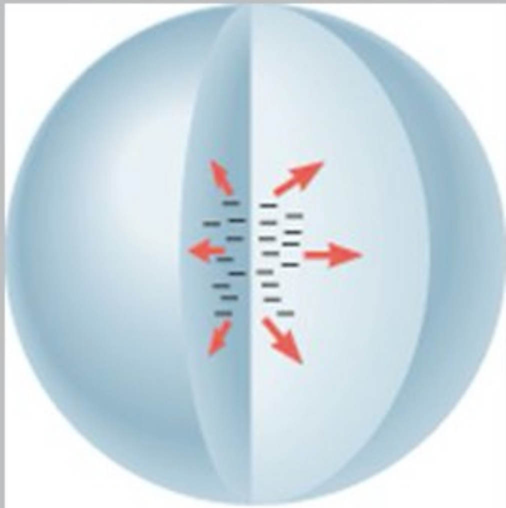
Note: This phenomenon is independent of **the shape of the conductor**

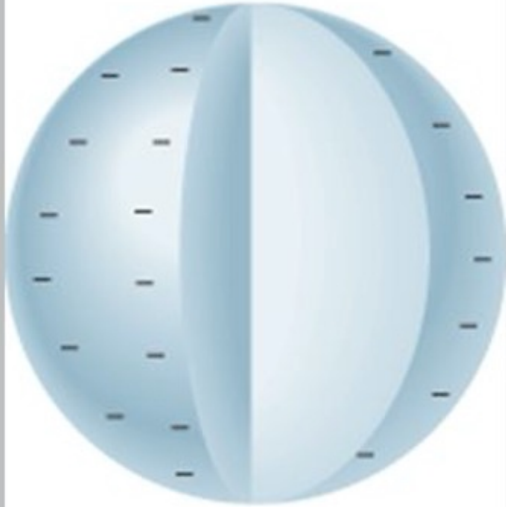


(a)
(b)

Charged Conductors

- **Electrostatic equilibrium** -- excess charge has distributed itself so as to reduce the total amount of repulsive forces.
- Once a charged conductor has reached the state of electrostatic equilibrium, there is no further motion of charge about the surface.


(a)


(b)

<u>Electrostatic Shielding</u>

1. A conductor **<u>shields</u>** its interior from external **<u>electric fields</u>**

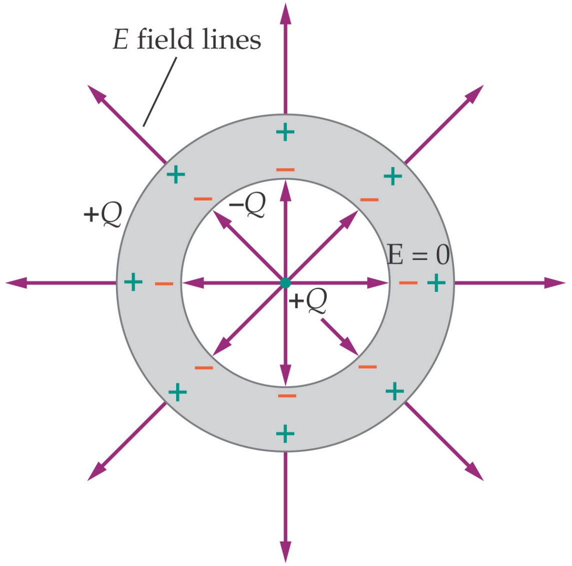
When electric charges are at rest, **<u>the electric field within a conductor is zero</u>**

E = 0 (Inside the conductor)

2. **<u>Shielding works in one direction only</u>**

A conductor shields its interior from external

Fields within it:



The charge (+Q) in the cavity induces a charge (-Q) on the interior surface (the internal field = zero)

And charge (+Q) will be induced on the exterior surface and so the external world will experience a field.

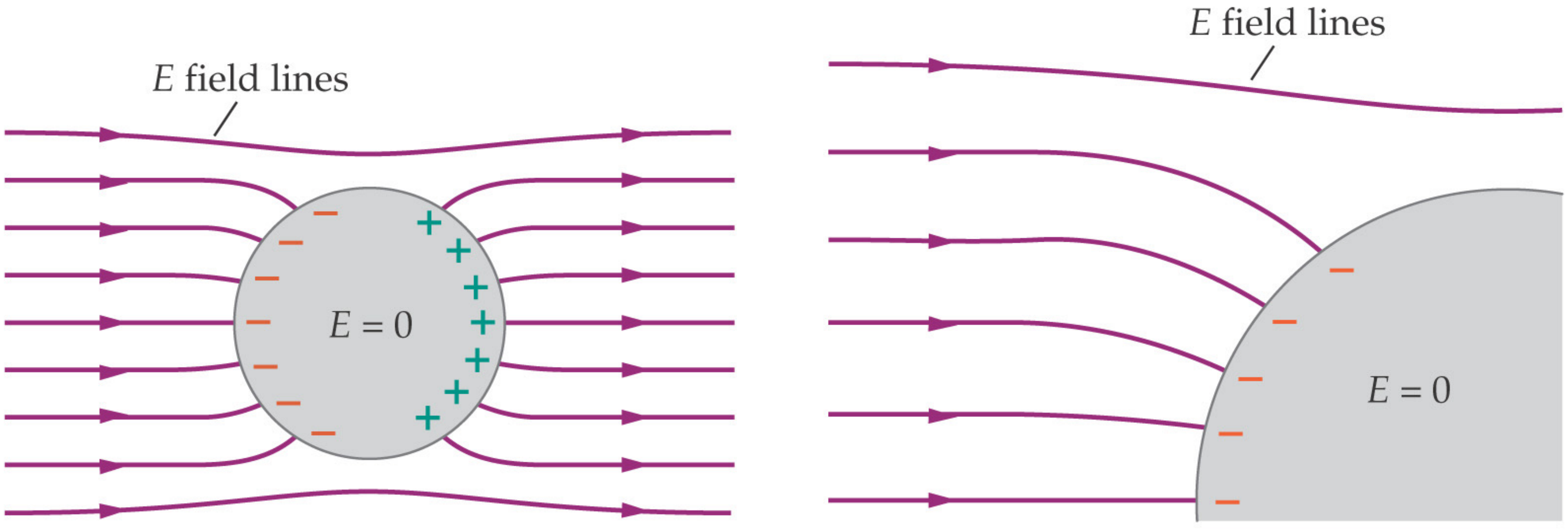
Faraday Cage

- Faraday stated that the charge on a charged conductor resided only on its exterior
- To demonstrate this fact he built a room coated with metal foil, and allowed high-voltage discharges from an electrostatic generator to strike the outside of the room

- He used an electroscope to show that there was no excess electric charge on the inside of the room's walls.

3. The electric field is always perpendicular to the surface of a conductor

If Not, the charges would move along the surface

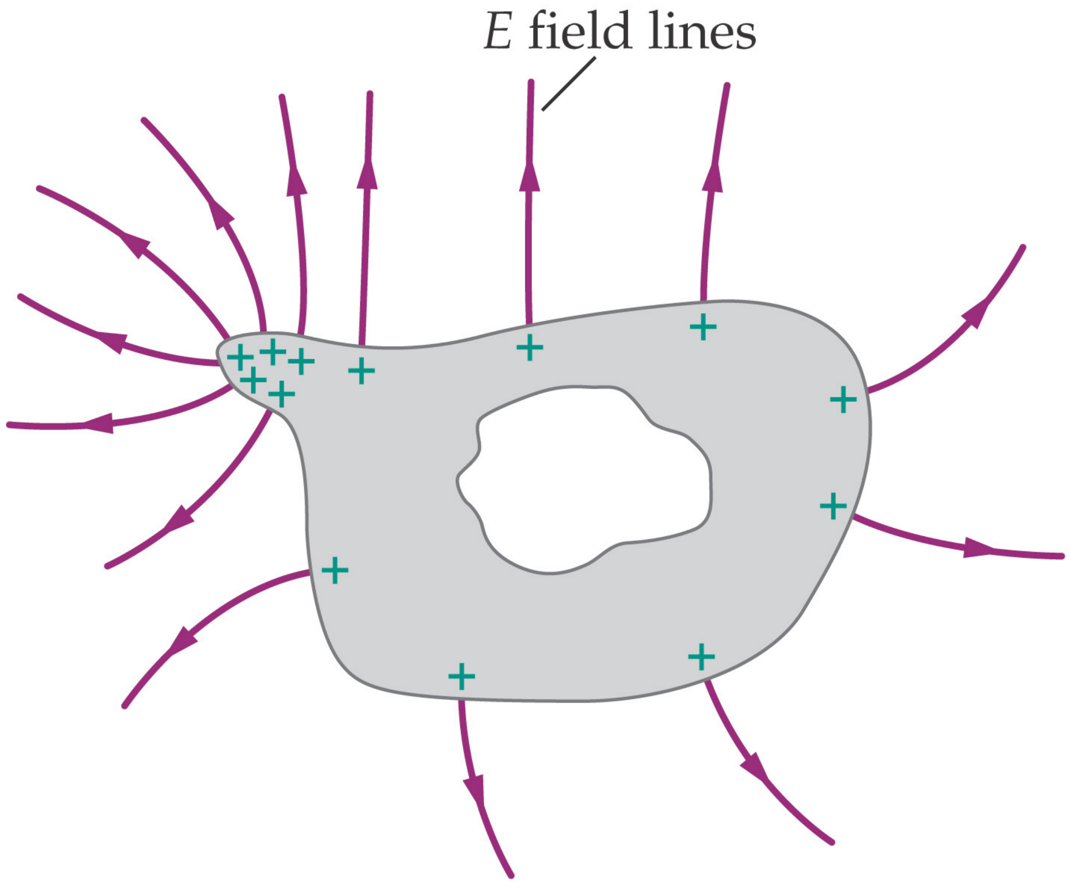


(a) (b)

4. The electric field is stronger where the surface is more sharply curved

(pointy bit)

Note : see the video (conductors in electrostatic equilibrium) .



❑ Charging By Induction

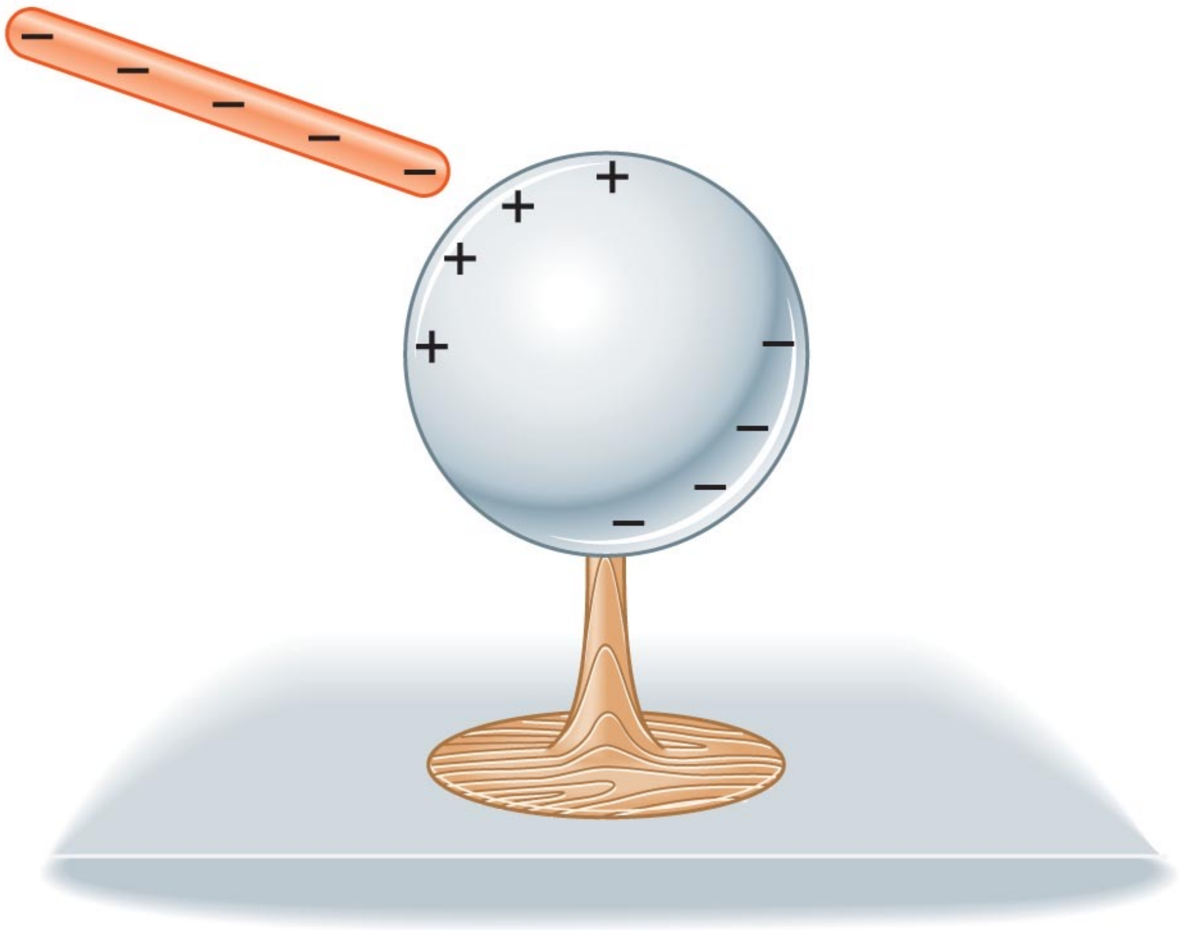
Charging by Induction is to charge an object without making direct physical contact

Question : Is it possible to charge a conductor by induction?

Answer: **YES**, a conductor can be charged by induction, if there is a way to ground it.

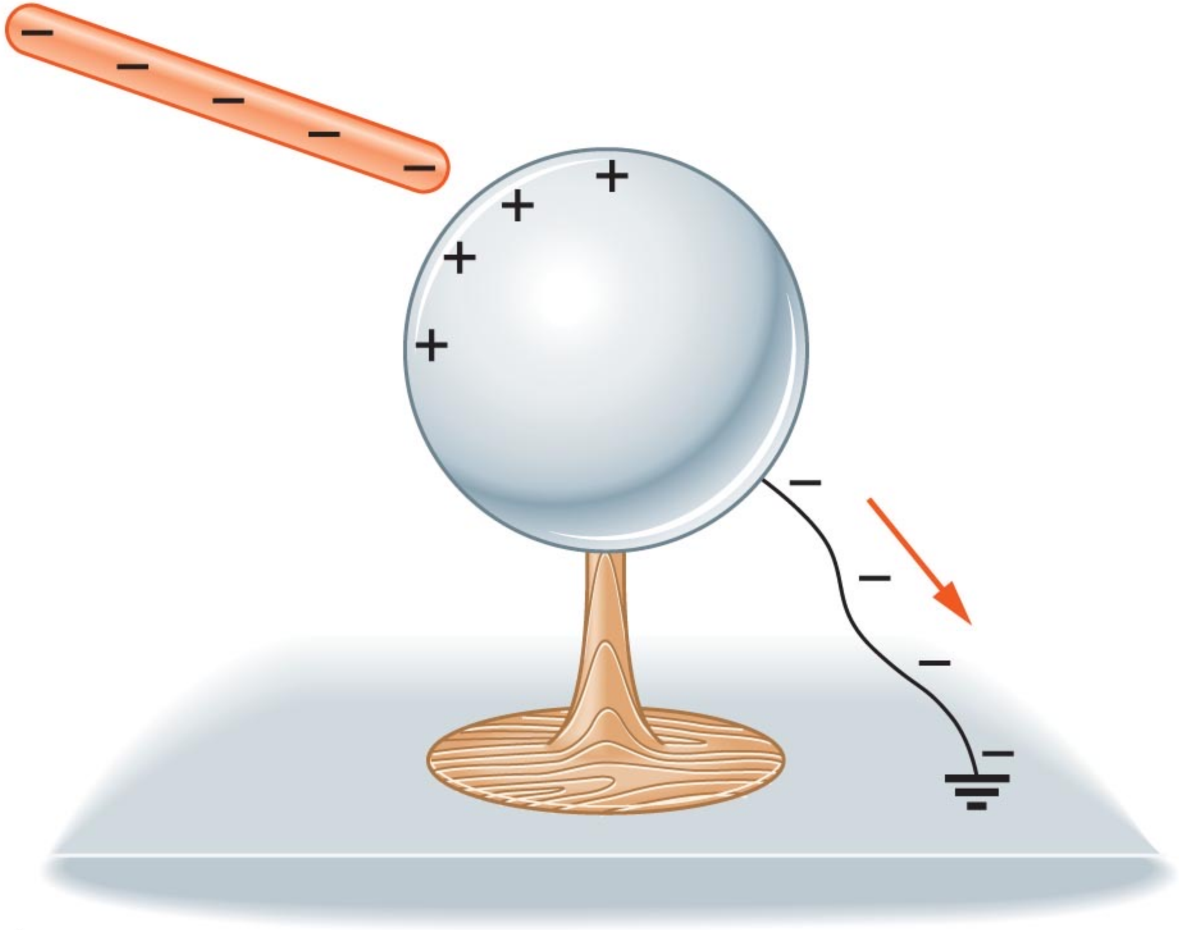
Note: When charging a conductor by induction, the final charge of the conductor will be opposite in sign to the charge of the charging rod

Figure 19-22A



(a)

Figure 19-22B



(b)

Figure 19-22C

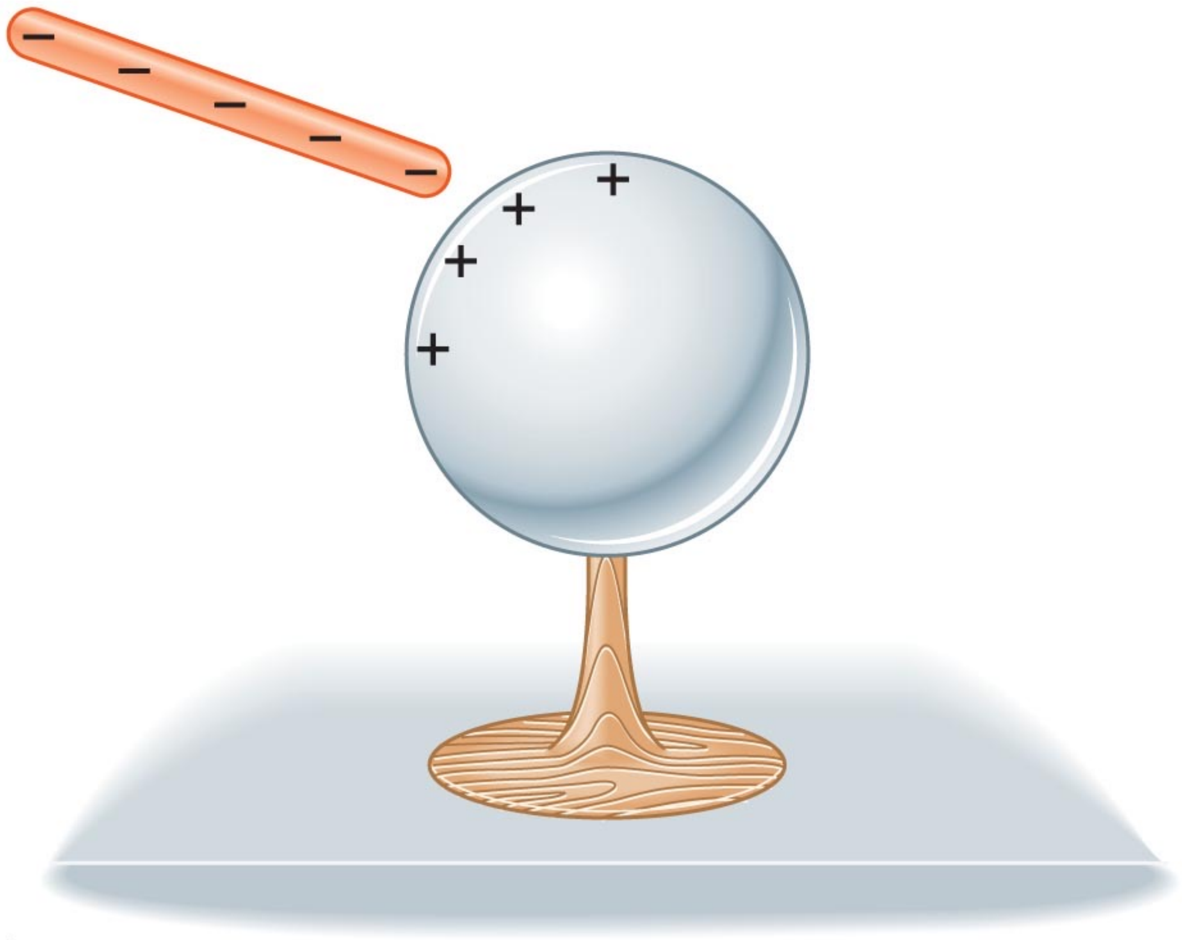
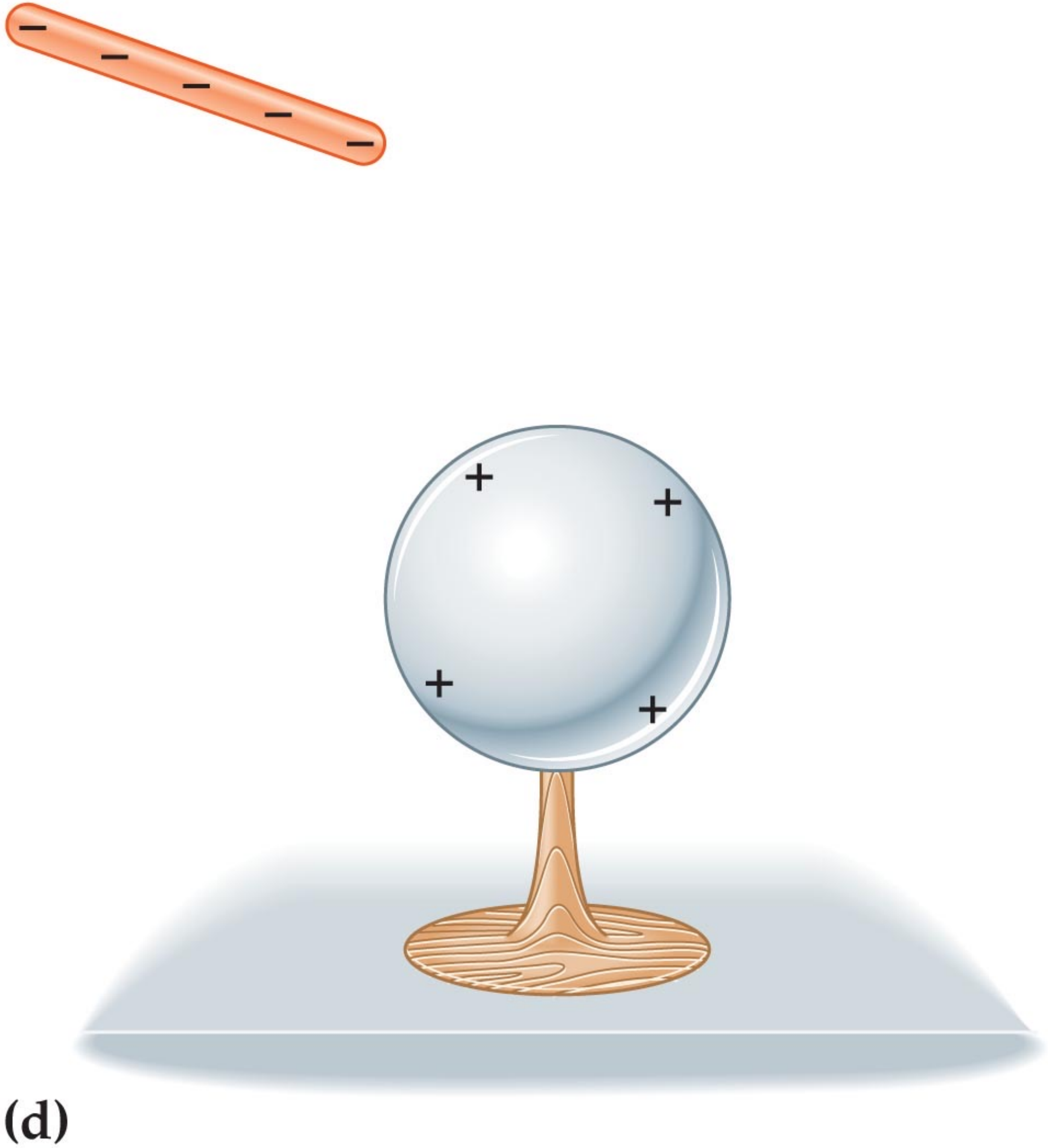


Figure 19-22D



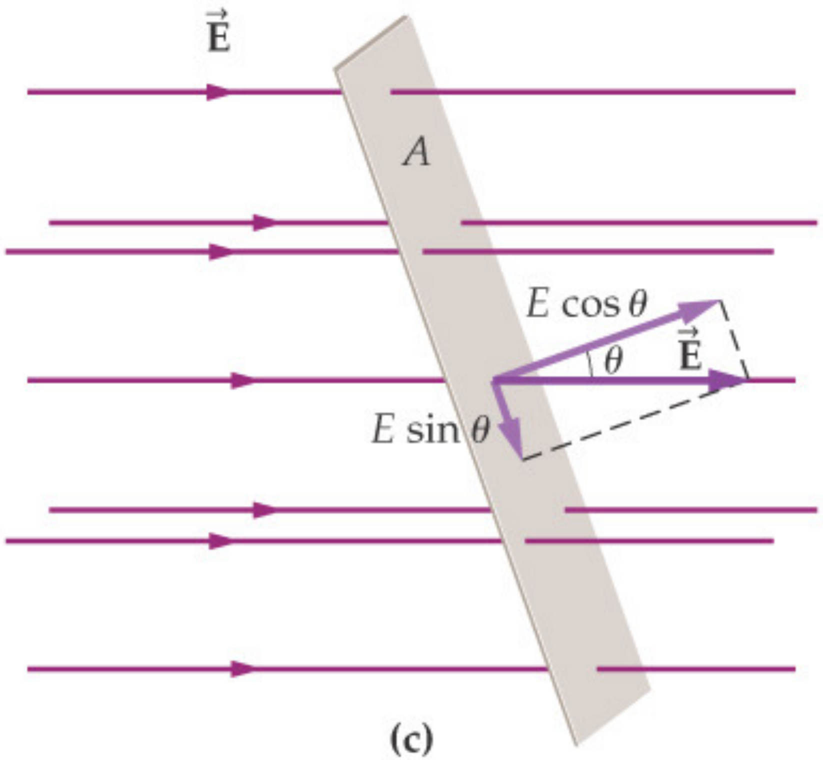
19.7 Electric Flux and Gauss's Law

Electric flux: Is a measure of the electric field perpendicular to a surface

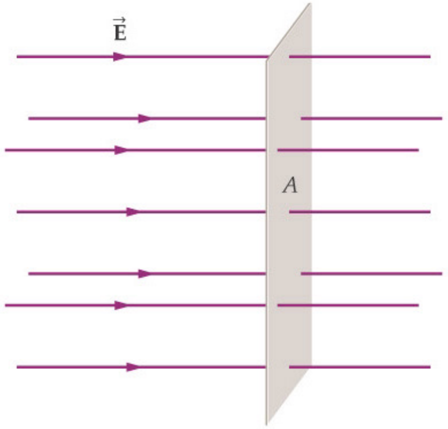
Definition of Electric Flux, Φ

$$\Phi = EA\cos\theta$$

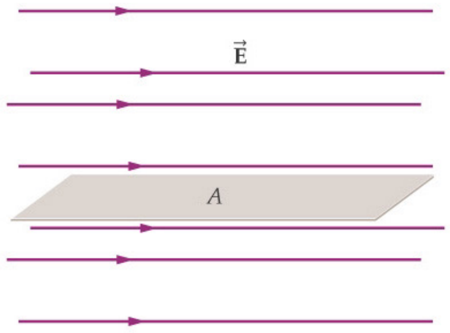
SI unit: $N \cdot m^2/C$



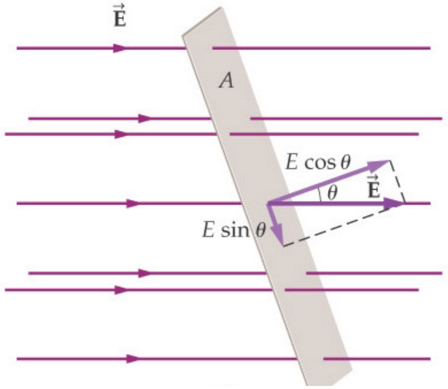
(c)



(a)



(b)



Example

Calculate the flux of the electric field E = 200 N/C, through the surface A = 350 cm^2, in each of the three cases shown. (In part c $\theta = 15^o$)

a) $\Phi =$

b) $\Phi =$

c) $\Phi =$

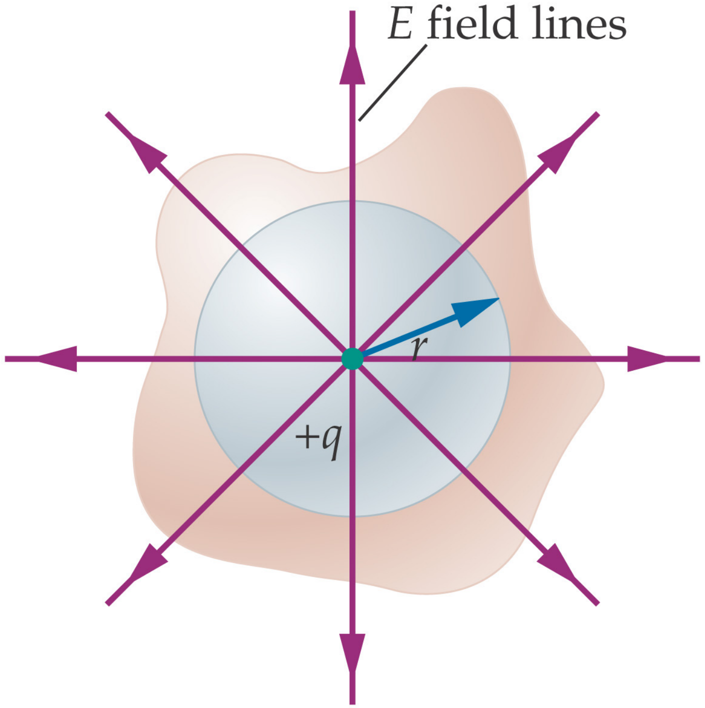
Gauss's Law

The **Electric Flux** through a closed surface **is proportional to the Charge Enclosed** by the surface:

$$\Phi = \frac{q}{\varepsilon_0}$$

SI unit: $N \cdot m^2/C$

$$\varepsilon_0 = \frac{1}{4\pi k} = 8.85 \times 10^{-12}\, C^2/N \cdot m^2$$



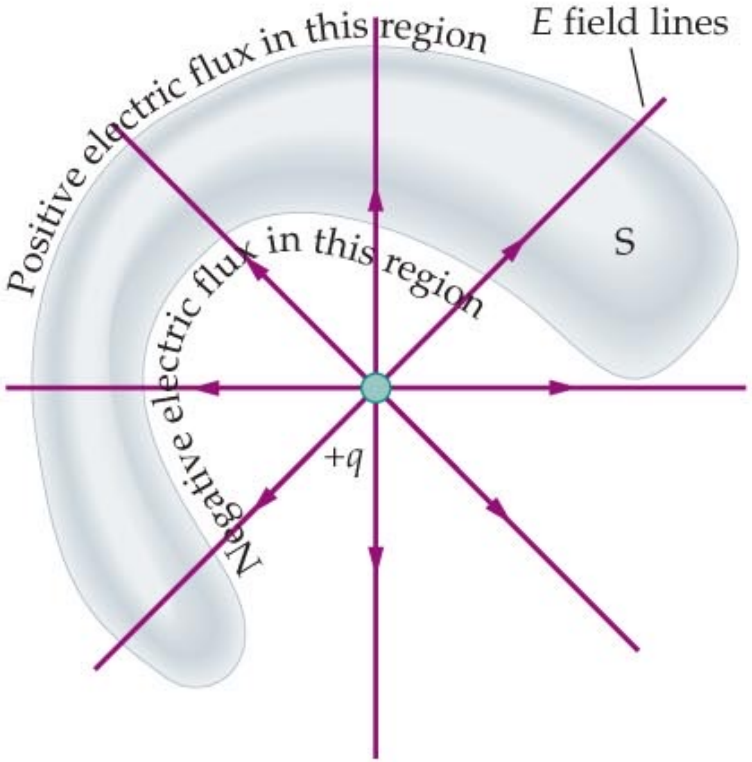
Remarks on the electrical flux formula

1. ε_o: is the permittivity of free space
2. In the electric flux notation, we use **q** rather than **|q|(WHY?)**
3. Electrical flux can be **positive** or **negative**
4. **q > 0**: field lines leave the enclosed volume, and the **flux is positive**
5. **q < 0:** field lines enter the enclosed volume, and the **flux is negative**

Checkpoint page 760

CONCEPTUAL CHECKPOINT 19–6 SIGN OF THE ELECTRIC FLUX

Consider the surface S shown in the sketch. Is the electric flux through this surface **(a)** negative, **(b)** positive, or **(c)** zero?



REASONING AND DISCUSSION

Because the surface S encloses no charge, the net electric flux through it must be zero, by Gauss's law. The fact that a charge $+q$ is nearby is irrelevant, because it is outside the volume enclosed by the surface.

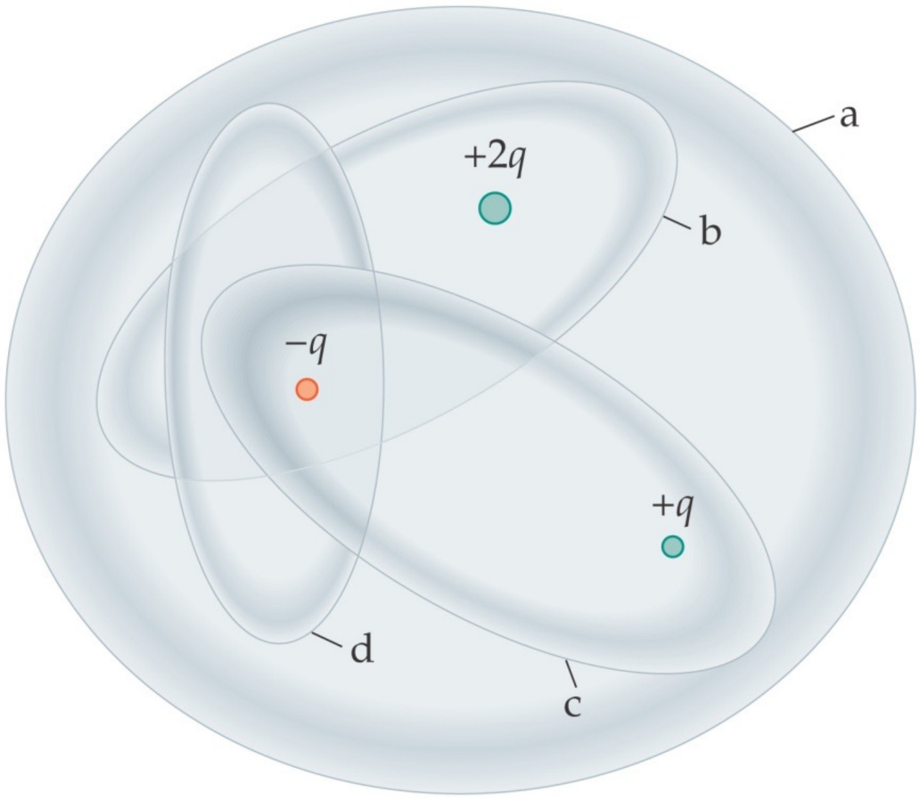
We can explain why the flux vanishes in another way. Notice that the flux on portions of S near the charge is negative, since field lines enter the enclosed volume there. On the other hand, the flux is positive on the outer portions of S where field lines exit the volume. The combination of these positive and negative contributions is a net flux of zero.

ANSWER

(c) The electric flux through the surface S is zero.

Example

Calculate the net electric flux (Φ) of the electric field for each of the closed surfaces a, b, c, and d, given that q = 26.55 nC



Surface a, Φ_a =

Surface b, Φ_b =

Surface c, Φ_c =

Surface d, Φ_d =