11/30: Five announcements:

1: Reminder: the Final Exam is Thursday morning, Dec 9, 08:00-11:00 a.m., in 2722 York Hall (location as of 11/29). You must bring:
Photo ID (e.g., UCSD I.D., driver's license, credit card w/ photo),
Scantron + pencils, Scientific Calculator, and three 3'x5' cards on which to write equations (I recommend taping/stapling them together).
If you neglect to bring your photo ID, you will have until 11:00 to go home, get your ID, and return to the final exam with it so we can verify your identify (otherwise you get a 0). The final exam will cover everything discussed in the lectures up through the end of lecture on Dec 2. There will be at least 2 problems repeated from the quizzes and at least 2 problems taken directly from the extra practice problems (see below).

2: We're aiming to hold two Review Sessions: One to review chapter 23 material, and one to review material for the entire course (plus practice problems: see below). Location/Time TBD: Likely 12/6 or 12/7. I'll post an announcement on the main web page as soon as the time/location are confirmed.

3: Some additional Practice Problems -- I'll post them on the web page approximately 12/3.

4. Next week, both Grigor and I will have regular Monday office hours as usual. Both of us will move office hours from Thursday 12/9 to Wednesday 12/8 (AM: 11:30-12:30; GA: 2:00-3:00)

5. 11/22/2010: A reminder, since I've been getting emails inquiring about letter grades: The course grades are curved, and I will not assign letter grades until after the final course grades are computed and their final distribution is examined. While the mean will likely be close to a B/B-, other letter grades will depend on the (to-be-determined) distribution. The weighted mean of the four quizzes so far is about 64% (the course mean thus MAY be in this range, too, but that depends on the outcome of the final exam, and of course we can't predict the future), and you can use the grading scheme on the syllabus to estimate how you are doing so far (lowest quiz grade = 9%, other 3 quizzes = 18% each, final exam = 37%).

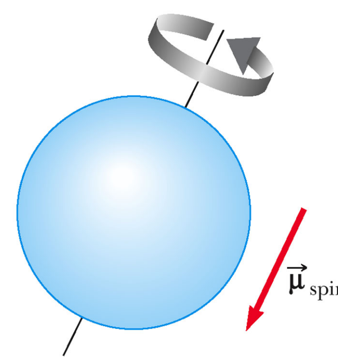
22.11: Magnetism in Matter / Magnetic Domains

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

Classical model for electrons in atoms:

1.Orbital motion of electron: like a loop current (but B-field produced by 1 electron can be cancelled out by an oppositely revolving electron in the same atom)

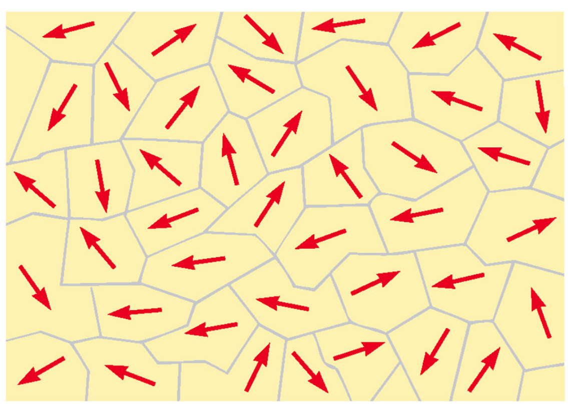
2. “spin” of individual electrons produces much stronger B-field: each electron itself acts like a magnetic dipole

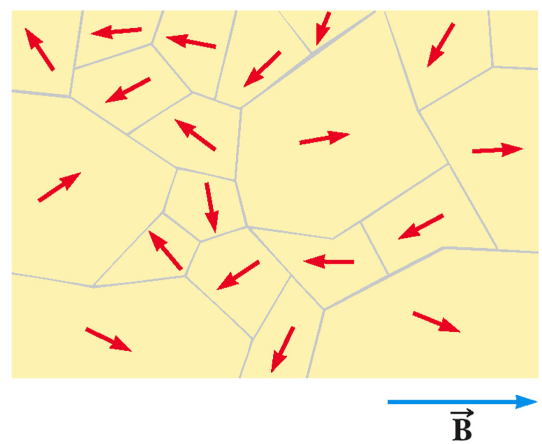


Magnetic Domains

Magnetic domains (10^{-4} - 10^{-1} cm): Each domain has a substantial fraction of atoms with magnetic moments coupled. They're separated by domain boundaries.

Ferromagnetic materials (e.g., Fe, Co, Ni, Gd, CrO_2): have these domains. Spins are randomly oriented, but when an external $\vec{B}$ is applied, domains tend to align with magnetic field; domain boundaries adjust accordingly.





Result: material produces its own **internal** $\vec{B}$

$(\vec{B}_{net} = \vec{B}_{external} + \vec{B}_{internal})$

Re-cap:

Soft magnetic materials (e.g. Fe): Easily magnetized in presence of external B, but doesn't retain magnetization for long. Used as cores for electromagnets.

When external B is turned off, thermal agitation returns dipoles to random orientations

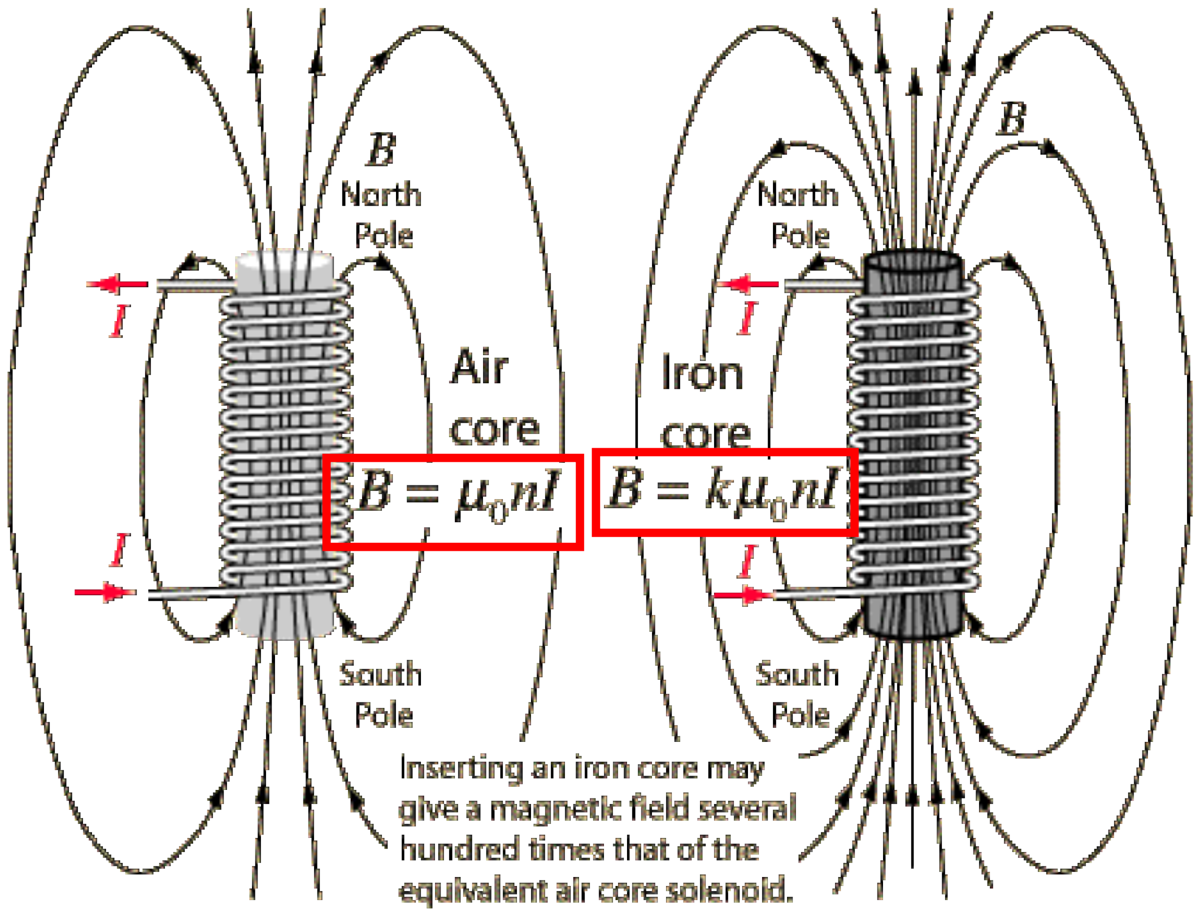
Hard magnetic materials (e.g. metal alloys: Alnico (Al+Ni+Co)): Harder to magnetize (requires higher $\vec{B}_{external}$) but retains the magnetization for a long time. Used as permanent magnets.

Air-core vs Fe-core solenoid electromagnets

Total B-field is much larger with an Fe-core

$B = \mu\, I\, n$

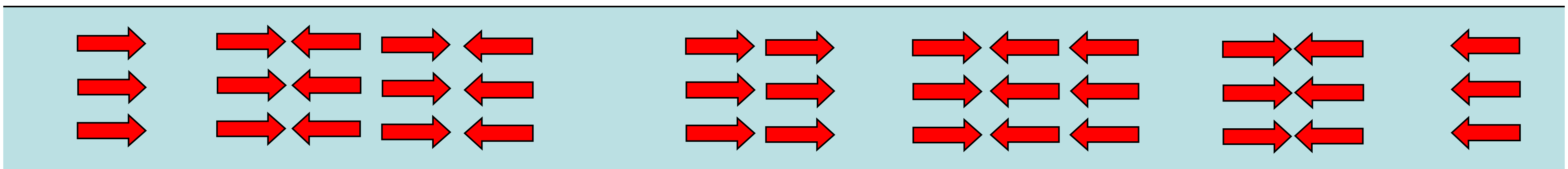
$k = \mu/\mu_0 \sim$ 500-1000 for Fe



Magnetic recording

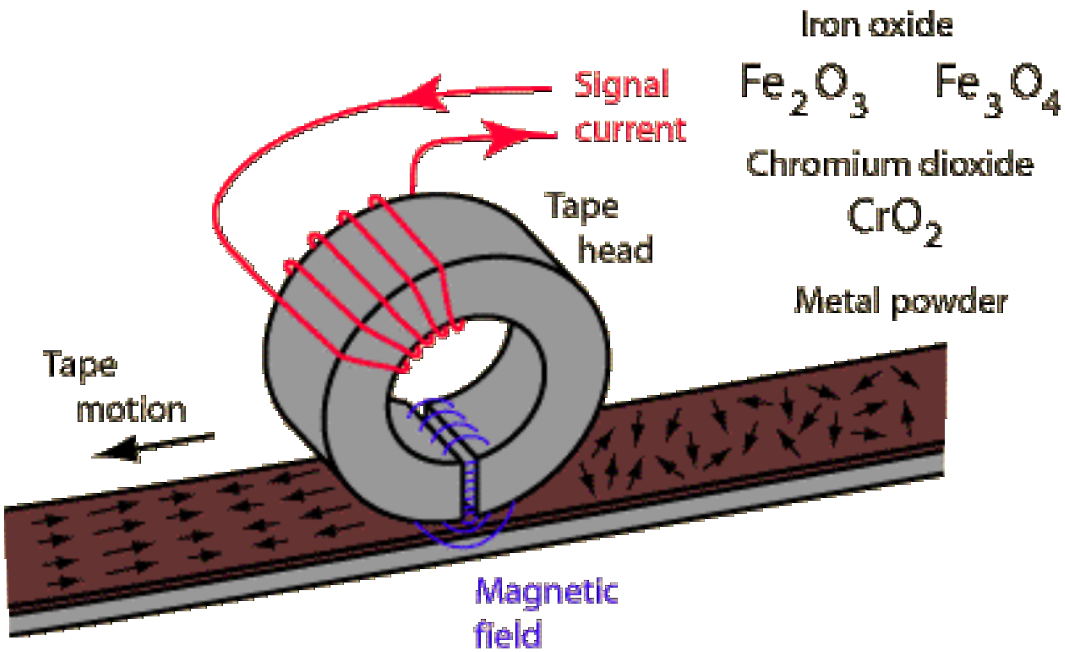
computer drives; cassette/VCR tapes; credit card strips

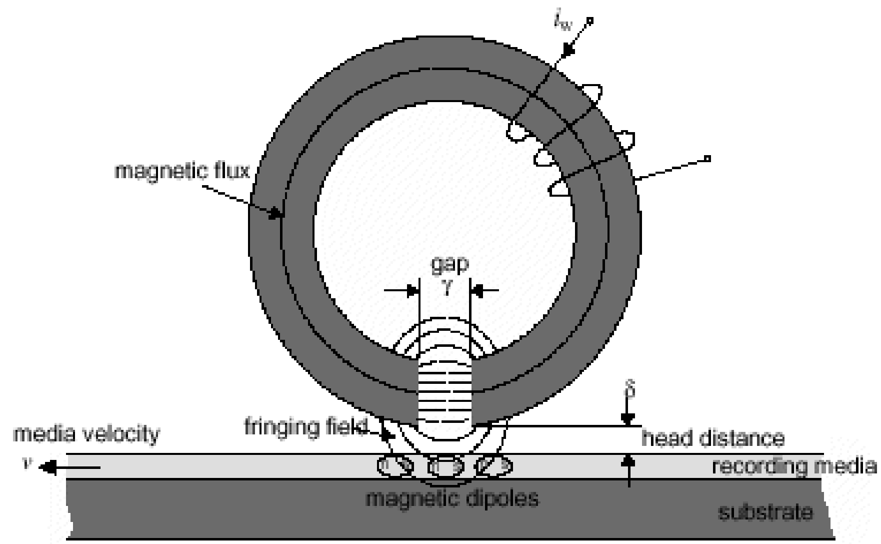
Information coded in the orientation of magnetic domains



Magnetization can be read on playback to generate a voltage signal

Info can be erased by applying VERY STRONG B-field to re-align all domains.





Basic Ring read/write head.

Basalt is expelled from volcanoes and cools, and the B-field becomes imprinted.

Mid-Atlantic Ridge shows that B-field direction changes every ~0.1–1 Myr

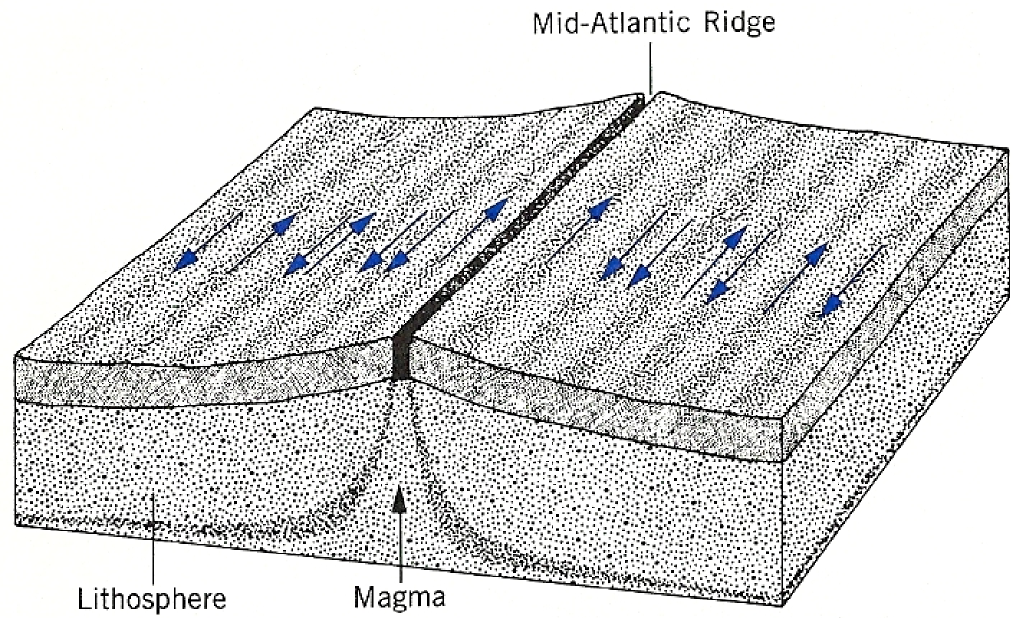


Figure 13 As molten material emerges through a ridge in the ocean floor and cools, it preserves a record of the direction of the Earth's magnetic field at that time (arrows). Each segment might represent a time of 100,000 to 1,000,000 years.

Mars Global Surveyor (JPL/NASA)

Mars: No ‘global’ B-field like Earth’s (no internal dynamo?)

Mars Global Surveyor’s magnetometers: very strong crustal fields:

Older crust is magnetized much more strongly than newer crust

Indicates that very strong global magnetic fields existed, but only before ~4 billion yr ago


(from comicvine.com)

Mars Global Surveyor (JPL/NASA)

Meteor impacts: crust melts and reforms; any imprinted magnetism is lost

Mars' surface area/ volume ratio (prop.to $4\pi r^2 / (4\pi/3)r^3$ prop.to $1/r$) is larger than Earth's: lost interior heat & dynamo mechanism faster

Moon: also evidence for a B-field that was stronger in the past (from Lunar Prospector mission)


(from comicvine.com)

I'm going off-script for the next few slides.
It is my hope (and expectation) that you can apply the material you've learned in the Physics 1 series to The Real World. There's a lot of "junk science" and "pseudo science" out there (particularly on the poorly-moderated internet) -- non-science based ideas, with poor supporting evidence, often wrapped meaninglessly in scientific jargon, from people with little or no scientific
background. This unfortunately includes a lot of goods and services (i.e., where your money is targeted). I recommend the book *Voodoo Science*, by Robert Park, for additional examples.

But you can apply Physics 1 course material to protect yourself and others from such ideas/scams, and also to combat ignorance in general.

Magnetic Therapy?

Magnetic therapy bracelets, magnetic shoes, etc. are advertised to improve blood circulation, relieve pain, give you more free energy, etc.

Magnetic Therapy?

The main selling point is usually with regard to influencing/increasing blood circulation, because red blood cells contain hemoglobin, which contains Fe.

However, hemoglobin is not ferromagnetic; the Fe cannot participate in forming magnetic domains.

The iron represents 0.4 percent, by weight, of the molecule
The hemoglobin in the blood is not analogous to a tiny magnet

If hemoglobin contained large quantities of ferromagnetic iron it would be simple to separate red blood cells from other bloods cells with a magnet. But magnetic fields do not affect blood flow!

Magnetic Therapy?

For a single magnetic dipole, B(r) is prop. to $1/r^3$

So for a ~0.4-cm magnet with B=0.005 T at its surface (typical fridge magnet strength), B ~ B_{Earth} after only a couple cm.

Multiple scientific studies: any effect from wearing a small static magnet is no better than placebo

* Researchers at the New York College of Podiatric Medicine have reported negative results in a study of patients with heel pain. Over a 4-week period, 19 patients wore a molded insole containing a magnetic foil, while 15 patients wore the same type of insole with no magnetic foil. In both groups, 60% reported improvement, which suggested that the magnetic foil conveyed no benefit [5]. (M. Caselli et al., 1997) Journal of the American Podiatric Medical Association
* Researchers at the VA Medical Center in Prescott, Arizona conducted a randomized, double-blind, placebo-controlled, crossover study involving 20 patients with chronic back pain. Each patient was exposed to real and sham bipolar permanent magnets during alternate weeks, for 6 hours per day, 3 days per week for a week, with a 1-week period between the treatment weeks. No difference in pain or mobility was found between the treatment and sham-treatment periods [6]. (EA Collacott et al, 2000, JAMA)
* Researchers at the Mayo Clinic compared the effects of wearing magnetic or sham-magnetic cushioned insoles over an 8-week period by 101 people with heel pain and found no difference between the treatment and control groups [7]. (NH Winemiller et al, 2000, JAMA)

Magnets have also been claimed to increase circulation. This claim is false. If it were true, placing a magnet on the skin would make the area under the magnet become red, which it does not. Moreover, a well-designed study that actually measured blood flow has found no increase. The study involved 12 healthy volunteers who were exposed to either a 1000-gauss magnetic disk or an identically appearing disk that was not magnetic. No change in the amount or speed of blood flow was observed when either disk was applied to their arm. [8]. The magnets were manufactured by Magnetherapy, Inc, of Riviera Beach, Florida, a company that has been subjected to two regulatory actions. (HN Mayrovitz et al 2002, Scient. Rev. of Altern. Med.)

(from quackwatch.org
See also http://www.sillybeliefs.com/magnets.html))

Magnetic Therapy?

Numerous legal actions (e.g., from the FTC) in the late '90s and early '00s against companies making these false claims about these products.
see http://www.quackwatch.org/04ConsumerEducation/QA/magnet.html

BTW, Copper is not a ferromagnetic material.

Ch. 23: Induced Voltages & Inductance

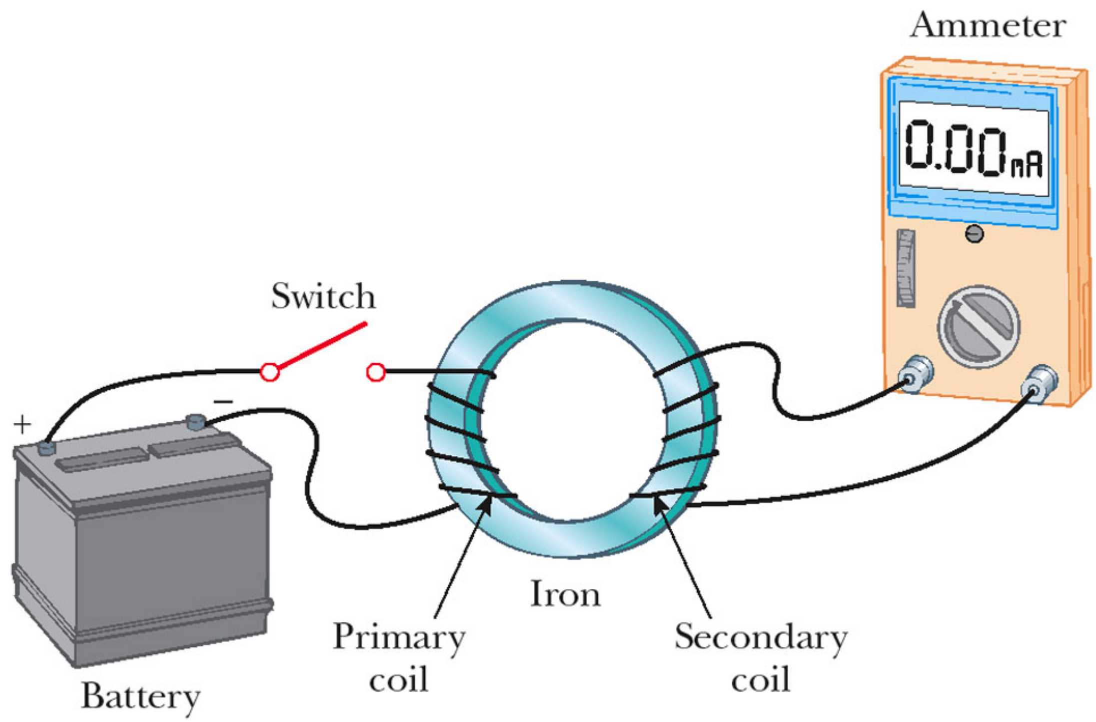
We've seen that electrical current can produce magnetic fields.

Can magnetic fields be used to generate electrical current?

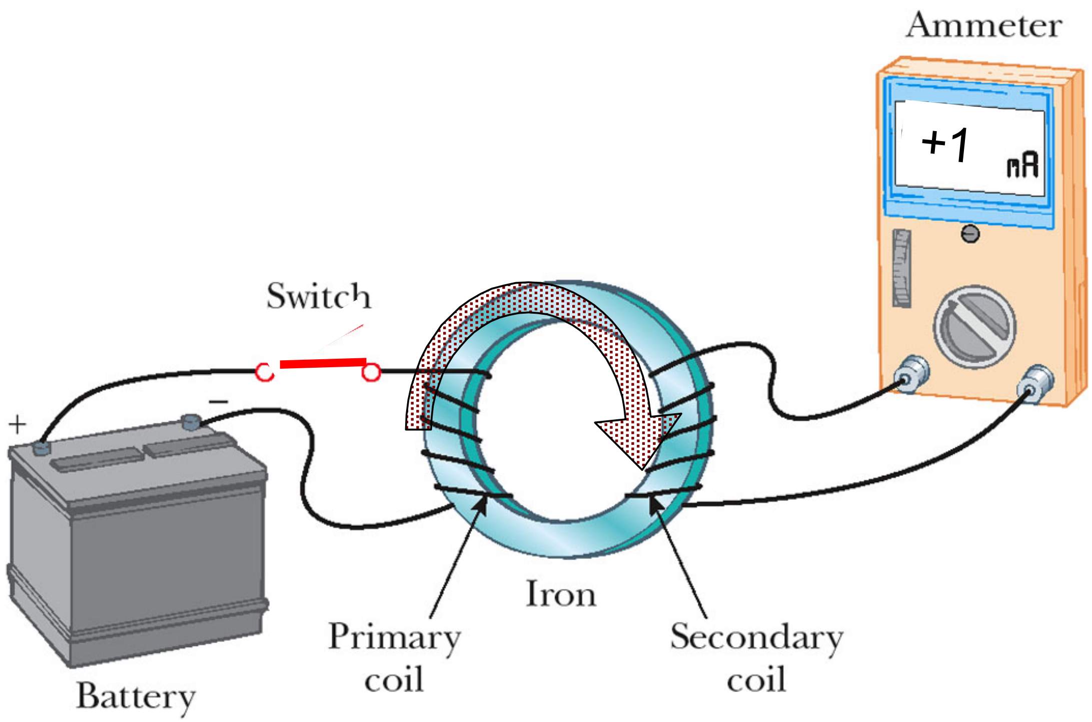
The answer, as discovered by Michael Faraday, is YES:

Applications include electrical generators, ground-fault interrupters, microphones

Faraday’s Experiments

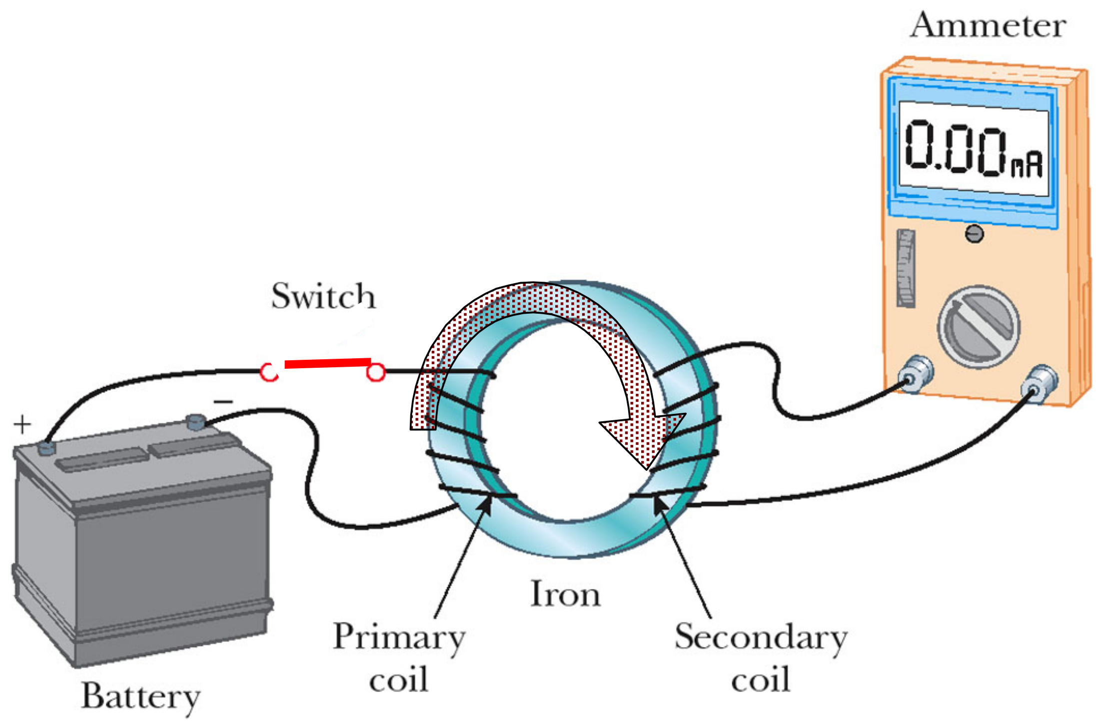


Faraday's Experiments



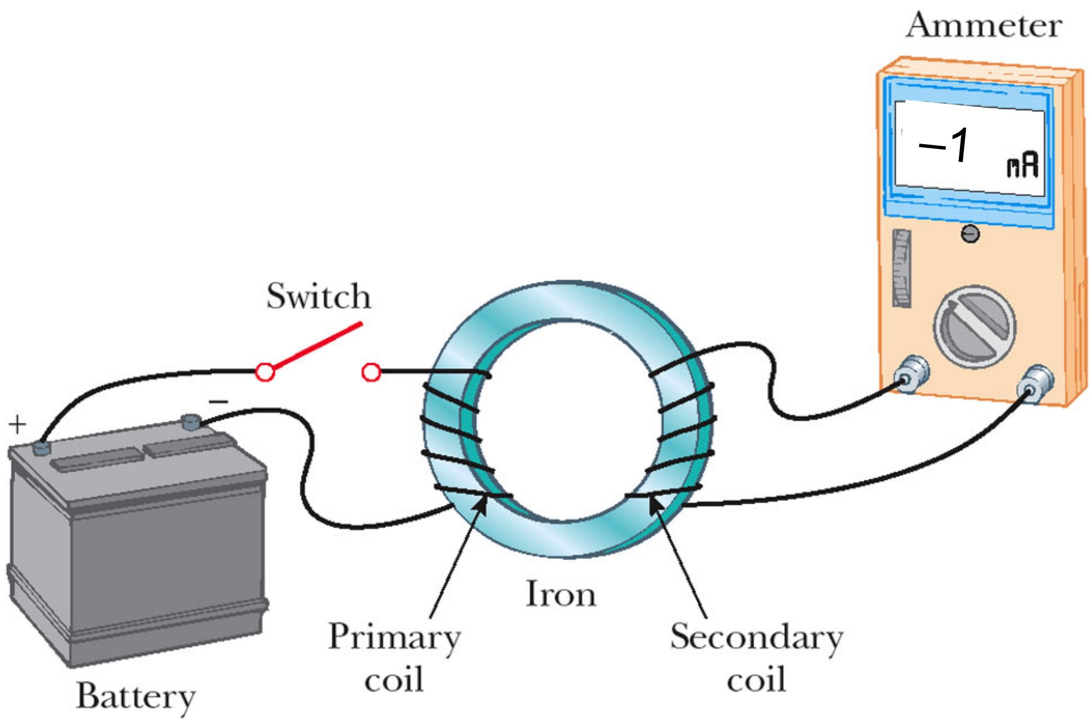
Close switch: immediately after switch closed, ammeter measures current in secondary circuit

Faraday's Experiments



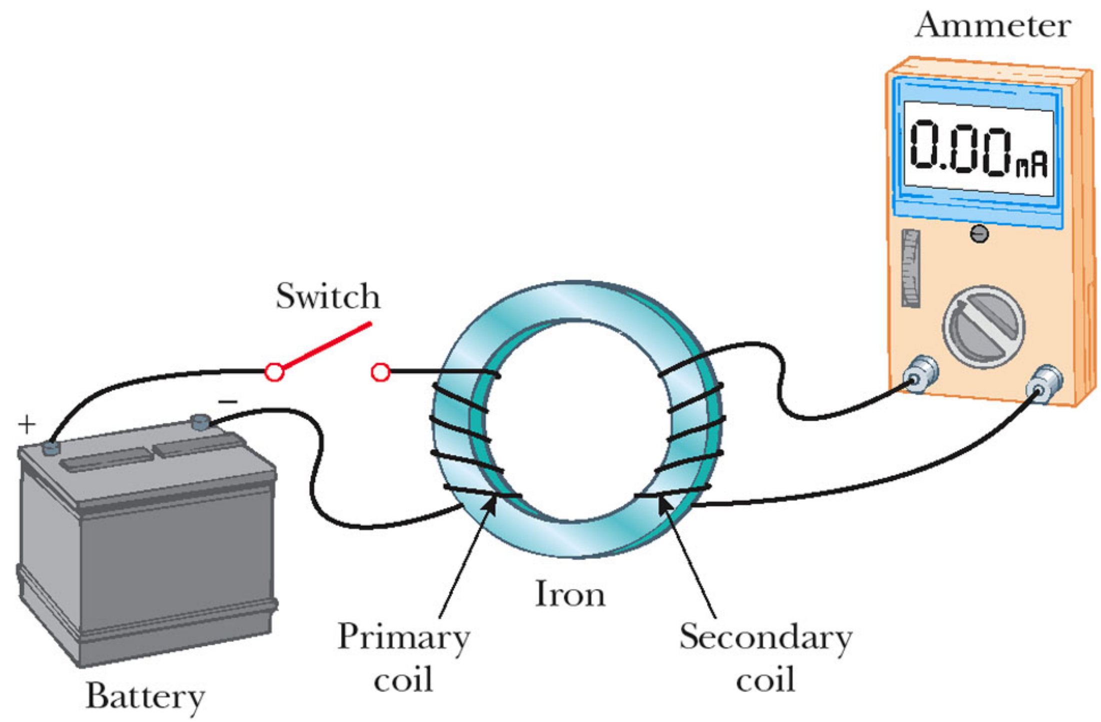
After the switch has been closed for a while, ammeter has returned to zero.

Faraday's Experiments



Open switch: immediately after opening switch, ammeter registers a current in the OPPOSITE direction

Faraday's Experiments



After the switch has been opened for a while, ammeter has returned to zero.

Conclusions from Faraday's experiment:

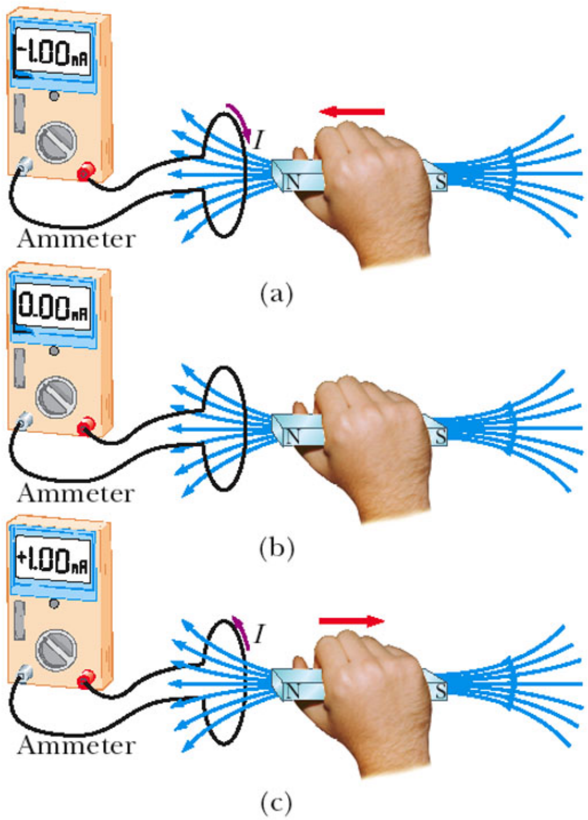
B-field going from OFF to ON-- induces a current in secondary circuit

B-field going from ON to OFF -- induces a current (opposite sign) in secondary circuit.

B-field level constant (zero or non-zero) -- no current induced!

Conclusion: The B-field itself does not induce any current -- **only a CHANGE in B-field.**

Electromagnetic Induction

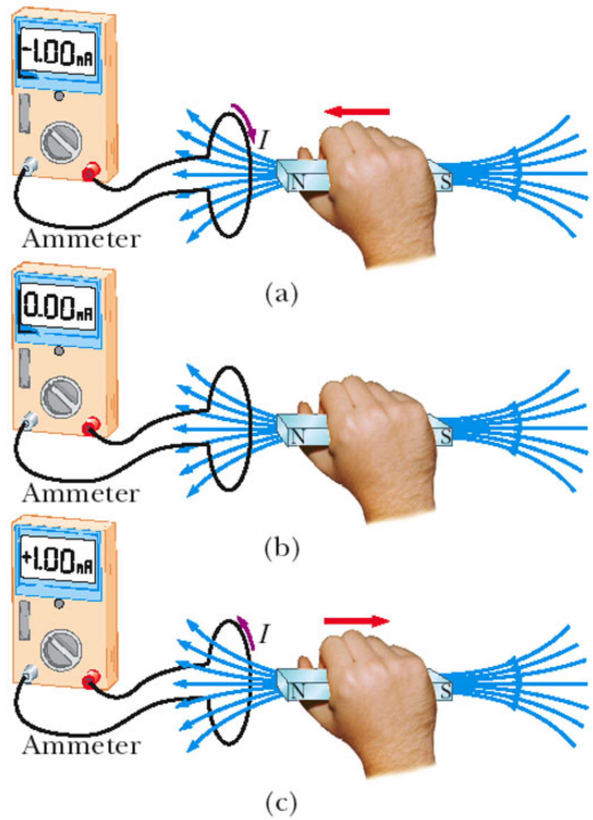


While a magnet is moving toward a loop of wire, the ammeter shows the presence of a current

While the magnet is held stationary, there is no current

While the magnet is moving away from the loop, the ammeter shows a current in the opposite direction

Electromagnetic Induction



If the magnet is held stationary and the LOOP is moving, you get the same effect.

A current is induced whenever there exists RELATIVE motion between the magnet & loop.

Direction of current depends on direction of motion.

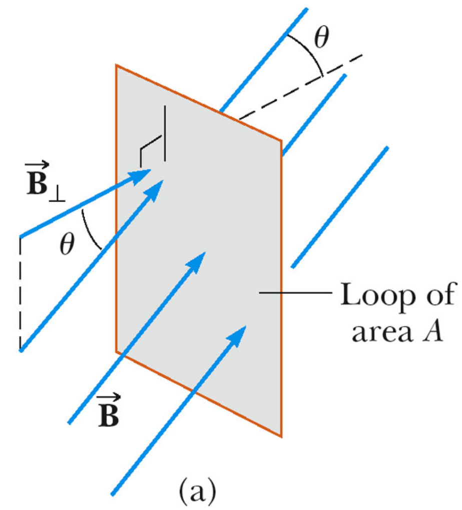
Magnetic Flux

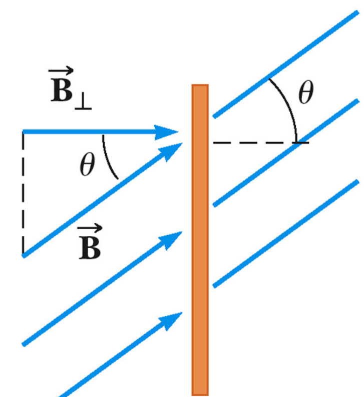
Assume B-field is uniform.
Area of loop = A.

Magn. Flux Φ_B through an area A:

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

SI unit: Weber (Wb) = $T \times m^2$



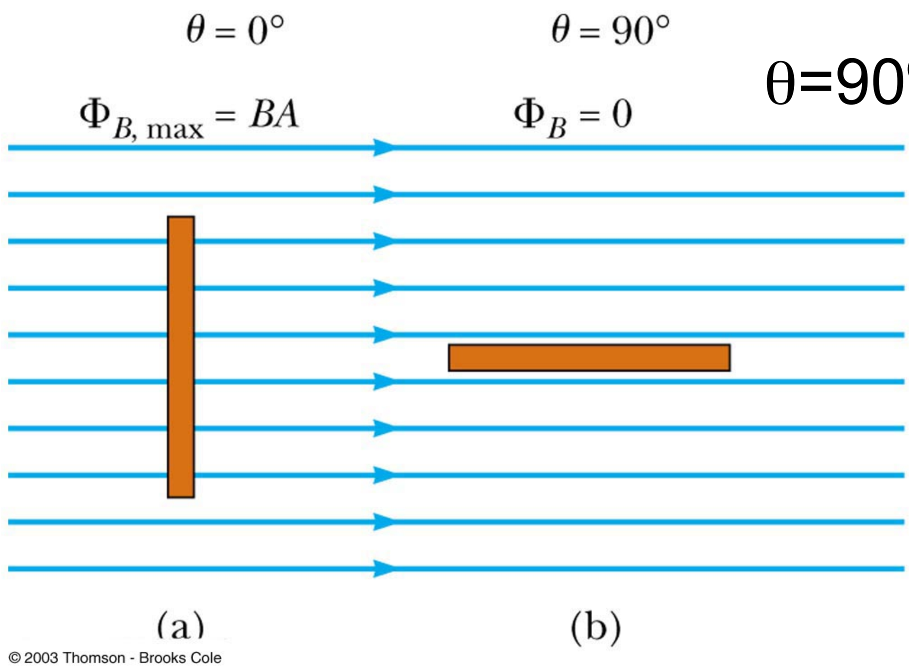


Φ_B is proportional to the total number of lines passing through the loop

Magnetic Flux

Edge view of loop in uniform B-field:

θ=0º: Φ_B is maximized: Φ_B = BA

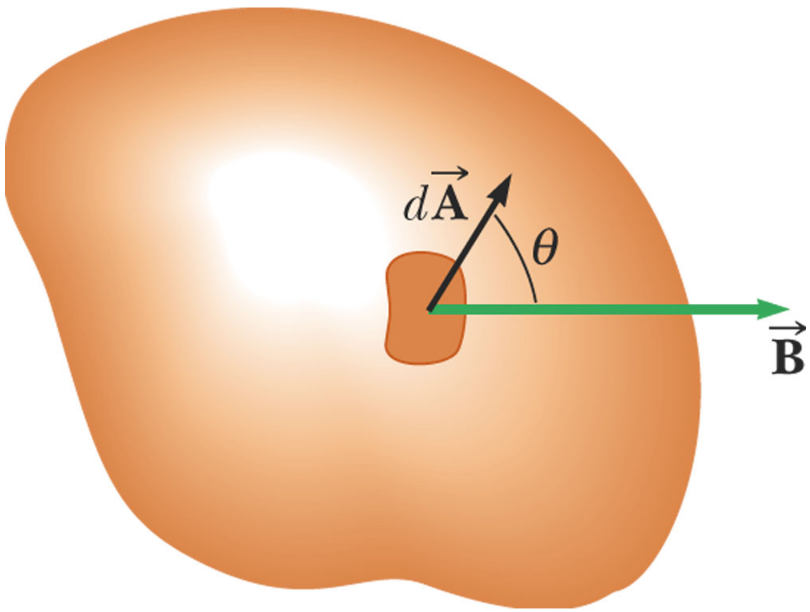


θ=90º: Φ_B is zero

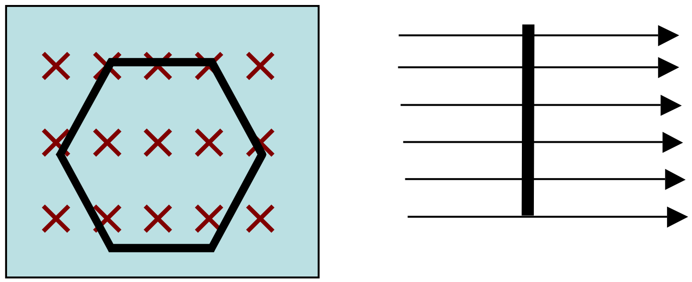
Change B-field direction so θ=180º: Φ_B = –BA

For non-uniform B-field or Area:

$$\Phi_B = \int \vec{\mathbf{B}} \cdot d\vec{\mathbf{A}}$$



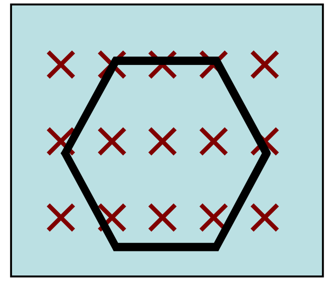
Φ_B & $\Delta\Phi_B$

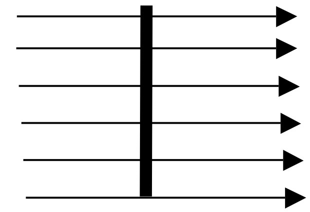


Example: A hexagon-shaped loop with area 0.5 m^2 is placed in a uniform B-field of 2 T such that the loop's normal is parallel to B. Calculate Φ_B.

Suppose the B-field strength is halved. Calculate Φ_B now. Calculate $\Delta\Phi_B$.

Φ_B & $\Delta\Phi_B$





Example: A hexagon-shaped loop with area 0.5 m^2 is placed in a uniform B-field of 2 T such that the loop's normal is parallel to B. Calculate Φ_B.

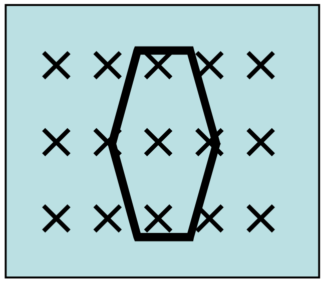
Φ_{B1} = BAcosθ = BAcos0º = (2T)(0.5 m^2) = 1.0 Wb

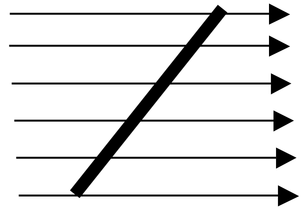
Suppose the B-field strength is halved. Calculate Φ_B now. Calculate $\Delta\Phi_B$.

$\Phi_{B2} = \Phi_{B1}/ 2$ = 0.5 Wb

$\Delta\Phi_B = \Phi_{B2} - \Phi_{B1}$ = (0.5–1.0)Wb = –0.5 Wb

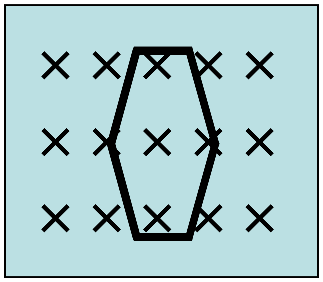
Φ_B & $\Delta\Phi_B$

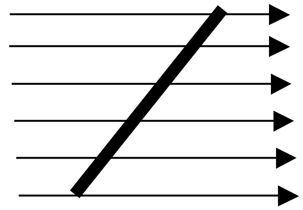




Example: Go back to B=2.0 T. Suppose the loop is rotated 45° as shown. Calculate Φ_B & $\Delta\Phi_B$.

Φ_B & $\Delta\Phi_B$





Example: Go back to B=2.0 T. Suppose the loop is rotated 45° as shown. Calculate Φ_B & $\Delta\Phi_B$.

Φ_{B2} = BAcosθ = BAcos45º = (2T)(0.5 m^2)(0.707) = 0.707 Wb

$\Delta\Phi_B = \Phi_{B2} - \Phi_{B1}$ = (1.0-0.707)Wb = 0.293 Wb

No magnetic monopoles

If we were to apply an analog of Gauss' law to MAGNETIC field lines for a Gaussian surface in any region of space:

No magnetic monopoles means there's no "magnetic charge" to enclose

All B-field lines which enter the surface must also leave it. So net Φ_B is always zero.

FARADAY'S LAW OF MAGNETIC INDUCTION

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 magn. flux changes by $d\Phi_B$ during a time interval dt, the average EMF induced is given by Faraday's Law:

$$\varepsilon = -N \frac{d\Phi_B}{dt}$$

FARADAY'S LAW OF MAGNETIC INDUCTION

$$\varepsilon = -N\frac{d\Phi_B}{dt}$$

$\Phi_B = BA\cos\theta$

So EMF can be induced by changing any of B, A or θ.

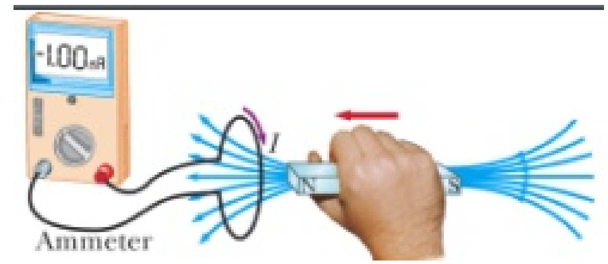
FARADAY'S LAW OF MAGNETIC INDUCTION

$$\varepsilon = -N\frac{d\Phi_B}{dt}$$

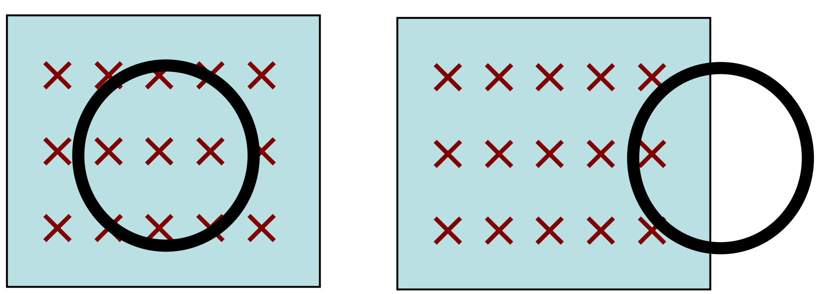
$\Phi_B = BA\cos\theta$

So EMF can be induced by changing any of B, A or θ.

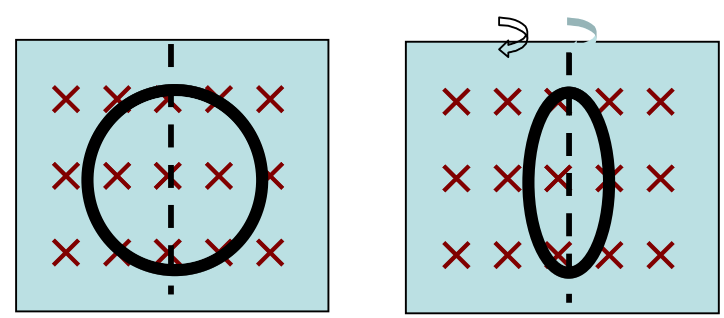
B: increase/decrease B-field strength



A: change area of loop inside B-field



θ: rotating coil in the field.



Note on previous slide: think of area in terms of an "effective area", that is, only the portion of the area of the loop which is subject to magnetic field lines -- it is only those areas which will contribute to the total magnetic flux

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

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

$\varepsilon = -N\, d\Phi_B/dt = -N\, (\Phi_{B2} - \Phi_{B1}) / dt$

$\Phi_{B1} = BA = (0.2T)(\pi(0.2m)^2) = 0.025$ Wb

$\Phi_{B2} = 0$

$N = 1$

$\varepsilon = 1(0.025Wb)/(0.3s) =$ **0.084V.**

Another example:

A 25-turn circular coil of wire with a diameter of 1.0 m is placed with its axis aligned with the Earth's B-field, which has a magnitude of 0.5×10^{-4} T = 0.5G. During a time interval of 0.2 s, it's flipped 180º. What's the magnitude of the average EMF generated during this time?

Another example:

A 25-turn circular coil of wire with a diameter of 1.0 m is placed with its axis aligned with the Earth's B-field, which has a magnitude of 0.5×10^{-4} T = 0.5G. During a time interval of 0.2 s, it's flipped 180º. What's the magnitude of the average EMF generated during this time?

$\Phi_{B1} = BA$

$\Phi_{B2} = -BA$

$\Delta\Phi_B = \Phi_{B2} - \Phi_{B1} = -2BA$

$\varepsilon = -N\,\Delta\Phi_B/\Delta t = -25(2BA)/\Delta t$

$\varepsilon = -25(2)(0.5\times10^{-4}\text{ T})(\pi(0.5\text{m})^2)\ /\ 0.2\text{ s}$

$\boldsymbol{\varepsilon = 9.8\times10^{-3}}$ **V.**

Comments:

0.0098 V is not much at all. To get 9 V (something more practical for our needs), we'd need 917 times more loops: 22916 loops.

A motor which has to turn 22916 1-meter-diameter loops will likely need much more than 9 V to operate.

If the Earth's B-field were a thousand times stronger, then we'd be in business.