PHYSICS 1B – Fall 2009

Electricity
&
Magnetism

Professor Brian Keating

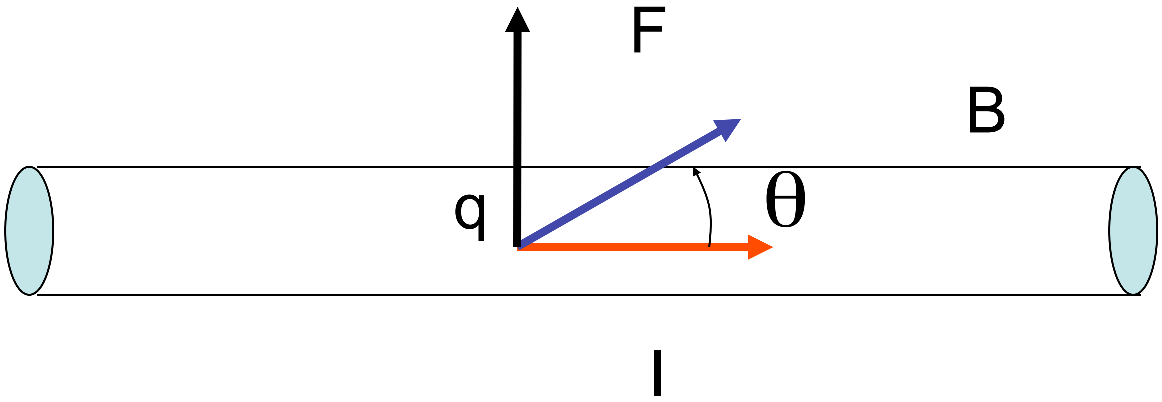
SERF Building. Room 333

UCSD

UCSD

Chapter 19.4 Force on a Current Carrying Wire

For angle θ between L and B



$$F = BIL\sin\theta$$

B parallel to direction of wire, θ=0, F=0

B perpendicular to direction of wire θ=90°, F= BIL

Forces on a loop of current in a uniform B field

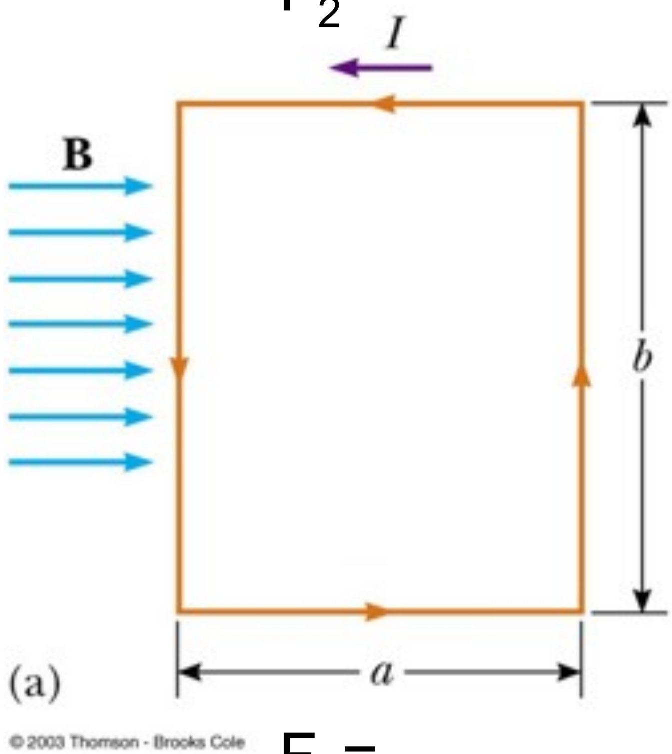
B field is uniform and in the plane of the current loop

Find the forces acting on the wires in the loop.
(a and b are the lengths)

$F_2=$

$F_1=$

$F_3=$



$F_4=$

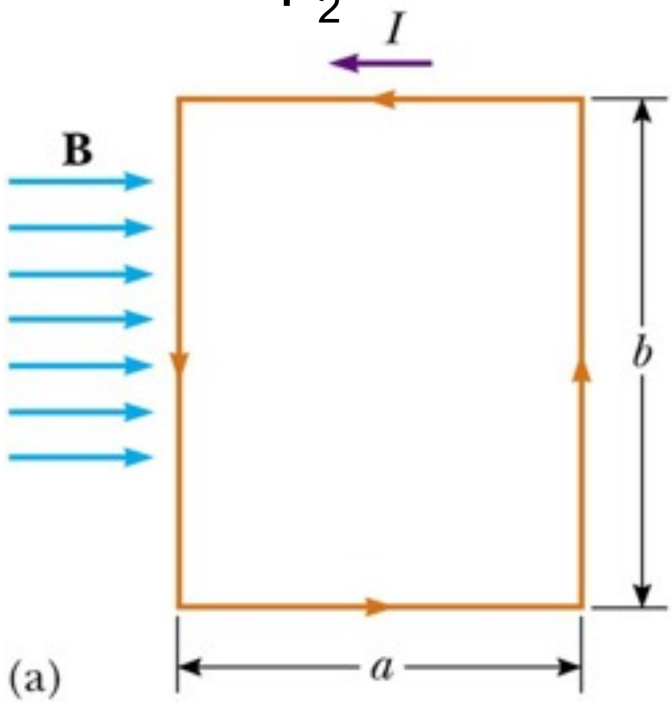
Forces on a loop of current in a uniform B field

B field is uniform and in the plane of the current loop

Find the forces acting on the wires in the loop.
(a and b are the lengths)

$F_2 =$

$F_1 = BIb$



$F_3 =$

$F_4 =$

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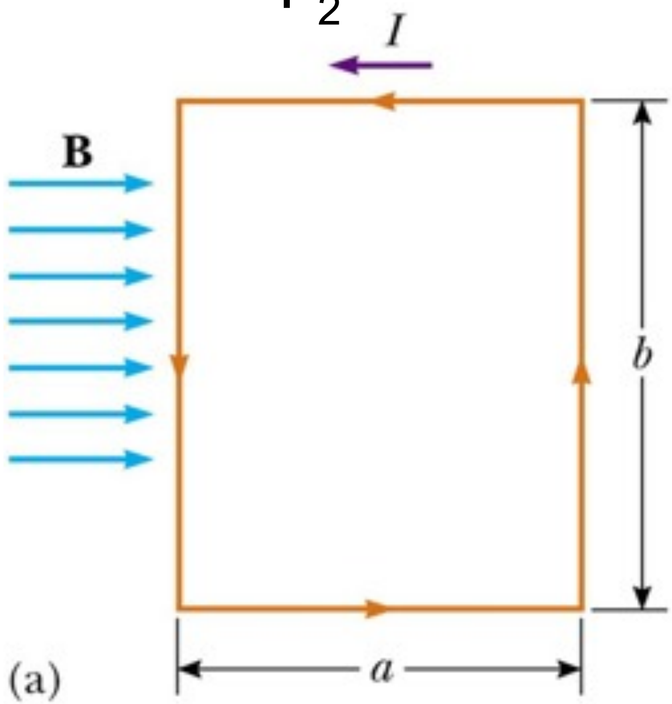

$F_1 = BIb$

out of page

$F_3 =$

$F_4 =$

Forces on a loop of current in a uniform B field

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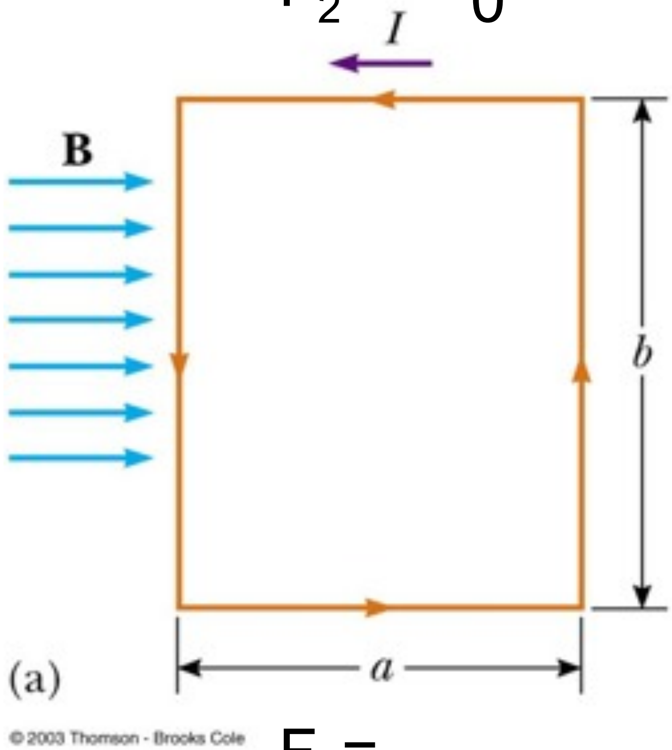
Find the forces acting on the wires in the loop.
(a and b are the lengths)

$F_2 =$ 0

$F_1 =$ BIb

out of page



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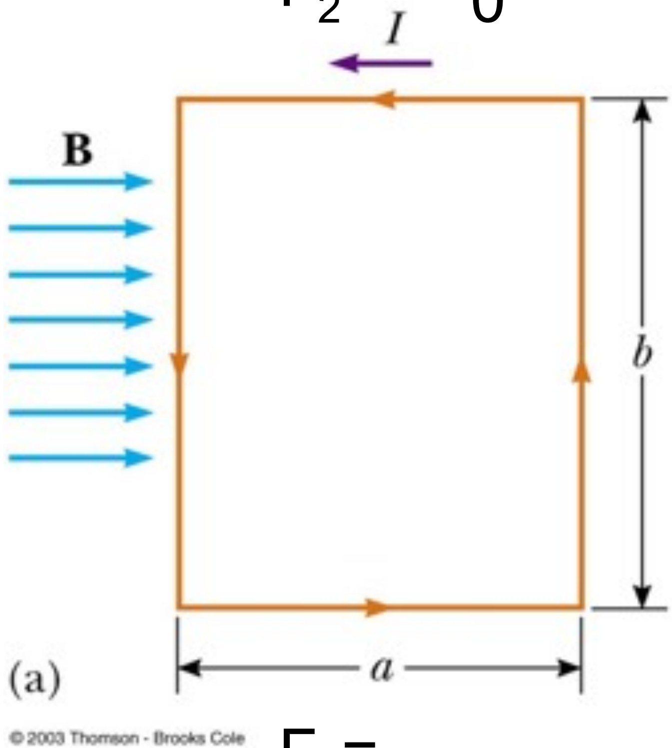

$F_1 =$ BIb

out of page

$F_3 =$ BIb

$F_4 =$

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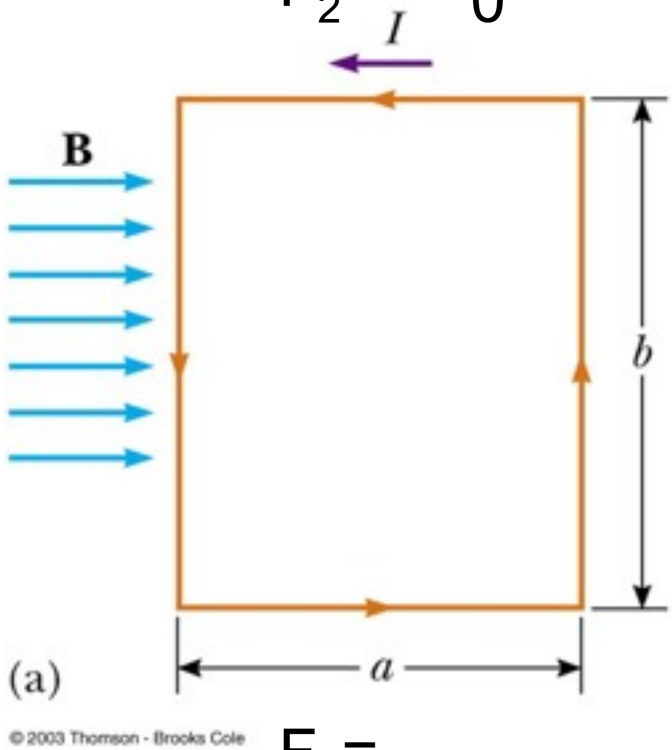

$F_1 =$ BIb

out of page

$F_3 =$ BIb

into page

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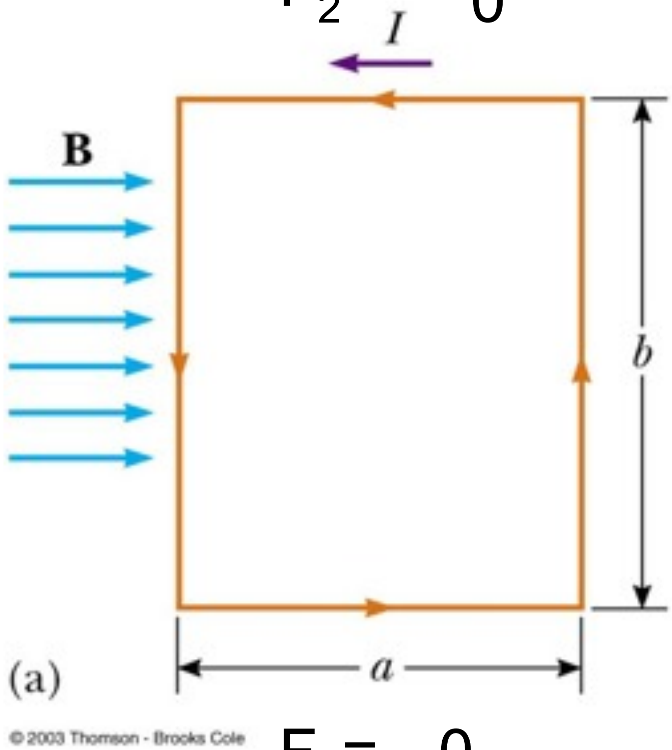


$F_1 =$ BIb

out of page

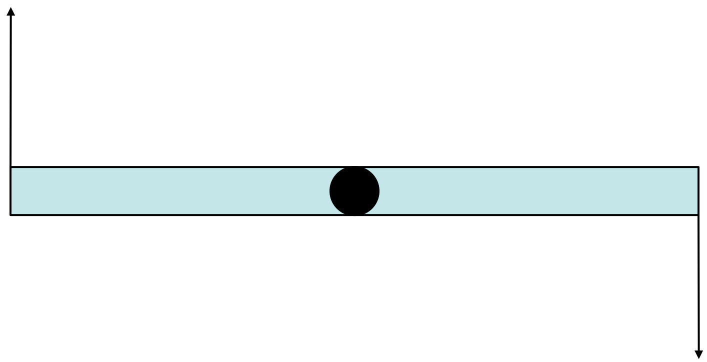
$F_3 =$ BIb

into page

$F_4 =$ 0

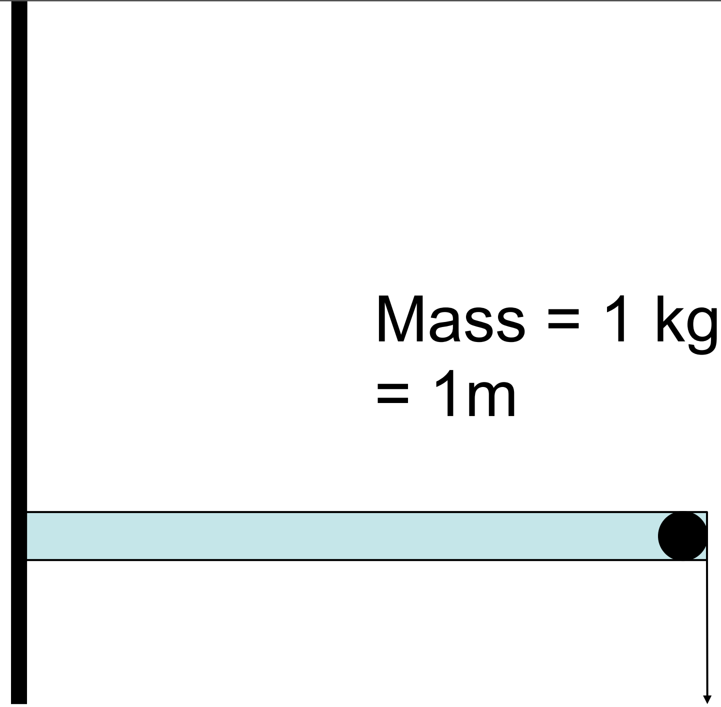
Ch 19.5 Torque on Current

First, a review of Torque



Torque= Force x perpendicular distance

$$\tau = Fd$$



Torque= Force x perpendicular distance $\tau = Fd$

What's the torque of the ball at the end of the lever?

A. 1 kg

B. 9.8 kg

C. 1 N-m

Last Quiz and Final Exam

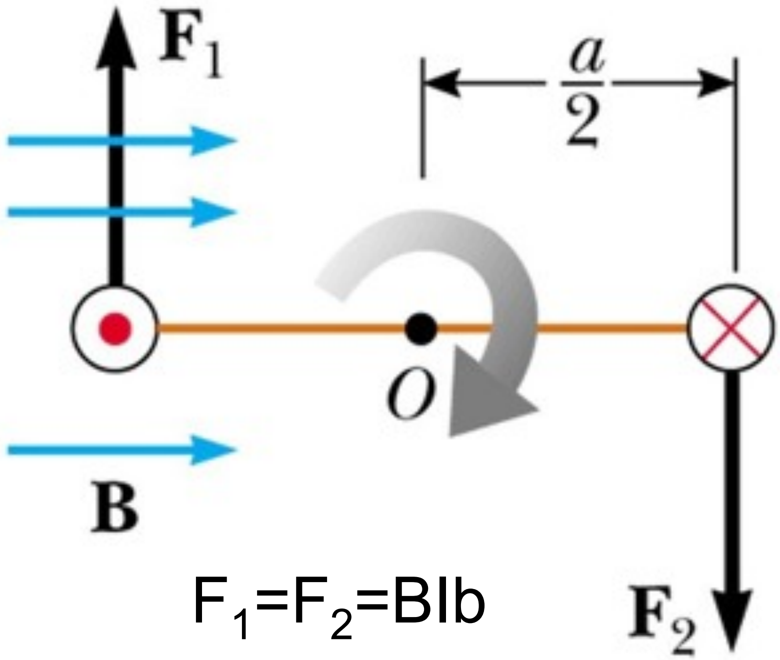
- Last quiz is ***this Friday*** in class.

- The Final Exam for Physics 1B will be on the Monday of Finals week,

  Monday December 7, 2009 from 11:30am to 2:30pm in York 2622

The current loop in a B field generates a torque around the center proportional to the area of the loop

Side view

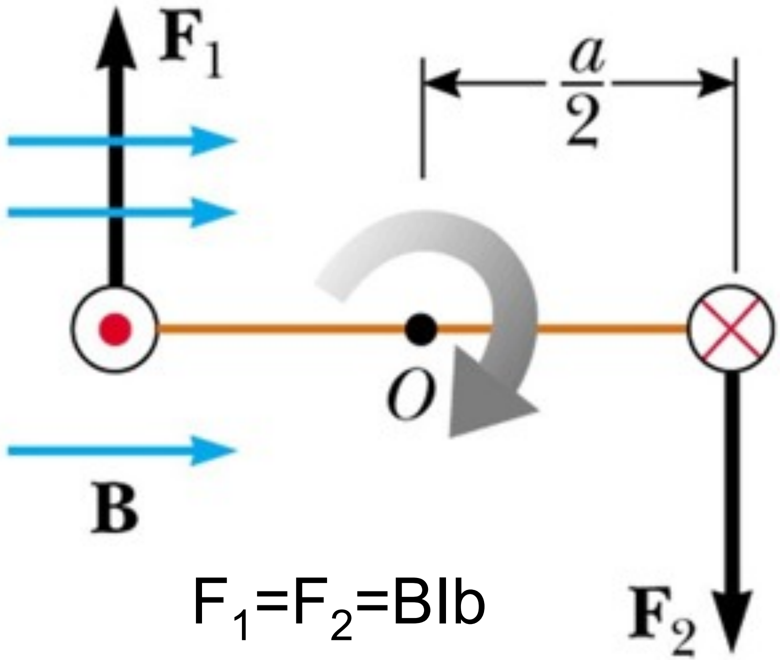


$F_1 = F_2 = BIb$

(b)

The current loop in a B field generates a torque around the center proportional to the area of the loop

Side view



(b)

$F_1=F_2=BIb$

The two forces generate a torque around the center

$$\hat{o}=F_1\left(\frac{a}{2}\right)+F_2\left(\frac{a}{2}\right)$$

$$\hat{o}=BIba$$

$$\tau = BIA$$

A=axb=area of loop

counterclockwise

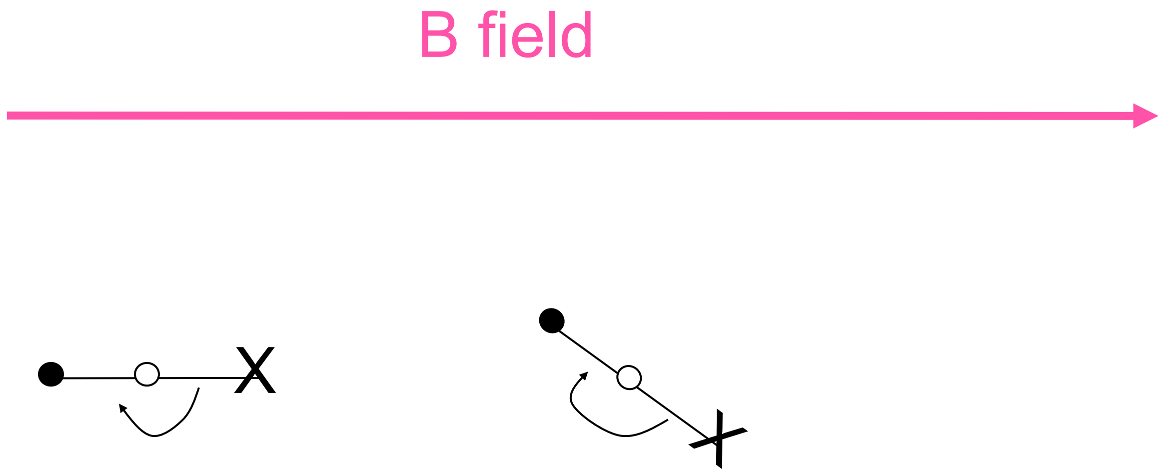
Same loop as before…current flowing
counter clockwise as viewed from above.

Which picture below has largest torque?

A. B. C.

Same loop as before…current flowing
counter clockwise as viewed from above.

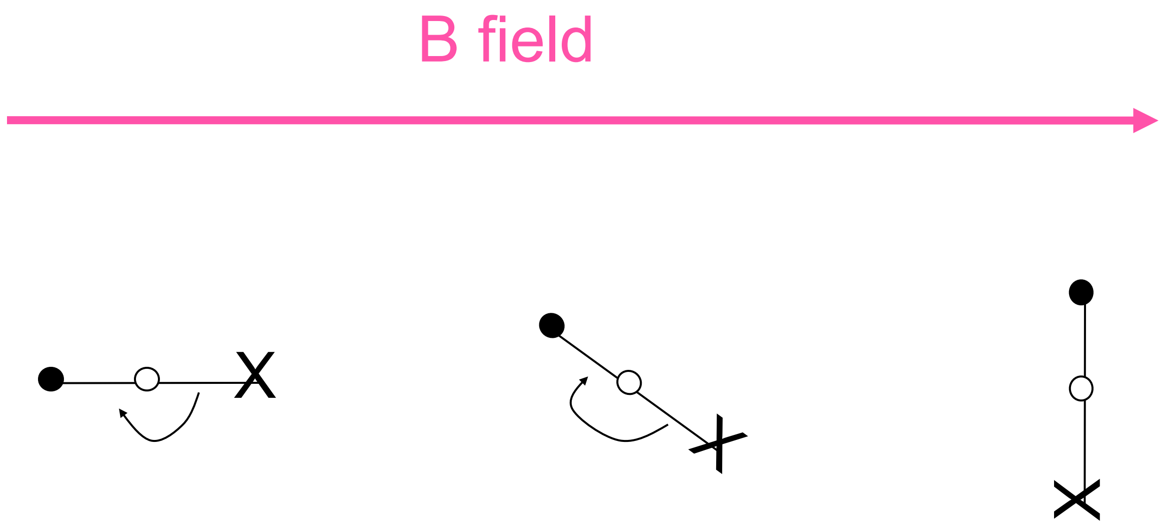
Which picture below has largest torque?



A. B. C.

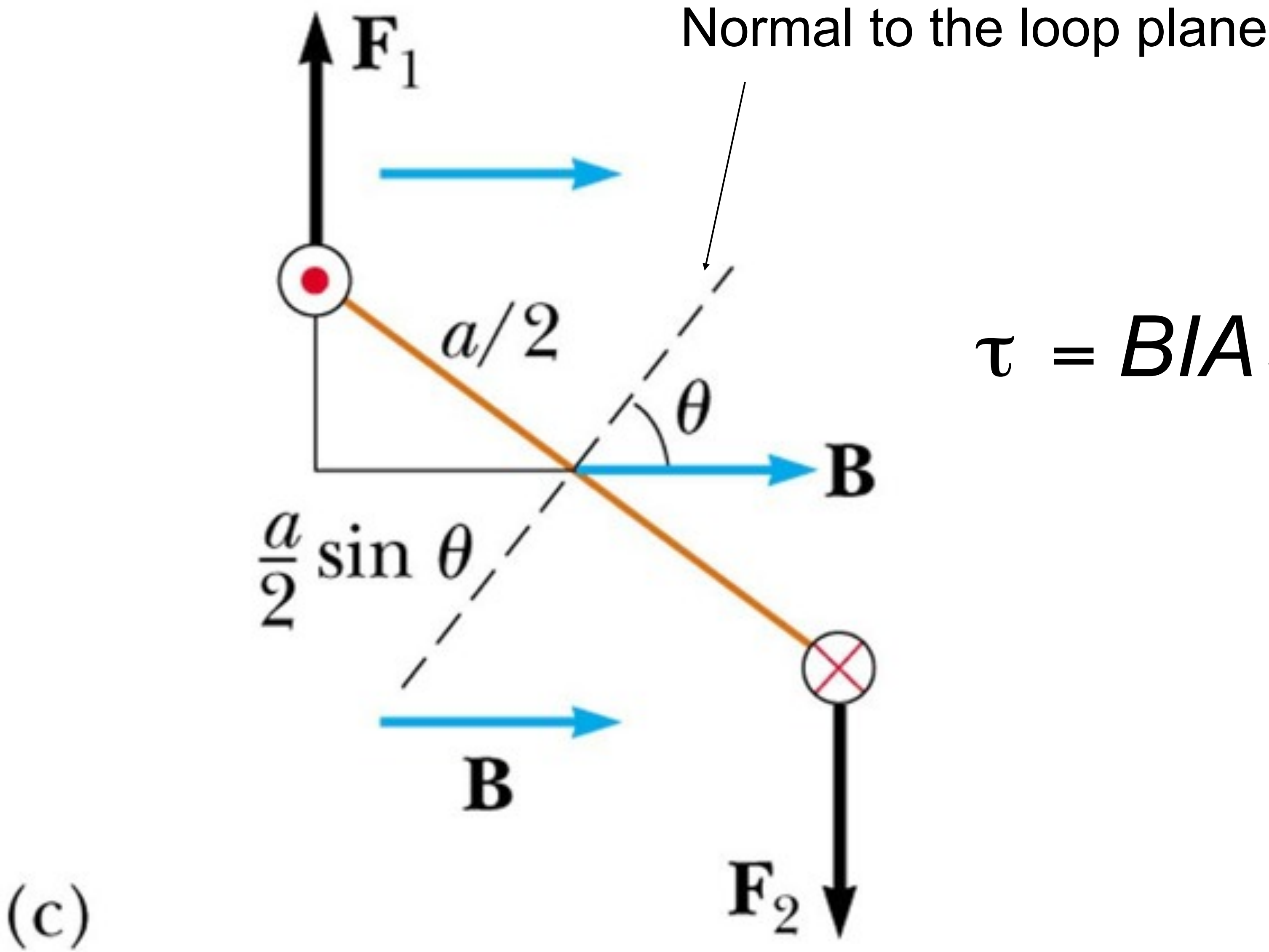
Same loop as before…current flowing
counter clockwise as viewed from above.

Which picture below has largest torque?



A.   B.   C.

Loop makes an angle with B



$$\tau = BIA\sin\theta$$

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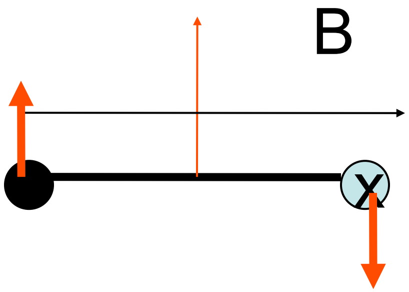

$\tau=$

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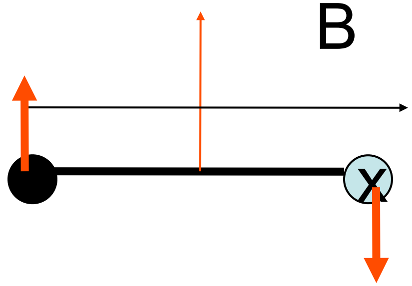

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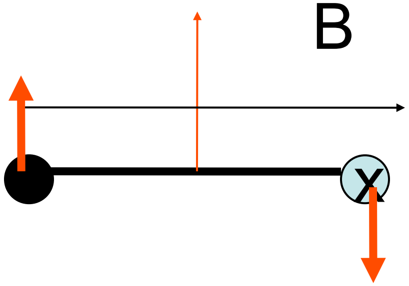

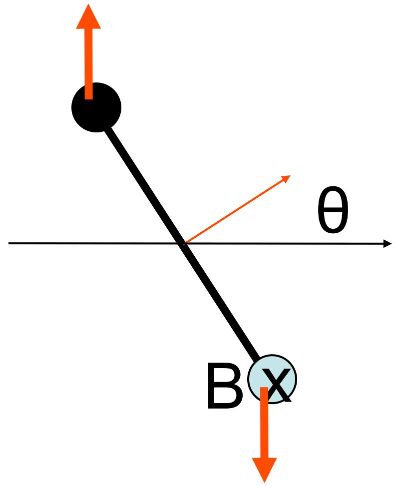

$\tau =$ BIA

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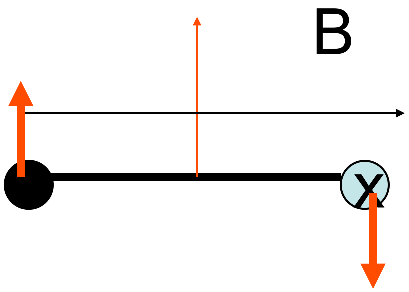
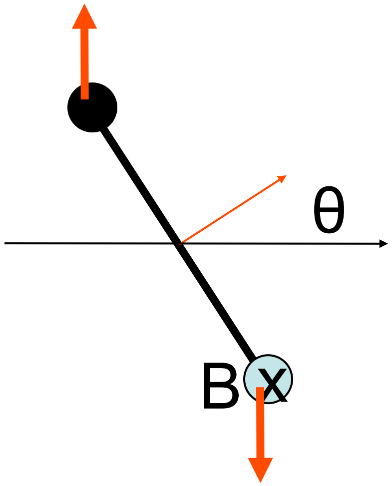
$$\tau = BIA\sin\theta$$

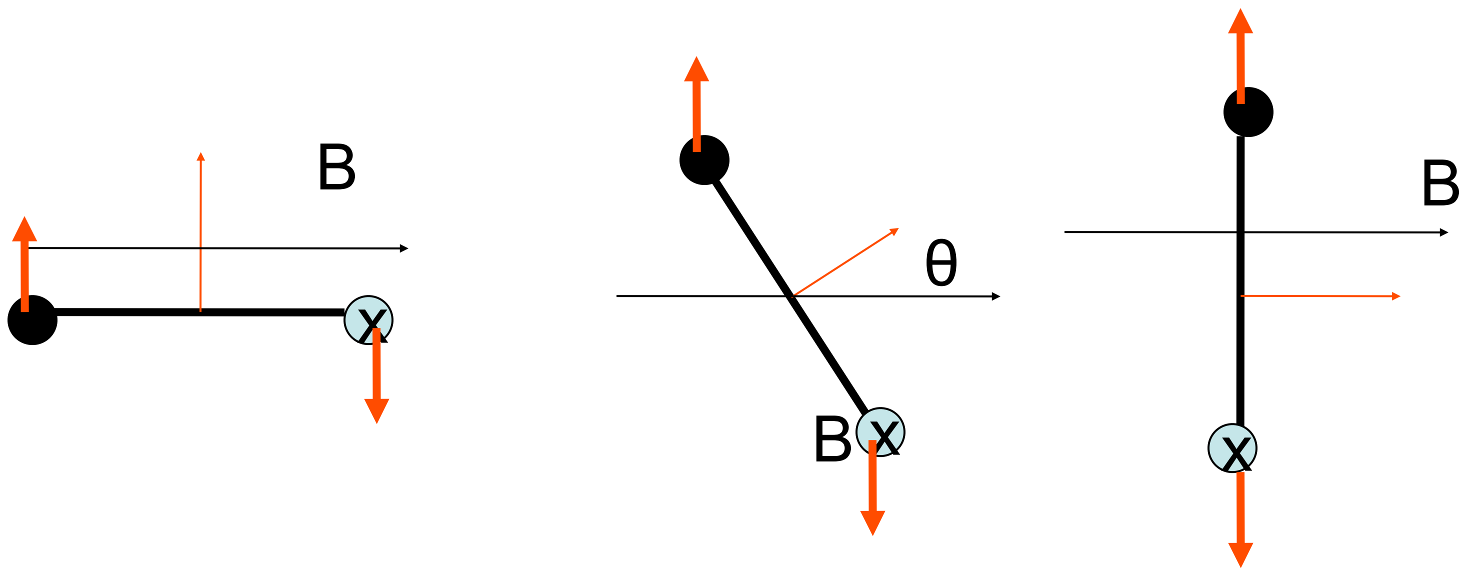




$\tau =$ BIA

$\tau =$ BIAsinθ

$$\tau = BIA\sin\theta$$

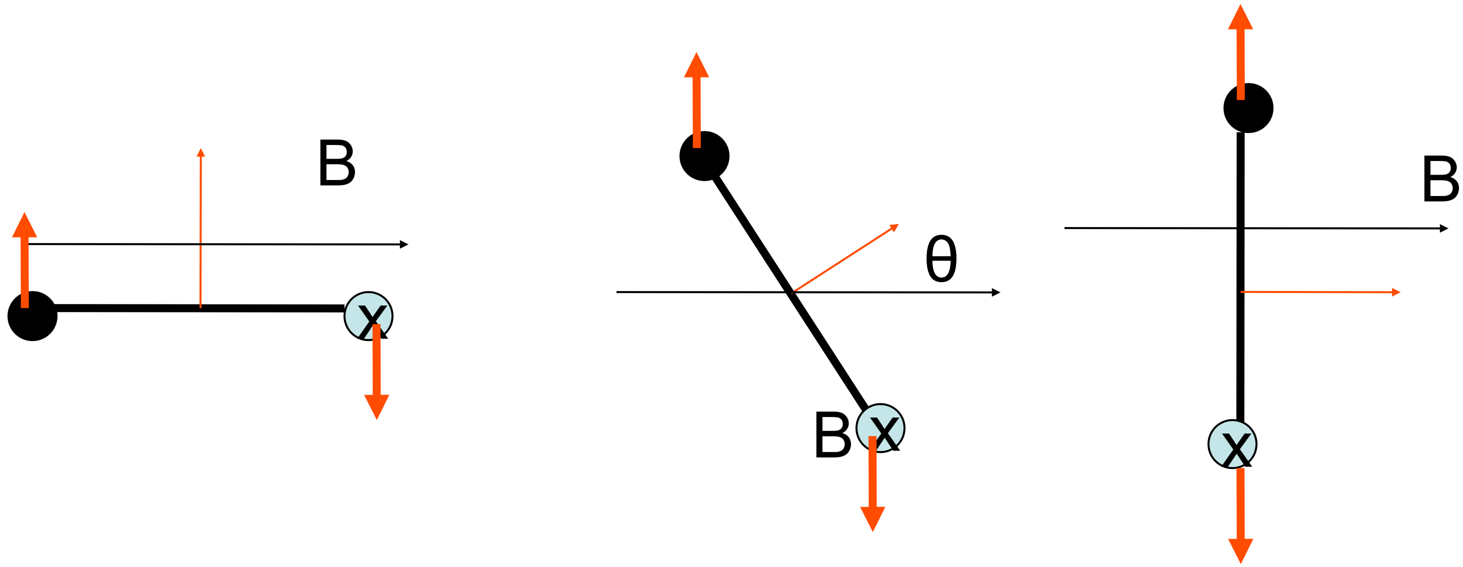


$\tau =$ BIA

$\tau =$ BIA$\sin\theta$

$\tau =$

$$\tau = BIA\sin\theta$$

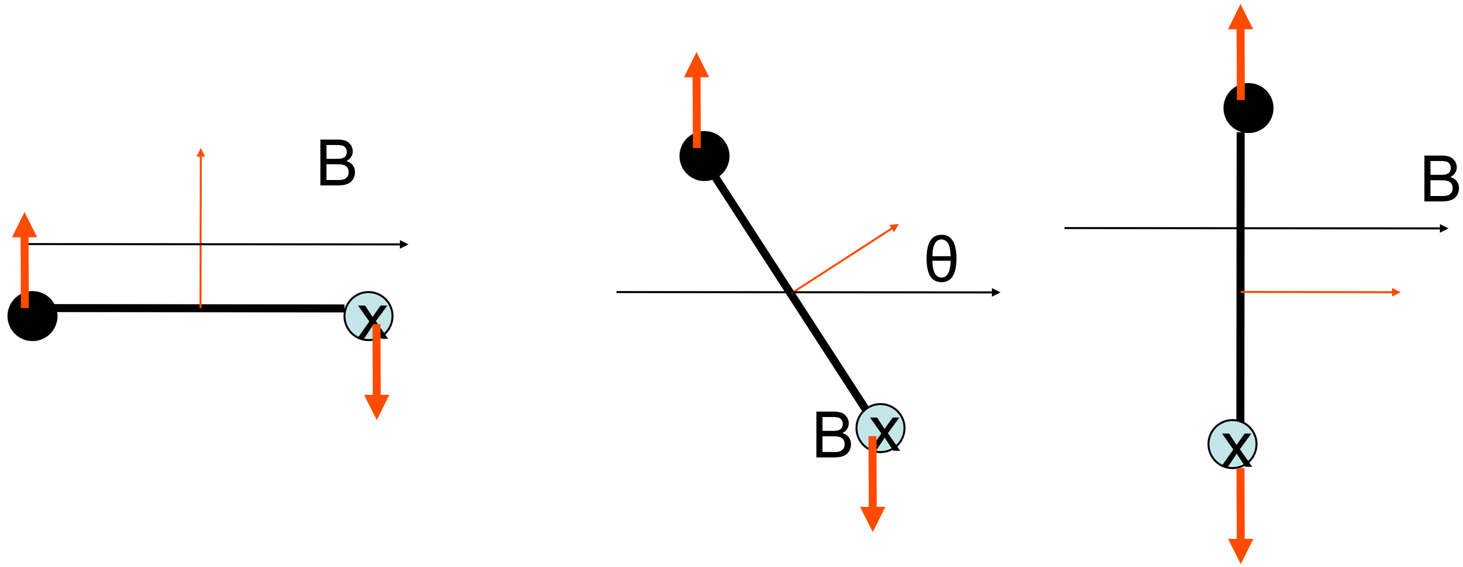


$\tau =$ BIA

$\tau =$ BIAsinθ

$\tau =$ 0

$$\tau = BIA\sin\theta$$



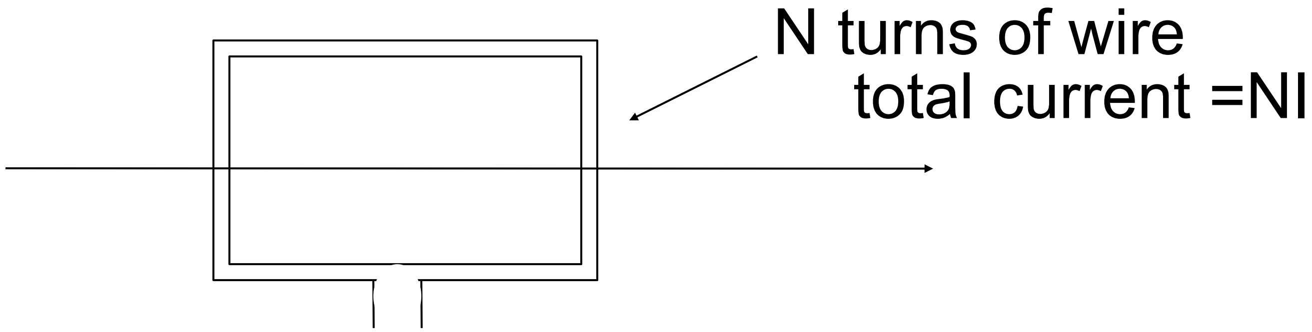
$\tau =$ BIA

$\tau =$ BIA$\sin\theta$

$\tau =$ 0

The torque tilts the loop so the normal is parallel to B

Loop with N turns of wire



$$\tau = NBIA\sin\theta$$

Torque increases with N, B, I and A

Torque is maximum when $\theta=90^o$, when the loop is parallel to the field

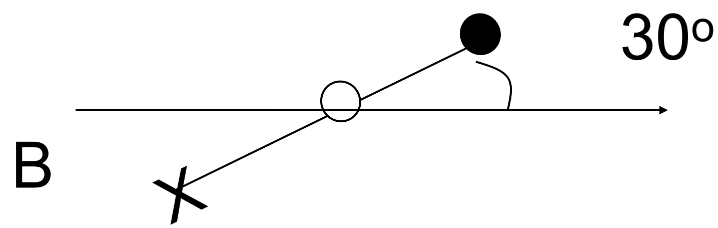
Torque is zero when $\theta=0$ when loop is perpendicular to the field

A 3A current wire-loop (with 100 turns) and an area of 0.2 m^2 makes an angle of 30^o with a magnetic field of 0.3T.

a) Find the torque exerted on the coil.

b) What is the direction of rotation?

c) What happens if the current is reversed in the coil?



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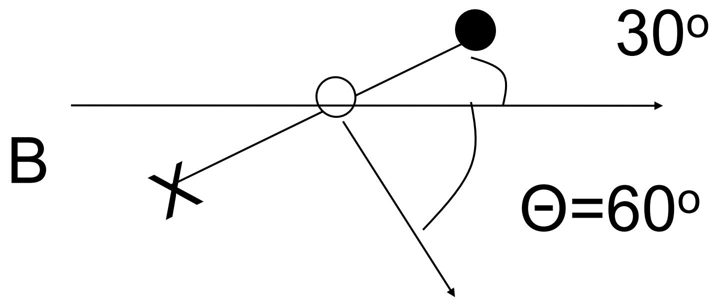

a) $$\tau = NBIA\sin\theta$$

$$= 100(0.3)(3.0)(0.2)\sin 60 = 1.6x10^1 Nm$$

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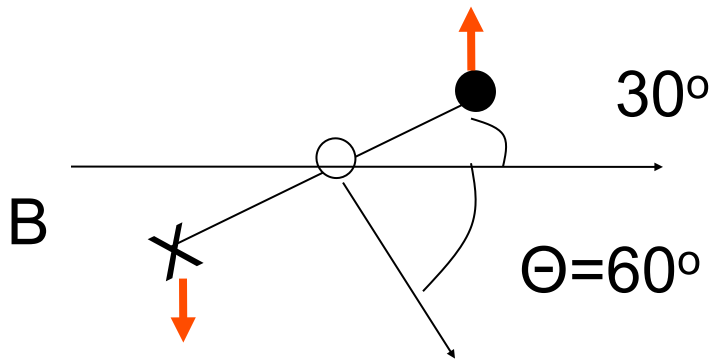

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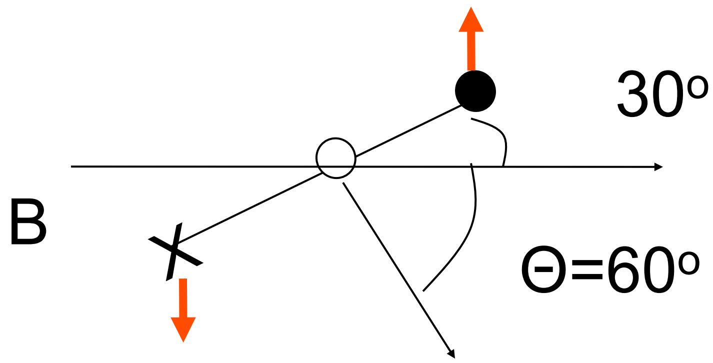

a) $$\tau = NBIA\sin\theta$$

$$= 100(0.3)(3.0)(0.2)\sin 60 = 1.6x10^1 Nm$$

b) counter clockwise direction

A 3A current wire-loop (with 100 turns) and an area of 0.2 m^2 makes an angle of 30^o with a magnetic field of 0.3T.

a) Find the torque exerted on the coil.

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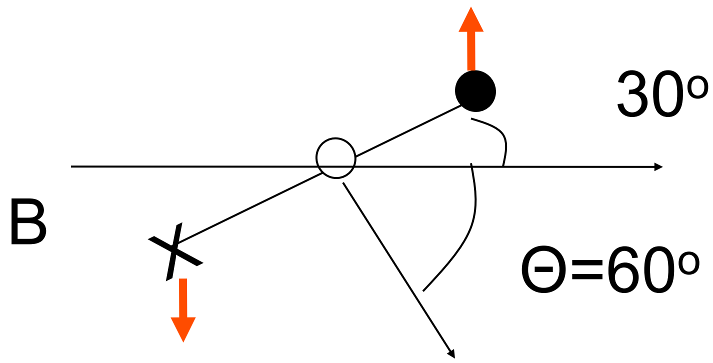


a) $$\tau = NBIA\sin\theta$$

$$= 100(0.3)(3.0)(0.2)\sin 60 = 1.6x10^{1} Nm$$

b) counter clockwise direction

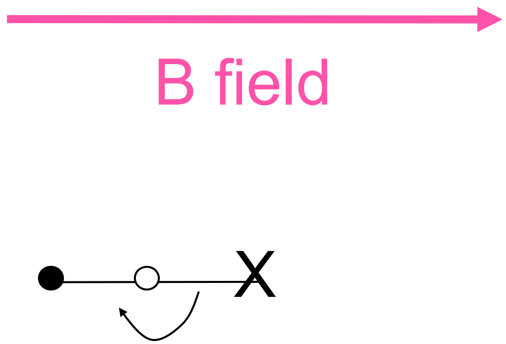
c) the torque will have the same magnitude but in the opposite (clockwise) direction,

Electric motors (not same as 'engines')

A current loop in a magnetic field produces a torque

Problem

A dc current does not produce complete rotation



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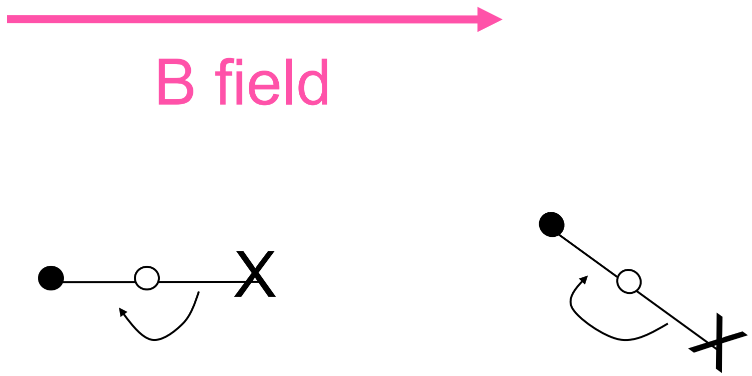

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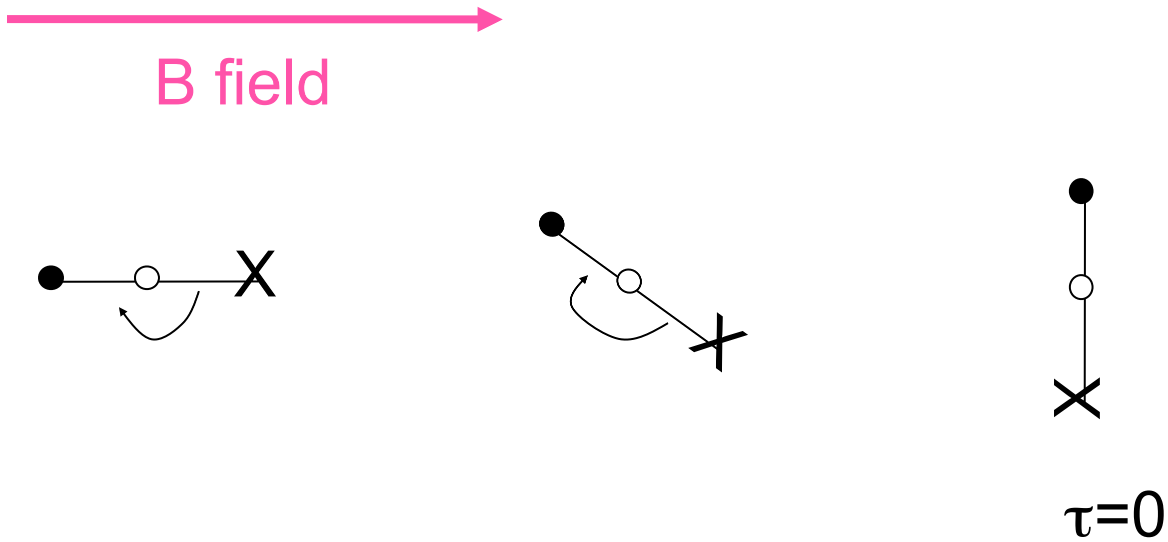

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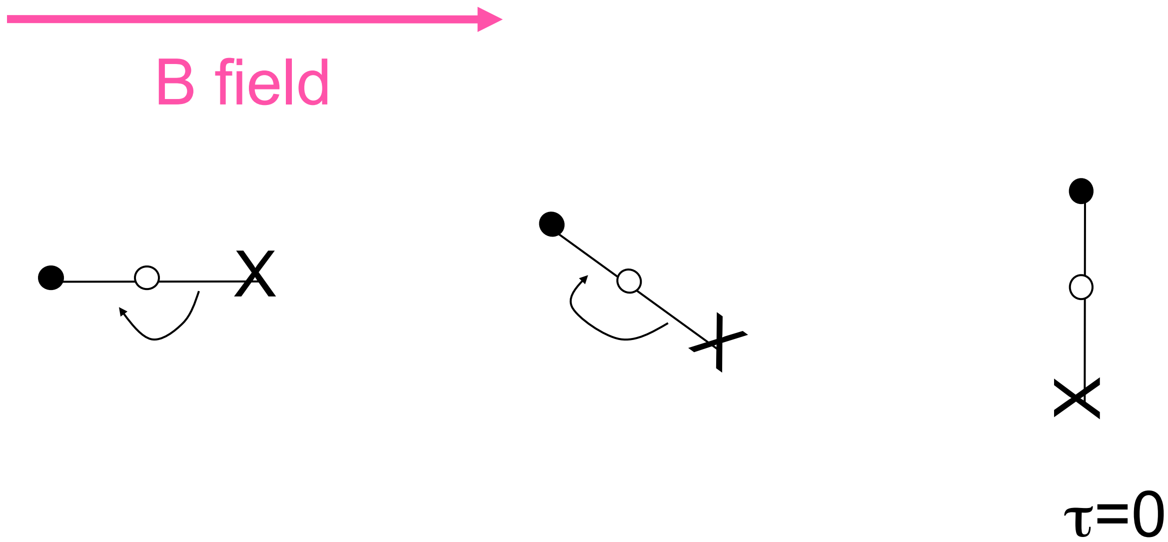
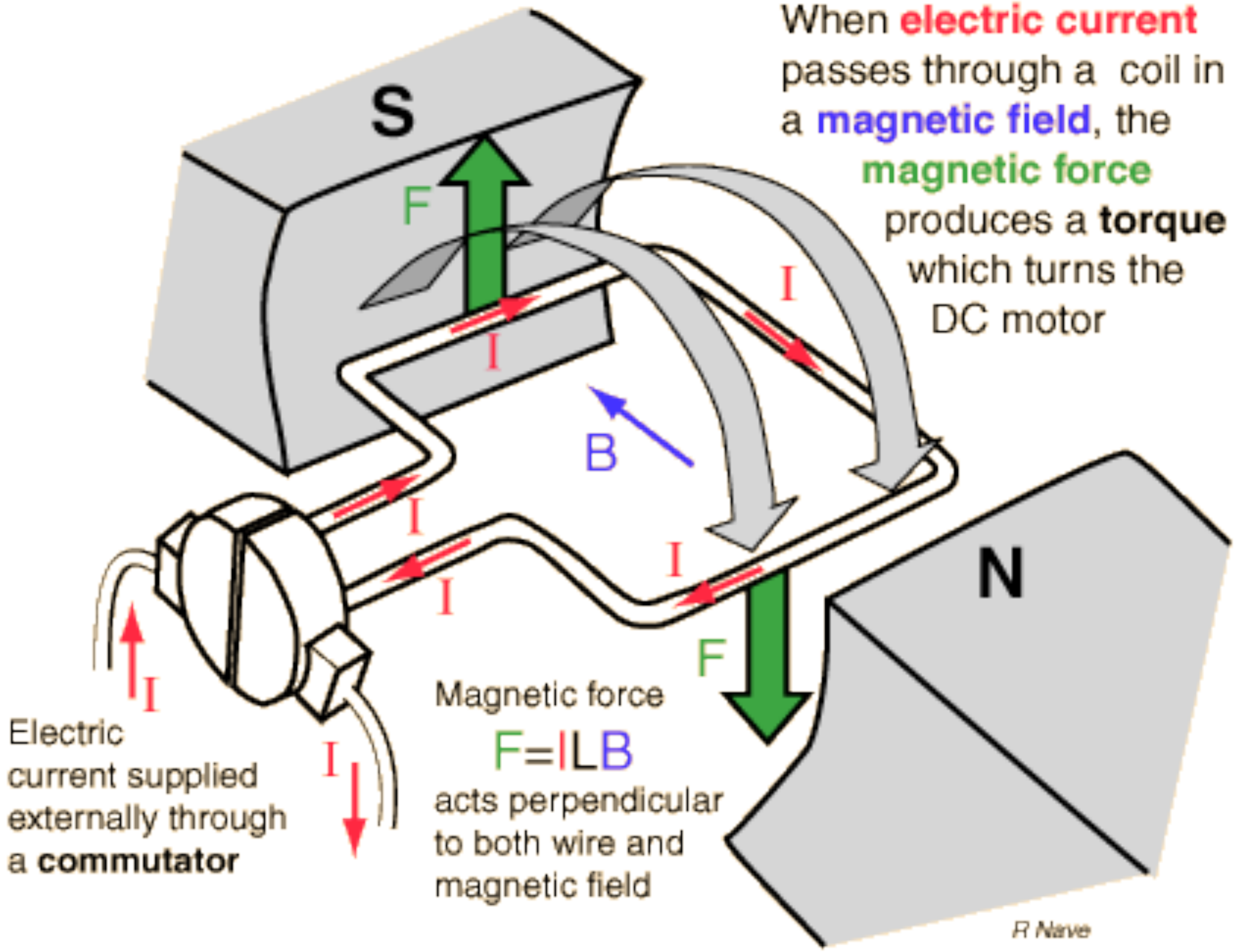
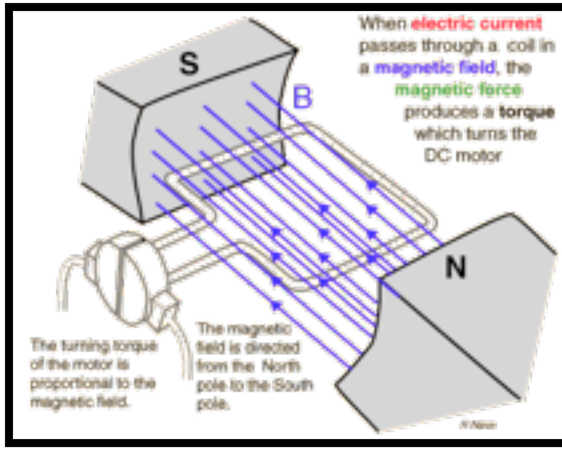


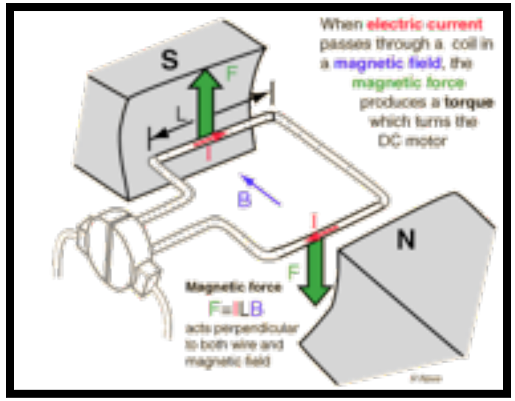
dc current only rotates coil until it is perpendicular to the field

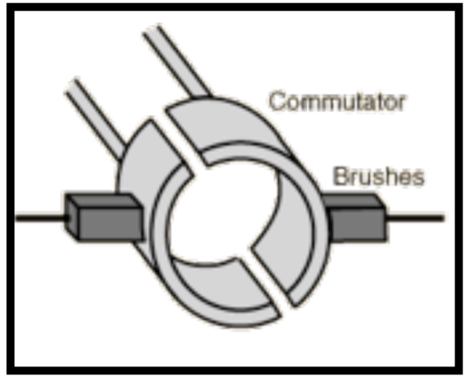
Solution with direct current source is to use a commutator.

Split-ring commutator reverses the current direction when $\tau=0$.









19.7 Magnetic field due to a current carrying wire

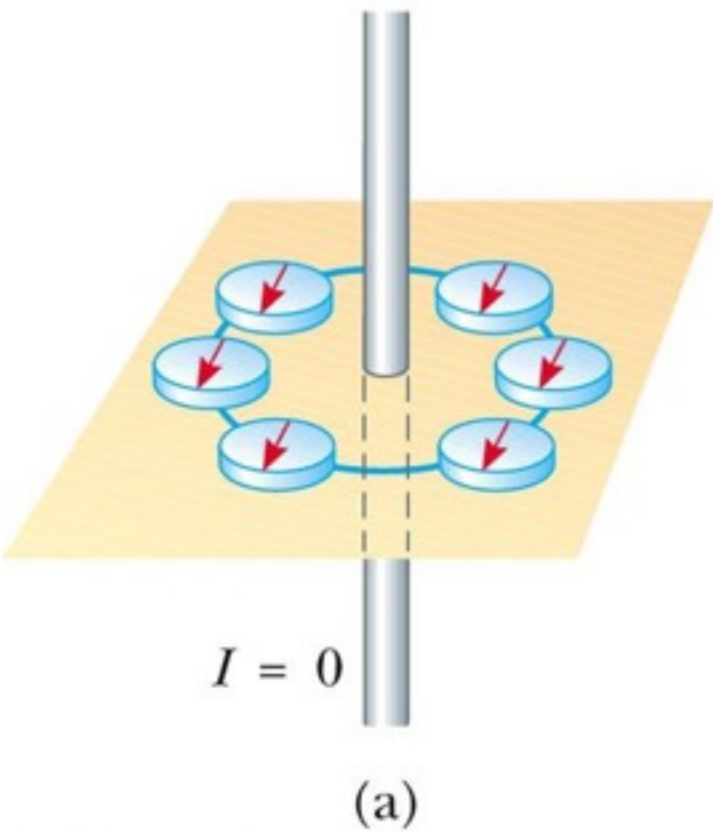
Magnetic field due to current

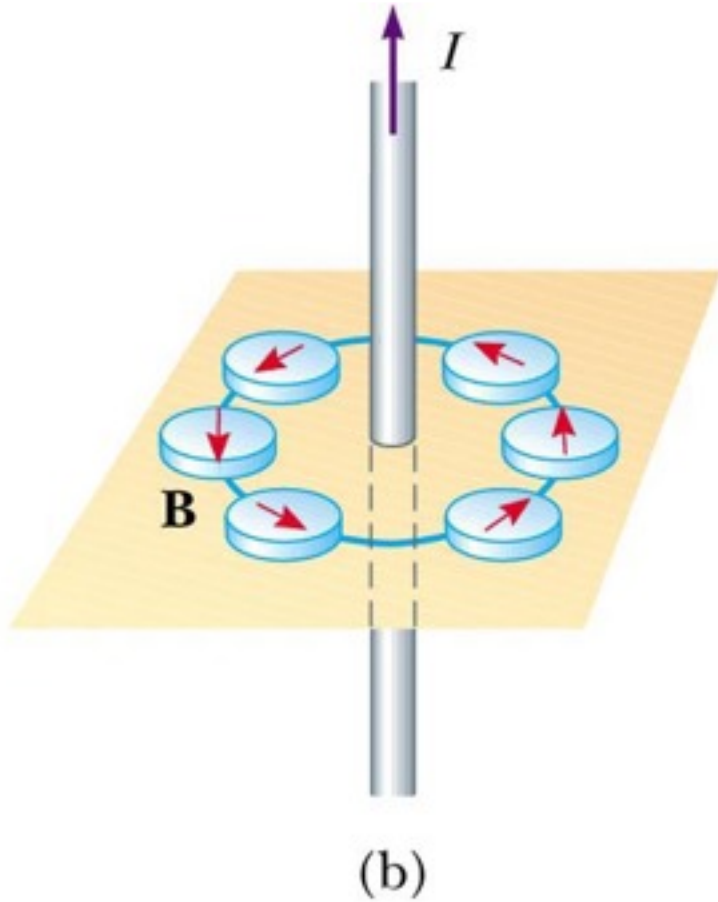
Ampere's Law

Force between current carrying wires

Magnetic fields are produced by an electric current

Hans Oersted 1820

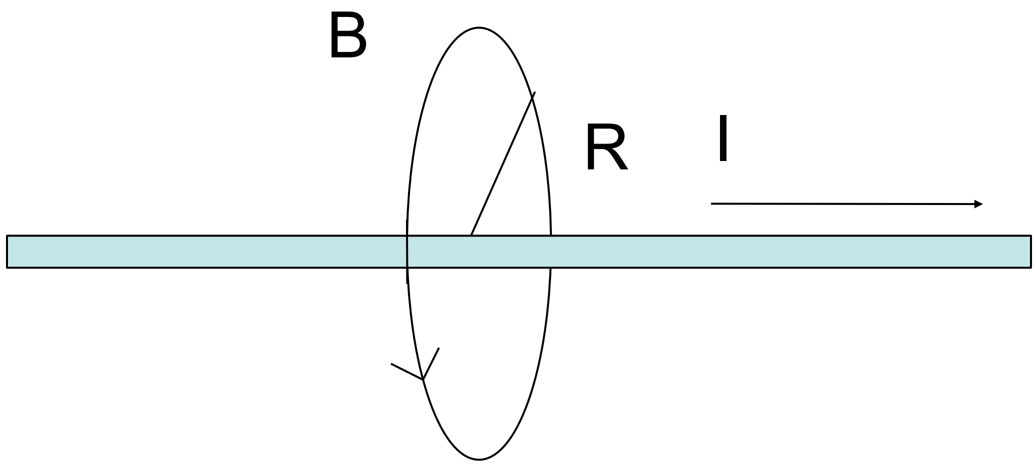




No Current

Current turned on

Magnetic field lines around a current in straight wire - circle with radius R

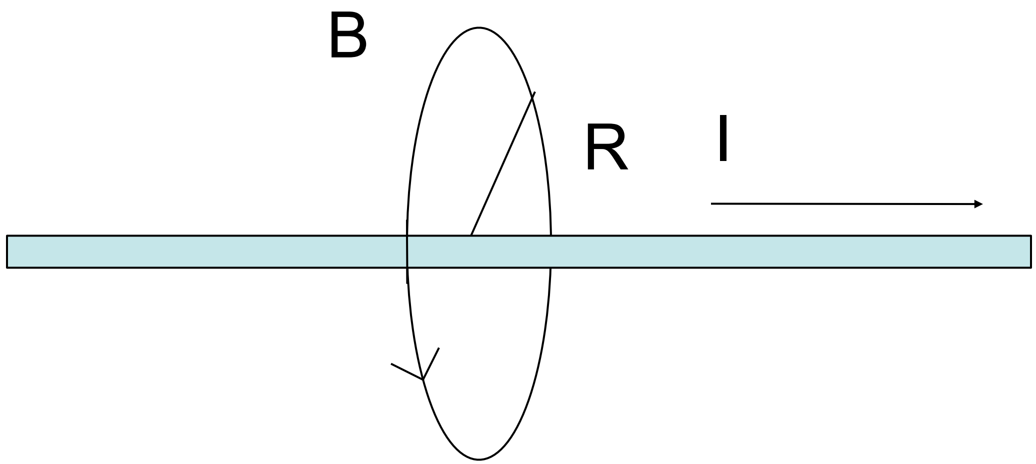


$$B = \frac{\mu_o I}{2\pi R}$$

B decreases with distance

μ_o = permeability of free space
$=4\pi x 10^{-7} T \cdot m/A$

Direction of the field- Right hand rule



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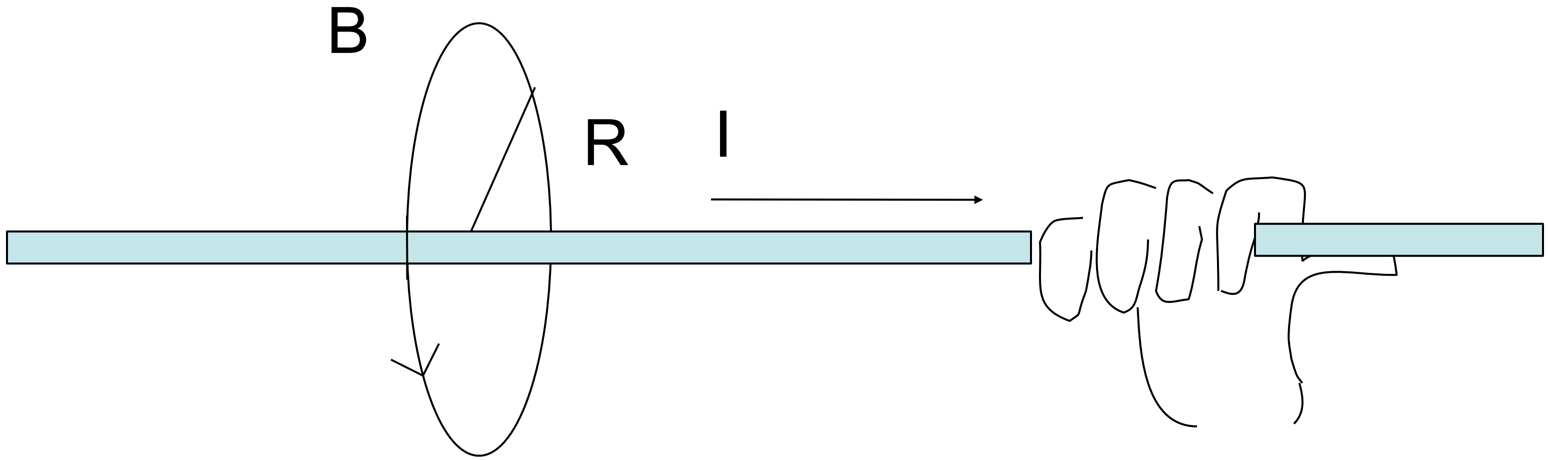


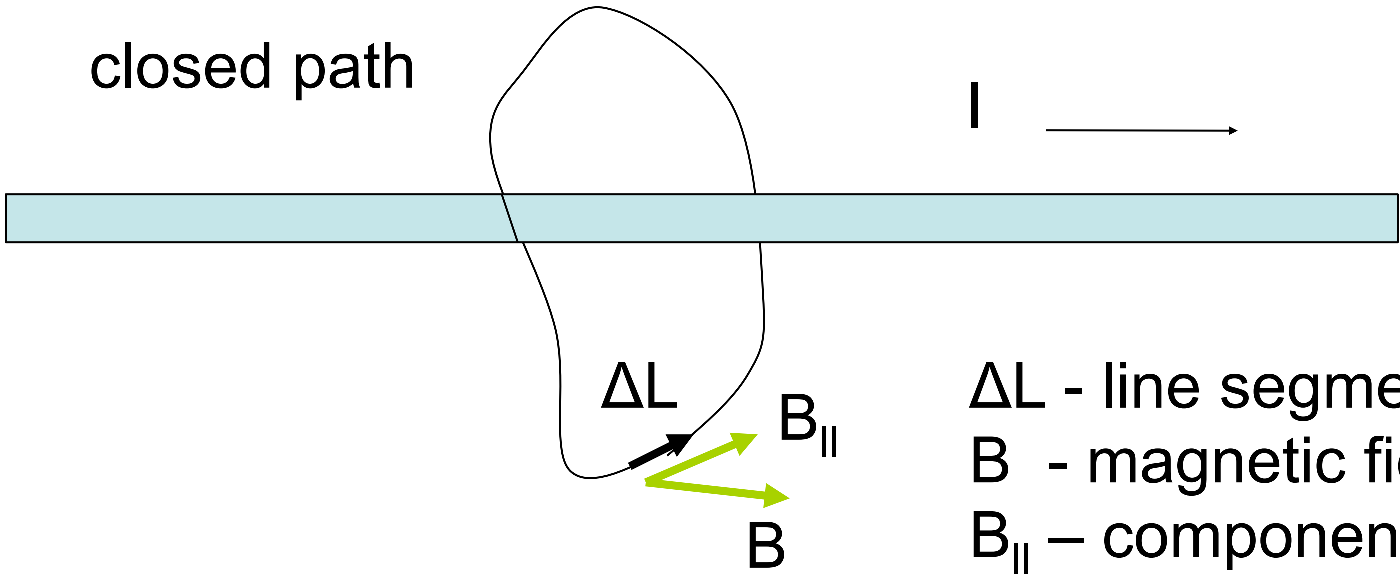
Thumb-along I

Fingers- around I point along B

Ampere's Law

Andre Marie Ampere (1775-1836)

General relation between current and magnetic field



ΔL - line segment

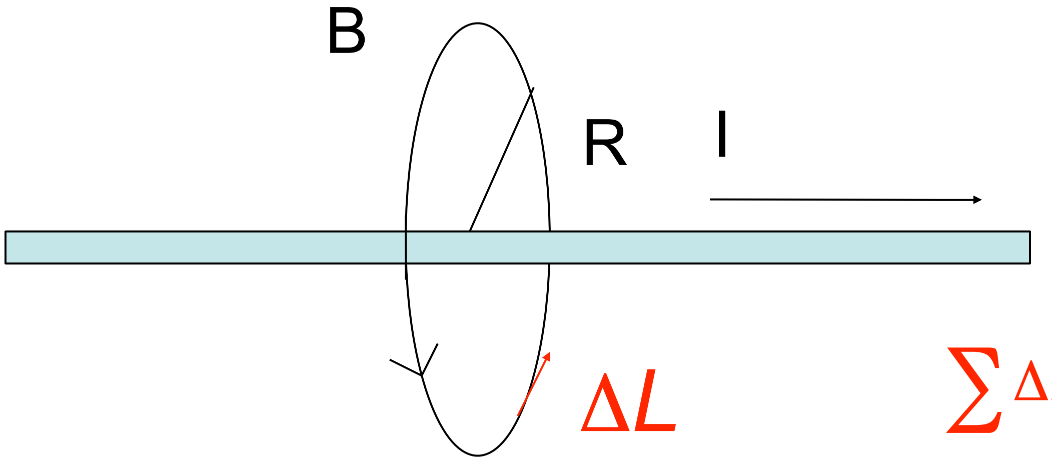
B - magnetic field

$B_{||}$ – component of B parallel to ΔL

$\sum B_{||}$ o

sum over all segments in the closed loop

The magnetic field around a straight wire calculated from Ampere's Law



$$\sum \Delta L = 2\pi R$$

The B field has a constant value at a constant radius R.
B and ΔL are in the same direction

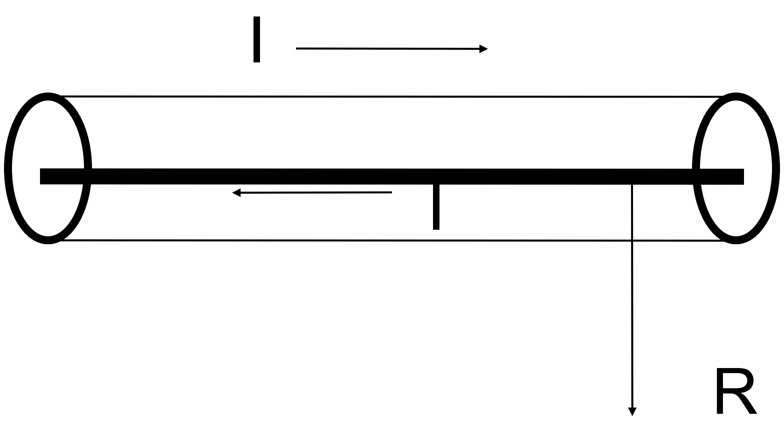
Therefore, from Ampere's Law

$\sum B_{||}$ $\sum$ o

$B=\frac{ì_o I}{2}$ from Ampere's Law

Application of Ampere's Law

A coaxial cable has an inner conductor carrying current in one direction and an outer conductor carrying an equal current in the opposite direction
Find the B field due to the currents at a radius R outside the coaxial cable.



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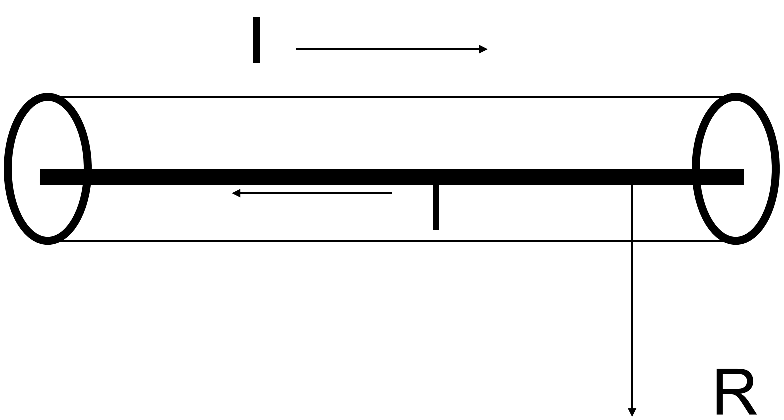
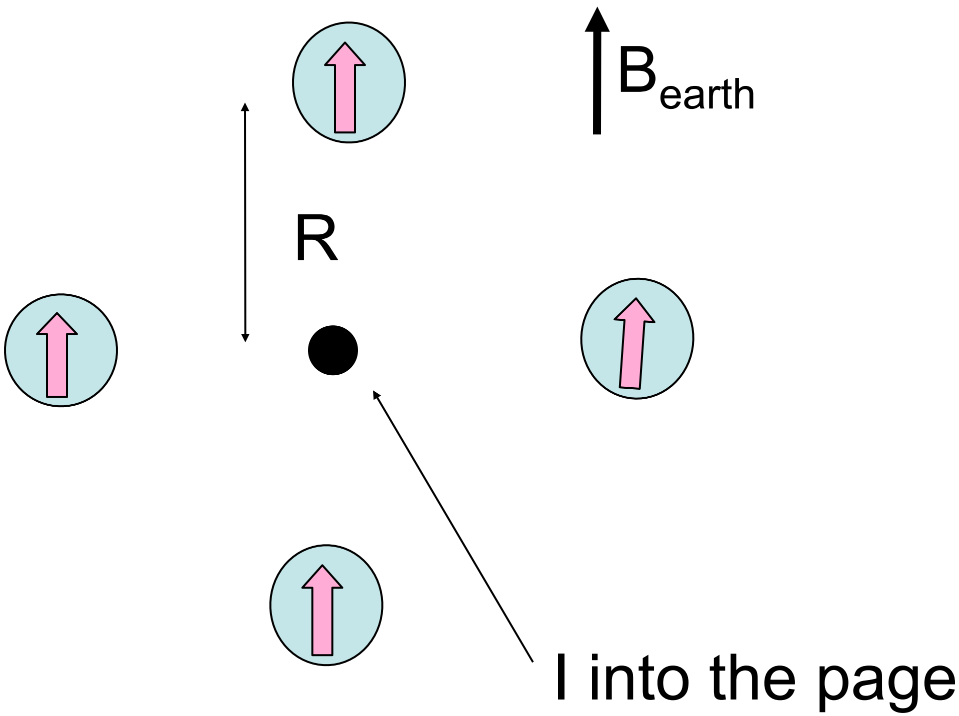


B=0 since the total current is equal to zero. The B fields due to the two currents cancel

A 5A current passes through a wire downward in the vertical direction. a) At what distance R from the wire will the magnetic field equal the earth's field $B=0.5x10^{-4}$ T.

How will the compass needles be deflected?



view from above

PHYSICS 1B – Fall 2009

Electricity
&
Magnetism

Professor Brian Keating

SERF Building. Room 333

UCSD UCSD

Today

Don't forget the Problem session Thursday night

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- Last quiz of course on Friday- covers Ch 19.

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- You ***CAN*** bring in 1 page (8.5” x 11”) notes for this quiz, as well as calculators.

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- Ch 19 HW solutions are on the web as are all lectures in Ch 19 after class today.
- No books, multiple pages, laptops etc.

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- Ch 19 HW solutions are on the web as are all lectures in Ch 19 after class today.
- No books, multiple pages, laptops etc.
- Magnetic field by wires review

Don't forget the Problem session Thursday night

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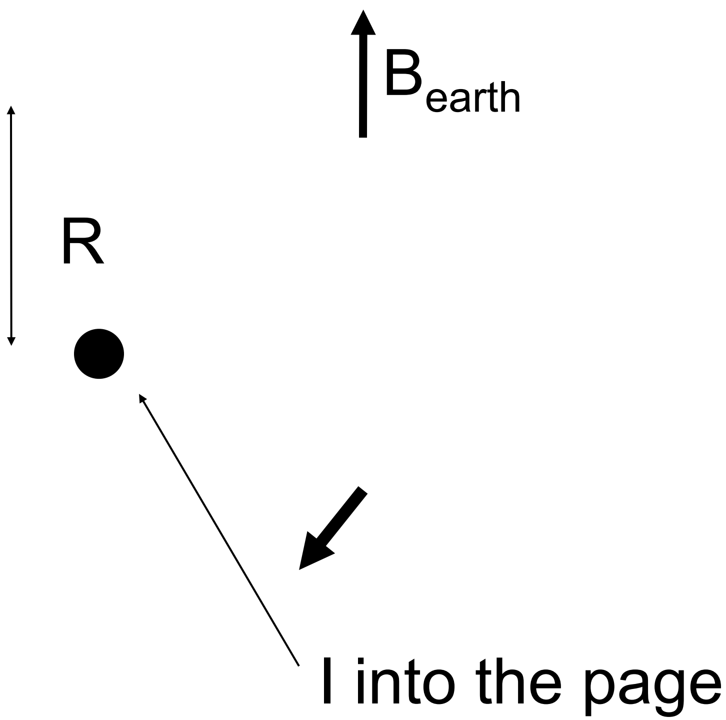
- New: current loops
- New: permanent magnets

Don't forget the Problem session Thursday night

A 5A current passes through a wire downward in the vertical direction. a) At what distance R from the wire will the magnetic field equal the earth's field B_{earth} =0.5×10^{-4} T.

How will the compass needles be deflected?



view from above

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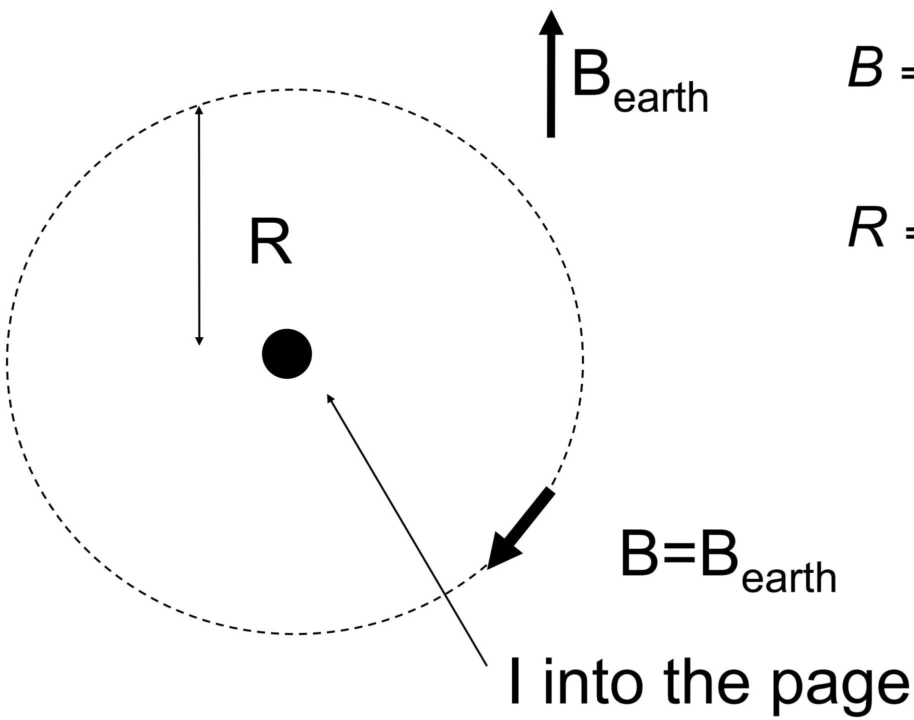

$$B = \frac{\mu_o I}{2\pi R}$$

$$R = \frac{\mu_o I}{2\pi B} = \frac{4\pi x10^{-7}(5)}{2\pi(0.5x10^{-4})} = 2x10^{-2} m$$

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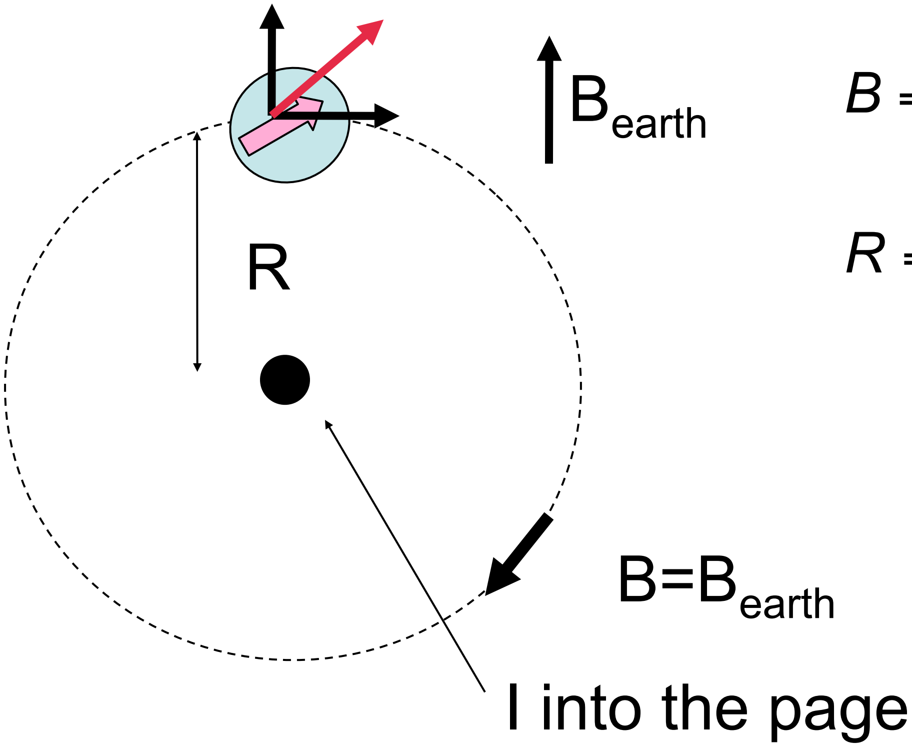

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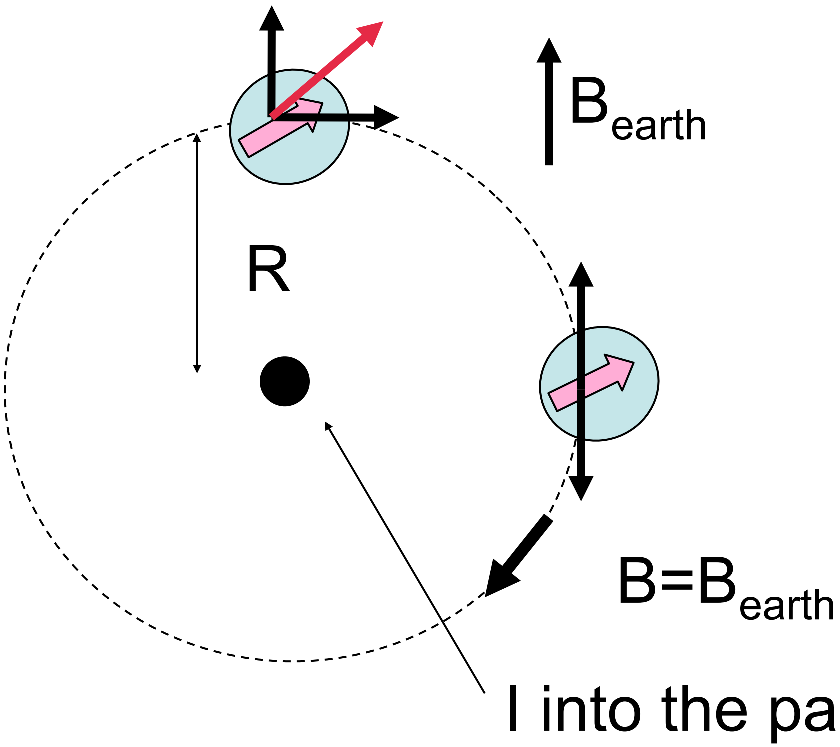

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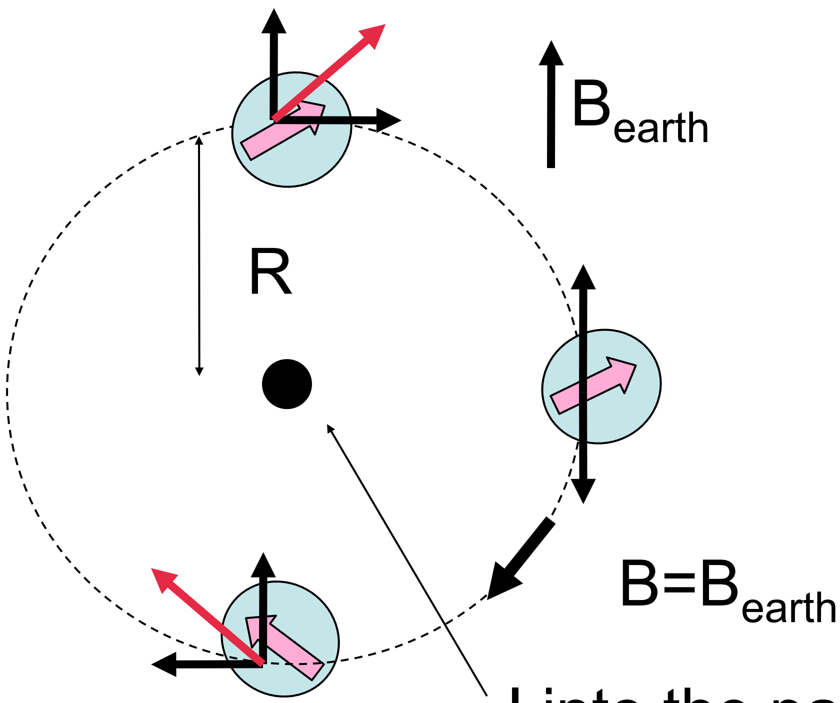

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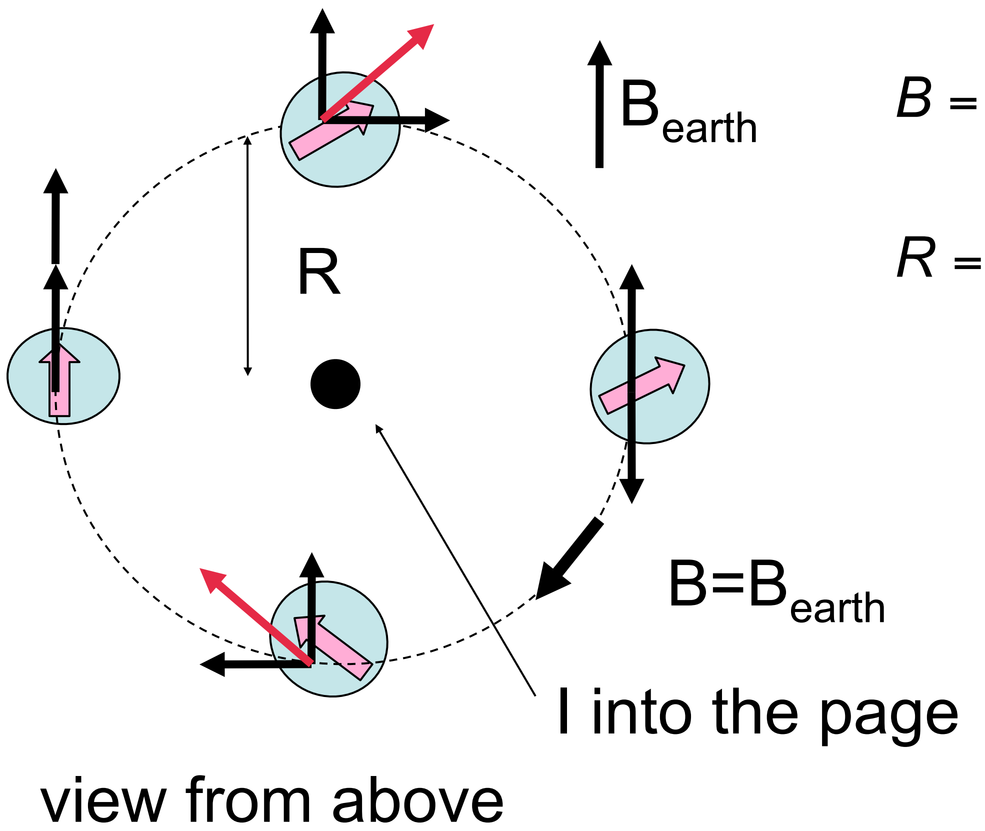

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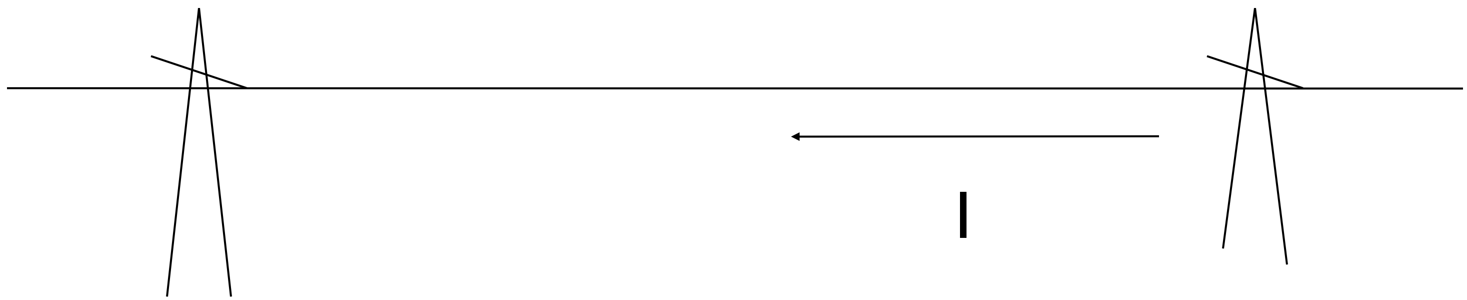
A power line carries a current of 100 A from east to west. a) Find the magnitude of the B field due to the wire at a position 20 m below the line due to the current. b) Find the direction of B.



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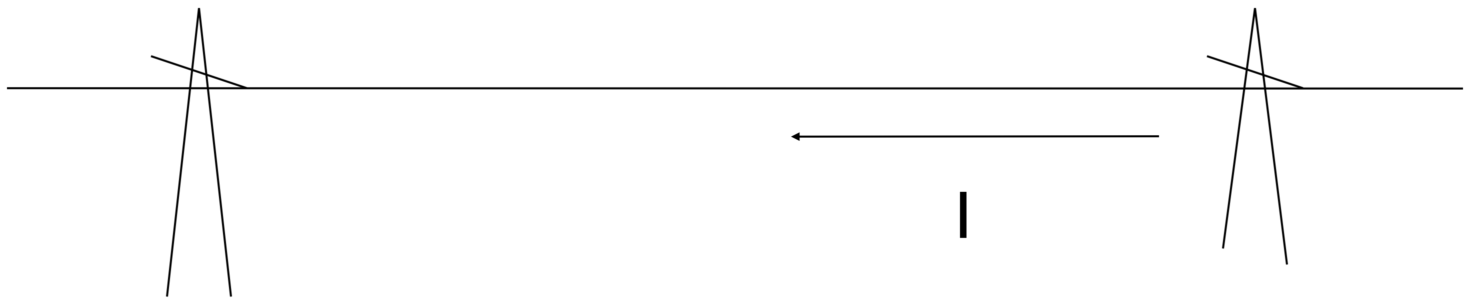

a)

$$B = \frac{\mu_o I}{2\pi R} = \frac{4\pi x 10^{-7}(100)}{2\pi(20)} = 10^{-6} T$$

this is much smaller than the earth's magnetic field $0.5x10^{-4}$ T

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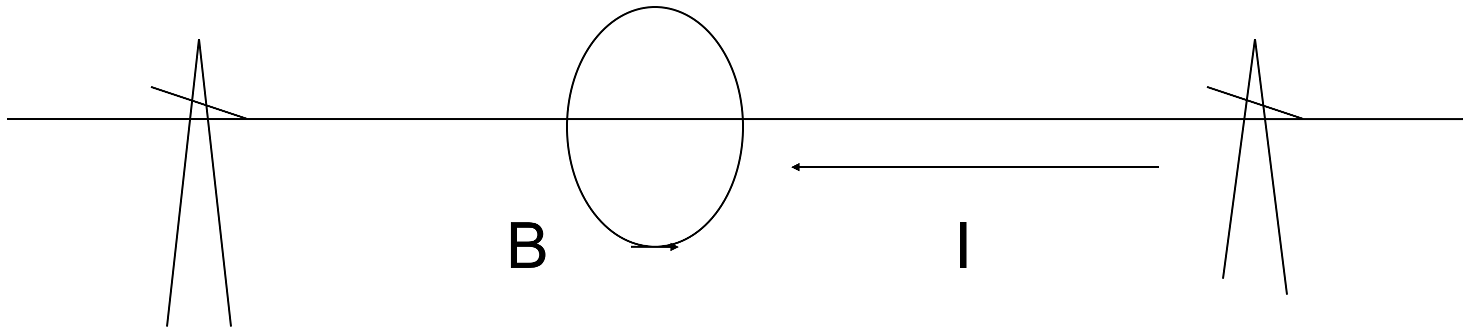

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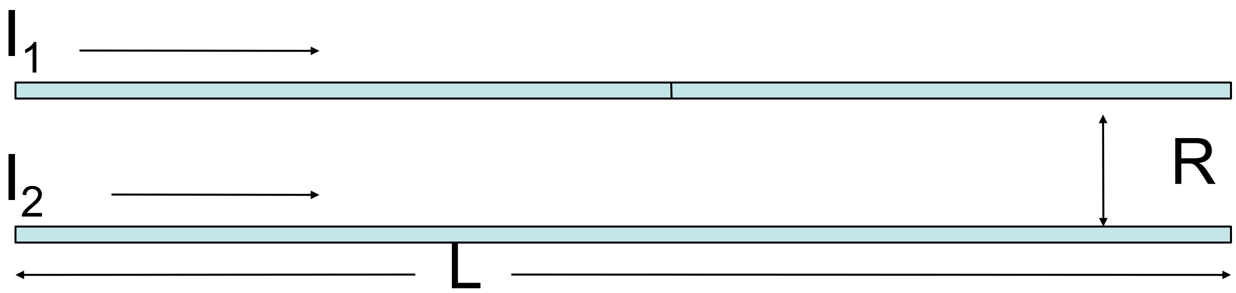
b) South- by the right-hand rule.

Force between two current carrying wires of length L, parallel at distance R.



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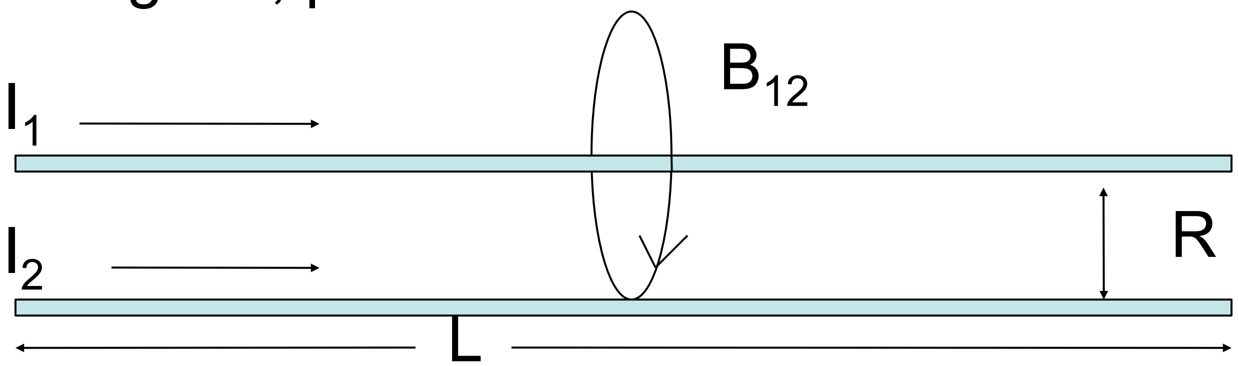

I_1 produces a field B_{12} at the position of wire 2.

$$B_{12} = \frac{\mu_o I_1}{2\pi R}$$

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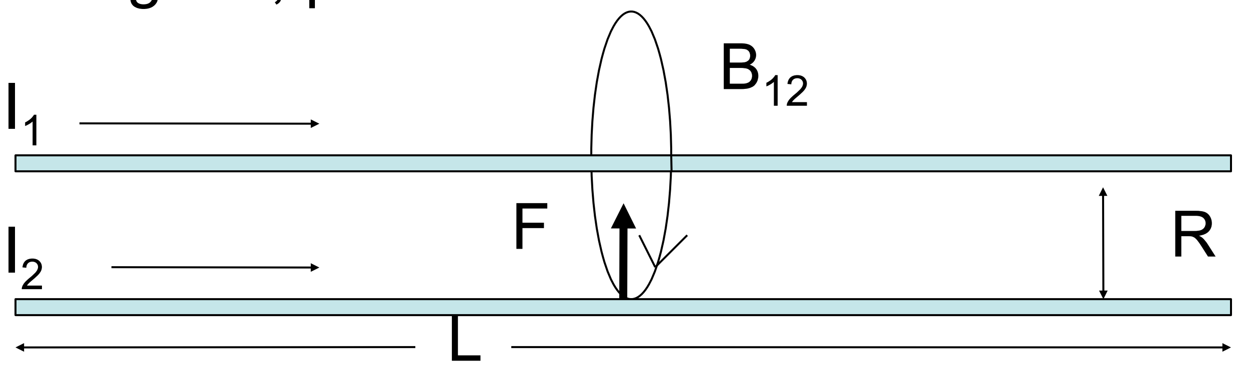

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I_2 experiences a force due to B_{12}

$$F = B_{12} I_2 L$$

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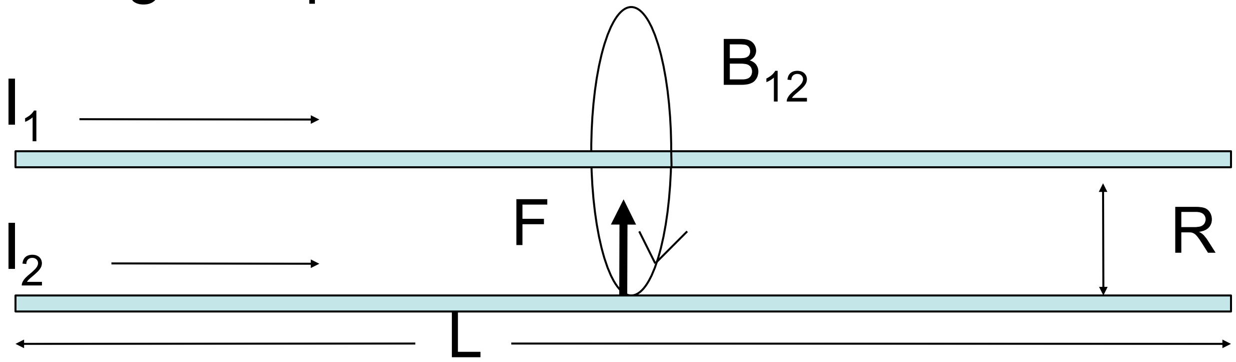

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The force between the two wires is

$$F = B_{12} I_2 L = \frac{\mu_o I_1 I_2 L}{2\pi R}$$

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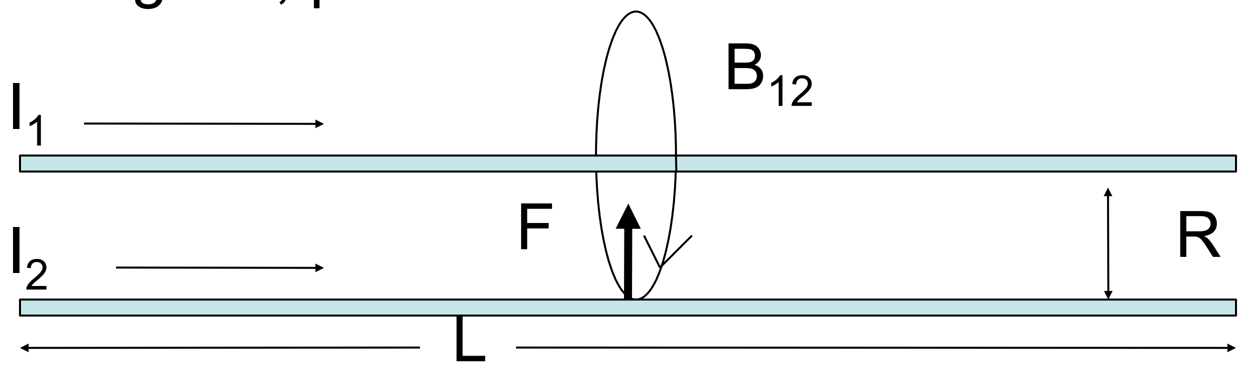

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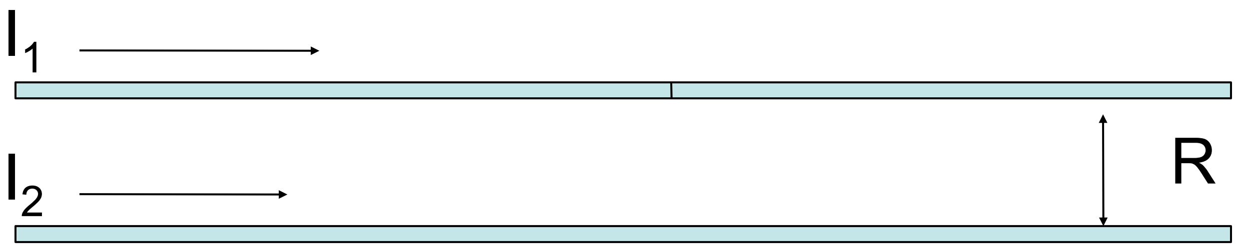
$$F = B_{12} I_2 L = \frac{\mu_o I_1 I_2 L}{2\pi R}$$

Directions

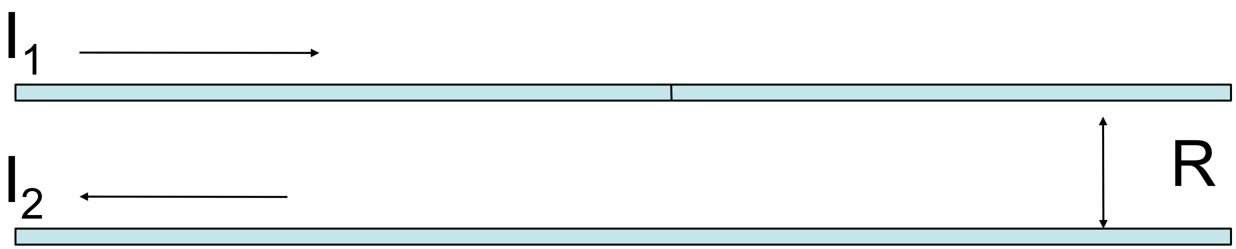
B inward

F attractive

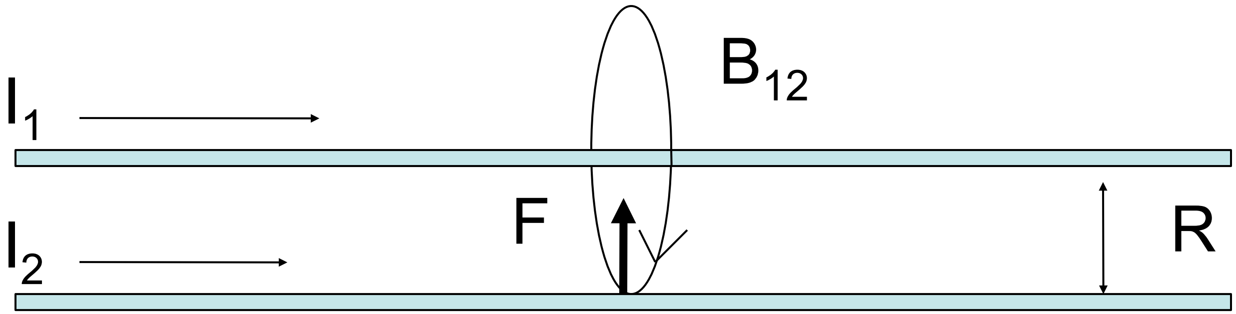
Current in same direction-



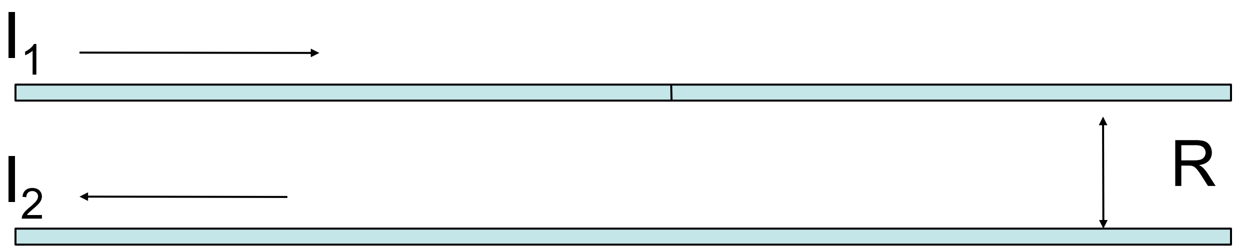
Current in opposite directions



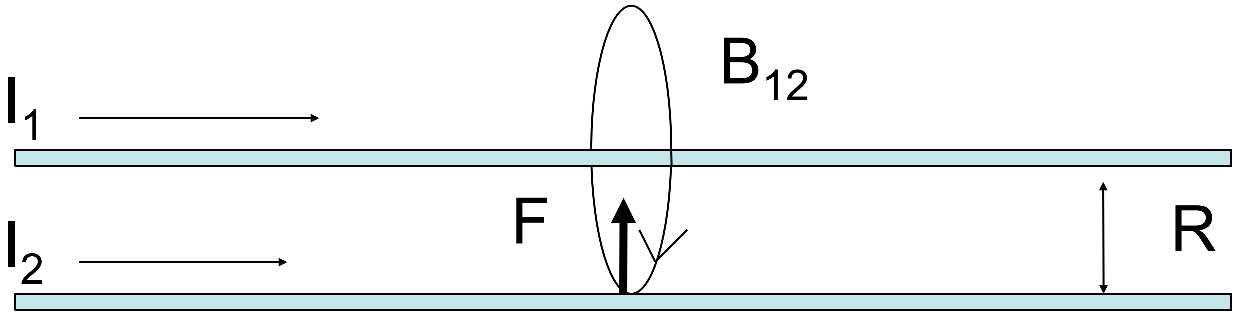
Current in same direction- Force - Attractive



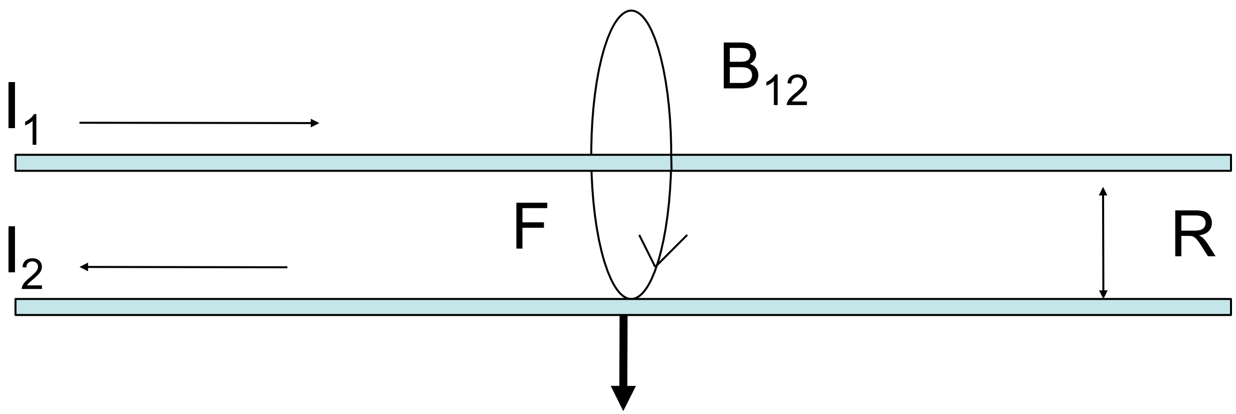
Current in opposite directions



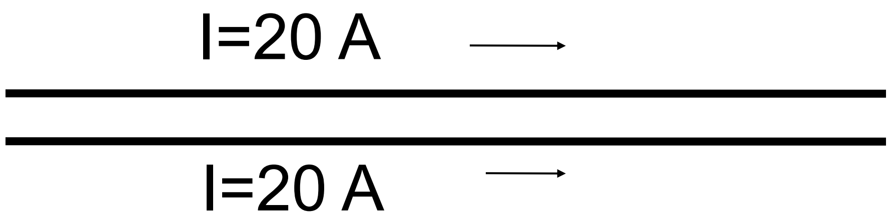
Current in same direction- Force - Attractive



Current in opposite directions Force - Repulsive



Two parallel wires 1.0 m in length separated by 4.0 cm each carry a current of 20 A in opposite directions. Find the force exerted between the two wires.



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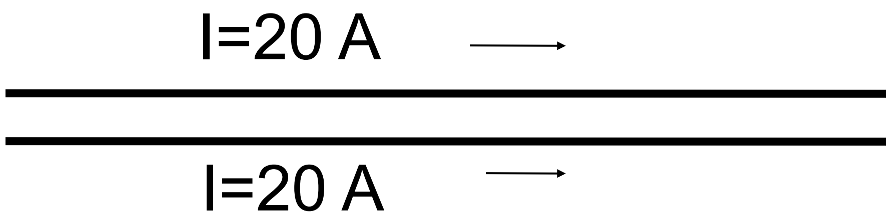

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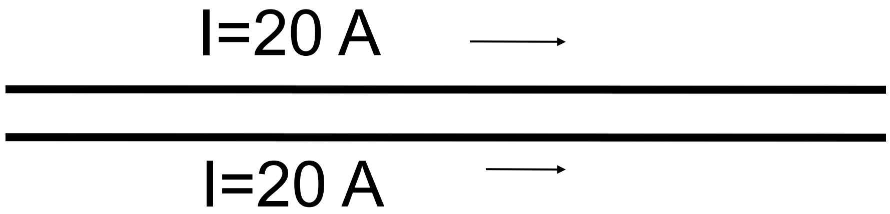
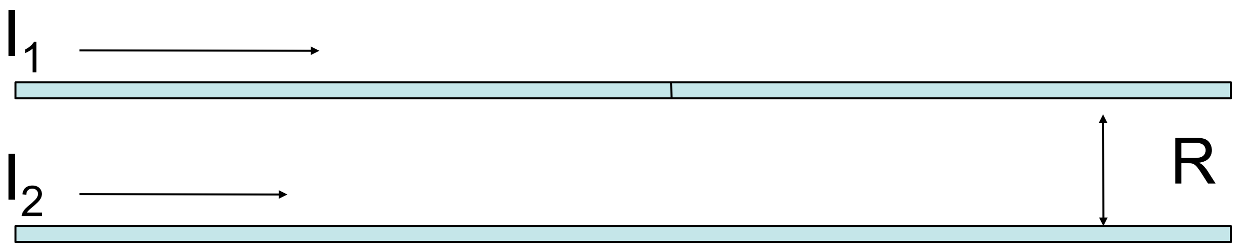
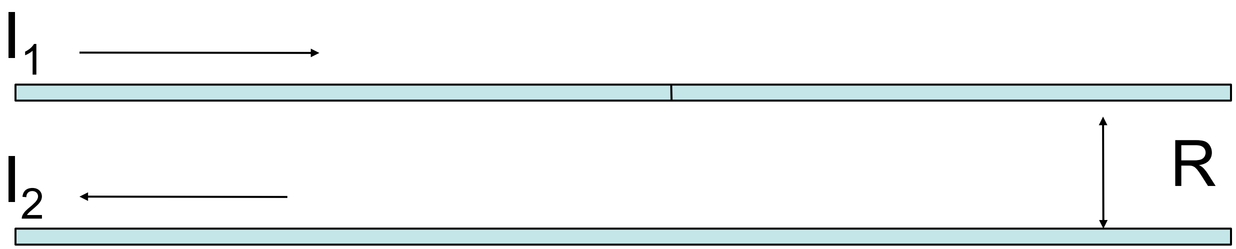


$$F = \frac{\mu_o I^2 L}{2\pi R} = \frac{4\pi 10^{-7}(20)^2(1)}{2\pi(0.04)} = 2x10^{-3}N$$

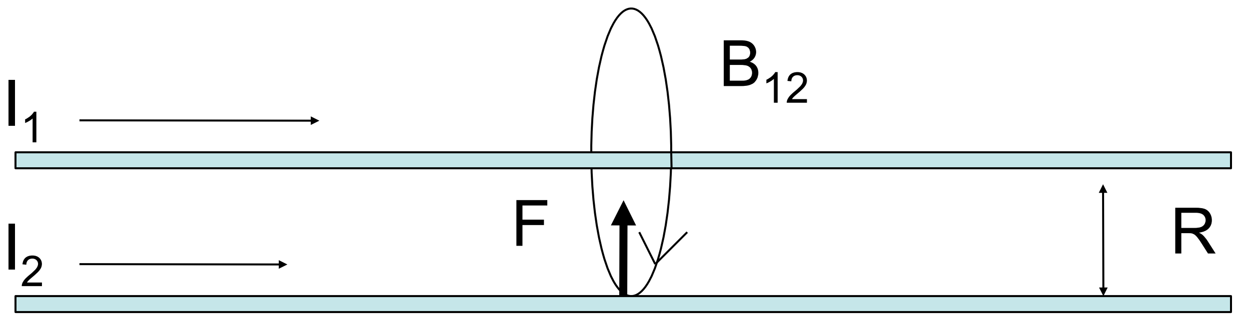
Current in same direction-



Current in opposite directions



Current in same direction- Force - Attractive



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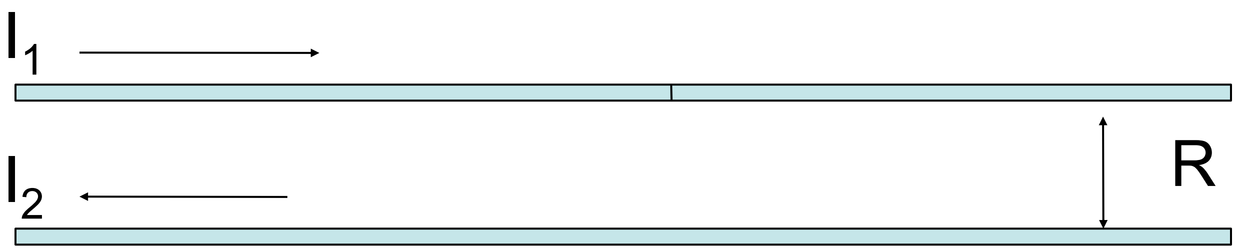
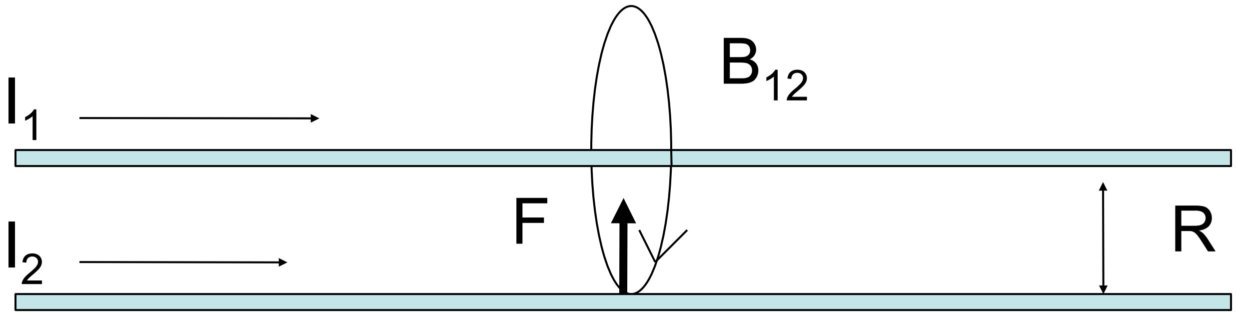
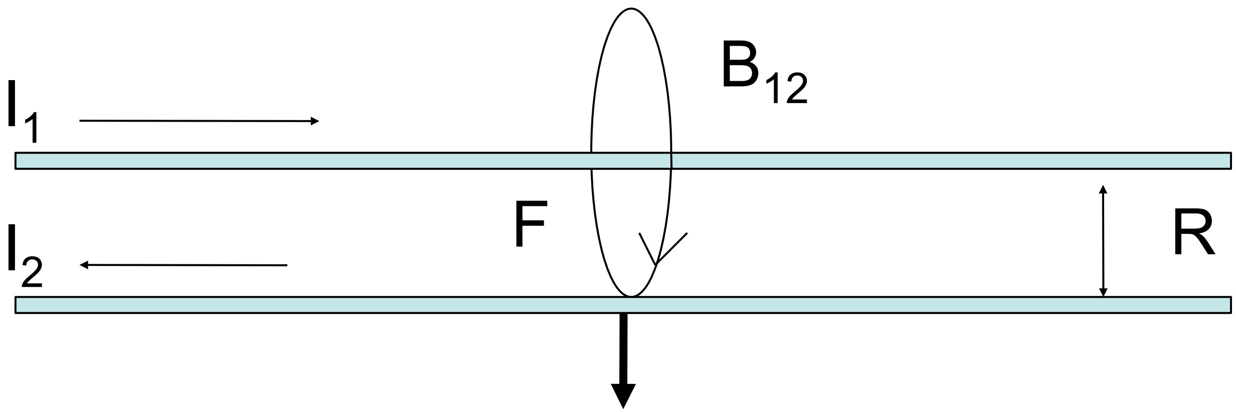


Current in same direction- Force - Attractive



Current in opposite directions Force - Repulsive



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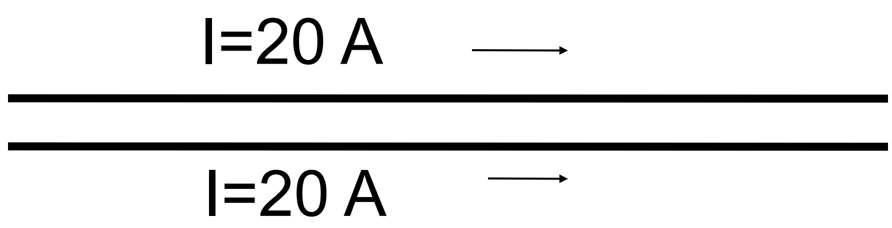

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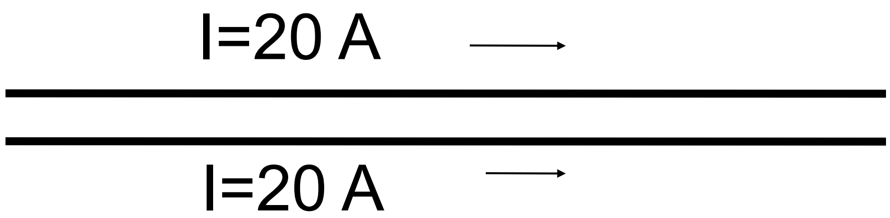

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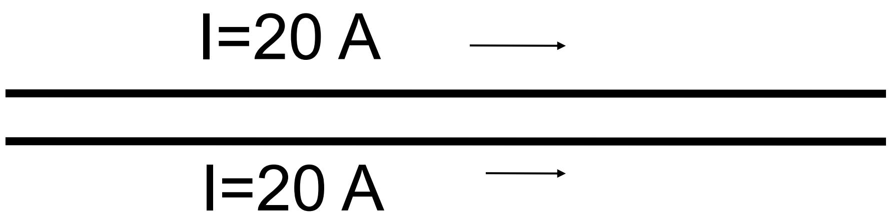

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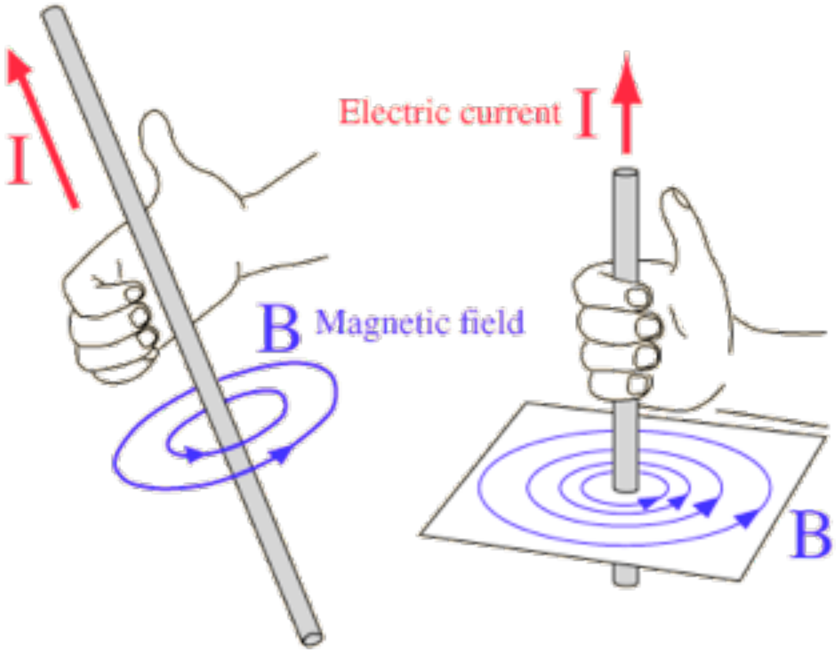
19.9 Magnetic field of a current loop

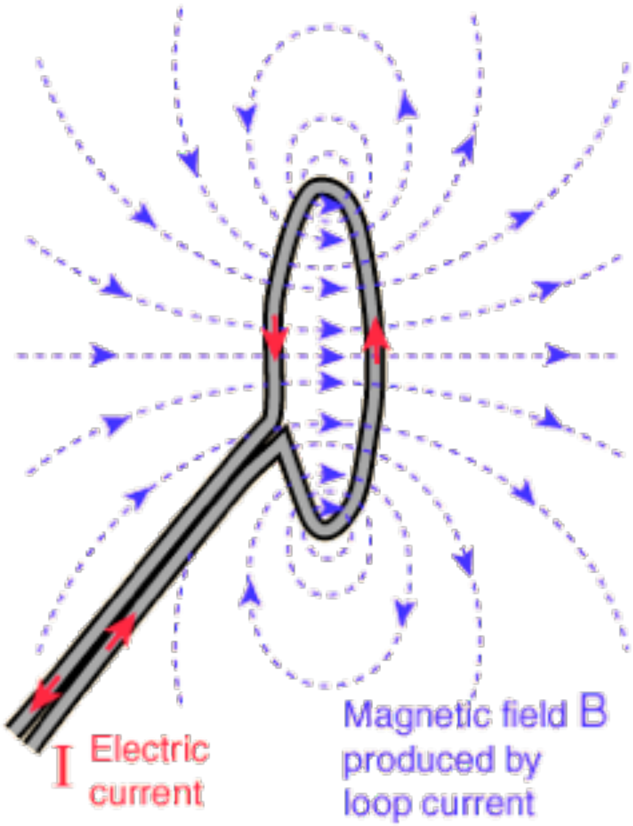
Current loop
Solenoid
Magnetic materials
Electromagnets
Motion of a charged particle in a magnetic field

Magnetic field in a current loop

B field- out of lo



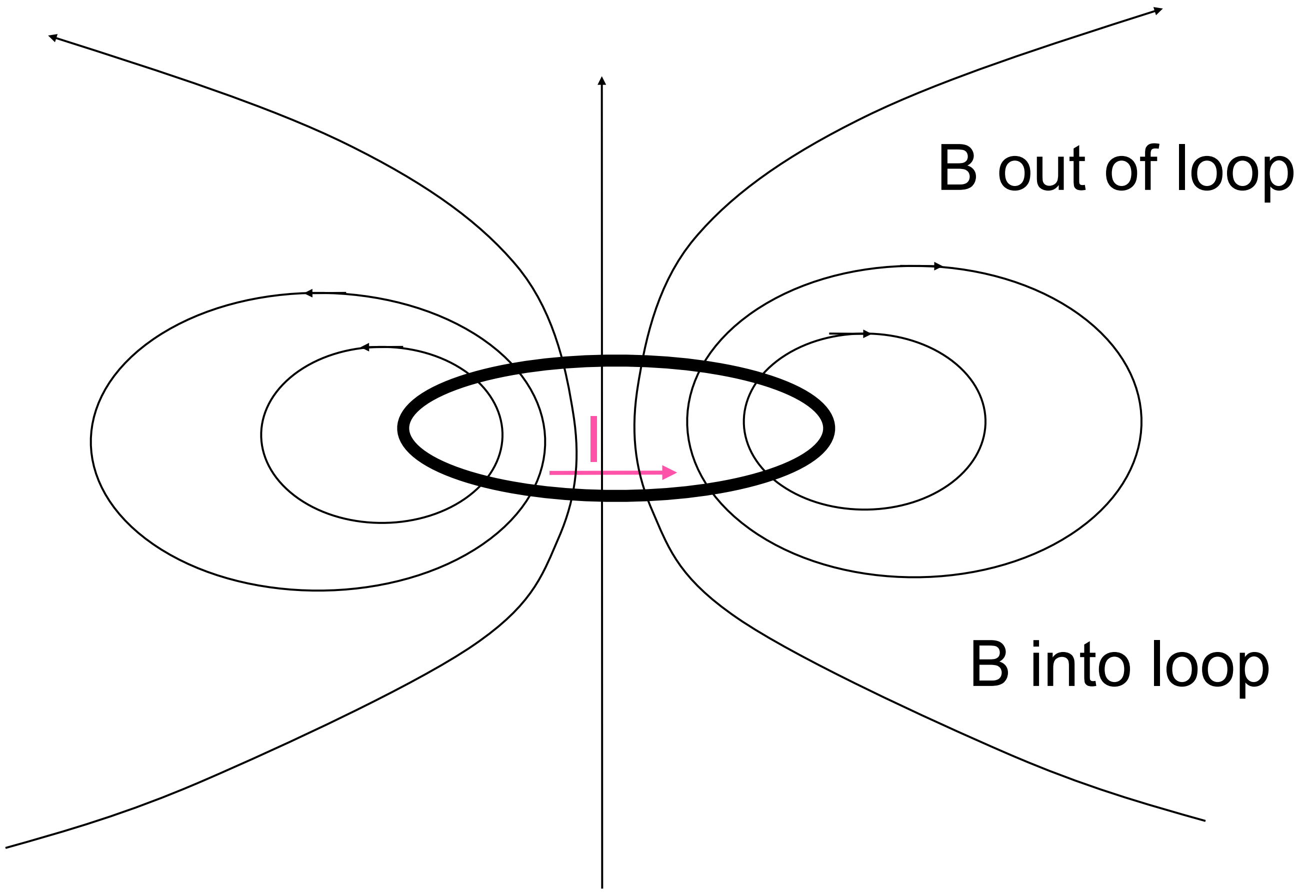
Straight wire



Current loop
B field is the sum of fields

B field due to current loop

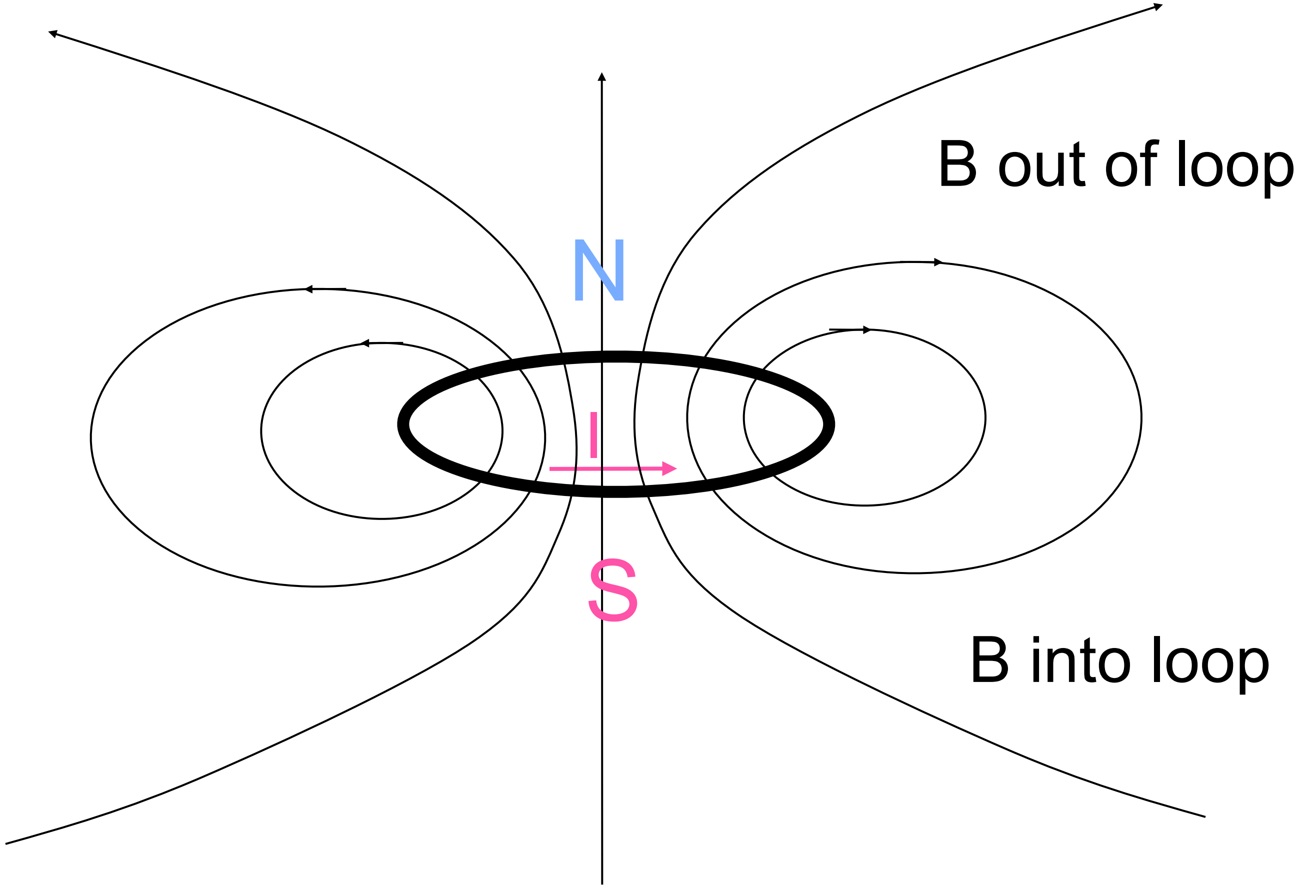
Side view



B field due to current loop

looks like a magnetic dipole

Side view



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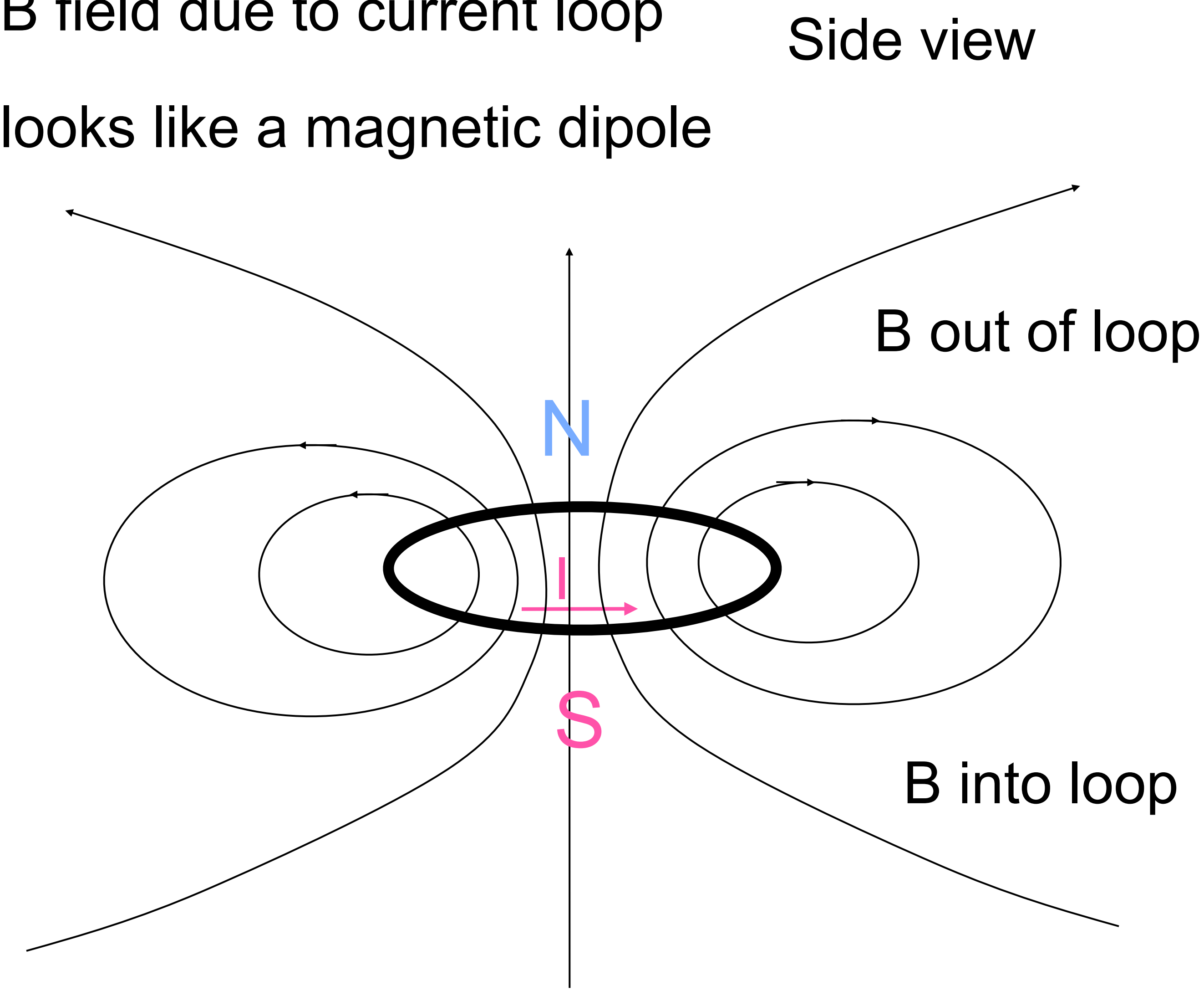
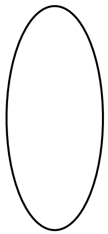


A current loop creates a magnetic dipole

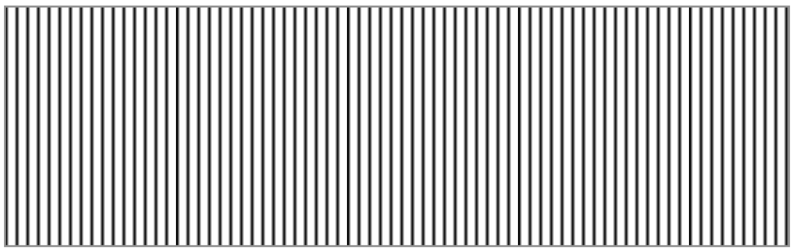
Solenoids

Motivation. To construct electromagnets, i.e. a device to convert current to magnetic field.

Some elements of design of electromagnets. The magnetic field due to current through loops or coils of wire.



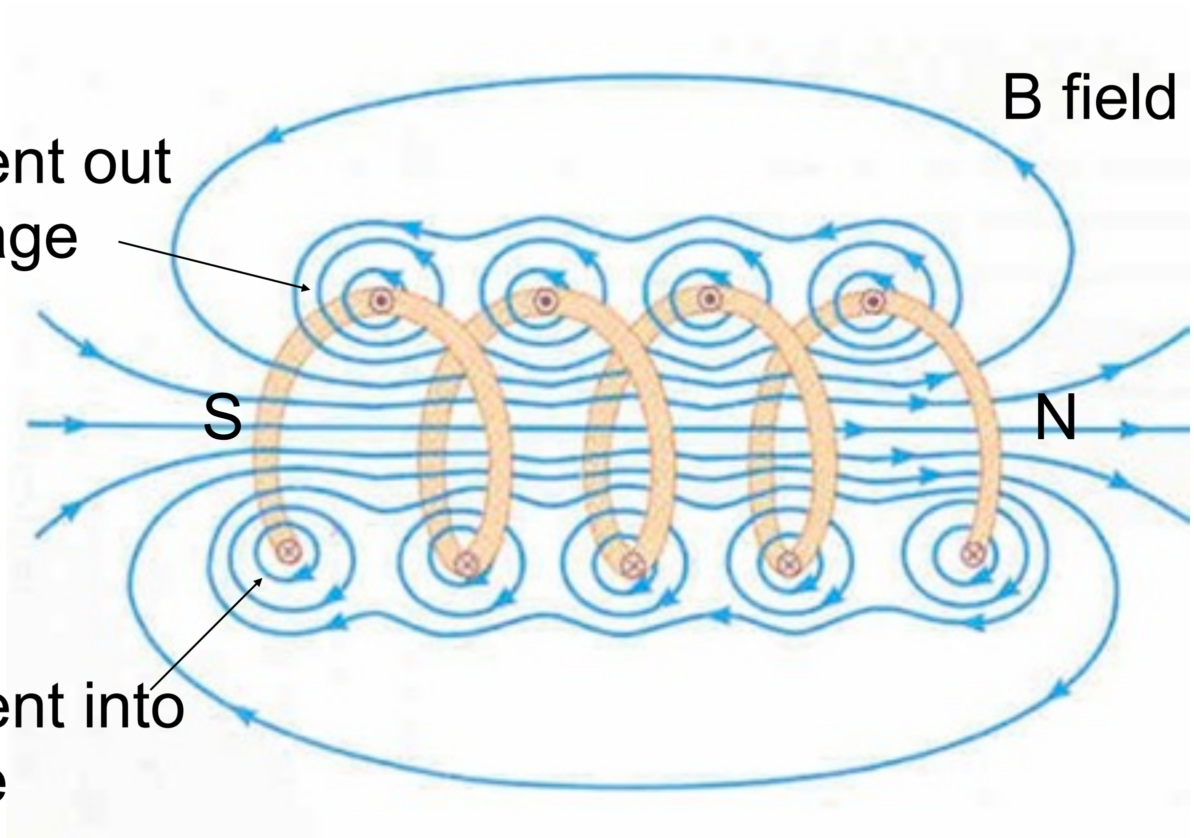
single coil



solenoid multiple turns of wire

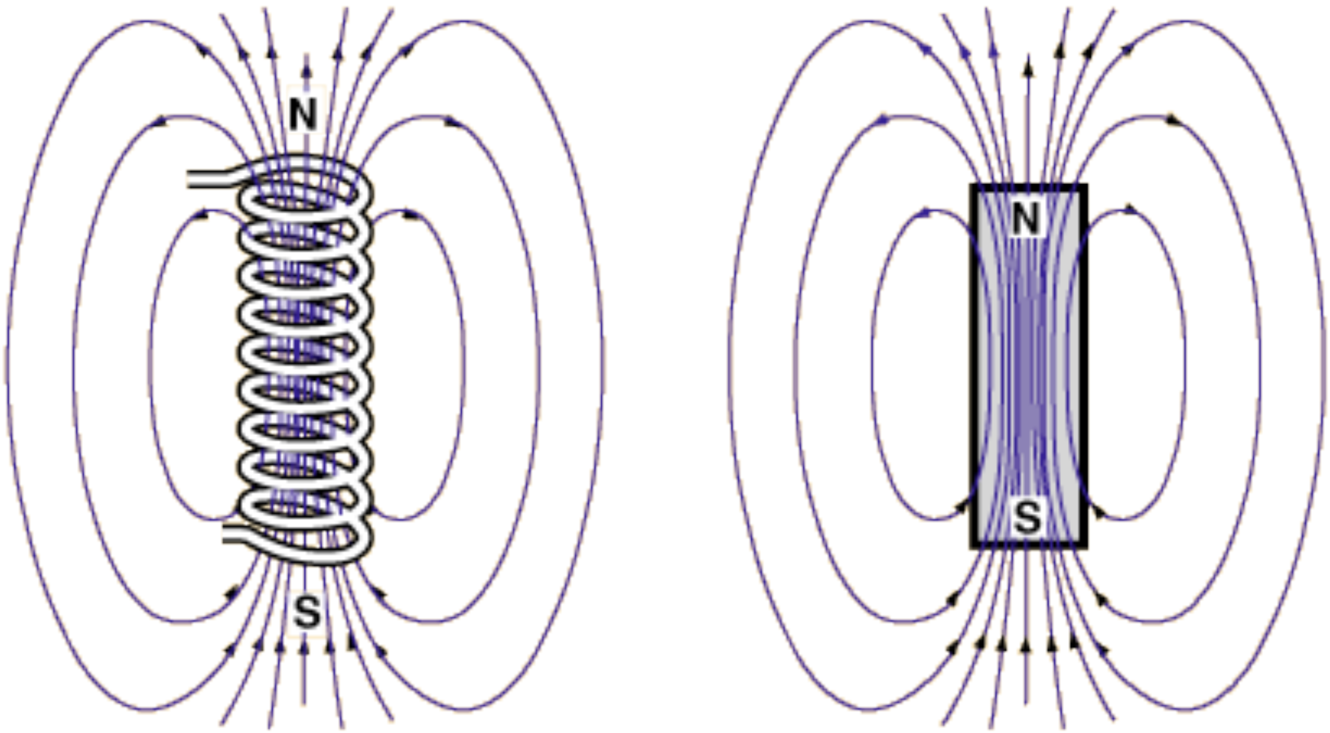
- Built up of current loops

Solenoid



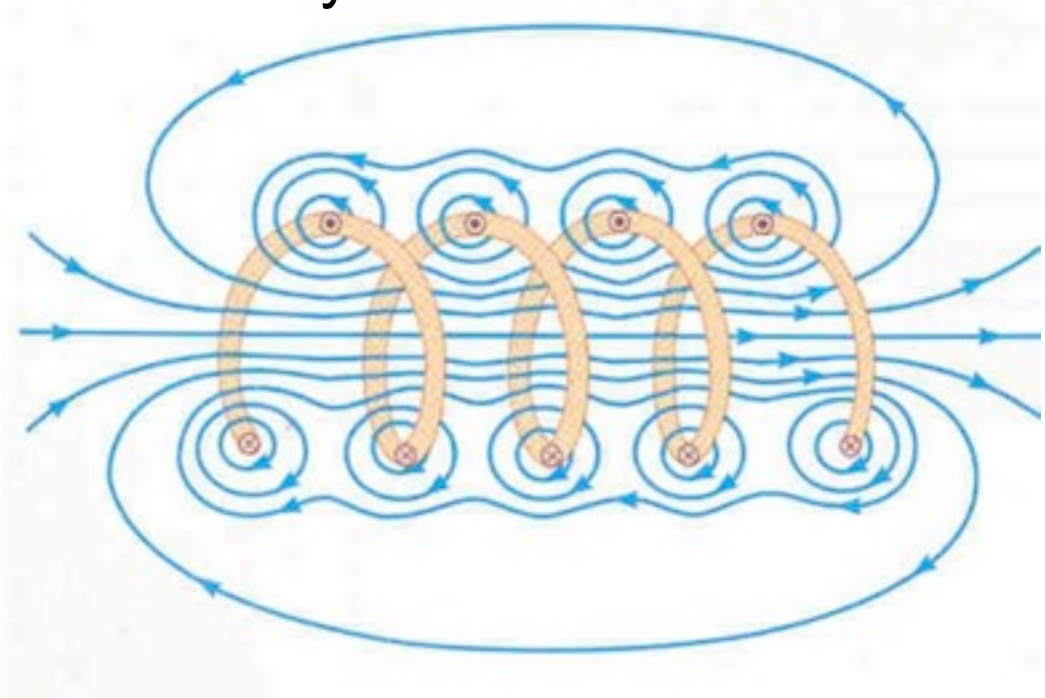
Current in a solenoid produces magnetic dipole

Air Core Solenoid vs. Bar Magnet

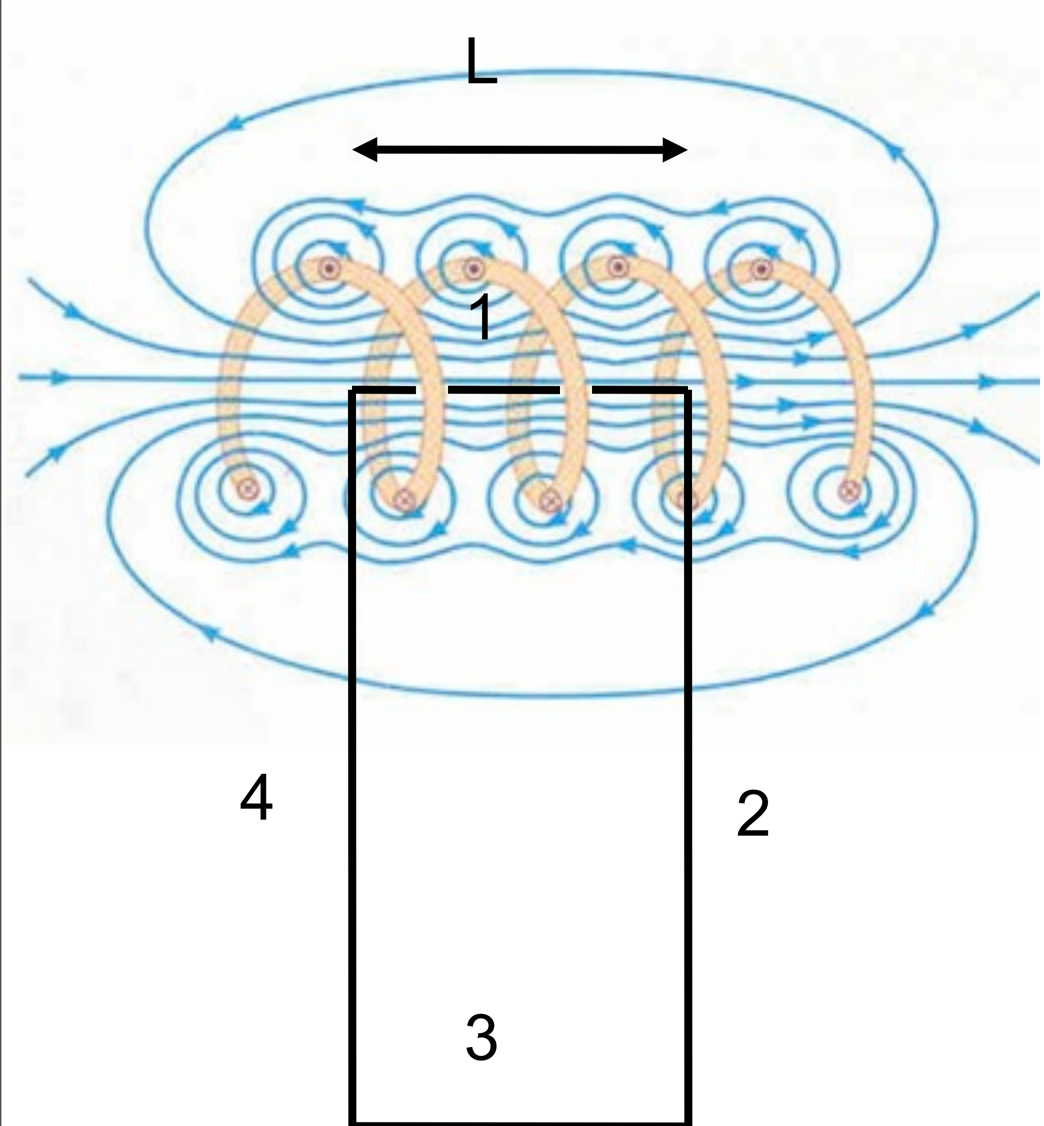


B field in solenoid

- High field inside solenoid
- Lower fields outside
- Uniform relatively constant field in central region



B-field in center by Ampere's Law



$$\sum_{closed-loop} B_{//}\Delta L = \mu_o \sum I = \mu_o NI$$

N=no. of turns in length L

Only segment 1 contributes because $B_{//}\Delta L$ for other segments =zero

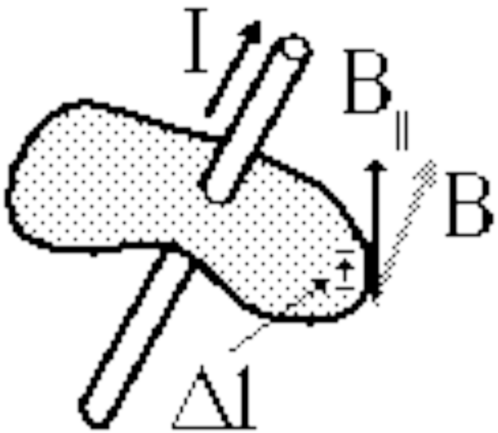
$$BL = \mu_o NI$$

$$B = \frac{\mu_o NI}{L}$$

$$B = \mu_o nI$$

$$n = \frac{N}{L}$$ i.e. 2 in the picture

Ampere's Law

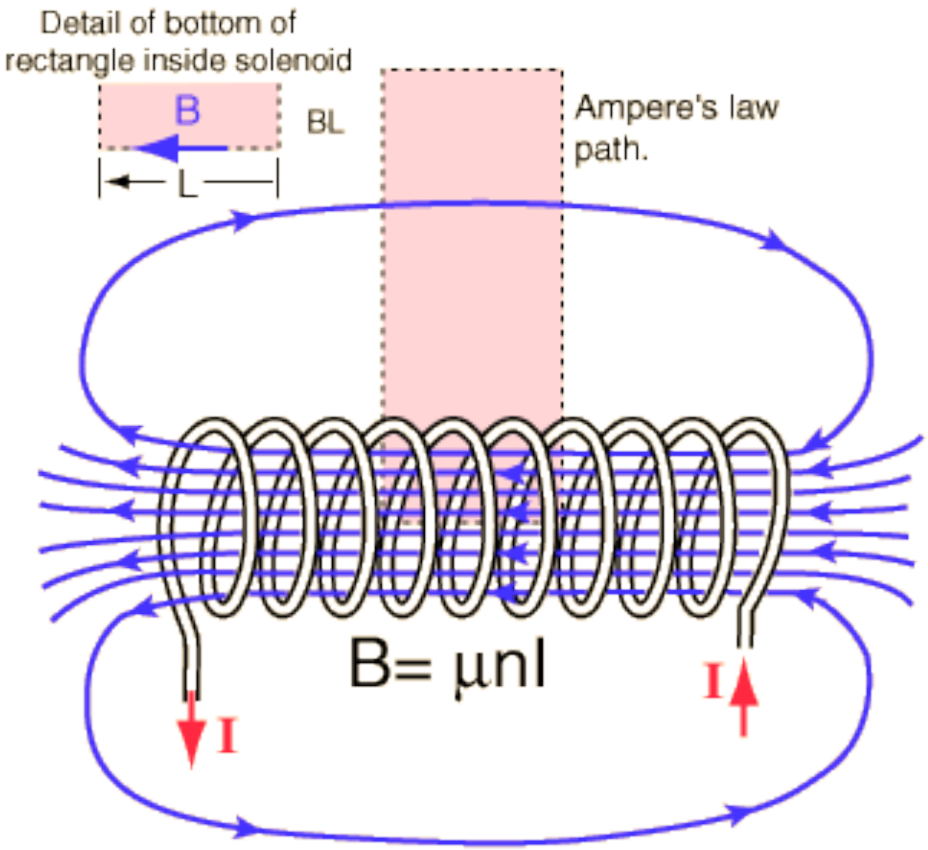


$$\sum B_{\parallel}\,\Delta l = \mu_0 I$$

Ampere's Law: for a closed loop path, the sum of the length elements times the magnetic field in the direction of the length element is equal to the permeability times the electric current enclosed in the loop.

Magnetic field in a long solenoid

$$B=\mu_o nI \quad \text{at center}$$



$$BL = \mu NI$$

$$B = \mu \frac{N}{L} I$$

$$B = \mu nI$$

Ampere's Law: for a closed loop path, the sum of the length elements times the magnetic field in the direction of the length element is equal to the permeability times the electric current enclosed in the loop.

An electromagnet with has 100 turns of wire wound around an air core with length of 3.0 cm. If a current of 20 A is passed through the wire, what is the B field at center of the magnet.

$$B = \mu_o nI = \mu_o \left(\frac{N}{L}\right) I$$

$$B = (4\pi x10^{-7})\left(\frac{100}{0.03}\right)20$$

$$B = 0.08T$$

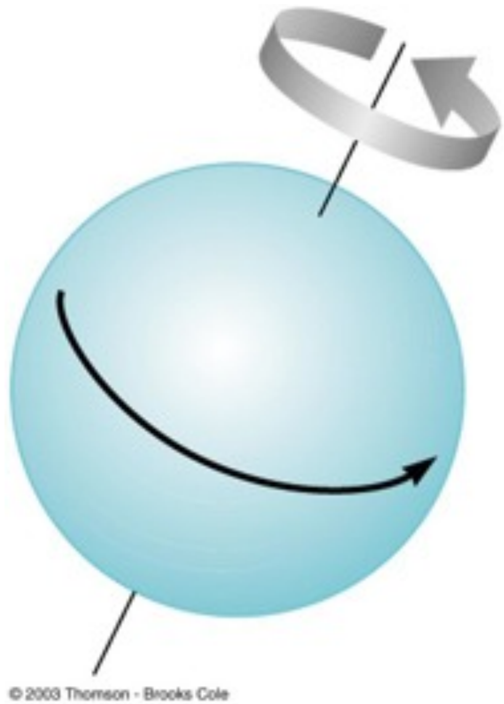
19.10 Magnetic Domains and Materials

Magnetic materials owe their properties to magnetic dipole moments of electrons in atoms.

Applications

- permanent magnets,
- magnetic core electromagnets
- magnetic recording, magnetic tape, computer drives,
- credit cards

An electron acts as a magnetic dipole



Spinning
charge

Classical model for magnetic dipole moment of electron

Magnetic properties of matter

		μ/μ_o
<u>diamagnetic</u>	Carbon	$1\text{-}2\times10^{-5}$ slightly less than vacuum
<u>paramagnetic</u>	Iron alum salt	1×10^{-5} slightly more than vacuum
<u>ferromagnetic</u>	Iron metal	1000-3000 much more than vacuum

Soft magnetic materials

e.g. iron

Easily magnetized but doesn’t retain magnetization for long

Used as core for electromagnets

Hard magnetic materials

e.g. metal alloys Alnico (Aluminum, Nickel, Cobalt)

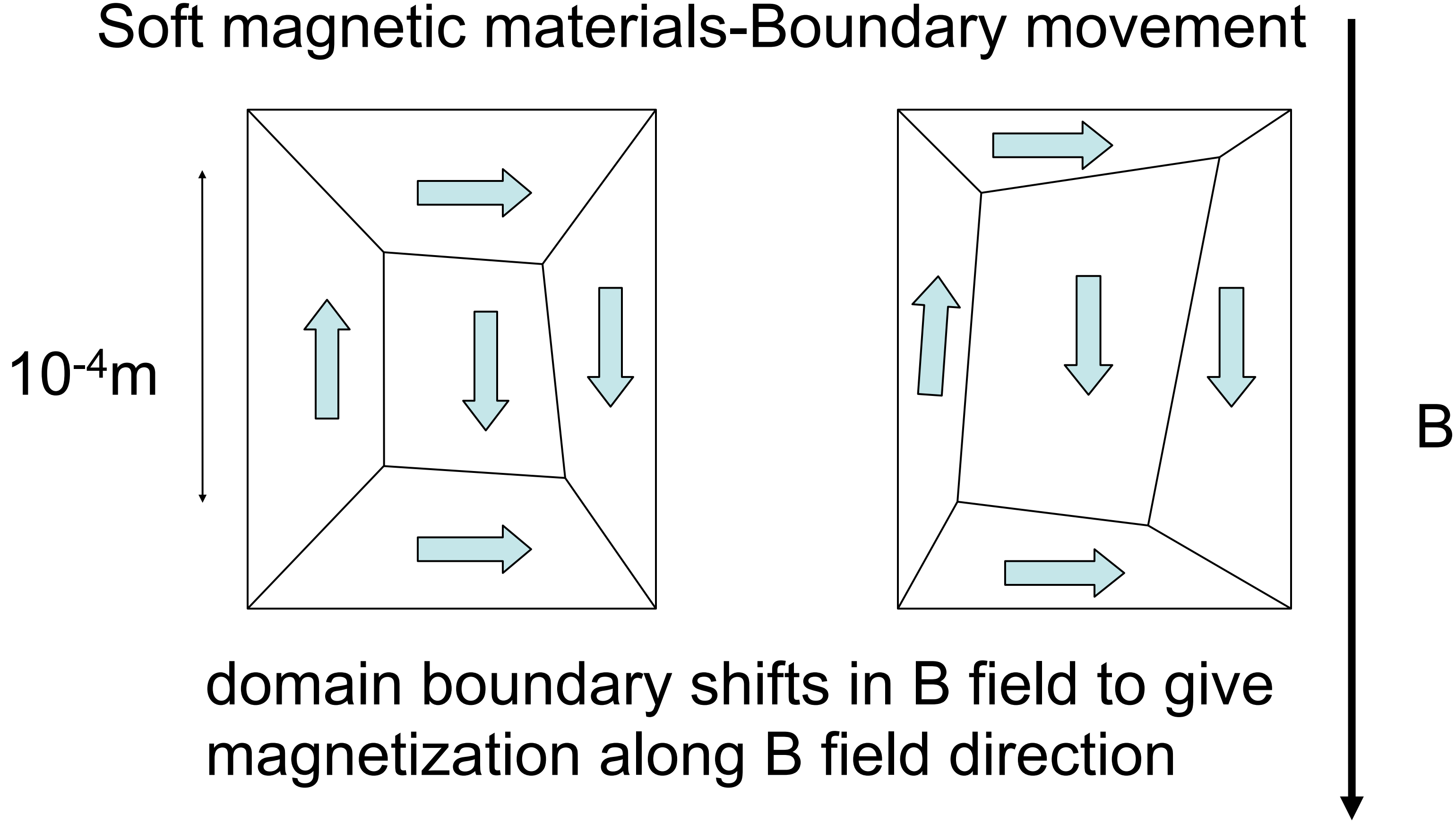
Hard to magnetize but retains the magnetization for a long time

Used as permanent magnets.

Magnetic Domains

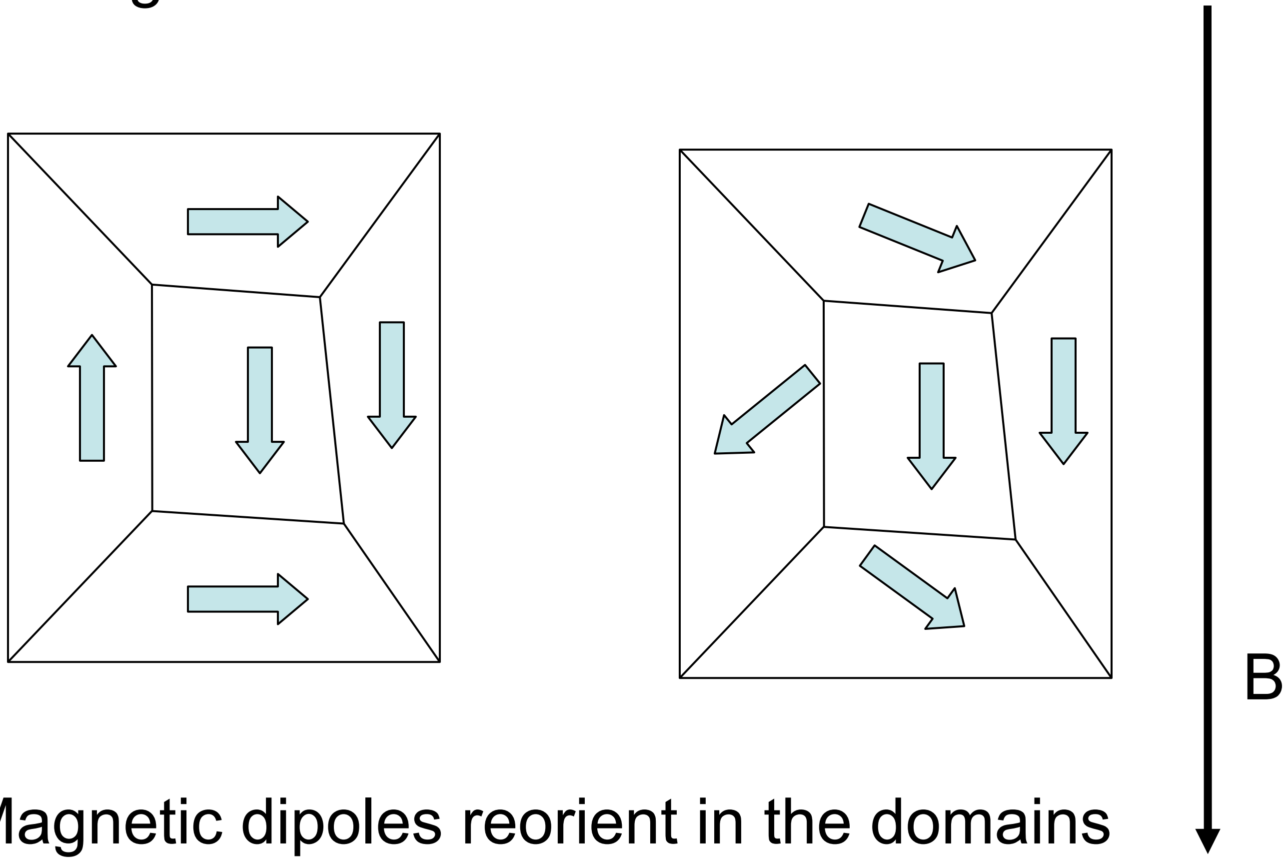
Magnetism due to magnetic domains.
Each domain has millions of atoms with magnetic moments coupled
Separated by domain boundaries

Soft magnetic materials-Boundary movement



domain boundary shifts in B field to give magnetization along B field direction

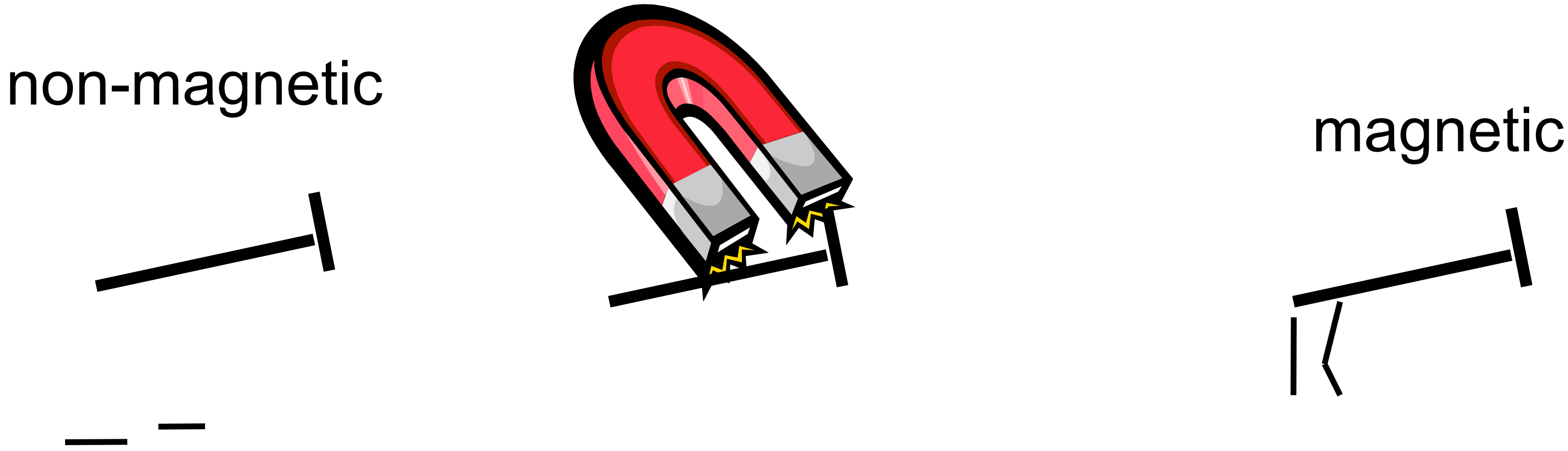
Hard magnetic materials

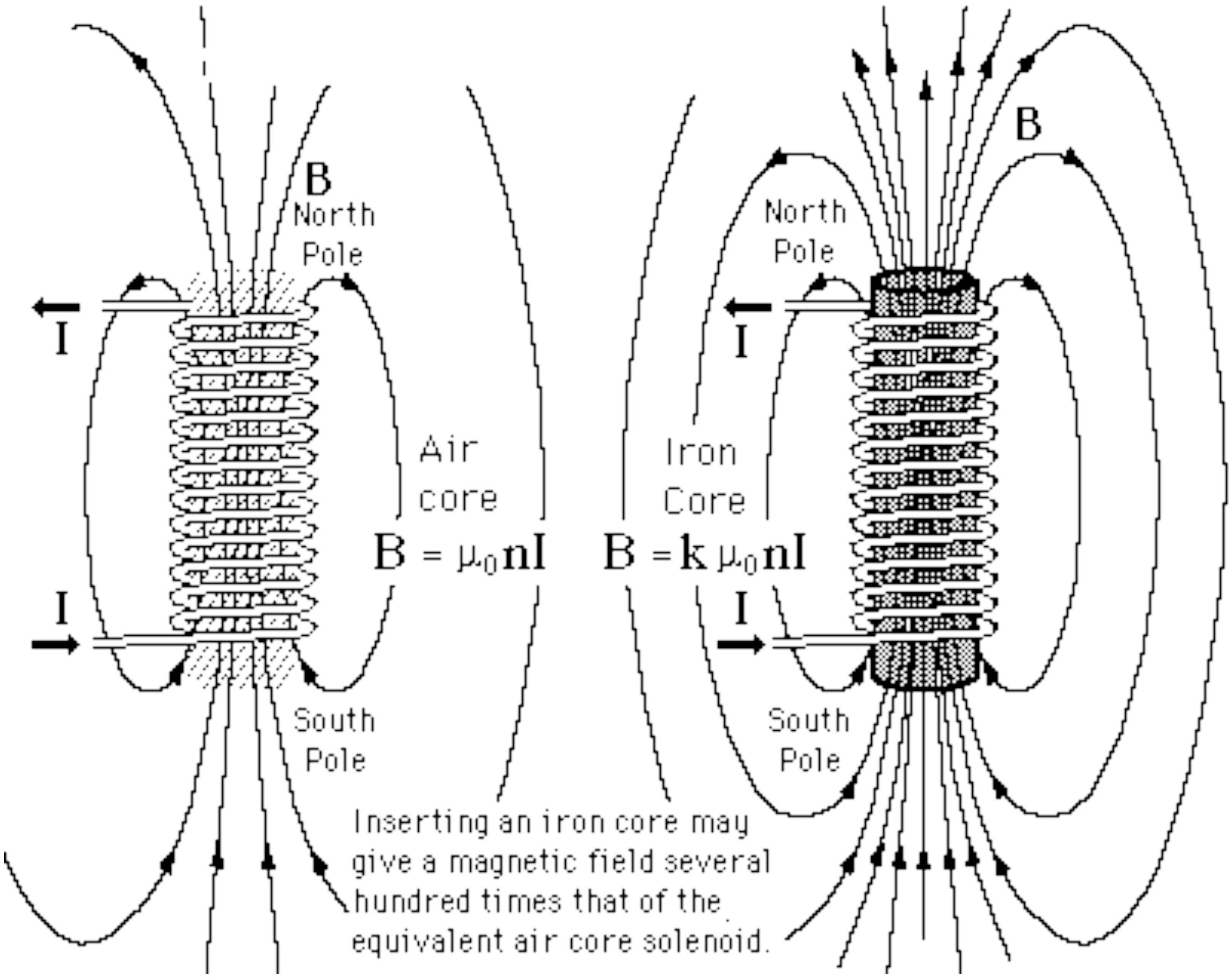


Magnetic dipoles reorient in the domains to give a net magnetic moment.
Harder to do, i.e requires higher B field.
but also harder to reverse.

Magnetization

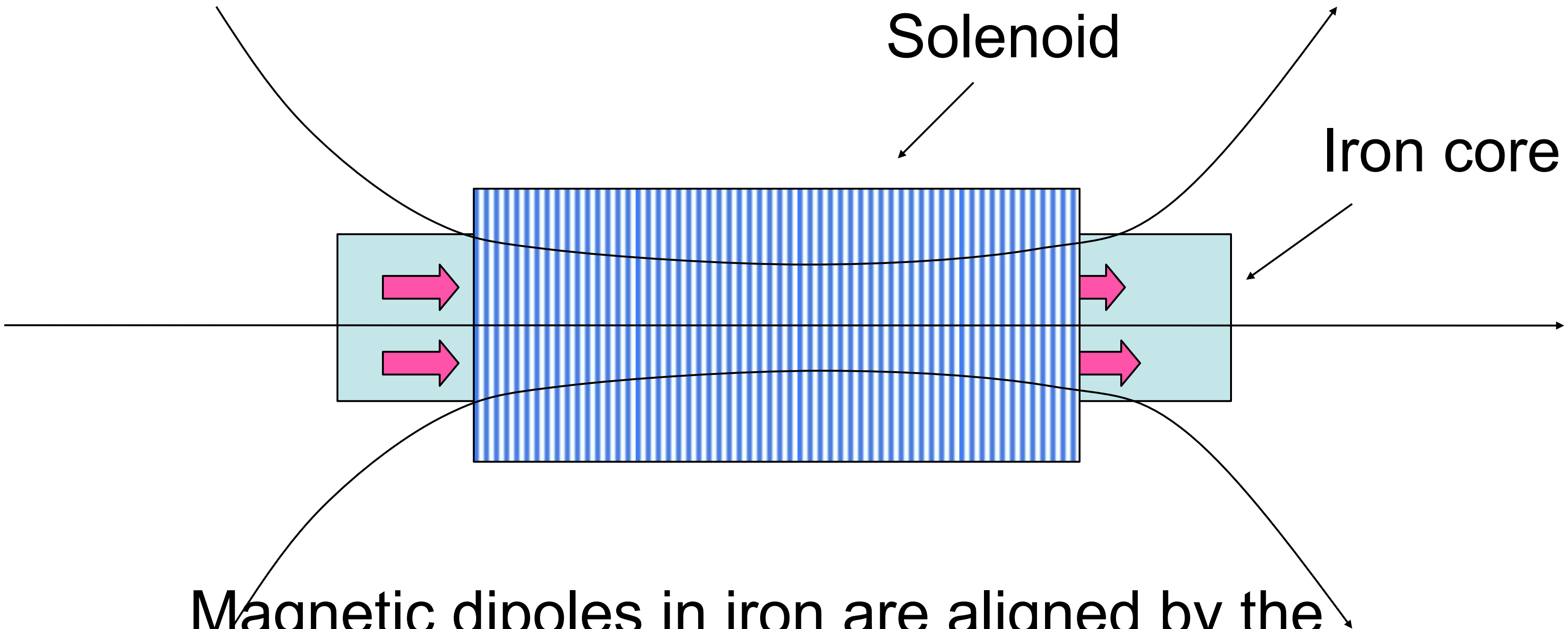
Soft magnetic materials e.g. Fe nail can be magnetized by exposure to a strong B field.





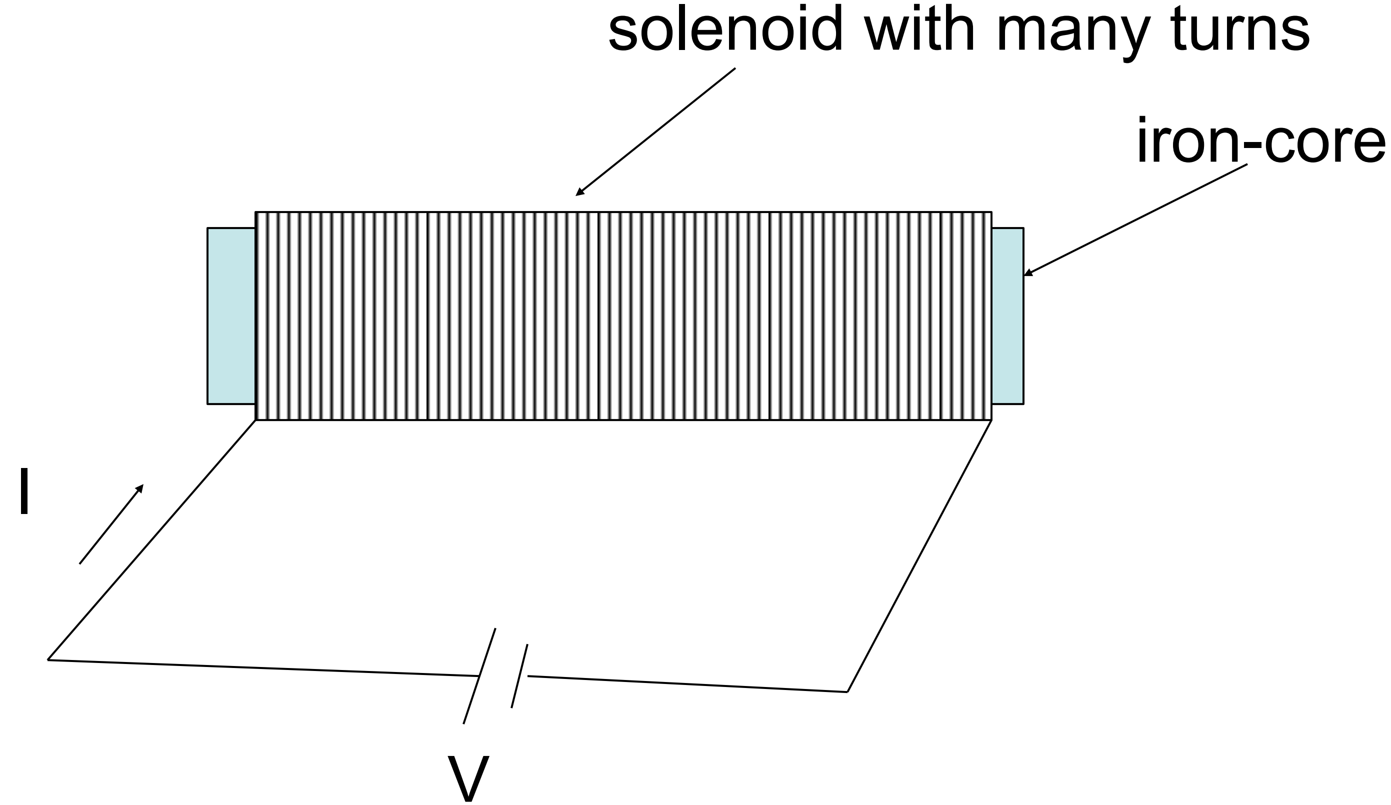
B
North
Pole
I
I
Air
core
$B = \mu_0 n I$
South
Pole
Inserting an iron core may
give a magnetic field several
hundred times that of the
equivalent air core solenoid.
B
North
Pole
I
I
Iron
Core
$B = k\,\mu_0 n I$
South
Pole

Magnetic material



Magnetic dipoles in iron are aligned by the B field to produce a larger B field

Iron core electromagnet



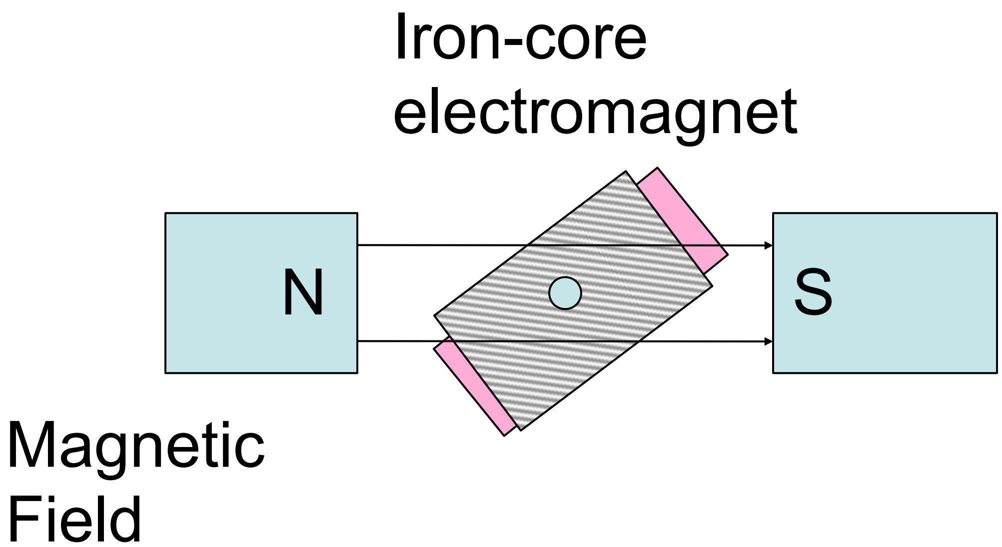
$$B = \mu n I$$

$$\frac{\mu}{\mu_o} \approx 1000$$

The B field in the electromagnet is much higher with an iron core than an air core.

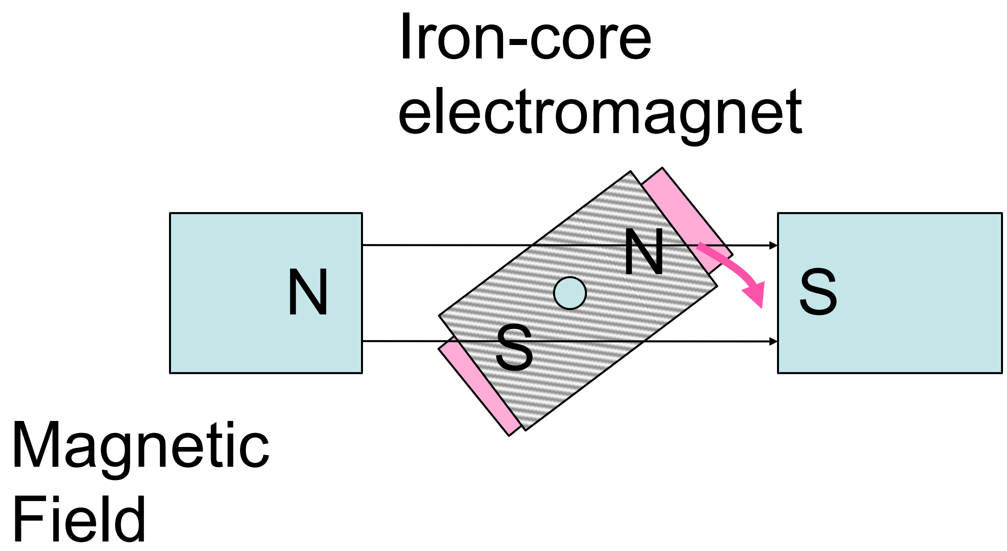
Applications of Iron core electromagnets

Electric motors, loudspeakers, electrical machinery



Applications of Iron core electromagnets

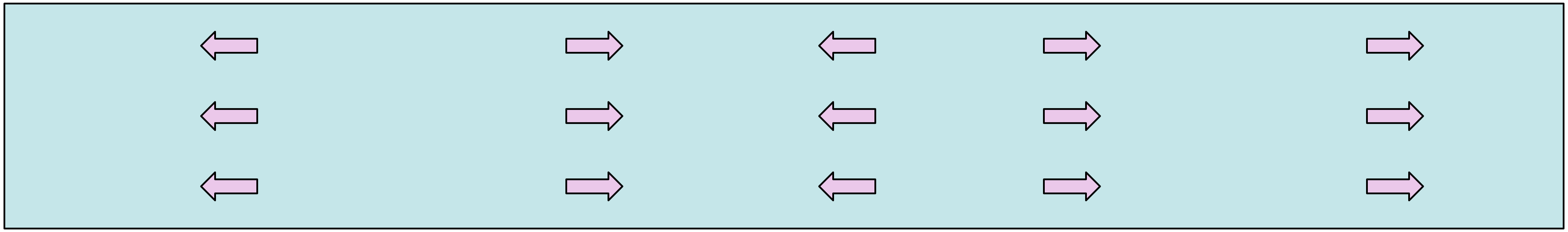
Electric motors, loudspeakers, electrical machinery



Homework/CAPE

Ch 19 Review

Magnetic tape
Information coded in the orientation of magnetic particles

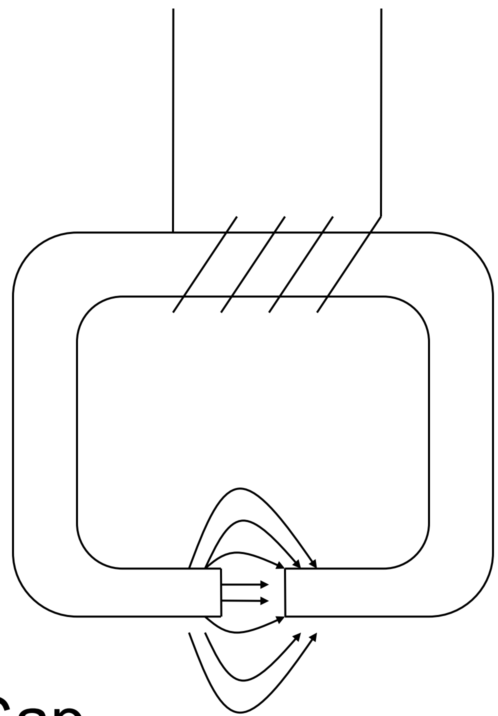


Magnetization can be read on playback to generate a voltage signal

Similar recording for computer hard disks, credit cards.

Information can be erased by magnetic fields.

Magnetic recording

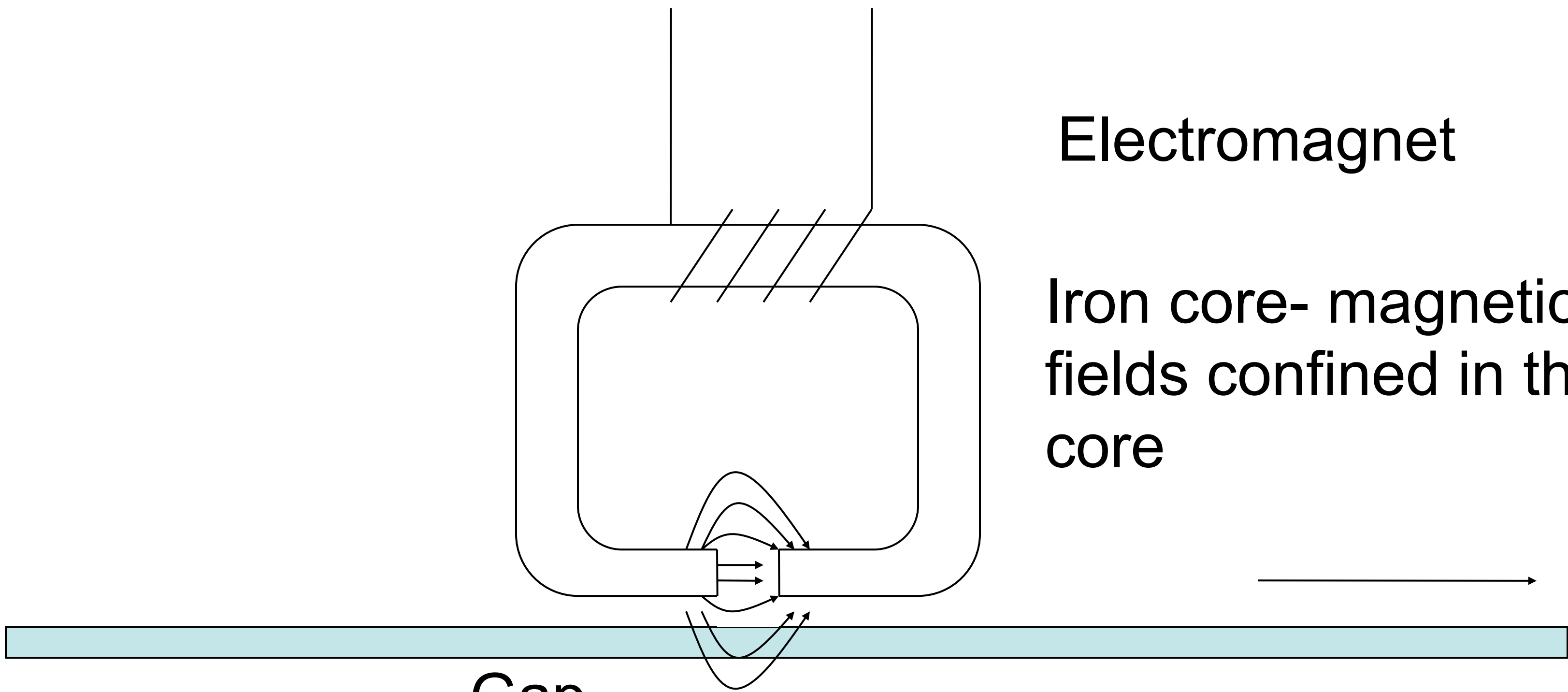


Magnetic recording

alternating current

Electromagnet

Iron core- magnetic fields confined in the core



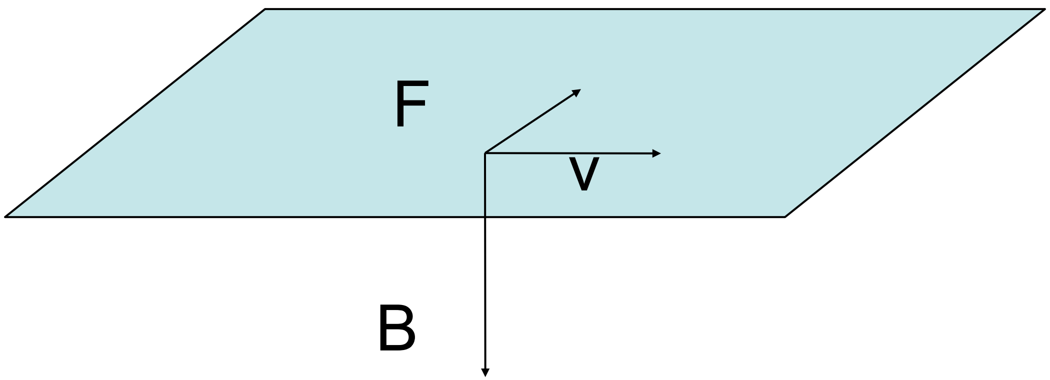
Gap

Fringe B-fields

Magnetic tape-magnetized by fringe fields

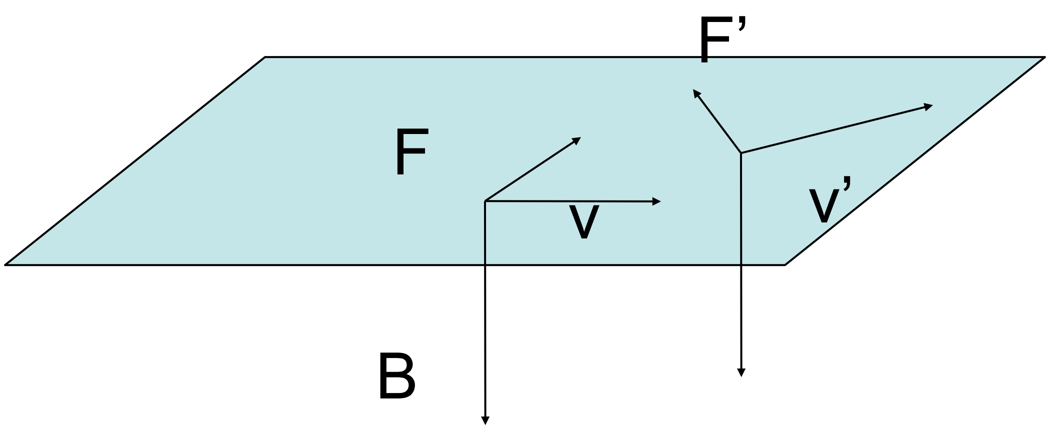
Motion of a charged particle in a magnetic field

F is in a plane perpendicular to B



(uniform magnetic field)

Motion of a charged particle in a magnetic field

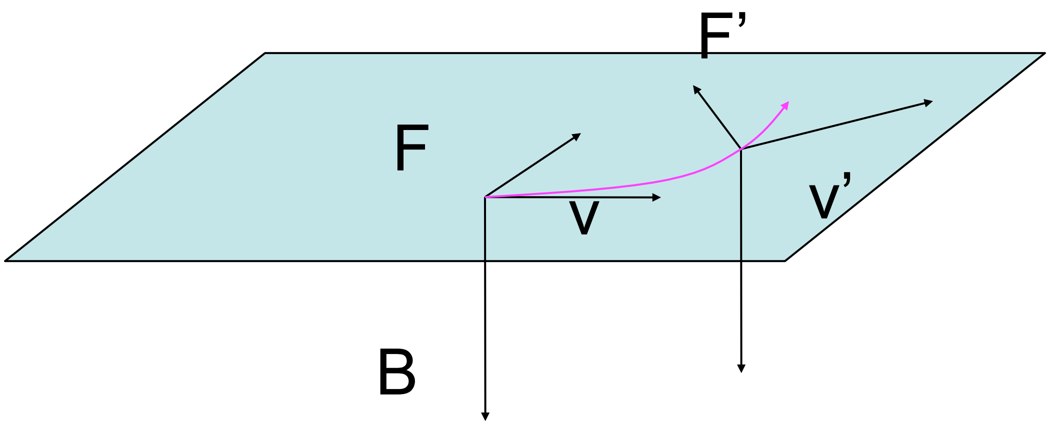


F is in a plane perpendicular to B

After Δt particle is in the same plane

(uniform magnetic field)

Motion of a charged particle in a magnetic field



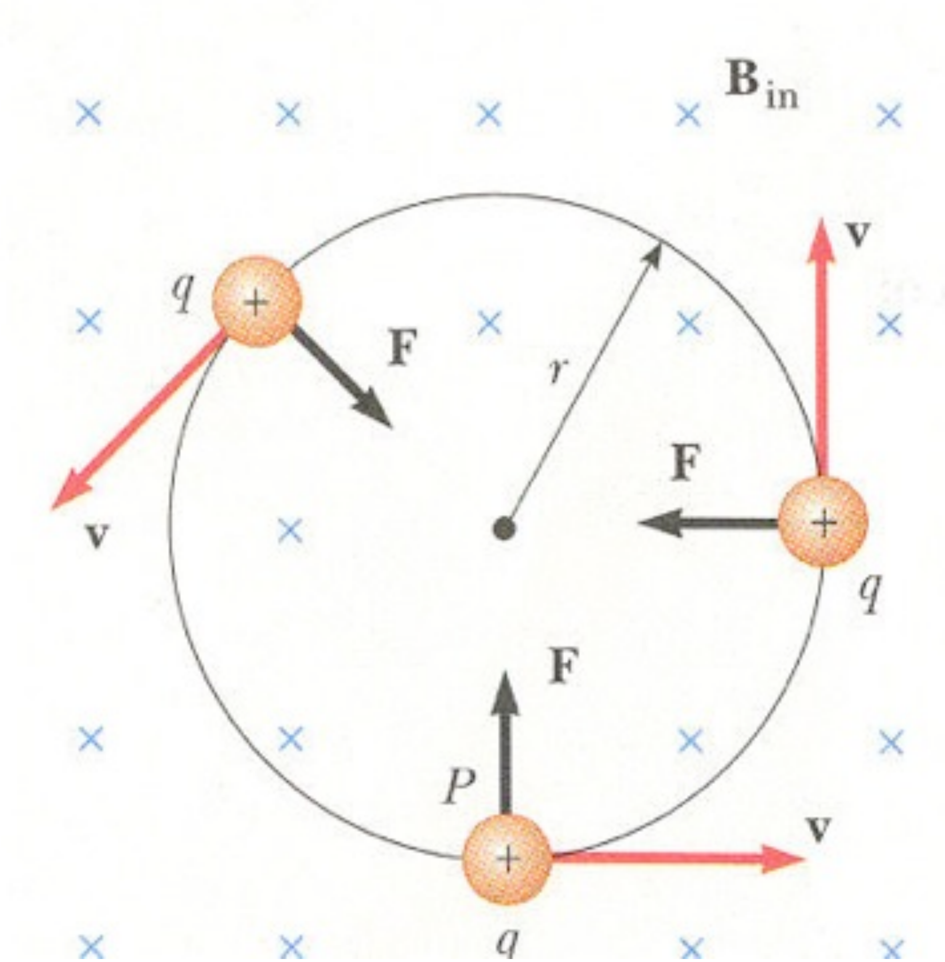
(uniform magnetic field)

F is in a plane perpendicular to B

After Δt particle is in the same plane

Particle moves in a plane perpendicular to B

Motion of particle in plane perpendicular to B



$$F = qvB = \frac{mv^2}{r}$$

$$r = \frac{mv}{qB}$$

The particle moves in a circular path

A proton with $v=1x10^6$ m/s is in a uniform magnetic field of 0.2 T. Find the radius of the trajectory

A proton with $v=1x10^6$ m/s is in a uniform magnetic field of 0.2 T. Find the radius of the trajectory

$$r = \frac{mv}{qB}$$

A proton with v=1x10^6 m/s is in a uniform magnetic field of 0.2 T. Find the radius of the trajectory

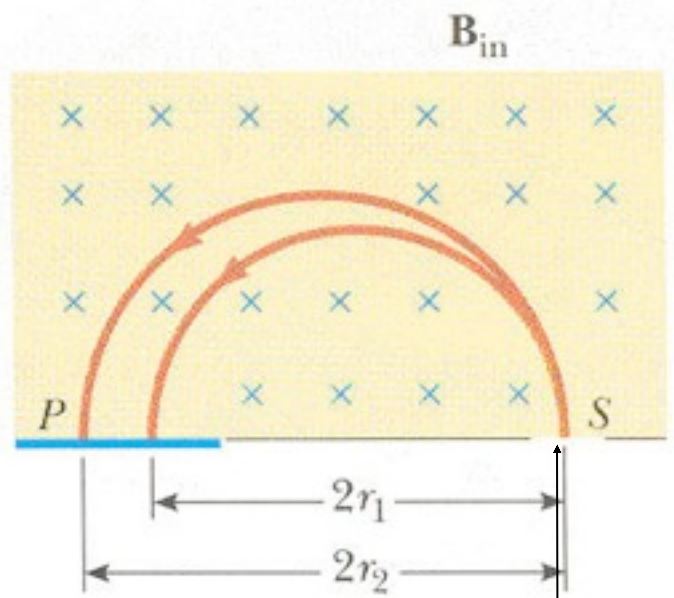
$$r = \frac{mv}{qB}$$

$$r = \frac{1.67x10^{-27}(1x10^{6})}{1.6x10^{-19}(0.2)}$$

$$r = 5.2x10^{-2}m = 5.2cm$$

Application

Mass spectrometer



Molecular ions
At velocity v

$$r = \frac{mv}{qB}$$

Ions separated by mass