Physics 201

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Magnetic flux

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  Here we look at the magnetic flux through a closed loop.

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  This is very similar to the concept of an electric flux through an area A.
  Here we look at the magnetic flux through a closed loop.
- Definition of magnetic flux:
  $\Phi_B = \vec{B}.\vec{A} = BA\cos\theta$
  θ: Angle between the magnetic field and the normal to the surface spanned by the closed loop.
  Unit: $1Wb = 1T.m^2$.

Magnetic flux

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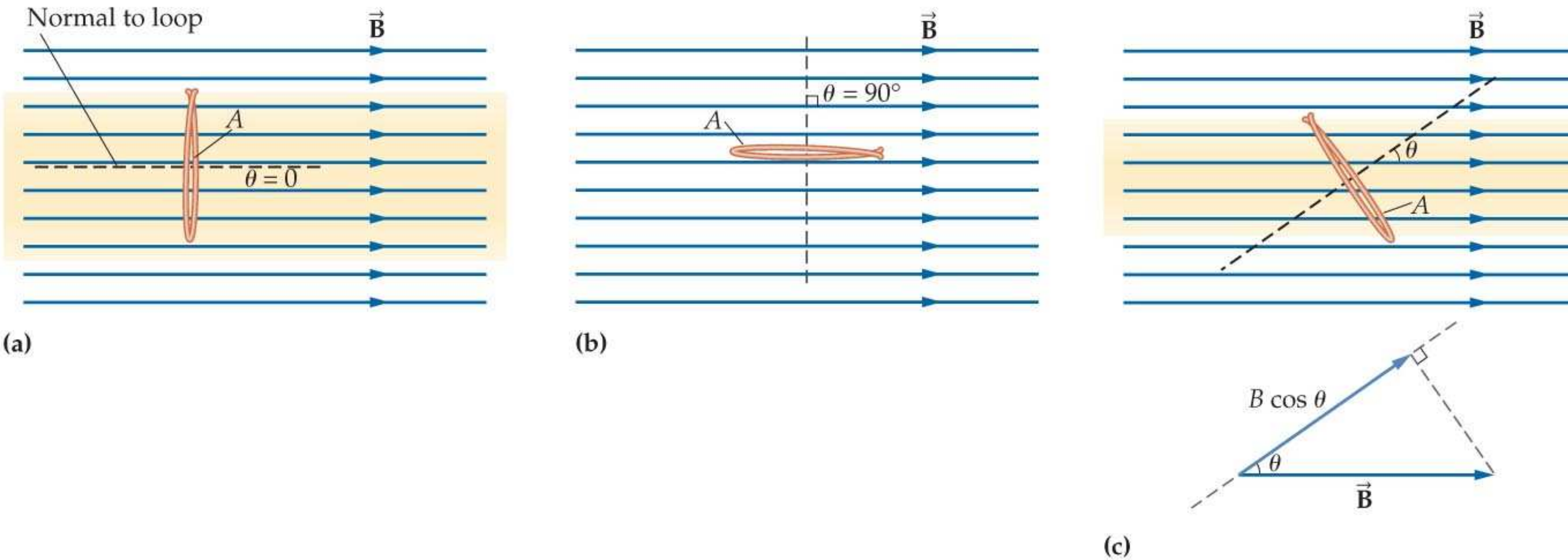
- Why am I interested in this?
  Because:
  It was discovered by Faraday that a changing magnetic flux induces an emf $\Rightarrow$ a current is produced if the magnetic flux changes with time $\Rightarrow$ This could happen if one can somehow mechanically generate a change in magnetic field. The dynamo is one of such examples.

Magnetic flux



Faraday's law of induction

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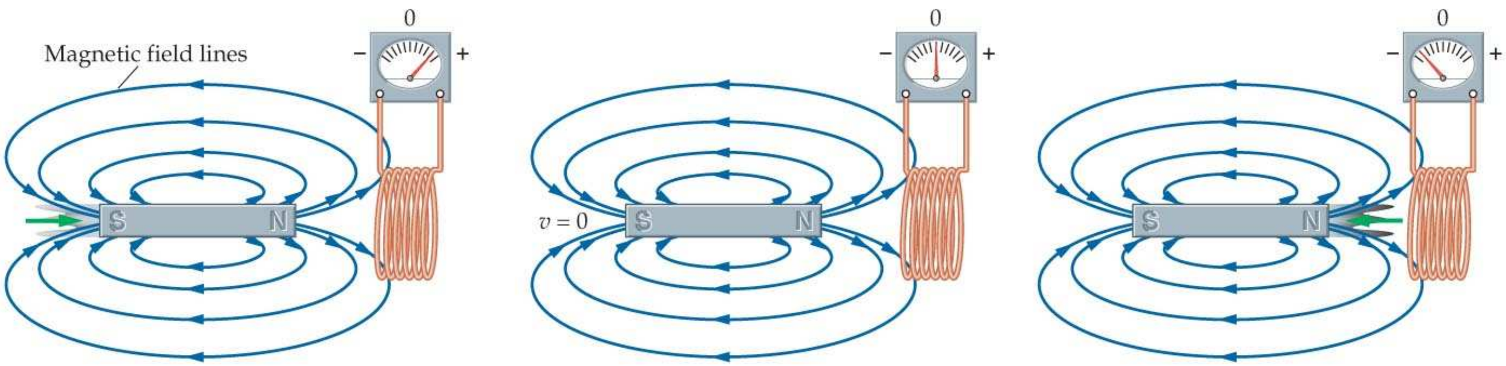
- Faraday's Law of magnetic induction:
  $\mathcal{E} = -N\frac{\Delta\Phi_B}{\Delta t}$
  where N is the number of turns in the coil.

Faraday's law of induction



(a) Moving magnet toward coil induces current in one direction

(b) No motion, no induced current

(c) Moving magnet away from coil induces current in opposite direction

Faraday's law of induction

- A coil of 50 loops is pulled in $0.020s$ from between the poles of a magnet, where its area intercepts a flux of $3.1 \times 10^{-4}\,Wb$, to a place where the intercepted flux is $0.10 \times 10^{-4}\,Wb$. Determine the average emf induced in the coil.
  Solution:
  $|\mathcal{E}| = N\frac{\Delta\Phi_B}{\Delta t} = 50\frac{(3.1-0.10)\times 10^{-4}\,Wb}{0.020s} = 0.75V$.

Faraday's law of induction

- A flat coil with radius $8.0mm$ has 50 loops of wire. It is placed in a magnetic field $B = 0.30T$ in such a way that the maximum flux goes through it. Later, it is rotated in $0.020s$ to a position such that no flux goes through it. Find the average emf induced between the terminals of the coil.
  Solution:
  A = $\pi r^2 = \pi(0.008m)^2 = 2.0 \times 10^{-4} m^2$
  $|\mathcal{E}| = 50 \frac{0.30T \times 2.0 \times 10^{-4} m^2}{0.020s} = 0.15V$.
  Various interesting applications: Ground Fault Interruptor, Induction stove, Electric guitar pickups, tape deck, etc..

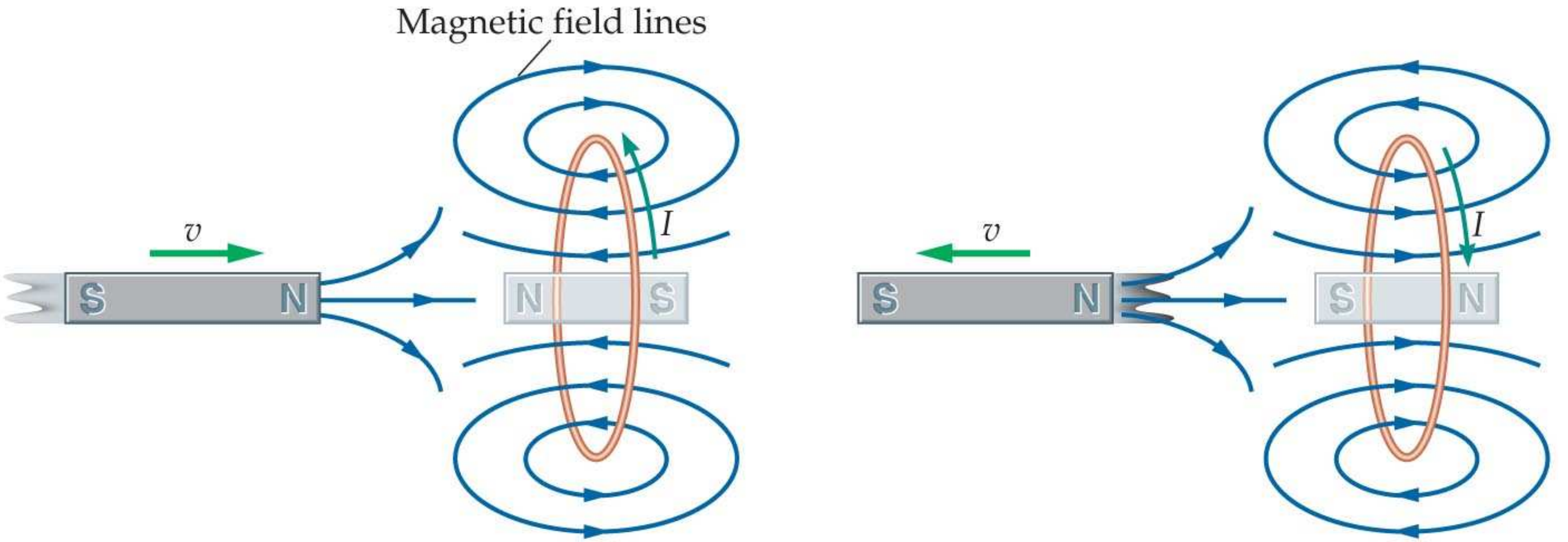
Lenz's Law

- How do I know which way the current goes when there is a changing magnetic flux going through a closed loop?

Lenz's Law

- How do I know which way the current goes when there is a changing magnetic flux going through a closed loop?
- Lenz's law:
  The induced current resulting from a changing magnetic flux flows in the direction such that the induced magnetic field opposes the original flux change.
  See the demos and the pictures shown in class.
  Illustrative discussion next concerning motional emf.

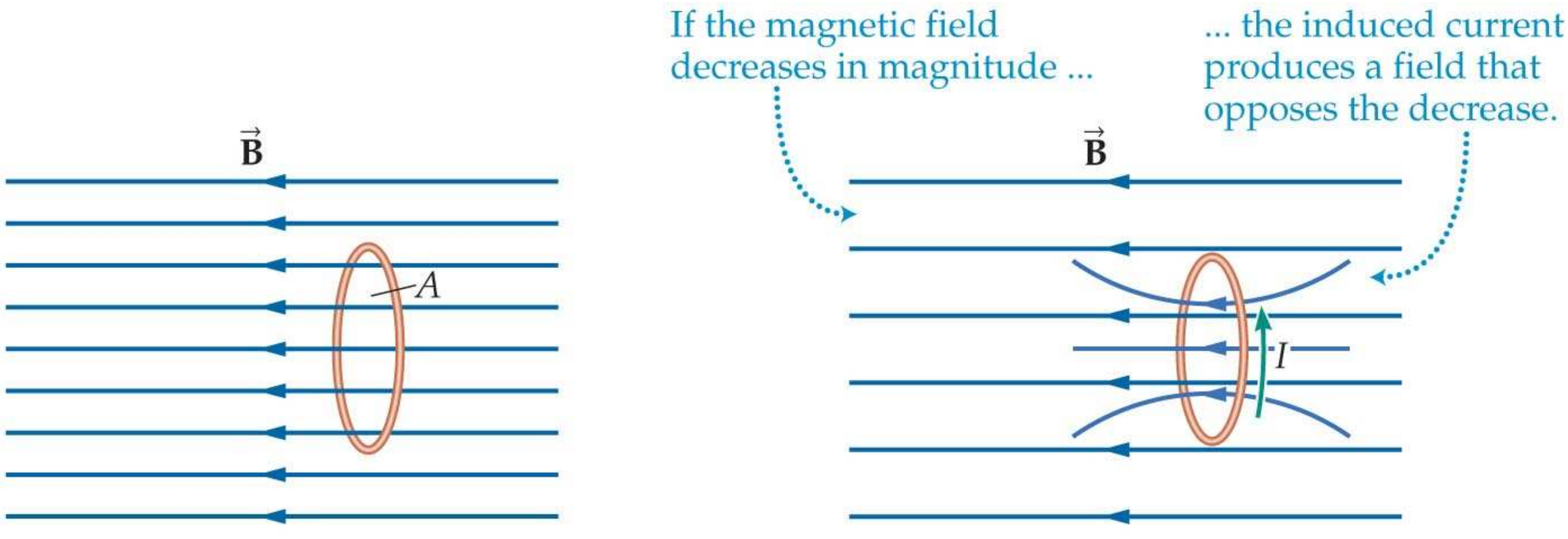
Lenz’s Law



(a) Moving magnet toward coil induces a field that repels the magnet

(b) Moving magnet away from coil induces a field that attracts the magnet

Lenz’s Law



(a) A conducting loop in a constant magnetic field

(b) A change in the field induces a current

Motional emf

In the Figure shown in class, a metal rod makes contact with a partial circuit and completes the circuit. The circuit is perpendicular to a magnetic field (going into the page) with $B = 0.15T$. If the resistance is 3.0Ω, how large a force is needed to move the rod as indicated with a constant speed of $2.0\,m/s$? At what rate is energy dissipated in the resistor? The width is $L = 50\,cm$

Motional emf: Solution and insight

- As the rod moves to the right as shown, the magnetic flux going through the closed circuit increases $\Rightarrow$ an induced current is produced and flowing counterclockwise.
  Why? The right-hand rule shows that the induced magnetic field inside the loop is going out of the page and opposes the external magnetic field which is going into the page.

Motional emf: Solution and insight

- As the rod moves to the right as shown, the magnetic flux going through the closed circuit increases $\Rightarrow$ an induced current is produced and flowing counterclockwise.
  Why? The right-hand rule shows that the induced magnetic field inside the loop is going out of the page and opposes the external magnetic field which is going into the page.
- What is the induced emf?
  $|\mathcal{E}| = N|\frac{\Delta\Phi_B}{\Delta t}| = (1)\frac{B\Delta A}{\Delta t} = \frac{BL\Delta x}{\Delta t} = BLv = (0.15T)(0.5m)(2.0m/s) = 0.15V$

Motional emf: Solution and insight

- Current:
  $I = \frac{|\mathcal{E}|}{R} = \frac{0.15V}{3.0\Omega} = 0.05A$.

Motional emf: Solution and insight

- Current:
$I = \frac{|\mathcal{E}|}{R} = \frac{0.15V}{3.0\Omega} = 0.05A$.
- Counterclockwise induced current $\Rightarrow$ the rod experiences a force pointing left due to the external magnetic field. Rod pulled to the right with constant speed $\Rightarrow$ this force must be balanced.
$F_M = ILB = (0.05A)(0.50m)(0.15T) = 3.75mN$.

Motional emf: Solution and insight

- The power loss in the resistor is
  $P = I^2R = (0.05A)^2(3.0\Omega) = 7.5mW$

Motional emf: Solution and insight

- The power loss in the resistor is
  $P = I^2R = (0.05A)^2(3.0\Omega) = 7.5mW$
- Alternatively
  $P = Fv = (3.75mN)(2.0m/s) = 7.5mW$

Motional emf