Chapter 12

Electrostatic Phenomena

Electric Charge

1. History

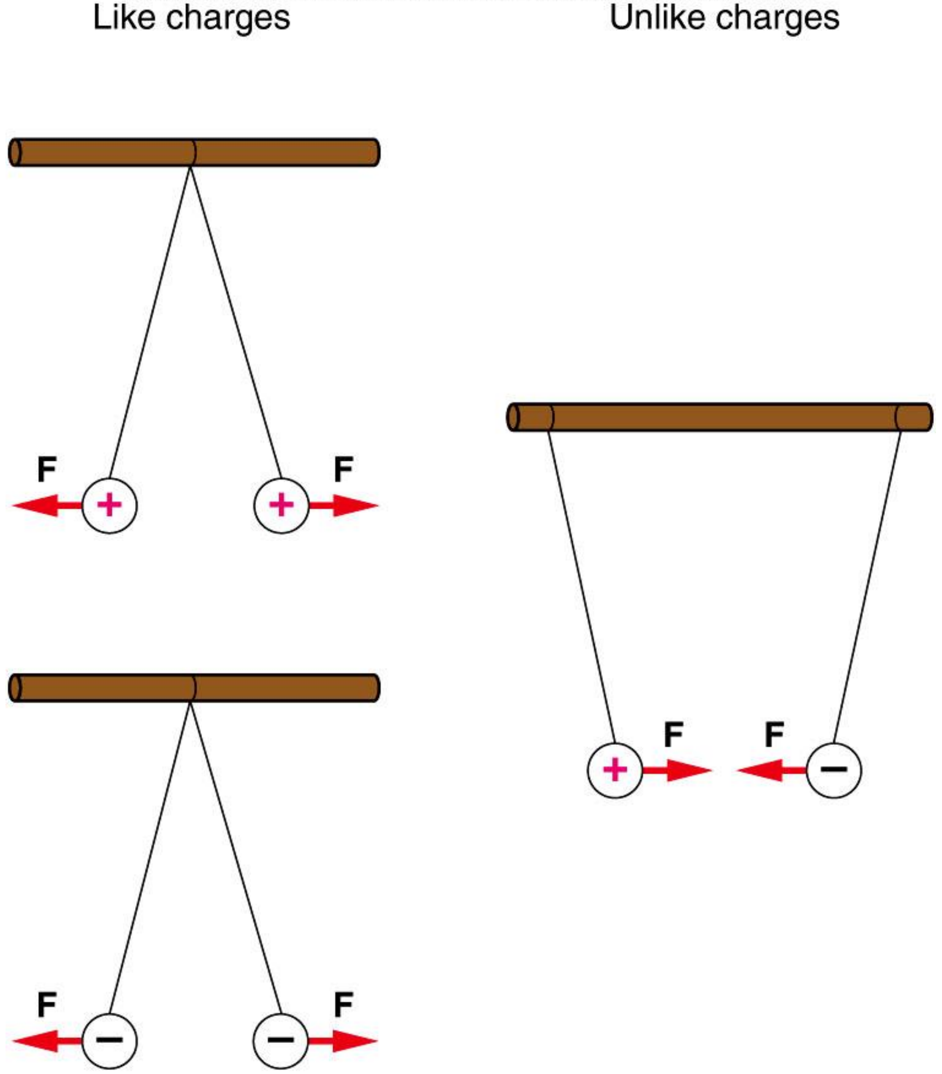
- The ancient Greeks noticed that if you rubbed amber (petrified tree resin) on fur, then the amber would have a property that it could attract and pick up leaves and other objects.
- The Greek word for amber is *elektron* from which we get our work "electric."
- Early experiments with electricity also were conducted by rubbing different objects together.

2. There are two kinds of electric charge

i. positive
ii. negative

- Ben Franklin named the charges.
- If there is no net charge on an object we say it is "neutral."
- Rubbing glass with silk or neoprene puts one kind of charge on the glass.
- Rubbing plastic with fur puts a different kind of charge on the plastic.

- Like charges repel and unlike charges attract.
- The force increases as the charge increases or as the distance between the two objects decreases.



3. Electric charge is quantized.

- This means it comes in discrete amounts.
- The smallest "amount" of charge is that contained in one electron or one proton given the symbol *e*.
  - $e = 1.60 \times 10^{-19}$ C where "C" stands for Coloumb, the SI unit of electric charge. Charge is often measured in millicoulombs (mC) 10^{-3} or microcoloumbs (μC) 10^{-6} or nanocoloumbs (10^{-9})
- When an atom loses or gains an electron, it gains a net charge and is called an *ion*.

4. Electric charge is conserved.

This means that in any process the total amount of charge remains the same.

Charge can move from one place to another, but the total amount of charge always remains the same.

- When the plastic rod gains more negative charge, the fur loses negative charge and has more positive charge.
- A composite object with no charge (neutral) will still have lots of protons and electrons, but just has the same number of each.
- A charged composite object will usually still have lots of protons and electrons. If it has a negative charge it has more electrons than protons and if it has a postive charge it has more protons than electrons.

Interactive Question

When a glass rod rubbed with silk acquires a positive charge, the silk acquires

A) a positive charge

B) a negative charge

C) no charge

D) either a positive or a negative charge

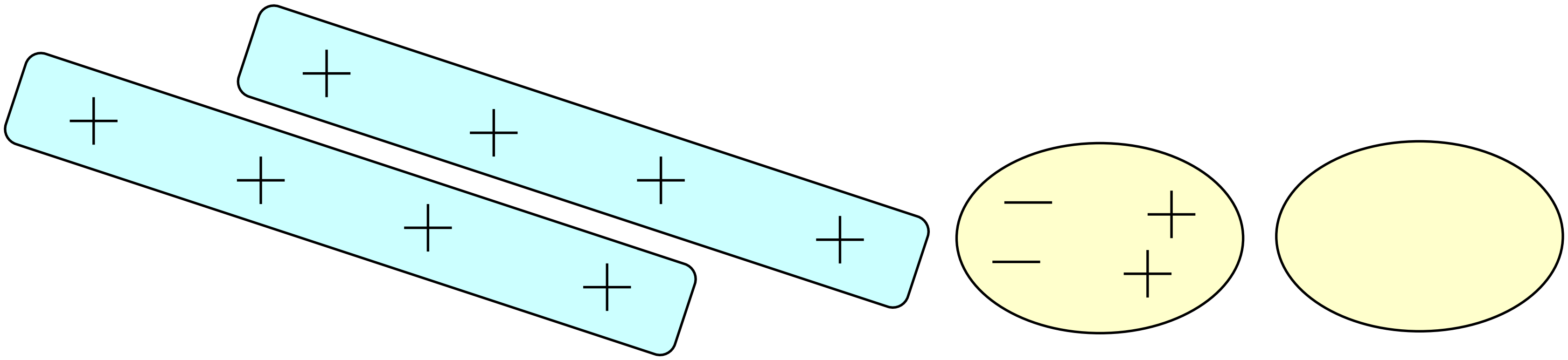
E) it is impossible to tell which sign of charge it acquires

5. Electric charge moves with varying ease

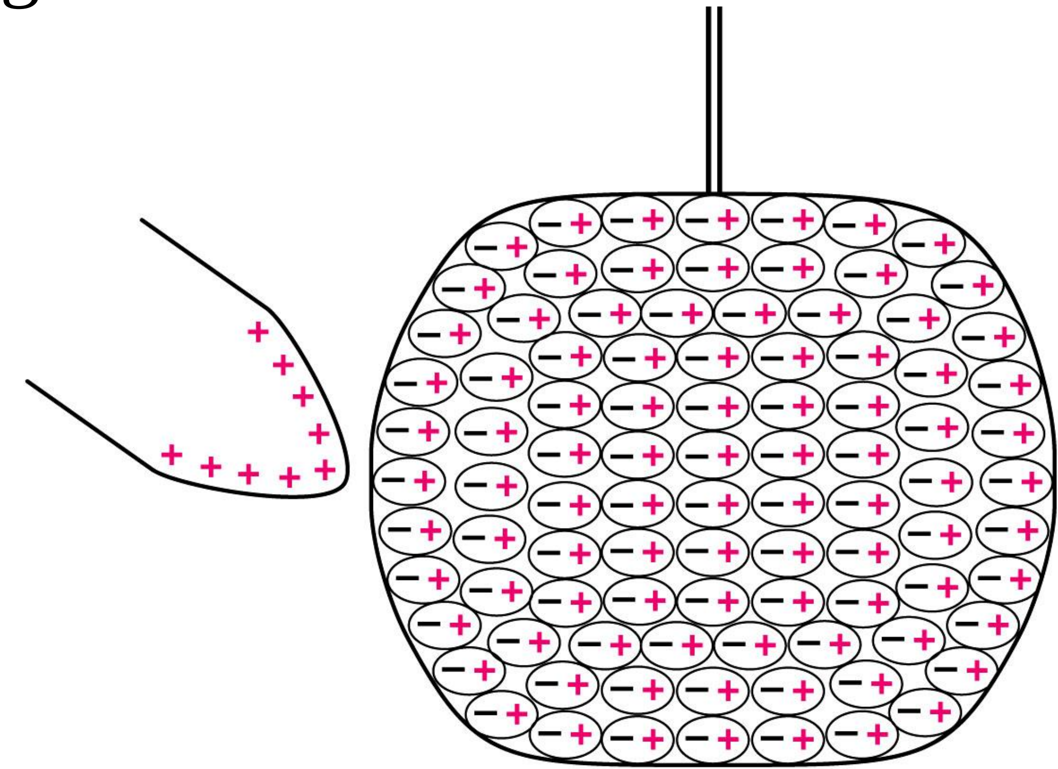
- Conductors easily conduct electricity (allow electrons to flow easily)
  - Metals are usually good conductors
- Insulators do not easily conduct electricity.
  - Plastic, rubber, and wood are good insulators
- Semiconductors are somewhere between conductors and insulators and are used in all modern electronic components
- Both conductors and insulators can be charged.

6. The electric charge of an object may be polarized

- Polarized means that part of the object has a greater negative charge and part a greater positive charge
- Insulators and conductors can be polarized
- Because of this, a charged object can attract a neutral object due to *induced polarization*.



- An insulator is polarized when the atoms change their orientation. In the figure, the negative charges in the hanging object are closer to the positive rod than the positive charges are, and so the hanging object is attracted to the rod.
- When two objects are attracted to each other it is because one of two things are true
  1. They have opposite charges
  2. One is charged and one is neutral



- Polarization explains why small bits of paper or styrofoam are attracted to a charged object such as a sweater rubbed against some other material.
- Many everyday phenomena are a result of different materials rubbing together which charges the objects, and the result of charged objects inducing polarization in neutral objects.

Interactive Question

A rod with a positive charge is brought near a styrofoam ball suspended from an insulating string. The ball is attracted to the rod. What do you know about the ball?

A) It definitely has a positive charge

B) It definitely has a negative charge

C) It definitely doesn’t have a positive charge

D) It definitely doesn’t have a negative charge

E) None of the above

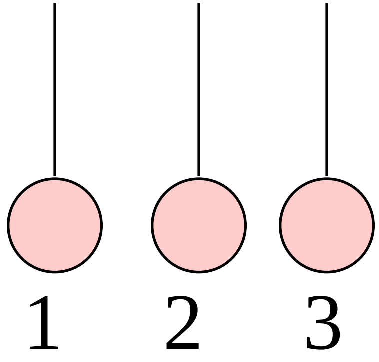
Interactive Question

Three styrofoam balls are suspended from insulating threads. Several experiments are performed and the following observations made:

I) Ball 2 attracts 1, but has no effect on ball 3.
II) Ball 1 is attracted to a negatively charged rod.

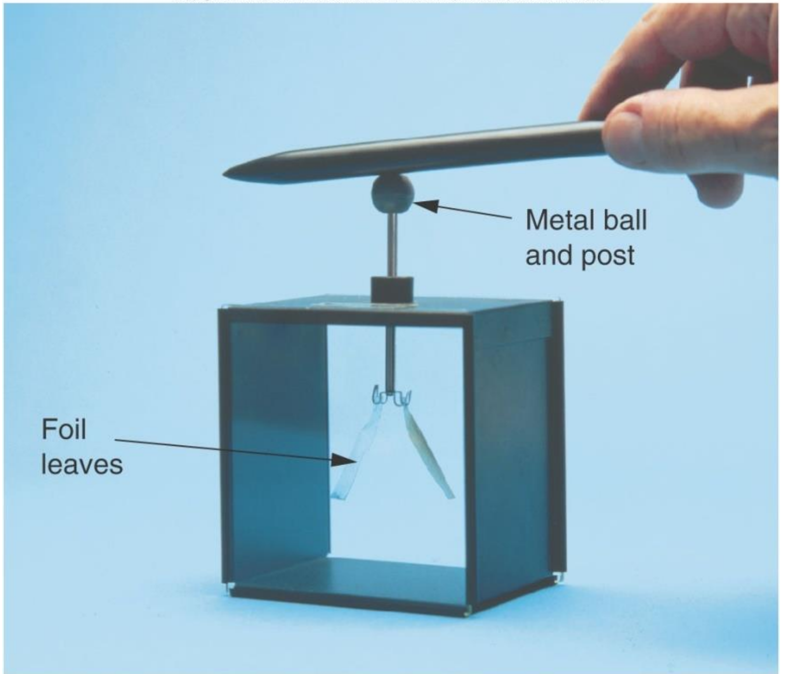
What are the charges on the balls?

	1	2	3
A)	+	–	0
B)	0	0	0
C)	+	0	0
D)	+	+	–
E)	0	+	–



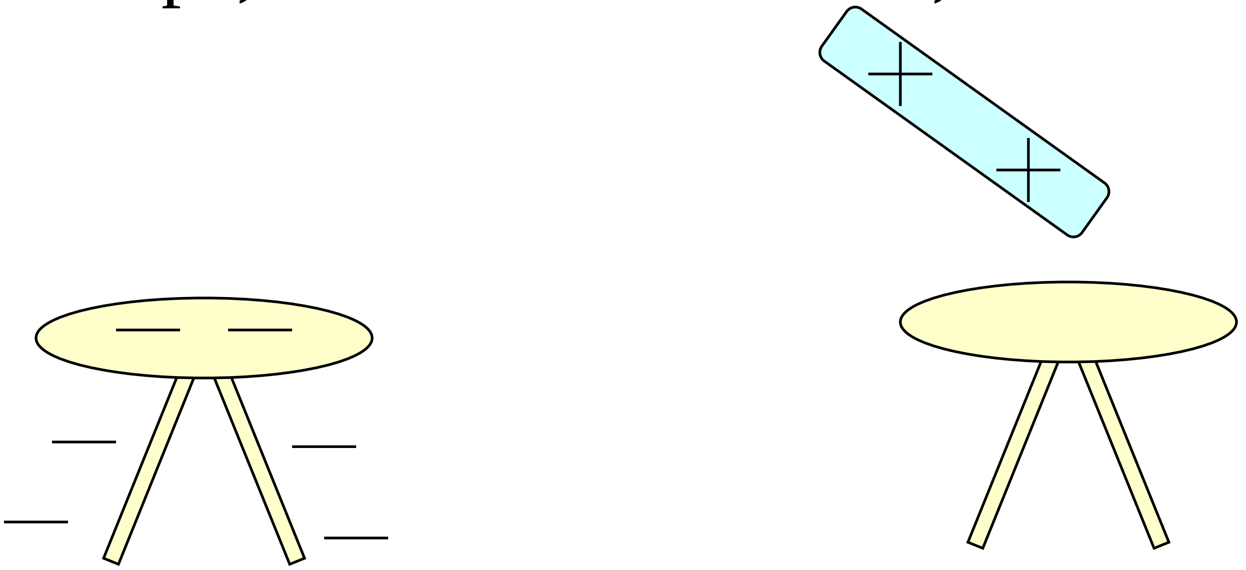
An electroscope can be used to illustrate many of the principles discussed so far.

- If the foil leaves are uncharged, they will hang straight down.
- If a charged rod is brought in contact with the metal ball on top, the leaves will be charged with the same charge as the rod and because like charges repel, the leave will spread apart and stay apart, even if the rod is removed.



Interactive Question

An electroscope is initially given a negative charge. When a rod that is positively charged is brought near to the electroscope, but does not touch it, the leaves will



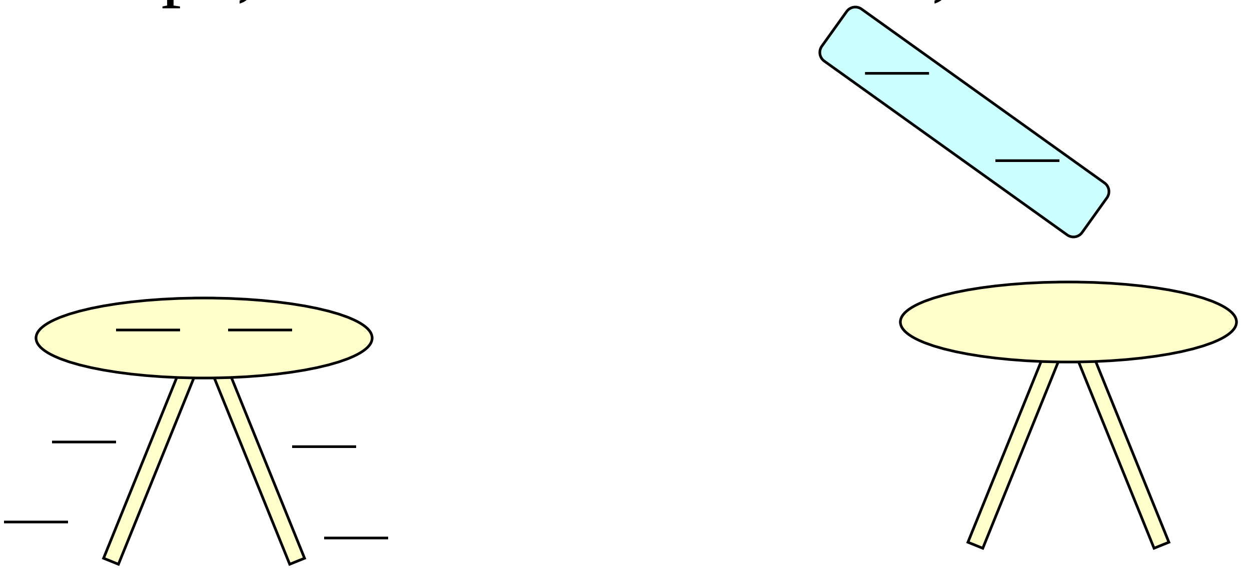
A) move closer together.

B) move farther apart.

C) remain where they are.

Interactive Question

An electroscope is initially given a negative charge. When a rod that is negatively charged is brought near to the electroscope, but does not touch it, the leaves will



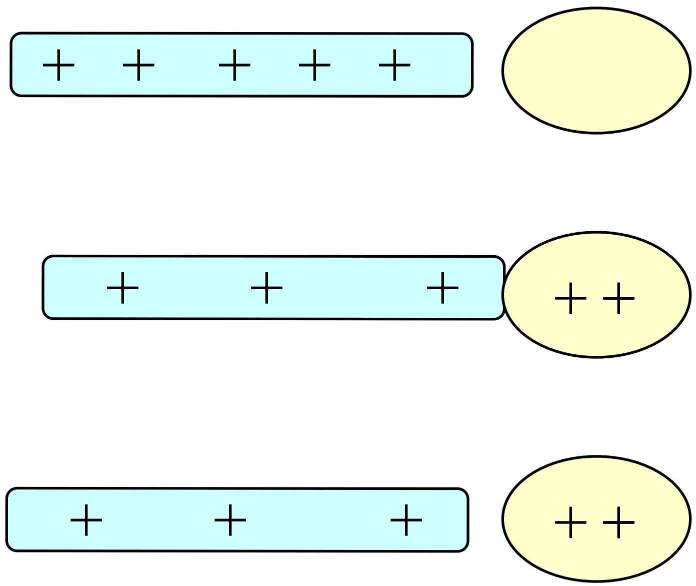
A) move closer together.

B) move farther apart.

C) remain where they are.

7) There are at least two ways to charge a neutral object

I. By conduction (works for conductors and insulators)

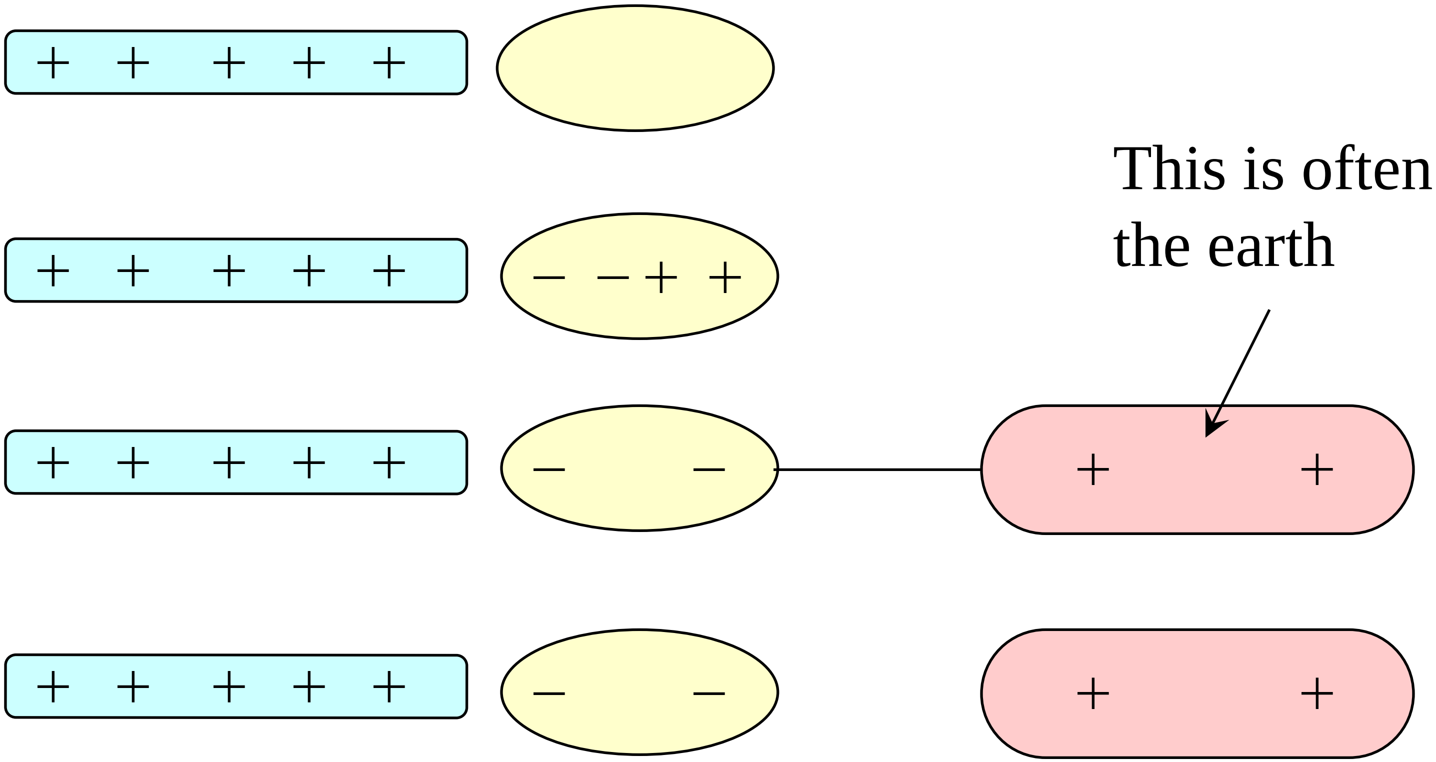


If the two objects are identical in composition, size, and shape, then after touching each other they will both have exactly the same amount of charge on them.

7) There are at least two ways to charge a neutral object

I. By conduction

II. By induction (works for conductors only)

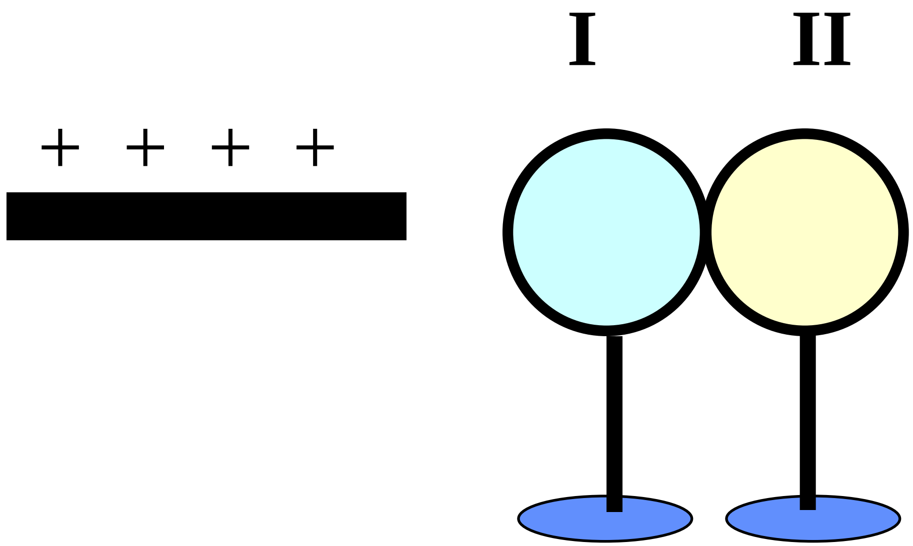


Interactive Question

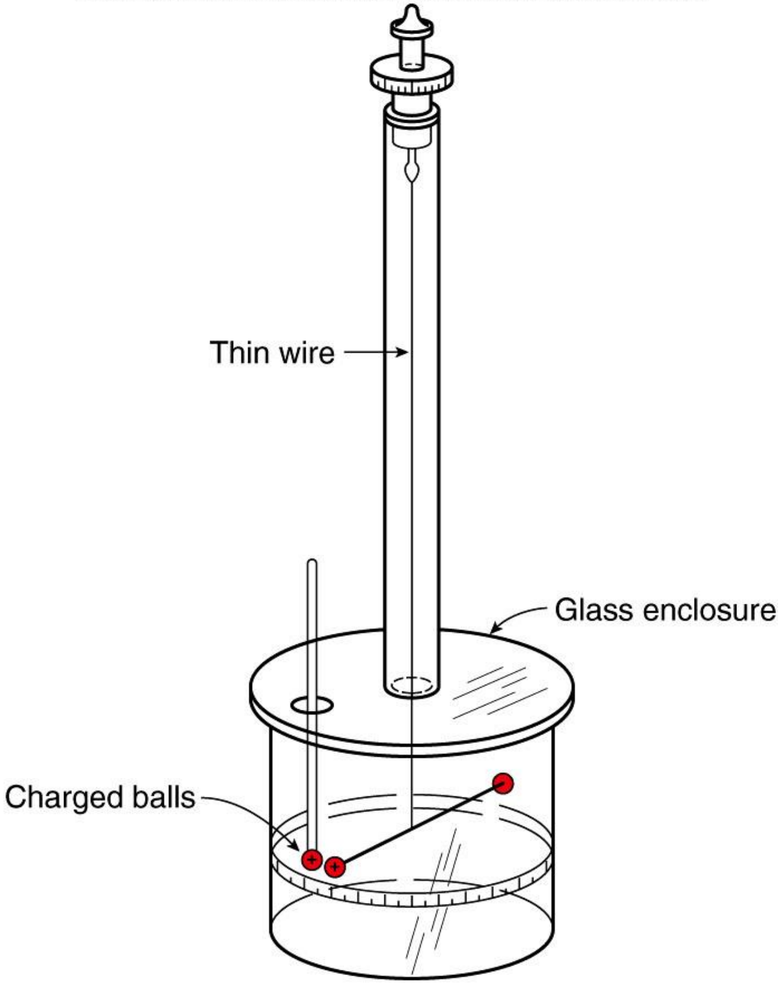
Two uncharged spheres, **I** and **II**, are at rest on insulating stands. A positively charged rod is held *near to*, *but not touching* sphere **I**. While the rod is in place, the two spheres are separated.

How will the spheres be charged, *if at all?*

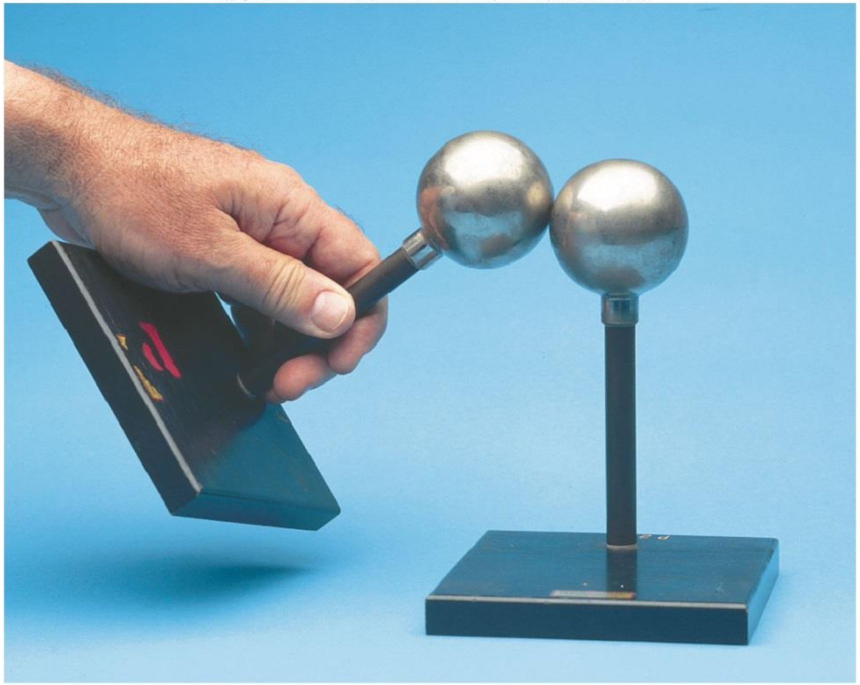
	I	**II**
A)	+	+
B)	+	–
C)	–	+
D)	0	+
E)	0	0



The Electrostatic Force: Coulomb's Law



Coulomb used the fact that when two identical objects touch each other they end up having exactly equal amounts of charge.



Coulomb's Law

Coulomb's law describes the electric force between two "point" objects that are at rest.

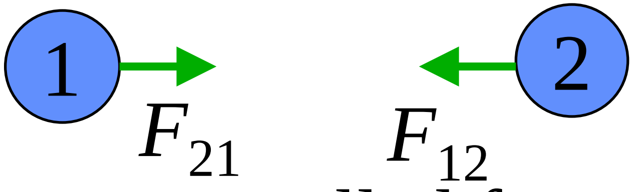
$$F = k\frac{q_1 q_2}{r^2}$$

- F is the force between the two objects
- q_1 is the *absolute value* of the charge of one object
- q_2 is the *absolute value* of the charge of one object
- r is the distance between the two objects
- k is a constant so the units work out

  $k = 9.0 \times 10^9\ \mathrm{N{\cdot}m^2/C^2}$
- The force is the same on each object.

The electric force, like all forces is a vector and has a direction.

- If two objects are attracted to each other, the direction of the force is directed from one object to the other

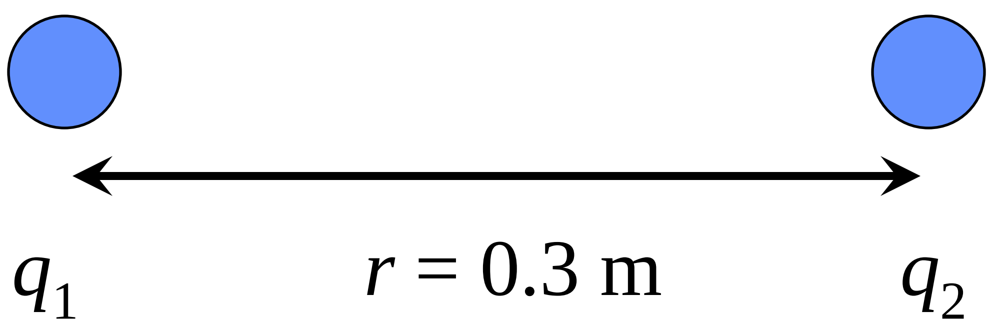


- If two objects are repelled from each other, the direction of the force is directed away from each other

Problem: Two identical spheres hold different charges, $q_1 = 12 \times 10^{-9}$ C and $q_2 = -18 \times 10^{-9}$ C, and are separated by 0.3 m.

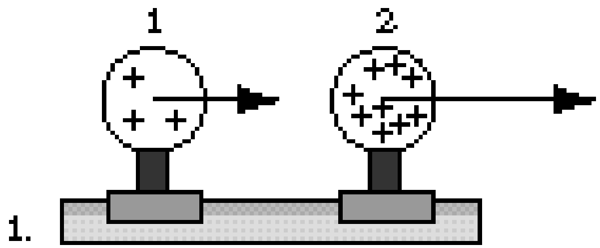
(a) What is the electrostatic force on q_1 from q_2 and what is the force on q_2 from q_1?

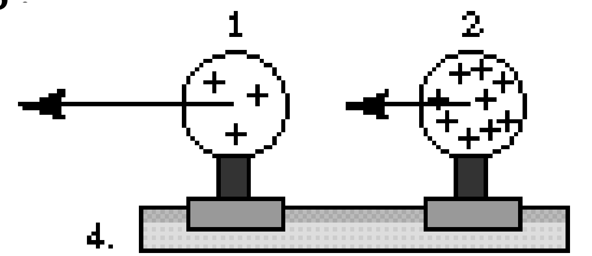
(b) q_1 and q_2 then touch each other and are put back in their original position. What is the new electrostatic force on q_1 from q_2 and what is the force on q_2 from q_1?

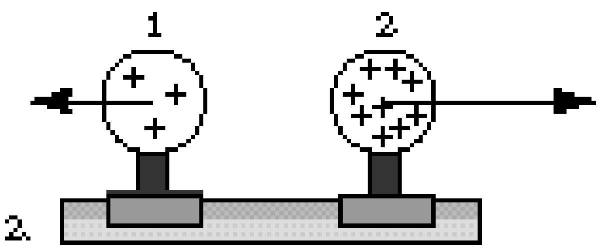


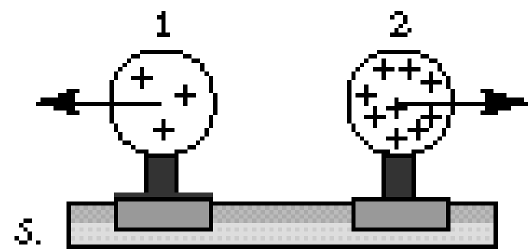
Interactive Question

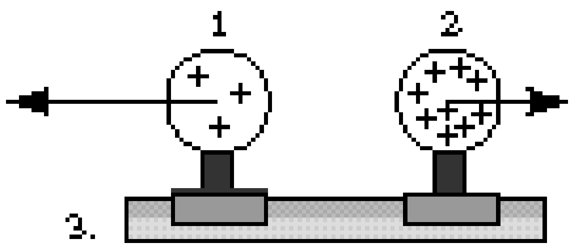
Two uniformly charged spheres are fastened to and electrically insulated from frictionless pucks on an air table. The charge on sphere 2 is three times the charge on sphere 1. Which force diagram correctly shows the magnitude and direction of the electrostatic forces?

A) 

D) 

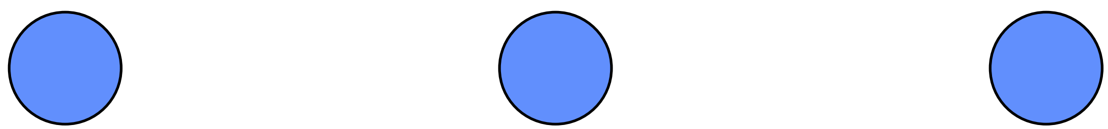
B) 

E) 

C) 

Interactive Question

Three objects with equal positive charge are placed at equal distance from each other along the x axis. What direction is the net force on the middle object?

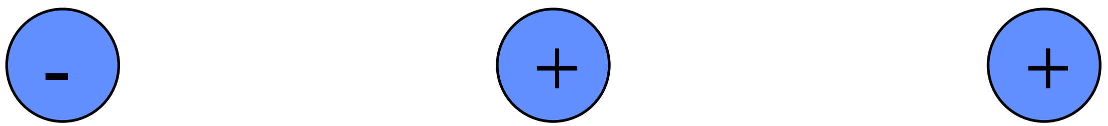


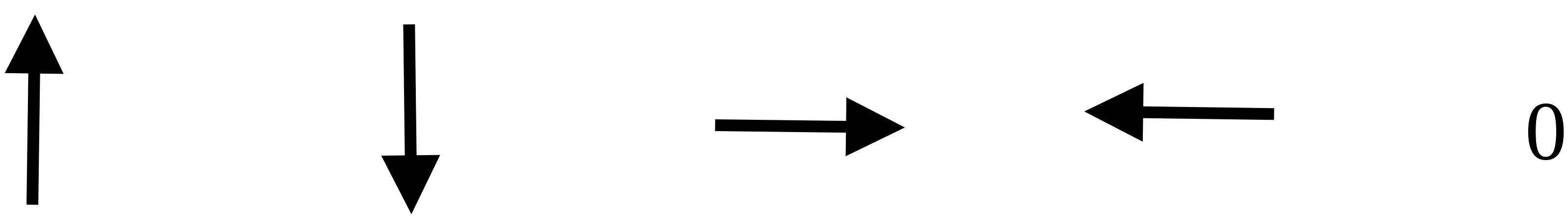
0

(A) (B) (C) (D) (E)

Interactive Question

Three charged objects are placed at equal distance from each other along the *x* axis. The objects have the same magnitude of charge with signs as given. What direction is the net force on the middle charge?

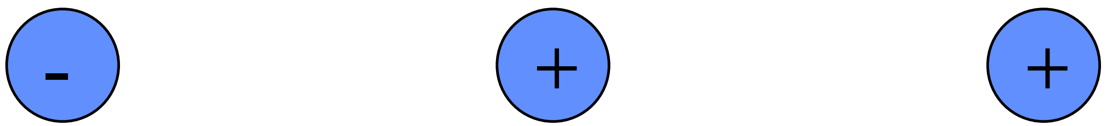




(A) (B) (C) (D) (E)

Interactive Question

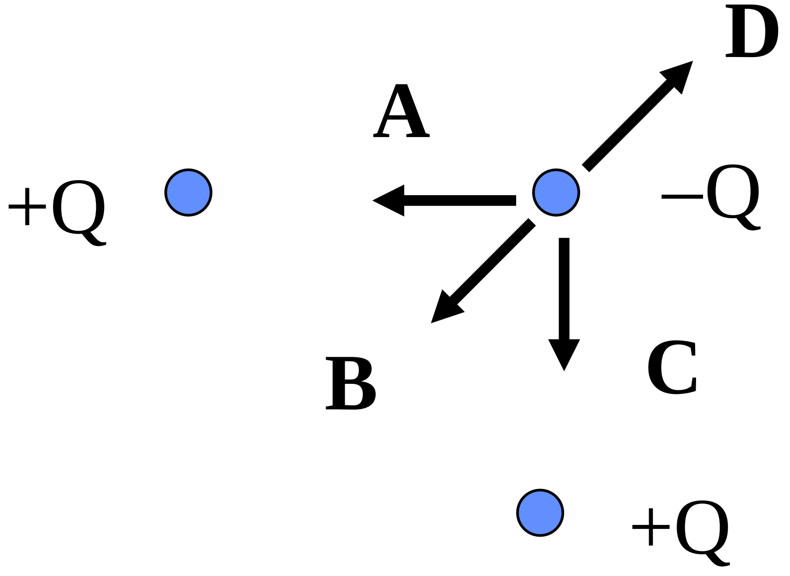
Three charged objects are placed at equal distance from each other along the *x* axis. The objects have the same magnitude of charge with signs as given. If the two positive charges exert a force of *F* on each other, what is the total force on the right most charge?



A) *F* to the right
B) *F* to the left
C) Less than *F* to the right, but not zero
D) More than *F* to the left, but not zero
E) Zero

Interactive Question

Three point charges, each with the same magnitude, but with varying signs are arranged at the corners of a square. Which of the arrows shows the directions of the net force that acts on the charge in the upper right hand corner?



A) **A**

B) **B**

C) **C**

D) **D**

E) The net force on that charge is zero.

Problem: Compare the electrostatic force to the gravitational force between the electron and the proton in a hydrogen atom. The distance between the electron and proton is about 5.29×10^{-11} m.

We will need to use $-q_e = q_P = 1.6\times10^{-19}$ C, $m_e = 9.11\times10^{-31}$ kg, and $m_P = 1.67\times10^{-27}$ kg.

Interactive Question

If the distance between two point charges remains constant while the size of one of the charges is quadrupled, the force between the charges is multiplied by

A) 16

B) 4

C) 1/4

D) 1/16

E) 1

Interactive Question

If the distance between two point charges is tripled while the size of the charges remains the same, the force between the charges is multiplied by

A) 9

B) 3

C) 1/3

D) 1/9

E) 1

Electric Fields

- Fields are a convenient way of describing how one object can affect another object it doesn't touch.
- Electric fields are vectors.
- Electric fields can exist at a point in space where there are no charged objects. The field is set up by either seen or unseen charged objects.
- Electric fields are related to electric forces by the equation,

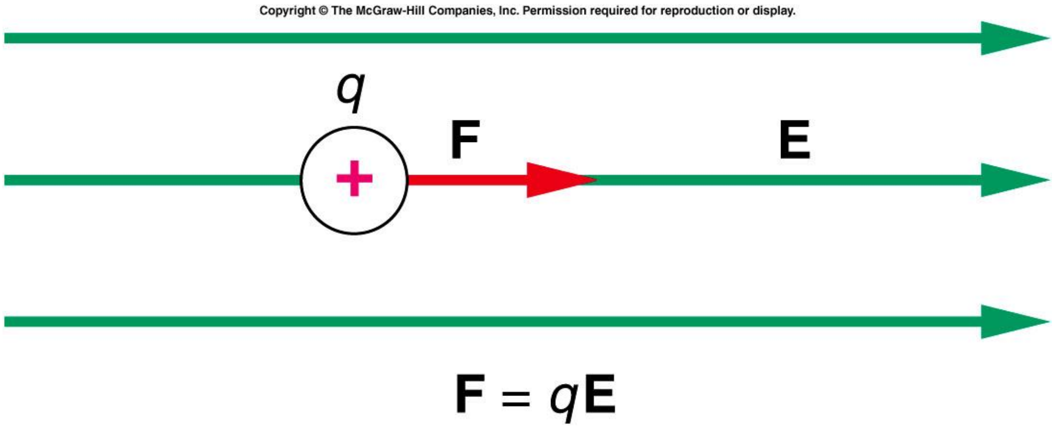
$$\mathbf{F} = \mathbf{E}q,$$

where q is the charge experiencing the force, or the "test" charge.

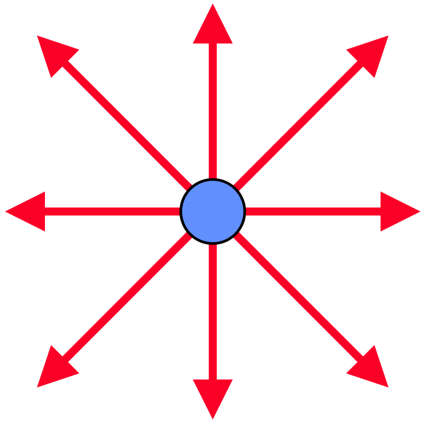
- A test charge is a charge that doesn't affect the other charges that set up the field.

We can illustrate electric fields using electric field lines having the following properties.

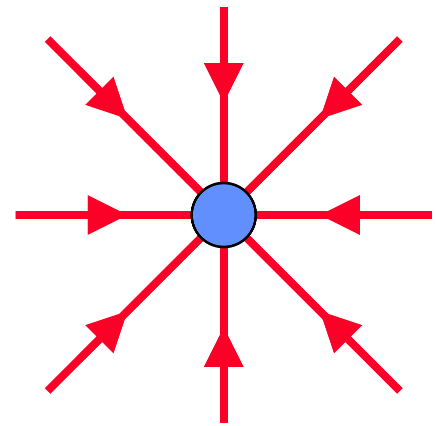
1. They point in the direction that a positive charge would feel a force and move.
   (Away from positive charges and toward negative charges.)
2. Their density is proportional to the magnitude of the electric field.
3. Field lines must begin and end on charged particles. (Sometimes not visible in the picture.)
4. The number of field lines beginning or ending on an object is proportional to the magnitude of the charge of the object.



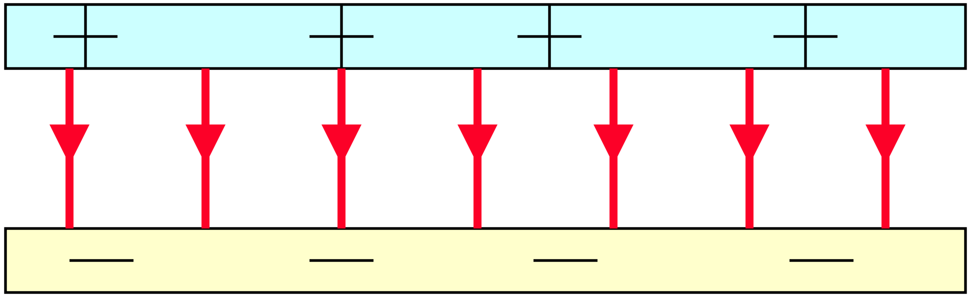
Examples of Electric Fields



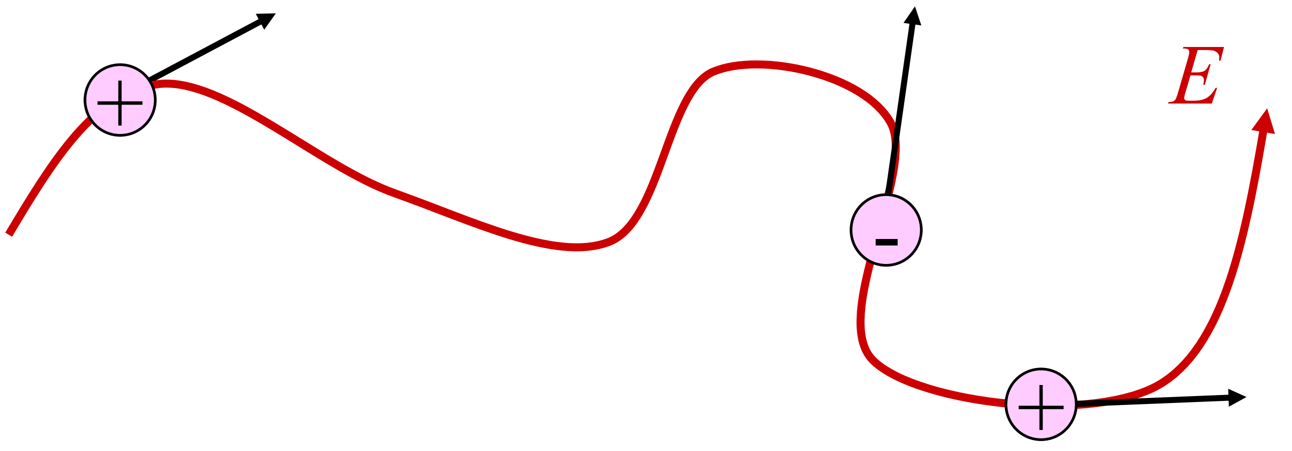
Positive Charge



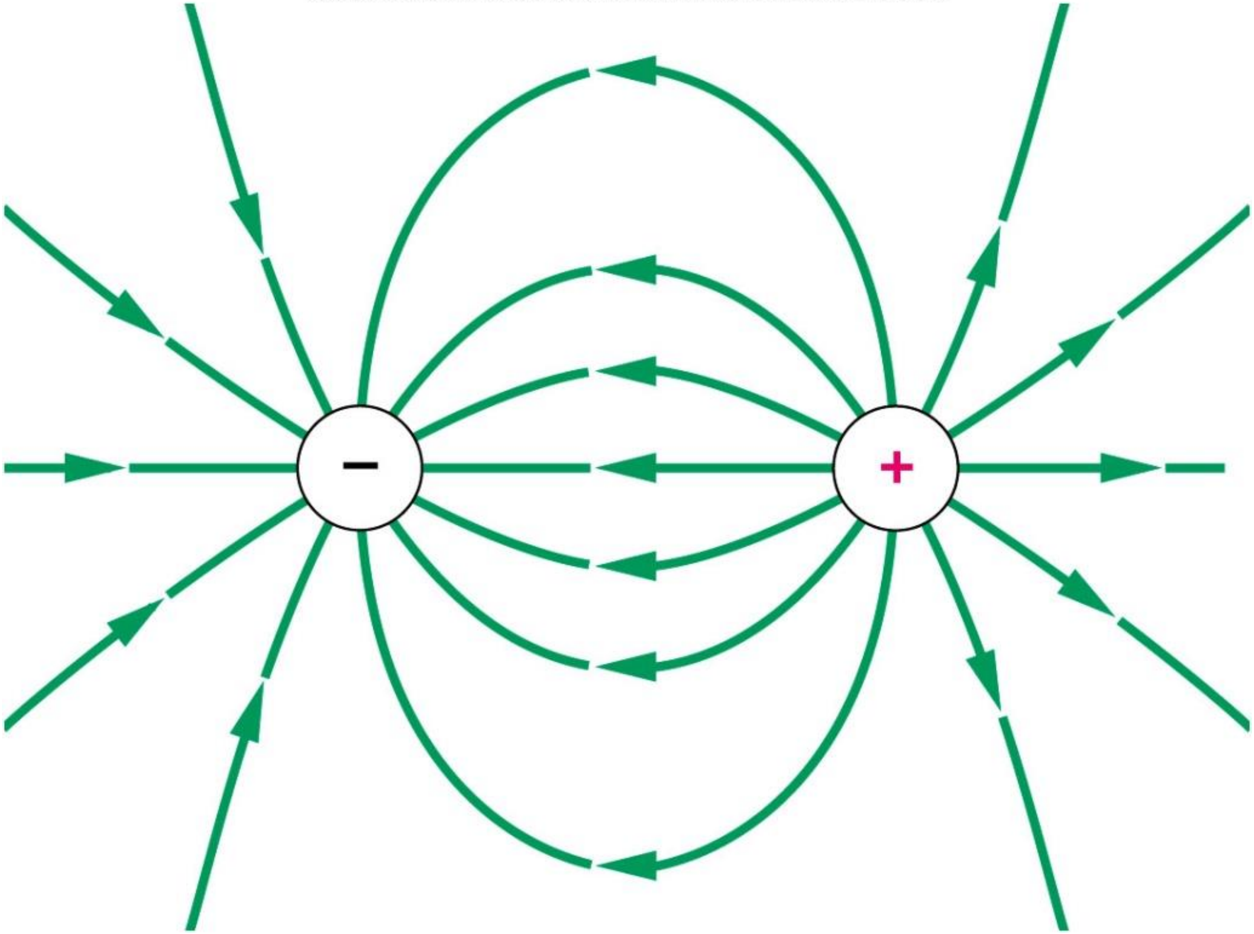
Negative Charge



Parallel Plate (Uniform Field)

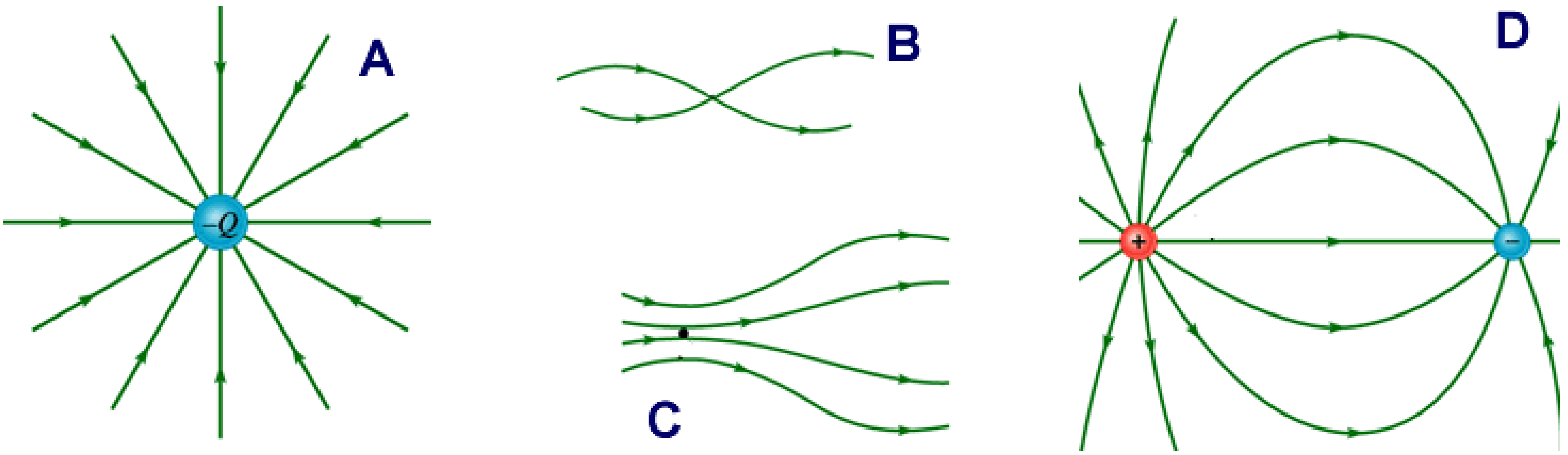

+
-
+
E

An electric dipole is two charges of equal magnitude but opposite sign, separated by a small distance.



Interactive Question

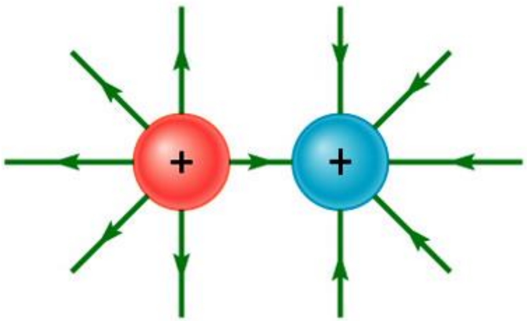
Which of these is not a possible representation of electric field lines?



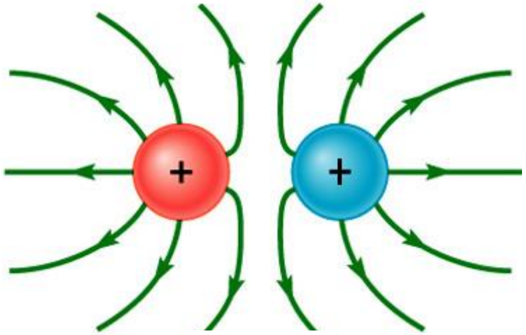
E) None of the above

Interactive Question

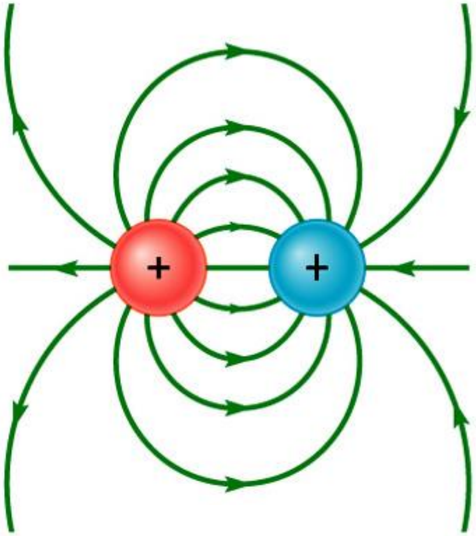
The field lines due to two spheres with like charges are shown by



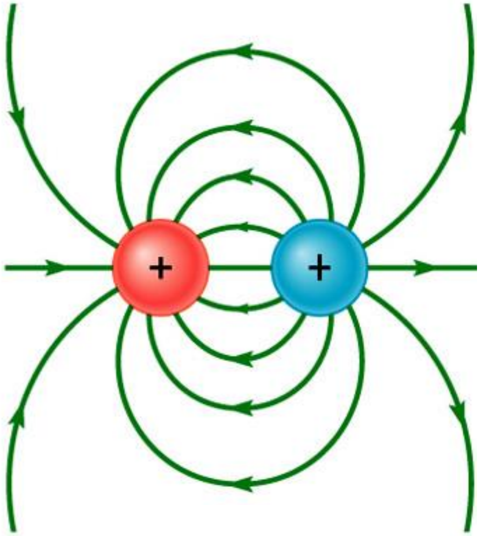
(A)



(B)



(C)



(D)

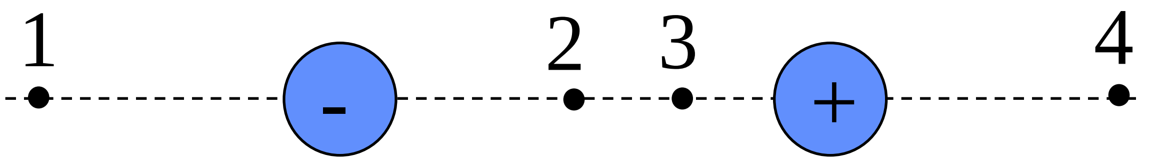
Interactive Question

An object with a charge of a –2.6 mC feels an electric force toward the east. Which direction does the electric field point at the place where the object is located?

A) North
B) South
C) East
D) West
E) None of the above

Interactive Question

Two objects with charge of equal magnitude but opposite sign, lie along a line as shown. What are the directions of the electric field at points 1, 2, 3, and 4?



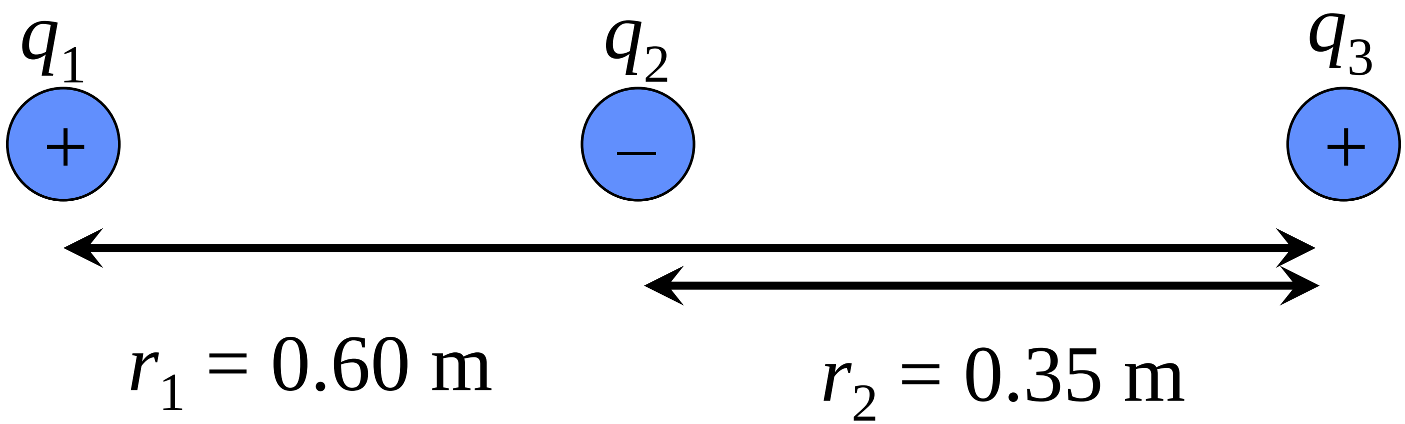
	1	2	3	4
A)	Left	Zero	Right	Right
B)	Right	Zero	Left	Right
C)	Right	Left	Right	Left
D)	Zero	Left	Left	Zero
E)	Right	Left	Left	Right

Problem: In a certain region of space, an electric field is pointing straight down with a strength of 250 N/C. If an object with a charge of –6.6 mC is placed there, what is the electrostatic force felt by that object?

Problem: Three spheres are oriented as shown in the figure with charges equal to $q_1 = 8.6\ \mu C$, $q_2 = -5.3\ \mu C$, and $q_3 = 3.2\ \mu C$.

(a) What is the net electrostatic force on q_3 from the other two spheres?

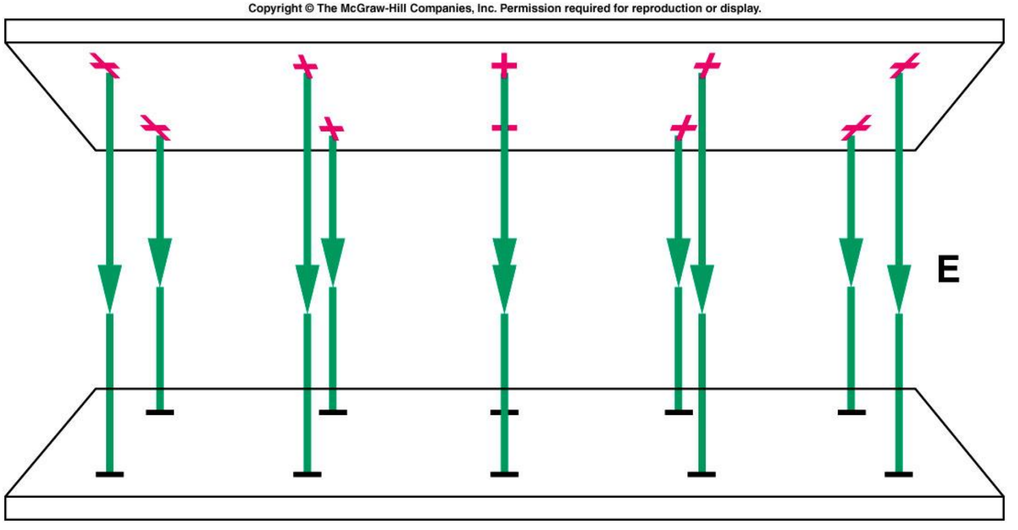
(b) If q_3 is considered a "test charge" what is the electrostatic field from the other two spheres at the point where q_3 is located?



Electric Potential and Potential Energy

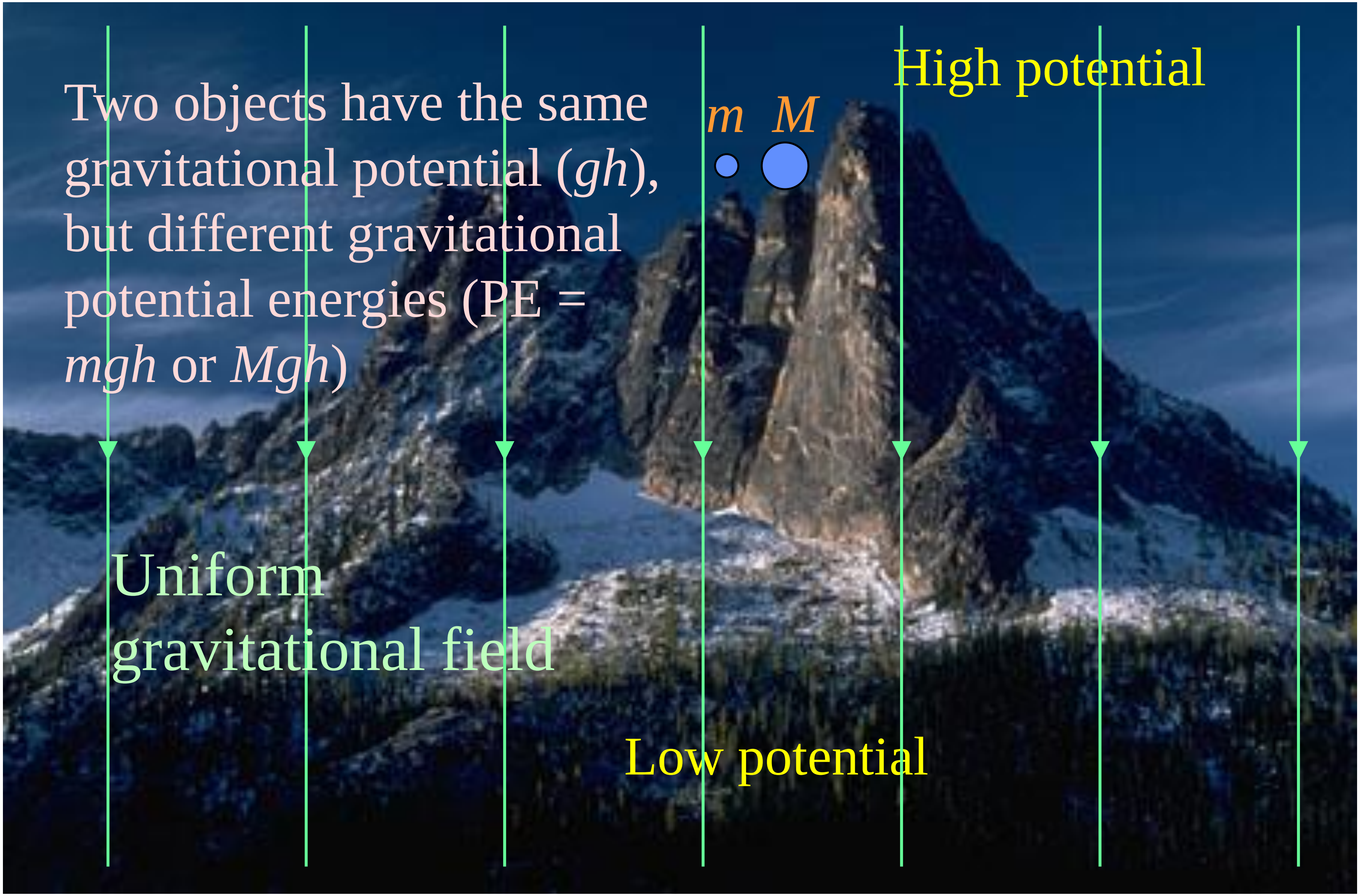
The electrostatic force is a conservative force, which means we can define an electrostatic potential energy.

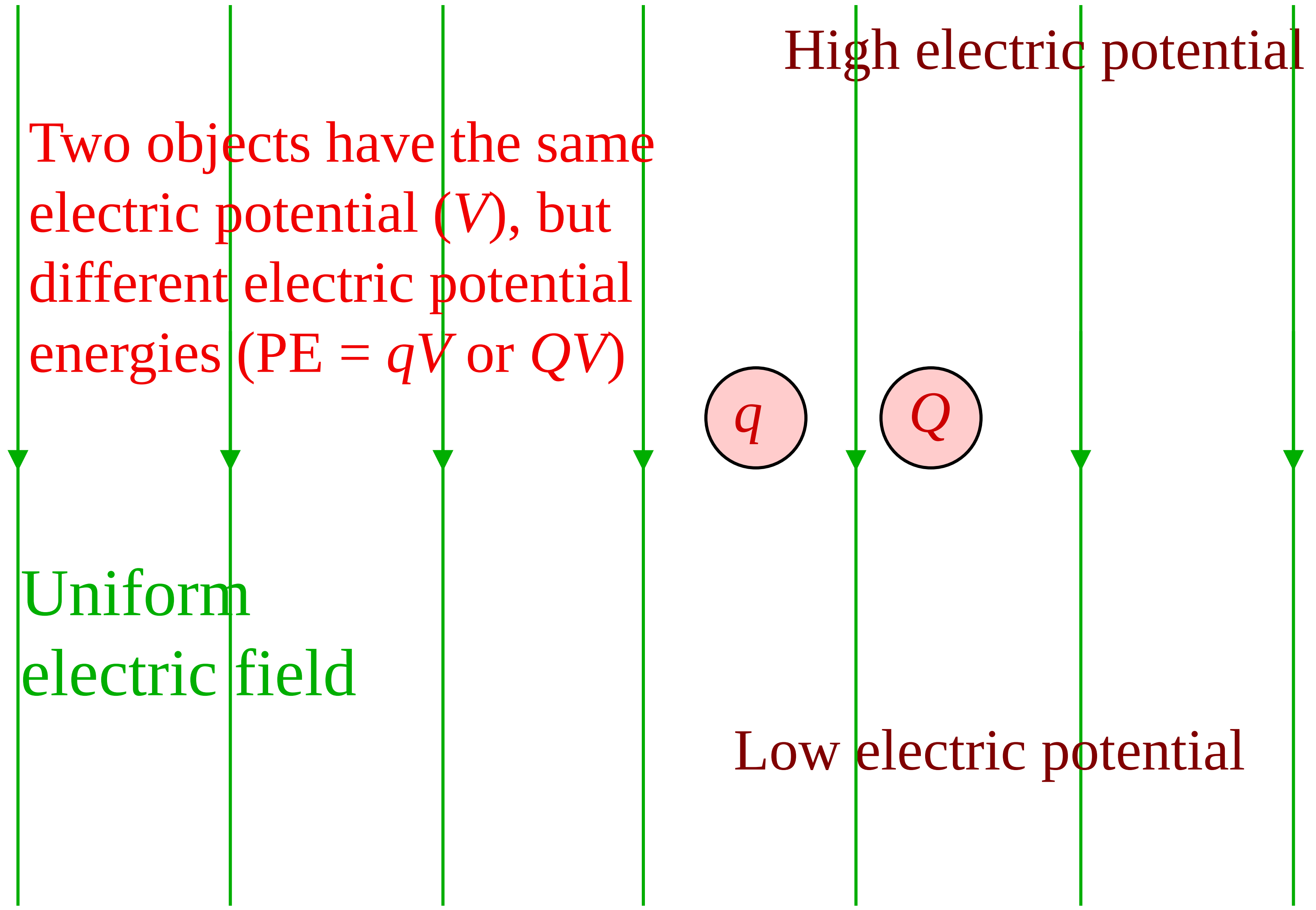
- We can also define something we will call ***electric potential*** or ***voltage***.



- Two parallel metal plates containing equal but opposite charges produce a uniform electric field between the plates.
- This arrangement is an example of a ***capacitor***, a device to store charge.

Gravitational/Electrical potential energy analogy

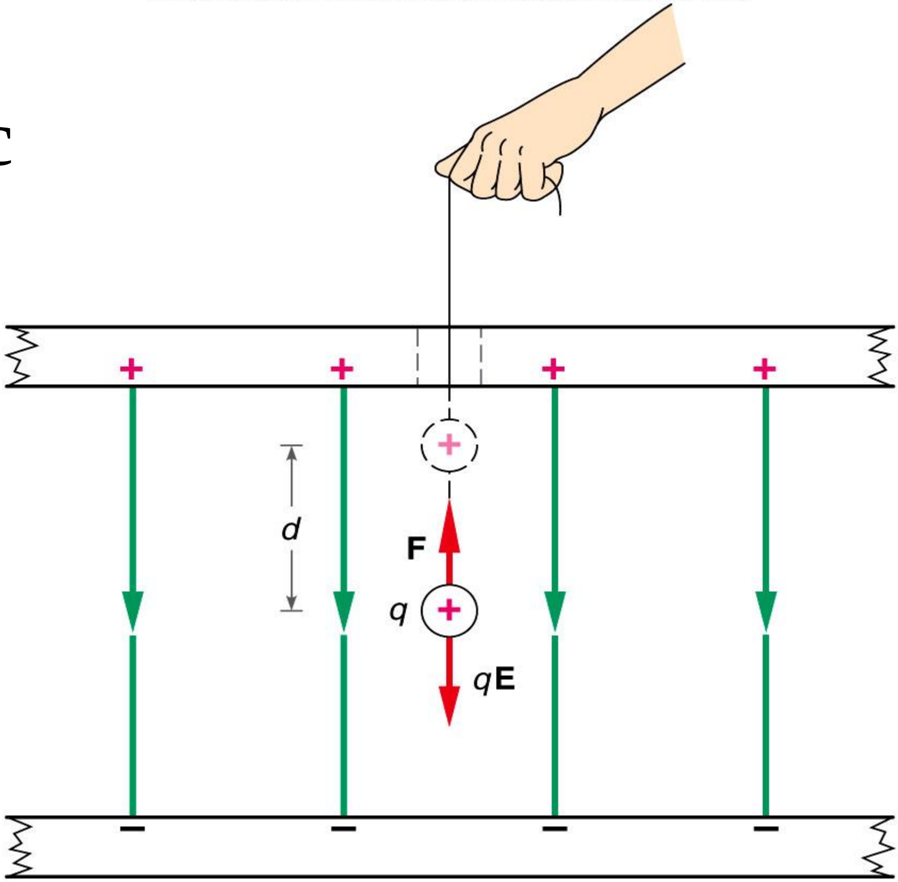




Positive charge plays the role of mass using this “gravitational analogy”.

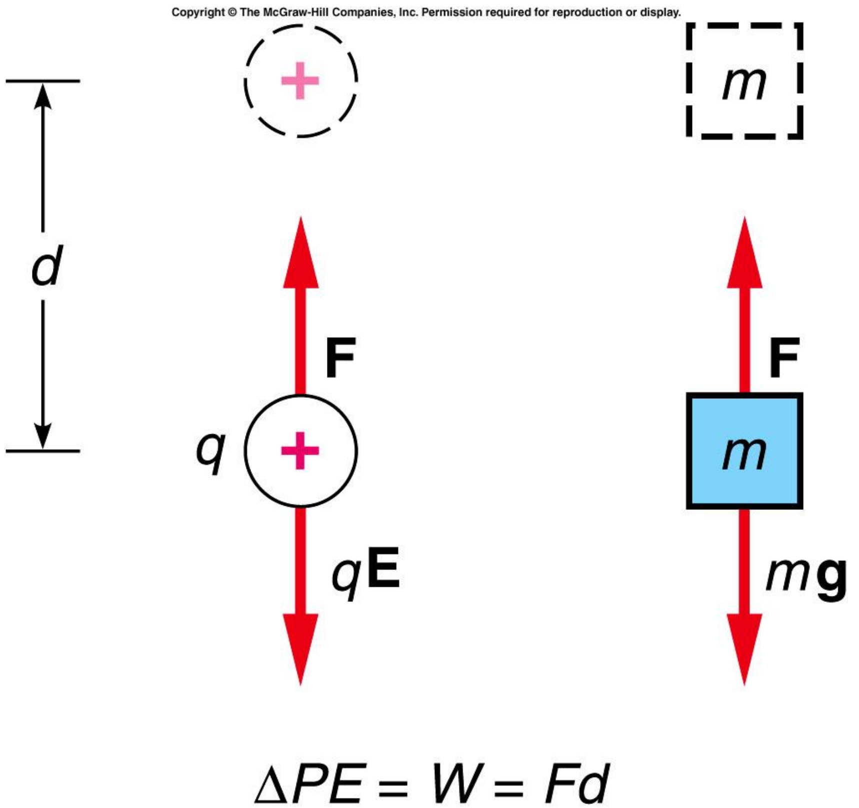
Electric Potential, Potential Energy, and Work

- A positive test charge placed in a uniform electric field will experience an electrostatic force in the direction of the electric field.
- An external force **F**, equal in magnitude to the electrostatic force $q\mathbf{E}$, can move the charge a distance d.
- The work done by the force is $W = Fd = qEd$ which is equal to the change in electrical potential energy, $\Delta PE = qEd$.



Electric Potential, Potential Energy, and Work

- We can compare the discussion on the previous page to our gravitational analogy.
- Since $\Delta PE = qEd = qV$, for a uniform electric field, $V = Ed$
- We write both V and ΔV which mean the same thing because only differences in potential can be measured.
- The units of electric potential are energy/charge which is J/C = V (volts)

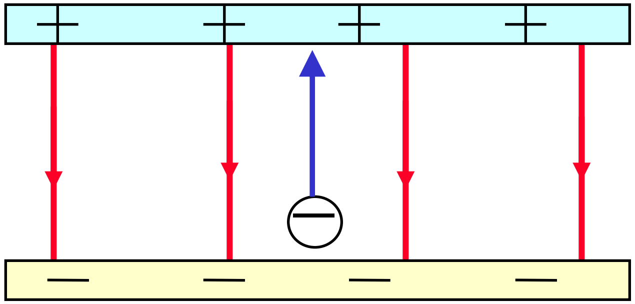


Problem: Two plates 27 mm apart and are oppositely charged so that they have a uniform electric field of 750 N/C between them. An object with a charge of –8.3 μC is moved from the negative plate to the positive plate.

A) What is the change in electric potential of the object?

B) What is the change in electric potential energy?

C) Answer the same two questions for a positive charge.



Sign of Electric Potential and Potential Energy

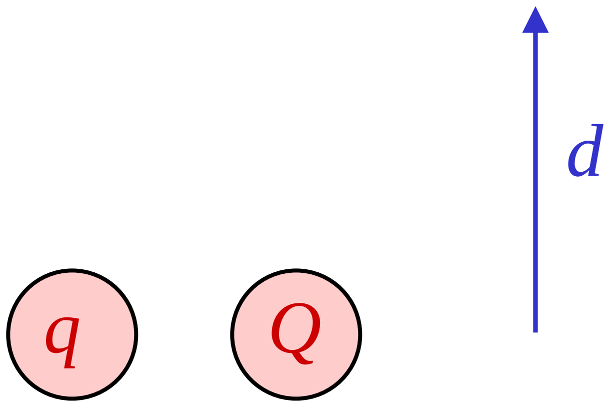
Uniform electric field (E)

In a uniform electric field: $\Delta PE = qEd$

Electric potential energy:

- Higher where the potential is higher for positively (+) charged objects
- Lower where the potential is higher for negatively (–) charged objects

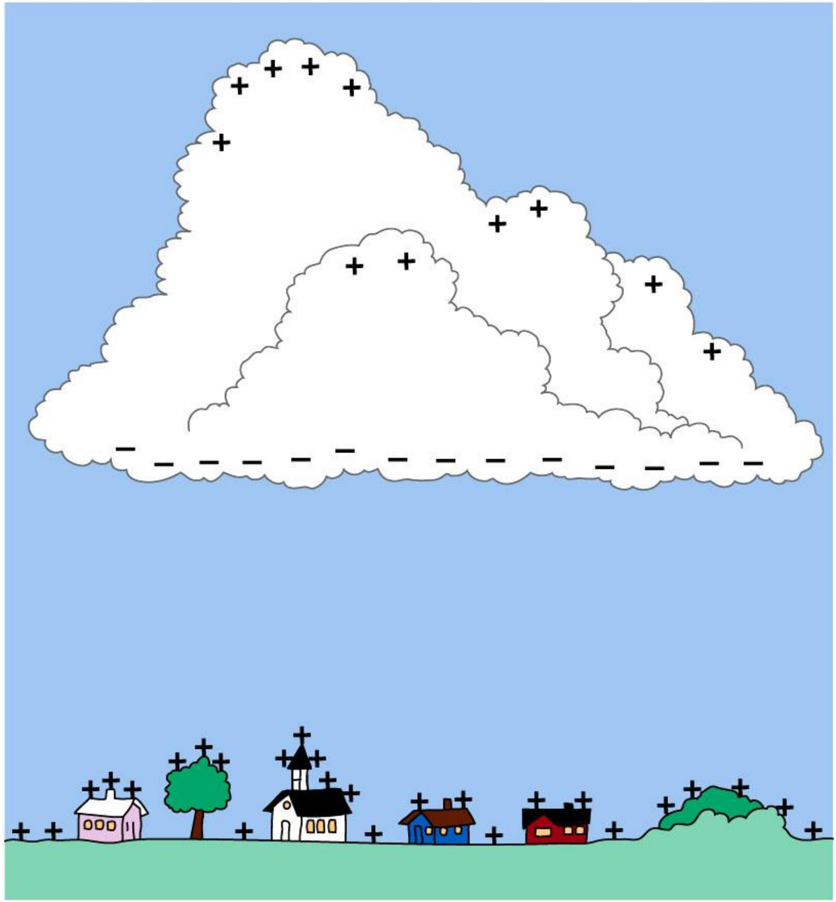
Electric potential: High here for all objects



Electric potential: Low here for all objects

Charge, Capacitors, and Lightning

- Thunderclouds generate a separation of charge in the clouds which induces a charge on the ground, and subsequent electric fields as high as thousands of volts per meter.
- The potential difference between the cloud and the earth can easily be several million volts.
- When the electric field gets too large charged particles will move from the cloud to the ground, heating and ionizing the air to produce the lightning we see.
- The thunder (sound waves) is produced at the same time, but takes longer to reach us since sound travels slower than light.

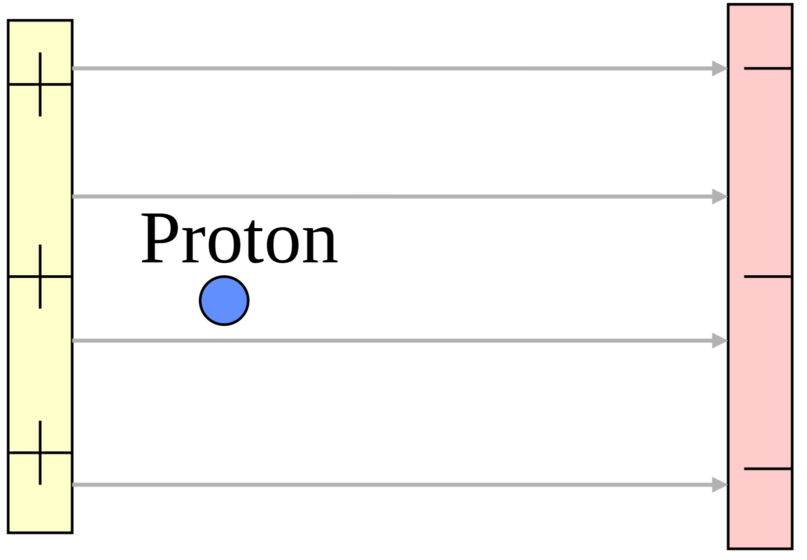


Problem: A proton is released from rest in a uniform electric field of magnitude 8×10^4 V/m. After the proton has moved 0.5 meters,

(a) What is the change in electric potential?

(b) What is the change in potential energy?

(c) What is the speed of the proton?



Interactive Question

The normal tendency of positive charges is to

A) move to regions of higher electric potential
B) move to regions of lower electric potential
C) remain stationary in an electric field
D) move perpendicularly to electric field lines
E) None of the above

Interactive Question

Which of the following is *not* true?

A) The natural tendency of a negative charge is to move to regions of higher electric potential.

B) A positive charge can be moved to regions of higher electric potential by an external force.

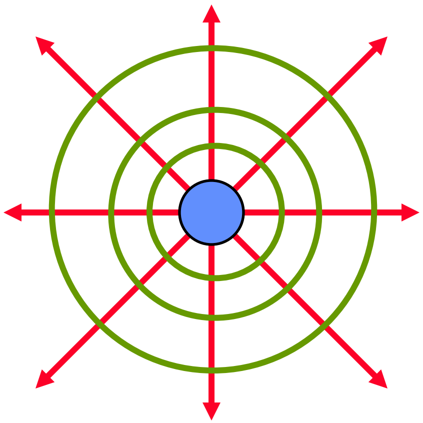
C) When a positive charge moves to a lower electric potential its potential energy decreases.

D) When a negative charge moves to a lower electric potential its potential energy increases.

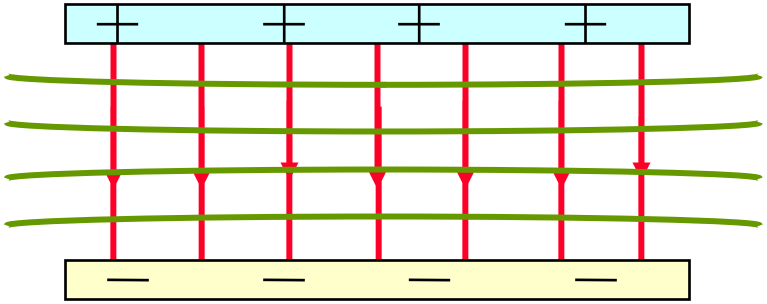
E) None of the above. They are all true.

Equipotential Surfaces

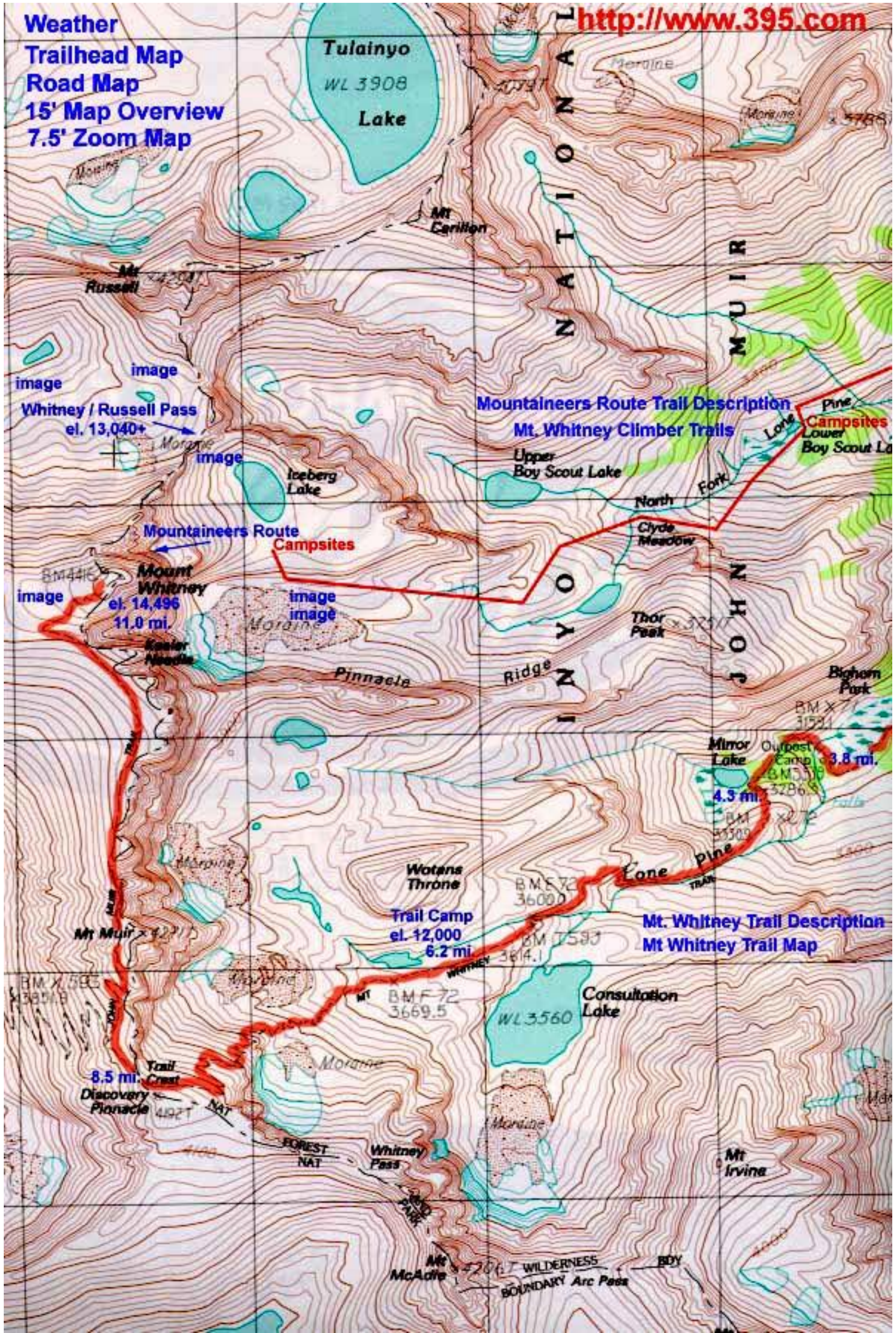
- Equipotential surfaces are imaginary surfaces that are at the same potential. For gravity, equipotential surfaces are lines of constant elevation.
- Equipotential surfaces are always perpendicular to field lines.
- No work is required to move a charge along an electrostatic equipotential.



Positive Charge



Uniform Field



Weather
Trailhead Map
Road Map
15' Map Overview
7.5' Zoom Map
http://www.395.com
Tulainyo
WL 3908
Lake
Mt Carillon
Mt Russell
image
image
Whitney / Russell Pass
el. 13,040+
image
Iceberg Lake
Mountaineers Route Trail Description
Mt. Whitney Climber Trails
Upper Boy Scout Lake
Lower Boy Scout Lake
Campsites
North Fork
Lone Pine
Clyde Meadow
Mountaineers Route
Campsites
Mount Whitney
el. 14,496
11.0 mi.
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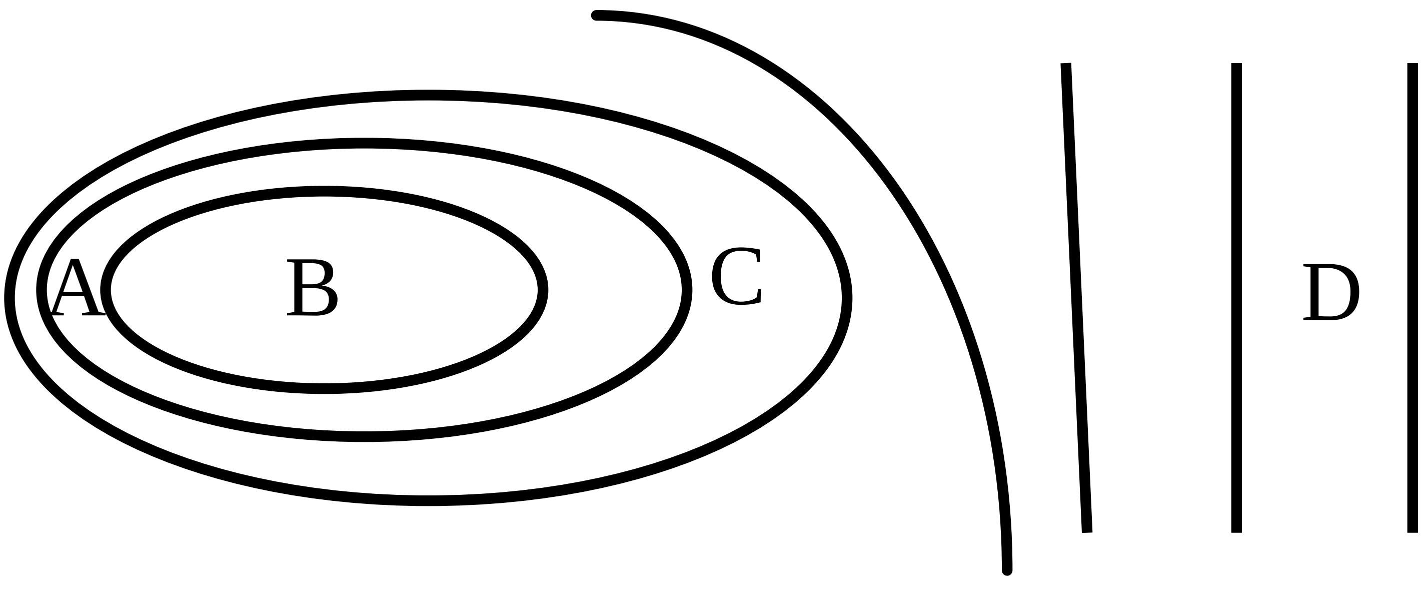
Keeler Needle
Pinnacle Ridge
Thor Peak
Bighorn Park
Mirror Lake
Outpost Camp
3.8 mi.
4.3 mi.
Wotans Throne
Lone Pine
Trail Camp
el. 12,000
6.2 mi
Mt. Whitney Trail Description
Mt Whitney Trail Map
Mt Muir
Consultation Lake
WL 3560
8.5 mi.
Trail Crest
Discovery Pinnacle
Whitney Pass
Mt Irvina
Mt McAdie
WILDERNESS BOUNDARY
Arc Pass
INYO NATIONAL
JOHN MUIR

Interactive Question

The picture shows equipotential lines. Where is the electric field the greatest?



Overview and Review

We have defined four concepts associated with electric charge. They are:

(1) the electric force $\mathbf{F}_E$

(2) the electric field $\mathbf{E}$

(3) the electric potential energy PE

(4) the electric potential V

- Two relationships are always valid: $\mathbf{F} = q\mathbf{E}$ and PE $= qV$
- One relationship is valid only for uniform electric fields: $V = Ed$
- One relationship is only valid for point charges: Between two objects: $F = kq_1q_2/r^2$