NEW JERSEY CENTER
FOR TEACHING & LEARNING

PSI®

Progressive Science Initiative®

njea

NEW JERSEY CENTER
FOR TEACHING & LEARNING

AP Physics 1
AP Physics 2

Electric Force and Field

2016-07-18

www.njctl.org

Electric Force and Field

Click on the topic to go to that section

- Electric Charge
- Atomic Structure and source of Charge
- Conduction and Induction
- Electroscope
- Electric Force - Coulomb's Law
- Electric Force in Two Dimensions
- Electric Field
- Electric and Gravitational Fields
- Electric Field of Multiple Charges
- Electric Field in Two Dimensions

Electric Charge

Demo

Return to Table of Contents

Charging by Rubbing

When you take two non metallic objects, such as a plastic ruler and animal fur and rub them together, you get an interesting effect. Before they are rubbed, the plastic ruler is held over bits of paper and nothing happens.

After the rubbing, the plastic ruler is held over the bits of paper and they are accelerated towards the ruler.

without rubbing

...rub

after rubbing

Electric Charge

Since the paper bits were accelerated upwards, against the force of gravity, what interaction was occurring between the ruler and the paper? A **Force**.

It has been known since ancient times that when certain materials are rubbed together, they develop an attraction for each other (This can be seen today when you take clothes out of a dryer).

In ancient Greece - people noticed that when thread was spun over a spindle of amber, the thread was attracted to the spindle.

The Greek word for amber was "elektron," hence this FORCE was called electric.

Electric Charge

Further experimentation showed that dissimilar materials would attract each other after rubbing, while similar materials would repel each other.

These effects would not happen without the contact, and later, given enough time, the forces of attraction and repulsion would stop.

This led to the thought that something was being exchanged between the materials - and this something was later named "charge." Because objects would be repelled or attracted, it was postulated that this charge came in two types.

Electric Charge

In the 18th century, Benjamin Franklin named the two types of charge when he observed the attraction between a rubber rod and animal fur when they were rubbed together. Benjamin named the charge on the rod, negative, and the charge on the fur, positive.

When a glass rod is rubbed by silk, the rod acquires a positive charge and the silk obtains a negative charge. The two rubber rods now repel each other, and a rubber rod is attracted to a glass rod.

Electric Charge

No new charge is created - instead, it is just separated - the positive charge acquired by one object is exactly **equal in magnitude and opposite in sign** to the charge lost by the other object.

What is another way of saying this?

Electric Charge

Electric Charge is a conserved quantity.

The total amount of electric charge in a closed system remains constant - it is neither created or destroyed.

Just like energy, linear momentum, and angular momentum are conserved quantities.

1 A neutral plastic rod is rubbed by a piece of animal fur. During the process, the plastic rod acquires a positive charge and the fur:

A acquires an equal positive charge.

B acquires an equal negative charge.

C acquires a smaller positive charge.

D acquires a smaller negative charge.

Answer

2 A positively charged object is moved towards a negatively charged object. What is the motion of the objects when they come close to each other?

A Neither object has any affect on the other.

B The objects move towards each other.

C The objects move away from each other.

D The objects move towards each other, then move away from each other as they get closer (but they don't touch).

Answer

3 A neutral glass rod is rubbed by a piece of silk with no net charge. The rod gains a positive net charge and the silk gains a net negative charge. What is the sum of the charges on the silk and the rod?

A Zero.

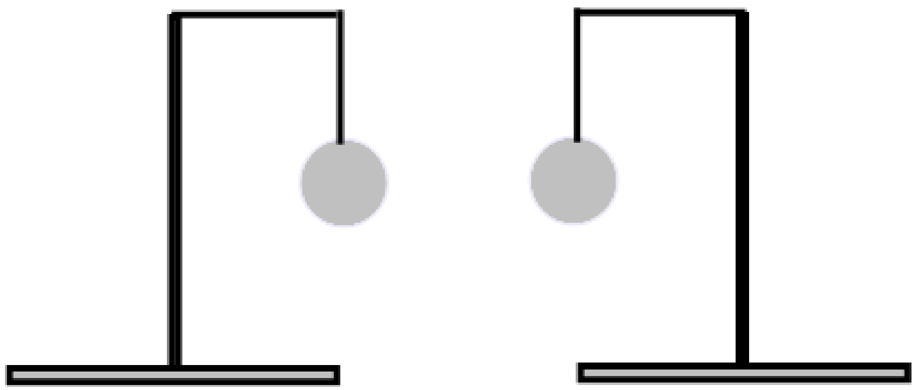
B Twice the charge on the rod.

C Twice the charge on the silk.

D One half of the charge on the rod.

Answer

4 Two pith spheres covered with conducting paint are hanging from two insulating threads. When the spheres are brought close to each other, they attract each other. What type of charge is on the spheres? After they touch, will they separate or cling together? Discuss all possibilities.



Answer

Atomic Structure and Source of Charge

Return to Table of Contents

Atomic Structure

To understand where the phenomenon of electric charge comes from, the basic structure of matter needs to be discussed.

All matter is made up of atoms, which are made up of protons, neutrons and electrons.

Each atom contain a central nucleus that is composed of protons and neutrons (nucleons). Electrons move around the nucleus in the empty space of the atom.

Electrons are *fundamental particles* - they have no underlying structure. Protons and neutrons are not fundamental particles. They are made up of quarks - which are fundamental particles.

The Electron

J.J.Thomson found a particle that had a very low mass for its charge. In fact, its mass per charge was 1800 times less than the previous lowest amount measured for a particle. Before this work, physicists were speculating that the Hydrogen atom was the smallest fundamental particle.

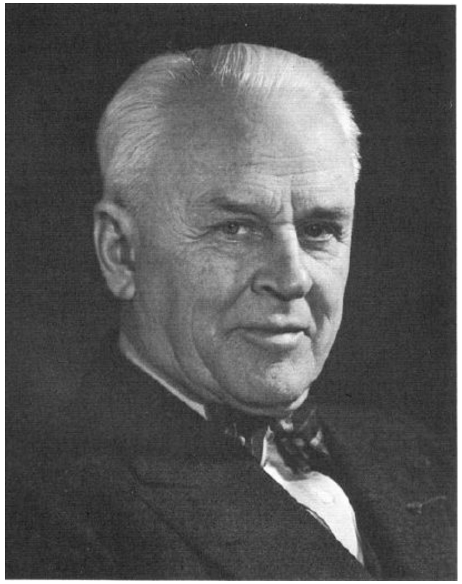
This led Thomson to propose that this negatively charged particle was new - and he called them "corpuscles." The name "electron" was taken from George Johnstone Stoney's work in 1874, and proposed again by George F. Fitzgerald - and the name stuck.

Furthermore, since the electron was so much lighter than the hydrogen atom, it was concluded that it must be part of the atom.

Measurement of Charge

The electron was discovered by J.J. Thomson in 1897, and in a series of experiments between 1909 and 1913, Robert Millikan and his graduate student, Harvey Fletcher, established the value of the charge, "e," on an electron.

J.J. Thomson



Robert Millikan

Measurement of Charge

Millikan and Fletcher's work and subsequent experiments have established the value of "e" as 1.602×10^{-19} Coulombs.

It has also been demonstrated that this is the smallest value of charge (with the exception of quarks which will be covered shortly) and all larger charges are an integral multiple of this number.

Because small amounts of charge can generate large amounts of force, charge is often measured in:

milli-Coulombs (mC) = 10^{-3} C

micro-Coulombs (μC) = 10^{-6} C

nano-Coulombs (nC) = 10^{-9} C

Properties of the Electron

Further research showed that the electron has a mass of
9.1×10^{-31} kg.

$$q_e = e = 1.6 \times 10^{-19} \text{ C}$$

$$m_e = 9.1 \times 10^{-31} \text{ kg}$$

While finding the charge on an electron, it was discovered that the charge on any object was an integral multiple of the electron charge.

Thus, you can have a charge of 3.2×10^{-19} C on an object, but you can't have a charge of 3.0×10^{-19} C!

The charge on any object is always an integral (1, 2, ..., 1,000,056, ...) multiple of 1.6×10^{-19} C.

5 Which of these choices could be the total charge on an object ($e = 1.6 \times 10^{-19}$ C)?

A 0.80×10^{-19} C

B 2.0×10^{-19} C

C 3.2×10^{-19} C

D All of the above.

Answer

6 Which of these choices could be the total charge on an object ($e = 1.6 \times 10^{-19}$ C)?

A 4.8 C

B 3.0 C

C 3.0 mC

D All of the above.

Answer

7 The electron was discovered by:

A J. J. Thomson

B Robert Millikan

C Harvey Fletcher

D Ernest Rutherford

Answer

8 The electron charge was first measured accurately by:

A J. J. Thomson

B Robert Millikan and Harvey Fletcher

C Niels Bohr and Paul Dirac

D Ernest Rutherford

Answer

Charge on Nucleons

Protons and electrons have equal and opposite charge. By convention (set by Ben Franklin), electrons have a negative charge and protons have a positive charge. This is the origin of charges on material objects. Neutrons have no charge (neutral).

Atoms are electrically neutral - not because they contain no charge - but because they have equal numbers of protons and electrons - their total charge adds up to zero.

If an atom gains electrons, it has a net negative charge and is called a negative ion. If it loses electrons, then it has a positive charge and is called a positive ion.

The Nature of Charge

Like energy and momentum, charge is neither created nor destroyed, it is conserved.

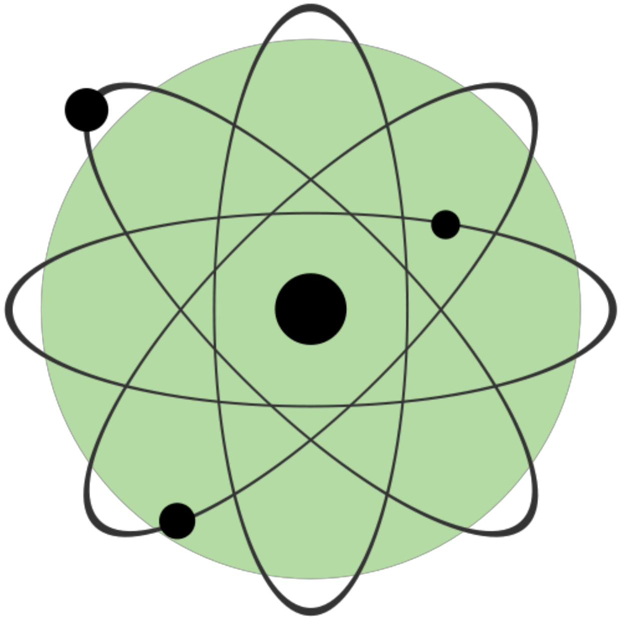
Opposite charges attract and like charges repel. As a result negatively charged electrons are attracted to the positive nucleus.

Despite the great mass difference, the charge on an electron is exactly equal in magnitude to the charge on a proton, and its magnitude is denoted by "e."

An electron is has a charge of -e and
a proton, a charge of +e.

What the atom doesn't look like:

This is NOT what an atom looks like!!!

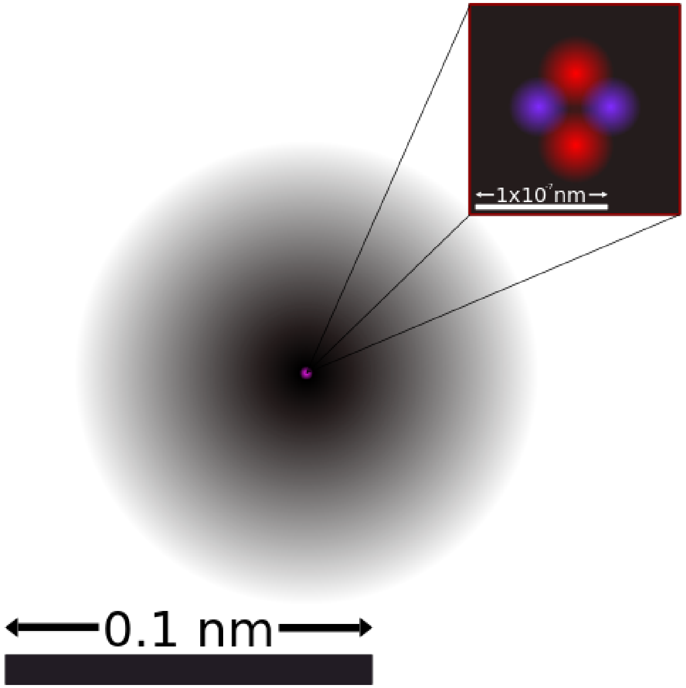


If an atom was magnified so that the nucleus was the size of a baseball, the atom would have a radius of 4 km.

And the electrons would be approximately the size of the period at the end of this sentence. Atoms are almost all empty space.

Since everything (including us) is made of atoms, that means everything (including us) is mostly empty space.

What the atom does look like:



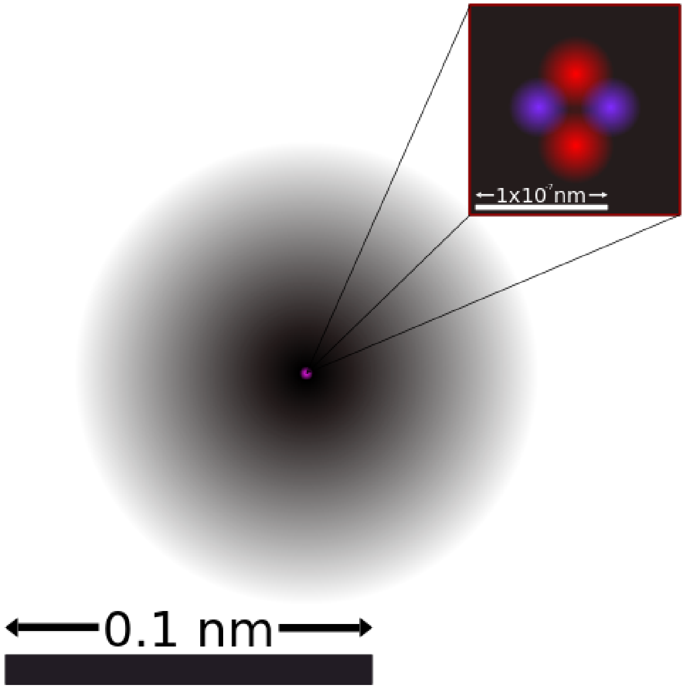
Here's a more realistic visualization of a Helium atom. The nucleus is buried deep within the atom and is 1,000,000 times smaller than the atom.

The two protons and two neutrons are shown in red and purple - the width of the nucleus is $1x10^{-7}$ nm.

The diagram shows a magnified view of the nucleus - it fits within the darker circle.

What is the significance of the dark circle surrounded by the lighter shades of gray and pink?

What the atom does look like:



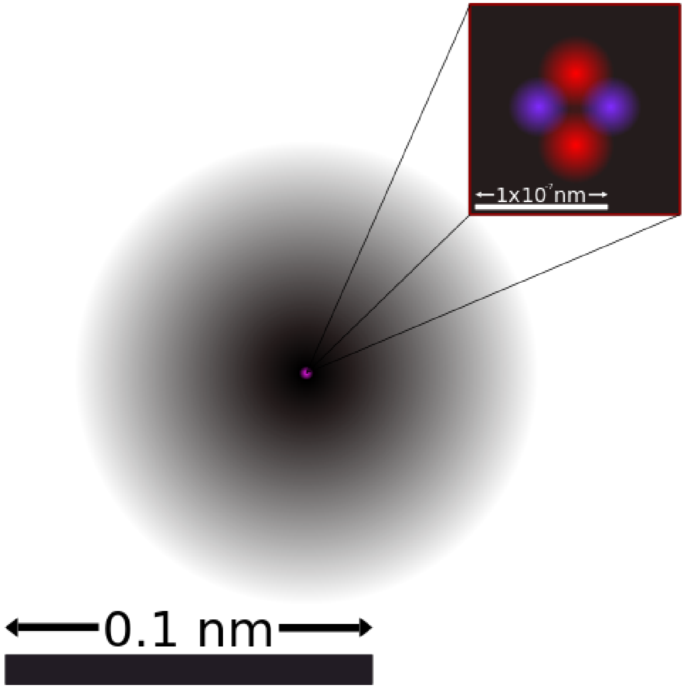
You know that Helium has two electrons - yet they're not shown on this picture.

That's because we don't know exactly where those electrons are. We only know a probability of where they are.

The darker the shade means that it is more probable that the electrons are found within that shape.

For more information, refer to the Quantum Physics and Atomic Modeling chapter of the AP 2 Physics class.

What the atom does look like:

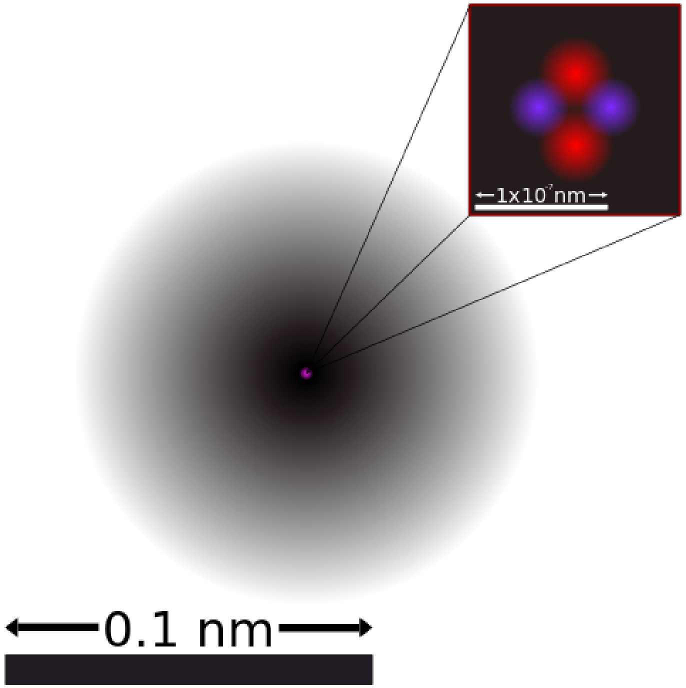


http://commons.wikimedia.org/wiki/File:Helium_atom_QM_rev1.svg

It has been shown that electric charges move between objects. Based on this picture of the atom, which of the constituents of the atom look like they could move?

Would it be the neutrons and protons buried deep within the atom or the electrons?

What the atom does look like:



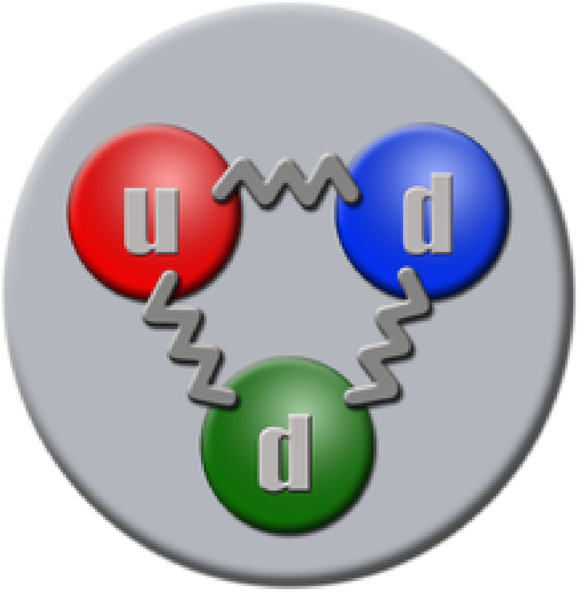
http://commons.wikimedia.org/wiki/File:Helium_atom_QM_rev1.svg

The electrons are the particles that will move between atoms - they are not bound together as tightly as the protons and the neutrons.

The electrons are fundamental particles. At the moment, physicists have not found any further structure within the electron.

However - the same cannot be said for the neutrons and the protons.

Neutron and Proton Structure - Quarks!

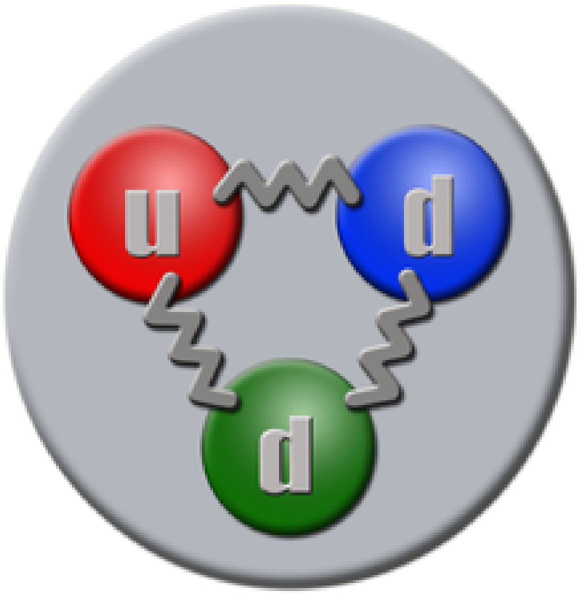


Neutron

Neutrons and protons are actually made up of elementary particles called **quarks**. Murray Gell-Man, along with George Zweig, proposed the existence of these particles to help explain the many different types of particles that make up matter.

Murray coined the term by taking it from James Joyce's novel, Finnegan's Wake, an interesting intersection of physics and art.

Neutron and Proton Structure - Quarks!



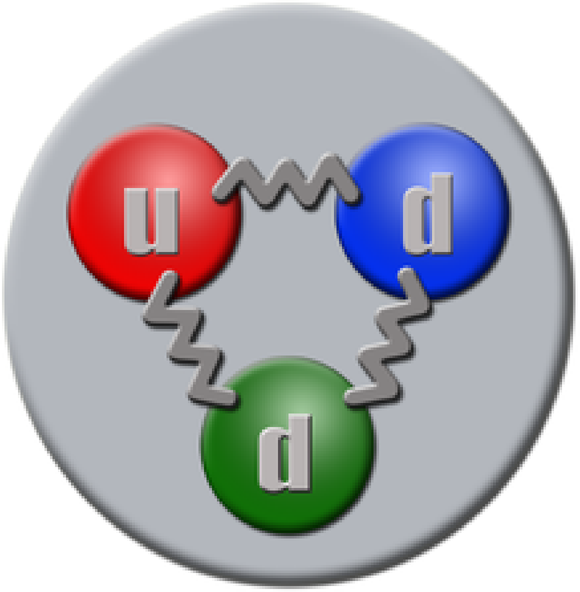
Neutron

There are six types, or flavors, of quarks that describe their properties, and they are further classified according to their color (not a real color - just a handy inventory management tool). They are: up, down, strange, charm, top and bottom.

And they have charges that are either $\pm$2/3 e or $\pm$1/3 e! Before this work in the 1960's, it was thought that the smallest charge on a particle was e.

A neutron (to the left) is composed of an up quark and two down quarks.

Neutron and Proton Structure - Quarks!



Neutron

The study of Quarks is called Quantum Chromodynamics and is way beyond this course.

But one final interesting point - the quark is subject to all four fundamental forces - electricity and magnetism, gravity, strong nuclear, and the weak nuclear.

9 Which of the following are fundamental particles?
Select two answers.

A Electrons

B Protons

C Neutrons

D Quarks

Answer

10 An atom in its normal (non-ionic) state has no charge. This is due to the fact that atoms:

A have only neutrons.

B have no protons or electrons.

C have equal numbers of protons and electrons.

D have an equal number of protons and neutrons.

Answer

11 What object moves freely within the entire atom?

A Electron.

B Neutron.

C Proton.

D Nucleus.

Answer

12 An atom is composed of:

A a central nucleus surrounded by electrons

B an even distribution of electrons and protons in a spherical shape.

C a central nucleus surrounded by neutrons.

D a central nucleus containing protons and electrons.

Answer

13 What are neutrons and protons composed of?

A Nothing - they are fundamental particles.

B Corpuscles

C Electrons

D Quarks

Answer

Solids

Solids are a form of matter whose atoms form a fixed structure. Nuclei, with their protons and neutrons, are "locked" into position.

Solids are classified as either conductors, insulators or semiconductors.

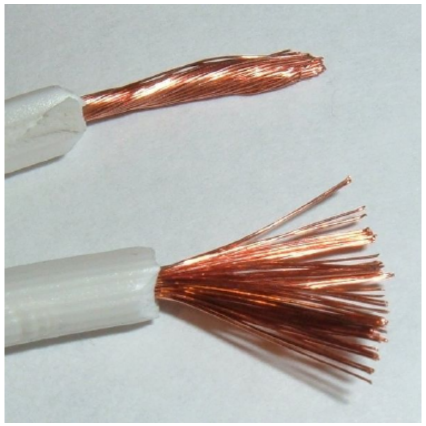
In **conductors**, some electrons are free to move through the solid and are not bound to any specific atom.

Electrons are bound to their atoms in **insulators**, and may move short distances, but much less than the electrons in a conductor.

Semiconductors, depending on their situation, act as either conductors or insulators.

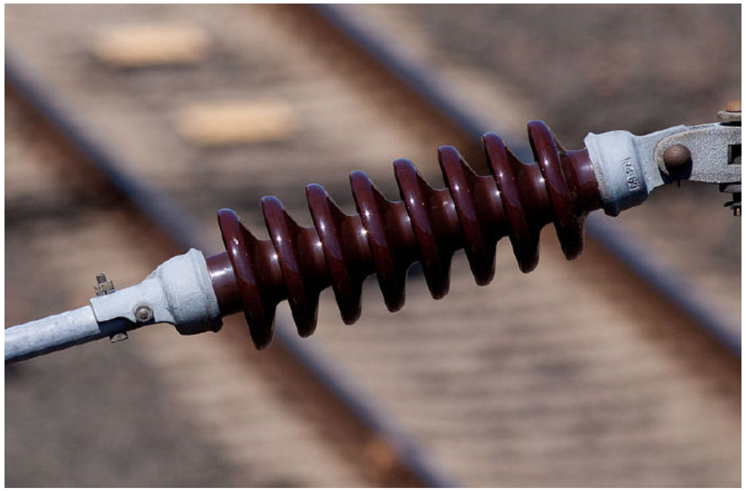
Conductors

In conductors, some electrons are mobile and can move freely inside and on the surface of the solid.



Insulators

Insulators are materials that have strongly bound electrons that can move only short distances within the solid. Different insulators have varying levels of insulation capabilities.



https://en.wikipedia.org/wiki/Insulator_(electricity)

14 Excess charge on a conductor will reside:

A on the surface of the conductor.

B at the center of the conductor.

C throughout the inside of the conductor.

D at the center and on the surface of the conductor.

Answer

15 Compared to insulators, metals are better conductors of electricity because metals contain more free ______.

A positive ions.
B negative ions.
C protons.
D electrons.

Answer

16 Electrons in an insulator are:

A bound to their atoms, but may move freely throughout the solid.

B not bound to their atoms and may move freely throughout the solid.

C bound to their atoms and may not move at all within the solid.

D bound to their atoms, but may move short distances within the solid.

Answer

17 Excess charge in an insulator will reside: **Select two answers**.

A within the insulator.

B midway between the center and the surface of the insulator.

C only at the exact center of the insulator.

D on the surface of the insulator.

Answer

Conduction and Induction

Return to Table of Contents

The Ground

Before a discussion of conduction and induction can take place, the concept of "the ground" needs to be understood.

Electrons can flow between objects - both conductors and insulators.

Electrons can also flow from Earth, which is an excellent conductor, to the objects, and from the objects to Earth. Because of its massive size, the Earth serves as the ultimate source and destination for electrons.

The concept of grounding will be discussed further in the Electric Potential unit of this course.

Grounding

When a wire is attached between the earth and a negatively charged conductor, excess electrons flow to the earth leaving the conductor neutral. This is "grounding." A positively charged object will cause electrons to flow to it from the ground.

When you touch an object with a net negative charge, you may get a shock. This is because the conductor wants to get rid of its excess electrons. To do this, electrons flow through you to the ground. If the conductor had an excess positive charge, the electrons would flow from the earth to you. In either case - there is a spark!

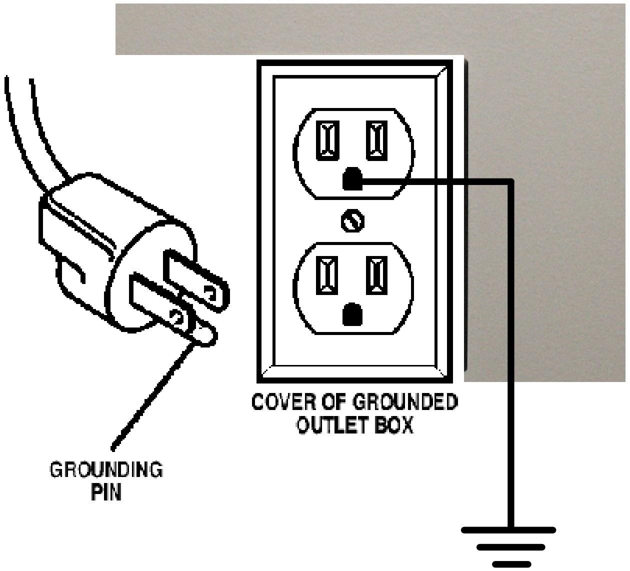
Note: grounding used to be called "*earthing*," because of the flow of electrons to and from the Earth.

Grounding

Electrical circuits and devices are usually grounded to protect them from accumulating a net charge that could shock you.

To ground an electrical device, a conductor must run from the device into the ground.

Plugs for many electrical devices have a third grounding pin that connects to a wire in the outlet box which goes to the ground.



(symbol for "ground")

Demo

18 A positively charged sphere is touched with a grounding wire. What is the charge on the sphere after the ground wire is removed?

A Depends on the magnitude of the sphere's charge.

B Neutral.

C Positive.

D Negative.

Answer

19 A negatively charged sphere is touched with a grounding wire. What is the charge on the sphere after the ground wire is removed?

A Depends on the magnitude of the sphere's charge.

B Neutral.

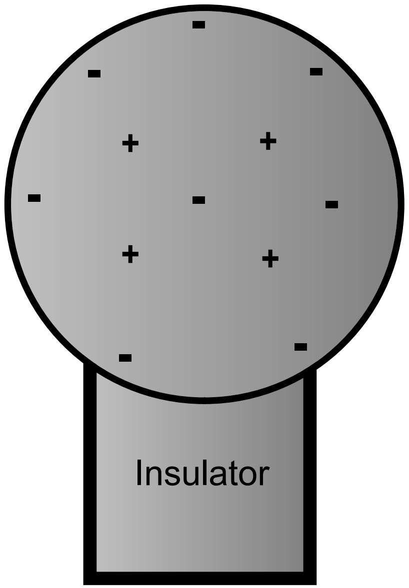
C Positive.

D Negative.

Answer

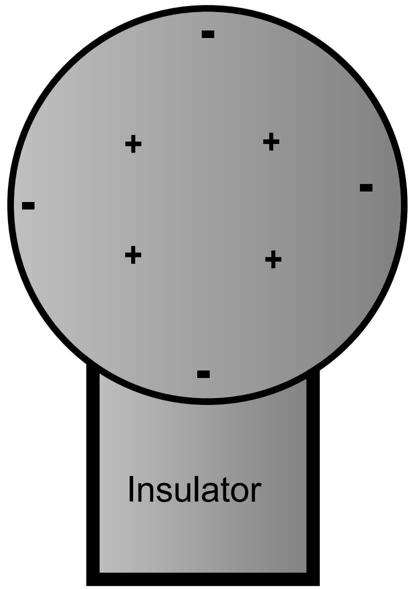
Charging by Conduction

Negatively Charged
(charge = -4Q)



Charging by conduction involves conductors that are insulated from the ground, touching and transferring the charge between them. The insulator is necessary to prevent electrons from leaving or entering the spheres from the Earth.

Neutral Charge
(charge = 0)

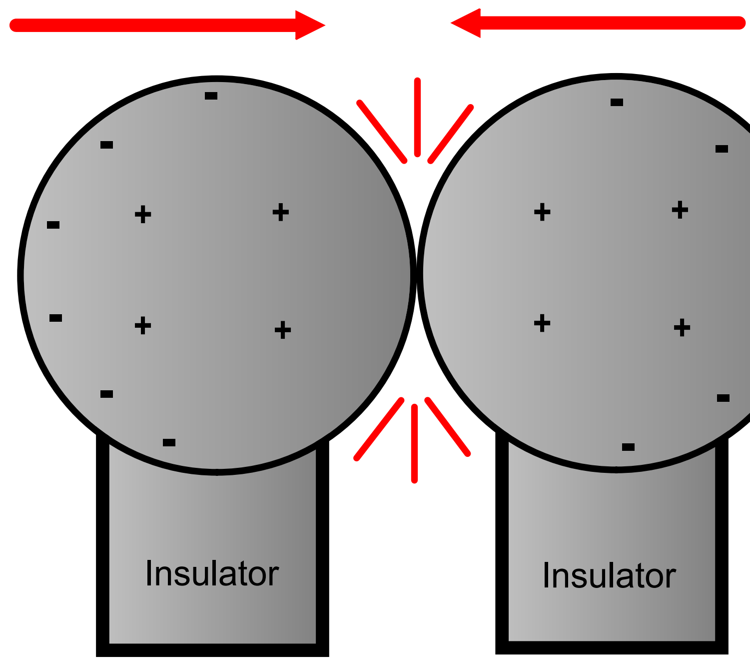


Total Charge = -4Q

(identical spheres very far apart)

Charging by Conduction

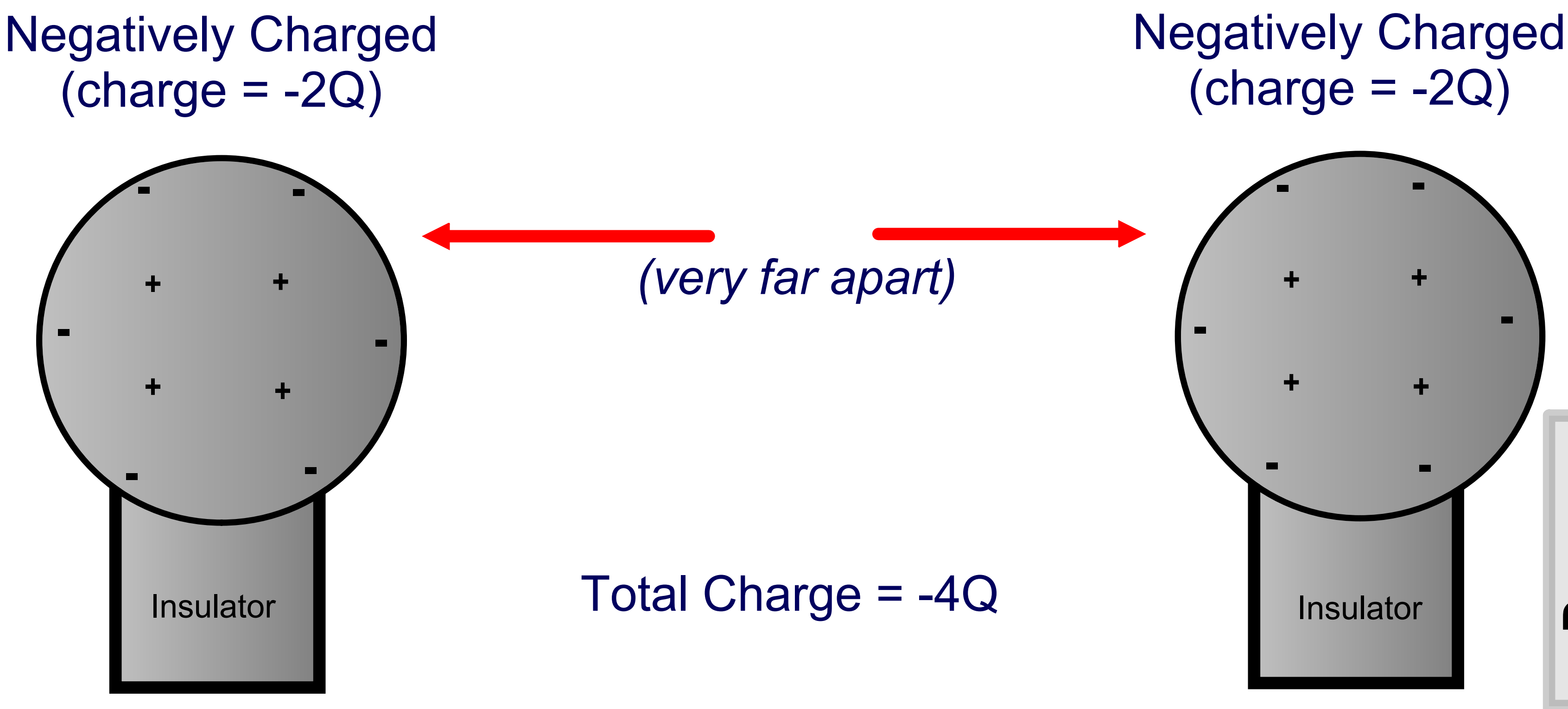
If the spheres are brought together to touch, their electrons push as far apart as they can, and the total charge is distributed equally between the two spheres. Note that the total charge stays the same.



Total Charge = -4Q

(remember, similar charges repel)

Charging by Conduction



Demo

Once they are moved apart again, the charges cannot get back to where they came from, as air serves as an excellent insulator.

This results in an equal distribution of charge.

20 If a conductor carrying a net charge of 8Q is brought into contact with an identical conductor with no net charge, what will be the charge on each conductor after they are separated?

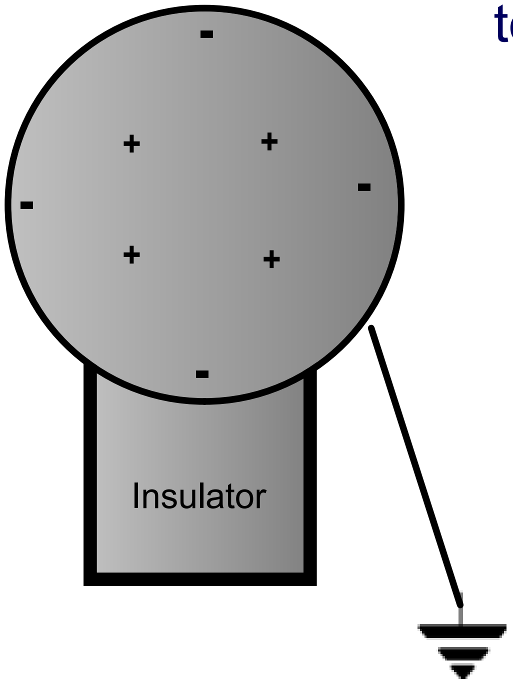
Answer

21 Metal sphere A has a charge of -2Q and an identical metal sphere B has a charge of -4Q. If they are brought into contact with each other and then separated, what is the final charge on sphere B?

Answer

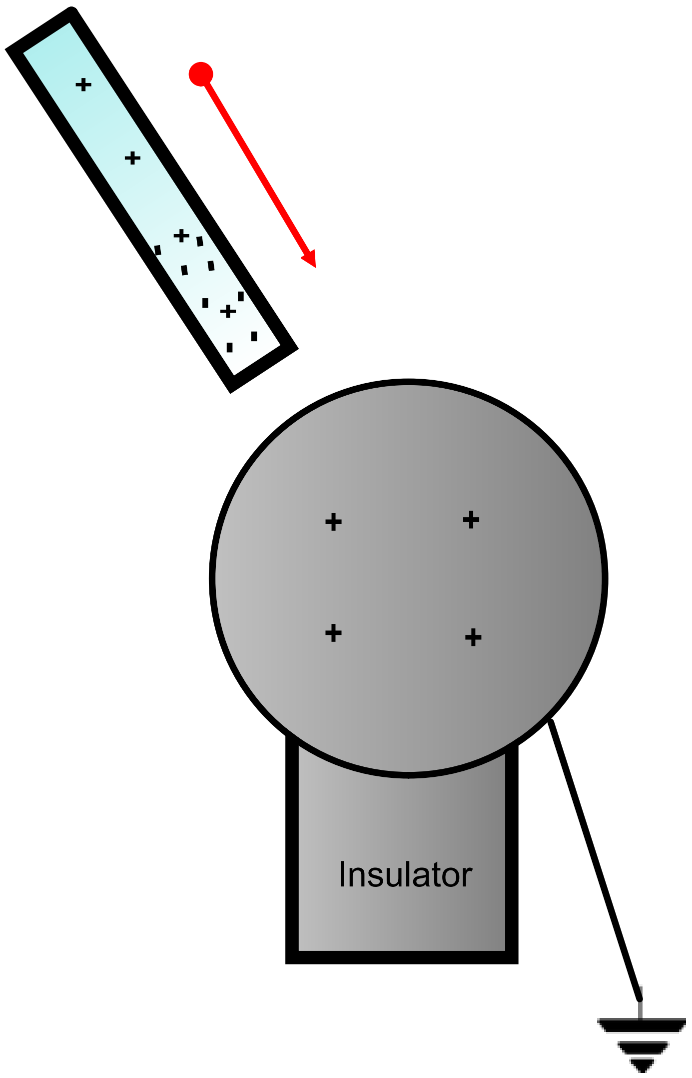
Charging by Induction

Charging by induction involves transferring charge between two objects without them touching.



This is a neutral conducting sphere, conducted to the ground via a wire.

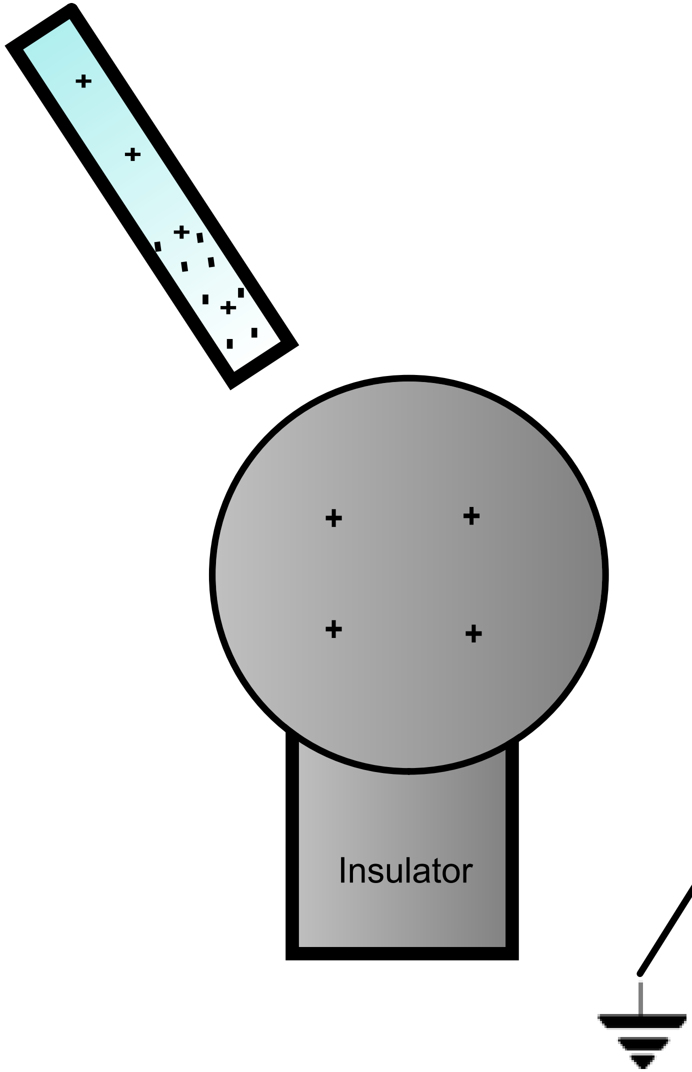
Charging by Induction



A negatively charged rod is brought near, but does not touch the sphere. Electrons within the sphere are repelled by the rod, and pass through the wire to the ground, leaving a net positive charge on the sphere.

The electrons are being pushed down this wire into the ground.

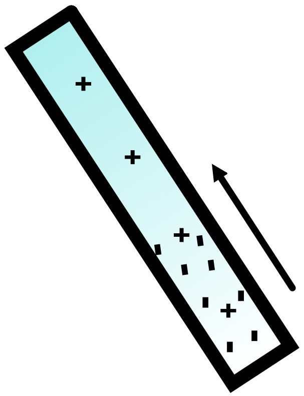
Charging by Induction



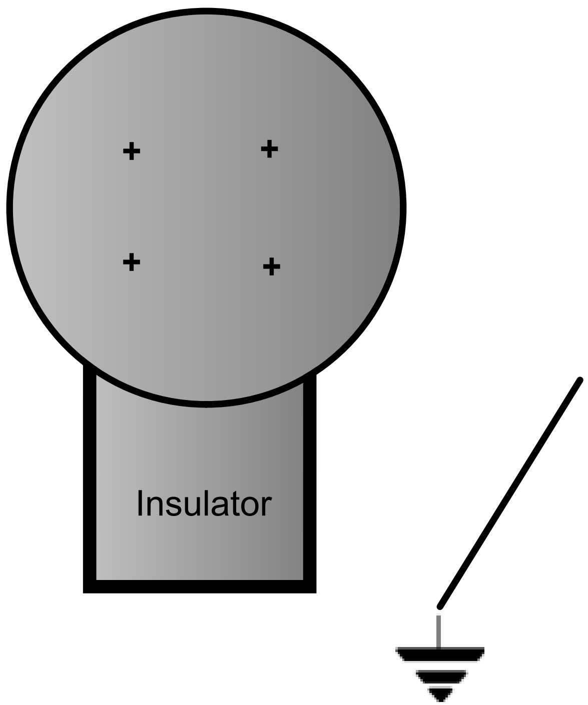
While the negatively charged rod remains near the sphere, the ground is removed. Note that there can be no more movement of electrons since the sphere is isolated from the ground. Electrons cannot jump the gap between the rod and the sphere or between the ground and the sphere.

The wire is removed, disconnecting the sphere from the ground.

Charging by Induction



The rod is then removed. It is important to note that the charge on the rod remains constant (negative). The charge on the sphere is now positive as it lost electrons to Earth.



Conduction Summary

Through physical contact, a charged object will transfer a portion of its charge to a neutral object. Because of the Conservation of Charge, the amount of charge on the initially charged object will decrease.

For example, a positively charged object will transfer positive charge to a neutral object, leaving it with a net positive charge. The amount of positive charge on the initial object will decrease.

Similarly, a negatively charged object will transfer negative charge to a neutral object.

Induction Summary

A charged rod will be brought close to a neutral, grounded object, but it will not touch it.

A positively charged rod will attract electrons from the ground to the neutral object. A negatively charged rod will repel electrons to the ground. The ground is then removed.

The neutral object will be left with a charge opposite to the charged rod.

Induction Summary

The rod will not lose any charge - the extra charge on the originally neutral object comes from the ground. As long as the ground is disconnected before the initial object is removed, the neutral object will gain charge.

If the ground were left in place, once the charged rod is removed, the neutral object will pass its gained charge back to the ground.

22 Sphere A carries a net positivecharge, and sphere B is neutral. They are placed near each other on an insulated table. Sphere B is briefly touched with a wire that is grounded. Which statement is correct?

A Sphere B remains neutral.

B Sphere B is now positively charged.

C Sphere B is now negatively charged.

D The charge on sphere B cannot be determined without additional information.

Answer

23 If a positively charged rod touches a neutral conducting sphere and is removed, what charge remains on the sphere? What happens to the magnitude of the charge on the rod?

A The sphere becomes positive and the rod's net charge stays the same.

B The sphere becomes positive and the rod's net charge decreases.

C The sphere becomes negative and the rod's net charge stays the same.

D The sphere remains neutral and the rod's net charge stays the same.

Answer

24 When the process of induction is used (a charged rod approaching, but not touching the neutral sphere connected to ground), what is the source of the charge added to the neutral sphere?

A The charged rod.

B The air.

C The rod and the sphere share their charges.

D The Earth.

Answer

25 Two identical neutral metal spheres are placed on insulated stands. Describe an experiment that will allow you to charge the spheres with equal and opposite amounts of charge.

Answer

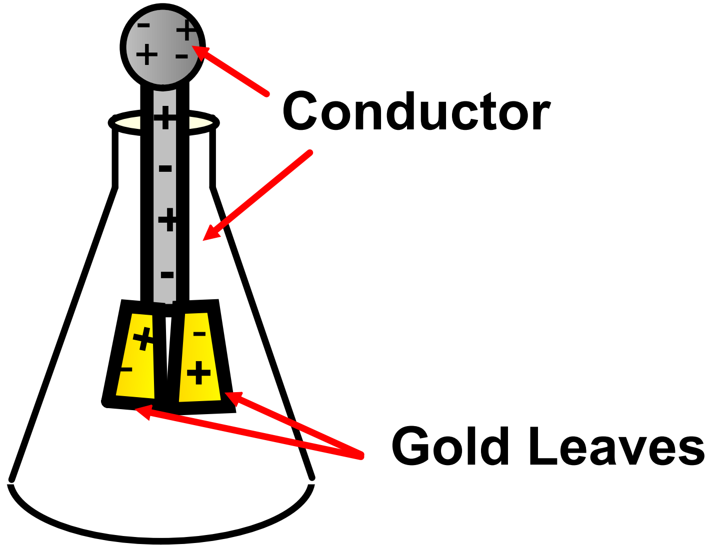
Electroscope

Return to
Table of
Contents

The Electroscope

The electroscope measures electrical charge (both sign and magnitude). The conductor rod is insulated from the glass container.

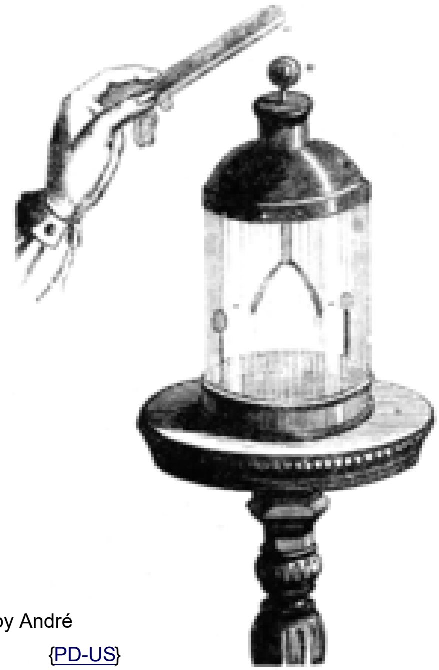
When the scope is neutral, the leaves hang down to due to their own mass.



Electroscopes can be charged by conduction or induction.

The Electroscope

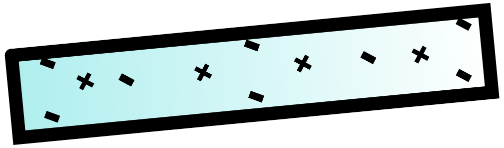
An antique Electroscope from 1878.



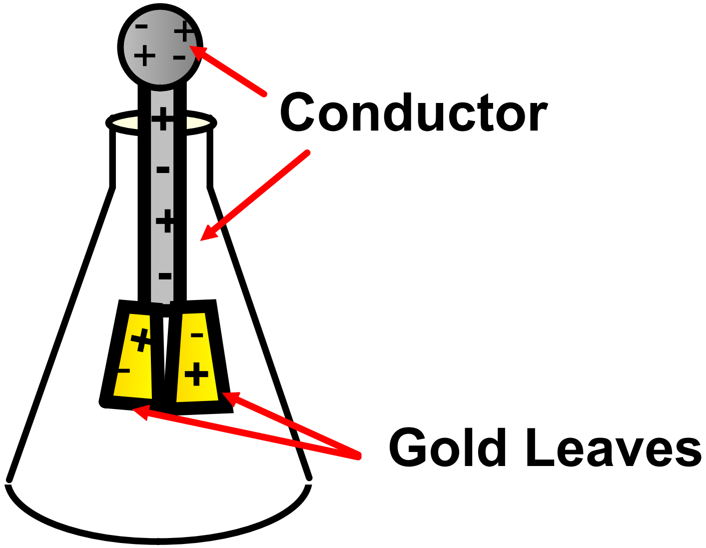
From the book "Opfindelsernes Bog" 1878 by André Lütken

{PD-US}

Charging by Conduction



Charge = -4q

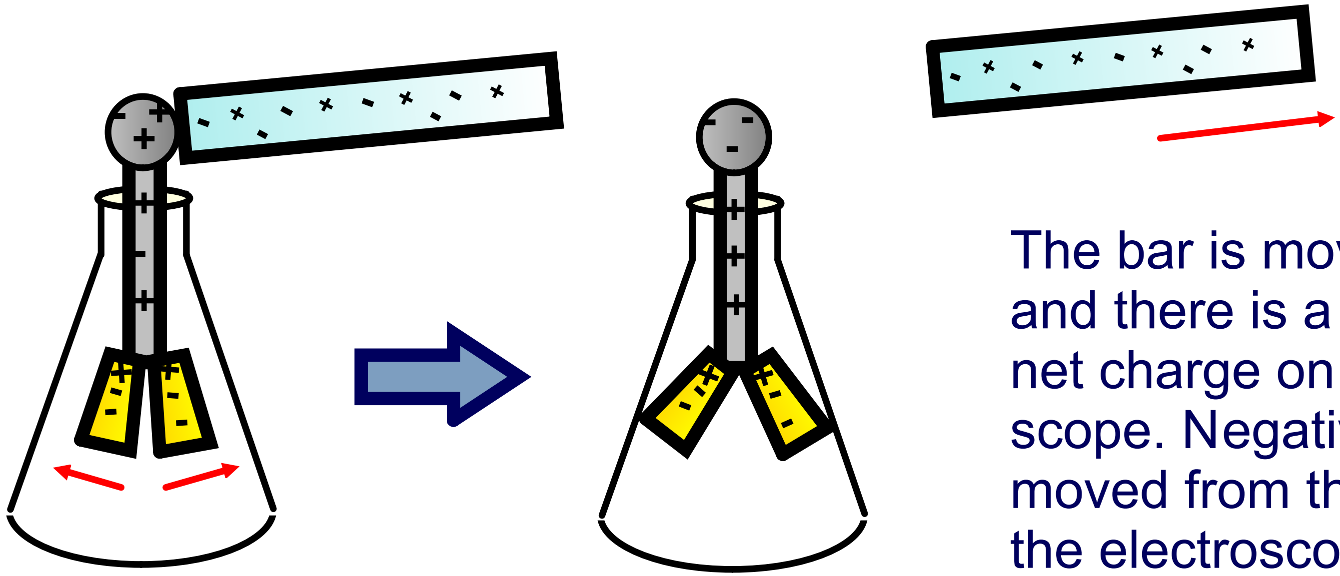


Neutrally Charged

A neutral electroscope will become negatively charged when touched by a negatively charged object.

Negative electrical charge will distribute across the electroscope and the gold leaves will repel, since they have the same charge, and like charges repel.

Charging by Conduction



The bar is moved away and there is a negative net charge on the scope. Negative charge moved from the rod to the electroscope; the rod has less negative charge (Conservation of Charge).

The gold leaves repel.

The leaves would also repel if the experiment had been done with a positively charged bar.

26 When a negatively charged rod touches the top of a neutral electroscope, the gold leaves separate. What is the charge on the leaves?

A Negative

B Positive

C Neutral

D Negative first, then changing to positive.

Answer

Charging by Induction

A neutral electroscope can also be charged by induction.

If a bar with a negative net charge is brought near the scope then the electrons in the electroscope will move down to the leaves and the leaves will repel. If the bar is removed, the leaves will go back to their original positions. This induction is *temporary* - and no charge is transferred from the rod to the leaves.

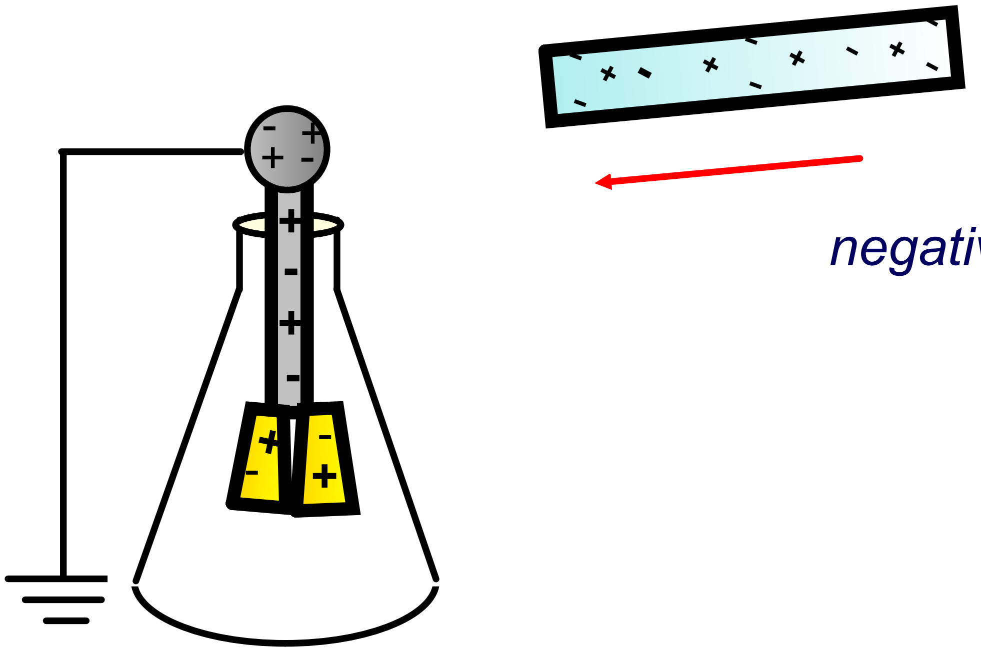
A similar effect is caused by a bar with a positive net charge. The leaves will again repel since like charges repel.

One more piece is needed to effect a permanent charge on the electroscope.

Demo

Electroscope charging by Induction

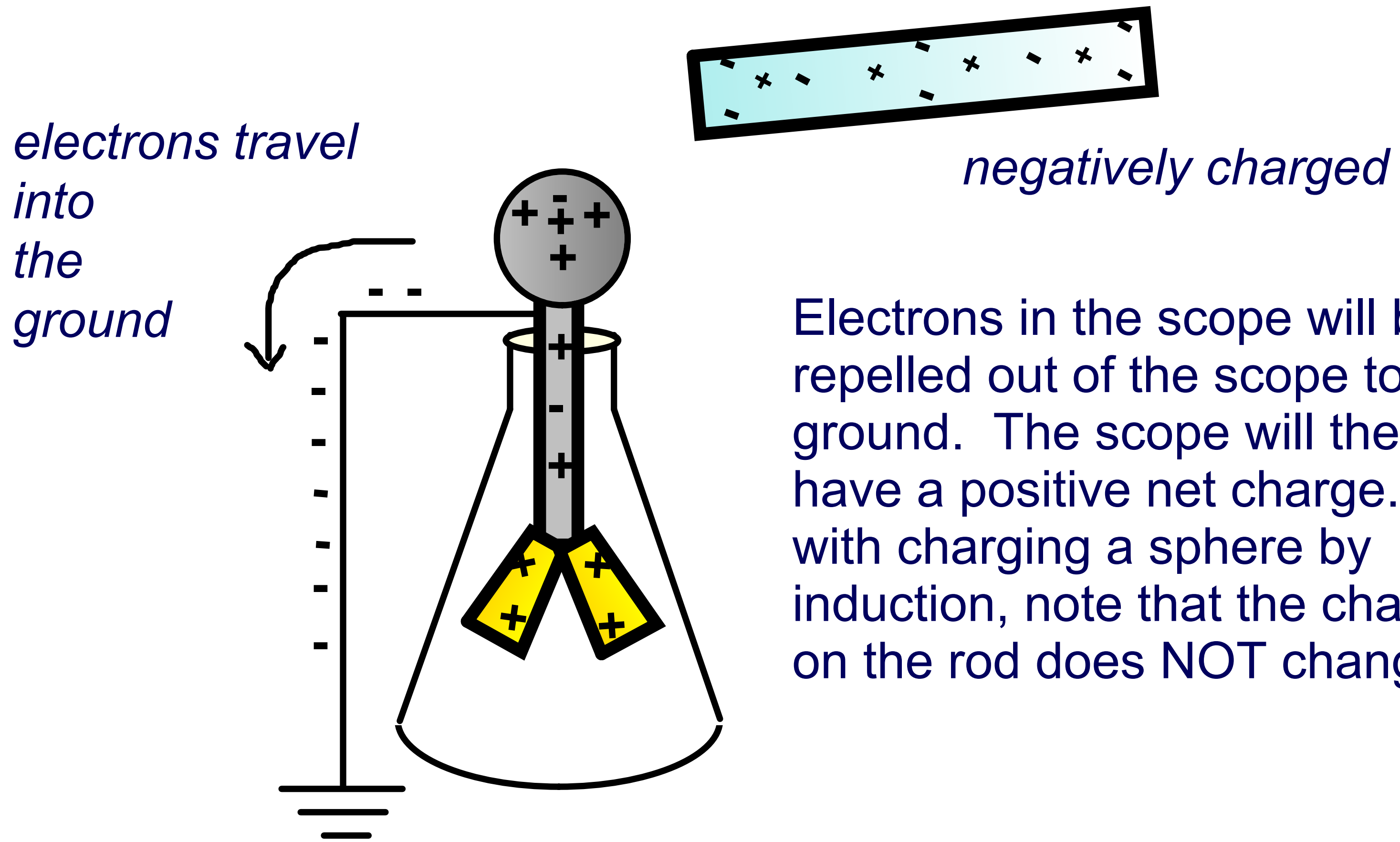
The missing piece is a ground. A neutral electroscope is connected to ground and a negatively charged bar is brought near.



negatively charged rod

initially neutral

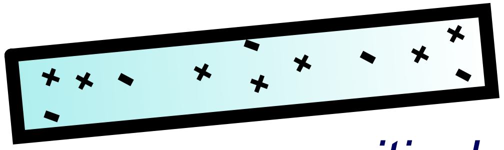
Electroscope charging by Induction



Electrons in the scope will be repelled out of the scope to the ground. The scope will then have a positive net charge. As with charging a sphere by induction, note that the charge on the rod does NOT change.

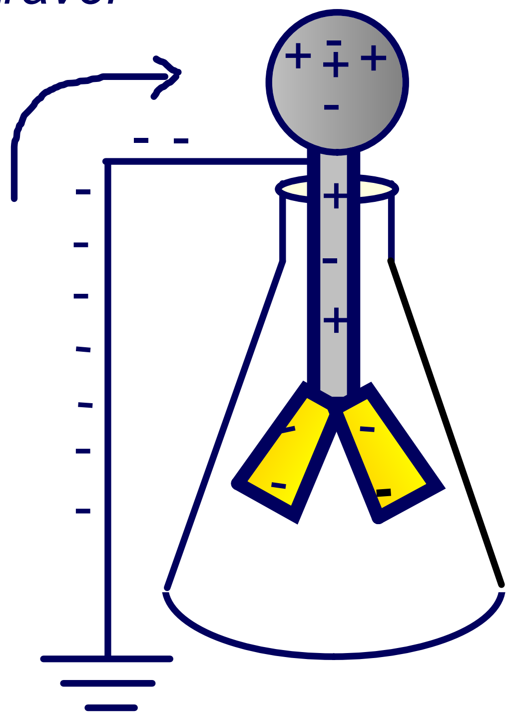
now positively charged - leaves repel each other

Electroscope charging by Induction



positively charged

electrons travel out of the ground



A similar effect occurs for a bar with a net positive charge; except the scope will end up with a net negative charge since electrons will come up from the ground to the scope. Again, the charge on the rod does NOT change.

now negatively charged - leaves repel each other

Charging by Induction

If the charging bar is removed while the ground is still attached, the electrons will return either to the ground or to the leaves until they have a neutral charge and will fall back together.

In order to leave the charge on the electroscope (and keep the leaves separated), the ground must be removed before the charging bar.

The electrons will now have no place to go and a net positive or negative charge will be left on the electroscope.

27 When an electroscope is charged via induction, what is the source of the charge that moves to the gold leaves?

A A charged rod that gets near the electroscope.

B A charged rod that touches the electroscope.

C The glass surrounding the leaves.

D The ground (Earth).

Answer

28 A positive object touches a neutral e lectroscope, and the leaves separate. Then a negative object is brought near the electroscope, but does not touch it. What happens to the leaves?

A They separate further.

B They move closer together.

C They are unaffected.

D Cannot be determined without additional information.

Answer

29 When charging an electroscope by induction, the leaves acquire a charge from the ground and separate. How could you keep the charge on the leaves which would keep them separate from each other?

Answer

Determining the type of charge

When the leaves of the electroscope repel, there is a charge present. It could be positive or negative.

The electroscope can also be used to find out the charge on the leaves. Take an object known to be positive or negative, place it near the top of the scope, and watch the reaction.

Object's Charge is:	Electroscope's Reaction:	Charge on the Scope is:
Positive	Leaves move apart	
Positive	Leaves move closer	
Negative	Leaves move apart	
Negative	Leaves move closer	

Determining the size of the Charge

Intuitively, it would seem that the further apart the leaves move, the greater the magnitude (size) of the charge present.

This is true, and the next section will talk about the force due to electric charges, which is responsible for the leaves moving against the forces of gravity and tension.

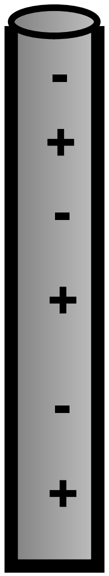
Electric Force (Coulomb's Law)

Return to Table of Contents

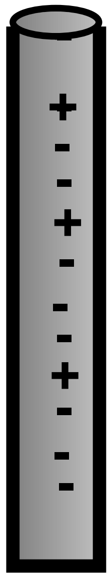
Charged Objects

Remember the earlier example of a plastic ruler obtaining a charge and then attracting neutral bits of paper? Let's look at it more closely and see what happened.

What will happen to the charges on Rod A if it is moved towards Rod B?



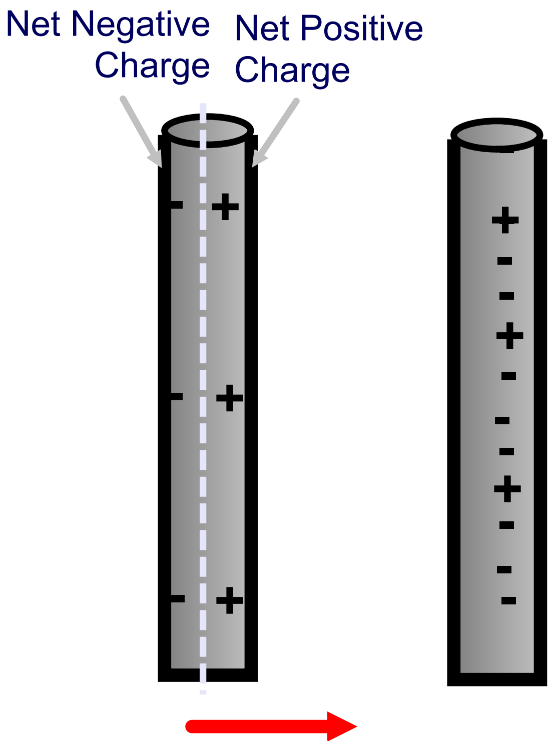
initially far apart



Rod A:
Neutral Rod
Conductor

Rod B:
Stationary,
Negatively
Charged

Charged Objects



Rod A:
Neutral Rod
Conductor

Rod B:
Stationary,
Negatively
Charged

When A is brought towards B the electrons in A will be repelled.

Electrons in A will move to the left side of the rod. This causes the left and right sides of the rod to have a different charge (overall, the rod remains neutral) - the rod is "polarized."

The positive net charge on the right side of A will cause A to move towards B (opposites attract).

30 What will happen when a neutral rod is brought near a negatively charged rod?

A The rods will feel an attractive forece.

B The rods will feel a repulsive force.

C Nothing; the neutral rod will only continue moving if it is pushed.

D The rods will first repel each other, then attract as they get closer.

Answer

31 What happens to the electrons in a neutral conductor that is brought close to a positively charged rod?

A The electrons move from the conductor to the rod.

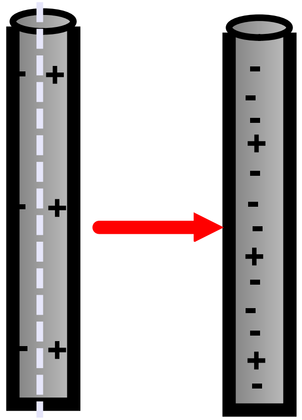
B The electrons move to the side of the conductor farthest from the positive rod.

C The electrons move to the side of the conductor nearest the positive rod.

D The electrons do not move.

Answer

Electric Force



Newton's First Law (the law of inertia) states that objects moving at a certain velocity will maintain that velocity unless acted on by an external force. Objects will only accelerate if acted on by an external force.

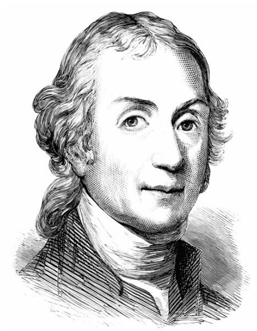
The free rod accelerated towards the stationary rod so there must be a force present. We call this the **Electric Force**, and as with all forces, it is measured in Newtons (N).

Electrical Force

In the late 18th Century, Joseph Priestly reasoned and John Robison measured that the force between two objects followed the same principles as the gravitational force.

And that the force between two charged objects depends on the inverse square of the distance between them:

$$\vec{F}_E \alpha \frac{1}{r^2}$$



Joseph Priestly

John Robison

Electric Force

Charles Coulomb published a paper (1785), based on detailed experiments, that definitively proved Priestly and Robison's work, and that the force was also proportional to the size of the charges.

He used a torsion balance which was based on the same principle as Henry Cavendish's experiment that measured the gravitational constant.

Charles Coulomb

Magnitude of Electric Force

Coulomb's Law states that the magnitude of the electrical force is:

$$F_E = \frac{k|q_1||q_2|}{r_{12}^2}$$

k = the Coulomb constant that equals $9.0\text{x}10^{9}$ N-m^2/C^2

$|q_1|$ = the absolute value of the net charge on one object

$|q_2|$ = the absolute value of the net charge on the other object

r_{12} = the distance between object 1 and object 2 if they are point charges, or between the centers of the objects if they are spherical.

Note the striking mathematical similarity to Newton's Law of Universal Gravitation.

Coulomb's Law

Coulomb's Law is used to calculate the magnitude of the force.

Each object exerts the same force on the other - except in opposite directions (Newton's Third Law applies to all forces, not just mechanical ones).

Since electric force, like all forces, is a vector, you need to specify the direction of the force whose magnitude was determined by Coulomb's Law.

This is done by looking at the signs of both charges (like charges repel & opposite charges attract).

Electric Force relationship to Gravitational Force

Both forces are expressed using a similar mathematical formula, where the magnitude of the force decreases as $1/r^2$.

Electric force can be attractive or repulsive (like charges repel, opposite charges attract). Gravitational force is always attractive.

The electric force is on the order of 10^{36} times stronger than the gravitational force!

Electric Force relationship to Contact Forces

Dynamics covered the contact forces - Normal, Tension, and Friction. Newton's Third Law applied to them, as it also applies to the electrical force.

Is there some deeper connection between the electric and the contact forces?

Within you group, discuss what you think this connection could be. Hint: what are cars, baseballs, water and people made of?

Electric Force relationship to Contact Forces

Large (macro) objects are made up of atoms.

Atoms are composed of a positive nucleus, surrounded by a "cloud" of negative electrons. The predominant force acting between atoms is the electric force (later we will see how this is really a part of the electromagnetic force).

At the macro level, the predominant force is still the electric force. Since there are so many atoms involved at this level, it is easier to describe these interactions in terms of *non fundamental* forces, such as the Normal force, Tension force and Friction.

Electric Force relationship to Contact Forces

The Normal, Tension and Friction forces are called Contact forces, as they involve objects touching each other.

The source of the Contact force is the Electric force.

32 A +20.0μC point charge is located 20.0 cm away from a -40.0 μC point charge. What is the force on each due to the other?

Answer

33 Compare and contrast the Electric force and the Gravitational force.

Answer

34 What is the distance between two charges of +7.8 µC and +9.2 µC, if they exert a force of 4.5 mN on each other?

Answer

35 A -4.2 μC charge exerts an attractive force of 1.8 mN on a second charge which is a distance of 2.4 m away. What is the magnitude and sign of the second charge?

Answer

36 Two equal negatively charged objects repel each other with a force of 18 mN. What is the charge on each object if the distance between them is 9 cm? How many extra electrons are on each object?

Answer

37 Which of the following forces are based on the electric force? **Select two answers**.

A Gravity

B Friction

C Normal

D Nuclear

Answer

38 Two conducting spheres each have a net charge of 5.0 mC and -9.0 mC and attract each other with a force of 4.05×10^3 N. The spheres are brought into contact and then moved apart to the initial distance. What is the new force between the spheres? Is the force attractive or repulsive?

Answer Part 1

Answer

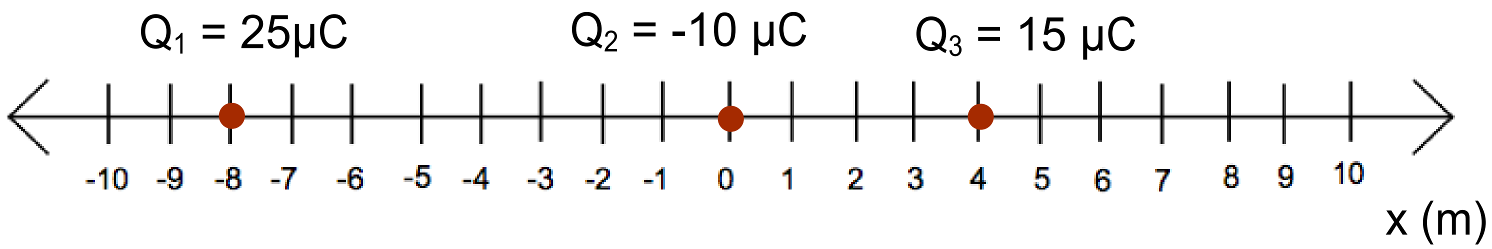
Answer Part 2

Answer

Superimposition of Electrical Forces

Many times, there is a configuration consisting of multiple charges and you need to calculate the **net initial force** on each charge. The charge configuration will then change, as the charges react to their initial net forces - but that is way beyond the scope of this course.

The simplest configuration to handle is when the charges are all in a line, for example, on the x axis.



Superimposition of Electrical Forces

Follow this procedure:

1. Assume all charges, other than the one that the initial net force is being calculated for, are immobile - this will allow the determination of the direction of the individual initial forces.

2. Draw a free body diagram for each charge, using the fact that opposite charges attract and like charges repel.

continued on next slide.......

Superimposition of Electrical Forces

continuing.....

3. Use Coulomb's Law to find the magnitude of each force.

4. Sum the forces, taking into account that they are vectors with direction and magnitudes.

Use the free body diagrams to assign signs to the forces - if they point to the right, they are positive; if they point to the left, they are negative.

Force Labeling Convention

$\mathbf{F}_{12}$ is the force that Q_1 exerts on Q_2.

$\mathbf{F}_{13}$ is the force that Q_1 exerts on Q_3.

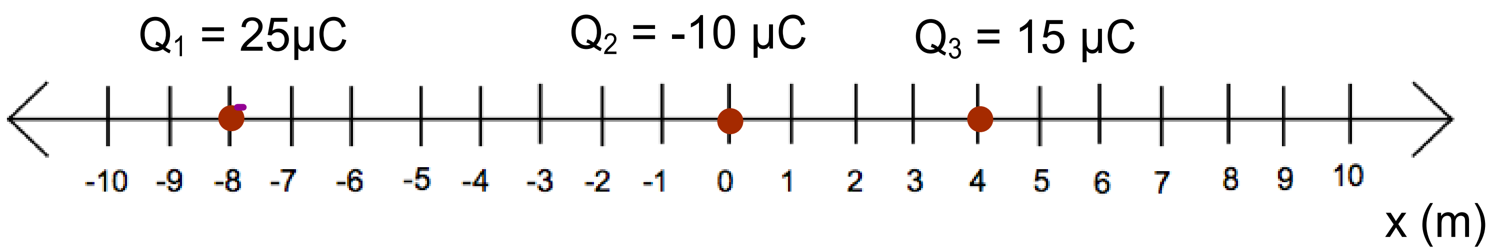
$\mathbf{F}_{23}$ is the force that Q_2 exerts on Q_3.

Note that by the application of Newton's Third Law:

$$\mathbf{F}_{12} = - \mathbf{F}_{21}$$
$$\mathbf{F}_{13} = - \mathbf{F}_{31}$$
$$\mathbf{F}_{23} = - \mathbf{F}_{32}$$

Other textbooks and websites may use a naming convention that is opposite to this one. Either works - just follow your instructor and stay consistent.

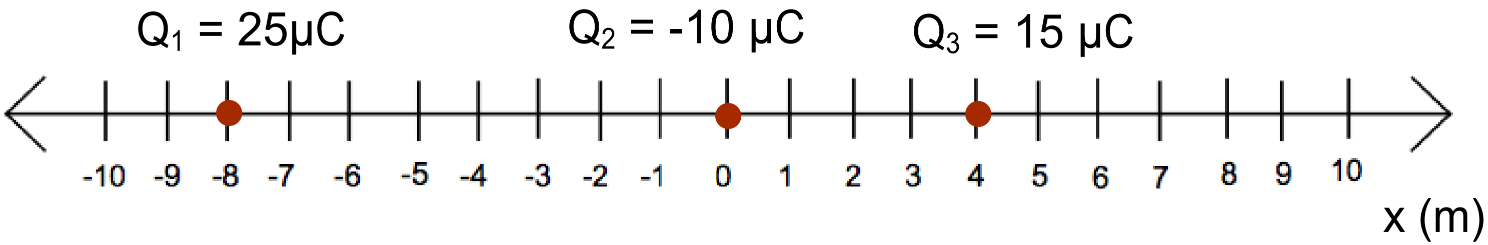
Superimposition of Electrical Forces



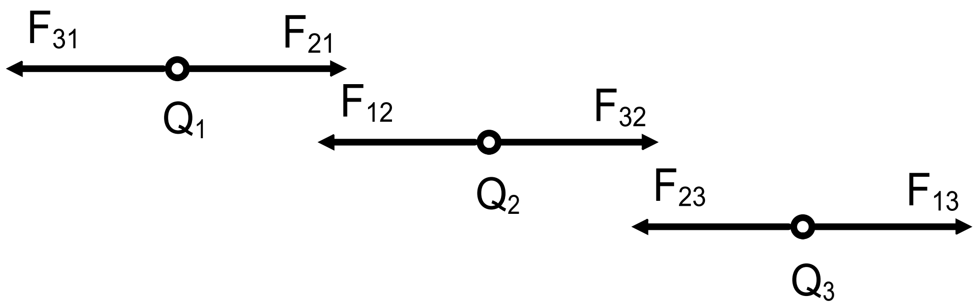
Let's now work this problem and find the initial forces on each charge. What's the first step in any force (dynamics problem)?

Discuss, and then check the next slide.

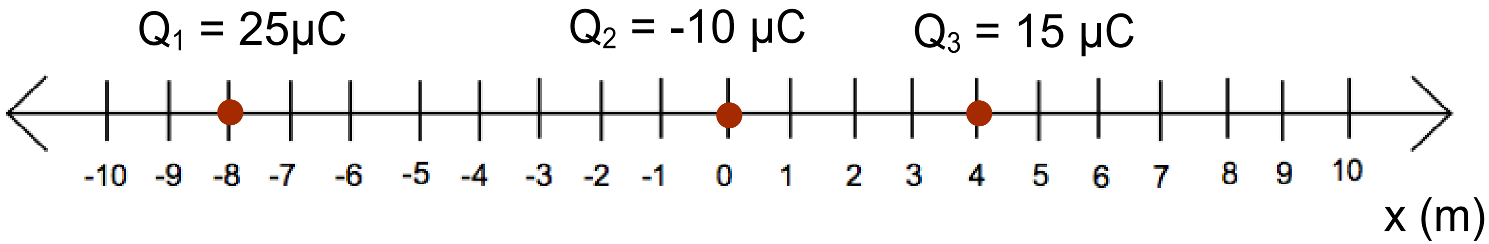
Superimposition of Electrical Forces



That's right (hopefully); draw free body diagrams for the forces acting on each charge.



Superimposition of Electrical Forces



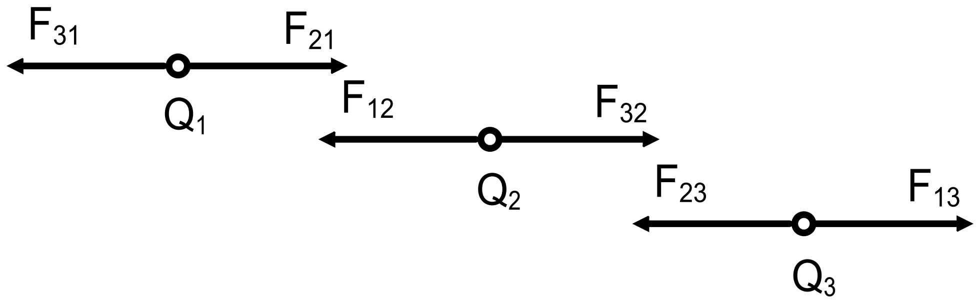
Use Coulomb's Law to find the magnitude of the forces acting between each pair of charges (Q_1 and Q_2; Q_1 and Q_3; Q_2 and Q_3).

$$F_{12} = \frac{k|q_1||q_2|}{r_{12}^2} = \frac{\left(9x10^9\, N\, m^2/C^2\right)\left|25x10^{-6}C\right|\left|-10x10^{-6}C\right|}{(8.0m)^2} = 3.51x10^{-2}\,N$$

$$F_{13} = \frac{k|q_1||q_3|}{r_{13}^2} = \frac{\left(9x10^9\, N\, m^2/C^2\right)\left|25x10^{-6}C\right|\left|15x10^{-6}C\right|}{(12.0m)^2} = 2.34x10^{-2}\,N$$

$$F_{23} = \frac{k|q_2||q_3|}{r_{23}^2} = \frac{\left(9x10^9\, N\, m^2/C^2\right)\left|-10x10^{-6}C\right|\left|15x10^{-6}C\right|}{(4.0m)^2} = 8.44x10^{-2}\,N$$

Superimposition of Electrical Forces



Use the free body diagrams and the magnitude of the forces to find the magnitude and direction of the initial force on each charge due to the configuration.

$$F_{Q1} = F_{21} + F_{31} = 3.51x10^{-2}\,N - 2.34x10^{-2}\,N = 1.17x10^{-2}\,N$$

$$F_{Q2} = F_{12} + F_{32} = -3.51x10^{-2}\,N + 8.44x10^{-2}\,N = 4.93x10^{-2}\,N$$

$$F_{Q3} = F_{13} + F_{23} = 2.34x10^{-2}\,N - 8.44x10^{-2}\,N = -6.10x10^{-2}\,N$$

Electric Force in Two Dimensions

Return to Table of Contents

Electric Force in Two Dimensions

So far, we have only looked at the force between charges on a line.

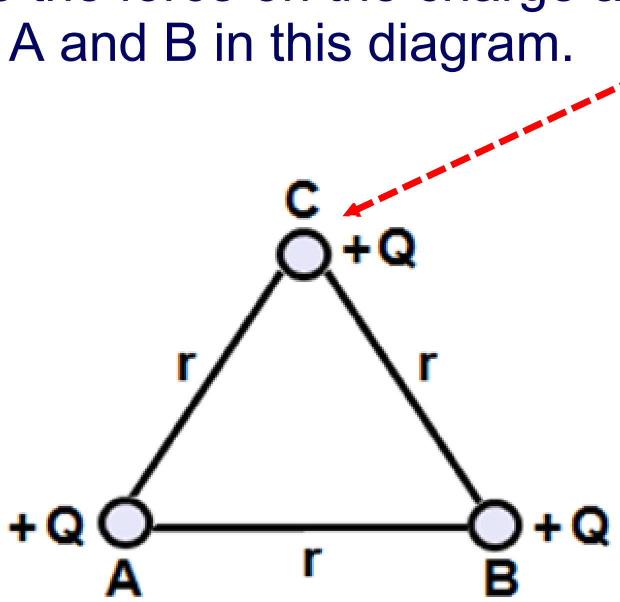
If we have three or more charges that do not fall on a line, we must add the forces just like we added vectors that were at angles to one another. This was done with kinematics, dynamics and momentum problems.

We're now working in two dimensions.

First, establish perpendicular axes that are symmetric to the problem.

Electric Force in Two Dimensions

Calculate the force on the charge at point C from the charges at points A and B in this diagram.

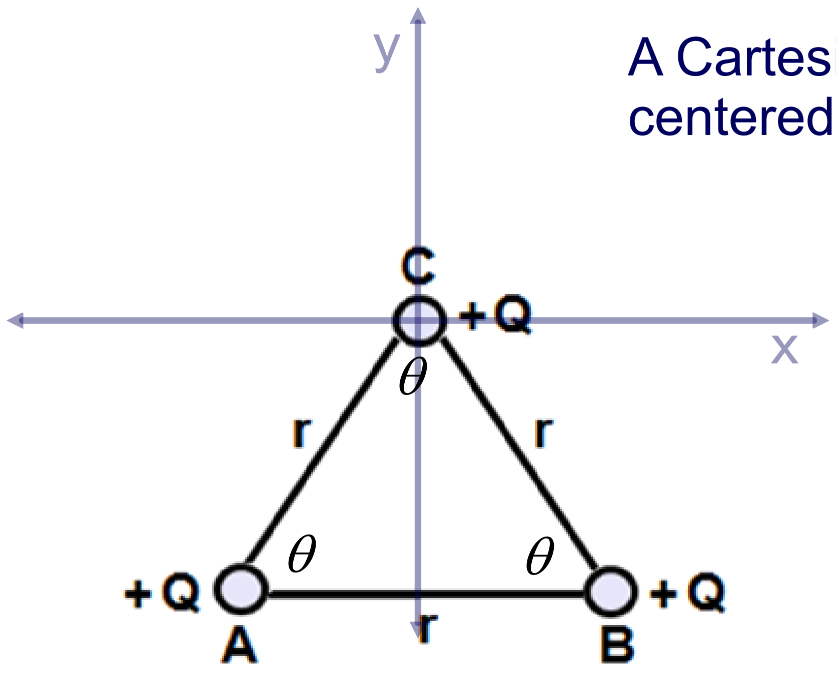


The charges at each point are equal to +Q.

We have a triangle with three equal sides, what is the value of θ?

Let's choose some axes for the problem to take advantage of the symmetry of the charges.

Electric Force in Two Dimensions

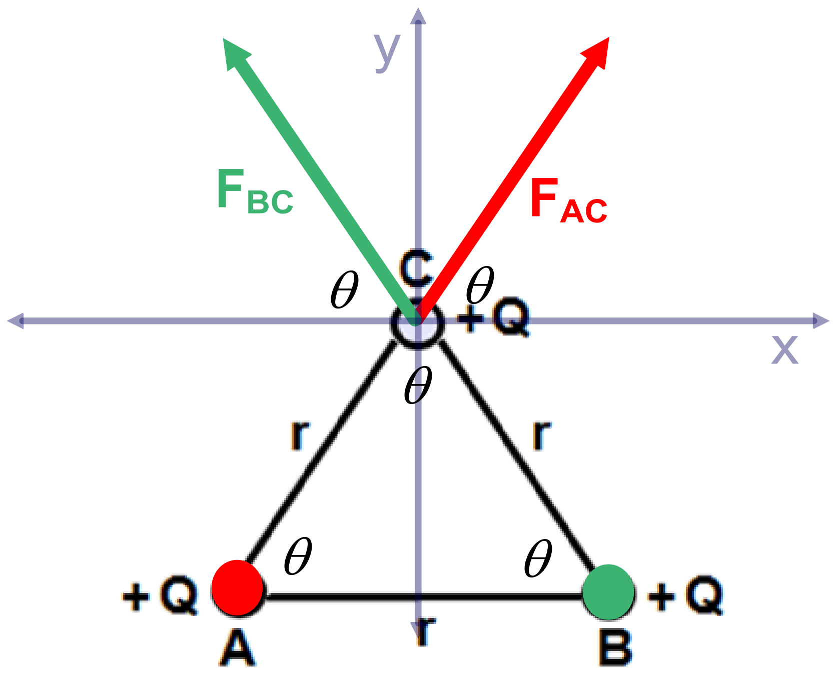


A Cartesian coordinate system centered at point C works well.

Draw the forces acting on the charge at point C due to the charges at A and B.

$\theta = 60^o$

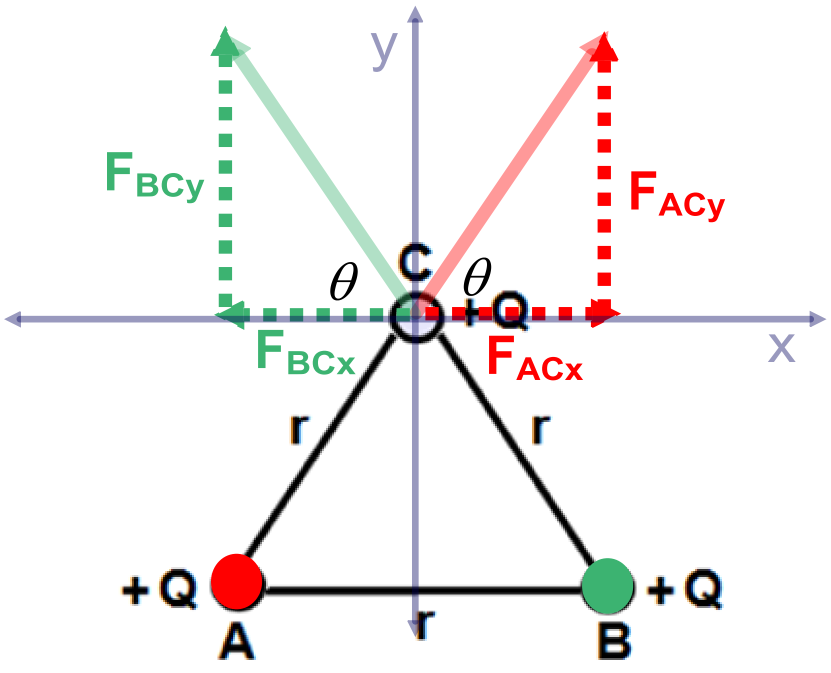
Electric Force in Two Dimensions



Since the charges at points A and B are equal in magnitude, $|\mathbf{F}_{AC}| = |\mathbf{F}_{BC}|$.

Resolve the forces into components that lie on the chosen axes, observing that the angles that $\mathbf{F}_{AC}$ and $\mathbf{F}_{BC}$ make with the x axis are equal to 60^{o}.

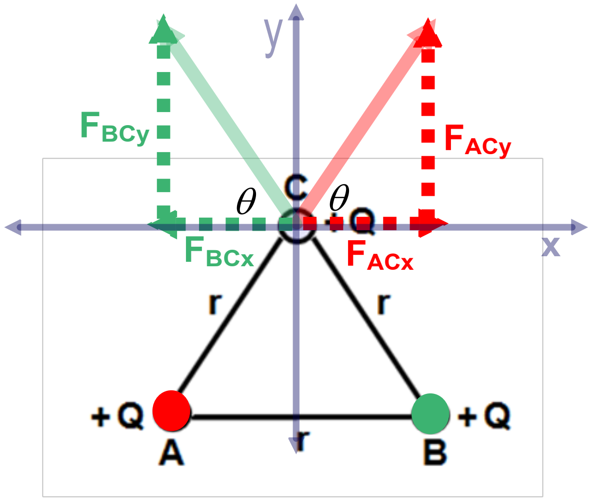
Electric Force in Two Dimensions



We now see that the x-components of the forces are equal in magnitude, but opposite in direction. So,they cancel.

This leaves the y-components which are equal in magnitude and in the same direction. Time to do the numbers.

Electric Force in Two Dimensions



<u>y-axis</u>

$$F_{AC} = F_{BC} = F = k\frac{QQ}{r^2} = k\frac{Q^2}{r^2}$$

$$F_y = F_{AC_y} + F_{BC_y}$$

$$F_y = F_{AC}\sin\theta + F_{BC}\sin\theta = 2F\sin\theta$$

$$F_y = 2k\frac{Q^2}{r^2}\sin 60^o = \sqrt{3}k\frac{Q^2}{r^2}$$

<u>x-axis</u>

$$F_x = F_{AC_x} + F_{BC_x} = F_{AC}\cos\theta - F_{BC}\cos\theta = 0$$

The total force is in the y direction and

is equal to $\sqrt{3}k\frac{Q^2}{r^2}$

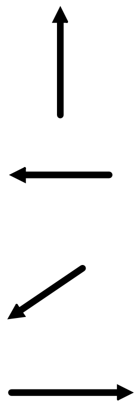
39 Three positive charges with an equal charge of Q are located at the corners of an equilateral triangle of side r. What is the direction of the net force on charge A due to charges B and C?

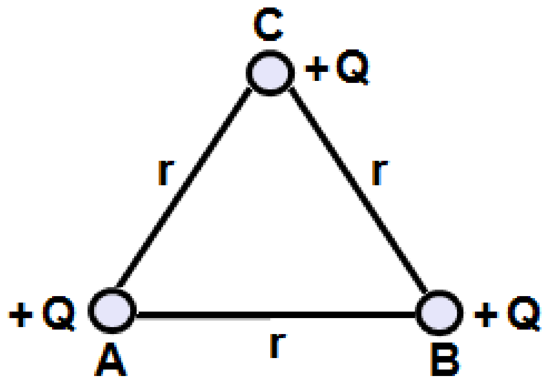
A

B

C

D





Answer

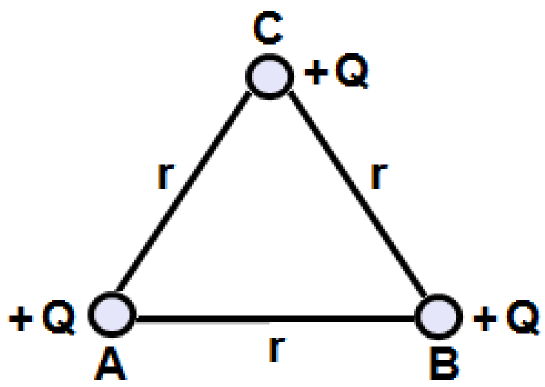
40 What is the magnitude of the net force on charge A due to the two charges B and C?

A $\frac{kQ^2}{r^2}$

B $\frac{2kQ^2}{r^2}$

C $\frac{3kQ^2}{r^2}$

D $\frac{\sqrt{3}kQ^2}{r^2}$



Answer

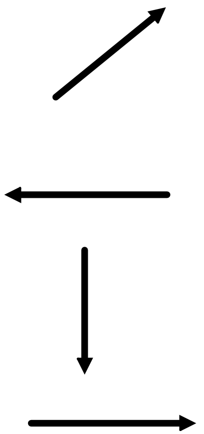
41 Four charges, each with magnitude Q, are arranged in the corner of a square as shown on the diagram. What is the direction of the net force on the charge -q placed at the center of the square?

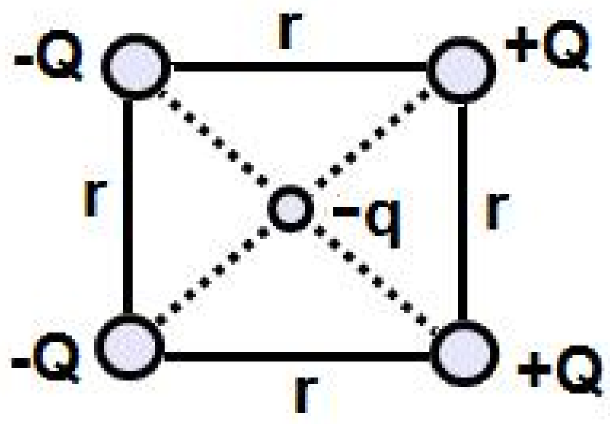
A

B

C

D





Answer

Electric Field

Return to
Table of
Contents

Electric Field

The Electric Field starts with Coulomb's Law:

$$F_E = \frac{k|q_1||q_2|}{r_{12}^2}$$

This gives the force between two charges, q_1 and q_2. Similar to the gravitational force, no contact is needed between the two charges for them to feel a force from the other charge.

This "action at a distance" is best understood by assuming that each charge has a field surrounding it that affects other charges - this is called the **Electric Field**.

Electric Field

Find the Electric Field due to one charge. The notation in Coulomb's Law will be modified slightly - assuming that one charge is very large - and the other charge is a **small, positive test charge** that will have a negligible Electric Field due to its size.

The large charge will be labeled, Q, and the small charge, q, and the distance between them is r.

$$F_E = \frac{k|Q||q|}{r^2}$$

Electric Field

The absolute value signs will be removed, as we will now consider the vector quality of the Force (note the arrow on the top of the F - that means that F is a vector - it has magnitude and direction).

$$\vec{F}_E = \frac{kQq}{r^2}\hat{r}$$

$\hat{r}$ is a **unit vector** - it has a magnitude of 1, and is in the direction of the force vector.

Electric Field

$$\vec{F}_E = \frac{kQq}{r^2}\hat{r}$$

Divide the above equation by q, and define the result, the **Electric Field**.

$$\vec{E} = \frac{\vec{F}_E}{q} = \frac{kQ}{r^2}\hat{r}$$

The charge Q creates the electric field - it is a property of the space surrounding Q. The size of charge Q and the distance to a point determine the strength of the electric field (**E**) at that point.

E is measured in N/C *(Newtons per Coulomb).*

Electric Field Visualization

Electric Field lines are mathematical abstractions that enable us to visualize the strength of the charge that generates the field, and the force that it exerts on other charges that enter the field.

When you multiply the strength of the Electric Field at any point by the charge which is placed there, it gives you the magnitude of the force on that charge.

The direction of the field gives you the direction of the force on a positive charge (the force on a negative charge would be in the opposite direction).

Electric Field Visualization

There are four rules to help us draw these fields:

1. Electric Field Lines begin on a positive charge and end on a negative charge.

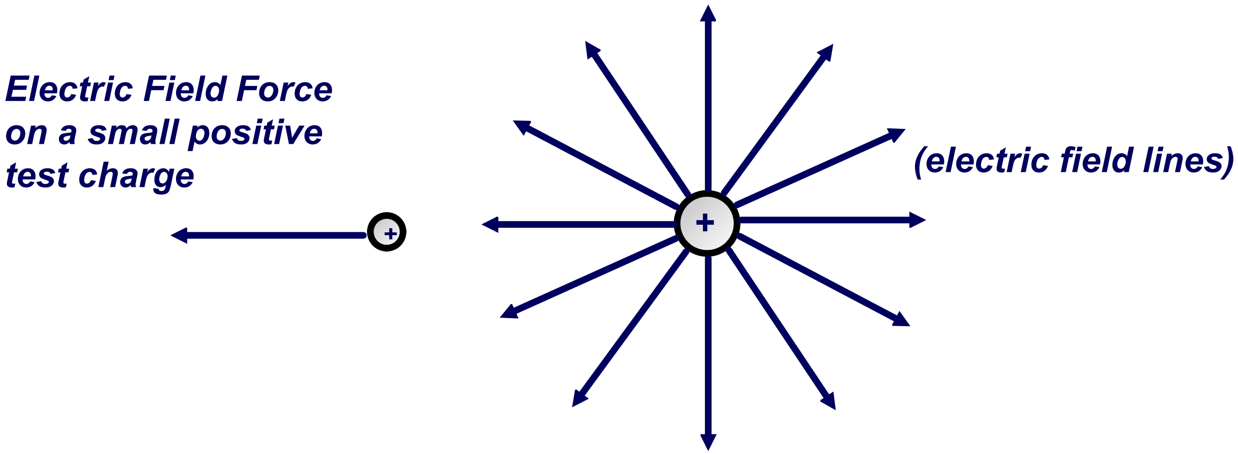
2. The density of the Electric Field lines distribution is proportional to the size of the charges.

3. The lines never cross (or else there would be multiple values of Electric Force at the intersection point).

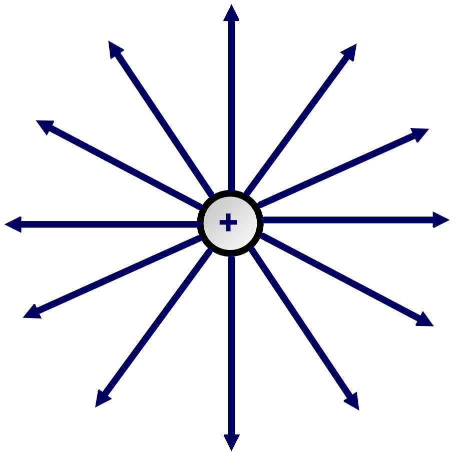
4. The lines are continuous.

Electric Field
due to a Positive Charge

If there is an isolated positive charge, it will create an Electric Field that points radially away from it in all directions, since a positive test charge in the field will be repelled by this charge.



Electric Field due to a Positive Charge

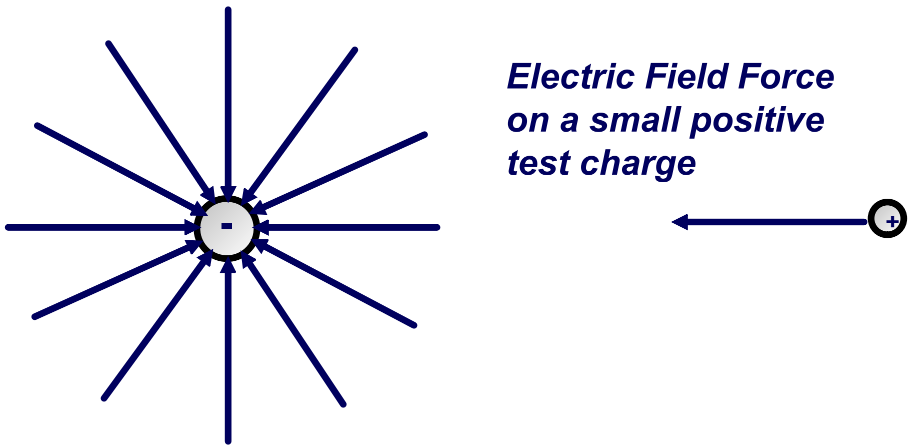


The charge creates a spherically symmetric field since it is proportional to $1/r^2$. At any distance, r, from the charge, the value of the field is the same.

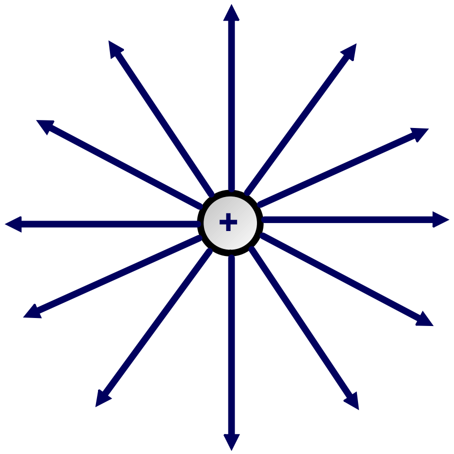
Since r can point in any direction, we get the field lines centered on the charge, generating a sphere (remember, a charge exists in three dimensional space, which is represented in two dimensions here).

Electric Field
due to a Negative Charge

If there is an isolated negative charge, it will create an Electric Field that points radially towards it in all directions, since a positive test charge in the field will be attracted by this charge.



Electric Field Direction and Magnitude



The definition of the Electric Field shows that the strength of the field decreases as distance increases

$$F \propto E \propto \frac{1}{r^2}$$

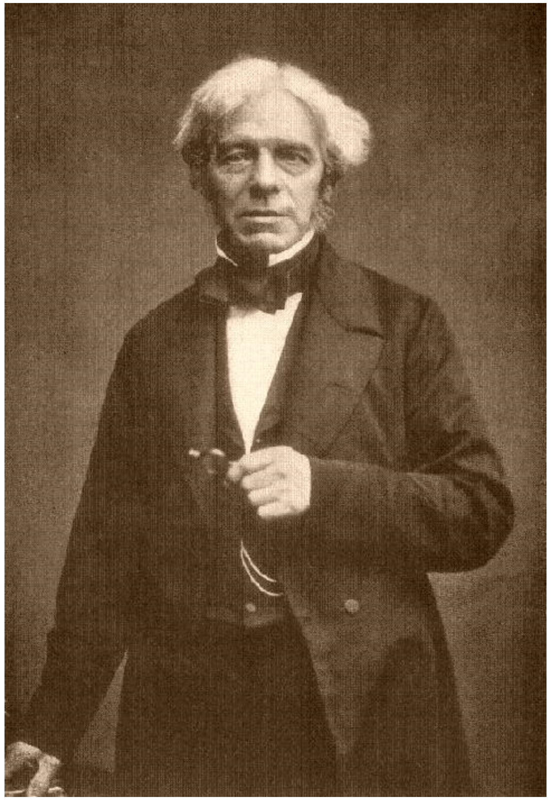
This can be seen by looking at the density of the field lines.

Note that the Electric Field lines are closer together (more dense) when they are closer to the charge that is generating the Field. This indicates the Electric Field is greater nearer the charge.

Click here to try an Electric Field simulation from PhET

Michael Faraday

Michael Faraday created the concept of the Electric Field. Faraday was born in London in 1791. He came from a poor family. At 13, he apprenticed asa book seller and binder while also attending local lectures on philosophical and scientific topics.



A member of the Royal Institute took notice of Faraday and bought him tickets to several Royal Institute lectures.

In 1813, he was invited to work at the Royal Institute where he made numerous contributions to physics and chemistry.

42 Find the magnitude of the electric field for a charge of 5.6 nC at a distance of 3.0 m.

Answer

43 A 4.5 mC charge experiences an electrical force of 9.0 mN in the presence of an electric field. What is the magnitude of the electric field?

Answer

44 If E_0 is the Electric Field generated at a distance r from a charge Q, what is the Electric Field at a distance 2r?

Answer

45 The Electric Field at a point in space is defined as/the:

A perpendicular to the direction that a positive test charge will accelerate.

B the direction that a positive test charge would accelerate.

C the direction that a negative test charge would accelerate.

D perpendicular to the direction that a negative test charge would accelerate.

Answer

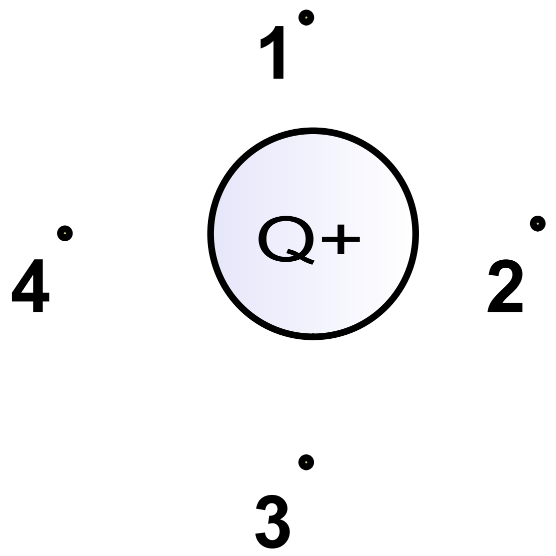
46 What is the direction of the Electric Field at points 1, 2, 3 and 4?

A up, right, down, left.

B up, left, down, right.

C down, right, up, left.

D down, left, up, right.



Answer

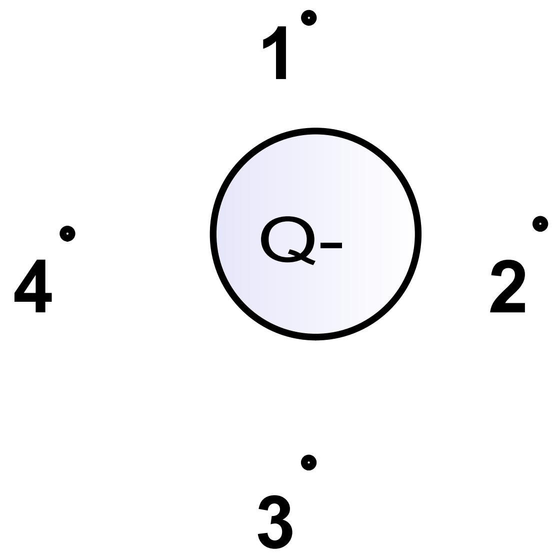
47 What is the direction of the Electric Field at points 1, 2, 3 and 4?

A up, right, down, left.

B up, left, down, right.

C down, right, up, left.

D down, left, up, right.



Answer

Electric and Gravitational Fields

Return to Table of Contents

Electric Field relationship to Gravitational Field

In the chapter on Electric Charge and Force, the similarity between the electric force and the gravitational force was noted.

There is a similar relationship between the Electric Field and the Gravitational Field because they are both generate **central forces**.

Central forces:

- are directed in a straight line to or from an object from a point in space.
- The magnitude of the force depends only on the distance between the point and the object.

Electric Field relationship to Gravitational Field

There is a key difference between the two fields and forces. Mass, which is the source of the gravitational field is always positive, and the force is always attractive.

The gravitational field always points towards the mass generating it.

Charge, the source of the Electric Field, can be negative or positive and the force is either attractive or repulsive.

The direction of the Electric Field points away from a positive charge and towards a negative charge.

Electric Field relationship to Gravitational Field

Given that a mass m is located at the surface of the planet with a mass of M and radius R, Newton's Law of Universal Gravitation is used to determine the magnitude of the gravitational force, F_G, between the planet and mass m:

$$F_g = \frac{GMm}{R^2}$$

Divide this expression by m (where m<<M) - similar to what was done with the small positive test charge, q, and call this "g", the Gravitational Field:

$$g = \frac{F_G}{m} = \frac{GM}{R^2}$$

Electric Field relationship to Gravitational Field

$$g = \frac{F_G}{m} = \frac{GM}{R^2}$$

The weight of an object on a planet, or the measure of the force between the obect and the planet is expressed by:

$$W = F_G = mg$$

The mass of the object remains the same wherever it is, but its weight is dependent on the gravitational attraction, g, of its surroundings.

Electric Field relationship to Gravitational Field

Gravity	Electric
Newton's Law of Universal Gravitation	Coulomb's Law
$F_G = \frac{GMm}{r^2}$	$F_E = \frac{kQq}{r^2}$
$G = 6.67x10^{-11} \frac{Nm^2}{kg^2}$	$k = 8.99x10^9 \frac{Nm^2}{C^2}$
mass (kg)	charge (Coulombs)
distance, r, between centers of mass	distance, r, between centers of charge
Gravitational Field	Electric Field
$g = \frac{GM}{r^2}$	$E = \frac{kQ}{r^2}$

48 How are Gravitational and Electric Fields similar?

A They both increase the further away you get from the source.

B They both decrease as a factor of the square of the distance between the two masses or charges.

C The fields decrease as a factor of the distance between the masses or charges.

D The fields are constant throughout space.

Answer

49 How are Gravitational and Electric Fields different?
Select two answers.

A The Gravitational Field is much stronger than the Electric Field.

B Masses in a Gravitational Field always feel a repulsive force, where charges in an Electric Field always feel an attractive force.

C Masses in a Gravitational Field always feel an attractive force, where charges in an Electric Field feel either an attractive or repulsive force depending on their polarity.

D The Gravitational Field is much weaker than the Electric Field.

Answer

50 An electron is placed near a proton. Which field is mainly responsible for the attraction between the two particles?

A Gravitational

B Electric

C Nuclear

D Magnetic

Answer

Electric Field of Multiple Charges

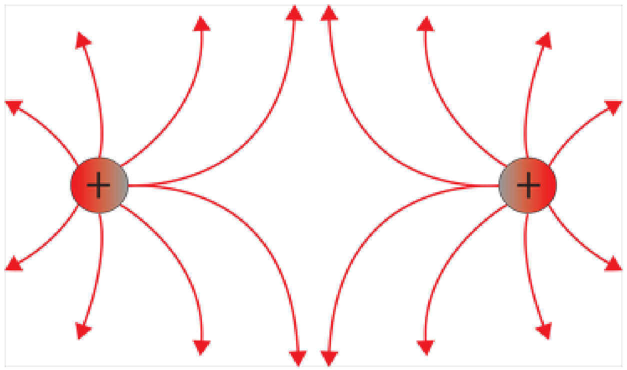
Return to Table of Contents

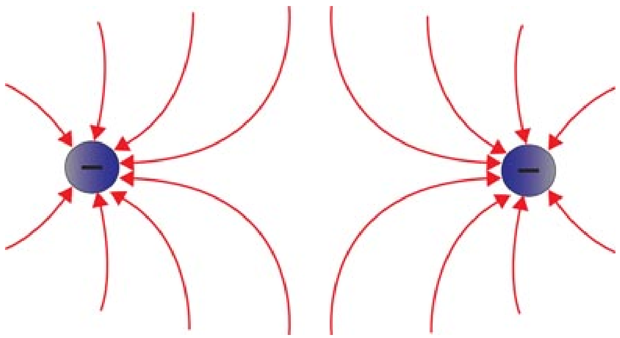
Electric Field of Multiple Charges

Since the Electric Field of a single charge is a vector, the Electric Field of multiple charges may be calculated by adding, point by point, the Electric Fields due to each charge.

The addition is not carried out by just adding the magnitudes of the individual fields. It must be done by adding their vectors - vector addition.

Electric Field of Multiple Charges



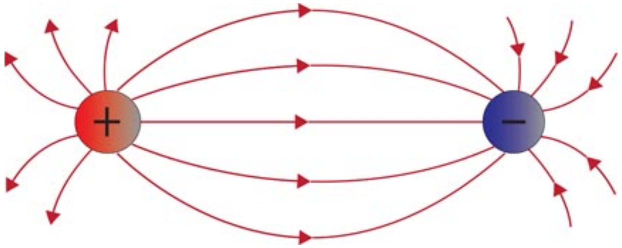


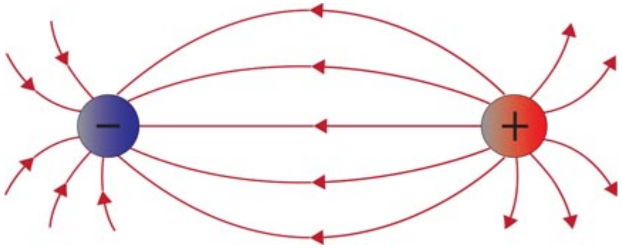
This is the electric field configuration due to two like charges.

There is no electric field midway between the two like charges - the individual electric field vectors cancel out.

The shape of the field is the same for both positive and negative charges - only the field direction is different.

Electric Field of Multiple Charges





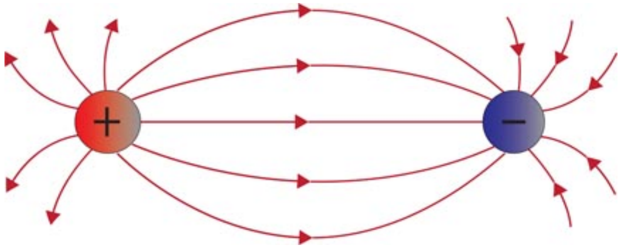
This is the electric dipole configuration, consisting of two unlike charges.

There are no places where the electric field is zero.

Again, the shape of the field is the same for both positive and negative charges - only the field direction is different.

Demo

Electric Dipoles



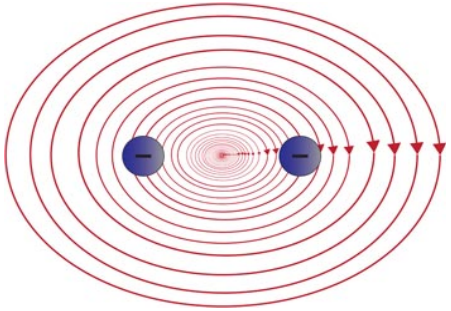
Electric dipoles appear over and over again in studies of the atom and molecules.

Water molecules are electric dipoles, and this helps explain how microwave ovens cook food, the high surface tension of water and why water is a universal biological solvent.

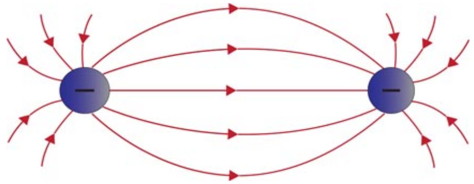
Later in the course, Magnetic dipoles will be discussed, and these have crucial applications.

51 Which of the following represents the electric field map due to a combination of two negative charges?

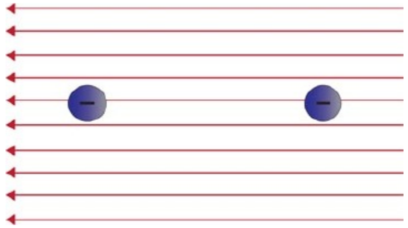
A



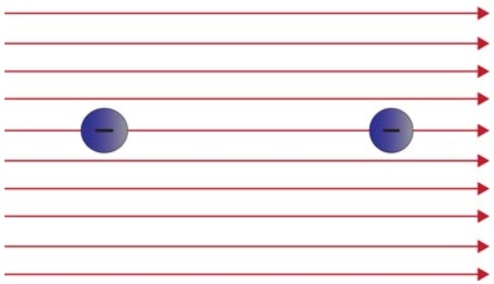
B



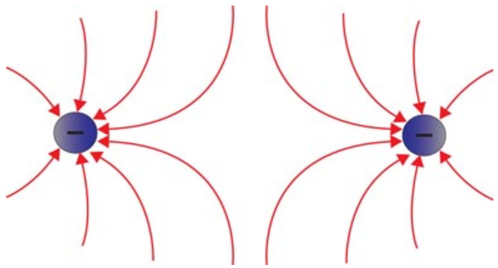
C



D



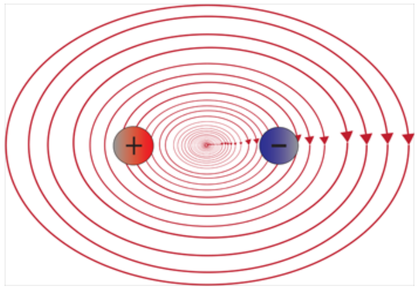
E



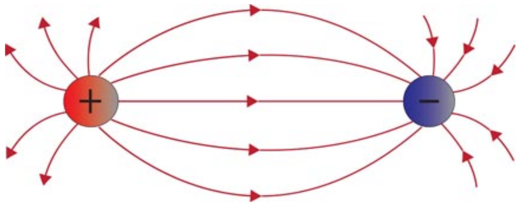
Answer

52 Which of the following represents the electric field map due to a combination of a positive and a negative charge?

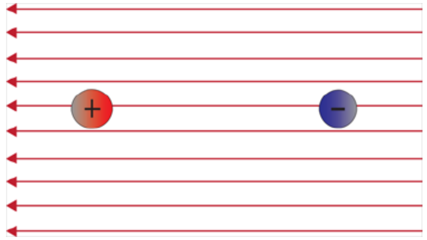
A



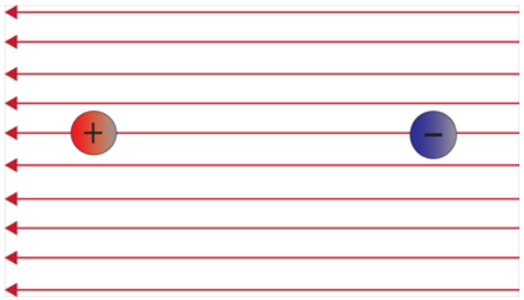
B



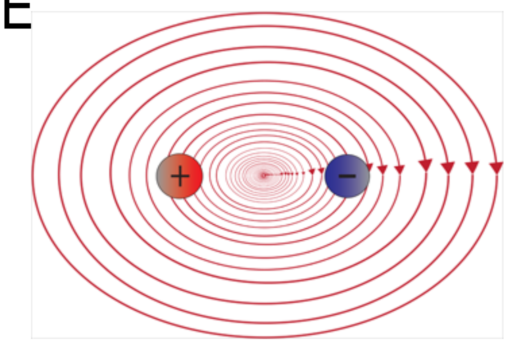
C



D



E



Answer

The Net Electric Field

Net Electric fields will now be calculated mathematically, and for more than just a pair of charges.

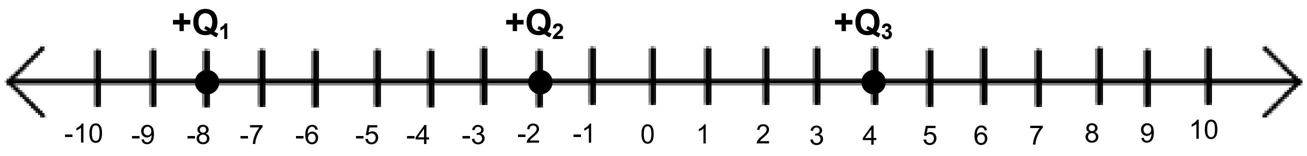
$$\vec{E}_{net} = \Sigma\vec{E}_n$$
$$\vec{E}_{net} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \ldots$$

Where n is the total number of fields present at a location.

The direction of each electric field determines the sign used.

The Net Electric Field

Objective: Find the net electric field at the origin for this charge configuration.

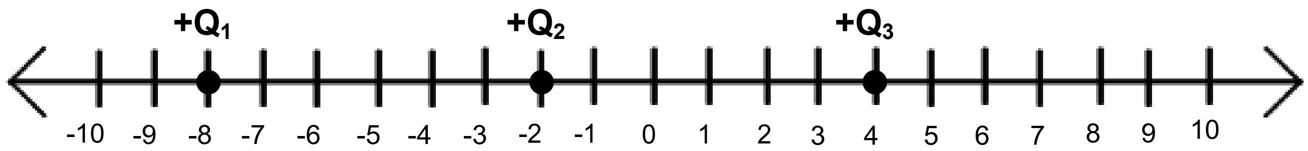


Strategy:

1. Mark the point on the sketch where the Electric Field is to be calculated (the point is at x = 0 in this example).
2. Draw the Electric fields acting at that point.
3. Calculate $\mathbf{E_1}$, $\mathbf{E_2}$ and $\mathbf{E_3}$, assigning negative values to fields pointing to the left, and positive values to fields pointing to the right.
4. Sum the electric fields: $\vec{E}_{net} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \ldots$

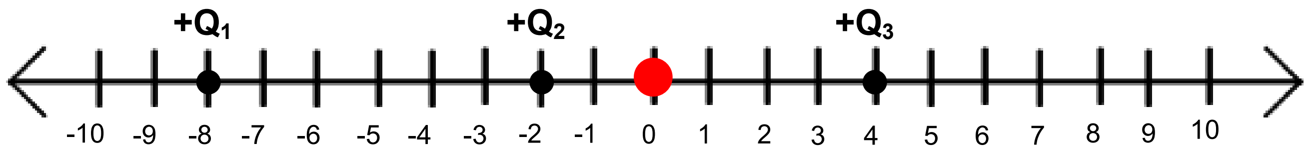
The Net Electric Field Example

Let's work this problem now with values for the charges.



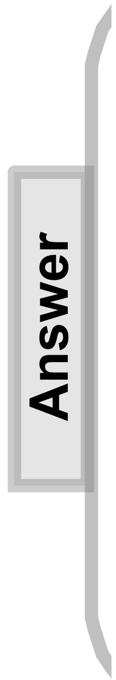
Three positive charges are located on the x axis: Q_1 = +9.1 μC is located at x_1 = -8.0 m, Q_2 = +3.0 μC is located at x_2 = -2.0 m, and Q_3 = 2.7 μC is located at x_3 = 4.0 m.

The Net Electric Field Example

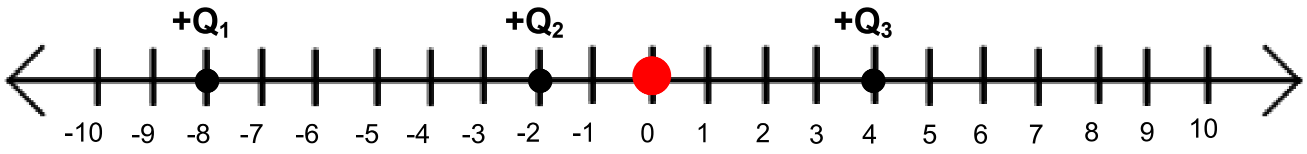


Step 1 - mark the point at which the Electric Field is to be calculated. That is done above in red.

Step 2 - draw the Electric Fields acting on that point due to the three charges. Pull out the answer tab to check your work.



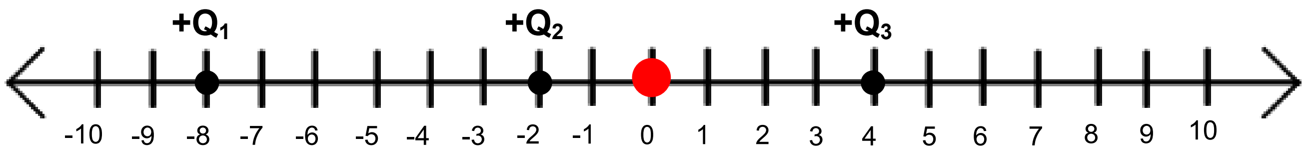
The Net Electric Field Example



Step 3 - calculate E_1, E_2 and $E_{3,}$ assigning negative values to fields pointing to the left, and positive values to fields pointing to the right. Pull out the answer tab to check your work.

Answer

The Net Electric Field Example



Step 4 - sum the individual electric fields.

Answer

Electric Field in Two Dimensions

Return to Table of Contents

The Electric Field in Two Dimensions

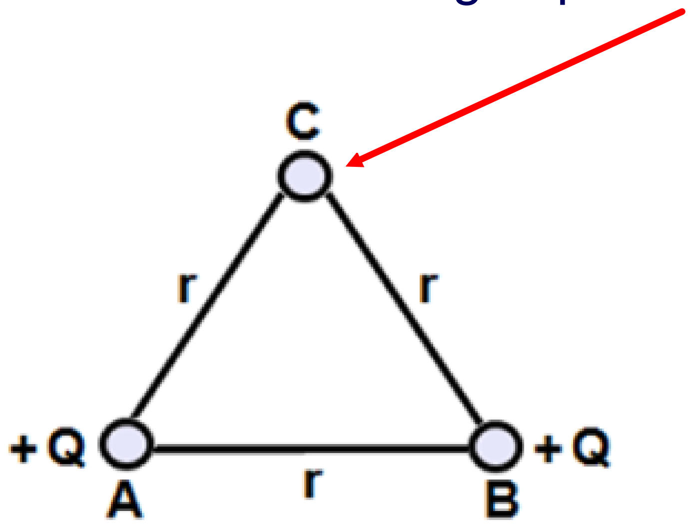
We can also find the Electric Field due to three or more charges that do not fall in a line.

The Electric Field is represented by vectors at every point in space. It will be calculated at a specific point in space - there doesn't have to be anything there.

Once again we start by establishing perpendicular axes that are symmetric to the problem.

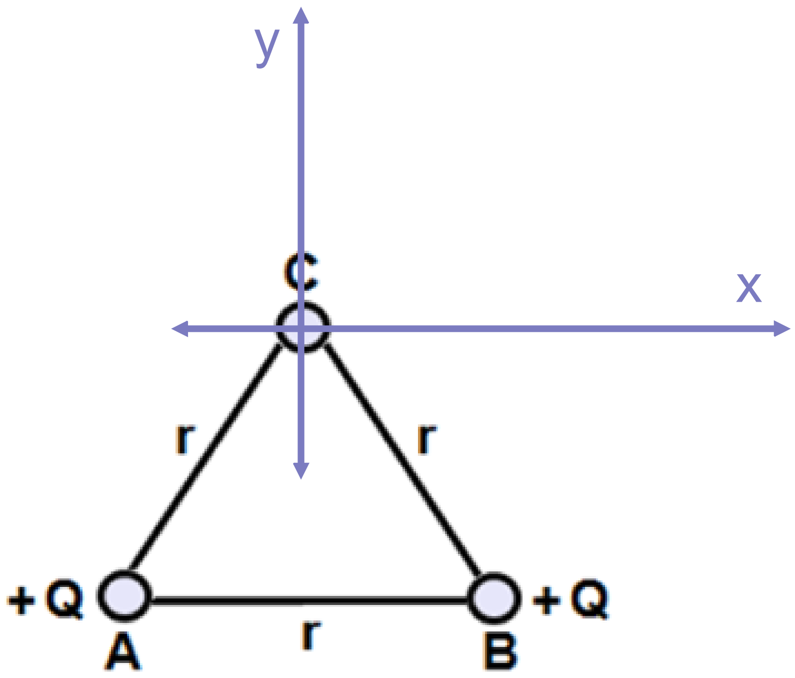
The Electric Field in Two Dimensions

Determine the field at point C due to charges A and B.
A, B and C are on the corners of an equilateral triangle of length r. Note that there is nothing at point C.



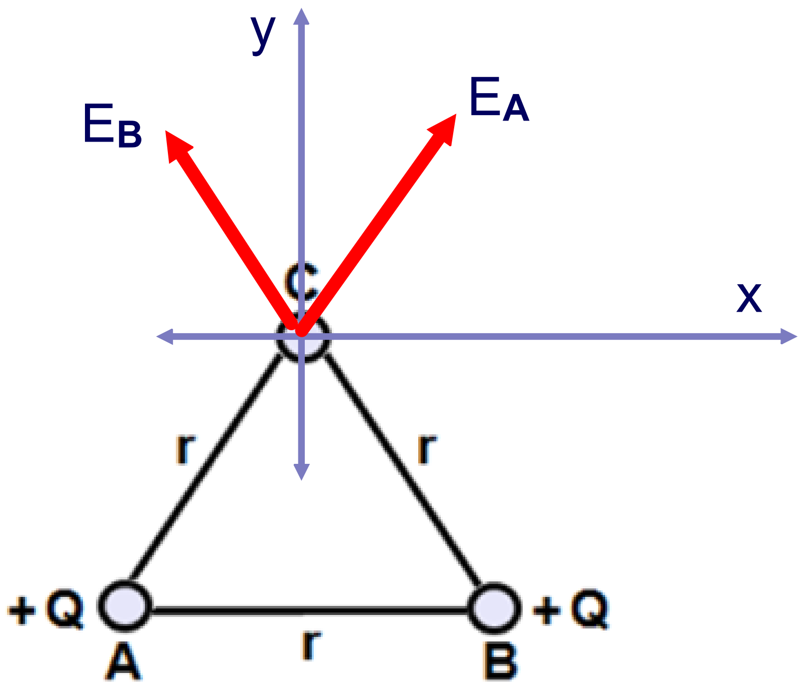
First, let's overlay an appropriate coordinate system and draw the electric field vectors at point C due to the two charges.

The Electric Field in Two Dimensions



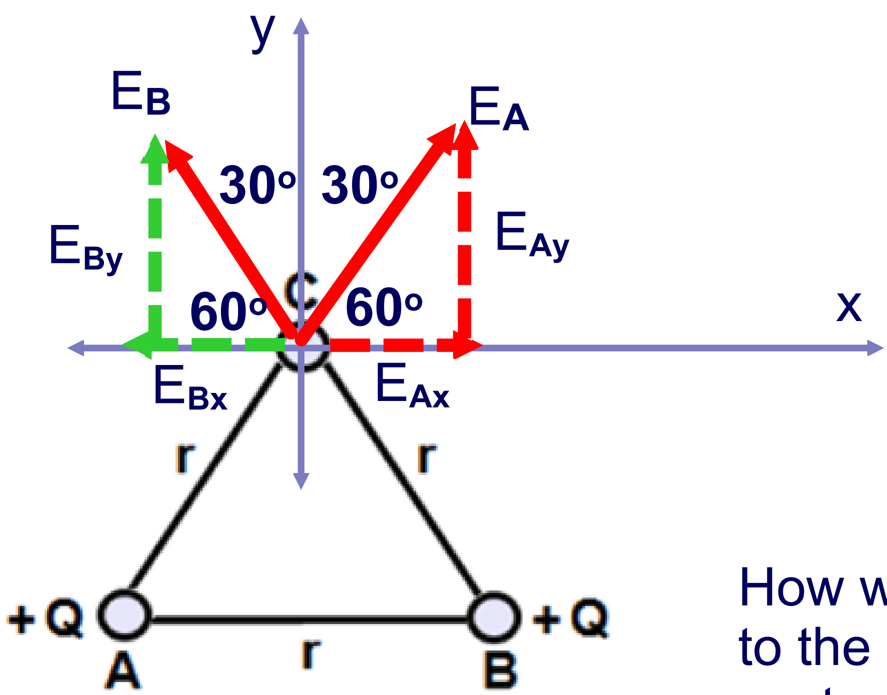
Now, let's show the vectors of the electric fields due to charges A and B at point C.

The Electric Field in Two Dimensions



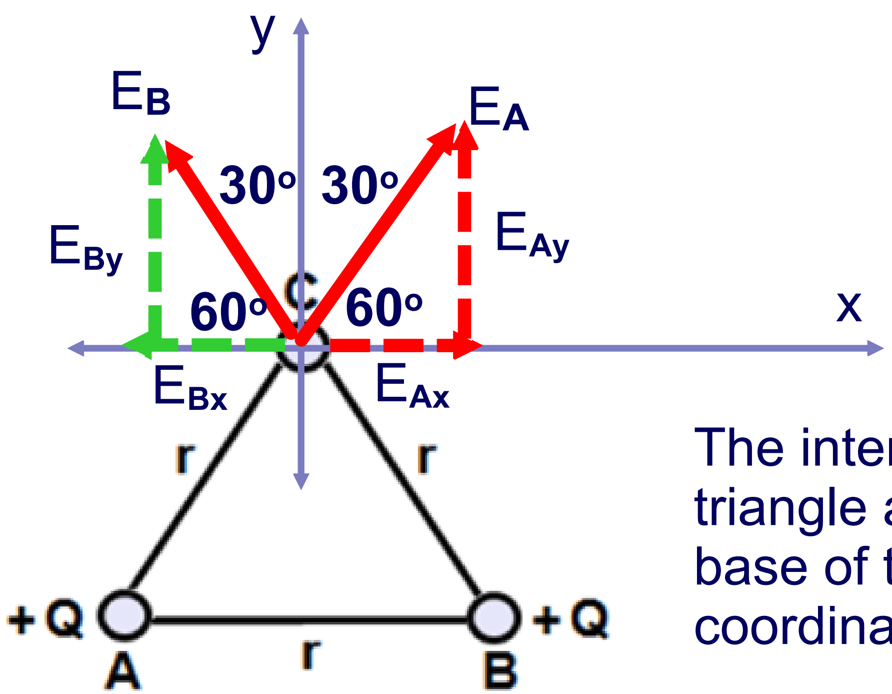
Find the vector components of E_A and E_B along the coordinate axes at point C.

The Electric Field in Two Dimensions



How were the angles assigned to the triangles made by the vector components of E_A and E_B?

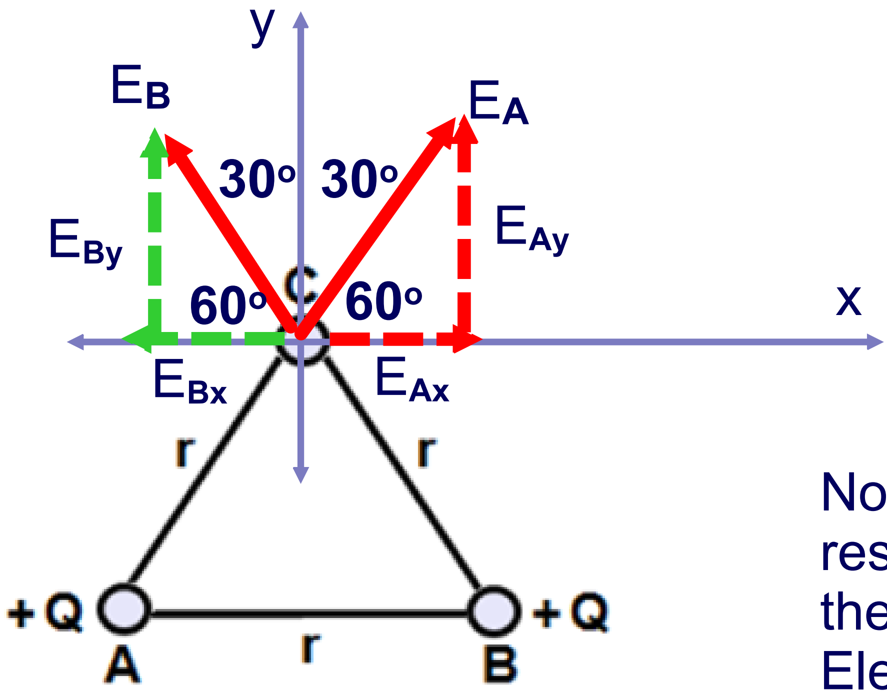
The Electric Field in Two Dimensions



The interior angles of an equilateral triangle are all equal to 60^0. The base of the triangle is parallel to the coordinate system at point C.

The corresponding angles theorem indicates that the angle at point A (60^0) is equal to the angle made by E_A and the x axis at point C.

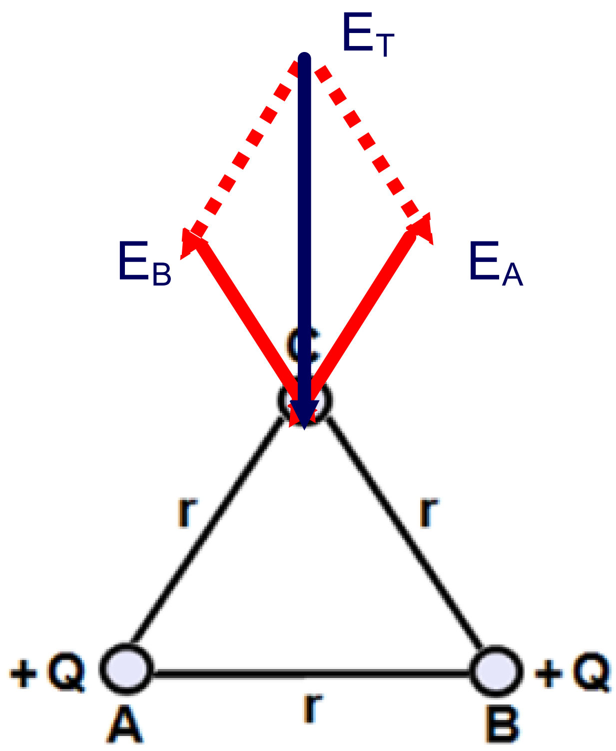
The Electric Field in Two Dimensions



Now use trigonometry to resolve the vectors and add them to come up with the Electric field at point C.

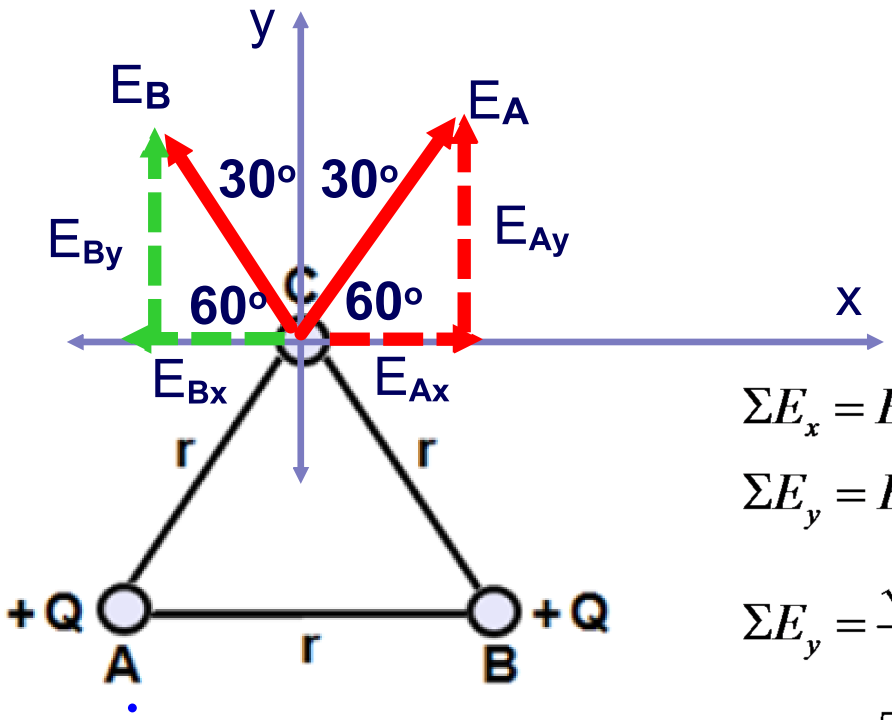
The next slide shows a vector representation of the solution.

The Electric Field in Two Dimensions



The vector representation of the total Electric field as a sum of the Electric fields due to charges A and B.

The Electric Field in Two Dimensions



$$E_A = E_B = E = \frac{kQ}{r^2}$$

$$\Sigma E_x = E_{Ax} + E_{Bx} = E\cos 60^\circ - E\cos 60^\circ = 0$$

$$\Sigma E_y = E_{Ay} + E_{By} = E\sin 60^\circ + E\sin 60^\circ$$

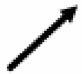
$$\Sigma E_y = \frac{\sqrt{3}E}{2} + \frac{\sqrt{3}E}{2} = \sqrt{3}E$$

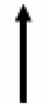
$$E_T = \sqrt{E_x^2 + E_y^2} = \sqrt{0^2 + (\sqrt{3}E)^2} = \sqrt{3}E$$

$$E_T = \frac{\sqrt{3}kQ}{r^2}$$

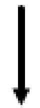
The Electric Field points straight up as shown on the previous slide.

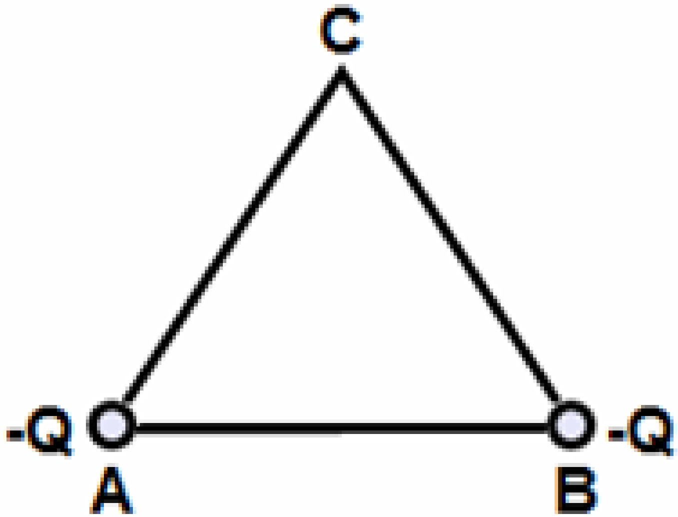
53 Two negative charges, A and B, are placed at the corners of an equilateral triangle. What is the direction of the net Electric field at point C?

A 

B 

C 

D 



Answer

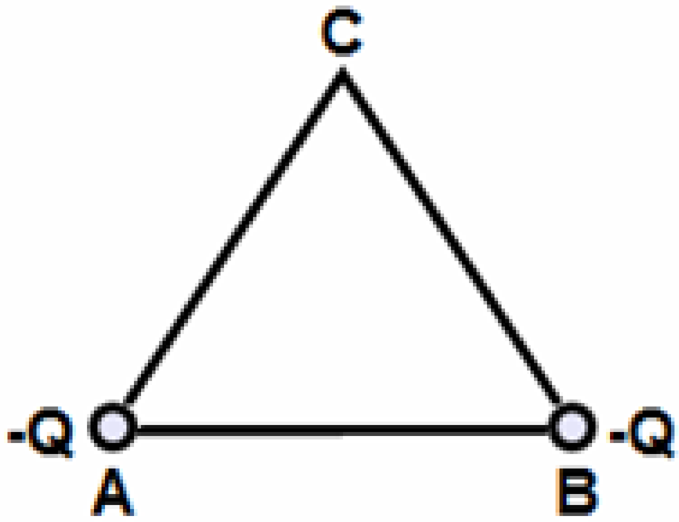
54 Two negative charges, A and B, are placed at the corners of an equilateral triangle. What is the magnitude of the net Electric field at point C?

A $\sqrt{2}\frac{kQ}{r^2}$

B $\sqrt{3}\frac{kQ}{r^2}$

C $\frac{kQ}{r^2}$

D $\sqrt{2}\frac{kQ}{r}$



Answer

Attachments

watch.webloc