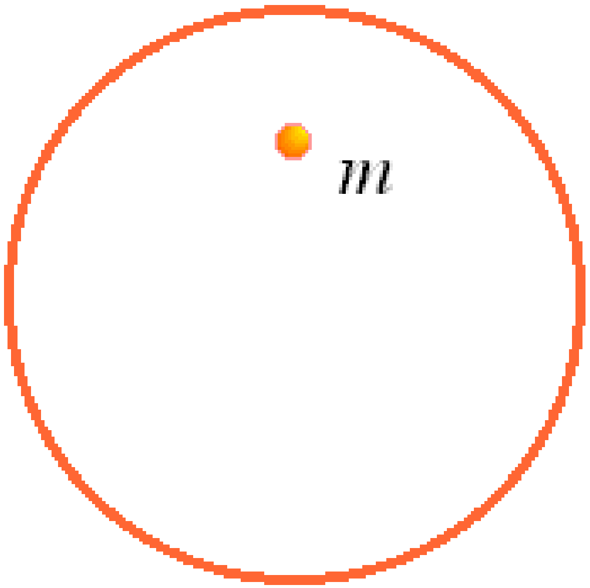
Measuring the Electric Force

Recall – Newton's Law of Universal Gravitation:

$$F_g = G\frac{m_1 m_2}{r^2}$$



Newton said: Imagine a hollow earth (a thin shell of uniform thickness) and a small object of mass *m* somewhere inside.

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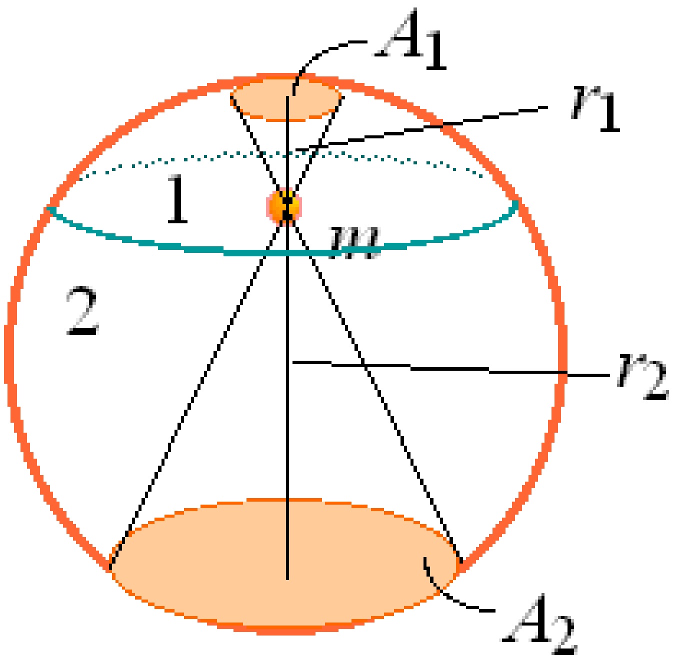

Divide the shell into two sectors, above and below the object.

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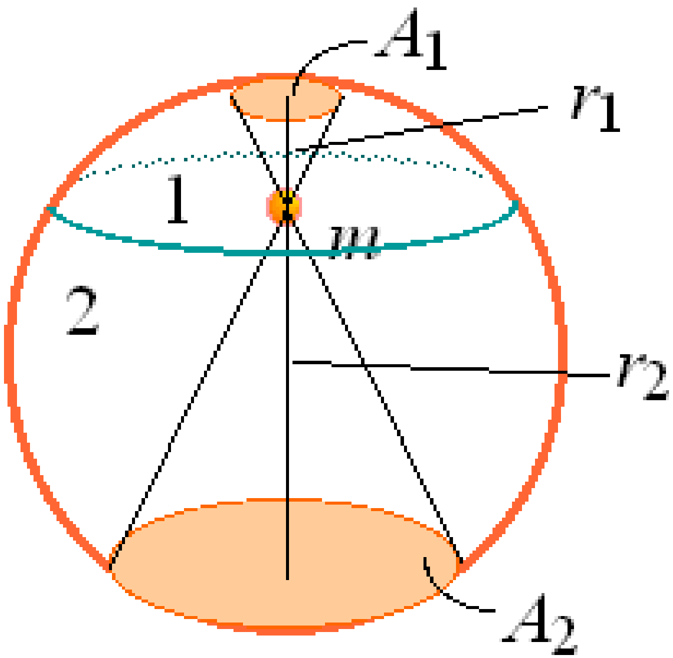

Select a small patch of area A_1 on the upper shell, and a corresponding patch of area A_2 on the lower shell. The mass of each patch is proportional to its area. From geometry – the areas are proportional to the squares of the distances from the shells to the object.

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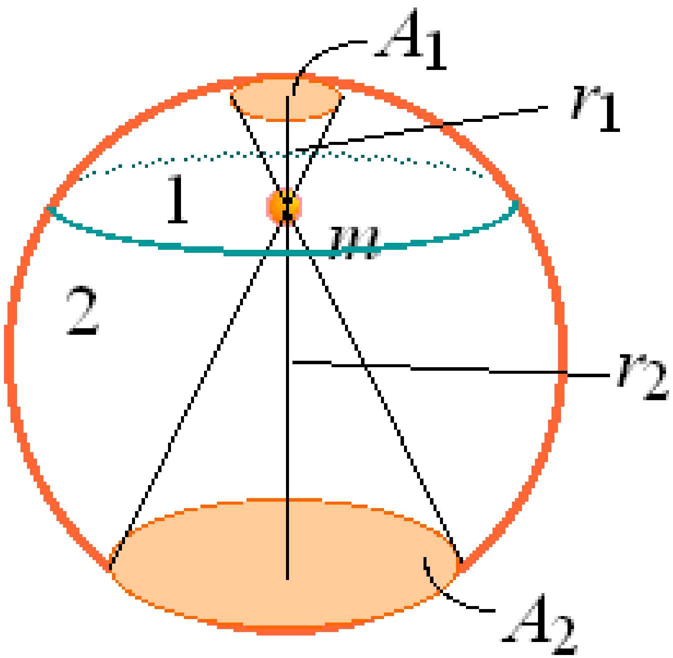

This means that

$$\frac{m_{\text{patch 1}}}{r_1^2} = \frac{m_{\text{patch 2}}}{r_2^2}$$

This means that the net gravitational force on the object due to the two patches is <u>zero</u>!!

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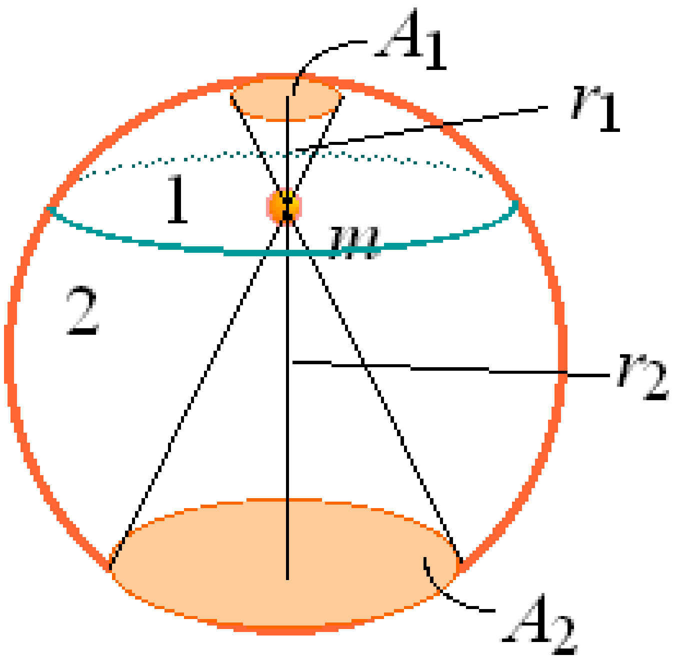
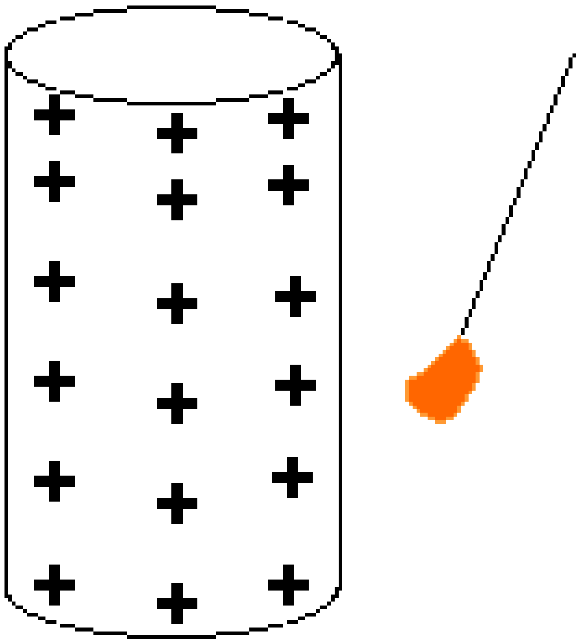
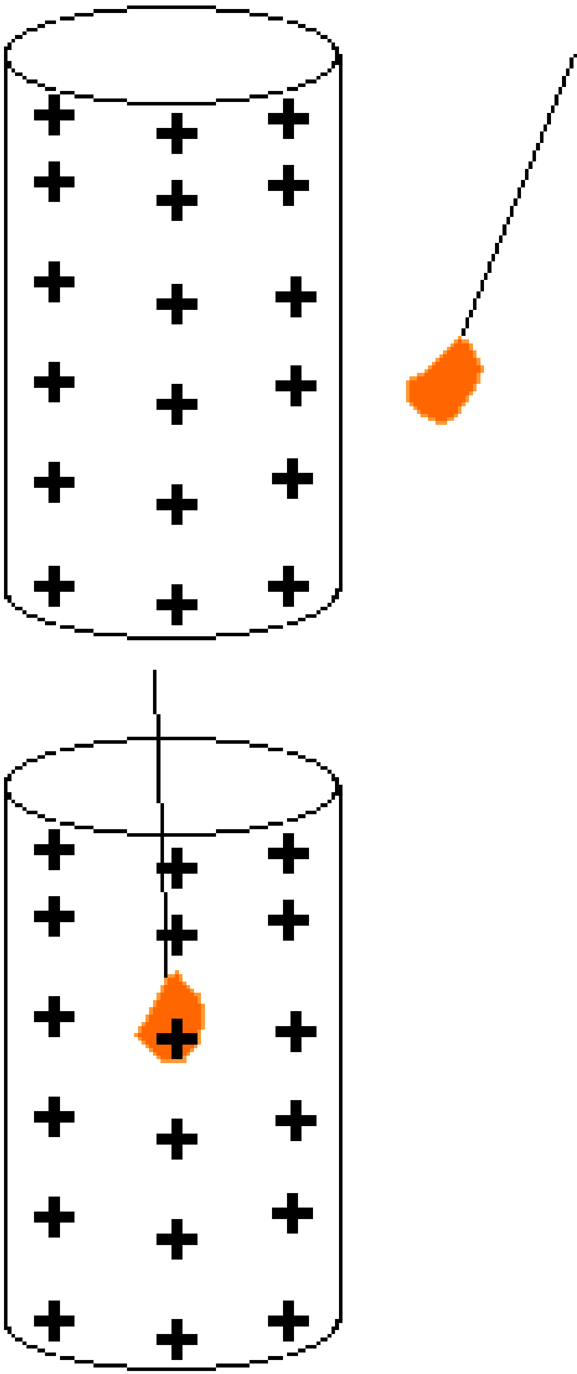


This means that the net gravitational force on the object due to the two patches is <u>zero</u>!! Corresponding canceling pairs of patches can be chosen for the remaining areas. The net gravitational force on any object inside the sphere is *<u>zero</u>*.

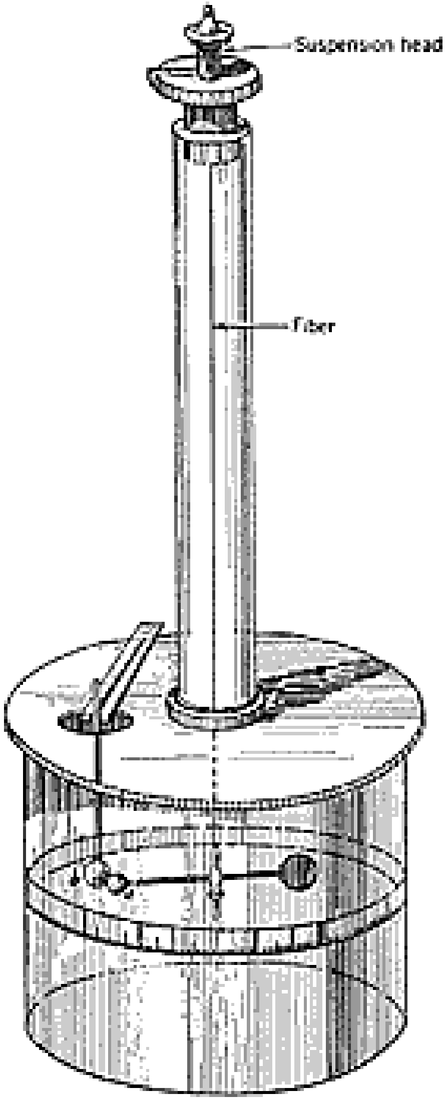
Benjamin Franklin (~1775) observed that a small piece of cork (electrically neutral) hanging from a string was attracted to the outside of a charged metal container.



Joseph Priestly, who had met Franklin in London, repeated the experiment. He recalled Newton's analysis of the gravitational force inside a hollow material body and concluded that the electric force between charged particles must also be an inverse square force.



Charles Augustin de Coulomb devised an experiment to test and verify the inverse square law (~1784). His torsion balance measured the force between small charged spheres as a function of the quantity of charge on each sphere and the separation distance between the spheres.



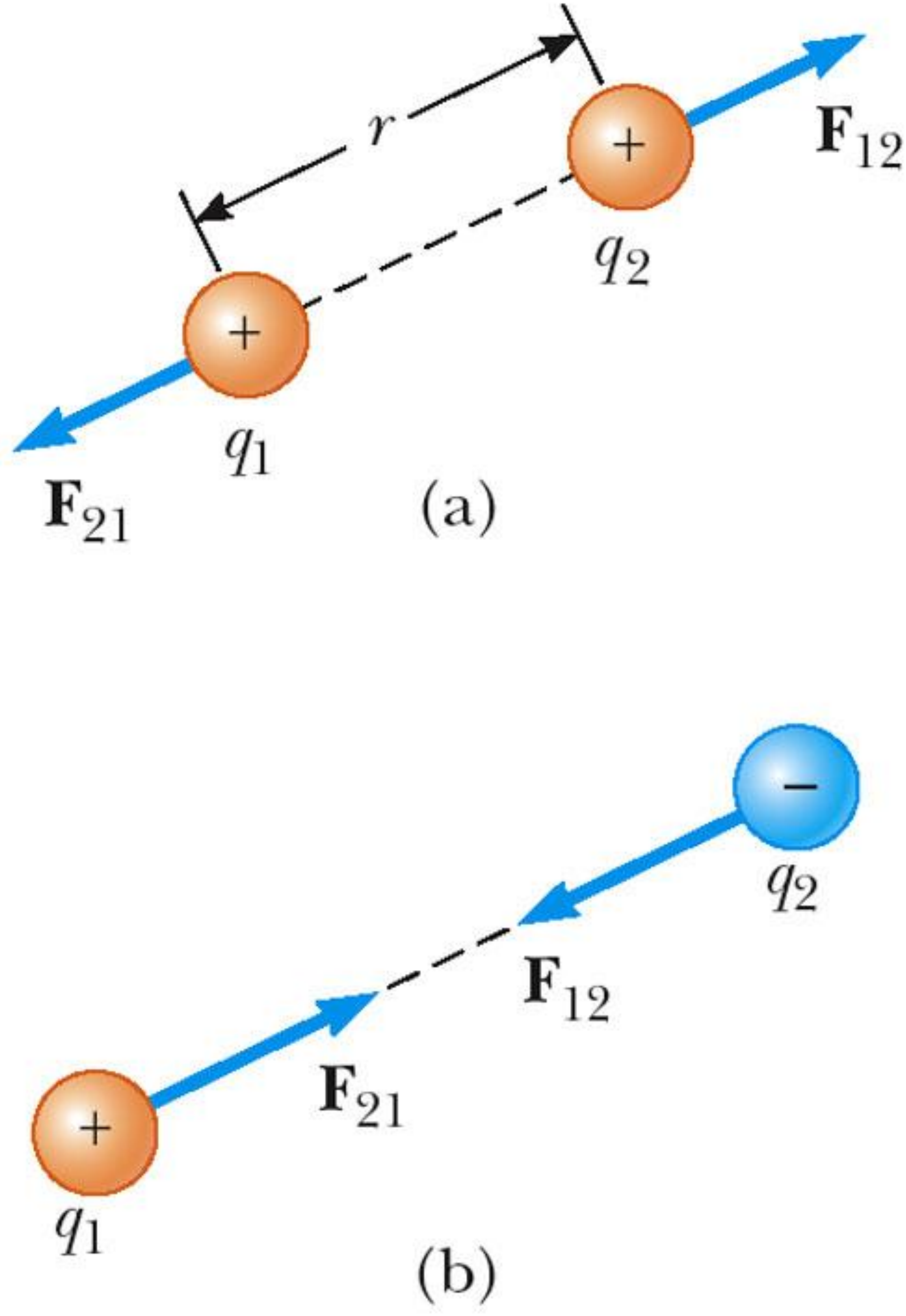
Coulomb's Torsion Balance

Coulomb's Experiment Applet

Coulomb's experiment led to a conclusion for <u>point charges</u>:

$$F_{electric} = k_e \frac{|q_1||q_2|}{r^2}$$

The Coulomb force is a *mutual* force (Newton's third law applies).
Like charges repel.
Unlike charges attract.



Coulomb's experiment led to a conclusion for point charges:

$$F_{electric} = k_e \frac{|q_1||q_2|}{r^2}$$

In this form, Coulomb's law expresses the MAGNITUDE of the MUTUAL force between point charges.

Units: Charge (q) is in Coulombs (C).

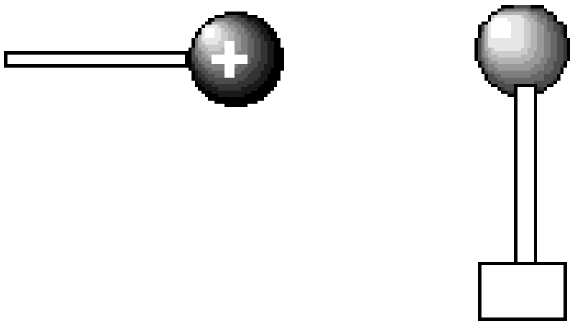
r is in meters

$$k_e = 8.99 \times 10^9 \ \ \mathrm{Nm^2/C^2}.$$

One “elementary” charge (e) is the magnitude of the charge of a single electron.

$$e = 1.60 \times 10^{-19}\ \mathrm{C}$$

A simple test of Coulomb’s law.



First – *charge sharing*.

A charged conducting sphere with an insulating handle is brought near an identical uncharged sphere.

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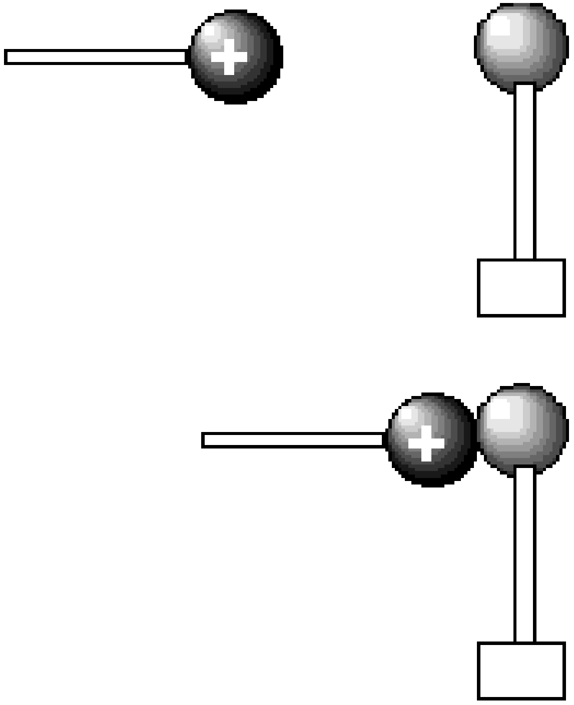

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A charged conducting sphere with an insulating handle is brought near an identical uncharged sphere.

The spheres are put in contact.

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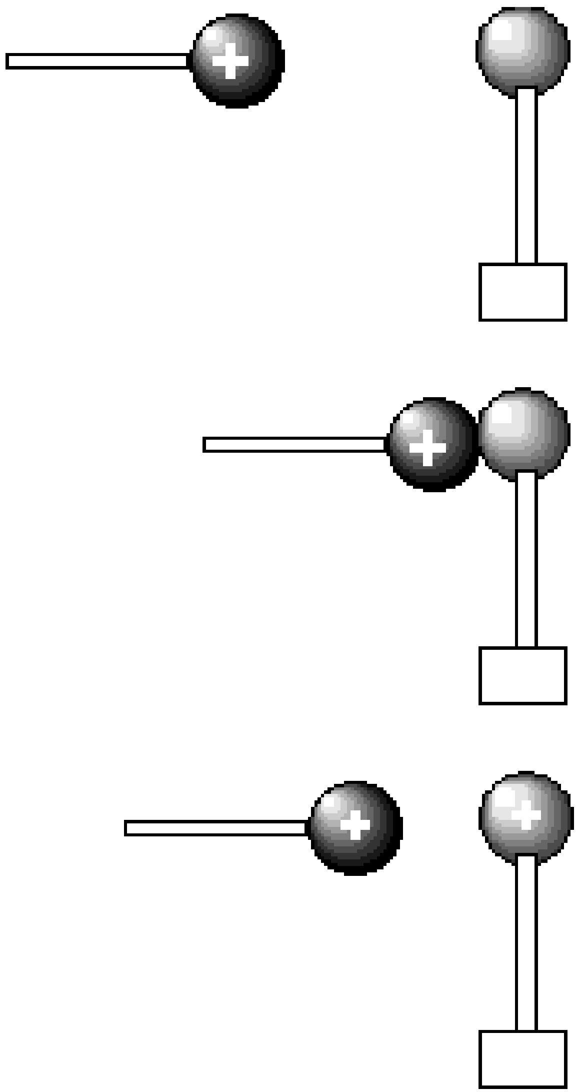
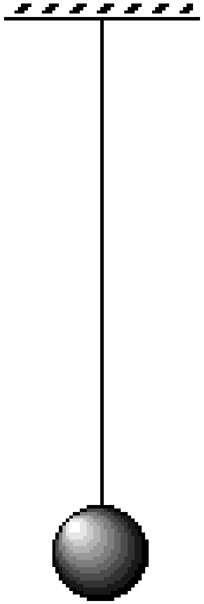


First – *charge sharing*.
A charged conducting sphere with an insulating handle is brought near an identical uncharged sphere.
The spheres are put in contact.
Each sphere now has half the initial charge.

A simple test of Coulomb's law.

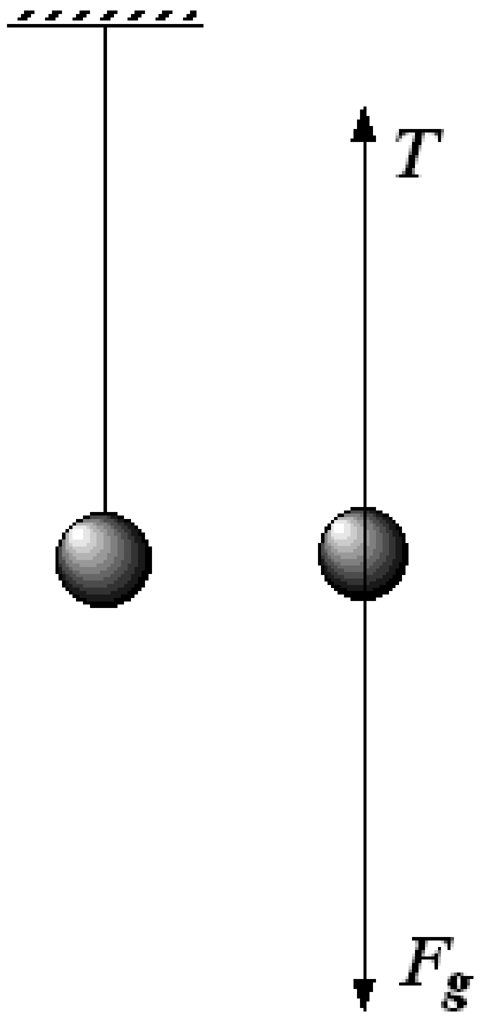
Hang a neutral sphere by an insulating cord.



A simple test of Coulomb's law.

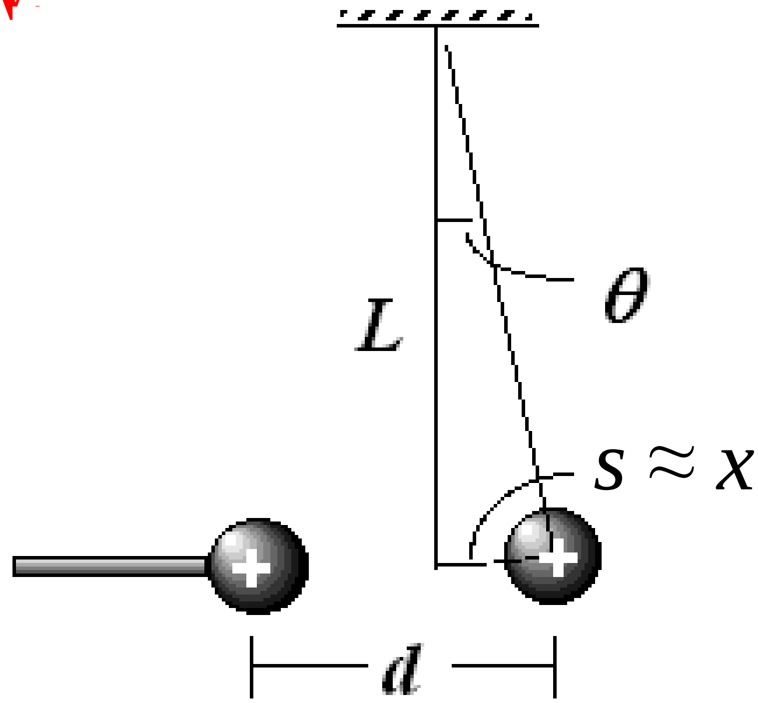
Hang a neutral sphere by an insulating cord.

Identify the forces on the sphere (free body diagram).



A simple test of Coulomb's law

Charge this sphere by contact and draw the free body diagram after the spheres are separated.



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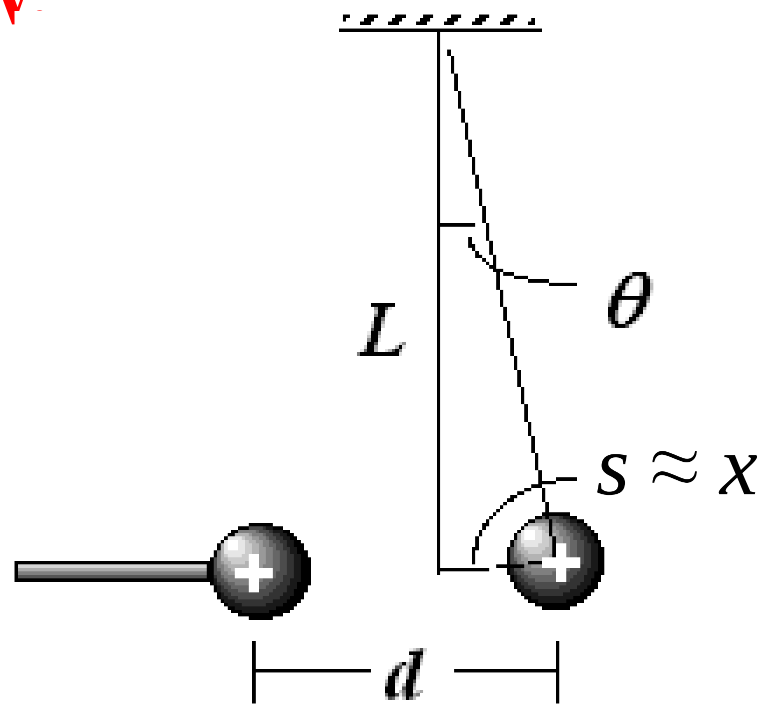

$$\sin\theta = \frac{s}{L} \approx \frac{x}{L} = \tan\theta = \frac{F_{electric}}{mg}$$

$$F_{electric} \approx \left(\frac{mg}{L}\right)x \qquad F_{electric} \propto x$$

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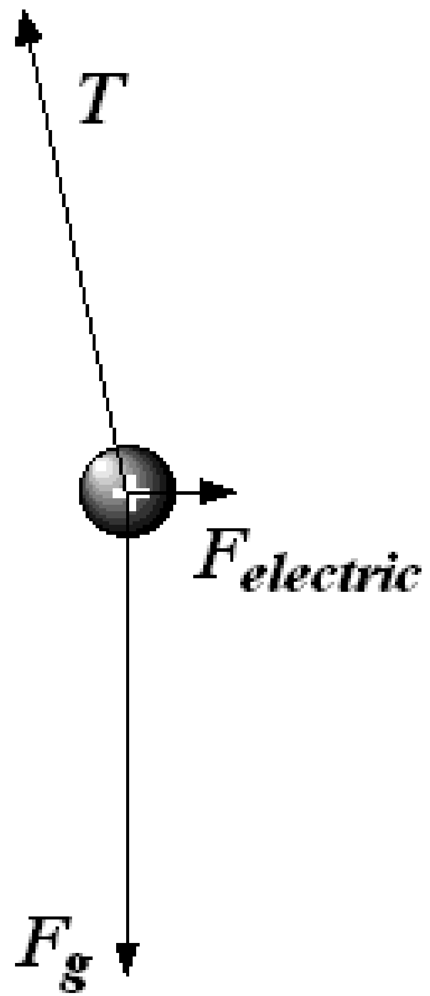

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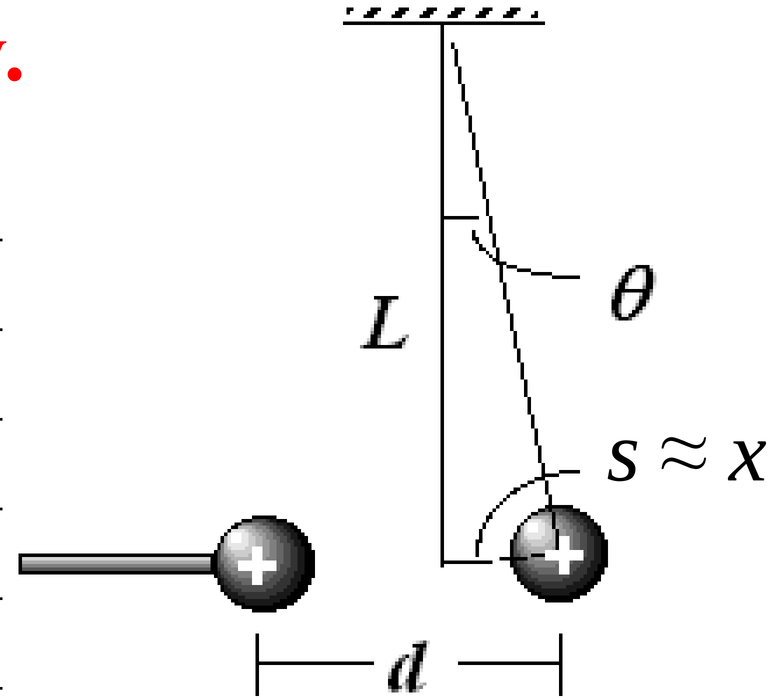
A simple test of Coulomb's law.

Values of *x* (proportional to force) and separation distance *d* are obtained.

x (Force)	*d*
0.3	11.0
0.4	0.0
0.7	7.4
1.0	6.6
1.2	5.8
1.6	5.2
2.0	4.6
2.4	4.0
3.1	3.7
3.6	3.2
4.3	2.9
4.7	2.8



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Values of *x* (proportional to force) and separation distance *d* are obtained.

The data are graphed and a fit is obtained.

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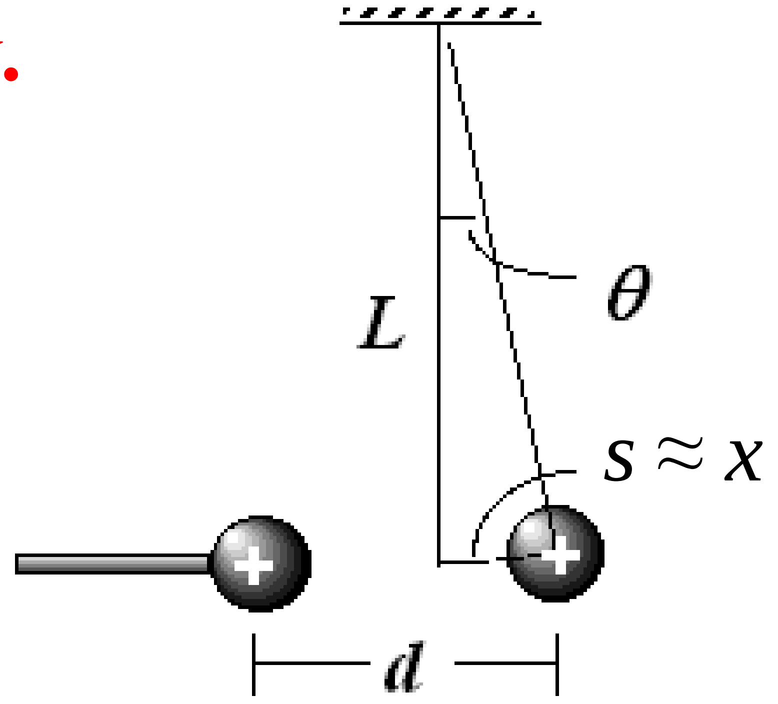

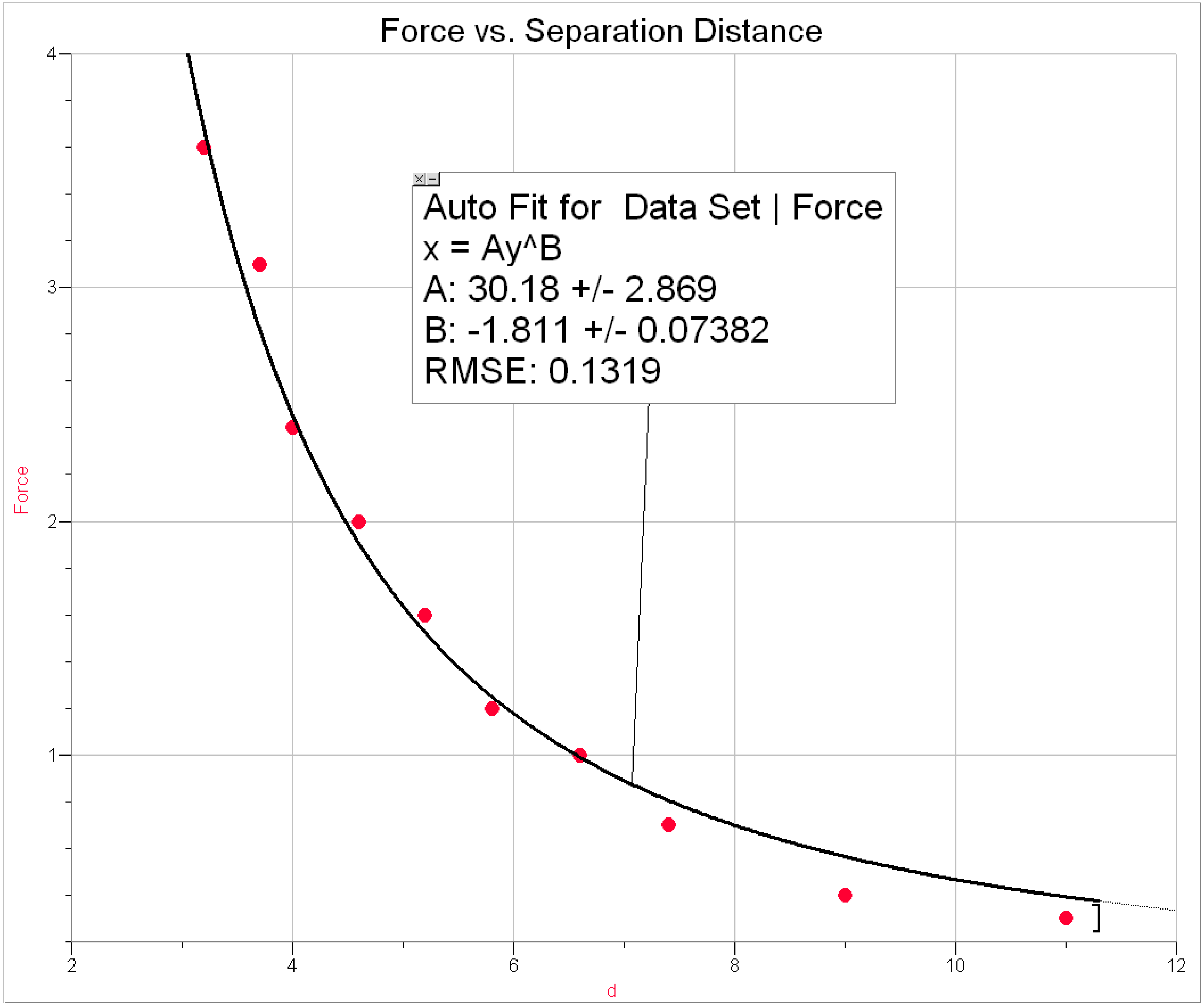
Force vs. Separation Distance
Auto Fit for Data Set | Force
x = Ay^B
A: 30.18 +/- 2.869
B: -1.811 +/- 0.07382
RMSE: 0.1319
Force
d
1
2
3
4
2
4
6
8
10
12

From the data:

$$\text{Force} \propto \frac{1}{(\text{distance})^{1.8}}$$

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Inverse square??

Coulomb says:

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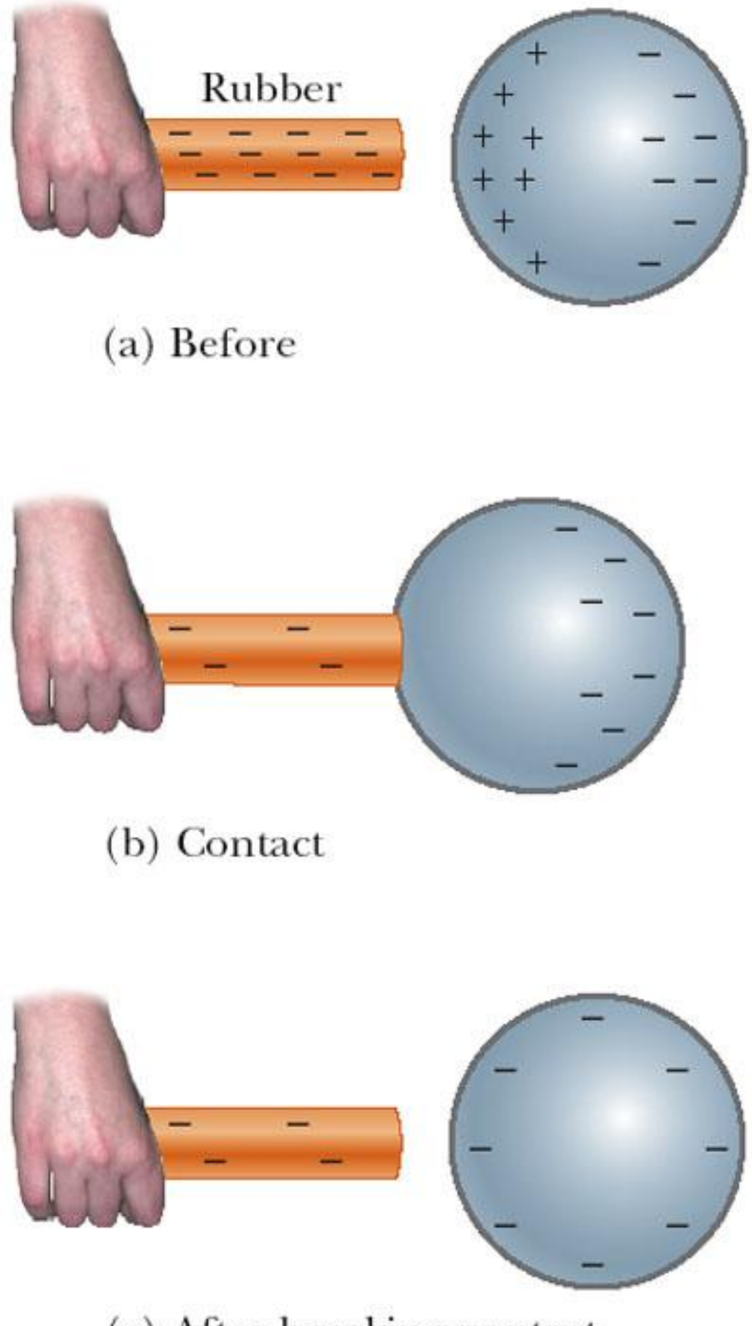
Inverse square??

Coulomb says:

“Close enough!”

Charge can be transferred by conduction. A charged object is put in contact with an uncharged object. Both objects carry the same charge.

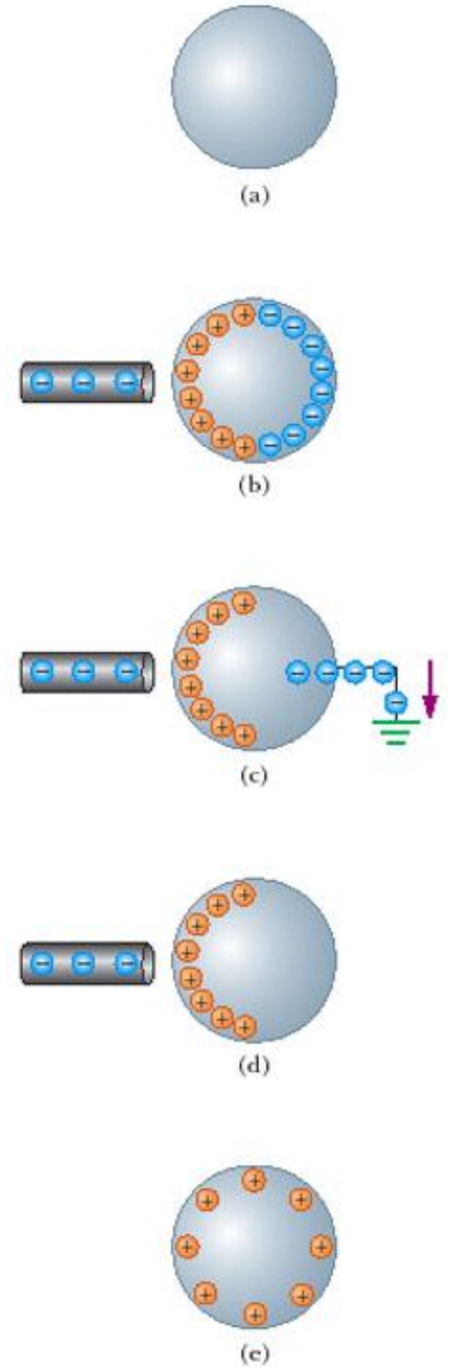


(a) Before

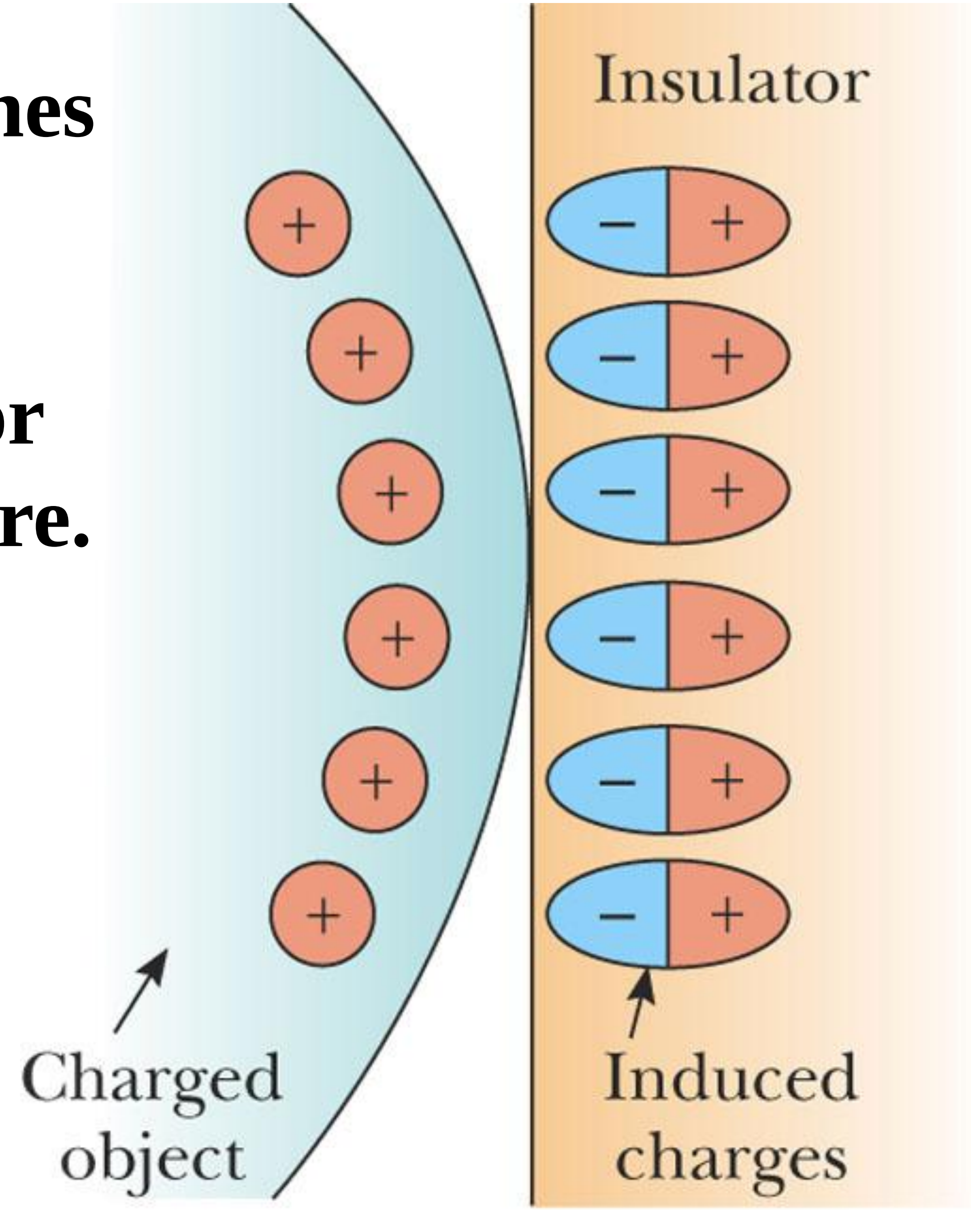
(b) Contact

(c) After breaking contact

Charge can be transferred by ***induction*****. (1) A charged object is brought near an uncharged** ***conductor*****. (2) The conductor is grounded (3) The ground connection is broken. (4) The charged object is removed. The objects carry opposite charges.**



If a charged object touches or is brought near an *insulator* the neutral molecules of the insulator are aligned, as shown here. This is *polarization*.



(a)