Electric vs Magnetic Force & Field

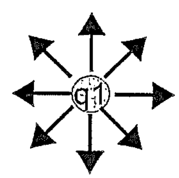
- The Electrostatic force / field E
  - Coulomb's Law between two charges
  - inverse square law.
  - Energy storage in capacitor and uniform E- field

Coulomb's Law

$$\vec{F} = k\,\frac{q_1 * q_2}{R^2}$$

$$\vec{F} = q_2 * \vec{E}$$

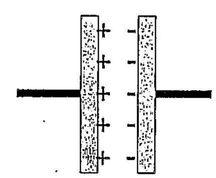
E-Field



$$\vec{E} = k\,\frac{q_1}{R^2}$$

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

Energy Storage



Capacitor

$$C = \frac{A}{4\pi k d}$$

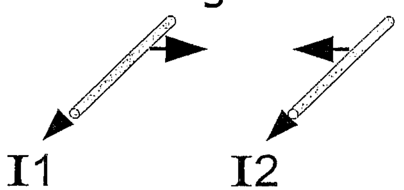
Capacitor Energy $U = \frac{1}{2} C V^2$

E-field is essentially the story of the inverse square law

Magnetic Force / Field B

- The magnetic force
  - between two parallel wires is an inverse R law.
  - Currents traveling in the same direction ***attract***.
  - A *solenoid* gives a uniform magnetic field, B.
    - Solenoid has 'inductance' and stores energy

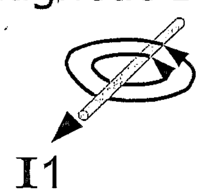
Magnetic Force



$$\frac{F}{L} = \frac{\mu_0}{2\pi}\,\frac{I_1 * I_2}{R}$$

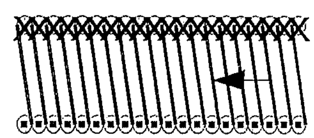
$$F = \left(B\,I_2\right)L$$

Magnetic B-Field



$$\vec{B} = \frac{\mu_0}{2\pi}\,\frac{I_1}{R}$$

Energy Storage



Solenoid

$$L = \mu_0 \frac{N^2 A}{l}$$

Inductor, ***L***

Inductor Energy

$$U = \frac{1}{2} L I^2$$

B-field is essentially a story of the inverse R law

Force between parallel Currents

- In magnetism, instead of k, force constant is $\mu_0/2\pi$

$$\frac{\mu_0}{2\pi} = 2\times10^{-7}$$

- The force equation gives the *force* ***per unit length*** of the wires

$$f = Force/Length = \frac{F}{L}$$

- This is proportional to product of both currents
  - And 1/R

$$f = \frac{\mu_0}{2\pi}\frac{I_1 * I_2}{R}$$

- The force is very small for typical current and distance

Parallel currents attract !!

Anti-parallel currents repel !!

M64

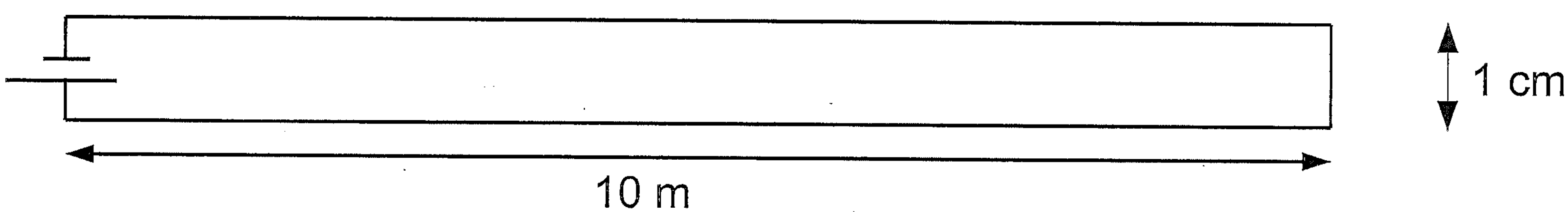
Without ferromagnetic or superconducting materials force is tiny

Problems: Force between Current-carrying wires

$$\vec{F} = L * \frac{\mu_0}{2\pi} \frac{I_1 * I_2}{R}$$

- Two wires carry a current of 1 ampere in the upward direction. They are separated by 1 meter and run parallel for a distance of 20 m. What is the magnitude and direction of the force between them?

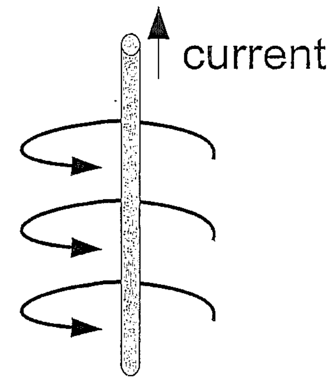
- A battery is connected to a long, rectangular loop of wire in the configuration shown. The battery voltage is 1.5 V and the resistance is 0.05 ohm. What is the magnetic force on the wire?

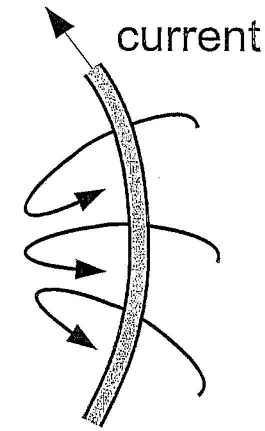


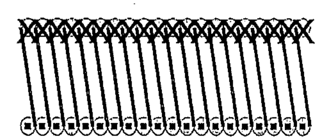
M65

Making Magnetic Field **Stronger**

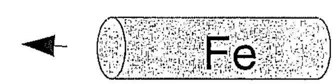
- The force field from a current carrying wire can be <u>*greatly*</u> enlarged by:
  - Highly conductive wire
  - Bending the wire into a loop
  - Looping the wire many times
  - Inserting an iron core into the solenoid
    - Make use of nature's atomic current loops in '*ferromagnetic*' material
      - Remember we found that atomic currents are *very* large

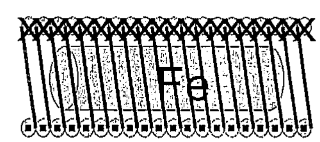




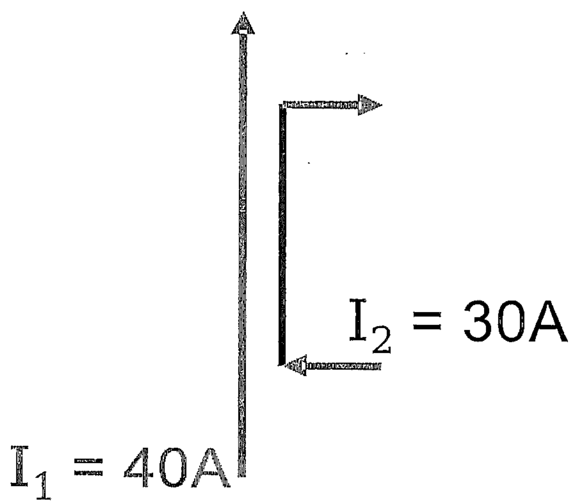


solenoid





Magnetic Force between wires



2) Wire2 is 0.8 m long and carries a current of 30 A in the upward direction. It is parallel to, and 1 cm away from wire1. What is the magnitude and direction of the force on wire2?

3) What is the magnitude and direction of the force on wire 1?

Force on current I in B-field

- To determine the direction of the force on a wire immersed in a magnetic B-field:

  1)Extend fingers so they point in the direction of **I**

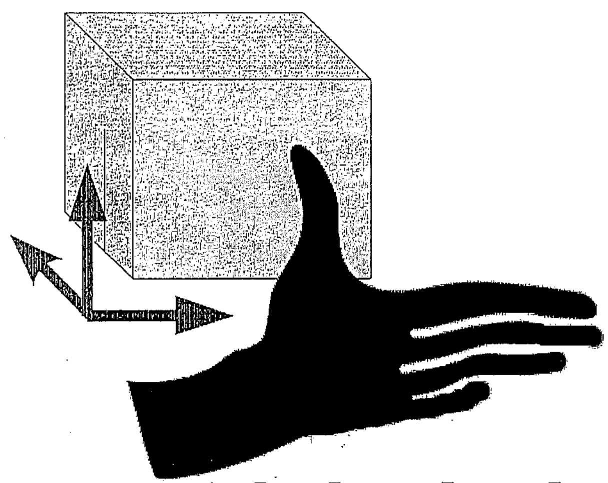
  2)Rotate hand until palm faces in the direction of **B**

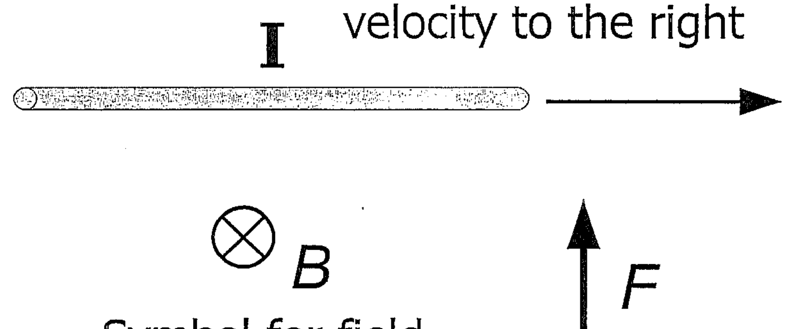
  - Fingers can bend from I to B

  3)Then the thumb shows the direction of **F**

"I Believe in the Force"

Current I or positive charge moving with velocity to the right





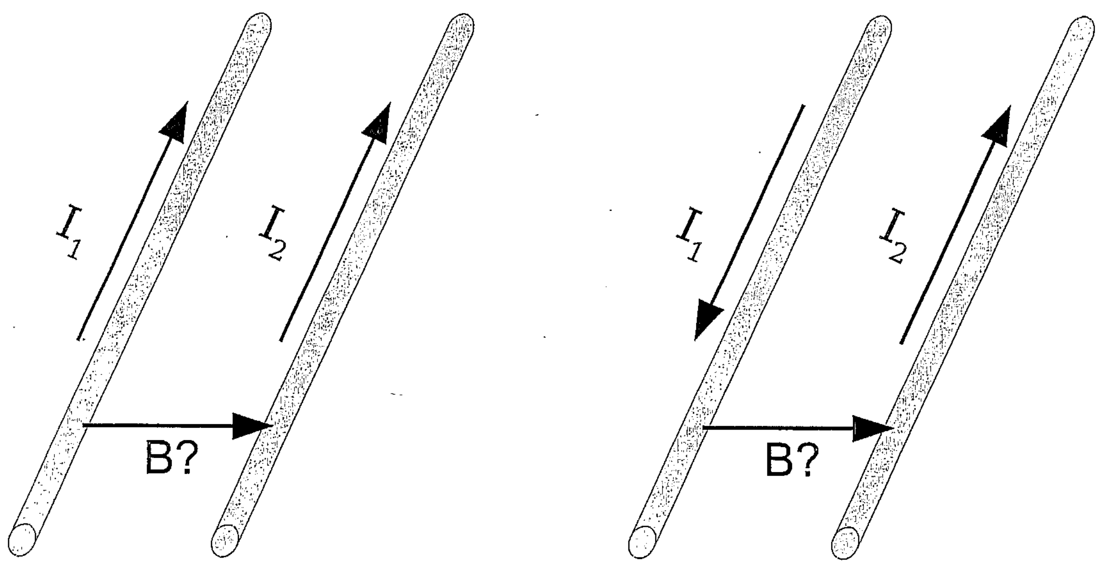
Symbol for field into the board

Right-hand Rule for I, B, and F

The Magnetic field B

- Unlike the electric field, the B field cannot point directly from one wire to the other
  - If it did, and we flipped the current in wire #1, how would wire #2 know that wire #1 had the current flipped?

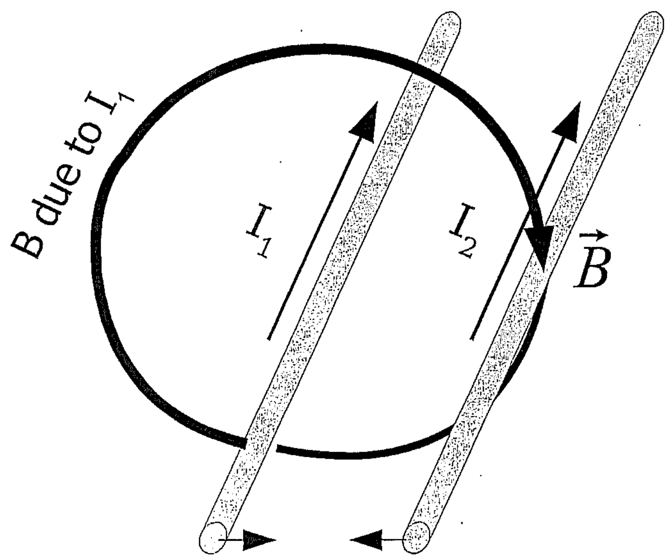
Can B point radially out from wire #1?



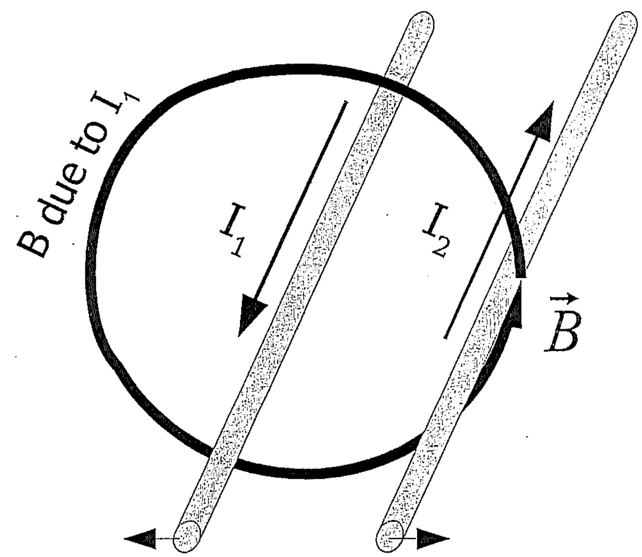
Wires attract **No** **Wires repel**

Magnetic field B is a circle centered around wire

- "Right-hand thumb" rule gives the direction of the magnetic field for a wire
  - Point right thumb in direction of current #1. Then fingers show the direction of the B-field due to current #1



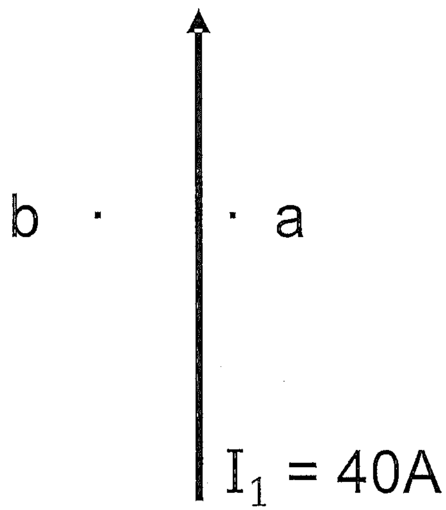
Wires attract:
B points down at wire #2,
Force on #2 is to the left



Wires repel:
B points up at wire #2
Force on #2 is to the right

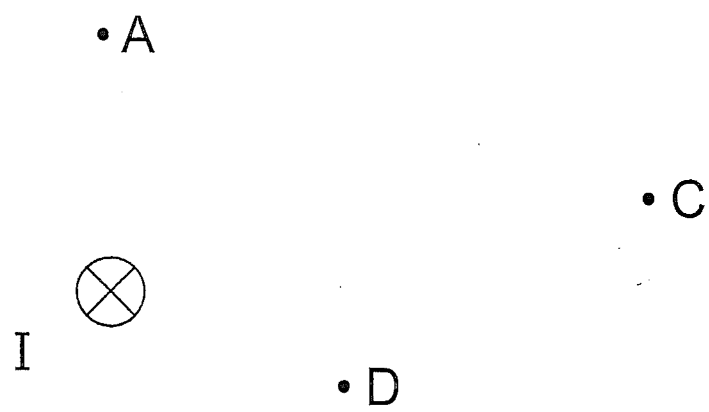
Next: Another rule to make the force f perpendicular to B

Magnetic Field size and direction around a wire



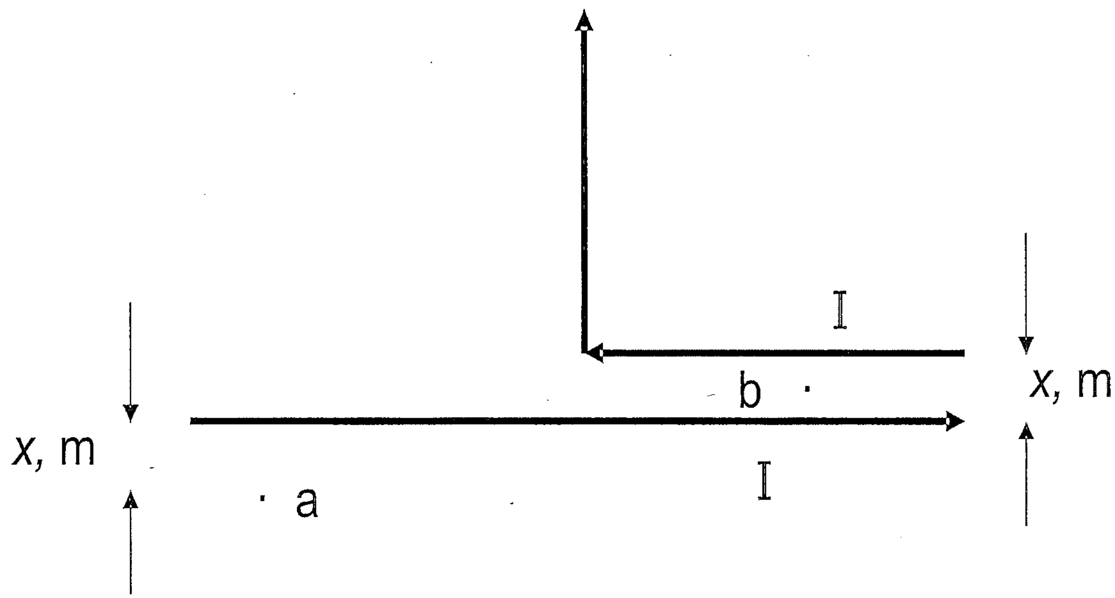
1) Wire1 is 1.7 m long and carries a current of 40 A in the upward direction. Draw the magnetic field and find it's value and direction at point a) 1 cm from the wire; and at point b) 3 cm from the wire?

B-field around a wire



Question: A current I points into the page as shown. Draw arrows to indicate the direction and magnitude of the B-field at points **A**, **C**, and **D**.

B-field around two wires



Two wires are carrying identical currents in the configuration shown. They are parallel and a distance x meters apart at the right side of the figure. The wires separate and the lower wire continues by itself on the left side of the figure. Point **b** is halfway between the two currents.

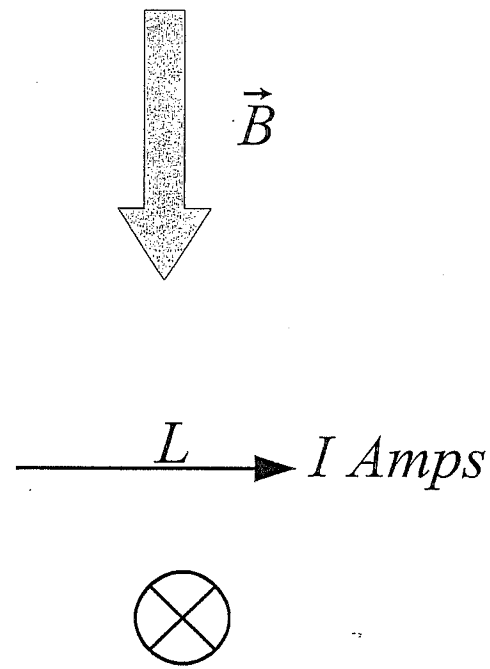
Question: If the B-field at **a** is 0.01T, what is the B-field at **b**? What are the directions of the two B-fields?

Magnitude of B-Force on Current

- The force on the wire is at right angles both to the magnetic field and to the wire
- The unit of Magnetic Field B is the tesla, T

1 T = 1 Newton per Amp-Meter

- Important details
  - Need to factor in the length of wire
  - (+) current flow, or charged particle
  - F is ⊥ to both I and B.
    - If I and B are in the same direction, F = 0



$$\vec{F} = \vec{L}\, I \times \vec{B}$$

M74

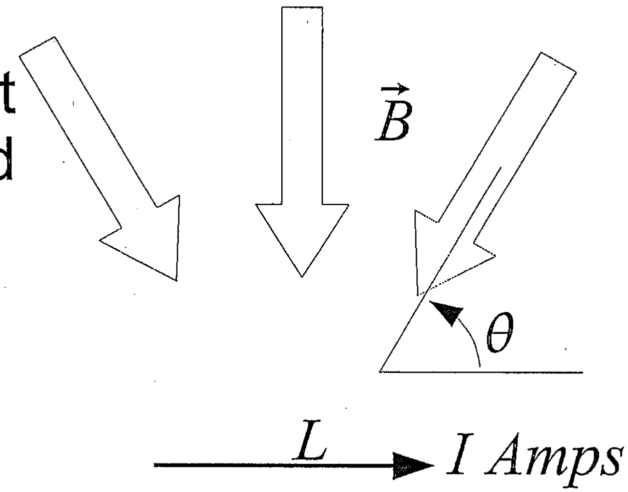
Magnetic force is maximum when current is perpendicular to B-field

Magnetic force problems

- Current through wire
  - A current of 10 ampere is carried by a wire perpendicular to a 1.38 T field (a very strong permanent magnet). The magnet is only 2 cm in diameter, so the part of the wire in the magnetic field is only 2 cm. What is the force on the wire?
  - Sketch the configuration and draw an arrow to indicate the direction of the force.
  - A current of 10 amperes is carried by a wire that is parallel to a 1.38 T field. What is the force on the wire
- Earth's magnetic field is 5.5 x 10^(-5) T. Earth's field is perpendicular to a powerline that is 100 m in length and carries a 700 Ampere current. What is the force on the powerline?

B-Field at an angle to Current

- The force on the wire is still at right angles both to the magnetic field and to the wire
- Sin θ factors into the force



Same direction ⊗

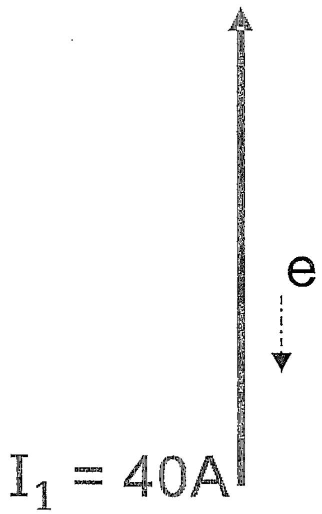
$$F = L\, I\, B \sin\theta$$

M76

Fingers should move from current direction to B-field direction

B-field → Force on a moving charge

$$F = B\,I\,L = B\frac{q}{t}L = B\,q\frac{L}{t} = B\,q\,v$$



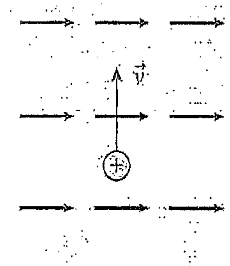
4) An electron is moving downward at a speed of 3 x 10^5 m/s. It is 1 cm away from, and parallel to wire1. (Wire1 is still carrying 40 A.) What is the magnitude and direction of the force on the electron?

Use e = 1.6 x 10^{-19} C

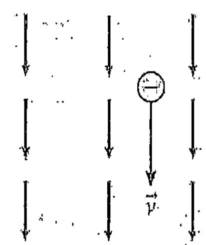
32.7 The Magnetic Force on a Moving Charge

27. For each of the following, draw the magnetic force vector on the charge or, if appropriate, write "$\vec{F}$ into page," "$\vec{F}$ out of page," or "$\vec{F} = \vec{0}$."

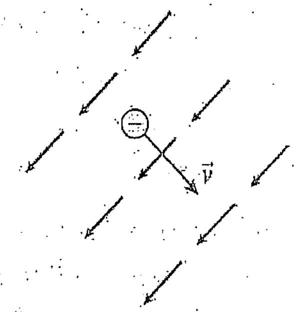
a.



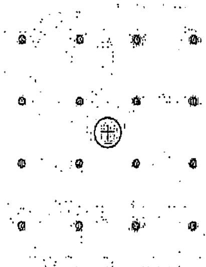
b.



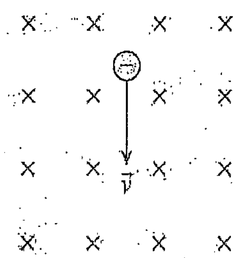
c.



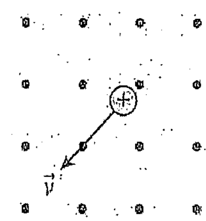
d.



e.



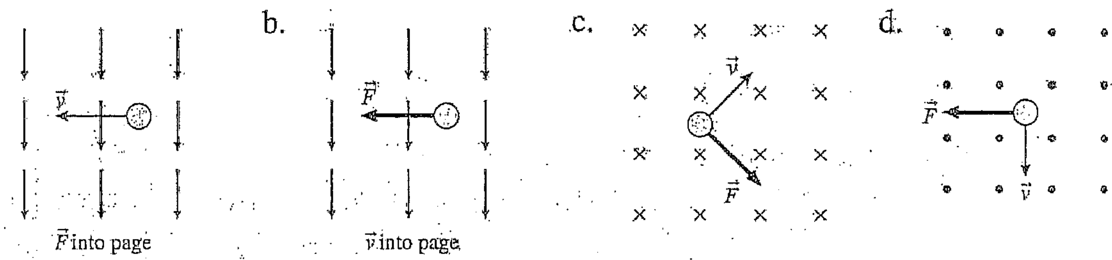
f.



Magnetic force on a moving charge

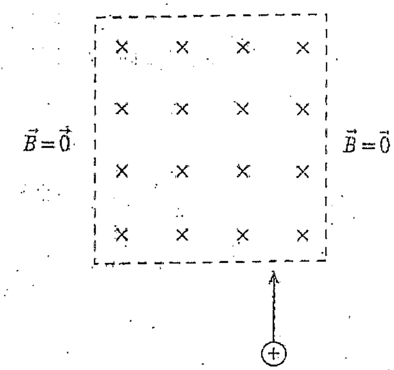
28. For each of the following, determine the sign of the charge (+ or –).

a. b. c. d.

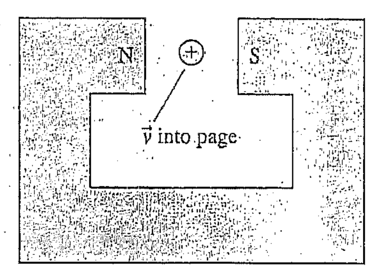


$q =$ ____ $q =$ ____ $q =$ ____ $q =$ ____

29. The magnetic field is constant magnitude inside the dotted lines and zero outside. Sketch and label the trajectory of the charge for
   a. A very weak field.
   b. A moderate field.
   c. A strong field.



30. A positive ion, initially traveling into the page, is shot through the gap in a magnet. Is the ion deflected up, down, left, or right? Explain.

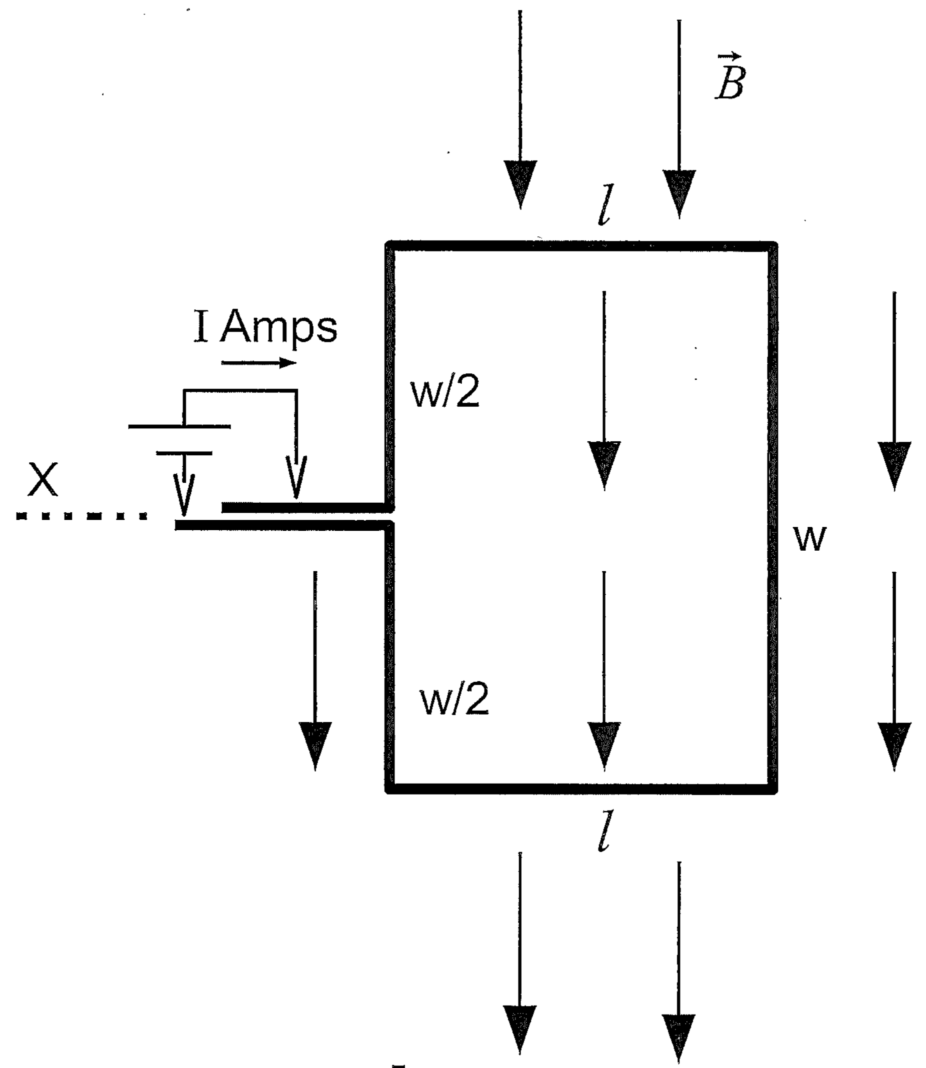


Torque on a current loop at 90° angle

- Loop upright, B-field is vertical and uniform

- Find the force on each of the four sides of the loop due to the field B

- Use the forces and the corresponding lever arms (w/2) to find the torque around the axis, X

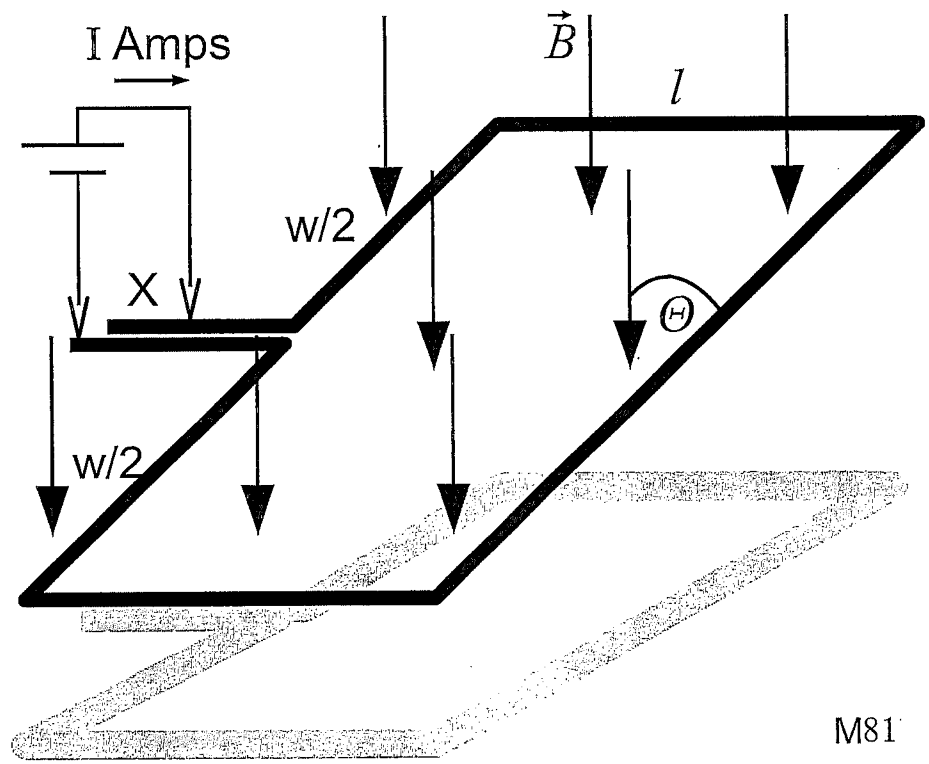


M80

Magr tic force causes a torque o a current loop

Torque on a current loop at angle θ

- Loop at angle θ to B-field
- Find the force on each of the four sides of the loop due to the field B
- Use the forces and the corresponding lever arms to find the torque around the axis, X

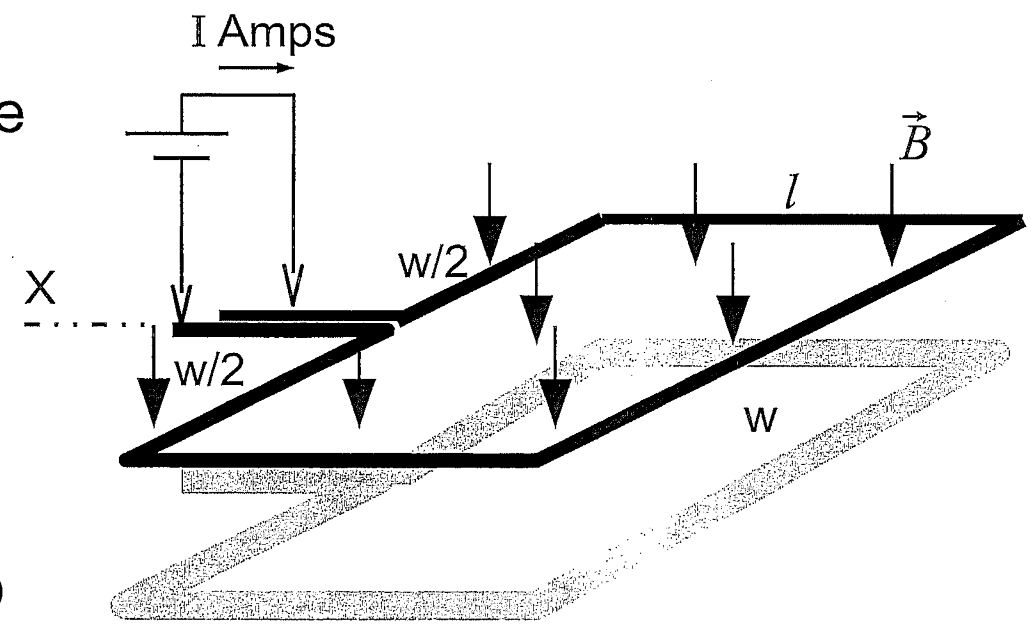


M81

Torque is proportional to cos Θ because lever arm is smaller

Torque on a flat current loop

- Loop lying flat, perpendicular to vertical B-field
- Find the force on each of the four sides of a rectangular current loop of dimensions as shown due to the field B
- Use the forces and the corresponding lever arms to show the torque around X is zero



M82

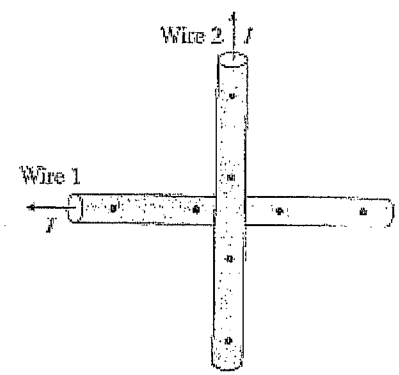
For a flat current loop, B just pushes the wires outward - no torque

Torques on current loops

15

32-12 CHAPTER 32 · The Magnetic Field

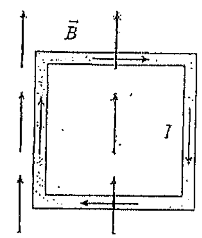
39. Two current-carrying wires cross at right angles.
    a. Draw magnetic force vectors on the wires at the points indicated with dots.
    b. If the wires aren't restrained, how will they behave?



40. A current loop is placed between two bar magnets. Does the loop move to the right, move to the left, rotate clockwise, rotate counterclockwise, some combination of these, or none of these? Explain.

Forces on current loops

41. A square current loop is placed in a magnetic field as shown.



a. Does the loop undergo a displacement? If so, is it up, down, left, or right? If not, why not?

b. Does the loop rotate? If so, which edge rotates out of the page and which edge into the page? If not, why not?

42. The south pole of a bar magnet is brought toward the current loop. Does the bar magnet attract the loop, repel the loop, or have no effect on the loop? Explain.