Electric and Magnetic Fields

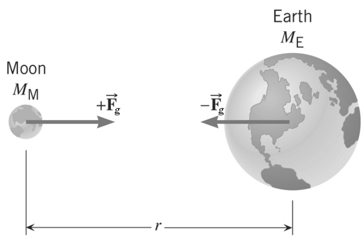
Gravitational Force

Gravitational Mass - the property of an object that determines how much gravitational force it feels when near another object with mass

Types: one type only

Symbol: m **Units:** kg

1 kg = the mass of a standard cylinder of platinum-iridium alloy kept at the International Bureau of Weights and Measures in Sèvres, France



$$F_g = \frac{G \cdot m_1 \cdot m_2}{r^2}$$

Universal Gravitational Constant :
G = 6.77 x 10^{-11} N m^2/kg^2

Newton's Universal Law of Gravitation
The force of gravity between two objects is directly proportional to the product of the two masses and inversely proportional to the square of the distance between them and acts along a line joining their centers. (Note: The masses act as point masses.)

Electric Force

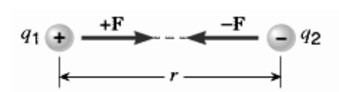
Electric Charge - the property of an object that determines how much electric force it feels when near another object with charge

Types: two types – positive and negative

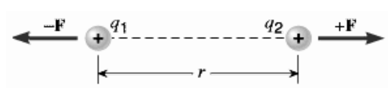
Symbol: q **Units:** e or C

e = elementary unit of charge (magnitude of charge on electron)

1 e = 1.60 x 10^{-19} C



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



$$F_e = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

Coulomb constant (electrostatic constant):
k =1/($4\pi\varepsilon_0$) = 8.99 x 10^9 N·m^2/C^2

ε_0 = permittivity of free space
= 8.85 x 10^{-12} $C^2/(N\ m^2)$

Coulomb's Law – The electric force between two point charges is directly proportional to the product of the two charges and inversely proportional to square of the distance between them, and acts along the line joining the two charges. (Note: The charges act as point charges.)

Conservation of Electric Charge: The total electric charge of an isolated system remains constant.

Example: Find the gravitational force of attraction between the proton and the electron in a hydrogen atom.

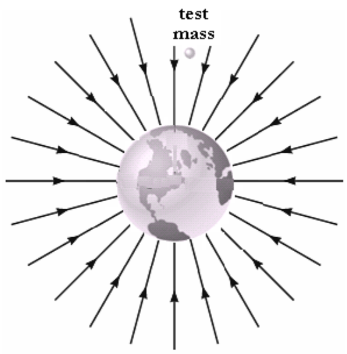
Example: Find the Coulomb force of attraction between the proton and the electron in a hydrogen atom.

Force Fields

Force field (field of force):

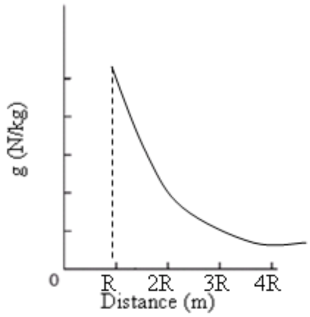
Gravitational Field

Gravitational Field Strength (g) – gravitational force per unit mass on a point mass

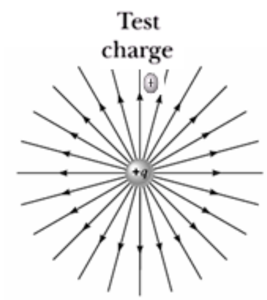


Formula: $g = \frac{F_g}{m}$ $\quad$ $g = \frac{G \cdot M}{r^2}$

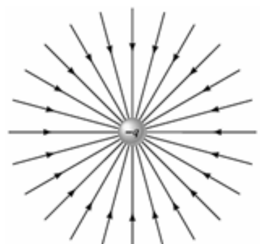
Units: $\frac{N}{kg}$ or $\frac{m}{s^2}$



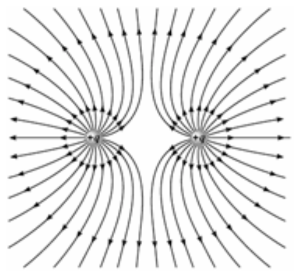
Electric Field



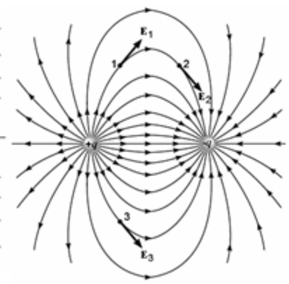
Single Positive Point Charge



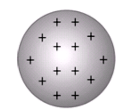
Single Negative Point Charge



Two Like Equal Charges



Two Unlike Equal Charges



Charged Sphere

Electric Field Strength (intensity) (E) -

Electric Field Lines

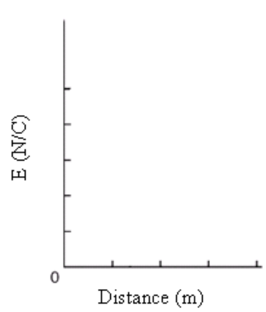
1. Never cross
2. Show the direction of force on a small positive test charge
3. Out of positive, into negative
4. Direction of electric field is tangent to the field lines
5. Density of field lines is proportional to field strength (density = intensity)
6. Perpendicular to surface
7. **Radial field**: field lines are extensions of radii

Formula:

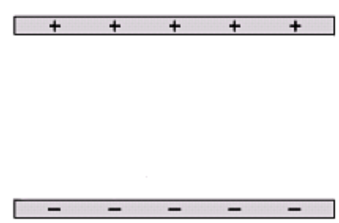
Units:

Electric Force:

For point charges:



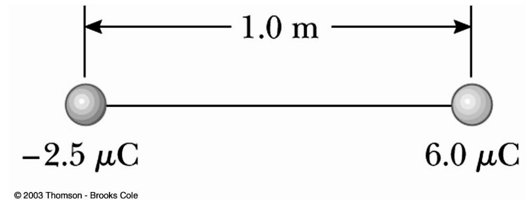
Oppositely charged parallel plates



Formula: Units:

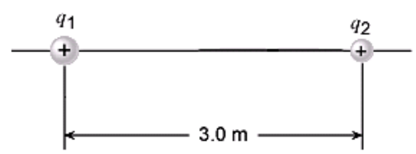
Superposition

1. a) Find the magnitude and direction of the net electric field halfway between the two charges shown below.

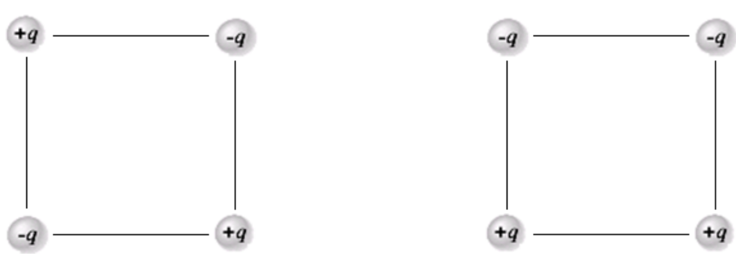


b) Determine the electric force on a proton placed at this spot.

2. Two positive point charges, $q_1 = +16\ \mu C$ and $q_2 = +4.0\ \mu C$, are separated in a vacuum by a distance of 3.0 m. Find the spot on the line between the charges where the net electric field is zero.



3. Determine the direction of the net electric field at the center of each square.



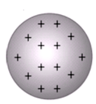
Gravitational Potential Energy: work done bringing a small point mass in from infinity to a point in a gravitational field

Gravitational potential: work done per unit mass bringing a small point mass in from infinity to a point in a gravitational field

	Gravitational Potential Energy	**Gravitational Potential**	**Relationships:**
	Units: J Type: scalar	Units: J/kg Type: scalar	$E_p = mV$ $W = \Delta E_p = m\Delta V$
	$E_p = -\dfrac{GMm}{r}$	$V = -\dfrac{GM}{r}$	

Electric Potential Energy: work done bringing a small positive test charge in from infinity to a point in an electric field

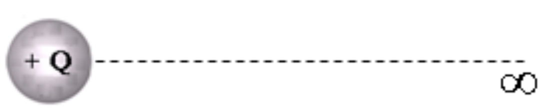
Electric Potential: work done per unit charge bringing a small positive test charge in from infinity to a point in an electric field

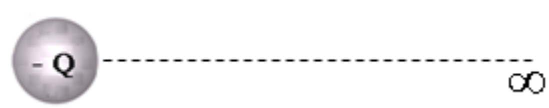


	Electric Potential Energy	**Electric Potential**	**Relationships:**
	Units: Type:	Units: Type:	

NOTE: 1)

2)

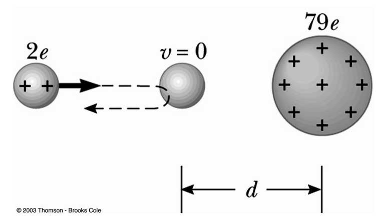




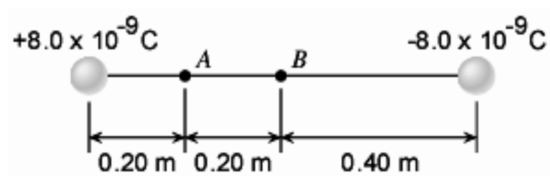
1. a) Calculate the potential at a point 2.50 cm away from a +4.8 μC charge.

b) How much potential energy will an electron have if it is at this spot? A proton?

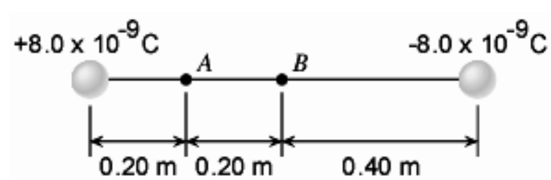
2. In Rutherford's famous scattering experiments (which led to the planetary model of the atom), alpha particles were fired toward a gold nucleus with charge +79*e*. An alpha particle, initially very far from the gold nucleus, is fired at 2.00×10^7 m/s directly toward the gold nucleus. Assume the gold nucleus remains stationary. How close does the alpha particle get to the gold nucleus before turning around? (the "distance of closest approach")



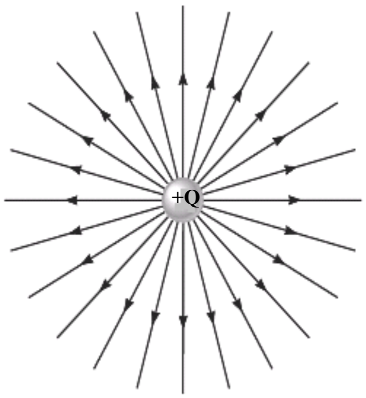
3. a) Find the magnitude and direction of the net electric field at each point (A and B).



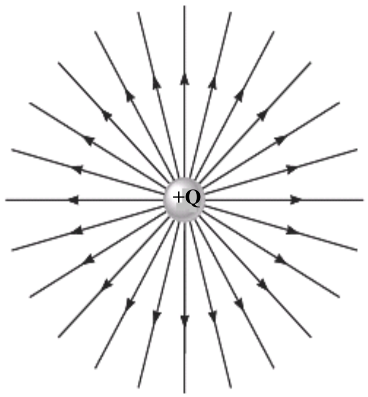
4. Calculate the net electric potential at each spot (A and B):



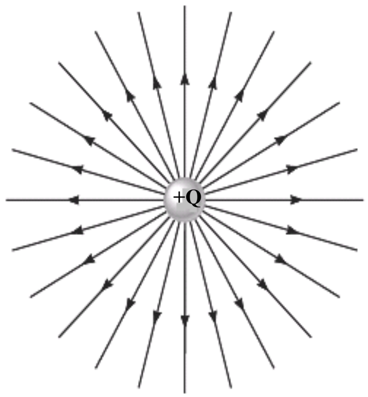
Point Charges



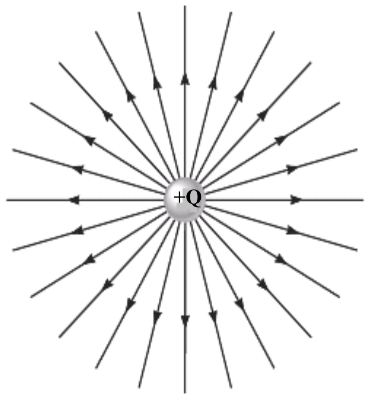
Electric Force



Electric Field



Electric Potential Energy

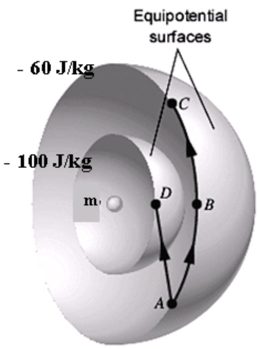


Electric Potential

Equipotential Surfaces

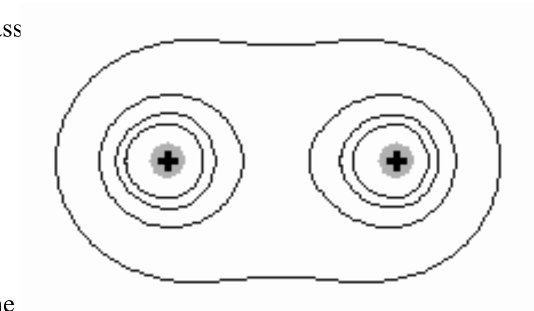
Equipotential surface: a surface on which the potential is the same everywhere

Gravitational Equipotentials



one point mass

1. The gravitational force does no work as a mass moves on along equipotential surface.
2. The work done in moving a mass between equipotential surfaces is path independent.
3. The work done in moving a mass along a closed path is zero.
4. The field lines are always perpendicular to the equipotential surfaces and point in the direction of decreasing potential.



two point masses

Gravitational potential gradient: The gravitational field is the negative gradient of the gravitational potential with respect to distance.

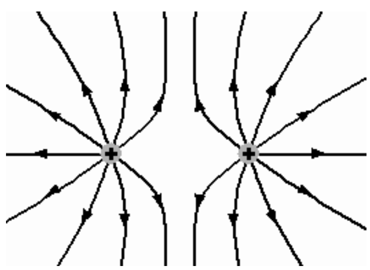
Formula:

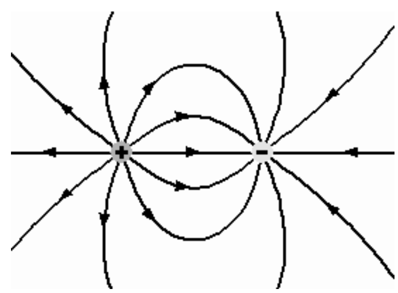
$$g = -\frac{\Delta V}{\Delta r}$$

Electric Equipotentials

For each electric field shown, sketch in equipotential surfaces.

Positive point charge





Negative point charge

Like equal charges

Opposite equal charges

Electric potential gradient: The electric field is the negative gradient of the electric potential with respect to distance.

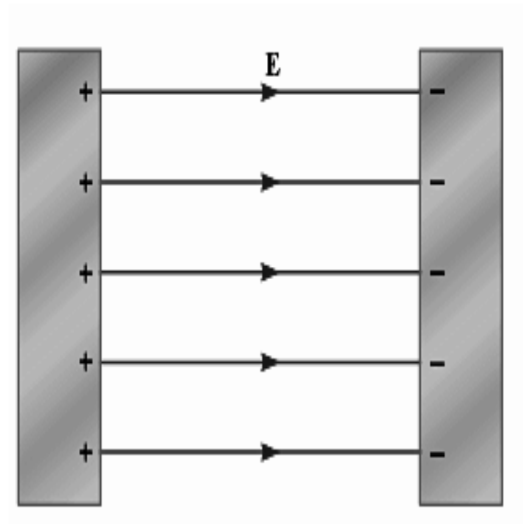
Formula:

Electric Potential Difference

Electric Potential Difference (ΔV) –

Formula:

Units:



High and Low Potential

1. a) Which plate is at a higher electric potential?

   b) Which plate is at a lower electric potential?

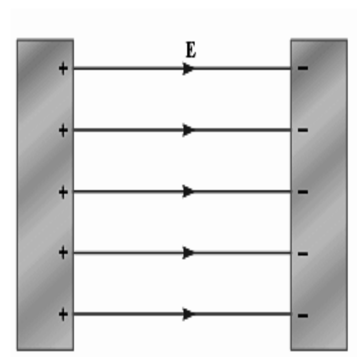
   c) What is the electric potential of each plate?

   d) What is the potential difference between the plates?

   e) Where will: a proton have the most electric potential energy?

   an electron? a neutron? an alpha particle?

2. An electron is released from rest near the negative plate and allowed to accelerate until it hits the positive plate. The distance between the plates is 2.00 cm and the potential difference between them is 100. volts.



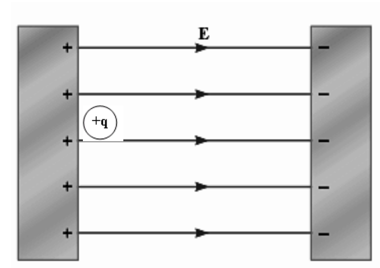
   a) Calculate how fast the electron strikes the positive plate.

Formula:

   b) Calculate the strength of the electric field.

Formula:

3. A proton is released from rest near the positive plate. The distance between the plates is 3.0 mm and the strength of the electric field is 4.0×10^3 N/C.



a) Describe the motion of the proton.

b) Write an expression for the acceleration of the proton.

c) Calculate the strength of the electric field.

d) Find the time it takes the proton to reach the negative plate.

e) Find the speed of the proton when it reaches the negative plate.

Electronvolt:

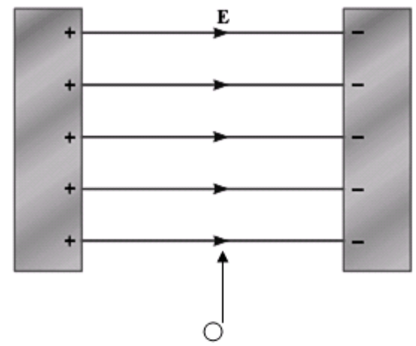
Derivation:

4. How much energy is gained by a proton moving through a potential difference of 150. V?

5. A charged particle has 5.4×10^{-16} J of energy. How many electronvolts of energy is this?

6. An electron gains 200 eV accelerating from rest in a uniform electric field of 150 N/C. Calculate the final speed of the electron.

7. A particle is shot with an initial speed through the two parallel plates as shown.



a) Sketch and describe the path it will take if it is a proton, an electron, or a neutron.

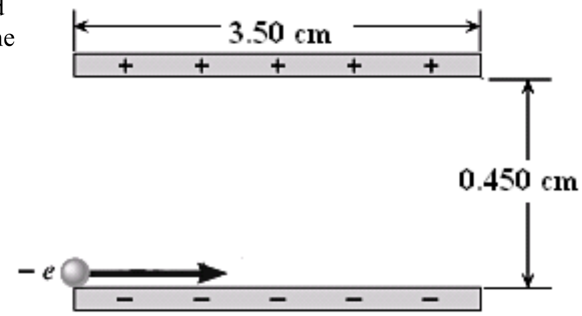
b) Which particle will experience a greater force?

c) Which particle will experience a greater acceleration?

d) Which particle will experience a greater displacement?

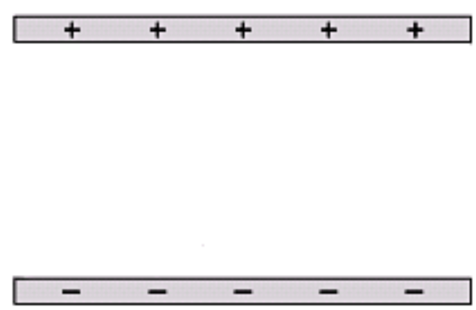
---

8. In the figure, an electron enters the lower left side of a parallel plate capacitor and exits at the upper right side. The initial speed of the electron is 5.50×10^6 m/s. The plates are 3.50 cm long and are separated by 0.450 cm. Assume that the electric field between the plates is uniform everywhere and find its magnitude.



---

9. An electron, a proton, and an alpha particle are each released from rest midway between the two parallel plates shown.



a) Draw a vector to represent the electric force on each particle.

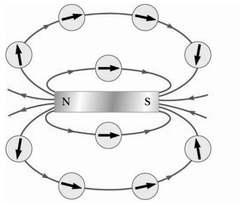
b) Draw a vector to represent the electric field at the location of each particle.

c) Compare the electric force on each particle.

c) Describe and compare the motion of each particle.

Magnetic Fields

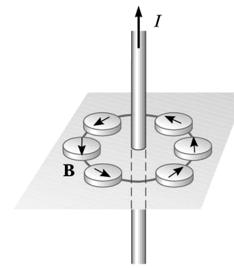
Magnetic Field around a Bar Magnet



Direction of magnetic field lines: the direction that the North pole of a small test compass would point if placed in the field (N to S)

What is the cause of magnetic fields?

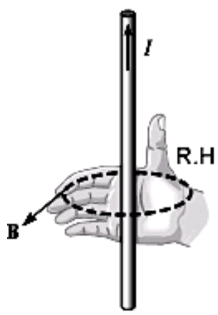
Therefore:



The Right Hand Rule for the Magnetic Field around a Wire

Thumb: direction of conventional current

Fingertips: direction of magnetic field – tangent to circle



a) head-on view

b) side view

c) side view

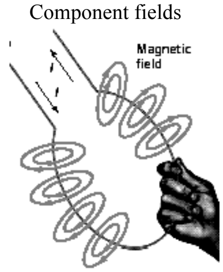
Alternate Right Hand Rule for Loops

Fingertips: direction of current

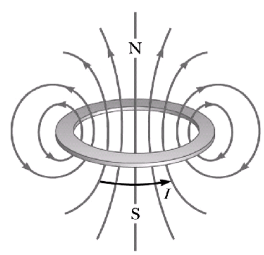
Thumb: points North

Note that a wire loop acts like a:

Component fields

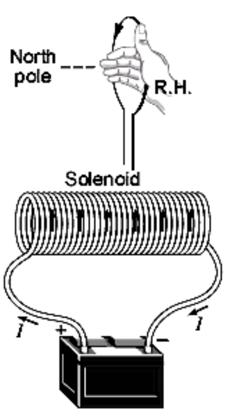


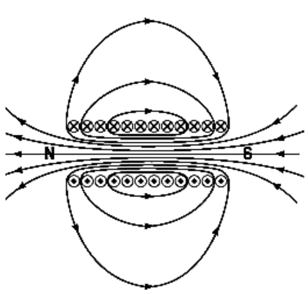
Resultant field



Your turn

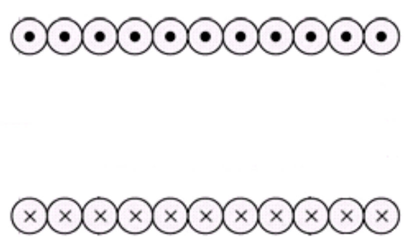
Solenoid:





Note that a solenoid acts like a:

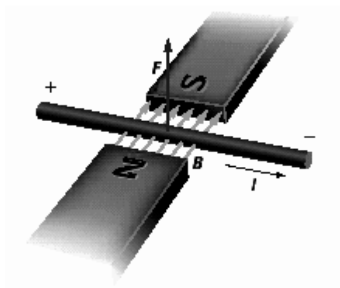
Draw the magnetic field around this solenoid.

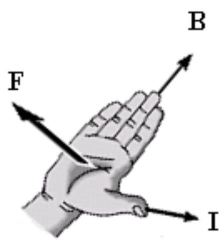


Magnetic Force on a Wire

If a wire with current flowing through it is placed in an external magnetic field, it will experience a force. Why?

The Right Hand Rule for the Magnetic Force on a Current-Carrying Conductor in a Magnetic Field





Flat Hand: thumb and fingers at right angles

Fingers: external B field – north to south

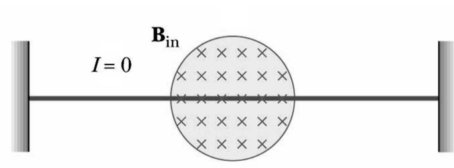
Thumb: current

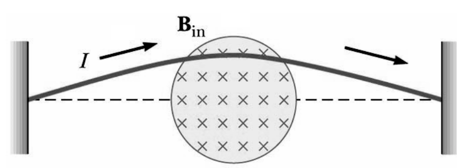
Palm: force – "palm pushes"

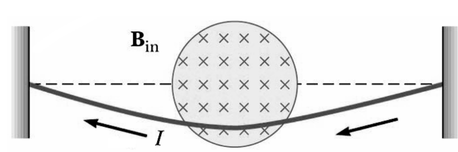
Maximum force occurs when:

No force occurs when:

Use the right hand rule for forces to confirm the direction of the force in each case.







Magnitude of the magnetic force on a wire:

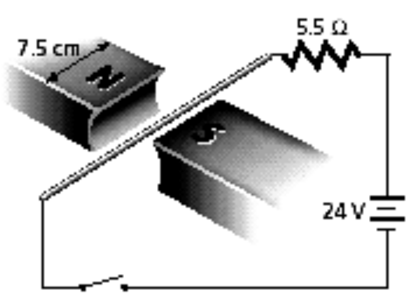
Magnetic field strength
Magnetic field intensity
Magnetic flux density

Units:

Definition of magnitude of magnetic field (#1):

The ratio of the magnetic force on a wire to the product of the current in the wire, the length of the wire and the sine of the angle between the current and the magnetic field

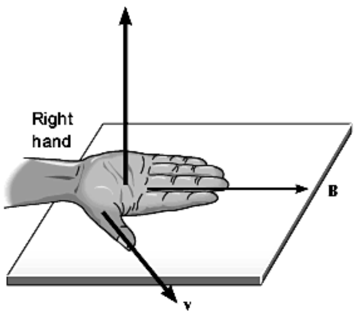
Find the magnitude and direction of the force on the wire segment confined to the gap between the two magnets as shown when the switch is closed. The strength of the magnetic field in the gap is 1.9 T.



Magnetic Force on a Moving Charged Particle

Why is there a magnetic force on a charged particle as it moves through a magnetic field?

Right Hand Rule: Magnetic Force on a Charged Particle



Flat Hand: thumb and fingers at right angles

Fingers: external B field – north to south

Right Hand: positive charge

Thumb: velocity

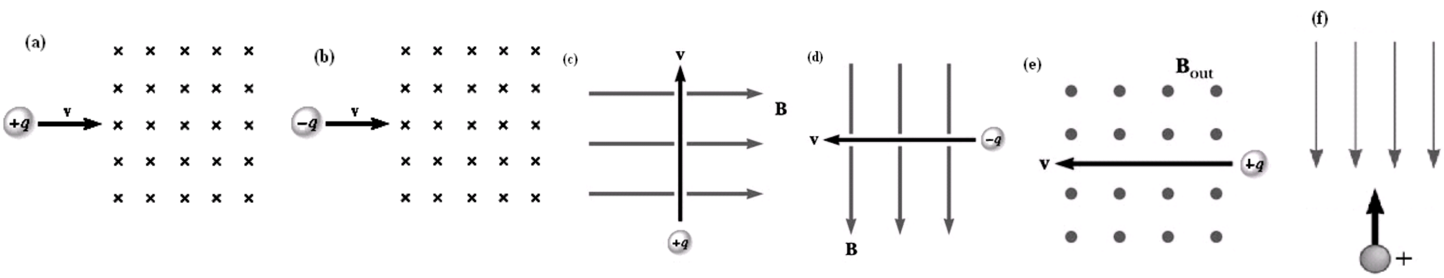
Left Hand: negative charge

Palm: force – "palm pushes"

Maximum force occurs when:

No force occurs when:

Find the direction of the magnetic force on each particle below as each enters the magnetic field shown.



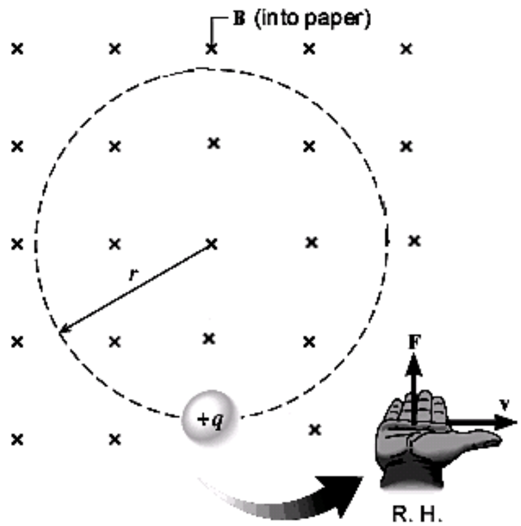
Magnitude of the magnetic force on a moving charged particle:

Definition of magnitude of magnetic field (#2):

The ratio of the force on a charged particle moving in a magnetic field to the product of the particle's charge, velocity and sine of the angle between the direction of the magnetic field and velocity.

A proton in a particle accelerator has a speed of 5.0×10^6 m/s. The proton encounters a magnetic field whose magnitude is 0.40T and whose direction makes an angle of $\theta = 30.0°$ with respect to the proton's velocity. Find the magnitude of the magnetic force on the proton and the proton's acceleration. How would these change if the particle was an electron?

Motion of a Charged Particle in a Magnetic Field



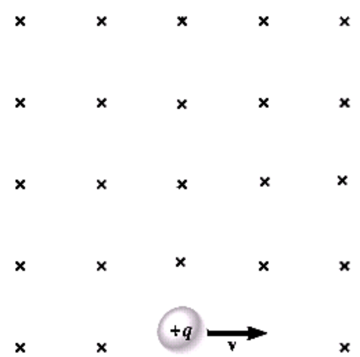
1. A charged particle will follow a circular path in a magnetic field since the magnetic force is always perpendicular to the velocity.

2. The magnetic force does no work on the particle since the magnetic force is always perpendicular to the motion.

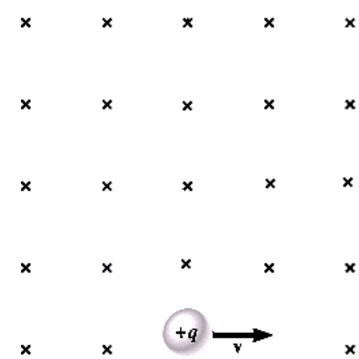
3. The particle accelerates centripetally but maintains a constant speed since the magnetic force does no work on it.

Radius of Circular Path

a) Sketch the paths of a slow and a fast moving proton at constant speed.



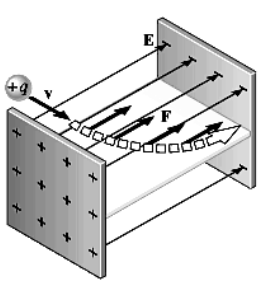
b) Sketch the path of a proton that is slowing down and one that is speeding up.



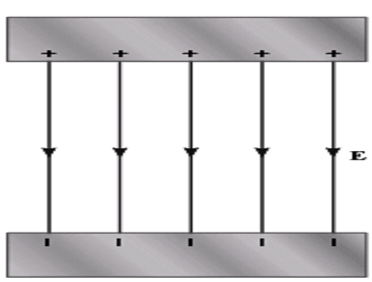
c) How would the radius of the path change if the particle were an alpha particle?

Comparing Electric and Magnetic Fields and Forces

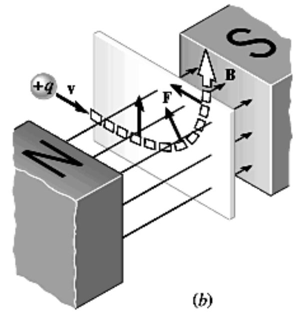
Electric Field



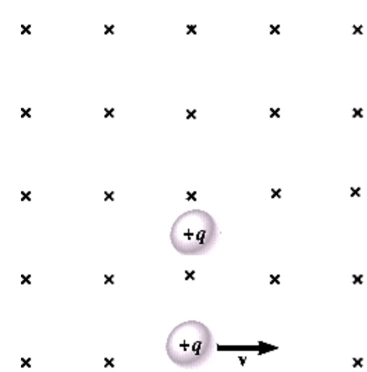
(a)



Magnetic Field

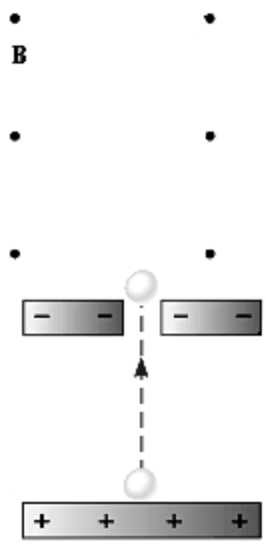


(b)



Electric Fields and Magnetic Fields

1. A proton is released from rest near the positive plate and leaves through a small hole in the negative plate where it enters a region of constant magnetic field of magnitude 0.10T. The electric potential difference between the plates is 2100 V.



a) Describe the motion of the proton while in the electric field

b) Describe the motion of the proton while in the magnetic field

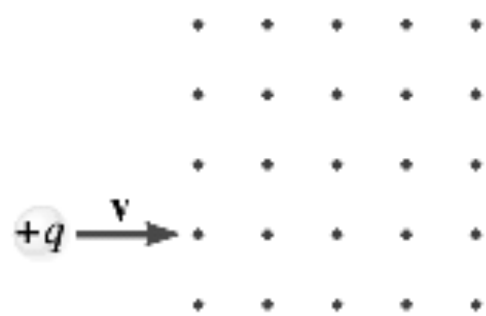
c) Find the speed of the proton as it enters the magnetic field.

d) Find the radius of the circular path of the proton in the magnetic field.

---

2. A **Velocity Selector** is a device for measuring the velocity of a charged particle. The device operates by applying electric and magnetic forces to the particle in such a way that these forces balance.

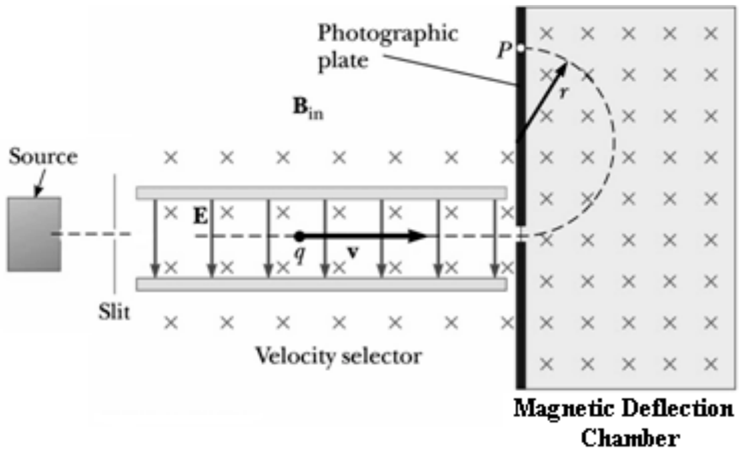
a) Determine the magnitude and direction of an electric field that will apply and electric force to balance the magnetic force on the proton.



b) What is the resulting speed and trajectory of the proton?

The Mass Spectrometer

A **mass spectrometer** is a device used to measure the masses of isotopes. Isotopes of the same element have the same charge and chemical properties so they cannot be separated by using chemical reactions but have different masses and so can be separated by a magnetic field. A common type of mass spectrometer is known as the **Bainbridge mass spectrometer** and its main parts are shown below.



Ion Source:

Velocity selector:

Magnetic deflection chamber:

1. A singly charged ion with mass 2.18×10^{-26} kg moves without deflection through a region of crossed magnetic and electric fields then is injected into a region containing only a magnetic field, as shown in the diagram, where it is deflected until it hits a photographic plate. The electric field between the plates of the velocity selector is 950 V/m and the magnetic field in both regions is 0.930 T. Determine the sign of the charge and calculate where the ion lands on the photographic plate.

2. A hydrogen atom and a deuterium atom (an isotope of hydrogen) move out of the velocity selector and into the region of a constant 0.10 T magnetic field at point S, as shown below. Each has a speed of 1.0×10^6 m/s. Calculate where they each hit the photographic plate at P.