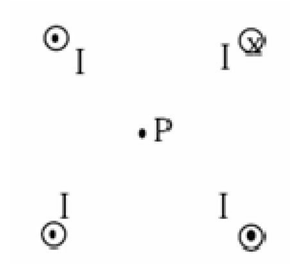
AP Physics Multiple Choice Practice – Magnetism and Electromagnetic Induction

SECTION A – Magnetism

1. Four infinitely long wires are arranged as shown in the accompanying figure end–on view. All four wires are perpendicular to the plane of the page and have the same magnitude of current I. The conventional current in the wire in the upper right–hand corner is directed into the plane of the page. The other conventional currents are out of the plan of the page. Point P is a distance a from all four wires. What is the total magnetic field at point P?



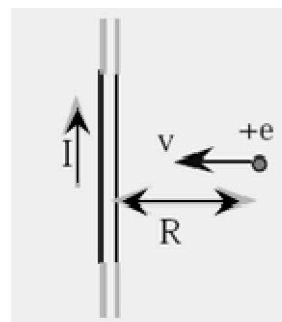
   A) $\frac{\mu_o}{2\pi}\frac{I}{a}$ toward the upper left hand corner

   B) $\frac{\mu_o}{2\pi}\frac{I}{a}$ toward the lower left hand corner

   C) $2\frac{\mu_o}{2\pi}\frac{I}{a}$ toward the upper left hand corner

   D) 0

2. The conventional current I in a long straight wire flows in the upward direction as shown in the figure. (Electron flow is downward.) At the instant a proton of charge +e is a distance R from the wire and heading directly toward it, the force on the proton is:



   A) $\frac{\mu_o}{2\pi}\frac{I^2L}{R}$ upward (in the same direction as I)

   B) $\frac{\mu_o}{2\pi}\frac{I^2L}{R}$ downward (in the opposite direction as I)

   C) $ev\frac{\mu_o}{2\pi}\frac{I}{R}$ upward (in the same direction as I)

   D) $ev\frac{\mu_o}{2\pi}\frac{I}{R}$ downward (in the opposite direction as I)

3. A charged particle with constant speed enters a uniform magnetic field whose direction is perpendicular to the particles velocity. The particle will:

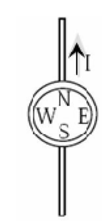
   A) Speed up　　B) Experience no change in velocity

   C) Follow a parabolic arc　　D) Follow a circular arc

4. A long straight wire conductor is placed below a compass as shown in the top view figure. When a large conventional current flows in the conductor as shown, the N pole of the compass:

   A) has its polarity reversed　　B) points to the south

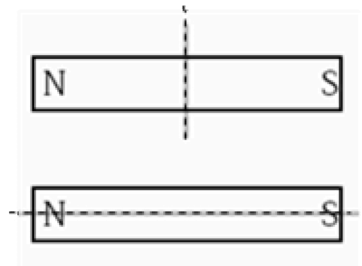
   C) points to the west　　D) points to the east



5. A proton of mass M and kinetic energy K passes undeflected through a region with electric and magnetic fields perpendicular to each other. The electric field has magnitude E. The magnitude of the magnetic field B is

A) $\sqrt{\frac{ME^2}{K}}$ B) $\sqrt{\frac{ME}{2K}}$ C) $\sqrt{\frac{2ME^2}{K}}$ D) $\sqrt{\frac{ME^2}{2K}}$

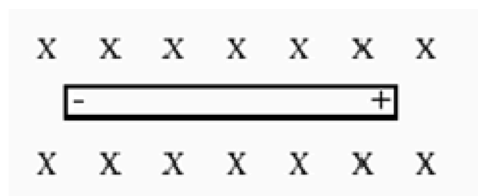
6. Two bar magnets are to be cut in half along the dotted lines shown. None of the pieces are rotated. After the cut:



A) The two halves of each magnet will attract each other
B) The two halves of each magnet will repel each other
C) The two halves of the top magnet will repel, the two halves of the bottom magnet will attract
D) The two halves of the top magnet will attract, the two halves of the bottom magnet will repel

7. An ion with charge q, mass m, and speed v enters a magnetic field B and is deflected into a path with a radius of curvature R. If a second ion has speed $2v$, while m, q, and B are unchanged, what will be the radius of the second ion's path?
A) 4R B) 2R C) R/2 D) R/4

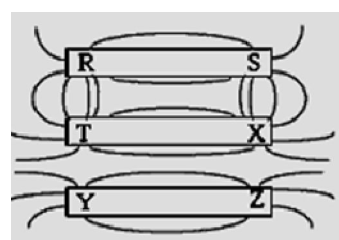
8. A wire moves through a magnetic field directed into the page. The wire experiences an induced charge separation as shown. Which way is the wire moving?



A) to the right C) toward the top of the page
B) to the left D) toward the bottom of the page

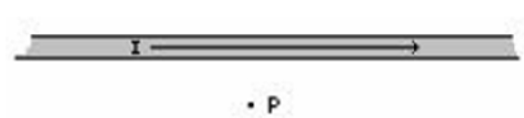
9. A charged particle with constant velocity enters a uniform magnetic field whose direction is parallel to the particle's velocity. The particle will
A) speed up
B) slow down
C) experience no change in velocity
D) follow a circular arc

10. The diagram to the right depicts iron filings sprinkled around three permanent magnets. Pole R is the same pole as



A) T and Y
B) T and Z
C) X and Y
D) X and Z

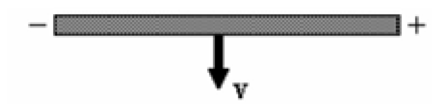
11. If conventional electric current flows from left to right in a wire as shown, what is the direction of the magnetic field at point P?



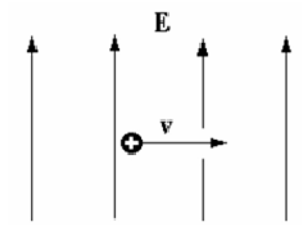
A) towards the top of the paper
B) towards the bottom of the paper
C) into the paper
D) out of the paper

12. Two light wires are hung vertically. With electrical current in both wires directed upwards
A) the wires will experience a force of attraction
B) the wires will experience a force of repulsion
C) the force on the right hand wire will cancel the force on the left hand wire
D) both wires will experience a torque until they are at right angles to each other

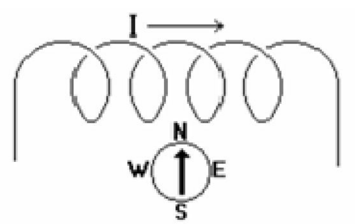
13. A wire moves with a velocity v through a magnetic field and experiences an induced charge separation as shown. What is the direction of the magnetic field?
A) into the page
B) towards the bottom of the page
C) out of the page
D) towards the top of the page



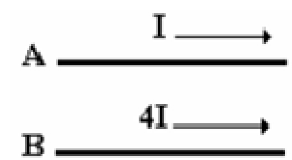
14. A positively charged particle moves to the right. It enters a region of space in which there is an electric field directed up the plane of the paper as shown. In which direction does the magnetic field have to point in this region so that the particle maintains a constant velocity?
A) into the plane of the page
B) out of the plane of the page
C) to the right
D) to the left



15. A compass is placed near a coil of wire. A conventional electrical current is then run through the coil from left to right as shown. This will cause the North pole of the compass to:
A) point toward the left
B) point toward the right
C) point toward the bottom of the paper
D) not move since the magnetic field of the coil is into the paper



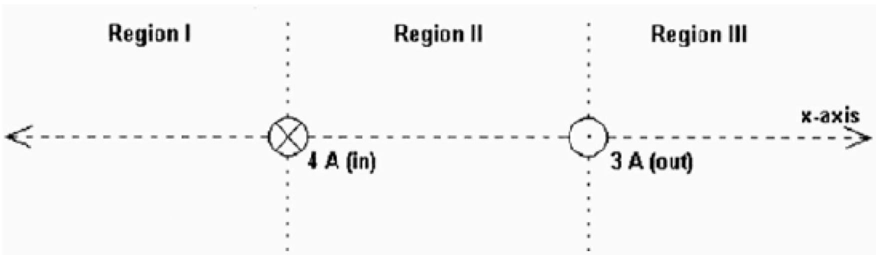
16. Two parallel wires are carrying different electric current in the same direction as shown. How does the magnitude of the force of A from B compare to the force of B from A



A) $F_{B\text{ on }A} = \frac{1}{4} F_{A\text{ on }B}$
B) $F_{B\text{ on }A} = 2 F_{A\text{ on }B}$
C) $F_{B\text{ on }A} = \frac{1}{2} F_{A\text{ on }B}$
D) $F_{B\text{ on }A} = F_{A\text{ on }B}$

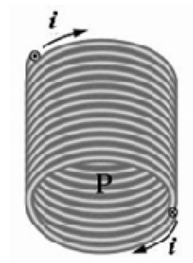
17. A positively charged particle of mass M is at rest on a table. A non–zero electric field E is directed into the plane of the table. A non–zero magnetic field B is directed out of the plane of the table. What is true about the magnitude of the electric force on the particle F_E compared to the magnetic force on the particle F_B?
A) $F_E > F_B$ B) $F_E < F_B$ C) $F_E = F_B$
D) It cannot be determined without knowing the exact value of the charge of the particle

18. Two very long current–carrying wires are shown end on in the figure. The wire on the left has a 4A current going into the plane of the paper and the wire on the right has a 3A current coming out of the paper. Disregarding the case of x → ∞, in which region(s) could the magnetic field from these two wires add to zero on the x–axis.

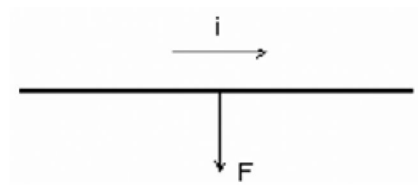


A) Region I only   B) Region II only   C) Region III only   D) Regions I and III only

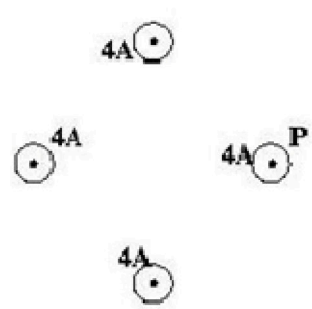
19. The magnetic field line passing through point P inside the solenoid is directed
A) to the right
B) to the left
C) downward toward the bottom of the page
D) upward toward the top of the page



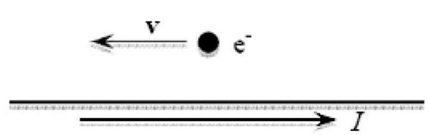
20. The diagram below shows a straight wire carrying a current i in a uniform magnetic field. An arrow indicates the magnetic force F on the wire. Of the following possibilities, the direction of the magnetic field must be
A) out of the page
B) into the page
C) up the plane of the page
D) down the plane of the page



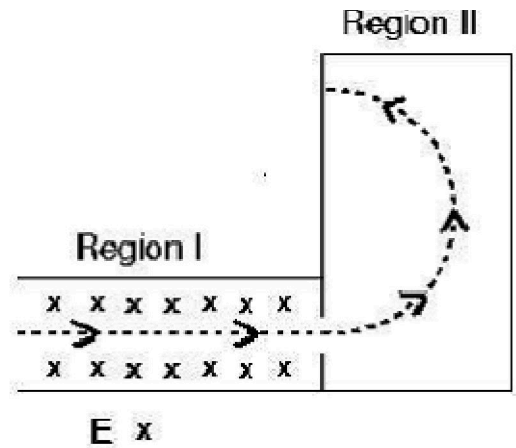
21. For the four identical current-carrying wires shown (with conventional current coming out of the plane of the page), the wire on the right is labeled P. What is the direction of the total magnetic force on the wire labeled P that is caused by the other wires?
A) To the left
B) To the right
C) Towards the top of the page
D) There is no force.



22. A wire has a conventional current *I* directed to the right. At the instant shown in the figure, an electron has a velocity directed to the left. The magnetic force on the electron at this instant is
A) directed toward the top of the page.
B) directed toward the bottom of the page.
C) directed out of the plane of the page.
D) directed into the plane of the page.



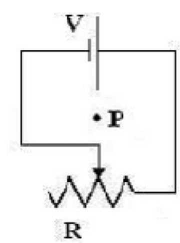
23. An electron moves in the plane of the page through two regions of space along the dotted-line trajectory shown in the figure. There is a uniform electric field in Region I directed into the plane of the page (as shown). There is no electric field in Region II. What is a necessary direction of the magnetic field in regions I and II? Ignore gravitational forces.



	Region I	Region II
A)	Toward bottom of page	Up on the page
B)	Toward top of page	Into the page
C)	Toward top of page	Out of the page
D)	Toward bottom of page	Out of the page

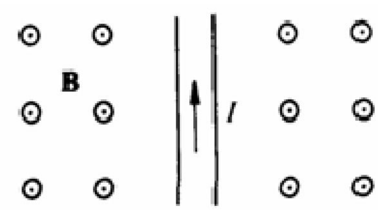
24. A proton moves toward the top of this page into a region that has a magnetic field directed to the right of this page. If the particle is undeflected as it passes through this region, in what direction must there be a component of electric field? Ignore gravity.
A) To the left B) Into the page C) Out of the page D) To the right

25. For the figure shown, the variable resistance in the circuit is increased at a constant rate. What is the direction of the magnetic field at the point P at the center of the circuit

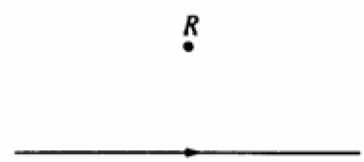


	Magnetic Field at P
A)	Into the page
B)	Out of the page
C)	To the left
D)	There is no field

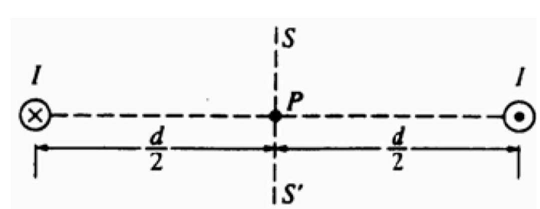
26. A wire in the plane of the page carries a current directed toward the top of the page as shown. If the wire is located in a uniform magnetic field B directed out of the page, the force on the wire resulting from the magnetic field is
(A) directed to the left
(B) directed out of the page
(C) directed to the right
(D) zero



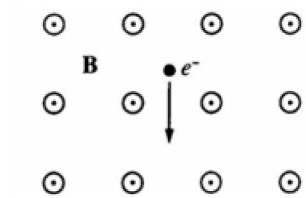
27. The direction of the magnetic field at point R caused by the current I in the wire shown is
(A) to the left (B) to the right
(C) into the page (D) out of the page



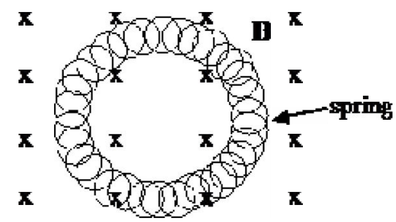
28. Two long, parallel wires are separated by a distance d, as shown. One wire carries a steady current I into the plane of the page while the other wire carries a steady current I out of the page. At what points in the plane of the page and outside the wires, besides points at infinity, is the magnetic field due to the currents zero?
(A) Only at point P
(B) At all points on the line SS'
(C) At all points on the line connecting the two wires
(D) At no points



29. An electron is in a uniform magnetic field **B** that is directed out of the plane of the page, as shown. When the electron is moving in the plane of the page in the direction indicated by the arrow, the force on the electron is directed
(A) toward the right
(B) out of the page
(C) into the page
(D) toward the top of the page



30. A metal spring has its ends attached so that it forms a circle. It is placed in a uniform magnetic field, as shown. Which of the following will not cause a current to be induced in the spring?
(A) Changing the magnitude of the magnetic field
(B) Rotating the spring about a diameter
(C) Moving the spring parallel to the magnetic field
(D) Moving the spring in and out of the magnetic field



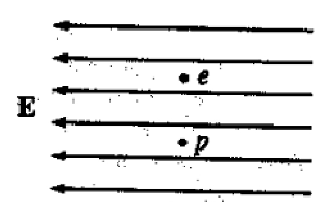
<u>Questions 31-32</u>
A magnetic field of 0.1T forces a proton beam of 1.5 mA to move in a circle of radius 0.1 m. The plane of the circle is perpendicular to the magnetic field.

31. Of the following, which is the best estimate of the work done by the magnetic field on the protons during one complete orbit of the circle?
(A) 0 J (B) 10^{-22} J (C) 10^{-5} J (D) 10^{2} J

32. Of the following, which is the best estimate of the speed of a proton in the beam as it moves in the circle?
(A) 10^{-2} m/s (B) 10^{3} m/s (C) 10^{6} m/s (D) 10^{8} m/s

33. Two parallel wires, each carrying a current I, repel each other with a force F. If both currents are doubled, the force of repulsion is
(B) $2\sqrt{2}$ F (C) 4F (C) $4\sqrt{2}$ F (E) 8F

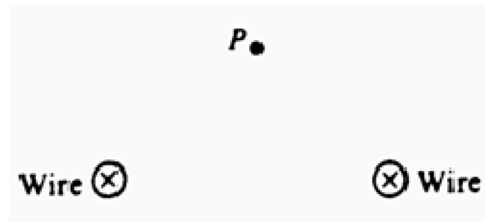
34. An electron e and a proton p are simultaneously released from rest in a uniform electric field E, as shown. Assume that the particles are sufficiently far apart so that the only force acting on each particle after it is released is that due to the electric field. At a later time when the particles are still in the field, the electron and the proton will have the same
(A) speed
(B) displacement
(C) magnitude of acceleration
(D) magnitude of force acting on them



35. Two long, parallel wires, fixed in space, carry currents I_1 and I_2. The force of attraction has magnitude F. What currents will give an attractive force of magnitude 4F?
(A) $2I_1$ and $\frac{1}{2}I_2$ (B) $\frac{1}{2}I_1$ and $\frac{1}{2}I_2$ (C) $2I_1$ and $2I_2$ (D) $4I_1$ and $4I_2$

36. A charged particle is projected with its initial velocity parallel to a uniform magnetic field. The resulting path is
(A) a spiral (B) a circular arc (C) a straight line parallel to the field
(D) a straight line perpendicular to the field

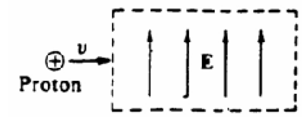
37. Two very long parallel wires carry equal currents in the same direction into the page, as shown. At point P, which is 10 centimeters from each wire, the magnetic field is
A) zero
B) directed into the page
C) directed out of the page
D) directed to the right



<u>Questions 38-39</u>

A proton traveling with speed v enters a uniform electric field of magnitude E, directed parallel to the plane of the page, as shown in the figure. There is also a magnetic force on the proton that is in the direction opposite to that of the electric force.

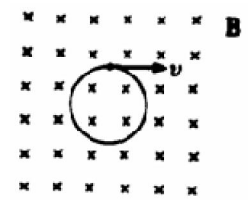
38. Which of the following is a possible direction for the magnetic field?

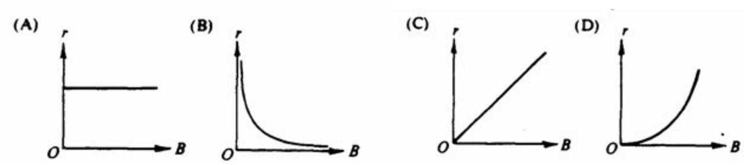


(A) ↓ (B) ↑ (C) ← (D) ⊙ (directed out of the page)

39. If e represents the magnitude of the proton charge, what minimum magnitude of the magnetic field could balance the electric force on the proton?
(A) E/v (B) eE/v (C) vE (D) eE

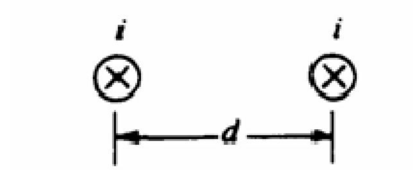
40. A negatively charged particle in a uniform magnetic field **B** moves with constant speed v in a circular path of radius r, as shown. Which of the following graphs best represents the radius r as a function of the magnitude of **B**, if the speed v is constant?





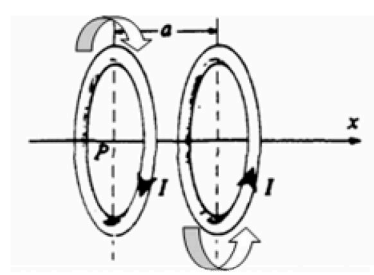
<u>Questions 41-42</u> relate to the two long parallel wires shown. Initially the wires are a distance d apart and each has a current i directed into the page. The force per unit length on each wire has magnitude F_o

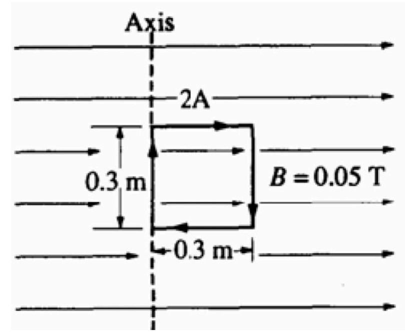
41. The direction of the force on the right-hand wire due to the current in the left-hand wire is
(A) to the right
(B) to the left
(C) upward in the plane of the page
(D) downward in the plane of the page



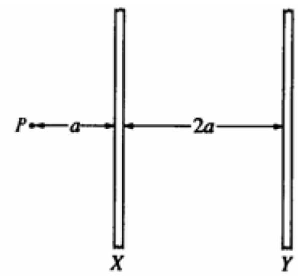
42. The wires are moved apart to a separation 2d and the current in each wire is increased to 2i. The new force per unit length on each wire is
(A) $F_0/4$ (B) $F_o/2$ (C) F_o (D) $2F_o$

43. Two identical parallel conducting rings have a common axis and are separated by a distance a, as shown. The two rings each carry a current I, but in opposite directions. At point P, the center of the ring on the left the magnetic field due to these currents is
(A) zero
(B) in the plane perpendicular to the x-axis
(C) directed in the positive x-direction
(D) directed in the negative x-direction

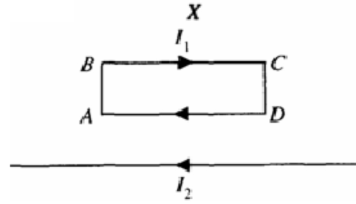




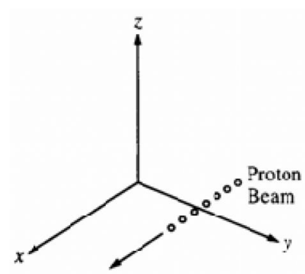
44. A square loop of wire 0.3 meter on a side carries a current of 2 amperes and is located in a uniform 0.05-tesla magnetic field. The left side of the loop is aligned along and attached to a fixed axis. When the plane of the loop is parallel to the magnetic field in the position shown, what is the magnitude of the torque exerted on the loop about the axis?
A) 0.00225 Nm
B) 0.0090 Nm
C) 0.278 Nm
D) 1.11 Nm



45. Two long parallel wires are a distance 2a apart, as shown. Point P is in the plane of the wires and a distance a from wire X. When there is a current I in wire X and no current in wire Y, the magnitude of the magnetic field at P is B_o. When there are equal currents I in the same direction in both wires, the magnitude of the magnetic field at P is
A) $2B_o/3$ B) $10B_o/9$ C) $4B_o/3$ D) $2 B_o$

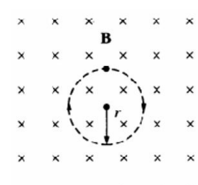


46. A rigid, rectangular wire loop ABCD carrying current I_1 lies in the plane of the page above a very long wire carrying current I_2 as shown. The net force on the loop is
(A) toward the very long wire
(B) away from the very long wire
(C) toward the left
(D) zero

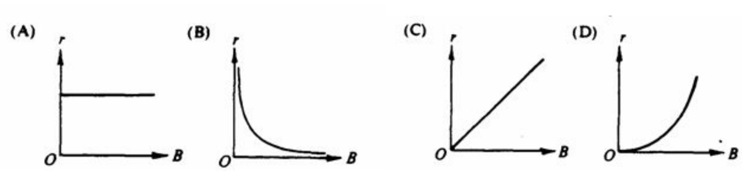


47. A beam of protons moves parallel to the x-axis in the positive x-direction, as shown, through a region of crossed electric and magnetic fields balanced for zero deflection of the beam. If the magnetic field is pointed in the positive y-direction, in what direction must the electric field be pointed?
(A) Negative y-direction
(B) Positive z-direction
(C) Negative z-direction
(D) Negative x-direction

48. A charged particle can move with constant velocity through a region containing both an electric field and a magnetic field only if the
(A) electric field is parallel to the magnetic field
(B) electric field is perpendicular to the magnetic field
(C) electric field is parallel to the velocity vector
(D) magnetic field is perpendicular to the velocity vector

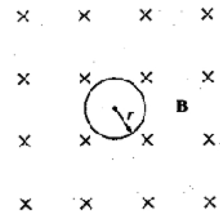


49. A negatively charged particle in a uniform magnetic field B moves in a circular path of radius r, as shown. Which of the following graphs best depicts how the frequency of revolution f of the particle depends on the radius r?



Questions 50-41

A particle of charge +e and mass m moves with speed v perpendicular to a uniform magnetic field B directed into the page. The path of the particle is a circle of radius r, as shown.



50. Which of the following correctly gives the direction of motion and the equation relating v and r ?

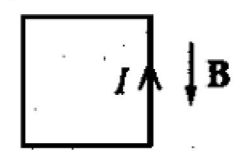
Direction	Equation
(A) Clockwise	$eBr = mv$
(B) Clockwise	$eBr = mv^2$
(C) Counterclockwise	$eBr = mv$
(D) Counterclockwise	$eBr^2 = mv^2$

51. The period of revolution of the particle is

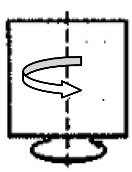
$(A)\ \dfrac{\mathrm{mr}}{\mathrm{eB}}$ $\qquad (C)\ \dfrac{2\pi m}{\mathrm{eB}}$

$(B)\ \sqrt{\dfrac{\mathrm{m}}{\mathrm{eB}}}$ $\qquad (D)\ 2\pi\sqrt{\dfrac{\mathrm{m}}{\mathrm{eB}}}$

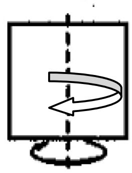
52. A square loop of wire carrying a current I is initially in the plane of the page and is located in a uniform magnetic field B that points toward the bottom of the page, as shown. Which of the following shows the correct initial rotation of the loop due to the force exerted on it by the magnetic field?



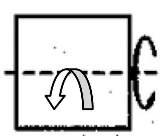
(A)



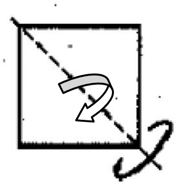
(B)



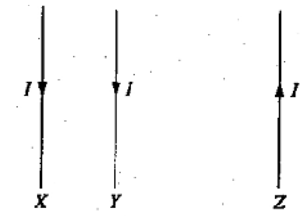
(C)



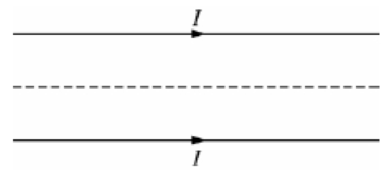
(D)



53. The currents in three parallel wires, X, Y, and Z, each have magnitude I and are in the directions shown. Wire y is closer to wire X than to wire z. The magnetic force on wire y is
(A) zero
(B) into the page
(C) out of the page
(D) toward the left



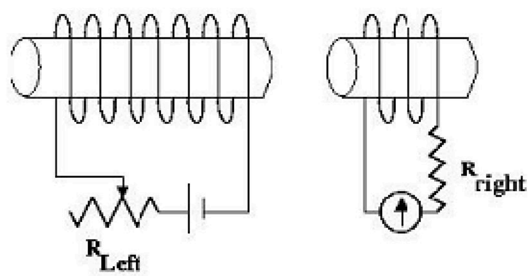
54. Two long, straight, parallel wires in the plane of the page carry equal currents *I* in the same direction, as shown above. Which of the following correctly describes the forces acting on the wires and the resultant magnetic field at points along the dotted line midway between the wires?



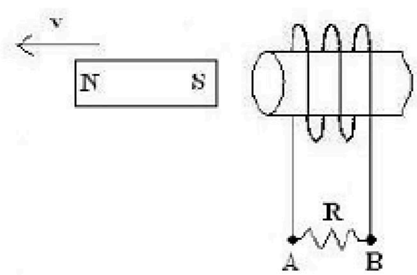
	Forces	Field
(A)	Attractive	Not zero
(B)	Attractive	Zero
(C)	Repulsive	Not zero
(D)	Repulsive	Zero

SECTION B – Electromagnetic Induction

1. For the solenoids shown in the diagram (which are assumed to be close to each other), the resistance of the left-hand circuit is slowly increased. In which direction does the ammeter needle (indicating the direction of conventional current) in the right-hand circuit deflect in response to this change?
   A) The needle deflects to the left.
   B) The needle deflects to the right.
   C) The needle oscillates back and forth.
   D) The needle never moves.



2. A strong bar magnet is held very close to the opening of a solenoid as shown in the diagram. As the magnet is moved away from the solenoid at constant speed, what is the direction of conventional current through the resistor shown and what is the direction of the force on the magnet because of the induced current?



	Current through resistor	Force on Magnet
A)	From A to B	To the left
B)	From B to A	To the left
C)	From A to B	To the right
D)	From B to A	To the right

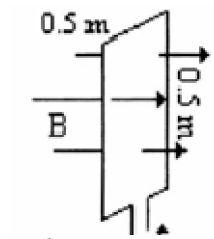
3. A magnet is dropped through a vertical copper pipe slightly larger than the magnet. Relative to the speed it would fall in air, the magnet in the pipe falls.
   A) more slowly because it is attracted by the innate magnetic field of the pipe
   B) more slowly because the currents induced in the pipe produce an opposing magnetic field
   C) at the same rate
   D) more quickly because the currents induced in the pipe produce an opposing magnetic field

4. A 0.20 m long copper rod has constant velocity 0.30 m/s traveling through a uniform magnetic field of 0.060 T. The rod, velocity, and magnetic field are all mutually perpendicular. What is the potential difference induced across the rod's length?
   A) 0.0036 V B) 0.040 V C) 0.090 V D) 1.0 V ~~E) 25 V~~

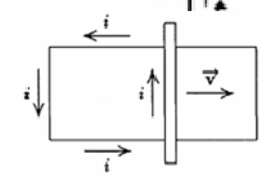
5. When a wire moving through a magnetic field has a voltage induced between the wire's ends, that voltage is
   I. directly proportional to the strength of the magnetic field
   II. directly proportional to the velocity of the wire
   III. directly proportional to the diameter of the wire
   A) I only B) II only C) III only D) I and II only

6. Lenz's law concerning the direction of an induced current in a conductor by a magnetic field could be considered a result of
   A) Ampere's law B) Ohm's Law C) Tesla's Law
   D) The Law of Conservation of Energy

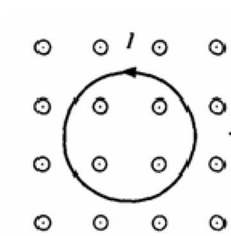
7. A square loop is placed in a uniform magnetic field perpendicular to the plane of the loop as shown. The loop is 0.50 meters on a side and the magnetic field B has a strength of 2 T. If the loop is rotated through an angle of 90° in 0.1 second what would be the average induced EMF in the loop?
   A) 0.025 C B) 0.40 V C) 5 V D) 10 V



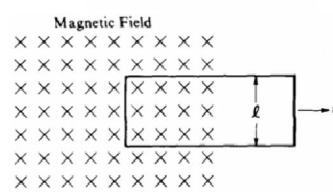
8. The figure shows a bar moving to the right on two conducting rails. To make an induced current i in the direction indicated, in what direction would the magnetic field be in the area contained within the conducting rails?
   A) out of the page B) into the page
   C) to the right D) to the left



9. There is a counterclockwise current I in a circular loop of wire situated in an external magnetic field directed out of the page as shown. The effect of the forces that act on this current is to make the loop
   (A) expand in size
   (B) contract in size
   (C) rotate about an axis perpendicular to the page
   (D) accelerate into the page

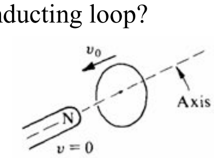


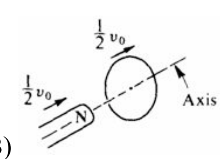
10. The figure shows a rectangular loop of wire of width *l* and resistance R. One end of the loop is in a uniform magnetic field of strength B at right angles to the plane of the loop. The loop is pulled to the right at a constant speed v. What are the magnitude and direction of the induced current in the loop?

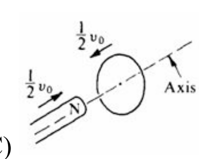


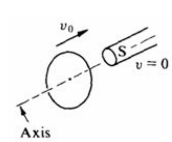
Magnitude	Direction
(A) BlvR	Clockwise
(B) BlvR	Counterclockwise
(C) Blv/R	Clockwise
(D) Blv/R	Counterclockwise

11. In each of the following situations, a bar magnet is aligned along the axis of a conducting loop. The magnet and the loop move with the indicated velocities. In which situation will the bar magnet NOT induce a current in the conducting loop?

(A) 

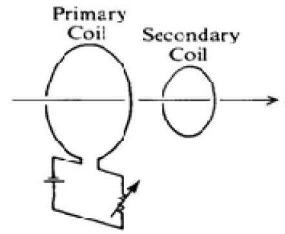
(B) 

(C) 

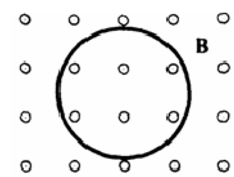
(D) 

12. A square loop of copper wire is initially placed perpendicular to the lines of a constant, uniform magnetic field of 5 x 10-3 tesla. The area enclosed by the loop is 0.2 square meter. The loop is then turned through an angle of 90° so that the plane of the loop is parallel to the field lines. The turn takes 0.1 second. The average emf induced in the loop during the turn is
(A) 1.0 x 10-4 V (B) 2.5 x 10-3 V (C) 0.01 V (D) 100

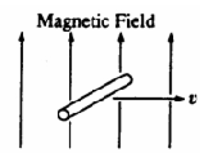
13. Two circular coils are situated perpendicular to the z-axis as shown. There is a current in the primary coil. All of the following procedures will induce a current in the secondary coil EXCEPT
(A) rotating the secondary coil about the z-axis
(B) rotating the secondary coil about a diameter
(C) moving the secondary coil closer to the primary coil
(D) varying the current in the primary coil

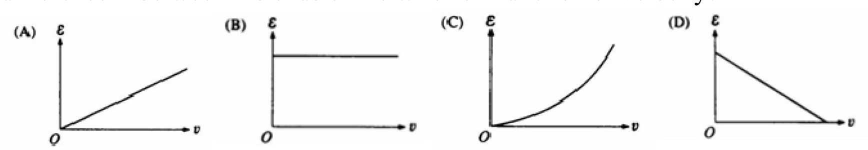


14. A magnetic field B that is decreasing with time is directed out of the page and passes through a loop of wire in the plane of the page, as shown. Which of the following is true of the induced current in the wire loop?
(A) It is counterclockwise in direction.
(B) It is clockwise in direction.
(C) It is directed out of the page.
(D) It is zero in magnitude.

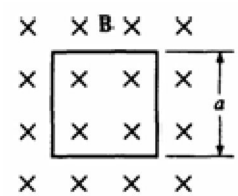


15. A wire of constant length is moving in a constant, uniform magnetic field, as shown. The wire and the velocity vector are perpendicular to each other and are both perpendicular to the field. Which of the following graphs best represents the potential difference E between the ends of the wire as a function of velocity?

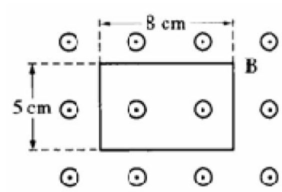




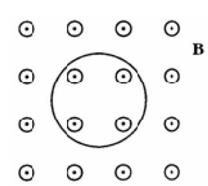
16. A square loop of wire of resistance *R* and side *a* is oriented with its plane perpendicular to a magnetic field **B**, as shown. What must be the rate of change of the magnetic field in order to produce a current *I* in the loop?
(A) IR/a^2 (B) Ia^2/R (C) Ia/R (D) IRa



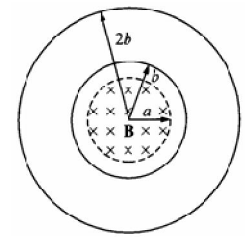
17. A rectangular wire loop is at rest in a uniform magnetic field **B** of magnitude 2 T that is directed out of the page. The loop measures 5 cm by 8 cm, and the plane of the loop is perpendicular to the field, as shown. The total magnetic flux through the loop is
(A) zero (B) 2×10^{-3} T-m^2 (C) 8×10^{-3} T-m^2
(D) 8×10^{-1} T-m



18. A single circular loop of wire in the plane of the page is perpendicular to a uniform magnetic field **B** directed out of the page, as shown. If the magnitude of the magnetic field is decreasing, then the induced current in the wire is
(A) directed out of the paper
(B) directed into the paper
(C) clockwise around the loop
(D) counterclockwise around the loop

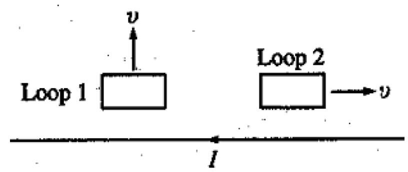


19. A uniform magnetic field **B** that is perpendicular to the plane of the page now passes through the loops, as shown. The field is confined to a region of radius a, where $a < b$, and is changing at a constant rate. The induced emf in the wire loop of radius b is ε. What is the induced emf in the wire loop of radius $2b$?



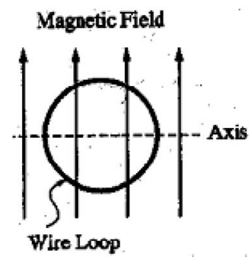
(A) Zero (B) $\varepsilon/2$ (C) ε (D) 4ε

20. Two conducting wire loops move near a very long, straight conducting wire that carries a current I. When the loops are in the positions shown, they are moving in the direction shown with the same constant speed v. Assume that the loops are far enough apart that they do not affect each other. Which of the following is true about the induced electric currents, if any, in the loops?



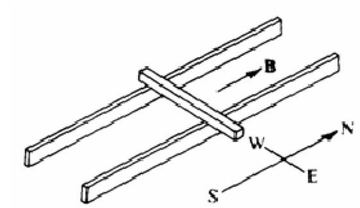
Loop 1	**Loop 2**
(A) No current	No current
(B) No current	Counterclockwise direction
(C) Clockwise direction	No current
(D) Counterclockwise direction	Clockwise direction

21. A wire loop is rotated in a uniform magnetic field about an axis perpendicular to the field, as shown. How many times is the induced current in the loop reversed if the loop makes 3 complete revolutions from the position shown?



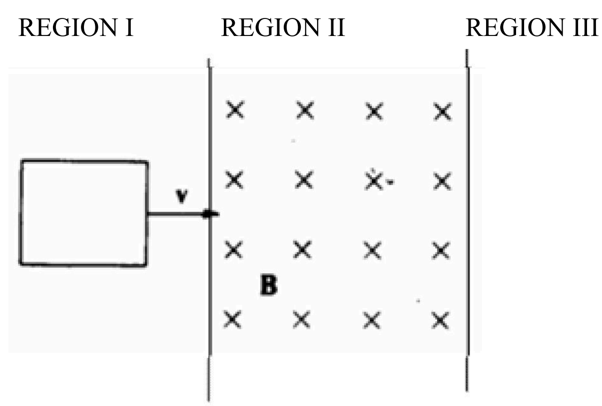
(A) One (B) Two C) Three (D) Six

22. The ends of a metal bar rest on two horizontal north-south rails as shown. The bar may slide without friction freely with its length horizontal and lying east and west as shown. There is a magnetic field parallel to the rails and directed north.If the bar is pushed northward on the rails, the electromotive force induced in the bar as a result of the magnetic field will



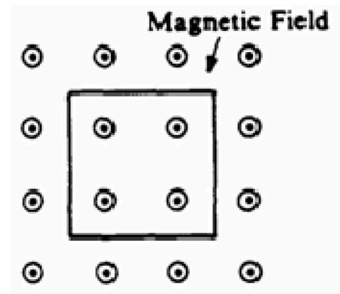
(A) be directed upward
(B) be zero
(C) produce a westward current
(D) stop the motion of the bar

23. A loop of wire is pulled with constant velocity v to the right through a region of space where there is a uniform magnetic field B directed into the page, as shown. The induced current is as follows

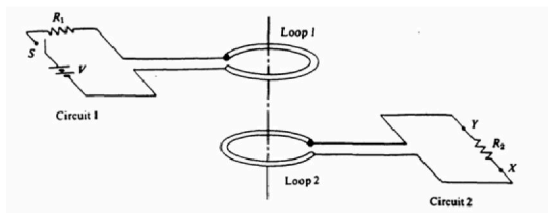


A) Directed CW both entering and leaving REGION II.
B) Directed CCW both entering and leaving REGION II.
C) Directed CW entering REGION II and CCW leaving REGION II
D) Directed CCW entering REGION II and CW leaving REGION II.

24. A square loop of wire of side 0.5 meter and resistance 10^{-2} ohm is located in a uniform magnetic field of intensity 0.4 tesla directed out of the page as shown. The magnitude of the field is decreased to zero at a constant rate in 2 seconds. As the field is decreased, what are the magnitude and direction of the current in the loop?
(A) Zero
(B) 5 A, counterclockwise
(C) 5 A, clockwise
(D) 20 A, counterclockwise



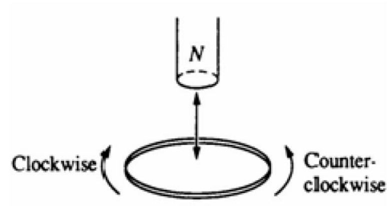
Questions 25-26



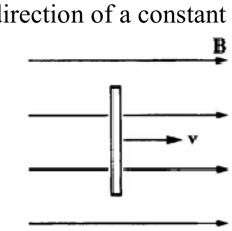
25. After the switch S is closed, the initial current through resistor R_2 is
(A) from point X to point Y
(B) from point Y to point X
(C) zero at all times
(D) impossible to determine its direction

26. After the switch S has been closed for a very long time, the currents in the two circuits are
(A) zero in both circuits
(B) zero in circuit 1 and V/R_2 in circuit 2
(C) V/R_1 in circuit 1 and zero in circuit 2
(D) V/R_1 in circuit I and V/R_2 in circuit 2

27. In the figure, the north pole of the magnet is first moved down toward the loop of wire, then withdrawn upward. As viewed from above, the induced current in the loop is
A) always clockwise with increasing magnitude
B) always counterclockwise with increasing magnitude
C) always counterclockwise with decreasing magnitude
D) first counterclockwise, then clockwise

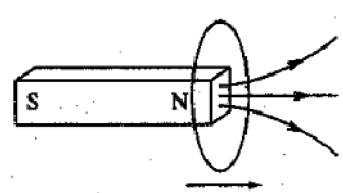


28. A vertical length of copper wire moves to the right with a steady velocity v in the direction of a constant horizontal magnetic field B as shown. Which of the following describes the induced charges on the ends of the wire?



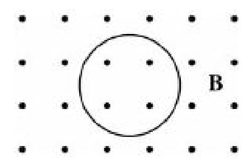
Top End	Bottom End
(A) Positive	Negative
(B) Negative	Positive
(C) Zero	Negative
(D) Zero	Zero

29. A conducting loop of wire that is initially around a magnet is pulled away from the magnet to the right, as indicated in the figure, inducing a current in the loop. What is the direction of the force on the magnet and the direction of the magnetic field at the center of the loop due to the induced current?



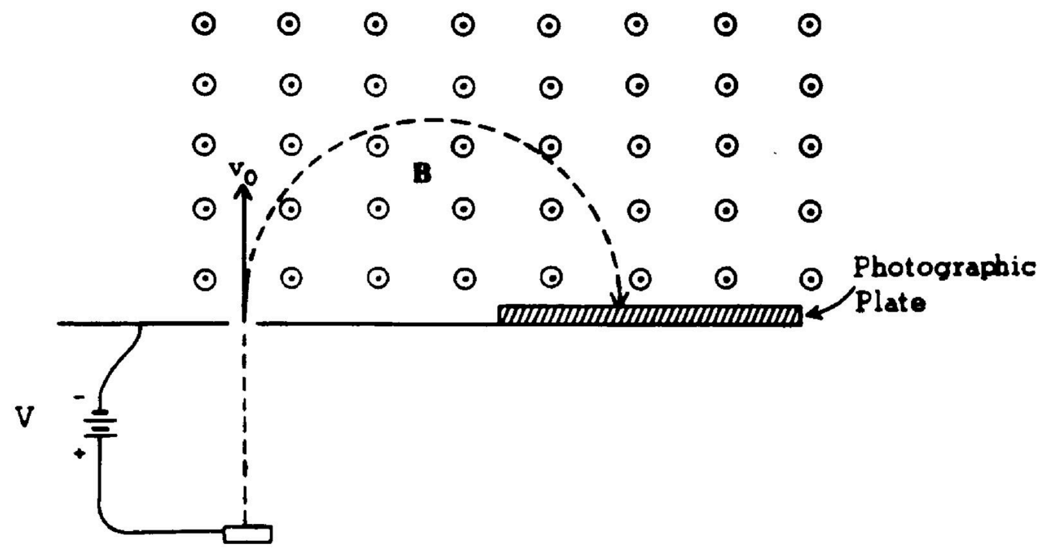
Direction of Force on the Magnet	Direction of Magnetic Field at Center of Loop due To Induced Current
(A) To the right	To the right
(B) To the right	To the left
(C) To the left	To the right
(D) No direction; the force is zero.	To the left

30. A uniform magnetic field **B** is directed out of the page, as shown to the right. A loop of wire of area 0.40 m^2 is in the plane of the page. At a certain instant the field has a magnitude of 3.0 T and is decreasing at the rate of 0.50 T/s. The magnitude of the induced emf in the wire loop at this instant is most nearly



(A) 0.20 V (B) 0.60 V (C) 1.2 V (D) 1.5 V

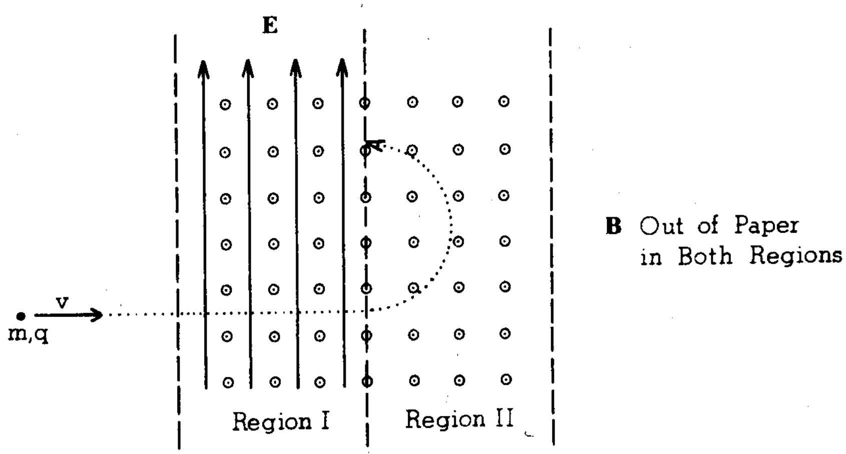
SECTION A – Magnetism



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.

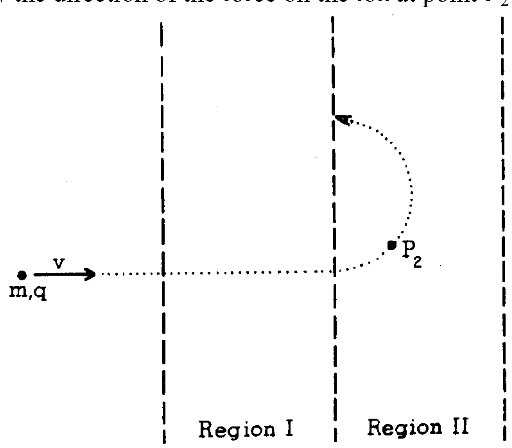
a. The ^{16}O ions are replaced with singly charged ^{32}S ions of twice the mass and the same charge. What will be their speed in terms of v_o for the same accelerating voltage?

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.



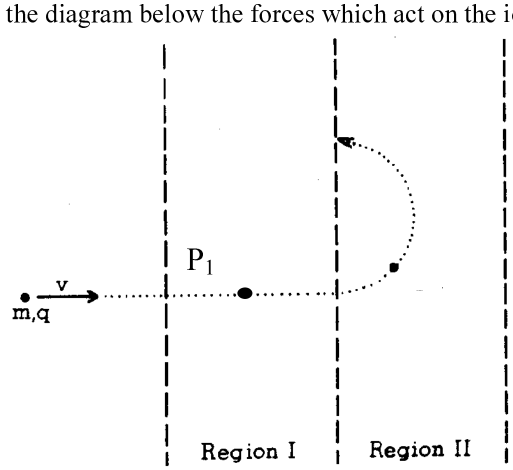
1976B4.
An ion of mass m and charge of known magnitude q is observed to move in a straight line through a region of space in which a uniform magnetic field B points out of the paper and a uniform electric field E points toward the top edge of the paper, as shown in region I above. The particle travels 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.



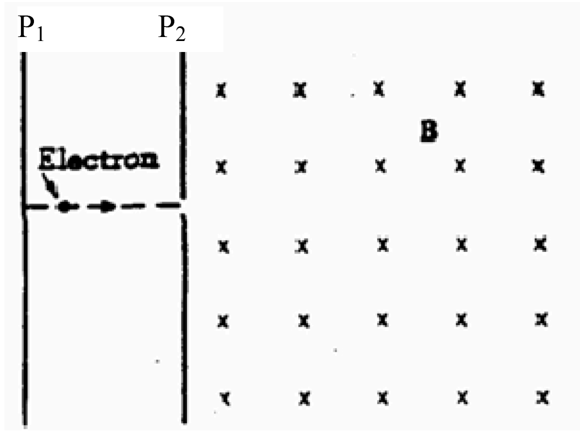
(b) Is the ion positively or negatively charged? Explain clearly the reasoning on which you base your conclusion.

(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.

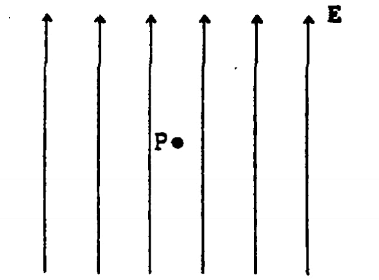
1977B3. An electron is accelerated from rest through a potential difference of magnitude V between infinite parallel plates P_1 and P_2. The electron then passes into a region of uniform magnetic field strength B which exists everywhere to the right of plate P_2. The magnetic field is directed into the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



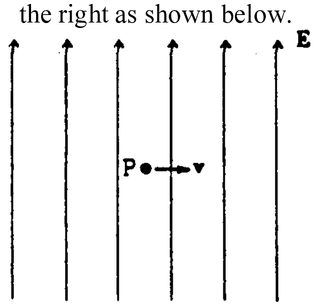
a. On the diagram above, clearly indicate the direction of the electric field between the plates.
b. In terms of V and the electron’s mass and charge, determine the electron's speed when it reaches plate P_2.
c. Describe in detail the motion of the electron through the magnetic field and explain why 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.

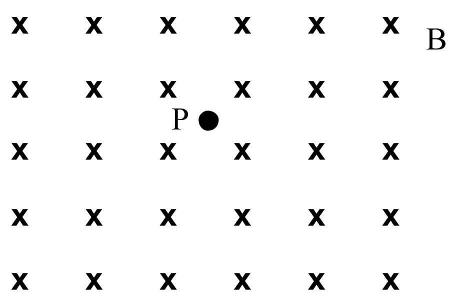
a. The proton is released from rest at the point P in an electric field E having intensity 10^4 newtons per coulomb and directed up in the plane of the page as shown below.



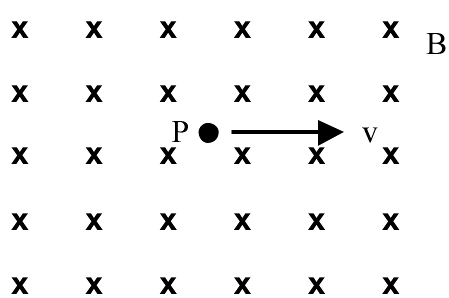
b. In the same electric field as in part (a), the proton at point P has velocity $v = 10^5$ meters per second directed to the right as shown below.



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.

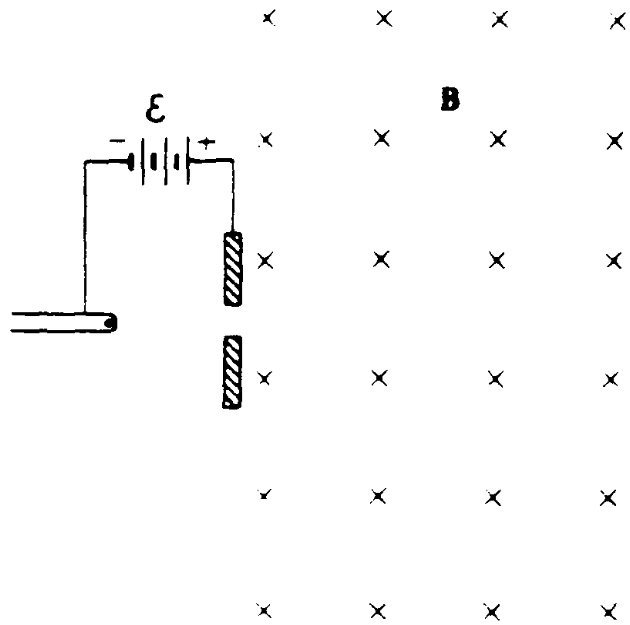


d. In the same magnetic field as in part (c), the proton at point P has velocity $v = 10^5$ meters per second directed to the right as shown below.



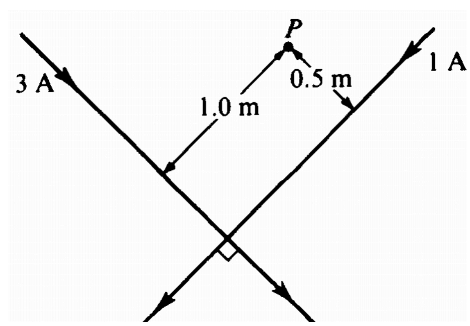
1984B4. An electron from a hot filament in a cathode ray tube is accelerated through a potential difference $\mathcal{E}$. It then passes into a region of uniform magnetic field B, directed into the page as shown. The mass of the electron is m and the charge has magnitude e.

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



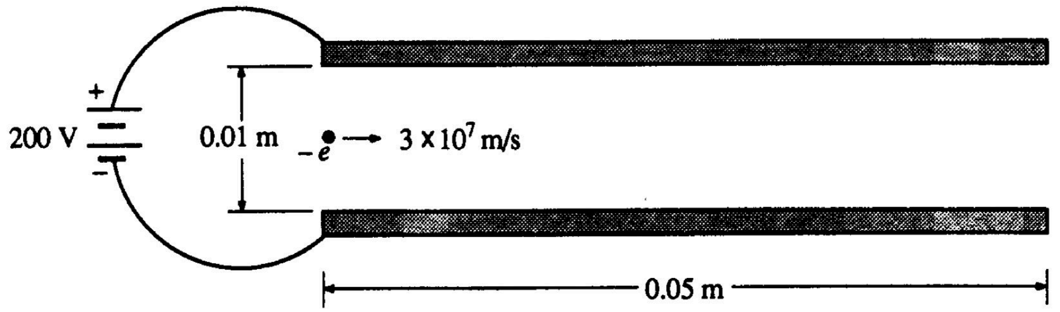
1988B4. The two long straight wires as shown are perpendicular, insulated from each other, and small enough so that they may be considered to be in the same plane. The wires are not free to move. Point P, in the same plane as the wires, is 0.5 meter from the wire carrying a current of 1 ampere and is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



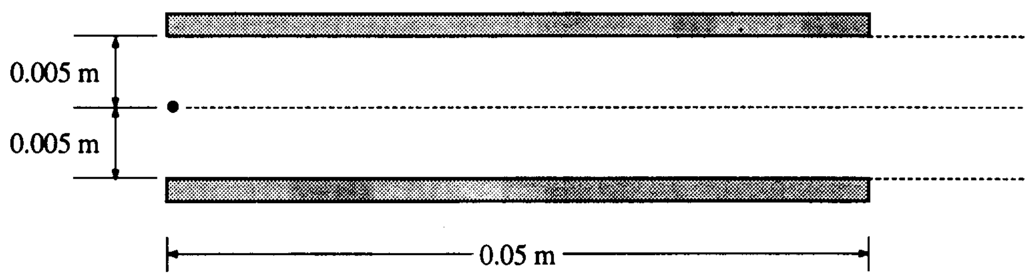
A charged particle at point P that is instantaneously moving with a velocity of 10^6 meters per second toward the top of the page experiences a force of 10^{-7} newtons to the left due to the two currents.

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.

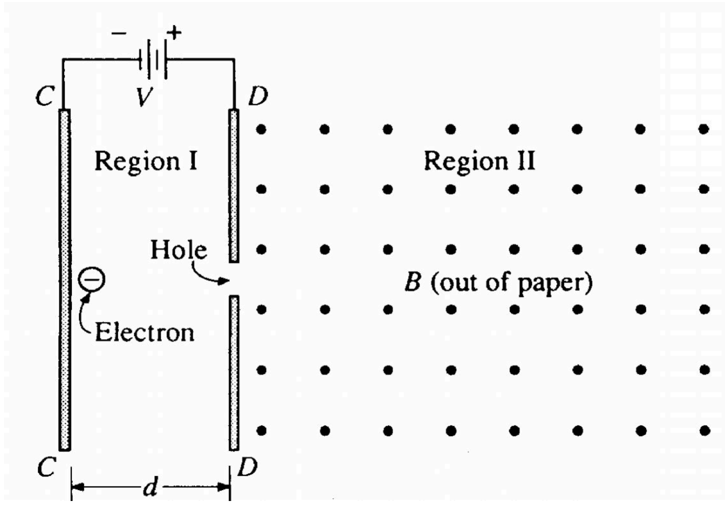


1990B2. A pair of square parallel conducting plates, having sides of length 0.05 meter, are 0.01 meter apart and are connected to a 200-volt power supply, as shown above. An electron is moving horizontally with a speed of 3×10^7 meters per second when it enters the region between the plates. Neglect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

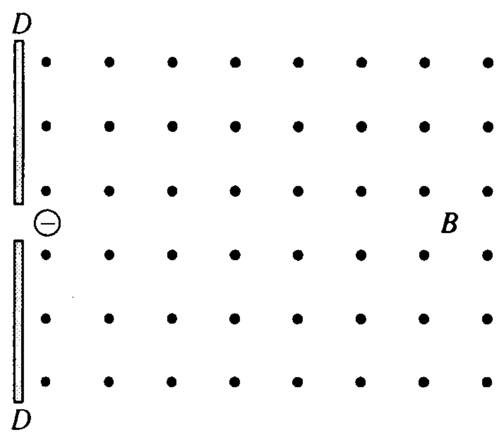
   i. The speed v_0 of the electron as it emerges from the hole in plate D

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

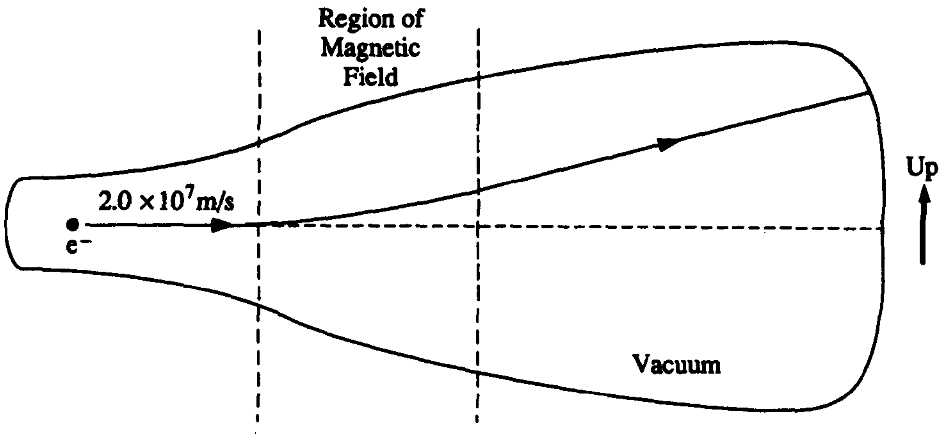
b. On the diagram below do the following.

   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

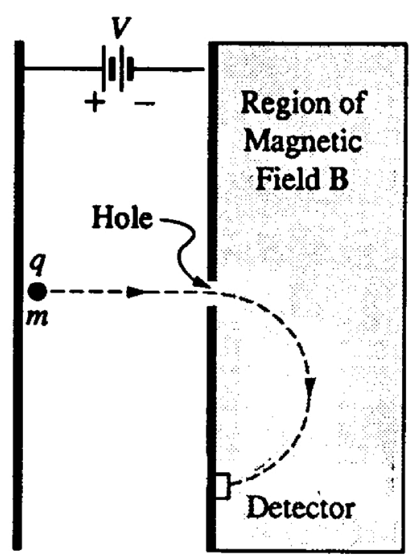
1992B5. The figure above shows a cross section of a cathode ray tube. An electron in the tube initially moves horizontally in the plane of the cross section at a speed of 2.0×10^7 meters per second. The electron is deflected upward by a magnetic field that has a field strength of 6.0×10^{-4} tesla.

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.

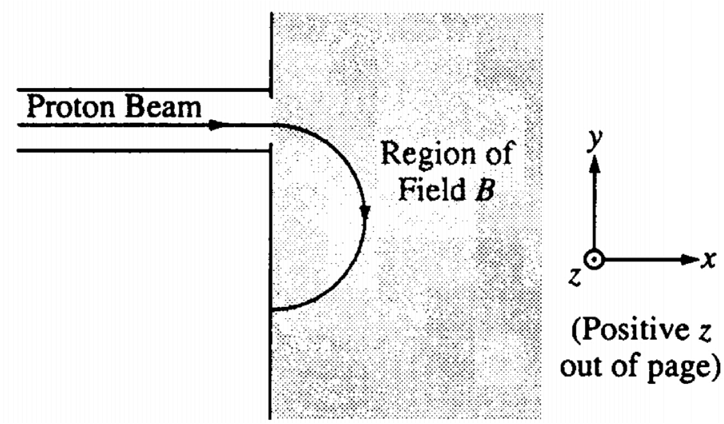
An electric field is later established in the same region as the magnetic field such that the electron now passes through the magnetic and electric fields without deflection.

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.



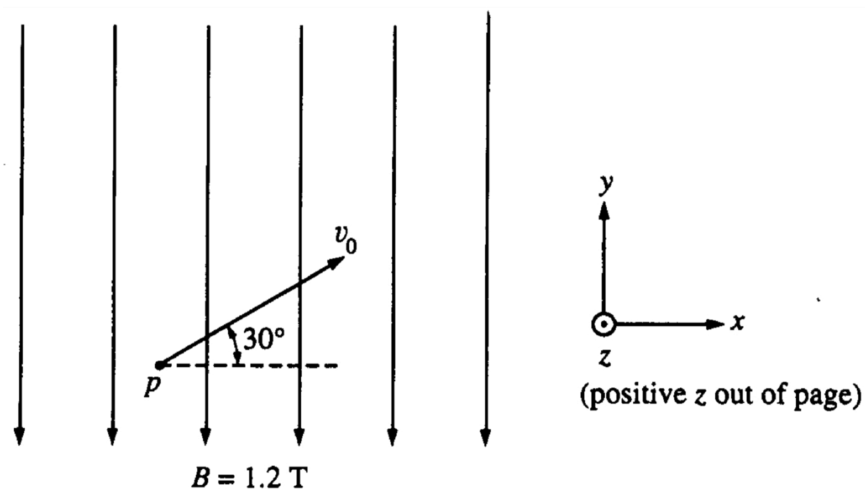
a. i. State whether the sign of the charge on the particle is positive or negative.
   ii. State whether the direction of the magnetic field is into the page or out of the page.
b. Determine each of the following in terms of m, q, V, and B.
   i. The speed of the charged particle as it enters the region 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 3.1×10^6 meters per second. The resulting proton beam produces a current of 2×10^{-6} ampere.

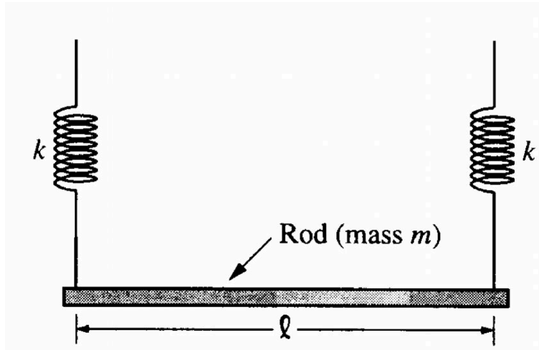
a. Determine the potential difference through which the protons were accelerated.
b. If the beam is stopped in a target, determine the amount of thermal energy that is produced in the target in one minute.

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?



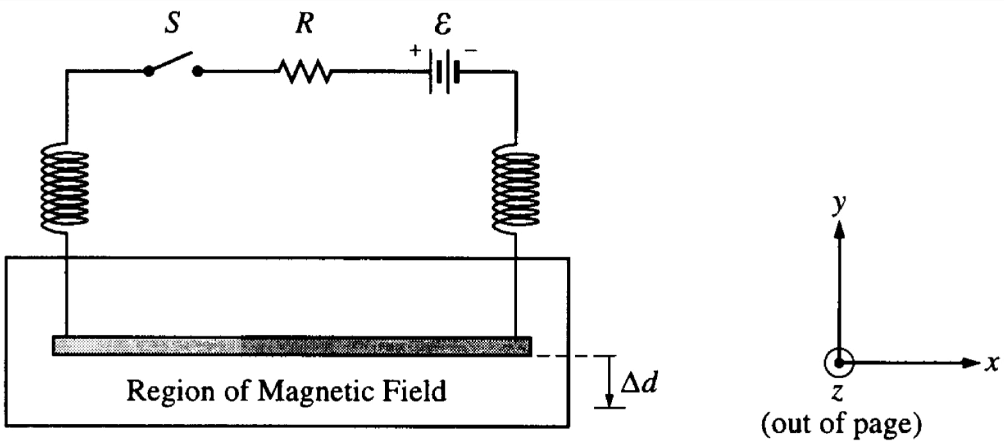
1995B7. A uniform magnetic field of magnitude B = 1.2 teslas is directed toward the bottom of the page in the –y direction, as shown above. At time t = 0, a proton p in the field is moving in the plane of the page with a speed $v_o = 4 \times 10^7$ meters per second in a direction 30° above the +x axis.

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

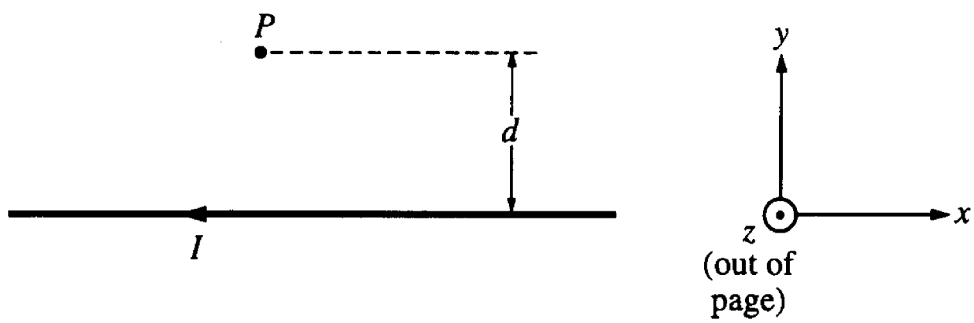


Figure 1

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.

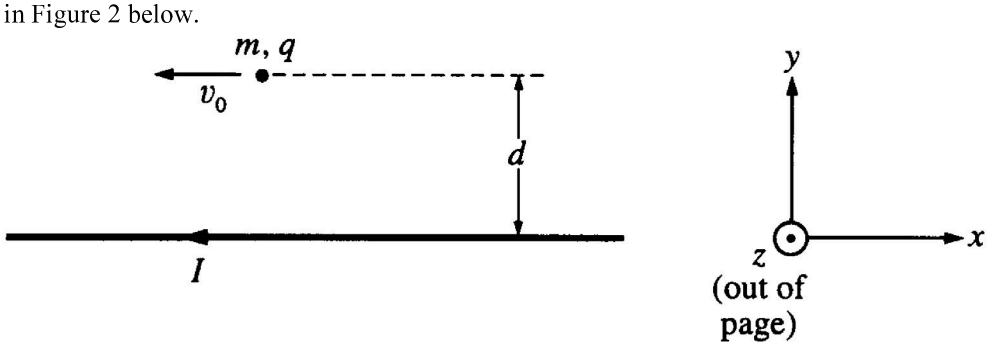
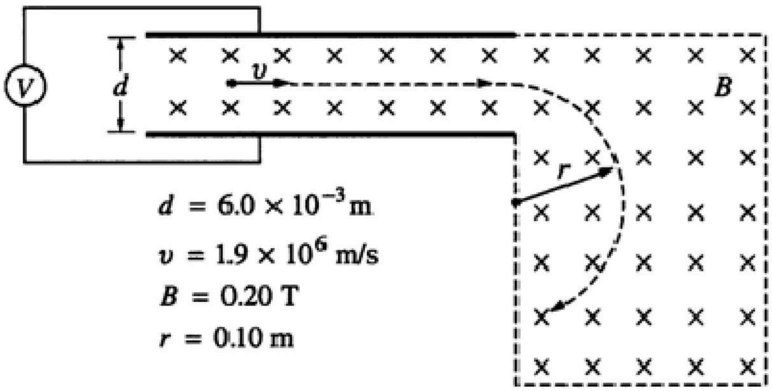


Figure 2

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.



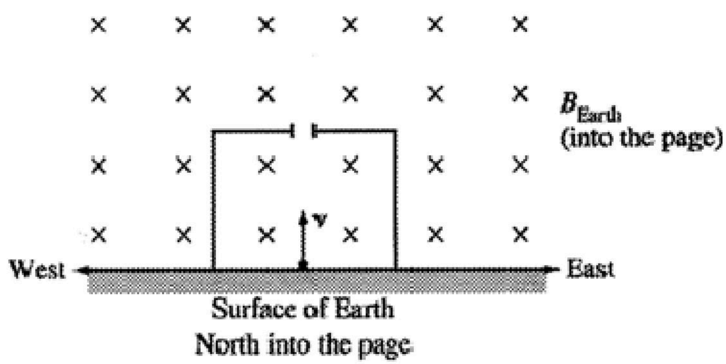
2000B7. A particle with unknown mass and charge moves with constant speed v = 1.9×10^6 m/s as it passes undeflected through a pair of parallel plates, as shown above. The plates are separated by a distance d = 6.0×10^{-3} m, and a constant potential difference V is maintained between them. A uniform 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.

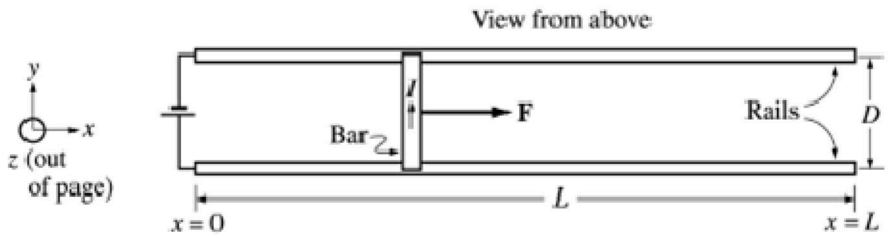
2002B5. A proton of mass m_p and charge e is in a box that contains an electric field E, and the box is located in Earth's magnetic field B. The proton moves with an initial velocity vertically upward from the surface of Earth. Assume gravity is negligible.



(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.

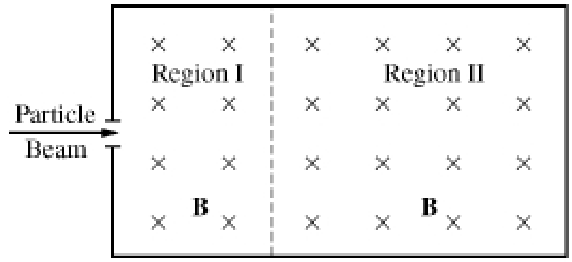
Express all algebraic answers to the following parts in terms of the magnitude F of the constant magnetic force, other quantities given above, and fundamental constants.

(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.

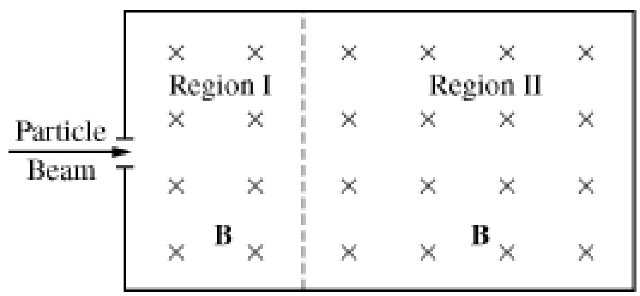
A beam of particles of charge $q = +3.2 \times 10^{-19}$ C and mass $m = 6.68 \times 10^{-26}$ kg enters region I with a range of velocities all in the direction shown in the diagram above. There is a magnetic field in region I directed into the page with magnitude $B = 0.12$ T. Charged metal plates 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.

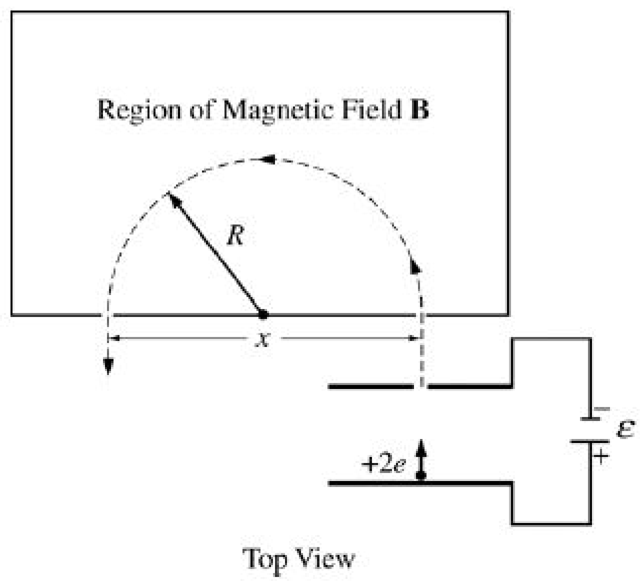


(a)
i. On the diagram above, sketch electric field lines in region I.
ii. Calculate the speed of the particles that pass straight through region I.

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 $\mathcal{E}$

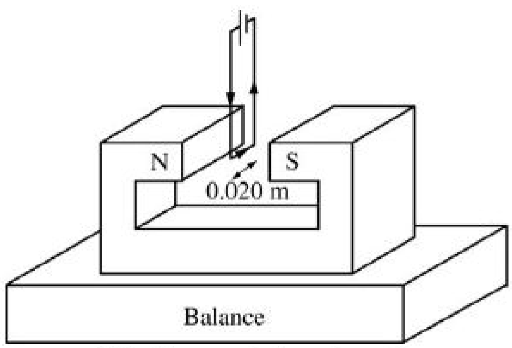
Numerical values for this experiment:
Strontium atomic number: 38
Strontium ion mass: 1.45 x 10^{-25} kg
Magnitude of B field: 0.090 T
Desired exit distance x: 1.75 m

(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.

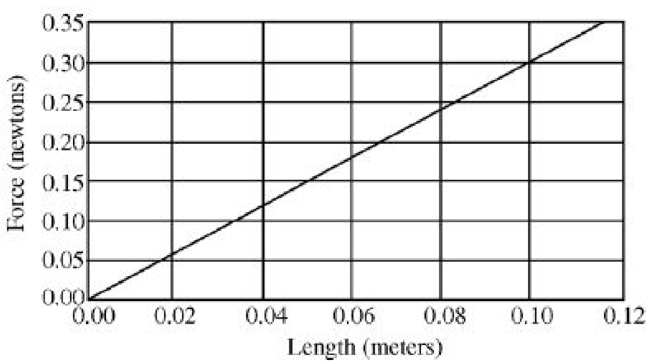
The wire loop is then used in an experiment to measure the strength of the magnetic field between the poles of a magnet. The magnet is placed on a digital balance, and the wire loop is held fixed between the poles of the magnet, as shown. The 0.020 m long horizontal segment of the loop is midway between 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?

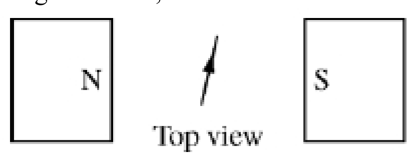
____Upward ____Downward   Justify your answer.

(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.

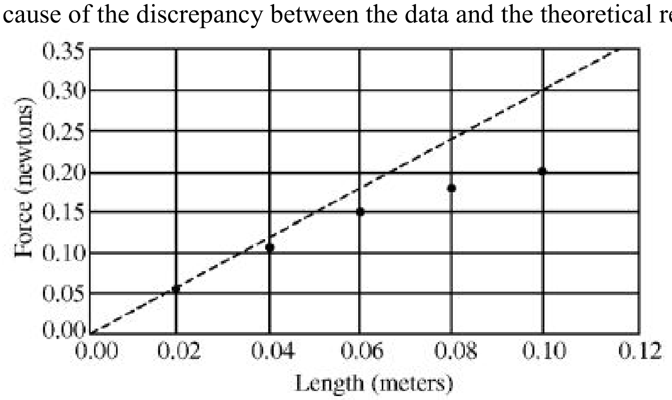


(d) Suppose the wire segments were misaligned and placed at a constant nonperpendicular angles to the magnetic field, as shown below.

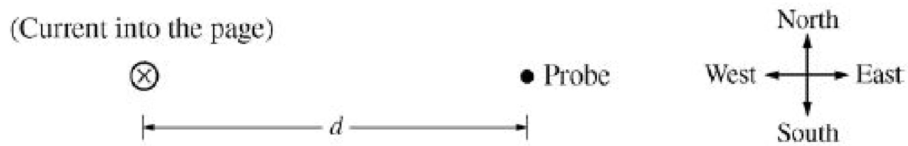


On the graph, sketch a possible relationship between the magnitude of the force on the magnet and the length of the wire segment

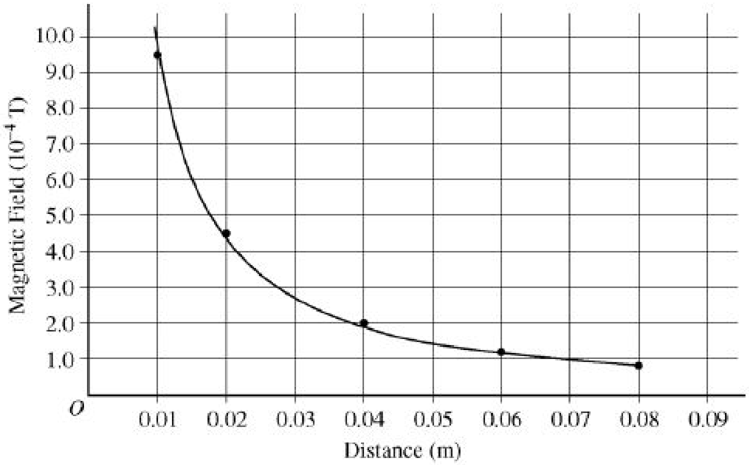
(e) Suppose the loops are correctly placed perpendicular to the field and the data below is obtained. Describe a likely cause of the discrepancy between the data and the theoretical relationship.



B2008B3.

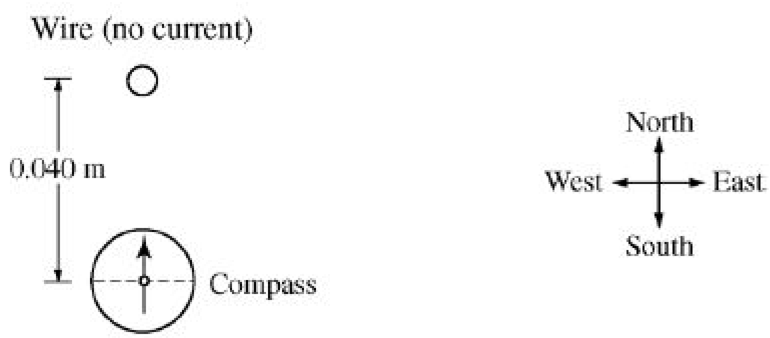


A student is measuring the magnetic field generated by a long, straight wire carrying a constant current. A magnetic field probe is held at various distances d from the wire, as shown above, and the magnetic field is measured.
The graph below shows the five data points the student measured and a best-fit 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.

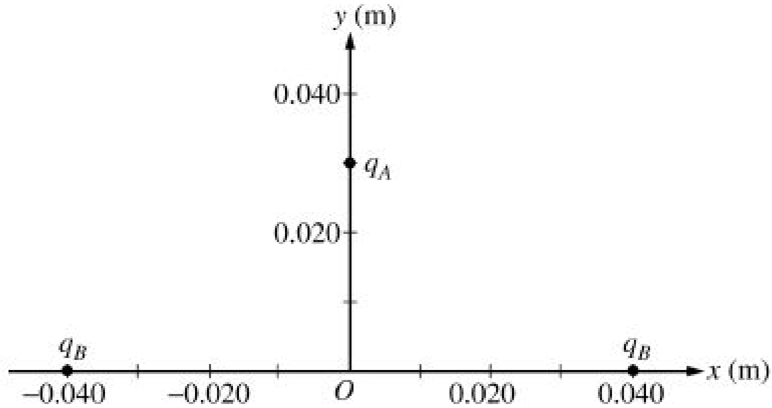


Note: Figure not drawn to scale.

(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.

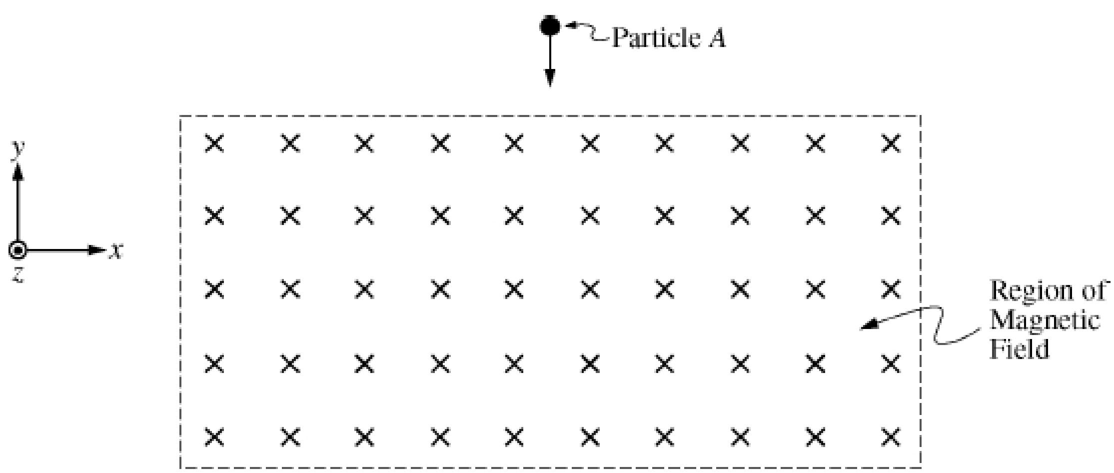
B2009B2.



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.

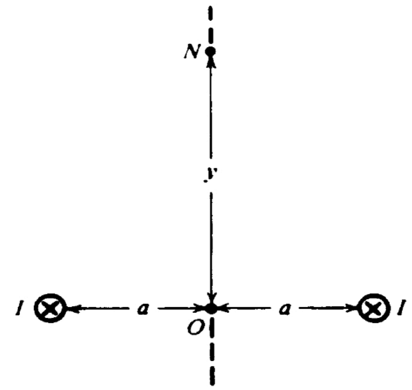
(a) Calculate the magnitude of the net electric force on particle A when it is at $y = 0.030$ m, and state its direction.
(b) Particle A is then released from rest. Qualitatively describe its motion over a long time.

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.

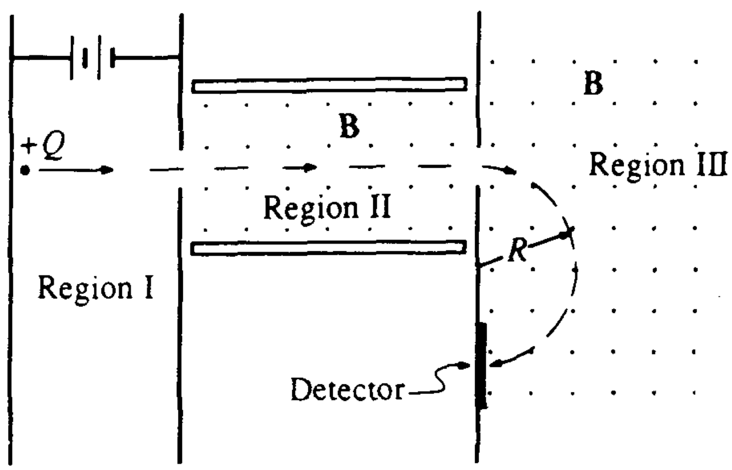


(c) On the diagram above, sketch a complete path of particle A as it moves in the magnetic field.
(d) Calculate the magnitude of the force the magnetic field exerts on particle A as it enters the magnetic field.
(e) An electric field can be applied to keep particle A moving in a straight line through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



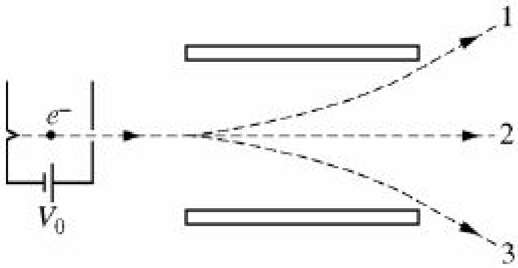
C1990E2. In the mass spectrometer shown above, particles having a net charge +Q are accelerated from rest through a potential difference in Region I. They then move in a straight line through Region II, which contains a magnetic field **B** and an electric field **E**. Finally, the particles enter Region 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.

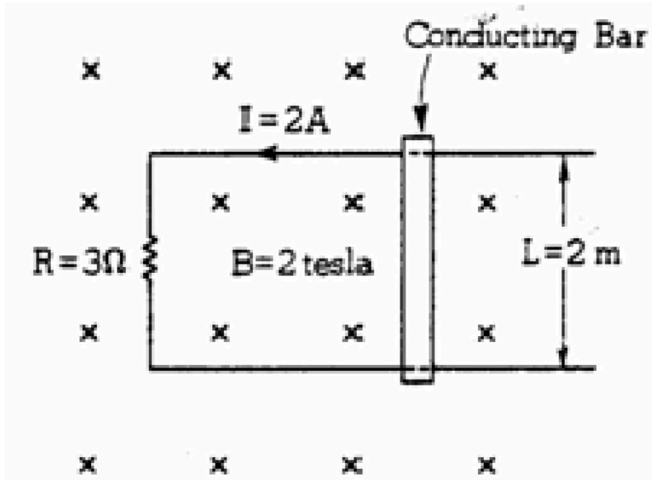
ii. What is the direction of the electric field?
____To the left ____To the top of the page ____Into the page
____To the right ____To the bottom of the page ____Out of the page
Justify your answer.

(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).

SECTION B – Induction



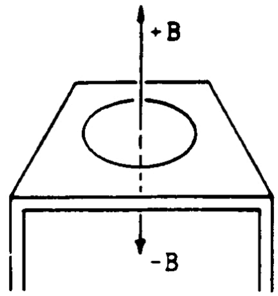
1978B4. Two parallel conducting rails, separated by a distance L of 2 meters, are connected through a resistance R of 3 ohms as shown above. A uniform magnetic field with a magnitude B of 2 tesla points into the page. A conducting bar with mass m of 4 kilograms can slide without friction across the rails.

(a) Determine at what speed the bar must be moved, and in what direction, to induce a counterclockwise current I of 2 amperes as shown.

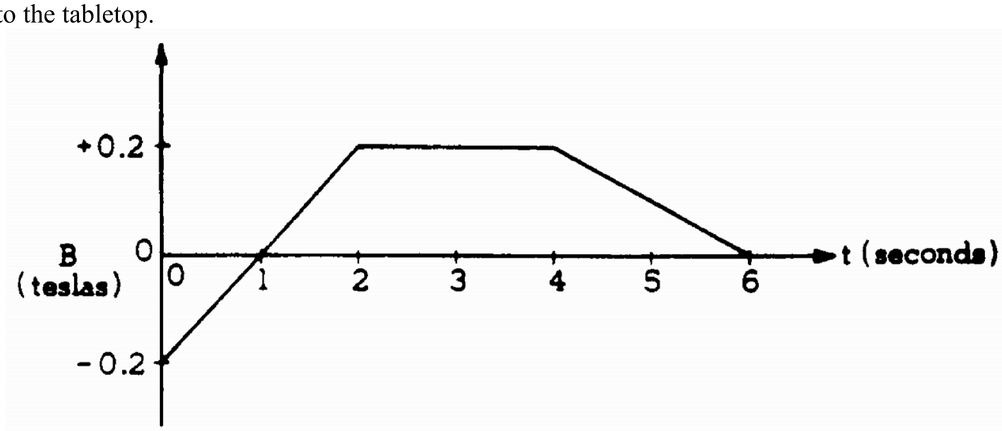
(b) Determine the magnitude and direction of the external force that must be applied to the bar to keep it moving at this velocity.

(c) Determine the rate at which heat is being produced in the resistor, and determine the mechanical power being supplied to the bar.

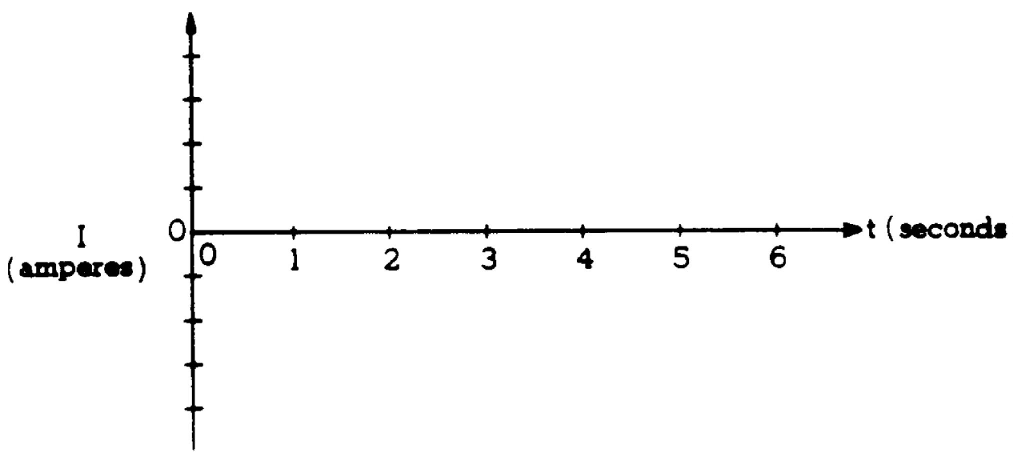
(d) Suppose the external force is suddenly removed from the bar. Determine the energy in joules dissipated in the resistor before the bar comes to rest.

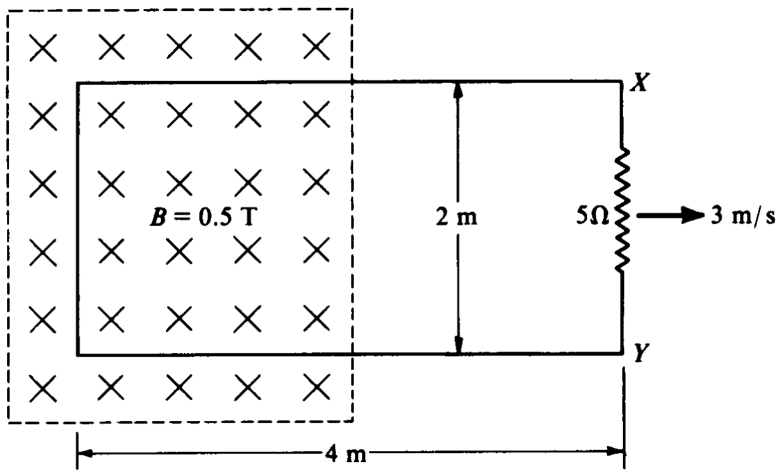


1982B5. A circular loop of wire of resistance 0.2 ohm encloses an area 0.3 square meter and lies flat on a wooden table as shown above. A magnetic field that varies with time t as shown below is perpendicular to the table. A positive value of B represents a field directed up from the surface of the table; a negative value represents a field directed into the tabletop.



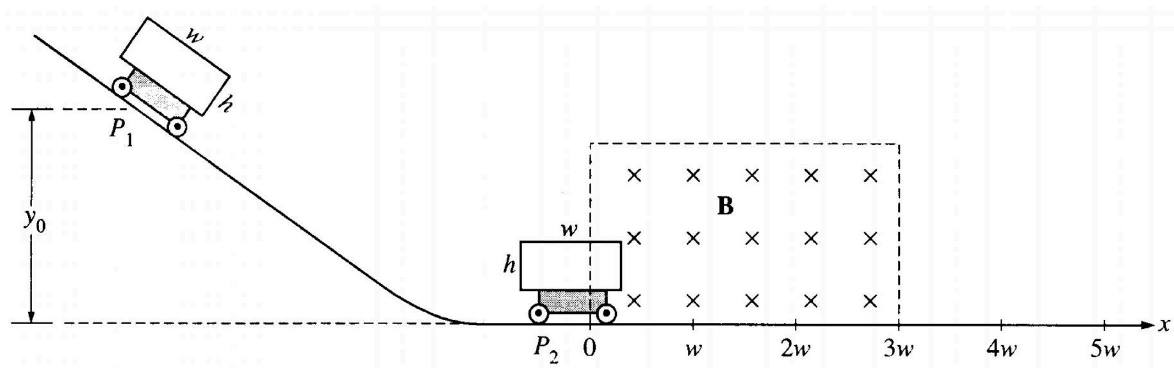
a. Calculate the value of the magnetic flux through the loop at time t = 3 seconds.
b. Calculate the magnitude of the emf induced in the loop during the time interval t = 0 to 2 seconds.
c. On the axes below, graph the current I through the coil as a function of time t, and put appropriate numbers on the vertical scale. Use the convention that positive values of I represent counterclockwise current as viewed from above.





1986B4. A wire loop, 2 meters by 4 meters, of negligible resistance is in the plane of the page with its left end in a uniform 0.5-tesla magnetic field directed into the page, as shown above. A 5-ohm resistor is connected between points X and Y. The field is zero outside the region enclosed by the dashed lines. The loop is being pulled to the right with a constant velocity of 3 meters per second. Make all determinations for the time that the left end of the loop is still in the field, and points X and Y are not in the field.

a. Determine the potential difference induced between points X and Y.
b. On the figure above show the direction of the current induced in the resistor.
c. Determine the force required to keep the loop moving at 3 meters per second.
d. Determine the rate at which work must be done to keep the loop moving at 3 meters per second.



1999B3. A rectangular conducting loop of width w, height h, and resistance R is mounted vertically on a non–conducting cart as shown above. The cart is placed on the inclined portion of a track and released from rest at position P_1 at a height y_0 above the horizontal portion of the track. It rolls with negligible friction down the incline and through a uniform magnetic field **B** in the region above the horizontal portion of the track. The conducting loop is in the plane of the page, and the magnetic field is directed into the page. The loop passes completely through the field with a negligible change in speed. Express your answers in terms of the given quantities and fundamental constants.

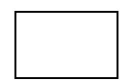
a. Determine the speed of the cart when it reaches the horizontal portion of the track.

b. Determine the following for the time at which the cart is at position P_2, with one-third of the loop in the magnetic field.

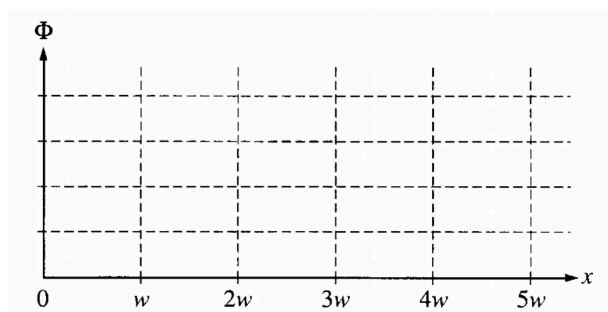
i. The magnitude of the emf induced in the conducting loop

ii. The magnitude of the current induced in the conducting loop

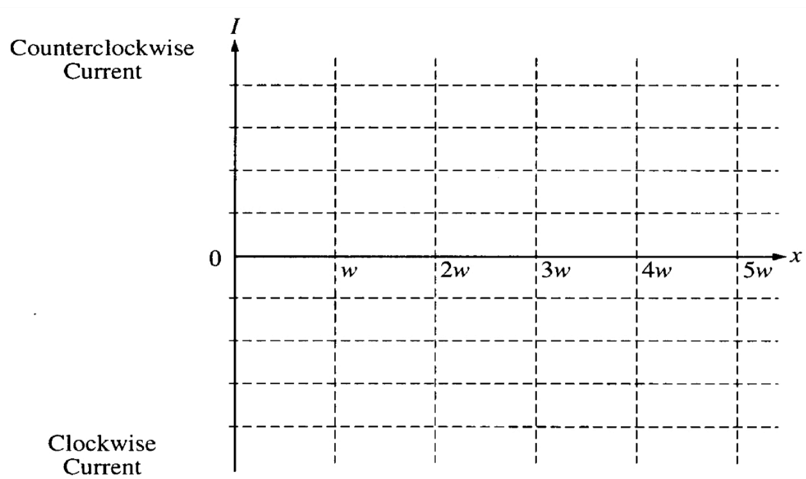
c. On the following diagram of the conducting loop, indicate the direction of the current when it is at Position P_2.



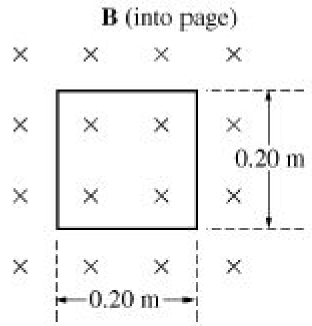
d. i. Using the axes shown, sketch a graph of the magnitude of the magnetic flux ϕ through the loop as a function of the horizontal distance x traveled by the cart, letting x = 0 be the position at which the front edge of the loop just enters the field. Label appropriate values on the vertical axis.



ii. Using the axes shown, sketch a graph of the current induced in the loop as a function of the horizontal distance x traveled by the cart, letting x = 0 be the position at which the front edge of the loop just enters the field. Let counterclockwise current be positive and label appropriate values on the vertical axis.



2004B3.



A square loop of wire of side 0.20 m has a total resistance of 0.60 Ω . The loop is positioned in a uniform magnetic field **B** of 0.030 T. The field is directed into the page, perpendicular to the plane of the loop, as shown above.

(a) Calculate the magnetic flux ϕ through the loop.

The field strength now increases uniformly to 0.20 T in 0.50 s.
(b) Calculate the emf ε induced in the loop during this period.

(c) i. Calculate the magnitude I of the current in the loop during this period.
ii. What is the direction of the current in the loop?
_____ Clockwise _____ Counterclockwise
Justify your answer.

(d) Describe a method by which you could induce a current in the loop if the magnetic field remained

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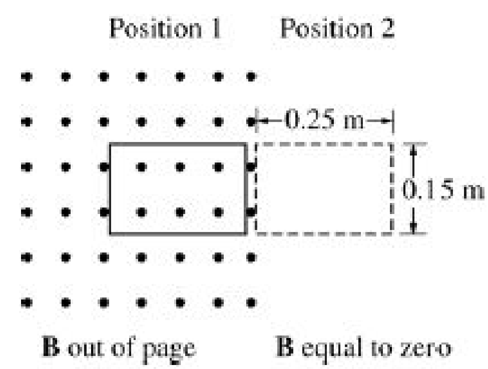
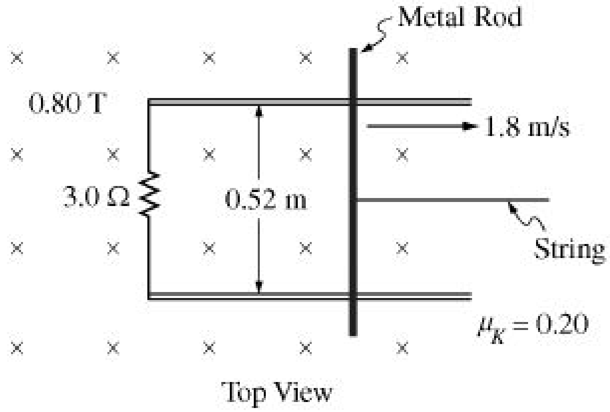
B2004B4.

A 20-turn wire coil in the shape of a rectangle, 0.25 m by 0.15 m, has a resistance of 5.0 **Ω**. In position 1 shown, the loop is in a uniform magnetic field **B** of 0.20 T. The field is directed out of the page, perpendicular to the plane of the loop. The loop is pulled to the right at a constant velocity, reaching position 2 in 0.50 s, where **B** is equal to zero.



(a) Calculate the average emf induced in the 20-turn coil during this period.
(b) Calculate the magnitude of the current induced in the 20-turn coil and state its direction.
(c) Calculate the power dissipated in the 20-turn coil.
(d) Calculate the magnitude of the average force necessary to remove the 20-turn coil from the magnetic field.
(e) Identical wire is used to add 20 more turns of wire to the original coil. How does this affect the current in the coil? Justify your answer.

2009B3.

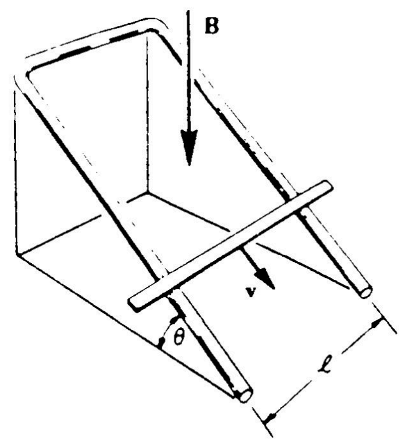


A metal rod of mass 0.22 kg lies across two parallel conducting rails that are a distance of 0.52 m apart on a tabletop, as shown in the top view. A 3.0 Ω resistor is connected across the left ends of the rails. The rod and rails have negligible resistance but significant friction with a coefficient of kinetic friction of 0.20.

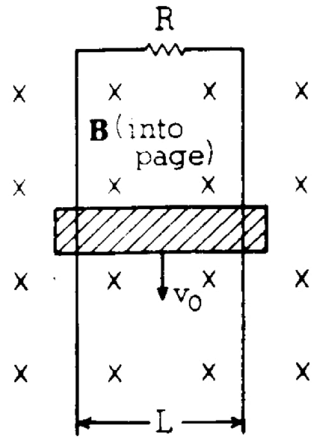
There is a magnetic field of 0.80 T perpendicular to the plane of the tabletop. A string pulls the metal rod to the right with a constant speed of 1.8 m/s.

(a) Calculate the magnitude of the current induced in the loop formed by the rod, the rails, and the resistor, and state its direction.
(b) Calculate the magnitude of the force required to pull the rod to the right with constant speed.
(c) Calculate the energy dissipated in the resistor in 2.0 s.
(d) Calculate the work done by the string pulling the rod in 2.0 s.
(e) Compare your answers to parts (c) and (d). Provide a physical explanation for why they are equal or unequal.

C1973E3. In a uniform magnetic field B directed vertically downward. a metal bar of mass m is released from rest and slides without friction down a track inclined at an angle θ, as shown. The electrical resistance of the bar between its two points of contact with the track is R. The track has negligible resistance. The width of the track is L.



a. Show on the diagram the direction of the current in the sliding bar.
b. Denoting by v the instantaneous speed with which the bar is sliding down the incline, determine an expression for the magnitude of the current in the bar.
c. Determine an expression for the force exerted on the bar by the magnetic field and state the direction of that force.
d. Determine an expression for the terminal velocity of the sliding bar.



C1976E2. A conducting bar of mass M slides without friction down two vertical conducting rails which are separated by a distance L and are joined at the top through an unknown resistance. The bar maintains electrical contact with the rails at all times. There is a uniform magnetic field B, directed into the page as shown above. The bar is observed to fall with a constant terminal speed v_o.

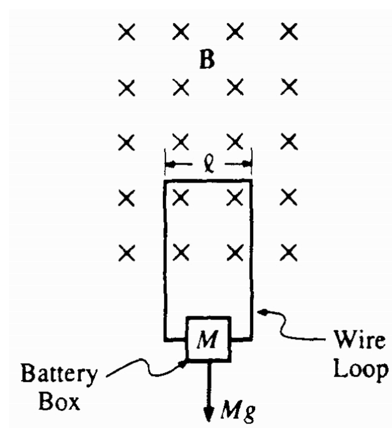
a. On the diagram here, draw and label all the forces acting on the bar.

b. Determine the magnitude of the induced current I in the bar as it falls with constant speed v_o in terms of B, L, g, v_o, and M.

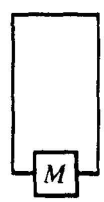
c. Determine the voltage induced in the bar in terms of B, L, g, v_o, and M.

d. Determine the resistance R in terms of B, L, g, v_o, and M.

C1990E3. A uniform magnetic field of magnitude B is horizontal and directed into the page in a rectangular region of space, as shown. A light, rigid wire loop, with one side of width *l*, has current I. The loop is supported by the magnetic field and hangs vertically, as shown. The wire has resistance R and supports a box that holds a battery to which the wire loop is connected. The total mass of the box and its contents is M.



a. On the following diagram, that represents the rigid wire loop, indicate the direction of the current I from the battery.



The loop remains at rest. In terms of any or all of the quantities B, *l*, M, *R*, and appropriate constants, determine expressions for

b. the current I in the loop;

c. the emf of the battery, assuming it has negligible internal resistance.

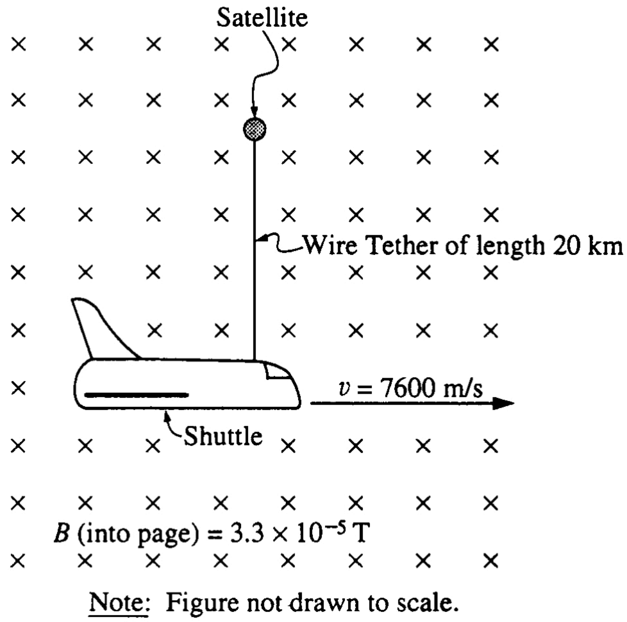
An amount of mass Δm is removed from the box and the loop then moves upward, reaching a terminal speed v in a very short time, before the box reaches the field region. In terms of v and any or all of the original variables, determine expressions for

d. the magnitude of the induced emf;

e. the current I' in the loop under these new conditions;

f. the amount of mass Δm removed.

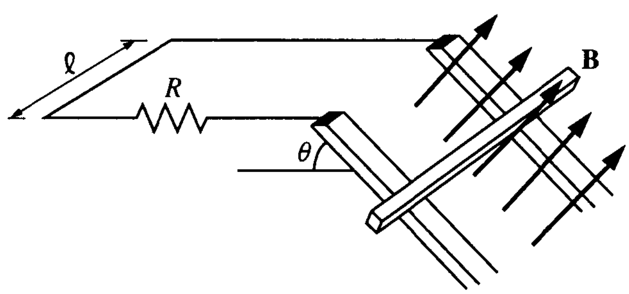
C1994E2. One of the space shuttle missions attempted to perform an experiment in orbit using a tethered satellite. The satellite was to be released and allowed to rise to a height of 20 kilometers above the shuttle. The tether was a 20-kilometer copper-core wire, thin and light, but extremely strong. The shuttle was in an orbit with speed 7,600 meters per second, which carried it through a region where the magnetic field of the Earth had a magnitude of 3.3×10^{-5} tesla. For your calculations, assume that the experiment was completed successfully, that the wire is perpendicular to the magnetic field, and that the field is uniform.



a. An emf is generated in the tether.
   i. Which end of the tether is negative?
   ii. Calculate the magnitude of the emf generated.

To complete the circuit, electrons are sprayed from the object at the negative end of the tether into the ionosphere and other electrons come from the ionosphere to the object at the positive end. The electric field that was induced in the wire is directed away from the shuttle and causes the current to flow in that direction in the tether.

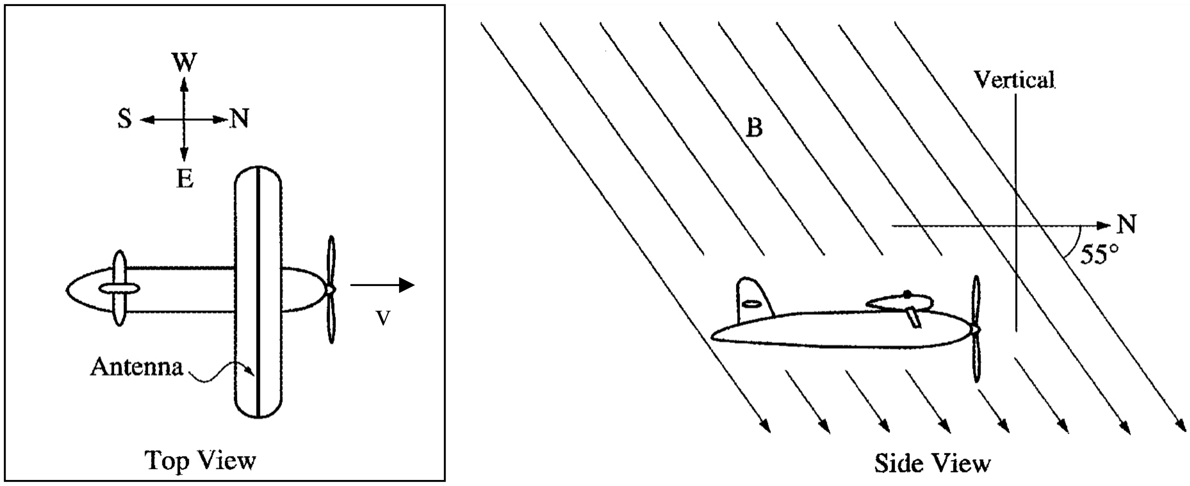
b. If the resistance of the entire circuit is about 10,000 ohms, calculate the current that flows in the tether.
c. A magnetic force acts on the wire as soon as the current begins to flow.
   i. Calculate the magnitude of the force.
   ii. State the direction of the force.



C1998E3. A conducting bar of mass m is placed on two long conducting rails a distance l apart. The rails are inclined at an angle θ with respect to the horizontal, as shown above, and the bar is able to slide on the rails with negligible friction. The bar and rails are in a uniform and constant magnetic field of magnitude B oriented perpendicular to the incline. A resistor of resistance R connects the upper ends of the rails and completes the circuit as shown. The bar is released from rest at the top of the incline. Express your answers to parts (a) through (d) in terms of m, l, θ, B, R, and g.

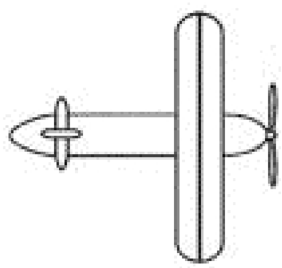
a. Determine the current in the circuit when the bar has reached a constant final speed.
b. Determine the constant final speed of the bar.
c. Determine the rate at which energy is being dissipated in the circuit when the bar has reached its constant final speed.
d. Suppose that the experiment is performed again, this time with a second identical resistor connecting the rails at the bottom of the incline. Will this affect the final speed attained by the bar, and if so, how? Justify your answer.

C2003E3



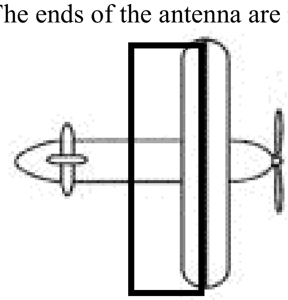
An airplane has an aluminum antenna attached to its wing that extends 15 m from wingtip to wingtip. The plane is traveling north at 75 m/s in a region where Earth's magnetic field of $6.0\text{x}10^{-5}$ T is oriented as shown above.

a. On the figure below, indicate the direction of the magnetic force on electrons in the antenna. Justify your answer.



b. Determine the potential difference between the ends of the antenna.

c. The ends of the antenna are now connected by a conducting wire so that a closed circuit is formed as shown.



   i. Describe the condition(s) that would be necessary for a current to be induced in the circuit. Give a specific example of how the condition(s) could be created.
   ii. For the example you gave in i. above, indicate the direction of the current in the antenna on the figure.

AP Physics Multiple Choice Practice – Magnetism and Electromagnetic Induction– ANSWERS

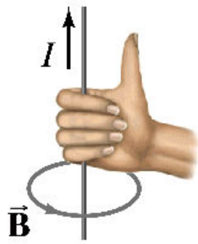
SECTION A – Magnetism

Solution

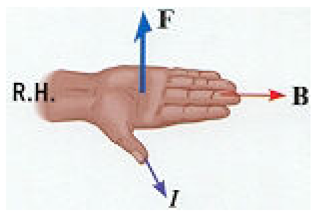
Answer

For the purposes of this solution guide. The following hand rules will be referred to.
RHR means right hand rule (for + current). LHR will be substituted for – current

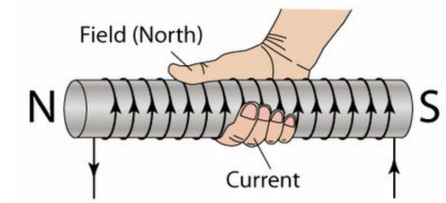
RHRcurl



RHRflat



RHR–Solenoid



1. Each wire contributes a B field given by $\mu_o I / 2\pi a$ in a direction found using RHRcurl. The direction of each B field is as follows, (1)Top right wire: B up&left, (2)Top left wire: B up&right, (3)Bottom left wire: B up&left, (4)Bottom right wire: B down&left. Forces from 1 and 4 cancel leaving both 3 and 4 B fields acting up and left and adding together. — C

2. The B field at the location of the charge +e is created by the wire next to it and given by $B = \mu_o I / 2\pi R$. Based on RHRcurl the direction of that B field is into the page at that location. Then the force on that charge is given by $F_b=qvB$, with q=e and B from before so $F_b = ev(\mu_o I / 2\pi R)$. Using the RHRflat for the + charge, the force comes out as down. — D

3. Charges moving through magnetic fields move in circles as in the diagram for question 39 — D

4. The compass is ABOVE the wire. Using RHRcurl on the wire, the B field points towards the right at the location above the wire. Since compasses follow B field lines, the compass will also point right, which is east. — A

5. To be undeflected, the electric and magnetic forces must balance. — D
   $F_e = F_b$ $Eq = qvB$ $B = E / v$ With v related to K by $K = ½ mv^2$
   gives $B = E /$ *2(K/m) … which is equivalent to choice D

6. When cutting a magnet, you must end up with two new magnets having 2 poles each. For the top magnet the current N and S must stay as is, so the left of center part becomes a S and the right of center part becomes a N. There are now two opposite poles that attract. For the bottom magnet, by slicing it down the center you now have two magnets on top of each other. The poles would not change their current locations so you have two north and two south poles near each other on top and bottom which makes repulsion. — A

7. For this scenario, The circular motion is provided by the magnetic force. So that $F_{net(C)} = mv^2/r$ — B
   $qvB = mv^2/r$ $qBr = mv$ $2 \times V \rightarrow 2 \times r$

8. Focus on a single + charge in the wire that gets pushed to the right. So this + charge is moving in a magnetic field pointing into the page with a force directed right, based on RHRflat, the charge must be moving down. — D

9. When moving parallel to magnetic fields, no forces are experienced. — C

10. Assume R is north. Based on the lines, T would have to be north and so would Y. This makes X and Z south and S north. C

11. Using RHRcurl, we get into the page C

12. Parallel current wires with same direction current attract. A

13. Focus on a single + charge in the wire that gets pushed to the right. So this + charge is moving down with a force directed right, based on RHRflat, the magnetic field must point into the page. A

14. By definition, E fields exert forces on + charges in the same direction as the E field. So the force from the E field must be UP. To maintain a constant velocity, this upwards force must be counterbalanced by a downwards force, which in this case it is to be provided by the magnetic field. With a + charge moving right, and a magnetic force down, RHRflat gives a magnetic field pointing out of the page. B

15. A coil of wire (solenoid) like this becomes an electromagnet when the current runs through it. Use the RHR–solenoid to determine that the right side of this electromagnet becomes the north side. Now pretend that the electromagnet is simply a regular magnet with a N pole on the right and a S pole on the left and draw the field lines. In doing so, the lines end up pointing to the left at the location of the compass. Since compasses follow magnetic field lines, the compass will also point left. A

16. Due to action reaction the forces must be the same. Another way to look at it is that wire A creates the field that wire B is sitting in based on its current I, $B_a = \mu_o I_a / 2\pi R$. The force on wire B is dependent on the field from A, and also the current in wire B itself and is given by $F_b=B_a I_b L$ $\quad F_b = (\mu_o I_a / 2\pi R)\, I_b\, L$. So since both currents from A and B affect each respective force, they should share the same force. D

17. Think about this as if you are looking down at a table top with the + particle on it. An E field is pointed down into the table so an electric force acts down into the table also. The electric force pushing down will not move the charge. A magnetic field comes up out of the table, but since the charge is at rest, the magnetic field exerts zero force on it. So $F_e > F_b$ A

18. First of all we should state that a larger current makes a bigger B field and the further from the wire the less the B field. Using RHRcurl, the 4A wire has decreasing magnitude B fields pointing down in regions II and III on the axis and upwards on region I. The 3A wire has B fields pointing upwards in region III and downwards in regions II and I. To cancel, fields would have to oppose each other. Region I is a possibility but since the distance from the 4A wire is smaller at every point and it also has a larger current it will always have a larger B field so there is no way to cancel. Region II has fields in the same direction and cannot cancel. Region III has opposing fields. Since the 4A wire has a larger current but also a larger distance away from any point in Region III and the 3A wire has a smaller current but a closer distance to any point in Region III it is possible that these two factors compensate to make equal B fields that oppose and could cancel out. C

19. Using RHR–solenoid the top of the loop is N and the bottom is S. Drawing a field line out of the top and looping outside down to the bottom, you have to continue up through the solenoid to complete the field line so the direction is UP. *(Note: this may seem counterintuitive because the field line points from the south to the north which is opposite of what you might think but this is INSIDE the solenoid (magnet). Only outside, do lines come out of N and into S.)* D

20. Use RHR–flat A

21. We first need to determine the direction of the B field at P due to the other wires using RHRcurl. The top wire creates a B field pointing up&right, the bottom wire creates a B field pointing up&left. The left and right parts of these cancel out making a field only up from these two wires. The wire on the left also produces a field only up so the net B field points up at location P. Now using RHRflat for the right wire, the force is left. A

22. First determine the B field direction created by the current wire at the location above the wire using RHRcurl. This gives B out of page. Then use LHRflat for the negative charge to get force acting down. B

23. In region I, the electric field pushes the negative electron with a force opposite the direction of the E field (out of the page). For the charge to not be pushed out, the magnetic field must create a force into the page to resist this. Based on LHRflat the B field must point up. Then in region II based on how the charge gets pushed, its magnetic force is up initially. Using LHRflat again in region II gives B field direction out of the page. C

24. Based on RHR–flat the magnetic force is directed into the page. To be undeflected, the E field must create a force out of the page to resist this, and since it's a + charge the E field points out. C

25. This is a loop. Current flows clockwise around the loop. Using the RHR–solenoid for the single loop the B field in the center is pointing into the page. A

26. Use RHRflat C

27. Use RHRcurl D

28. Using RHRcurl we find the direction of the magnetic field from each wire. To the right of the leftmost wire, its field points down along the axis with a decreasing magnitude as you move away from it. For the rightmost wire its field also points down when you move left of it. Since both fields point down between the wires, they will add and cannot cancel. On the far right side of the arrangement, the leftmost wire makes a field down and the rightmost wire makes a field up but since the distances to any location are different from each wire the magnitude of the fields would be different so no way to cancel. The same would happen on the far left of the wires. D

29. Use LHRflat A

30. To induce a current, the flux through the spring loop must change. When moving the spring parallel to the magnetic field, the same B field and the same area is enclosed in the loop so the flux stays constant and there is no induced current. C

31. When moving in a circle at constant velocity, no work is done as explained in previous answers. A

32. Choose 1 proton moving in the circle. For this proton. $F_{net(C)} = mv^2/r$ $F_b = mv^2/r$ C
$qvB = mv^2/r$ $v = qBr/m = 1.6\text{x}10^{-19}\,(0.1)(0.1) / (1.67\text{x}10^{-27}) \sim 10^{-21} / 10^{-27}$

33. As described in question 17, the force on either wire is $F_b = (\mu_o I_a / 2\pi R)\, I_b\, L$. So doubling both I's in the equation gives 4x the force. C

34. Not a magnetism question, but lets review. Since the charge magnitude is the same, they will experience the same forces based on F_e=Eq, but move in opposite directions. Since the masses are different, the same forces will affect each object differently so that the smaller mass electron accelerates more, thus gains more speed and covers more distance in equal time periods. So only the force is the same. D

35. Same as question 33 C

36. Since the particle is moving parallel to the field it does not cut across lines and has no force. C

37. Using RHRcurl for each wire, the left wire makes a field pointing down&right at P and the right wire makes a field pointing up&right. The up and down parts cancel leaving only right. D

38. The electric force would act upwards on the proton so the magnetic force would act down. Using RHRflat, the B field must point out of the page. D

39. $F_e = F_b$ $Eq = qvB$ $E = vB$ $B = E/v$ A

40. Based on … $F_{net(C)} = mv^2/r$ … $F_b = mv^2/r$ … $qvB = mv^2/r$ … $r = mv/qB$ … inverse B

41. Wires with current flowing in the same direction attract. B

42. From question 17, $F_b = (\mu_o I_a / 2\pi R)\, I_b\, L$ … R is x2 and both I's are x2 so it's a net effect of x2. C

43. Using RHR–solenoid, the B field at the center of that loop is directed right. Since the other loop is further away, its direction is irrelevant at the left loop will dominate. C

44. Based on the axis given. The left side wire is on the axis and makes no torque. The top and bottom wires essentially cancel each other out due to opposite direction forces, so the torque can be found from the right wire only. Finding the force on the right wire … $F_b = BIL = (0.05)(2)(0.3) = .03$ N, then torque = Fr = (0.03)(0.3). B

45. The field from a single wire is given by $\mu_o I_a / 2\pi R$. The additional field from wire Y would be based on this formula with R = 3R, so in comparison it has 1/3 the strength of wire X. So adding wire X's field B_o + the relative field of wire Y's of 1/3 B_o gives a total of 4/3 B_o. C

46. First we use RHRcurl to find the B field above the wire as into the page, and we note that the magnitude of the B field decreases as we move away from it. Since the left AB and right CD wires are sitting in the same average value of B field and have current in opposite directions, they repel each other and those forces cancel out. Now we look at the wire AD closest to the wire. Using RHRflat for this wire we get down as a force. The force on the top wire BC is irrelevant because the top and bottom wires have the same current but the B field is smaller for the top wire so the bottom wire will dominate the force direction no matter what. Therefore, the direction is down towards the wire. A

47. Using RHRflat for the magnetic field direction given, the magnetic force would be up (+z). To counteract this upwards force on the + charge, the E field would have to point down (– z). C

48. A little tricky since its talking about fields and not forces. To move at constant velocity the magnetic FORCE must be opposite to the electric FORCE. Electric fields make force in the same plane as the field (ex: a field in the x plane makes a force in the x plane), but magnetic fields make forces in a plane 90 degrees away from it (ex: a field in the x plane can only make magnetic forces in the y or z plane). So to create forces in the same place, the fields have to be perpendicular to each other. B

49. First we have … $F_{net(C)} = mv^2/r$ … $F_b = mv^2/r$ … $qvB = mv^2/r$ … $v = qBr/m$ A
Then using $v = 2\pi R / T$ we have $qBr/m = 2\pi R / T$ … radius cancels so period is unchanged and frequency also is unaffected by the radius. Another way to think about this with the two equations given above is: by increasing R, the speed increases, but the $2\pi R$ distance term increases the same amount so the time to rotate is the same.

50. Pick any small segment of wire. The force should point to the center of the circle. For any small segment of wire, use RHRflat and you get velocity direction is CCW. Equation is the same as the problem above … $qvB = mv^2/r$ … $eBr = mv$. C

51. Same as in question 53 … $qBr/m = 2\pi R / T$ … $T = 2\pi m / eB$. C

52. The left and right sides of the loop wires are parallel to the field and experience no forces. Based on RHRflat, the top part of the loop would have a force out of the page and the bottom part of the loop would have a force into of the page which rotates as in choice C. C

53. Each wire creates a magnetic field around itself. Since all the currents are the same, and wire Y is closer to wire X, wire X's field will be stronger there and dominate the force on wire Y. So we can essentially ignore wire Z to determine the direction of the force. Since X and Y are in the same direction they attract and Y gets pulled to the left. D

54. Wires with current in the same direction are attractive. Using RHRcurl for each wire at the location shown has the top wire having B_{in} and the bottom wire making B_{out}. Since its at the midpoint the fields are equal and cancel to zero. B

SECTION B – Electromagnetic Induction

Solution	Answer
1. A complex problem. On the left diagram, the battery shows how + current flows. Based on this it flows left through the resistor and then down on the front side wires of the solenoid. Using the RHR–solenoid, the right side of the solenoid is the North pole. So field lines from the left solenoid are pointing to the right plunging into the solenoid core of the right side circuit. As the resistance in the left side increases, less current flows, which makes the magnetic field lines created decrease in value. Based on Lenz law, the right side solenoid wants to preserve the field lines so current flows to generate field lines to the right in order to maintain the flux. Using the RHR–solenoid for the right hand solenoid, current has to flow down on the front side wires to create the required B field. Based on this, current would then flow down the resistor and to the left through the ammeter.	A
2. Similar to the problem above. The field lines from the bar magnet are directed to the left through the solenoid. As the magnet is moved away, the magnitude of the field lines directed left in the solenoid decrease so by Lenz law the solenoid makes additional leftward field to maintain the flux. Based on RHR–solenoid, the current would flow up the front side wires of the solenoid and then to the right across the resistor. This also means that the left side of the solenoid is a N pole so it attracts the S pole of the nearby magnet.	B
3. As the magnet falls down towards the pipe, which is a looped conductor, the magnetic field lines plunging into that conductor increase in magnitude. Based on Lenz's law, current flows in the conductor to oppose the gain in field and maintain the flux. The copper loop will create a B field upwards to maintain flux and this upwards B field will be opposite from the magnets B field which will make it slow.	C
4. Plug into $\varepsilon = BLv$	A
5. Based on $\varepsilon = BLv$	D
6. This is a fact. It is best thought about through example and thinking about how non–conservative forces are at play. Lenz law says opposing fields are induced for moving magnets, this slows them … if the opposite was true you would get accelerated systems where energy would not be conserved	D
7. Use $\varepsilon = \Delta\Phi / t$ $\quad \varepsilon = (BAf - BAi) / t$ $\quad \varepsilon = (0-(2)(0.5x0.5))/0.1$	C
8. The rail makes a loop of wire as shown by the current flow. Using Lenz law, as the loop expands with the motion of the bar, it is gaining flux lines in whatever direction the B field is and the loop current flows in a direction to oppose that gain. Using RHR–solenoid for the single loop, the B field induced is directed out of the page so it must be opposing the gain of B field that is already there going into the page.	B
9. Take a small section of wire on the loop at the top, bottom, right and left hand sides and find the forces on them. For example, the section of wire on the top has current pointing left and B pointing out … using RHRflat for that piece gives a force pointing up. At all of the positions, the force acts in a manner to pull the loop outwards and expand it.	A
10. The induced emf occurs in the left side vertical wire as that is where the charge separation happens. Looking at that wire, the induced emf is given by $\varepsilon = BLv$. This emf then causes a current I to flow in the loop based on V=IR, so I is given as BLv / R. The direction of that current is found with Lenz law as there is a loss of flux into the page, RHR–solenoid shows	C

current must flow CW to add back flux into the page and maintain it.

11. As long as the flux inside the loop is changing, there will be an induced current. Since choice E has both objects moving in the same direction, the flux through the loop remains constant so no need to induce a current. B

12. Same as question 7, different numbers. C

13. Looking at the primary coil, current flows CCW around it so based on RHR–solenoid the magnetic field lines from that coil are pointing to the left and they extend into the secondary coil. To induce a current in the secondary coil, the flux through the secondary coil needs to be changed so an induced current will flow based on Lenz law. Choice A means spinning the coil in place like a hula–hoop or a spinning top and this will not cause a change in flux. A

14. Based on Lenz law, as the flux pointing up decreases, current flows in the loop to add back that lost flux and maintain it. Based on RHR–solenoid, current would have to flow CCW A

15. Based on ε =BLv, its a linear variation A

16. We are looking to find rate of change of magnetic field $\Delta B/t$ so we need to arrange equations to find that quantity. Using induced emf for a loop we have. $\varepsilon = \Delta\Phi / t = \Delta BA/t$, and substituting V=IR, and area = a2 we have … IR = ΔB (a2) / t … isolate $\Delta B/t$ to get answer. A

17. $\Phi = BA = (2)(0.05)(0.08)$ C

18. From Lenz law, as the flux decreases the loop induces current to add back that declining field. Based on RHR–solenoid, current flows CCW to add field coming out of page. D

19. Since both loops contain the same value of BA and it is changing the same for both of them, the quantity $\Delta BA/t$ is the same for both so both have the same induced emf. C

20. Above the wire is a B field which is directed into the page based on RHRcurl. That B field has a decreasing magnitude as you move away from the wire. Loop 1 is pulled up and therefore is loosing flux lines into the page. By Lenz Law current flows to maintain those lines into the page and by RHR–solenoid current would have to flow CW to add lines into the page and maintain the flux. Loop 2 is moving in a direction so that the magnitude of flux lines is not changing and therefore there is no induced current C

21. This is best done holding a small circular object like a small plate and rotating it towards you keeping track of the current flow. Grab the top of the plate and pull it towards you out of the page and move down at the same time to rotate it. This will increase the flux lines into the loop as you rotate and cause a current to flow to fight the increase until it becomes flat and you have moved 90 degrees in relations to the rotation you are making. Then as you pass this point and begin pushing the part of the loop you are holding down and into the page away from you, you start to lose field lines and current will flow the other way to try and maintain the flux lines until your hand has moved what was once the top of the loop all the way to the bottom. At this point you are 180 degrees through the rotation and have changed direction once. As you pass through 180, you will notice that the current flows the same way to maintain the zero flux you get at the 180 location (even though you might think there should be a change here, this is where the physical object helps). Then as you move up the back and do the same thing on the reverse side to return the part of the loop you are holding to the top you will undergo another direction change at 270 degrees so you have 2 direction changes total in one revolution. Do it two more times and you get 6 reversals. D

22. Since the bar is not cutting across field lines and has no component in a perpendicular direction to the field line there will be no induced emf. B

23. As you enter region II, flux into the page is gained. To counteract that, current flows to create a field out of the page to maintain flux. Based on RHR–solenoid, that current is CCW. When leaving the region, the flux into the page is decreasing so current flows to add to that field which gives CW. D

24. First use $\varepsilon = \Delta\Phi / t$ $\varepsilon = (BAf - BAi) / t$ $\varepsilon = (0-(0.4)(0.5x0.5))/2$ $\varepsilon = 0.05$ V B
Then use V=IR 0.05V = I(.01) I = 5A
Direction is found with Lenz law. As the field out decreases, the current flows to add outward field to maintain flux. Based on RHR–solenoid, current flows CCW.

25. Loop 2 initially has zero flux. When the circuit is turned on, current flows through loop 1 in a CW direction, and using RHR–solenoid it generates a B field down towards loop 2. As the field lines begin to enter loop 2, loop 2 has current begin to flow based on lenz law to try and maintain the initial zero flux so it makes a field upwards. Based on RHR–solenoid for loop 2, current would have to flow CCW around that loop which makes it go from X to Y. A

26. After a long time, the flux in loop 2 becomes constant and no emf is induced so no current flows. In circuit 1, the loop simply acts as a wire and the current is set by the resistance and V=IR C

27. As the magnet moves down, flux increase in the down direction. Based on Lenz law, current in the loop would flow to create a field upwards to cancel the increasing downwards field. Using RHR–solenoid, the current would flow CCW. Then, when the magnet is pulled upwards, you have downward flux lines that are decreasing in magnitude so current flows to add more downward field to maintain flux. Using RHR–solenoid you now get CW. D

28. Since the wire is not cutting across the field lines, there is no force and no charge separation D

29. As the loop is pulled to the right, it loses flux lines right so current is generated by Lenz law to add more flux lines right. This newly created field to the right from the loop is in the same direction as the magnetic field so makes an attractive force pulling the magnet right also. A

30. Use a 1 second time period, the field would decrease to 2.5 T in that time. A
Then apply $\varepsilon = \Delta\Phi / t$
$\varepsilon = (BA_f - BA_i) / t$ … $\varepsilon = A (B_f - B_i)$ … $\varepsilon = (0.4)(3 - 2.5) / 1$

SECTION A – Magnetism

1975B6.

a) Since the ions have the same charge, the same work (Vq) will be done on them to accelerate them and they will gain the same amount of K as they are accelerating. Set the energies of the two ions equal.
$K_o = K_s$ $\quad \frac{1}{2} m_o v_o^2 = \frac{1}{2} (2m_o)v_s^2$ $\quad v_s = v_o / \sqrt{2}$

b) In the region of the magnetic field, apply $F_{net(C)} = mv^2/r$ □ $qvB = mv^2 / r$ □ $r = mv / Bq$

For the O ion $\quad$ For the S ion
$r_1 = m_o v_o / Bq$ $\quad r_2 = (2m_o)(v_o / \sqrt{2}) / Bq$ $\quad$ comparing the two. $R_2 = (2 / \sqrt{2}) R_1$

1976B4.

a) Arrow should point radially inwards ↖

b) Since the LHR gives the proper direction for F, v, B the charge is negative

c) Force F_e should points down (E field pushes opposite on – charges) and F_b should point up.

d) To move horizontally, $F_{net} = 0$ □ $F_e = F_b$ □ $Eq = qvB$ □ $v = E/B$

1977B3.

a) The E field points left since it's a negative charge and is moved opposite the E field.

b) Work done by the accelerating plate = kinetic energy gained. $W = K$ □ $Vq = \frac{1}{2} mv^2$ □ $v = \sqrt{(2Ve/m)}$

c) Using the LHR, the force on the electron would be down when it enters the B field. This will turn the charge and the resulting B force will act as a centripetal force making the charge circle.

d) Using an E field to create a force equal and opposite to the F_b could make the charge move in a straight line. Since the charge is negative and the initial F_b is down, The E field would point down to make an upwards F_e

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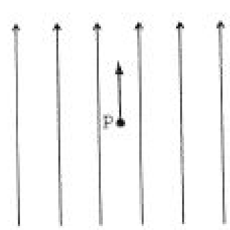
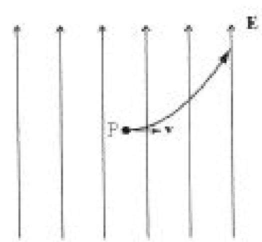
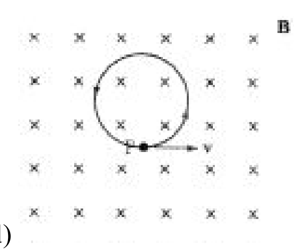
1979B4.

We will show the sketches of the paths first

a) 

b) 

c) No motion

d) 

Now determine the magnitudes

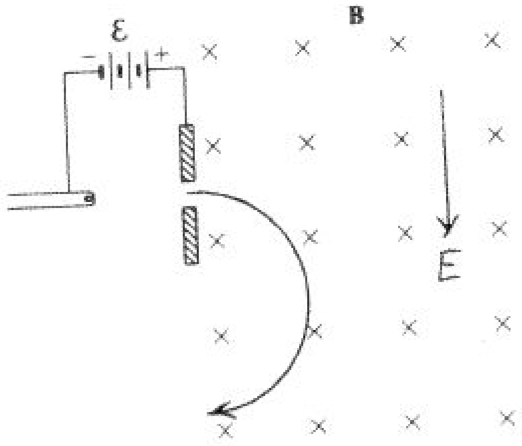
a) $F_e=Eq$
$(10^4)(1.2\text{x}10^{-19})$
$= 1.6 \text{ x } 10^{-15}$ N

b) The force from the E field is independent of the velocity so it's the same as (a)

c) F=0

d) $F_b = qvB$
$(1.6\text{x}10^{-19})(10^5)(10^{-1})$
$1.6\text{x}10^{-19}$ N

1984B4.



a) $W = K$ □ $Vq = ½ mv^2$ □ $\varepsilon = mv^2 / 2e$

b) Shown on diagram

c) $F_{net(C)} = mv^2/r$ □ $qvB = mv^2 / r$ □ $r = mv / Be$

d) i) $F_{net} = 0$ □ $F_e = F_b$ □ $Eq = qvB$ □ $E = vB$
ii) shown on diagram

1988B4.

a) Use the RHR to determine the magnetic field from each wire. The 3A wire makes a field out of the page and the 1A wire makes a field into the page. Since the B field of each wire is given by $\mu_o I / (2R$□$)$ we can see that the 3A wire will have the stronger field and thus dominate the direction, making the net field out of the page.

b) $B_{net} = B_{3A} – B_{1A} = \mu_o /(2$□$)[I_3 /R_3 – I_1 / R_1] \quad = 2x10^{–7}$ T

c) With Force left, velocity up, and B field out .. The LHR works to produce this result so it must be negative

d) $F = qvB \qquad 10^{–7} = q (10^6)(2x10^{–7}) \qquad q = 5x10^{–7}$ C

e) Need $F_e = F_b \qquad Eq = F_b \qquad E (5x10^{–7}) = 10^{–7} \qquad E = 0.2$ N/C directed left.
The electric field is directed left so that the negative particle will have a rightward electric force to balance the magnetic force which is pointing left

1990B2.

a) $E = V/d$ 200 / 0.1 20000 V/m downward (from + to –)

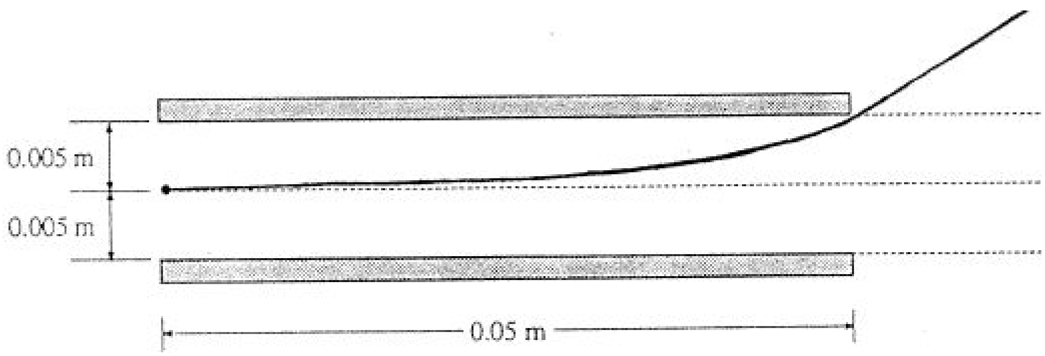
b) $F_{net} = ma$ $F_e = ma$ $Eq = ma$ $(20000)(1.6\text{x}10^{-19}) = 9.11\text{x}10^{-31}\ a$ $a = 3.5\text{x}10^{15}\ \text{m/s}^2$ upward

c) Treat the electron as a projectile acting with an acceleration of gravity upwards of the value from part b.

$d_x = v_x t$ $(0.05) = (3\text{x}10^7)\ t$ $t = 1.67\text{x}10^{-9}$ sec

$d_y = v_{iy}t + \frac{1}{2} at^2$ $d_y = 0 + \frac{1}{2}(3.5\text{x}10^{15})(1.67\text{x}10^{-9})^2 = 0.0049$ m

d)



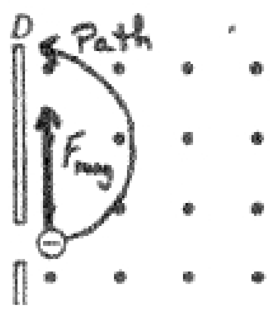
e) Need to balance $F_e = F_b$ $Eq = qvB$ → $B = E/v = (20000) / (3\text{x}10^7) = 6.67 \text{ x } 10^{-4}$ T. Since the force on the electron from the E field points upwards, the force from the B field would have to point down. Using the LHR for the electron with the given, F and v gives a B field direction into the page.

1991B2.

a) i) $W = K$ → $Vq = \frac{1}{2} mv^2$ → $v = \sqrt{2Ve/m}$

ii) $F_{net} = ma$ $F_e = ma$ $Eq = ma$ $(V/d)\ e = ma$ $a = Ve / md$

b) i & ii



c) $F_{net(c)} = ma_c$ $F_b = ma_c$ $qvB = ma_c$ $a_c = evB/m$

sub in v from part a-i → $a_c = \dfrac{eB}{m}\sqrt{\dfrac{2Ve}{m}}$

1992B5.

a) Using LHR for the electron, force up, velocity right, the B field points out of the page.

b) $F_b = qvB = (1.6\text{x}10^{-19})(2\text{x}10^7)(6\text{x}10^{-4}) = 1.9\text{x}10^{-15}$ N

c) $F_{net(C)} = mv^2/r$ → $qvB = mv^2 / r$ → $r = mv / Be$ → $r = (9.11\text{x}10^{-31})(2\text{x}10^7) / (6\text{x}10^{-4})(1.6\text{x}10^{-19}) = 0.19$ m

d)) Need $F_e = F_b$ $Eq = qvB$ $E = vB$ $E = (2\text{x}10^7)(6\text{x}10^{-4}) = 12000$ N/C

e) The E field must provide an electric force downwards on the negative charge to counteract the upwards B field. For a negative charge, this would require an upwards E field.

1993B3.

a) i) since the particle is accelerated toward the negatively charged plate, it must be positively charged
ii) The force on the particle due to the magnetic field is towards the center of the circular arc. By RHR the magnetic field must point out of the page.

b) i) W = K → $Vq = \frac{1}{2} mv^2$ → $v = \sqrt{2Vq/m}$
ii) $F_b = qvB = qB\left(\sqrt{2Vq/m}\right)$
iii) $F_{net(C)} = mv^2/r$ → $qvB = mv^2 / r$ → $r = mv / Bq$ → distance is 2xr = 2mv/qB
iv) Work traveled in a circle at constant speed is zero as described in previous units.

1994B4.

a) W = K → $Vq = \frac{1}{2} mv^2$ → $V = (1.67\text{x}10^{-27})(3.1\text{x}10^{6})^2 / 2(1.6\text{x}10^{-19}\ C)$ → 50000 V

b) Method I – The thermal energy produced by a single proton will be equal to the conversion of the kinetic energy into internal energy. The kinetic energy can be found with $\frac{1}{2} mv^2$ and the v is the same at the target as it was when it entered the B field.

For a single proton we have $\frac{1}{2} mv^2 = \frac{1}{2}(1.67\text{x}10^{-27})(3.1\text{x}10^{6})^2 = 8\text{x}10^{-15}$ J.

Now we have to find out how many protons hit the target in 1 minute using the current.
$I = Q/t$ → $2\text{x}10^{-6}$ Amp = Q / 60 sec → $Q = 1.2\text{x}10^{-4}$ C total charge.
$1.2\text{x}10^{-4}$ C / $1.6\text{x}10^{-19}$ C/proton → $7.5\text{x}10^{14}$ protons.

Now multiply the number of protons by the energy for each one. $7.5\text{x}10^{14} * 8\text{x}10^{-15} = 6$ J

Alternate (easier) solution – Find the power of the beam P=IV. Then, W = Pt, directly gives the energy that will be delivered in 1 minute. $W = IVt = (2\text{x}10^{-6})(50000)(60) = 6$ J

c) $F_{net(C)} = mv^2/r$ → $qvB = mv^2 / r$ → $B = mv / qr$ → $B = (1.67\text{x}10^{-27})(3.1\text{x}10^{6}) / (1.6\text{x}10^{-19})(0.1)$ B=0.32 T

d) Using the RHR gives B field out of the page in the positive z direction.

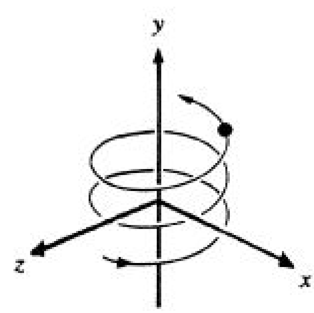
1995B7.

a) Force is given by $qvB_\perp$, to make $B_\perp$ use B sin θ → $F_b = qvB\cos\theta = (1.6\text{x}10^{-19})(4\text{x}10^{7})(1.2)(\cos 30) = 6.7\text{x}10^{-12}$ N

b) Using the RHR for given direction, Force must be into the page in – z direction.

c) The magnetic force is perpendicular to the distance caused by the magnetic force at all points so work = 0

d) Since the velocity is not ⊥ to the field, this will not be a simple circle, though a version of circular motion will ensue. If the particle was traveling exactly horizontal, the motion would simply be a horizontal circle coming into and out of the page in the z direction. But since there is a component of the velocity that is in the upwards y direction, inertia will keep the particle moving upwards in the y direction in addition to circling in and out of the page. This will make it move in a helical fashion as shown here



1997B3.

a) Using hookes law. $2F_{sp} = mg$ $2(kx) = mg$ $k = mg/2d$

b) From the battery, we can see that + current flows to the right through the rod. In order to move the rod down a distance d , the magnetic force must act down. Based on the RHR, the B field would have to act out of the page (+z).

c) The extra spring stretch must be balanced by the magnetic force. $F_{sp(extra)} = F_b$

$kd = BIL$ □ $(mg/2d\ d) = BIL$ Now substitute $\varepsilon = IR$ for I and we get B → $B = mgRd / \ \varepsilon Ld$

d) i) $T = 2\pi\sqrt{\dfrac{m}{k}} = 2\pi\sqrt{\dfrac{m}{2k}} = 2\pi\sqrt{\dfrac{m}{2\dfrac{mg}{2d}}} = 2\pi\sqrt{\dfrac{d}{g}}$ (use 2k, for k since there are two springs)

ii) Set the equilibrium position (at x = d) as zero spring energy to use the turn horizontal trick. This is the maximum speed location and we now set the kinetic energy here to the spring energy and the d stretch position.

$K = U_{sp}$ $\tfrac{1}{2} mv^2 = \tfrac{1}{2} kx\ ^2$ $mv^2 = (2k)(d)\ ^2$ $v = \sqrt{\dfrac{2k\Delta d^2}{m}} = \Delta d\sqrt{\dfrac{2k}{m}}$

Now sub in for k. $v = \Delta d\sqrt{\dfrac{2\dfrac{mg}{2d}}{m}} = \Delta d\sqrt{\dfrac{g}{d}}$

1998B8.

a) Based on the RHR, the B field is directed into the page on the – z axis.

b) Based on the RHR, the force is directed down on the – y axis.

c) First determine the B field at point A from the wire. $B = \mu_o I / (2d)$

Then the force on the particle is given by $F_b = qvB = qv_o\mu_o I / (2d)$

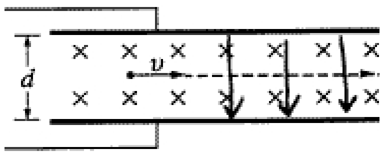
d) Since the magnetic force is directed down, the electric force would have to act upwards to cancel. Since the charge is positive, the E field would also have to point upwards in the +y direction

e) $F_e = F_b$ $Eq = qvB$ $E = vB$ $E = v_o\mu_o I / (2d)$

2000B7.

a) Looking in the region where the particle curves, the LHR gives the proper force direction so its a – charge

b)



To counteract the F_b downward, an electric force must point upwards. For a negative charge, an E field down makes an electric force upwards.

c) Find the E field and use V=Ed to get the V.

Between the plates. $\rightarrow F_e = F_b \rightarrow Eq = qvB \rightarrow E = vB \rightarrow$ (now sub into V=Ed) $\rightarrow$

$V = vBd = (1.9\times10^{6})(0.2)(6\times10^{-3}) = 2300$ V

d) $F_{net(C)} = mv^2/r \rightarrow qvB = mv^2 / r \rightarrow q/m = v / rB \rightarrow q/m = (1.9\times10^{6}) / (0.1)(0.2) = 9.5 \times 10^{7}$ C/kg

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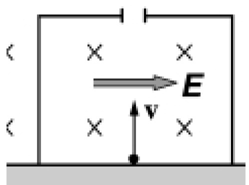
2002B5.

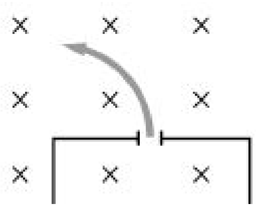
a)



For the proton to maintain a straight trajectory, the magnetic force would have to be balanced by the electric force. Using the RHR for the + charge moving up, the magnetic force points left, so the electric force needed should point right. For a + charge an E field directed left would make an electric force also directed left.

b) $F_e = F_b \rightarrow Eq = qvB \rightarrow v = E/B$

c)



Using the RHR, the charge gets forced to the left in a circular fashion

d) Using $F_{net(C)} = ma_c \rightarrow qvB = ma_c \rightarrow$ sub in v=E/B, and q=e $\rightarrow e(E/B)B = ma_c \rightarrow a_c = eE / m_p$

2003B3.

a) Determine the acceleration of the bar with $F_{net} = ma \rightarrow a = F/M$

Then use kinematics. $d = v_i t + ½ at^2 \rightarrow d = 0 + ½ (F/m)t^2$ $\qquad d = Ft^2 / 2m$

b) $v_f^2 = v_i^2 + 2ad \rightarrow v_f^2 = 0 + 2(F/M)L \rightarrow v = \sqrt{2FL/M}$

c) The energy given to the gun equals the kinetic energy at the end. $K= ½ mv^2 = ½ M(2FL/M) = FL$

OR: simply W=Fd = FL and work equals energy transfer.

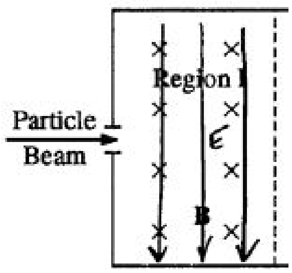
d) Based on the given current flow direction and force, using the RHR, the field points out of the page +z

e) Using the formula from part (b) $\rightarrow v = \sqrt{2FL/M} \rightarrow$ sub in F=BIL, with L=D $\rightarrow v = \sqrt{2(BID)L/M} \rightarrow$

$v = \sqrt{2(5)(200)(0.1)(10)/(0.5)}$ $\qquad v = 63$ m/s

B2007B2.

a)



i) Based on the RHR, the magnetic force on the positive charge acts upwards so an electric force directed down would need to be in place for an undeflected beam. For + charges, E field acts in the same direction as the electric force.

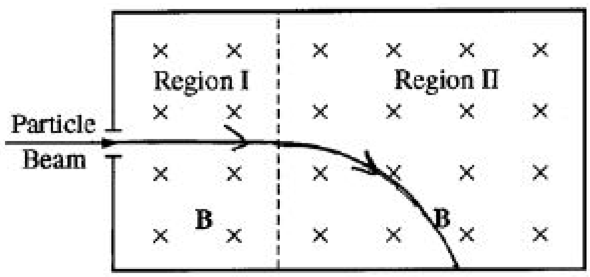
ii) Using this logic just explained, we have

$F_e = F_b \rightarrow Eq = qvB \rightarrow v = E/B = 4800/0.12 \quad 4 \times 10^4$ m/s

b) Using $F_{net(C)} = mv^2/r \rightarrow qvB = mv^2 / r \rightarrow r = mv / Bq \rightarrow r = (6.68 \times 10^{-26})(4 \times 10^4) / (0.12)(3.2 \times 10^{-19}) = 0.07$ m

c) Since the speed is slower than the speed where $F_e = F_b$ and since F_b is based on the speed (qvB) the F_b will now be smaller than the F_e so the net force will act down.

d)



2007B2.

a) To make the + particles deflect left as shown a leftward magnetic force should be created. Based on the RHR and the given force and velocity, the B field should point into the page in the –z direction.

b) The magnetic force is given by qvB. The magnetic force acts perpendicular to the velocity so does not accelerate the velocity in the direction of motion; rather it acts as a centripetal force to turn the particle and accelerate it centripetally only.

c) Using $F_{net(C)} = mv^2/r \rightarrow qvB = mv^2 / r \rightarrow v = qBR / m$ ... *(note that the radius is ½ of distance x)*

$v = (2*1.6 \times 10^{-19})(0.09)(1.75 / 2) / (1.45 \times 10^{-25}) = 1.74 \times 10^5$ m/s

d) The speed we are looking for is the speed when the charge exits the accelerating plates at the bottom of the diagram. In those plates:

$W = K \rightarrow Vq = ½ mv^2 \rightarrow V(2*1.6 \times 10^{-19}) = ½ (1.45 \times 10^{-25})(1.74 \times 10^5)^2 \rightarrow V = 6860$ V

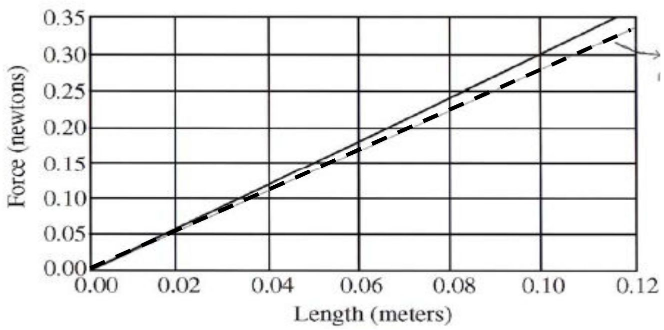
2008B3.

a) This circuit has two resistance elements that are in series on it: the internal resistance (0.5 Ω) and the wires resistance. First find the total resistance of the circuit $\mathcal{E} = IR_{tot}$ $16 = 4\ R$ $R = 4\ \Omega$.
Since the internal resistance makes up 0.5 of this total, the wires resistance must be 3.5 Ω
Now find the wires length with $R = \rho L/A$ $3.5 = (1.7\text{x}10^{-8})\ L\ /\ 3.5\text{x}10^{-9}$ $L = 0.72$ m

b) Tricky, this asks for the force on the magnet which is the opposite of the force on the wire. Based on action–reaction, the force on the magnet is equal and opposite of the force on the wire. Now finding the force on the wire: the field points right, the current is into the page as shown, so the RHR gives the force down on the wire. Therefore the force on the magnet would be up (this will make the scale reading lighter).

c) The change in the scales weight is caused by the magnetic force pulling up on the magnet and this extra force is exactly equal to F_b so $F_b = BIL$ $0.06\ N = B\ (4)(0.02)$ $B = 0.75$ T

d) Since the length of the wire is not perpendicular, only a component of the B field is used to determine the force. So in the equation $F_b = BIL$, the B value is reduced and for increasing lengths, there should be less and less force compared to the ideal line shown.



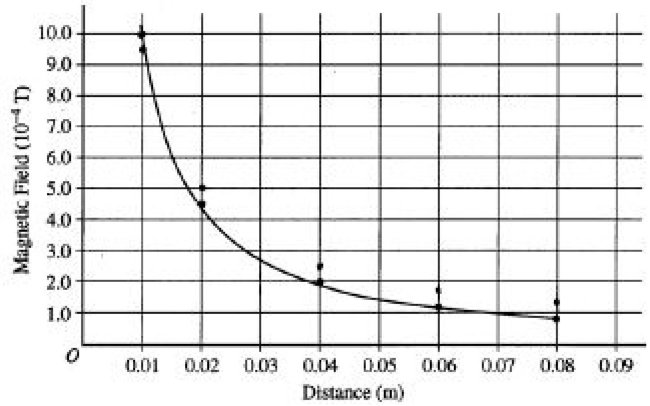
Dotted line is the relationship for the misaligned wire.

e) The new graph shows decreasing magnetic force but the explanation in part d cannot be applied because the wire was not misaligned. This means there must be a reason that the B field was having lessened effects as the wire lengthened. Looking the original diagram in the problem, one explanation could be that as the wire segment in between the magnets got longer, it moved outward away from the poles of the N–S magnet and some of the wire had a smaller field acting on it compared to the parts in the center of the magnet.

Another possible source of error is that as the bottom part of the loop gets longer, the sides would get shorter brining the top part of the loop lower down and the top part of the loop will begin to exert a force in the opposite direction lessening the net force on the wire.

B2008B3.

a) Based on the RHR for a current wire creating a field, the magnetic field at the location in question is directed down (south). So the students reading was less than it should have been for the wire since the meter was measuring both fields and the earths field was acting against the wires field. If the earth's field was not present, the meter reading would have been larger. So each Field data point should be shifted up by the amount that the earths field had reduced it reading, as shown.

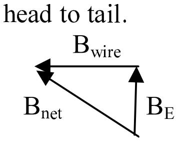


b) The field in the wire is given by $B = \mu_o I / (2\pi d)$. Use one of the new data points.

$10x10^{-4} = 4\pi \times 10^{-7}$ (I) / $2\pi(0.01)$ I = 50 A

c) To figure out the direction the needle points, we first need to determine how strong the wires field is with the 35 A current in the given location. $B = \mu_o I / (2\pi d)$ ⇒ $B = 4\pi \times 10^{-7} (35) / 2\pi(0.04)$ ⇒ $B = 17.5x10^{-5}$ T, as compared to the earths field given in the problem, $5x10^{-5}$ T. Since the fields are on the same order of magnitude, the compass will not be totally overpowered by the external field and will point in a North–westerly direction though it would be angled more towards west since the external western field is larger.

d) Using the value of the earths field, and the value of the external field, we can determine the exact angle by setting them up head to tail.



The angle θ is found using tan θ = o/a   tan θ = $17.5x10^{-5} / 5x10^{-5}$

θ = 74 degrees.

e) V = IR ⇒ 120 = 35 R ⇒ R = 3.4 Ω

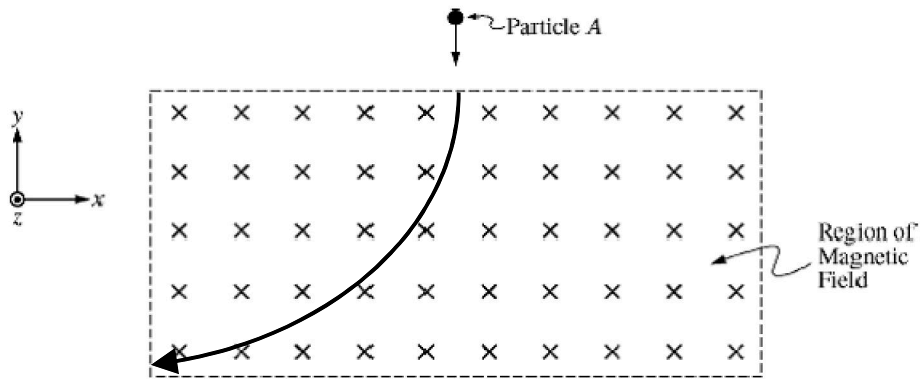
f) Rate of energy is power. P = IV = (35)(120) = 4200 W

B2009B2.

a) The distance between A and B on each side is a diagonal and can be found using the graph and Pythagorean theorem → $x^2 + y^2 = d^2$ → $(0.04)^2 + (0.03)^2 = d^2$ → $d = 0.05$ m (3-4-5 triangle). Since charge q_a is equidistant from both q_b's, and the charges on either side are identical since they are both q_b, the forces on q_a from each q_b are identical in magnitude and given by $F_e = k\, q_a q_b / r^2 = (9\text{x}10^9)(0.2\text{x}10^{-9})(0.3\text{x}10^{-9})/(0.05)^2 = 2.16\text{x}10^{-7}$ N. Each force acts in the direction down along the diagonal in the 3-4-5 triangle from A–B at 53.13° measured away from the y axis. Since both forces are equal and act at the same angle, the x components of these forces cancel leaving only the y components to add together. So the total net force is simply double the y component of one of the forces. → $2\,F_y = 2{*}2.16\text{x}10^{-7}\,(\cos\ 53.13) = 2.6\text{ x }10^{-7}$ N directed down.

b) The x components of the forces on particle *a* will always cancel so it will only move along the y axis. It will be accelerated down along the axis and at the origin the net force will be zero. It will move past the origin on the negative y axis at which point the force starts to pull upwards towards +y and it will slow down until it stops and is pulled back up towards the origin again. It will oscillate up and down.

c) Based on the LHR for the negative charge and the given v and B, the force on the particle would be directed towards the left initially and act as a centripetal force to make the particle circle.



Depending on the strength and width of the B field, the particle may take a different radius turn in the field.

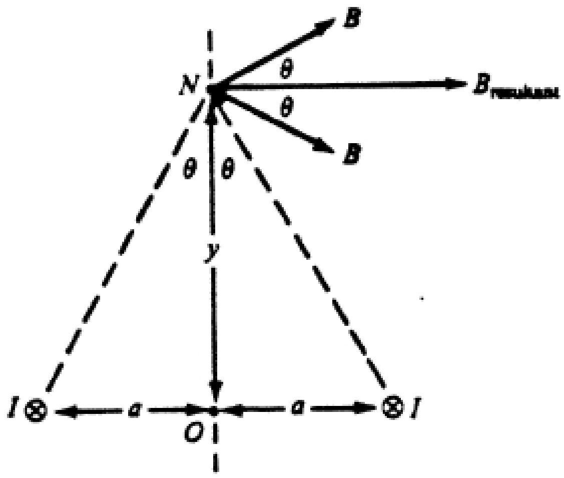
d) $F_b = qvB = (0.2\text{x}10^{-9})(6000)(0.5) = 6\text{x}10^{-7}$ N

e) $F_e = F_b$ → $Eq = qvB$ → $E = vB$ → $E = (6000)(0.5) = 3000$ N/C.
The force would need to oppose the magnetic force and point to the right. Since this is a negative charge, the E field would have to point left to create a rightward electric force.

C1983E3.

a) The field from a wire is given by $B = \mu_o I / (2R\pi)$, with R and I equal for both wires at point O. Based on the RHR for the current wires, the right wire makes a field down and the left wire makes a field up so cancel to zero.

b)



Based on the RHR, the resultant fields from each wire are directed as shown. Since the distance to each wire is the same, the resultant B field will simply be twice the x component of one of the wire's B fields.

The distance to point N is $\sqrt{a^2 + y^2}$ so the total field at that location from a single wire is

$$B = \frac{\mu_o I}{2\pi\sqrt{a^2 + y^2}}$$

The x component of that field is given by B cos θ, where cos θ can be replaced with cos θ = a/h = y / $\sqrt{a^2 + y^2}$

Giving B_{net} = 2 B cos θ = 2 B y / $\sqrt{a^2+y^2}$ = $\dfrac{2y\mu_o I}{2\pi\sqrt{a^2+y^2}\sqrt{a^2+y^2}}$ = $\dfrac{y\mu_o I}{\pi(a^2+y^2)}$

C1990E2.

a) Based on the RHR, the magnetic force on the + charge is down, so the electric force should point up. For + charges, and E field upwards would be needed to make a force up.

b) The speed on region III is equal the whole time and is the same as the speed of the particles in region II. For region II we have $\Sigma F_e = F_b$ → Eq = qvB → v = E/B

c) Using region III $\Sigma F_{net(C)} = mv^2/r$ → $qvB = mv^2 / r$ → m = QBR / v (sub in v) → $= QB^2R / E$

d) In between the plates, W = K → Vq = ½ mv^2 → $V = mv^2/2Q$ → (sub in v and m) → = RE / 2

e) In region three, the acceleration is the centripetal acceleration. $a_c = v^2 / R$ → (sub in v) → E^2 / RB^2

f) Time of travel can be found with v = d / t with the distance as half the circumference (2Rπ/2) then sub in v giving → t = RπB / E

Supplemental.

a) i) Parabolic. The electrons have constant speed to the right. The constant electric force provides a constant acceleration toward the top of the page. This is similar to a projectile under the influence of gravity, so the shape is parabolic.

ii) Down. To create path 1, the electric force must be toward the top of the page. The electron is negatively charged, so the field must point in the opposite direction to the electric force.

b) i) Circular. The magnetic force is always perpendicular to the velocity of the electrons and has constant magnitude. Thus it acts as a centripetal force making the electrons follow a circular path.

ii) Into the page. To create path 3, the initial magnetic force must be toward the bottom of the page. With the initial velocity to the right, the right-hand rule gives a field pointing out of the page. But the electron is negatively charged, so the field must point in the opposite direction.

c) $F_e = F_b \Rightarrow Eq = qvB \Rightarrow v = E/B \Rightarrow v = (3.4\text{x}10^{-4}) / (2\text{x}10^{-3}) = 1.7\text{x}10^{7}$ m/s

d) $W = K \Rightarrow Vq = \frac{1}{2} mv^2 \Rightarrow V = mv^2/2Q \Rightarrow V = (9.11\text{x}10^{-31})(1.7\text{x}10^{7})^2 / 2(1.6\text{x}10^{-19}) = 823$ V

<u>SECTION B – Induction</u>

1978B4.

a) Use Lenz law to determine the direction to make a CCW current. The bar forms a loop with the rails. If the bar slides right, the flux into the page increases and current will flow to create field out of the page to counter this. Based on the RHR solenoid this would make a CCW current. To find the current, find the emf induced in the bar then use V=IR □ε = Blv □ IR=Blv □ (2)(3)=(2)(2)v □v = 1.5 m/s

b) When the bar slides, it will experience a magnetic force pushing left based on the RHR so a pulling force equal to this magnetic force would need to be applied to move the bar at a constant v. $F=F_b=BIL=(2)(2)(2) = 8$ N

c) Rate of heat dissipated = rate of work = power. In resistor, $P = I^2R = (2)^2(3) = 12\ \Omega$.
Mechanical power = $P=Fv = (8)(1.5) = 12\ \Omega$.

d) All of the kinetic energy will be removed and that is the amount dissipated. $K = ½\ mv^2 = ½\ (4)(1.5)^2 = 4.5$ J

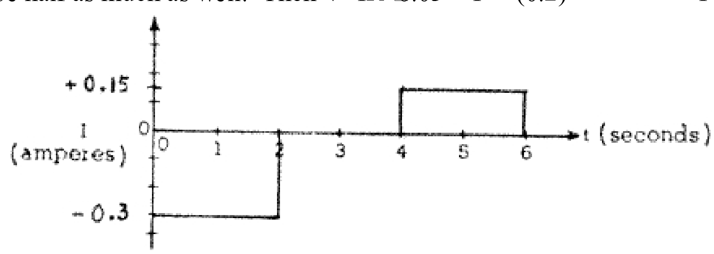
1982B5.

a) =BA, read B from the graph at 3 seconds and use the given area (0.2)(0.3) = 0.06 Wb

b) Induced emf = ε=N /t□ □ = $1*(BA_f – BA_i) / t = A(B_f – B_i) / t = (0.3)(0.2 – (–0.2)) / 2 = 0.06$ V

c) First, the directions are found based on Lenz Law. From 0–1 the downward flux is decreasing so current flows CW to add back the downward field. Then we hit zero flux at 1 second. Moving 1–2 seconds we want to maintain the zero flux and we have an increasing upwards flux so the current still flows CW to add downward field to cancel the gaining flux. At 2 seconds the flux becomes constant so current does not flow up until 4 seconds. From 4–6 seconds we are loosing upwards flux so current flows CCW to add back that upwards field.

To determine the current magnitudes. Use V=IR.
From 0–2 sec. 0.06 = I (0.2) I = 0.3 A
From 2–4, I=0.
From 4–6, first determine new emf. Since the slope is half as much as 0–2 sec, the emf should be half as much as well. Then V=IR □0.03 = I (0.2) I = 0.15 A



1986B4.

a) The potential difference is induced due to charge separation on the vertical hand wire of the loop. Points X and Y are the same as the top and bottom of the left wire. The emf induced in the wire is given by ε = Blv
ε = Blv = (0.5)(2)(3) = 3 V

b) Use Lenz law for the loop. The loop is loosing inward flux so current flows to maintain the inward field. Based on RHR solenoid for Lenz law, current would flow CW and down the resistor to add inward field and maintain flux.

c) The leftmost wire has a magnetic force directed left and a pulling force to right equal to that magnetic force needs to be applied to maintain the speed. First determine the magnitude of the current. V=IR, 3=I(5), I=0.6A, then $F = F_b = BIL = (0.5)(0.6)(2) = 0.6$ N

d) Rate of work is power. Either the electrical power (I^2R) or mechanical power (Fv) can be found. P = 1.8 W.

1999B3.

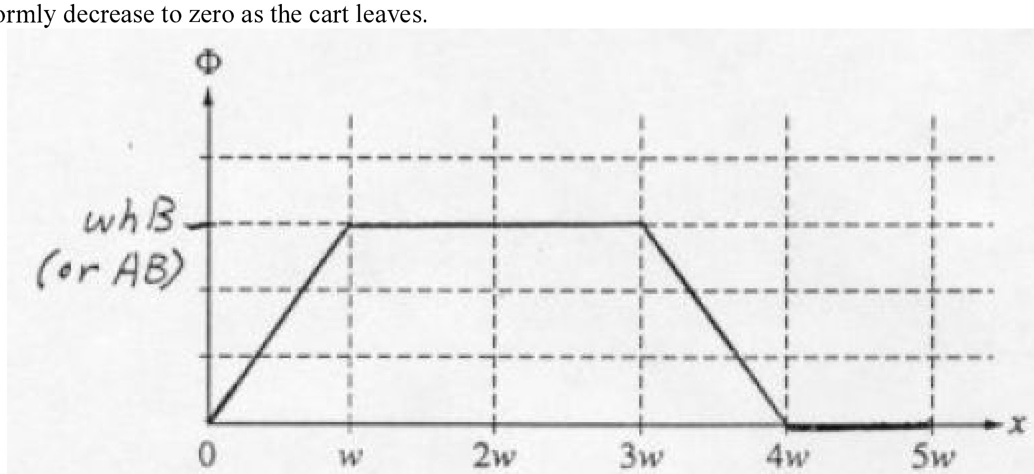
a) Use energy conservation. $U = K$ $\quad mgh = \frac{1}{2} mv^2$ $\quad v = \sqrt{2gy_o}$

b) i) The wire on the right side edge of the loop is the one where the emf is being induced due to charge separation. For this wire, the induced emf is given by $\varepsilon = BLv = Bh\sqrt{2gy_o}$

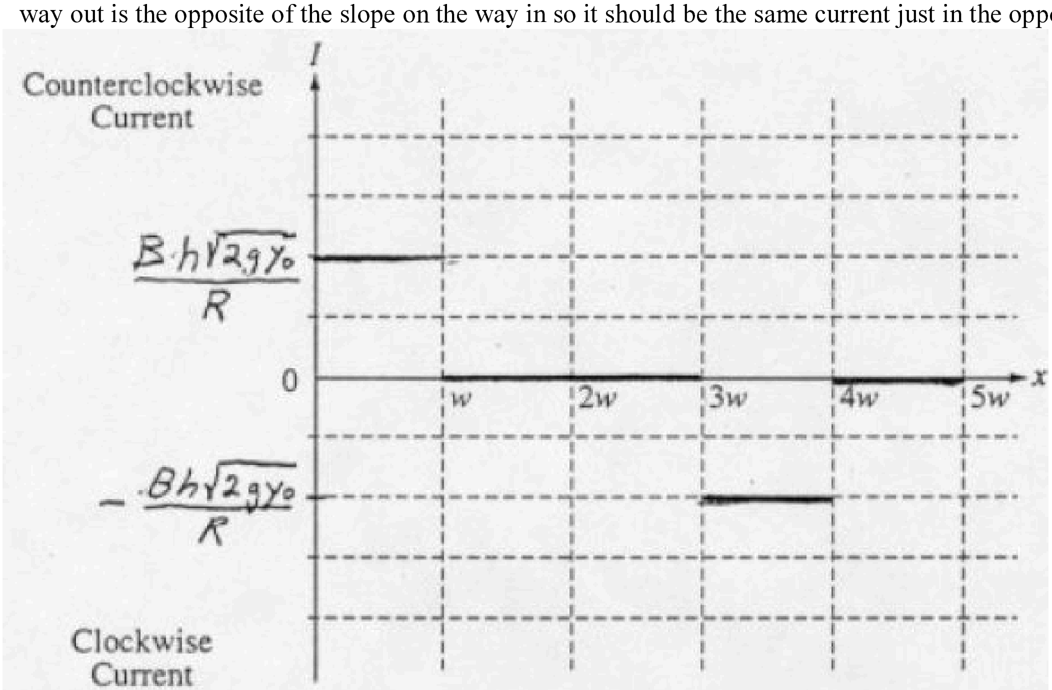
ii) The current is found with $V=IR$ $\quad Bh\sqrt{2gy_o} = IR$ $\quad I = \dfrac{Bh\sqrt{2gy_o}}{R}$

c) As the loop enters the field, it is gaining flux into the page. By Lenz law, to counteract this change, current flows to produce field lines out of the page. Using the solenoid RHR the current must flow CCW.

d) i) Note that the graph calls for the magnitude so you must put the flux magnitude on the graph. The flux is found by $\Phi = BA$. From 0 to w the flux uniformly increases as the loop enters the field. Once fully in the field the full flux would be given by B(wh) which would remain constant as the whole loop was in the field and then uniformly decrease to zero as the cart leaves.



ii) The current upon entering the loop was found in part b, so that is the proper magnitude. Based on the diagram above, we can see the flux does not change in the middle part so there would be no current and the slope on the way out is the opposite of the slope on the way in so it should be the same current just in the opposite direction



2004B3.

a) $\Phi = BA = (0.3)(0.2\text{x}0.2) = 1.2\text{x}10^{-3}$ Wb

b) Induced emf $\varepsilon = N\Delta\Phi/\Delta t \rightarrow (1)(BA_f - BA_i) / t \rightarrow A(B_f - B_i) / t \rightarrow (0.2\text{x}0.2)(0.20 - 0.03) / 0.5 = 0.014$ V

c) i) $V=IR \rightarrow (0.014) = I\,(0.6) \rightarrow I = 0.023$ A

ii) The magnetic field is increasing into the page. Current will be induced to oppose that change. By the RHR, to create a field out of the page the current must be counterclockwise.

d) If the magnetic field was constant, the area would have to be changed to change the flux and induce the current. To change the area, the loop could be pulled out of the field or it could be rotated in place.

B2004B4.

a) Induced emf $\varepsilon = N\Delta\Phi/\Delta t \rightarrow 20{*}(BA_f - BA_i) / t \rightarrow 20B(A_f - A_i) / t \rightarrow 20(0.2)(0 - 0.25\text{x}0.15) / 0.5 = 0.30$ V

b) $V=IR \rightarrow (0.30) = I\,(5) \rightarrow I = 0.06$A

Based on Lenz law, as the loop is pulled out of the field it loses flux out of the page so current flows to create field outward to add back that flux. By the RHR solenoid current flows CCW.

c) $P = IV = (0.06)(0.30) = 0.018$ W

d) The wire resisting the pull is the leftmost wire of the loop. For that wire, the pulling force would equal the magnetic force of the wire. $F_b = BIL = (0.2)(0.06)(0.15)$ for 1 wire, but there are 20 wires there as per the 20 turns of the loop so it would be 20x this force $F_{pull} = 0.036$ N.

– or – using the mechanical power P=Fd/t and solve for F

e) By adding 20 turns, both the V and the R double so based on V=IR the current remains the same.

2009B3.

a) Combine induced emf, $\mathcal{E} = Blv$, with $V = IR \rightarrow$

$IR = Blv \rightarrow I(3) = (0.8)(0.52)(1.8) \rightarrow I(3) = 0.749$ $\quad I = 0.25$ A

Based on lenz law for the loop formed by the rod, resistor and rails, flux is gained into the page as the rod moves so current is generated to add field out of the page to counteract the flux change. Using the RHR solenoid for lenz law, the current would flow CCW and up the rod.

b) Using the RHR for the rod, the magnetic force acts left. In addition there is friction. So the FBD has the string force to the right and friction + magnetic force to the left. $F_{net} = 0 \rightarrow F_{pull} - F_b - f_k = 0 \rightarrow$

$F_{pull} = \mu_k mg + BIL = (0.2)(0.22)(9.8) + (0.8)(0.25)(0.52) = 0.535$ N

c) $W = IVt = (0.25)(0.75)(2) = 0.374$ J

d) moving at 1.8 m/s for 2 seconds. v = d/t, the string moves 3.6 m. $W = Fd = (0.535)(3.6) = 1.93$ J

e) The work of the string is more because it has to provide the energy to the resistor and work against friction also.

C1973E3.

a) The rod forms a loop with the upper part of the rails. Based on Lenz law, as the rod slides down, the perpendicular component of B increases the flux in the loop and current flows to create a field in the outward normal direction to the rails to counteract the flux change. Using the RHR solenoid, the current would flow towards the right side of the bar pictured.

b) The induced emf in the bar is given by $\mathcal{E} = Blv_\perp$. The perpendicular B is given with B cos θ (simiar to F_{gx}) so the induced emf is BLv cos θ. With V = IR. This gives, IR = BLv cos θ and the current is I = BLv cos θ / R

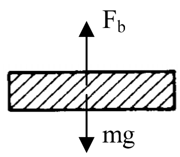
c) $F = BIL_\perp$, again using B cos θ we have F_b = B cos θ IL, now sub in I from above. F_b = B cos θ (BLv cos θ / R)L

$F_b = B^2L^2v\cos^2\theta / R$. Based on the RHR for the bar, the force acts up the inclined rails parallel to them.

d) The terminal velocity will occur when $F_{net(x)} = 0$ with x being the direction along the rails. This gives:

$F_{gx} = F_b$ mg sin θ = $B^2L^2v\cos^2\theta / R$ v = mg sin θ R / $B^2L^2\cos^2\theta$

C1976E2.

a) 

b) Since the bar falls at constant velocity $F_{net} = 0$ so → mg = F_b → mg = BIL → I = mg / BL

c) Simply use the formula $\mathcal{E} = BLv_o$

d) Using V = IR → BLv_o = (mg / BL)(R) → R = $B^2L^2v_o$ / mg

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C1990E3.

a) Since the loop is at rest, the magnetic force upwards must counteract the gravitational force down. Based on the RHR, the current must flow to the right in the top part of the loop to make a magnetic force upwards so the current flow is CW.

b) Mg = F_b → Mg = BIL → I = Mg / BL

c) V = IR V = MgR / BL

d) Simply use the formula $\mathcal{E} = BLv$

e) The batteries current flows to the right in the top bar as determined before. As the bar moves upwards, the induced emf would produce a current flowing to the left in the top bar based on Lenz law. These two effects oppose each other and the actual emf produced would be the difference between them.

$V_{net} = (V_{battery} - \mathcal{E}_{induced})$ = MgR / BL – BLv. The current is then found with V=IR. I = Mg/BL – BLv/R

f) Since the box moves at a constant speed, the new gravity force due to the new mass (M – m) must equal the magnetic force in the top bar due to the current and field. The current flowing is that found in part e.

$F_g = F_b$ (M–m)g = BIL Mg – mg = B(Mg/BL – BLv/R)L Mg – mg = Mg – B^2L^2v / R

m = B^2L^2v / Rg

C1991E3.

a) i) Consider the wire as a tube full of charges and focus on a single charge in the tube. That single charge is moving to the right in a B field pointing into the page. Using the RHR, that charge is pushed up to the satellite so the shuttle side is negative.

ii) Induced emf is given by $\varepsilon = BLv = (3.3\text{x}10^{-5})(20000\text{m})(7600) = 5016$ V

b) $V = IR$ $\quad 5016 = I\,(10000)$ $\quad I = 0.5016$ A

c) i) $F_b = BIL = (3.3\text{x}10^{-5})\,(0.5016)(20000)$ $\quad F_b = 0.331$ N

ii) The current flows up, away from the shuttle as indicated. Using the RHR for the given I and B gives the force direction on the wire pointing left which is opposite of the shuttles velocity.

C1998E3.

a) At constant speed $F_{net} = 0$ $\quad F_b = F_{gx}$ $\quad BIL = mg \sin\theta$ $\quad I = mg \sin\theta / BL$

b) Using the induced emf and equating to V=IR we have $\quad IR = BLv$, sub in I from above

$(mg \sin\theta / BL)R = BLv$ $\quad$ solve for $v = mgR \sin\theta / B^2L^2$

c) Rate of energy is power. $P = I^2R$ $\quad P = (mg \sin\theta / BL)^2 R$

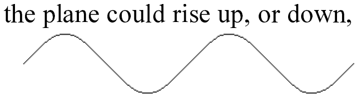
d) Since the resistor is placed between the rails at the bottom, it is now in parallel with the top resistor because the current has two pathways to chose, the top loop with resistor R or the new bottom loop with the new resistor R. This effectively decreases the total resistance of the circuit. Based on the formula found in part b, lower resistance equates to less velocity.

C2003E3.

a) Looking at the side view and then transferring back to the top view, we see that in the top view the magnetic field is basically pointing into the page. The component of the magnetic field we are concerned with actually does point directly into the page. Now using the LHR rule for the electrons they get pushed down, which is towards east.

b) The emf is induced and given by $\varepsilon = Blv_{\perp}$. The perpendicular B is B sin θ as can be seen in the side view

$\varepsilon = B \sin\theta\, Lv = (6\text{x}10^{-5})(\sin 55)(15)(75) = .055$ V

c) To induce a current, the flux needs to change. The earths magnetic field strength cannot be changed, but the $\perp$ component of that B field in the enclosed area can be altered which will change the flux and induce current flow. In order to do this, the plane could rise up, or down, or to sustain a current the plane could follow a wavelike pattern.  .

Or the plane could rock its wings back and forth. However, simply turning left or right would not work.

Direction: Let's say the plane rises up, this will increase the $\perp$ component of the B field in the loop so current will flow to reduce this increased downward field in the loop. Current flows CCW to create and upwards field to cancel out the increased downwards B field based on Lenz Law.