New Jersey Center for Teaching and Learning

Progressive Science Initiative

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Electric Charge And Force

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Electric Charge and Force

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- Electric Charge
- Atomic Structure and Source of Charge
- Conduction and Induction
- Electroscope
- Electric Force (Coulomb's Law)

Electric Charge

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http://njc.tl/er

Charging by Rubbing

When you take two non metallic objects and rub them together, you get an interesting effect.

Before the contact, there is no interaction between them.

Afterwards, the two materials are attracted to each other.

ithout
bbing

...rub

after
rubbing

http://njc.tl/er

Electric Charge

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.

http://njc.tl/er

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.

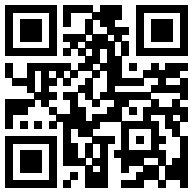
This led to the thought that something was being exchanged between the materials - and this something was later named "charge." Because objects would be repelled or attracted, it was postulated that this charge came in two types.

Electric Charge

In the 18th century, American Ben Franklin noticed when a rubber rod is rubbed by animal fur, the rod acquires a negative charge, and the animal fur acquires a positive charge.

When a glass rod is rubbed by silk, the rod acquires a positive charge and the silk obtains a negative charge. Thus, two rubber rods after being charged would repel each other, while a rubber rod would be attracted to a glass rod.

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.



http://njc.tl/er

1 A neutral plastic rod is rubbed by a piece of animal fur. Describe the charge on each item.

A Both items will be neutral.

B The fur and the rod will both have a negative net charge.

C The rod will have a negative net charge and the fur will have a positive net charge.

D The rod will have a positive net charge and the fur will have a negative net charge.

Answer

http://njc.tl/es

1 A neutral plastic rod is rubbed by a piece of animal fur. Describe the charge on each item.

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- C The rod will have a negative net charge and the fur will have a positive n
- D The rod will have a
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Answer

C

http://njc.tl/es

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 effect on the other.

B The objects move away from each other.

C The objects move towards each other.

Answer

http://njc.tl/et

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 effect on the other

B The objects mov

C The objects mov

Answer

C

http://njc.tl/et

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

http://njc.tl/eu

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- ○ **B** Twice the charge
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- ○ **D** One half of the c

Answer

A

http://njc.tl/eu

Atomic Structure and Source of Charge

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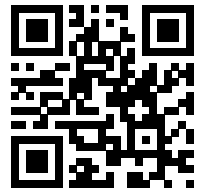

Atomic Structure

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.

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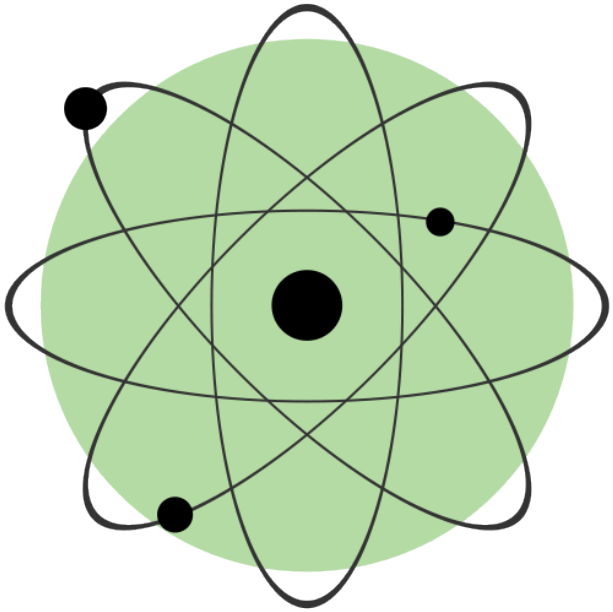
What the atom doesn't look like:

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.

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

http://njc.tl/ev

Charge on Nucleons

Protons and electrons have equal and opposite charge. By convention (as we discussed from Ben Franklin's work on charged materials), 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, that it has a positive charge and is called a positive ion.

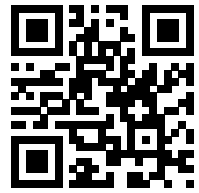
http://njc.tl/ev

The Source of the Movement of Charge

The nuclei of atoms are much more massive than electrons. Each proton or neutron is roughly 1800 times more massive than an electron; with each nucleus containing at least one proton.

That's one reason when electric charge moves within or between objects, it's the result of electrons moving, not protons.

The other reason is that in solids, the nuclei are locked together so they can't move - regardless of their mass.



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 areattracted 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 said to have a charge of -e and

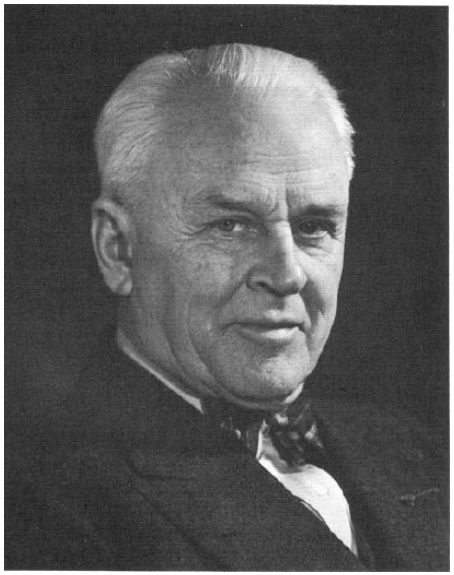
a proton a charge of +e.

http://njc.tl/ev

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

http://njc.tl/ev

Measurement of Charge

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

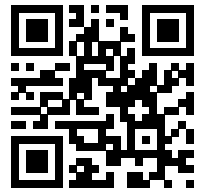
It has also been demonstrated that this is the smallest value of charge (with the exception of quarks which are covered in more advanced physics courses) and all larger charges are an integral multiple of this number.

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

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

micro-Coulombs (μC) = 10^{-6} C

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



4 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

http://njc.tl/ew

4 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
- **C** have equal nu
- **D** have an equal

Answer

C

http://njc.tl/ew

5 What object moves freely within the entire atom?

- **A** Electron.
- **B** Neutron.
- **C** Proton.
- **D** Nucleus.

Answer

http://njc.tl/ex

5 What object moves freely within the entire atom?

- **A** Electron.
- **B** Neutron.
- **C** Proton.
- **D** Nucleus.

Answer

A

http://njc.tl/ex

6 An atom is composed of:

A a central nucleus that is surrounded by neutrons.

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

C a central nucleus surrounded by electrons.

D a central nucleus containing protons and electrons.

Answer

http://njc.tl/ey

6 An atom is composed of:

- **A** a central nucleus that is surrounded by neutrons.
- **B** an even distribution of electrons and protons in a spherical shape.
- **C** a central nucleus
- **D** a central nucleus

Answer

C

http://njc.tl/ey

Solids

Solids are a form of matter whose nuclei form a fixed structure. Nuclei, and 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. In insulators, electrons are bound to their atoms, 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.

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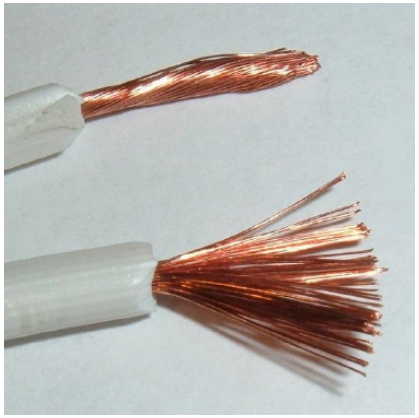
Conductors

In conductors, electrons move freely inside the solid. Like charges repel, therefore the electrons tend to spread as far apart as possible - which means that they will move to the surface of the conductor.



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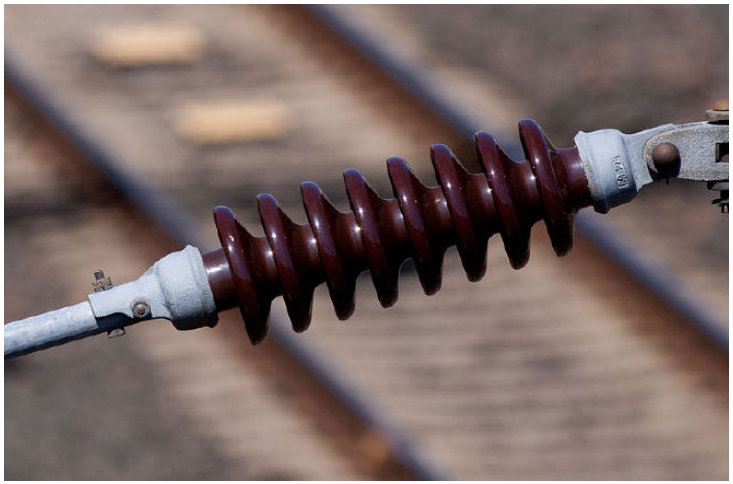
Insulators

Insulators are materials that have strongly bound electrons that can move only short distances within the solid. Thus, it will be harder for charges to move any significant distance within an insulator. Different insulators have varying levels of insulation capabilities.



http://njc.tl/ez

7 Free electrons in a conductor will:

- **A** move freely in random directions throughout the entire volume of the conductor.
- **B** be located at the center of the conductor.
- **C** have no organized distribution.
- **D** only move short distances.

Answer

http://njc.tl/f0

7 Free electrons in a conductor will:

A move freely in random directions throughout the entire volume of the conductor.

B be located at the center of the conductor

C have no organi

D only move sho

Answer

A

http://njc.tl/f0

8 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

http://njc.tl/f1

8 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

D

http://njc.tl/f1

9 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 their solid.

Answer

http://njc.tl/f2

9 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 at…es within their solid.

Answer

D

http://njc.tl/f2

Conduction and Induction

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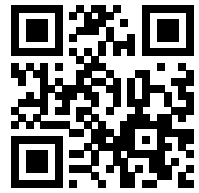

The Ground

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. Earth serves as the ultimate source and destination for electrons because of its huge size.

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

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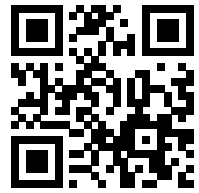
Grounding

When a wire is attached between the earth and another conductor, excess electrons will flow to the earth leaving the conductor neutral. This is "grounding." Also, 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!



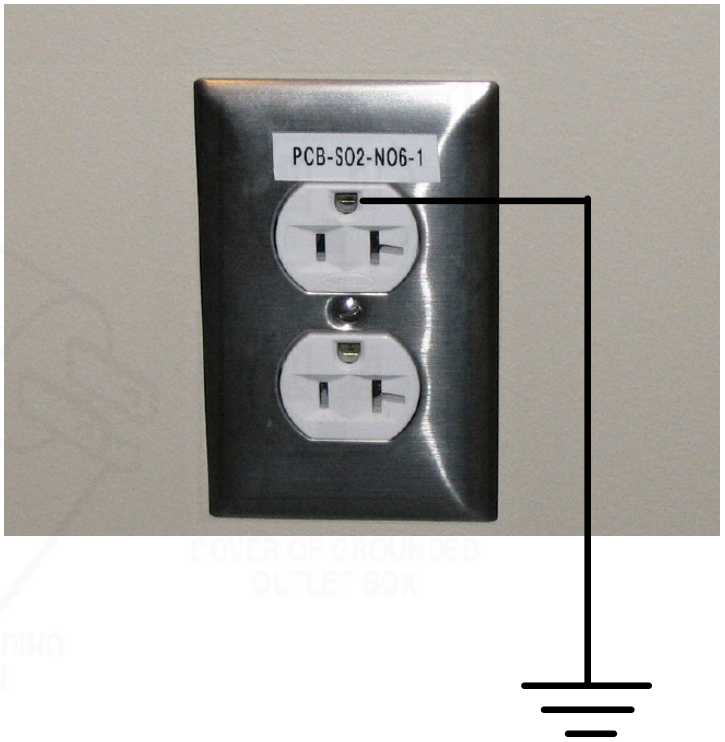
Note: grounding is also called "earthing," because of the relationship to Earth.

Grounding

Electrical circuits and devices are usually grounded to protect 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 which goes to the ground.



(symbol for "ground")

http://njc.tl/f3

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

- A Positive.
- B Neutral.
- C Negative.

Answer

http://njc.tl/f4

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

A Positive.

B Neutral.

C Negative.

Answer

B

http://njc.tl/f4

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

A Positive.

B Neutral.

C Negative.

Answer

http://njc.tl/f5

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

A Positive.

B Neutral.

C Negative.

Answer

B

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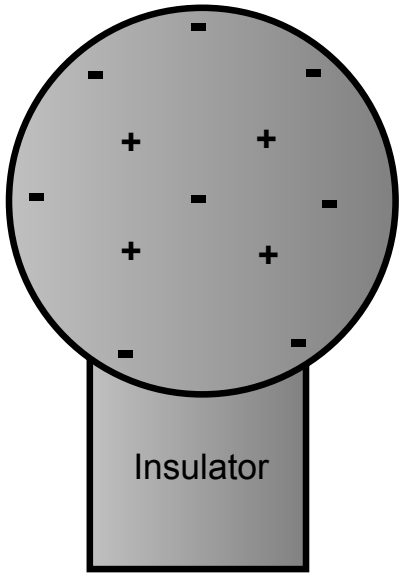
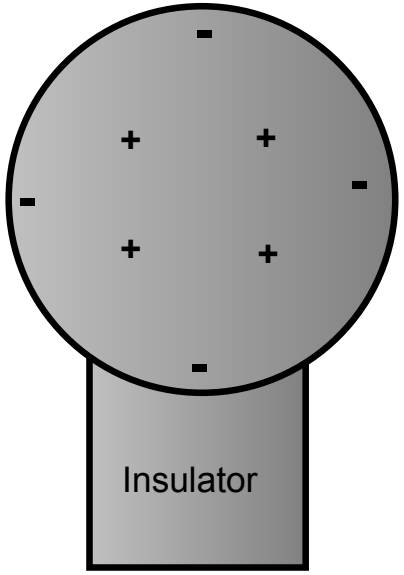
Charging by Conduction

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 Earth.

Neutral Charge
(charge = 0)



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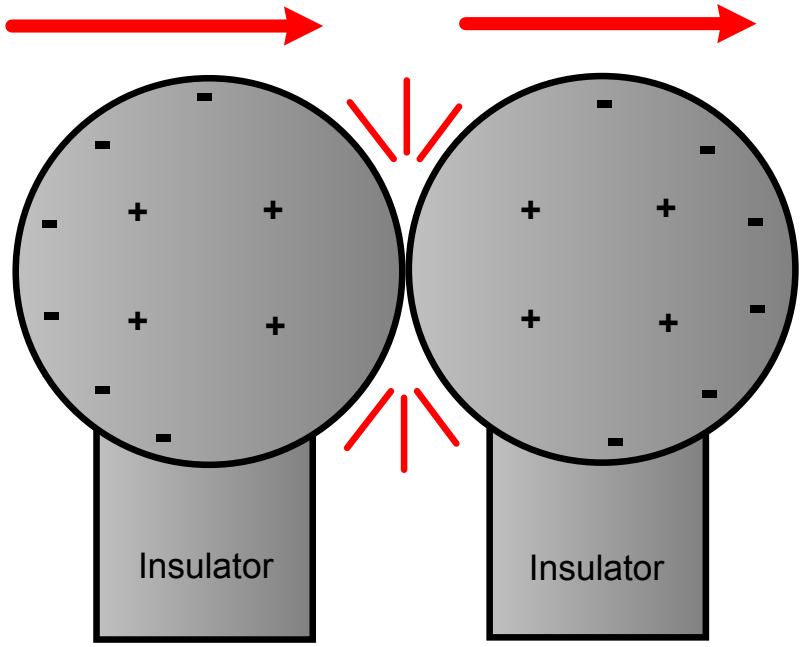
Total Charge = -4Q

(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.



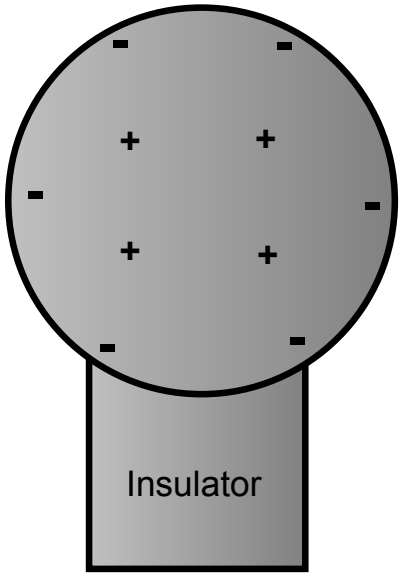
Total Charge = -4Q

ıber, similar charges repel)

http://njc.tl/f6

Charging by Conduction

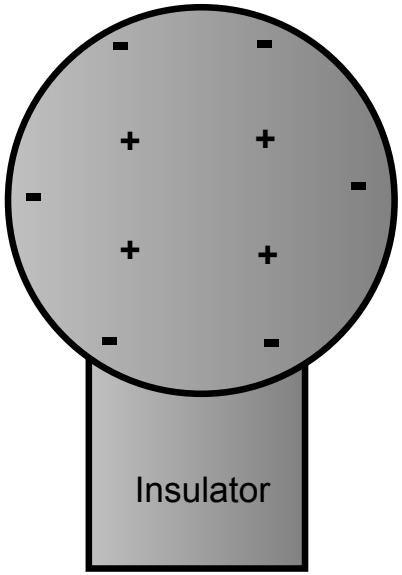
Negatively Charged
(charge = -2Q)



(very far apart)

Total Charge = -4Q

Negatively Charged
(charge = -2Q)



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.

http://njc.tl/f6

12 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

http://njc.tl/f7

12 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

4Q

http://njc.tl/f7

13 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

http://njc.tl/f8

13 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

-3Q

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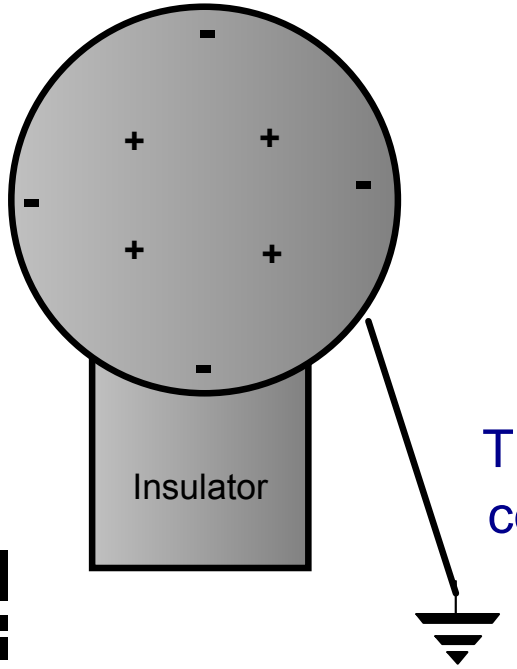
Charging by Induction

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.

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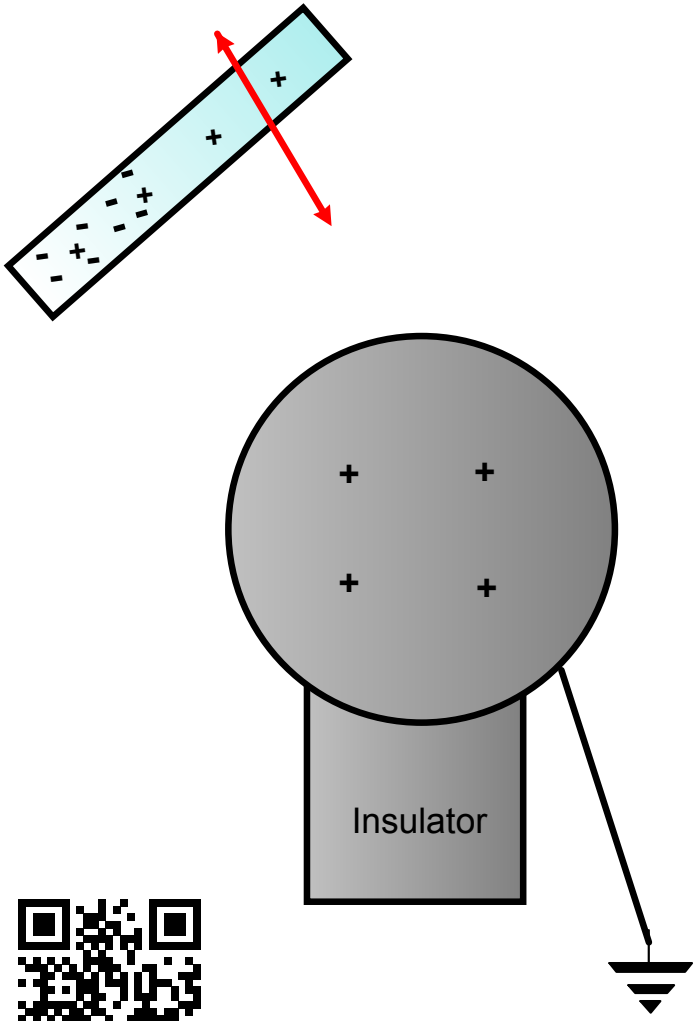
Charging by Induction



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.

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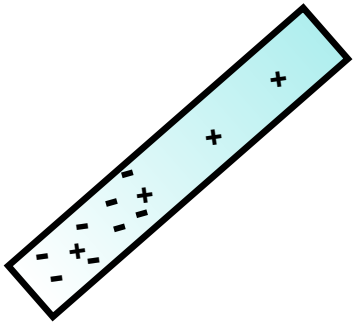
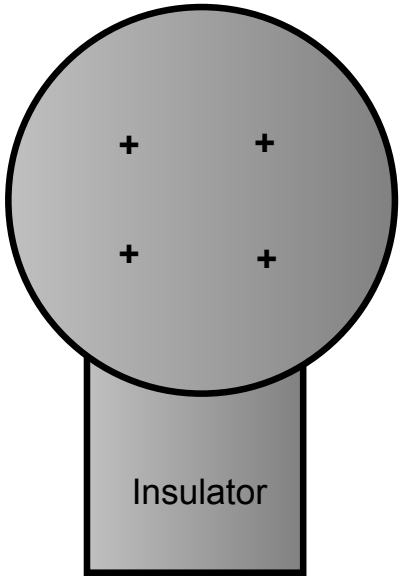
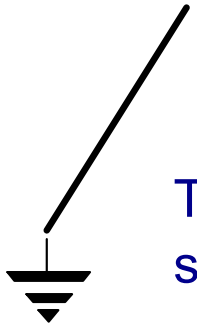
Charging by Induction





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.

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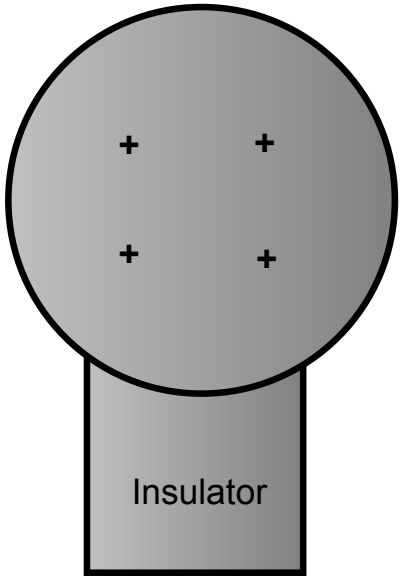
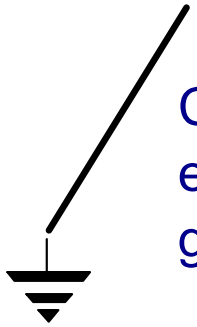
Charging by Induction

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.





Compared to the amount of free electrons already in Earth, it has gained an insignificant amount of charge.

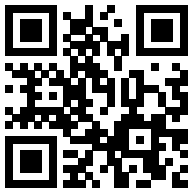
http://njc.tl/f9

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 object will be brought close to a neutral object, but it will not touch it. The neutral object will be grounded - it will have an electrical conducting path to ground. The charged object will repel similar charges on the neutral object to the ground.

Thus, the neutral object will be left with a charge *opposite* to the initially charged object. The initial object will not lose any charge - the extra charge 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 initially charged object was removed, the neutral object will pass its gained charge back to the ground.

http://njc.tl/f9

14 Sphere A carries a net positive charge, 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

http://njc.tl/fa

14 Sphere A carries a net positive charge, 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 remai

B Sphere B is nov

C Sphere B is n

D The charge on s without addition

Answer

C

http://njc.tl/fa

15 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.

http://njc.tl/fb

Answer

15 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 s

○ **B** The sphere beco net charge decre

○ **C** The sphere bec rod's net charge s

○ **D** The sphere rema rod's net charge

Answer

B

http://njc.tl/fb

16 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

http://njc.tl/fc

16 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
- **D** The Earth.

Answer

D

http://njc.tl/fc

Electroscope

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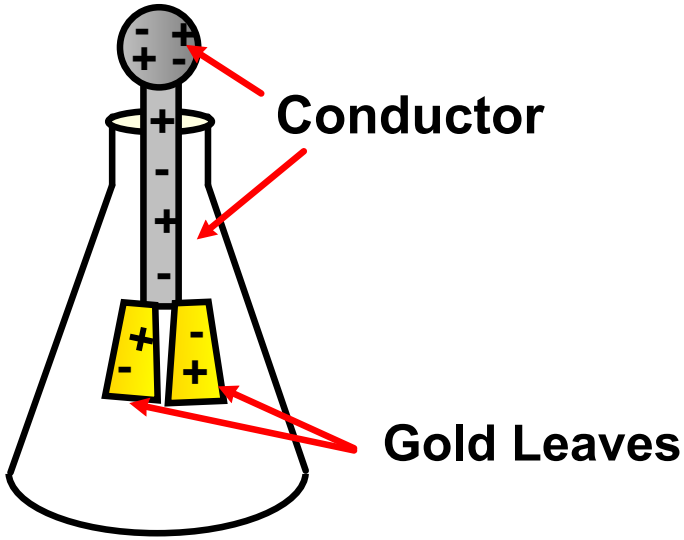
http://njc.tl/fd

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.



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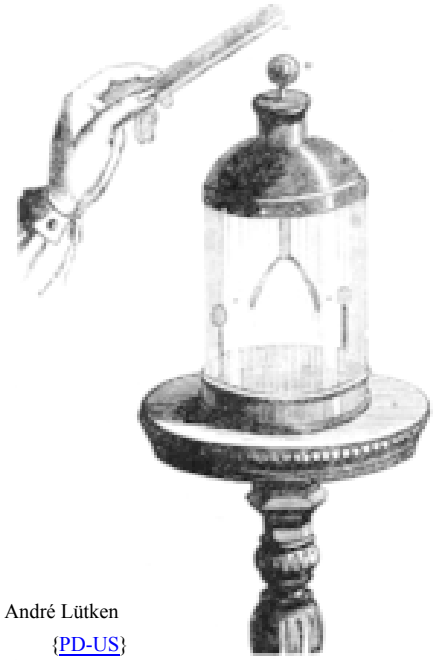
ectroscopes can be charged by conduction or induction.

The Electroscope

An antique Electroscope from 1878.



From the book "Opfindelsernes Bog" 1878 by André Lütken

{PD-US}

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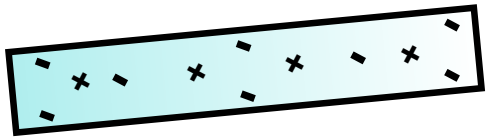
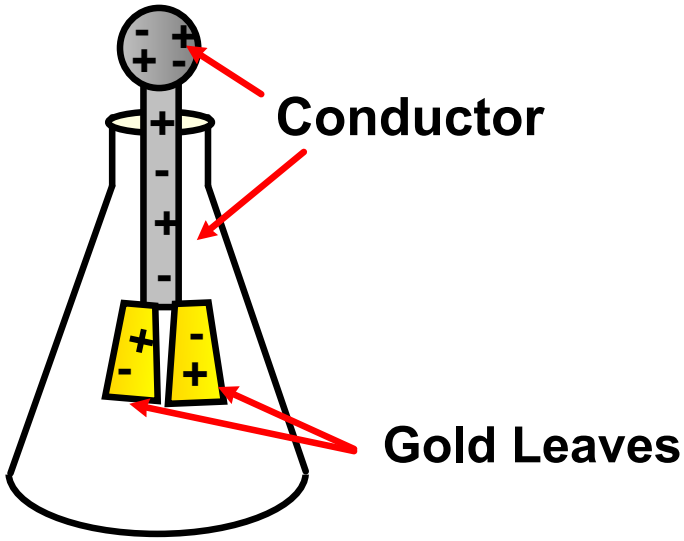
Charging by Conduction



Charge = -4e



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.

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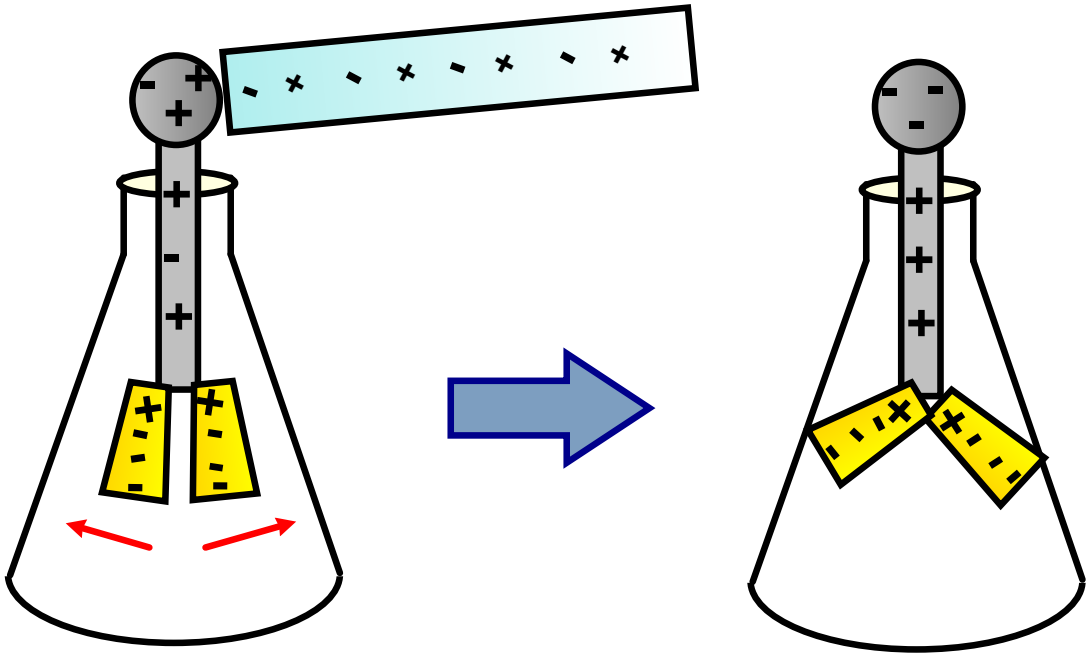
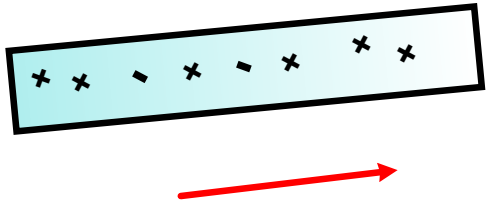
Charging by Conduction





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

The gold leaves repel.

http://njc.tl/fd

es would also repel if the experiment
done with a bar of positive net charge.

17 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

Answer

17 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

Answer

A

18 What is the source of the charge that is moved to the gold leaves?

A The charged bar.

B The ground.

C The glass surrounding the leaves.

Answer

http://njc.tl/fe

18 What is the source of the charge that is moved to the gold leaves?

A The charged bar.

B The ground.

C The glass surrou

Answer

A

http://njc.tl/fe

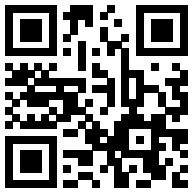
Charging by Induction

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.

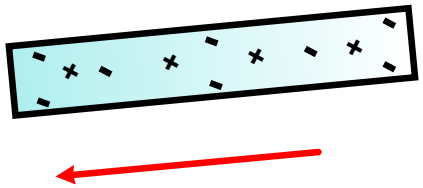
A similar effect is caused by a bar with a positive net charge. The leaves will again repel since like charges repel.

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

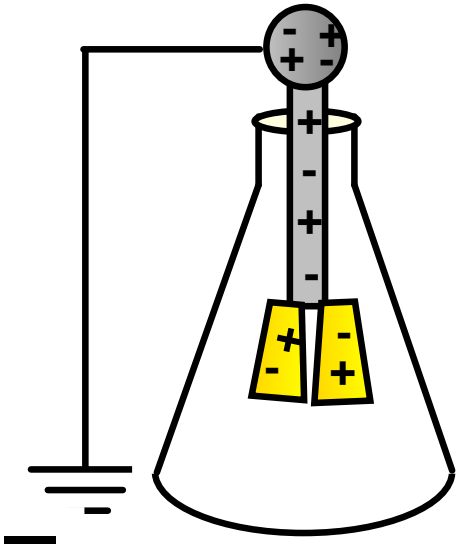


Electroscope charging by Induction

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



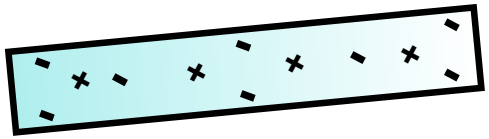
negatively charged rod



initially neutral

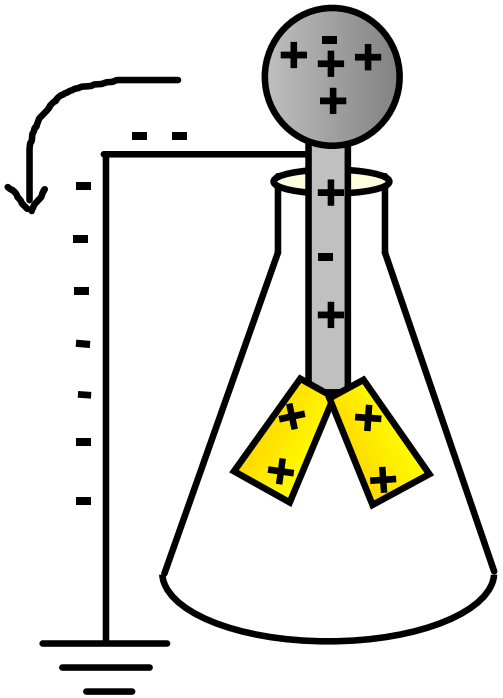
http://njc.tl/ff

Electroscope charging by Induction



negatively charged

electrons travel into the ground

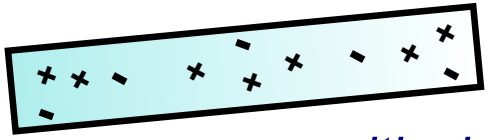


Electrons in the scope will be repelled out of the scope to the ground. The scope will then have a positive net charge. As with charging a sphere by induction, note that the charge on the rod does NOT change.

now positively charged - leaves repel each other

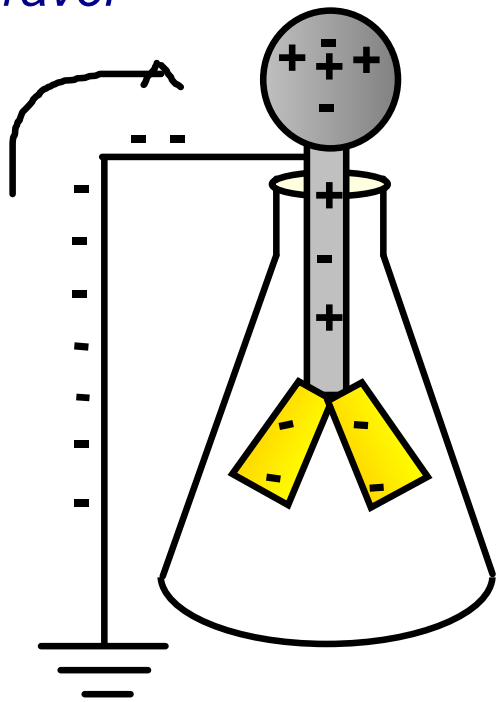
http://njc.tl/ff

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

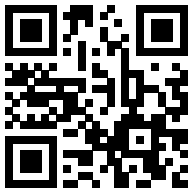
http://njc.tl/ff

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.



19 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

http://njc.tl/fg

19 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 t[illegible]?

A They separate f[illegible]

B They move clos[illegible]

C They are unaff[illegible]

D Cannot be deter[illegible] information.

Answer

B

http://njc.tl/fg

20 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 and keep them separate from each other?

Students type their answers here

Answer

http://njc.tl/fh

20 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 and keep them separate from each other?

Students type the

Answer

Remove the ground while the rod is still held close to the Electroscope. When the rod is then removed, the charges will stay on the leaves as there is no place for them to go.

http://njc.tl/fh

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.

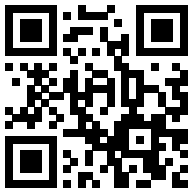
Object's Charge is:	Electroscope's Reaction:	Charge on the Scope is:
Positive	Leaves move apart	positive
Positive	Leaves move closer	negative
Negative	Leaves move apart	negative
Negative	Leaves move closer	positive

http://njc.tl/fi

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)

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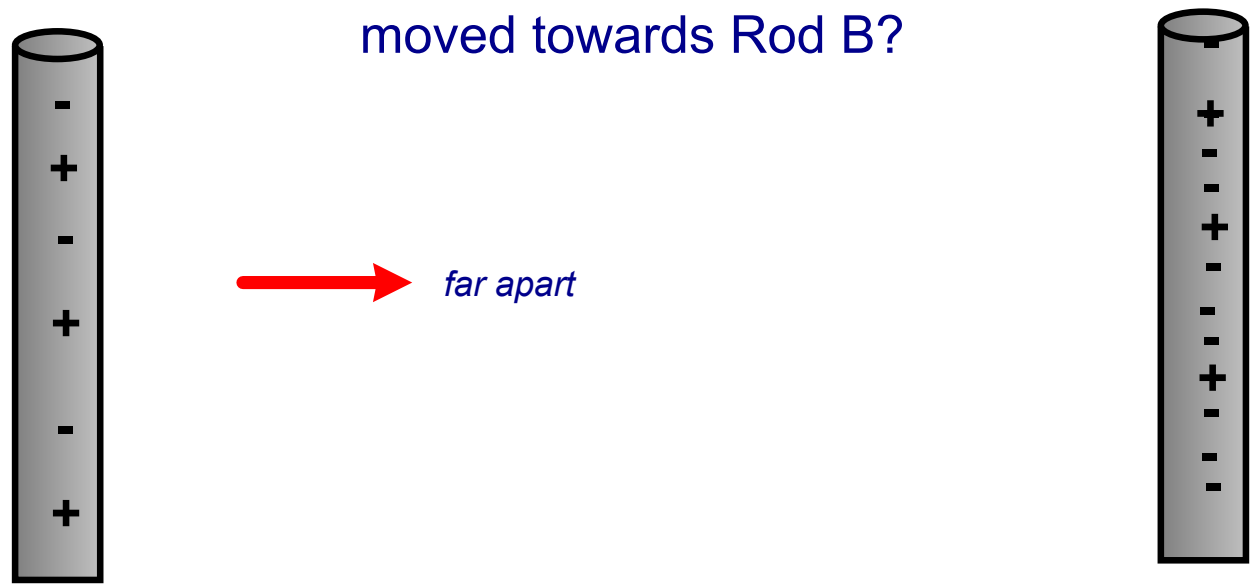
Charged Objects

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.

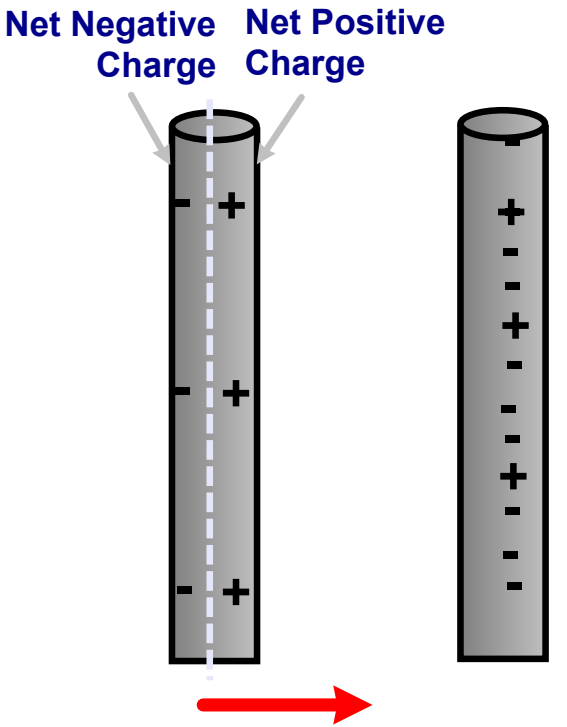
What will happen to the charges on Rod A if it is moved towards Rod B?



Rod A: Neutral Rod Conductor

Rod B: Stationary, Negatively Charged

Charged Objects



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).

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

A The rods will move towards each other.

B The rods will move away from each other.

C Nothing; the rods will remain at rest.

Answer

http://njc.tl/fj

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

A The rods will mov

B The rods will m

C Nothing; the ro

Answer

A

http://njc.tl/fj

22 What happens to the electrons on a neutral conductor that is brought near a positively charged rod?

A All electrons move to the side of the conductor furthest from the rod.

B Each electron moves to the side of their atom closest to the rod.

C Nothing happens.

Answer

http://njc.tl/fk

22 What happens to the electrons on a neutral conductor that is brought near a positively charged rod?

A All electrons move to the side of the conductor furthes

B Each electron m their atom close

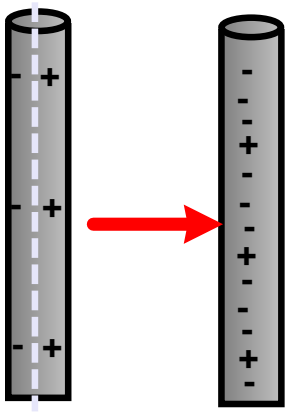
C Nothing happe

Answer

B

http://njc.tl/fk

Electrical Force



Newton's First Law (the law of inertia) states that objects at rest tend to stay at rest unless an external net force acts on the object. This, of course, is the special case of objects in motion tend to stay in motion (where the velocity of the object is zero).

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

Electrical Force

In the late 18th Century, several physicists (Joseph Priestly and John Robison) reasoned (and 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:

$$F_E \alpha \frac{1}{r^2}$$

Joseph Priestly

John Robison

Electrical Force

Charles Coulomb published a paper (1785), based on detailed experiments, that definitively proved the above, 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 Electrical Force

Thus, the magnitude of the electrical force is:

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

k = the Coulomb constant that equals 9.0×10^9 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 electrical force, like all forces, is a vector, you need to specify the direction of the force magnitude determined by Coulomb's Law. This is done by looking atthe sign of both charges (like charges repel & opposite charges attract).

Electrical Force relationship to Gravitational Force

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

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

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

[23] A +20.0 μC 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

http://njc.tl/fl

23 A +20.0 μC 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?

0x10 $^{-6}$ C
).0x10 $^{-6}$ C
0x10 $^{-2}$m

0.0x10^{-6} C|

:her

http://njc.tl/fl

24 Compare and contrast the Electrical force and the Gravitational force.

Students type their answers here

Answer

24 Compare and contrast the Electrical force and the Gravitational force.

Students type their answers

Answer

The Electrical force can be either attractive and repulsive; while the Gravitational force is always attractive. They follow the same mathematical formula and the Electrical force is much stronger.

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

Answer

http://njc.tl/fm

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

Answer

$$F = \frac{K|q_1||q_2|}{r^2} \qquad Fr^2 = K|q_1||q_2|$$

$$r = \sqrt{\frac{K|q_1||q_2|}{F}}$$

$$r = \sqrt{\frac{9\times10^9\left(7.8\times10^{-6}\right)\left(9.2\times10^{-6}\right)}{4.5\times10^{-3}}}$$

$$r = 12m$$

http://njc.tl/fm

26 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

http://njc.tl/fn

26 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

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

$$q_2 = \frac{Fr^2}{Kq_1} = \frac{\left(1.8\times10^{-3}\right)\left(2.4\right)^2}{\left(9\times10^{9}\right)\left(4.2\times10^{-6}\right)}$$

$$q_2 = 2.7x10^{-7}\,C$$

http://njc.tl/fn

27 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

http://njc.tl/fo

27 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

$$F = \frac{K|q_1||q_2|}{r^2} \qquad q_1 = q_2$$

$$F = \frac{Kq^2}{r^2}$$

$$q = \sqrt{\frac{Fr^2}{K}} = \sqrt{\frac{\left(18\times10^{-3}\right)\left(9\times10^{-2}\right)^2}{9\times10^{9}}} = 127nC$$

$$\#electrons = \frac{Q_{net}}{Q_{electron}} = \frac{127\times10^{-9}C}{1.6\times10^{-19}C} = 7.9\times10^{11}electrons$$

http://njc.tl/fo

28 Two conducting spheres 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

http://njc.tl/fp

28 Two conducting spheres have a net charge of 5.0 mC and -9.0 mC and attract each other with a force of 4.05x
and th
is the
attract

Answer

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

$$r = \sqrt{\frac{K|q_1||q_2|}{F}}$$

$$r = \sqrt{\frac{(9\times10^9)(5\times10^{-3})(9\times10^{-3})}{4.05\times10^3}} = 10m$$

$$q_{net} = q_{1i} + q_{2i} = 5mc - 9mc = -4mc$$

$$q_{1f} = q_{2f} = \frac{Q_{net}}{2} = -2mc$$

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

$$F = \frac{(9\times10^9)(2\times10^{-3})(2\times10^{-3})}{(10m)^2}$$

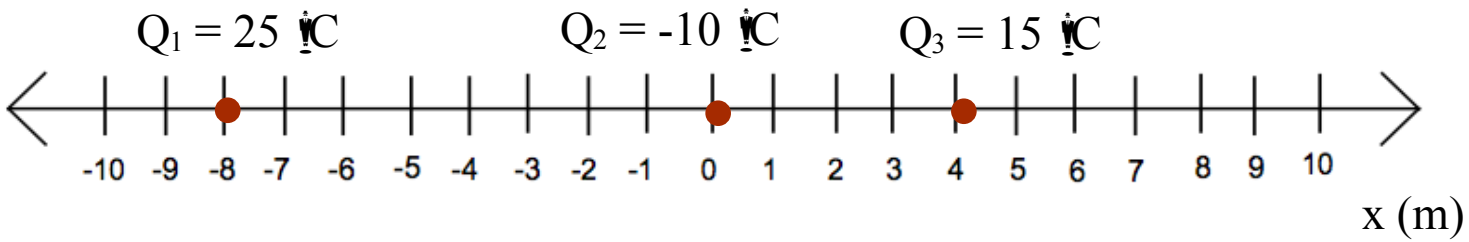
$$F = 360N \quad \text{repulsive}$$

http://njc.tl/fp

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. Of course, the charge configuration will then change, as the charges react to their initial net forces.

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.

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

F_{12} is the force that Q_1 exerts on Q_2.

F_{13} is the force that Q_1 exerts on Q_3.

F_{23} is the force that Q_2 exerts on Q_3.

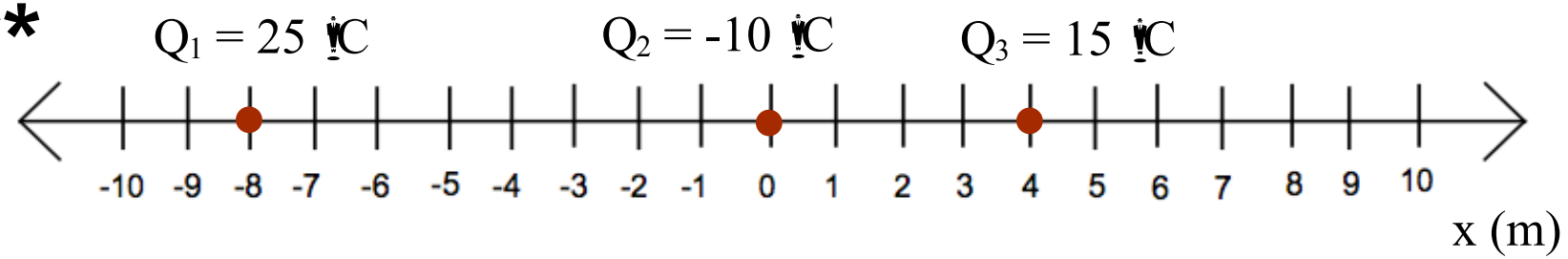
Note that by the application of Newton's Third Law:

$$F_{12} = - F_{21}$$

$$F_{13} = - F_{31}$$

$$F_{23} = - F_{32}$$

**

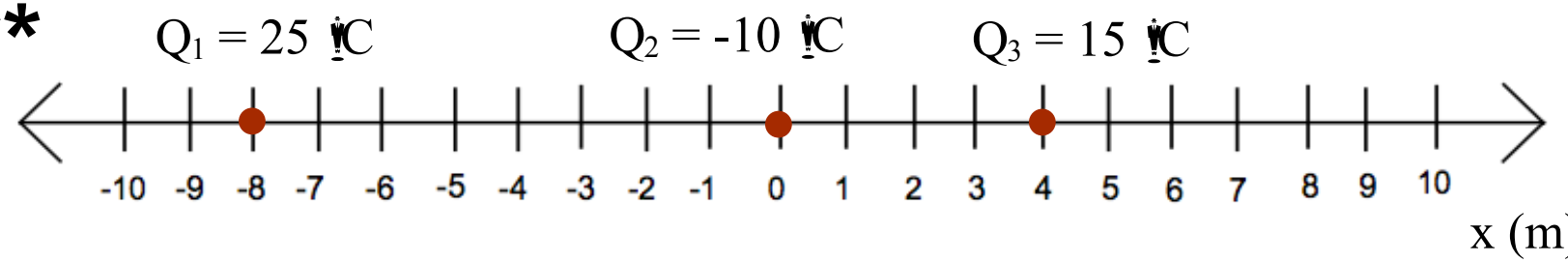


A positive charge Q_1 = 25 μC is located at a point x_1 = -8 m, a negative charge Q_2 = -10 μC is located at a point x_2 = 0 m and a positive charge Q_3 = 15 μC is located at a point x_3 = 4 m.

a. Draw free body diagrams for the electric force acting on Q_1, Q_2 and Q_3.

Answer

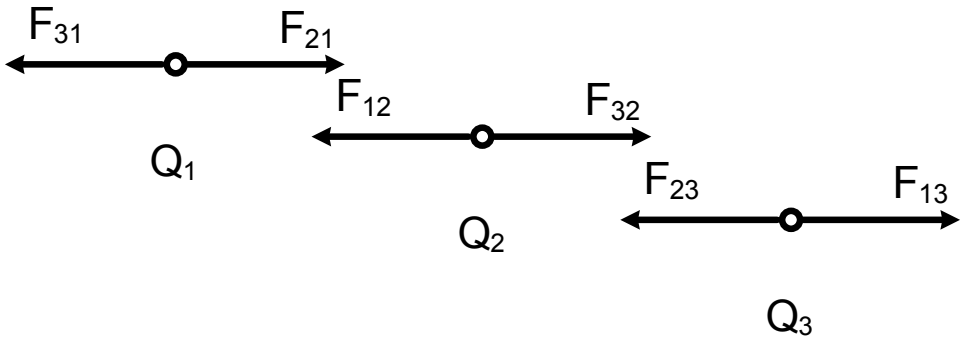
**



A positive charge Q_1 = 25 μC is located at a point x_1 = -8 m, a negative charge Q_2 [illegible] 0 m and a positive ch[illegible] x_3 = 4 m.

a. Draw free b[illegible] Q_1, Q_2 and Q_3.

Answer



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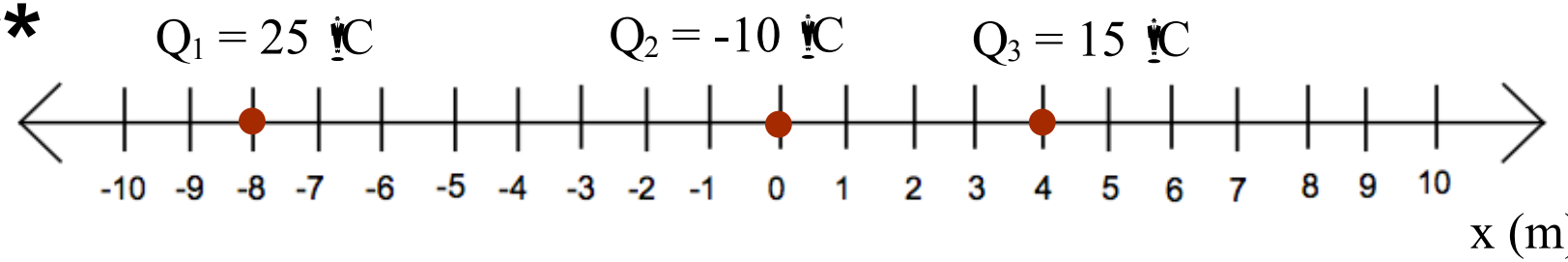

b. Find the magnitude of the force between Q_1 and Q_2.
c. Find the magnitude of the force between Q_1 and Q_3.
d. Find the magnitude of the force between Q_2 and Q_3.

Answer

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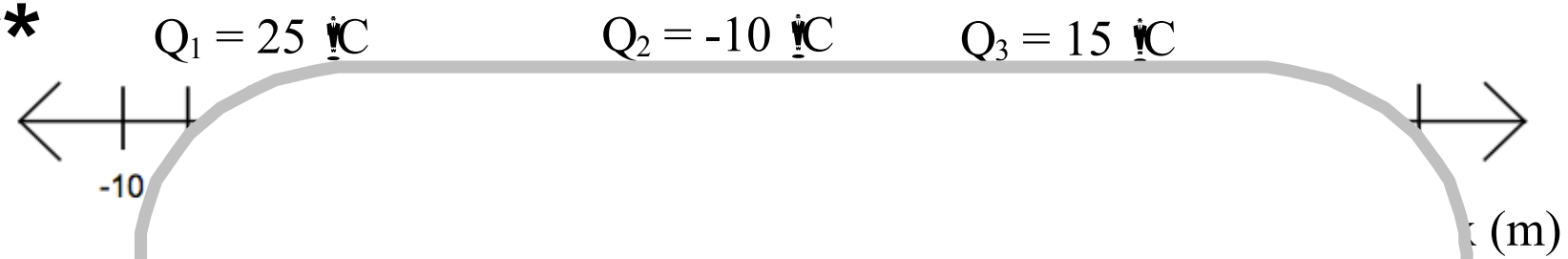

b.

c.

d.

Answer

$$F_{12} = \frac{k|q_1||q_2|}{r_{12}^2} = \frac{(9\times10^9\ Nm^2/C^2)\ |25.0\times10^{-6}\ C||-10.0\times10^{-6}\ C|}{(8.00\ m)^2} = 3.51\times10^{2}\ N$$

$$F_{13} = \frac{k|q_1||q_3|}{r_{13}^2} = \frac{(9\times10^9\ Nm^2/C^2)\ |25.0\times10^{-6}\ C||15.0\times10^{-6}\ C|}{(12.00\ m)^2} = 2.34\times10^{2}\ N$$

$$F_{23} = \frac{k|q_2||q_3|}{r_{23}^2} = \frac{(9\times10^9\ Nm^2/C^2)\ |-10.0\times10^{-6}\ C||15.0\times10^{-6}\ C|}{(4.00\ m)^2} = 8.44\times10^{2}\ N$$

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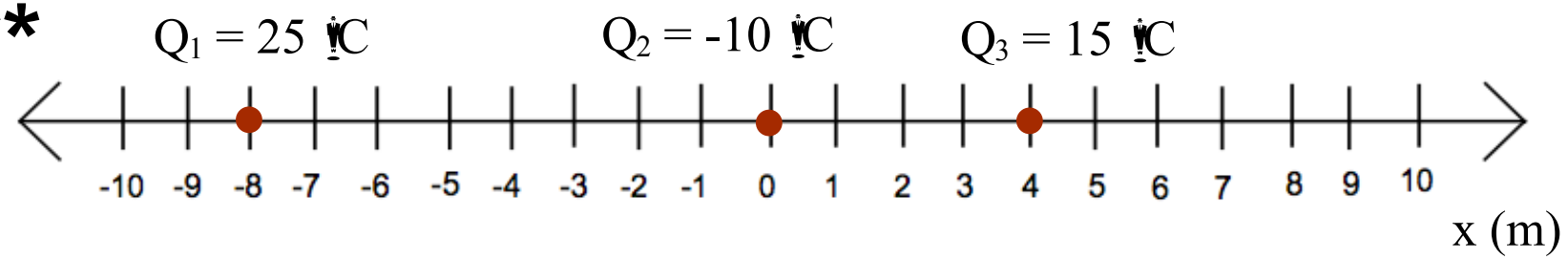

e. Find the magnitude and direction of the net force on Q_1.

f. Find the magnitude and direction of the net force on Q_2.

g. Find the magnitude and direction of the net force on Q_3.

Answer

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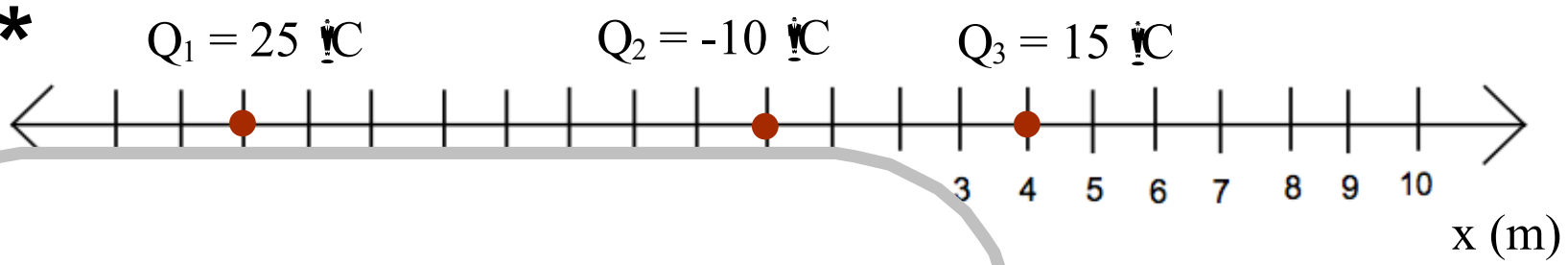

e net force on Q_1.
e net force on Q_2.
e net force on Q_3.

$Q_1 = F_{31} + F_{21} = -2.34\text{x}10^{-2}$ N + $3.51\text{x}10^{-2}$ N = $1.17\text{x}10^{-2}$ N to the right.

$Q_2 = F_{12} + F_{32} = -3.51\text{x}10^{-2}$ N + $8.44\text{x}10^{-2}$ N = $4.93\text{x}10^{-2}$ N to the right.

$Q_3 = F_{13} + F_{23} = 2.34\text{x}10^{-2}$ N - $8.44\text{x}10^{-2}$ N = $-6.10\text{x}10^{-2}$ N to the left.