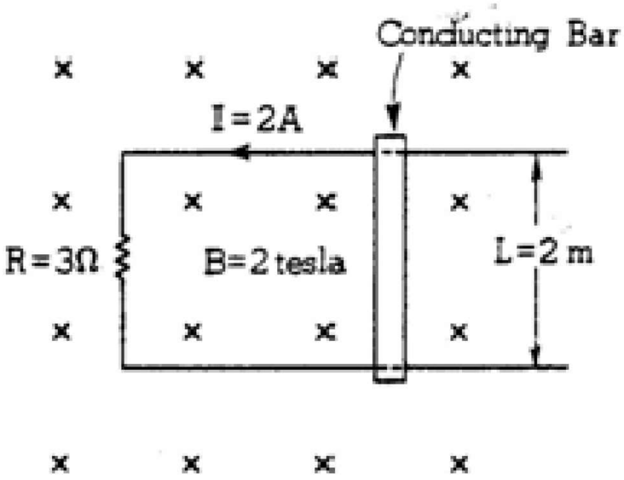
SECTION B – Induction



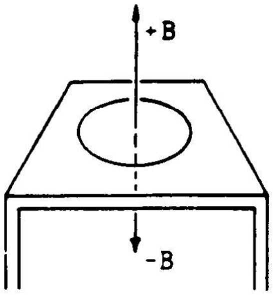
1978B4. Two parallel conducting rails, separated by a distance L of 2 meters, are connected through a resistance R of 3 ohms as shown above. A uniform magnetic field with a magnitude B of 2 tesla points into the page. A conducting bar with mass m of 4 kilograms can slide without friction across the rails.

(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.

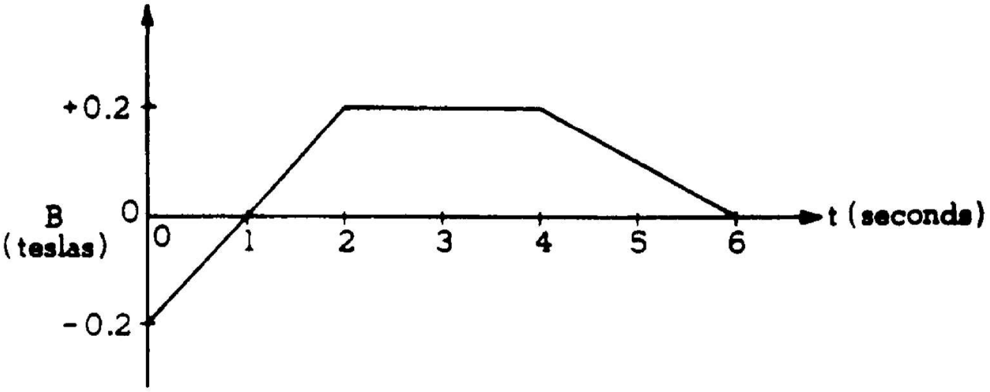
(b) Determine the magnitude and direction of the external force that must be applied to the bar to keep it moving at this velocity.

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

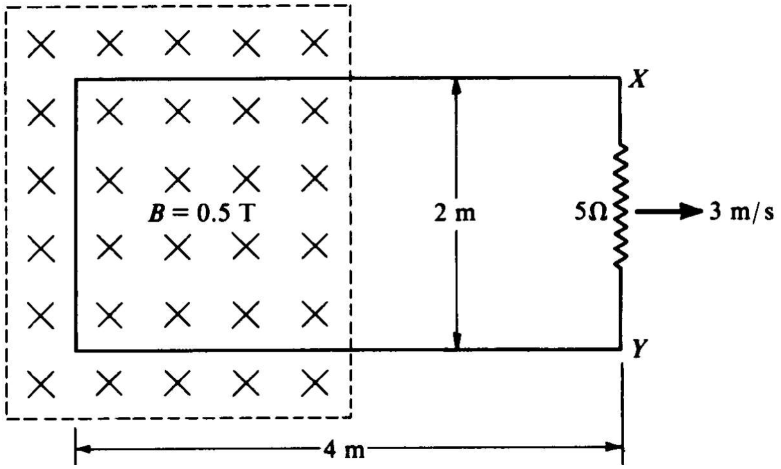
(d) Suppose the external force is suddenly removed from the bar. Determine the energy in joules dissipated in the resistor before the bar comes to rest.



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.

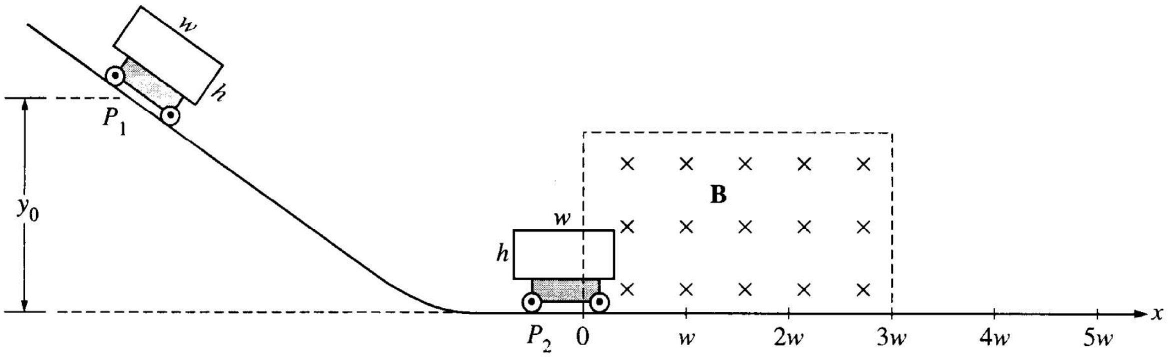


a. Calculate the value of the magnetic flux through the loop at time t = 3 seconds.
b. Calculate the magnitude of the emf induced in the loop during the time interval t = 0 to 2 seconds.
c. On the axes below, graph the current I through the coil as a function of time t, and put appropriate numbers on 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.

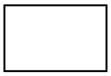


1999B3. A rectangular conducting loop of width w, height h, and resistance R is mounted vertically on a non–conducting cart as shown above. The cart is placed on the inclined portion of a track and released from rest at position P_1 at a height y_0 above the horizontal portion of the track. It rolls 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.

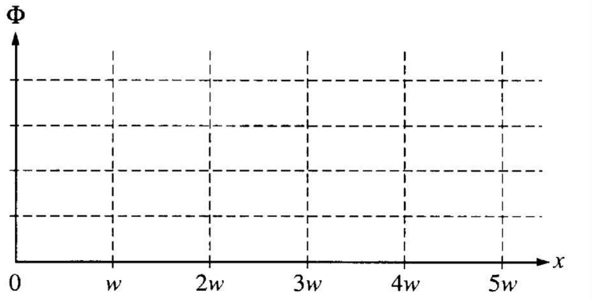
a. Determine the speed of the cart when it reaches the horizontal portion of the track.

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

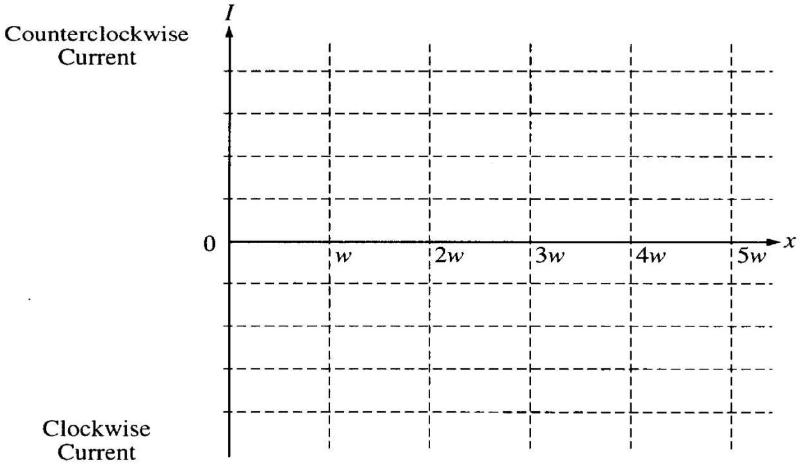
c. On the following diagram of the conducting loop, indicate the direction of the current when it is at Position P_2.



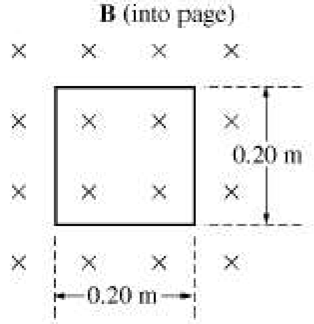
d. i. Using the axes shown, sketch a graph of the magnitude of the magnetic flux ϕ through the loop as a function of the horizontal distance x traveled by the cart, letting x = 0 be the position at which the front edge of the loop just enters the field. Label appropriate values on the vertical axis.



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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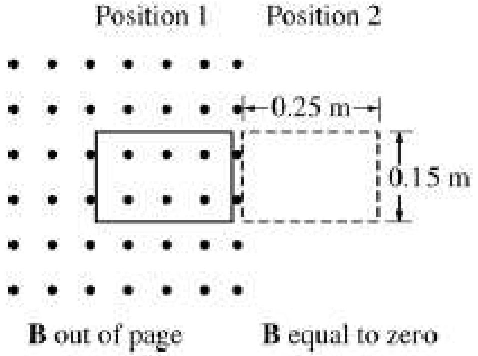
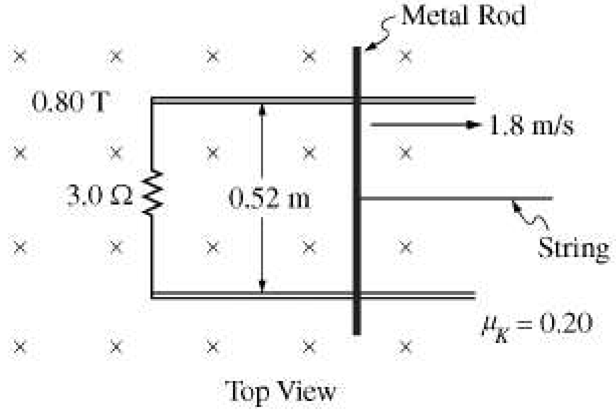
B2004B4.
A 20-turn wire coil in the shape of a rectangle, 0.25 m by 0.15 m, has a resistance of 5.0 Ω. In position 1 shown, the loop is in a uniform magnetic field **B** of 0.20 T. The field is directed out of the page, perpendicular to the plane of the loop. The loop is pulled to the right at a constant 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.



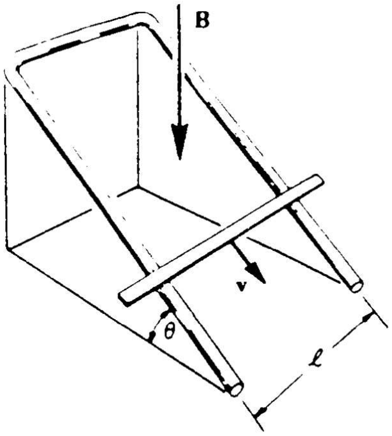
A metal rod of mass 0.22 kg lies across two parallel conducting rails that are a distance of 0.52 m apart on a tabletop, as shown in the top view. A 3.0 Ω resistor is connected across the left ends of the rails. The rod and rails have negligible resistance but significant friction with a coefficient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

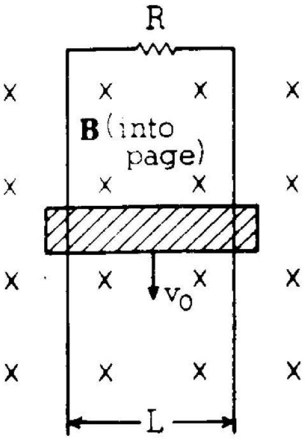
There is a magnetic field of 0.80 T perpendicular to the plane of the tabletop. A string pulls the metal rod to the right with a constant speed of 1.8 m/s.

(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.

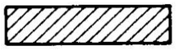
a. Show on the diagram the direction of the current in the sliding bar.
b. Denoting by v the instantaneous speed with which the bar is sliding down the incline, determine an expression for the magnitude of the current in the bar.
c. Determine an expression for the force exerted on the bar by the magnetic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

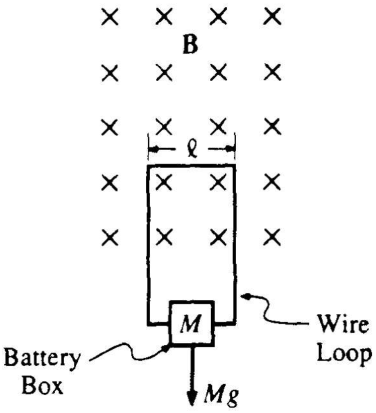


b. Determine the magnitude of the induced current I in the bar as it falls with constant speed v_o in terms of B, L, g, v_o, and M.

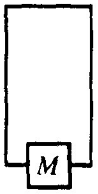
c. Determine the voltage induced in the bar in terms of B, L, g, v_o, and M.

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

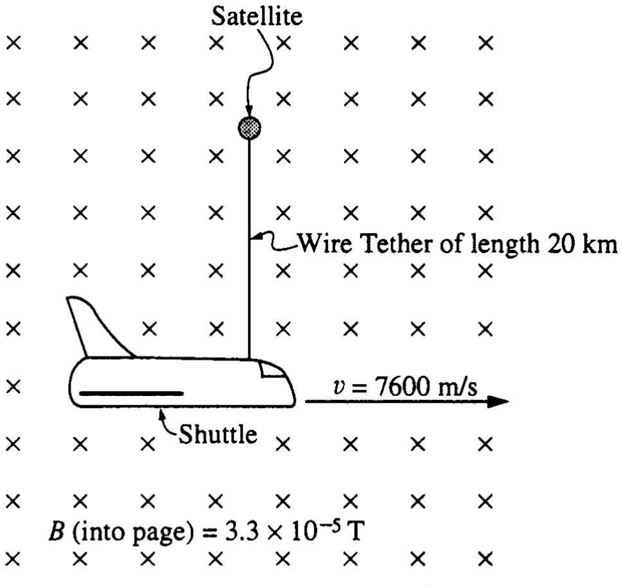
d. the magnitude of the induced emf;

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.

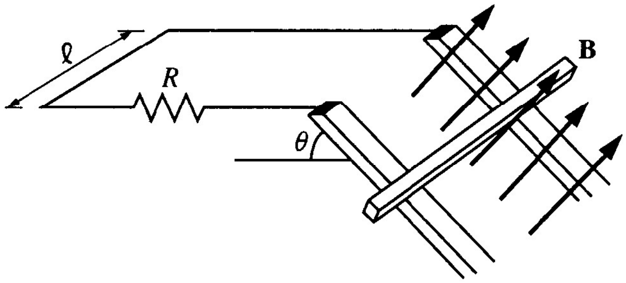
a. An emf is generated in the tether.
    i. Which end of the tether is negative?
    ii. Calculate the magnitude of the emf generated.



Note: Figure not drawn to scale.

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.

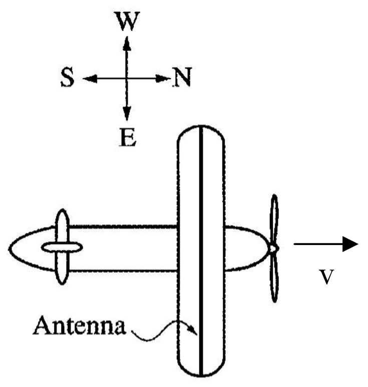
b. If the resistance of the entire circuit is about 10,000 ohms, calculate the current that flows in the tether.
c. A magnetic force acts on the wire as soon as the current begins to flow.
    i. Calculate the magnitude of the force.
    ii. State the direction of the force.



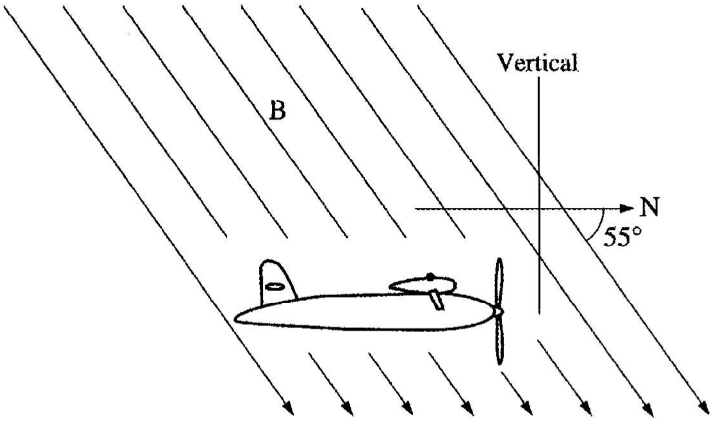
C1998E3. A conducting bar of mass m is placed on two long conducting rails a distance l apart. The rails are inclined at an angle θ with respect to the horizontal, as shown above, and the bar is able to slide on the rails with negligible friction. The bar and rails are in a uniform and constant magnetic 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



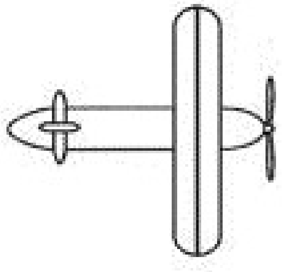
Top View



Side View

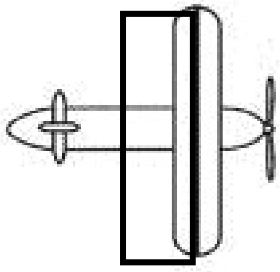
An airplane has an aluminum antenna attached to its wing that extends 15 m from wingtip to wingtip. The plane is traveling north at 75 m/s in a region where Earth's magnetic field of 6.0×10^{-5} T is oriented as shown above.

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.