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NEW JERSEY CENTER
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Algebra Based Physics

Electric Field, Potential Energy and Voltage

2016-04-19

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Electric Field, Potential Energy and Voltage

Click on the topic to go to that section

https://www.njctl.org/video/?v=OBin44Pm2g0

Electric Field

https://www.njctl.org/video/?v=TDD4O-a1AF4

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Electric Force and Field

Electric force is an attractive or repulsive force between two charged objects.

Electric force can be determined using Coulomb's Law:

$$F_E = \frac{kq_1q_2}{r_{12}^2}$$

Like gravitational force, electric force is a non-contact force.

This "action at a distance" is best understood by assuming that each charge has a field surrounding it that affects other charges.

Electric Field

The electric field is a region around a charged particle or object within which a force would be exerted on other charged particles or objects.

To find the electric field due to one charge, begin with the electric force between two charged objects and assume that one charge is very large and the other is a small, positive test charge.

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

Electric Field

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

The electric field (E) due to the larger charge can be found by dividing the force above by the smaller charge, q:

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

The electric field now shows both the magnitude and direction of the force exerted by Q on any charge.

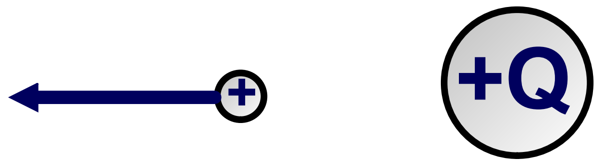
Q creates the electric field. The size of charge Q and the distance from Q determine the strength of the electric field.

The units for E are Newtons/Coulomb or N/C.

Direction of the Electric Field

The direction of an electric field is determined by the direction a positive test charged would accelerate if placed in the space surrounding a charge Q.

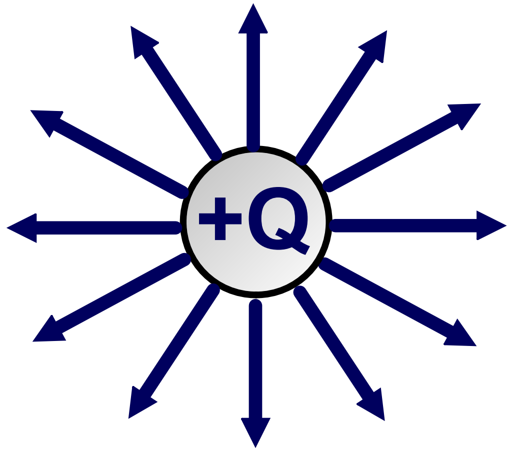
What would happen if an isolated positive test charge were placed near a positive charge Q?



Electric Field due to a Positive Charge

An isolated positive charge Q will repel a positive test charge; therefore, the direction of the electric field surrounding a positive charge points radially outward or away from the positive charge in all directions.

Electric field force on a small positive test charge

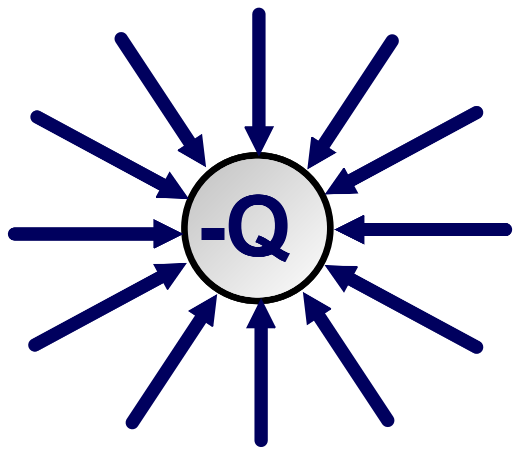


Electric Field Lines

Electric Field due to a Negative Charge

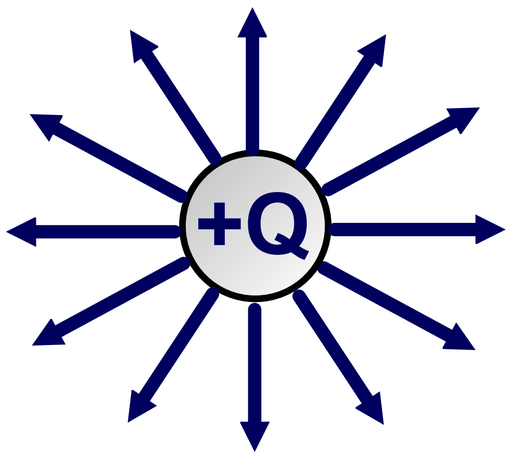
An isolated negative charge -Q will create an electric field that points radially inward towards the charge in all directions, since a positive test charge will be attracted by -Q.

Electric field force on a small positive test charge



Electric Field Lines

Electric Field Direction and Magnitude



The definition of the electric field shows that the strength of the field decreases as distance increases:

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

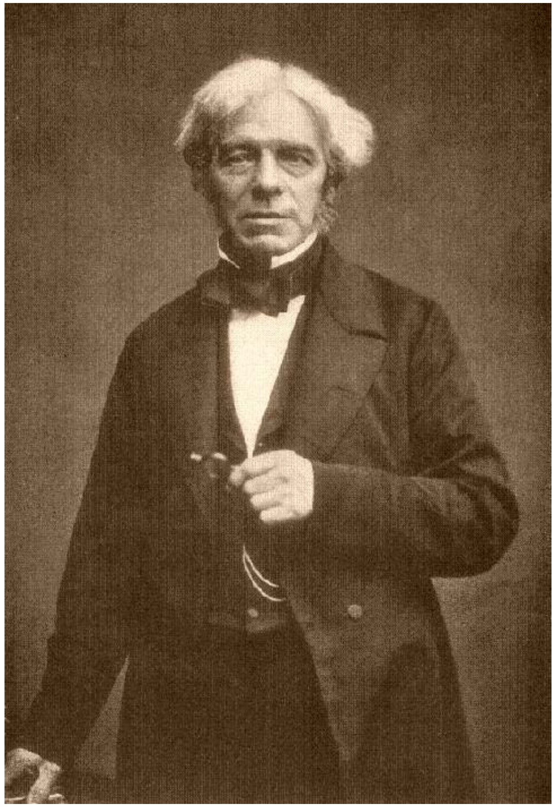
This can be seen by looking at the density of the field lines.

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 a simulator from PhET

Michael Faraday

The discovery of the electric field is attributed to Michael Faraday. Faraday was born in London in 1791. He came from a poor family. At 13, he apprenticed as a 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.

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

Answer

https://www.njctl.org/video/?v=9ZMQozvAe_w

2 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

https://www.njctl.org/video/?v=9-6gSvSik2Y

3 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

https://www.njctl.org/video/?v=lNtL0qbvQsA

4 The direction of the Electric Field can be found by using:

A the direction of the gravitational force.

B the direction that a positive test charge would accelerate.

C the direction that a negative test charge would accelerate.

Answer

https://www.njctl.org/video/?v=h5VHz4A01T0

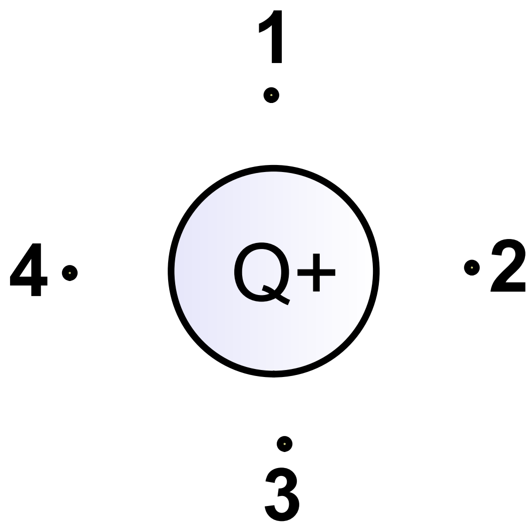
5 What is the direction of the Electric Field at points 1, 2, 3 and 4?

A up, right, down, left.

B up, left, down, right.

C down, right, up, left.

D down, left, up, right.



Answer

https://www.njctl.org/video/?v=BodIViPml2g

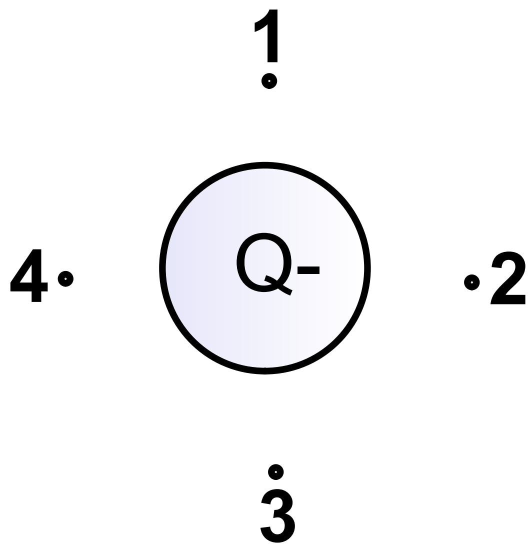
6 What is the direction of the Electric Field at points 1, 2, 3 and 4?

A up, right, down, left.

B up, left, down, right.

C down, right, up, left.

D down, left, up, right.



Answer

https://www.njctl.org/video/?v=hzHAYXstOQk

7 What is the magnitude and direction of the electric field at a distance of 2.3 m due to a charge of -4.9 μC?

Answer

https://www.njctl.org/video/?v=YhLxeo8POMg

*Electric Field
&
Gravitational Field

https://www.njctl.org/video/?v=QxyeHM-I7LM

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*Electric Field & 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 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 & Gravitational Field

There are many parallels between gravitational force and field and electric force and field.

Both are non-contact forces that act along the line connecting objects.

The 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.

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

*Electric Field & Gravitational Field

Electric Force	Gravitational Force
$F_E = \frac{kQq}{r^2}$	$F_G = \frac{GMm}{r^2}$
$k = 8.99 \times 10^9$ (Nm^2/C^2)	$G = 6.67 \times 10^{-11}$ (Nm^2/kg^2)
q = charge (C)	m = mass (kg)
r = distance between centers of charges (m)	r = distance between centers of mass (m)
Electric Field	Gravitational Field
$E = \frac{kQ}{r^2}$	$g = \frac{GM}{r^2}$

* 8 How are Gravitational and Electric Fields similar?

A They both increase the farther 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

https://www.njctl.org/video/?v=-MKatRfvyf8

* 9 How are Gravitational and Electric Fields different?

A The Gravitational Field can exert a repulsive force on a mass, where an Electric Field always attracts charges independent of their polarity (positive or negative).

B The Gravitational Field always exerts a repulsive force on masses, where the Electric Field always exerts an attractive force.

C Masses in a Gravitational Field always feel an attractive force, where an Electric Field can either repel or attract a charge depending on its polarity.

D There are no differences.

Answer

https://www.njctl.org/video/?v=OolRJQ_dM6c

Electric Field of Multiple Charges

https://www.njctl.org/video/?v=c5RI7uybv6I

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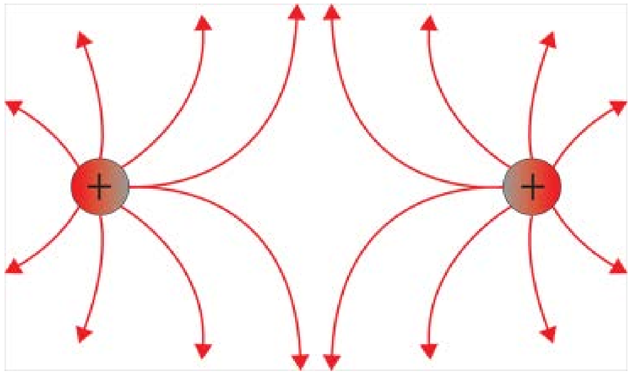
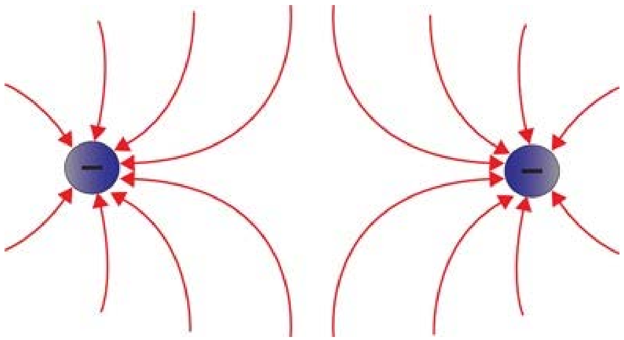
Electric Field of Multiple Charges

Adding individual electric fields will give lines of electric force:

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 crossing point).
4. The lines are continuous.

Electric Field of Multiple Charges



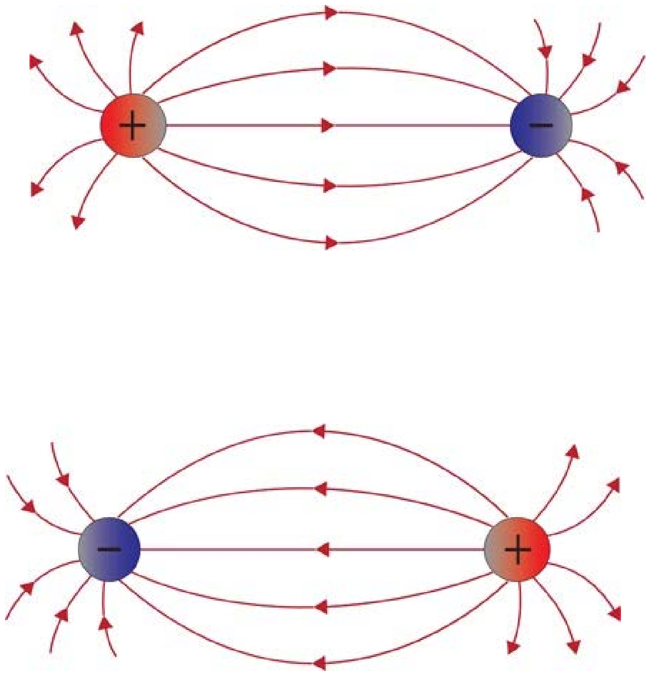


This is the electric field configuration due to two like charges.

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



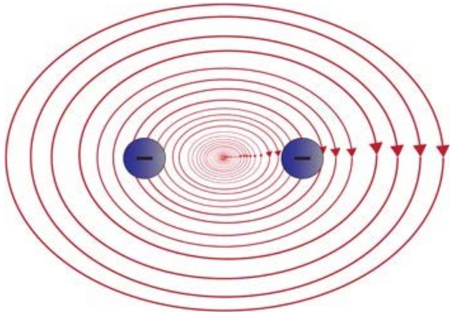
This is the electric dipole configuration, consisting of two unlike charges.

There are no places where the electric field is zero.

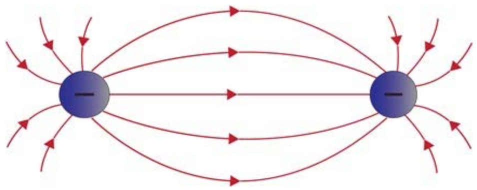
Again, the shape of the field is the same for both positive and negative charges - only the field direction is different.

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

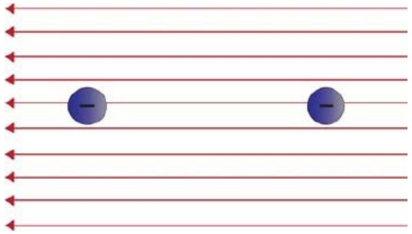
A



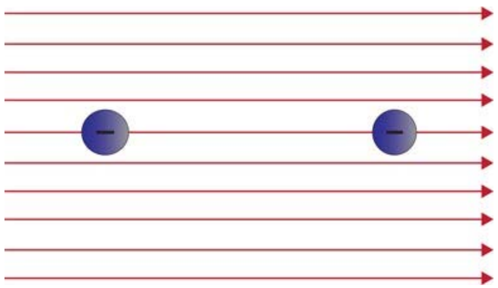
B



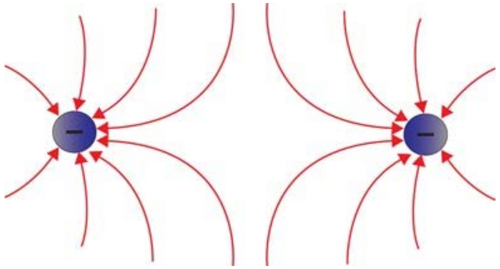
C



D



E

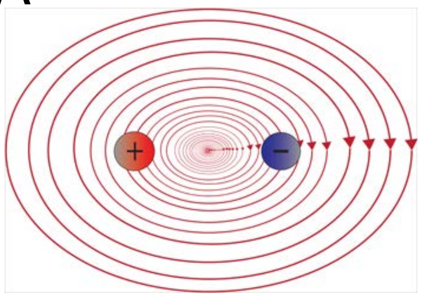


Answer

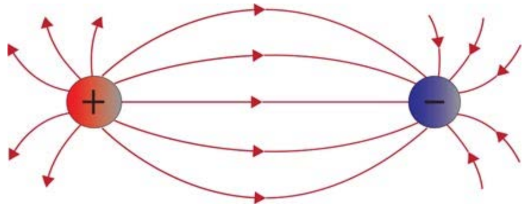
https://www.njctl.org/video/?v=M1KOmqnYm2w

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

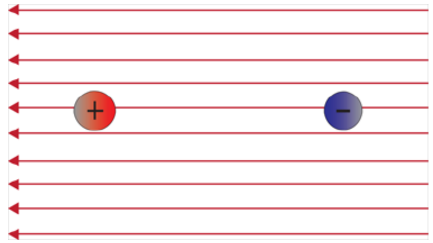
A



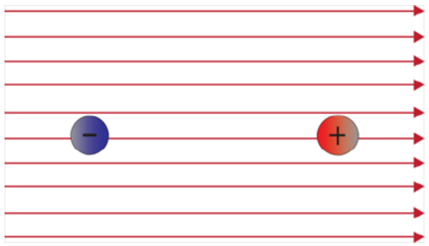
B



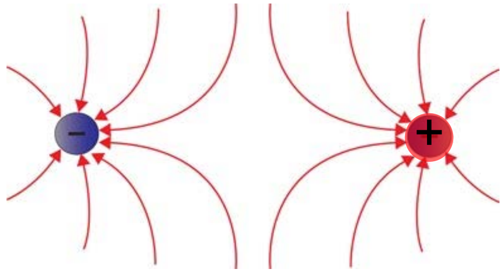
C



D



E



Answer

https://www.njctl.org/video/?v=wQwnLnBgWgs

**The Net Electric Field

https://www.njctl.org/video/?v=h9EVeRgaIA8

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**The Net Electric Field

Since the Electric Field is represented by vectors, the net Electric Field at a location due to multiple charges is calculated by adding each of the vectors together.

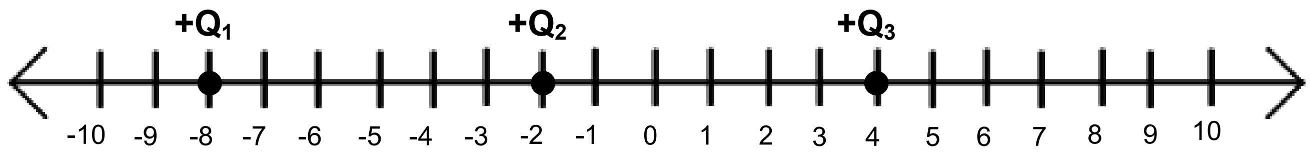
$$\sum E = E_1 + E_2 + E_3 + \ldots E_n$$

Where n is the total number of fields acting on 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.



1. Mark the origin point on the drawing where the electric field is to be calculated. Here the origin is x=0.

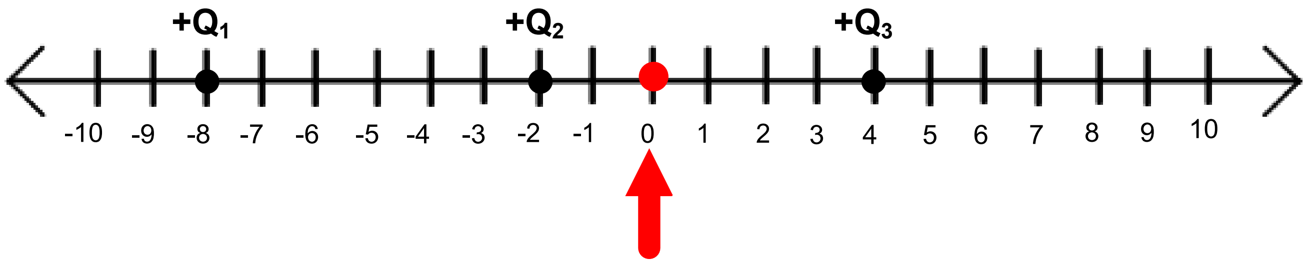
2. Draw the electric field at the origin due to each charge.

3. Determine the magnitude for E_1, E_2 and E_3.

4. Find the net electric field at the origin.

**The Net Electric Field

Objective: Find the net electric field at the origin.



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**The Net Electric Field

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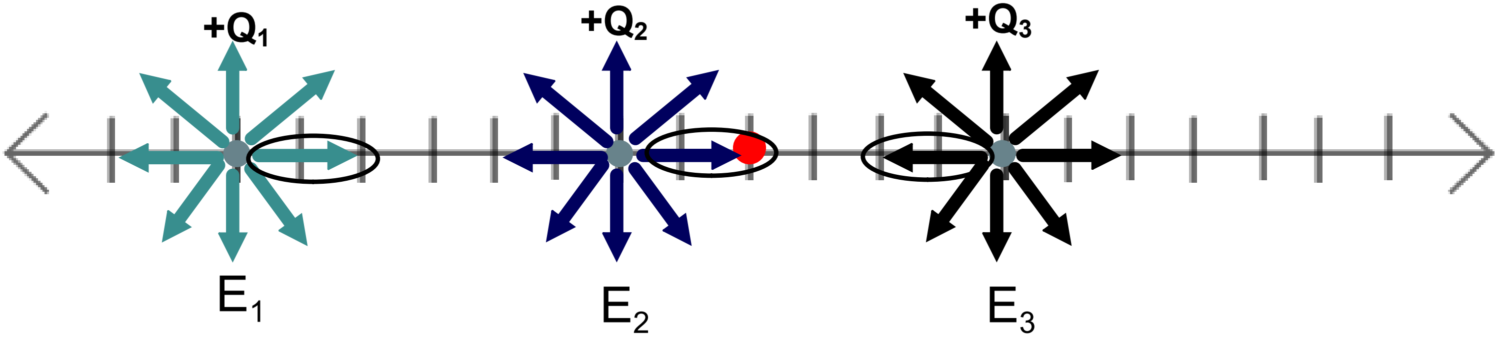
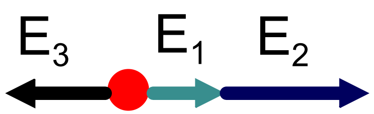


1. Mark the origin point on the drawing where the electric field is to be calculated. Here the origin is x=0.

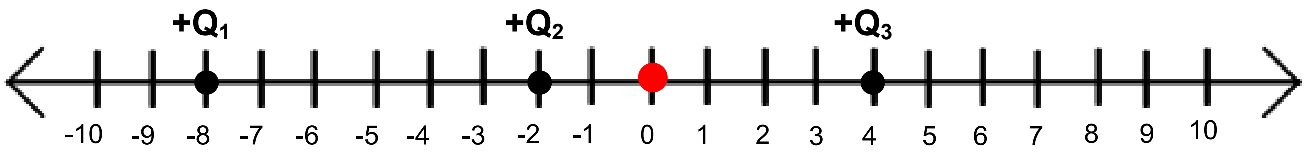
2. Draw the electric field at the origin due to each charge.

   Each charge has an electric field. To find the electric fields acting at the origin, draw the electric field around each charge and identify the direction of the field at the origin for each charge.



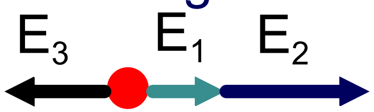
**The Net Electric Field

Objective: Find the net electric field at the origin.



1. Mark the origin point on the drawing where the electric field is to be calculated. Here the origin is x=0.

2. Draw the electric field at the origin due to each charge.

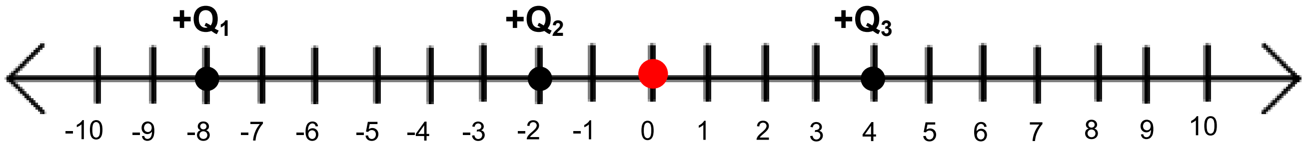


3. Determine the magnitude for E_1, E_2 and E_3.

$$E_1 = \frac{kQ_1}{r^2} \qquad E_2 = \frac{kQ_2}{r^2} \qquad E_3 = \frac{kQ_3}{r^2}$$

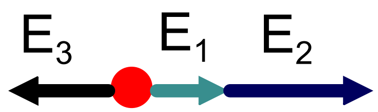
**The Net Electric Field

Objective: Find the net electric field at the origin.



1. Mark the origin point on the drawing where the electric field is to be calculated. Here the origin is x=0.

2. Draw the electric field at the origin due to each charge.



3. Determine the magnitude for E_1, E_2 and E_3.

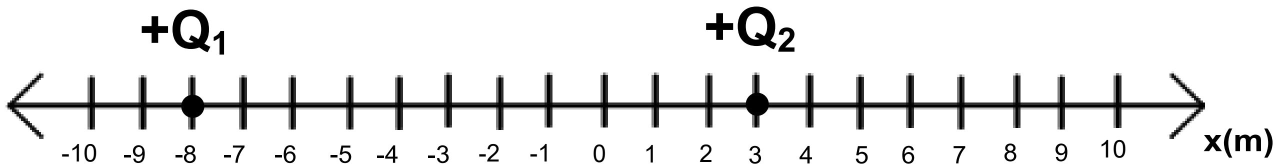
$$E_1 = \frac{kQ_1}{r^2} \qquad E_2 = \frac{kQ_2}{r^2} \qquad E_3 = \frac{kQ_3}{r^2}$$

4. Find the net electric field at the origin.

$$\Sigma E = E_1 + E_2 - E_3$$

**The Net Electric Field Example

Find the net electric field at the origin.

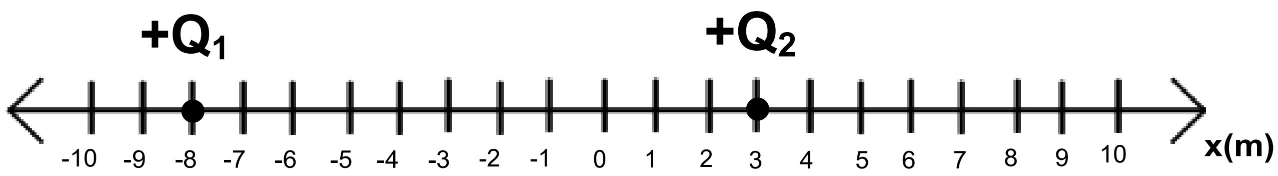


a. Draw the electric fields acting at x=0.

Answer

**The Net Electric Field Example

Find the net electric field at the origin.

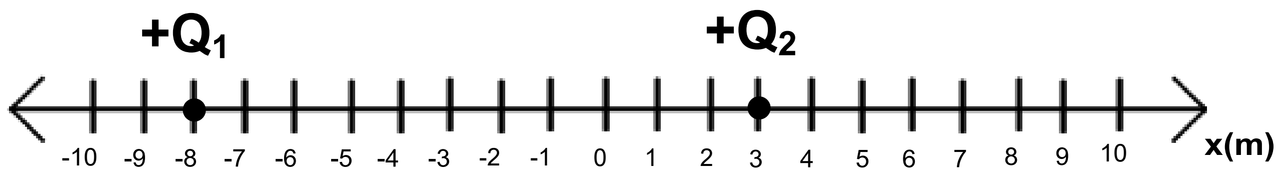


b. Find the magnitude and direction of the electric field at the origin due to the charge Q_1, which has a magnitude of 9.1 μC

Answer

**The Net Electric Field Example

Find the net electric field at the origin.

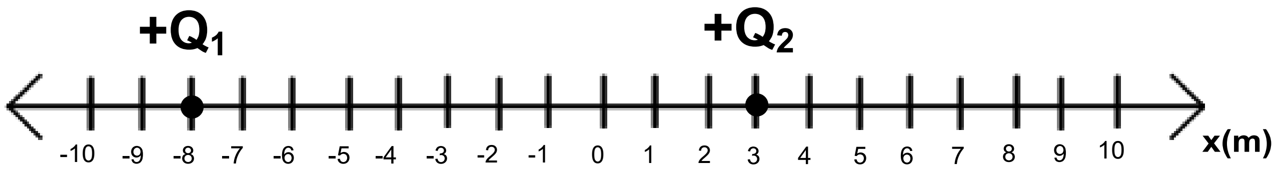


c. Find the magnitude and direction of the electric field at the origin due to charge Q_2, which has a magnitude of 3.0 μC

Answer

**The Net Electric Field Example

Find the net electric field at the origin.



d. Find the magnitude and direction of the net electric field at the origin.

Answer

Electric Potential Energy

https://www.njctl.org/video/?v=xWkNhkM7QfQ

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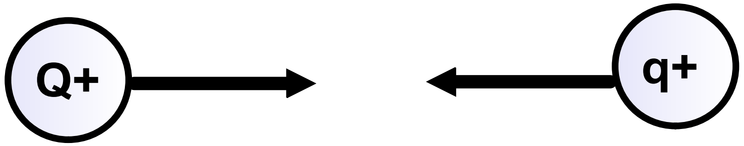
Electric Potential Energy



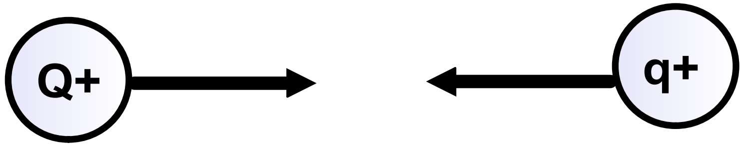
Start with two like charges initially at rest, with Q at the origin, and q at infinity.

In order for q to move towards Q, a force **opposite** to the Coulomb repulsive force needs to be applied since like charges repel.

Note that this force is constantly increasing as q gets closer to Q, since it depends on the distance between the charges, r, and r is decreasing.

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

Work and Potential Energy



Recall that Work is defined as: $W = Fr_{parallel}$

To calculate the work needed to bring q from infinity, until it is a distance r from Q, we would need to use calculus because of the non-constant force, then use conservation of energy: change in electric potential energy = -work: $\Delta U_E = -W$

Assume that the potential energy of the Q-q system is zero at infinity, and adding up the incremental force times the distance between the charges at each point, we find that the Electric Potential Energy, U_E, is:

$$U_E = -W = Fr_{parallel} = \frac{kQq}{r^2} r = \frac{kQq}{r}$$

Electric Potential Energy

This is the equation for the potential energy due to two point charges separated by a distance r.

$$U_E = \frac{kQq}{r}$$

This process summarized on the previous page is similar to how Gravitational Potential Energy was developed.

The benefit of using Electric Potential Energy instead of the Electrical Force is that energy is a scalar, and calculations are much simpler. There is no direction, but the sign matters.

Electric Potential Energy

Again, just like in Gravitational Potential Energy, Electric Potential Energy requires a system - it is not a property of just one object. In this case, we have a system of two charges, Q and q.

Another way to define the system is by assuming that the magnitude of Q is much greater than the magnitude of q, thus, the
Electric Field generated by Q is also much greater than the field generated by q (which may be ignored).

Now we have a field-charge system, and the Electric Potential Energy is a measure of the interaction between the field and the charge, q.

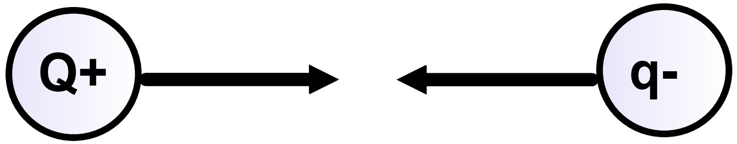
Electric Potential Energy

What is this Electric Potential Energy?

It tells you how much energy is stored by work being done on the system, and is now available to return that energy in a different form, such as kinetic energy.

If two positive charges are placed near each other, they are a system, and they have Electric Potential Energy.   Once released, they will accelerate away from each other - turning potential energy into kinetic energy. These moving charges can now perform work on another system.

Electric Potential Energy

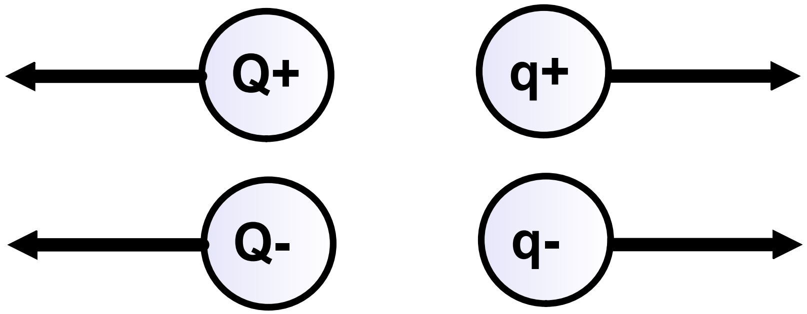


If you have a positive charge and a negative charge near each other, you will have a negative potential energy.

$$U_E = \frac{kQ(-q)}{r} = \frac{-kQq}{r}$$

This means that it takes work by an external agent to keep them from getting closer together.

Electric Potential Energy

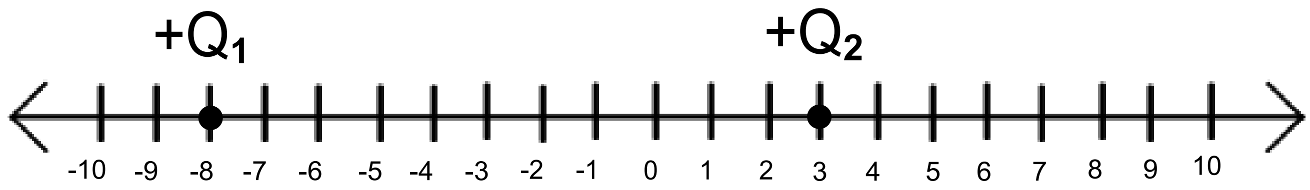


If you have two positive charges or two negative charges, there will be a positive potential energy.

$$U_E = \frac{kQq}{r} \qquad U_E = \frac{k(-Q)(-q)}{r}$$

This means that it takes work by an external agent to keep them from flying apart.

12 Compute the potential energy of the two charges in the following configuration:

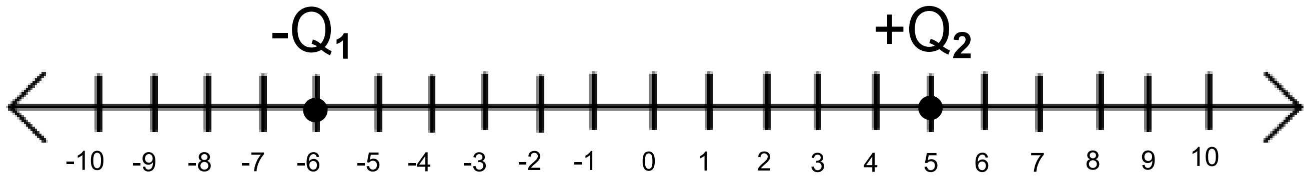


A positive charge, Q_1 = 5.00 mC is located at x_1 = -8.00 m, and a positive charge Q_2 = 2.50 mC is located at x_2 = 3.00 m.

Answer

https://www.njctl.org/video/?v=CzzCQehcHuc

13 Compute the potential energy of the two charges in the following configuration:

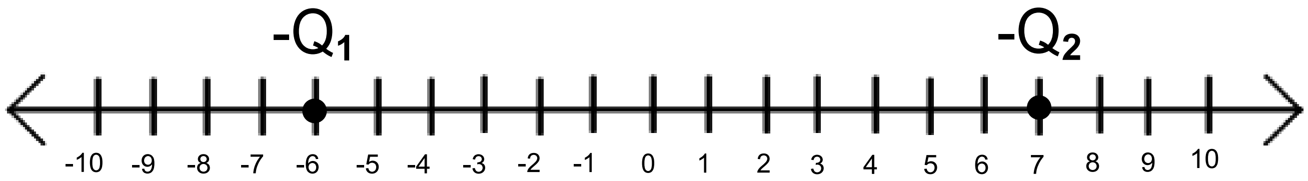


A negative charge, Q_1 = -3.00 mC is located at x_1 = -6.00 m, and a positive charge Q_2 = 4.50 mC is located at x_2 = 5.00 m.

Answer

https://www.njctl.org/video/?v=1fv15PMlkww

14 Compute the potential energy of the two charges in the following configuration:



A negative chage Q_1 = -3.00 mC is located at x_1 = -6.00 m, and a negative charge Q_2 = -2.50 mC is located at x_2 = 7.00 m.

Answer

https://www.njctl.org/video/?v=k6dbZWtByAc

Electric Potential Energy of Multiple Charges

To get the total energy for multiple charges, you must first find the energy due to each pair of charges.

Then, you can add these energies together. Since energy is a scalar, there is no direction involved - but, there is a positive or negative sign associated with each energy pair.

For example, if there are three charges, the total potential energy is:

$$U_T = U_{12} + U_{23} + U_{13}$$

Where U_{xy} is the Potential Energy of charges x and y.

https://www.njctl.org/video/?v=1vDDYDI6nbM

15 Compute the potential energy of the three charges in the following configuration:

A positive charge Q_1 = 5.00 mC is loacted at x_1 = -8.00 m, a negative charge Q_2 = -4.50 mC is located at x_2 = -3.00 m, and a positive charge Q_3 = 2.50 mC is located at x_3 = 3.00 m.

Answer

https://www.njctl.org/video/?v=MeehvWRdvZc

Electric Potential (Voltage)

https://www.njctl.org/video/?v=1NxSDkqMO5s

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Electric Potential or Voltage

Our study of electricity began with Coulomb's Law which calculated the electric force between two charges, Q and q. By assuming q was a small positive charge, and dividing F by q, the electric field E due to the charge Q was defined.

$$F = \frac{kQq}{r^2} \qquad E = \frac{F}{q} = \frac{kQ}{r^2}$$

The same process will be used to define the Electric Potential, or V, from the Electric Potential Energy, where V is a property of the space surrounding the charge Q:

$$U_E = \frac{kQq}{r} \qquad V = \frac{U_E}{q} = \frac{kQ}{r}$$

V is also called the voltage and is measured in volts.

Electric Potential or Voltage

What we've done here is removed the system that was required to define Electric Potential Energy (needed two objects or a field and an object). Voltage is a property of the space surrounding a single, or multiple charges or a continuous charge distribution.

$$V = \frac{U_E}{q} = \frac{kQ}{r}$$

It tells you how much potential energy is in each charge - and if the charges are moving, how much work, per charge, they can do on another system.

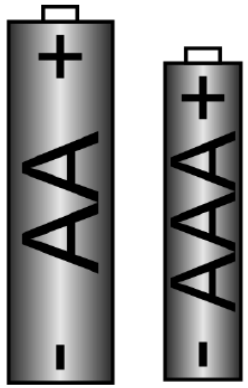
Electric Potential or Voltage

Voltage is the Electric Potential Energy per charge, which is expressed as Joules/Coulomb. Hence:

$$V = \frac{J}{C}$$

To make this more understandable, a Volt is visualized as a battery adding 1 Joule of Energy to every Coulomb of Charge that goes through the battery.

Electric Potential or Voltage



Despite the different size of these two batteries, they both have the same Voltage (1.5 V). That means that every electron that leaves each battery has the same Electric Potential - the same ability to do work.

The AA battery just has more electrons - so it will deliver more current and last longer than the AAA battery.

Electric Potential or Voltage

Another helpful equation can be found from $V = \frac{U_E}{q}$ by realizing

that the work done on a positive charge by an external force (a force that is external to the force generated by the electric field) will increase the potential energy of the charge, so that:

$$W = U_E = qV$$

Note, that the work done on a negative charge will be negative - the sign of the charge counts!

16 What is the Electric Potential (Voltage) 5.00 m away from a charge of 6.23×10^{-6} C?

Answer

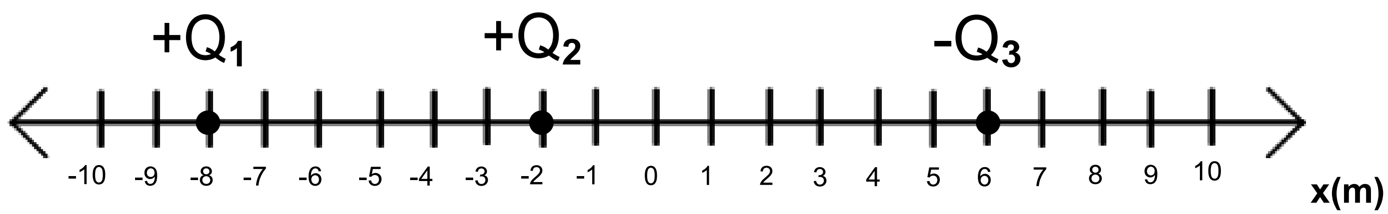
https://www.njctl.org/video/?v=l4mULqsoJvA

17 What is the Electric Potential (Voltage) 7.50 m away from a charge of -3.32×10^{-6} C?

Answer

https://www.njctl.org/video/?v=pnljwVRZvls

18 Compute the electric potential of three charges at the origin in the following configuration:

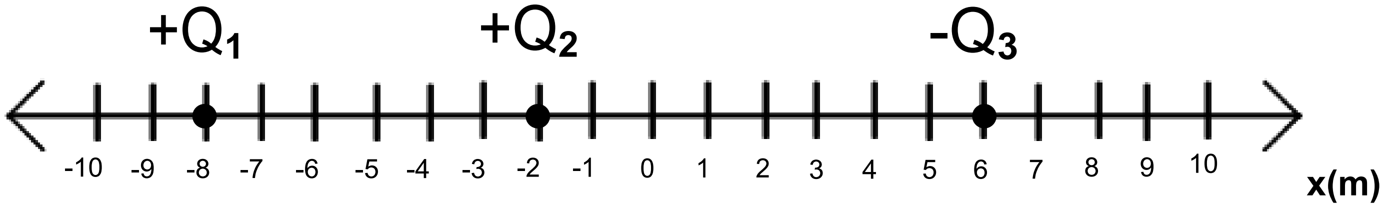


A positive charge Q_1 = 5.00 nC is located at x_1 = -8.00 m, a positive charge Q_2 = 3.00 nC is located at x_2 = -2.00 m, and a negative charge Q_3 = -9.00 nC is located at x_3 = 6.00 m.

Answer

https://www.njctl.org/video/?v=l4mULqsoJvA

19 How much work must be done by an external force to bring a $1x10^{-6}$ C charge from infinity to the origin of the following configuration?

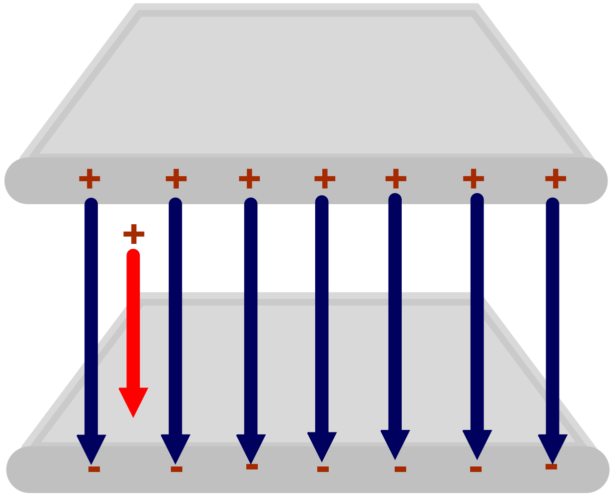


A positive charge Q_1 = 5.00 nC is located at x_1 = -8.00 m, a positive charge Q_2 = 3.00 nC is located at x_2 = -2.00 m, and a negative charge Q_3 = -9.00 nC is located at x_3 = 6.00 m.

Answer

https://www.njctl.org/video/?v=pnljwVRZvls

Electric Potential or Voltage

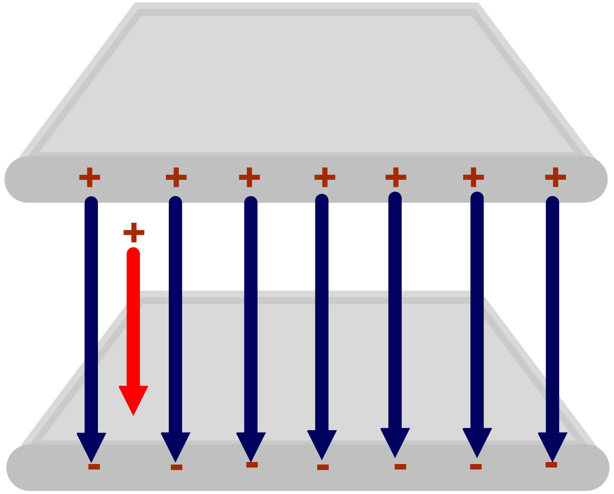


Consider two parallel plates that are oppositely charged. This will generate a uniform electric field pointing from top to bottom, which means the strength of the electric field is the same anywhere.

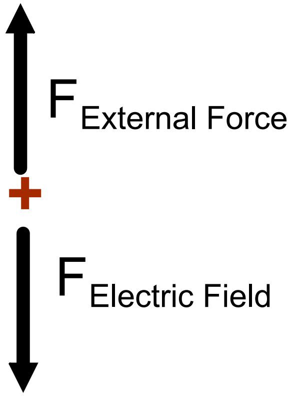
A positive charge placed within the field will move from top to bottom. In this case, the work done by the electric field is positive (the field is in the same direction as the charge's motion). The potential energy of the system will decrease - this is directly analogous to the movement of a mass within a gravitational field.

https://www.njctl.org/video/?v=1NxSDkqMO5s

Electric Potential or Voltage

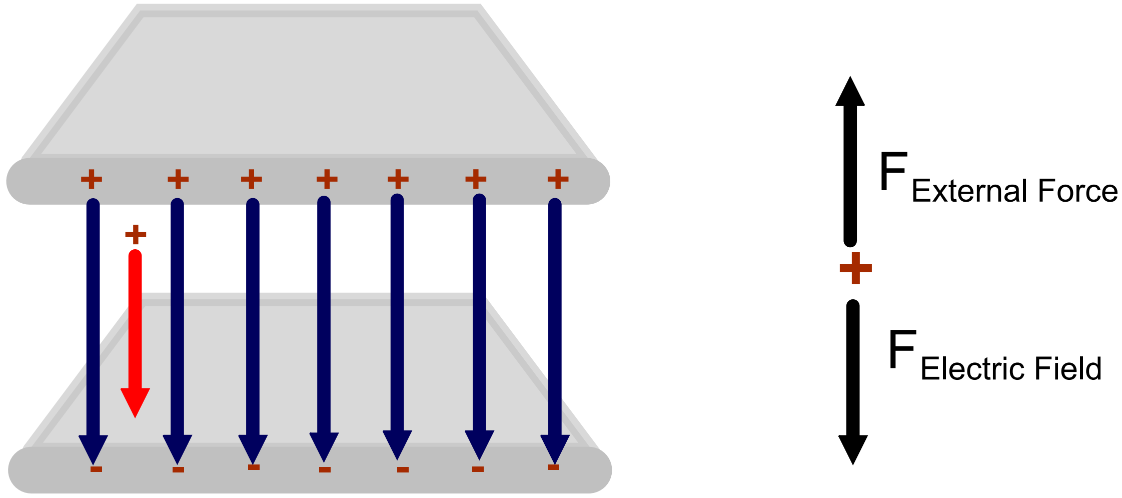


If there is no other force present, then the charge will accelerate to the bottom by Newton's Second Law.



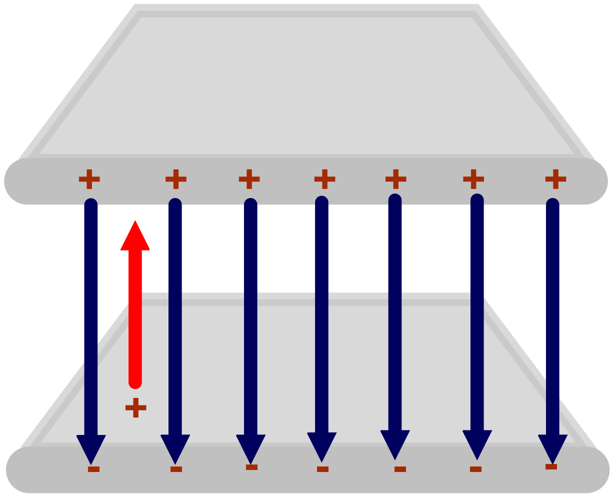
But, if we want the charge to move with a constant velocity, then an external force must act opposite to the Electric Field force. This external force is directed upwards. Since the charge is still moving down (but not accelerating), the Work done by the external force is negative.

Electric Potential or Voltage



The Work done by the external force is negative.
The Work done by the Electric Field is positive.
The Net force, and hence, the Net Work, is zero.
The Potential Energy of the system decreases.

Electric Potential or Voltage

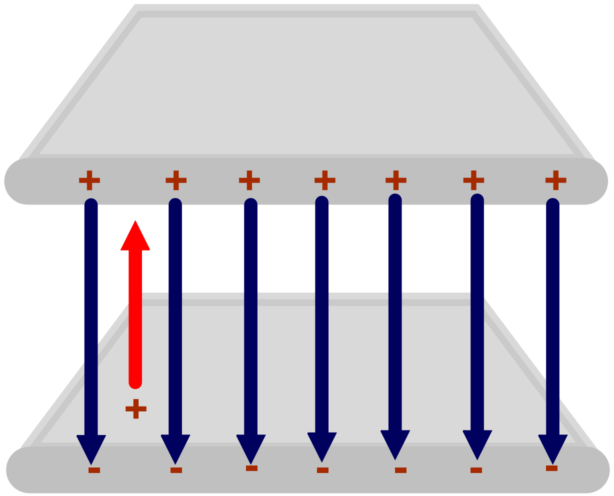


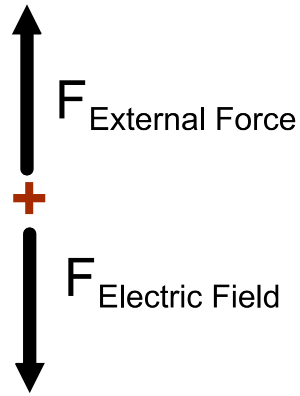
Now consider the case of moving a positive charge from the bottom of the field to the top.

In order to move the charge to the top, an external force must act in the upward direction to oppose the electric force, which is directed downward.

In this case the work done by the electric field is negative. The potential energy of the system will increase - again, this is directly analogous to the movement of a mass within a gravitational field.

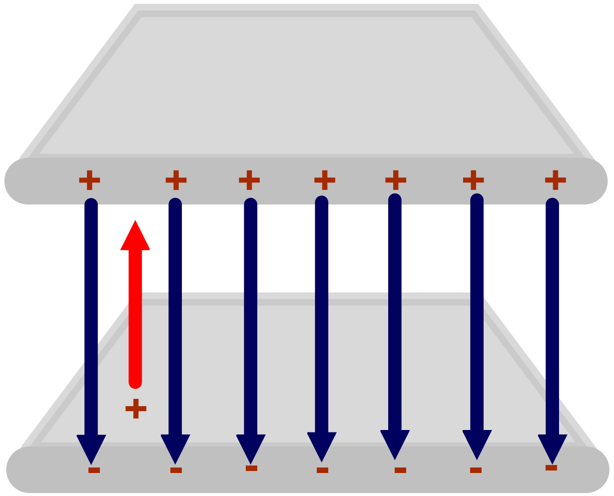
Electric Potential or Voltage

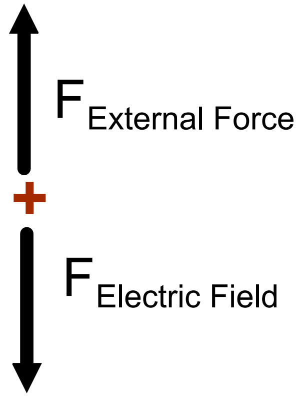




If the charge moves with a constant velocity, then the external force is equal to the electric field force. Since the charge is moving up (but not accelerating), the work done by the external force is positive.

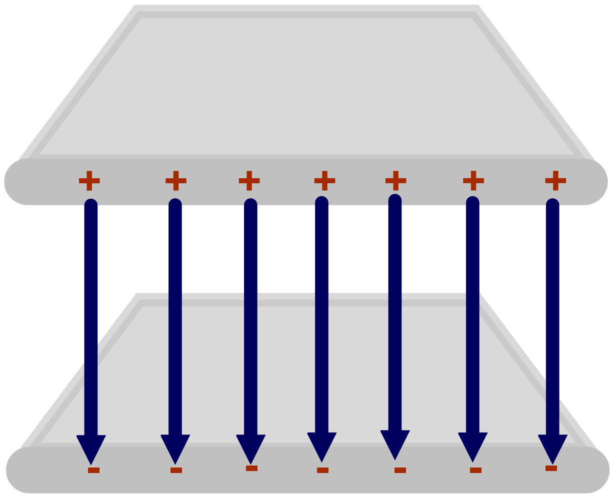
Electric Potential or Voltage





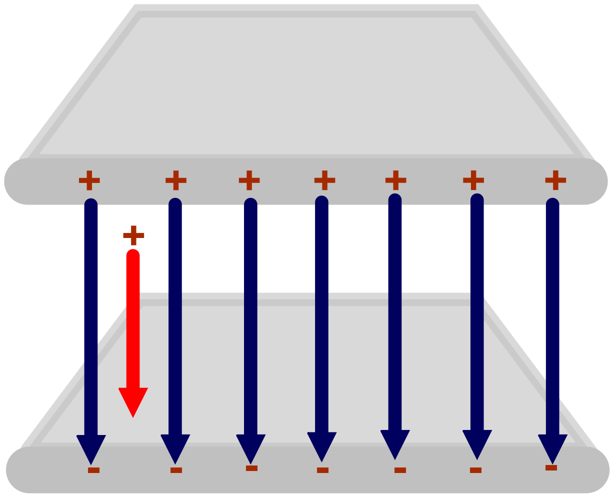
The Work done by the external force is positive.
The Work done by the Electric Field is negative.
The Net force, and hence, the Net Work, is zero.
The Potential Energy of the system increases.

20 A positive charge is placed between two oppositely charged plates as shown below. Which way will the charge move? What happens to the potential energy of the charge/plate system?



Answer

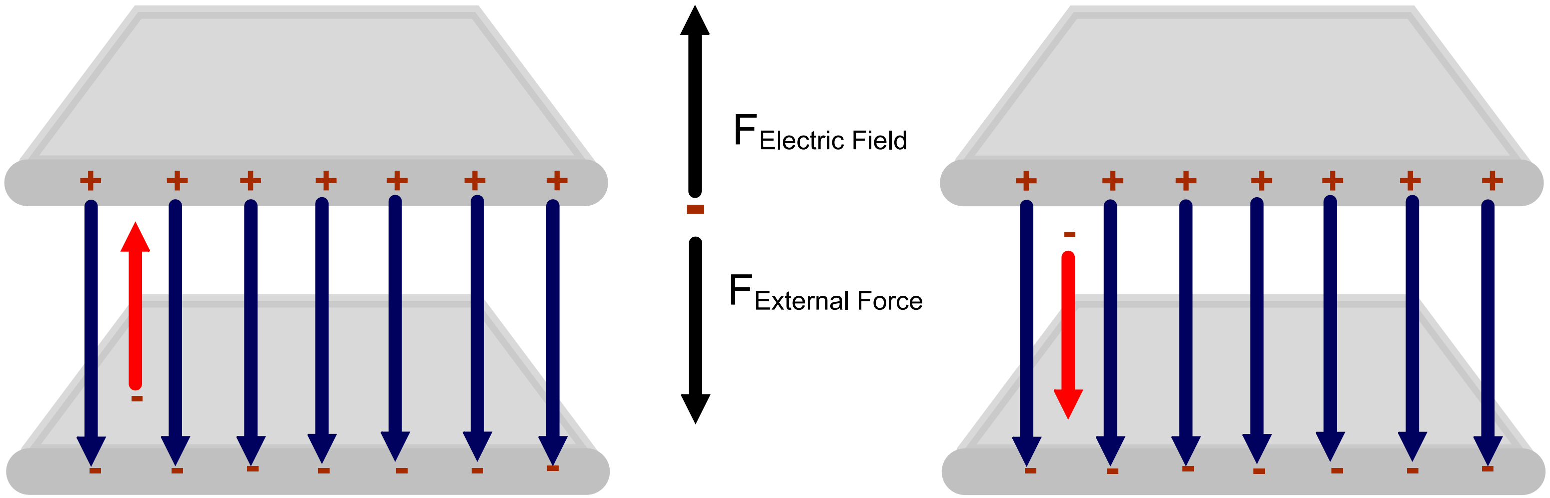
21 A positive charge is placed between two oppositely charged plates. If the charge moves with a constant velocity (no acceleration) as shown below, what is the sign of the work done by the Electric field force? What is the sign of the work done by the external force? What is the total work done by the two forces?



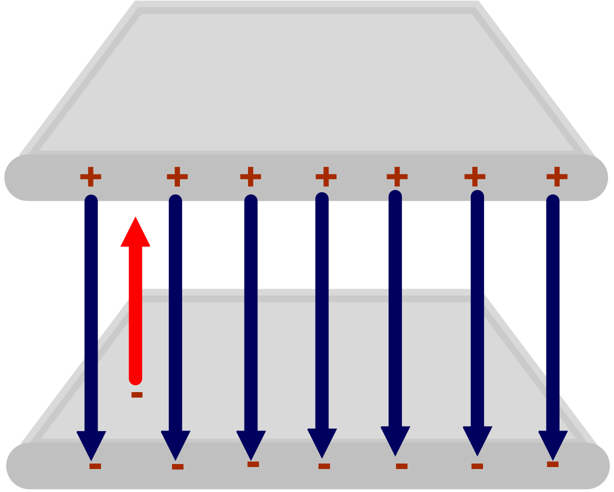
Answer

Electric Potential or Voltage

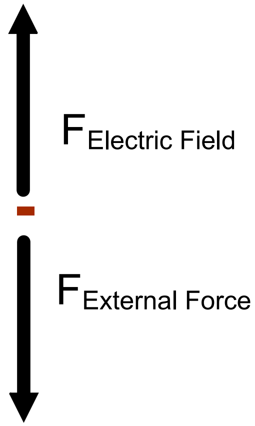
Similar logic works for a negative charge in the same Electric Field. But, the directions of the Electric Field force and the external force are reversed, which will change their signs, and the potential energy as summarized on the next slide.

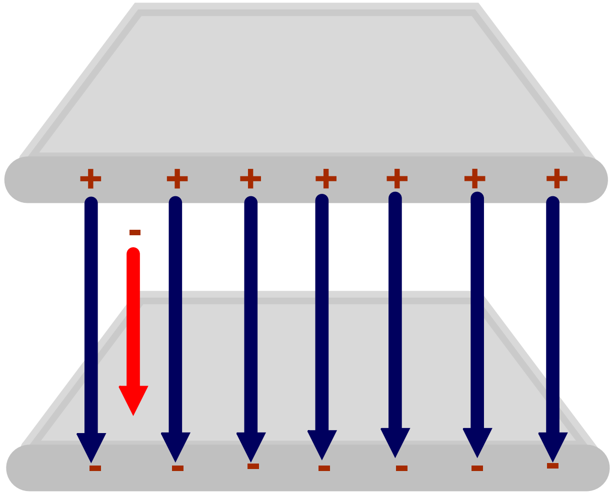


Electric Potential or Voltage



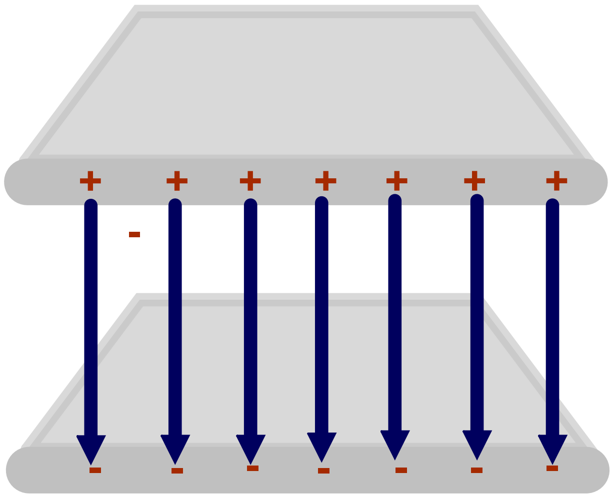
Work done by the external force is negative.
Work done by the Electric Field is positive.
Net force, and hence, the Net Work, is zero.
Potential Energy of the system decreases.





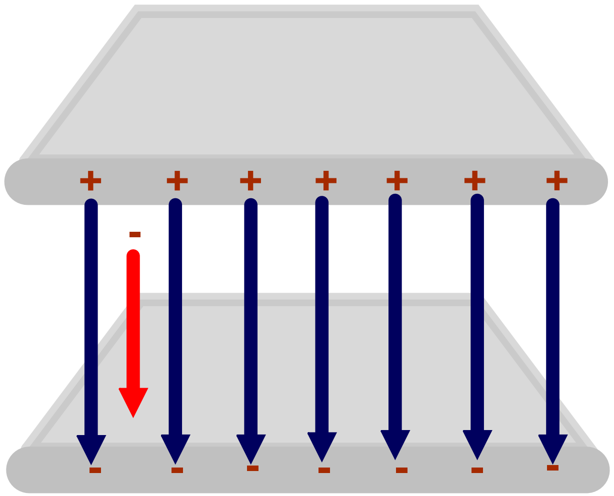
Work done by the external force is positive.
Work done by the Electric Field is negative.
Net force, and hence, the Net Work, is zero.
Potential Energy of the system increases.

22 A negative charge is placed between two oppositely charged plates as shown below. Which way will the charge move? What happens to the potential energy of the charge/plate system?



Answer

23 A negative charge is placed between two oppositely charged plates, and due to an external force moves down with a constant velocity, as shown below. What sign is the work done by the external force? What sign is the work done by the Electric field? What happens to the potential energy of the charge/plate system?



Answer

Electric Potential or Voltage

Like Electric Potential Energy, Voltage is NOT a vector, so multiple voltages can be added directly, taking into account the positive or negative sign.

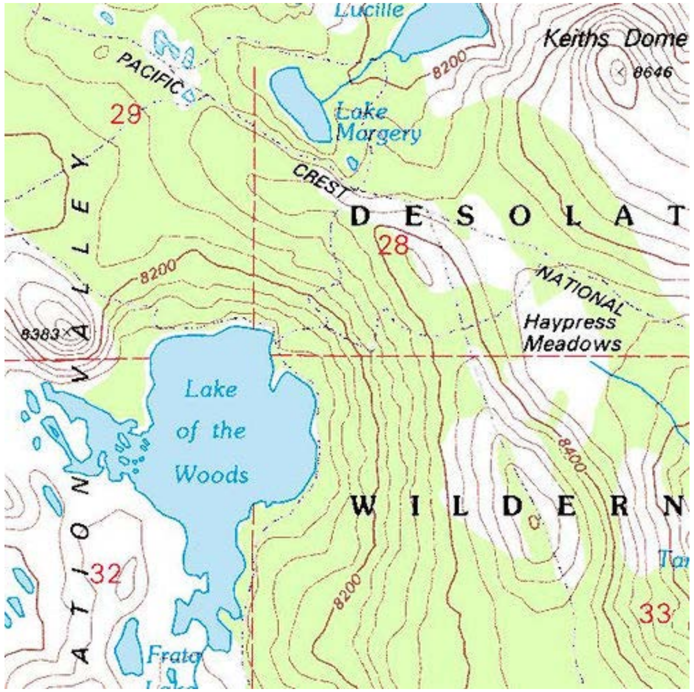
Like Gravitational Potential Energy, Voltage is not an absolute value - it is compared to a reference level. By assuming a reference level where V=0 (as we do when the distance from the charge generating the voltage is infinity), it is allowable to assign a specific value to V in calculations.

The next slide will continue the gravitational analogy to help understand this concept.

Topographic Maps

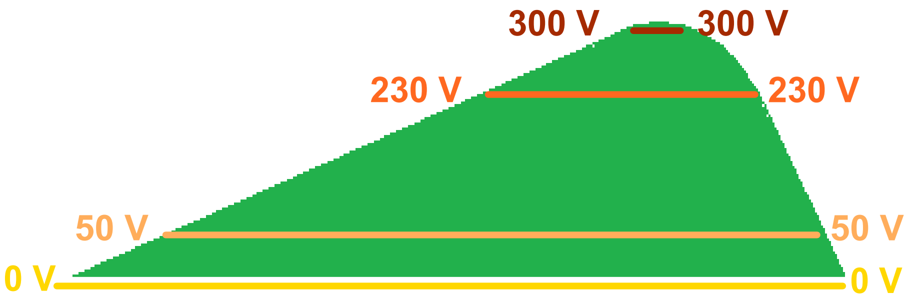
Each line represents the same height value.The area between lines represents the change between lines.

A big space between lines indicates a slow change in height. A little space between lines means there is a very quick change in height.

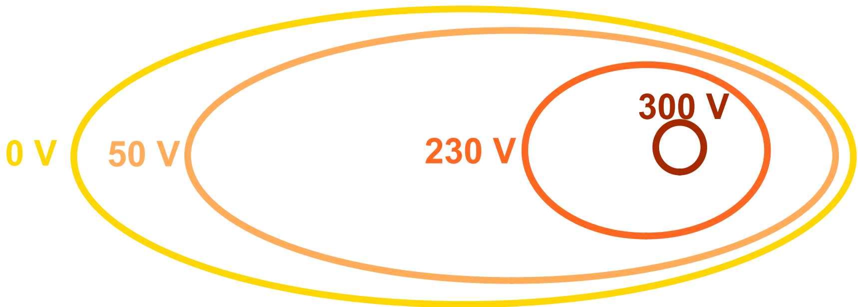


Where in this picture is the steepest incline?

Equipotential Lines



These "topography" lines are called "Equipotential Lines" when we use them to represent the Electric Potential - they represent lines where the Electric Potential is the same.



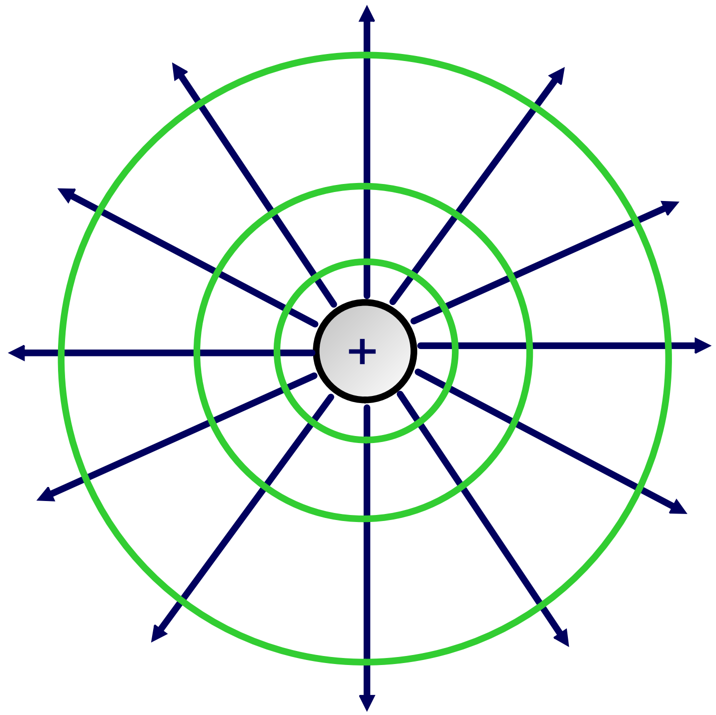
The closer the lines, the faster the change in voltage.... the bigger the change in Voltage, the larger the Electric Field.

Equipotential Lines

The direction of the Electric Field lines are always perpendicular to the Equipotential lines.

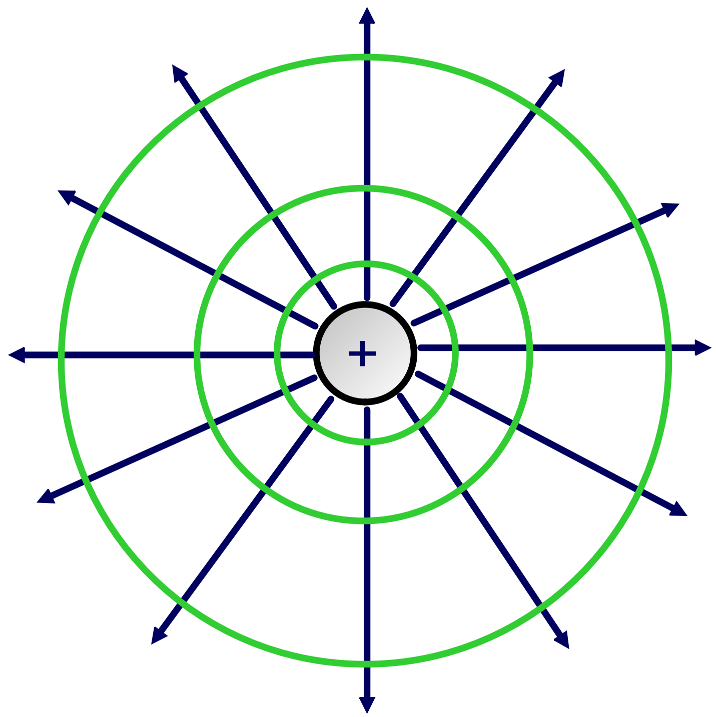
The Electric Field lines are farther apart when the Equipotential lines are farther apart.

The Electric Field goes from high to low potential (just like a positive charge).



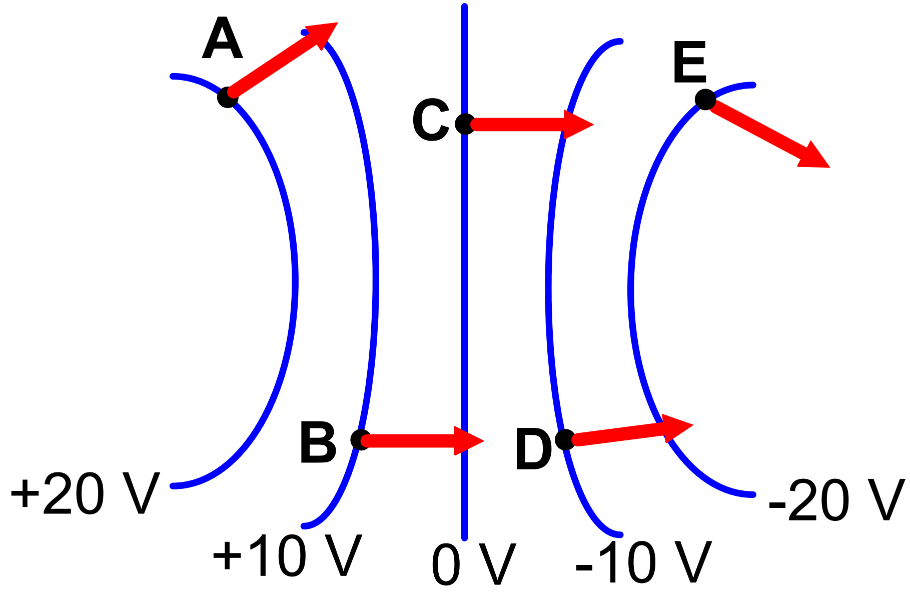
Equipotential Lines

For a positive charge like this one the equipotential lines are positive, and decrease to zero at infinity. A negative charge would be surrounded by negative equipotential lines, which would also go to zero at infinity.



More interesting equipotential lines (like the topographic lines on a map) are generated by more complex charge configurations.

Equipotential Lines



This configuration is created by a positive charge to the left of the +20 V line and a negative charge to the right of the -20 V line.

Note the signs of the Equipotential lines, and the directions Electric Field vectors (in red) which are perpendicular to the lines tangent to the Equipotential lines.

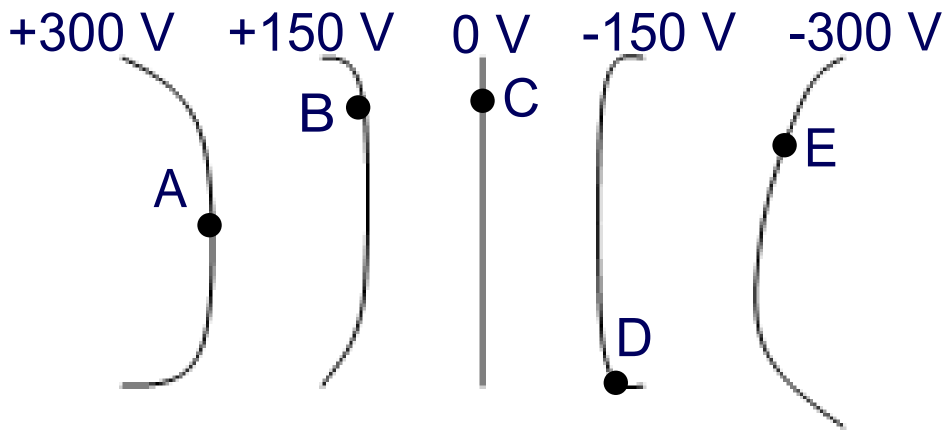
24 At point A in the diagram, what is the direction of the Electric Field?

A Up

B Down

C Left

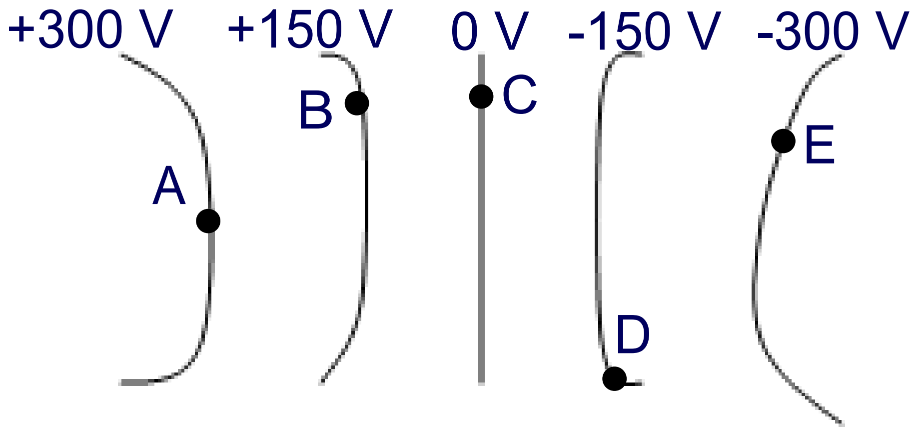
D Right



Answer

https://www.njctl.org/video/?v=lZFuP-bNvOc

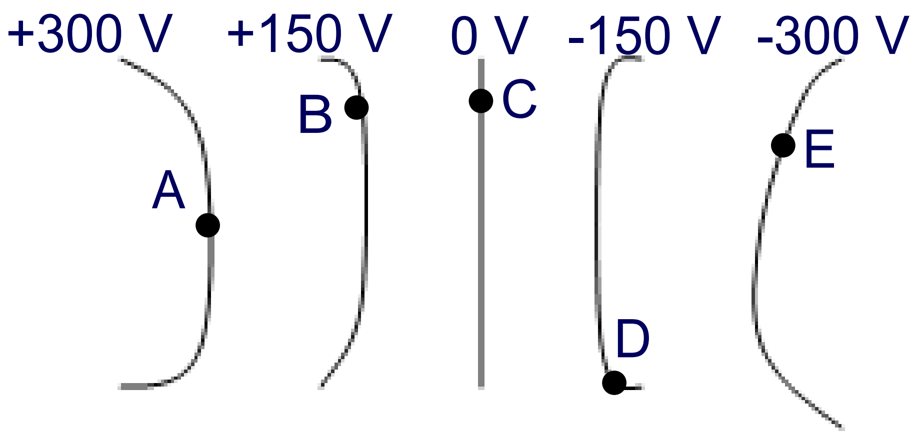
25 How much work is done by an external force on a 10μC charge that moves from point C to B?



Answer

https://www.njctl.org/video/?v=HegD_MWGB44

26 How much work is done by an external force on a -10μC charge that moves from point C to B?



Answer

https://www.njctl.org/video/?v=wE8iN2VJb-Q

Uniform Electric Field

https://www.njctl.org/video/?v=mEe3PSZwyr0

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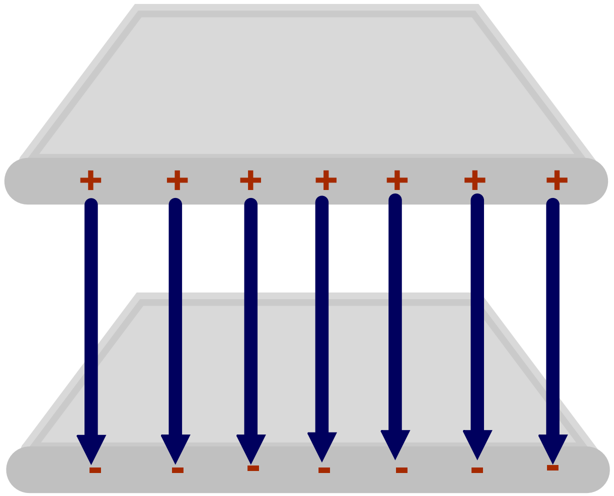
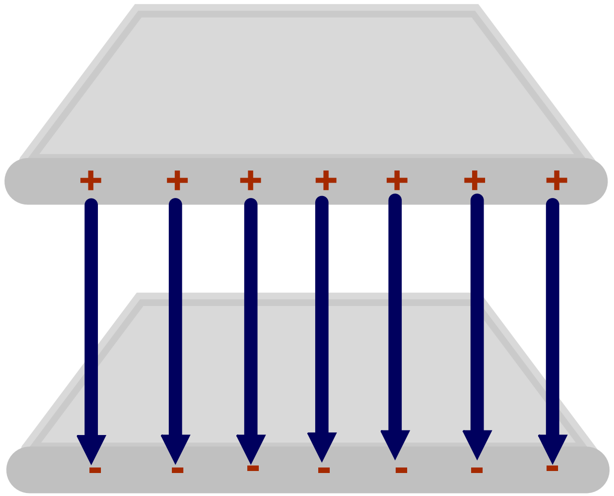
Uniform Electric Field



Up until now, we've dealt with Electric Fields and Potentials due to individual charges. What is more interesting, and relates to practical applications is when you have configurations of a massive amount of charges.

Let's begin by examining two infinite planes of charge that are separated by a small distance. The planes have equal amounts of charge, with one plate being charged positively, and the other, negatively. The above is a representation of two infinite planes (its rather hard to draw infinity).

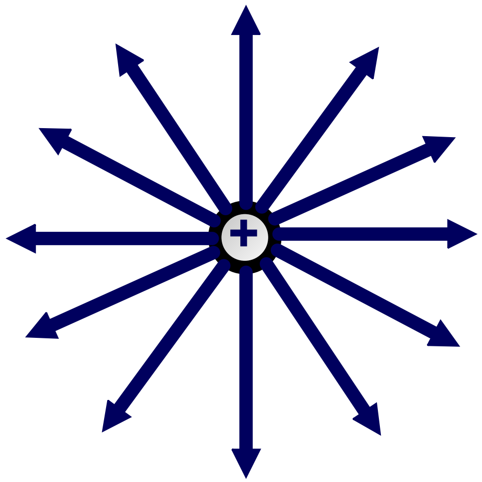
Uniform Electric Field



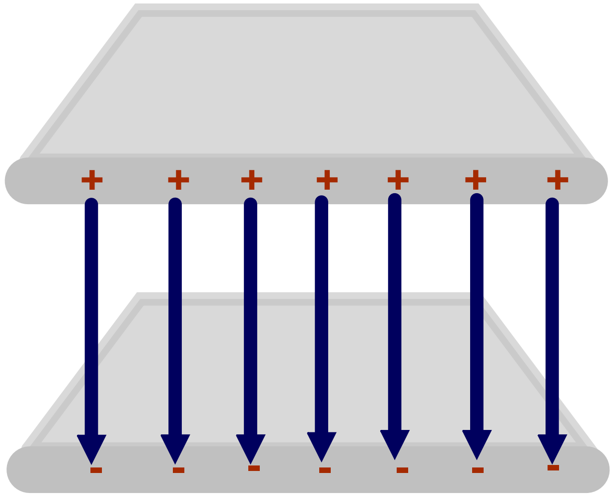
By applying Gauss's Law (a law that will be learned in AP Physics), it is found that the strength of the Electric Field will be uniform between the planes - it will have the same value everywhere between the plates.

And, the Electric Field outside the two plates will equal zero.

Uniform Electric Field

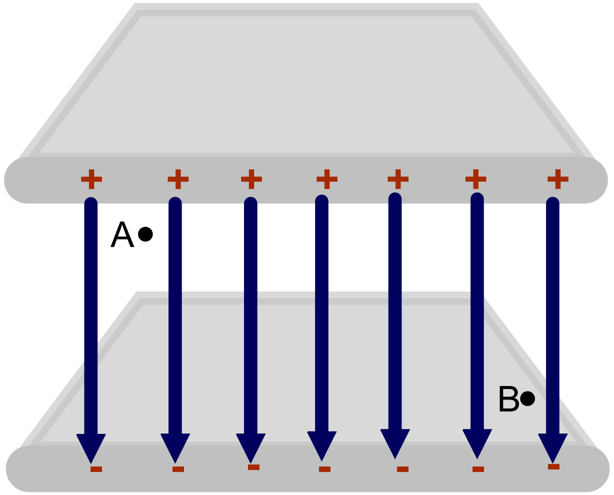


Point charges have a non-uniform field strength since the field weakens with distance.



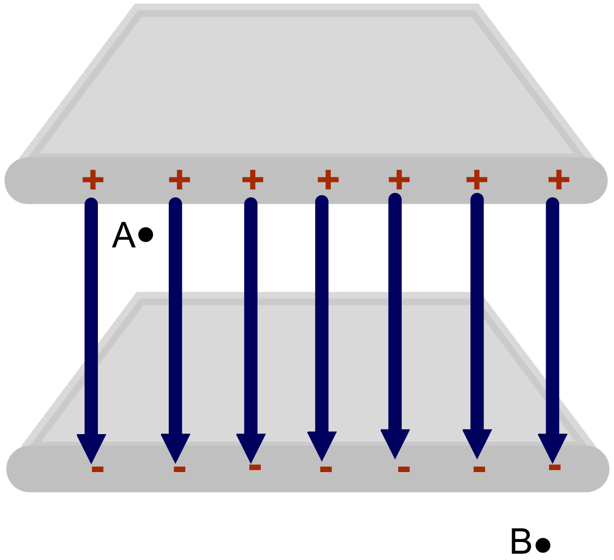
Only some equations we have learned will apply to uniform electric fields.

27 If the strength of the electric field at point A is 5,000 N/C, what is the strength of the electric field at point B?



Answer

28 If the strength of the electric field at point A is 5,000 N/C, what is the strength of the electric field at point B?

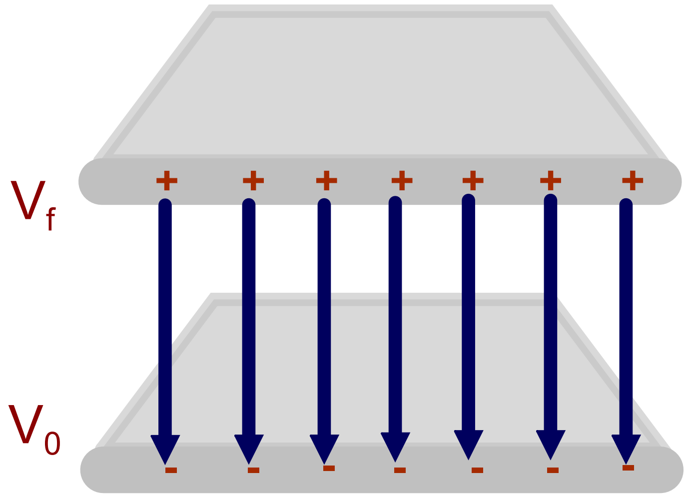


Answer

Uniform Electric Field & Voltage

For the parallel planes, the Electric Field is generated by the separation of charge - with the field lines originating on the positive charges and terminating on the negative charges.

The difference in electric potential (voltage) is responsible for the electric field.

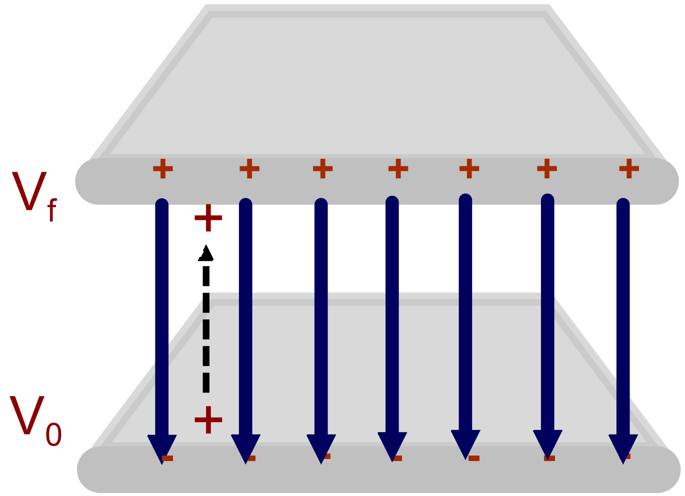


Uniform Electric Field & Voltage

The change in voltage is defined as the word done per unit charge against the electric field.

Therefore, energy is being put into the system when a positive charge moves in the opposite direction of the electric field (or when a negative charge moves in the same direction of the electric field).

Positive work is being done by the external force, and since the positive charge is moving opposite the electric field, negative work is being done in the field.



Uniform Electric Field & Voltage

For a field like this, a very interesting equation relating Voltage and the Electric Field can be derived.

Since the work done by the Electric Field is negative, and the force is constant on the positive charge, the Work-Energy Equation is used:

$$U_E = -W = -F\Delta x = -qE\Delta x$$

where d is the distance between the two planes.

Divide both sides by q.

$\frac{U_E}{q} = -Ed$ and recognize that $\frac{U_E}{q} = \Delta V$

$\Delta V = -Ed$ or $E = -\frac{\Delta V}{d}$

Uniform Electric Field & Voltage

$$E = -\frac{\Delta V}{\Delta x} = -\frac{\Delta V}{d}$$

A more intuitive way to understand the negative sign in the relationship is to consider that just like a mass falls down in a gravitational field, from higher gravitational potential energy to lower, a positive charge "falls down" from a higher electric potential (V) to a lower value.

Uniform Electric Field & Voltage

$$E = -\frac{\Delta V}{\Delta x} = -\frac{\Delta V}{d}$$

Since the electric field points in the direction of the force on a hypothetical positive test charge, it must also point from higher to lower potential.

The negative sign just means that objects feel a force from locations with greater potential energy to locations with lower potential energy.

This applies to all forms of potential energy.

This "sign" issue is a little tricky - and will be covered in more depth in the AP Physics course. For now, we will just use the magnitude of the Electric Field in the problems (so, no negative sign).

Uniform Electric Field & Voltage

The equation only applies to uniform electric fields.

$$E = -\frac{\Delta V}{\Delta x} = -\frac{\Delta V}{d}$$

It follows that the electric field can also be shown in terms of volts per meter (V/m) in addition to Newtons per Coulomb (N/C).

$$\frac{V}{m} = \frac{J/C}{m}$$ Since V = J/C.

$$\frac{J/C}{m} = \frac{N\text{-}m/C}{m}$$ Since J = N*m.

$$\frac{N\text{-}m/C}{m} = \frac{N}{C}$$

The units are equivalent.

29 In order for a charged object to experience an electric force, there must be a:

A large electric potential

B small electric potential

C the same electric potential everywhere

D difference in electric potential

Answer

https://www.njctl.org/video/?v=iAIowzNayFw

30 How strong (in V/m) is the electric field between two metal plates 0.25 m apart if the potential difference between them is 100 V?

Answer

https://www.njctl.org/video/?v=nms0ONNd0jk

31 An electric field of 3500 N/C is desired between two plates which are 0.0040 m apart; what Voltage should be applied?

Answer

https://www.njctl.org/video/?v=ZhSFPG-tJfo

32 A uniform 300 N/C Electric Field accelerates a charge of 6.1 mC a distance of 0.20 m? How much work is done by the Electric Field?

Answer

https://www.njctl.org/video/?v=mHUTILsfM7s

Uniform Electric Field & Voltage Summary

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

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

Use **only** with point charges.

$$U_E = \frac{kQq}{r}$$

$$V = \frac{kQ}{r}$$

Equations with "k" are point charges **only**.

$$F = qE$$

$$U_E = qV$$

Use in **any** situation.

$$U_E = -qEd$$

$$E = -\frac{\Delta V}{d}$$

Only for uniform electric fields