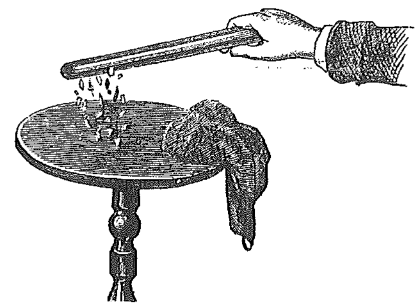
ELECTROSTATICS

Lesson 1

Physics 12 – **Electrostatics**



Electrostatics is the study of charges that are not in motion and the interactions between them.

STATIC ELECTRICITY:

We will begin our study of electricity by looking at the electrical nature of matter. **Static electricity is electricity at rest.**

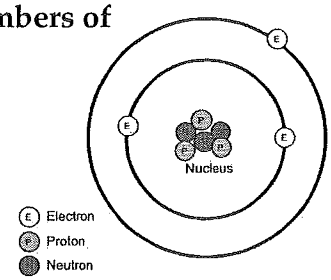
We are aware that many materials including amber, fur, glass, rubber and plastic will produce the effect of attracting other objects when rubbed. This attraction involves accelerating matter so there must be a FORCE at work.

Neutral vs. Charged Objects:

As we know from science 9, 10 and chemistry, atoms contain neutrons, protons and electrons.

The number of electrons that surround the nucleus will determine whether or not an atom is electrically charged or electrically neutral. If an atom contains **equal numbers of protons and electrons**, the atom is described as being **electrically neutral**.

If an atom has an unequal number of protons and electrons, then the atom is electrically charged (and in fact, is then referred to as an **ion** rather than an atom).



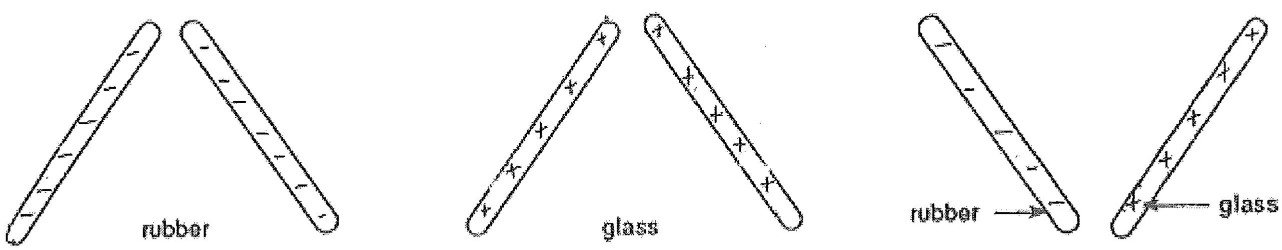
Charged versus Uncharged Particles

Positively Charged	**Negatively Charged**	**Uncharged**
Possesses more protons than electrons	Possesses more electrons than protons	Equal numbers of protons and electrons

A **conductor** is a material that…	An **insulator** is a material that…

It is possible to build up charge on insulators because electrons cannot easily flow off of a negatively charged object or onto a positively charged object.

CHARGING BY FRICTION

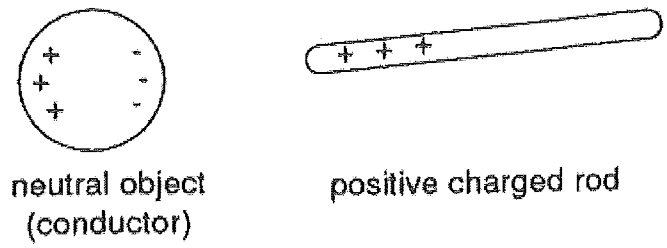


The Law of Charges states:

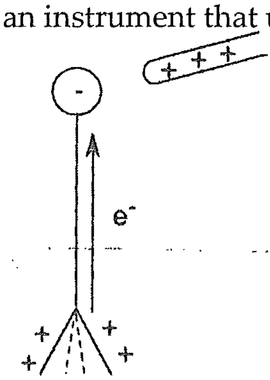
1. Like charges repel.
2. Opposite charges attract.
3. Neutral charges are attracted to charged (+ or -) objects.

CHARGING BY INDUCTION

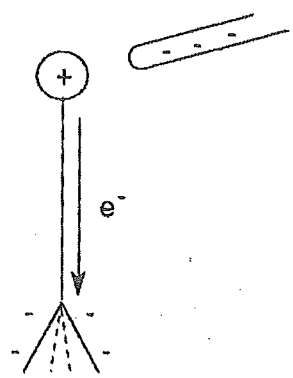
In this process of charging, the neutral conductor will not lose or gain any electrons (remaining neutral), but the electrons will be rearranged. This is referred to charging by **induction.**



An **electroscope** is an instrument that uses induction to detect the presence and nature (- and +) of a charge.



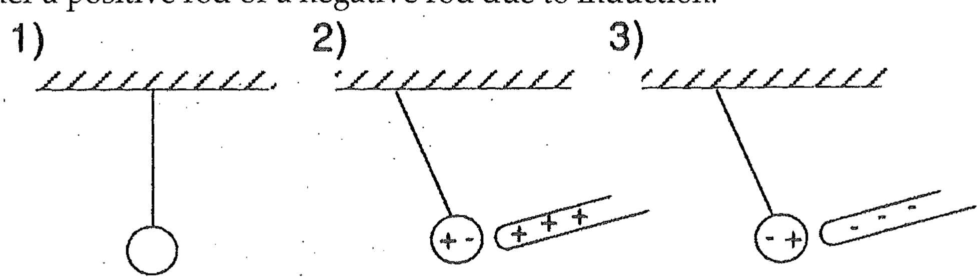
A positively charged rod will attract electors through induction to the head of the electroscope, leaving the leaves positive.



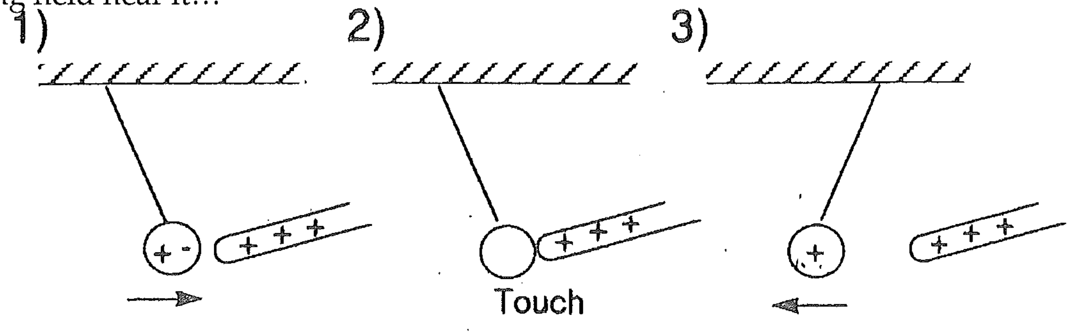
A negatively charged rod will repel electrons from the head of the electroscope into the leaves through induction, leaving the leaves negative.

CHARGING BY CONTACT

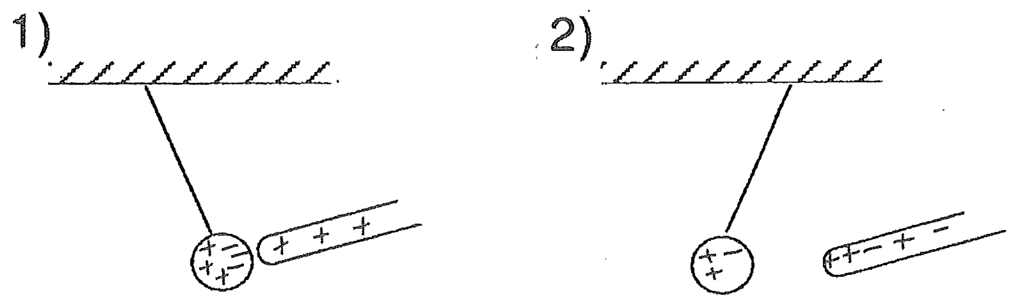
A pith ball is a light ball with a conductive surface. A neutral pith ball is initially attracted to either a positive rod or a negative rod due to induction.



Now we will see what happens when the rod actually touches the ball rather than just being held near it…



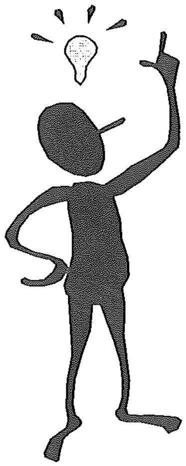
Why? When the ball comes in contact with the rod, the **ball transfers some of its electrons to the rod**. The rod is still positive, but now so is the previously neutral ball. Therefore, both are positive and they will now repel.



The Law of Conservation of Charges -

It is very important to note that if an object is charged by friction, induction or conduction, the electric charges are neither created or destroyed – they are just moved from one place to another.

Next lesson we will investigate the force behind the attraction and repulsion →(F_e)



Checking for Understanding:

Electrostatics

i.) PREDICTIONS:

Situation 1:

A curious physics 12 student is playing with two pieces of tape. He/she sticks both pieces of tape to the desk, removes them and then brings the two pieces of tape close together and notices:

a. The two pieces of tape attract
b. The two pieces of tape repel
c. Nothing happens

ii) COMPARE your answers with a partner
iii) TEST your predictions

i.) PREDICTIONS:

Situation 2: Now the curious physics student places one piece of tape on the desk and the second piece of tape on top of the first. He/she then removes and then brings the two pieces of tape close together and notices:

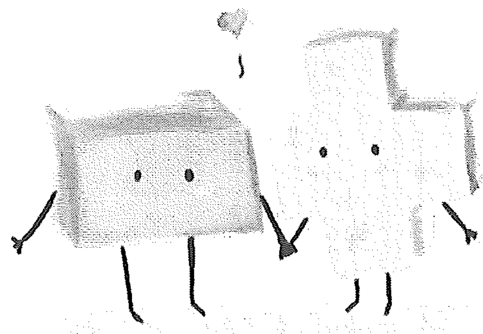
a. The two pieces of tape attract
b. The two pieces of tape repel
c. Nothing happens

ii) COMPARE your answers with a partner
iii) TEST your predictions

vi) EXPLAIN WHY the tape behaved as it did in EACH situation

Physics 12 – **Coulomb's Law**

As we saw last lesson, electric charges can attract and repel other charges. With this attraction and repulsion there must be a **force acting to change the velocity of the object**. This force is referred to as the **Electric Force (F_e).**



There is a parallel relationship that exists between charges (and the resulting electric force) and that of masses (and the resulting gravitational force).

Joseph Priestly made this connection when he found that placing a charged pith ball inside a hollow sphere has no electrical force acting on it just as a mass inside a hollow mass will have no gravitational force acting on it. This is because there are forces in all directions and they will cancel each other out.

ELECTRIC FORCE LAW (COULOMB'S LAW)

This law states that the electric force between two charges depends on:

It is important to remember that **electric charge is always conserved**. **The net electric charge of an isolated system remains constant during any process.**

Coulomb's Law -

The unit of charge is a **Coulomb.**

Comparing this equation to universal gravitation, we can see the ***similarity.***

Electrostatic Force: **Gravitational Force:**

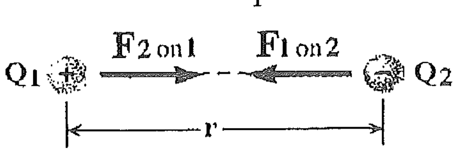
While this equation is similar to universal gravitation, there are a ***number of differences:***

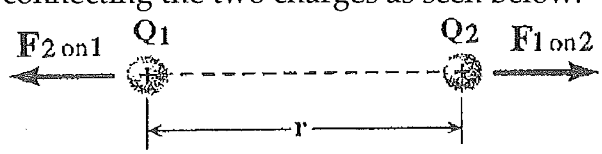
First, electrostatic forces are much stronger than gravitational forces.

Secondly, Gravity ALWAYS... while Electrostatic force can....

Thirdly, we will determine the direction of the force (+ or -) based on...

The electric force produced acts along the line connecting the two charges as seen below.





Electric charge has a specific quantity. The elementary charge is the **charge on one electron** (*negative*) or **one proton** (*positive*).

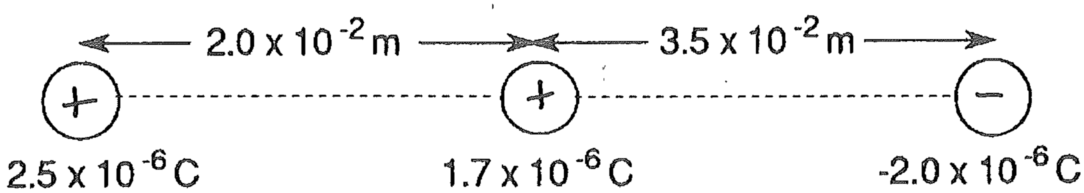
$$\mathbf{e = 1.60 \times 10^{-19}\ C}$$

Example 1:

Calculate the electric force between charges of 1.00×10^{-6} C and 1.50×10^{-6} C when they are 5.00×10^{-1} m apart.

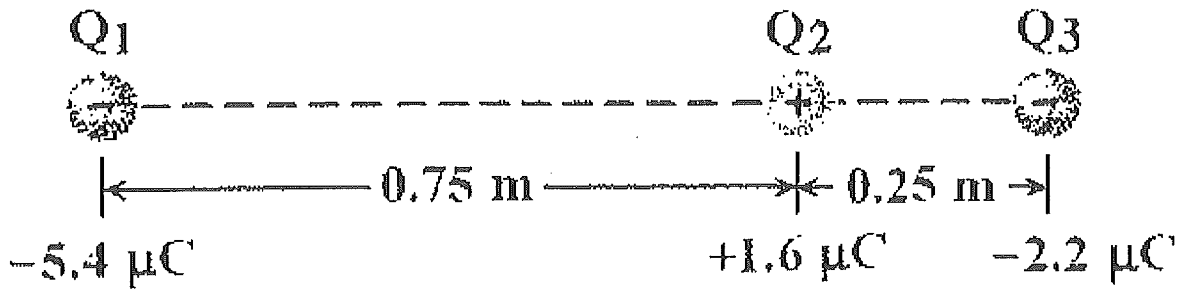
Example 2:

A charge of 1.7×10^{-6} C is placed 2.0×10^{-2} m from a charge of 2.5×10^{-6} C and 3.5×10^{-2} m from a charge of -2.0×10^{-6} C as shown in the diagram. Calculate the magnitude of the net electric force on the center (1.7×10^{-6} C) charge.

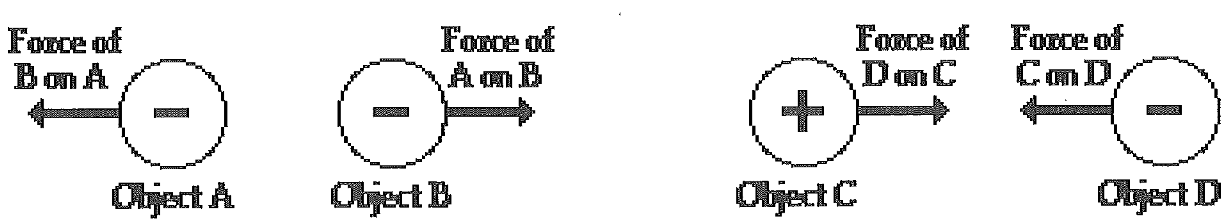


Example Three:

Three charged particles are arranged in a line as shown in the diagram. ($1\mu C = x10^{-6}$). Find the net electric force on q_2 due to q_1 and q_3.



Determining the Direction of the Electrical Force Vector



Lesson 1 homework

Example Four: Two small spheres have the ***same mass and volume.*** One of the spheres has a charge of 3.50×10^{-6} C and the other sphere has a charge of -1.50×10^{-6} C. If these two spheres are brought into brief contact with each other and then separated to a distance of 0.500 m, what is the electric force between them at this distance?

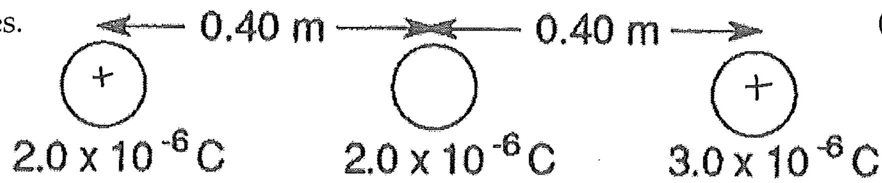
Coulomb's Law Problems: Lesson 1 homework.

1. Calculate the electrical force between two charges of 4.00×10^{-6} C and 3.00×10^{-6} C when they are 2.00 cm apart. (270 N)

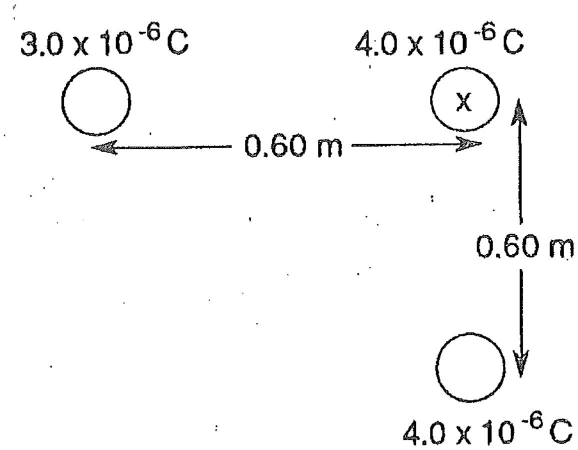
2. Two points of equal charge produce an electric force on each other of 3.40×10^{-2} N when they are placed 0.100 m apart. What is the charge on each point? (1.94×10^{-7} C)

3. How far apart are two point charges (**a point charge is a charge that occupies so little space that is can be regarded as a mathematical point**) of 2.0×10^{-6} C and 4.0×10^{-6} C if they produce an electric force on each other of 5.6×10^{-1} N? (0.36 m)

4. Three positively point charged objects are placed in a line as shown in the diagram. Calculate the magnitude of the net electric force on the center charge caused by the other two charges. (0.113 N)



5. Three charged objects are placed at the corners of a right angle triangle as shown in the diagram. Calculate the magnitude of the net electric force on the charge marked x caused by the other two charges. (0.500 N)



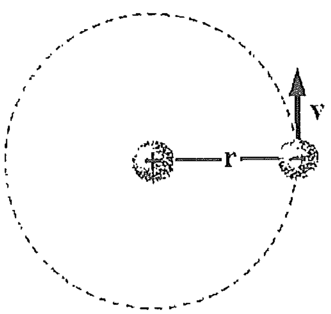
6. Two small spheres have the same mass and volume. One of the spheres has a charge of 4.00×10^{-6} C and the other sphere has a charge of -1.00×10^{-6} C. If these two spheres are brought into brief contact with each other and then separated to a distance of 0.200 m, what is the electric force between them at this distance? (5.06×10^{-1} N)

7. Two small spheres, each with a mass of 2.00×10^{-5} kg, are placed 0.350 m apart. One sphere has a charge of -2.00 μC (**remember μC = x10^{-6}**) and is fixed in position. The other sphere has a charge of -3.00 μC but is free to move without friction. What is the initial acceleration caused by the electric force on the sphere that is free to move? (2.20×10^4 m/s^2)

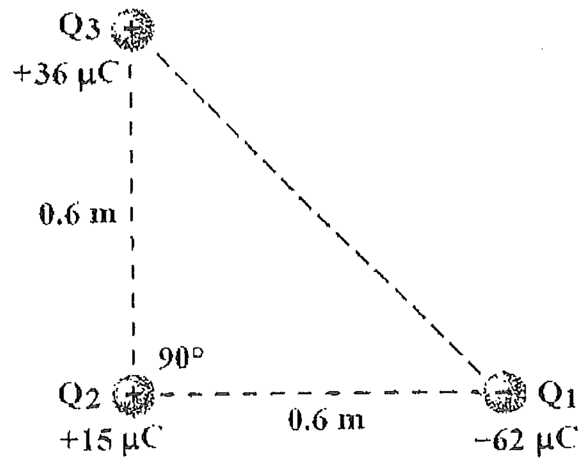
8. A hydrogen atom consists of a stationary proton and an electron orbiting the proton at a distance of 5.3×10^{-11} m with a speed v.

a) Find the electric force (with direction) exerted by the proton on the electron. ($-8.2\text{x}10^{-8}$N)

b) Find the electric force (with direction) exerted by the electron on the proton. ($+8.2\text{x}10^{-8}$N)



9. Three charges are placed at three corners of a right triangle as shown in the diagram.
a) Find the net electric force (magnitude and direction) on charge q_3 due to the charges q_1 and q_2. (20.7 N @ 17° S of E)



PHYSICS 12

Concept Development

Electric Forces and Fields

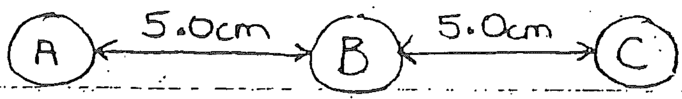
Directions - Extra Practice

Electric Forces

- For "like" charges F_e repels (pushes away) and for "unlike" charges F_e attracts (pulls towar

Find the net F_e and direction on B if:

1.



a) $A = +10\mu C$ $B = +10\mu C$ $C = +10\mu C$

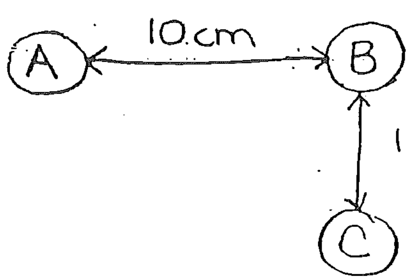
b) $A = +10\mu C$ $B = -10\mu C$ $C = +10\mu C$

c) $A = +10\mu C$ $B = -10\mu C$ $C = -10\mu C$

d) $A = +30\mu C$ $B = +10\mu C$ $C = +10\mu C$

e) $A = -10\mu C$ $B = +10\mu C$ $C = -20\mu C$

2.



a) $A = B = C = 4.0\mu C$

b) $A = B = 4.0\mu C$, $C = -4.0\mu C$

c) $A = -4.0\mu C$, $B = C = 4.0\mu C$

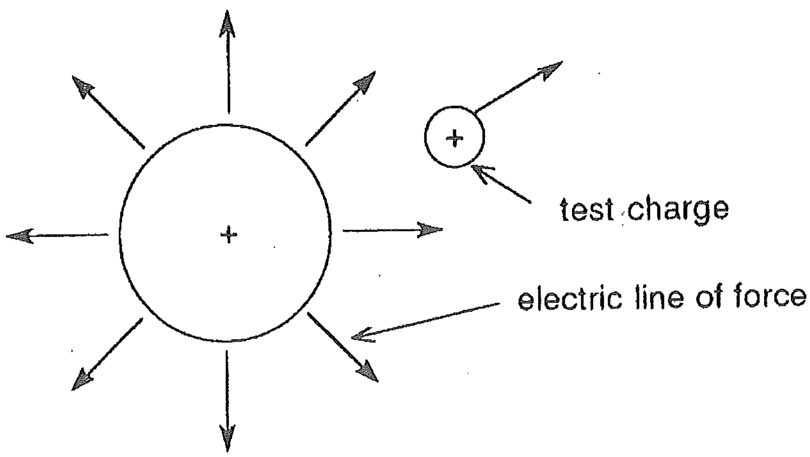
Lesson 2 (part 1)

Physics 12 – **Electric Fields**

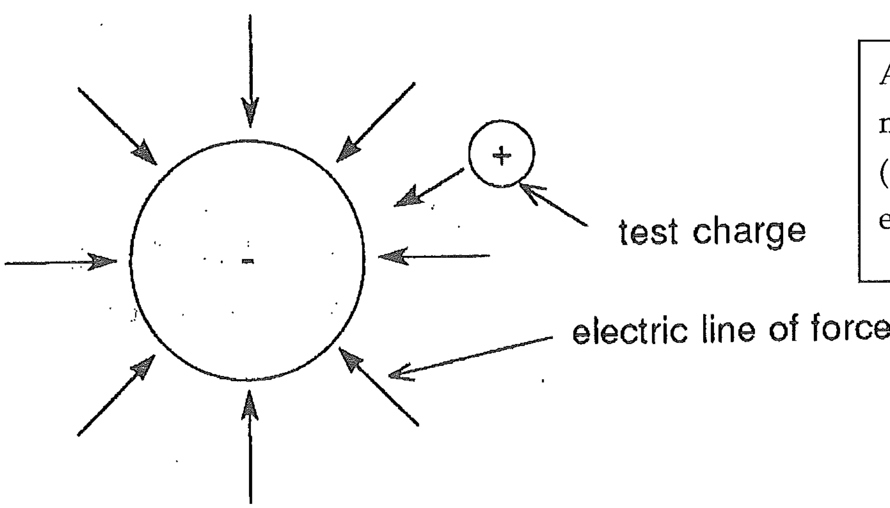
The concept of fields is used to explain how forces are exerted between objects that are not in contact with each other. Any mass, like Earth, is surrounded by a gravitational field. In the same way, an electrical charge is surrounded by an electric field.

Fields are defined as spheres of influence and can be classified as scalar and vector. **Electric fields** are **vector fields** and therefore have direction as well as magnitude.

The direction of an electric field is defined as the direction that a positive test charge will move when placed in the field.



A positive charge will always move away from a positive object ("like" charges repelling each other).



A positive charge will always move toward a negative object ("opposite" charges attracting each other).

There are two formulas to determine the size of an electric field:

$$\bar{E} = \frac{F_e}{q}$$

The field strength at any point around a charged object can be found by using a test charge and find the electric force acting on it. If we divide this by the charge on the test object, we have the electric field strength.

$$\bar{E} = \frac{kq}{r^2}$$

Some problems that we will be dealing with include alpha particles, protons and electrons. Therefore it is necessary to be familiar with the mass and charge of each particle.

	Mass	Charge
alpha particles	6.65×10^{-27} kg	3.20×10^{-19} C
electron	9.11×10^{-31} kg	-1.60×10^{-19} C
proton	1.67×10^{-27} kg	1.60×10^{-19} C

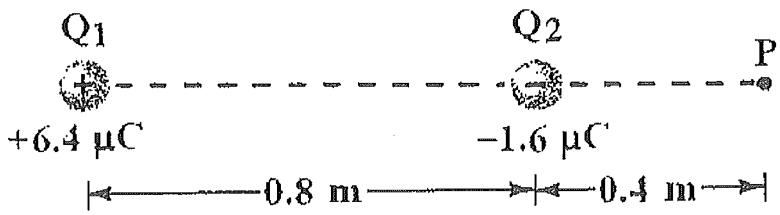
In solving electric field problems, we use absolute values and ignore the sign on the charge just like we did in problems involving electric force. **<u>This will give us the magnitude of the field strength.</u>** The **<u>sign on the charge is used to determine the direction of the field.</u>**

Example One: Find the electric field strength 4.50×10^{-1} m from a $5.00 \mu C$ charged object.

Example Two: What is the electric field strength at a point where a $-2.00\ \mu C$ test charge experiences an electric force of 5.30×10^{-2} N?

Example Three: What is the electric field strength midway between charged objects $-3.50\ \mu C$ and $3.00\ \mu C$ that are placed 4.40×10^{-1} m apart?

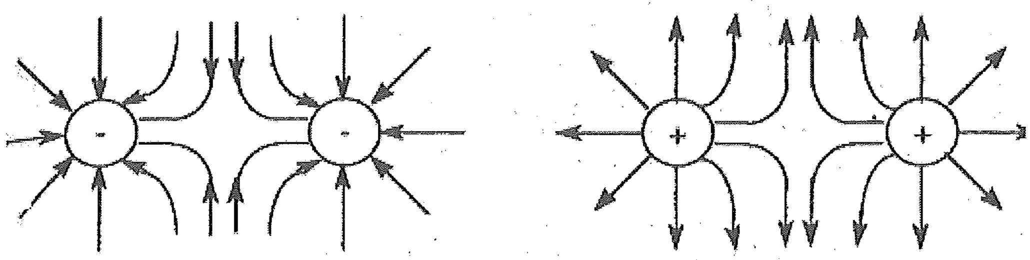
Example Four: Two charges are placed as shown in the diagram. A) Find the magnitude and direction of the electric field at point P. B) If a charge placed at point P experiences an electric force of 1.4 x 10^{-1} N toward the right, what are the magnitude and polarity of this charge?

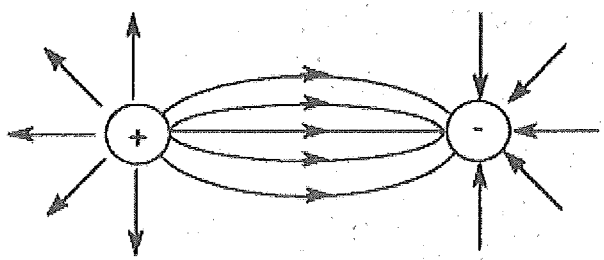


Physics 12 – **Electric Field Lines**

Electric field lines are lines that provide information about the direction and strength of the electric field.

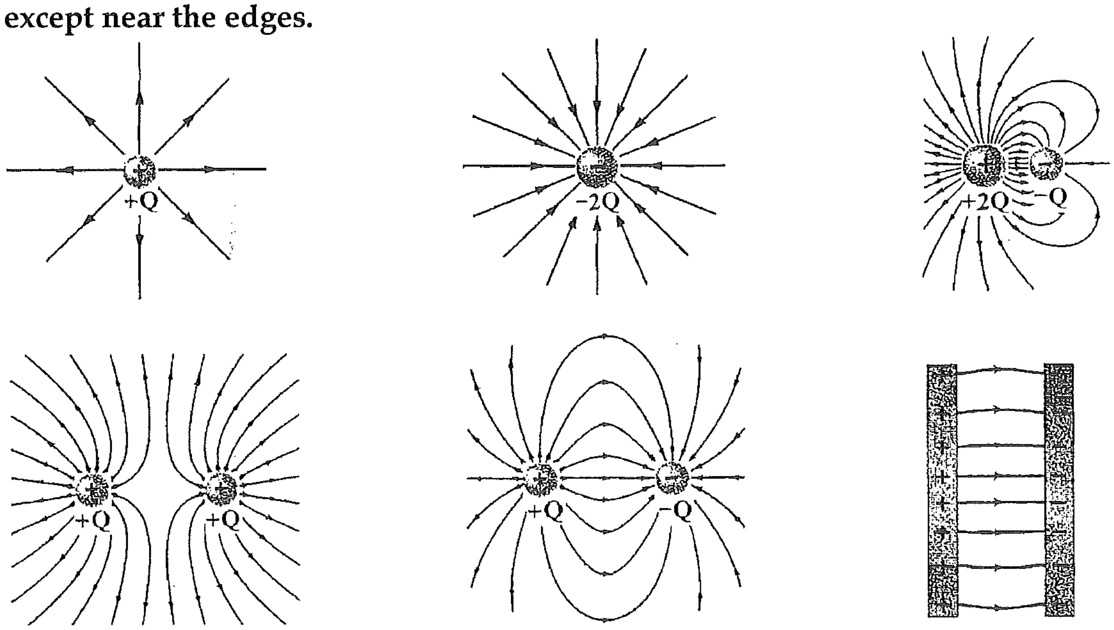
We describe electric fields in terms of field lines (or lines of force) –





Rules for Drawing:

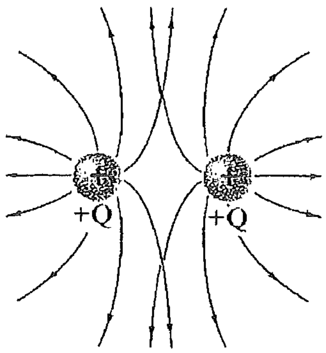
1. **Electric field lines start on positive charges and end on negative charges and the lines never cross.**
2. **The magnitude of the electric field is proportional to the number of lines crossing the unit area perpendicular to the lines.**
3. **The number of lines starting or ending is proportional to the magnitude of the charge.**
4. **The lines between two oppositely charged plates are parallel and equally spaced, except near the edges.**



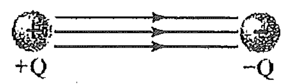
Electric Field Line Problems:

1. The diagrams show the electric field between two charges. There is a mistake in each drawing. Find the mistake and correct it. Explain your answer.

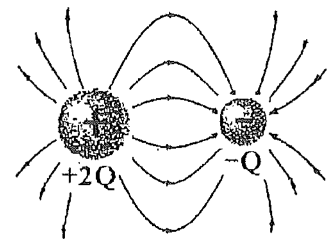
a)



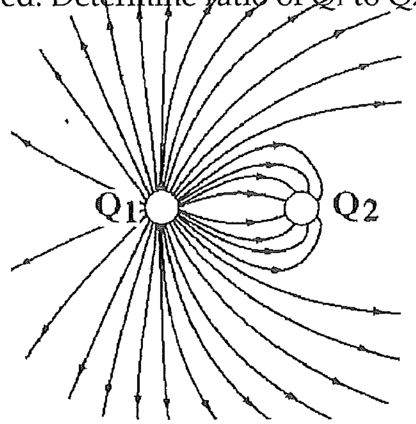
b)



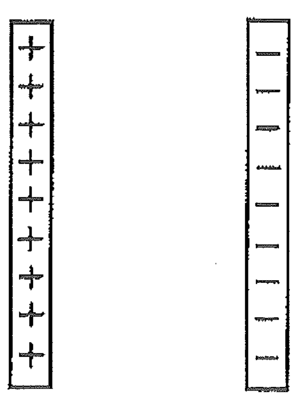
c)



2. The diagram shows electric field lines for two point charges separated by a small distance. Identify the polarity and relative strength of each charge and explain how you decided. Determine ratio of Q_1 to Q_2.



3. Sketch the electric field lines between oppositely charged parallel plates.



Lesson 2 homework

Electric Fields - Exercise 1.

- The direction of the electric field is simply the direction a POSITIVE test charge would travel in that field.

State the direction of the electric field in each of the following:

1. An e^- (in an electric field) experiences a force
   a) upward
   b) North
   c) West
2. An alpha particle experiences a force
   a) upward
   b) North
   c) West

3. Directly above a
   a) positive charge
   b) negative charge

4. Below a
   a) positive charge
   b) negative charge

Lesson 2 homework

Electric Field Problems:

1. What is the electric field strength 7.50×10^{-1} m from an 8.00μC charged object? (1.28×10^{5} N/C)

2. At a point a short distance from a 4.60 μC charged object there is an electric field strength of 2.75×10^{5} N/C. What is the distance to the charged object producing this field? (0.388 m)

3. If an alpha particle experiences an electric force of 0.250 N at a point in space, what electric force would a proton experience at the same point? (0.125 N)

4. What is the electric field strength at a point in space where a 5.20×10^{-6} C charged object experiences an electric force of 7.11×10^{-3} N? (1.37×10^{3} N/C)

5. What is the initial acceleration of an alpha particle when it is placed at a point in space where the electric field strength is 7.60×10^{4} N/C? (3.66×10^{12} m/s^2)

6. Calculate the electric field strength mid-way between a 4.50 μC charged object and a -4.50 μC charged object if the two charged objects are 5.00×10^{-1} m apart. (1.30×10^{6} N/C)

7. Calculate the electric field strength mid-way between a 3.0 μC charged object and a 6.0 μC charged object if the two charged objects are 0.80 m apart. (1.69×10^5 N/C towards 3.0 μC charge)

8. The electric field strength at a distance of 3.00×10^{-1} m from a charged object is 3.60×10^5 N/C. What is the electric field strength at a distance of 4.50×10^{-1} m from the same object? (1.60×10^5 N/C)

9. A lead nucleus has a charge of 82 protons within a sphere of radius of 6.3×10^{-15} m.

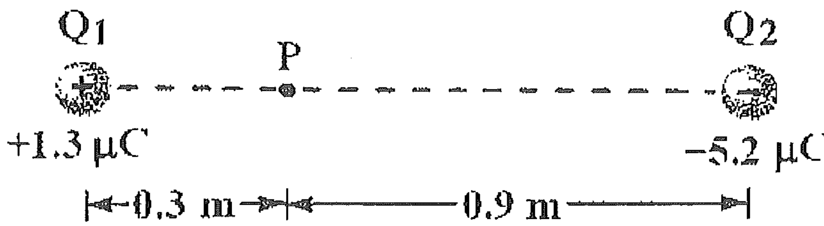
a) What are the magnitude and direction of the electric field at the surface of the nucleus? (2.97×10^{21} N/C outwards from the nucleus)

b) What are the magnitude and direction of the electric force on an electron located at the surface of the nucleus? (475 N towards center of nucleus)

10. Two point charges are separated by a distance of 1.2 m as shown in the diagram.

a) What are the magnitude and direction of the electric field at point P due to the two point charges? (1.88×10^5 N/C to the right)

b) If an electron is placed at rest at point P, what is its acceleration initially? (3.30×10^{16} m/s^2 to the left)



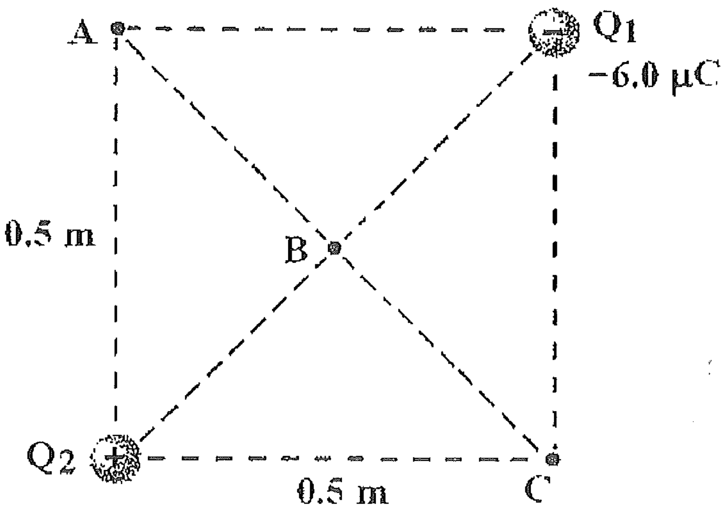
11. At a distance of 7.50×10^{-1} m from a small charged object, the electric field strength is 2.10×10^4 N/C. At what distance from this same object would the electric field strength be 4.20×10^4 N/C? (0.530 m)

12. Two point charges are placed at the two corners of a square as shown in the diagram.

a) If the magnitude of the net electric field at point A is 2.6×10^5 N/C, what is the magnitude of positive charge Q_2? (4.02×10^{-6} C)

b) What is the magnitude and direction of the net electric field at point B? (7.18×10^5 N/C towards Q_1)

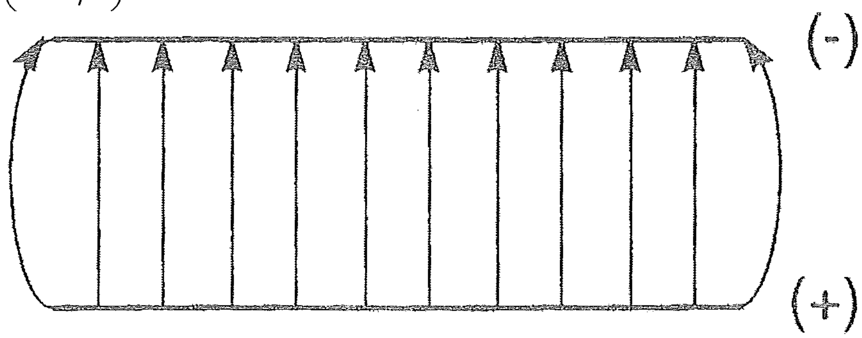
c) If a proton is placed at point C, what is the magnitude and direction of the electric force experienced by the proton? (4.16×10^{-14} N @ 56° N of E)



Lesson 3

Physics 12 – **Electric Potential in a Uniform Electric Field**

When we look at the electric field lines between parallel charged plates we can see that the density of the lines of force is **uniform**. If the field is uniform, the formula that we have been using $\left(\overline{E} = \frac{kq}{r^2}\right)$ **cannot be used to describe this field.**



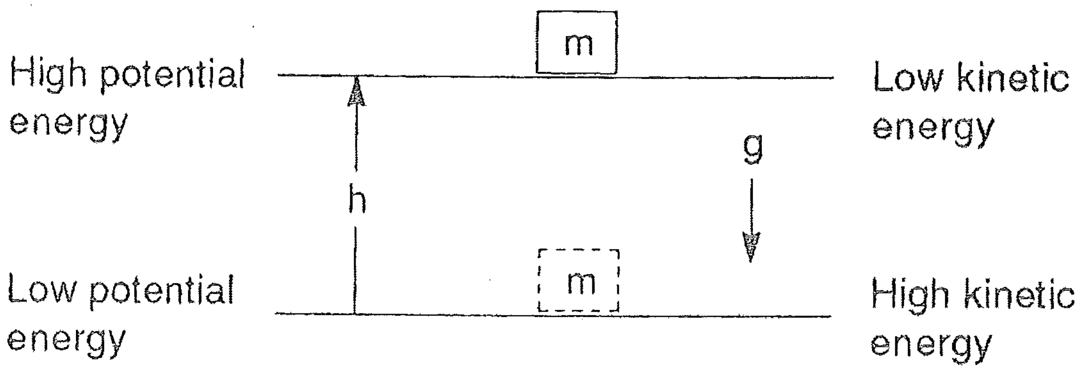
We need a new formula to describe a **uniform electric field**. In order to describe this field, it is important to look back at some of the concepts we have learned from our study of mechanics in Physics 11 and 12.

- An object will change its velocity when an unbalanced force acts on it (Newton's First Law of Motion).
- When a mass is allowed to fall in a gravitational field, the mass will accelerate from a position of high gravitational potential energy to a position of low gravitational potential energy due to the force of gravity acting on it (the unbalanced force).
- If we want to move a mass from a position of low gravitational potential energy to a position of higher gravitational potential energy, we do work on the mass against gravity.
    - **Work done against gravity** can be defined as:

- From this we see what the **gravitational potential of an object** depends on:

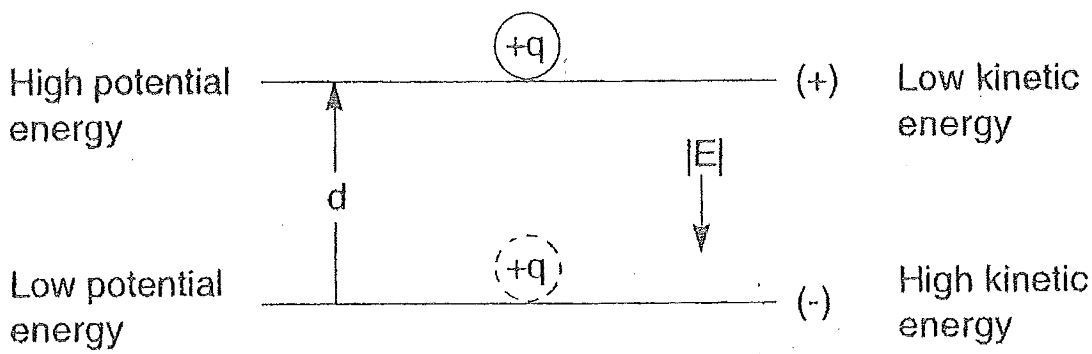
From the Law of Conservation of Energy, the loss in gravitational potential energy of an object becomes kinetic energy.

Diagram of change in gravitational potential and kinetic energy:



Now, we will look at how this applies to **electrical energy.**

When a charged object is allowed to move in a uniform electric field, the charge will accelerate from a position of high electric potential energy to a position of low electric potential energy because of the electric force acting on it.



If we want to move a charged object against the electric field, then we must do work on the object. This work is represented in terms of

From this, we can see that the electrical potential energy in a uniform field depends on:

When studying electricity, we are interested in the electric potential per unit charge.

Energy per unit charge is how electric potential is defined.

Potential Difference (Voltage) -

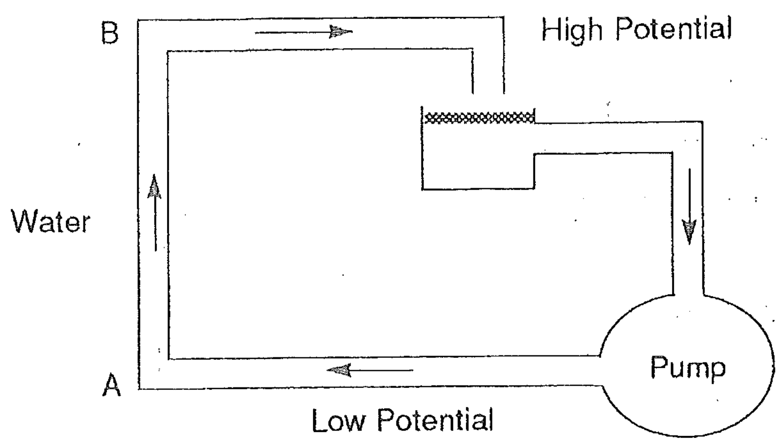
When an electric charge is moved in an electric field, the electric potential may change. This change is what we call the **potential difference = voltage.**

When we are dealing with a uniform electric field, voltage (V) is a useful quantity.

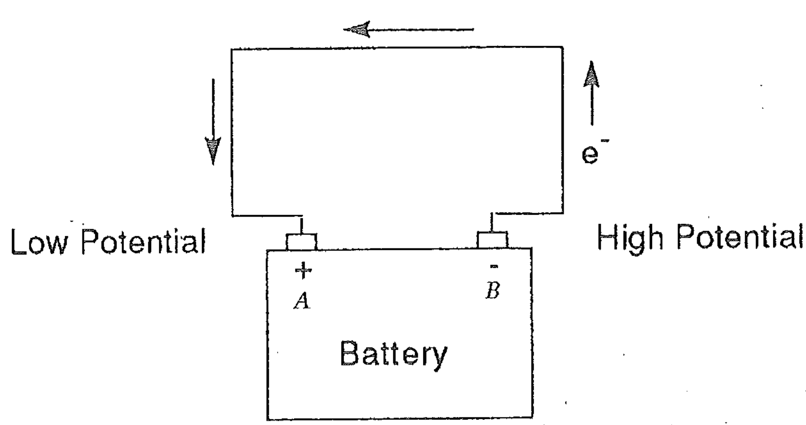
Voltage = the change in the electric potential, or the change in the electric potential energy per unit charge. *(Scalar Quantity)*

Analogy:

A water pump can increase the gravitational potential energy of water.



An increase in electric potential will take place within a battery.

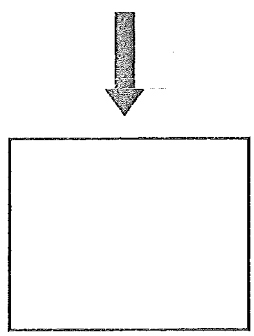


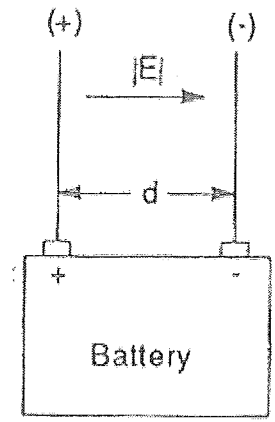
The Law of Conservation of Energy becomes:

A negative sign indicates that if kinetic energy is gained, electric potential energy is lost.

After all of this, we can now think of parallel charge plates (which produce a **uniform electric field)** as extensions of the terminals of a battery.

The electric field between the parallel plates can be determined in terms of the potential difference between the plates and the distance the plates are apart.





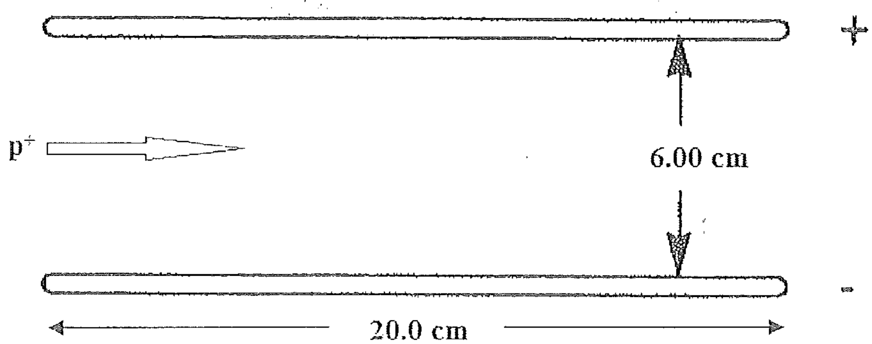
Example One: Calculate the electric field strength between two parallel plates that are 6.00 x 10^{-2} m apart. The potential difference between the plates is 12.0 V.

Example Two: An electron is accelerated from rest through the potential difference of 3.00×10^{4} V. What is the final speed of the electron?

Example Three: An electron is placed between two horizontal parallel charged plates that are 4.00 cm apart. The potential difference between the plates is 32.0 V.

What is the electric force acting on the electron?

Example Four: A proton travelling horizontally at a speed of 1.70×10^5 m/s enters an electric field of 2.40×10^2 N/C between two horizontal parallel plates as illustrated below. Calculate the vertical displacement of the electron as it travels between the plates.



Lesson 3 part I homework

Where will the Electric Field Strength be ZERO?

Relative to point P, state the direction of E and E_{net} in each case and indicate if E_{net} is zero. Use L for left and R for right.

Distance from X to:

P_1 = 0.25cm
P_2 = 0.50cm
P_3 = 0.75cm
P_4 = 1.25cm

a. X and Y are equal in magnitude and are both positive

	E_x	E_y	E_{net}
P_1			
P_2			
P_3			
P_4			

b. X and Y are equal in magnitude X is positive but Y is negative

	E_x	E_y	E_{net}
P_1			
P_2			
P_3			
P_4			

E_{net} = 0 between ____________

c. X and Y are positive and X is twice the magnitude of Y

	E_x	E_y	E_{net}
P_1			
P_2			
P_3			
P_4			

E_{net} = 0 between ____________

What would happen to the direction of E if the particles in "c" were both negative? Where would E_{net} = 0?

d. Y is negative, X is positive and twice the magnitude of Y

	E_x	E_y	E_{net}
P_1			
P_2			
P_3			
P_4			

E_{net} = 0 between ____________

Lesson 3 part 2 homework.

Electric Potential-Uniform Field Problems:

1. Two parallel plates are connected to a 12.0 V battery. If the plates are 9.00×10^{-2} m apart, what is the electric field strength between them? (133 V/m)

2. The electric field between two parallel plates is 5.0×10^{3} V/m. If the potential difference between the plates is 2.0×10^{2} V, how far apart are the plates? (0.040 m)

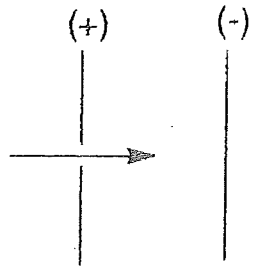
3. Two parallel plates are 7.3 cm apart. If the electric field strength between the plates is 2.0×10^{3} V/m, what is the potential difference between the plates? (146 V)

4. An alpha particle gains 1.50×10^{-15} J of kinetic energy. Through what potential difference was it accelerated? (4.69×10^{3} V)

5. What maximum speed will an alpha particle reach if it moves from rest through a potential difference of 7.50×10^{3} V? (8.48×10^{5} m/s)

6. A charged particle was accelerated from rest by a potential difference of 4.20×10^{2} V. If this particle increased its kinetic energy to 3.00×10^{-17} J, what potential difference would be needed to increase the kinetic energy of the same particle to 9.00×10^{-17} J? (1.26×10^{3} V)

7. An alpha particle with an initial speed of 7.15×10^4 m/s enters through a hole in the positive plate between two parallel plates that are 9.00×10^{-2} m apart. If the electric field between the plates is 1.70×10^2 V/m, what is the speed of the alpha particle when it reaches the negative plate? (8.12×10^4 m/s)

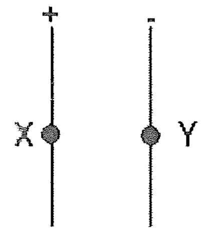


8. What is the electric field strength 1.00 cm from the positive charged plate if the parallel plates are 5.00 cm apart and the potential difference between the plates is 3.00×10^2 V? (6000 V/m)

9. A proton accelerates from rest from plate X to plate Y at the same time as an electron accelerates from rest from plate Y to plate X. If the potential difference between the two plates is 60.0 V,

a) What is the speed of the proton when it reaches plate Y? (1.07×10^5 m/s)

b) What is the speed of the electron when it reaches plate X? (4.59×10^6 m/s)

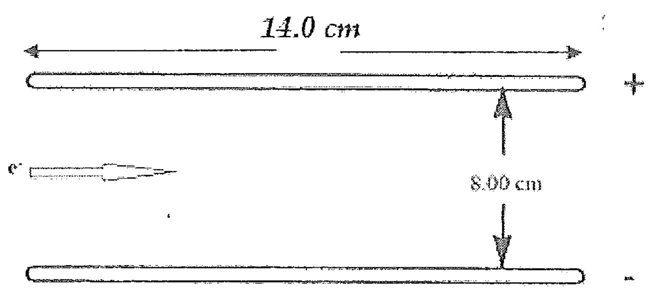


10. An alpha particle is placed between two horizontal parallel charged plates that are 2.00 cm apart. The potential difference between the plates is 12.0 V.

a) What is the electric force acting on the alpha particle? (1.92×10^{-16} N)

b) What is the gravitational force acting on the alpha particle (on the surface of the Earth)? (6.52×10^{-26} N)

11. An electron travelling horizontally at a speed of 8.70×10^{6} m/s enters an electric field of 1.32×10^{3} N/C between two horizontal parallel plates as illustrated below. Calculate the vertical displacement of the electron as it travels between the plates. (3.0 cm)

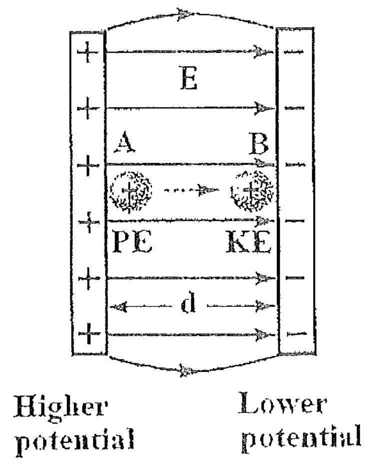


Lesson 4

Physics 12 – **Electric Potential Energy, Electric Potential and Work**

A positive charge accelerates from a region of higher potential to a region of lower potential.

A negative charge accelerates from a region of lower potential to a region of higher potential.

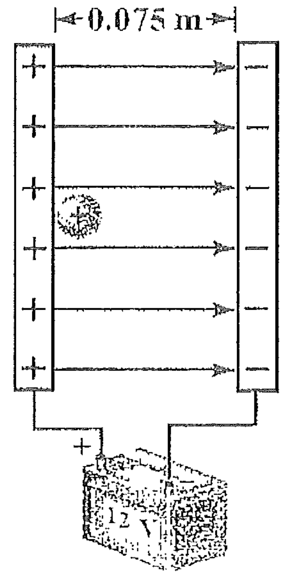


In terms of energy, when a charge moves, electric potential energy is transformed into kinetic energy, and the total energy is conserved.

When a positive test charge moves from point A to point B in an electric field, work is done by the electric force. The work equals the difference of the electric potential energy between two points.

The electric potential V at a given point is the electric potential energy per unit charge.

Today, we are going to work through more problems dealing with a uniform electric field while including the concept of work.



Example One: A uniform electric field is established by connecting the parallel plates separated by 0.075 m to a 12 V battery as shown in the diagram. A proton is released from rest in the electric field and moves from the positive plate to the negative plate.

a) Find the magnitude of the electric field.

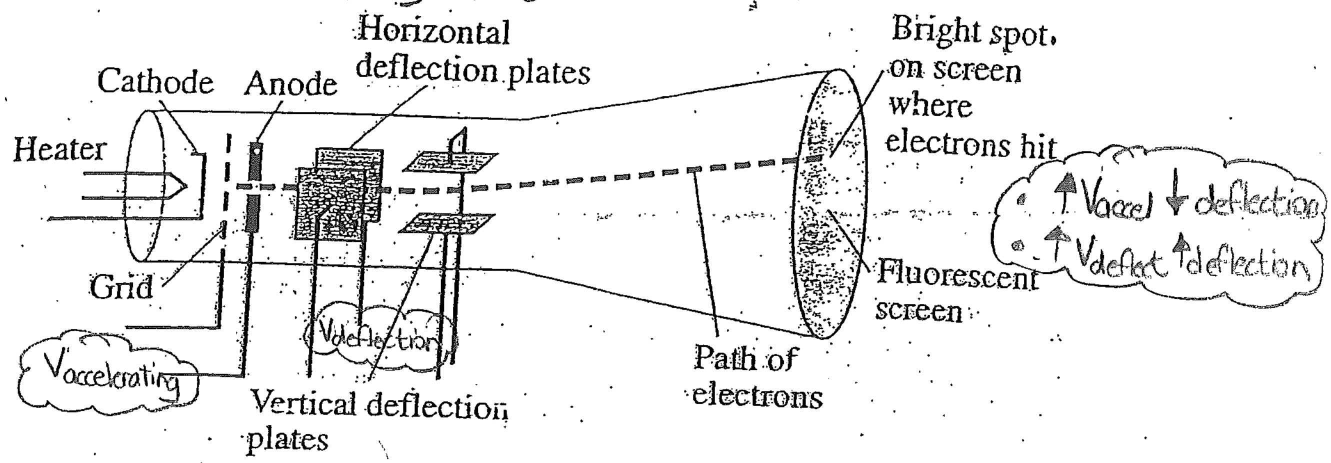
b) Find the change in electric potential energy of the proton. Does the potential energy of the proton increase or decrease?

c) Find the speed of the proton after it has moved 0.075 m.

Example Two: Through what potential difference must an electron be accelerated from rest to give it a speed of 6.00×10^{6} m/s?

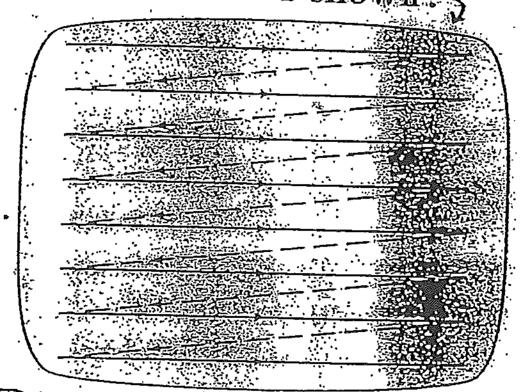
Lesson 4 part 2

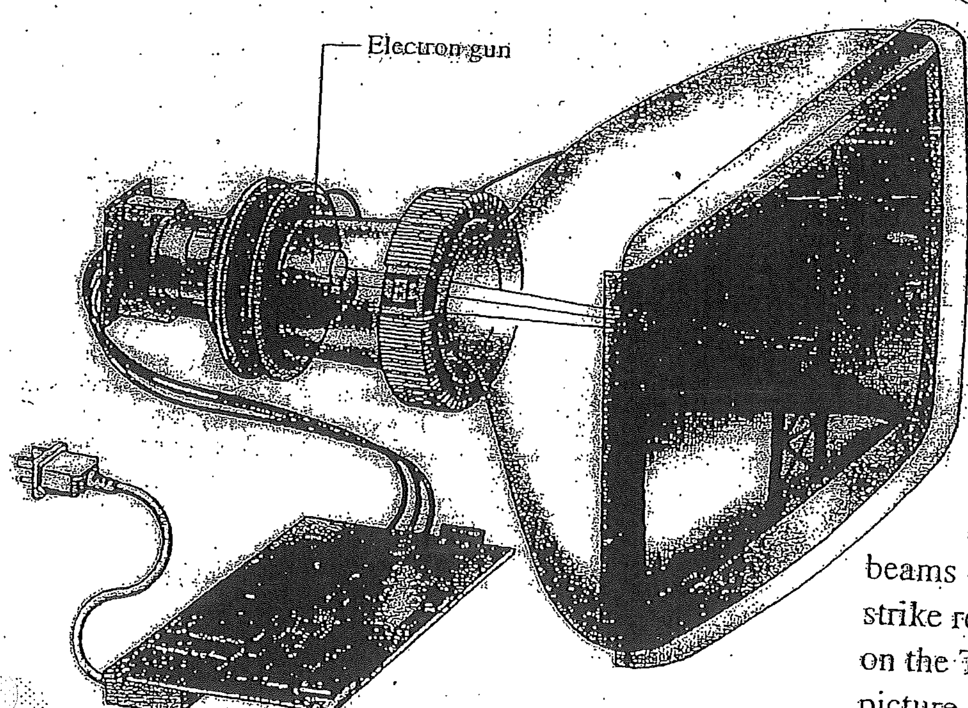
Cathode Ray Tube (Electron Gun) and Television - A Practical Application of Physics (includes Millikan's)



In the picture tube or monitor for a computer or television set, the electron beam is made to sweep over the screen in the manner shown:

The beam is swept horizontally by the horizontal deflection plates or coils. 525 lines constitutes a complete sweep over the entire screen and is swept out in $\frac{1}{30}$ s. (High-definition TV will provide more than double this number).





Calculate the new deflection if:
2.4 cm deflection from
Vdeflect = 36V, Vaccel = 480V
is changed to
Vdeflect = 18V, Vaccel = 960V

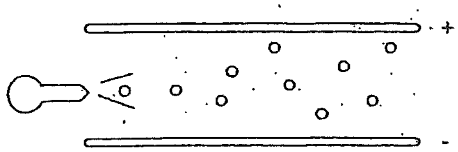
Electron guns produce three beams of high speed electrons that strike red, green, and blue phosphors on the TV screen to produce the color picture. As each electron is accelerated from rest within an electron gun, electrical potential energy is converted into kinetic energy; the total energy is conserved during the process.

MILLIKAN'S OIL DROP EXPERIMENT

After Thomson discovered the electron, Millikan performed an experiment from which he determined the elementary charge. (The elementary charge is the charge on an electron and a proton.)

Millikan determined the elementary charge to be 1.60×10^{-19} C.

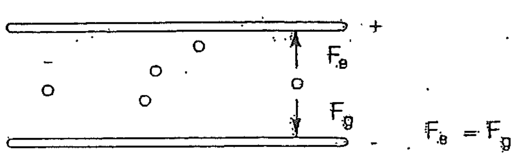
In this experiment he blew oil droplets between horizontal parallel plates. These plates were connected to a variable voltage source so that one could become positive and the other negative. With no charge on the plates, the oil droplets would fall to the lower plate because of the gravitational force. However, when the plates were charged, some of the oil droplets would rise



to the top plate. What force would cause them to rise? This force was found to be an electric force. In order for there to be an electric force, the oil droplets must have a charge. Where would this charge on the oil droplets come from? The charge was created by friction when the oil droplets formed. As the droplets slid over one another, some droplets became positive while others became negative. The negative droplets would be attracted to the positive plate. There is an electric force.

Millikan was able to adjust the voltage so that some oil droplets became suspended. When this happened, he reasoned that the electric force acting on the oil droplet and the gravitational force are equal.

When the oil drop is suspended, the gravitational force and the electric force on the drop are equal.



The electric force is given by the equation $F_e = q|E|$ and the gravitational force is given by the equation $F_g = mg$. If $F_e = F_g$, then $q|E| = mg$ and q can be calculated using $q = \frac{mg}{|E|}$.

Millikan was able to calculate the mass of the oil droplet using its density $d = \frac{m}{v}$. Density is equal to mass divided by volume. Therefore, $m = dv$. The volume is obtained by measuring the diameter of the oil droplet and using the formula for the volume of a sphere to find its mass. g is a constant and $|E|$ can be found by knowing the voltage between the plates.

$$|E| = \frac{V}{d}$$

Millikan repeated this experiment a number of times and he found that the charge on the oil droplet was a multiple of 1.60×10^{-19} C. He concluded the charge on an elementary particle is 1.60×10^{-19} C.

* * * * * * * * * *

Problems: Millikan's Oil Drop Experiment

Formula: Using the following equations, derive the relationship to determine the charge on the electron

$$F = ma \qquad F_g = mg \qquad F_e = q|E|$$

Example Problems:

1. An oil drop with a mass of 9.80×10^{-16} kg is suspended between two horizontal parallel charged plates. If the electric field strength between the plates is 2.0×10^4 V/m, what is the magnitude of the charge on the oil drop?

$$F_e = F_g$$

$$q|E| = mg$$

$$q = \frac{mg}{|E|} = \frac{(9.80 \times 10^{-16}\ \text{kg})(9.81\ \text{N/kg})}{2.0 \times 10^4\ \text{V/m}} = 4.8 \times 10^{-19}\ \text{C}$$

2. An oil drop with a weight of 4.80×10^{-14} N is suspended between two horizontal parallel charged plates that are placed 5.00 cm apart. If the potential difference between these plates is 3.00×10^3 V, how many excess electrons does the oil drop carry?

$$|E| = \frac{V}{d} = \frac{3.00 \times 10^3\ \text{V}}{5.00 \times 10^{-2}\ \text{m}} = 6.00 \times 10^4\ \text{V/m}$$

$$F_e = F_g$$

$$q|E| = mg$$

$$q = \frac{mg}{|E|} = \frac{4.80 \times 10^{-14}\ \text{N}}{6.00 \times 10^4\ \text{V/m}} = 8.00 \times 10^{-19}\ \text{C}$$

$$\#e = \frac{8.00 \times 10^{-19}\ \text{C}}{1.60 \times 10^{-19}\ \text{C}} = 5$$

Lesson 4 part 2 homework

Practice Problems:

1. An oil drop weighs 3.84×10^{-15} N. If it is suspended between two horizontal parallel plates where the electric field strength is 1.20×10^{4} N/C, what is the magnitude of the charge on the oil drop?

(3.20×10^{-19} C)

2. An oil drop with a mass of 4.80×10^{-16} kg is suspended between two horizontal parallel plates that are 6.00 cm apart. If the potential difference between the plates is 5.90×10^{2} V, how many excess electrons does the oil drop carry?

(3)

3. An oil drop with a mass of 7.20×10^{-16} kg is moving up at a constant speed of 2.50 m/s between two horizontal parallel plates. If the electric field strength between these plates is 2.20×10^{4} V/m, what is the magnitude of the charge on the oil drop?

(3.21×10^{-19} C)

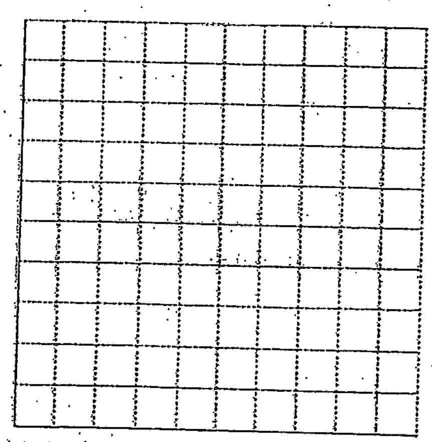
4. An oil drop whose mass is 3.50×10^{-15} kg accelerates downward at a rate of 2.50 m/s^2 when placed between two horizontal parallel plates that are 1.00 cm apart. Assuming the oil drop is negative and the top plate positive, how many excess electrons does the oil drop carry if the potential difference between the plates is 5.38×10^{2} V?

(3)

5. During a Millikan oil drop experiment, a student records the weight of five different oil drops. A record is also made of the electric field intensity necessary to hold each drop stationary between the two horizontal parallel plates.

Weight ($\times 10^{-14}$ N)	$\lvert E \rvert$ ($\times 10^{5}$ N/C)
1.7	1.1
5.6	3.5
6.1	3.8
2.9	1.8
4.0	2.5

a) Using $\lvert E \rvert$ as the manipulated variable, draw a graph showing the relationship between the weight and the electric field.



b) Determine the elementary charge. (hint: what does the slope represent?)

Lesson 4 part 1 homework

Electric Potential Energy and Electric Potential Assignment

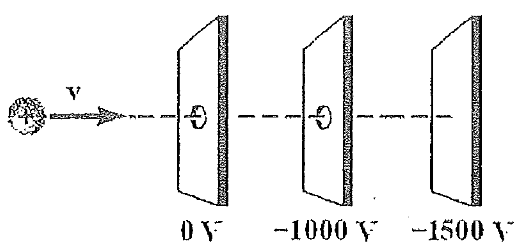
1. A proton is held between two charged parallel plates.

   a) If a proton moves in the direction of the electric field, what happens to the electric potential? (decreases)

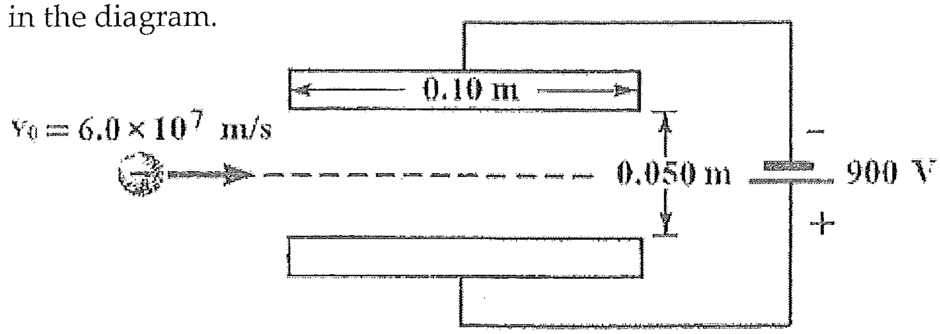
   b) If the proton moves in the electric field from point A with a potential 50 V to point B with a potential of 200 V, how much work is done? (2.4×10^{-17} J)

   c) If the electric potential is constant between two plates, what happens to the electric field? (0)

2. A proton with kinetic energy of 1.2×10^{-16} J moves into a series of charged parallel plates as shown. What is the impact speed on the third plate? (6.57×10^{5} m/s)



3. An electron is projected into the electric field with an initial speed of 6.0×10^7 m/s as shown in the diagram.



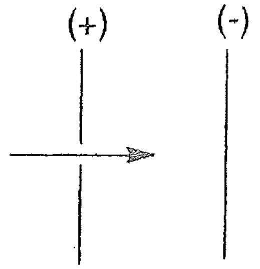
a) Find the magnitude and direction of the electric field between the plates. (18000 V/m [up]

b) Find the magnitude and direction of the electric force on the electron while it is between the plates. (2.88×10^{-15} N [down]

c) Find the acceleration of the electron while it is between the plates. (3.16×10^{15} m/s^2 [down]

4. A proton is accelerated by a potential difference of 7.20×10^2 V. What is the change in kinetic energy of the proton? (1.15×10^{-16} J)

5. An electron with a speed of 5.0×10^5 m/s enters through a hole in the positive plate and collides with the negative plate at a speed of 1.0×10^5 m/s. What is the potential difference between the plates? (0.681 V)



6. If an alpha particle is accelerated from rest through a distance of 4.00 cm by a uniform electric field in 2.50×10^{-5} s, what is the electric field strength? (2.66 N/C)

7. An electric field of 2.40×10^2 N/C is produced by two horizontal parallel plates set 4.00cm apart. If a charged particle of 2.00 μC is moved 3.00 cm **perpendicular** to the electric field, what is the work done against the electric field? (0 J)

8. A charged particle (2.0×10^{-17} kg) accelerated from rest by a potential difference of 2.50×10^5 V. If the particle reached a maximum speed of 2.90×10^4 m/s, what potential difference would be required to accelerate this particle from rest to a velocity of 7.25×10^4 m/s? (1.6×10^6 V)

9. An alpha particle is placed between two horizontal parallel charged plates that are 2.00 cm apart. The potential difference between the plates is 12.0 V.

a) What is the electric force acting on the alpha particle? (1.92×10^{-16} N)

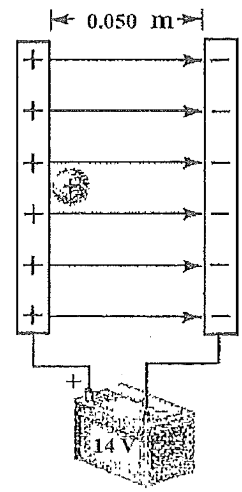
b) What is the gravitational force acting on the alpha particle? (6.52×10^{-26} N)

c) If it assumed that the electric force and the gravitational force are acting in opposite directions, what is the net force acting on the alpha particle? (1.92×10^{-16} N)

d) What is the acceleration of the alpha particle? (2.89×10^{10} m/s^2)

e) What potential difference would be required between the plates so that the alpha particle becomes suspended? (4.0×10^{-9} V)

10. A uniform electric field is established by connecting the parallel plates separated by 0.050 m to a 14 V battery as shown. An alpha particle is released from rest in the electric field and moves from the positive plate to the negative plate.



a) Find the magnitude of the electric field. (280 V/m)

b) Find the change in electric potential energy of the alpha particle. ($4.48 x 10^{-18}$J)

c) Find the speed of the proton after it has moved 0.050 m. (3.67×10^{4} m/s)

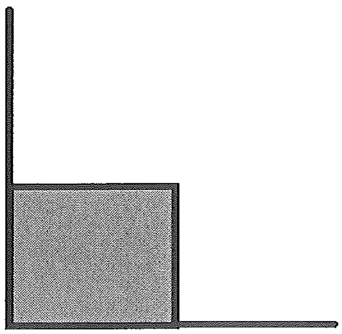
Lesson 5

Physics 12 – <u>**Electric Potential and Potential Energy of Point Charges**</u>

If a charged object is in an electric field, it has electric potential energy (E_P). Just as any other type of potential energy, this means that work was done on the charged object to move it into its current position. It now has the potential to move in the field when it is "let go".

In a **uniform electric field** (such as one that exists between two charged parallel plates), **work done is equal to the electric potential energy** gained by the charged object.

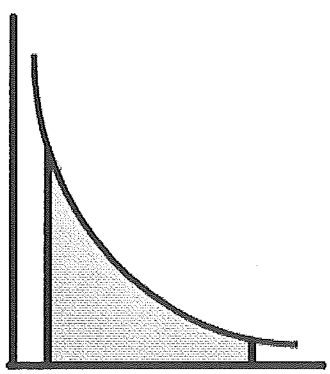
F_e (qE)



d

In the **non-uniform electric field** caused by a point charge, the electric potential energy cannot be found as easily, but the reasoning is the same.

F_e $\left(\frac{kq_1q_2}{r^2}\right)$



d

This area (the electric potential energy) can be determined to be:

Electric potential (V) is defined as the electric potential energy per unit charge.

From this definition, we can derive the equation:

Derivation:

$$V = \frac{E_p}{q_2} \rightarrow V = \frac{\frac{kq_1 \cancel{q_2}}{r}}{\cancel{q_2}} \quad \textbf{OR} \quad V = \frac{kq_1}{r}$$

Important Note: The <u>electric potential at a point is defined in terms of the moving of a positive charge</u>. Therefore, *V* can be positive or negative.

<u>Finding the Electric Potential Between Two Points = Potential Difference</u>

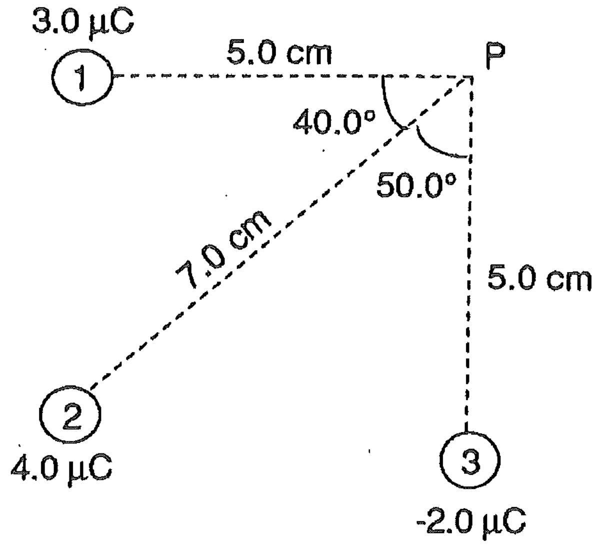
Given two points, A and B, the potential difference between A and B is:

$$V_{AB} = V_B - V_A$$

When we are dealing with the potential at a point, we are actually talking about the potential difference between that point and infinity. The potential at infinity is assigned a value of zero.

Example One:

Calculate the potential at point P.



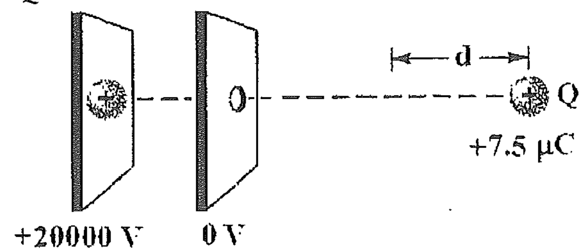
Example Two:

How much work is done against an electric field produced by a 2.5 μC charged object when an 0.025 μC charge is moved from r = 3.0 cm to r = 1.0 cm?

Example Three – A proton is accelerated from rest through a potential difference of 20000V and moves toward a fixed +7.5 μC charge Q.

a) Find the speed of the proton when it leaves the parallel plates.

b) Find the distance (d) from the fixed charge Q when the proton stops.



Lesson 5 homework

Potential Energy at a Point Problems

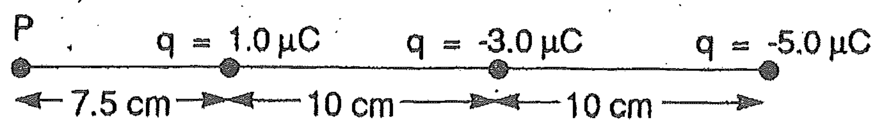
1. What is the potential at a distance of 6.0 cm from a 2.5 μC charge? (3.75×10^5 V)

2. What is the potential at a distance of 25 cm from a -2.5 μC charge? (-9.00×10^4 V)

3. How much work is done against the electric field produced by a 5.0 μC charged object when a 0.030 μC charge is moved from r = 45 cm to r = 15 cm? (6.0×10^{-3} J)

4. A proton released 2.0×10^{-11} m from the center of a 6.4×10^{-18} C charged sphere. What is the speed of this proton when it is 0.50 m from this center?

5. Three charges are located on a line as shown below. Find the potential at point P. (-1.98×10^5 V)



6. The centers of two alpha particles are held 2.5×10^{-12} m apart and then released. Calculate the speed of each alpha particle when they are 0.75 m apart. (2.4×10^5 m/s)

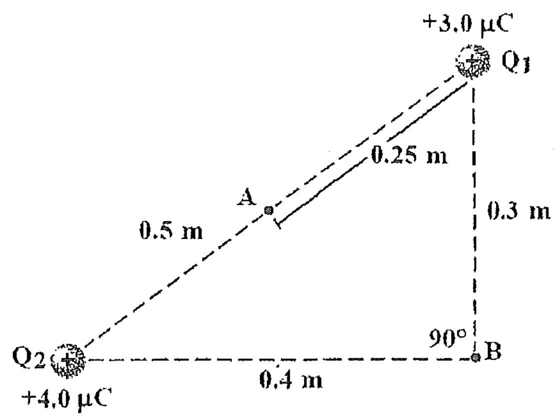
7. In moving a 3.00 μC charge at a constant speed from point A to point B, 4.40×10^{-5} J of work is done. If A and B are 2.4 cm apart, what is the potential difference between A and B? (14.7 V)

8. In a hydrogen atom, an electron is separated from a proton by a distance of 5.3×10^{-11} m.

a) What is the electric potential at a distance of 5.3×10^{-11} m from the proton? (27.2 V)

b) What is the potential energy of the electron and proton at this distance? (-4.3×10^{-18} J)

9. Two point charges are placed as shown in the diagram.

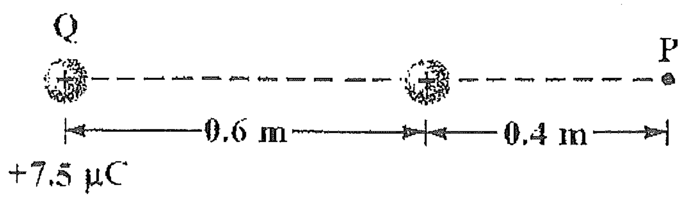


a) What are the electric potentials at point A and at point B due to two point charges? (A: 2.52×10^5 V, B: 1.80×10^5 V)

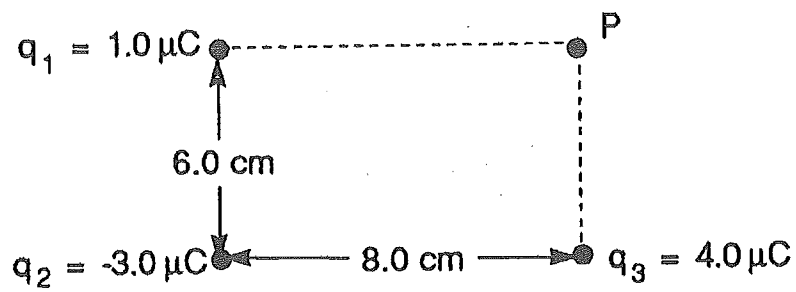
b) What is the electric potential difference between points A and B? (7.2×10^4 V)

c) How much work must be done to move the charge Q_1 to point B? (5.4×10^{-2} J)

10. A proton is separated initially at rest from a fixed point charge Q by a distance of 0.60m. If the proton is released, what is the speed of the proton at point P? (2.94×10^6 m/s)



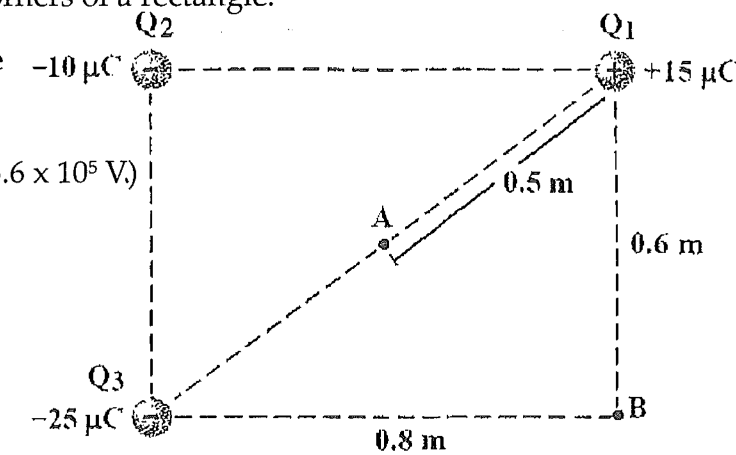
11. Three charges are located at the corners of a rectangle as shown. Find the potential at point P. (4.43×10^5 V)



12. The diagram shows three charges at the corners of a rectangle.

a) How much work must be done to move the charge Q_2 to point B? (1.5 J)

b) What is the electric potential at point A? (-3.6×10^5 V.)



Electrostatics Review

Forces: a) $F_e = \frac{kQ_1Q_2}{R^2}$ b) $F_g = \frac{Gm_1m_2}{R^2}$

used to show the direction of the F_e (push or pull)

Field Strength: a) $E = \frac{F}{Q} = \frac{V}{d}$ use only for parallel plates   b) $g = a_g = \frac{F}{m} = \frac{Gm}{R^2}$

$E = \frac{kQ}{R^2}$ } from $E = \frac{\frac{kQ_1Q_2}{R^2}}{Q}$

* direction of E is direction of +ve (positive) test charge

Work: a) $E_p = \frac{kQ_1Q_2}{R}$ b) $E_p = -\frac{Gm_1m_2}{R}$

$V = \frac{\Delta E_p}{Q}$

$V = \frac{kQ}{R}$ to find voltage of a single point relative to a charge.

* voltage is not a vector! (see handout)

Potential at a Point

- "V" is not a vector so the values just add regardless of their position (see eg. 1)
- example 2 can be solved either from:

$E_{p_1} = V_1 d$, $E_{p_2} = V_2 d$ and $\Delta E_p = E_{p_2} - E_{p_1}$

$\hookrightarrow V = \frac{E_p}{d}$

OR

$E_{p_1} = \frac{kQ_1Q_2}{r}$, $E_{p_2} = \frac{KQ_1Q_2}{R}$ and $\Delta E_p = E_{p_2} - E_{p_1}$

Lesson 6

Physics 12

ADDITIONAL PROBLEMS – ELECTROSTATICS

1. If the electric field strength at a point 1.50 m from a charged point source is 2.70×10^4 N/C, what is the electric field strength at a point 7.50×10^{-1} m from the same source?

   (1.08×10^5 N/C)

2. Calculate the electric force between two point charges of 2.00 μC and 2.70 μC that are 1.00×10^{-1} m apart.

   (4.86 N)

3. Calculate the electric field strength mid-way between two point charges of 3.00 μC and 4.20 μC that are 4.60×10^{-1} m apart.

   (2.04×10^5 N/C)

4. The potential difference between two parallel plates which are 3.00 cm apart is 7.10×10^3 V. If an object with a charge of 4.80×10^{-15} C is placed between these plates, what is the electric force acting on the object?

   (1.14×10^{-9} N)

5. What is the potential difference between two parallel plates 5.00 cm apart that produces an electric force of 3.50×10^{-13} N on an object containing a charge of 2.00×10^{-16} C when it is placed between the plates?

(8.75×10^{1} V)

6. Calculate the work done against an electric field on a charged object of 5.50 μC if the object is moved 3.00 cm perpendicular to the electric field of 2.10×10^{3} N/C produced by two parallel plates 5.00 cm apart.

(0 J)

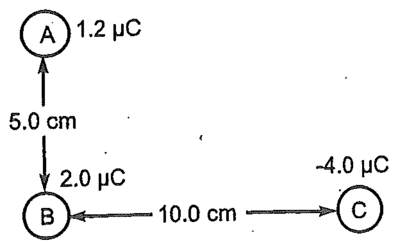
7. If a lithium nucleus (Li^{3+}) experiences an electric force of 2.44×10^{-14} N at a point in space, what is the electric field intensity at this point?

(5.08×10^{4} N/C)

8. What is the electric field strength between two parallel charged plates that causes a proton to accelerate at a rate of 2.0×10^{10} m/s^2?

(2.1×10^{2} N/C)

9. Three point charged objects are at the corners of a triangle as shown in the diagram.



What is the magnitude of the electric force acting on charge B due to the other two charges?

(1.1×10^{1} N)

10. Two small charged objects of the same mass and volume are brought into brief contact with each other. If the initial charges on the two objects are $-3.00\ \mu C$ and $-1.50\ \mu C$, what is the electric force between the objects when they are separated to a distance of 5.00×10^{-1} m after contact?

(1.82×10^{-1} N)

11. Two disk like objects of equal mass of 7.30×10^{-6} kg and equal charge of 4.90×10^{-6} C are placed on a smooth horizontal surface. When the two objects are placed on this surface, they repel each other to a separation of 5.50×10^{-1} m. What is the force of friction on each object due to the surface?

(7.14×10^{-1} N)

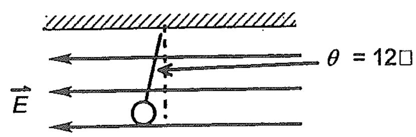
12. What is the electric potential at a distance of 5.0 cm from a $-3.0\ \mu C$ charge?

(-5.4×10^{5} V)

13. What is the electric potential energy of a proton located 2.00×10^{-9} m from another proton?

(1.15×10^{-19} J)

14. A 0.30 kg ball is suspended in a uniform electric field as shown in the diagram.



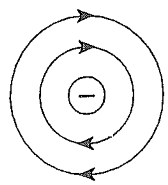
If the charge on the ball is 5.0×10^{-4} C, what is the electric field strength?

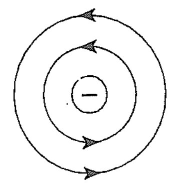
(1.2×10^{3} N/C)

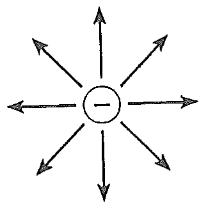
* * * * * * * * * *

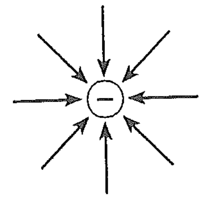
Electrostatics Provincial Exam Questions Lesson 7

1. Which diagram shows the electric field near a negative point charge?

A.


B.


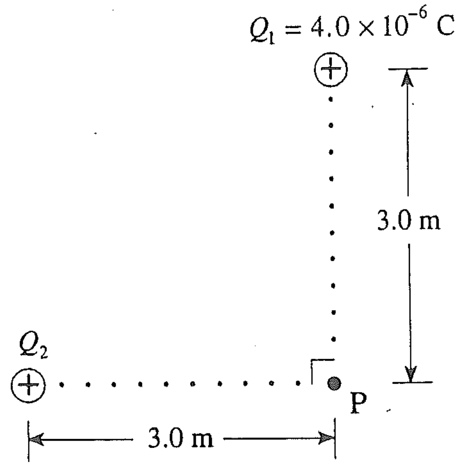
C.


D.


2. Which pair of values will cause the greatest deflection of an electron beam in a cathode ray tube?

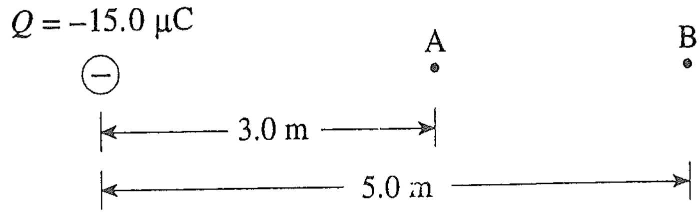
	ACCELERATING VOLTAGE	DEFLECTION (PLATE) VOLTAGE
A.	400 V	20 V
B.	400 V	40 V
C.	800 V	20 V
D.	800 V	40 V

3. The magnitude of the net electric field at P in the diagram below is 5.0×10^{3} N/C.



Find the magnitude of charge Q_2.

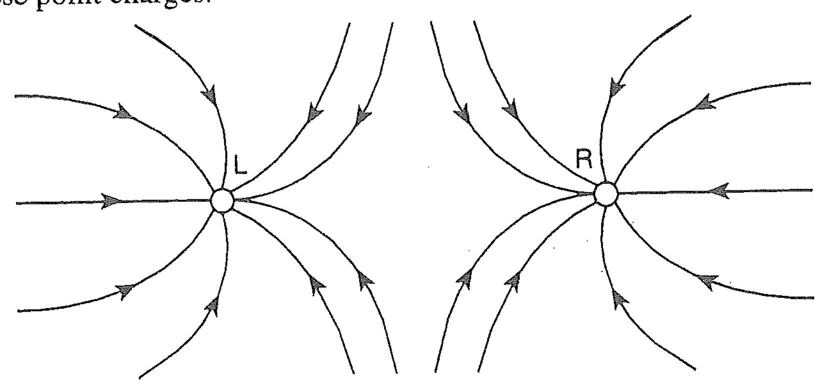
4. a) Find the electric potential at point A and at point B. (Note: $1.0\ \mu C$ is 1.0×10^{-6} C) **(3 marks)**



b) What is the potential difference between A and B? **(1 mark)**

c) 0.036 J of work must be done to move a charge q from A to B. Find the magnitude and polarity of this charge. **(3 marks)**

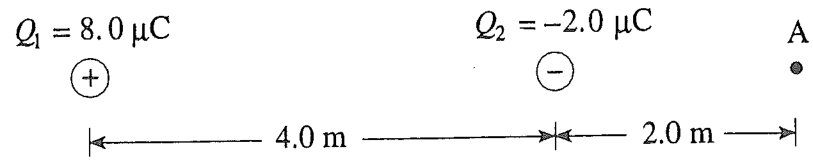
5. The diagram shows the electric field lines near two point charges, L and R. Identify the polarity of these point charges.



	POLARITY OF L	POLARITY OF R
A.	Negative	Negative
B.	Negative	Positive
C.	Positive	Negative
D.	Positive	Positive

6. An electron orbits a nucleus which carries a charge of $+9.6 \times 10^{-19}$ C. If the electron's or radius is 2.0×10^{-10} m, what is its electric potential energy?

7. Two charges are positioned as shown in the diagram below.



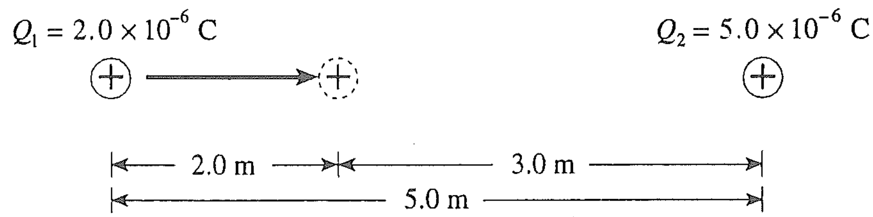
a) Find the magnitude and direction of the electric field at A. (Note: $1.0\ \mu C = 1.0 \times 10^{-6}\ C$) **(4 marks)**

b) A charge placed at A experiences a force of 4.0×10^{-3} N towards the right. What are the magnitude and polarity of this charge? **(3 marks)**

8. In a cathode ray tube,

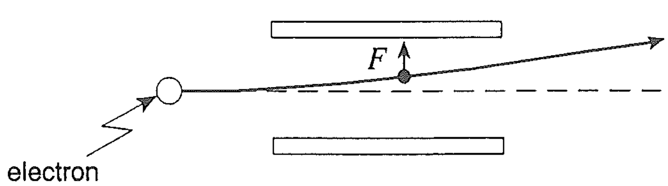
A. protons are accelerated from anode (positive) to cathode (negative).
B. protons are accelerated from cathode (negative) to anode (positive).
C. electrons are accelerated from anode (positive) to cathode (negative).
D. electrons are accelerated from cathode (negative) to anode (positive).

9. Charge Q_1 is located 5.0 m from charge Q_2 as shown.



How much work must be done to move charge Q_1 2.0 m closer to charge Q_2?

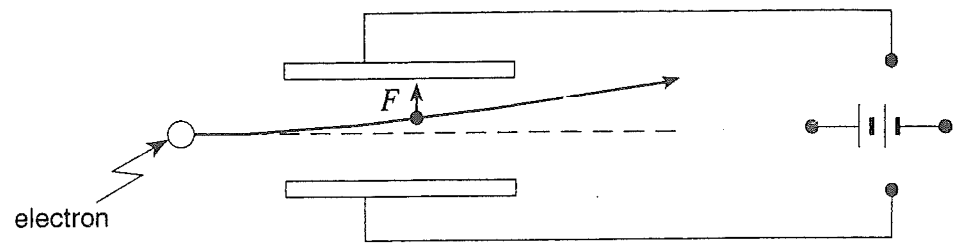
10 An electron passing between parallel plates 0.025 m apart experiences an upward electrostatic force of 5.1×10^{-16} N.



a) What is the magnitude of the electric field between the plates? **(3 marks)**

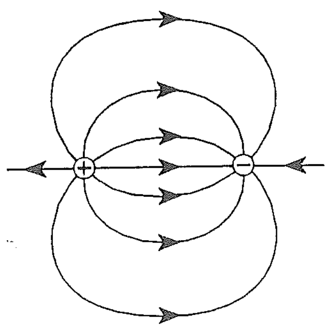
b) What is the potential difference between the plates? **(2 marks)**

c) On the diagram below draw in the connections to the power supply necessary for the electron to experience this upward force. **(2 marks)**

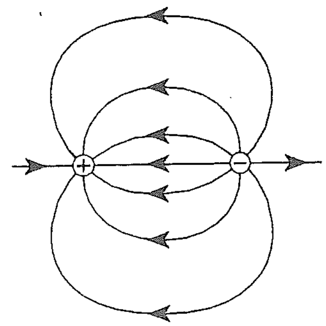


11. Which of the following diagrams shows the electric field between two equal but opposite charges?

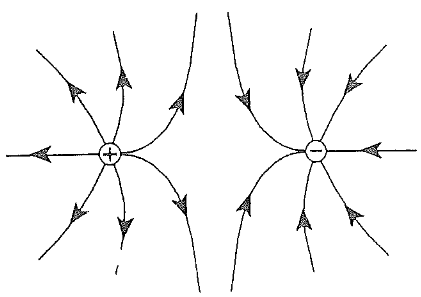
A.



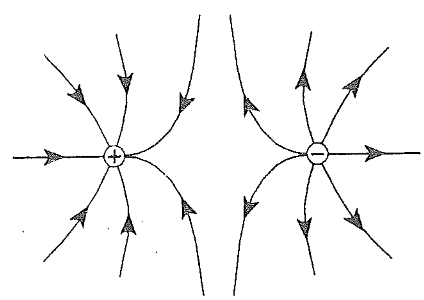
B.



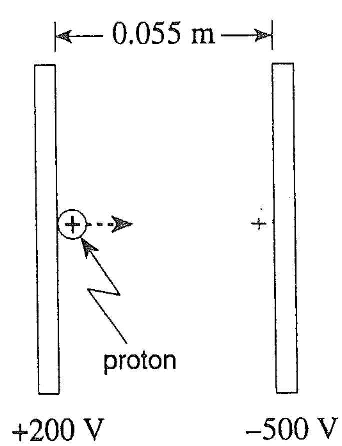
C.



D.

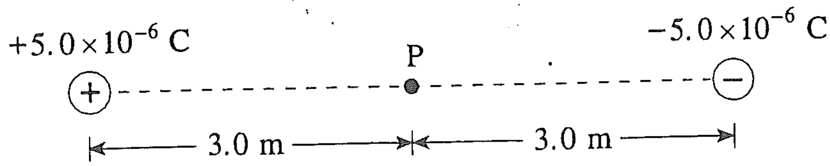


12. A proton initially at rest is accelerated between parallel plates through a potential difference of 700 V.



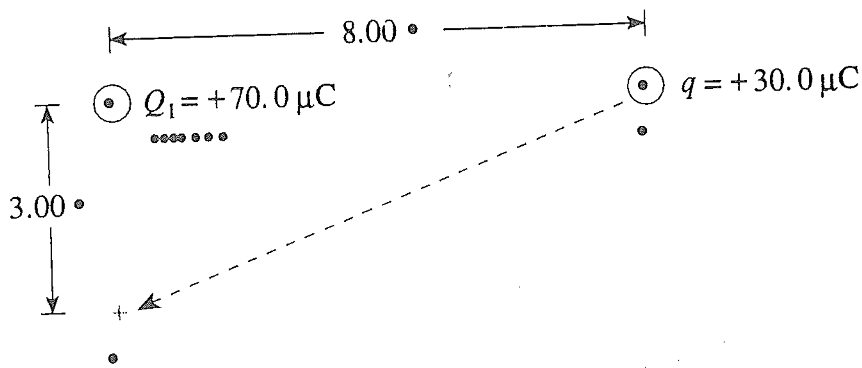
What is the maximum speed reached by the proton?

13. What are the magnitudes of the electric field and the electric potential at point P midway between the two fixed charges?



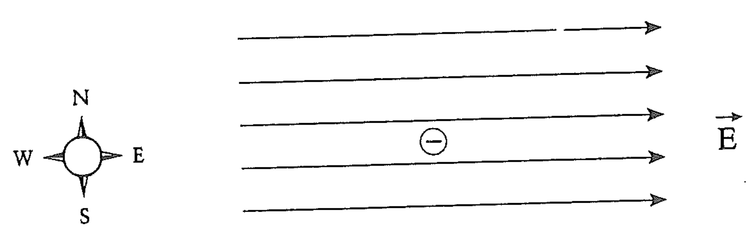
	MAGNITUDE OF ELECTRIC FIELD	ELECTRIC POTENTIAL
A.	0 N/C	0 V
B.	0 N/C	30 000 V
C.	10 000 N/C	0 V
D.	10 000 N/C	30 000 V

14. A charge q of $30.0\ \mu C$ is moved from point X to point Y.

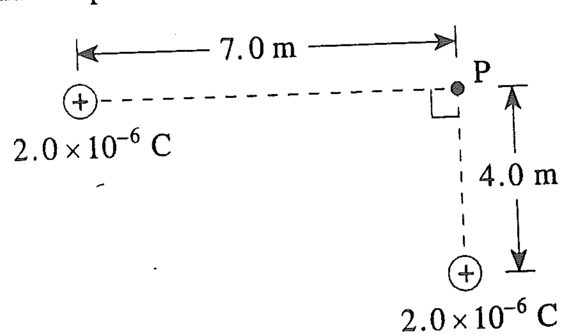


How much work is done on the $30.0\ \mu C$ charge? $\left(1\ \mu C = 1 \times 10^{-6}\ C\right)$ **(7 marks)**

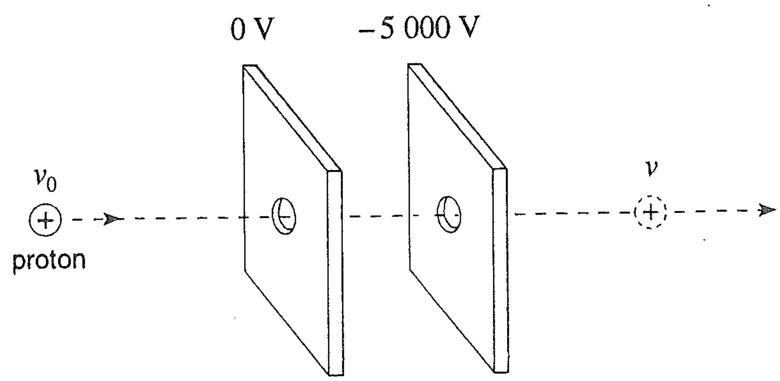
15. An electron in the electric field has an electric force acting on it in what direction?



16. What is the electric potential at point P due to the two fixed charges as shown?

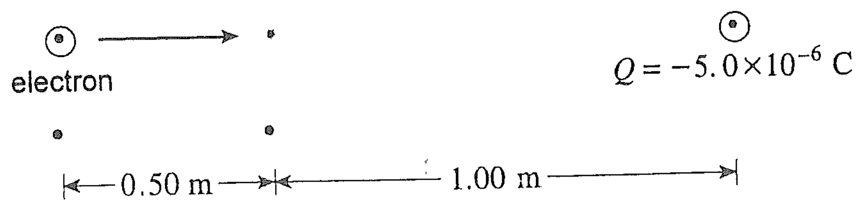


17. A moving proton has 6.4×10^{-16} J of kinetic energy. The proton is accelerated by a potential difference of 5 000 V between parallel plates.



The proton emerges from the parallel plates with what speed?

18. a) How much work is done in moving an electron from point X to point Y? **(5 marks)**

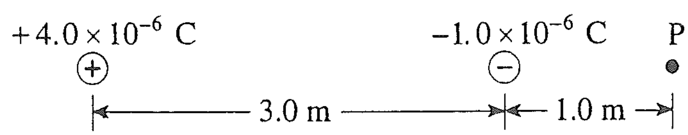


b) What is the potential difference between point X and point Y?

19. The electric field is uniform between

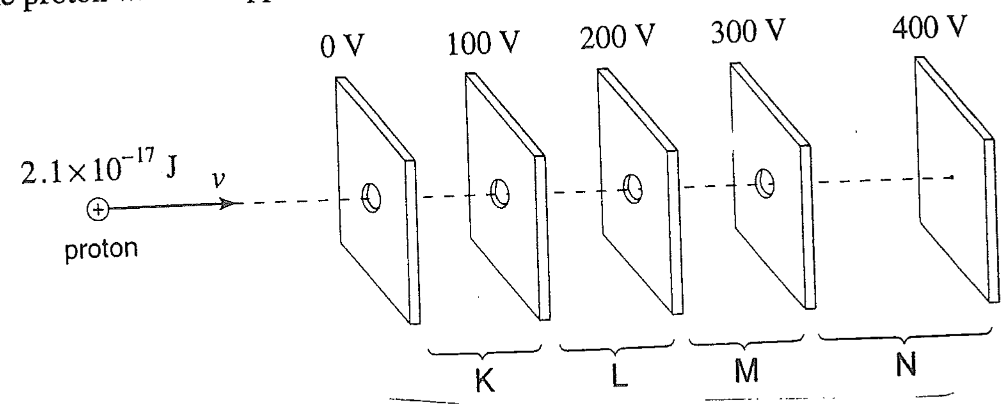
A. two positive point charges.
B. two negative point charges.
C. two opposite point charges.
D. two oppositely charged parallel plates.

20. What is the magnitude and direction of the electric field at point P due to the two fixed charges?



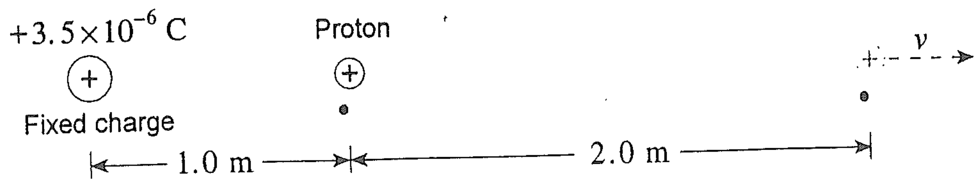
	ELECTRIC FIELD AT POINT P	
	MAGNITUDE	DIRECTION
A.	6 800 N/C	Right
B.	6 800 N/C	Left
C.	11 000 N/C	Right
D.	11 000 N/C	Left

21. A proton with kinetic energy of 2.1×10^{-17} J is moving into a region of charged parallel plates. The proton will be stopped momentarily in what region?



22. A proton, initially at rest at point X, will have what speed at point Y?

(7 marks)



23. Which of the following best describes how electric potential varies with distance in the region around a point charge?

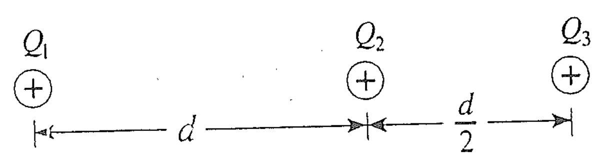
A. $V \propto r$

B. $V \propto \frac{1}{r}$

C. $V \propto r^2$

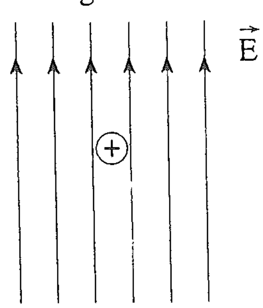
D. $V \propto \frac{1}{r^2}$

24. Three **identical** positive electric charges are fixed as shown in the diagram below.



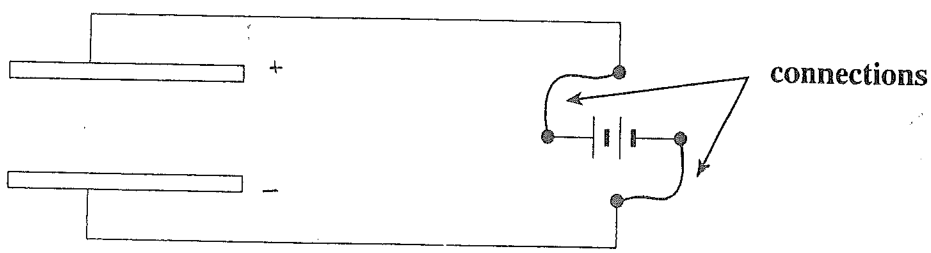
What is the direction of the net electric force on Q_2 due to Q_1 and Q_3?

25. In an experiment, a positively charged oil droplet weighing 6.5×10^{-15} N is held stationary by a vertical electric field as shown in the diagram.



If the electric field strength is 5.3×10^{3} N/C, what is the charge on the oil droplet?

1. D (Aug '99, 18)
2. B (Aug '99, 19)
3. 3.0×10^{-6} (Aug '99, 20)
4 a) $V_A = -4.5 \times 10^{4}$ V, $V_B = -2.7 \times 10^{4}$ V (Aug '99, 5LA)
b) 1.8×10^{4} V c) $+2.0 \times 10^{-6}$ C
5. A (Jan '99, 18)
6. -6.9×10^{-19} J (Jan '99, 19)
7. a) $E = 2.5 \times 10^{3}$ N/C to the left (Jan '99, 5LA)
b) -1.6×10^{-6} C
8. D (June '99, 19)
9. 1.2×10^{-2} (June '99, 20)
10. a. 3.2×10^{3} N/C (June '99, 5LA)
b. 80 V c.



11 A (Jan '00, 19)
12. 3.7×10^{5} m/s (Jan '00, 20)
13. C (Jan '00, 21)

14. (Jan '00, 5LA)

$W = \Delta E$ ← **1 mark**

$= E_{p_y} - E_{p_x}$ ← **2 marks**

$= \dfrac{kQq}{r_y} - \dfrac{kQq}{r_x}$ ← **1 mark**

$= \dfrac{9.00 \times 10^{9} \cdot 70.0 \times 10^{-6} \cdot 30.0 \times 10^{-6}}{3.00} - \dfrac{9.00 \times 10^{9} \cdot 70.0 \times 10^{-6} \cdot 30.0 \times 10^{-6}}{8.00}$ ← **2 marks**

$= (6.3 - 2.4)$ J

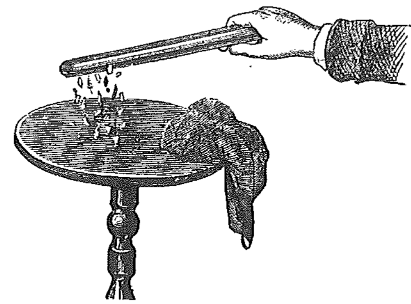
$= 3.9$ J (3.94 J) ← **1 mark**

15. West (June '00, 18)
16. 7.1×10^{3} V (June '00, 19)
17. 1.3×10^{6} m/s (June '00, 20)
18. a) 2.4×10^{-15} J b) 1.5×10^{4} V (Jun '00, 5LA)
19. D (Aug '00, 18)
20 B (Aug '00, 19)
21. L (Aug '00, 20)
22 2.0×10^{6} m/s (Aug '00, 5LA)
23. B (Jan '01, 20)
24. to the left (Jan '01, 21)
25. 1.2×10^{-18} C (Jan '01, 22)

Electrostatics

Key

Physics 12 – Electrostatics



Electrostatics is the study of charges that are not in motion and the interactions between them.

STATIC ELECTRICITY:

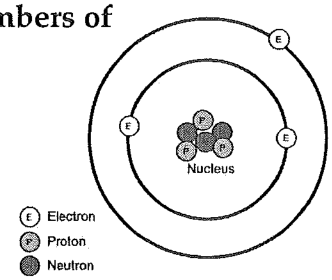
We will begin our study of electricity by looking at the electrical nature of matter. **Static electricity is electricity at rest.**

We are aware that many materials including amber, fur, glass, rubber and plastic will produce the effect of attracting other objects when rubbed. This attraction involves accelerating matter so there must be a FORCE at work. → Electrostatic Force (F_e)

Neutral vs. Charged Objects:

As we know from science 9, 10 and chemistry, atoms contain neutrons, protons and electrons.

The number of electrons that surround the nucleus will determine whether or not an atom is electrically charged or electrically neutral. If an atom contains **equal numbers of protons and electrons**, the atom is described as being **electrically neutral**. If an atom has an unequal number of protons and electrons, then the atom is electrically charged (and in fact, is then referred to as an **ion** rather than an atom).



Charged versus Uncharged Particles

Positively Charged	Negatively Charged	Uncharged
Possesses more protons than electrons	Possesses more electrons than protons	Equal numbers of protons and electrons

A **conductor** is a material that…
allow electrons to flow.

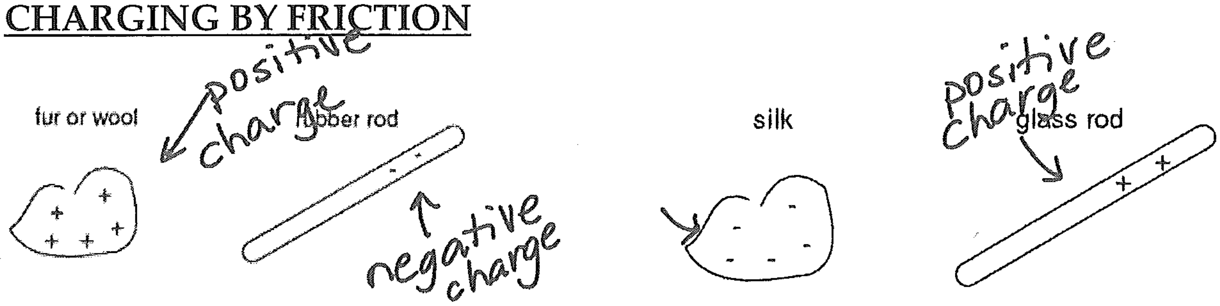
Example – metals are good conductors

An **insulator** is a material that…
"holds" onto electrons or slows electron flow
- can become "charged" when rubbed.

Examples – amber, glass, rubber, fur, silk and plastic are good insulators.

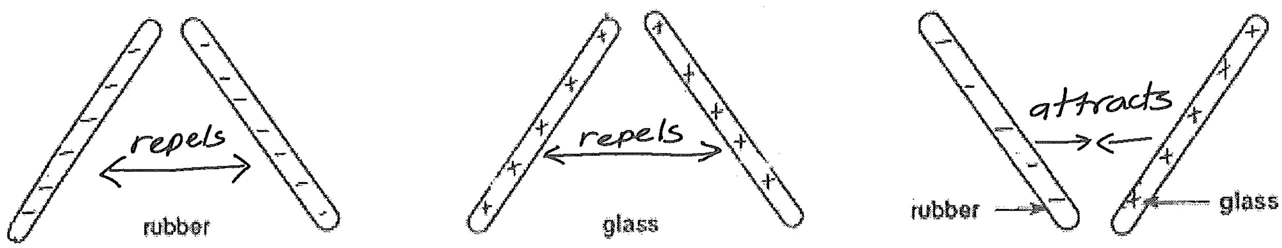
It is possible to build up charge on insulators because electrons cannot easily flow off of a negatively charged object or onto a positively charged object.

CHARGING BY FRICTION



when rubbed, the rubber rod gains electrons.

when rubbed, electrons are transferred from glass to silk.



*"like" charges repel

*"unlike" charges attract (opposite)

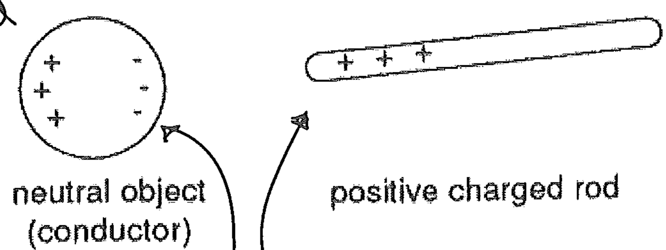
The Law of Charges states:

1. Like charges repel.
2. Opposite charges attract.
3. Neutral charges are attracted to charged (+ or -) objects.

CHARGING BY INDUCTION

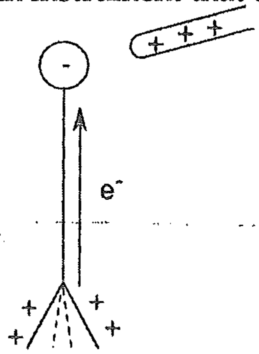
In this process of charging, the neutral conductor will not lose or gain any electrons (remaining neutral), but the electrons will be rearranged. This is referred to charging by **induction.**

*neutral / charged = will attract eachother

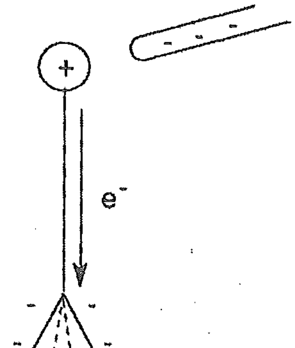


the positively charged rod is brought near the conductor = electrons are attracted to the side of the object nearest to the positively charged rod

An **electroscope** is an instrument that uses induction to detect the presence and nature (- and +) of a charge.



A positively charged rod will attract electors through induction to the head of the electroscope, leaving the leaves positive.

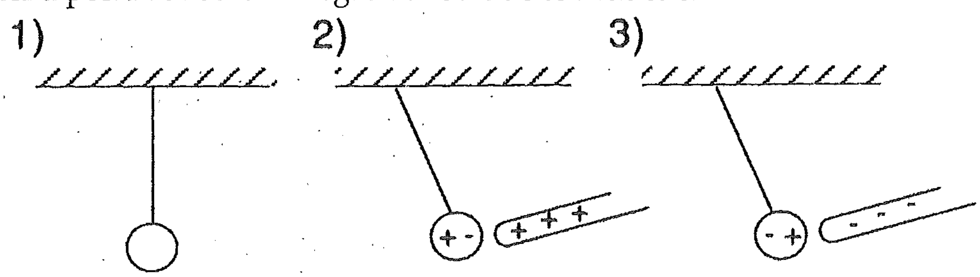


A negatively charged rod will repel electrons from the head of the electroscope into the leaves through induction, leaving the leaves negative.

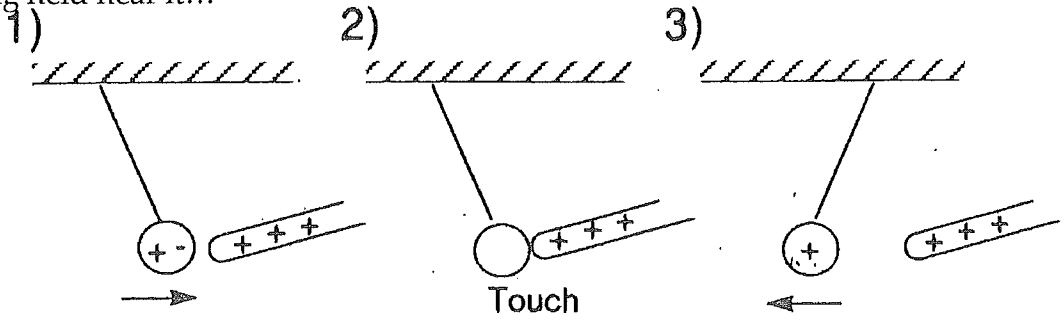
In both cases, the electroscope is neutral, but we have induced the electrons to change their relative position without touching. = INDUCTION

CHARGING BY CONTACT

A pith ball is a light ball with a conductive surface. A neutral pith ball is initially attracted to either a positive rod or a negative rod due to induction.

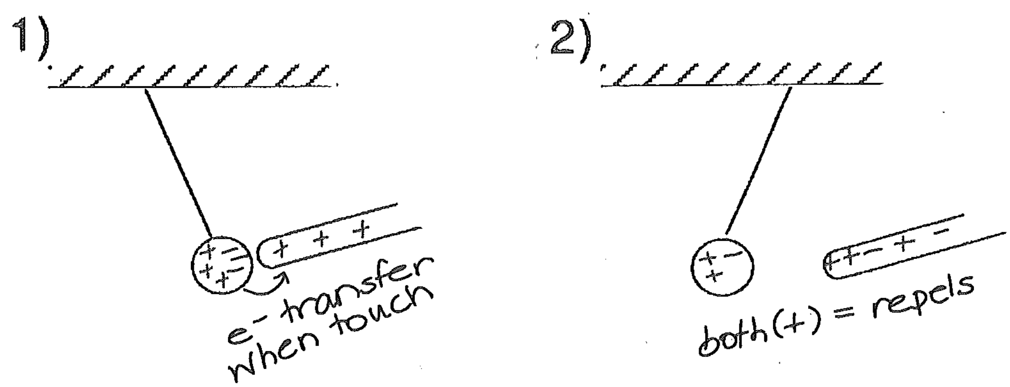


Now we will see what happens when the rod actually touches the ball rather than just being held near it…



*In both cases, the electroscope is neutral, but we have induced the electrons to change their relative position <u>without</u> touching.

Why? When the ball comes in contact with the rod, the **ball transfers some of its electrons to the rod**. The rod is still positive, but now so is the previously neutral ball. Therefore, both are positive and they will now repel.



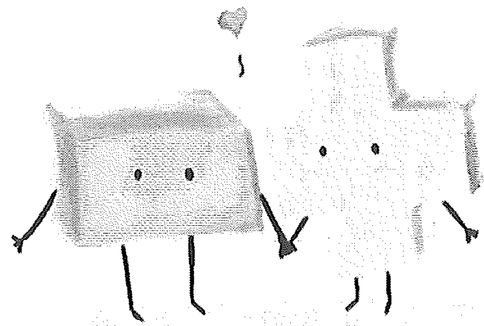
The Law of Conservation of Charges -

It is very important to note that if an object is charged by friction, induction or conduction, the electric charges are neither created or destroyed – they are just moved from one place to another.

Next lesson we will investigate the force behind the attraction and repulsion – (F_e)

Physics 12 – **Coulomb's Law**

As we saw last lesson, electric charges can attract and repel other charges. With this attraction and repulsion there must be a **force acting to change the velocity of the object**. This force is referred to as the **Electric Force (F_e).**



There is a parallel relationship that exists between charges (and the resulting electric force) and that of masses (and the resulting gravitational force).

Joseph Priestly made this connection when he found that placing a charged pith ball inside a hollow sphere has no electrical force acting on it just as a mass inside a hollow mass will have no gravitational force acting on it. This is because there are forces in all directions and they will cancel each other out.

ELECTRIC FORCE LAW (COULOMB'S LAW)

This law states that the electric force between two charges depends on:

- the size of the two charges.
- the distance between the two charges.

It is important to remember that **electric charge is always conserved**. **The net electric charge of an isolated system remains constant during any process.**

Coulomb's Law -

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

K = Coulomb's constant
↳ $9.00 \times 10^9 \frac{N \cdot m^2}{C^2}$

q_1, q_2 } charges (in coulombs - C)

r = distance between charges

The unit of charge is a **Coulomb.** (C)

Comparing this equation to universal gravitation, we can see the ***similarity.***

Electrostatic Force:

$$F_e = \frac{Kq_1q_2}{r^2}$$

Gravitational Force:

$$F_g = \frac{Gm_1m_2}{r^2}$$

While this equation is similar to universal gravitation, there are a ***number of differences:***

First, electrostatic forces are much stronger than gravitational forces.

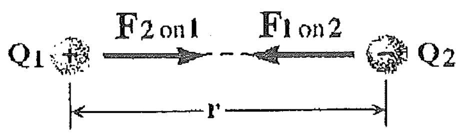
$$K = 9.0 \times 10^{9}\ \frac{N \cdot m^2}{C^2} \qquad G = 6.67 \times 10^{-11}\ \frac{N \cdot m^2}{kg^2}$$

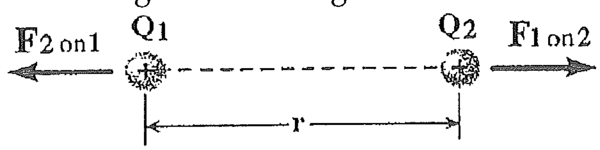
Secondly, Gravity ALWAYS... attracts

while Electrostatic force can.... attract or repel

Thirdly, we will determine the direction of the force (+ or -) based on... whether it is an attraction or repulsion

The electric force produced acts along the line connecting the two charges as seen below.





$$F_{e1on2} = -F_{e2on1}$$

- equal and opposite
- directed along a straight line

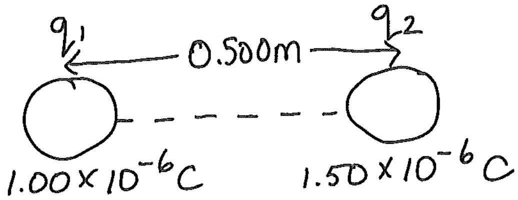
* Coulomb's Law only provides the magnitude of the electric force → direction determined based on attraction or repulsion

Electric charge has a specific quantity. The elementary charge is the **charge on one electron** (*negative*) or **one proton** (*positive*).

$$\mathbf{e = 1.60 \times 10^{-19}\ C}$$

Example 1:

Calculate the electric force between charges of 1.00×10^{-6} C and 1.50×10^{-6} C when they are 5.00×10^{-1} m apart. * at this point – no indication of + or – charge



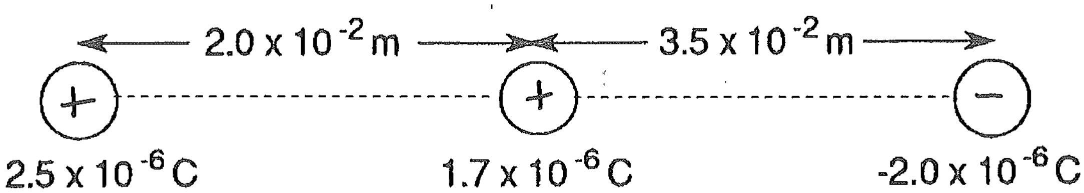
$$F_e = \frac{K q_1 q_2}{r^2}$$

$$F_e = \frac{(9.00\times10^{9})(1.0\times10^{-6})(1.5\times10^{-6})}{(0.500)^2}$$

$$F_e = \underline{5.40 \times 10^{-2}\ N}$$

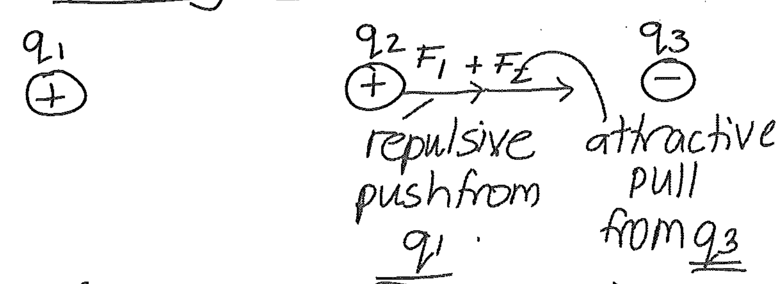
Example 2:

A charge of 1.7×10^{-6} C is placed 2.0×10^{-2} m from a charge of 2.5×10^{-6} C and 3.5×10^{-2} m from a charge of -2.0×10^{-6} C as shown in the diagram. Calculate the magnitude of the net electric force on the center (1.7×10^{-6} C) charge.



There are two forces acting on the center charge

* identify forces and direction



$$F_1 = \frac{K q_1 q_2}{r^2} = \frac{(9.0\times10^{9})(2.5\times10^{-6})(1.7\times10^{-6})}{(2.0\times10^{-2})^2}$$

$F_1 = 96$ N $(\rightarrow)$ so $+96$ N

$$F_2 = \frac{K q_1 q_2}{r^2} = \frac{(9.0\times10^{9})(1.7\times10^{-6})(2.0\times10^{-6})}{(3.5\times10^{-2})^2}$$

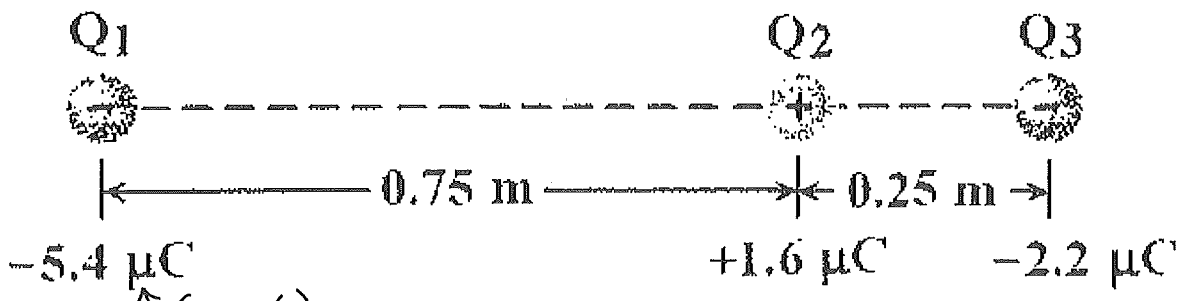
$F_2 = 25$ N $(\rightarrow)$ so... $+25$ N

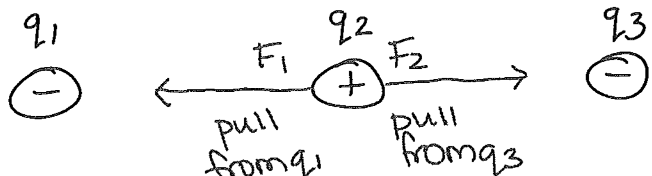
* do not use (–) in formula as it determines magnitude only

$$\Sigma F = F_1 + F_2$$
$$= 96 + 25 = \underline{121\ N}$$

Example Three:

Three charged particles are arranged in a line as shown in the diagram. ($1\mu C = x10^{-6}$). Find the net electric force on q_2 due to q_1 and q_3.





a) $F_1 = \frac{(9.0\times10^9)(5.4\times10^{-6})(1.6\times10^{-6})}{(0.75)^2}$ $\quad F_1 = 0.14\,N\,(\leftarrow)$

$= -0.14\,N$

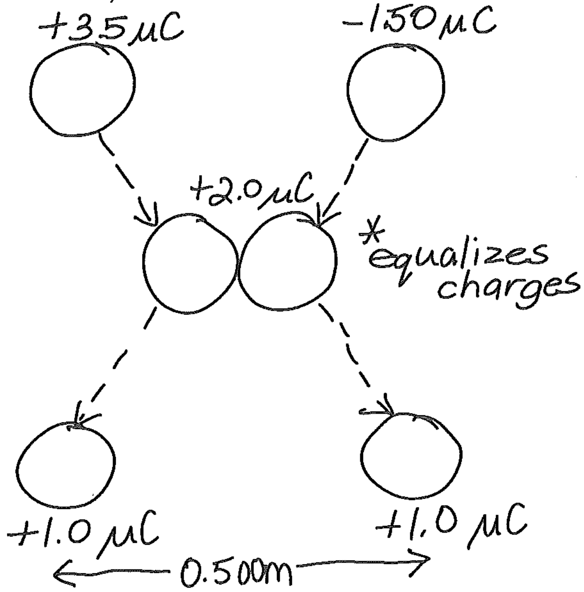
b) $F_2 = \frac{(9.0\times10^9)(1.6\times10^{-6})(2.2\times10^{-6})}{(0.25)^2}$ $\quad F_2 = 0.51\,N\,(\rightarrow)$

$= +0.51\,N$

$\Sigma F = F_1 + F_2 = -0.14 + 0.51 = \underline{+0.37\,N}$

Determining the Direction of the Electrical Force Vector

Example Four: Two small spheres have the ***same mass and volume***. One of the spheres has a charge of 3.50 x 10^{-6} C and the other sphere has a charge of -1.50 x 10^{-6} C. If these two spheres are brought into brief contact with each other and then separated to a distance of 0.500 m, what is the electric force between them at this distance?



$$F_e = \frac{(9.0\times10^{9})(1.0\times10^{-6})^2}{(0.50)^2}$$

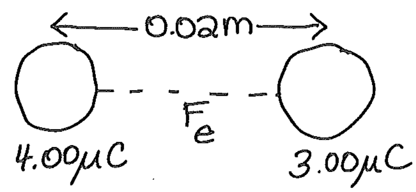
$$F_e = \underline{0.036\ N} = \underline{3.6\times10^{-2}\ N}$$

Coulomb's Law Problems:

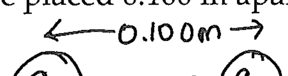
1. Calculate the electrical force between two charges of 4.00 x 10^{-6} C and 3.00 x 10^{-6} C when they are 2.00 cm apart. (270 N)

$$F_e = \frac{(9.00\times10^{9})(4\times10^{-6})(3\times10^{-6})}{(0.02)^2}$$

$$= \underline{270\ N}$$



2. Two points of equal charge produce an electric force on each other of 3.40 x 10^{-2} N when they are placed 0.100 m apart. What is the charge on each point? (1.94 x 10^{-7} C)

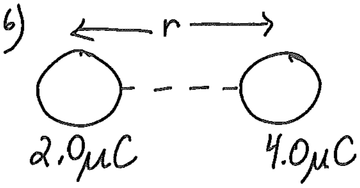


$$3.4\times10^{-2} = \frac{(9.0\times10^{9})q^2}{(0.1)^2} \qquad q = \underline{1.94\times10^{-7}\ C}$$

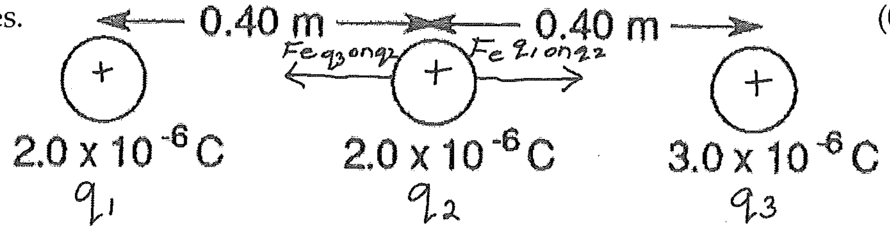
3. How far apart are two point charges (**a point charge is a charge that occupies so little space that is can be regarded as a mathematical point**) of 2.0 x 10^{-6} C and 4.0 x 10^{-6} C if they produce an electric force on each other of 5.6 x 10^{-1} N? (0.36 m)

$$5.6\times10^{-1} = \frac{(9.0\times10^{9})(2\times10^{-6})(4\times10^{-6})}{r^2}$$

$$r = \underline{0.36m}$$



4. Three positively point charged objects are placed in a line as shown in the diagram. Calculate the magnitude of the net electric force on the center charge caused by the other two charges. (0.113 N)



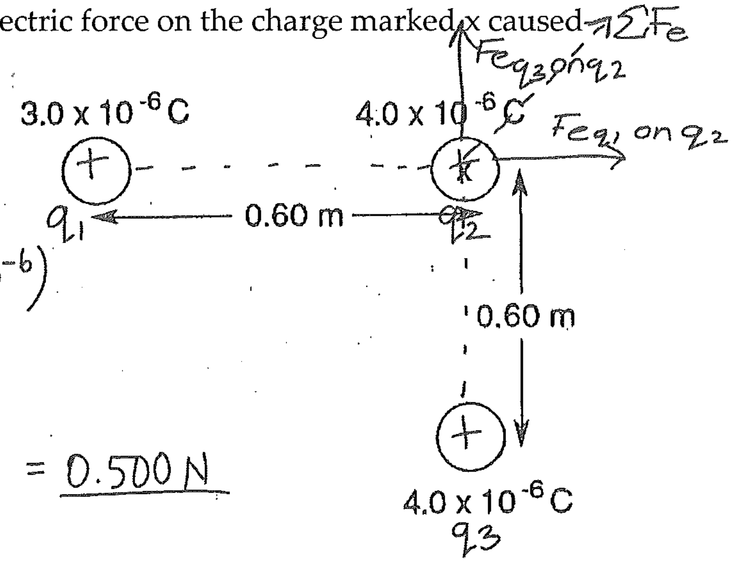
$$Fe_{1 on 2} = \frac{(9.0\times10^{9})(2\times10^{-6})(2.0\times10^{-6})}{(0.4)^2} = 0.225 N (\longrightarrow) = +0.225 N$$

$$Fe_{3 on 2} = \frac{(9.0\times10^{9})(2.0\times10^{-6})(3\times10^{-6})}{(0.4)^2} = 0.338 N (\longleftarrow) = -0.338 N$$

$$\Sigma F_e = 0.225 + (-0.338) = -0.113 N$$

magnitude: <u>0.113 N</u>

5. Three charged objects are placed at the corners of a right angle triangle as shown in the diagram. Calculate the magnitude of the net electric force on the charge marked x caused by the other two charges. (0.500 N)

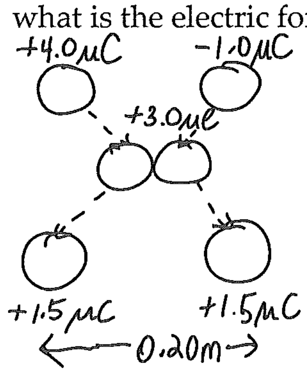


$$Fe_{1 on 2} = \frac{(9.0\times10^{9})(3\times10^{-6})(4\times10^{-6})}{(0.60)^2} = 0.300 N$$

$$Fe_{3 on 2} = \frac{(9.0\times10^{9})(4.0\times10^{-6})(4\times10^{-6})}{(0.60)^2} = 0.400 N$$

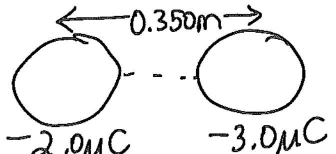
$$\text{magnitude: } \Sigma F_e = \sqrt{(0.400)^2 + (0.300)^2} = \underline{0.500 N}$$

6. Two small spheres have the same mass and volume. One of the spheres has a charge of 4.00×10^{-6} C and the other sphere has a charge of -1.00×10^{-6} C. If these two spheres are brought into brief contact with each other and then separated to a distance of 0.200 m, what is the electric force between them at this distance? (5.06×10^{-1} N)



$$Fe = \frac{(9.0\times10^{9})(1.5\times10^{-6})^2}{(0.20)^2} = \underline{0.506 N}$$

7. Two small spheres, each with a mass of 2.00 x 10^{-5} kg, are placed 0.350 m apart. One sphere has a charge of -2.00 μC (**remember μC = x10^{-6}**) and is fixed in position. The other sphere has a charge of -3.00 μC but is free to move without friction. What is the initial acceleration caused by the electric force on the sphere that is free to move? (2.20 x 10^4 m/s^2)



$$F_e = \frac{(9.0\times10^9)(2.0\times10^{-6})(3.0\times10^{-6})}{(0.350)^2}$$

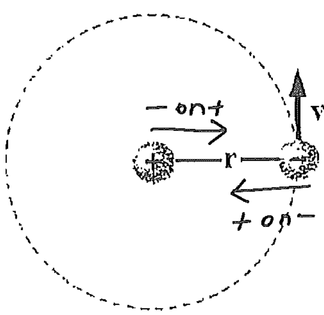
$F_e = 0.441\,N$

$\Sigma F = m\vec{a}$ $\quad 0.441 = (2.0\times10^{-5})\vec{a}$ $\quad \vec{a} = 2.20\times10^4\,m/s^2$

8. A hydrogen atom consists of a stationary proton and an electron orbiting the proton at a distance of 5.3 x 10^{-11} m with a speed v.

a) Find the electric force (with direction) exerted by the proton on the electron. (-8.2x10^{-8}N)

b) Find the electric force (with direction) exerted by the electron on the proton. (+8.2x10^{-8}N)



charge on e^-, p^+ $= 1.6\times10^{-19}$ C

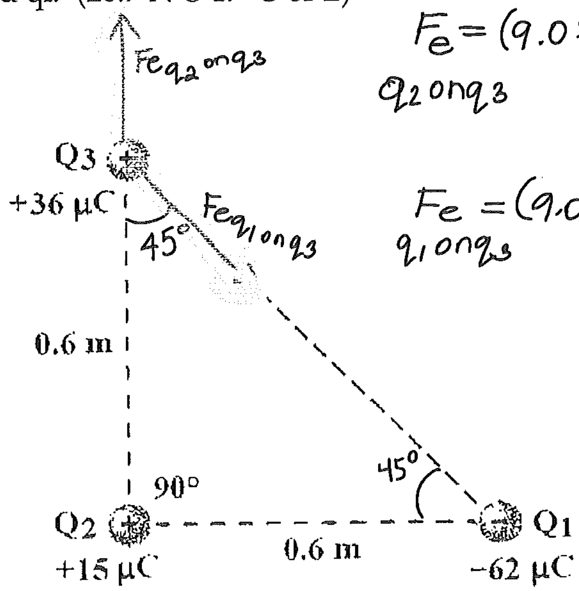
a) $$F_e = \frac{(9.0\times10^9)(1.6\times10^{-19})^2}{(5.3\times10^{-11})^2}$$

$F_e = 8.2\times10^{-8}$ N towards ⊕

b) F_e is equal and opposite

$F_e = 8.2\times10^{-8}$ N towards ⊖

9. Three charges are placed at three corners of a right triangle as shown in the diagram.
a) Find the net electric force (magnitude and direction) on charge q_3 due to the charges q_1 and q_2. (20.7 N @ 17° S of E)



$$F_{e\,q_2 \text{ on } q_3} = \frac{(9.0\times10^9)(15\mu C)(36\mu C)}{(0.6)^2} = 13.5C$$

$$F_{e\,q_1 \text{ on } q_3} = \frac{(9.0\times10^9)(36\mu C)(62\mu C)}{\left(\sqrt{0.6^2+0.6^2}\right)^2} = 27.9C$$

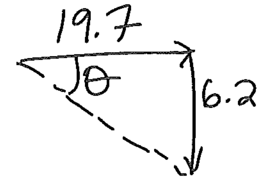
↓ split into components

X: $\sin 45(27.9) = +19.7C$

y: $\cos 45(27.9) = -19.7C$

$$\Sigma F_{e_x} = 19.7 + 0 = +19.7C$$

$$\Sigma F_{e_y} = 13.5 + (-19.7) = -6.2C$$



$$\Sigma F_{e \text{ on } Q3} = \sqrt{19.7^2 + 6.2^2} = 20.7C$$

$$\tan^{-1}\left(\frac{6.2}{19.7}\right) = 17° \text{ S of E}$$

$$\Sigma F_{e \text{ on } Q3} = \underline{20.7C \text{ @ } 17° \text{ S of E}}$$

Key

PHYSICS 12

Concept Development

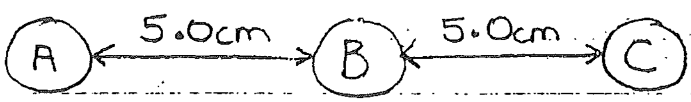
Electric Forces and Fields

Directions - Extra Practice

Electric Forces

- For "like" charges F_e repels (pushes away) + for "unlike" charges F_e attracts (pulls toward)

Find the net F_e and direction on B if:

1. 

$F_e = \frac{kQ_1Q_2}{r^2}$

a) $A = {}^{+}10\mu C$ $B = {}^{+}10\mu C$ $C = {}^{+}10\mu C$

b) $A = {}^{+}10\mu C$ $B = {}^{-}10\mu C$ $C = {}^{+}10\mu C$

c) $A = {}^{+}10\mu C$ $B = {}^{-}10\mu C$ $C = {}^{-}10\mu C$

d) $A = {}^{+}20\mu C$ $B = {}^{+}10\mu C$ $C = {}^{+}10\mu C$

e) $A = {}^{-}10\mu C$ $B = {}^{+}10\mu C$ $C = {}^{-}20\mu C$

1. $F_{A on B} = \frac{9.00\times10^{9}\times10\times10^{-6}\times10\times10^{-6}}{(0.050)^2} = 3.6\times10^{2}\ N$

a) A $\xrightarrow{F_{AB}}$ B $\xleftarrow{F_{CB}}$ C ∴ $F_{net} = 0$

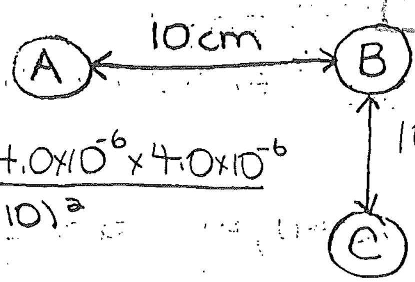
b) A $\xleftarrow{F_{AB}}$ B $\xrightarrow{F_{CB}}$ C ∴ $F_{net} = 0$

c) A ← $F_{AB} = 3.6\times10^2 N$ B ← $F_{CB} = 3.6\times10^2 N$ C
∴ $F_{net} = 7.2\times10^2 N$, TOWARD A

d) $F = \frac{9.00\times10^{9}\times20\times10^{-6}\times10\times10^{-6}}{(0.050)^2} = 1.08\times10^{3}\ N$

A → $F_{AB} = 1.08\times10^3 N$ B ← $F_{CB} = 3.6\times10^2 N$ C
∴ $F_{net} = 1.08\times10^3 - 3.6\times10^2 = 7.2\times10^2 N$ toward C

e) A ← $F_{AB} = 3.6\times10^2 N$ B → $F_{CB} = 1.08\times10^3 N$ C
∴ $F_{net} = 1.08\times10^3 - 3.6\times10^2 = 7.2\times10^2 N$, toward C

2. 

a) $A = B = C = 4.0\mu C$

$F = \frac{9.00\times10^{9}\times4.0\times10^{-6}\times4.0\times10^{-6}}{(0.10)^2}$
$= 14.4\ N$

b) $A = B = 4.0\mu C$, $C = {}^{-}4.0\mu C$

c) $A = {}^{-}4.0\mu C$, $B = C = 4.0\mu C$

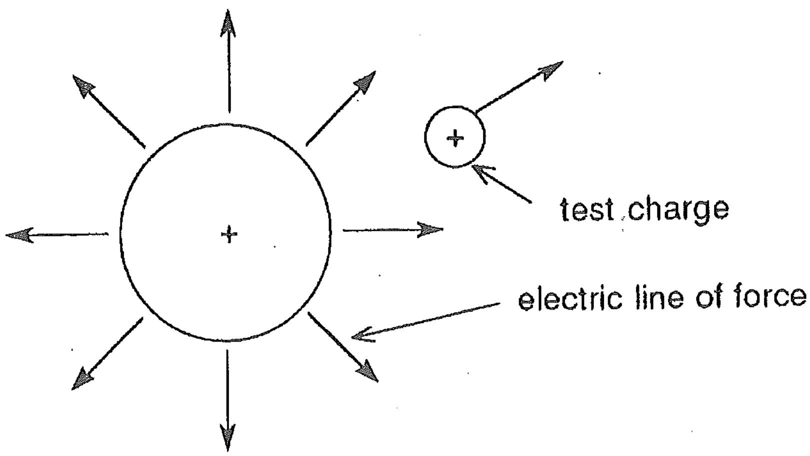
au verso →

Physics 12 – **<u>Electric Fields</u>**

The concept of fields is used to explain how forces are exerted between objects that are not in contact with each other. Any mass, like Earth, is surrounded by a gravitational field. In the same way, an electrical charge is surrounded by an electric field.

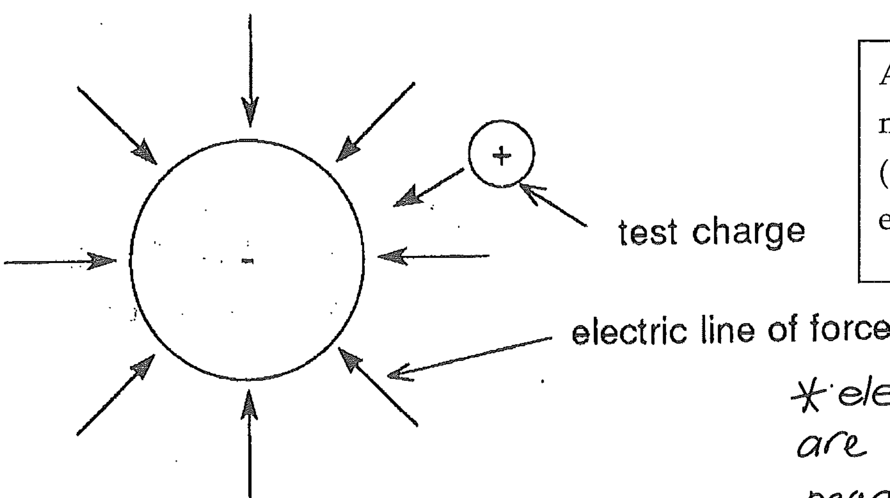
Fields are defined as spheres of influence and can be classified as scalar and vector. **<u>Electric fields</u>** are **<u>vector fields</u>** and therefore have direction as well as magnitude.

The direction of an electric field is defined as the direction that a positive test charge will move when placed in the field.



A positive charge will always move away from a positive object ("like" charges repelling each other).

*electric field lines <u>always</u> drawn <u>away</u> <u>from</u> <u>positive</u> <u>charges</u>



A positive charge will always move toward a negative object ("opposite" charges attracting each other).

*electric field lines are <u>always</u> drawn <u>towards</u> <u>negative</u> <u>charges</u>.

There are two formulas to determine the size of an electric field:

(1)

$$\bar{E} = \frac{F_e}{q}$$

Electric Field Strength → $\bar{E}$; electric force on test object (F_e) → F_e; test charge → q

→ this formula is based on the test charge.

* this formula is the definition of an electric field = force per unit charge

$\bar{E}$ → units = N/C

The field strength at any point around a charged object can be found by using a test charge and find the electric force acting on it. If we divide this by the charge on the test object, we have the electric field strength.

(2)

$$\bar{E} = \frac{kq}{r^2}$$

charge on the object producing field → q; distance from object producing field → r

units = N/C

→ this formula is based on the charge producing the field.

Some problems that we will be dealing with include alpha particles, protons and electrons. Therefore it is necessary to be familiar with the mass and charge of each particle.

☆ on formula sheet

	Mass	Charge
alpha particles	6.65×10^{-27} kg	3.20×10^{-19} C
electron	9.11×10^{-31} kg	-1.60×10^{-19} C
proton	1.67×10^{-27} kg	1.60×10^{-19} C

In solving electric field problems, we use absolute values and ignore the sign on the charge just like we did in problems involving electric force. **This will give us the magnitude of the field strength.** The **sign on the charge is used to determine the direction of the field.**

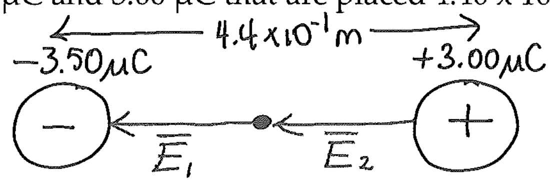
Example One: Find the electric field strength 4.50 x 10^{-1} m from a 5.00μC charged object.

$$\bar{E} = \frac{kq}{r^2} = \frac{(9.0\times10^9)(5.0\times10^{-6})}{(0.45)^2} = 2.2\times10^5\ N/C$$

Example Two: What is the electric field strength at a point where a -2.00 μC test charge experiences an electric force of 5.30 x 10^{-2} N?

$$\bar{E} = \frac{F_e}{q} = \frac{5.30\times10^{-2}}{2.0\times10^{-6}} = 2.65\times10^4\ N/C$$

Example Three: What is the electric field strength midway between charged objects -3.50 μC and 3.00 μC that are placed 4.40 x 10^{-1} m apart?



→always from ⊕ to ⊖

*in order to find the field strength midpoint we will find the $\Sigma\bar{E}$ at that point.

$$\bar{E} = \frac{kq}{r^2}$$

$$\bar{E}_1 = \frac{(9.0\times10^9)(3.5\times10^{-6})}{(0.220)^2} = 6.51\times10^5\ N/C$$

midpoint

$$\bar{E}_2 = \frac{(9.0\times10^9)(3.0\times10^{-6})}{(0.220)^2} = 5.58\times10^5\ N/C$$

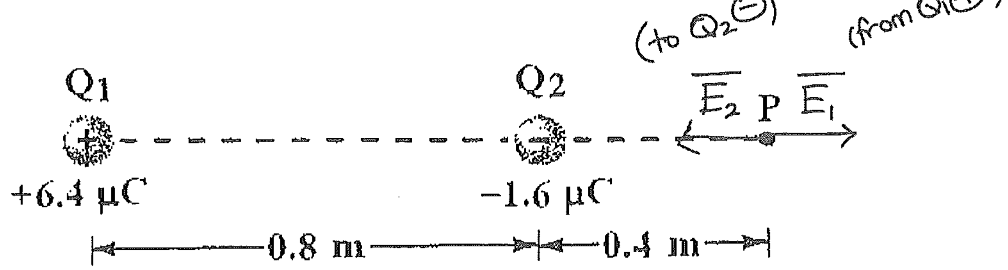
$$\Sigma\bar{E} = \bar{E}_1 + \bar{E}_2$$

$$= 6.51\times10^5 + 5.58\times10^5$$

*both acting in same direction so they have the same sign.

$$= 1.21\times10^6\ N/C$$

Example Four: Two charges are placed as shown in the diagram. A) Find the magnitude and direction of the electric field at point P. B) If a charge placed at point P experiences an electric force of 1.4×10^{-1} N toward the right, what are the magnitude and polarity of this charge?



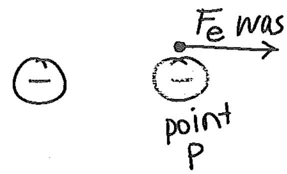
A) $\bar{E}_1 = \frac{(9.0\times10^{9})(6.4\times10^{-6})}{(1.2)^2} = 4.00\times10^{4}$ N/C (right)

$\bar{E}_2 = \frac{(9.0\times10^{9})(1.6\times10^{-6})}{(0.4)^2} = 9.00\times10^{4}$ N/C (left)

$\Sigma\bar{E} = 4.00\times10^{4} + (-9.00\times10^{4}) = -5.00\times10^{4}$ N/C

B) $\bar{E} = \frac{F_e}{q}$ $= 5.00\times10^{4} = \frac{1.4\times10^{-1}}{q}$ $q = -2.8\times10^{-6}$ C

looking for charge



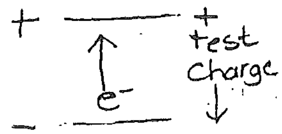
F_e was to the right = repulsion from Q_2 ⊖ so must also be ⊖

Electric Fields

- The direction of the electric field is simply the direction a POSITIVE test charge would travel in that field.

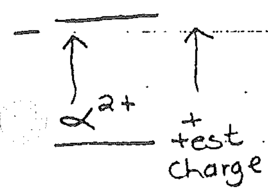
State the direction of the electric field in each of the following:

1. An e^- (in an electric field) experiences a force



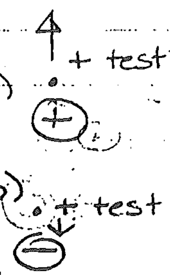
a) upward — $\vec{E}$ is down
b) North — $\vec{E}$ is South
c) West — $\vec{E}$ is East

2. An alpha particle experiences a force



a) upward — up
b) North — north
c) West — west

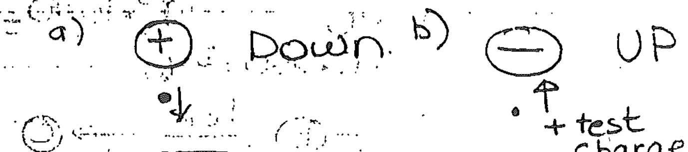
3. Directly above a



a) positive charge — up
b) negative charge — Down

4. Below a

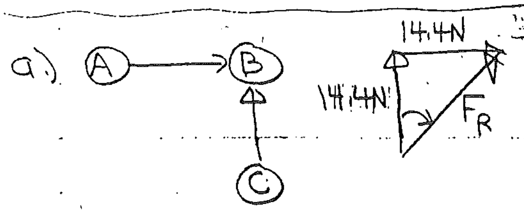
a) positive charge
b) negative charge



a) Down
b) UP

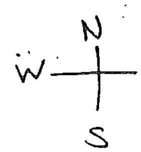
---

2. a)

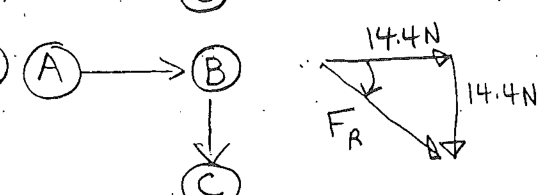


$F_R = \sqrt{(14.4)^2 + (14.4)^2} = 20.4N$

$\tan\theta = \frac{14.4}{14.4}$ $\theta = 45°$ E of N

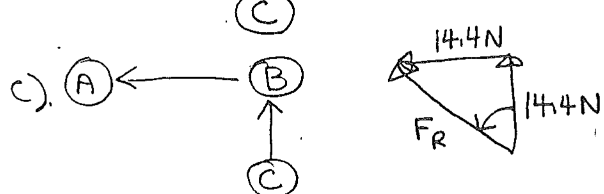


b)



$F_R = 20.4N$, $45°$ S of E

c)



$F_R = 20.4N$, $45°$ W of N

Electric Field Problems: $\bar{E} = \frac{kq}{r^2}$ $\bar{E} = \frac{F_e}{q}$

1. What is the electric field strength 7.50 x 10^{-1} m from an 8.00μC charged object? (1.28x10^{5} N/C)

$$\bar{E} = \frac{kq}{r^2} = \frac{(9.0\times10^9)(8.0\times10^{-6})}{(0.75)^2} = 1.28\times10^5\ N/C$$

2. At a point a short distance from a 4.60 μC charged object there is an electric field strength of 2.75 x 10^{5} N/C. What is the distance to the charged object producing this field? (0.388 m)

$$2.75\times10^5 = \frac{(9.0\times10^9)(4.6\times10^{-6})}{r^2} \qquad \underline{r = 0.388m}$$

3. If an alpha particle experiences an electric force of 0.250 N at a point in space, what electric force would a proton experience at the same point? (0.125 N)

$$\bar{E} = \frac{F_e}{q} = \frac{0.250}{3.20\times10^{-19}} = 7.81\times10^{17}\ N/C$$

$$\bar{E} = \frac{F_e}{q} \qquad 7.81\times10^{17} = \frac{F_e}{1.6\times10^{-19}} \qquad F_e = \underline{0.125\ N}$$

4. What is the electric field strength at a point in space where a 5.20 x 10^{-6} C charged object experiences an electric force of 7.11 x 10^{-3} N? (1.37 x 10^{3} N/C)

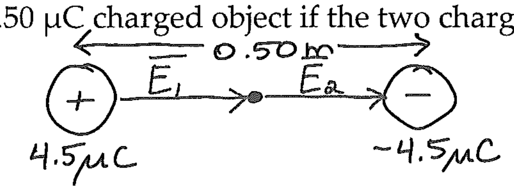
$$\bar{E} = \frac{7.11\times10^{-3}}{5.2\times10^{-6}} = 1.37\times10^3\ N/C$$

5. What is the initial acceleration of an alpha particle when it is placed at a point in space where the electric field strength is 7.60 x 10^{4} N/C? (3.66 x 10^{12} m/s^{2})

$$7.60\times10^4 = \frac{F_e}{3.20\times10^{-19}} \qquad F_e = 2.43\times10^{-14}\ N$$

$$\Sigma F = m\vec{a} \qquad 2.43\times10^{-14} = 6.65\times10^{-27}\vec{a} \qquad \vec{a} = 3.66\times10^{12}\ m/s^2$$

6. Calculate the electric field strength mid-way between a 4.50 μC charged object and a -4.50 μC charged object if the two charged objects are 5.00 x 10^{-1} m apart. (1.30x10^{6} N/C) →

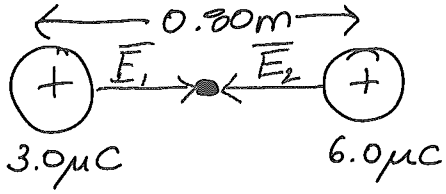


$$\bar{E}_1 = \frac{(9.0\times10^9)(4.5\times10^{-6})}{(0.25)^2} = 6.48\times10^5\ N/C$$

$$\bar{E}_2 = \frac{(9.0\times10^9)(4.5\times10^{-6})}{(0.25)^2} = \overrightarrow{6.48\times10^5\ N/C}$$

$$\Sigma\bar{E} = 6.48\times10^5 + 6.48\times10^5 = \underline{1.30\times10^6\ N/C}$$

7. Calculate the electric field strength mid-way between a 3.0 μC charged object and a 6.0 μC charged object if the two charged objects are 0.80 m apart. (1.69×10^5 N/C towards 3.0 μC charge)



$$\vec{E}_1 = \frac{(9.0\times10^9)(3.0\times10^{-6})}{(0.40)^2} = 1.69\times10^5 \text{ N/C} \rightarrow$$

$$\vec{E}_2 = \frac{(9.0\times10^9)(6.0\times10^{-6})}{(0.40)^2} = 3.38\times10^5 \text{ N/C} \leftarrow$$

$$\Sigma\vec{E} = 1.69\times10^5 + (-3.38\times10^5) = -1.69\times10^5 \text{ N/C}$$

(towards the 3.0μC charge)

8. The electric field strength at a distance of 3.00×10^{-1} m from a charged object is 3.60×10^5 N/C. What is the electric field strength at a distance of 4.50×10^{-1} m from the same object? (1.60×10^5 N/C)

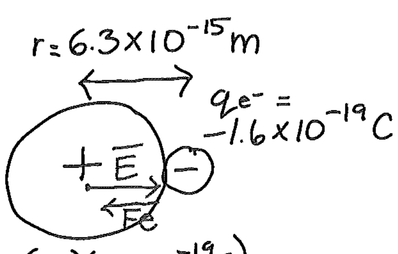
$$\vec{E} = \frac{kq}{r^2} \qquad 3.60\times10^5 = \frac{(9.0\times10^9)(q)}{(0.30)^2} \qquad q = 3.6\times10^{-6} \text{ C}$$

$$\vec{E} = \frac{(9.0\times10^9)(3.6\times10^{-6})}{(0.45)^2} \qquad \vec{E} = 1.60\times10^5 \text{ N/C}$$

9. A lead nucleus has a charge of 82 protons within a sphere of radius of 6.3×10^{-15} m.

a) What are the magnitude and direction of the electric field at the surface of the nucleus? (2.97×10^{21} N/C outwards from the nucleus)

b) What are the magnitude and direction of the electric force on an electron located at the surface of the nucleus? (475 N towards center of nucleus)



$q_{p^+} = (82)(1.6\times10^{-19}\text{C})$
$= 1.31\times10^{-17}\text{C}$

a) $$\vec{E} = \frac{(9.0\times10^9)(1.31\times10^{-17})}{(6.3\times10^{-15})^2} = 2.97\times10^{21} \text{ N/C}$$ towards surface

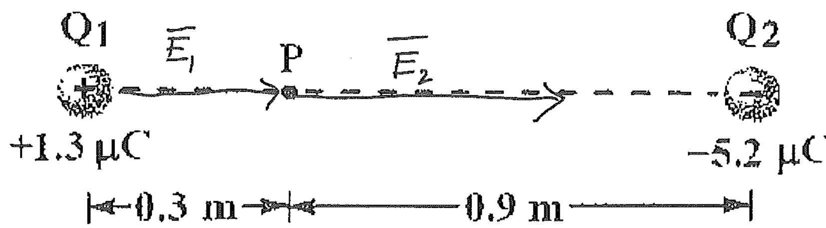
b) $$F_e = \frac{(9.0\times10^9)(1.6\times10^{-19})(1.31\times10^{-17})}{(6.3\times10^{-15})^2}$$

= 475 N towards center of nucleus (pull on ⊖ from ⊕)

10. Two point charges are separated by a distance of 1.2 m as shown in the diagram.

a) What are the magnitude and direction of the electric field at point P due to the two point charges? (1.88×10^5 N/C to the right)

b) If an electron is placed at rest at point P, what is its acceleration initially? (3.30×10^{16} m/s^2 to the left)



a)

$$\overline{E}_1 = \frac{(9.0\times10^9)(1.3\times10^{-6})}{(0.3)^2} = 1.30\times10^5 \text{ N/C}$$

$$\overline{E}_2 = \frac{(9.0\times10^9)(5.2\times10^{-6})}{(0.9)^2} = 5.78\times10^4 \text{ N/C}$$

$$\Sigma\overline{E} = 1.30\times10^5 + 5.78\times10^4 = 1.88\times10^5 \text{ N/C (to the right)}$$

b) $$\overline{E} = \frac{F_e}{q} \qquad 1.88\times10^5 = \frac{F_e}{1.6\times10^{-19}}$$

$$F_e = 3.0\times10^{-14} \text{ N}$$

$$\Sigma F = m\vec{a} \qquad 3.0\times10^{-14} = (9.11\times10^{-31})\vec{a}$$

$$\vec{a} = 3.30\times10^{16} \text{ m/s}^2 \text{ (to left)}$$

[away from ⊖ to ⊕]

11. At a distance of 7.50×10^{-1} m from a small charged object, the electric field strength is 2.10×10^4 N/C. At what distance from this same object would the electric field strength be 4.20×10^4 N/C? (0.530 m)

$$\overline{E} = \frac{kq}{r^2} \qquad 2.10\times10^4 = \frac{(9.0\times10^9)q}{(0.75)^2} \qquad q = 1.31\times10^{-6} \text{ C}$$

$$4.20\times10^4 = \frac{(9.0\times10^9)(1.31\times10^{-6})}{r^2} \qquad r = 0.530 \text{ m}$$

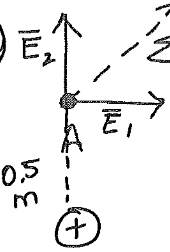
12. Two point charges are placed at the two corners of a square as shown in the diagram.

a) If the magnitude of the net electric field at point A is 2.6×10^5 N/C, what is the magnitude of positive charge Q_2? (4.02×10^{-6} C)

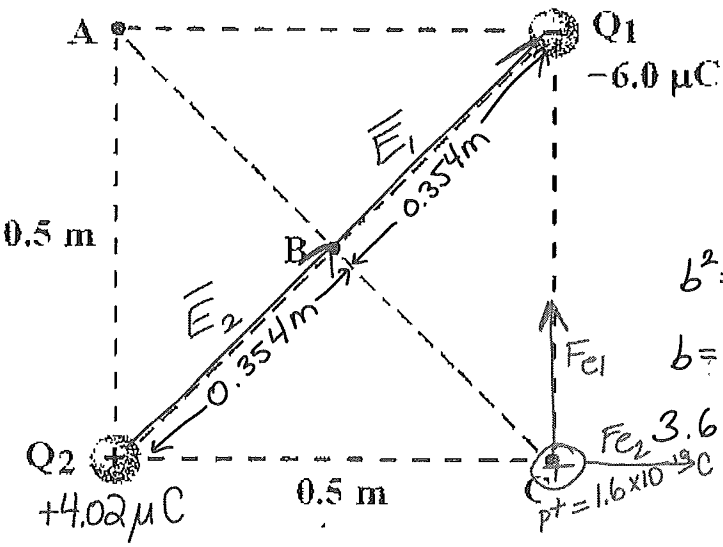
b) What is the magnitude and direction of the net electric field at point B? (7.18×10^5 N/C towards Q_1)

c) If a proton is placed at point C, what is the magnitude and direction of the electric force experienced by the proton? (4.16×10^{-14} N @ 56° N of E)

a)



$\Sigma \vec{E} = 2.6 \times 10^5$ N/C



$\bar{E}_1 = \frac{(9.0\times10^9)(6.0\times10^{-6})}{(0.5)^2}$

$= 2.16 \times 10^5$ N/C

$\bar{E}_2 = \frac{(9.0\times10^9)(q_2)}{(0.5)^2}$

$= 3.6 \times 10^{10} q_2$ N/C

$b^2 = c^2 - a^2$

$b = \sqrt{c^2 - a^2}$

$3.6 \times 10^{10} q_2 = \sqrt{(2.6\times10^5)^2 - (2.16\times10^5)^2}$

$q_2 = 4.02 \times 10^{-6}$ C

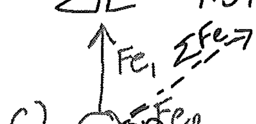
$d_B = \sqrt{0.5^2 + 0.5^2} = 0.707$ m

b) $\bar{E}_1 = \frac{(9.0\times10^9)(6.0\times10^{-6})}{(0.354)^2} = 4.31\times10^5$ N/C

$\bar{E}_2 = \frac{(9.0\times10^9)(4.02\times10^{-6})}{(0.354)^2} = 2.89\times10^5$ N/C

$\Sigma \bar{E} = 4.31\times10^5 + 2.89\times10^5 = 7.18\times10^5$ N/C

c)



$F_{e1} = \frac{(9.0\times10^9)(1.6\times10^{-19})(6.0\times10^{-6})}{(0.5)^2} = 3.46\times10^{-14}$ N

$F_{e2} = \frac{(9.0\times10^9)(1.6\times10^{-19})(4.02\times10^{-6})}{(0.5)^2} = 2.32\times10^{-14}$ N

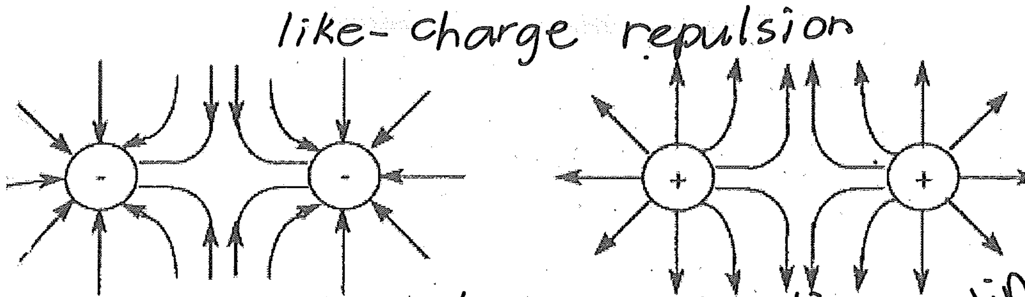
$\Sigma F_e = \sqrt{(3.46\times10^{-14})^2 + (2.32\times10^{-14})^2} = 4.16\times10^{-14}$ N @ 56° N of E

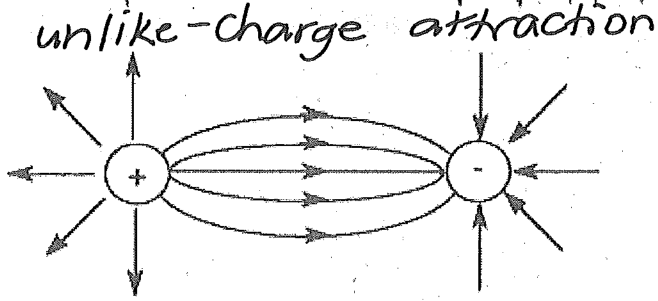
$\tan^{-1}\left(\frac{F_{e1}}{F_{e2}}\right) = 56°$ N of E

Physics 12 – **Electric Field Lines**

Electric field lines are lines that provide information about the direction and strength of the electric field.

We describe electric fields in terms of field lines (or lines of force) –

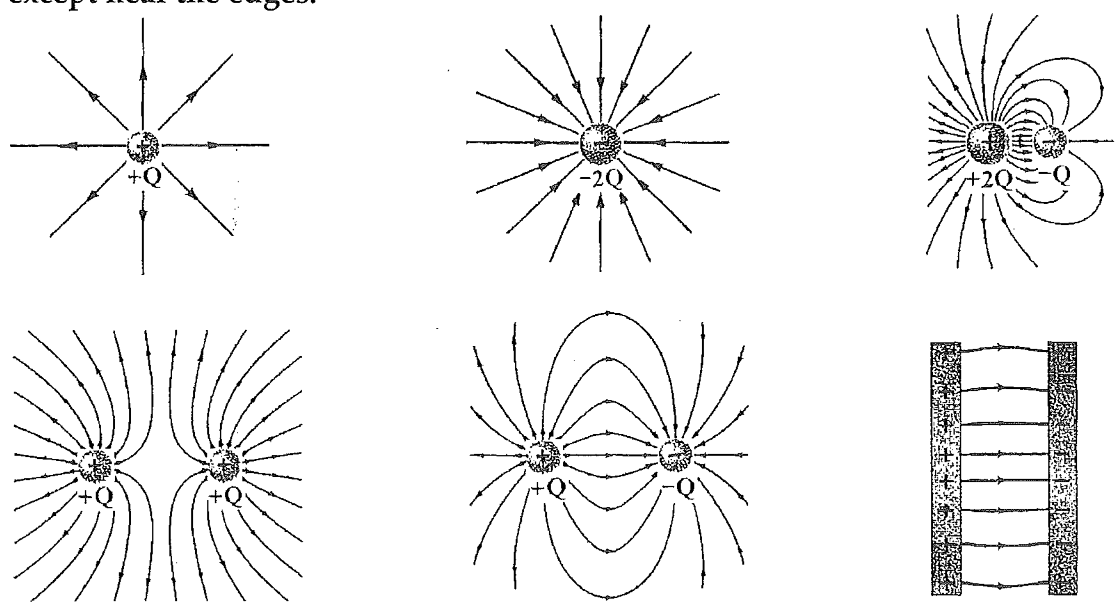




*lines are always drawn toward (-) and away from (+)

Rules for Drawing:

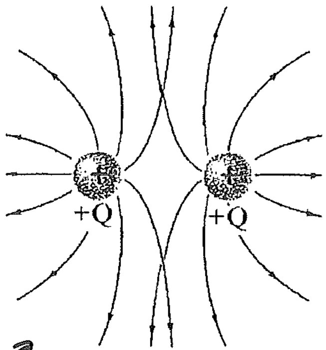
1. **Electric field lines start on positive charges and end on negative charges and the lines never cross.**
2. **The magnitude of the electric field is proportional to the number of lines crossing the unit area perpendicular to the lines.**
3. **The number of lines starting or ending is proportional to the magnitude of the charge.**
4. **The lines between two oppositely charged plates are parallel and equally spaced, except near the edges.**



Electric Field Line Problems:

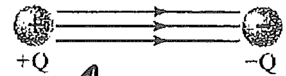
1. The diagrams show the electric field between two charges. There is a mistake in each drawing. Find the mistake and correct it. Explain your answer.

a)



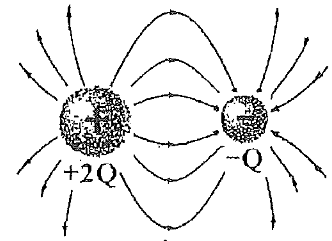
error: ↗ lines cross = can only be one field value at any point

b)



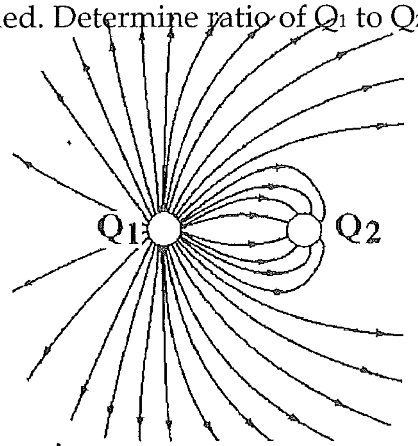
error: ↑ lines are parallel & evenly spaced = distance between charges affects field strength
* stronger closer to charge than at midpoint = lines must be curved

c)



error: too many lines entering −Q
= +2Q is twice as strong so should have twice as many lines coming from it than −Q has going into it.

2. The diagram shows electric field lines for two point charges separated by a small distance. Identify the polarity and relative strength of each charge and explain how you decided. Determine ratio of Q_1 to Q_2.

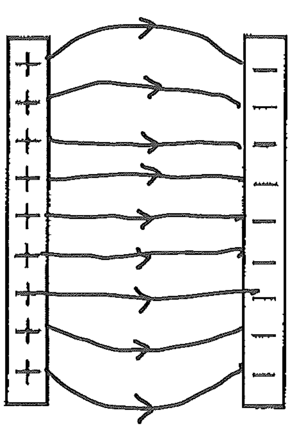


Q_1 = (+) strong
→ all lines coming from Q_1
→ many more lines from Q_1 than Q_2

Q_2 = (−) weak
→ all lines going to Q_2
→ less lines

ratio = $32Q_1 : 8Q_2$ = **$4Q_1 : -Q$**

3. Sketch the electric field lines between oppositely charged parallel plates.



KEY

Where will the Electric Field Strength be ZERO?

Relative to point P, state the direction of E and E_{net} in each case and indicate if E_{net} is zero. Use L for left and R for right.

Distance from X to:

P_1= 0.25cm P_3= 0.75cm

P_2= 0.50cm P_4= 1.25cm

a. X and Y are equal in magnitude and are both positive

	E_x	E_y	E_{net}
P_1	R →	L ←	R
P_2	R →	L ←	0
P_3	R →	L ←	L
P_4	R →	R →	R

b. X and Y are equal in magnitude X is positive but Y is negative

	E_x	E_y	E_{net}
P_1	R →	R	R
P_2	R →	R →	R
P_3	R →	R →	R
P_4	R →	L ←	L

E_{net} = 0 between never / nowhere (only possible between Y & P4 BUT Ex will be very small there & Ey will be very large so they will never cancel)

c. X and Y are positive and X is twice the magnitude of Y

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

$\frac{k2Q}{.75^2} = 3.6kQ$ →

$\frac{kQ}{.25^2} = 16kQ$ ←

	E_x	E_y	E_{net}
P_1	R →	L ←	R
P_2	R →	L ←	R
P_3	R →	L ←	L
P_4	R →	R →	R

E_{net} = 0 between P2 and P3

What would happen to the direction of E if the particles in "c" were both negative? ↳ all the directions would be reversed

Where would E_{net} =0? between P2 & P3 (SAME PLACE)

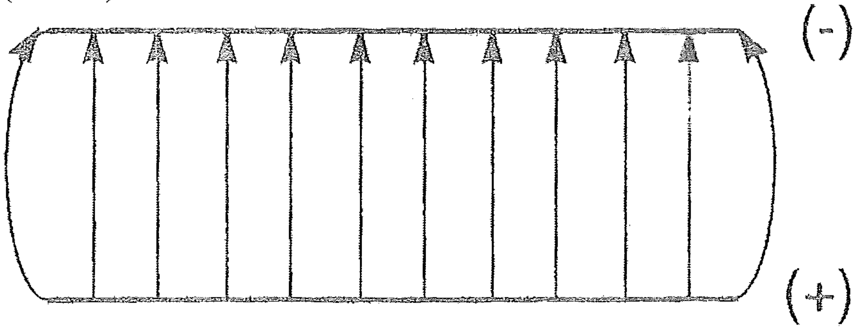
d. Y is negative, X is positive and twice the magnitude of Y

	E_x	E_y	E_{net}
P_1	R	R	R
P_2	R	R	R
P_3	R	R	R
P_4	R	L	L

E_{net} = 0 between never (same reason as in "b.")

Physics 12 – **Electric Potential in a Uniform Electric Field**

When we look at the electric field lines between parallel charged plates we can see that the density of the lines of force is **uniform**. If the field is uniform, the formula that we have been using $\left(\bar{E} = \frac{kq}{r^2}\right)$ **cannot be used to describe this field.**



We need a new formula to describe a **uniform electric field**. In order to describe this field, it is important to look back at some of the concepts we have learned from our study of mechanics in Physics 11 and 12.

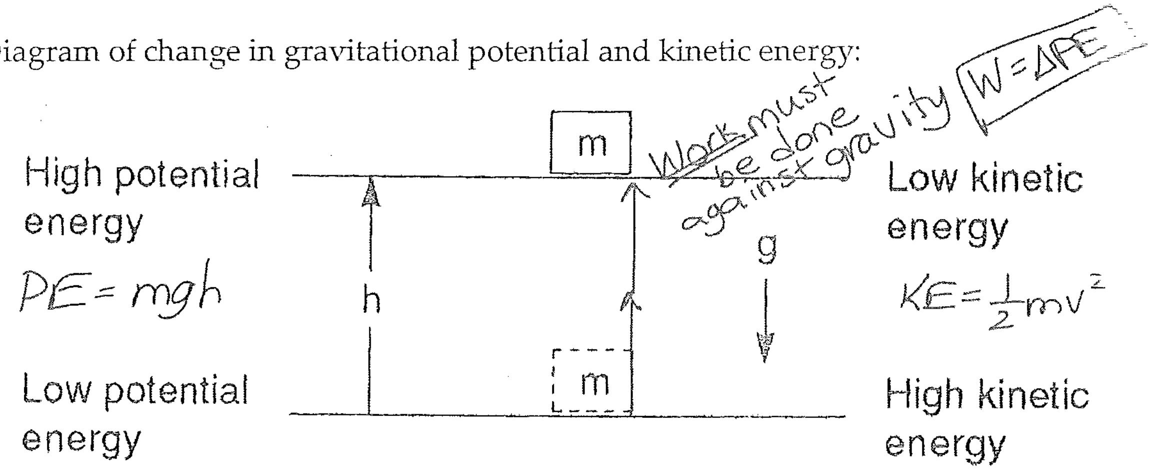
- An object will change its velocity when an unbalanced force acts on it (Newton's First Law of Motion).
- When a mass is allowed to fall in a gravitational field, the mass will accelerate from a position of high gravitational potential energy to a position of low gravitational potential energy due to the force of gravity acting on it (the unbalanced force).
- If we want to move a mass from a position of low gravitational potential energy to a position of higher gravitational potential energy, we do work on the mass against gravity.
  - **Work done against gravity** can be defined as

$$W = \Delta PE = mg\Delta h$$

- From this we see what the **gravitational potential of an object** depends on:
  - mass (kg)
  - change in height (Δh)
  - gravitational field strength (g)

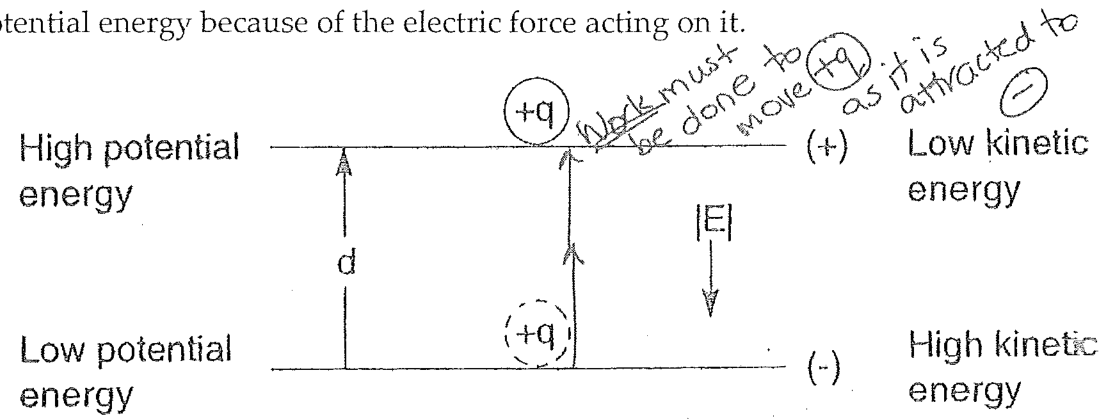
From the Law of Conservation of Energy, the loss in gravitational potential energy of an object becomes kinetic energy. $-\Delta PE = \Delta KE = \frac{1}{2}m\Delta v^2$

Diagram of change in gravitational potential and kinetic energy:



Now, we will look at how this applies **to electrical energy.**

When a charged object is allowed to move in a uniform electric field, the charge will accelerate from a position of high electric potential energy to a position of low electric potential energy because of the electric force acting on it.



If we want to move a charged object against the electric field, then we must do work on the object. This work is represented in terms of:

*work must be done to move ⊕ away from ⊖

in this case: $W = F_e \cdot d$ and $\bar{E} = \frac{F_e}{q}$ or $F_e = q\bar{E}$

so... $W = q\bar{E} \cdot d$

From this, we can see that the electrical potential energy in a uniform field depends on:

- charge of the object
- electric field strength
- distance moved <u>parallel</u> to the force

When studying electricity, we are interested in the electric potential per unit charge.

Energy per unit charge is how electric potential is defined.

Potential Difference (Voltage) -

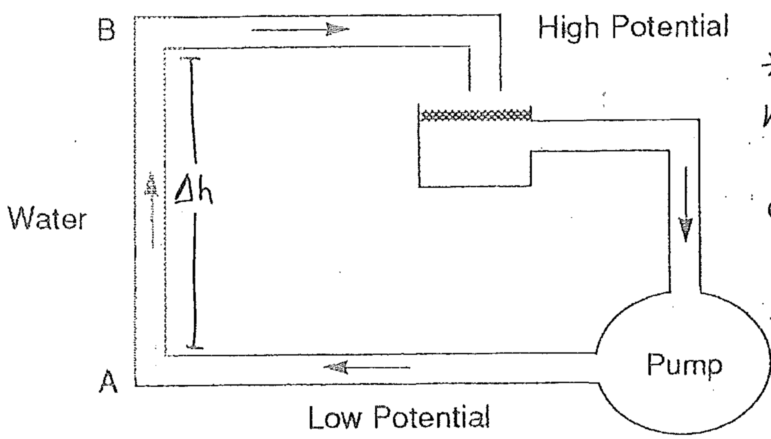
When an electric charge is moved in an electric field, the electric potential may change. This change is what we call the potential difference = voltage.

When we are dealing with a uniform electric field, voltage (V) is a useful quantity.

Voltage = the change in the electric potential, or the change in the electric potential energy per unit charge. *(Scalar Quantity)*

Analogy:

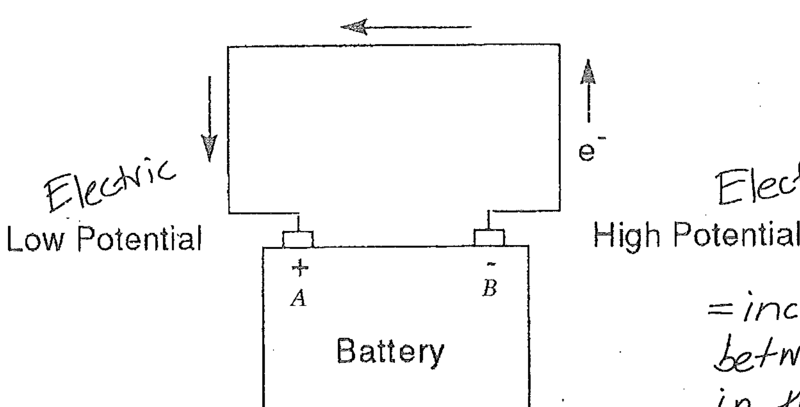
A water pump can increase the gravitational potential energy of water.



*pump pushes the water up(Δh) and increases the potential energy ($mg\Delta h$) of the water.

= the increase in PE occurs between A & B

An increase in electric potential will take place within a battery.



= increase in PE occurs between point A and B in the battery

The Law of Conservation of Energy becomes:

$$\Delta KE = -\Delta PE$$

A negative sign indicates that if kinetic energy is gained, electric potential energy is lost.

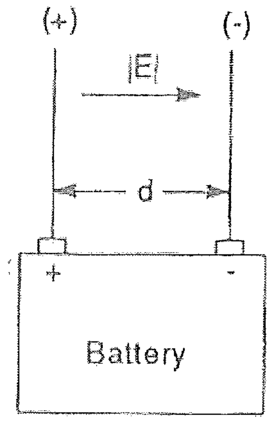
After all of this, we can now think of parallel charge plates (which produce a uniform electric field) as extensions of the terminals of a battery.

The electric field between the parallel plates can be determined in terms of the potential difference between the plates and the distance the plates are apart.

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

V: potential difference (voltage)

d: distance between plates



Voltage is measured in volts (V)

$$V = \frac{\Delta E}{q}$$

Example One: Calculate the electric field strength between two parallel plates that are 6.00 x 10^{-2} m apart. The potential difference between the plates is 12.0 V.

$$E = \frac{V}{d} = \frac{12.0}{6.0 \times 10^{-2}} = 2.00 \times 10^{2}\ V/m$$

Example Two: An electron is accelerated from rest through the potential difference of 3.00x10^4 V. What is the final speed of the electron?

$$\Delta KE = q \cdot V \qquad KE = (1.6 \times 10^{-19})(30000) = 4.8 \times 10^{-15}\ J$$

or

$$V = \frac{\Delta E}{q}$$

$$KE = \frac{1}{2} m v^2$$

$$4.8 \times 10^{-15} = \frac{1}{2}(9.11 \times 10^{-31}) v^2 \qquad v = 1.03 \times 10^{8}\ m/s$$

Example Three: An electron is placed between two horizontal parallel charged plates that are 4.00 cm apart. The potential difference between the plates is 32.0 V.

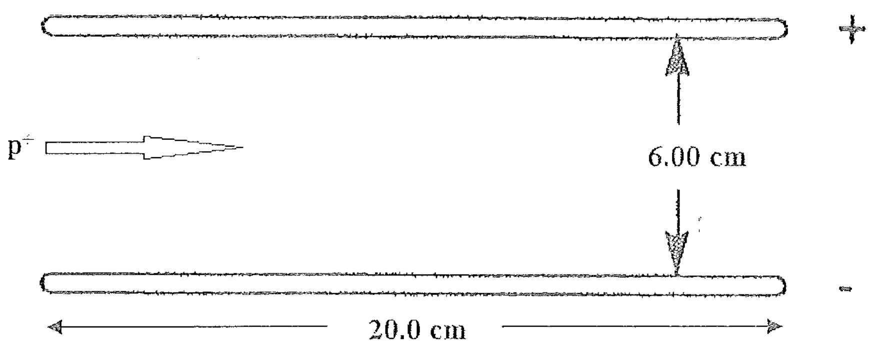
What is the electric force acting on the electron?

$$F_e = q\vec{E} \qquad \vec{E} = \frac{V}{d} = \frac{32.0}{0.04} = 800 \text{ V/m}$$

$$= (1.6\times10^{-19})(800)$$

$$= 1.28\times10^{-16}\ \text{N}$$

Example Four: A proton travelling horizontally at a speed of 1.70 x 10⁵ m/s enters an electric field of 2.40 x 10² N/C between two horizontal parallel plates as illustrated below. Calculate the vertical displacement of the electron as it travels between the plates.



① horizontal speed is constant

use $v = \frac{d}{t}$ to find time of travel

$$1.7\times10^{5} = \frac{0.20}{t} \qquad t = 1.18\times10^{-6}\ \text{s}$$

② Find Force causing change in direction:

$$F_e = q\vec{E} = (1.6\times10^{-19})(2.40\times10^{2}) = 3.84\times10^{-17}\ \text{N}$$

③ $\Sigma F = m\vec{a}$ $\qquad 3.84\times10^{-17} = (1.67\times10^{-27})\vec{a} \qquad \vec{a} = 2.3\times10^{10}\ \text{m/s}^2$

③ use kinematics: $\vec{d} = 0 + \frac{1}{2}(2.3\times10^{10})(1.18\times10^{-6})^2 \qquad \vec{d} = 0.016$ m
w accel

vertical $V_0 = 0$ m/s

or 1.6 cm

Electric Potential-Uniform Field Problems:

1. Two parallel plates are connected to a 12.0 V battery. If the plates are 9.00×10^{-2} m apart, what is the electric field strength between them? (133 V/m)

$$\bar{E} = \frac{V}{d} = \frac{12.0}{9.0 \times 10^{-2}} \qquad \bar{E} = 133\ V/m$$

2. The electric field between two parallel plates is 5.0×10^3 V/m. If the potential difference between the plates is 2.0×10^2 V, how far apart are the plates? (0.040 m)

$$\bar{E} = \frac{V}{d} \qquad 5000 = \frac{200}{d} \qquad d = 0.040\ m$$

3. Two parallel plates are 7.3 cm apart. If the electric field strength between the plates is 2.0×10^3 V/m, what is the potential difference between the plates? (146 V)

$$\bar{E} = \frac{V}{d} \qquad 2000 = \frac{V}{0.073} \qquad V = 146\ V.$$

4. An alpha particle gains 1.50×10^{-15} J of kinetic energy. Through what potential difference was it accelerated? (4.69×10^3 V)

$$\Delta KE = q \cdot V \qquad 1.50 \times 10^{-15} = (3.20 \times 10^{-19})V$$
$$V = 4.69 \times 10^3\ V$$

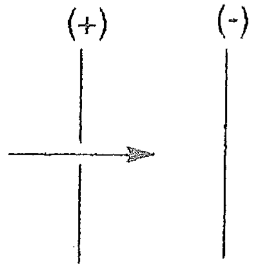
5. What maximum speed will an alpha particle reach if it moves from rest through a potential difference of 7.50×10^3 V? (8.48×10^5 m/s)

$$V = \frac{\Delta E}{q} \qquad 7500 = \frac{\Delta E}{3.2 \times 10^{-19}} \qquad \Delta E = KE = 2.4 \times 10^{-15} J = \frac{1}{2}mv^2$$
$$2.4 \times 10^{-15} = \frac{1}{2}(6.65 \times 10^{-27})v^2$$
$$v = 8.5 \times 10^5\ m/s$$

6. A charged particle was accelerated from rest by a potential difference of 4.20×10^2 V. If this particle increased its kinetic energy to 3.00×10^{-17} J, what potential difference would be needed to increase the kinetic energy of the same particle to 9.00×10^{-17} J? (1.26×10^3 V)

$$3.00 \times 10^{-17} = q \cdot 420 \qquad q = 7.14 \times 10^{-20}\ C$$
$$9.00 \times 10^{-17} = (7.14 \times 10^{-20}) \cdot V \qquad V = 1260\ V$$
$$= 1.26 \times 10^3\ V$$

7. An alpha particle with an initial speed of 7.15 x 10^4 m/s enters through a hole in the positive plate between two parallel plates that are 9.00 x 10^{-2} m apart. If the electric field between the plates is 1.70 x 10^2 V/m, what is the speed of the alpha particle when it reaches the negative plate? (8.12 x 10^4 m/s)



$E = \frac{V}{d}$ $\quad 1.70 \times 10^2 = \frac{V}{0.09}$ $\quad V = 15.3\ V$

$V = \frac{\Delta E}{q}$ $\quad 15.3 = \frac{\Delta E}{3.2 \times 10^{-19}}$ $\quad \Delta E = 4.9 \times 10^{-18} J$

$KE_o + \Delta E = KE_f$

$\left(\frac{1}{2}(6.65 \times 10^{-27})(7.15 \times 10^4)\right) + 4.9 \times 10^{-18} = \frac{1}{2}(6.65 \times 10^{-27}) v^2$ $\quad$ $v = 8.12 \times 10^4 m/s$

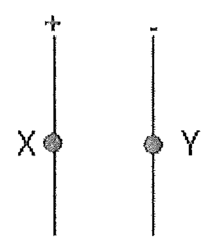
8. What is the electric field strength 1.00 cm from the positive charged plate if the parallel plates are 5.00 cm apart and the potential difference between the plates is 3.00 x 10^2 V? (6000 V/m)

$E = \frac{V}{d} = \frac{300}{0.05} = 6000\ V/m$ (uniform field)

9. A proton accelerates from rest from plate X to plate Y at the same time as an electron accelerates from rest from plate Y to plate X. If the potential difference between the two plates is 60.0 V,

a) What is the speed of the proton when it reaches plate Y? (1.07 x 10^5 m/s)

b) What is the speed of the electron when it reaches plate X? (4.59 x 10^6 m/s)



a) $V = \frac{\Delta E}{q}$ $\quad 60 = \frac{\Delta E}{1.6 \times 10^{-19}}$ $\quad \Delta E = 9.6 \times 10^{-18} J$

$9.6 \times 10^{-18} = \frac{1}{2}(1.67 \times 10^{-27}) v^2$ $\quad$ $v = 1.07 \times 10^5 m/s$

b) charge on p^+ & e^- is the same

$9.6 \times 10^{-18} = \frac{1}{2}(9.11 \times 10^{-31}) v^2$ $\quad$ $v = 4.59 \times 10^6 m/s$

10. An alpha particle is placed between two horizontal parallel charged plates that are 2.00 cm apart. The potential difference between the plates is 12.0 V.

a) What is the electric force acting on the alpha particle? (1.92×10^{-16} N)

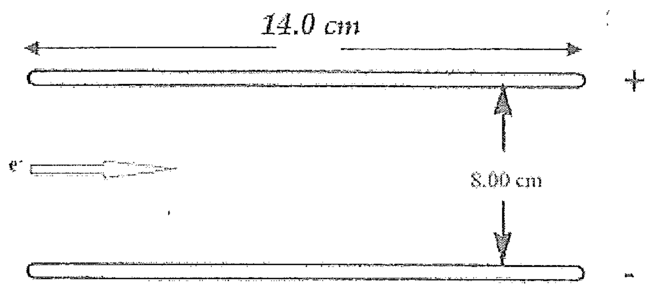
b) What is the gravitational force acting on the alpha particle (on the surface of the Earth)? (6.52×10^{-26} N)

a) $E = \frac{V}{d} = \frac{12.0}{0.02} = 600 \text{ V/m}$ $\quad E = \frac{F_e}{q}$ $\quad 600 = \frac{F_e}{3.2 \times 10^{-19}}$

$F_e = 1.92 \times 10^{-16}$ N

b) $F_g = mg = (6.65 \times 10^{-27})(9.8) = 6.52 \times 10^{-26}$ N

11. An electron travelling horizontally at a speed of 8.70×10^6 m/s enters an electric field of 1.32×10^3 N/C between two horizontal parallel plates as illustrated below. Calculate the vertical displacement of the electron as it travels between the plates. (3.0 cm)



① $8.70 \times 10^6 = \frac{0.14}{t}$

$t = 1.6 \times 10^{-8}$ s

② $E = \frac{F_e}{q}$ $\quad 1320 = \frac{F_e}{(1.6 \times 10^{-19})}$

$F_e = 2.11 \times 10^{-16}$ N

③ $\Sigma F = m\vec{a}$

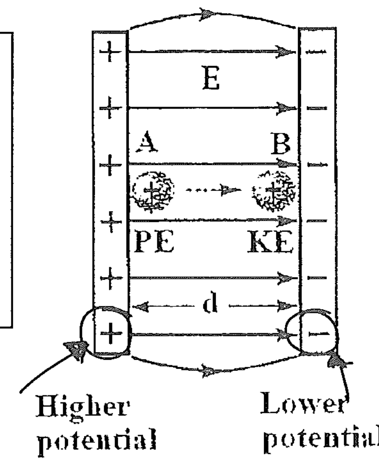
$2.11 \times 10^{-16} = (9.11 \times 10^{-31})\vec{a}$ $\quad \vec{a} = 2.32 \times 10^{14} \text{ m/s}^2$

④ $d = 0 + \frac{1}{2}(2.32 \times 10^{14})(1.6 \times 10^{-8})^2$ $\quad d = 0.030$ m

$= 3.0$ cm

Physics 12 – **Electric Potential Energy and Electric Potential**

> **A positive charge accelerates from a region of higher potential to a region of lower potential.** ⊕ → ⊖
>
> **A negative charge accelerates from a region of lower potential to a region of higher potential.** ⊖ → ⊕



higher electric potential ⊕
lower electric potential ⊖

In terms of energy, when a charge moves, electric potential energy is transformed into kinetic energy, and the total energy is conserved.

$$KE_A + PE_A = KE_B + PE_B$$

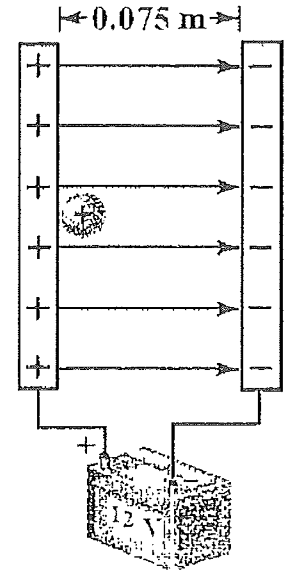
When a positive test charge moves from point A to point B in an electric field, work is done by the electric force. The work equals the difference of the electric potential energy between two points.

$$W = \Delta PE = PE_A - PE_B$$

The electric potential V at a given point is the electric potential energy per unit charge.

$$\underset{(\Delta E)}{W} = \Delta V \cdot q \quad \text{or} \quad V = \frac{\Delta E}{q}$$

Today, we are going to work through more problems dealing with a uniform electric field while including the concept of work.



Example One: A uniform electric field is established by connecting the parallel plates separated by 0.075 m to a 12 V battery as shown in the diagram. A proton is released from rest in the electric field and moves from the positive plate to the negative plate.

a) Find the magnitude of the electric field.

b) Find the change in electric potential energy of the proton. Does the potential energy of the proton increase or decrease?

c) Find the speed of the proton after it has moved 0.075 m.

a) $\bar{E} = \frac{V}{d} = \frac{12}{0.075} = 160\ V/m$

b) $V = \frac{\Delta E}{q}$ ← (ΔPE) $12 = \frac{\Delta PE}{1.60 \times 10^{-19}}$ $\Delta PE = 1.92 \times 10^{-18}\ J$

+ (+) ⟶ −

higher PE lower PE

*decreases as it is moving from high → low

c) $-\Delta PE = \Delta KE$

$-(-1.92 \times 10^{-18}) = \frac{1}{2}(1.67 \times 10^{-27})(v_F^2 - 0^2)$

$v_F = 4.8 \times 10^4\ m/s$

Example Two: Through what potential difference must an electron be accelerated from rest to give it a speed of 6.00 x 10⁶ m/s? (V)

$V = \frac{\Delta E}{q}$ $\Delta E = \Delta KE = \frac{1}{2}(9.11 \times 10^{-31})((6.0 \times 10^6)^2 - 0^2)$

$= 1.64 \times 10^{-17}\ J$

$V = \frac{1.64 \times 10^{-17}}{1.6 \times 10^{-19}}$ $V = 102\ V$

Electric Potential Energy and Electric Potential Assignment **Name:**

1. A proton is held between two charged parallel plates.

   a) If a proton moves in the direction of the electric field, what happens to the electric potential? (decreases)

   b) If the proton moves in the electric field from point A with a potential 50 V to point B with a potential of 200 V, how much work is done? (2.4×10^{-17} J)

   c) If the electric potential is constant between two plates, what happens to the electric field? (0)

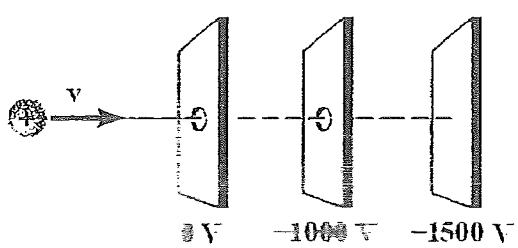
a) $\oplus \xrightarrow{\bar{E}}$ electric potential decreases (high → low)

\+ ——→—— −

b) $W = \Delta V \cdot q = (200 - 50)(1.6 \times 10^{-19}) = 2.4 \times 10^{-17}\ \text{J}$

c) $\bar{E} = \frac{V}{d}$ so if there is no potential difference $V = 0$ $\bar{E} = \frac{0}{d} = 0$

2. A proton with kinetic energy of 1.2×10^{-16} J moves into a series of charged parallel plates as shown. What is the impact speed on the third plate? (6.57×10^{5} m/s)



$\Delta V = \frac{\Delta E}{q} = \frac{\Delta PE}{q}$

$-1500 = \frac{\Delta PE}{1.6 \times 10^{-19}}$

$\Delta PE = -2.4 \times 10^{-16}\ \text{J}$

↓ PE lost = KE gained

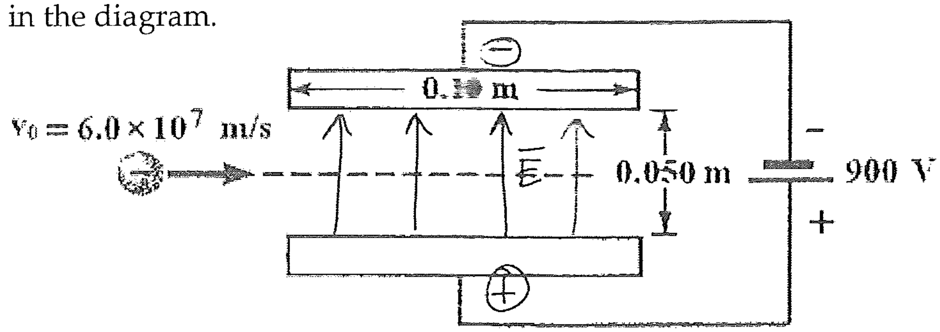
$\Delta KE = +2.4 \times 10^{-16}\ \text{J}$

(KE at start) + (↑KE)

$1.2 \times 10^{-16} + 2.4 \times 10^{-16} = \frac{1}{2}(1.67 \times 10^{-27})v^2$

$v = 6.57 \times 10^{5}\ \text{m/s}$

3. An electron is projected into the electric field with an initial speed of 6.0 x 10^7 m/s as shown in the diagram.



a) Find the magnitude and direction of the electric field between the plates. (18000 V/m [up]

b) Find the magnitude and direction of the electric force on the electron while it is between the plates. (2.88 x 10^{-15} N [down]

c) Find the acceleration of the electron while it is between the plates. (3.16 x 10^{15} m/s^2 [down]

a) $\vec{E} = \frac{V}{d} = \frac{900}{0.05} = 18{,}000$ V/m [upward] (field always moves from ⊕ to ⊖)

b) $\vec{E} = \frac{F_e}{q}$ $\quad 18\,000 = \frac{F_e}{(1.6\times10^{-19})}$ $\quad F_e = 2.88\times10^{-15}$ N [down] (⊖ will be pulled toward ⊕)

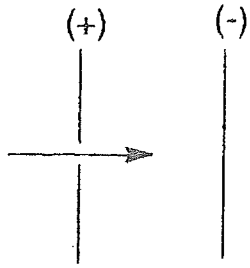
c) $\Sigma F = m\vec{a}$ $\quad 2.88\times10^{-15} = (9.11\times10^{-31})\vec{a}$

$\vec{a} = 3.16\times10^{15}$ m/s^2 [down]

4. A proton is accelerated by a potential difference of 7.20 x 10^2 V. What is the change in kinetic energy of the proton? (1.15 x 10^{-16} J)

$V = \frac{\Delta E}{q} = \frac{\Delta KE}{q}$ $\quad 720 = \frac{\Delta KE}{1.6\times10^{-19}}$ $\quad \Delta KE = 1.15\times10^{-16}$ J

5. An electron with a speed of 5.0 x 10^5 m/s enters through a hole in the positive plate and collides with the negative plate at a speed of 1.0 x 10^5 m/s. What is the potential difference between the plates? (0.681 V)



$V = \frac{\Delta E}{q} = \frac{\Delta KE}{q}$ $KE_0 - KE_f = \Delta KE$

$= \left(\frac{1}{2}(9.11\times10^{-31})(5.0\times10^{5})^2\right) - \left(\frac{1}{2}(9.11\times10^{-31})(1.0\times10^{5})^2\right)$

$= 1.09\times10^{-19}\ J$

$V = \frac{1.09\times10^{-19}}{1.6\times10^{-19}}$ $V = 0.681\ V$

6. If an alpha particle is accelerated from rest through a distance of 4.00 cm by a uniform electric field in 2.50 x 10^{-5} s, what is the electric field strength? (2.66 N/C)

$F_e = q\bar{E}$

$0.04 = 0 + \frac{1}{2}(\vec{a})(2.5\times10^{-5})^2$ $\vec{a} = 1.28\times10^{8}\ m/s^2$

$\Sigma F_e = m\vec{a} = (6.65\times10^{-27})(1.28\times10^{8})$

$= 8.51\times10^{-19}\ N$

$8.51\times10^{-19} = (3.20\times10^{-19})\bar{E}$

$\bar{E} = \boxed{2.66\ N/C}$

7. An electric field of 2.40 x 10^2 N/C is produced by two horizontal parallel plates set 4.00cm apart. If a charged particle of 2.00 μC is moved 3.00 cm **perpendicular** to the electric field, what is the work done against the electric field? (0 J)

→ F_e is not in the same direction as displacement → NO work done

8. A charged particle (2.0 x 10^{-17} kg) accelerated from rest by a potential difference of 2.50 x 10^5 V. If the particle reached a maximum speed of 2.90 x 10^4 m/s what potential difference would be required to accelerate this particle from rest to a velocity of 7.25 x 10^4 m/s? (1.6 x 10^6 V)

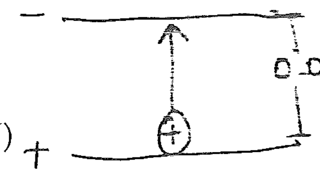
$V = \frac{\Delta KE}{q}$ $\Delta KE = \frac{1}{2}(2.0\times10^{-17})((2.90\times10^{4})^2 - 0^2) = 8.0\times10^{-9}\ J$

$2.50\times10^{5} = \frac{8.0\times10^{-9}}{q}$ $q = 3.20\times10^{-14}\ C$

$V = \frac{\Delta KE}{q}$ $\Delta KE = \frac{1}{2}(2.0\times10^{-17})((7.25\times10^{4})^2 - 0^2) = 5.2\times10^{-8}\ J$

$V = \frac{5.2\times10^{-8}}{3.20\times10^{-14}}$ $V = 1.6\times10^{6}\ V$

9. An alpha particle is placed between two horizontal parallel charged plates that are 2.00 cm apart. The potential difference between the plates is 12.0 V.



a) What is the electric force acting on the alpha particle? (1.92×10^{-16} N)

b) What is the gravitational force acting on the alpha particle? (6.52×10^{-26} N)

c) If it assumed that the electric force and the gravitational force are acting in opposite directions, what is the net force acting on the alpha particle? (1.92×10^{-16} N)

d) What is the acceleration of the alpha particle? (2.89×10^{10} m/s²)

e) What potential difference would be required between the plates so that the alpha particle becomes suspended? (4.0×10^{-9} V)

a) $\bar{E} = \frac{V}{d} = \frac{12.0}{0.02} = 600\ V/m$ $\quad F_e = q \cdot \bar{E} = (3.20 \times 10^{-19})(600) = \underline{1.92 \times 10^{-16}\ N}$

b) $F_g = (6.65 \times 10^{-27})(9.8) = \underline{6.52 \times 10^{-26}}\ N$

c) $\Sigma F = F_e + F_g = 1.92 \times 10^{-16} + (-6.52 \times 10^{-26}) = \underline{1.92 \times 10^{-16}}\ N$

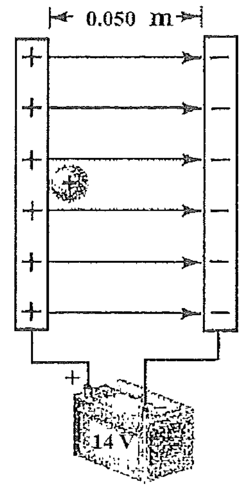
d) $\Sigma F = m\vec{a} \quad 1.92 \times 10^{-16} = (6.65 \times 10^{-27})\vec{a} \quad \underline{\vec{a} = 2.89 \times 10^{10}\ m/s^2}$

e) F_e will need to balance F_g $\quad \Sigma F = 0\ N$

$F_e = 6.52 \times 10^{-26}\ N \quad \bar{E} = \frac{F_e}{q} = \frac{6.52 \times 10^{-26}}{3.20 \times 10^{-19}} = 2.03 \times 10^{-7}\ N/C$

$\bar{E} = \frac{V}{d} \quad 2.03 \times 10^{-7} = \frac{V}{0.02} \quad \underline{V = 4.0 \times 10^{-9}\ V}$

10. A uniform electric field is established by connecting the parallel plates separated by 0.050 m to a 14 V battery as shown. An alpha particle is released from rest in the electric field and moves from the positive plate to the negative plate.



a) Find the magnitude of the electric field. (280 V/m)

b) Find the change in electric potential energy of the alpha particle. (4.48×10^{-18}J)

c) Find the speed of the proton after it has moved 0.050 m. (3.67×10^4 m/s)

a) $\bar{E} = \frac{V}{d} = \frac{14}{0.050} = 280\ V/m$

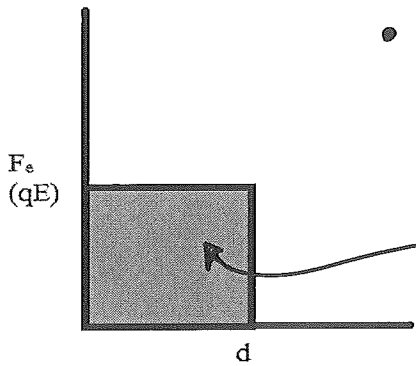
b) $V = \frac{\Delta E}{q}$ $14 = \frac{\Delta PE}{3.20 \times 10^{-19}}$ $\Delta PE = 4.48 \times 10^{-18}\ J$

c) $4.48 \times 10^{-18} = \frac{1}{2}(6.65 \times 10^{-27})(v_F^2 - 0^2)$ $V_F = 3.67 \times 10^4\ m/s$

Physics 12 – **Electric Potential and Potential Energy of Point Charges**

If a charged object is in an electric field, it has electric potential energy (E_P). Just as any other type of potential energy, this means that work was done on the charged object to move it into its current position. It now has the potential to move in the field when it is "let go".

In a **uniform electric field** (such as one that exists between two charged parallel plates), **work done is equal to the electric potential energy** gained by the charged object.

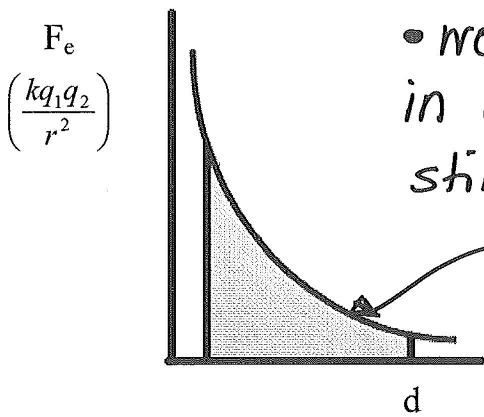


- Work done against the electric force

$\rightarrow W_e = F_e \cdot d = qE \cdot d$

= area under the graph line

In the non-uniform electric field caused by a point charge, the electric potential energy cannot be found as easily, but the reasoning is the same.



- work done in moving a charge in a non-uniform field is still equal to ΔPE_e

* area under the graph

This area (the electric potential energy) can be determined to be:

$$PE_e = \frac{kq_1q_2}{r}$$

Electric potential (V) is defined as the electric potential energy per unit charge.

$$V = \frac{PE}{q_2}$$ q_2 = charge of test object

From this definition, we can derive the equation:

$$V_{point} = \frac{kq_1}{r}$$ q_1 = charge of the object producing the PE_e

Derivation:

$$V = \frac{E_p}{q_2} \rightarrow V = \frac{\frac{kq_1 q_2}{r}}{q_2} \quad \text{OR} \quad V = \frac{kq_1}{r}$$

* the test charge cancels so we are left with the charge of the object producing the electric potential.

Important Note: The electric potential at a point is defined in terms of the moving of a positive charge. Therefore, V can be positive or negative.

Finding the Electric Potential Between Two Points = Potential Difference

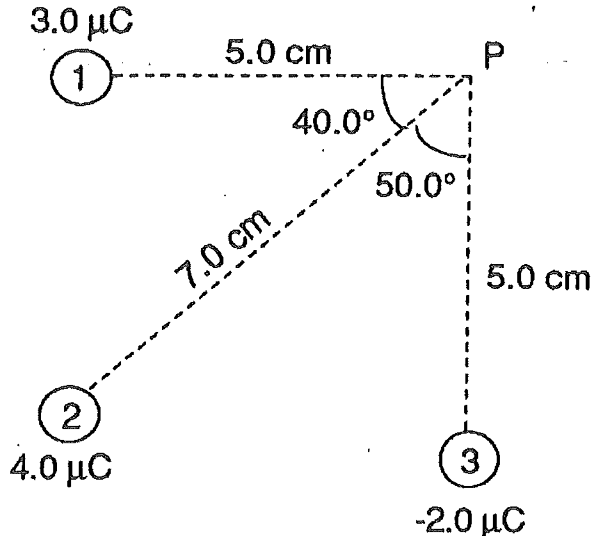
Given two points, A and B, the potential difference between A and B is:

V_{AB}	=	V_B	–	V_A
potential difference betw. A and B	=	Electric potential at B	–	Electric potential at A

When we are dealing with the potential at a point, we are actually talking about the potential difference between that point and infinity. The potential at infinity is assigned a value of zero.

Example One:

Calculate the potential at point P.



① Find the potential due to each charge

$V_1 = \frac{kq_1}{r_1} = \frac{(9.0\times10^9)(3.0\times10^{-6})}{(0.05)}$

$V_1 = 5.4\times10^5$ V

$V_2 = \frac{kq_2}{r_2} = \frac{(9.0\times10^9)(4.0\times10^{-6})}{(0.07)}$

$V_2 = 5.14\times10^5$ V

$V_3 = \frac{kq_3}{r_3} = \frac{(9.0\times10^9)(2.0\times10^{-6})}{(0.05)}$

$V_3 = -3.6\times10^5$ V

(potential due to (−) charges are neg. (+ test charge))

Add potentials:

*note: potentials are not vector quantities

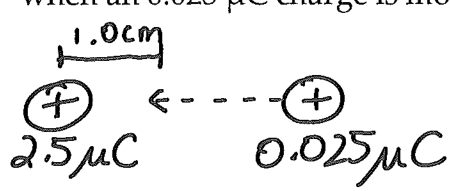
$V_T = V_1 + V_2 + V_3$

$= 5.4\times10^5 + 5.14\times10^5 + (-3.6\times10^5)$

$= 6.9\times10^5$ V

Example Two:

How much work is done against an electric field produced by a 2.5 μC charged object when an 0.025 μC charge is moved from r = 3.0 cm to r = 1.0 cm?



$W = \Delta E \rightarrow \Delta V = \frac{\Delta E}{q_2}$

$1.50\times10^6 = \frac{\Delta E}{(2.5\times10^{-8})}$

$W = 3.75\times10^{-2}$ J

Find ΔV by finding V at each point for 2.5μC (* the charge producing the field)

$V_{point} = \frac{kq_1}{r}$

$V_1 = \frac{(9.0\times10^9)(2.5\times10^{-6})}{0.03} = 7.5\times10^5$ V ← r_o

$V_2 = \frac{(9.0\times10^9)(2.5\times10^{-6})}{0.01} = 2.25\times10^6$ V ← r_f

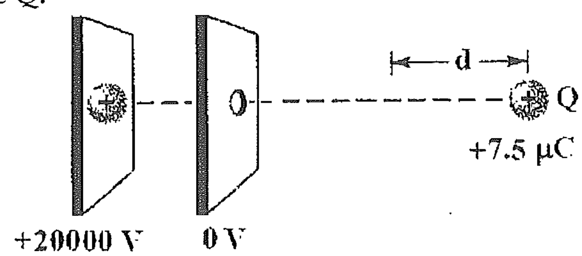
$\Delta V = 2.25\times10^6 - 7.5\times10^5$

$= 1.50\times10^6$ V

Example Three – A proton is accelerated from rest through a potential difference of 20000V and moves toward a fixed +7.5 μC charge Q.

a) Find the speed of the proton when it leaves the parallel plates.

b) Find the distance (d) from the fixed charge Q when the proton stops.



a) PE_e will convert to KE

$\Delta V = \frac{\Delta PE}{q}$ $20000 = \frac{\Delta PE}{(1.6\times10^{-19})}$ $\Delta PE = 3.2\times10^{-15}\,J$

$3.2\times10^{-15} = \frac{1}{2}(1.67\times10^{-27})v^2$

$v = 1.96\times10^{6}\ m/s$

b) KE will convert back into PE_e

☆ conservation of E → $PE_e = 3.2\times10^{-15}\,J$

$PE_e = \frac{kq_1q_2}{r}$ $3.2\times10^{-15} = \frac{(9.0\times10^{9})(7.5\times10^{-6})(1.6\times10^{-19})}{r}$

$r = 3.38\,m$

Potential Energy at a Point Problems

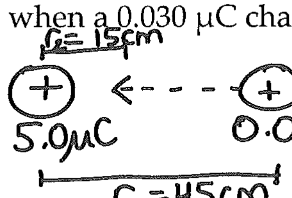
1. What is the potential at a distance of 6.0 cm from a 2.5 μC charge? (3.75×10^5 V)

$$V = \frac{kq}{r} = \frac{(9.0\times10^{9})(2.5\times10^{-6})}{(0.06)} = 3.75\times10^{5}\ V$$

2. What is the potential at a distance of 25 cm from a -2.5 μC charge? (-9.00×10^4 V)

$$V = \frac{kq}{r} = \frac{(9.0\times10^{9})(2.5\times10^{-6})}{(0.25)} = -9.00\times10^{4}\ V$$

3. How much work is done against the electric field produced by a 5.0 μC charged object when a 0.030 μC charge is moved from r = 45 cm to r = 15 cm? (6.0×10^{-3} J)



$$V_1 = \frac{(9.0\times10^{9})(5.0\times10^{-6})}{(0.45)} = 1.00\times10^{5}\ V$$

$$V_2 = \frac{(9.0\times10^{9})(5.0\times10^{-6})}{(0.15)} = 3.00\times10^{5}\ V$$

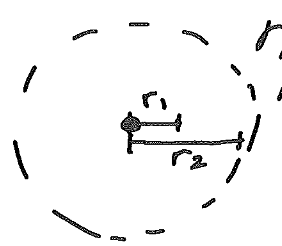
$$\Delta V = 3.00\times10^{5} - 1.00\times10^{5} = 2.00\times10^{5}\ V$$

$$W = q\Delta V$$

$$W = (3.0\times10^{-8})(2.00\times10^{5})$$

$$W = 6.0\times10^{-3}\ J$$

4. A proton released 2.0×10^{-11} m from the center of a 6.4×10^{-18} C charged sphere. What is the speed of this proton when it is 0.50 m from this center?



$r_1 = 2.0\times10^{-11}$ m

$r_2 = 0.50$ m

$$V_1 = \frac{(9.0\times10^{9})(6.4\times10^{-18})}{(2.0\times10^{-11})} = 2880\ V$$

$$V_2 = \frac{(9.0\times10^{9})(6.4\times10^{-18})}{(0.50)} = 1.15\times10^{-7}\ V$$

$$\Delta V = 1.15\times10^{-7} - 2880 = -2880\ V$$

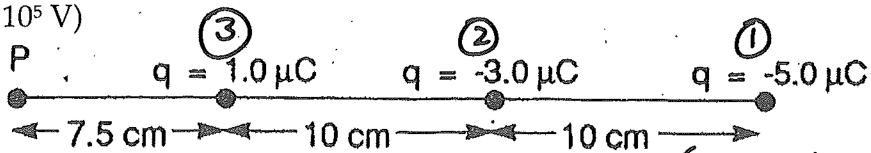
$$\Delta V = \frac{\Delta PE_e}{q} \quad -2880 = \frac{\Delta PE_e}{1.6\times10^{-19}}$$

$$\Delta PE_e = -4.61\times10^{-16}\ J$$

$$4.61\times10^{-16} = \frac{1}{2}(1.67\times10^{-27})v^2$$

$$v = 7.43\times10^{5}\ m/s$$

5. Three charges are located on a line as shown below. Find the potential at point P. (-1.98 x 10^5 V)



$V_T = V_1 + V_2 + V_3 = -1.64 \times 10^5 + (-1.54 \times 10^5) + 1.2 \times 10^5$

$V_1 = \frac{(9.0 \times 10^9)(5.0 \times 10^{-6})}{0.275} = -1.64 \times 10^5 \text{ V}$

$V_T = -1.98 \times 10^5 \text{ V}$

$V_2 = \frac{(9.0 \times 10^9)(3.0 \times 10^{-6})}{0.175} = -1.54 \times 10^5 \text{ V}$

$V_3 = \frac{(9.0 \times 10^9)(1.0 \times 10^{-6})}{0.075} = 1.2 \times 10^5 \text{ V}$

6. The centers of two alpha particles are held 2.5 x 10^{-12} m apart and then released. Calculate the speed of each alpha particle when they are 0.75 m apart. (2.4 x 10^5 m/s)

$KE_o + PE_o = KE_f + PE_f$

$0 + \frac{kq_1q_2}{r_1} = \left(\frac{1}{2}m_1v^2 + \frac{1}{2}m_2v^2\right) + \frac{kq_1q_2}{r_2}$

$\frac{(9.0 \times 10^9)(3.2 \times 10^{-19})^2}{2.5 \times 10^{-12}} = (6.65 \times 10^{-27} v^2) + \frac{(9.0 \times 10^9)(3.2 \times 10^{-19})^2}{0.75}$

$3.69 \times 10^{-16} = 6.65 \times 10^{-27} v^2$

$v = 2.4 \times 10^5 \text{ m/s}$

* PE & KE so need to use cons of E not $\Delta V = \frac{\Delta E}{q}$

7. In moving a 3.00 μC charge at a constant speed from point A to point B, 4.40 x 10^{-5} J of work is done. If A and B are 2.4 cm apart, what is the potential difference between A and B? (14.7 V)

$W = \Delta E = 4.40 \times 10^{-5} \text{ J}$

$\Delta V = \frac{\Delta E}{q} = \frac{4.40 \times 10^{-5}}{(3.0 \times 10^{-6})}$

$\Delta V = 14.7 \text{ V}$

8. In a hydrogen atom, an electron is separated from a proton by a distance of 5.3×10^{-11} m.

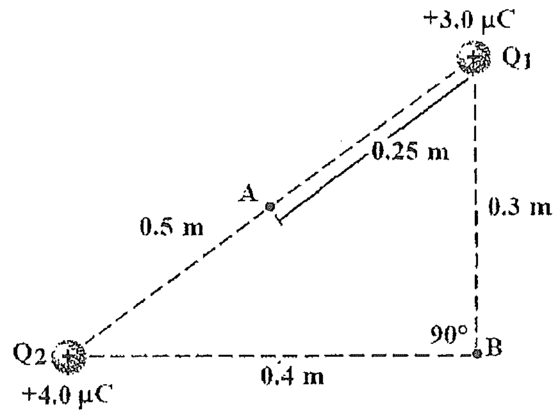
a) What is the electric potential at a distance of 5.3×10^{-11} m from the proton? (27.2 V)

b) What is the potential energy of the electron and proton at this distance? (-4.3×10^{-18} J)

a) $V = \frac{kq}{r} = \frac{(9.0\times10^{9})(1.6\times10^{-19})}{5.3\times10^{-11}} = \underline{27.2\ V}$

b) $PE_e = \frac{kq_1q_2}{r} = \frac{(9.0\times10^{9})(1.6\times10^{-19})(-1.6\times10^{-19})}{5.3\times10^{-11}} = \underline{-4.3\times10^{-18}\ J}$

9. Two point charges are placed as shown in the diagram.



a) What are the electric potentials at point A and at point B due to two point charges? (A: 2.52×10^5 V, B: 1.80×10^5 V)

b) What is the electric potential difference between points A and B? (7.2×10^4 V)

c) How much work must be done to move the charge Q_1 to point B? (5.4×10^{-2} J)

A:

a) $V_T = V_1 + V_2$ $\quad V_1 = \frac{(9.0\times10^{9})(3.0\times10^{-6})}{0.25} = 1.08\times10^{5}\ V$

$V_2 = \frac{(9.0\times10^{9})(4.0\times10^{-6})}{0.25} = 1.44\times10^{5}\ V$

$V_{T_A} = 2.52\times10^{5}\ V$

B: $V_T = V_1 + V_2$ $\quad V_1 = \frac{(9.0\times10^{9})(3.0\times10^{-6})}{0.30} = 9.0\times10^{4}\ V$

$V_2 = \frac{(9.0\times10^{9})(4.0\times10^{-6})}{0.40} = 9.0\times10^{4}\ V$

$V_{T_B} = 1.80\times10^{5}\ V$

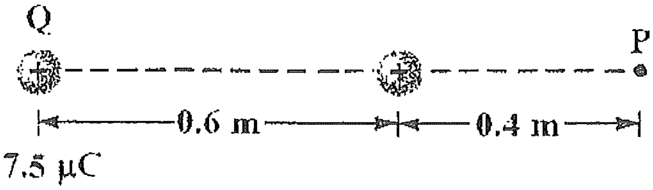
b) $\Delta V = 2.52\times10^{5} - 1.80\times10^{5} = 7.2\times10^{4}\ V$

c) $W = \Delta PE = PE_{e_f} - PE_{e_o} = \frac{kq_1q_2}{r_f} - \frac{kq_1q_2}{r_o}$

$= \frac{(9.0\times10^{9})(3.0\times10^{-6})(4.0\times10^{-6})}{0.40} - \frac{(9.0\times10^{9})(3.0\times10^{-6})(4.0\times10^{-6})}{0.50}$

$= 0.270 - 0.216 = \underline{5.4\times10^{-2}\ J}$

10. A proton is separated initially at rest from a fixed point charge Q by a distance of 0.60m. If the proton is released, what is the speed of the proton at point P? (2.94×10^6 m/s)



$$KE_o + PE_o = KE_f + PE_f$$

$$0 + \frac{kq_1q_2}{r} = \frac{1}{2}mv^2 + \frac{kq_1q_2}{r}$$

$$\frac{(9.0\times10^9)(7.5\times10^{-6})(1.6\times10^{-19})}{0.60} = \frac{1}{2}(1.67\times10^{-27})v^2 + \frac{(9.0\times10^9)(7.5\times10^{-6})(1.6\times10^{-19})}{1.0}$$

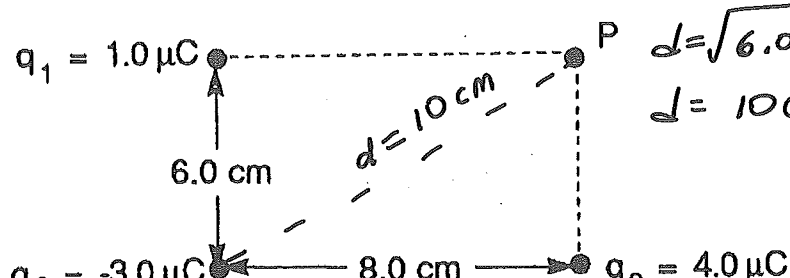
$$1.8\times10^{-14} = 8.35\times10^{-28}v^2 + 1.08\times10^{-14}$$

$$v = 2.94\times10^6 \text{ m/s}$$

11. Three charges are located at the corners of a rectangle as shown. Find the potential at point P. (4.43×10^5 V)

Again... V is scalar

$V_T = V_1 + V_2 + V_3$



$d = \sqrt{6.0^2 + 8.0^2}$

$d = 10$ cm

$$V_1 = \frac{kq_1}{r_1} = \frac{(9.0\times10^9)(1.0\times10^{-6})}{0.08}$$

$$V_1 = 1.13\times10^5 \text{ V}$$

$$V_2 = \frac{kq_2}{r_2} = \frac{(9.0\times10^9)(3.0\times10^{-6})}{(0.10)}$$

$$V_2 = -2.7\times10^5 \text{ V}$$

$$V_3 = \frac{kq_3}{r_3} = \frac{(9.0\times10^9)(4.0\times10^{-6})}{(0.06)}$$

$$V_3 = 6.0\times10^5 \text{ V}$$

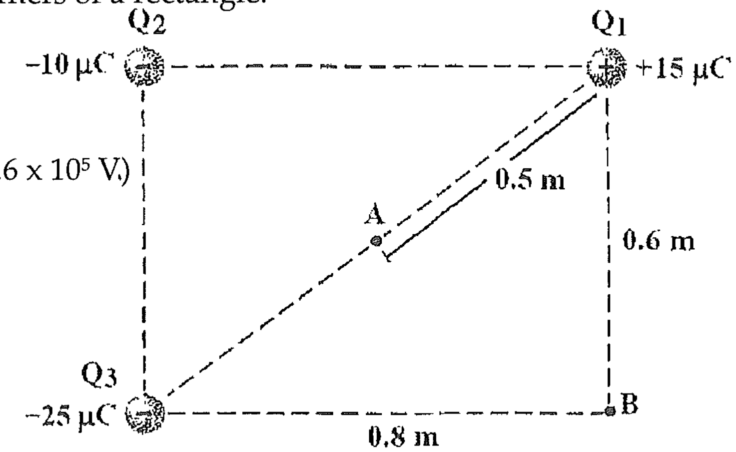
$$V_T = 1.13\times10^5 + (-2.7\times10^5) + 6.0\times10^5$$

$$= 4.43\times10^5 \text{ V}$$

12. The diagram shows three charges at the corners of a rectangle.

a) How much work must be done to move the charge Q_2 to point B? (1.5 J)

b) What is the electric potential at point A? (-3.6×10^5 V.)



a) $W = \Delta PE_e$

$= PE_{e_f} - PE_{e_o}$

$= \left(\frac{kq_1q_2}{r_{f_1}} + \frac{kq_1q_2}{r_{f_3}}\right) - \left(\frac{kq_1q_2}{r_{o_1}} + \frac{kq_1q_2}{r_{o_3}}\right)$

$= \left(\frac{9.0\times10^9 \cdot -10\mu C \cdot 15\mu C}{0.8} + \frac{9.0\times10^9 \cdot -10\mu C \cdot -25\mu C}{0.6}\right) - \left(\frac{9.0\times10^9 \cdot -10\mu C \cdot 15\mu C}{0.6} + \frac{9.0\times10^9 \cdot -10\mu C \cdot -25\mu C}{0.8}\right)$

$= (-1.6875 + 3.75) - (-2.25 + 2.8125)$

$= 1.5\ J$

b) $V_T = V_1 + V_2 + V_3$

$= \frac{kq_1}{r_1} + \frac{kq_2}{r_2} + \frac{kq_3}{r_3}$

$= \frac{(9.0\times10^9)(15\mu C)}{0.50} + \frac{(9.0\times10^9)(-10\mu C)}{0.50} + \frac{(9.0\times10^9)(-25\mu C)}{0.50}$

$= 2.70\times10^5 + (-1.80\times10^5) + (-4.50\times10^5)$

$= -3.6\times10^5\ J$