Lecture 2: Chapter 16

Electric Charge and Electric Field

Electricity

- Two kinds of electric charge – positive and negative
- Charge is conserved (net charge is never created or destroyed)
- Charge on electron: $e = 1.602 \times 10^{-19}\ \mathrm{C}$

- Conductors: electrons free to move
- Insulators: electrons no free to move between atoms
- Semiconductors - insulators that conduct in response to electric field
- Objects can be charged by conduction or induction
- The electric force is very strong compared to all other forces.
- Coulomb's law $F = k\dfrac{Q_1 Q_2}{r^2}$
- Electric field can be represented by electric field lines

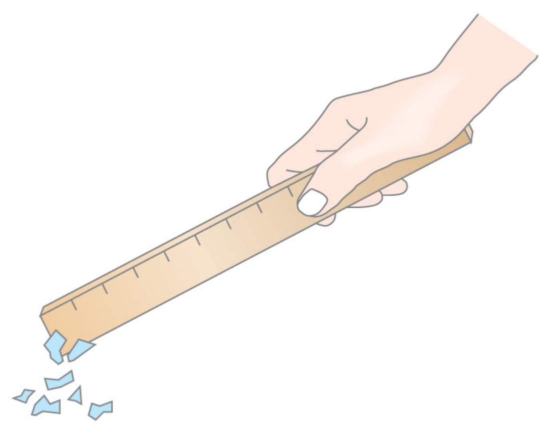
Electric Charge and its Origin

Atoms are 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)

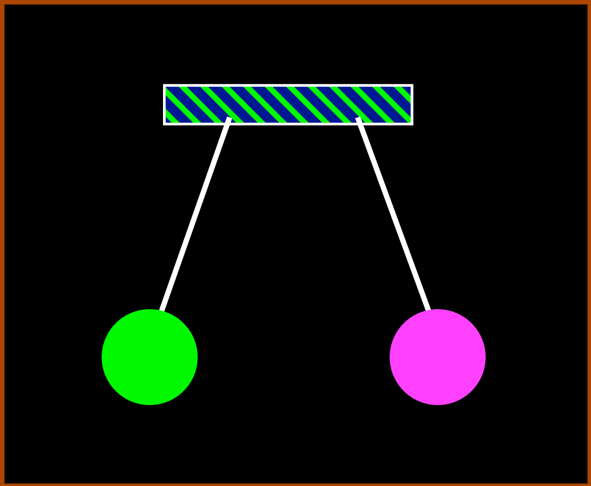


(b)

ConcepTest 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

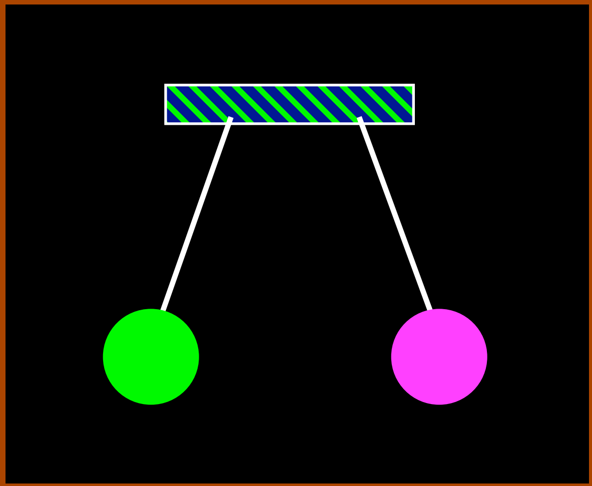


ConcepTest 16.1a Electric Charge I

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

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?

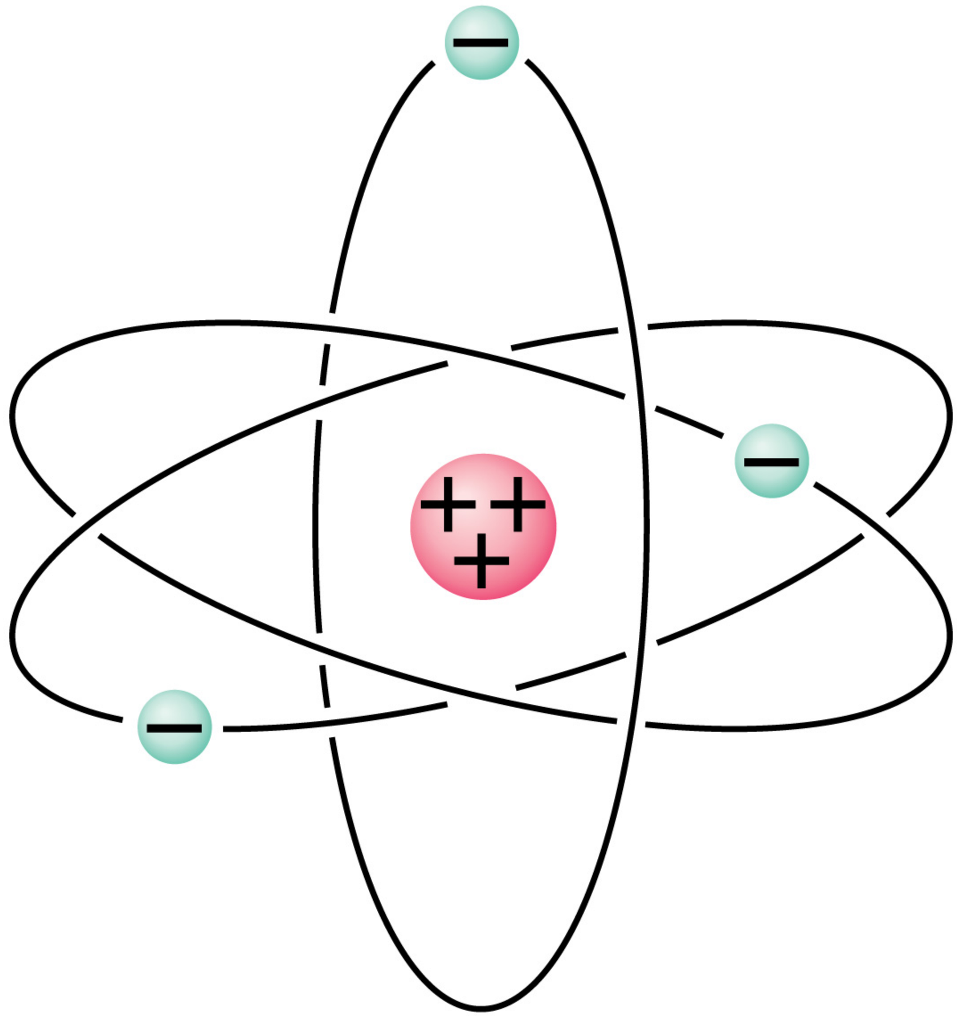
The Electric Force Originates with subatomic particles

Atom:

Nucleus (small, massive, positive charge)

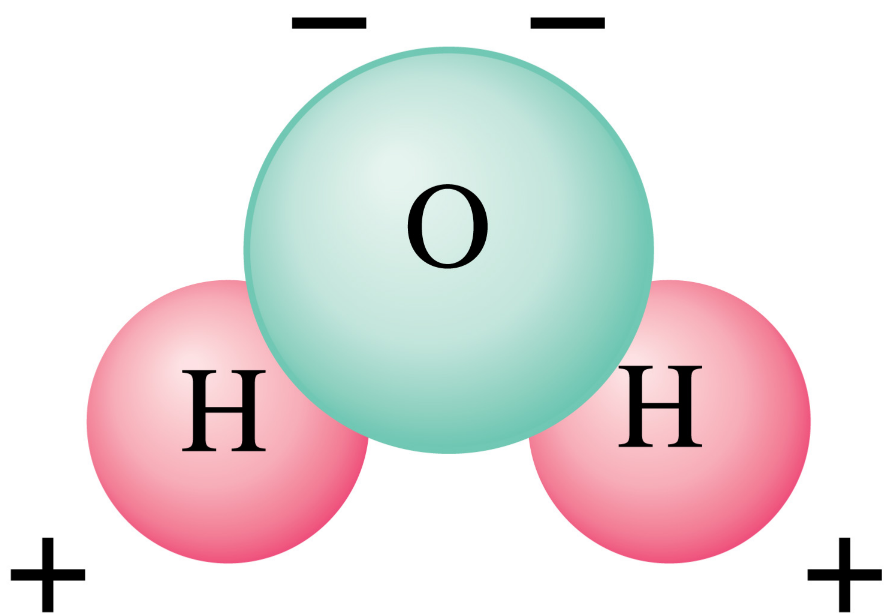
Electron cloud (large, very low density, negative charge)

An overly simplistic model for several reasons. -What might they be?



Electric Charge and Molecules

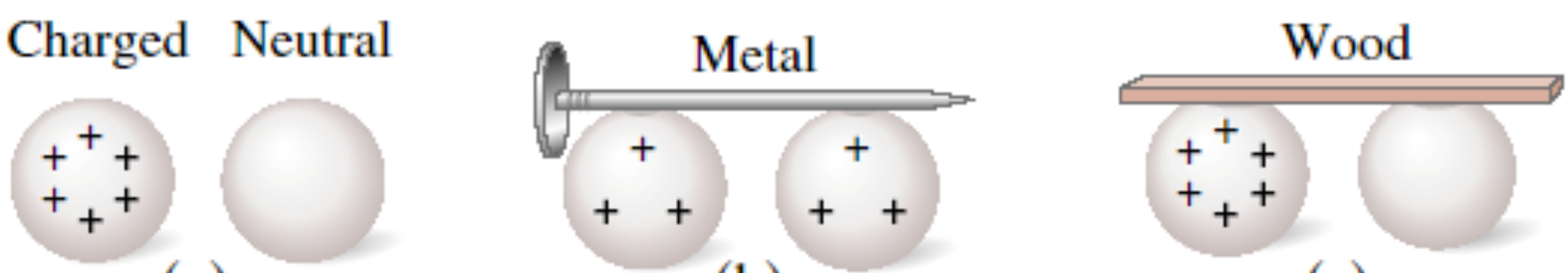
- Molecules (like atoms) are electrically neutral
- But the charges are not evenly distributed
- Polar molecules include - Water
- Thanks to this phenomenon, molecules can attract one another
- This fact complicates the simplified behavior of gasses that we studied last semester



Insulators and Conductors

Conductor:	Insulator:
Charge flows freely	Almost no charge flows
Metals	Most other materials

Some materials are semiconductors.

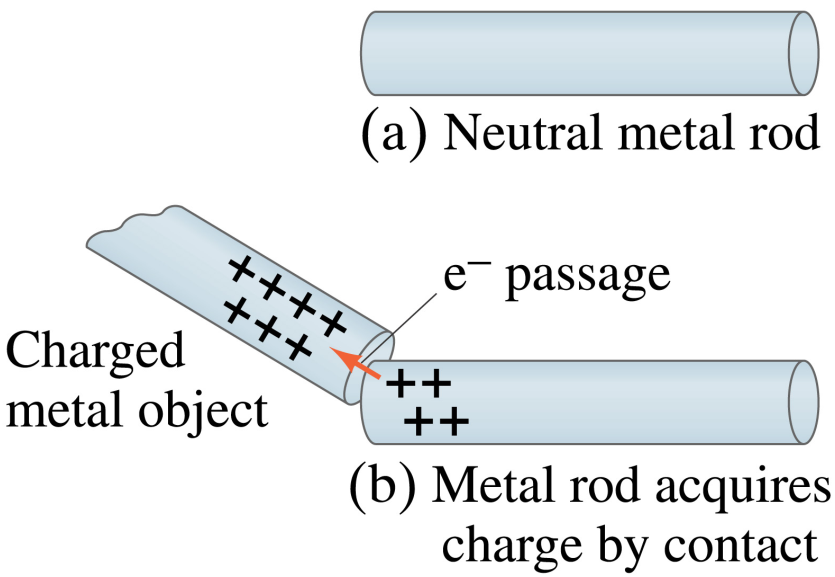


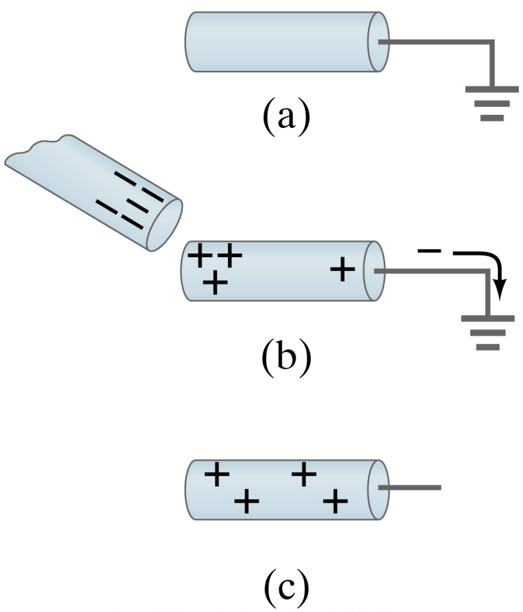
(a) (b) (c)

Induced Charge in conductors

Metal objects can be charged by

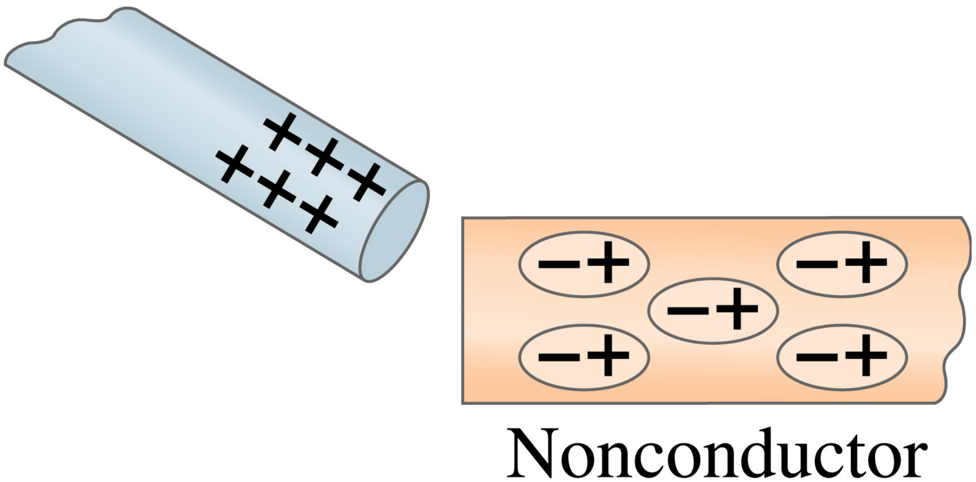
conduction or induction:





Induced Charge and non-conductors

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



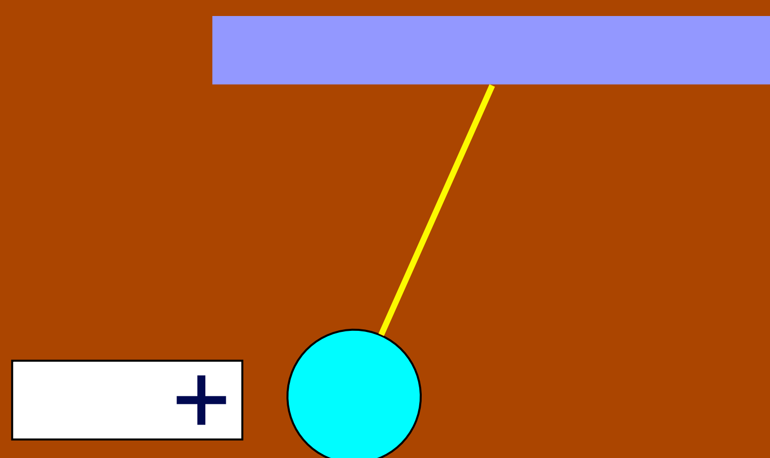
This is why dust sticks to your furniture, screen, glasses etc.

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

ConcepTest 16.2a Conductors I

A metal ball hangs from the ceiling by an insulating thread. The ball is **attracted** to a **positive**-charged rod held near the ball. The charge of the ball must be:

1) positive
2) negative
3) neutral
4) positive or neutral
5) negative or neutral

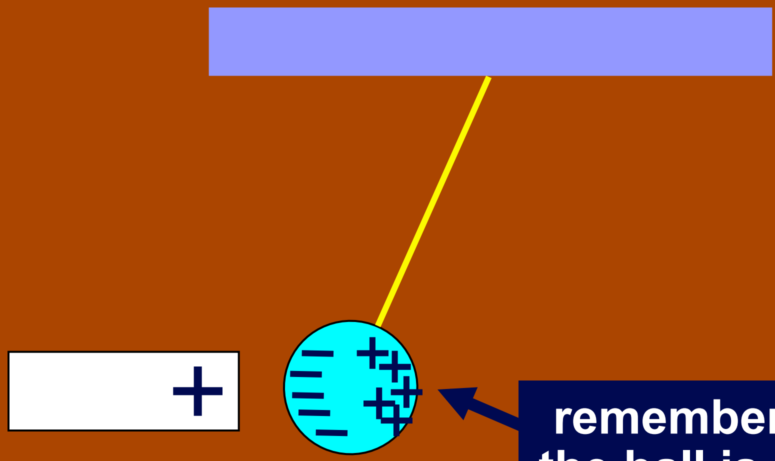


ConcepTest 16.2a Conductors I

A metal ball hangs from the ceiling by an insulating thread. The ball is attracted to a positive-charged rod held near the ball. The charge of the ball must be:

1) positive
2) negative
3) neutral
4) positive or neutral
5) negative or neutral

Clearly, the ball will be attracted if its charge is **negative**. However, even if the ball is **neutral**, the charges in the ball can be separated by **induction** (polarization), leading to a net attraction.



remember the ball is a conductor!

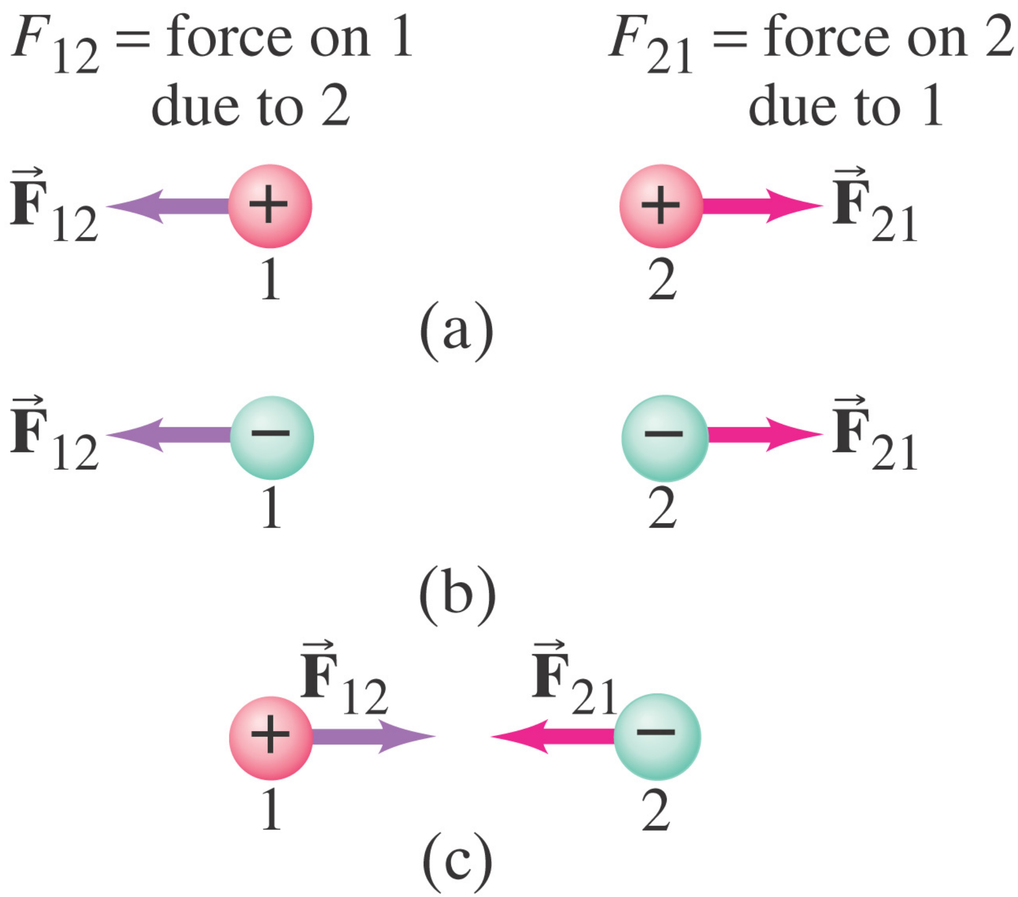
Follow-up: What happens if the **metal ball** is replaced by a **plastic ball**?

Like Charges Repel

These people have been charged to 1000's of volts,
so they are coated in a huge number of excess electrons.
The electrons are trying to get as far away from each other
as possible

Like Charges Repel, Opposites Attract:

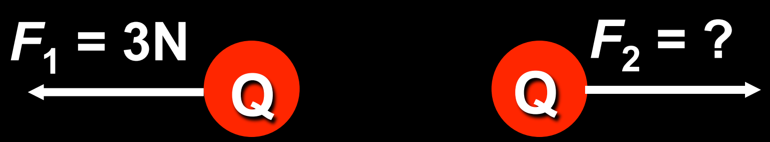
They also Obey Newton's 3rd Law….



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

ConcepTest 16.3a Coulomb's Law I

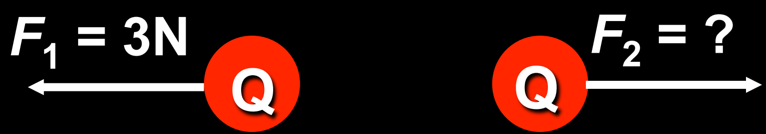
What is the magnitude of the force F_2?



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

ConcepTest 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!!**

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:

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

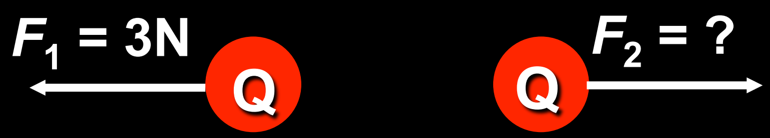
Charges produced by rubbing are typically around a microcoulomb: $1\ \mu\mathrm{C} = 10^{-6}\ \mathrm{C}$

Charge on the Electron = 1.6×10^{-19} C

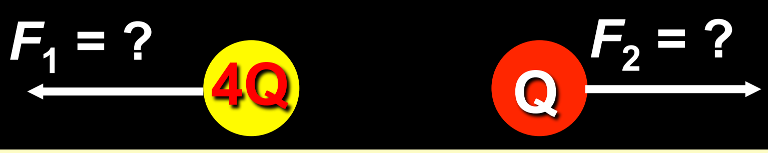
One Coulomb may seem huge, but is only the amount of charge passing through a household lightbulb in about one second.

Remind me to prove this when we get to Current and Voltage!

ConcepTest 16.3b Coulomb's Law II

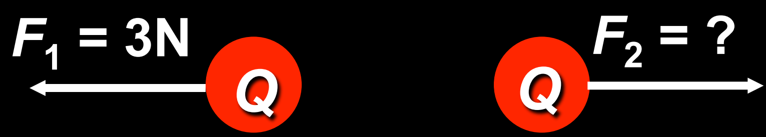


If we increase one charge to 4Q, what is the magnitude of F_1?



1) 3/4 N
2) 3.0 N
3) 12 N
4) 16 N
5) 48 N

ConcepTest 16.3b Coulomb's Law II



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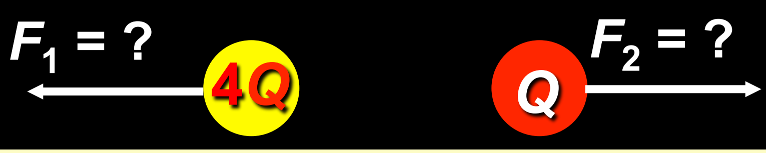


1) 3/4 N
2) 3.0 N
3) 12 N
4) 16 N
5) 48 N

Originally we had:

$$F_1 = k(Q)(Q)/r^2 = 3\text{ N}$$

Now we have:

$$F_1 = k(4Q)(Q)/r^2$$

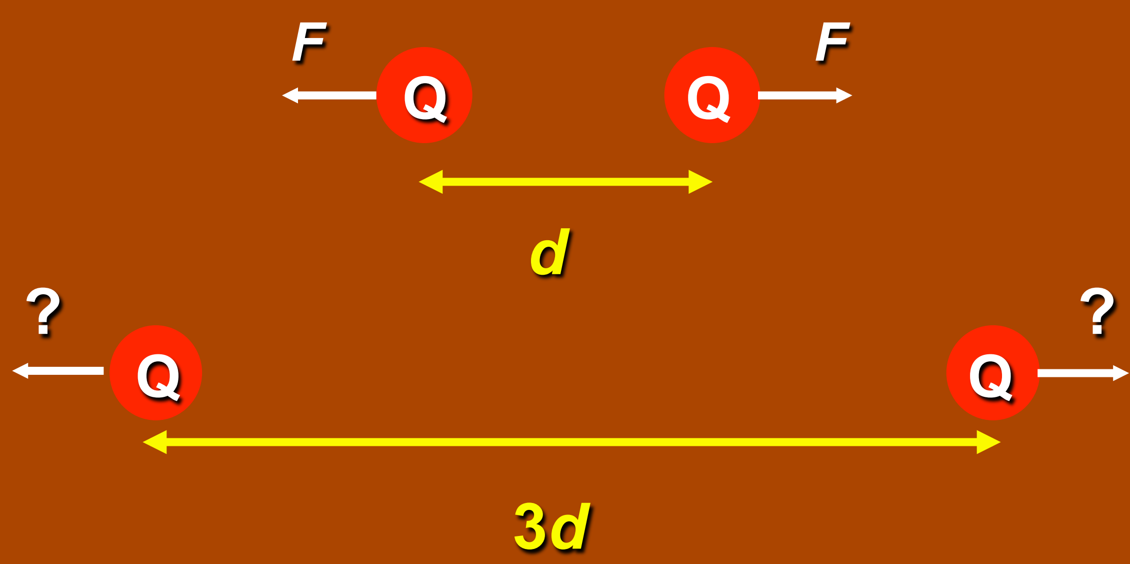
which is 4 times bigger than before.

Follow-up: Now what is the magnitude of F_2?

ConcepTest 16.3c Coulomb's Law III

The force between two charges separated by a distance *d* is *F*. If the charges are pulled apart to a distance 3*d*, what is the force on each charge?

1) 9 *F*
2) 3 *F*
3) *F*
4) 1/3 *F*
5) 1/9 *F*



ConcepTest 16.3c Coulomb's Law III

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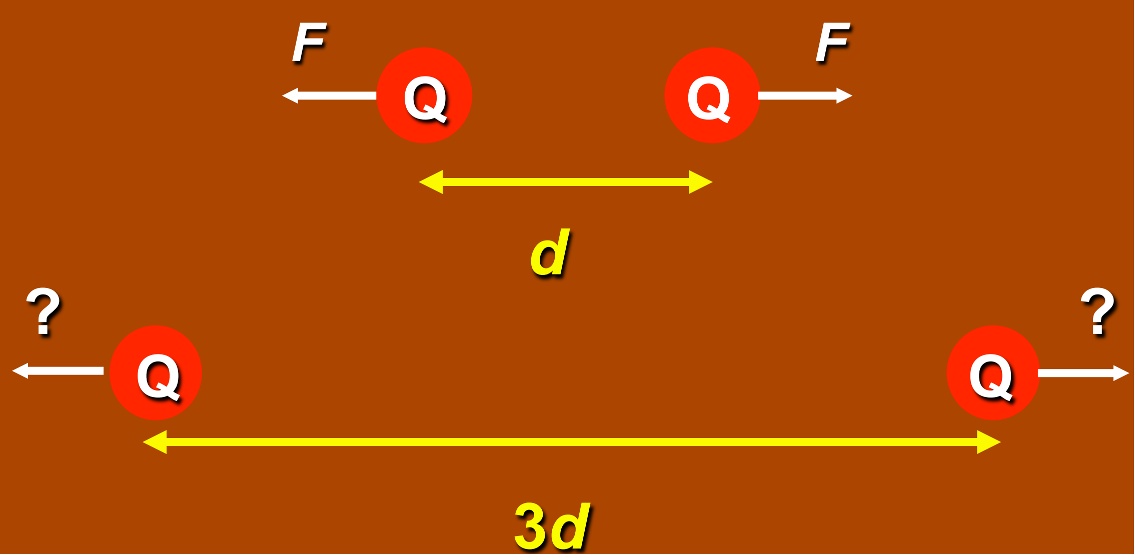
1) 9 *F*
2) 3 *F*
3) *F*
4) 1/3 *F*
5) 1/9 *F*

Originally we had:

$F_{before} = k(Q)(Q)/d^2 = F$

Now we have:

$F_{after} = k(Q)(Q)/(3d)^2 = 1/9\ F$



Follow-up: What is the force if the original distance is halved?

Coulomb's Law in another form:

The proportionality constant k can also be written in terms of ϵ_0, the permittivity of free space:

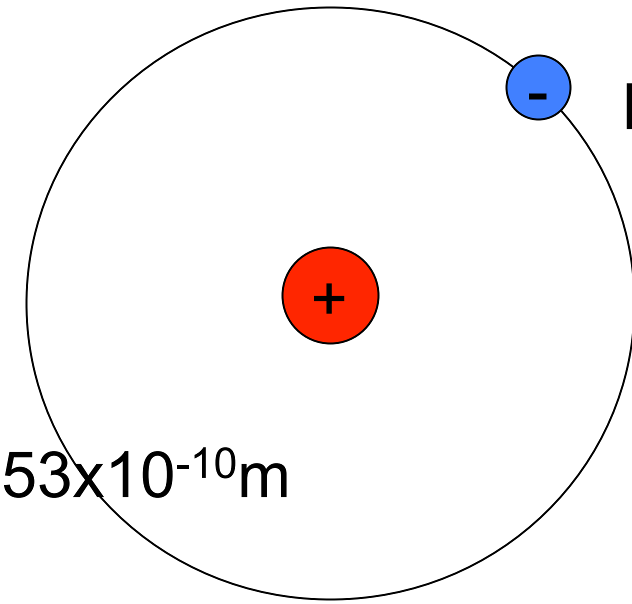
$$F = \frac{1}{4\pi\epsilon_0}\frac{Q_1 Q_2}{r^2}$$

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

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

A simple but profound Coulomb's law calculation…

The forces holding together a Hydrogen Atom



Electron: charge=-1.6×10^{-19} C
mass = 9.1×10^{-31} kg

Proton: charge=$+1.6\times10^{-19}$ C
mass=1.67×10^{-27} kg

$r = 0.53\times10^{-10}$m

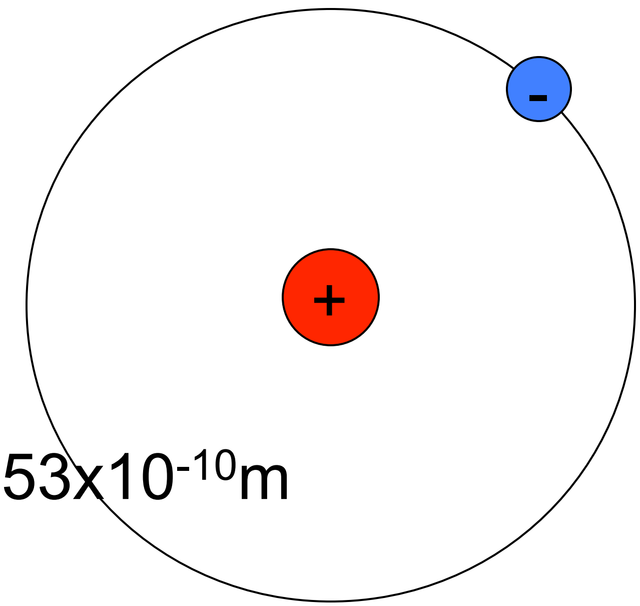
$Fc = k\ Q_eQ_p/r^2$

$Fg = G\ M_eM_p/r^2$

<u>Working In Pairs</u>, compare Coulomb's law and Newton's Law of gravitation

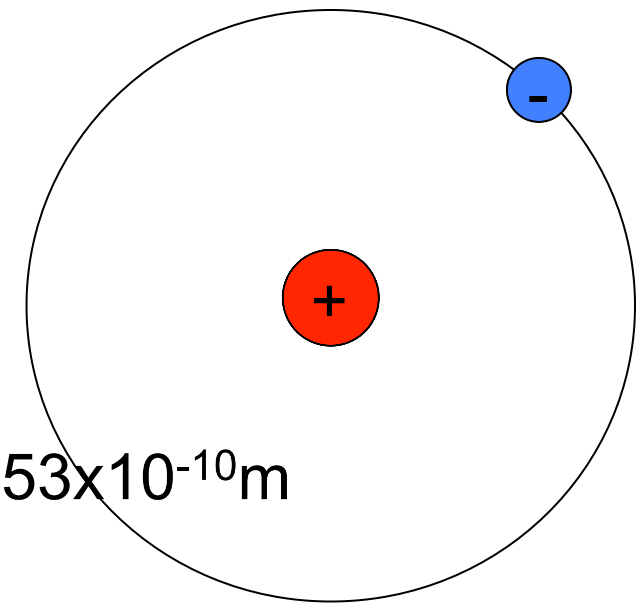
For Hydrogen, which force is Larger?

A. The Electric force
B. The Gravitational force
C. It depends on the distance



$r = 0.53 \times 10^{-10}$m

For Hydrogen, What should be the approximate velocity of the orbiting electron ?

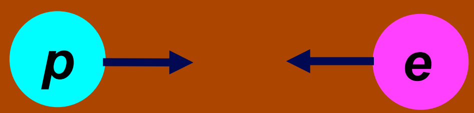


$r = 0.53 \times 10^{-10} m$

ConcepTest 16.5a Proton and Electron I

A proton and an electron are held apart a distance of 1 m and then released. As they approach each other, what happens to the force between them?

1) it gets bigger
2) it gets smaller
3) it stays the same

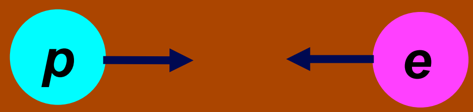


ConcepTest 16.5a Proton and Electron I

A proton and an electron are held apart a distance of 1 m and then released. As they approach each other, what happens to the force between them?

1) it gets bigger
2) it gets smaller
3) it stays the same

By Coulomb's Law, the **force between the two charges is inversely proportional to the distance squared**. So, the closer they get to each other, the bigger the electric force between them gets!



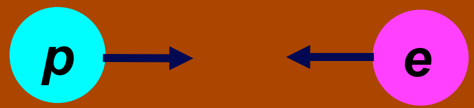
$$F = k\frac{Q_1 Q_2}{r^2}$$

Follow-up: Which particle feels the larger force at any one moment?

ConcepTest 16.5b Proton and Electron II

A proton and an electron are held apart a distance of 1 m and then released. Which particle has the larger acceleration at any one moment?

1) proton
2) electron
3) both the same



ConcepTest 16.5b Proton and Electron II

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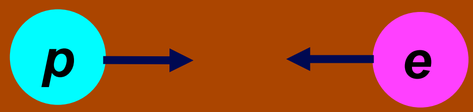


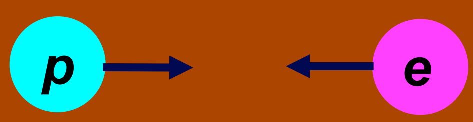
The two particles feel the **same force**. Since $F = ma$, the particle with the **smaller mass** will have the **larger acceleration**. **This would be the electron.**

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

ConcepTest 16.5c Proton and Electron III

A proton and an electron are held apart a distance of 1 m and then let go. Where would they meet?

1) in the middle
2) closer to the electron's side
3) closer to the proton's side



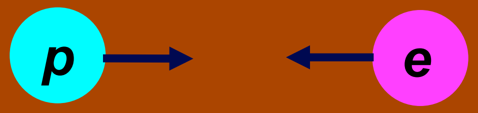
ConcepTest 16.5c Proton and Electron III

A proton and an electron are held apart a distance of 1 m and then let go. Where would they meet?

1) in the middle
2) closer to the electron's side
3) closer to the proton's side

By Newton's 3rd Law, the electron and proton feel the **same force**. But, since *F* = *ma*, and since the **proton's mass is much greater**, the **proton's acceleration will be much smaller**!

Thus, they will meet **closer to the proton's original position**.

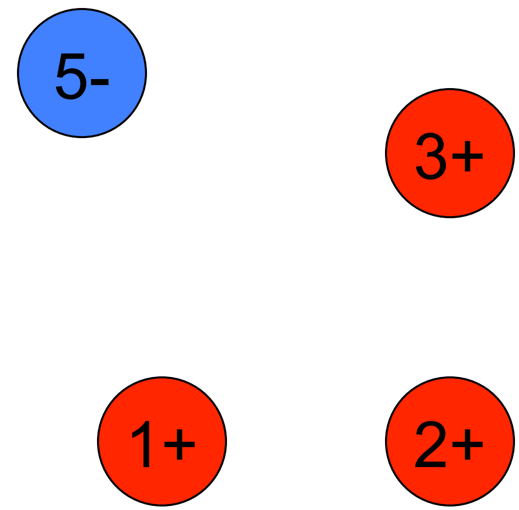


Follow-up: Which particle will be moving faster when they meet?

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.

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



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

Where would this sort of thing be important?

Wait a minute……Where do Electric Forces Come From?

Before we get bogged down with math, what's all this about charges attracting and repelling each other?

How do they do it?

Notice that the charges do not need to touch.

The Electric Field

Early scientists and philosophers struggled with the idea of "action at a distance".

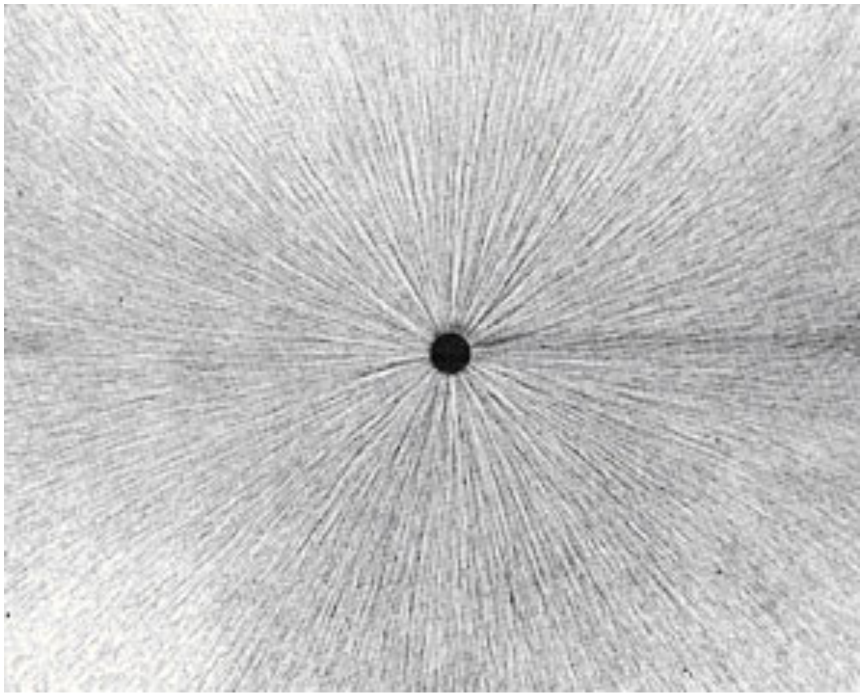
How was the electric force propagated?

Michael Faraday proposed that a "field" extended outwards from all charged objects, and that these fields interacted with one another.

Fields are a great mathematical convenience.

The Field can be visualized mentally, graphically, and actually <u>seen</u> under certain circumstances……

Visualizing the Electric Field



These figures are from the book "Conceptual Physics" by Paul Hewitt

- This is a photograph of a tank of oil (an electrical insulator) with millions of tiny cotton fibers (insulating and non-magnetic) suspended in it.
- In the center is a metal object that is electrically charged
- The cotton fibers mysteriously align themselves pointing radially outward from the charge.
- Nothing is touching them, and they are not touching each other
- "Something" with Faraday decided to call "The Electric Field" is reaching out through space and moving the fibers.