PHYS 1444 – Section 003
Lecture #18

Thurs., November 1, 2012

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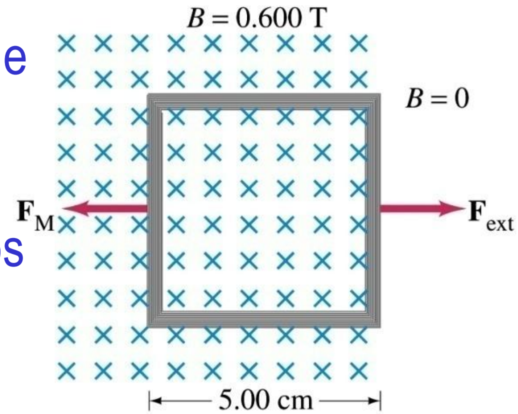
Chapter 29

- Motional emf
- Generator
- Transformer
- Domains

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 $\Phi_B = \vec{B}\cdot\vec{A} = BA = 0.600T\cdot\left(5\times10^{-2}m\right)^2 = 1.50\times10^{-3}Wb$

The change of flux is $\Delta\Phi_B = 0 - 1.50\times10^{-3}Wb = -1.50\times10^{-3}Wb$

Thus the rate of change of the flux is

$$\frac{\Delta\Phi_B}{\Delta t} = \frac{-1.50\times10^{-3}Wb}{0.100s} = -1.50\times10^{-2}\,Wb/s$$

Example 29 – 2, cnt'd

Thus the total emf induced in this period is

$$\varepsilon = -N\frac{d\Phi_B}{dt} = -100\cdot\left(-1.50\times10^{-2}\,Wb/s\right) = 1.5V$$

The induced current in this period is

$$I = \frac{\varepsilon}{R} = \frac{1.5V}{100\Omega} = 1.50\times10^{-2}A = 15.0mA$$

Which direction would the induced current flow?

Clockwise to compensate for the loss of flux through coil

The total energy dissipated is

$$E = Pt = I^2Rt = \left(1.50\times10^{-2}A\right)^2\cdot100\Omega\cdot0.100s = 2.25\times10^{-3}J$$

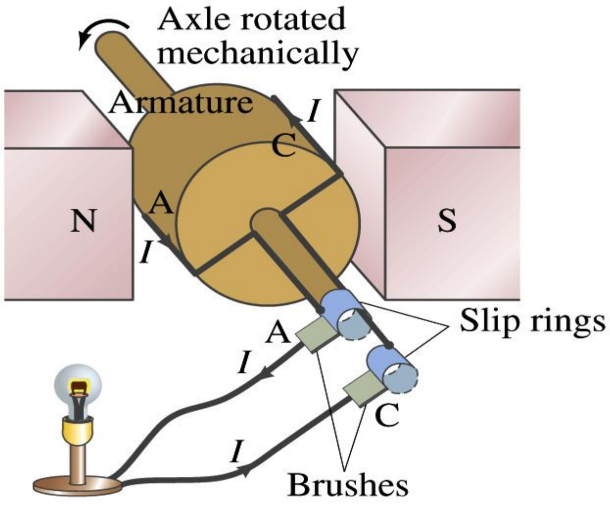
Force for each coil is $\vec{F} = I\vec{l}\times\vec{B}$ Force for N coil is $\vec{F} = NI\vec{l}\times\vec{B}$

$$|F| = NIlB = 100\cdot\left(1.50\times10^{-2}A\right)\cdot\left(4\times5\times10^{-2}\right)\cdot0.600T = 0.045N$$

This 4 was wrong, only far side matters

Electric Generator (Dynamo)

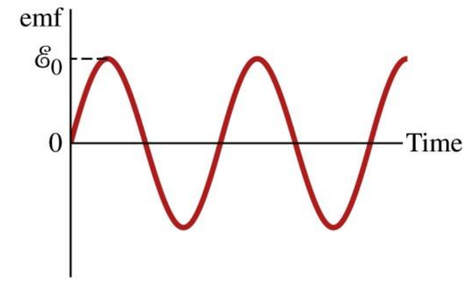
- An electric generator transforms mechanical energy into electrical energy
- It consists of many coils of wires wound on an armature that can be rotated in a magnetic field
- An emf is induced in the rotating coil
- Electric current is the output of a generator



- 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
  - $\varepsilon = -BA\frac{d}{dt}\cos\varpi t = BA\varpi\sin\varpi t$
  - If the coil contains N loops: $\varepsilon = -N\frac{d\Phi_B}{dt} = NBA\varpi\sin\varpi t = \varepsilon_0\sin\varpi t$
  - What is the shape of the output?
    - Sinusoidal w/ amplitude $\varepsilon_0=NBA\omega$
- US AC frequency is 60Hz. Europe uses 50Hz



Example 29 – 5

An AC generator. The armature of a 60-Hz AC generator rotates in a 0.15-T magnetic field. If the area of the coil is $2.0\times10^{-2}m^2$, how many loops must the coil contain if the peak output is to be ε_0=170V?

The maximum emf of a generator is $\varepsilon_0 = NBA\varpi$

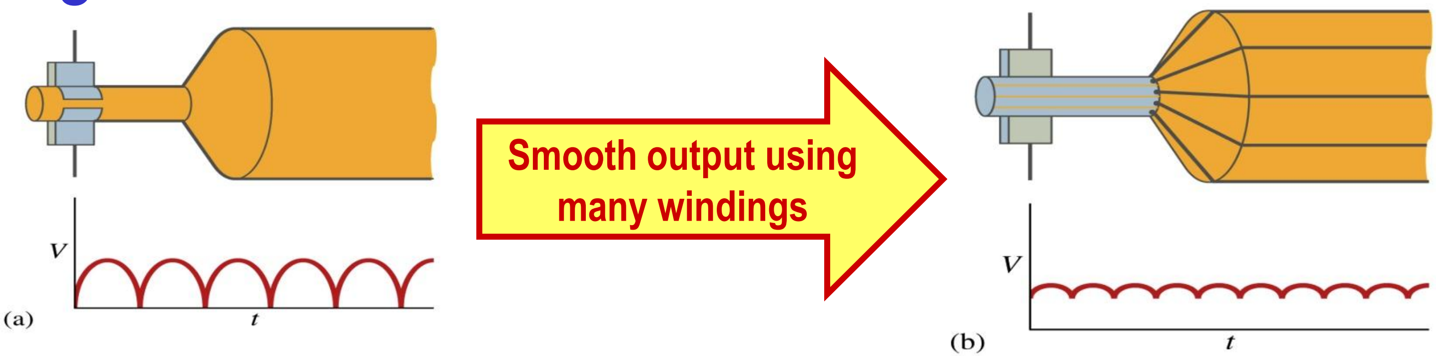
Solving for N $N = \frac{\varepsilon_0}{BA\varpi}$

Since $\varpi = 2\pi f$ We obtain

$$N = \frac{\varepsilon_0}{2\pi BAf} = \frac{170V}{2\pi \cdot \ 0.15T \ \cdot \ 2.0\times10^{-2}m^2 \ \cdot \ 60s^{-1}} = 150turns$$

A DC Generator

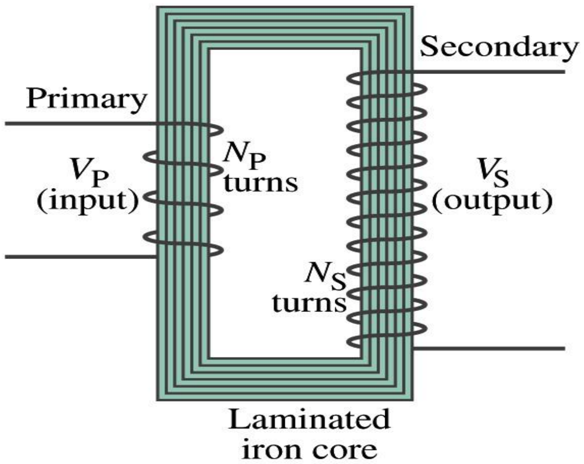
- A DC generator is almost the same as an ac generator except the slip rings are replaced by split-ring commutators



- Dips in output voltage can be reduced by using a capacitor, or more commonly, by using many armature windings

Transformer

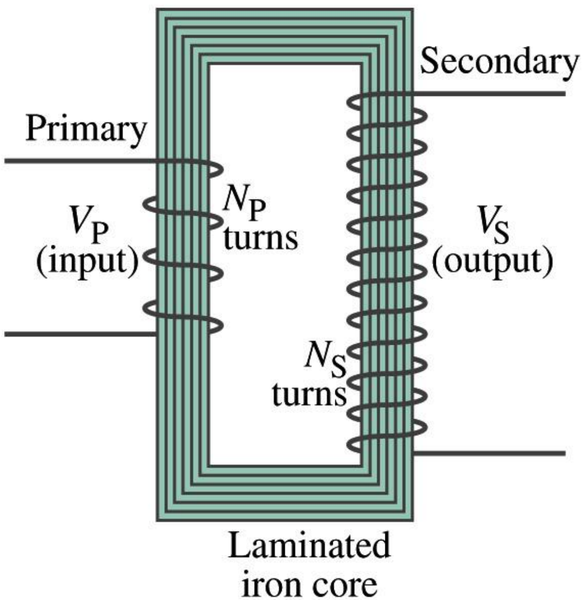
- What is a transformer?
  - A device for increasing or decreasing an AC voltage
  - Examples, the complete power chain from generator to your house, high voltage electronics
  - A transformer consists of two coils of wires known as the primary and secondary
  - The two coils can be interwoven or linked by a laminated soft iron core to reduce eddy current losses
- Transformers are designed so that all magnetic flux produced by the primary coil pass through the secondary



How does a transformer work?

- When an AC voltage is applied to the primary, the changing B it produces will induce voltage of the same frequency in the secondary wire
- So how would we make the voltage different?
  - By varying the number of loops in each coil
  - From Faraday's law, the induced emf in the secondary is
  - $V_S = N_S \frac{d\Phi_B}{dt}$
  - The input primary voltage is
  - $V_P = N_P \frac{d\Phi_B}{dt}$
  - Since $d\Phi_B/dt$ is the same, we obtain
  - $\frac{V_S}{V_P} = \frac{N_S}{N_P}$

Transformer Equation



Transformer Equation

- The transformer equation does not work for DC current since there is no change of magnetic flux
- If $N_S > N_P$, the output voltage is greater than the input so it is called a step-up transformer while $N_S < N_P$ is called step-down transformer
- Now, it looks like energy conservation is violated since we can get a larger emf from a smaller ones, right?
  - Wrong! Wrong! Wrong! Energy is always conserved!
  - A well designed transformer can be more than 99% efficient
  - The power output is the same as the input:
  - $V_P I_P = V_S I_S$
  - $$\frac{I_S}{I_P} = \frac{V_P}{V_S} = \frac{N_P}{N_S}$$

The output current for step-up transformer will be lower than the input, while it is larger for a step-down transformer than the input.

Example 29 – 8

Portable radio transformer. A transformer for use with a portable radio reduces 120-V ac to 9.0V ac. The secondary contains 30 turns, and the radio draws 400mA. Calculate (a) the number of turns in the primary; (b) the current in the primary; and (c) the power transformed.

(a) What kind of a transformer is this? A step-down transformer

Since $\frac{V_P}{V_S} = \frac{N_P}{N_S}$ We obtain $N_P = N_S \frac{V_P}{V_S} = 30 \frac{120V}{9V} = 400 turns$

(b) Also from the transformer equation $\frac{I_S}{I_P} = \frac{V_P}{V_S}$ We obtain

$$I_P = I_S \frac{V_S}{V_P} = 0.4A \frac{9V}{120V} = 0.03A$$

(c) Thus the power transformed is

$$P = I_S V_S = 0.4A \cdot 9V = 3.6W$$

How about the input power? The same assuming 100% efficiency.

Example 29 – 9: Power Transmission

Transmission lines. An average of 120kW of electric power is sent to a small town from a power plant 10km away. The transmission lines have a total resistance of 0.4Ω. Calculate the power loss if the power is transmitted at (a) 240V and (b) 24,000V.

We cannot use $P=V^2/R$ since we do not know the voltage along the transmission line. We, however, can use $P=I^2R$.

(a) If 120kW is sent at 240V, the total current is $I=\frac{P}{V}=\frac{120\times10^3}{240}=500A.$

Thus the power loss due to the transmission line is

$$P=I^2R=\left(500A\right)^2\cdot\left(0.4\Omega\right)=100kW$$

(b) If 120kW is sent at 24,000V, the total current is $I=\frac{P}{V}=\frac{120\times10^3}{24\times10^3}=5.0A.$

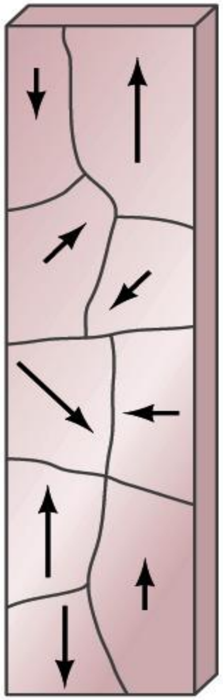
Thus the power loss due to transmission line is

$$P=I^2R=\left(5A\right)^2\cdot\left(0.4\Omega\right)=10W$$

The higher the transmission voltage, the smaller the current, causing less loss of energy. This is why power is transmitted w/ HV, as high as 170kV.

Magnetic Materials - Ferromagnetism

- Iron is a material that can turn into a strong magnet
  - This kind of material is called **ferromagnetic**
- In the microscopic sense, ferromagnetic materials consists of many tiny regions called **domains**
  - Domains are like little magnets usually smaller than 1mm in length or width
- What do you think the alignment of domains are like when they are not magnetized?
  - Randomly arranged



- What if they are magnetized?
  - The number of domains aligned with the external magnetic field direction grows
  - This gives magnetization to the material
- How do we demagnetize a bar magnet?
  - Hit the magnet hard or heat it over the Curie temperature

B in Magnetic Materials

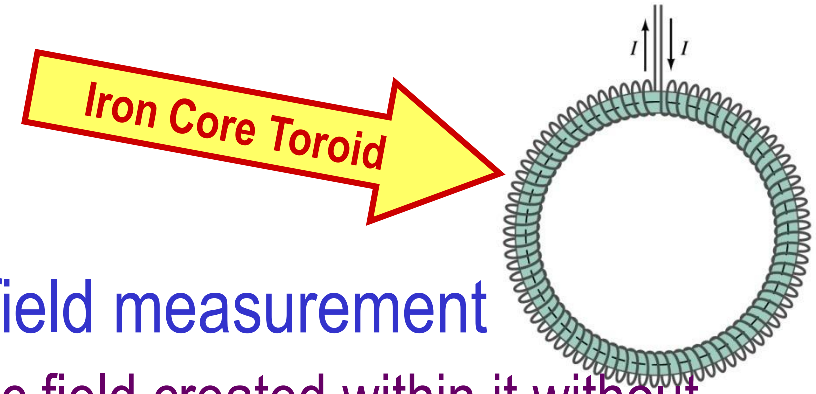
- What is the magnetic field inside a solenoid?
- $$B_0 = \mu_0 n I$$
  - Magnetic field in a long solenoid is directly proportional to the current.
  - This is valid only if air is inside the coil
- What do you think will happen to B if we have something other than the air inside the solenoid?
  - It could be increased dramatically: if a ferromagnetic material such as iron is put inside, the field could increase by several orders of magnitude
- Why?
  - Since the domains in the iron are aligned by the external field.
  - The resulting magnetic field is the sum of that due to the current in the solenoid and due to the iron

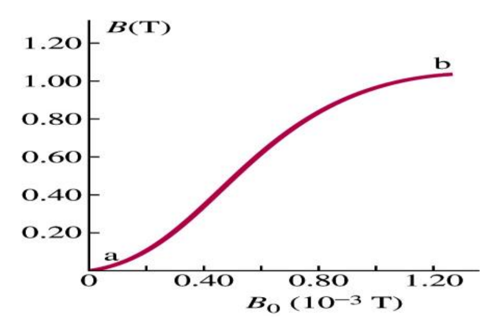
B in Magnetic Materials

- It is sometimes convenient to write the total field as the sum of two terms
- $\vec{B} = \vec{B}_0 + \vec{B}_M$
  - **B_0** is the field due only to the current in the wire, namely the external field
    - The field that would be present without a ferromagnetic material
  - **B_M** is the additional field due to the ferromagnetic material itself; often **B_M>>B_0**
- The total field in this case can be written by replacing μ_0 with another proportionality constant μ, the magnetic permeability of the material $B = \mu n I$
  - μ is a property of a magnetic material
  - μ is not a constant but varies with the external field

Hysteresis

- What is a toroid?
  - A solenoid bent into a circle
- Toroids can be used for magnetic field measurement
  - A toroid fully contains all the magnetic field created within it without leakage
- Consider an un-magnetized iron core toroid, without any current flowing in the wire
  - What do you think will happen if the current slowly increases?
  - B_0 increases linearly with the current.
  - And B increases also but follows the curved line shown in the graph
  - As B_0 increases, the domains become more aligned until nearly all are aligned (point b on the graph)
    - The iron is said to be approaching saturation
    - Point b is typically at 70% of the max





Hysteresis

- What do you think will happen to B if the external field B_0 is reduced to 0 by decreasing the current in the coil?
  - ~~Of course it goes to 0!!~~
  - Wrong! Wrong! Wrong! They do not go to 0. Why not?
  - The domains do not completely return to random alignment state
- Now if the current direction is reversed, the external magnetic field direction is reversed, causing the total field B to pass 0, and the direction reverses to the opposite side
  - If the current is reversed again, the total field B will increase but never goes through the origin
- This kind of curve whose path does not retrace themselves and does not go through the origin is called **Hysteresis**.