

# Lecture Power Points

## Chapter 16

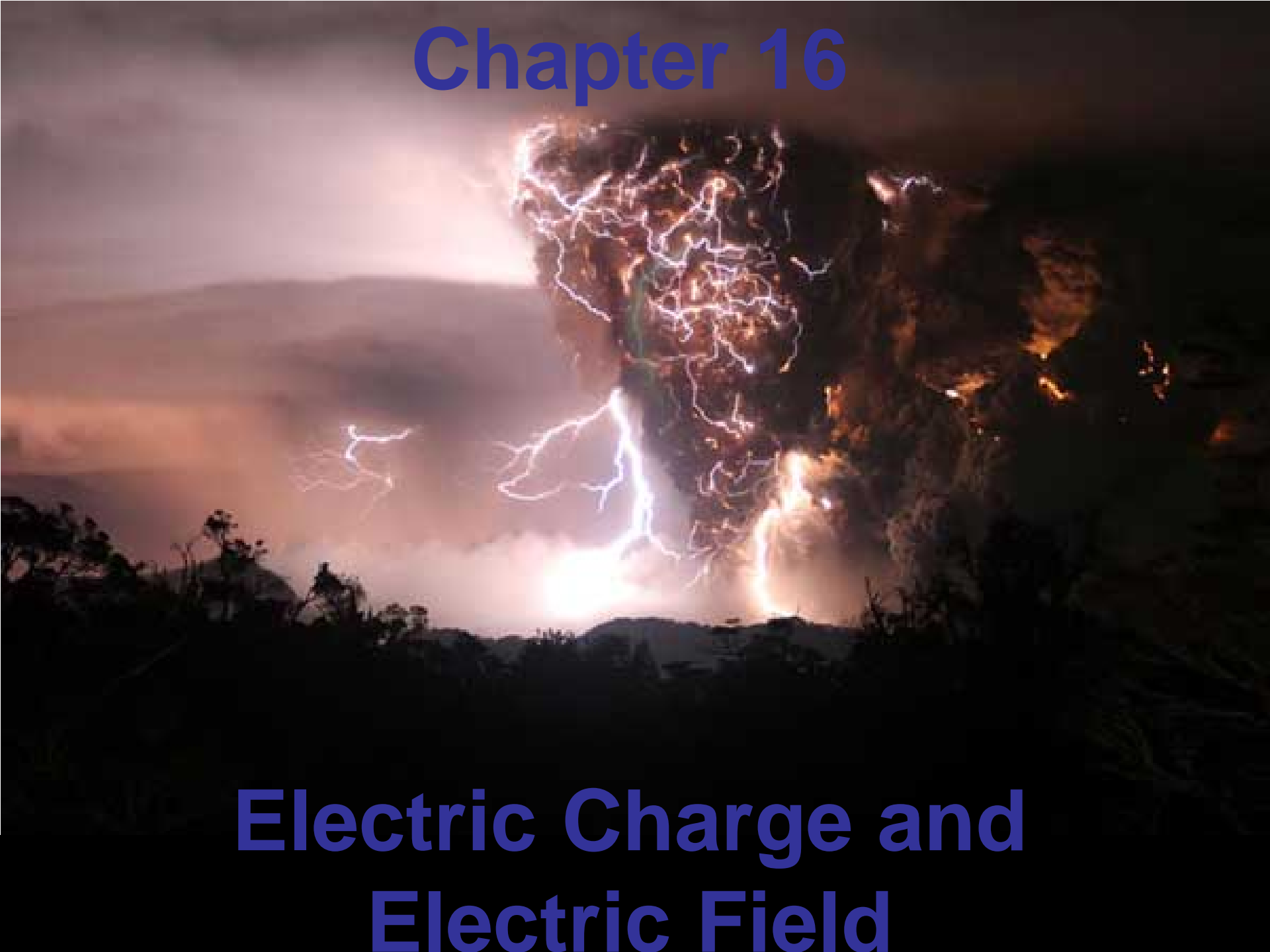
### *Physics: Principles with Applications, 6<sup>th</sup> edition*

Giancoli

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# Chapter 16



## Electric Charge and Electric Field

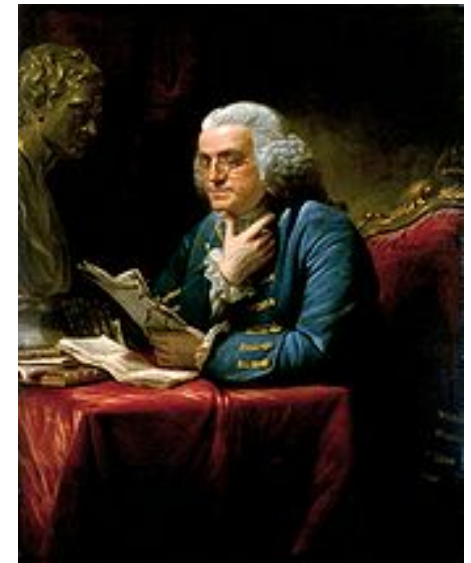
## Electricity & Magnetism - Chapters 16-21

### Key learning points for E&M Course Section

1. What is Electricity?
2. What is a Magnet?
3. And what do they have to do with each other?
4. What does Light have to do with E&M ?
5. Role in the fundamental workings of nature?
6. How are E&M manipulated to empower humanity?
7. Historical background on how we know these things.

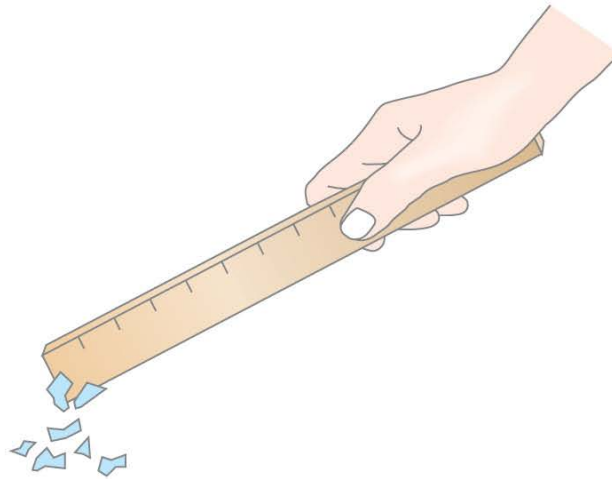
# Electricity and Charge

- **Static Electricity and the nature of Electric Charge**
- **Electric Charge in the Atom**
- **Insulators and Conductors**
- **Coulomb's Law**
- **The Electric Field**
- **Gauss's Law**



# 16.1 Static Electricity and Electric Charge

Objects can be charged by rubbing

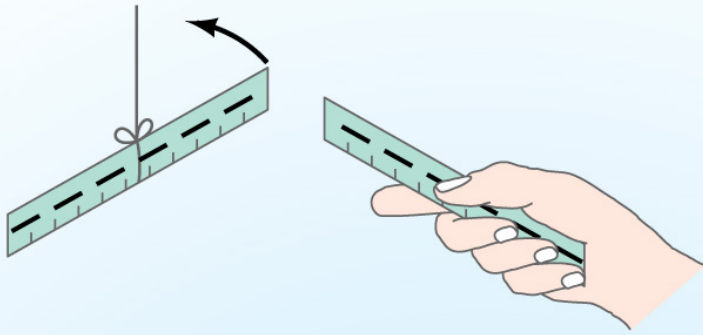


# Electric Charges: Positive and Negative

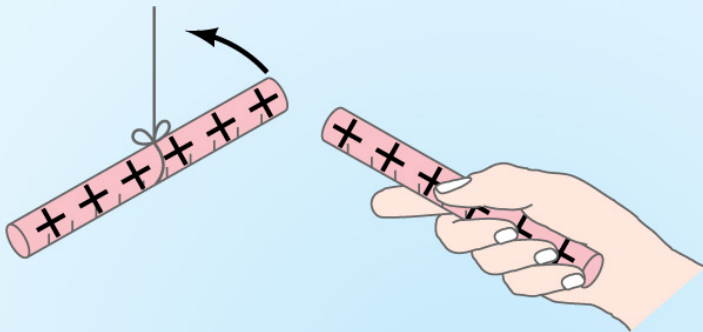
**Charge comes in two types, like charges repel and opposite charges attract**

Benjamin Franklin coined the terms **Positive and Negative**, in line with his theory that there is single “electrical fluid”, that flows in response to some kind of pressure, from positive to negative.

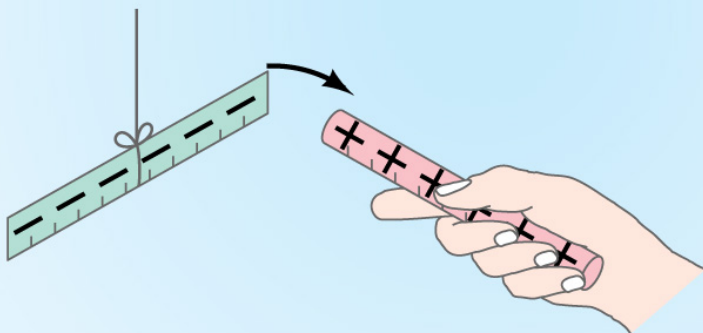
Franklin’s terms were arbitrary, and in fact electricity (electrons) flow in the opposite direction to his “guess”.



(a) Two charged plastic rulers repel



(b) Two charged glass rods repel



(c) Charged glass rod attracts charged plastic ruler

# Conservation of Electric Charge

**Electric charge is conserved – the arithmetic sum of the total charge cannot change in any interaction.**

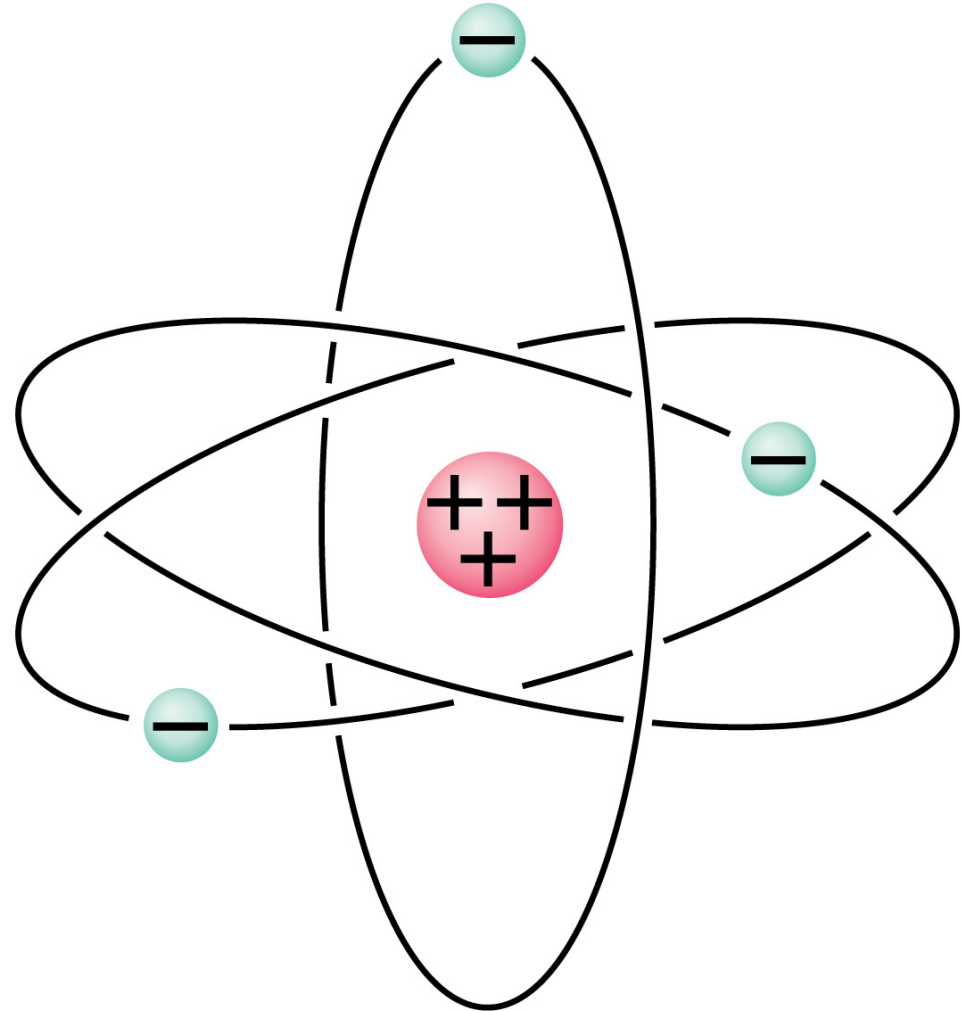
**What other Conservation Laws are there?**

# The Electric Force Originates with subatomic particles - an explanation for the conservation of charges

**Atom:**

**Nucleus (small, massive, positive charge)**

**Electron cloud (large, very low density, negative charge)**



# Electric Charge and its Origin

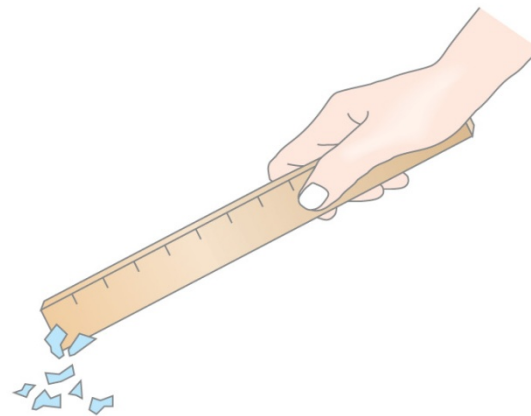
Atom is electrically neutral.

But in some elements the outer electrons are only loosely bound to the nucleus, and can be easily dislodged.

Rubbing charges objects by moving electrons from one to the other.



(a)



(b)

# 16.3 Insulators and Conductors

**Conductor:**

**Charge flows freely**

**Metals**

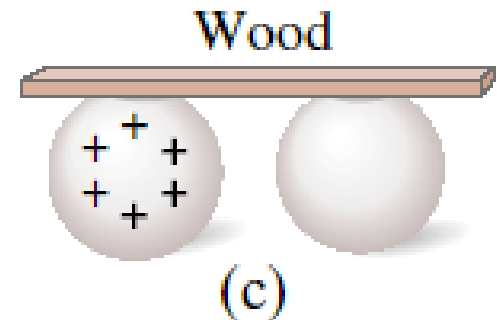
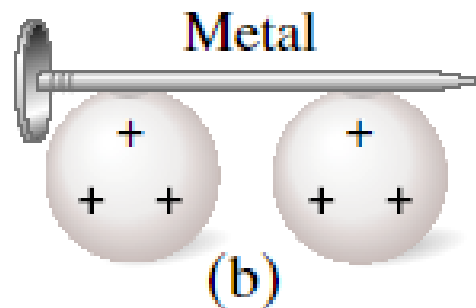
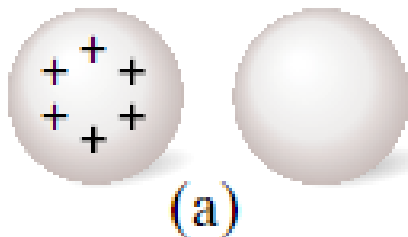
**Insulator:**

**Almost no charge flows**

**Most other materials**

**Some materials are semiconductors.**

**Charged    Neutral**



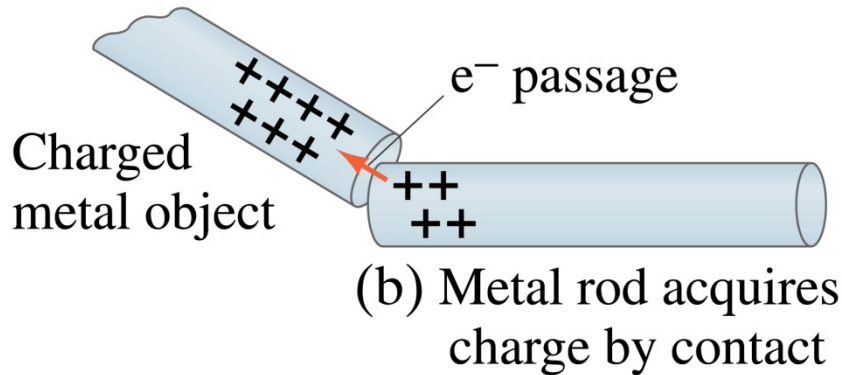
# 16.4 Induced Charge

Metal objects can be charged by

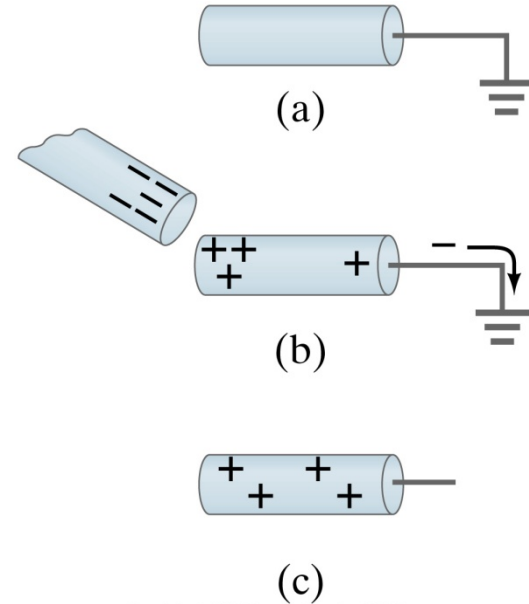
**conduction**

**or**

**induction:**



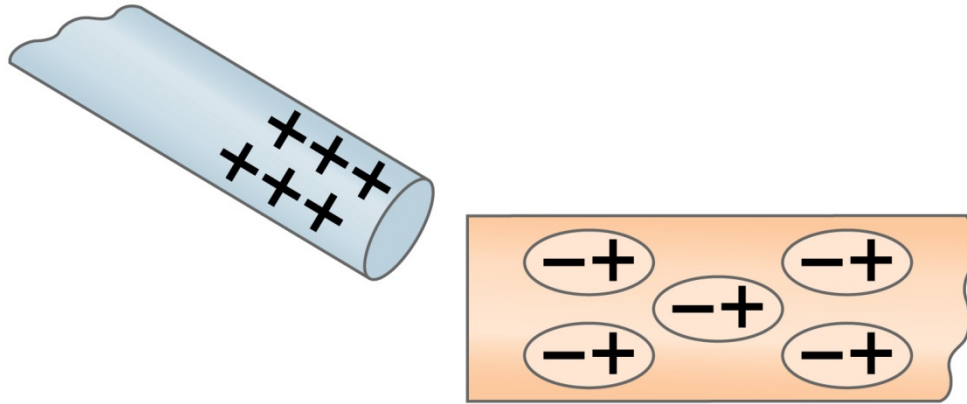
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# Induced Charge and non-conductors

Nonconductors won't become charged by conduction or induction, but will experience charge separation:



Nonconductor

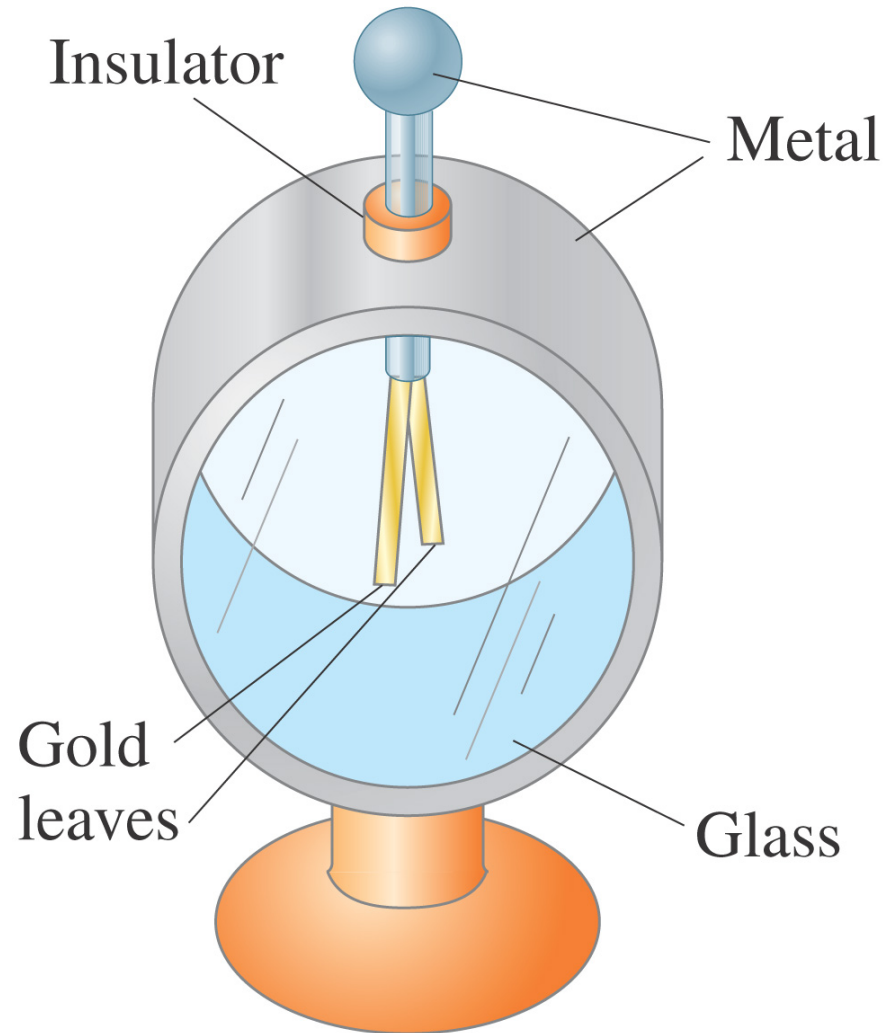
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This is why dust sticks to your furniture, screen, glasses etc.

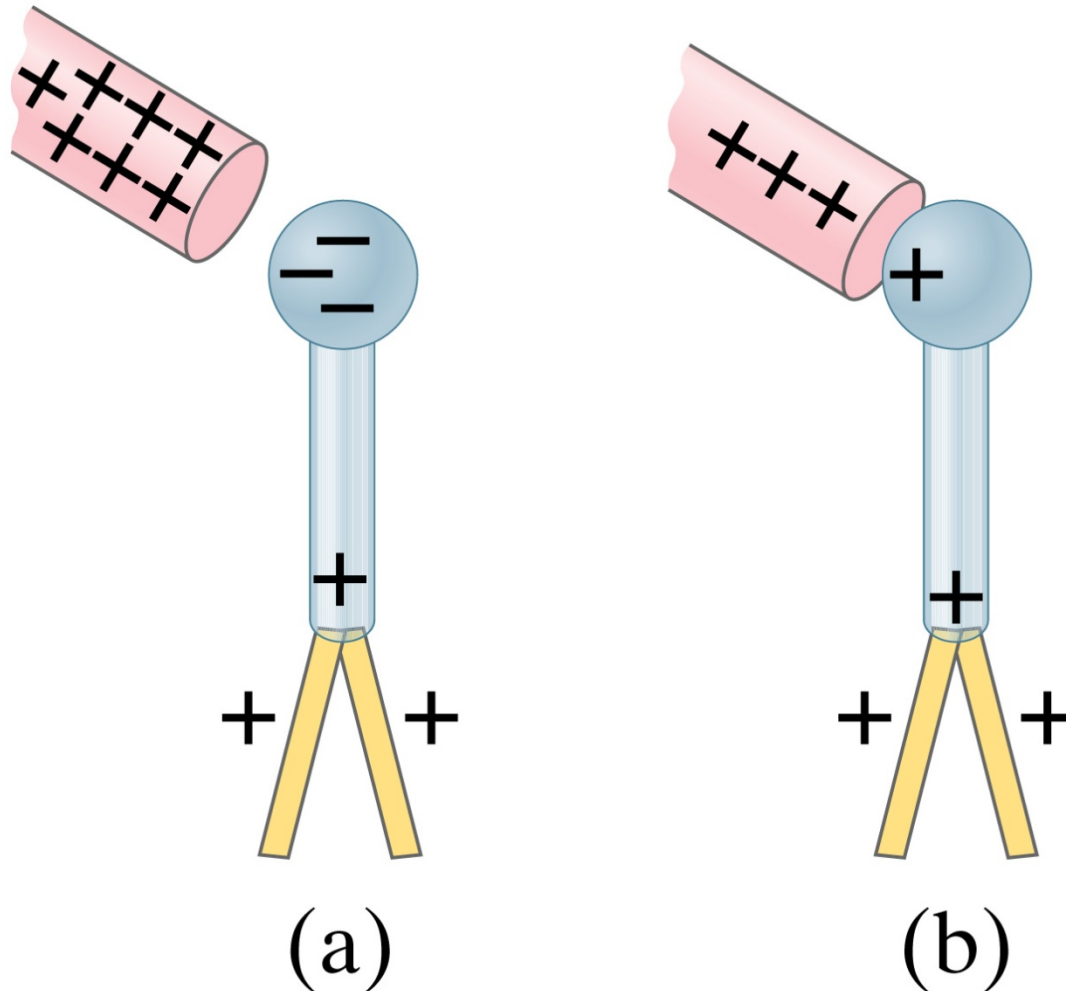
Note how the insulator becomes POLARIZED, while a conductor does not.

# The Electroscope

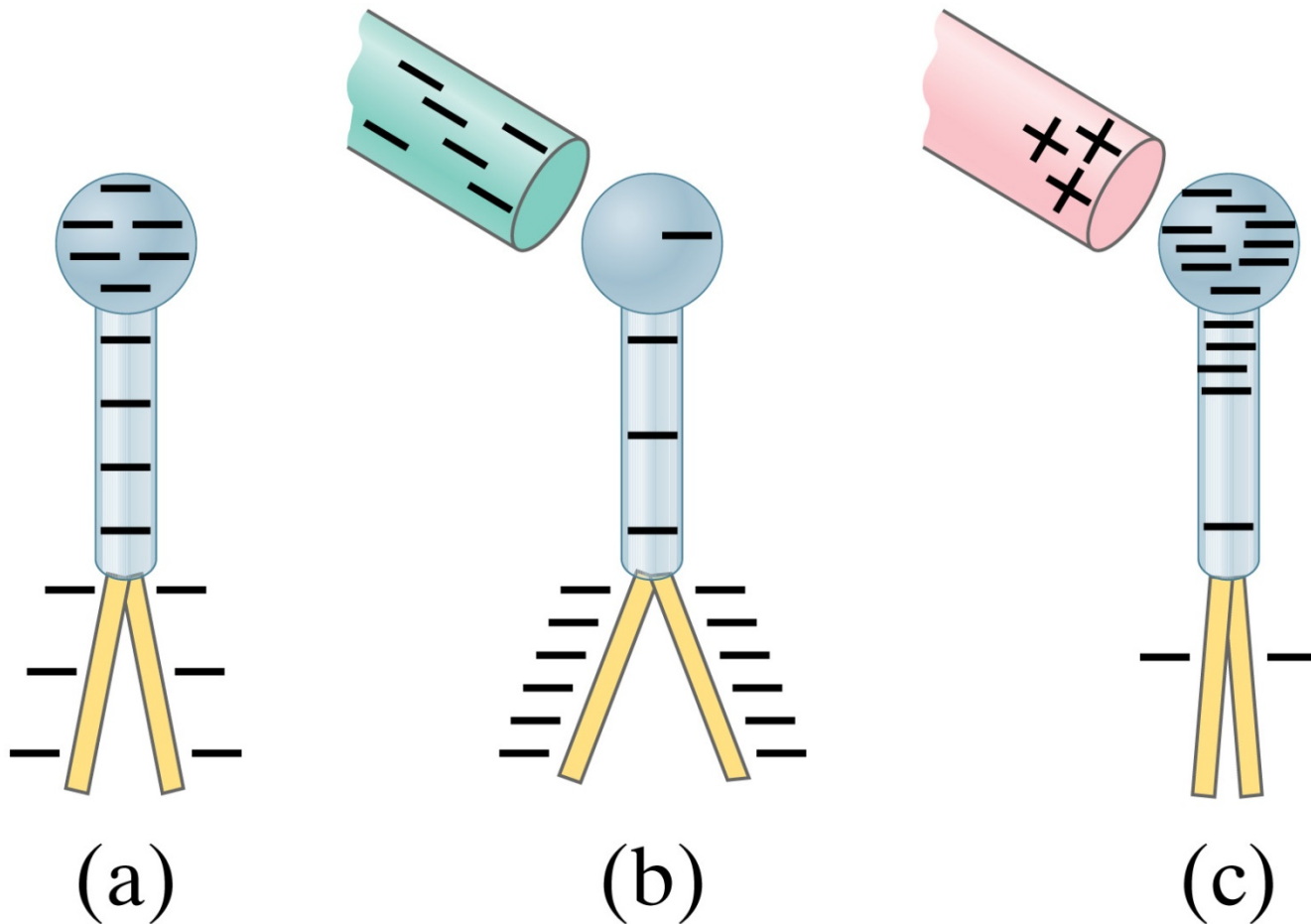
The electroscope can be used for detecting charge:



An electroscope can be charged either by conduction or by induction.



The charged electroscope can then be used to determine the sign of an unknown charge.



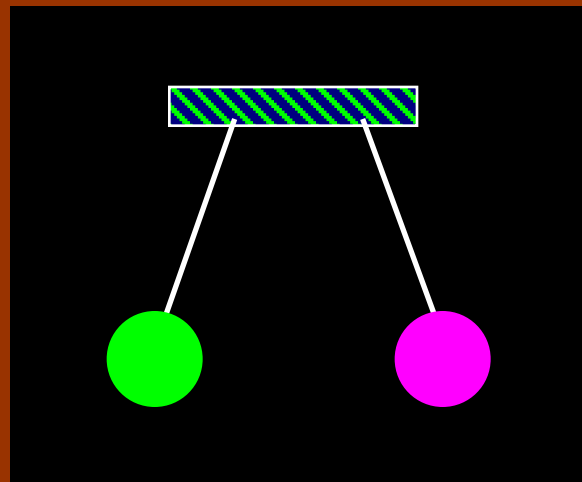
## Another Sort of Electroscope.....



## **ConceptTest 16.1a Electric Charge I**

Two charged balls are repelling each other as they hang from the ceiling. What can you say about their charges?

- 1) one is positive, the other is negative
- 2) both are positive
- 3) both are negative
- 4) both are positive or both are negative

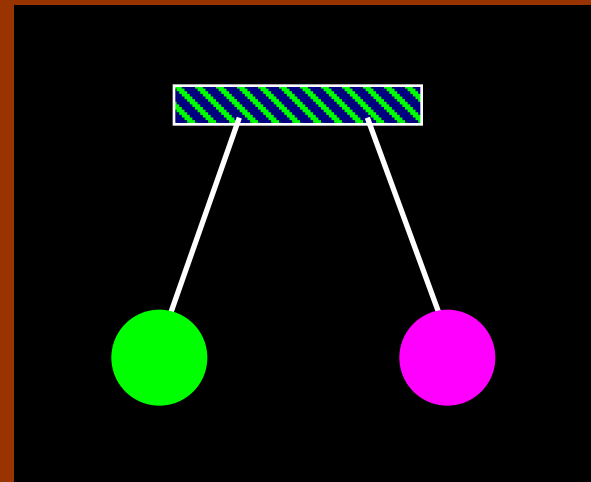


## ConceptTest 16.1a Electric Charge I

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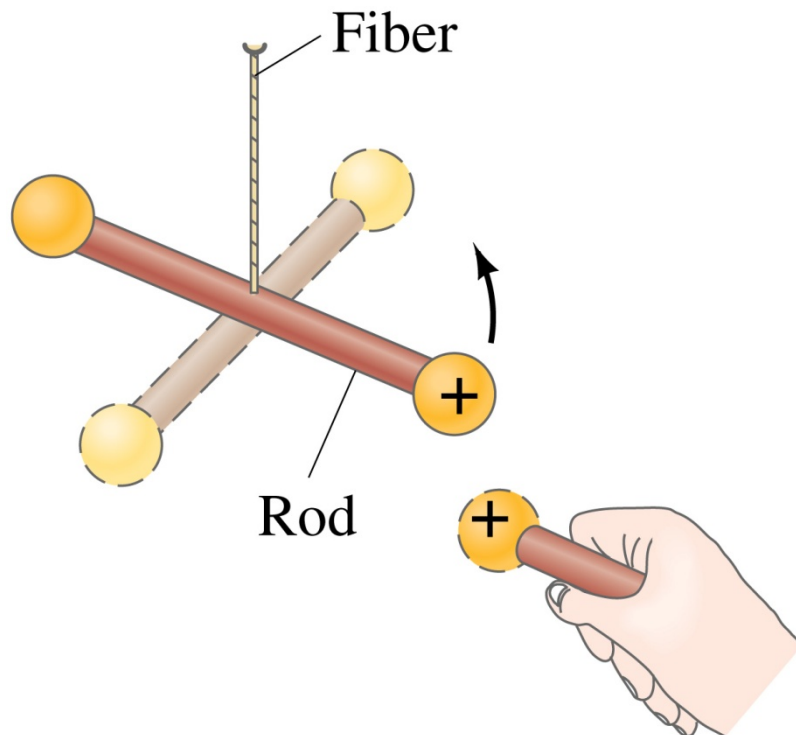
The fact that the balls repel each other only can tell you that they have the **same charge**, but you do not know the sign. So they can be either both positive or both negative.



**Follow-up:** What does the picture look like if the two balls are oppositely charged? What about if both balls are neutral?

# 16.5 Electric Forces: Coulomb's Law

Experiment shows that the electric force between two charges is proportional to the product of the charges and inversely proportional to the distance between them.



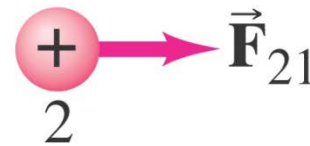
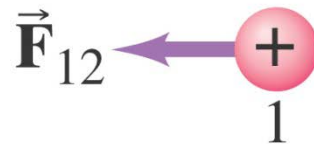
$$F = k \frac{Q_1 Q_2}{r^2}$$

Compare this with the law of Gravitation  $F = \frac{GM_1M_2}{r^2}$

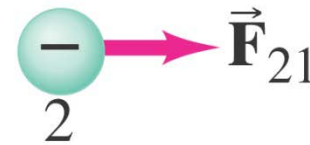
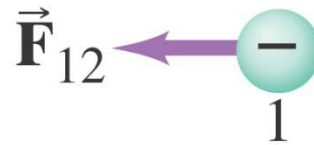
# Like Charges Repel, Opposites Attract: They also Obey Newton's 3rd Law....

$F_{12}$  = force on 1  
due to 2

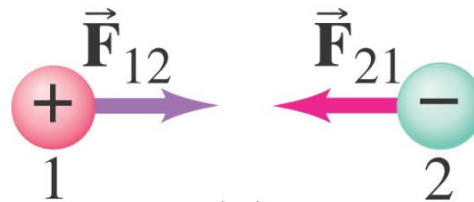
$F_{21}$  = force on 2  
due to 1



(a)



(b)



(c)

**The forces act along the line connecting the charges, and are equal and opposite**

# Coulomb's Law and the Strength of the Electric Force

$$F = k \frac{Q_1 Q_2}{r^2}$$

Unit of charge: coulomb, C

The proportionality constant in Coulomb's law is:

$$k = 8.988 \times 10^9 \text{ N} \cdot \text{m}^2 / \text{C}^2$$

Charges produced by rubbing are typically around a microcoulomb:

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

One Coulomb may seem huge, but is only the amount of charge passing through a household lightbulb in about one second.

## Coulomb's Law in another form:

The proportionality constant  $k$  can also be written in terms of  $\epsilon_0$ , the permittivity of free space:

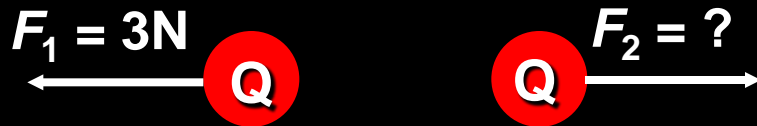
$$F = \frac{1}{4\pi\epsilon_0} \frac{Q_1 Q_2}{r^2}$$

$$\epsilon_0 = \frac{1}{4\pi k} = 8.85 \times 10^{-12} \text{ C}^2/\text{N} \cdot \text{m}^2$$

In real materials, the permittivity changes, it relates to how well the material can sustain an electric field

## ConceptTest 16.3a Coulomb's Law I

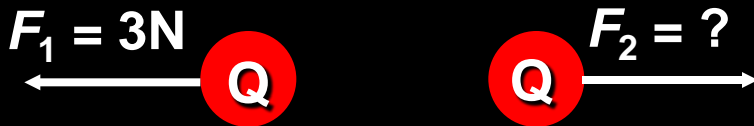
What is the magnitude  
of the force  $F_2$ ?



- 1) 1.0 N
- 2) 1.5 N
- 3) 2.0 N
- 4) 3.0 N
- 5) 6.0 N

## ConceptTest 16.3a Coulomb's Law I

What is the magnitude of the force  $F_2$ ?



1) 1.0 N

2) 1.5 N

3) 2.0 N

4) 3.0 N

5) 6.0 N

The force  $F_2$  must have the *same magnitude* as  $F_1$ . This is due to the fact that the form of Coulomb's Law is totally symmetric with respect to the two charges involved. The **force of one on the other of a pair is the same as the reverse.** Note that this sounds suspiciously like Newton's 3rd Law!!

# Charge on the electron

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

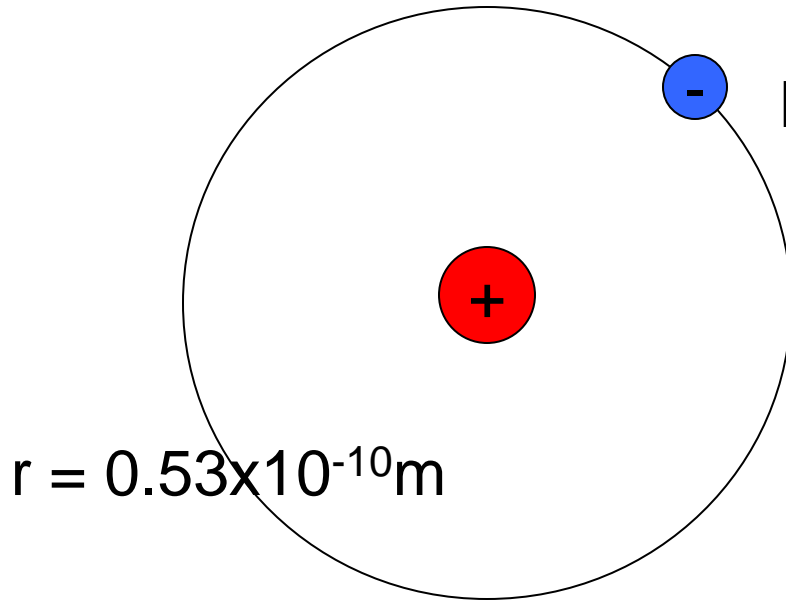
## Electric charge is quantized in units of the electron's charge.

Robert Millikan's oil-drop experiment (1908-13) demonstrated this fact directly, and measured the elementary charge. His experiment measured the force on tiny charged droplets of oil suspended against gravity between two metal electrodes. Knowing the electric field, the charge on the droplet could be determined. Repeating the experiment for many droplets, Millikan showed that the results could be explained as **integer** multiples of a common value ( $1.6 \times 10^{-19}$  coulomb), the charge on a single electron.

This was a key piece of evidence for the existence of electrons, atoms and molecules

A simple but profound Coulomb's law calculation...

The forces holding together a Hydrogen Atom



Electron: charge= $-1.6 \times 10^{-19} \text{ C}$   
mass =  $9.1 \times 10^{-31} \text{ kg}$

Proton: charge= $+1.6 \times 10^{-19} \text{ C}$   
mass= $1.67 \times 10^{-27} \text{ kg}$

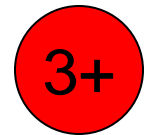
$$F_c = k Q_e Q_p / r^2$$

$$F_g = G M_e M_p / r^2$$

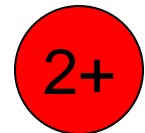
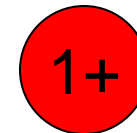
## 16.6 Using Coulomb's Law for Multiple Charges

**Superposition:** for multiple point charges, the forces on each charge from every other charge can be calculated and then added as vectors.

$$\vec{\mathbf{F}}_{\text{net}} = \vec{\mathbf{F}}_1 + \vec{\mathbf{F}}_2 + \dots$$

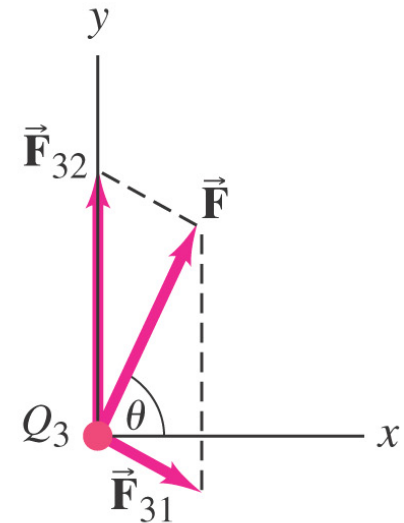
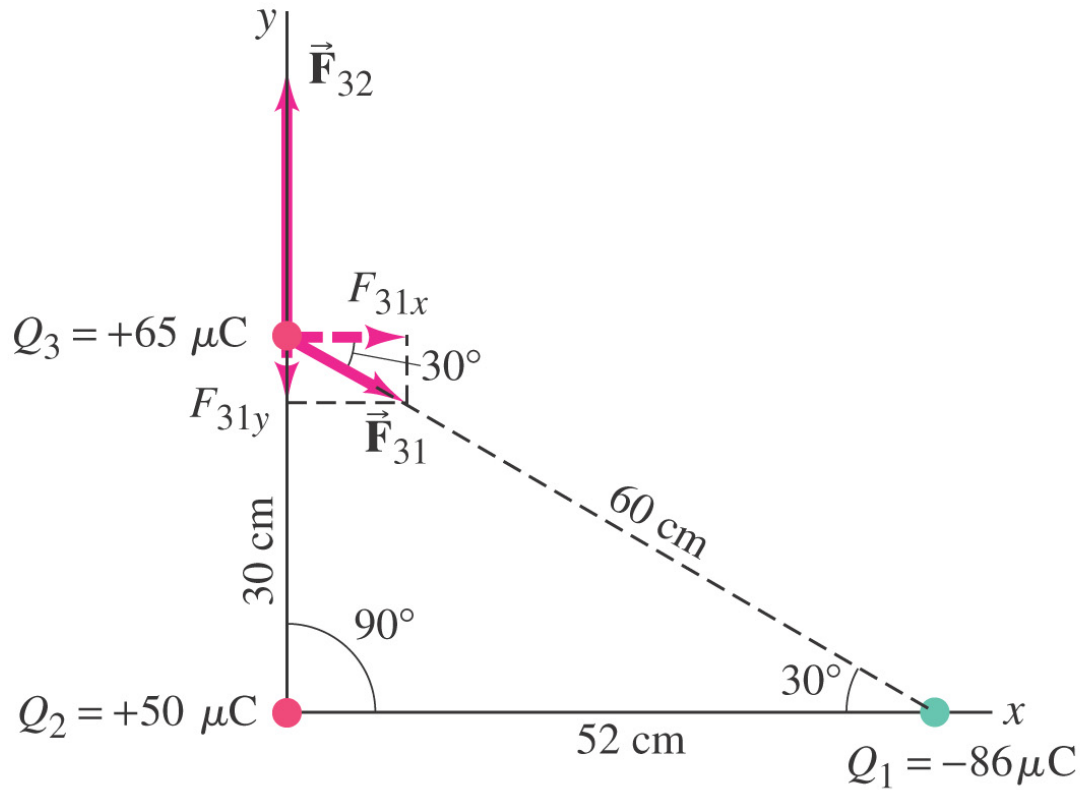


The net force on a charge is the vector sum of all the forces acting on it. This could rapidly get very complicated!



# Using Coulomb's Law for Multiple Charges

Coulomb's law strictly describes point charges.



$$\vec{\mathbf{F}}_{\text{net}} = \vec{\mathbf{F}}_1 + \vec{\mathbf{F}}_2 + \dots$$