Electrostatics

I. Charge and Force
  - Coulomb's Law
  - conservation of charge
  - quantization of charge

II. Electric Fields
  - field strength
  - motion of charged particles
  - field lines
  - distributions of charge

	The student will be able to:	HW:
1	Relate electrical phenomena to the motion and position of the fundamental charge found on electrons and protons and explain process of charging in terms of conduction or induction and relate to properties of conductors and insulators.	1 – 6
2	State and apply Coulomb's Law to solve problems relating force and separation of discrete charges and recognize the coulomb as the SI unit of charge and *e* as the elementary quantum of charge.	7 – 15
3	Define and apply the concept of electric field in terms of force acting on a charge within the field and solve related problems	16 – 19
4	Solve problems involving the motion of a charged particle in a uniform electric field.	20 – 24
5	Determine the electric field produced by a discrete charge or a set of such charges and solve related problems.	25 – 29
6	State and apply the rules for sketching electric fields.	30
7	Determine the electric field produced by a continuous charge distribution and solve related problems.	31 – 42

What is “electricity”?

What is "electricity"?

All electrical phenomena relate to the fundamental quantity of **electric charge**.

"Charge" is a property of matter that governs electromagnetic forces.

Based on observations of the electric force it is clear that there are two *types* of charge, denoted as **positive** and **negative**.

Like charges repel and opposite charges attract.

Type of Charge and Force

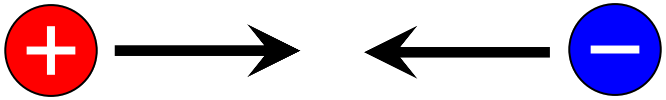
Like charges repel one another:

positive repels positive

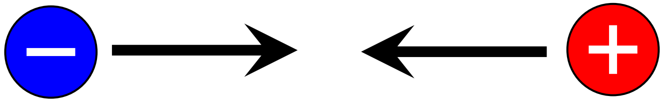
negative repels negative

Opposite charges attract one another:

positive attracts negative



negative attracts positive



“Modern” Explanation of Charge

In ordinary matter, positive charge is found on protons and negative charge is found on electrons. The two particles have equal amounts of charge (but opposite signs).

Often the number of protons equals the number of electrons. This is said to be zero net charge. An object becomes charged (*i.e.* has a *net* charge) if the number of protons is unequal to the number of electrons.

This occurs almost always as a result of electrons being transferred to or from an object.

Conservation of Charge

Charge is conserved! The net amount of charge produced in any process is zero.

This may seem to mean that protons and electrons cannot be created or destroyed, but in fact they can! Nonetheless, the *charge* of these particles is a conserved property.

Insulators and Conductors

Both conductors and insulators can possess charge.

Key difference:

Charge can travel freely through a conductor.

Charge cannot travel freely through an insulator, but rather tends to be "locked" in place.

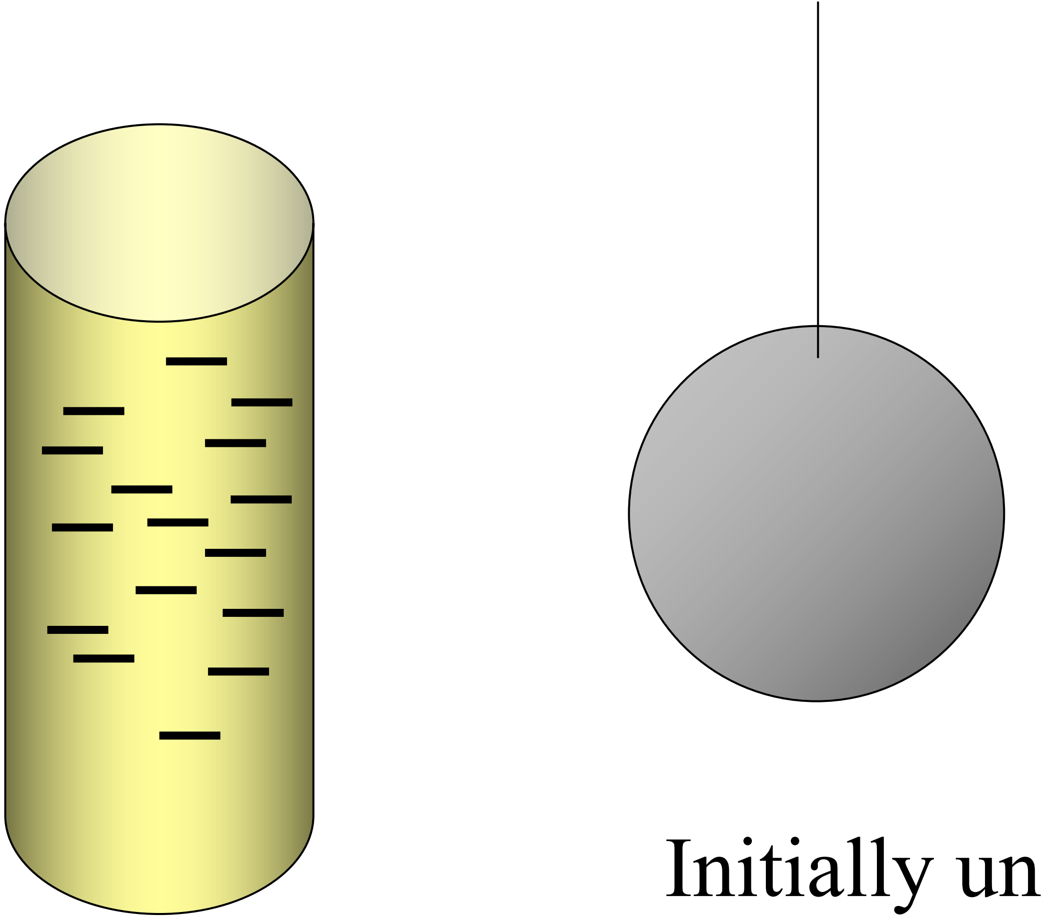
In conductors, (metals) the outermost electrons are not bound tightly to nuclei and are hence "free to roam" through the material. In insulators, electrons are more tightly bound to nuclei and cannot freely move through the material.

Two Means of Charging:

Conduction occurs when charge is literally transferred from one object to another as a result of contact or sparking.

Induction occurs when charge within an object is rearranged due to the proximity of a charged object (or presence of an external electric field).

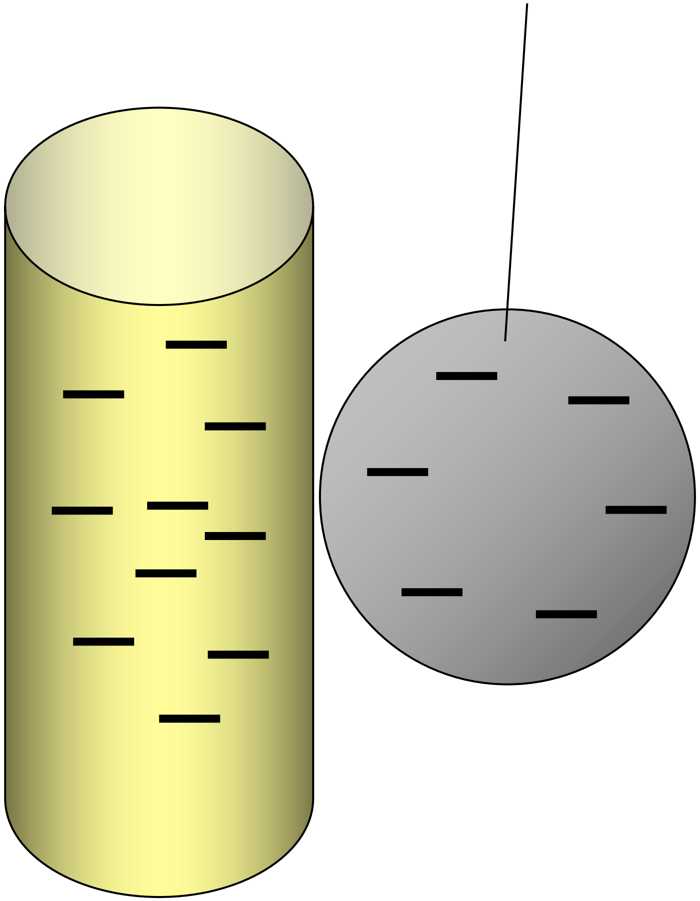
Charge by Conduction



Initially uncharged (neutral) pith ball

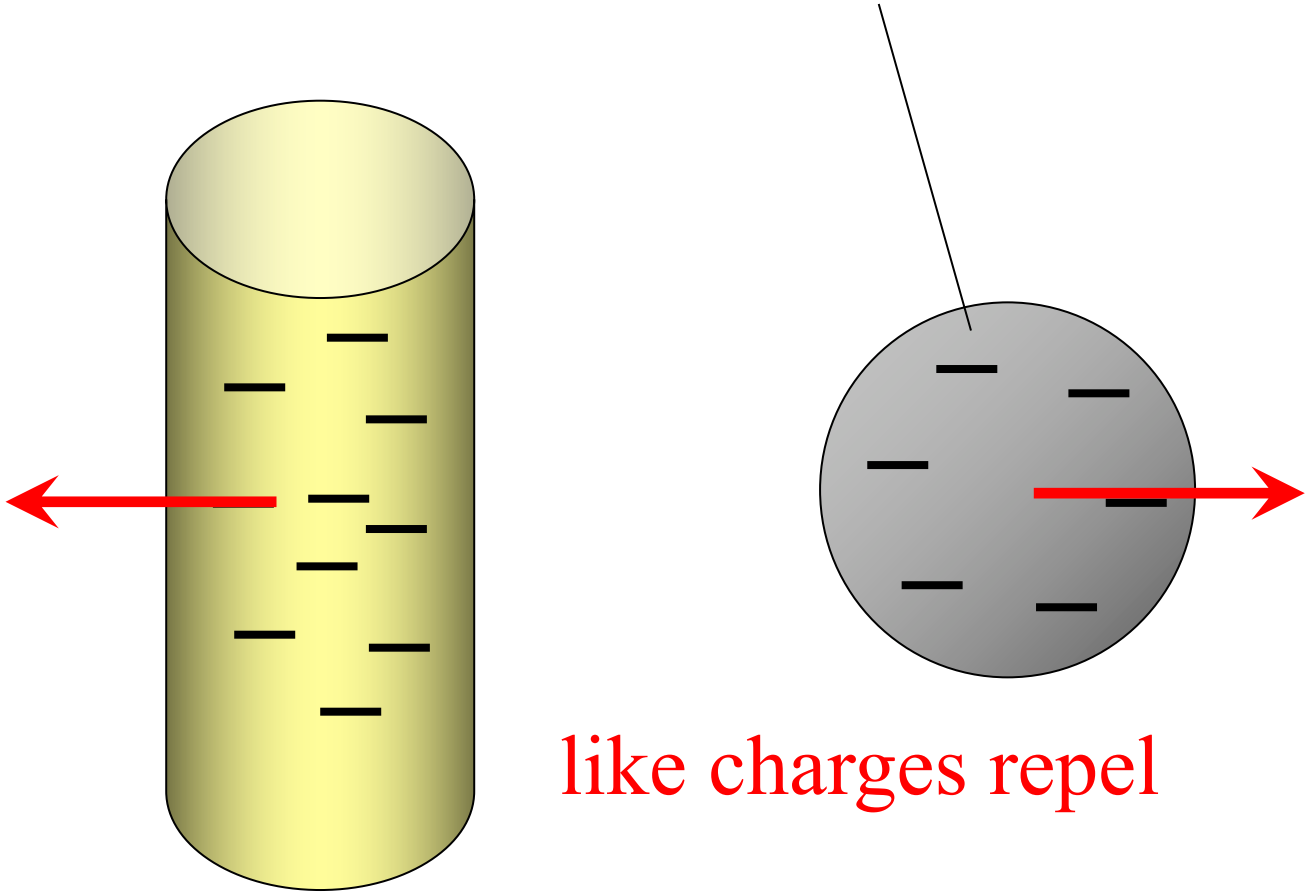
Negatively charged CPVC Pipe

Charge by Conduction



Negative charge is transferred from the pipe to the ball through the point of contact or a spark.

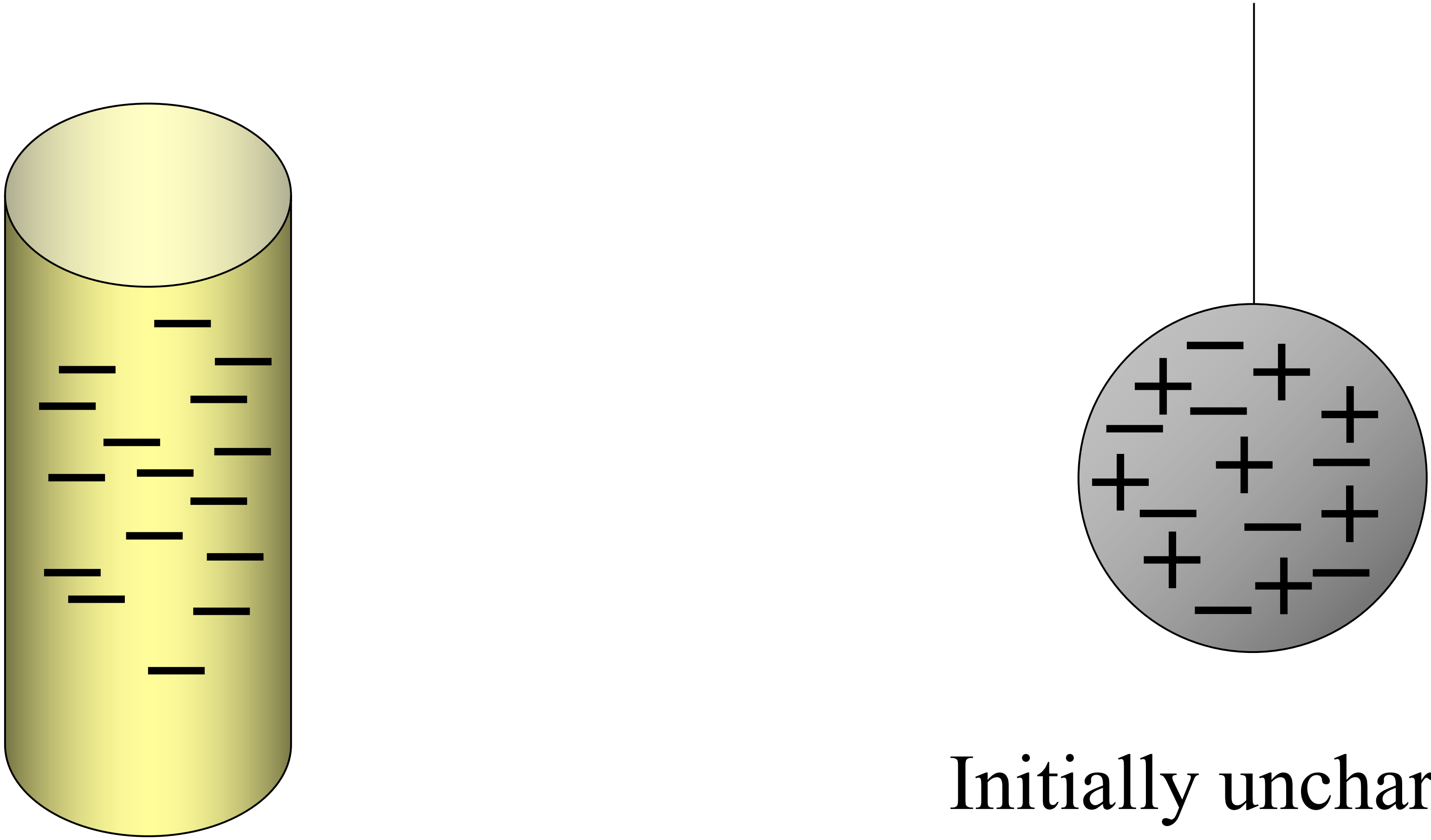
Charge by Conduction



like charges repel

Although the pipe loses some charge it remains negative (and does not become neutral).

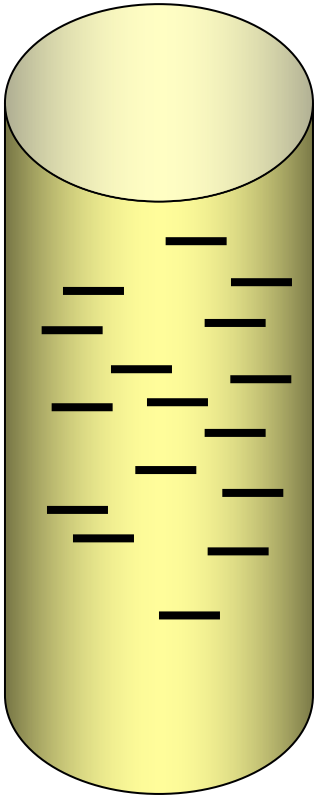
Charge by Induction



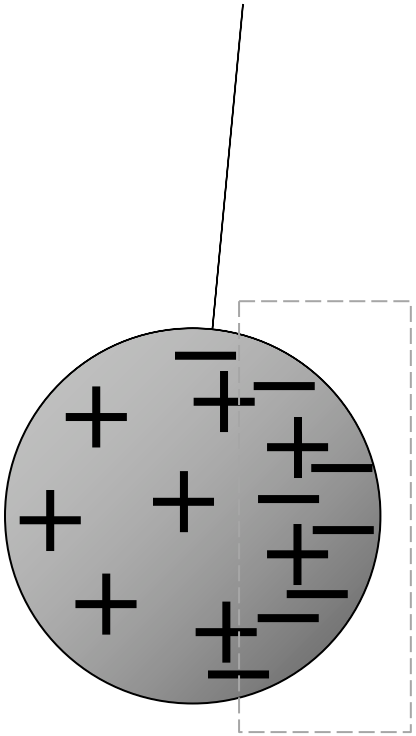
Negatively charged
CPVC Pipe

Initially uncharged
(neutral) pith ball

Charge by Induction

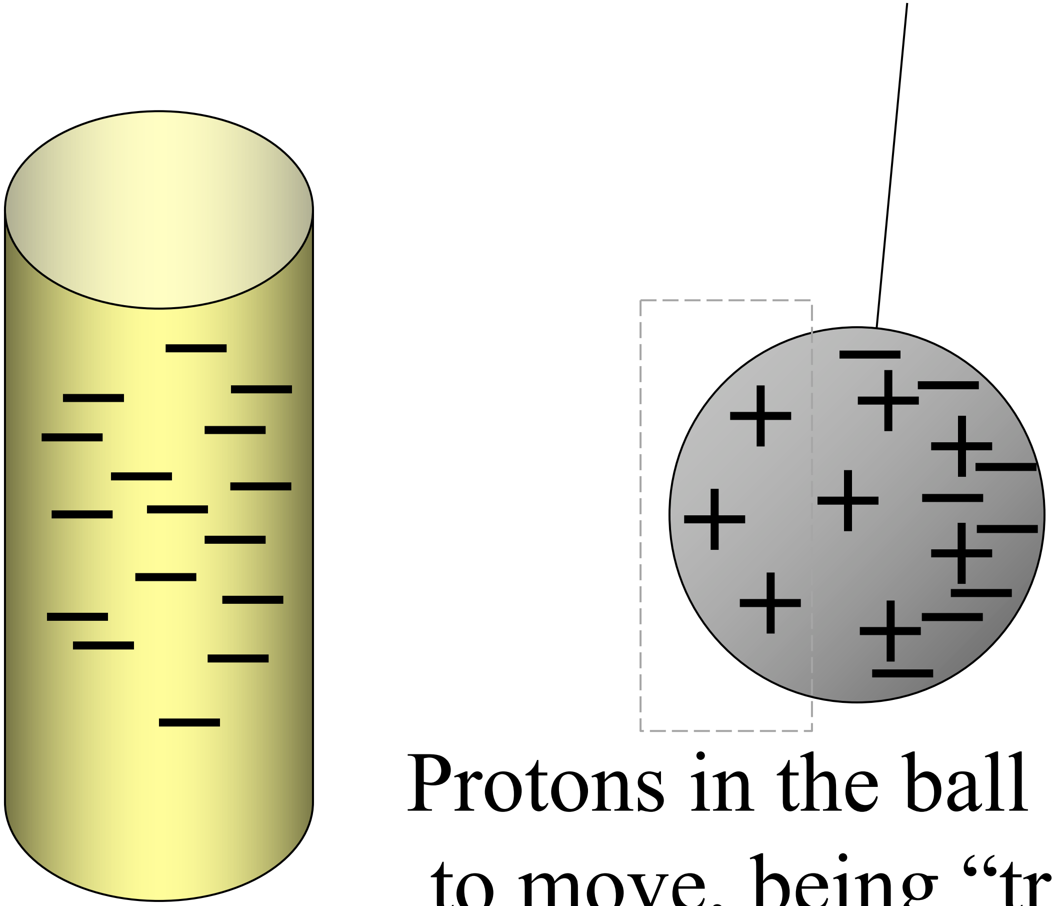


No charge is transferred from pipe to ball.



The ball is still neutral, but electrons have shifted to one side of the ball because of repulsion from the pipe.

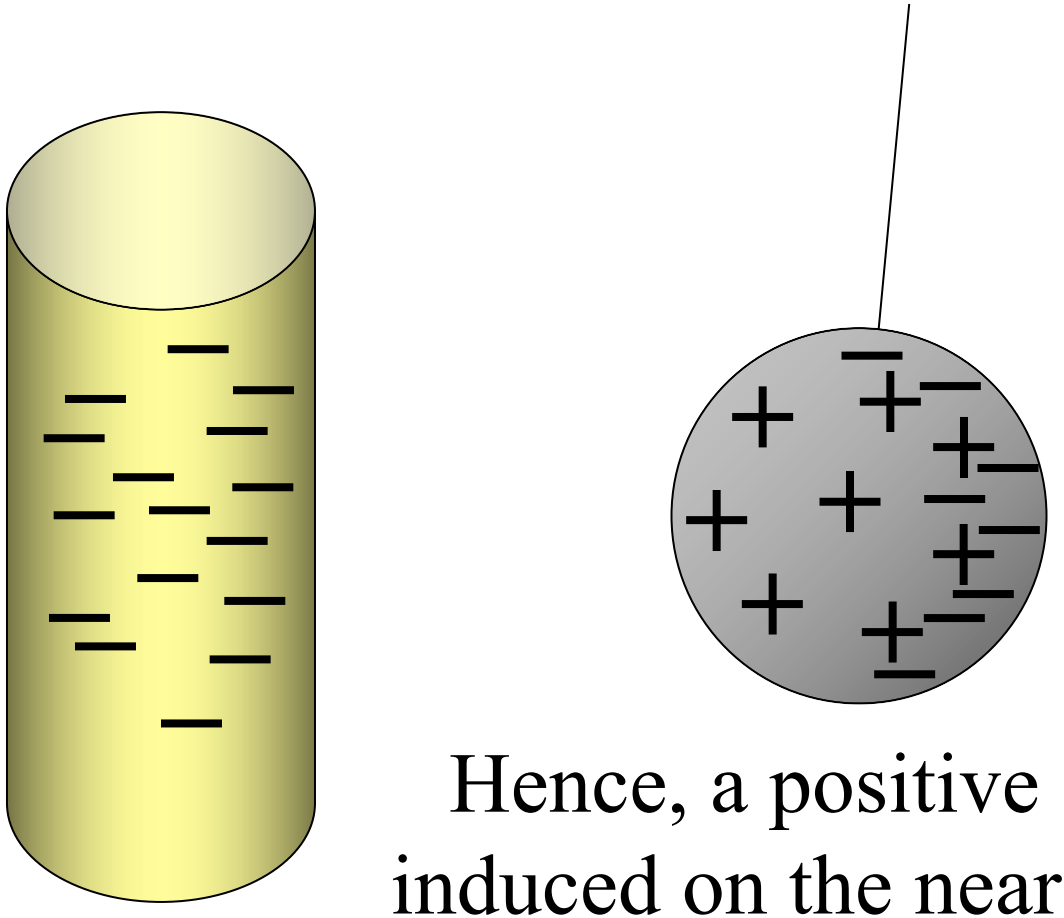
Charge by Induction



No charge is transferred from pipe to ball.

Protons in the ball are unable to move, being "trapped" in the nucleus. This leaves the other side of the ball positive.

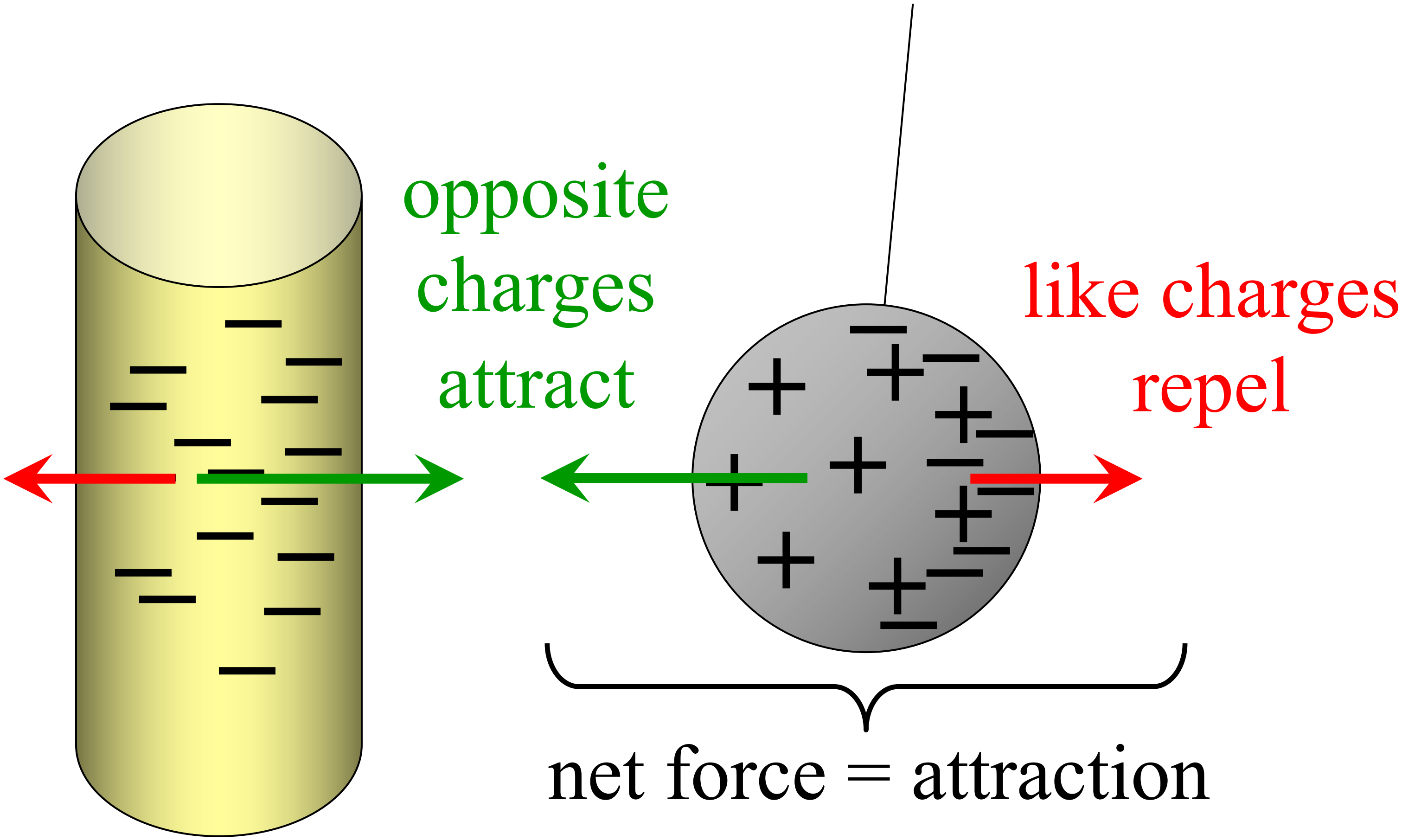
Charge by Induction



No charge is transferred from pipe to ball.

Hence, a positive charge is induced on the near side and a negative charge is induced on the far side of the ball.

Charge by Induction



Because the negative side of the ball is farther from the pipe than the positive side, the attraction is greater.

Electrostatics

I. Charge and Force
  - **Coulomb's Law**
  - conservation of charge
  - **quantization of charge**
  - distributions of charge

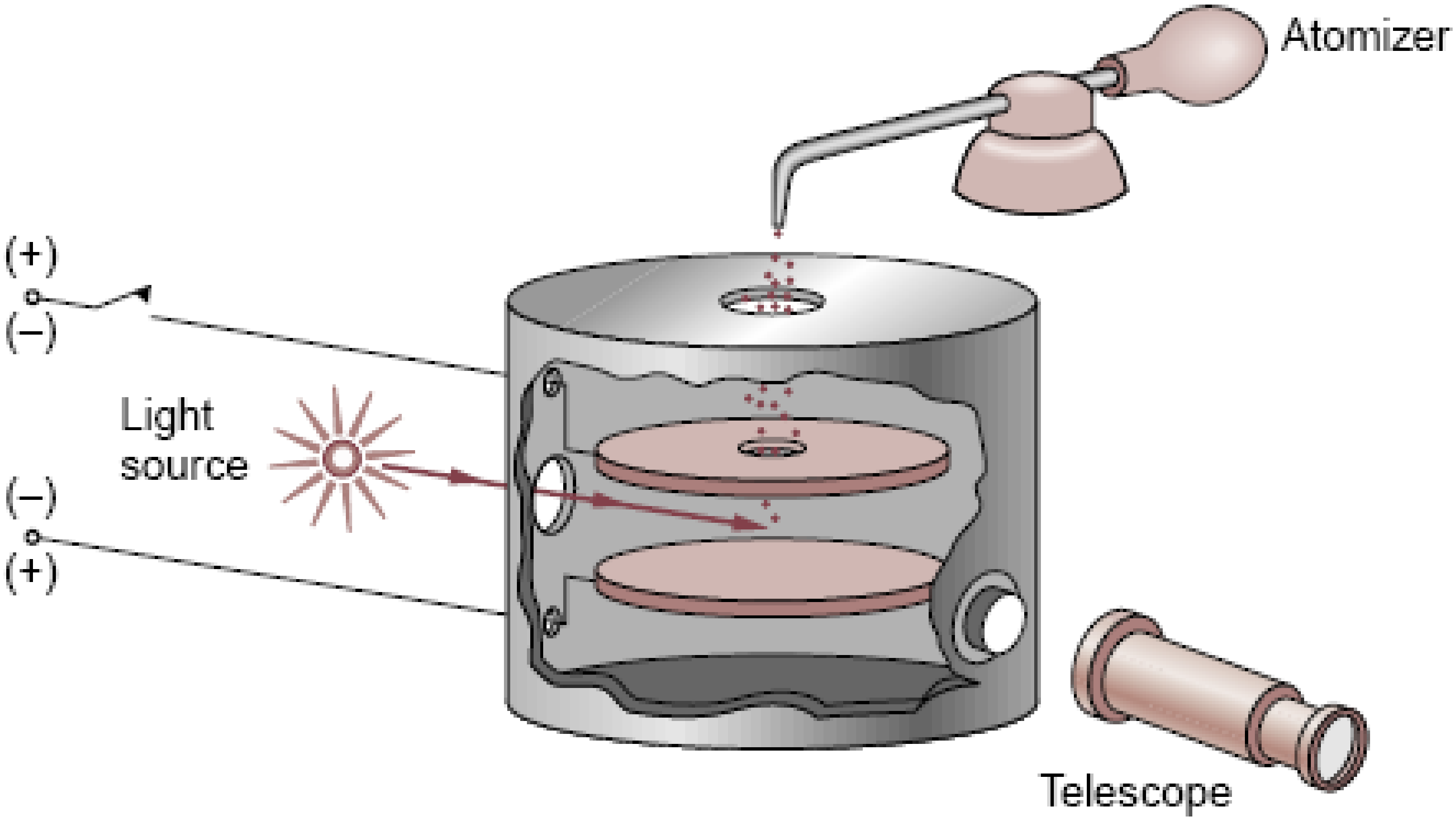
II. Electric Fields
  - field strength
  - motion of charged particles
  - field lines

	The student will be able to:	HW:
1	Relate electrical phenomena to the motion and position of the fundamental charge found on electrons and protons and explain process of charging in terms of conduction or induction and relate to properties of conductors and insulators.	1 – 6 ✓
2	State and apply Coulomb’s Law to solve problems relating force and separation of discrete charges and recognize the coulomb as the SI unit of charge and *e* as the elementary quantum of charge.	7 – 15
3	Define and apply the concept of electric field in terms of force acting on a charge within the field and solve related problems	16 – 19
4	Solve problems involving the motion of a charged particle in a uniform electric field.	20 – 24
5	Determine the electric field produced by a discrete charge or a set of such charges and solve related problems.	25 – 29
6	State and apply the rules for sketching electric fields.	30
7	Determine the electric field produced by a continuous charge distribution and solve related problems.	31 – 42

Quantization of Charge

A Curious Property…

Millikan's Oil Drop Experiment



Millikan’s Oil Drop Experiment

In 1909 Robert Millikan carefully determined the charge on tiny drops of oil and discovered values such as these:

$$q = \pm\ 3.2\ \times\ 10^{-19}\ \mathrm{C}$$
$$q = \pm\ 4.8\ \times\ 10^{-19}\ \mathrm{C}$$
$$q = \pm\ 6.4\ \times\ 10^{-19}\ \mathrm{C}$$
$$q = \pm\ 8.0\ \times\ 10^{-19}\ \mathrm{C}$$

etc.

Millikan's Oil Drop Experiment

$$q = \pm\ 3.2 \times 10^{-19}\ \mathrm{C}$$
$$q = \pm\ 4.8 \times 10^{-19}\ \mathrm{C}$$
$$q = \pm\ 6.4 \times 10^{-19}\ \mathrm{C}$$
$$q = \pm\ 8.0 \times 10^{-19}\ \mathrm{C}$$

etc.

The implication of these results is that charge occurs in *integer multiples* of 1.6×10^{-19} C.

It also implies that 1.6×10^{-19} C is the *smallest possible charge*!

The Elementary Charge

The smallest possible amount of charge is equal to that on an electron or proton. This amount is called the fundamental or elementary charge, *e*.

$$\boxed{e = 1.602 \times 10^{-19}\ \text{C}}$$

an electron's charge: $q = -e = -1.602 \times 10^{-19}$ C

a proton's charge: $q = +e = +1.602 \times 10^{-19}$ C

Quantization of Charge

Any amount of charge greater than e is an integer multiple of e:

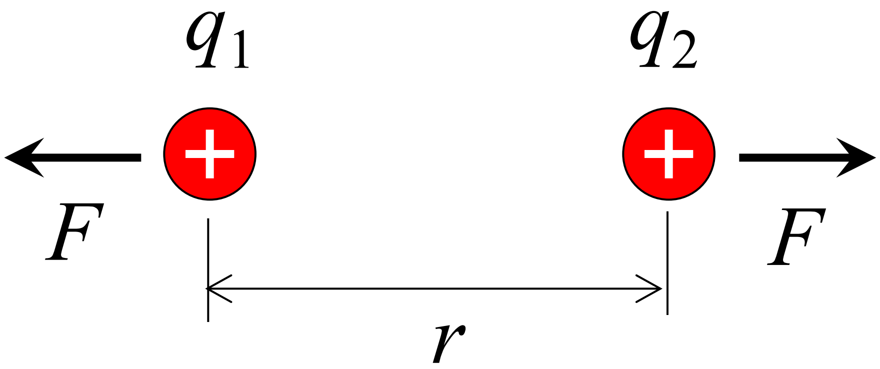
$$q = n \cdot e$$

where: $n = \pm 1, \pm 2, \pm 3,$ etc.

Coulomb's Law

Coulomb's Law describes the force that acts between two charged particles:

$$\left|\vec{F}_E\right| = k\left|\frac{q_1 q_2}{r^2}\right|$$



where: q = amount of charge
r = separation
k = the "electrostatic constant"

Coulomb's Law Alternate Version!

$$\left|\vec{F}_E\right| = \frac{1}{4\pi\varepsilon_0}\left|\frac{q_1 q_2}{r^2}\right|$$

The constant ε_0 is called the
"permittivity of free space" or vacuum permittivity:

$$\varepsilon_0 = 8.85 \times 10^{-12}\ \mathrm{C^2/N\ m^2}$$

$$k = \frac{1}{4\pi\varepsilon_0} \qquad \varepsilon_0 = \frac{1}{4\pi k}$$

Coulomb's Law Details

Charge is measured in SI units of coulombs.

In 2019 the coulomb was redefined such that the elementary charge (on a proton or electron) has magnitude: $e = 1.602176634 \times 10^{-19}$ C
The amount of charge on 6.2415×10^{18} electrons (or protons) is approximately one coulomb.

The constants used in Coulomb's Law:

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

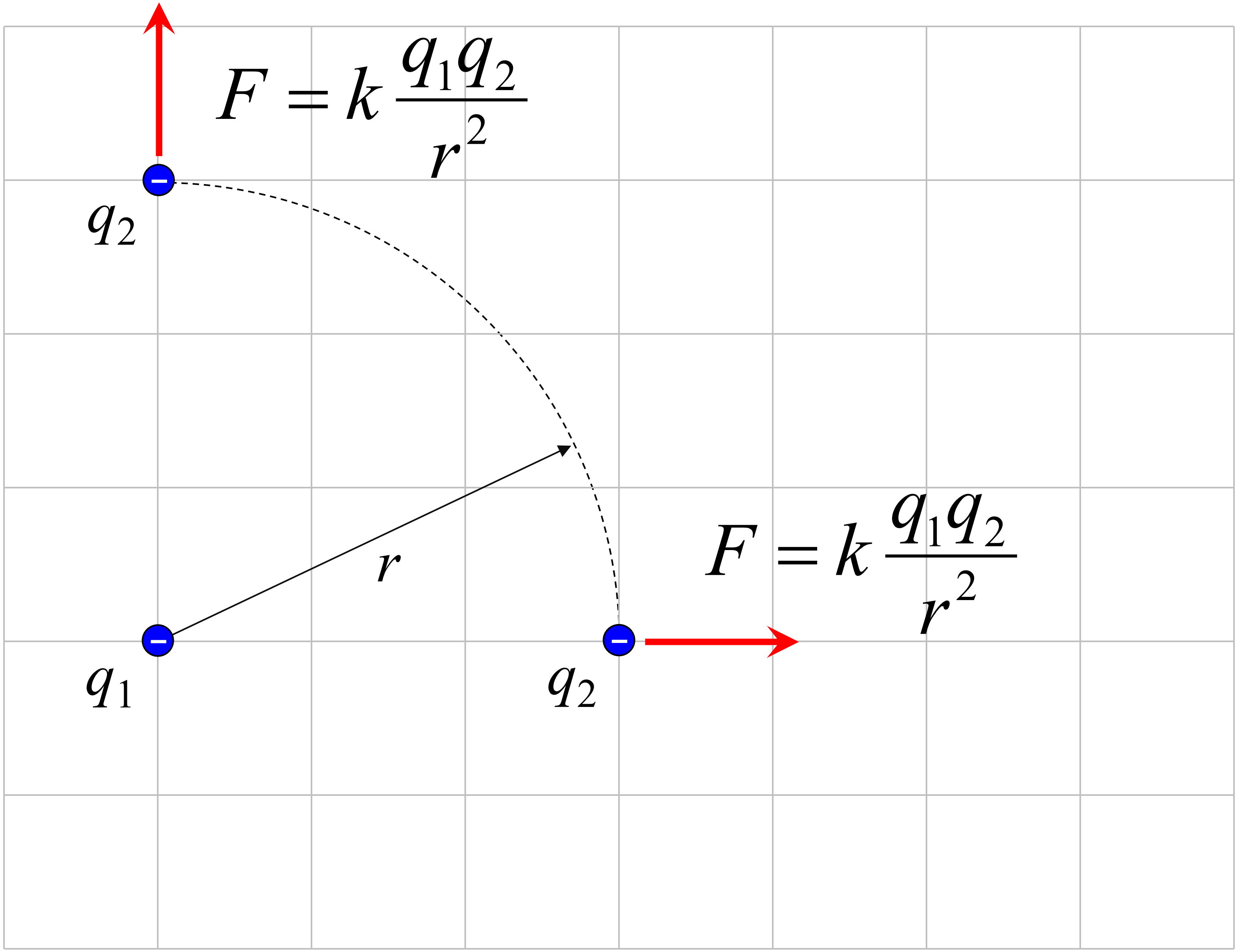
$$\varepsilon_0 = 8.85 \times 10^{-12}\ \mathrm{C^2/N\ m^2}$$

Coulomb's Law *Limitations*

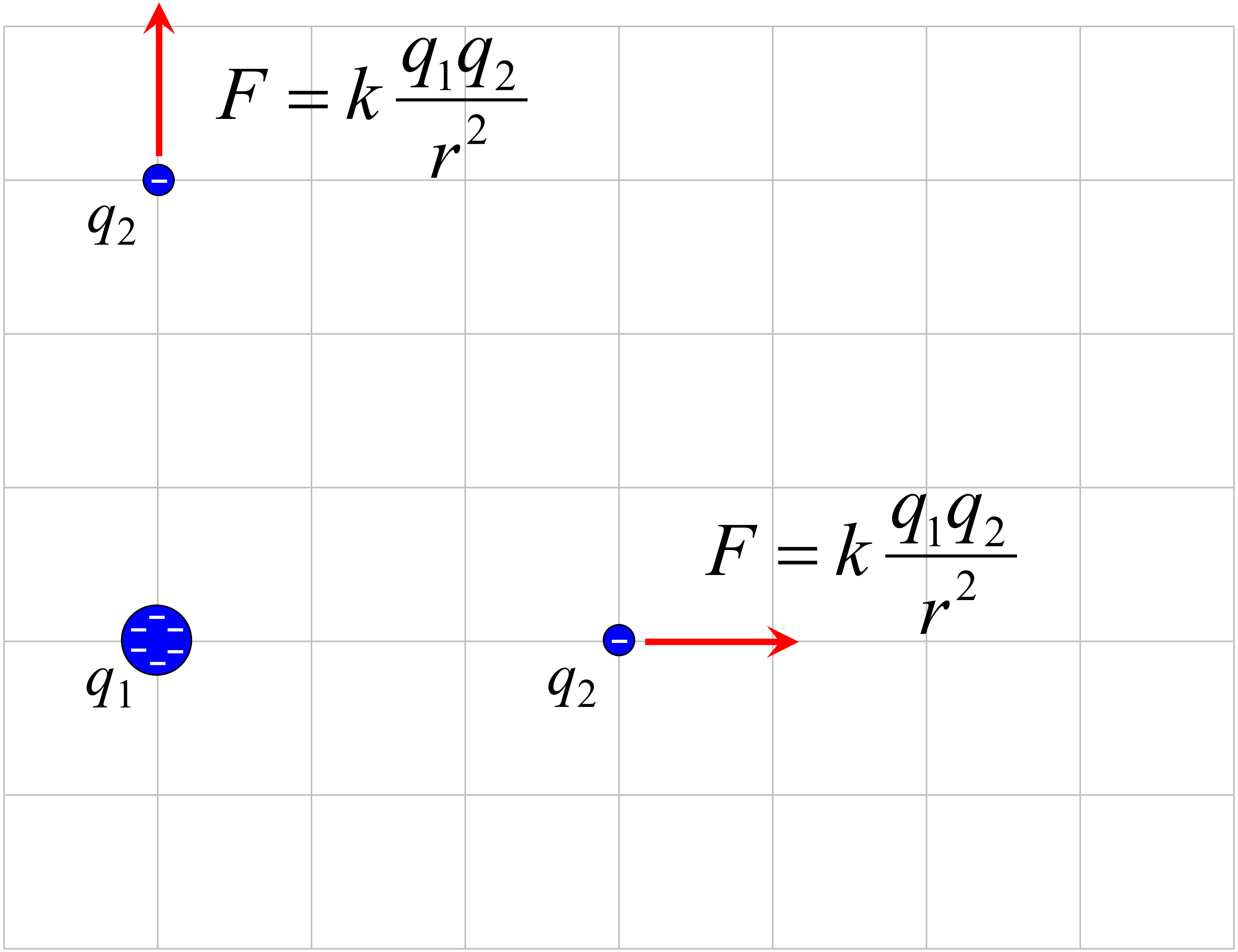
The constants given are technically only true for charge separated by a vacuum (*i.e.* charges in "free space"). However, the presence of air is not a very significant factor and the discrepancy is typically ignored.

Coulomb's Law applies only to "point charges" or "spherically symmetric charges".

The distance, r, is measured from center to center of such charges.

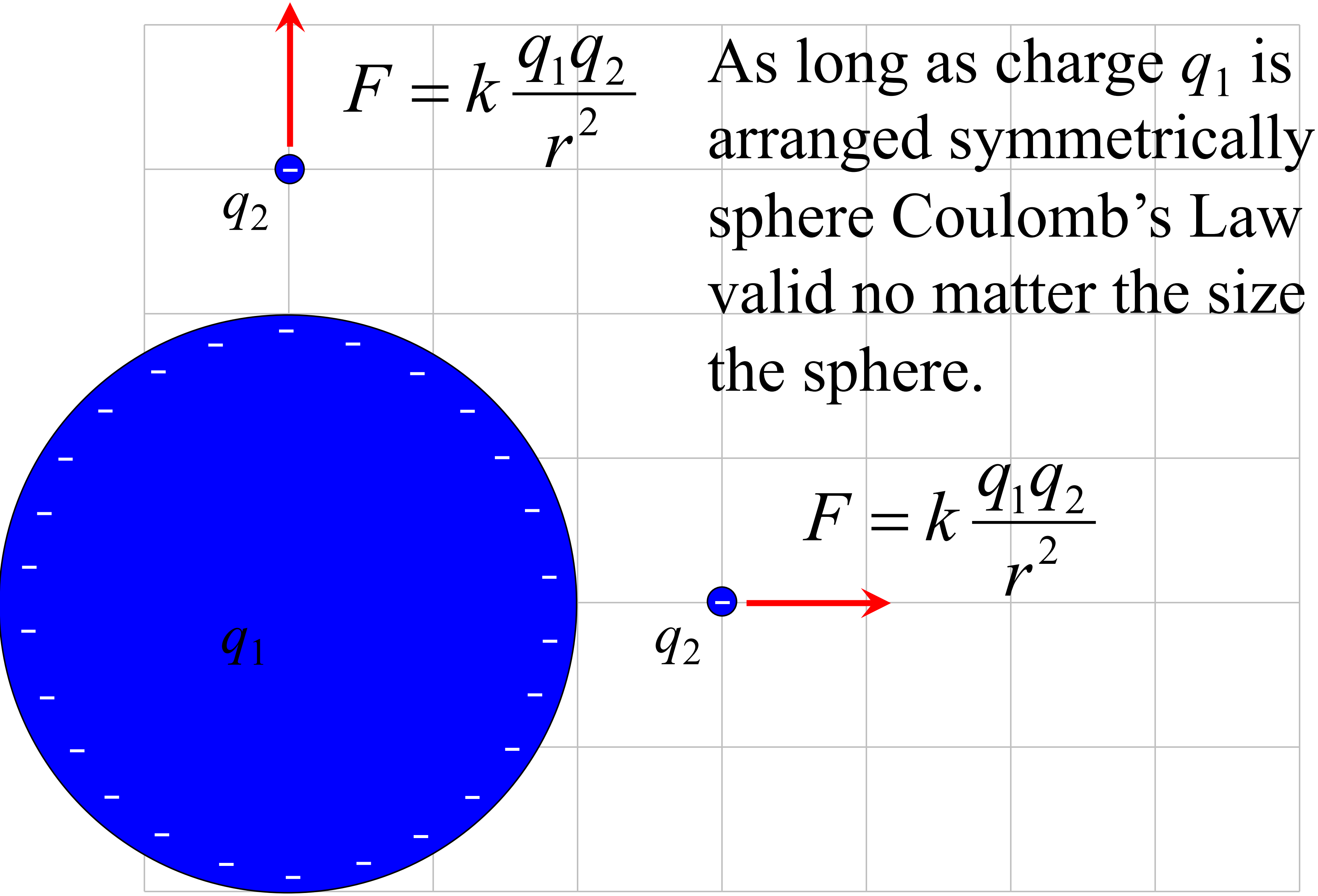


$F = k\frac{q_1 q_2}{r^2}$
q_2
r
$F = k\frac{q_1 q_2}{r^2}$
q_1
q_2



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

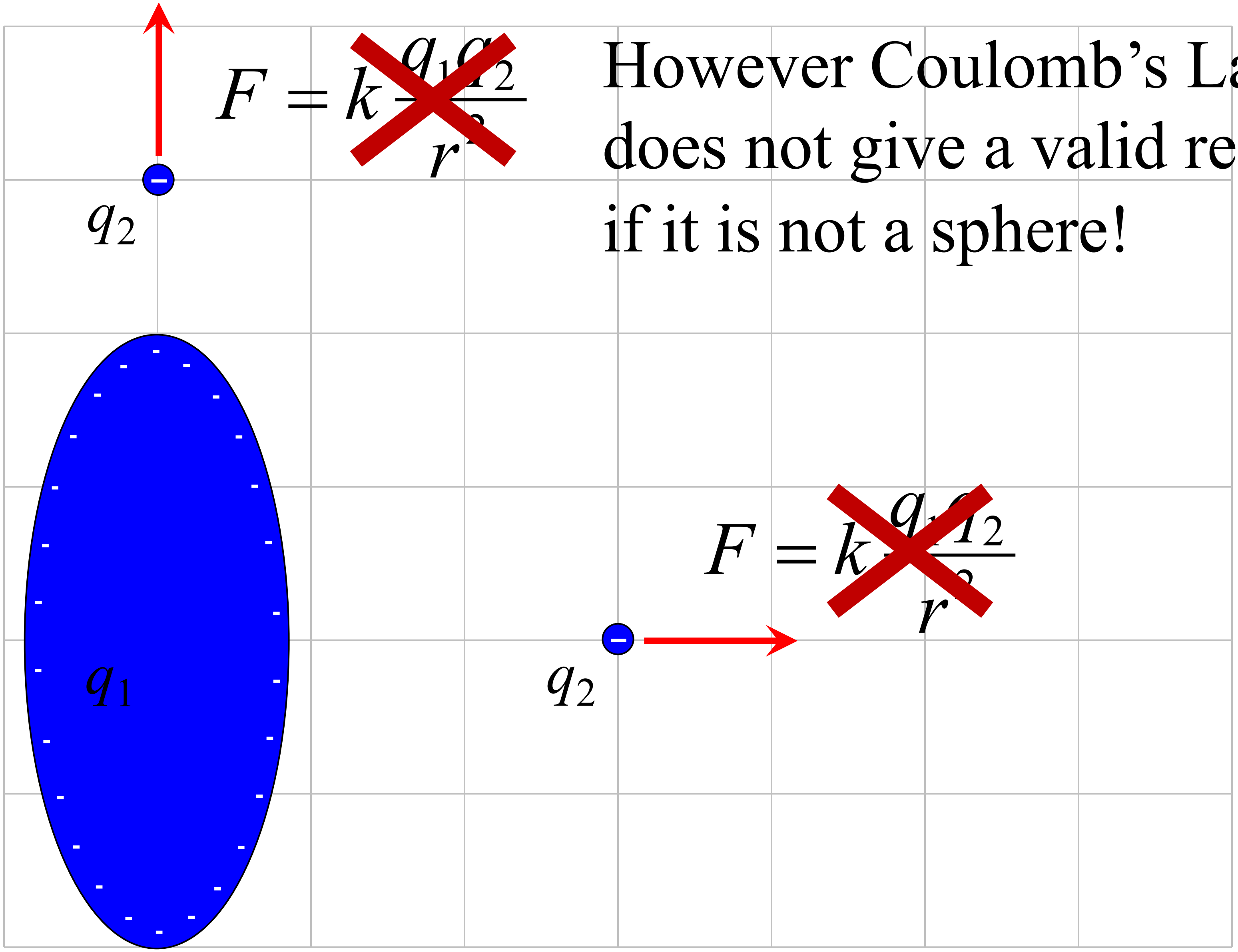
$$F = k\frac{q_1 q_2}{r^2}$$



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

As long as charge q_1 is arranged symmetrically in a sphere Coulomb’s Law is valid no matter the size of the sphere.

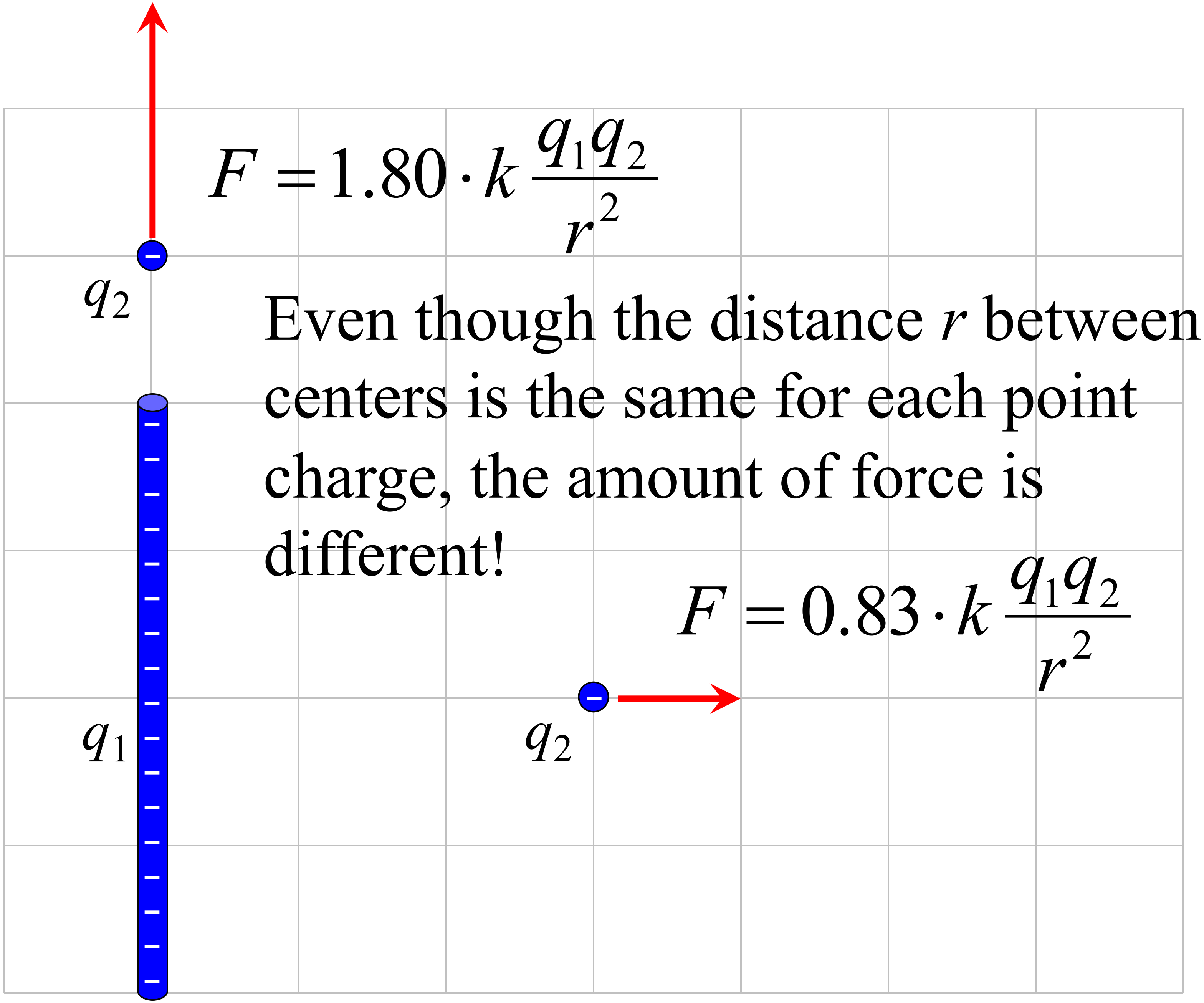
$$F = k\frac{q_1 q_2}{r^2}$$



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

However Coulomb's Law does not give a valid result if it is not a sphere!

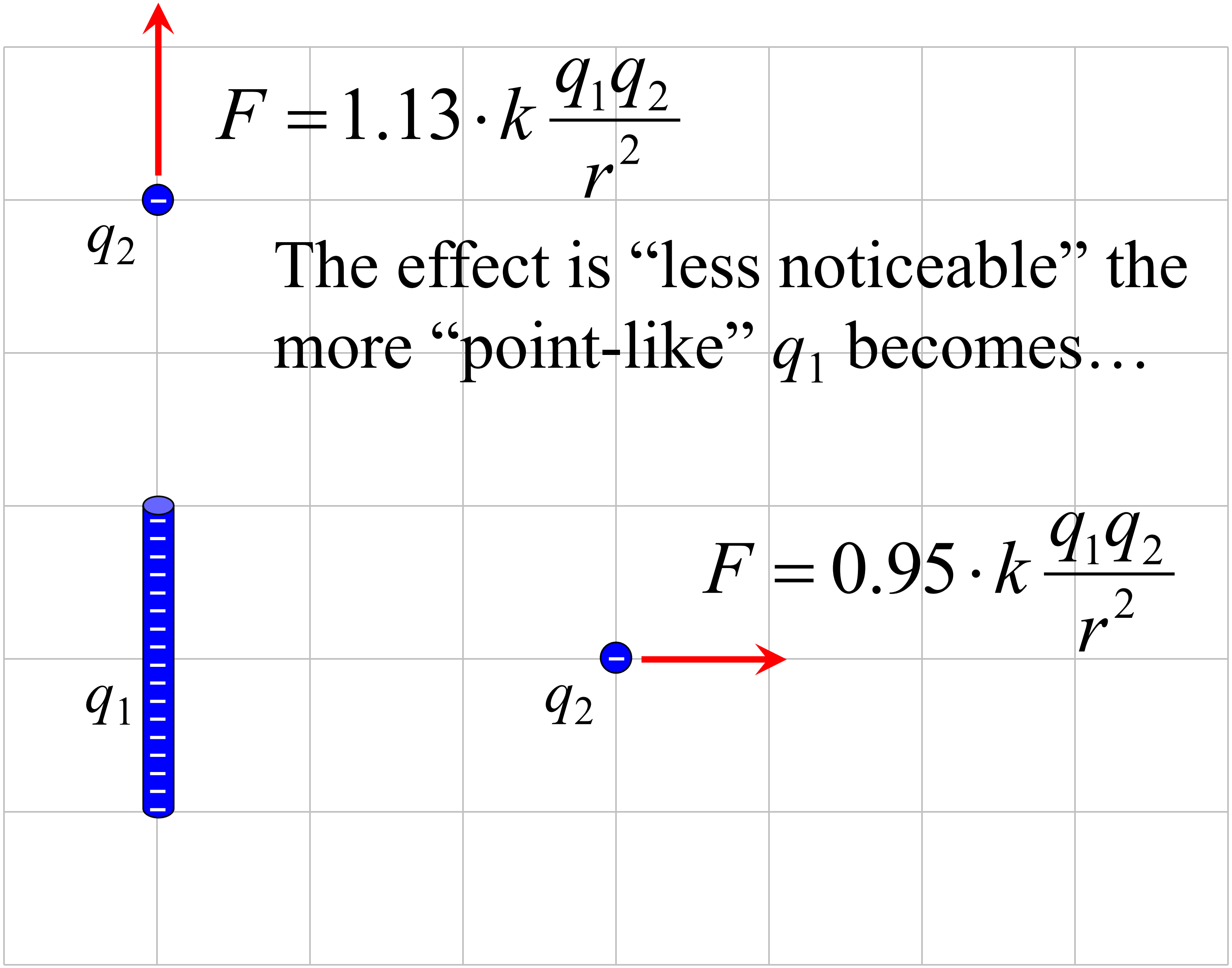
$$F = k\cancel{\frac{q_1 q_2}{r^2}}$$



$$F = 1.80 \cdot k \frac{q_1 q_2}{r^2}$$

Even though the distance r between centers is the same for each point charge, the amount of force is different!

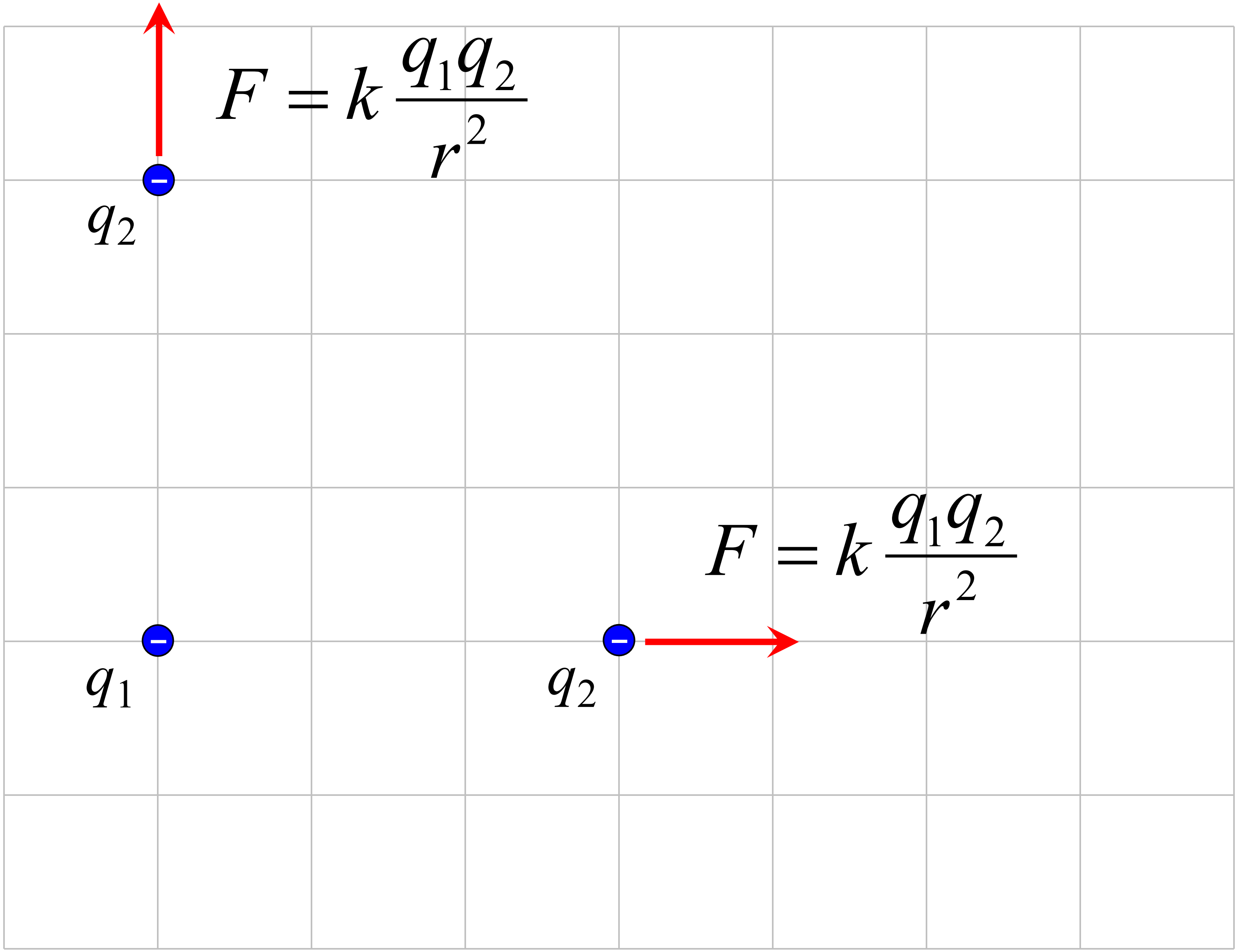
$$F = 0.83 \cdot k \frac{q_1 q_2}{r^2}$$



$$F = 1.13 \cdot k \frac{q_1 q_2}{r^2}$$

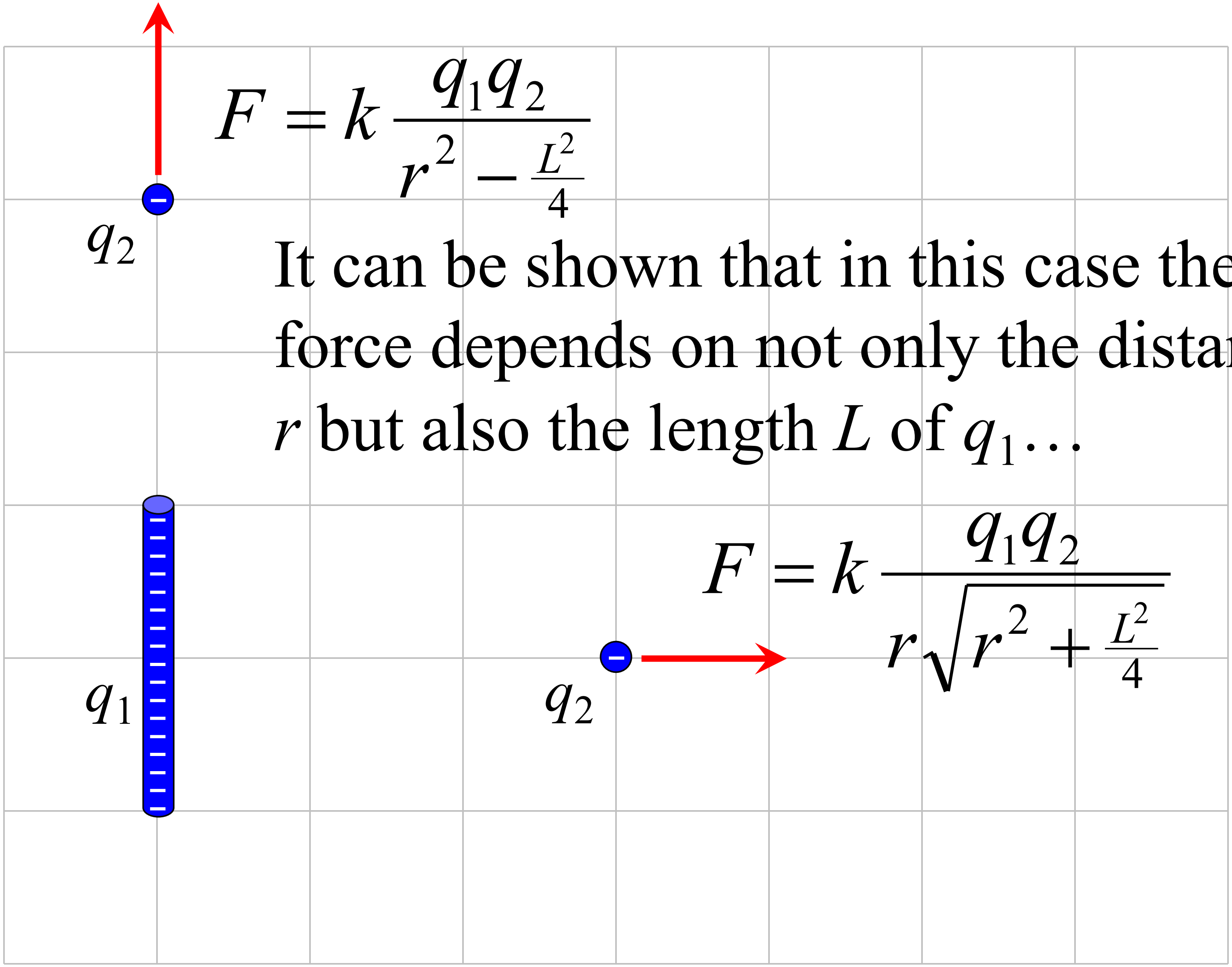
The effect is “less noticeable” the more “point-like” q_1 becomes…

$$F = 0.95 \cdot k \frac{q_1 q_2}{r^2}$$



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

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



$$F = k\frac{q_1 q_2}{r^2 - \frac{L^2}{4}}$$

It can be shown that in this case the force depends on not only the distance r but also the length L of q_1…

$$F = k\frac{q_1 q_2}{r\sqrt{r^2 + \frac{L^2}{4}}}$$