- Final Exam (40% of grade) on Monday December 7th 1130a-230pm in York 2622
- You can bring ***two*** 8.5x11” pages, front and back, of notes
- Calculators may be used
- multiple choice like quizzes, only longer by about 2-3x more questions...
- Covers ALL of 1B: Ch15 - 21, inclusive

A few topics not covered in ch 19 that are applicable...

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.

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

$$B = (4\pi x 10^{-7})\left(\frac{100}{0.03}\right)20$$

$$B = 0.08T$$

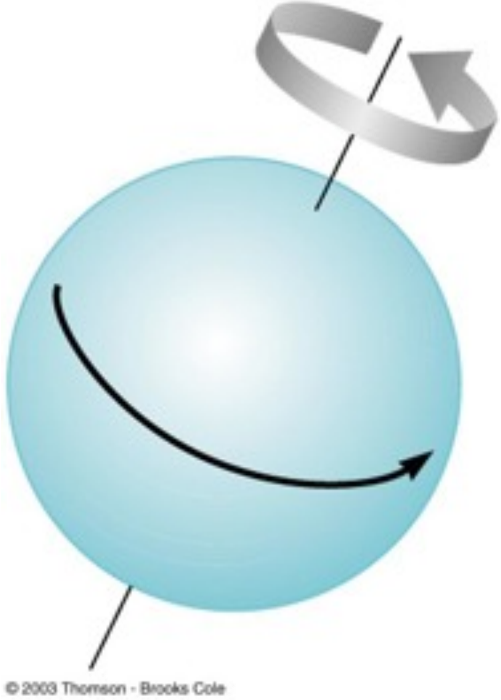
19.10 Magnetic Domains and Materials

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
diamagnetic	Carbon	$1-2x10^{-5}$ slightly less than vacuum
paramagnetic	Iron alum salt	slightly more than vacuum $1x10^{-5}$
ferromagnetic	Iron metal	much more than vacuum 1000-3000

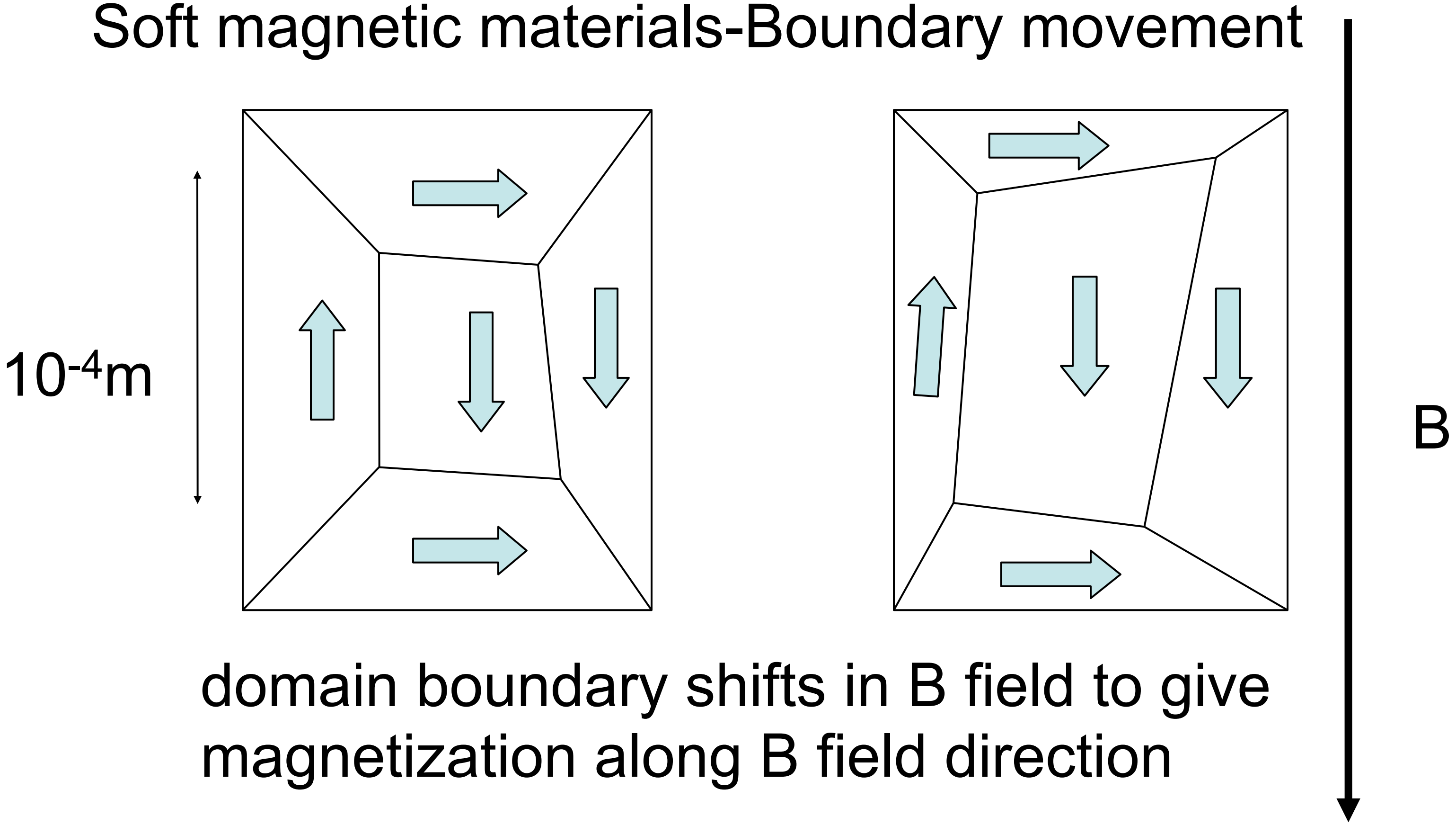
Soft magnetic materials
e.g. iron
Easily magnetized but doesn’t retain magnetization for long
Used as core for electromagnets

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

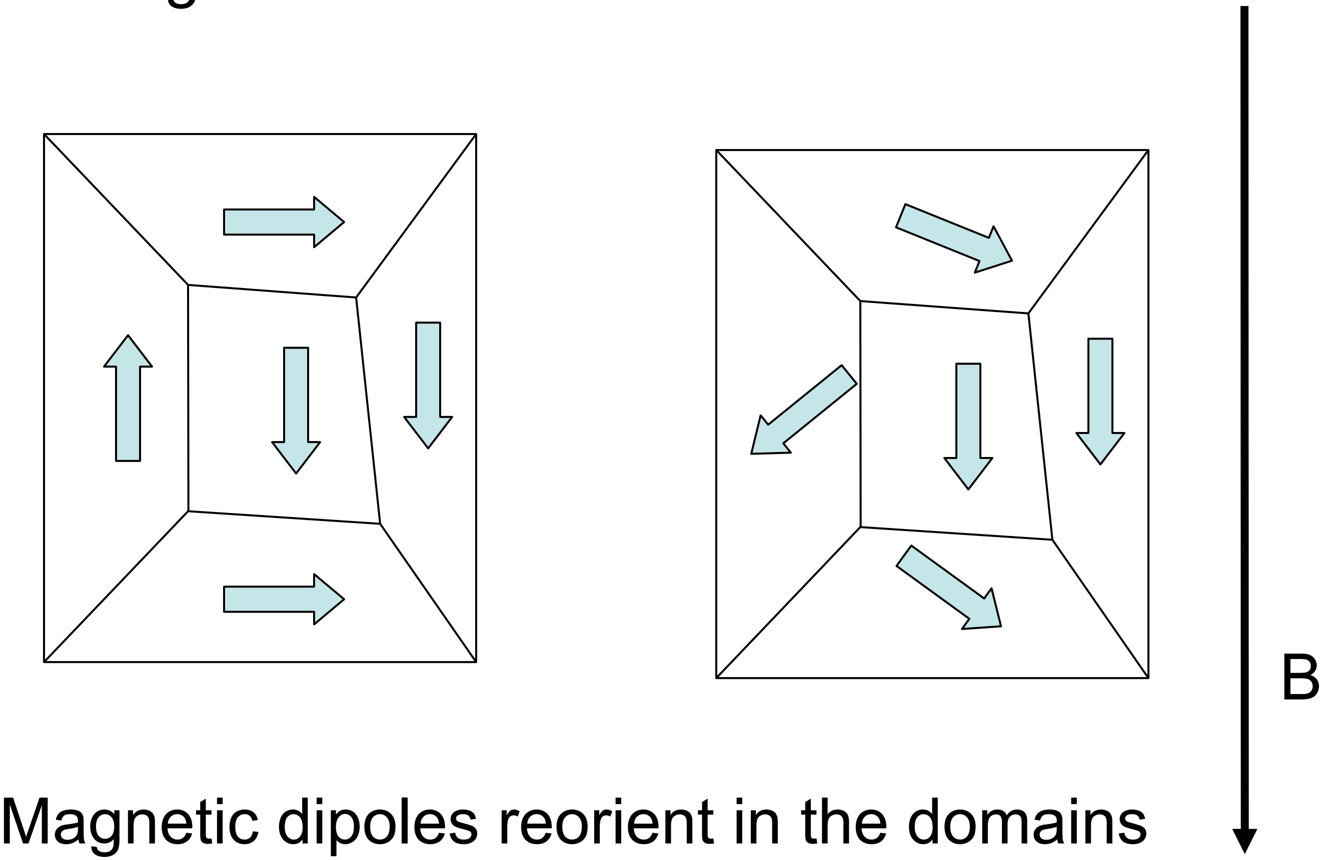
Magnetism due to magnetic domains.
Each domain has millions of atoms with magnetic moments coupled
Separated by domain boundaries

Soft magnetic materials-Boundary movement



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

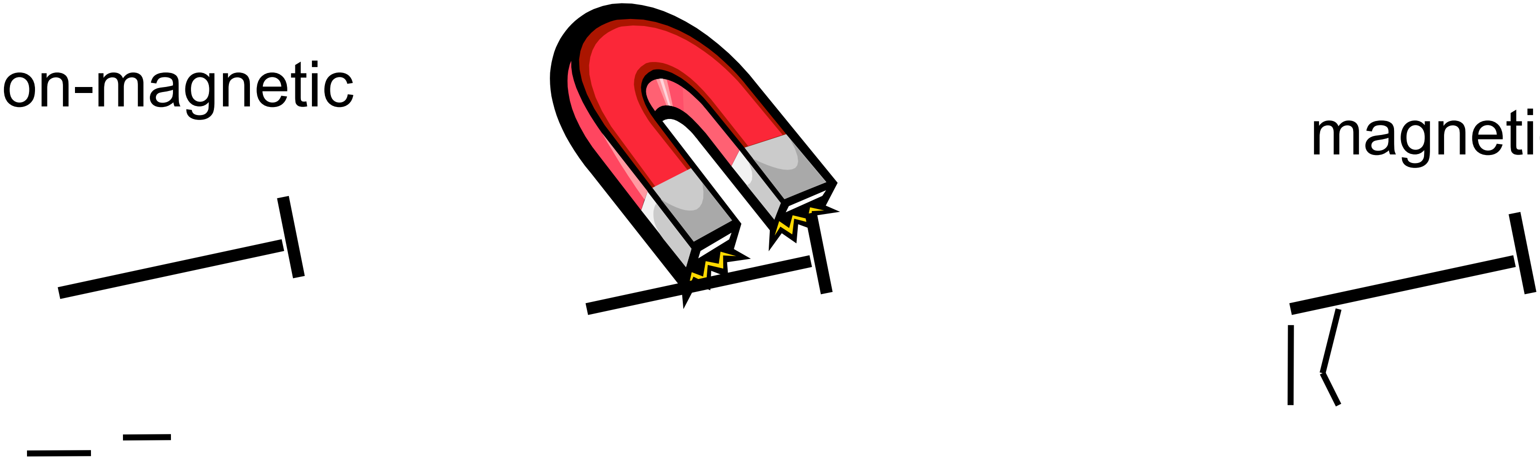
Hard magnetic materials



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.

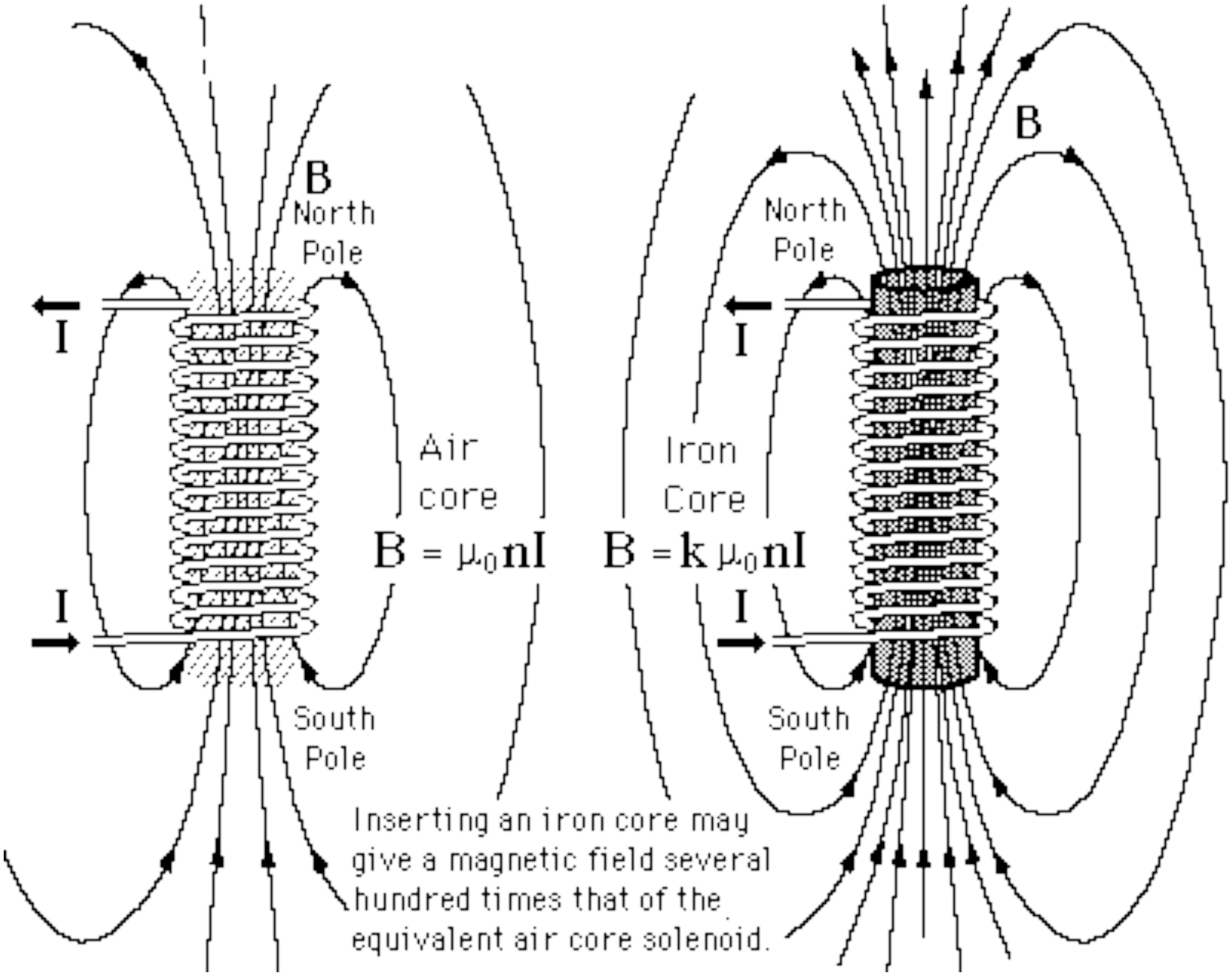
Magnetization

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



non-magnetic

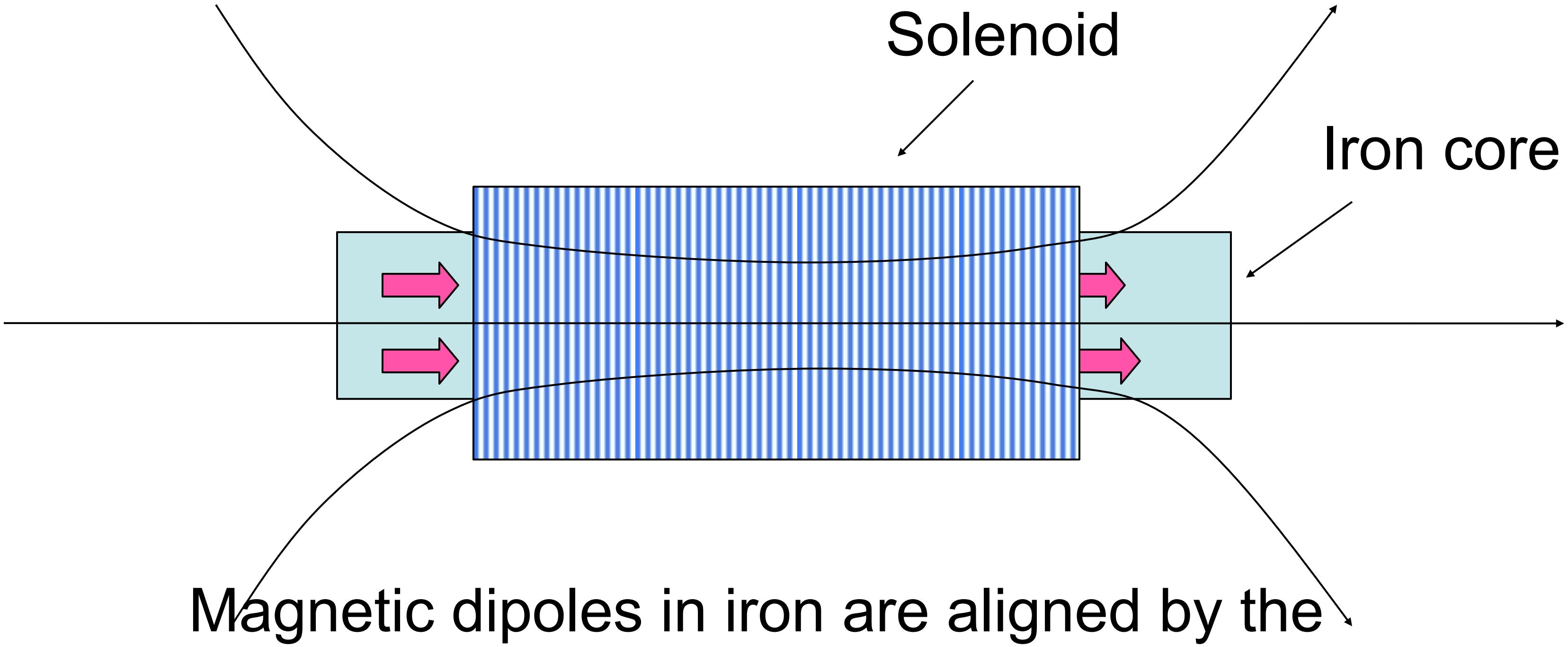
magnetic



$B = \mu_0 \mathbf{nI}$

$B = \mathbf{k}\,\mu_0 \mathbf{nI}$

Inserting an iron core may give a magnetic field several hundred times that of the equivalent air core solenoid.



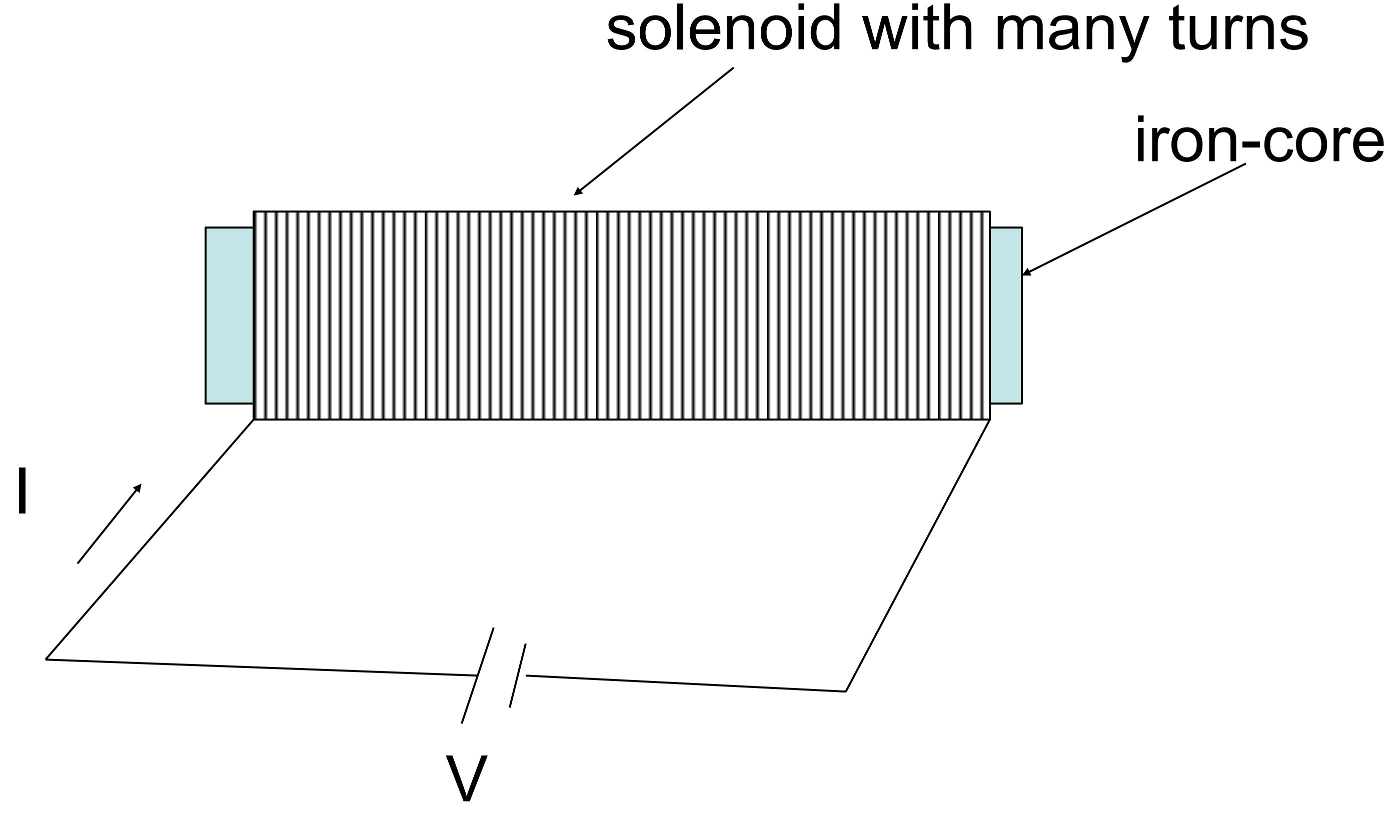
Magnetic material

Solenoid

Iron core

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

Iron core electromagnet



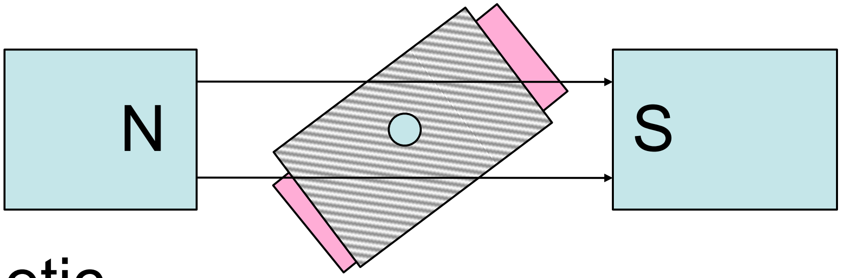
$B = \mu n I$

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

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



Iron-core electromagnet

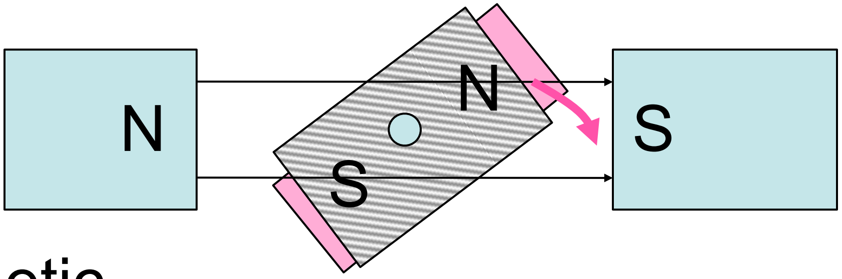
N

S

Magnetic Field

Applications of Iron core electromagnets

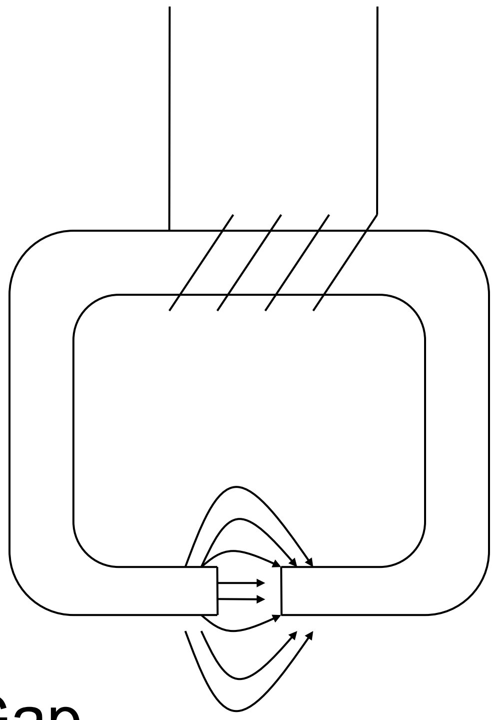
Electric motors, loudspeakers, electrical machinery



Iron-core electromagnet

Magnetic Field

Magnetic recording



alternating current

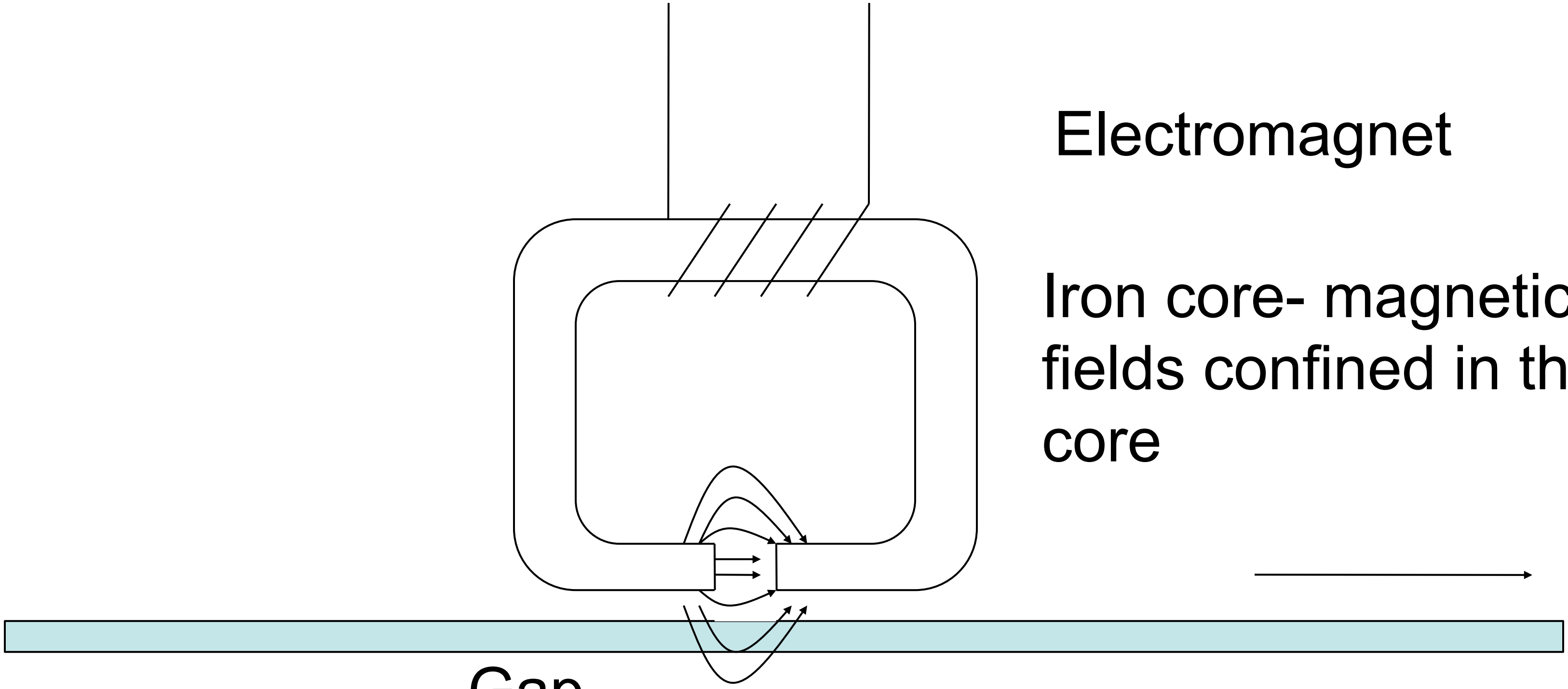
Electromagnet

Iron core- magnetic fields confined in the core

Gap

Fringe B-fields

Magnetic recording



alternating current

Electromagnet

Iron core- magnetic fields confined in the core

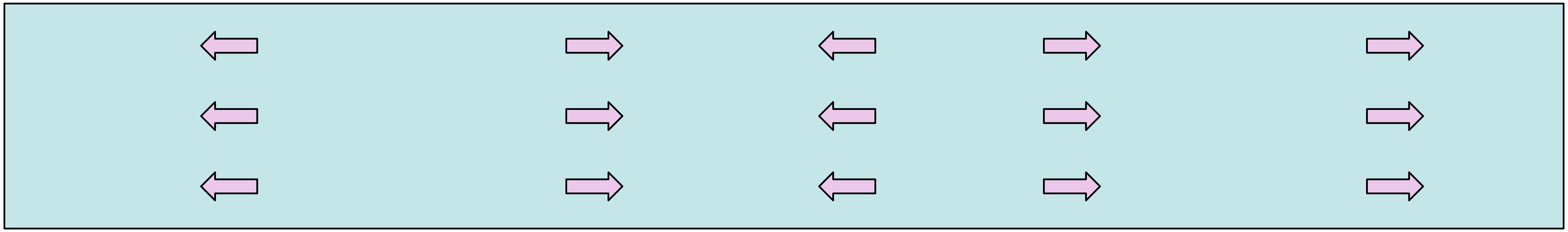
Gap

Fringe B-fields

Magnetic tape-magnetized by fringe fields

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.

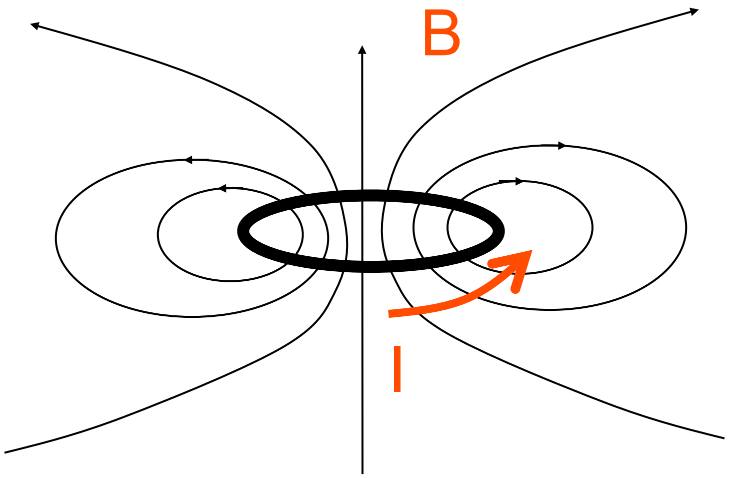
Today

Chapter 20.1 Induced EMF

Induced EMF

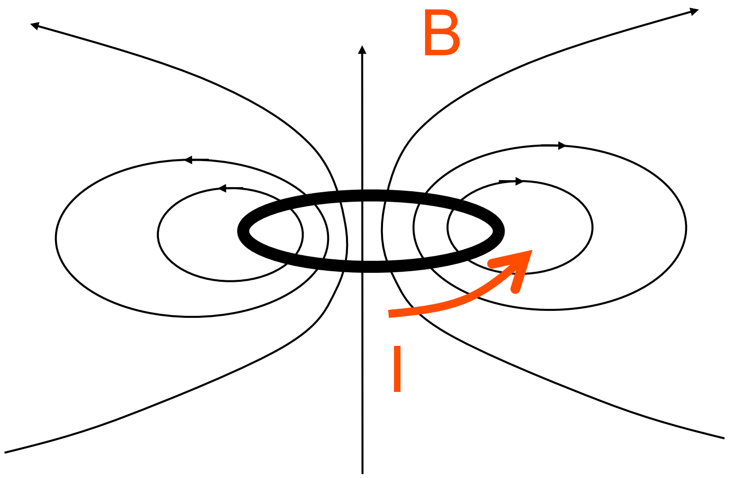
Faraday’s Law

Electric current gives rise to magnetic fields



Can a magnetic field give rise to a current?

Electric current gives rise to magnetic fields

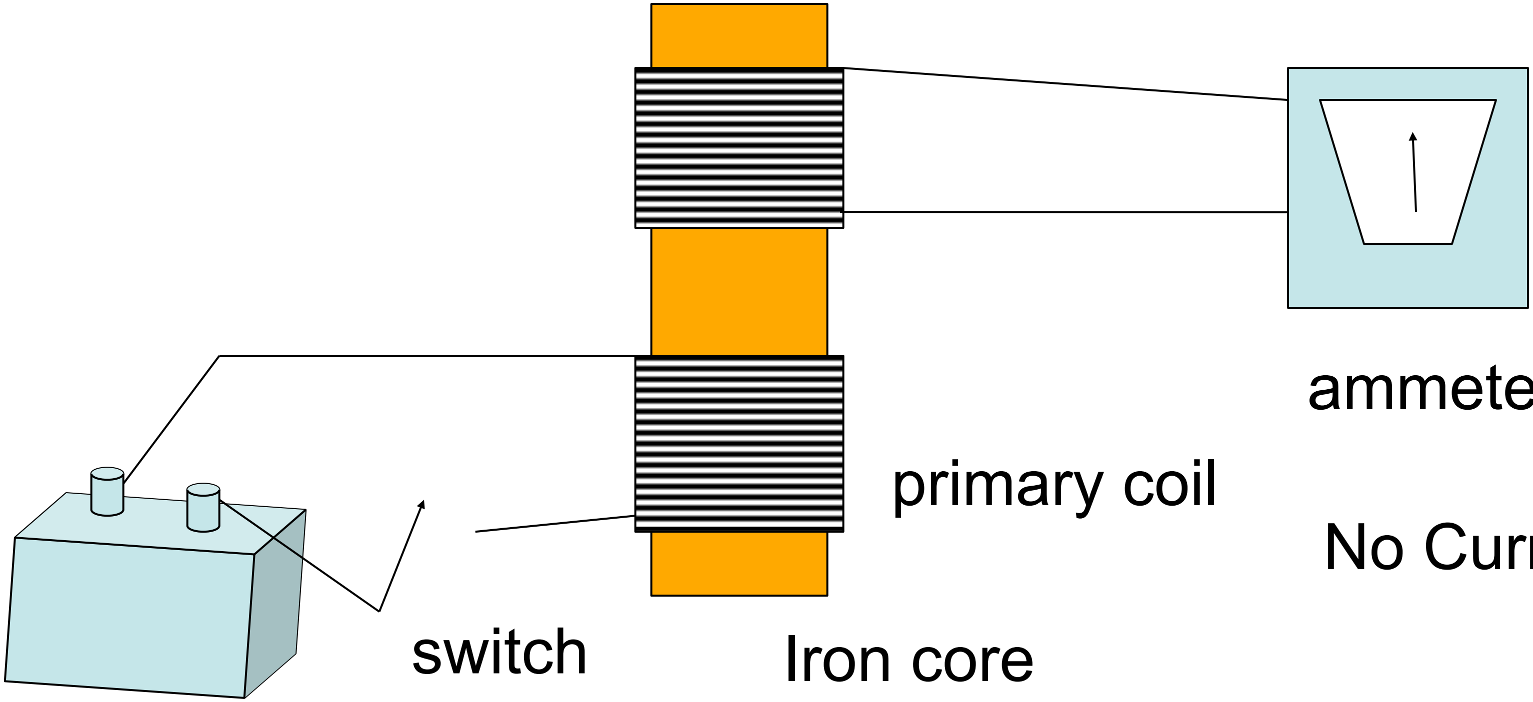


Can a magnetic field give rise to a current?

The answer is yes as discovered by Michael Faraday.

This discovery lead to important applications such as the electrical generator.

Michael Faraday



secondary coil

ammeter

primary coil

No Current

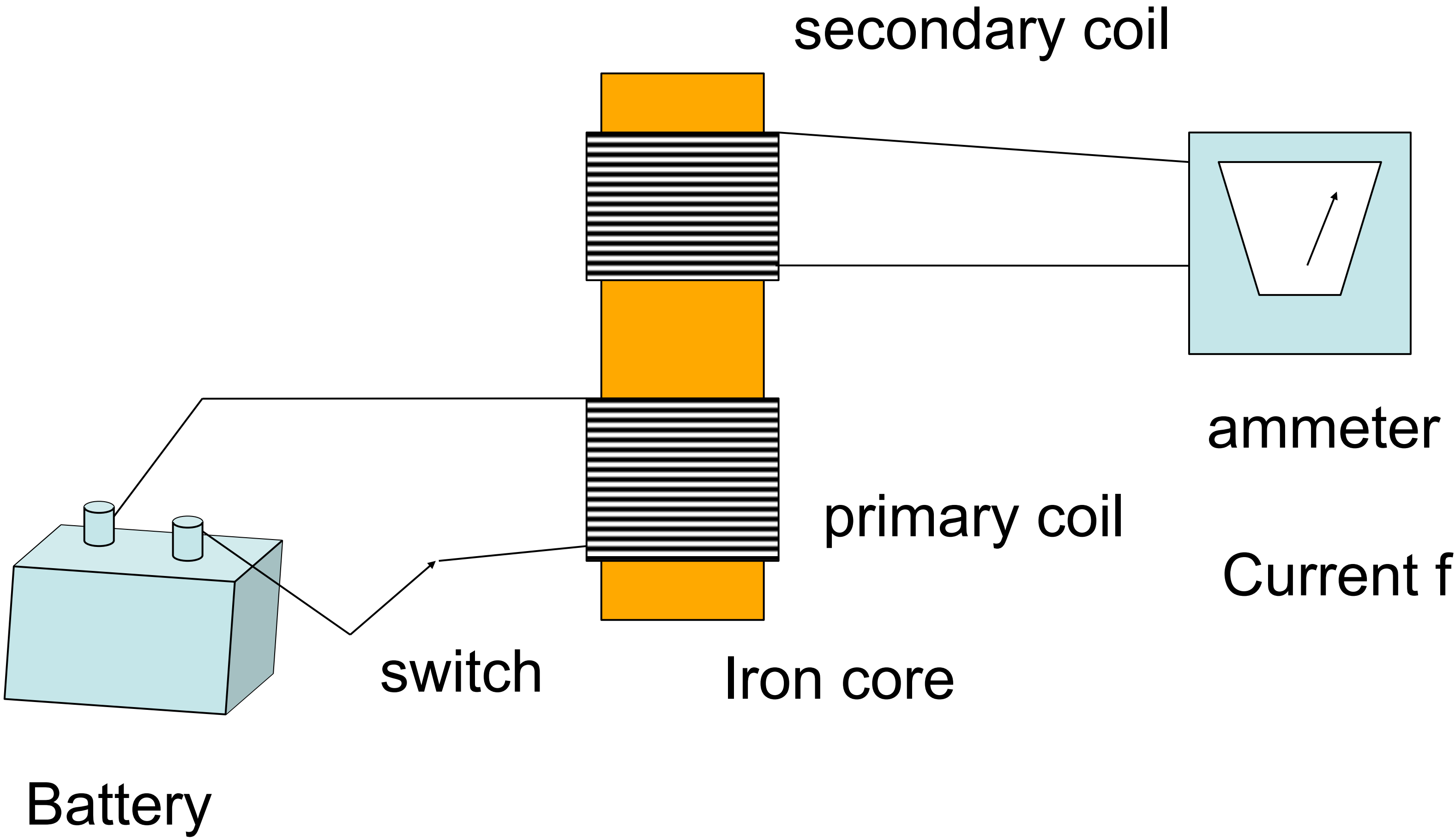
switch

Iron core

Battery

Battery off

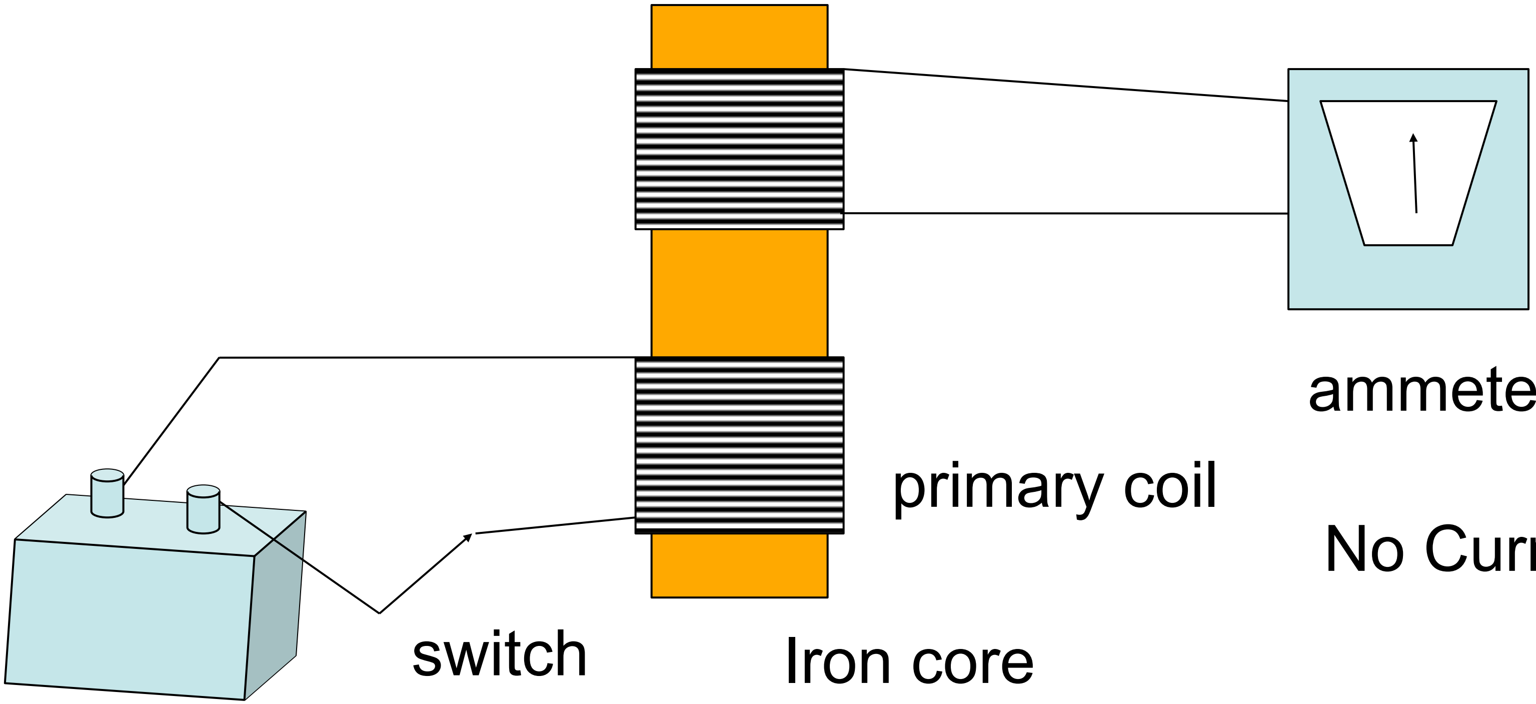
Michael Faraday



Current flows

Battery just switched on

Michael Faraday



secondary coil

ammeter

primary coil

No Current

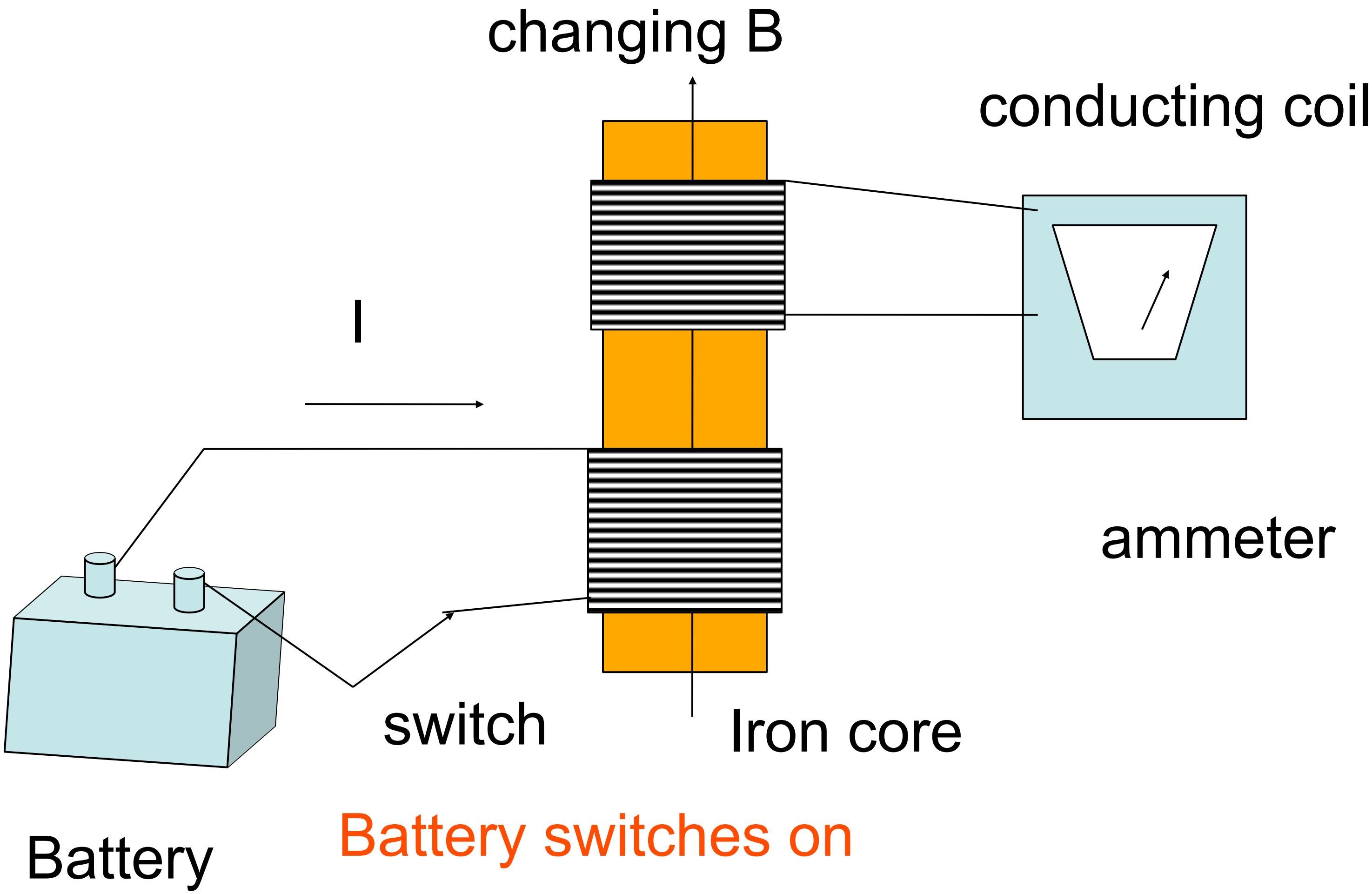
switch

Iron core

Battery

Battery on for a time

A changing magnetic field induces current flow



Battery switches on

Current in lower coil induces a changing B field in the iron

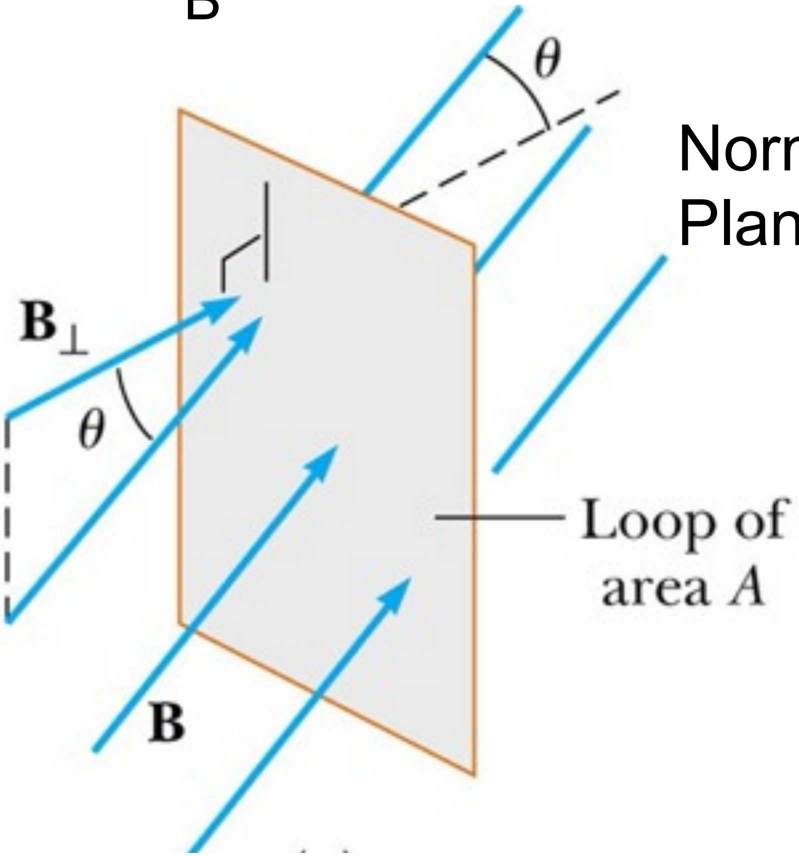
B field increases in upper coil

Conclusion

A changing magnetic field through the coil produces a current flow.

General description

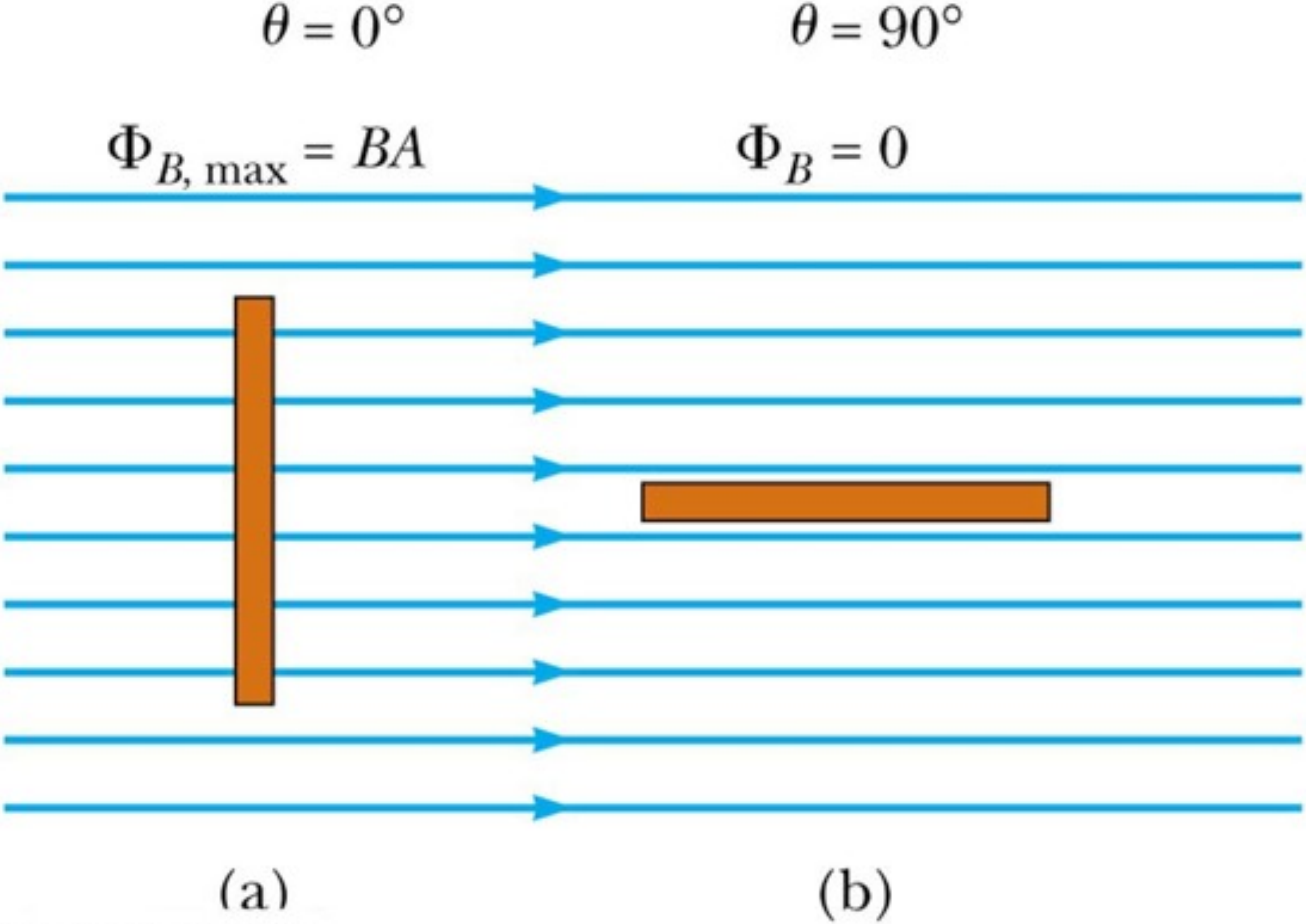
Magnetic flux Φ_B



Normal to the
Plane of the loop

$$\Phi_B = B_\perp A = BA\cos\theta$$

units Tesla m^2, weber (Wb)


$\theta = 0°$
$\theta = 90°$
$\Phi_{B,\max} = BA$
$\Phi_B = 0$
(a)
(b)

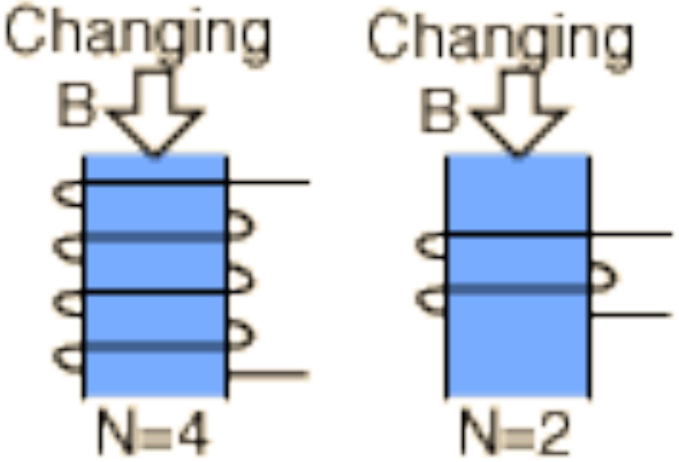
Faraday's Law

- The instantaneous emf induced in a circuit equals the time rate of change of MAGNETIC FLUX through the circuit
- If a circuit contains N tightly wound loops and the flux changes by ΔΦ during a time interval Δt, the average emf induced is given by *Faraday's Law:*

$$\varepsilon = -N\frac{\Delta\Phi_B}{\Delta t}$$

$$\frac{\Delta(BA)}{\Delta t} = 4\ \mathrm{Tm^2/s}$$

Changing magnetic flux



V_{gen} = -16 volts

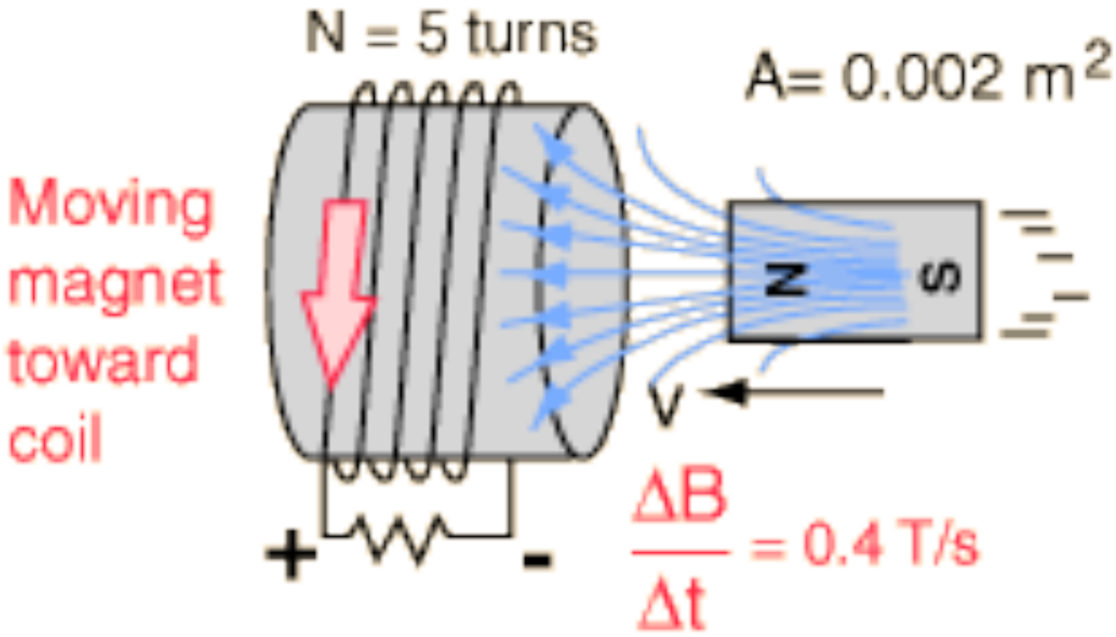
V_{gen} = -8 volts

$$\text{Voltage generated} = -N\frac{\Delta(BA)}{\Delta t}$$

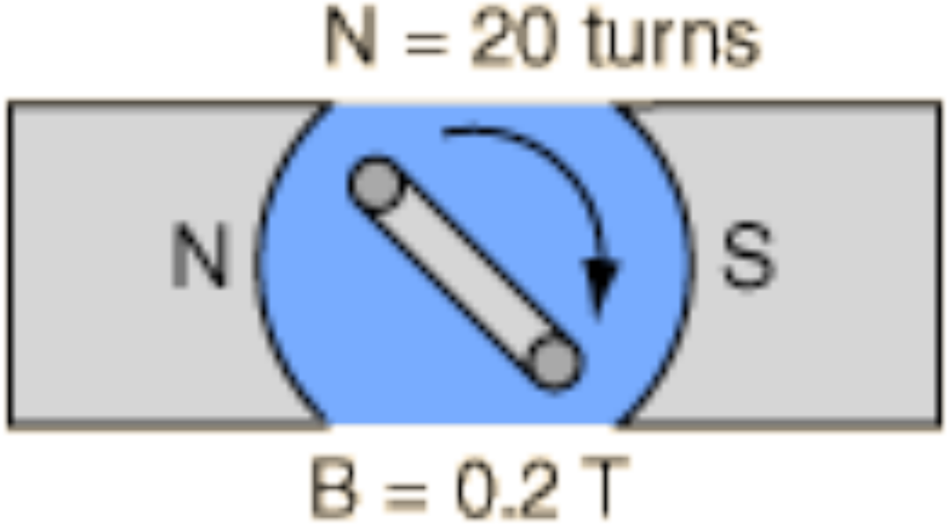
Faraday's Law

$$\text{Voltage generated} = -N\frac{\Delta(BA)}{\Delta t}$$

Faraday's Law



$$V_{gen} = -5 \times 0.002\ m^2 \times 0.4\ T/s$$
$$= -0.004\ \text{volts}$$

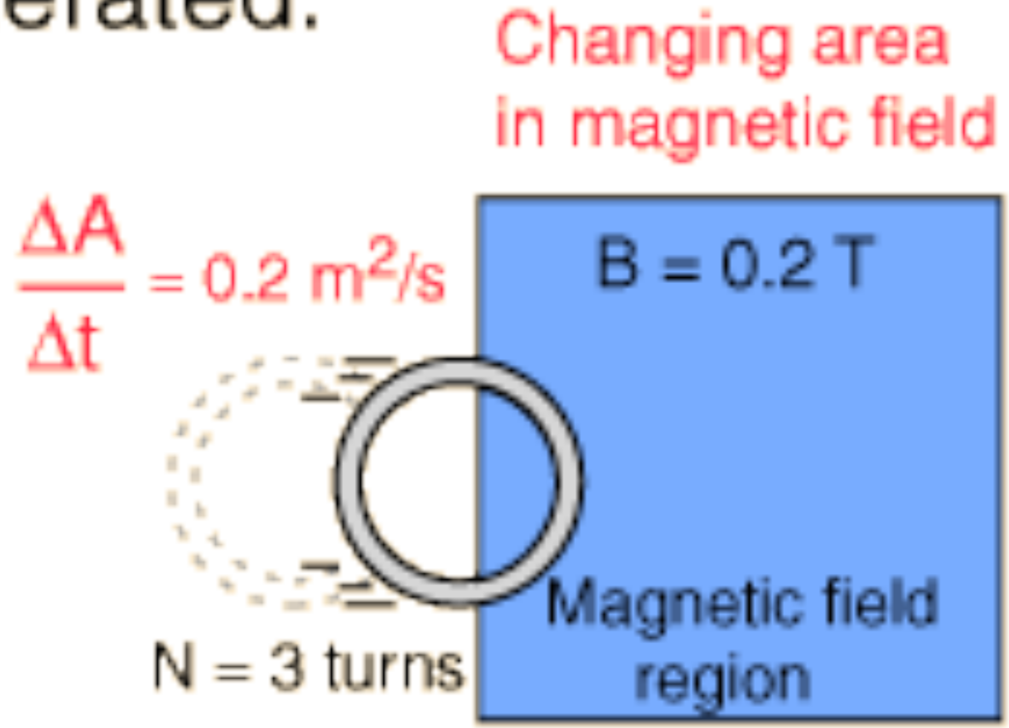


$$\frac{\Delta A}{\Delta t} = 0.2\ \text{m}^2/\text{s}$$

Rotating
coil in
magnetic
field

$$V_{gen} = -20 \times 0.2\ \text{T} \times 0.2\ \text{m}^2/\text{s}$$
$$= -0.8\ \text{volts}$$

Faraday's Law summarizes the ways voltage can be generated.



$$V_{gen} = -3 \times 0.2\ T \times 0.2\ m^2/s$$
$$= -0.12\ \text{volts}$$

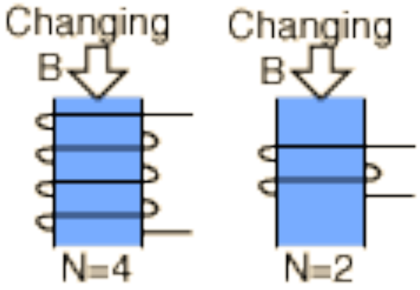
Faraday's Law summarizes the ways voltage can be generated.

$$\text{Voltage generated} = -N\frac{\Delta(BA)}{\Delta t}$$

Faraday's Law

Changing magnetic flux

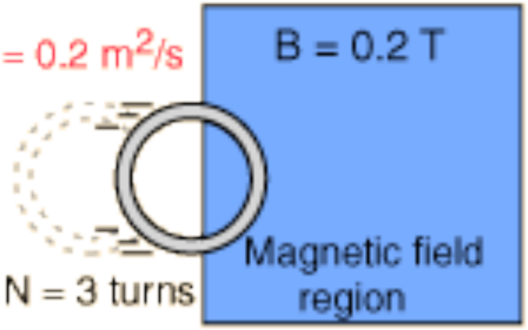
$\frac{\Delta(BA)}{\Delta t} = 4\ \mathrm{Tm^2/s}$



$V_{gen} = -16$ volts $V_{gen} = -8$ volts

Changing area in magnetic field

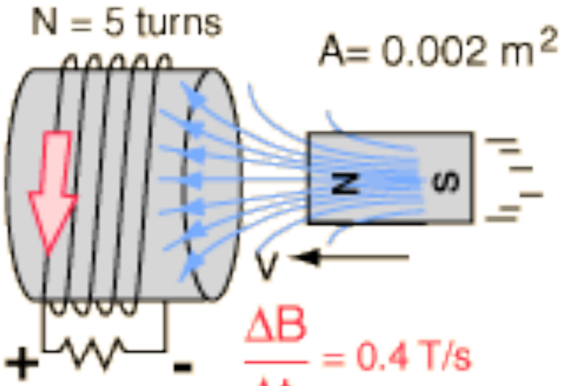
$\frac{\Delta A}{\Delta t} = 0.2\ \mathrm{m^2/s}$



$V_{gen} = -3 \times 0.2\ \mathrm{T} \times 0.2\ \mathrm{m^2/s}$

$= -0.12$ volts

Moving magnet toward coil



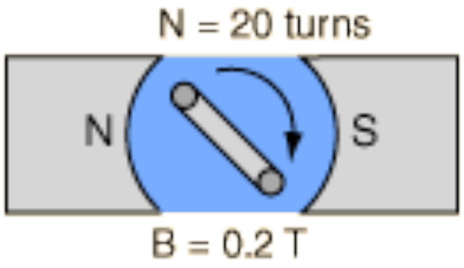
$\frac{\Delta B}{\Delta t} = 0.4\ \mathrm{T/s}$

$V_{gen} = -5 \times 0.002\ \mathrm{m^2} \times 0.4\ \mathrm{T/s}$

$= -0.004$ volts

Rotating coil in magnetic field

$\frac{\Delta A}{\Delta t} = 0.2\ \mathrm{m^2/s}$



$V_{gen} = -20 \times 0.2\ \mathrm{T} \times 0.2\ \mathrm{m^2/s}$

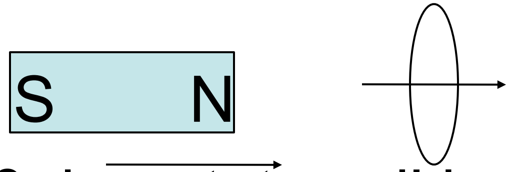
$= -0.8$ volts

The change in the flux, $\Delta\Phi$, can be produced by a change in B, A or θ

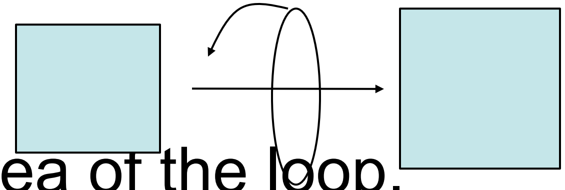
Since $\Phi_B = B\ A \cos\theta$

- Change B

B increases



- Change θ, i.e rotate coil in B field



- Change the area of the loop.

Lenz’s Law

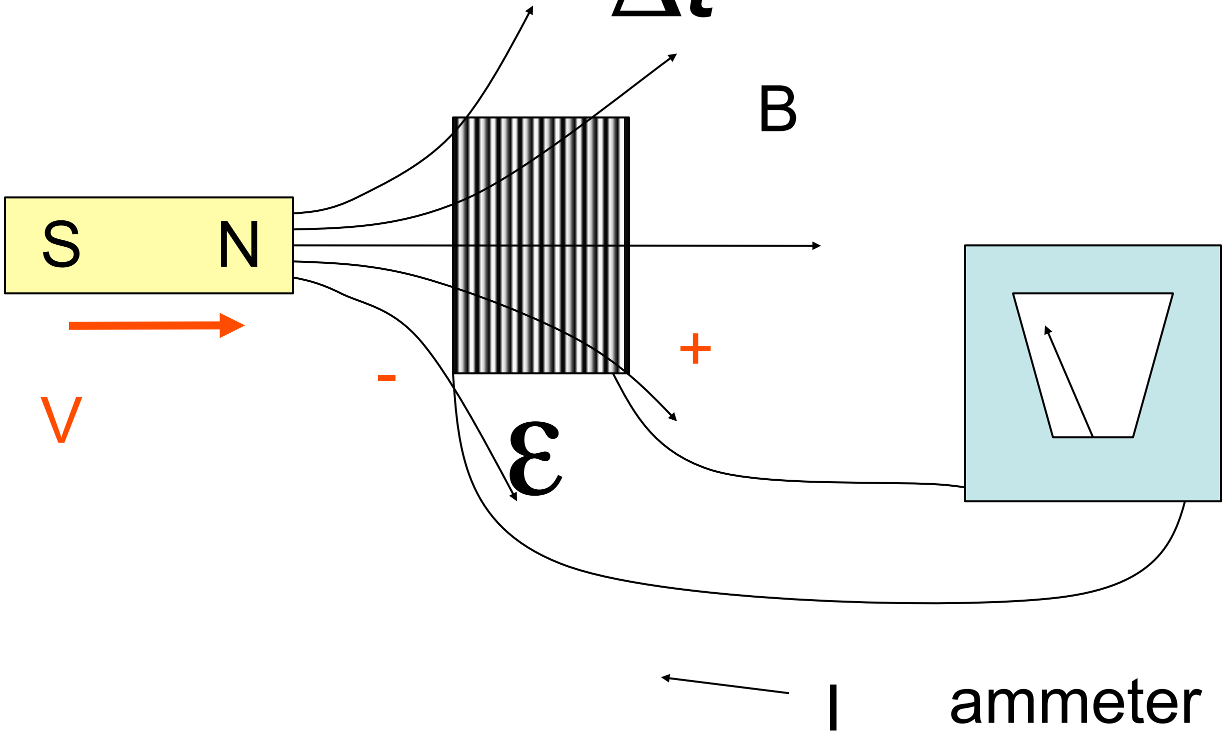
- The negative sign in Faraday’s Law is included to indicate the polarity of the induced emf, which is found by *Lenz’ s Law* .
- The polarity of the induced emf is such that it produces a current whose magnetic field opposes the change in magnetic flux through the loop.

Faraday’s Law

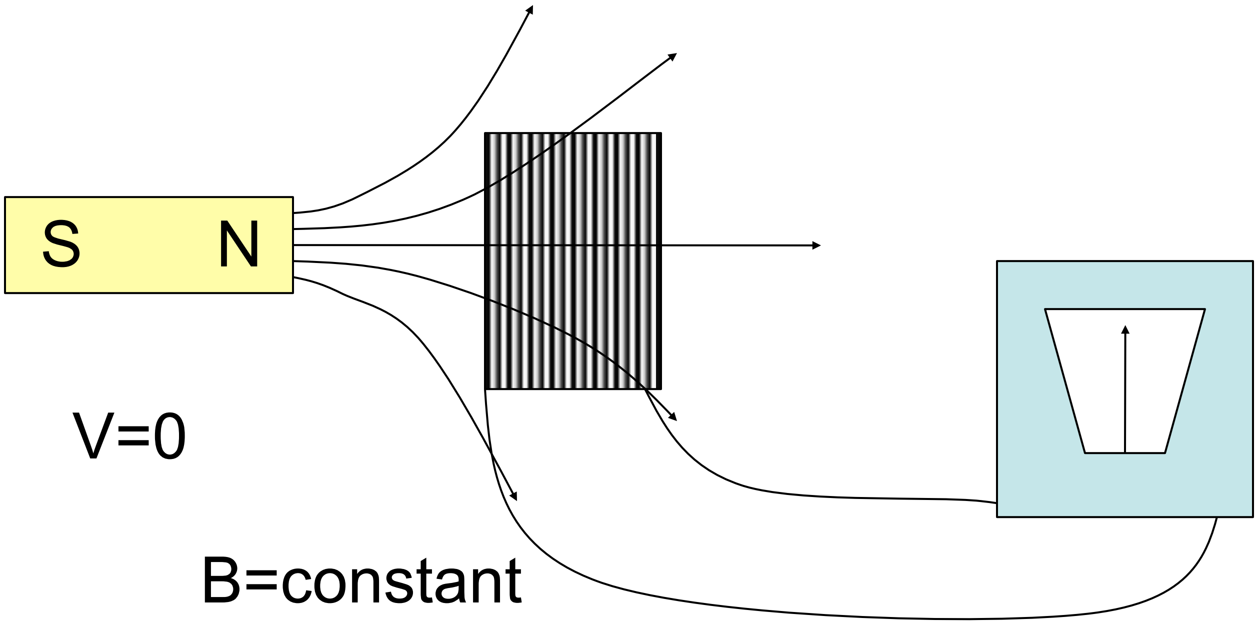
The instantaneous emf across a loop is equal to the rate of change of the flux through the loop. Eg. For a coil with N turns

$$\varepsilon = -N\frac{\Delta\Phi_B}{\Delta t}$$

N number of turns in coil



Faraday Experiment



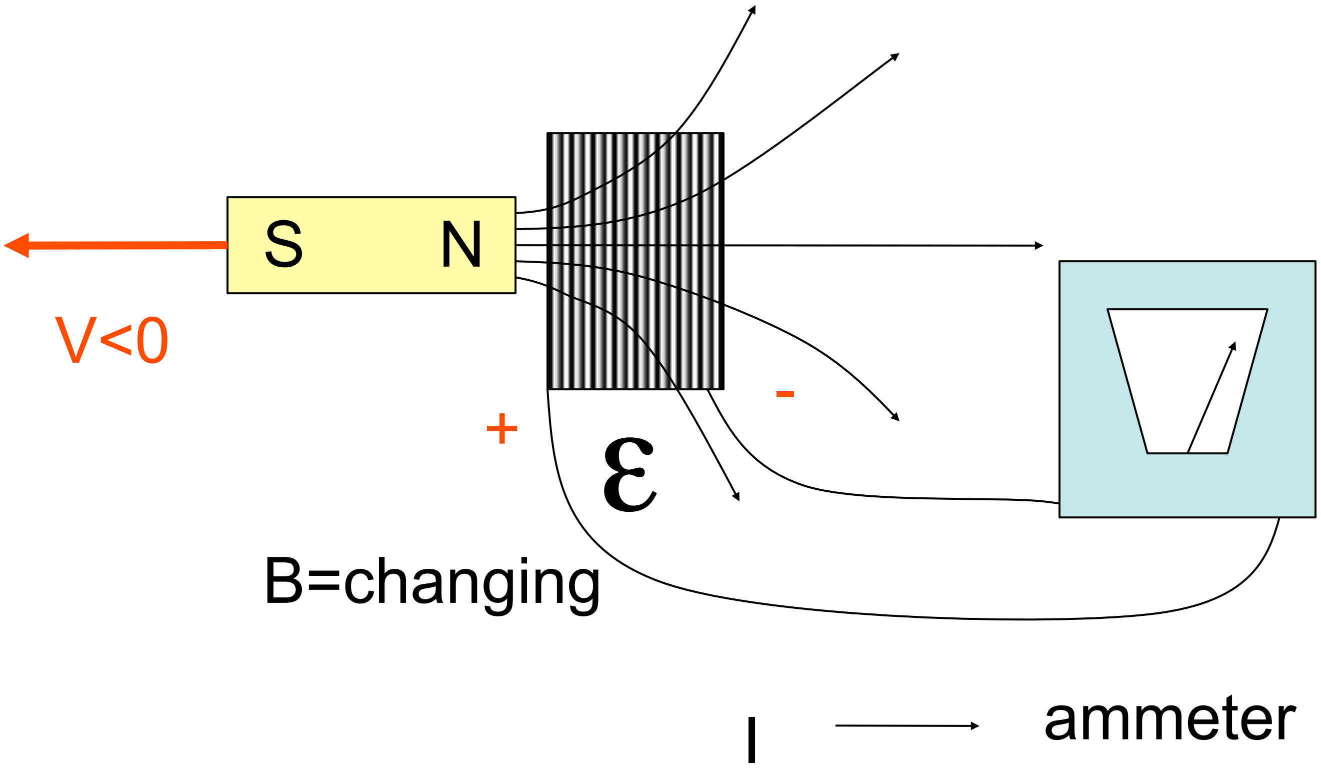
V=0

B=constant

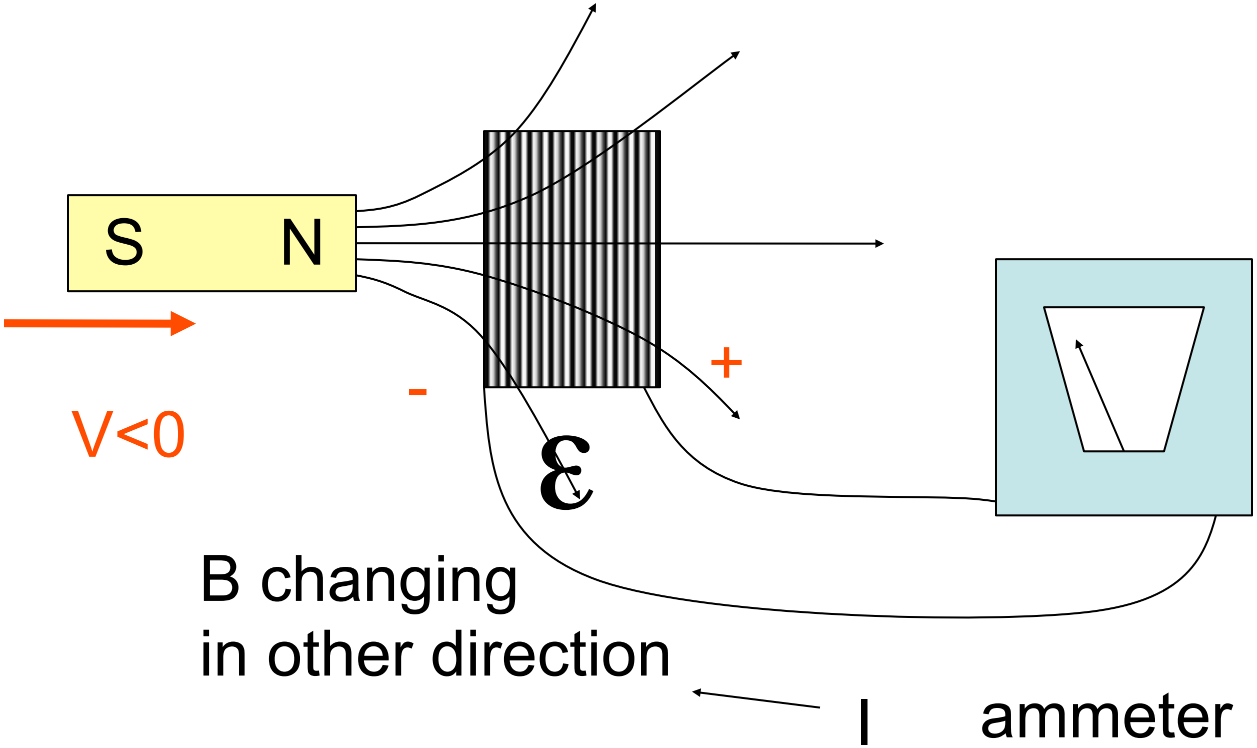
I=0

ammeter

Changing magnetic flux produces an EMF (voltage difference) that drives current



Changing magnetic flux in the opposite direction
Reverses the sign of the emf.



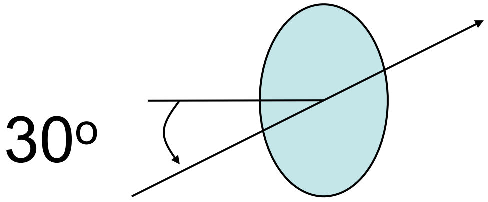
B changing
in other direction

ammeter

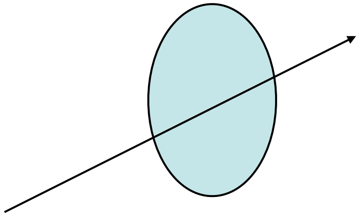
Current flows in opposite direction

2. A circular loop with a radius of 0.20 m is placed in a uniform magnetic field B=0.85 T. The normal to the loop makes an angle of 30^{o} with the direction of B. The field increases to 0.95 T what is the change in the magnetic flux through the loop?

Change in flux?

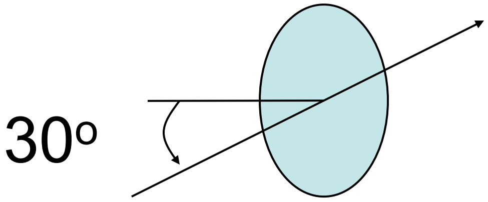


B=0.85T

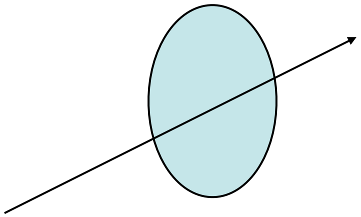


B’=0.95T

2. A circular loop with a radius of 0.20 m is placed in a uniform magnetic field B=0.85 T. The normal to the loop makes an angle of 30° with the direction of B. The field increases to 0.95 T what is the change in the magnetic flux through the loop?



B=0.85T

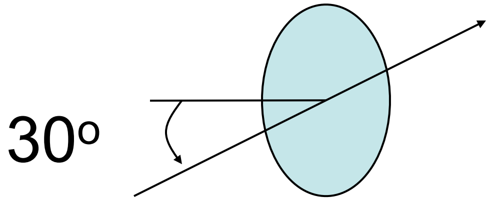


B’=0.95T

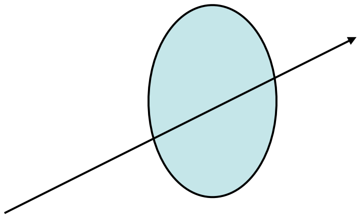
Change in flux?

$$\Delta\Phi_B = B'A'\cos\theta' - BA\cos\theta$$

2. A circular loop with a radius of 0.20 m is placed in a uniform magnetic field B=0.85 T. The normal to the loop makes an angle of 30° with the direction of B. The field increases to 0.95 T what is the change in the magnetic flux through the loop?



B=0.85T



B’=0.95T

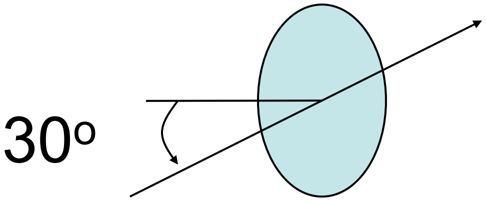
Change in flux?

$$\Delta\Phi_B = B'A'\cos\theta' - BA\cos\theta$$

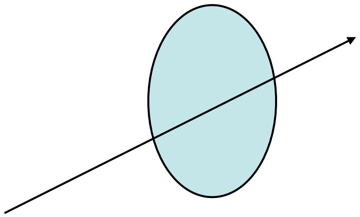
$$A' = A = \pi R^2$$

$$\theta' = \theta = 30^o$$

2. A circular loop with a radius of 0.20 m is placed in a uniform magnetic field B=0.85 T. The normal to the loop makes an angle of 30^o with the direction of B. The field increases to 0.95 T what is the change in the magnetic flux through the loop?



B=0.85T



B’=0.95T

Change in flux?

$$\Delta\Phi_B = B'A'\cos\theta' - BA\cos\theta$$

$$A' = A = \pi R^2$$

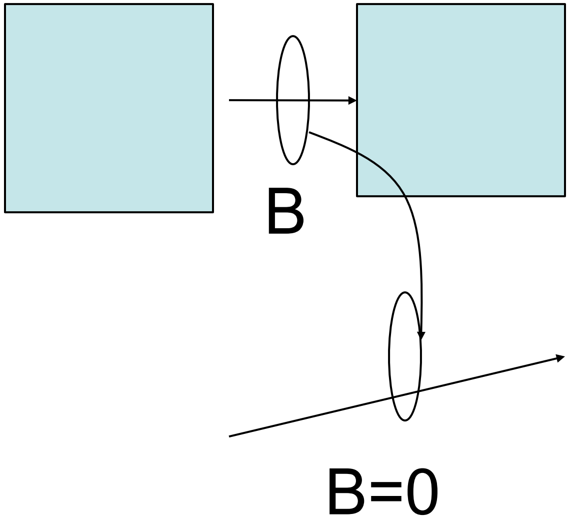
$$\theta' = \theta = 30^o$$

$$\Delta\Phi_B = A\cos\theta(B'-B) = \pi R^2\cos 30(B'-B)$$

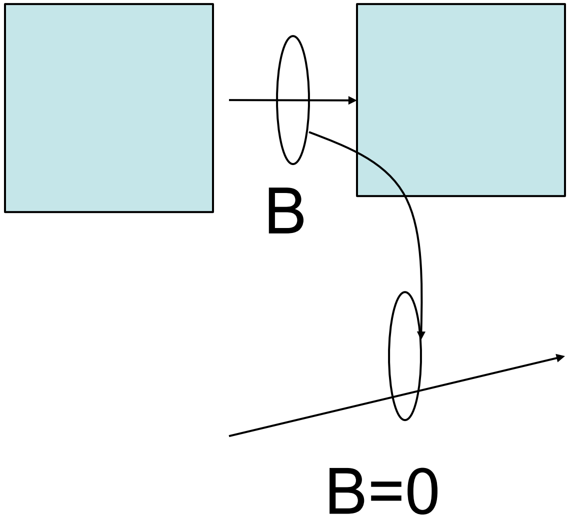
$$\Delta\Phi_B = \pi(0.2)^2\cos 30(0.95-0.85)$$

$$\Delta\Phi_B = 1.1x10^{-2}Wb$$

8. A circular coil with a radius of 20 cm is in a field of 0.2 T with the plane of the coil perpendicular to the field. If the coil is pulled out of the field in 0.30 s find the average emf during this interval



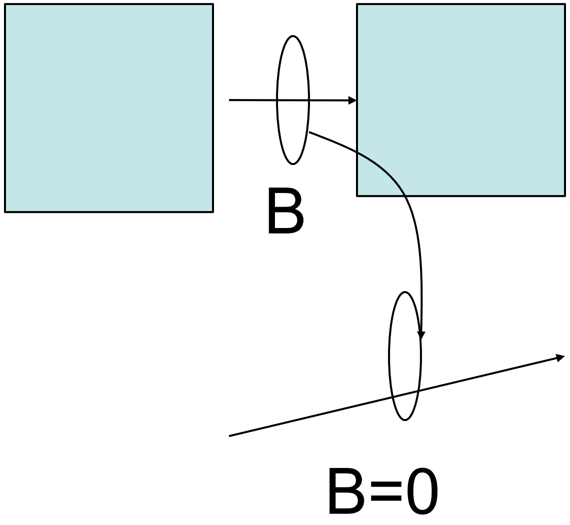
8. A circular coil with a radius of 20 cm is in a field of 0.2 T with the plane of the coil perpendicular to the field. If the coil is pulled out of the field in 0.30 s find the average emf during this interval



$$\varepsilon = N\frac{\Delta\Phi_B}{\Delta t} = N\frac{BA\cos\theta - 0}{\Delta t}$$

N=
cosθ=
A=

8. A circular coil with a radius of 20 cm is in a field of 0.2 T with the plane of the coil perpendicular to the field. If the coil is pulled out of the field in 0.30 s find the average emf during this interval



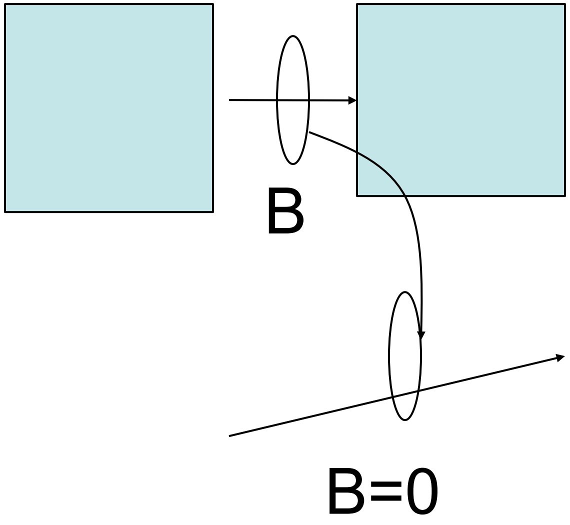
$$\varepsilon = N\frac{\Delta\Phi_B}{\Delta t} = N\frac{BA\cos\theta - 0}{\Delta t}$$

N= 1

cosθ=

A=

8. A circular coil with a radius of 20 cm is in a field of 0.2 T with the plane of the coil perpendicular to the field. If the coil is pulled out of the field in 0.30 s find the average emf during this interval



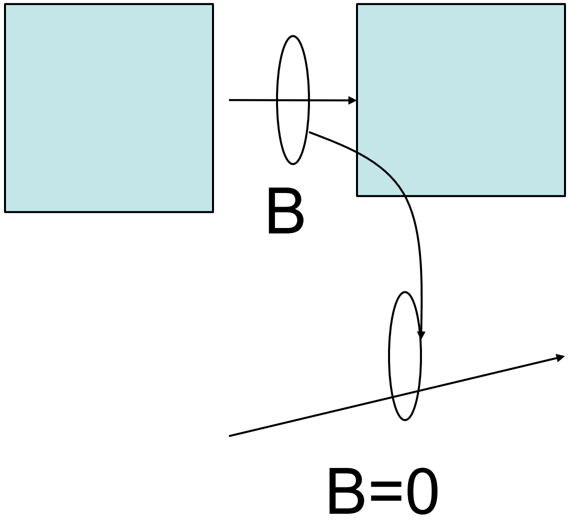
$$\varepsilon = N\frac{\Delta\Phi_B}{\Delta t} = N\frac{BA\cos\theta - 0}{\Delta t}$$

N= 1

cosθ= 1

A=

8. A circular coil with a radius of 20 cm is in a field of 0.2 T with the plane of the coil perpendicular to the field. If the coil is pulled out of the field in 0.30 s find the average emf during this interval



$$\varepsilon = N\frac{\Delta\Phi_B}{\Delta t} = N\frac{BA\cos\theta - 0}{\Delta t}$$

N= 1
cosθ= 1
A= πR^2

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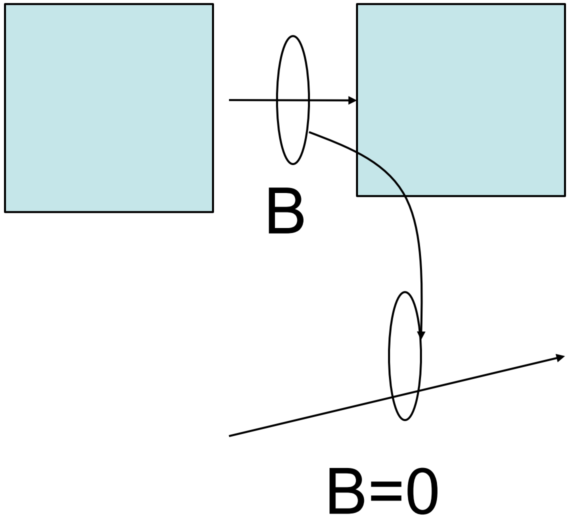


$$\varepsilon = N\frac{\Delta\Phi_B}{\Delta t} = N\frac{BA\cos\theta - 0}{\Delta t}$$

N= 1

cosθ= 1

A= πR^2

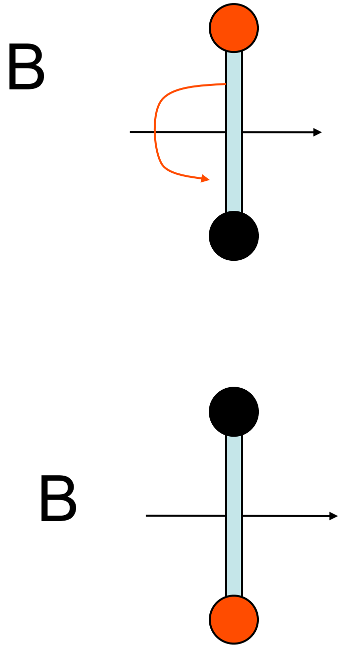
$$\varepsilon = \frac{B\pi R^2}{\Delta t} = \frac{0.2\pi(0.2)^2}{0.3}$$

$$\varepsilon = 8.4x10^{-2}V$$

9. A 25 turn circular coil of wire has a diameter of 1.00 m it is placed with its axis along the direction of the earth’s magnetic field of 50 x10^{-6} T. Then in 0.2 s it is flipped 180°. What is the magnitude of the average emf generated?

Change in flux?

Emf?



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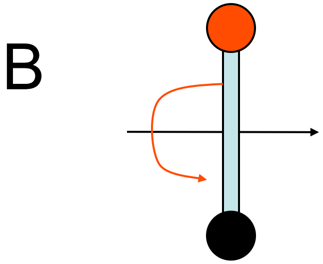
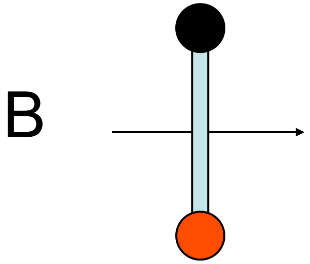


Φ_B=BA

B field in

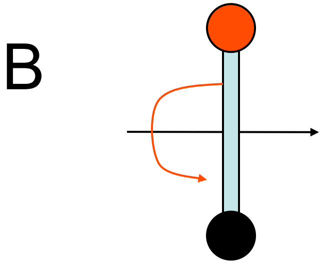
Emf?



-Φ_B=-BA

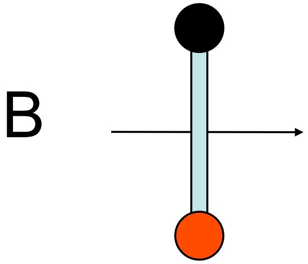
B field out

9. A 25 turn circular coil of wire has a diameter of 1.00 m it is placed with its axis along the direction of the earth's magnetic field of 50 x10^{-6} T. Then in 0.2 s it is flipped 180°. What is the magnitude of the average emf generated?



Φ_B=BA

B field in



-Φ_B=-BA

B field out

Change in flux?

$\Delta\Phi_B = \Phi_B - (-\Phi_B) = 2\,\Phi_B = 2BA$

Emf?

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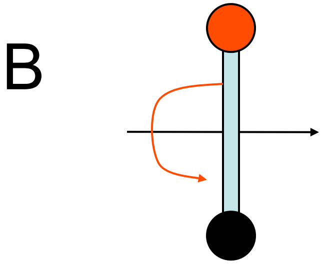
Change in flux?

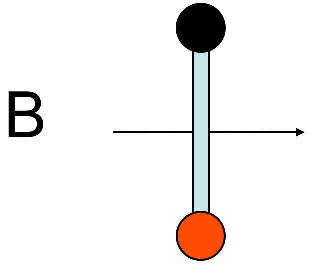


Φ_B=BA

B field in

$$\Delta\Phi_B = \Phi_B - (-\Phi_B) = 2\,\Phi_B = 2BA$$

Emf?



-Φ_B=-BA

B field out

$$\varepsilon = N\frac{\Delta\Phi_B}{\Delta t} = N\frac{2BA}{\Delta t} = N\frac{2B\pi\left(\frac{D}{2}\right)^2}{\Delta t}$$

$$\varepsilon = 25\frac{2x50x10^{-6}\pi\left(\frac{1}{2}\right)^2}{0.2} = 9.8x10^{-3}V$$

Electric Guitar

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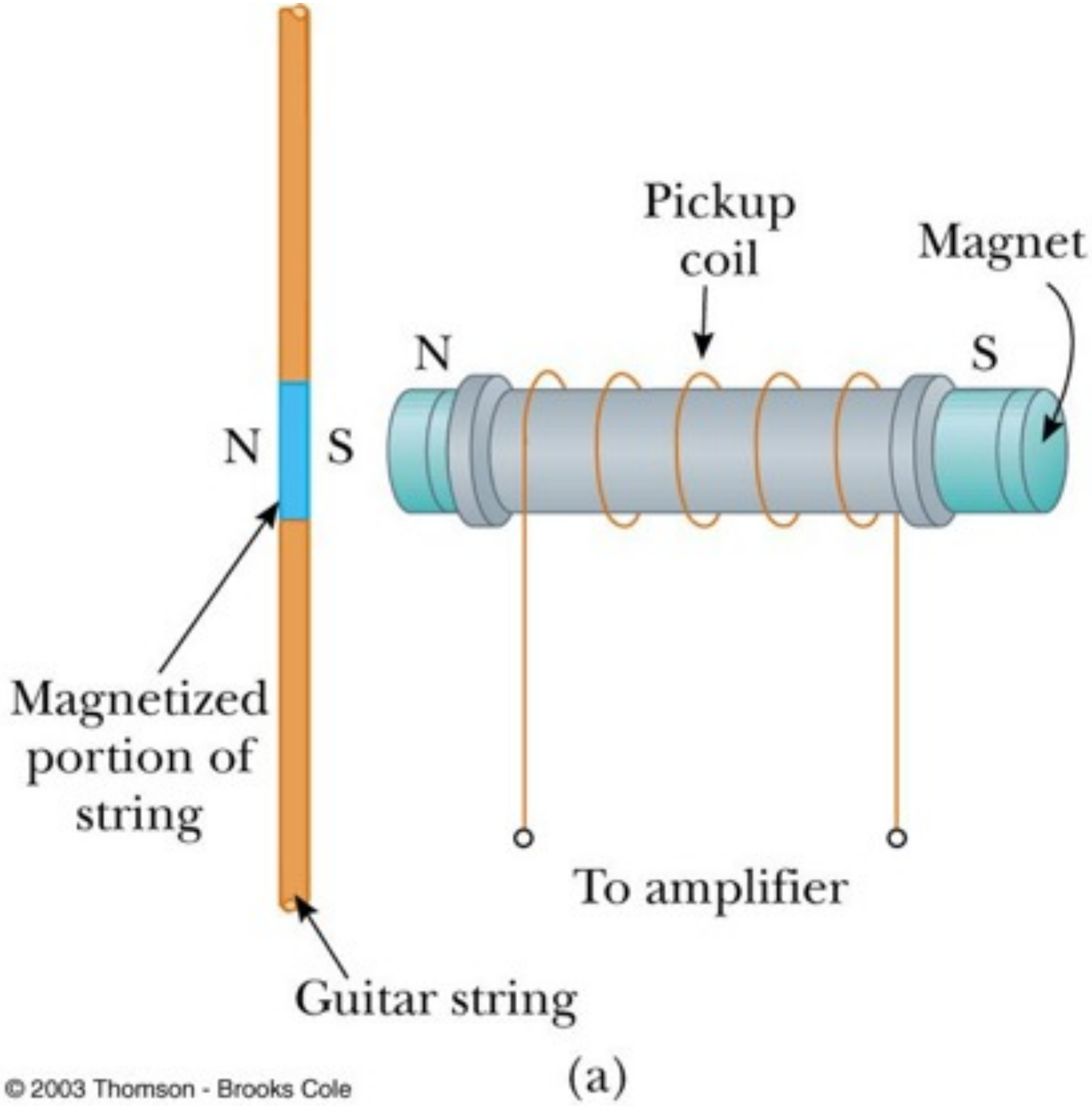
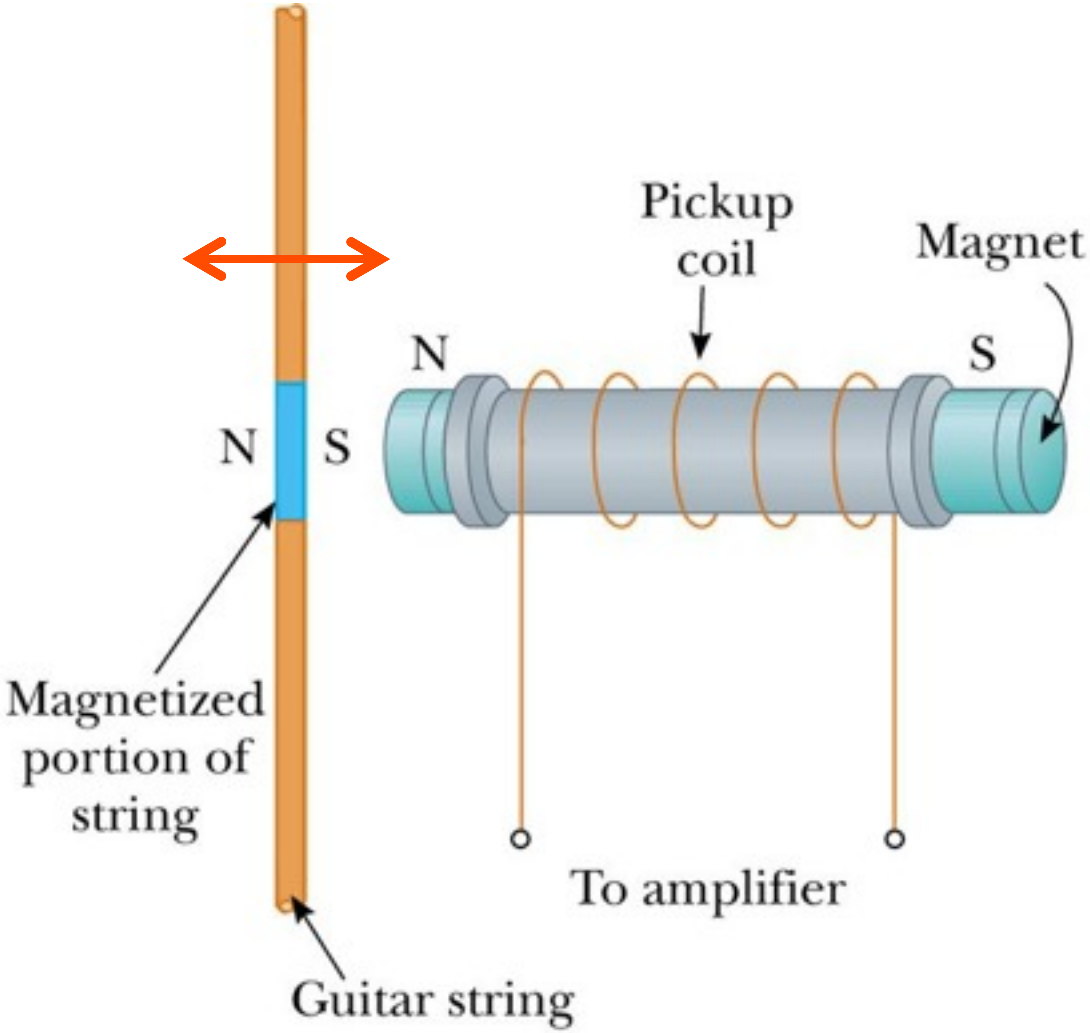
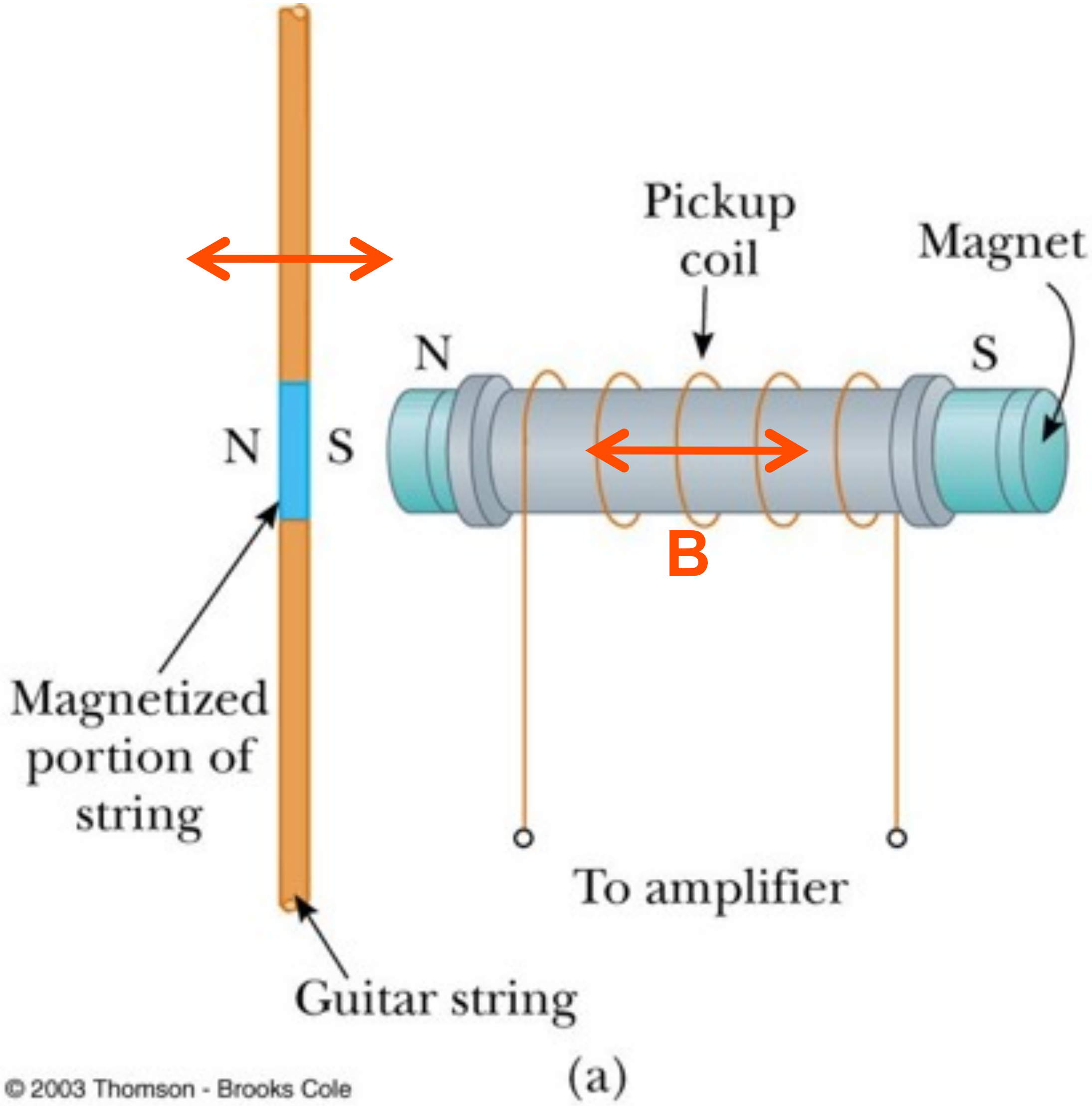

Pickup
coil
Magnet
N
S
N
S
Magnetized
portion of
string
To amplifier
Guitar string

(a)


Pickup
coil
Magnet
N
S
N
S
Magnetized
portion of
string
To amplifier
Guitar string

(a)


Pickup coil
Magnet
N
S
N
S
B
Magnetized portion of string
To amplifier
Guitar string
(a)
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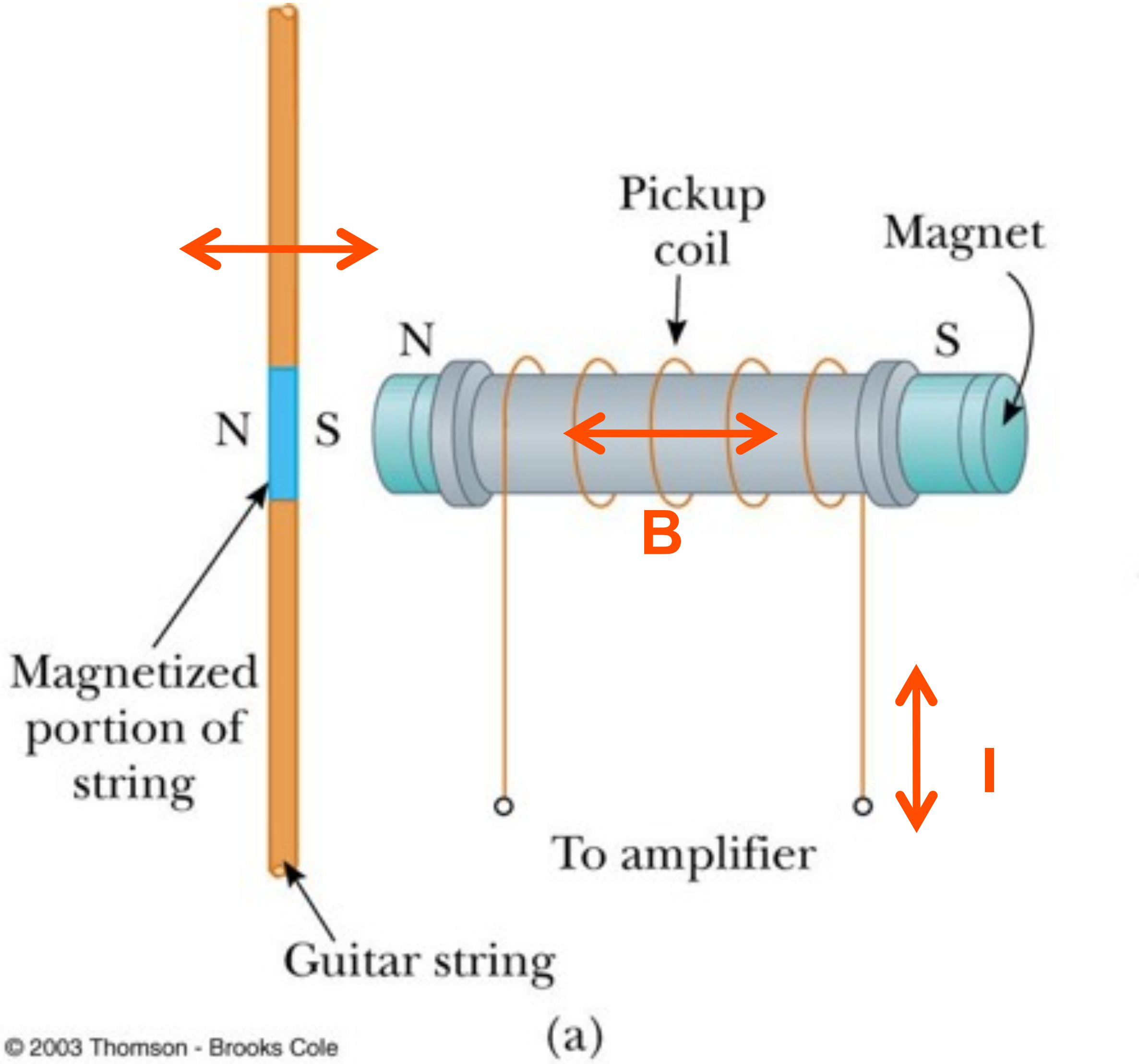
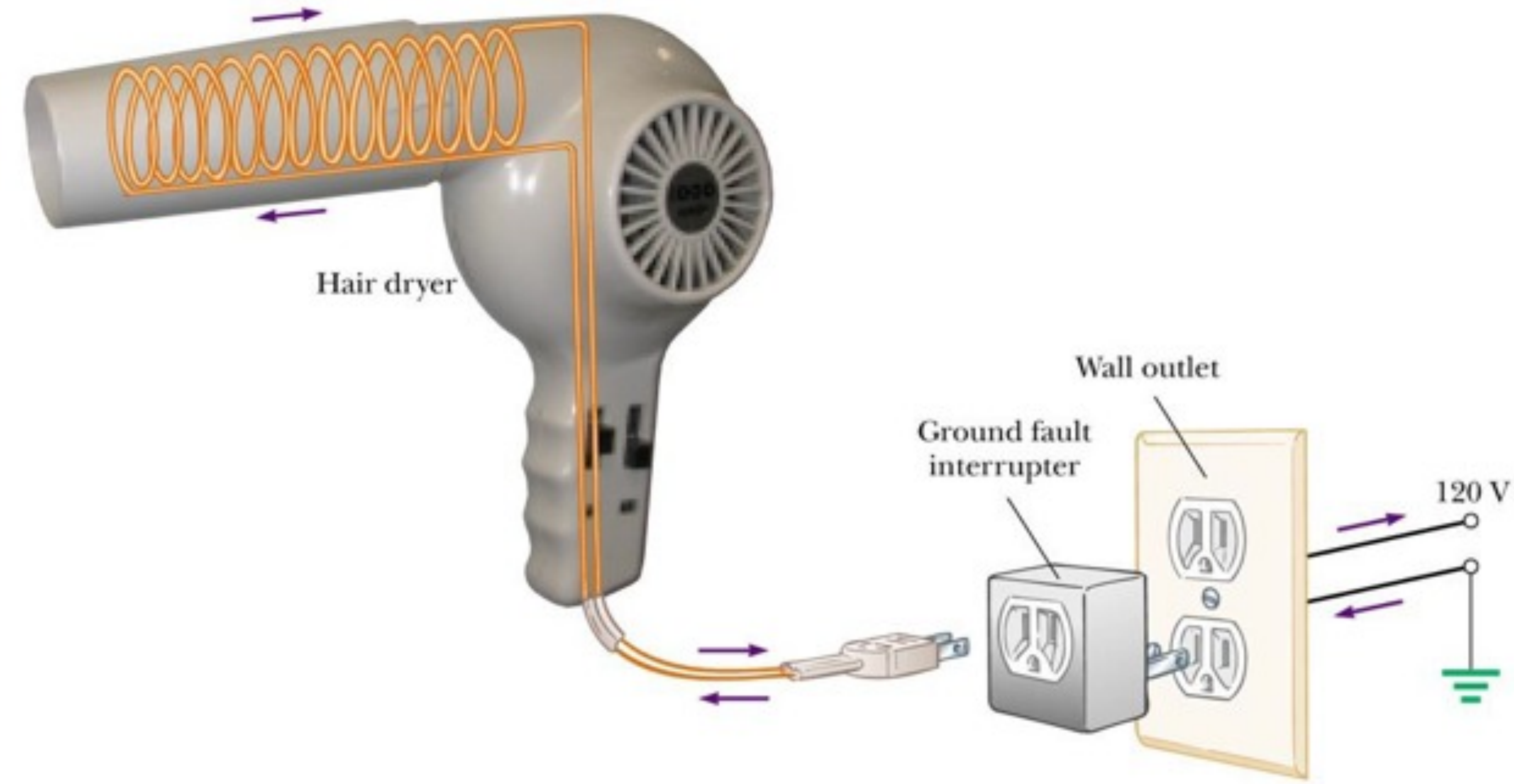

Pickup
coil
Magnet
N
S
N
S
B
I
Magnetized
portion of
string
To amplifier
Guitar string

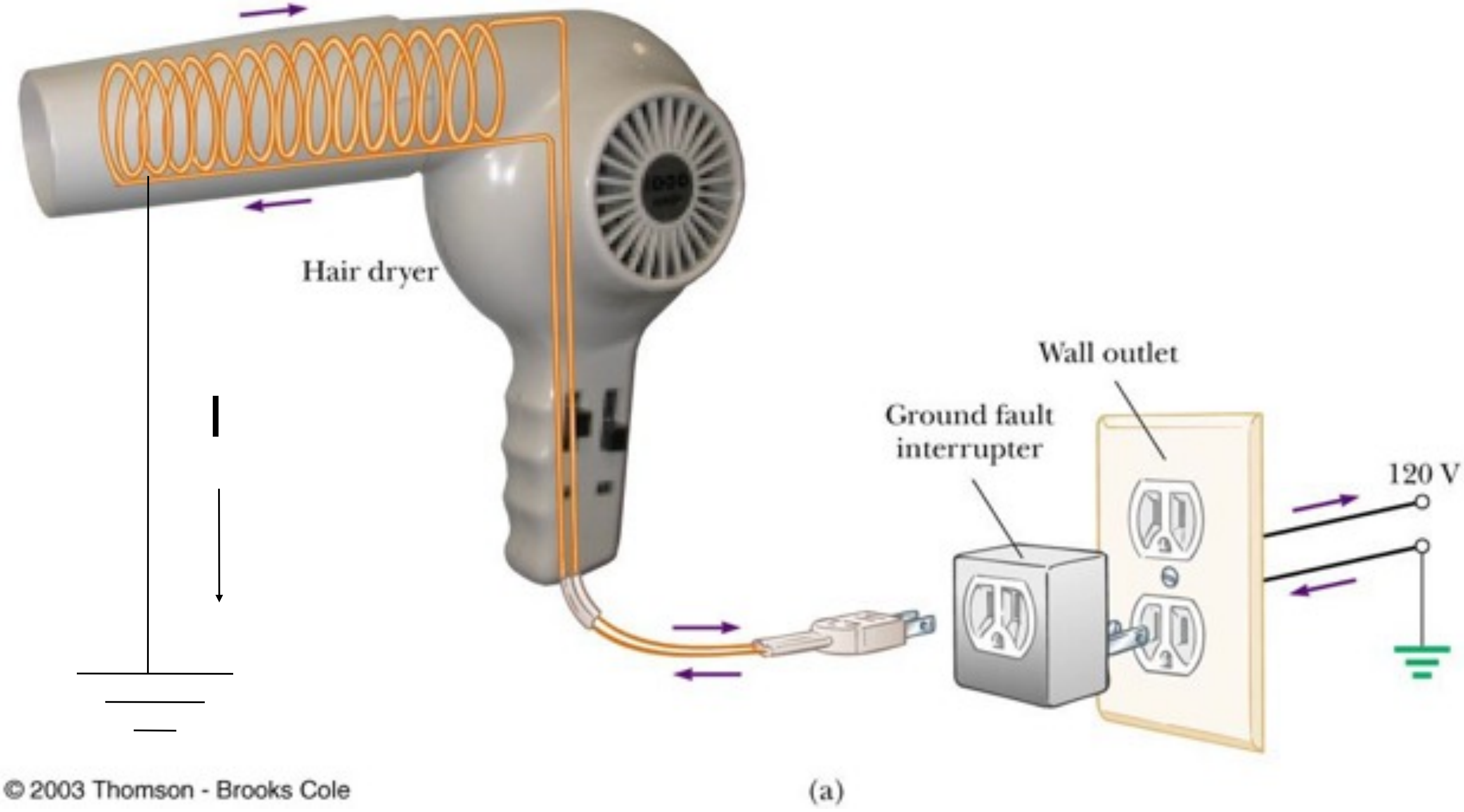
(a)

Ground fault interrupter

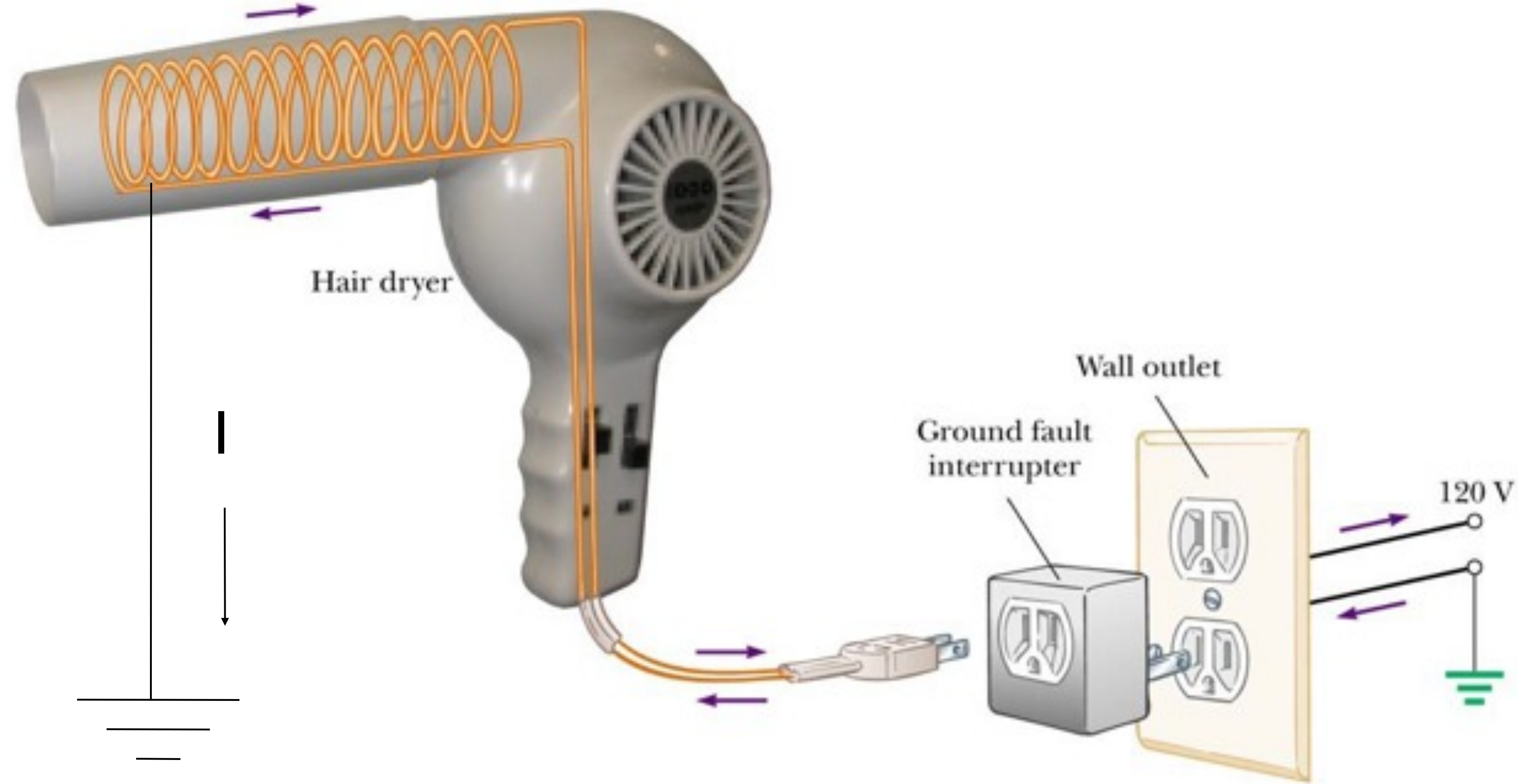


(a)

Ground fault interrupter



Ground fault interrupter



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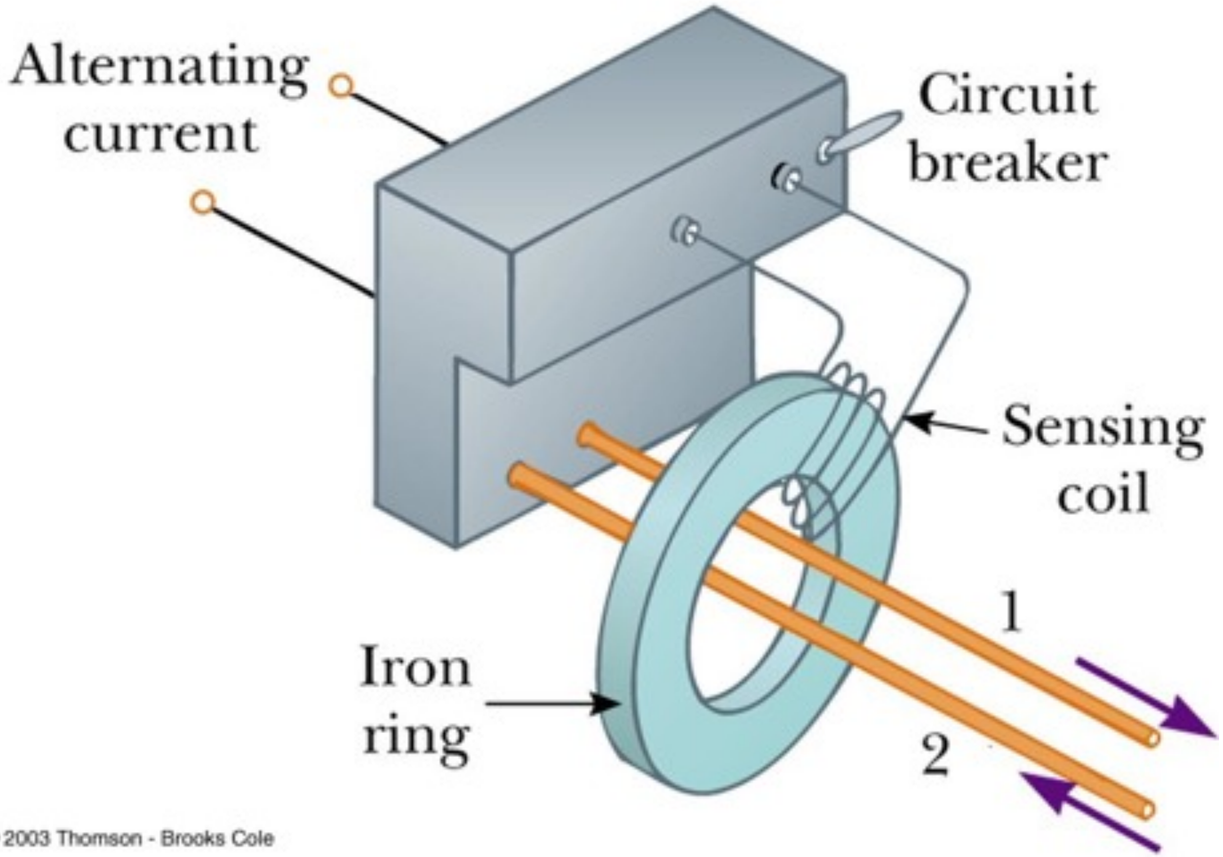
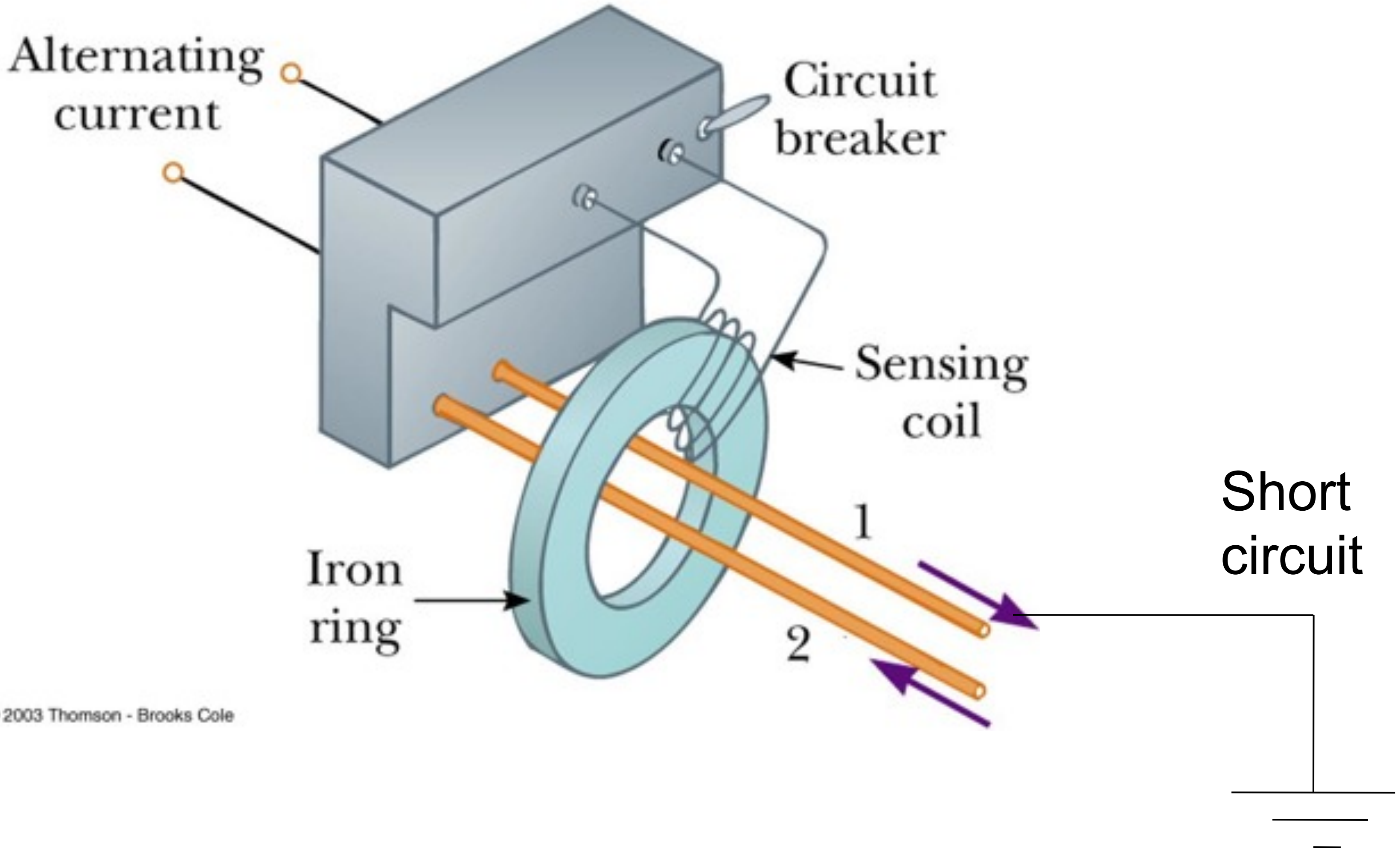
(a)

Shuts off

Application Ground Fault interrupter



Application Ground Fault interrupter



Short circuit

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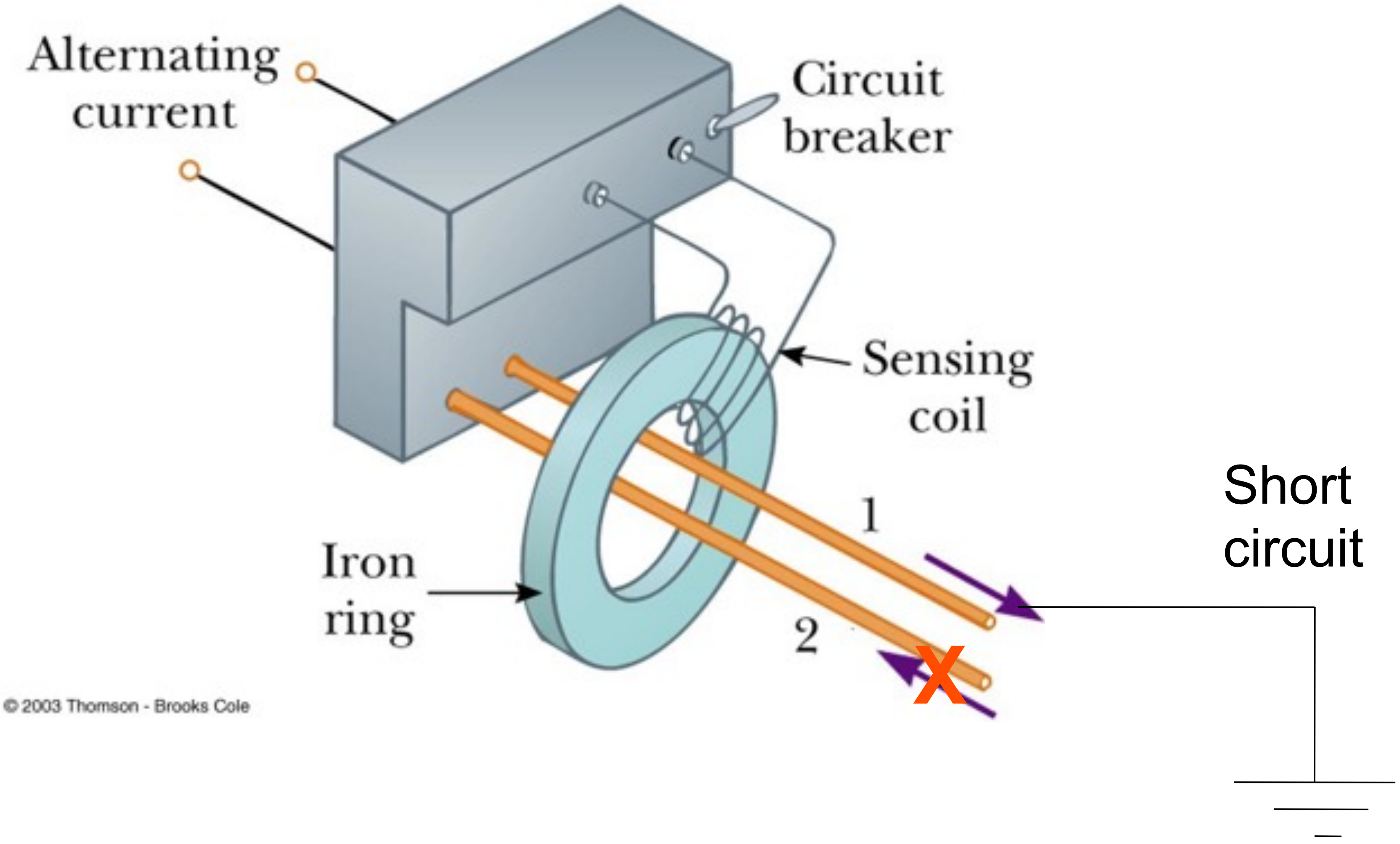
Application Ground Fault interrupter



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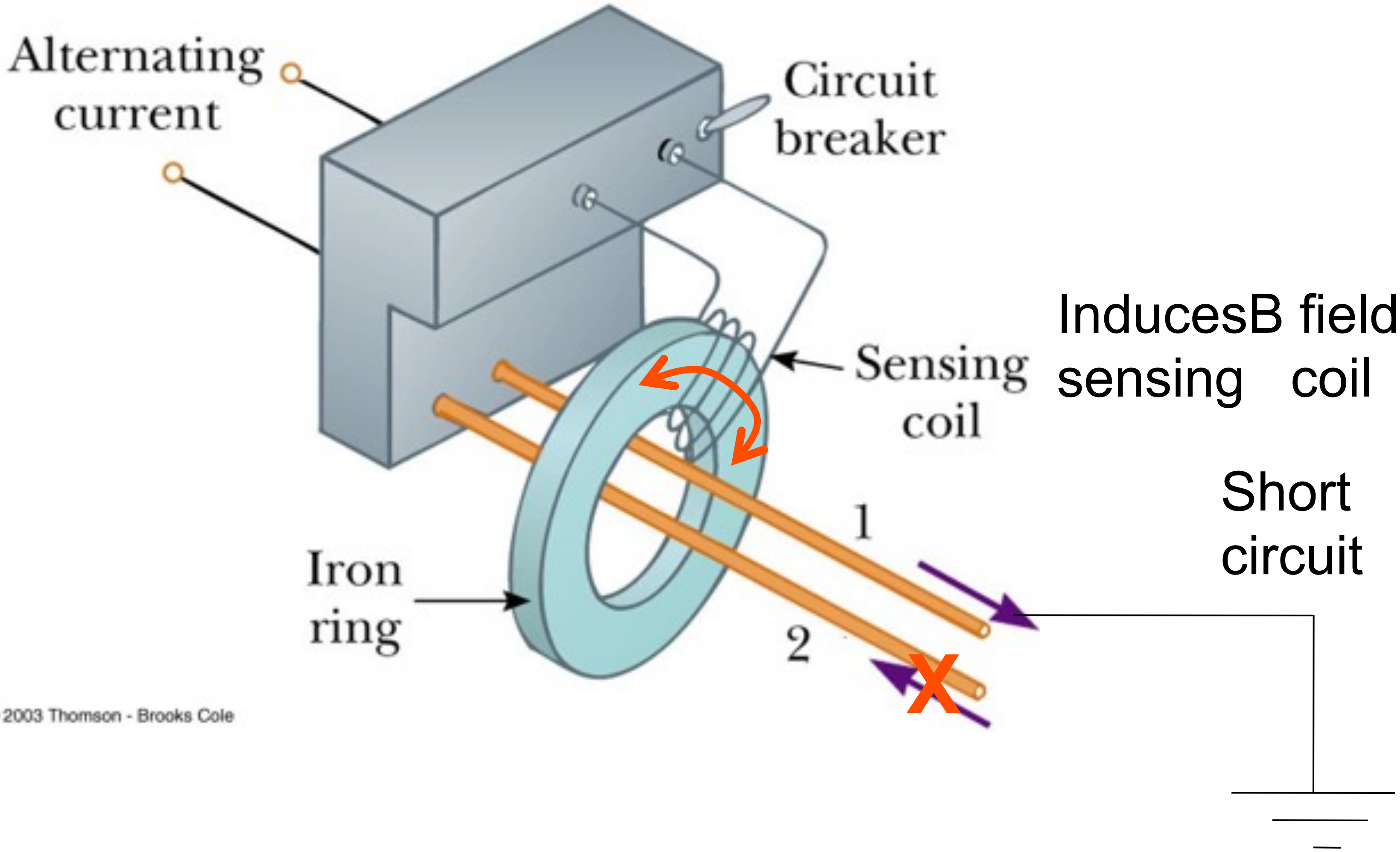
Application Ground Fault interrupter



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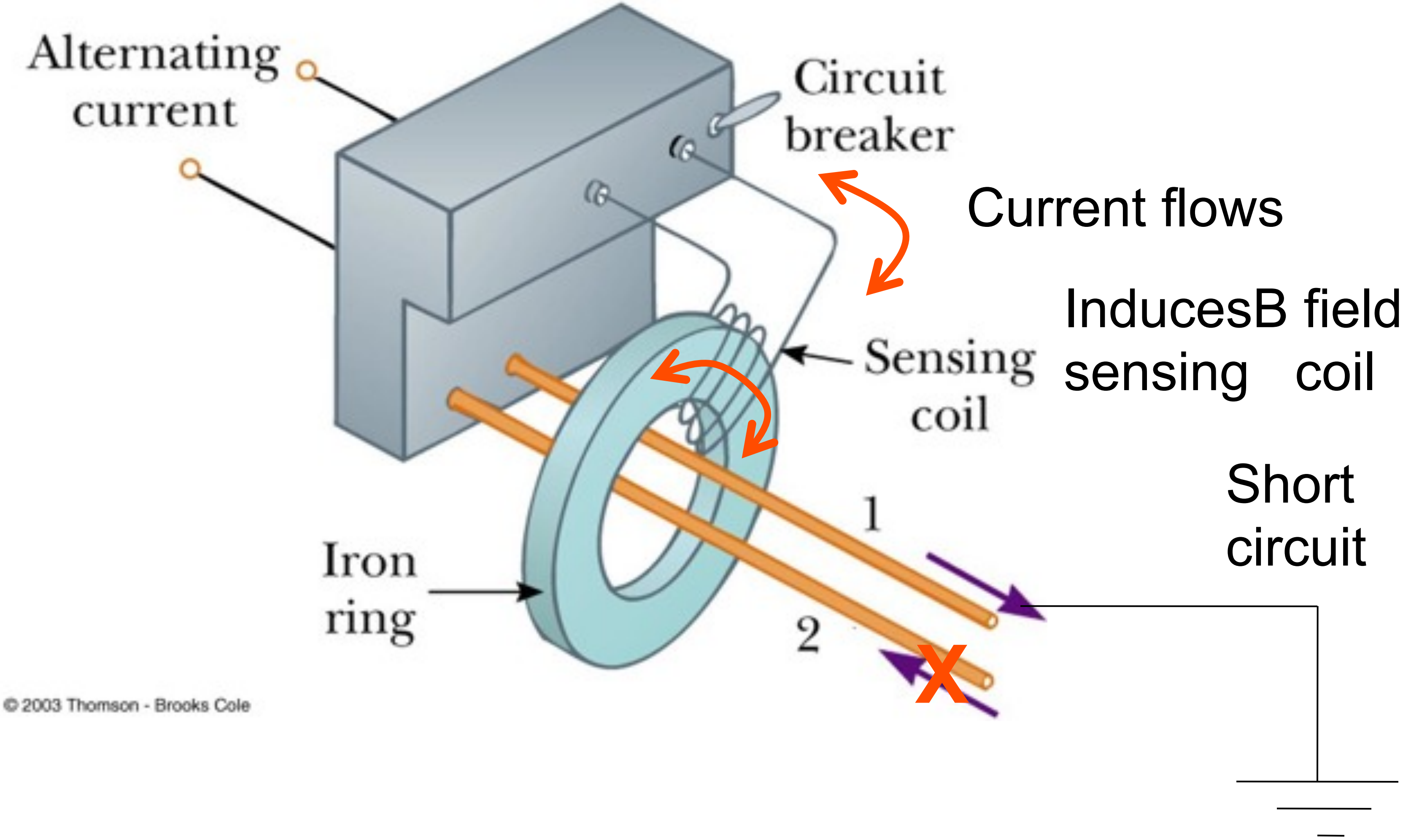
InducesB field in sensing coil

Short circuit

Application Ground Fault interrupter



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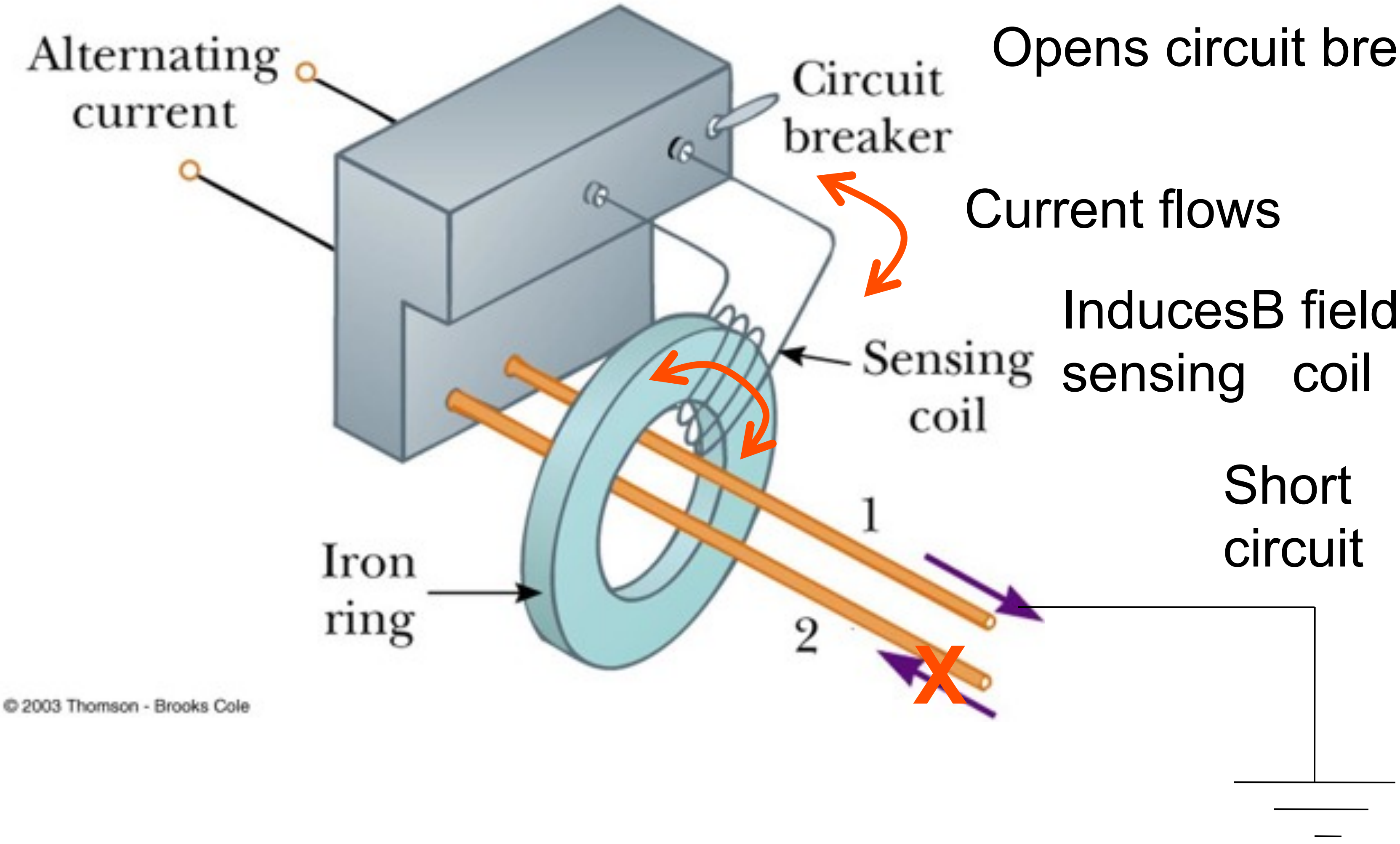
Current flows

InducesB field in sensing coil

Short circuit

Application Ground Fault interrupter



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Opens circuit breaker

Current flows

InducesB field in sensing   coil

Short circuit