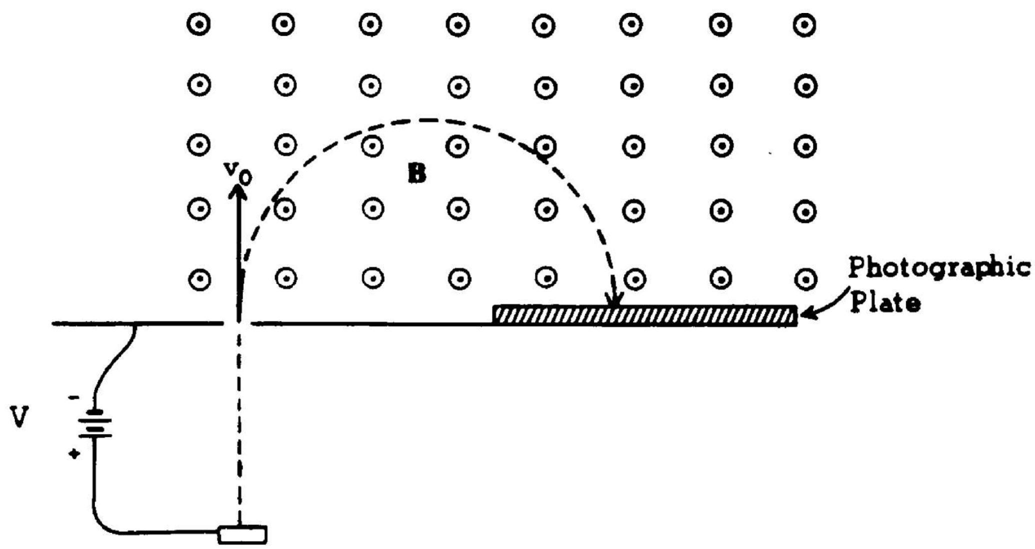
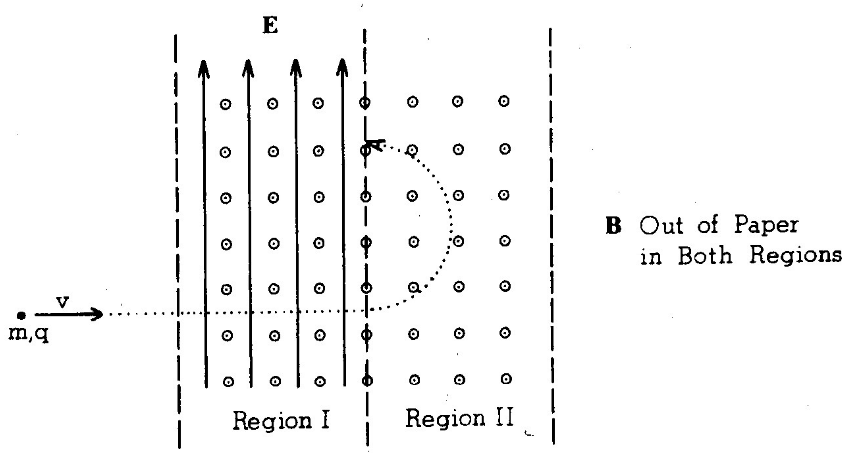
SECTION A – Magnetism



1975B6. In a mass spectrometer, singly charged ^{16}O ions are first accelerated electrostatically through a voltage V to a speed v_o. They then enter a region of uniform magnetic field B directed out of the plane of the paper.

a. The ^{16}O ions are replaced with singly charged ^{32}S ions of twice the mass and the same charge. What will be their speed in terms of v_o for the same accelerating voltage?

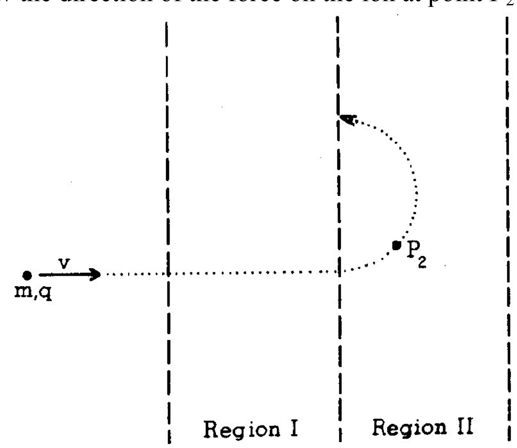
b. When ^{32}S is substituted for ^{16}O in part (a), determine by what factor the radius of curvature of the ions' path in the magnetic field changes.



1976B4.

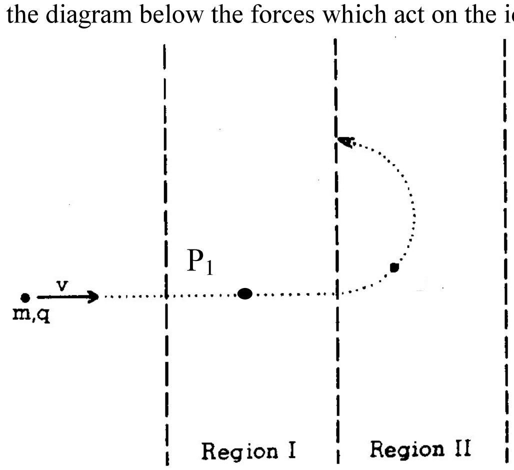
An ion of mass m and charge of known magnitude q is observed to move in a straight line through a region of space in which a uniform magnetic field B points out of the paper and a uniform electric field E points toward the top edge of the paper, as shown in region I above. The particle travels into region II in which the same magnetic field is present, but the electric field is zero. In region II the ion moves in a circular path as shown.

(a) Indicate on the diagram below the direction of the force on the ion at point P_2 in region II.



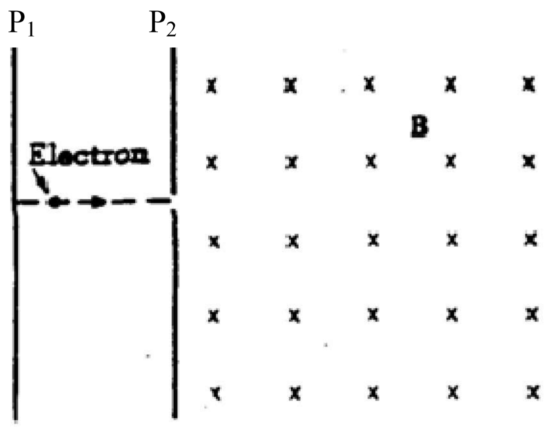
(b) Is the ion positively or negatively charged? Explain clearly the reasoning on which you base your conclusion.

(c) Indicate and label clearly on the diagram below the forces which act on the ion at point P_1 in region I.



(d) Find an expression for the ion's speed v at point P_1 in terms of E and B.

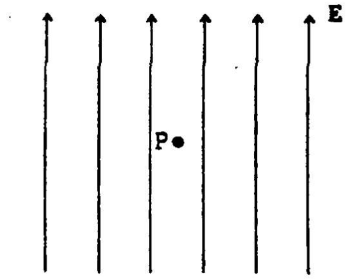
1977B3. An electron is accelerated from rest through a potential difference of magnitude V between infinite parallel plates P_1 and P_2. The electron then passes into a region of uniform magnetic field strength B which exists everywhere to the right of plate P_2. The magnetic field is directed into the page.



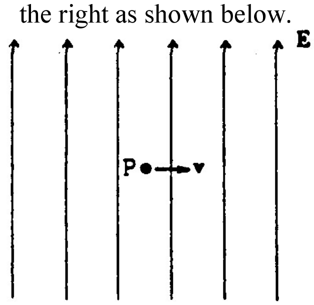
a. On the diagram above, clearly indicate the direction of the electric field between the plates.
b. In terms of V and the electron's mass and charge, determine the electron's speed when it reaches plate P_2.
c. Describe in detail the motion of the electron through the magnetic field and explain why the electron moves this way.
d. If the magnetic field remains unchanged, what could be done to cause the electron to follow a straight-line path to the right of plate P_2?

1979B4. Determine the magnitude and direction of the force on a proton in each of the following situations. Describe qualitatively the path followed by the proton in each situation and sketch the path on each diagram. Neglect gravity.

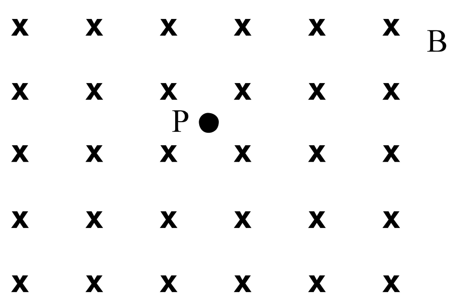
a. The proton is released from rest at the point P in an electric field E having intensity 10^4 newtons per coulomb and directed up in the plane of the page as shown below.



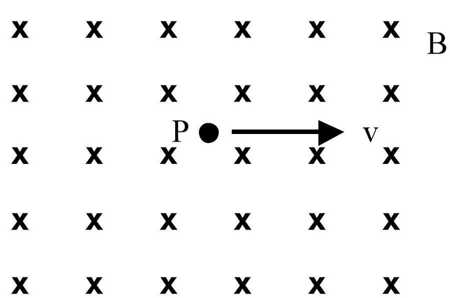
b. In the same electric field as in part (a), the proton at point P has velocity $v = 10^5$ meters per second directed to the right as shown below.



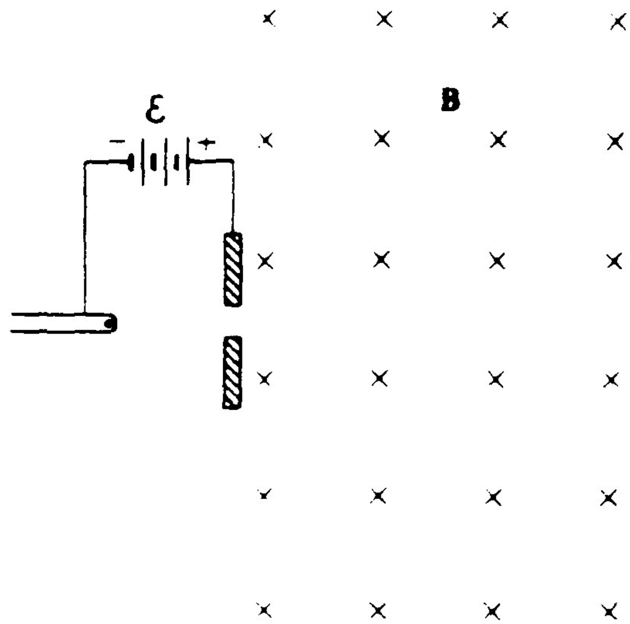
c. The proton is released from rest at point P in a magnetic field B having intensity 10^{-1} tesla and directed into the page as shown below.



d. In the same magnetic field as in part (c), the proton at point P has velocity $v = 10^5$ meters per second directed to the right as shown below.

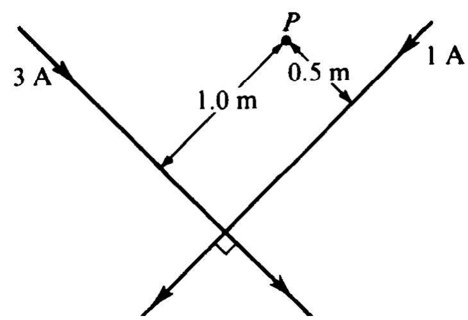


1984B4. An electron from a hot filament in a cathode ray tube is accelerated through a potential difference $\mathcal{E}$. It then passes into a region of uniform magnetic field B, directed into the page as shown. The mass of the electron is m and the charge has magnitude e.



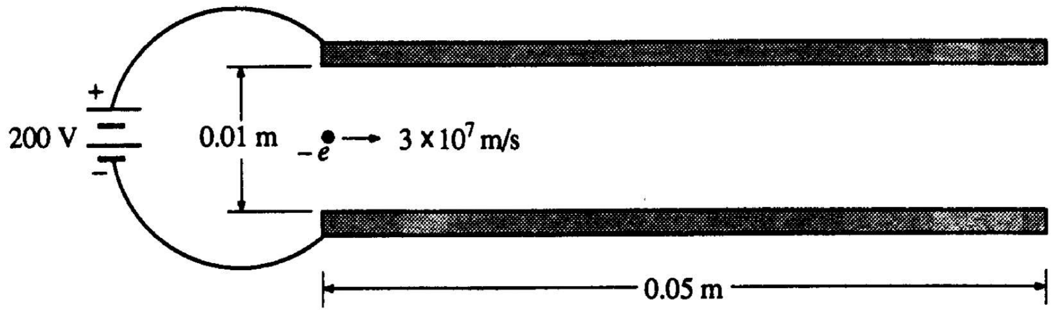
a. Find the potential difference $\mathcal{E}$ necessary to give the electron a speed v as it enters the magnetic field.
b. On the diagram, sketch the path of the electron in the magnetic field.
e. In terms of mass m, speed v, charge e, and field strength B, develop an expression for r, the radius of the circular path of the electron.
d. An electric field E is now established in the same region as the magnetic field, so that the electron passes through the region undeflected.
   i. Determine the magnitude of E.
   ii. Indicate the direction of E on the diagram

1988B4. The two long straight wires as shown are perpendicular, insulated from each other, and small enough so that they may be considered to be in the same plane. The wires are not free to move. Point P, in the same plane as the wires, is 0.5 meter from the wire carrying a current of 1 ampere and is 1.0 meter from the wire carrying a current of 3 amperes.



a. What is the direction of the net magnetic field at P due to the currents?
b. Determine the magnitude of the net magnetic field at P due to the currents.

A charged particle at point P that is instantaneously moving with a velocity of 10^6 meters per second toward the top of the page experiences a force of 10^{-7} newtons to the left due to the two currents.
c. State whether the charge on the particle is positive or negative.
d. Determine the magnitude of the charge on the particle.
e. Determine the magnitude and direction of an electric field also at point P that would make the net force on this moving charge equal to zero.



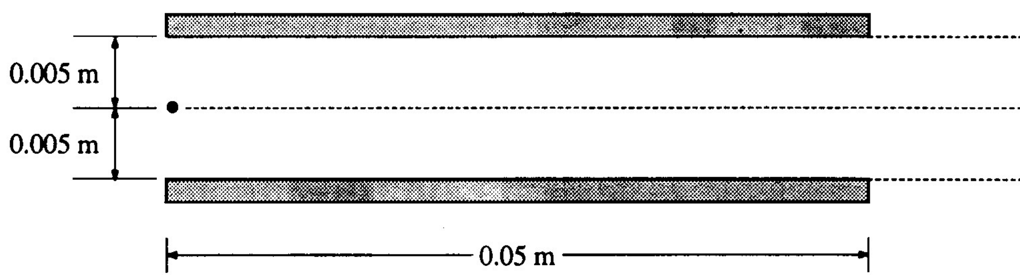
1990B2. A pair of square parallel conducting plates, having sides of length 0.05 meter, are 0.01 meter apart and are connected to a 200-volt power supply, as shown above. An electron is moving horizontally with a speed of 3×10^7 meters per second when it enters the region between the plates. Neglect gravitation and the distortion of the electric field around the edges of the plates.

a. Determine the magnitude of the electric field in the region between the plates and indicate its direction on the figure above.

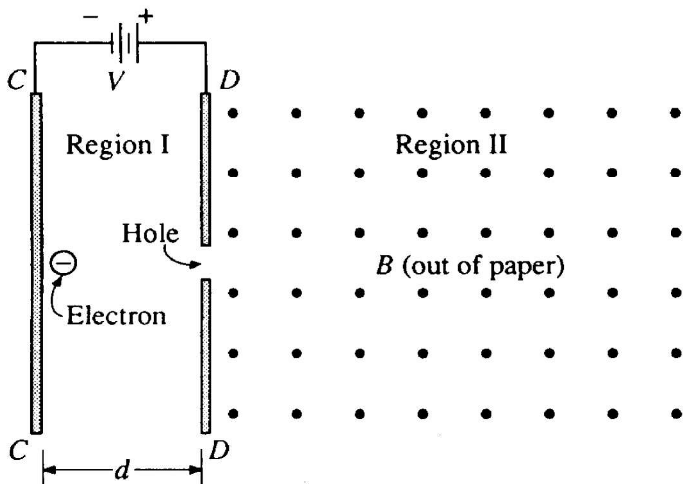
b. Determine the magnitude and direction of the acceleration of the electron in the region between the plates.

c. Determine the magnitude of the vertical displacement of the electron for the time interval during which it moves through the region between the plates.

d. On the diagram below, sketch the path of the electron as it moves through and after it emerges from the region between the plates. The dashed lines in the diagram have been added for reference only.



e. A magnetic field could be placed in the region between the plates which would cause the electron to continue to travel horizontally in a straight line through the region between the plates. Determine both the magnitude and the direction of this magnetic field.



1991B2. In region I shown above, there is a potential difference V between two large, parallel plates separated by a distance d. In region II, to the right of plate D, there is a uniform magnetic field B pointing perpendicularly out of the paper. An electron, charge –e and mass m, is released from rest at plate C as shown, and passes through a hole in plate D into region II. Neglect gravity.

a. In terms of e, V, m, and d, determine the following.

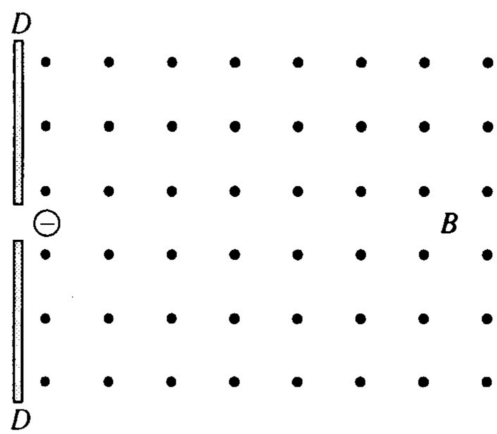
   i. The speed v_o of the electron as it emerges from the hole in plate D

   ii. The acceleration of the electron in region I between the plates

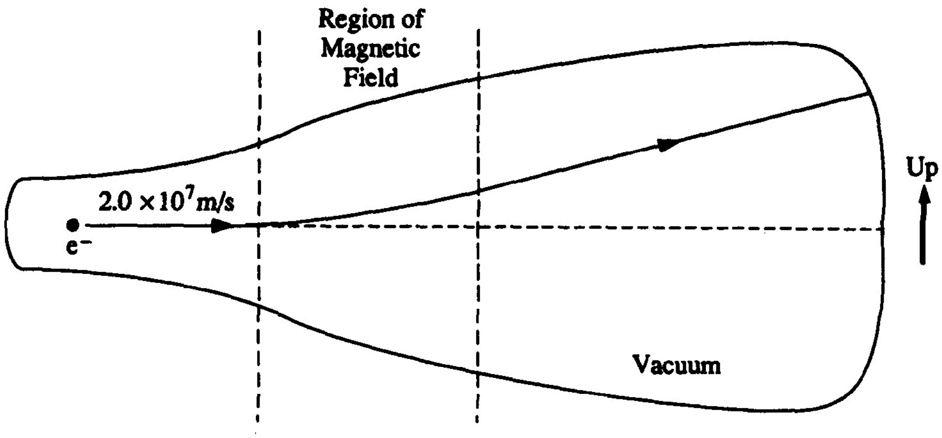
b. On the diagram below do the following.

   i. Draw and label an arrow to indicate the direction of the magnetic force on the electron as it enters the constant magnetic field.

   ii. Sketch the path that the electron follows in region II.



c. In terms of e, B, V, and m, determine the magnitude of the acceleration of the electron in region II.



Cross Section of Cathode Ray Tube

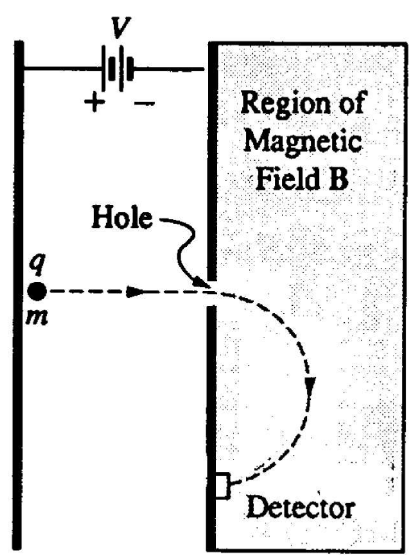
1992B5. The figure above shows a cross section of a cathode ray tube. An electron in the tube initially moves horizontally in the plane of the cross section at a speed of 2.0×10^7 meters per second. The electron is deflected upward by a magnetic field that has a field strength of 6.0×10^{-4} tesla.

a. What is the direction of the magnetic field?
b. Determine the magnitude of the magnetic force acting on the electron.
c. Determine the radius of curvature of the path followed by the electron while it is in the magnetic field.

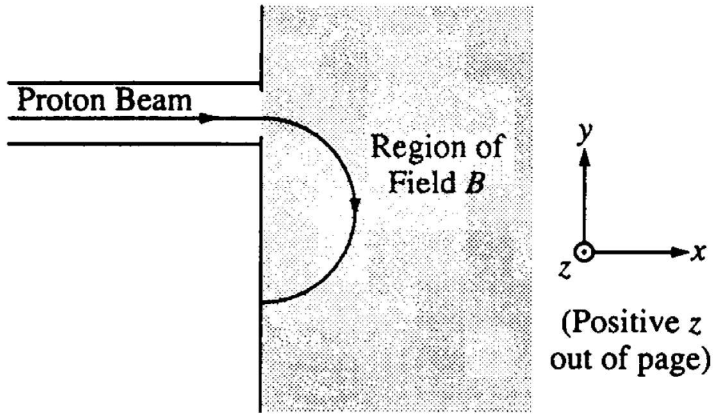
An electric field is later established in the same region as the magnetic field such that the electron now passes through the magnetic and electric fields without deflection.

d. Determine the magnitude of the electric field.
e. What is the direction of the electric field?

1993B3. A particle of mass m and charge q is accelerated from rest in the plane of the page through a potential difference V between two parallel plates as shown. The particle is injected through a hole in the right-hand plate into a region of space containing a uniform magnetic field of magnitude B oriented perpendicular to the plane of the page. The particle curves in a semicircular path and strikes a detector.



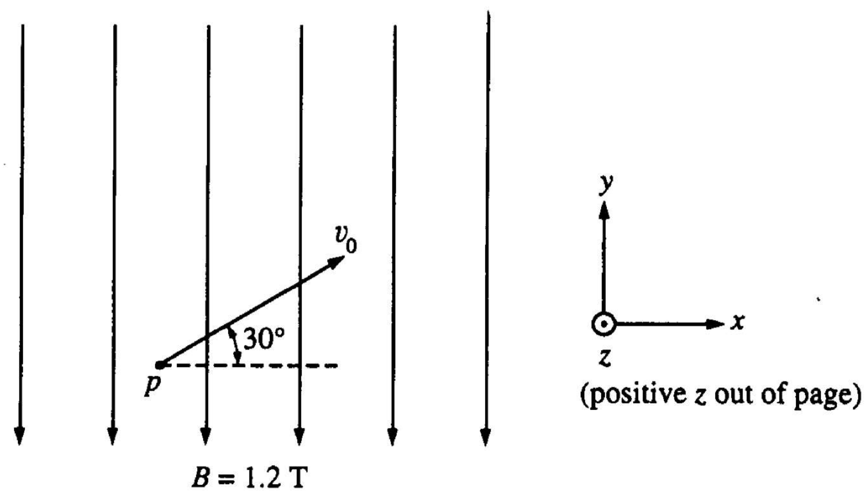
a. i. State whether the sign of the charge on the particle is positive or negative.
   ii. State whether the direction of the magnetic field is into the page or out of the page.
b. Determine each of the following in terms of m, q, V, and B.
   i. The speed of the charged particle as it enters the region of the magnetic field B
   ii. The force exerted on the charged particle by the magnetic field B
   iii. The distance from the point of injection to the detector
   iv. The work done by the magnetic field on the charged particle during the semicircular trip



1994B4. In a linear accelerator, protons are accelerated from rest through a potential difference to a speed of approximately 3.1 x 10^6 meters per second. The resulting proton beam produces a current of 2 x 10^{-6} ampere.

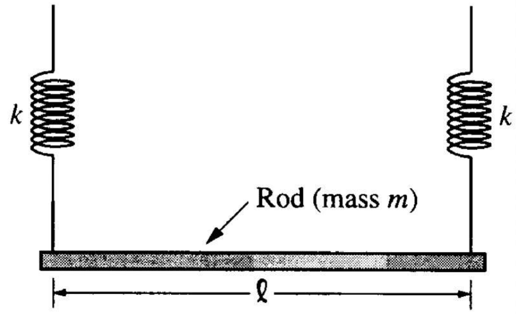
a. Determine the potential difference through which the protons were accelerated.
b. If the beam is stopped in a target, determine the amount of thermal energy that is produced in the target in one minute.

The proton beam enters a region of uniform magnetic field B, as shown above, that causes the beam to follow a semicircular path.
c. Determine the magnitude of the field that is required to cause an arc of radius 0.10 meter.
d. What is the direction of the magnetic field relative to the axes shown above on the right?



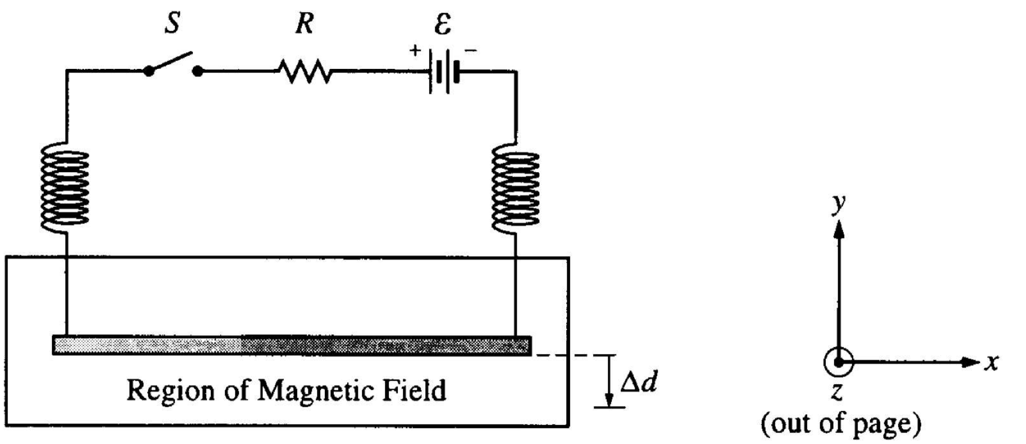
1995B7. A uniform magnetic field of magnitude B = 1.2 teslas is directed toward the bottom of the page in the –y direction, as shown above. At time t = 0, a proton p in the field is moving in the plane of the page with a speed v_o = 4 x 10^7 meters per second in a direction 30° above the +x axis.

a. Calculate the magnetic force on the proton at t = 0.
b. With reference to the coordinate system shown above on the right, state the direction of the force on the proton at t = 0.
c. How much work will the magnetic field do on the proton during the interval from t = 0 to t = 0.5 second?
d. Describe (but do not calculate) the path of the proton in the field.



1997B3. A rigid rod of mass m and length Lis suspended from two identical springs of negligible mass as shown in the diagram above. The upper ends of the springs are fixed in place and the springs stretch a distance d under the weight of the suspended rod.

a. Determine the spring constant k of each spring in terms of the other given quantities and fundamental constants.



As shown above, the upper end of the springs are connected by a circuit branch containing a battery of emf ε and a switch S so that a complete circuit is formed with the metal rod and springs. The circuit has a total resistance R, represented by the resistor in the diagram. The rod is in a uniform magnetic field directed perpendicular to the page. The upper ends of the springs remain fixed in place and the switch S is closed. When the system comes to equilibrium, the rod has been lowered an additional distance Δd.

b. With reference to the coordinate system shown above on the right, what is the direction of the magnetic field?

c. Determine the magnitude of the magnetic field in terms of m, L, d, Δd, ε, R, and fundamental constants.

d. When the switch is suddenly opened, the rod oscillates. For these oscillations, determine the following quantities in terms of d, Δd, and fundamental constants:
   i. The period
   ii. The maximum speed of the rod

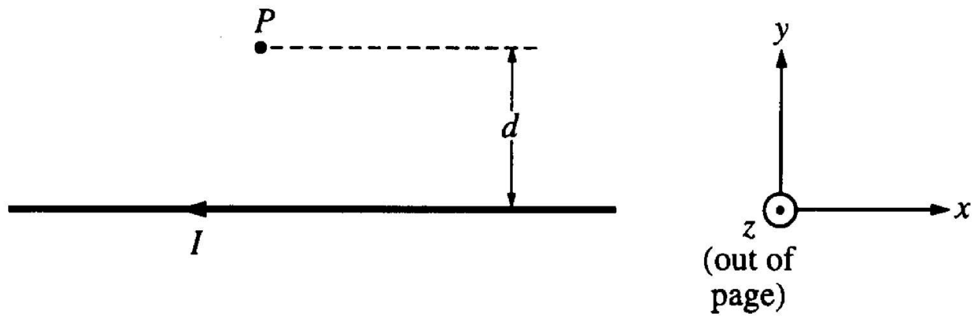


Figure 1

1998B8. The long, straight wire shown in Figure 1 above is in the plane of the page and carries a current I. Point P is also in the plane of the page and is a perpendicular distance d from the wire. Gravitational effects are negligible.

a. With reference to the coordinate system in Figure 1, what is the direction of the magnetic field at point P due to the current in the wire?

A particle of mass m and positive charge a is initially moving parallel to the wire with a speed v_o when it is at point P. as shown in Figure 2 below.

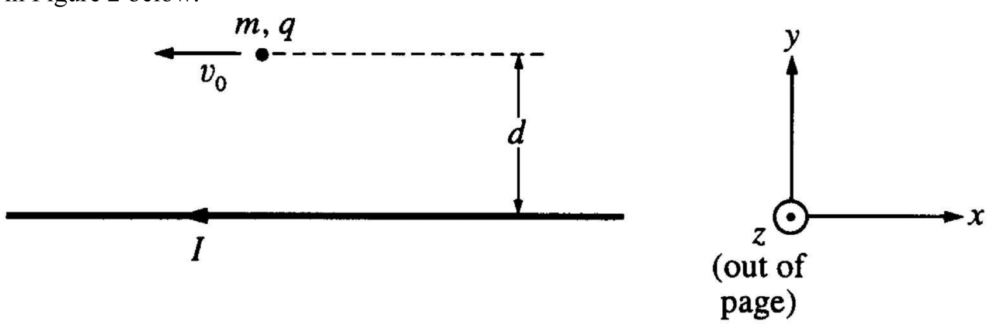
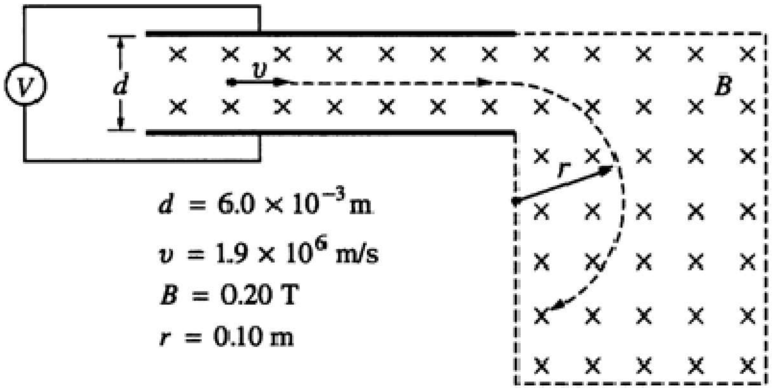


Figure 2

b. With reference to the coordinate system in Figure 2, what is the direction of the magnetic force acting on the particle at point P ?
c. Determine the magnitude of the magnetic force acting on the particle at point P in terms of the given quantities and fundamental constants.
d. An electric field is applied that causes the net force on the particle to be zero at point P.
   i. With reference to the coordinate system in Figure 2, what is the direction of the electric field at point P that could accomplish this?
   ii. Determine the magnitude of the electric field in terms of the given quantities and fundamental constants.



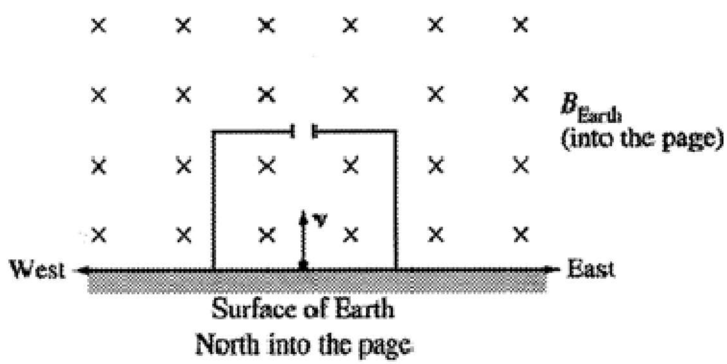
2000B7. A particle with unknown mass and charge moves with constant speed v = 1.9 x 10^6 m/s as it passes undeflected through a pair of parallel plates, as shown above. The plates are separated by a distance d = 6.0 x 10^{-3} m, and a constant potential difference V is maintained between them. A uniform magnetic field of magnitude B = 0.20 T directed into the page exists both between the plates and in a region to the right of them as shown. After the particle passes into the region to the right of the plates where only the magnetic field exists, its trajectory is circular with radius r = 0.10 m.

a. What is the sign of the charge of the particle? Check the appropriate space below.
 ___ Positive ___ Negative ___ Neutral ___ It cannot be determined from this information.

 Justify your answer.

b. On the diagram above, clearly indicate the direction of the electric field between the plates.
c. Determine the magnitude of the potential difference V between the plates.
d. Determine the ratio of the charge to the mass (q/m) of the particle.

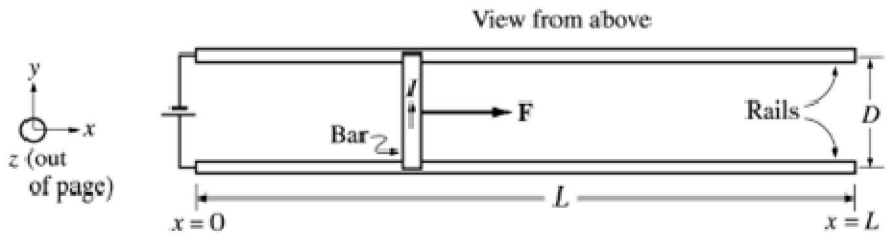
2002B5. A proton of mass m_p and charge e is in a box that contains an electric field E, and the box is located in Earth's magnetic field B. The proton moves with an initial velocity vertically upward from the surface of Earth. Assume gravity is negligible.



(a) On the diagram above, indicate the direction of the electric field inside the box so that there is no change in the trajectory of the proton while it moves upward in the box. Explain your reasoning.

(b) Determine the speed v of the proton while in the box if it continues to move vertically upward. Express your answer in terms of the fields and the given quantities.

The proton now exits the box through the opening at the top.
(c) On the diagram above, sketch the path of the proton after it leaves the box.
(d) Determine the magnitude of the acceleration a of the proton just after it leaves the box, in terms of the given quantities and fundamental constants.



2003B3.
A rail gun is a device that propels a projectile using a magnetic force. A simplified diagram of this device is shown above. The projectile in the picture is a bar of mass M and length D, which has a constant current I flowing through it in the $+y$ direction, as shown. The space between the thin frictionless rails contains a uniform magnetic field **B**, perpendicular to the plane of the page. The magnetic field and rails extend for a distance L. The magnetic field exerts a constant force **F** on the projectile, as shown.

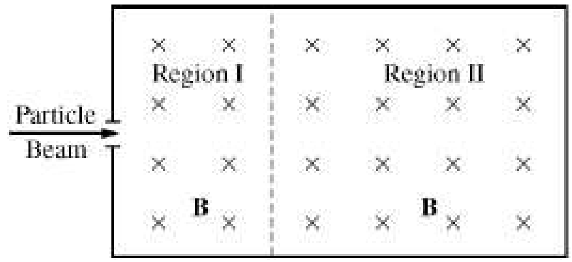
Express all algebraic answers to the following parts in terms of the magnitude F of the constant magnetic force, other quantities given above, and fundamental constants.

(a) Determine the position x of the projectile as a function of time t while it is on the rail if the projectile starts from rest at $x = 0$ when $t = 0$.
(b) Determine the speed of the projectile as it leaves the right-hand end of the track.
(c) Determine the energy supplied to the projectile by the rail gun.
(d) In what direction must the magnetic field **B** point in order to create the force **F**? Explain your reasoning.
(e) Calculate the speed of the bar when it reaches the end of the rail given the following values.

$B = 5$ T $\quad L = 10$ m $\quad I = 200$ A $\quad M = 0.5$ kg $\quad D = 10$ cm

B2007B2.

A beam of particles of charge $q = +3.2 \times 10^{-19}$ C and mass $m = 6.68 \times 10^{-26}$ kg enters region I with a range of velocities all in the direction shown in the diagram above. There is a magnetic field in region I directed into the page with magnitude $B = 0.12$ T. Charged metal plates are placed in appropriate locations to create a uniform electric field of magnitude $E = 4800$ N/C in region I. As a result, some of the charged particles pass straight through region I undeflected. Gravitational effects are negligible.



(a)
i. On the diagram above, sketch electric field lines in region I.
ii. Calculate the speed of the particles that pass straight through region I.

The particles that pass straight through enter region II, in which there is no electric field and the magnetic field has the same magnitude and direction as in region I. The path of the particles in region II is a circular arc of radius R.

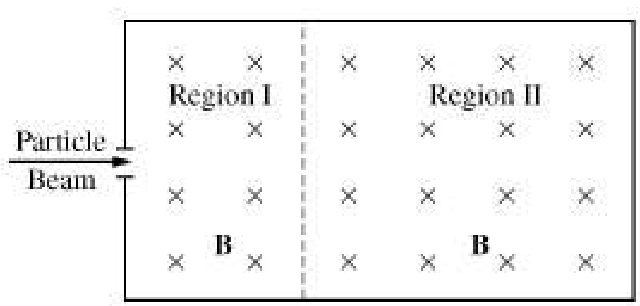
(b) Calculate the radius R.

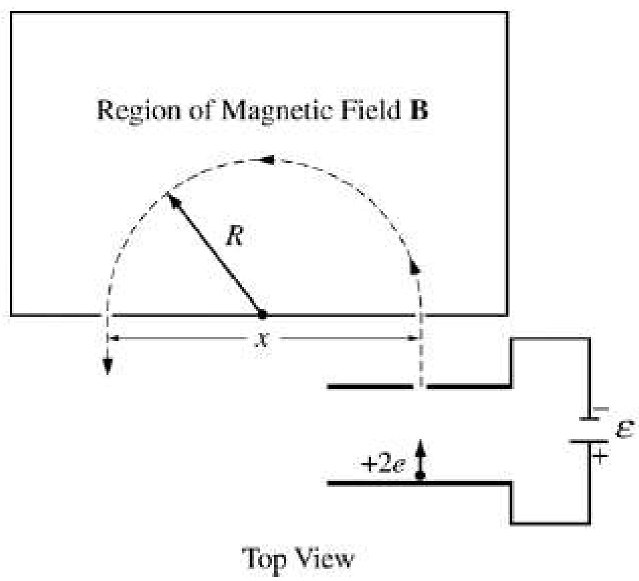
(c) Within the beam there are particles moving slower than the speed you calculated in (a)ii. In what direction is the net initial force on these particles as they enter region I?

____ To the left ____ Toward the top of the page ____ Out of the plane of the page
____ To the right ____ Toward the bottom of the page ____ Into the plane of the page

Justify your answer.

(d) A particle of the same mass and the same speed as in (a)ii but with charge $q = -3.2 \times 10^{-19}$ C enters region I. On the following diagram, sketch the complete resulting path of the particle.





2007B2.

Your research director has assigned you to set up the laboratory's mass spectrometer so that it will separate strontium ions having a net charge of $+2e$ from a beam of mixed ions. The spectrometer above accelerates a beam of ions from rest through a potential difference $\mathcal{E}$, after which the beam enters a region containing a uniform magnetic field **B** of constant magnitude and perpendicular to the plane of the path of the ions. The ions leave the spectrometer at a distance x from the entrance point. You can manually change $\mathcal{E}$

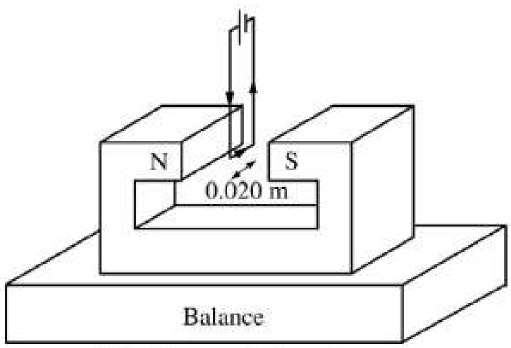
Numerical values for this experiment:
Strontium atomic number: 38
Strontium ion mass: 1.45×10^{-25} kg
Magnitude of B field: 0.090 T
Desired exit distance x: 1.75 m

(a) In what direction must **B** point to produce the trajectory of the ions shown?
(b) The ions travel at constant speed around the semicircular path. Explain why the speed remains constant.
(c) Calculate the speed of the ions with charge $+2e$ that exit at distance x.
(d) Calculate the accelerating voltage $\mathcal{E}$ needed for the ions with charge $+2e$ to attain the speed you calculated in part (c).

2008B3.

A rectangular wire loop is connected across a power supply with an internal resistance of 0.50 Ω and an emf of 16 V. The wire has resistivity 1.7×10^{-8} W•m and cross-sectional area 3.5×10^{-9} m^2. When the power supply is turned on, the current in the wire is 4.0 A.

(a) Calculate the length of wire used to make the loop.



Note: Figure not drawn to scale.

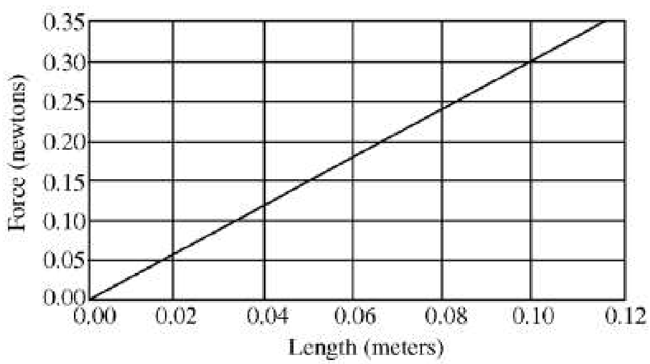
The wire loop is then used in an experiment to measure the strength of the magnetic field between the poles of a magnet. The magnet is placed on a digital balance, and the wire loop is held fixed between the poles of the magnet, as shown. The 0.020 m long horizontal segment of the loop is midway between the poles and perpendicular to the direction of the magnetic field. The power supply in the loop is turned on, so that the 4.0 A current is in the direction shown.

(b) In which direction is the force on the magnet due to the current in the wire segment?

____Upward ____Downward   Justify your answer.

(c) The reading on the balance changed by 0.060 N when the power supply was turned on. Calculate the strength of the magnetic field.

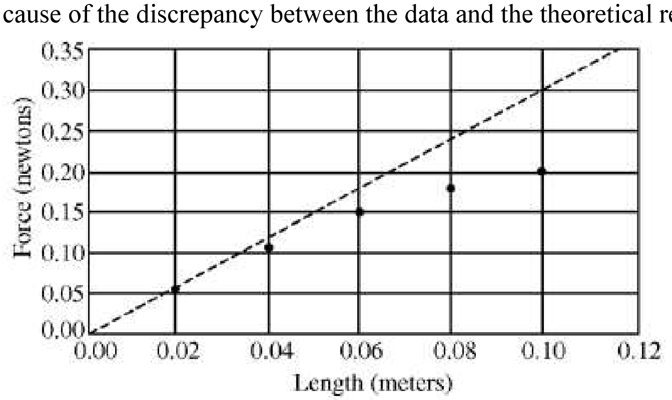
Various rectangular loops with the same total length of wire as found in part (a) were constructed such that the lengths of the horizontal segments of the wire loops varied between 0.02 m and 0.10 m. The horizontal segment of each loop was always centered between the poles, and the current in each loop was always 4.0 A. The following graph represents the theoretical relationship between the magnitude of the force on the magnet and the wire length.



(d) Suppose the wire segments were misaligned and placed at a constant nonperpendicular angles to the magnetic field, as shown below.

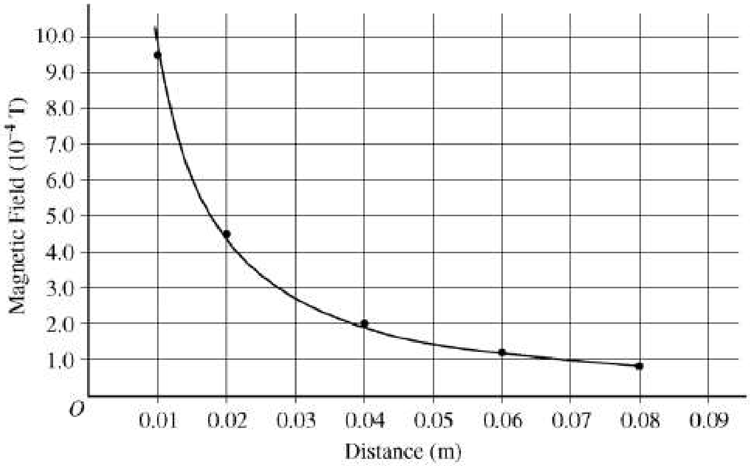
On the graph, sketch a possible relationship between the magnitude of the force on the magnet and the length of the wire segment

(e) Suppose the loops are correctly placed perpendicular to the field and the data below is obtained. Describe a likely cause of the discrepancy between the data and the theoretical relationship.



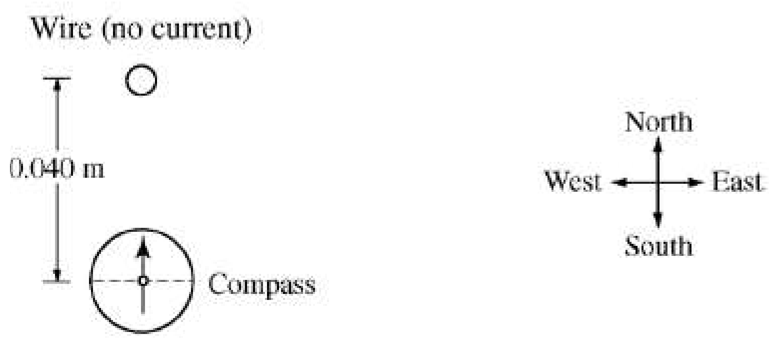
B2008B3.

A student is measuring the magnetic field generated by a long, straight wire carrying a constant current. A magnetic field probe is held at various distances *d* from the wire, as shown above, and the magnetic field is measured.
The graph below shows the five data points the student measured and a best-fit curve for the data. Unfortunately, the student forgot about Earth's magnetic field, which has a value of 5.0×10^{-5} T at this location and is directed north.



(a) On the graph, plot new points for the field due only to the wire.
(b) Calculate the value of the current in the wire.

Another student, who does not have a magnetic field probe, uses a compass and the known value of Earth's magnetic field to determine the magnetic field generated by the wire. With the current turned off, the student places the compass 0.040 m from the wire, and the compass points directly toward the wire as shown below. The student then turns on a 35 A current directed into the page.

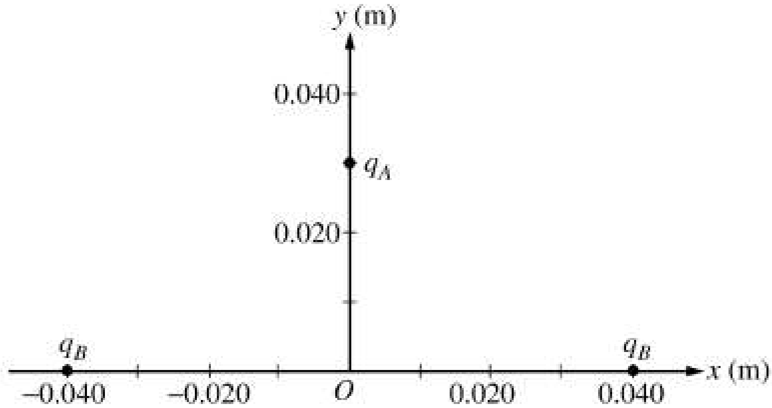


Note: Figure not drawn to scale.

(c) On the compass, sketch the general direction the needle points after the current is established.
(d) Calculate how many degrees the compass needle rotates from its initial position pointing directly north.

The wire is part of a circuit containing a power source with an emf of 120 V and negligible internal resistance.
(e) Calculate the total resistance of the circuit.
(f) Calculate the rate at which energy is dissipated in the circuit.

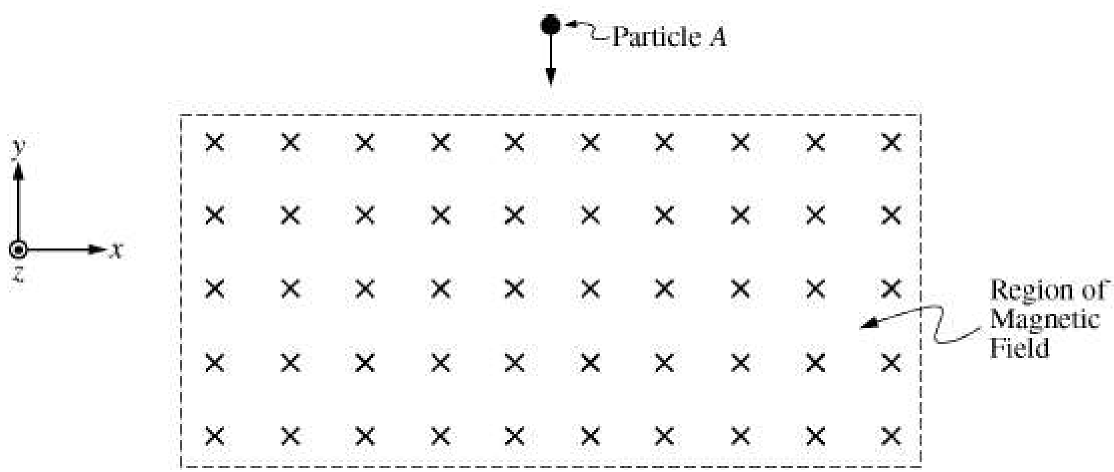
B2009B2.



Three particles are arranged on coordinate axes as shown above. Particle *A* has charge q_A = – 0.20 nC, and is initially on the *y*-axis at *y* = 0.030 m. The other two particles each have charge q_B = +0.30 nC and are held fixed on the *x*-axis at *x* = – 0.040 m and *x* = +0.040 m respectively.

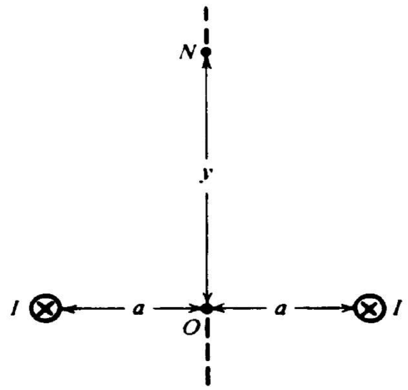
(a) Calculate the magnitude of the net electric force on particle *A* when it is at *y* = 0.030 m, and state its direction.
(b) Particle *A* is then released from rest. Qualitatively describe its motion over a long time.

In another experiment, particle *A* of charge q_A = – 0.20 nC is injected into a uniform magnetic field of strength 0.50 T directed into the page, as shown below, entering the field with speed 6000 m/s.

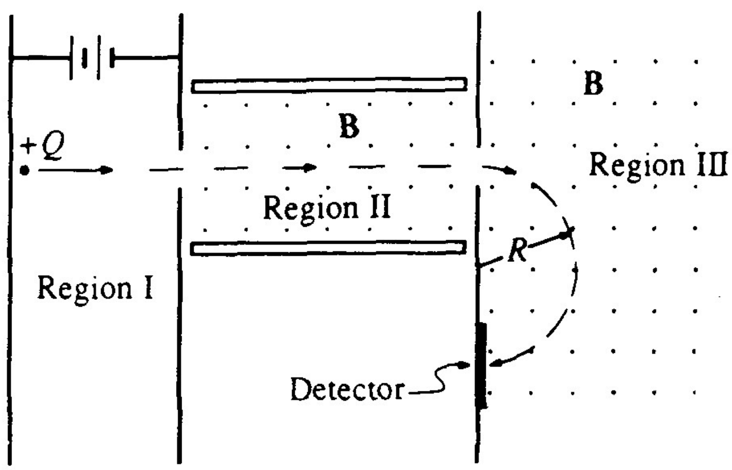


(c) On the diagram above, sketch a complete path of particle *A* as it moves in the magnetic field.
(d) Calculate the magnitude of the force the magnetic field exerts on particle *A* as it enters the magnetic field.
(e) An electric field can be applied to keep particle *A* moving in a straight line through the magnetic field. Calculate the magnitude of this electric field and state its direction.

C1983E3.



a. Two long parallel wires that are a distance 2a apart carry equal currents I into the plane of the page as shown above.
   i. Determine the resultant magnetic field intensity at the point O midway between the wires.
   ii. Develop an expression for the resultant magnetic field intensity at the point N. which is a vertical distance y above point O. On the diagram above indicate the direction of the resultant magnetic field at point N.



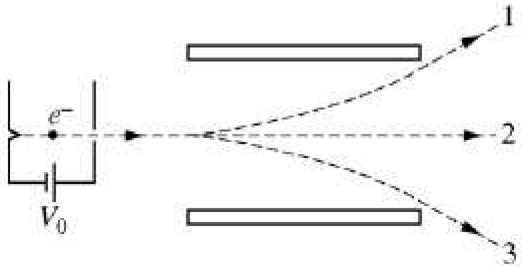
C1990E2. In the mass spectrometer shown above, particles having a net charge +Q are accelerated from rest through a potential difference in Region I. They then move in a straight line through Region II, which contains a magnetic field **B** and an electric field **E**. Finally, the particles enter Region III, which contains only a magnetic field **B**, and move in a semicircular path of radius R before striking the detector. The magnetic fields in Regions II and III are uniform, have the same magnitude **B**, and are directed out of the page as shown.

a. In the figure above, indicate the direction of the electric field necessary for the particles to move in a straight line through Region II.

In terms of any or all the quantities Q, B, E, and R, determine expressions for

b. the speed v of the charged particles as they enter Region III;
c. the mass m of the charged particles;
d. the accelerating potential V in Region I;
e. the acceleration a of the particles in Region III;
f. the time required for the particles to move along the semicircular path in Region III.

Supplemental Problem.



Electrons are accelerated from rest through a potential difference V_o and then pass through a region between two parallel metal plates, as shown above. The region between the plates can contain a uniform electric field **E** and a uniform magnetic field **B**. With only the electric field present, the electrons follow path 1. With only the magnetic field present, the electrons follow path 3. As drawn, the curved paths between the plates show the correct direction of deflection for each field, but not necessarily the correct path shape. With both fields present, the electrons pass undeflected along the straight path 2.

(a)
i. Which of the following describes the shape of the portion of path 1 between the plates?
____Circular ____Parabolic ____Hyperbolic ____Exponential
Justify your answer.

ii. What is the direction of the electric field?
____To the left ____To the top of the page ____Into the page
____To the right ____To the bottom of the page ____Out of the page
Justify your answer.

(b)
i. Which of the following describes the shape of the portion of path 3 between the plates?
____Circular ____Parabolic ____Hyperbolic ____Exponential
Justify your answer.

ii. What is the direction of the magnetic field?
____To the left ____To the top of the page ____Into the page
____To the right ____To the bottom of the page ____Out of the page
Justify your answer.

Between the plates the magnitude of the electric field is 3.4×10^4 V/m, and that of the magnetic field is 2.0×10^{-3} T .
(c) Calculate the speed of the electrons given that they are undeflected when both fields are present.
(d) Calculate the potential difference V_o required to accelerate the electrons to the speed determined in part (c).