Electric Charge- Coulomb’s law

Phy 108 course

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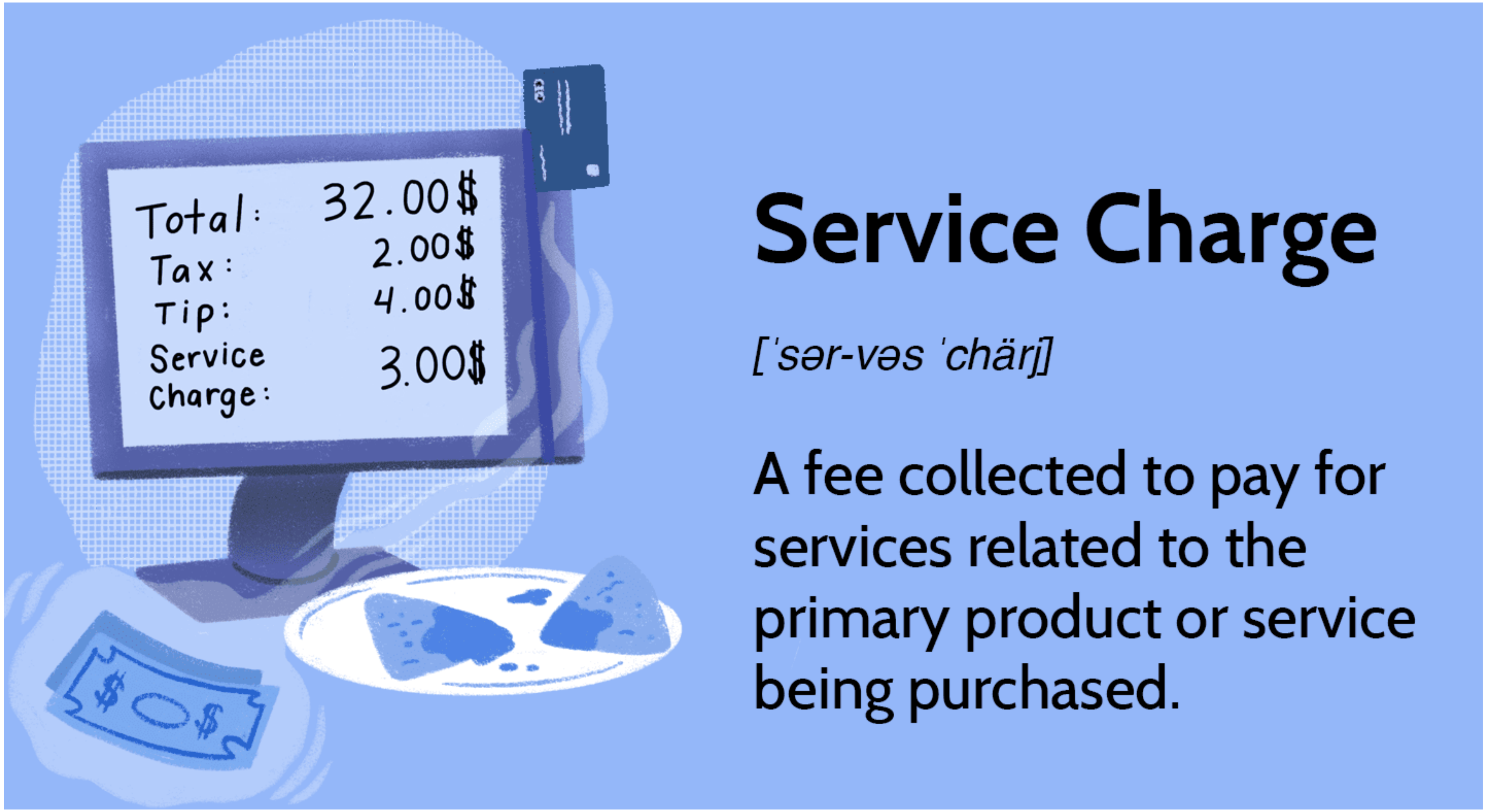
DMP, SEPS, NSU

Charge!!!

Charge!!!

Charge!!!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Service Charge
[ˈsər-vəs ˈchärj]
A fee collected to pay for services related to the primary product or service being purchased.

Learning Objectives

By the end of this lesson, students should be able to:

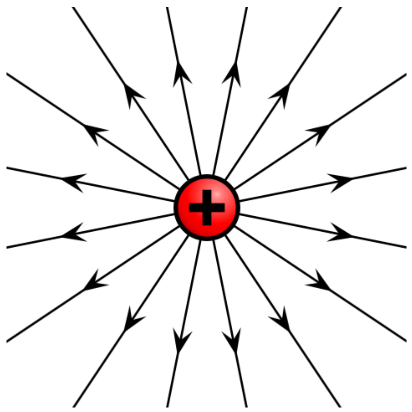
- ❑ **Describe** the nature and origin of electric charge in matter.
- ❑ **Differentiate** between conductors, insulators, and semiconductors based on their electrical properties.
- ❑ **Explain** the atomic view of charging (ions, electron transfer, and polarization).
- ❑ **Apply** Coulomb’s Law to determine the magnitude and direction of electrostatic forces.
- ❑ **Analyze** charge interactions using vector resolution.
- ❑ **Understand** the law of conservation of electric charge and its implications.
- ❑ **Identify** the behavior of charge in practical scenarios (e.g., static discharge in dry environments).
- ❑ **Compare** electrostatic and gravitational forces qualitatively and quantitatively.
- ❑ **Explain** induced charge and charge polarization phenomena.
- ❑ **Solve** basic problems involving electric charges using diagrams and vector components.

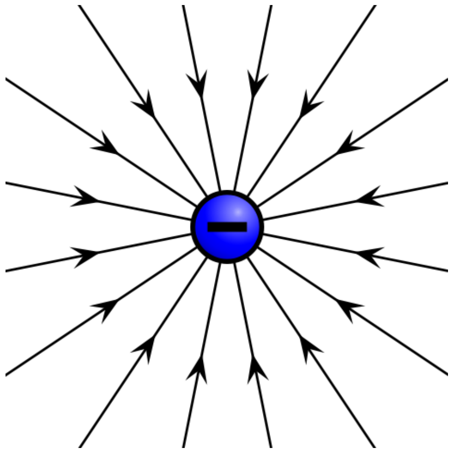
Electric Charge

Electric charge is an intrinsic property of the fundamental particles that make up objects such as the rods, silk, and fur.

That is, charge is a property that comes automatically with those particles wherever they exist.

There are two kinds of charge





Electric Charge

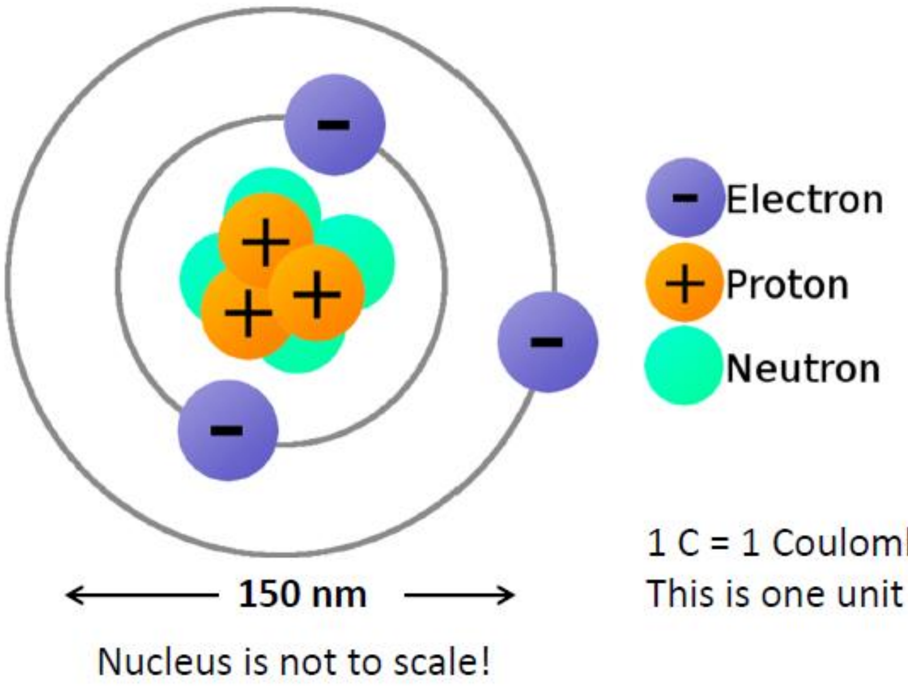
Atomic view: Brief

•Electrons and protons are the basic charges in ordinary matter.

•There are no other sources of charge.

•An object is charged if it has an unequal number of protons and electrons.

•Most macroscopic objects have an *equal number* of protons and electrons. Such objects are *electrically neutral.*



1 C = 1 Coulomb
This is one unit of electric charge.

Particle	Mass (kg)	Charge (C)
Proton	1.67×10^{-27}	$+e = 1.60 \times 10^{-19}$
Electron	9.11×10^{-31}	$-e = -1.60 \times 10^{-19}$

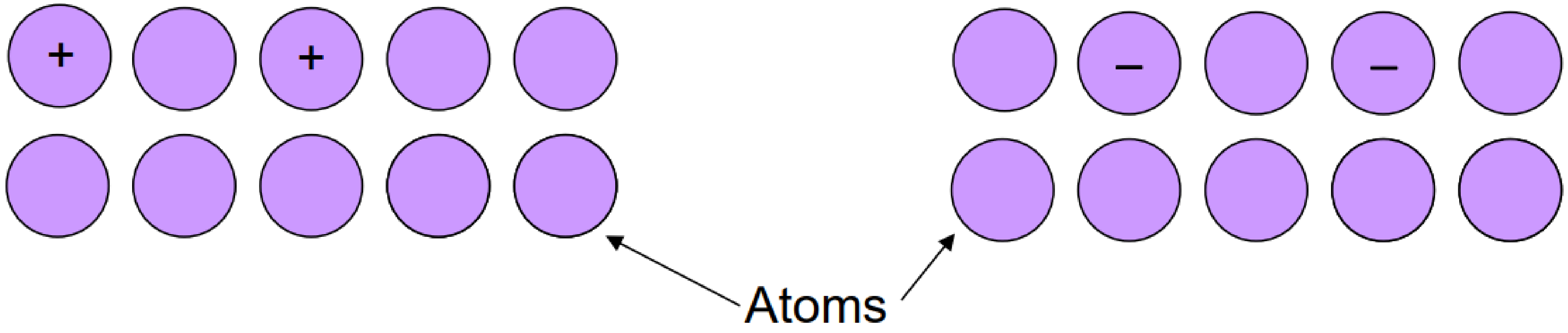
Electric Charge

Atomic view: Brief

Normally atoms are not charged as the charge of their electrons balances the charge of their core.

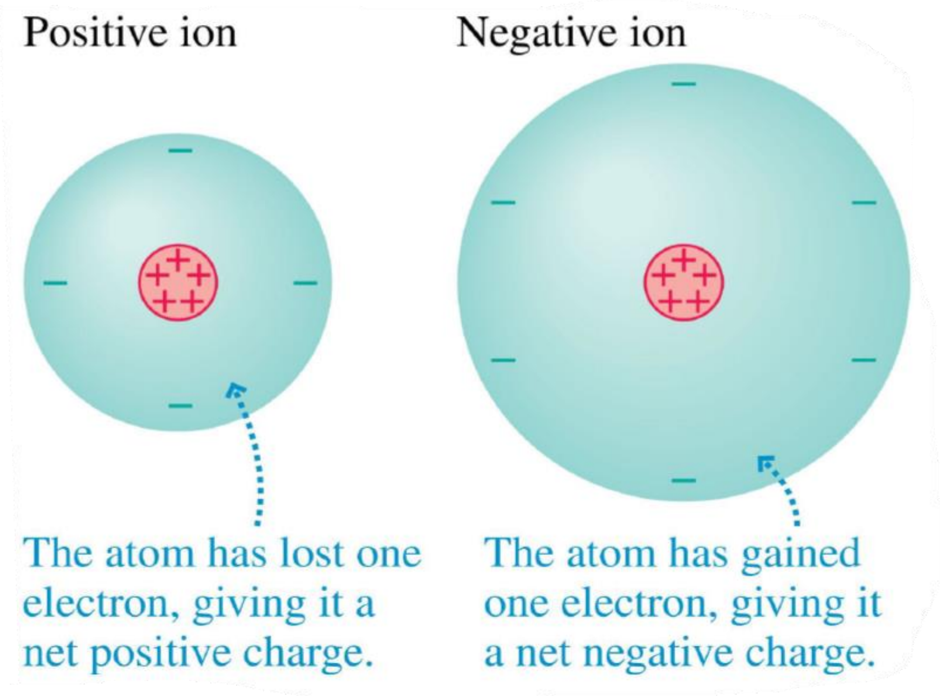
Positively charged material:
Some electrons are removed

Negatively charged material:
There are excessive electrons

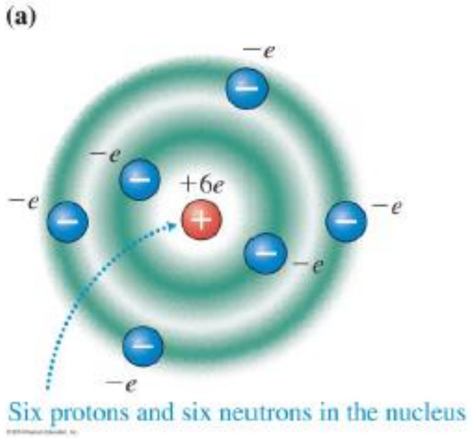


Electric Charge

Atomic view: Brief

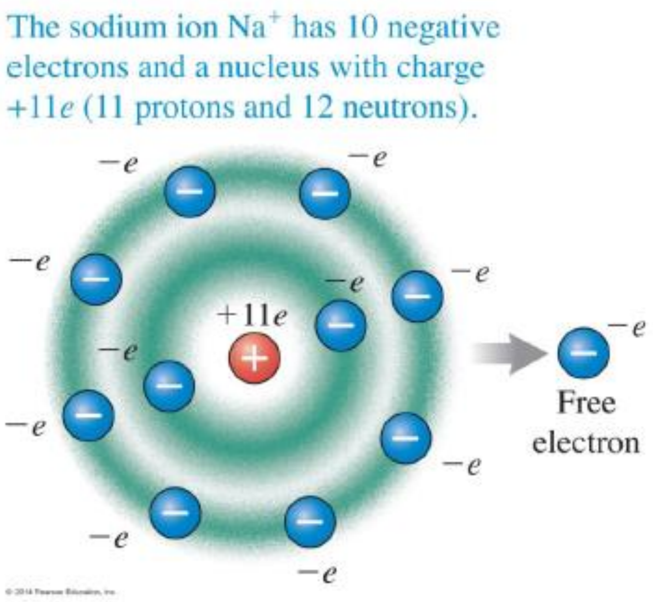


Example 1 : Carbon atom



Net charge = 0

Example 2 : Sodium ion



Net charge = +e

Removing electrons creates a positively charged ion, and placing additional electrons on the atom creates a negatively charged ion.

Jumping of electrons from one body to the other can cause sparks.

Atomic view: Brief

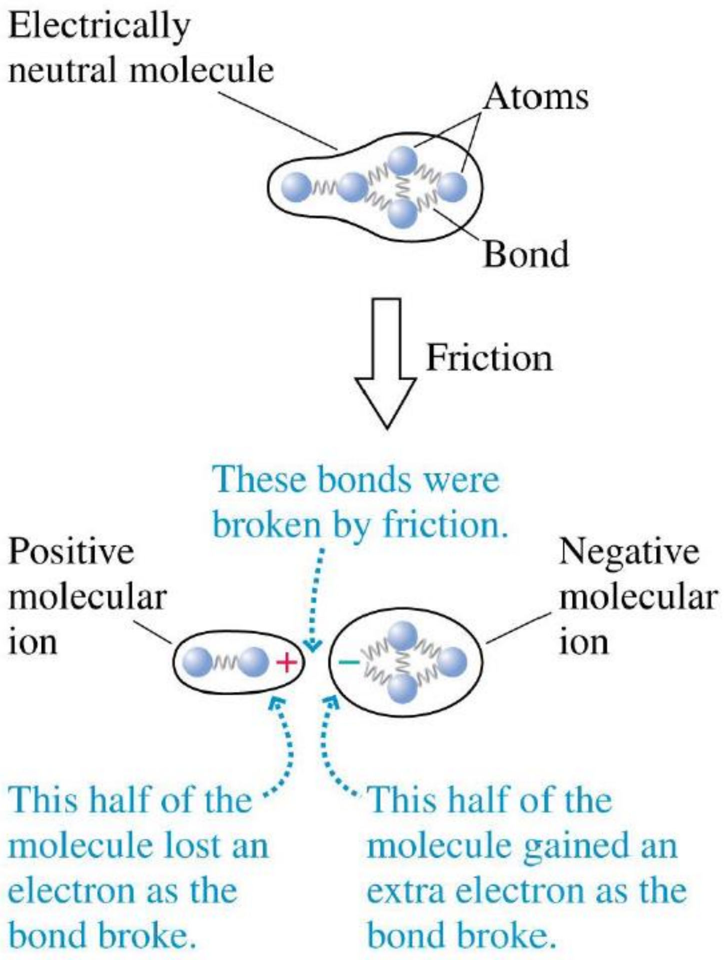
•Objects gain a positive charge not by gaining protons, but by losing electrons.

•Protons are *extremely* tightly bound within the nucleus, but electrons are bound much more loosely.

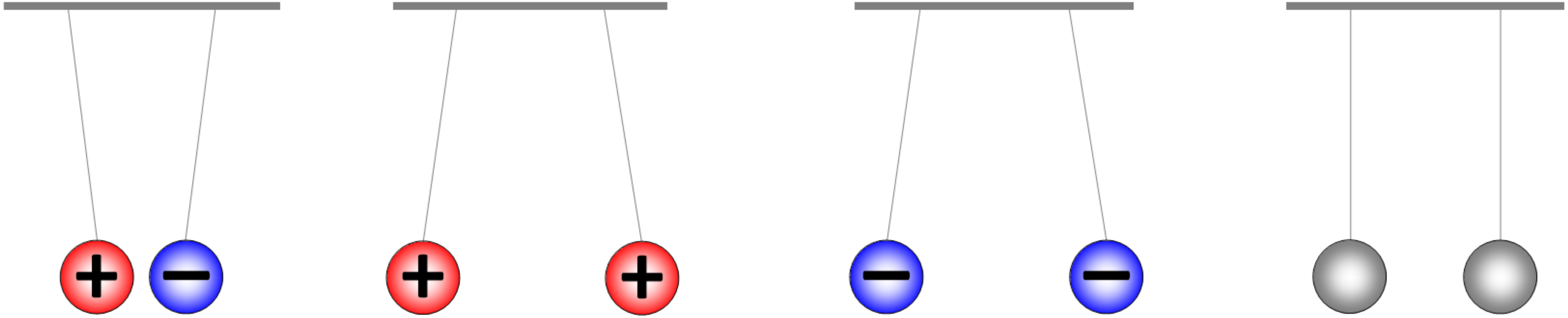
•An atom that is missing an electron is called a *positive ion.*

•Atoms that can accommodate an *extra* electron become negative ions.

Molecular ions can be created when one of the bonds in a large molecule is broken.



Electric Charge



Properties of charges

- unlike charges attract
- like charges repel
- charges can move but charge is conserved
- the magnitude of charge of the electron or proton is a natural unit of charge

Electric Charge

Two of the grand mysteries in physics are

(1) *why* does the universe have particles with electric charge (what is it, really?)

(2) *why* does electric charge come in two types (and not, say, one type or three types).

We just do not know.

https://www.youtube.com/watch?time_continue=1&v=oU8Fe6846d4&feature=emb_logo

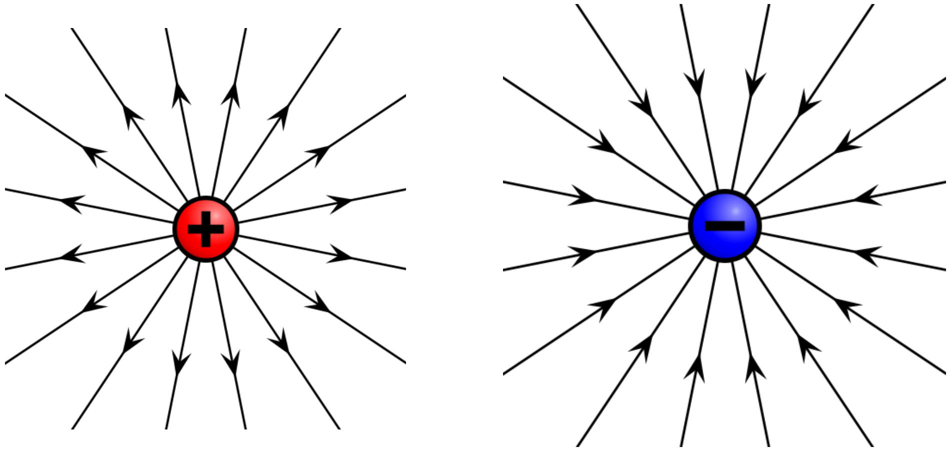
Electric Charge

Elementary charge

1 electron = 1.602×10^{-19} coulomb

Coulomb

1 coulomb= 6.24×10^{18} electrons



Unit. The SI unit of charge is the **coulomb**. For practical reasons having to do with the accuracy of measurements, the coulomb unit is derived from the SI unit *ampere* for electric current i.

We shall discuss current in detail later, but here let's just note that current i is the rate dq/dt at which charge moves past a point or through a region: (electric current).

Rearranging the relation $\mathrm{i} = \frac{dq}{dt}$ and replacing the symbols with their units (coulombs C, amperes A, and seconds s) we see that $1\,C = (1\,A)(1\,s)$.

Atomic view: Brief

Elementary charge

1 electron = 1.602×10^{-19} coulomb

Coulomb

1 coulomb= 6.24×10^{18} electrons

One coulomb represents the negative of the total charge of about 6×10^{18} electrons.

For comparison, a copper cube 1 cm on a side contains about 2.4×10^{24} electrons!!

About 10^{19} electrons pass through the glowing filament of a flashlight bulb every second!!

Charge Is Quantized

Any positive or negative charge q that can be detected can be written as
$q = ne,\ n = \pm 1, \pm 2, \pm 3, \ldots$, in which e, the **elementary charge,** has the approximate value

The elementary charge e is one of the important constants of nature. The electron and proton both have a charge of magnitude e

Quarks, the constituent particles of protons and neutrons, have charges of $\pm e/3$ or $\pm 2e/3$, but they apparently cannot be detected individually. For this and for historical reasons, we do not take their charges to be the elementary charge.

Electricity

Electricity is a form of energy resulting from the existence of charged particles (such as electrons or protons), either statically as an accumulation of charge or dynamically as a current.

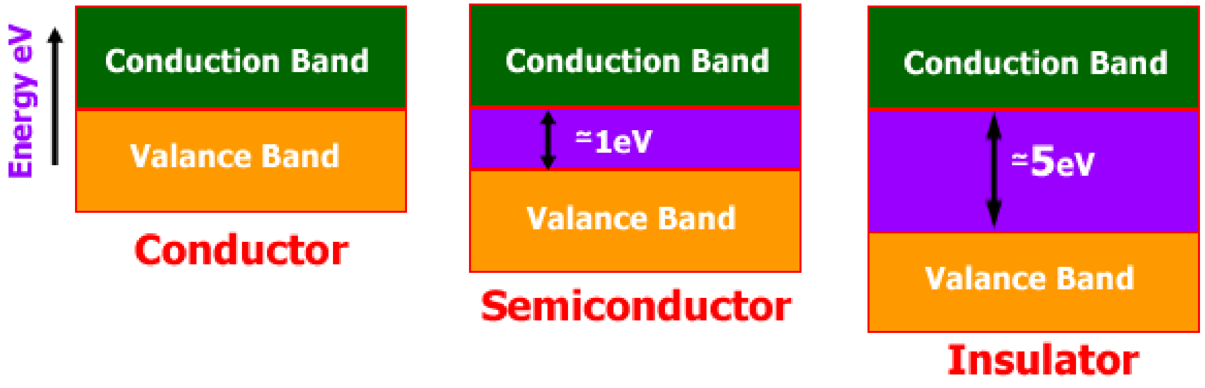


Fig: Classification of Solids on the basis of electricity Conduction

Conductor

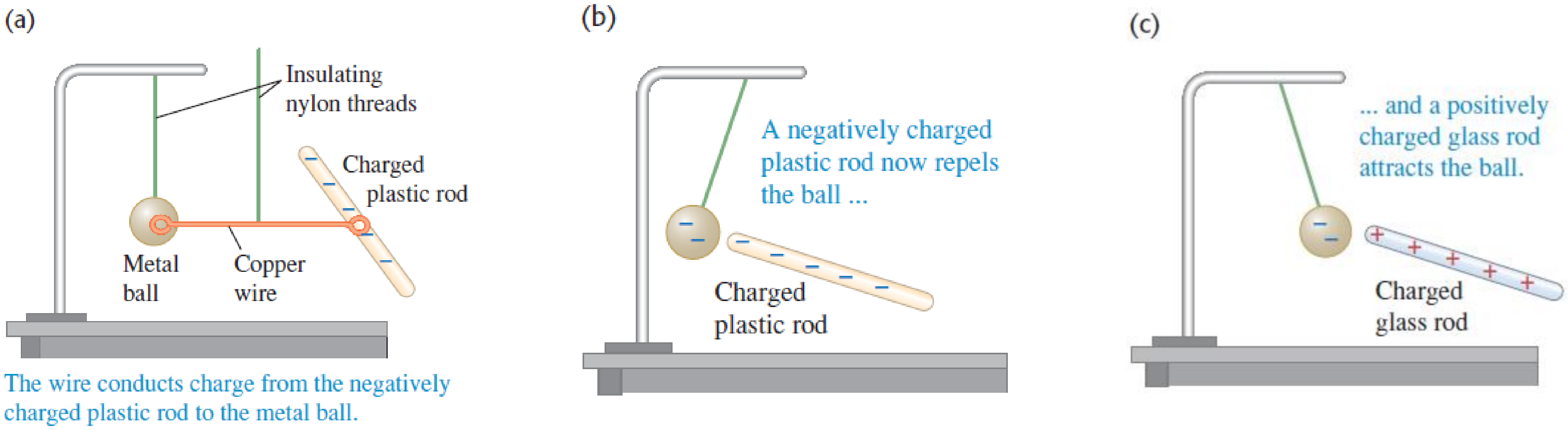
A conductor is a material that readily allows the flow of electricity. A good conductor has a high numerical value of *conductivity*, and a low numerical value of *resistance*.

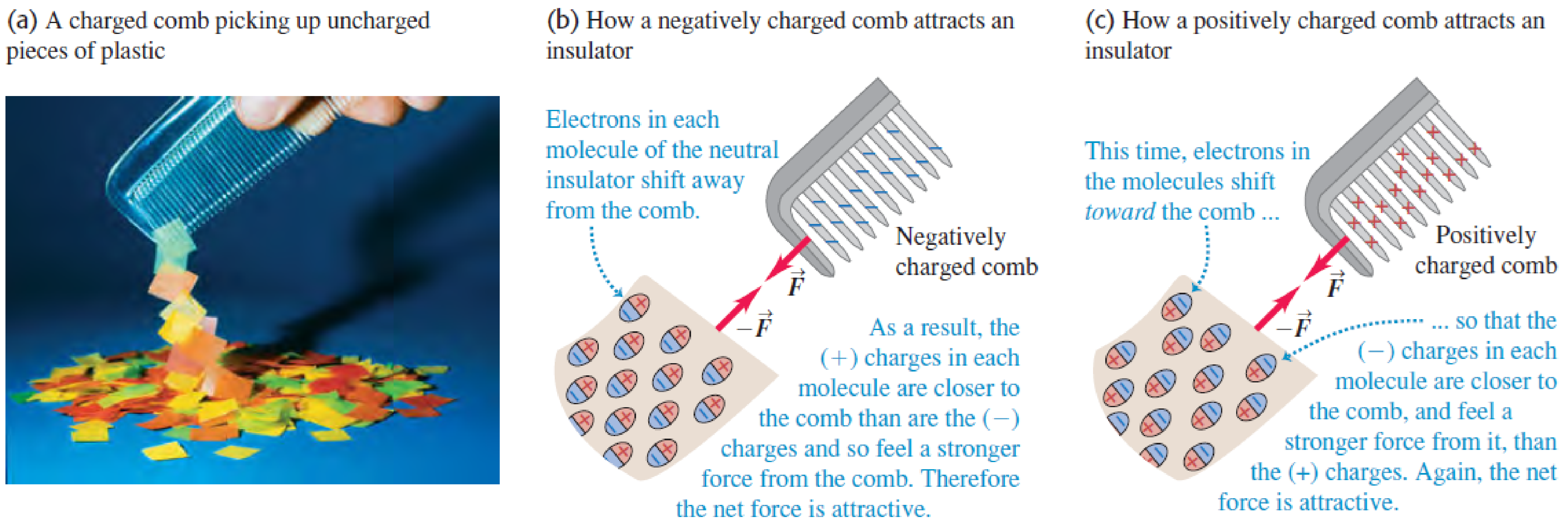
Insulator

An insulator is a material that tends to impede the flow of electricity. An insulator has a low numerical value of *conductivity*, and a high numerical value of *resistance*.

Semiconductor

A semiconductor is a material with conductivity between that of a conductor and insulator. The conductivity of a semiconductor can be changed by exposing it to an electrical field, light, mechanical pressure, or heat.





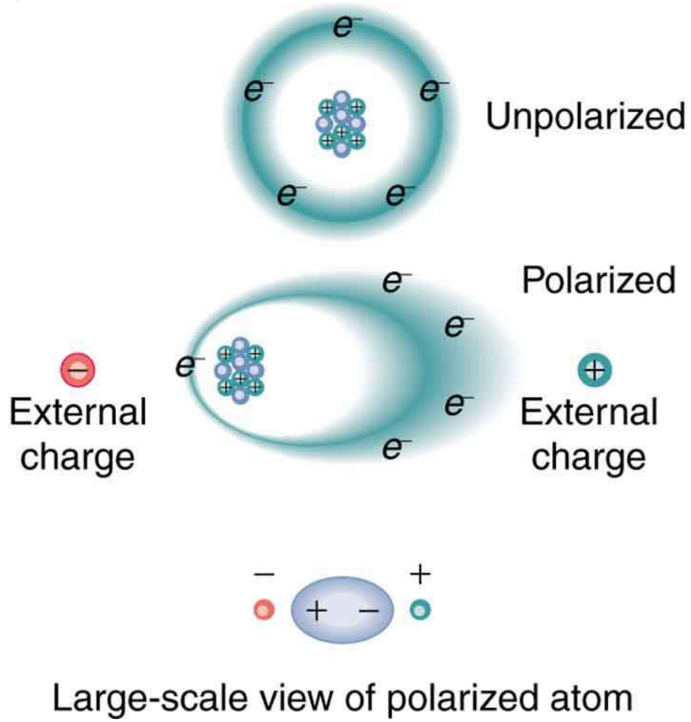
Electrostatic induction, modification in the distribution of electric charge on one material under the influence of nearby objects that have electric charge.

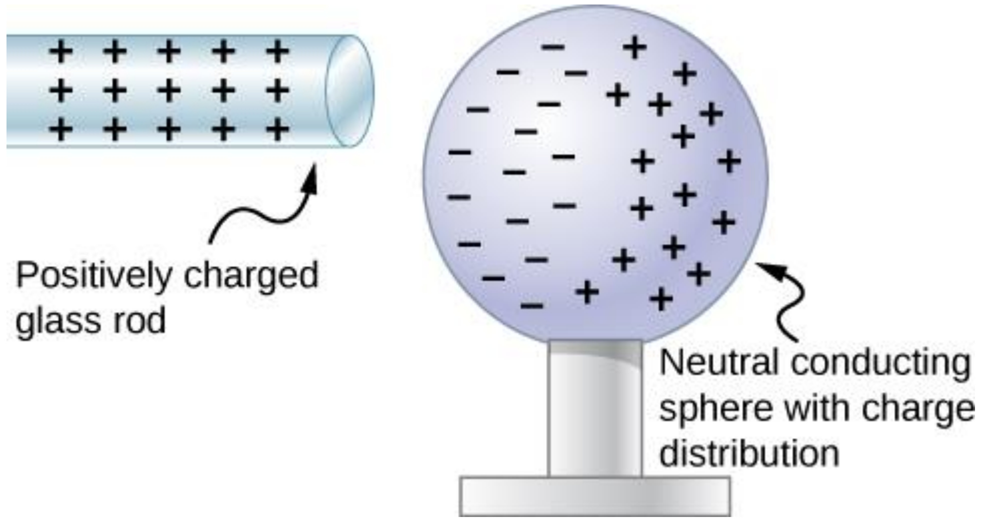
Charge polarization

Charge polarization is the slight separation of the positive and negative charges in a neutral object when a charged object is brought near.

The **polarization force** arises because the charges in a neutral object are slightly separated, *not* because the objects are oppositely charged.

The polarization force between a charged object and a neutral one is always attractive.





https://javalab.org/en/electrostatic_induction_metal_bonding_en/

Charge in our body! Normally you are approximately neutral.

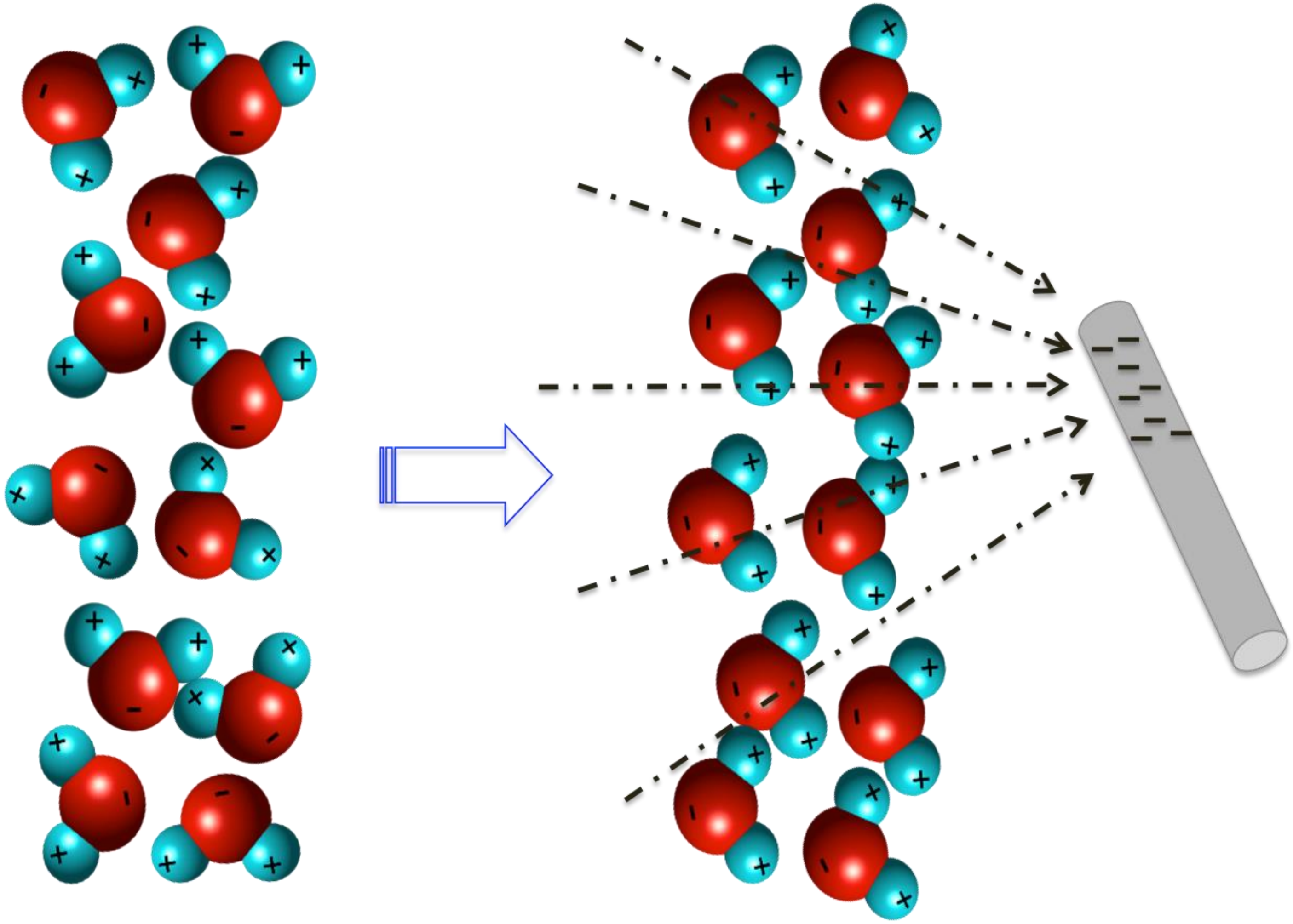
However, if you live in regions where the humidity is low, you know that the charge on your body can become slightly unbalanced when you walk across certain carpets.

Either you gain negative charge from the carpet (at the points of contact between your shoes with the carpet) and become negatively charged, or you lose negative charge and become positively charged. Either way, the extra charge is said to be an *excess charge*.

You probably don’t notice it until you reach for a door handle or another person.

Then, if your excess charge is enough, a spark leaps between you and the other object, eliminating your excess charge. Such sparking can be annoying and even somewhat painful.

https://phet.colorado.edu/sims/html/john-travoltage/latest/john-travoltage_en.html



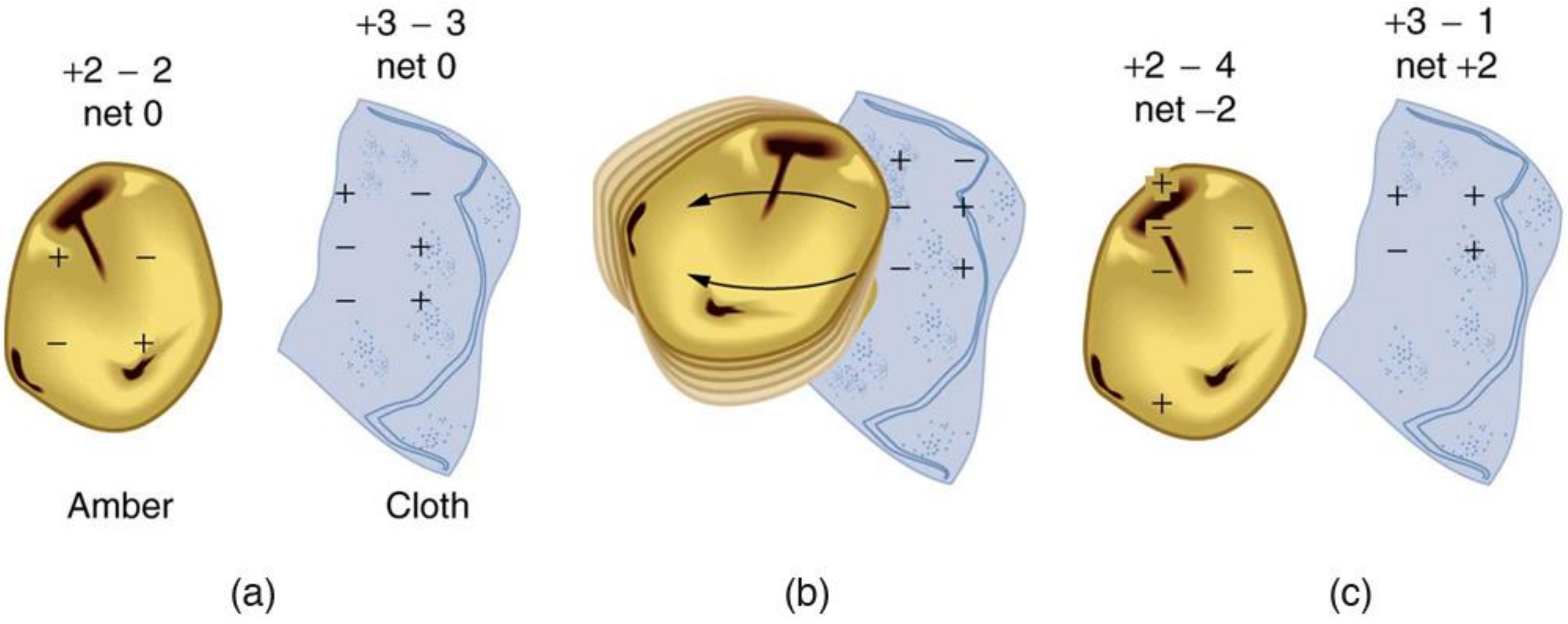
https://javalab.org/en/polarity_of_water_en/

https://javalab.org/en/conductor_and_insulator_en/

Charge Is Conserved

The net electric charge of any isolated system is always conserved.

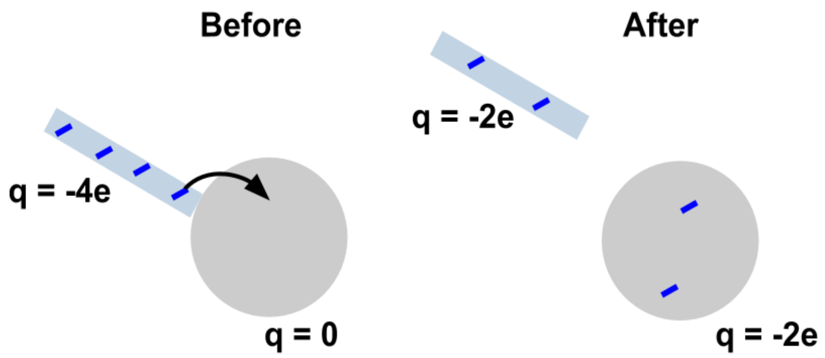
“Law” of conservation of charge: **The algebraic sum of all the electric charges in any closed system is constant. Thus the net amount of electric charge produced in any process is zero.**

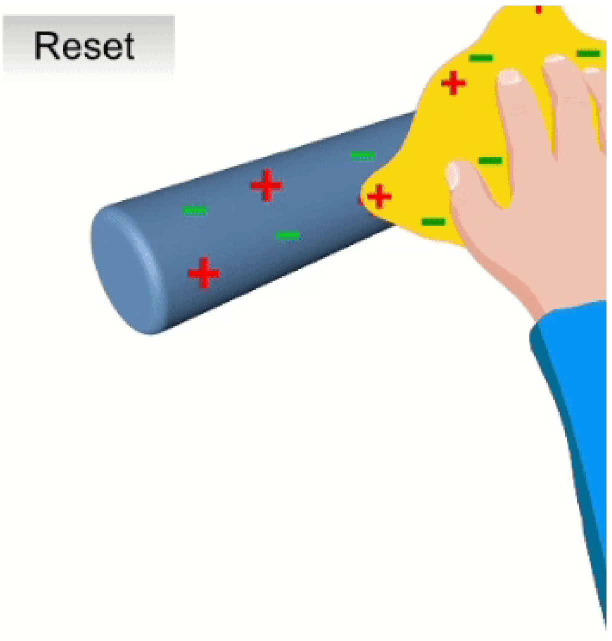


“Law” of conservation of charge: The algebraic sum of all the electric charges in any closed system is constant. Thus the net amount of electric charge produced in any process is zero.

$$e^- + e^+ \rightarrow \gamma + \gamma \quad \text{(annihilation)}$$

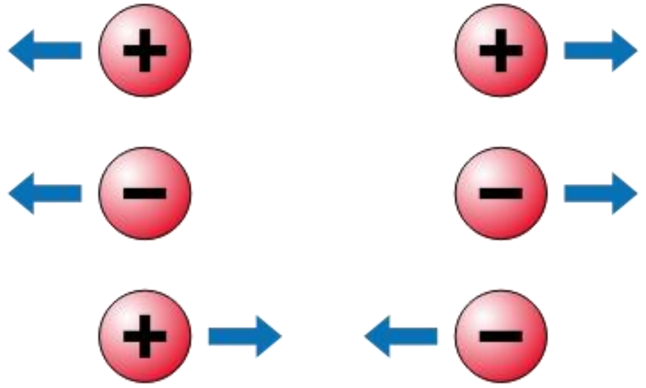
$$\gamma \rightarrow e^- + e^+ \quad \text{(pair production)}$$



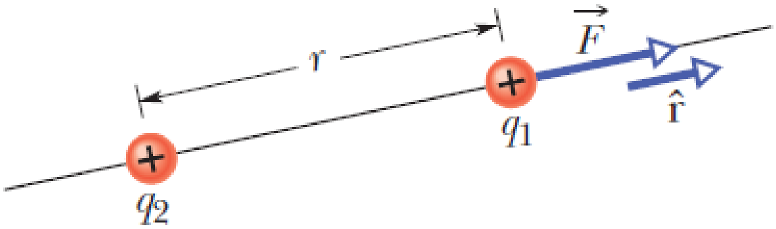


Coulomb’s Law

Coulomb (1736-1806) carried out accurate experiments to determine how the electrostatic force depends on the distance between charged "point" objects as well on the magnitudes of their charges. He demonstrated that the magnitude of the electrostatic force varies as $1/r^2$ where r is the distance between the point objects.



If two charged particles are brought near each other, they each exert an **electrostatic force** on the other.



Coulomb’s Law

The direction of the force vectors depends on the signs of the charges.

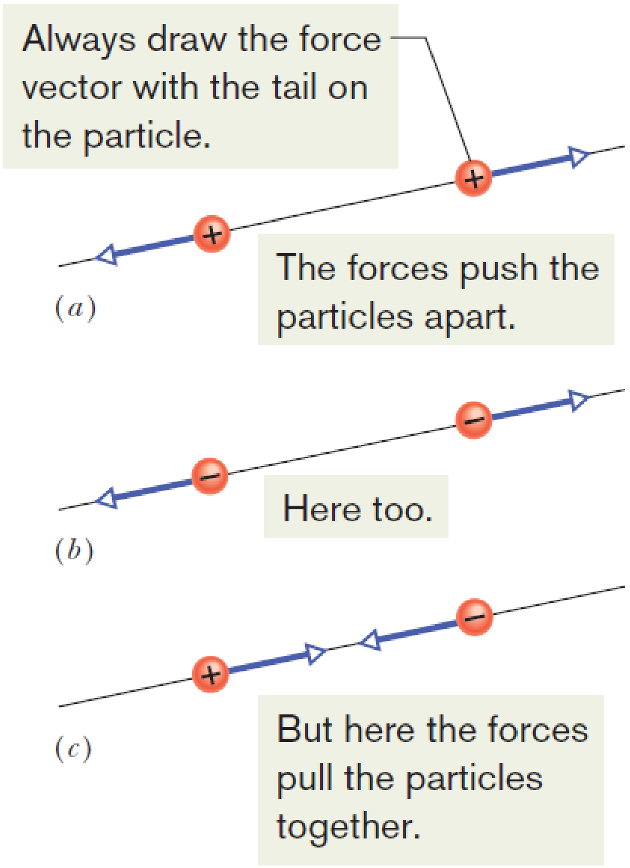
If the particles have the same sign of charge, they repel each other.

That means that the force vector on each is directly away from the other particle.

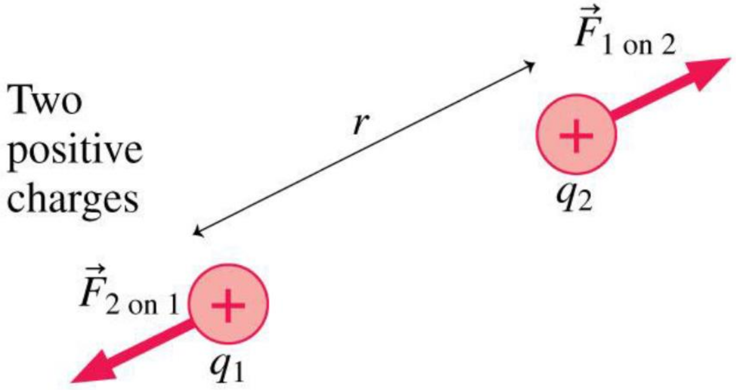
If we release the particles, they accelerate away from each other.

If, instead, the particles have opposite signs of charge, they attract each ot

That means that the force vector on each is directly toward the other particle. If we release the particles, they accelerate toward each other.



Coulomb's Law



Expression:

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

where r is the separation between the particles and k is a positive constant called the *electrostatic constant* or the *Coulomb constant*.

- The force between the charges is proportional to each charge separately.
- The force acts along the line connecting the two charges.
- The force is repulsive if the charges have the same sign, attractive if they have different signs.
- The force is inversely proportional to the square of the distance between them.

where $k = 9 \times 10^9\ Nm^2/C^2$ and carries the units of charge.

The constant k is also written in terms of the permittivity of free space ϵ_0: $k = 1/4\pi\epsilon_0$, where $\epsilon_0 = 8.854 \times 10^{-12}\ C^2/Nm^2$

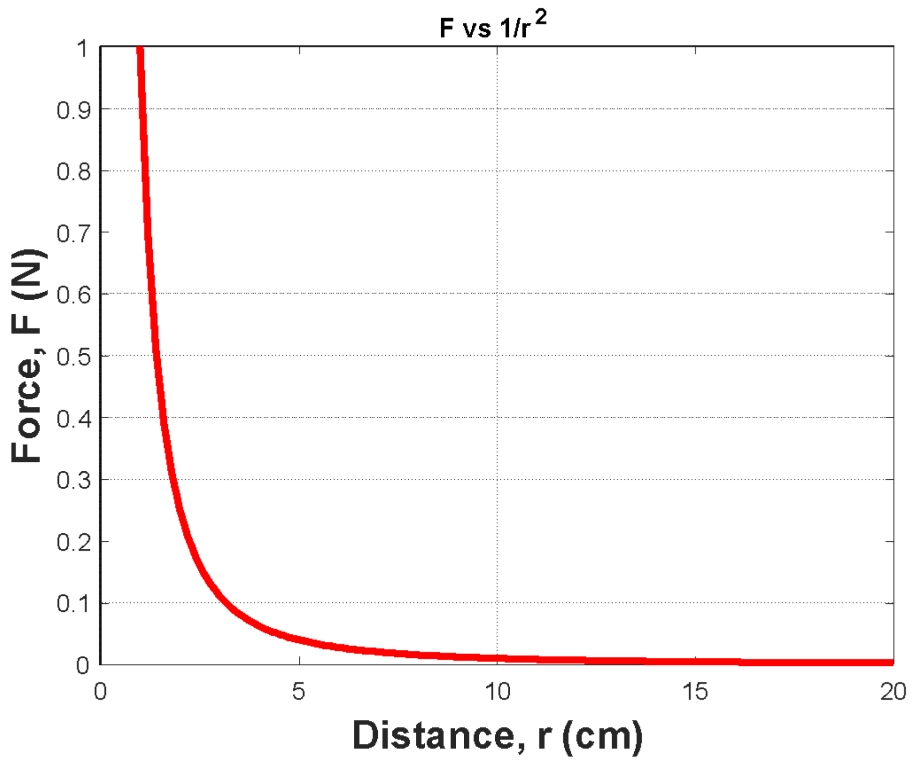
Coulomb's Law

Comparison with Gravitational law:

$$\vec{F}_{12} = k\frac{q_1 q_2}{r^2}\hat{r}_{12}$$

$$\vec{F}_{12} = G\frac{m_1 m_2}{r^2}\hat{r}_{12}$$

Although the two types of forces are wildly different, both equations describe inverse square laws (the $\frac{1}{r^2}$ dependences) that involve a product of a property of the interacting particles—the charge in one case and the mass in the other.



http://physics.bu.edu/~duffy/HTML5/coulomb1.html

https://ophysics.com/em1.html

$k = 9\times10^{9}\ Nm^2/C^2$

$G = 6.6\times10^{-11}\ Nm^2/kg^2$

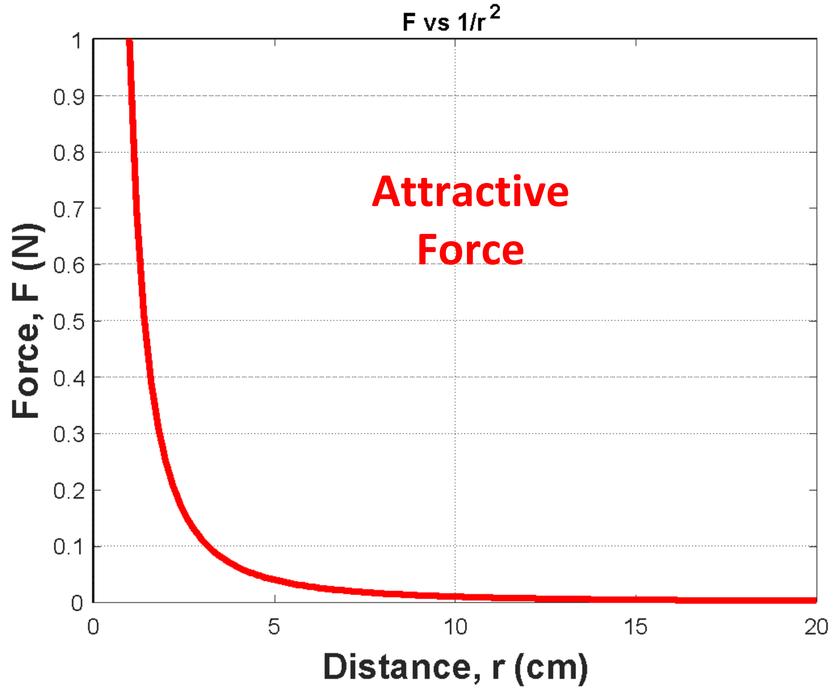
Coulomb's Law

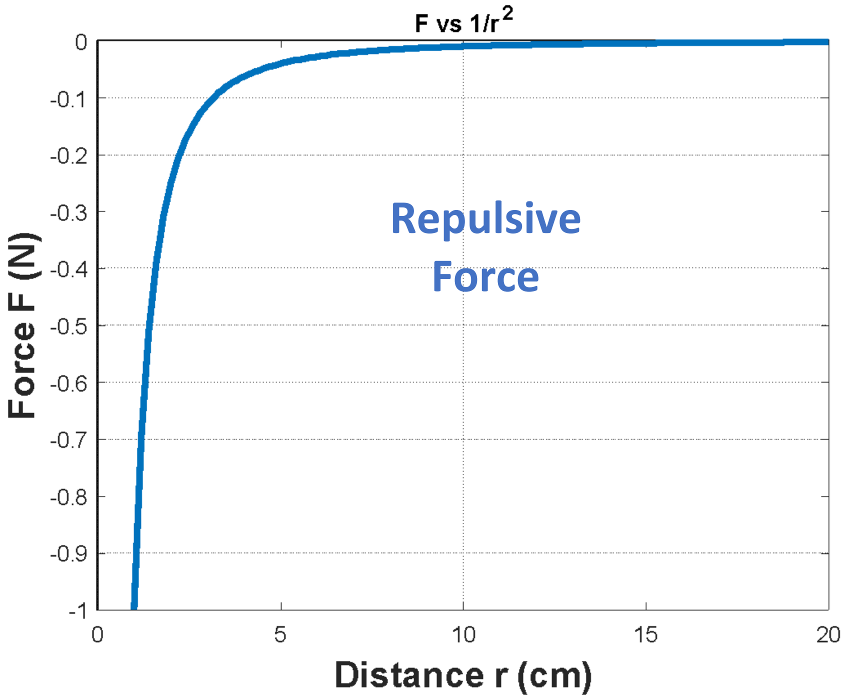
Comparison with Gravitational law:

However, the laws differ in that gravitational forces are always attractive but electrostatic forces may be either attractive or repulsive, depending on the signs of the charges.

This difference arises from the fact that there is only one type of mass but two types of charge.

We will see the difference in strength of these two forces.





Coulomb’s Law

It is sometimes convenient to express Coulomb's electrostatic force law with direction, that is to use vectors for the appropriate quantities.

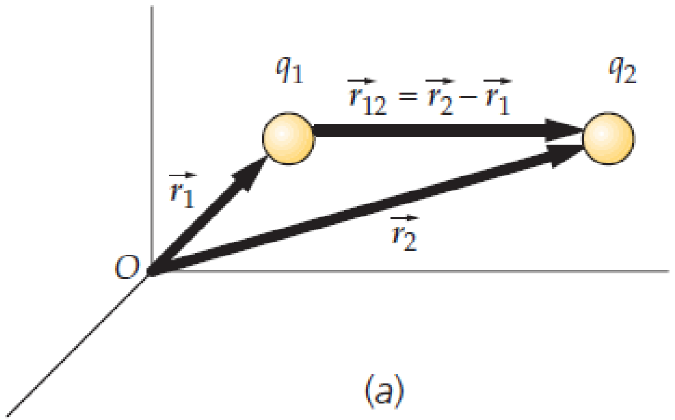
If we define $\vec{F}_{12}$ as the force on point particle 2 due to point particle 1, then

$$\vec{F}_{12} = k\frac{q_1 q_2}{r^2}\hat{r}_{12}$$

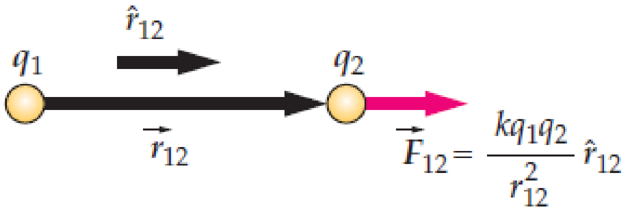
where $\hat{r}_{12} = \frac{\vec{r}_{12}}{|\vec{r}_{12}|}$ is the unit vector pointing from particle 1 to particle 2

and $\vec{r}_{12} = \vec{r}_2 - \vec{r}_1$

Note, that for like charges the product $q_1 q_2$ is positive and particle 2 feels a force away from particle 1, $+\hat{r}_{12}$. For unlike charges the product $q_1 q_2$ is negative the force 1 feels is toward 2, $-\hat{r}_{12}$.



(a)



(b)

https://phet.colorado.edu/sims/html/coulombs-law/latest/coulombs-law_en.html

Coulomb’s Law: Notes

1. The formula is only valid for point particles

How small is small enough to be considered a "point particle"? If the largest dimension of the particles is d, and the separation of the particles is r, then if $\frac{d}{r} << 1$ the particles can be considered as points and the formula should apply.

2. The mass of the particles does not effect the electrical force

3. The force is called electro-static

It is because the force does not depend on the velocity of the particles. The Coulomb's law force is the same if the particles are stationary or moving. We will see (later in the course) that if the charged particles are moving there is another force that depends on their speeds: the magnetic force.

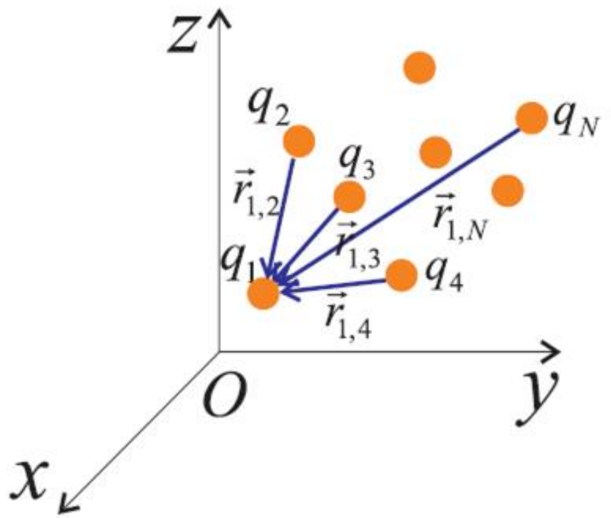
4. The magnitude of the force decrease as $1/r^2$

5. Coulomb's Law holds at atomic length scales. It is one of the more important forces in the atom.

Coulomb's Law

Multiple Forces

As with all forces, the electrostatic force obeys the principle of superposition. Suppose we have *n* charged particles near a chosen particle called particle 1; then the net force on particle 1 is given by the vector sum



$$\vec{F}_{1,net} = \vec{F}_{1,2} + \vec{F}_{1,3} + \vec{F}_{1,4} + \cdots + \vec{F}_{1,n}$$

This equation is the key to many of the homework problems

http://physics.bu.edu/~duffy/HTML5/coulomb_interaction.html

Coulomb's Law: Notes

In electrostatics problems (that is, problems that involve charges at rest), it's very unusual to encounter charges as large as 1 coulomb.

Two 1-C charges separated by 1 m would exert forces on each other of magnitude $9 \times 10^9 N$(about 1 million tons)!

The total charge of all the electrons in a copper one-cent coin is even greater, about $1.4 \times 10^5 C$ which shows that we can't disturb electric neutrality very much without using enormous forces.

More typical values of charge range from about microcoulomb, $1\ \mu C = 10^{-6} C$
to about nanocoulomb, $1\ nC = 10^{-9} C$

It turns out that 1 C is the charge associated with 6.25 billion billion electrons.

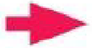
Static electricity is a problem at gasoline pumps. Even the tiniest spark can ignite gasoline vapors and cause fires frequently lethal.

A good safety rule is to touch metal and discharge static charge from your body before you fuel. Also, don’t use a mobile phone when fueling.

Looking Ahead: Charges and Coulomb's Law

- A comb rubbed through your hair attracts a thin stream of water. The **charge model** of electricity explains this force.

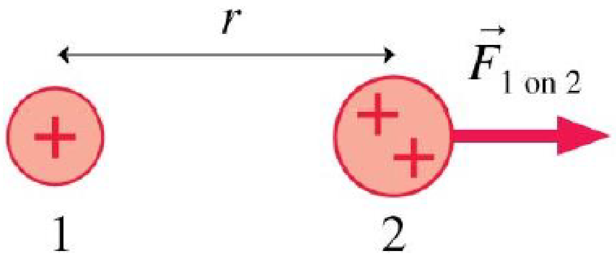
The charge of sphere 2 is twice that of sphere 1. Which vector below shows the force of 1 on 2 if the distance between the spheres is reduced to $r/2$?

A. 

B. 

C. 

D. None of the above.



The direction of the force on charge $-q$ is

A. Up
B. Down
C. Left
D. Right
E. The force on $-q$ is zero

Which of the three right-hand charges experiences the largest force?

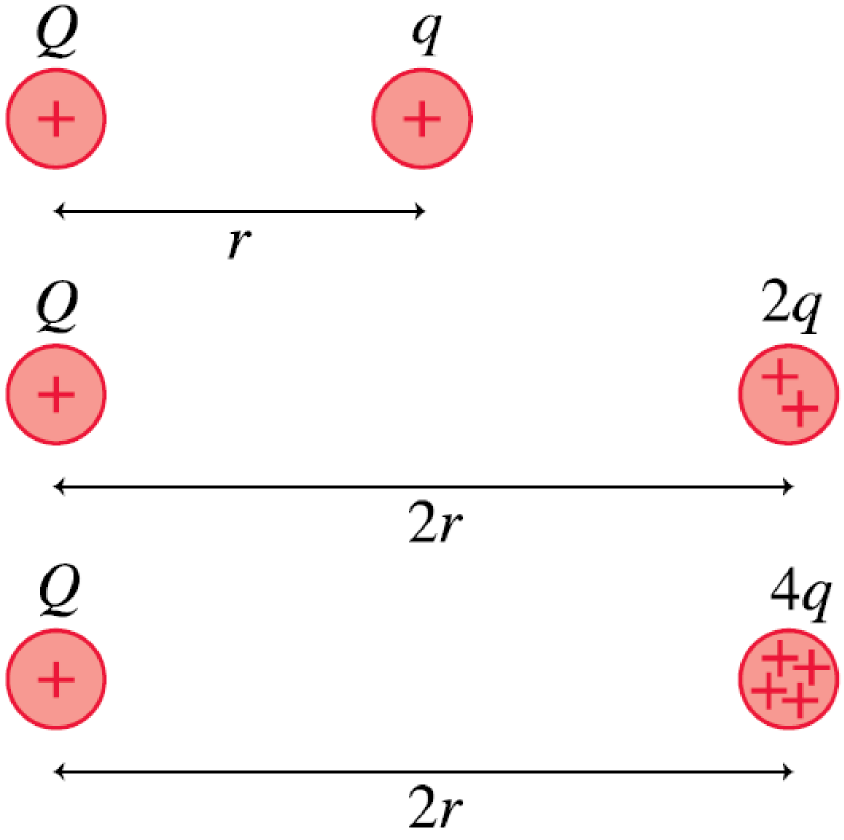
A. q

B. $2q$

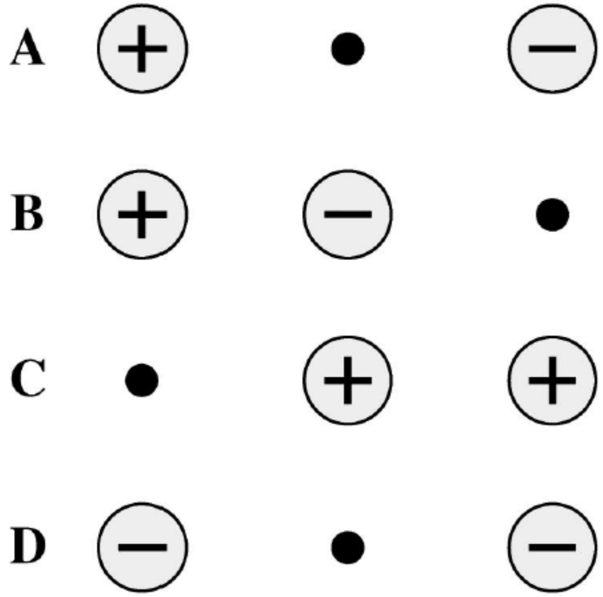
C. $4q$

D. q and $2q$ are tied

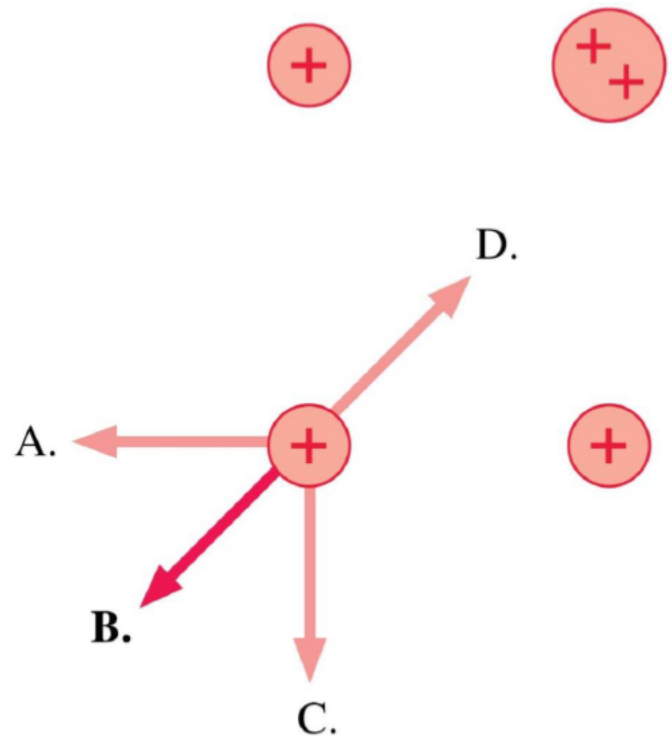
E. q and $4q$ are tied



In each of the following cases, an identical small, positive charge is placed at the black dot. In which case is the force on the small charge the largest? (All charges shown are of equal magnitude.)

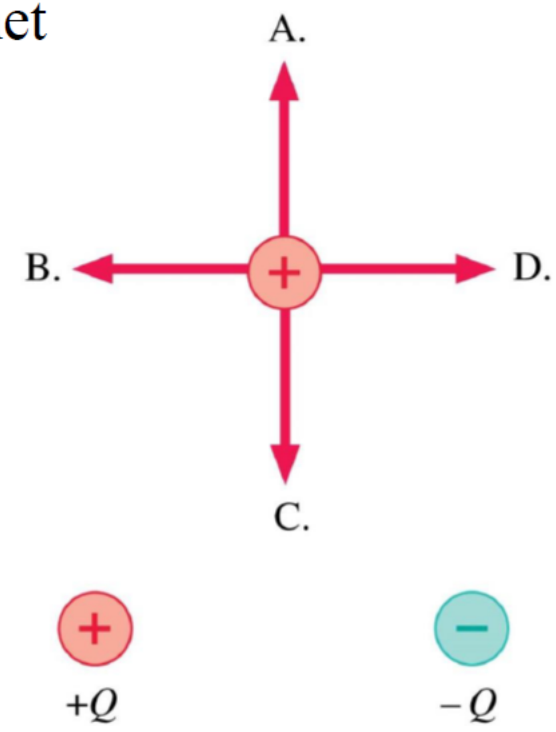


Which is the direction of the net force on the charge at the lower left?



E. None of these.

Which is the direction of the net force on the charge at the top?

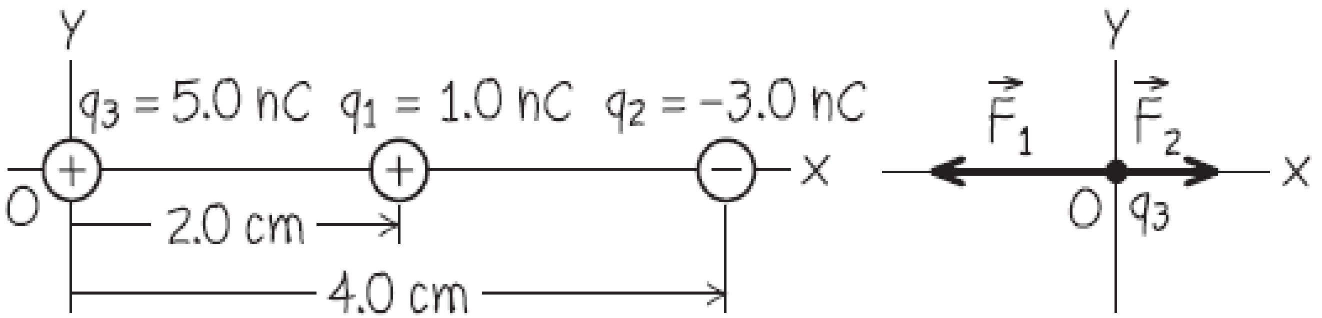


E. None of these.

Two point charges are located on the x-axis of a coordinate system: $q_1 = 1.0$ nC is at $x = +2.0$ cm, and $q_2 = -3.0$ nC is at $x = +4.0$ cm. What is the total electric force exerted by q_1 and q_2 on a charge $q_3 = 5.0$ nC at $x = 0$?

(a) Our diagram of the situation

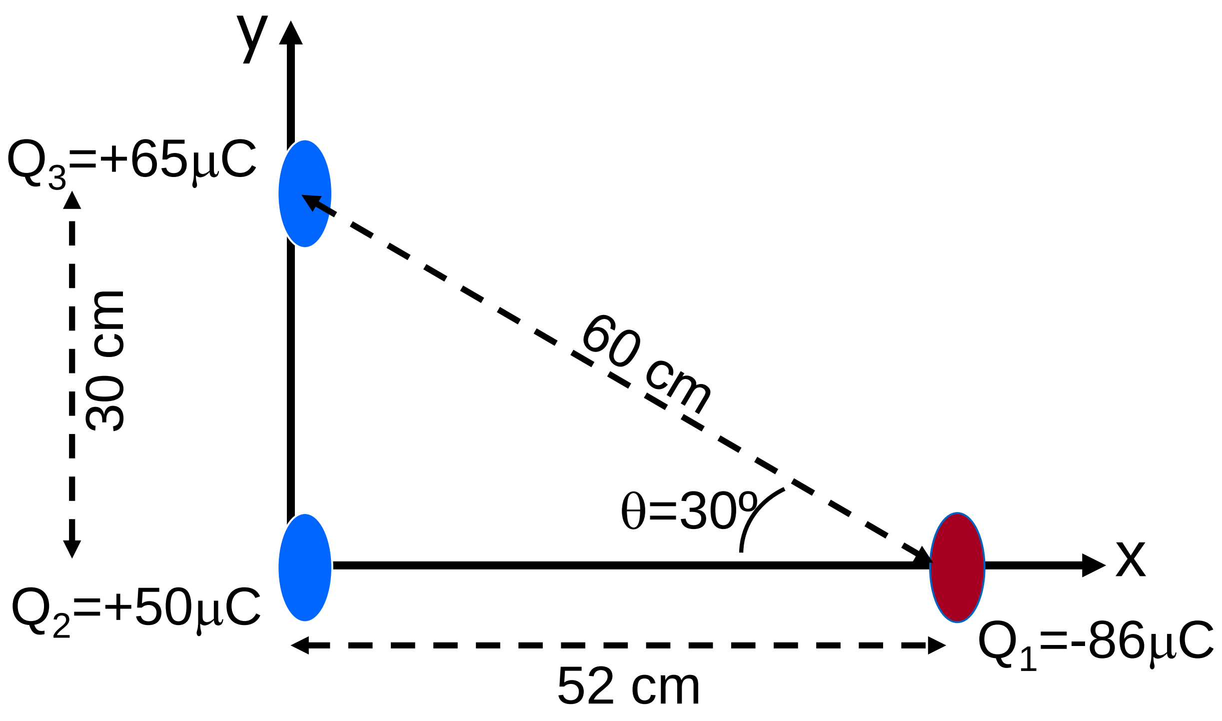
(b) Free-body diagram for q_3



Solving Problems Involving Coulomb’s “Law” and Vectors

You may wish to review vectors (on your own).

Example: Calculate the net electrostatic force on charge Q_3 due to the charges Q_1 and Q_2.

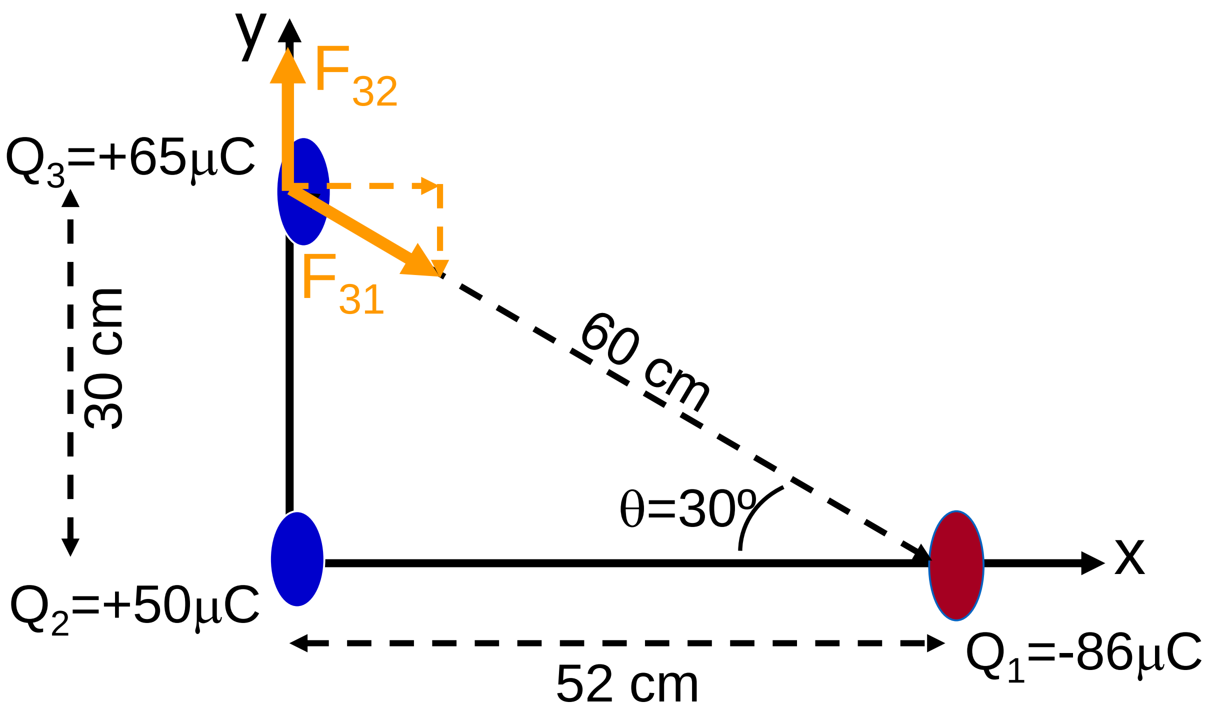


Step 1: Diagram

Draw a representative sketch

Draw and label relevant quantities

Draw axes, showing origin and directions

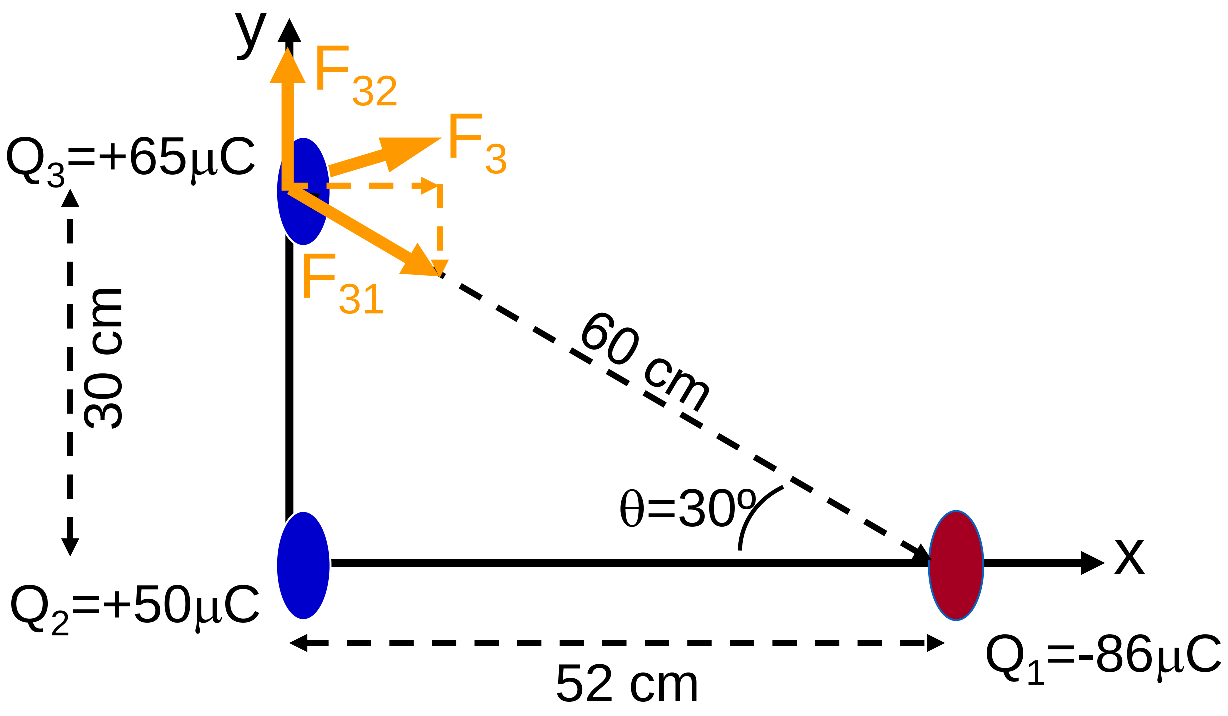


Draw and label forces (only those <u>on</u> Q_3).

Draw components of forces which are not along axes.

Step 3: Complete the Math

The net force is the vector sum of all the forces on Q_3.

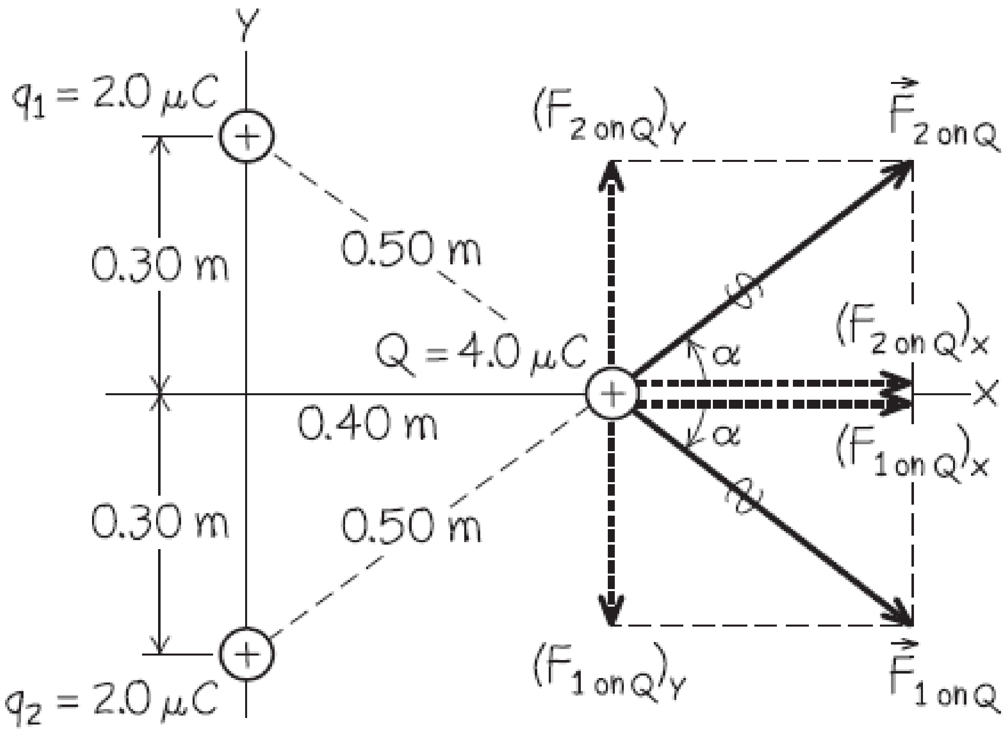


$F_{3x} = F_{31,x} + F_{32,x}$ = 120 N + 0 N = 120 N

$F_{3y} = F_{31,y} + F_{32,y}$ = -70 N + 330 N = 260 N

You know how to calculate the magnitude F_3 and the angle between $\vec{F}_3$ and the x-axis. (If not, holler!)

Two equal positive charges $q_1 = q_2 = 2.0\ \mu C$ are located at $x = 0$, $y = 0.30$ m and $x = 0$, $y = -0.30$ m, respectively. What are the magnitude and direction of the total electric force that q_1 and q_2 exert on a third charge $Q = 4.0\ \mu C$ at $x = 0.40$ m, $y = 0$?



Summary Topics

- Distinguish between being electrically neutral, negatively charged, and positively charged and identify excess charge.

- Explain how a charged object can set up induced charge in a second object.

- For either of the particles in a pair of charged particles, apply Coulomb's law to relate the magnitude of the electrostatic force, the charge magnitudes of the particles, and the separation between the particles.

- Identify that a shell of uniform charge attracts or repels a charged particle that is outside the shell as if all the shell's charge were concentrated as a particle at the shell's center. Identify that if a charged particle is located inside a shell of uniform charge, there is no net electrostatic force on the particle from the shell.