



PHYS 1444 – Section 003

Lecture #17

Tues., October 30, 2012

Dr. Andrew Brandt

Chapter 29

- Lenz Law
- Generator
- Transformer



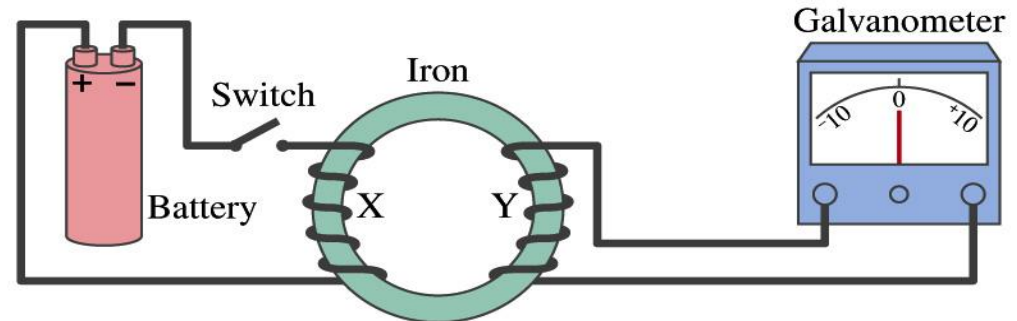
Induced EMF

- It has been discovered by Oersted and company in early 19th century that
 - Magnetic fields can be produced by an electric current
 - A magnetic field can exert force on electric charge
- So if you were scientists at that time, what would you wonder?
 - Yes, you are absolutely right. You would wonder if a magnetic field can create an electric current.
 - An American scientist Joseph Henry and an English scientist Michael Faraday independently found that it was possible
 - Though, Faraday was given the credit since he published his work before Henry did
 - He also did a lot of detailed studies on magnetic induction



Electromagnetic Induction

- Faraday used the apparatus below to show that magnetic field can induce current

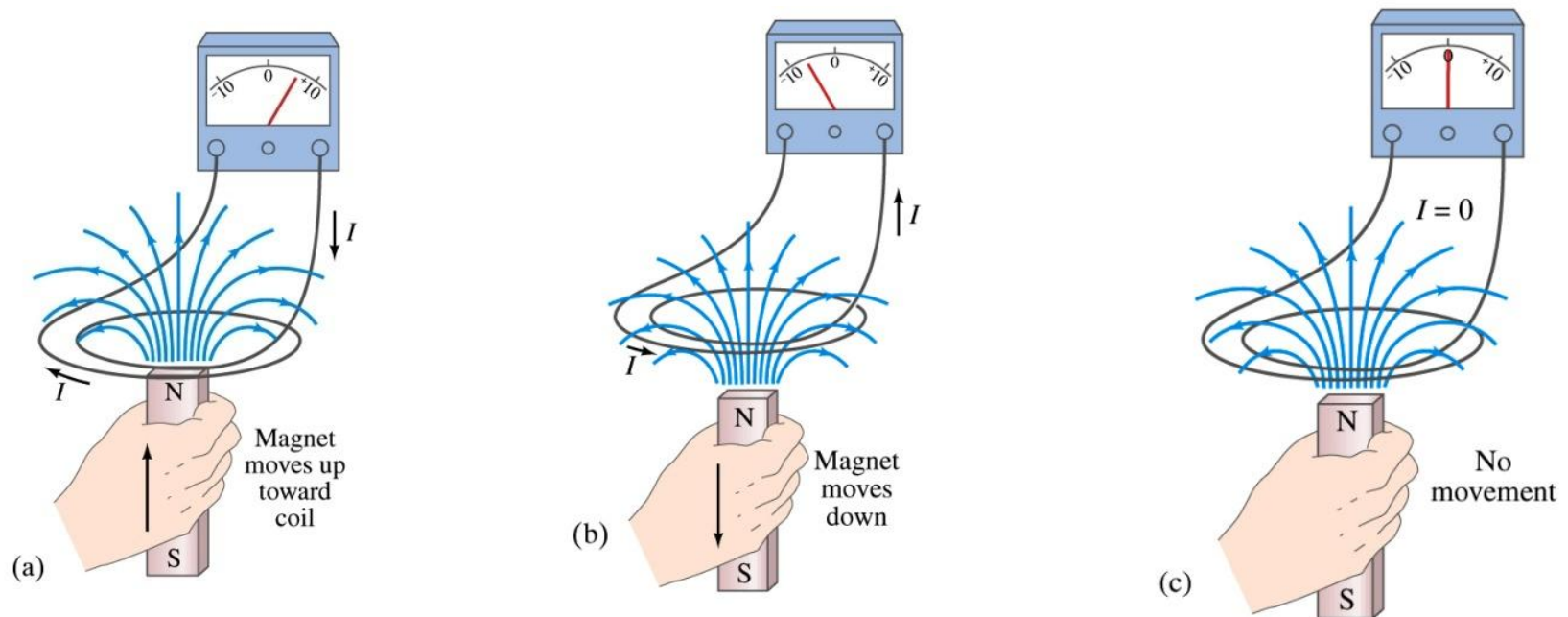


- Despite his hope he did not see steady current induced on the other side when the switch is thrown
- But he did see that the needle on the Galvanometer turns strongly when the switch is initially thrown and is opened
 - When the magnetic field through coil Y changes, a current flows as if there were a source of emf
- Thus he concluded that **an induced emf is produced by a changing magnetic field** → **Electromagnetic Induction**



Electromagnetic Induction

- Well known that a current produces a magnetic field, so by symmetry might expect that a magnetic field can produce a current (or voltage)
- It was found that relative motion of a wire coil and a magnet induces a current (and consequently an emf) in the wire.





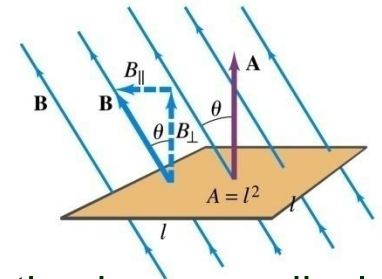
Magnetic Flux

- So what do you think the induced emf is proportional to?
 - The rate of changes of the magnetic field?
 - the higher the change the larger the induced EMF?
 - Close! It actually depends on the rate of change of the **magnetic flux**, Φ_B .

- Magnetic flux is similar to electric flux

- $$\Phi_B = B_{\perp} A = BA \cos \theta = \vec{B} \cdot \vec{A}$$

- θ is the angle between \mathbf{B} and the area vector \mathbf{A} whose direction is perpendicular to the face of the loop based on the right-hand rule



- What kind of quantity is the magnetic flux?

- Scalar. Unit?

- $T \cdot m^2$ or weber

$$1\text{Wb} = 1\text{T} \cdot m^2$$

- If the area of the loop is not simple or \mathbf{B} is not uniform, the magnetic flux can be written as

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



Faraday's Law of Induction

- In terms of magnetic flux, we can formulate Faraday's findings
 - The emf induced in a circuit is equal to the rate of change of magnetic flux through the circuit

$$\mathcal{E} = -N \frac{d\Phi_B}{dt}$$

Faraday's Law of Induction

- For a single loop of wire $N=1$, for closely wrapped loops, N is the number of loops
- The negative sign has to do with the direction of the induced emf (Lenz's Law)

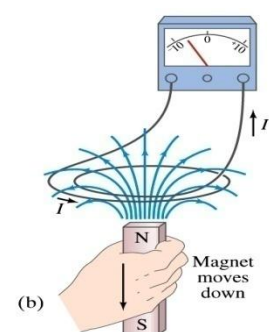
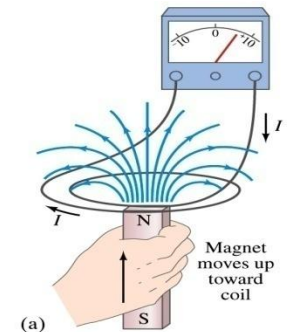


Lenz's Law

- It is experimentally found that
 - An induced emf gives rise to a current whose magnetic field opposes the original change in flux → This is known as **Lenz's Law**
 - We can use Lenz's law to explain the following cases in the figures

- When the magnet is moving into the coil
 - Since the external flux increases, the field inside the coil takes the opposite direction to minimize the change and causes the current to flow clockwise
- When the magnet is moving out
 - Since the external flux decreases, the field inside the coil takes the opposite direction to compensate the loss, causing the current to flow counter-clockwise

- Which law is Lenz's law result of?
 - Energy conservation. Why? (no free lunch)

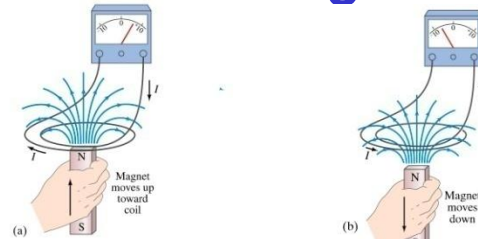




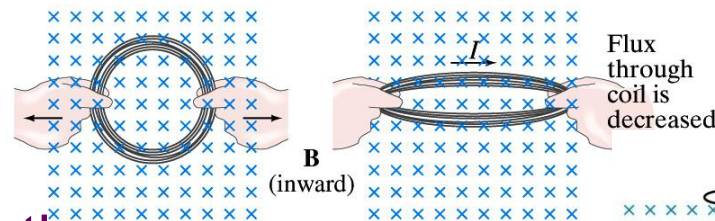
Induction of EMF

- How can we induce an emf?
- Let's look at the formula for magnetic flux
- $$\Phi_B = \int \vec{B} \cdot d\vec{A} = \int B \cos \theta dA$$
- What do you see? What are the things that can change with time to result in change of magnetic flux?

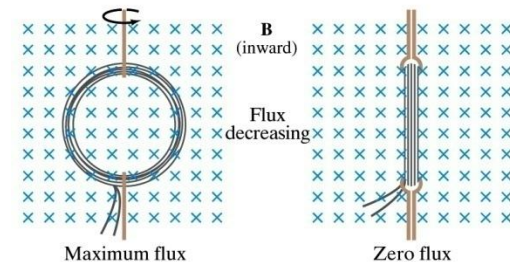
– Magnetic field



– The area of the loop



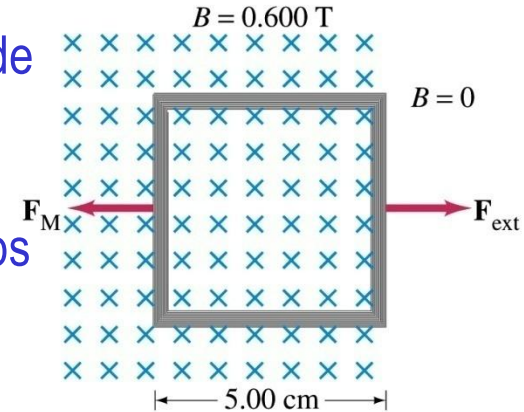
– The angle θ between the field and the area vector





Example 29 – 2

Pulling a coil from a magnetic field. A square coil of wire with side 5.00cm contains 100 loops and is positioned perpendicular to a uniform 0.600-T magnetic field. It is quickly and uniformly pulled from the field (moving perpendicular to B) to a region where B drops abruptly to zero. At $t=0$, the right edge of the coil is at the edge of the field. It takes 0.100s for the whole coil to reach the field-free region. Find (a) the rate of change in flux through the coil, (b) the emf and current induced, and (c) how much energy is dissipated in the coil if its resistance is 100Ω . (d) what was the average force required?



What should be computed first? The initial flux at $t=0$.

The flux at $t=0$ is $\Phi_B = \vec{B} \cdot \vec{A} = BA = 0.600T \cdot 5 \times 10^{-2}m^2 = 1.50 \times 10^{-3}Wb$

The change of flux is $\Delta\Phi_B = 0 - 1.50 \times 10^{-3}Wb = -1.50 \times 10^{-3}Wb$

Thus the rate of change of the flux is

$$\frac{\Delta\Phi_B}{\Delta t} = \frac{-1.50 \times 10^{-3}Wb}{0.100s} = -1.50 \times 10^{-2}Wb/s$$



Example 29 – 2, cnt'd

Thus the total emf induced in this period is

$$\varepsilon = -N \frac{d\Phi_B}{dt} = -100 \cdot -1.50 \times 10^{-2} \text{ Wb/s} = 1.5\text{V}$$

The induced current in this period is

$$I = \frac{\varepsilon}{R} = \frac{1.5\text{V}}{100\Omega} = 1.50 \times 10^{-2} \text{ A} = 15.0\text{mA}$$

Clockwise to
compensate for
the loss of flux
through coil

Which direction would the induced current flow?

The total energy dissipated is

$$E = Pt = I^2 R t = 1.50 \times 10^{-2} \text{ A}^2 \cdot 100\Omega \cdot 0.100\text{s} = 2.25 \times 10^{-3} \text{ J}$$

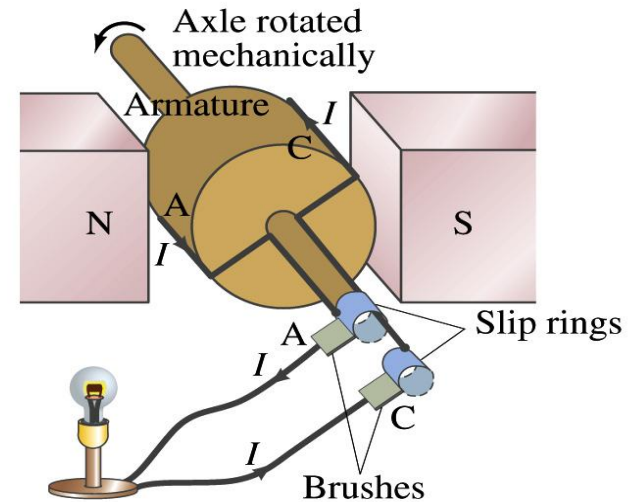
Force for each coil is $\vec{F} = I\vec{l} \times \vec{B}$ Force for N coil is $\vec{F} = NI\vec{l} \times \vec{B}$

$$|F| = NI l B = 100 \cdot 1.50 \times 10^{-2} \text{ A} \cdot 4 \times 5 \times 10^{-2} \cdot 0.600\text{T} = 0.045\text{N}$$



Electric Generator (Dynamo)

- An electric generator transforms mechanical energy into electrical energy
- It consists of many coils of wires wound on an armature that can be rotated in a magnetic field
- An emf is induced in the rotating coil
- Electric current is the output of a generator



- Which direction does the output current flow when the armature rotates counterclockwise?
 - Initially the current flows as shown in figure to reduce flux through the loop
 - After half a revolution, the current flow is reversed
- Thus a generator produces alternating current



How does an Electric Generator work?

- Let's assume the loop is rotating in a uniform B field with constant angular velocity ω . The induced emf is

- $$\varepsilon = -\frac{d\Phi_B}{dt} = -\frac{d}{dt} \int \vec{B} \cdot d\vec{A} = -\frac{d}{dt} BA \cos \theta$$

- What is the variable that changes above?

- The angle θ . What is $d\theta/dt$?

- The angular speed ω .

- So $\theta = \theta_0 + \omega t$

- If we choose $\theta_0 = 0$, we obtain

- $$\varepsilon = -BA \frac{d}{dt} \cos \omega t = BA\omega \sin \omega t$$

- If the coil contains N loops:

$$\varepsilon = -N \frac{d\Phi_B}{dt} = NBA\omega \sin \omega t = \varepsilon_0 \sin \omega t$$

- What is the shape of the output?

- Sinusoidal w/ amplitude $\varepsilon_0 = NBA\omega$

- US AC frequency is 60Hz. Europe uses 50Hz

