Unit - III

3.2 Problems in Electromagnetics

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Syllabus

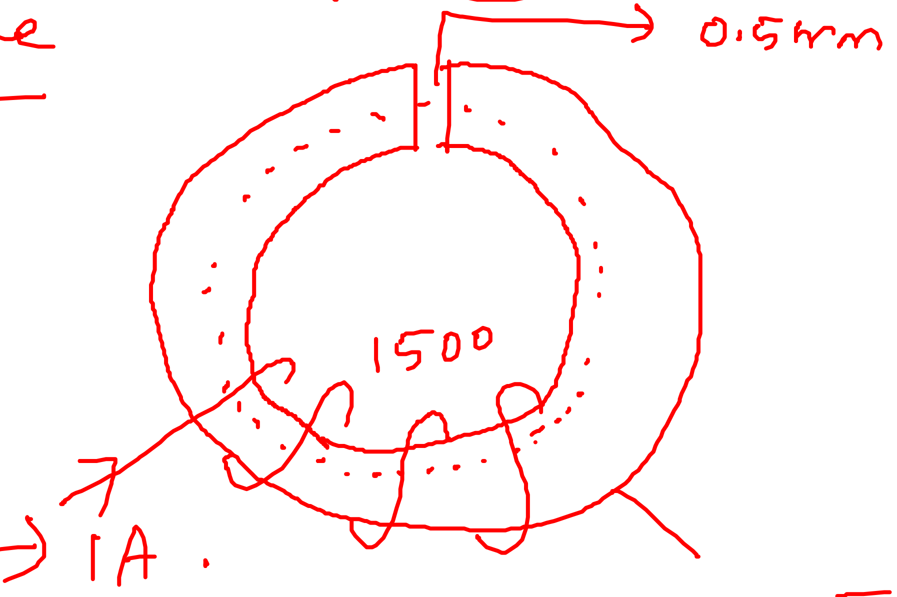
UNIT – III **10 Periods**

Principles of Electro Magnetics and Electro-mechanics: Electricity and Magnetism - magnetic field and faraday's law - self and mutual inductance - Ampere's law - Magnetic circuit - Magnetic material and B-H Curve – Single phase transformer - principle of operation - EMF equation - voltage ratio - current ratio – KVA rating - Electromechanical energy conversion – Elementary generator and motors.

A ring has mean diameter of 15 cm, a cross section of 1.7 cm^2 and has a radial gap of 0.5 mm in it. It is uniformly wound with 1500 turns of insulated wire and a current of 1 A produces a flux of 0.1 mwb across the gap. Calculate the relative permeability of iron on the assumption that there is no magnetic leakage.

Exercise

B_g



μ_r

$\boxed{AT_i = 1266 \quad (AT)}$

$H_i l = NI = 1266$

$\boxed{l_i = 0.4705 m}$

$\boxed{H_i = 2690.75 (A/m)}$

$AT_t = AT_g + AT_i$

$1500 = 234 + AT_i$

$B_i = \mu_0 \mu_r H_i \Rightarrow$

$\boxed{\mu_r = \frac{B_i}{\mu_0 H_i}}$

$\boxed{\mu_r =}$

A series magnetic circuit has an iron path of length 50 cm and an air gap of length 1 mm. The cross-sectional area of the iron is 6.66 cm^2 and the exciting coil has 400 turns. Determine the current required to produce a flux of 0.9 mwb in the circuit. The following points are taken from the magnetization curve for iron.

iron / gap

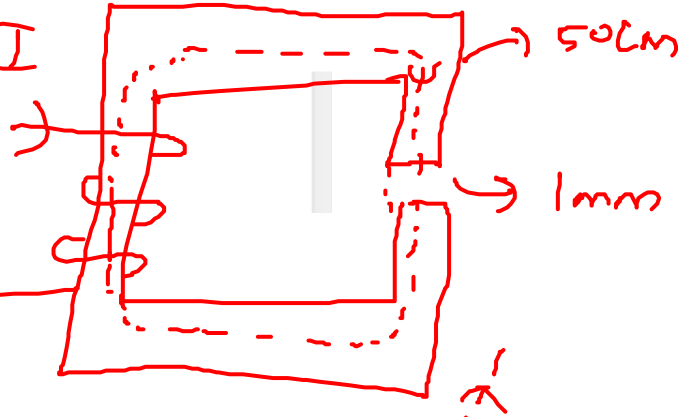
B	Flux density (wb/m^2) :	1.2	1.35	1.45	1.55
H	Magnetizing force (A/m) :	500	1000	2000	4000

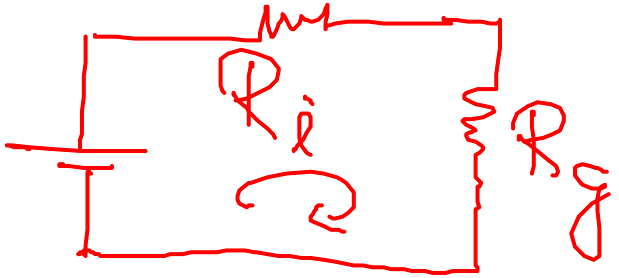
$I = ?$

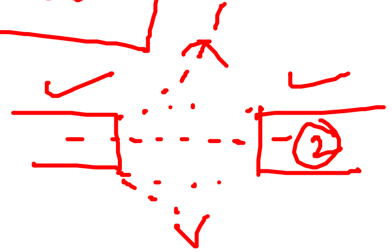
$a = 6.66 \times 10^{-4}\ m^2$

$N = 400$

$\phi_g = 0.9 \times 10^{-3}\ wb$







$AT_t = AT_i + AT_g$

$AT_t = NI$

$\boxed{I = \dfrac{AT_t}{N}}$

Air gap

$B_g = \dfrac{\phi_g}{a} = \dfrac{0.9 \times 10^{-3}}{6.66 \times 10^{-4}}$

$\boxed{B_g = 1.351\ (T)}$

$\boxed{H_g = \dfrac{B_g}{\mu r} = 0.107 \times 10^{7}\ (A/m)}$

$$AT_g = H_g \cdot l_g = MMF$$

$$AT_g = H_g \cdot l_g$$

$$= 0.107 \times 10^{7} \times 1 \times 10^{-3}$$

$$\boxed{AT_g = \quad} \ (AT)$$

For iron path

$$B_i = \frac{\phi}{a} = B_g = 1.35T$$

$$\boxed{H_i = \frac{B_i}{\mu_0 \mu_r}}$$

$$\boxed{H_i = 1000 \ A/m}$$

from table

$$AT_i = H_i \times l_i$$

$$= 1000 \times 50 \times 10^{-2}$$

$$\boxed{AT_i = 500 \ (A/m)}$$

$$AT_t = AT_g + AT_i$$

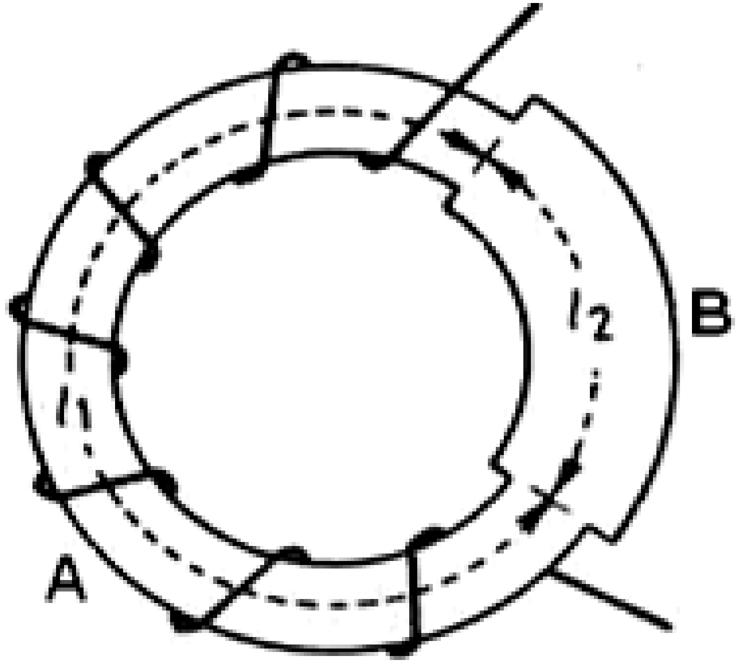
$$\boxed{AT_t = 1570}$$

$$I = \frac{AT_t}{N}$$

$$\boxed{I = 3.92 \ (A)}$$

Composite Magnetic Circuit

Case 1 :



$$\mathcal{R}_1 = \frac{l_1}{\mu_1 A_1}$$

$$\mathcal{R}_2 = \frac{l_2}{\mu_2 A_2}$$

$$\therefore \text{ Total Reluctance}, \mathcal{R} = \mathcal{R}_1 + \mathcal{R}_2 = \frac{l_1}{\mu_1 A_1} + \frac{l_2}{\mu_2 A_2}$$

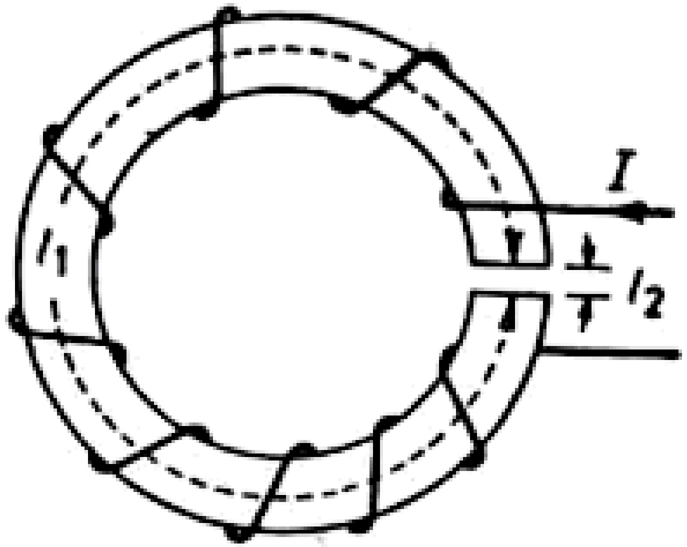
Next

$$\therefore \ \text{Total flux, } \Phi = \frac{\text{mmf of coil}}{\text{total reluctance}}$$

$$= \frac{\mathcal{F}}{\mathcal{R}} = \frac{NI}{\dfrac{l_1}{\mu_1 A_1} + \dfrac{l_2}{\mu_2 A_2}}$$

Next

Case 2 : (with air gap)



Total reluctance,

$$\mathcal{R} = \frac{l_1}{\mu_1 A} + \frac{l_2}{\mu_0 A}$$

$$= \frac{1}{\mu_0 A}\left(\frac{l_1}{(\mu_1 / \mu_0)} + l_2\right)$$

$$= \frac{1}{\mu_0 A}\left(\frac{l_1}{\mu_r} + l_2\right)$$

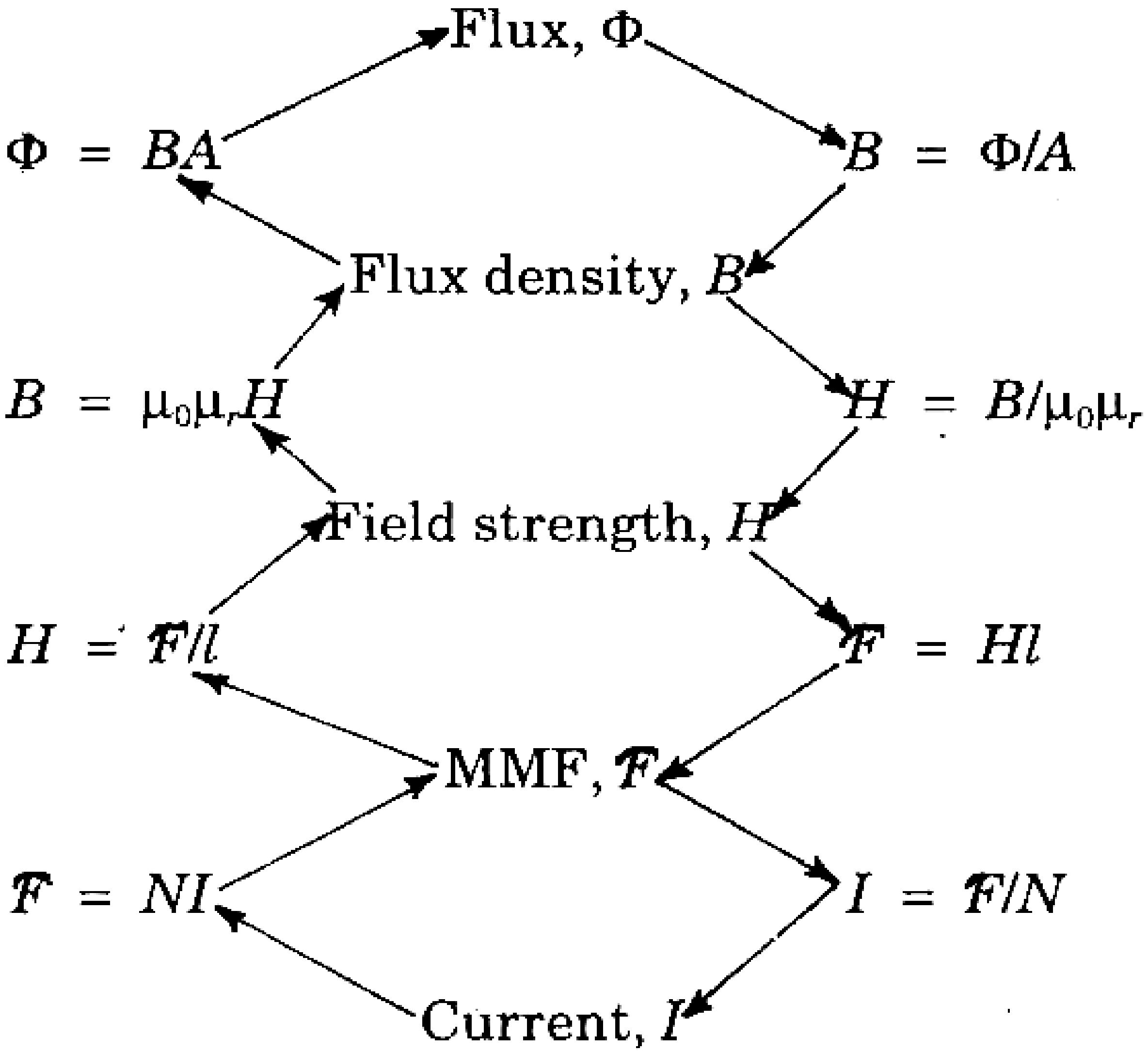
Next

Kirchhoff's Laws

- ***Kirchhoff's Flux Law* (KFL)** **:** *The total magnetic flux towards a junction is equal to the total magnetic flux away from that junction.*
- ***Kirchhoff's Magnetomotive Force Law* (KML)** **:** *In a closed magnetic circuit, the algebraic sum of the product of the magnetic field strength and the length of each part of the circuit is equal to the resultant magnetomotive force.*

Next

Steps to solve a problem on magnetic circuit

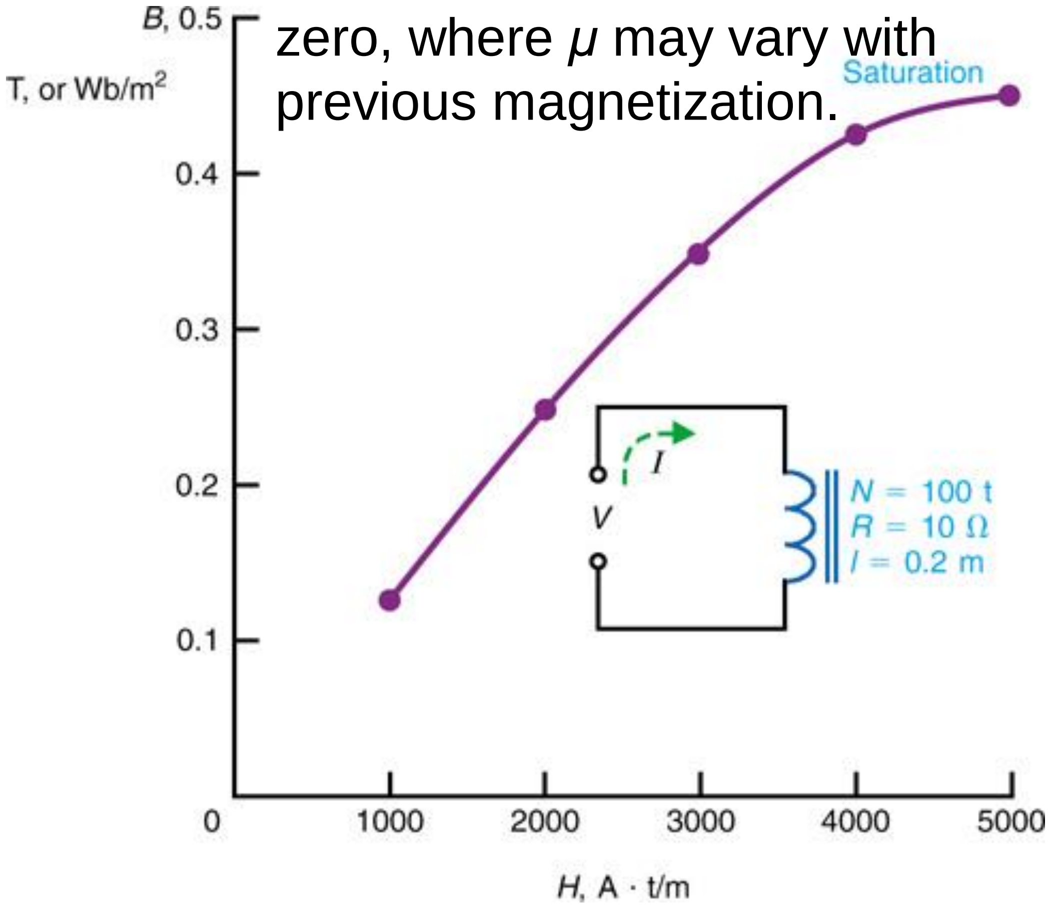


Inductance

B-H Magnetization Curve

- The *B-H* magnetization curve shows how much flux density *B* results from increasing field intensity *H*.
- **Saturation** is the effect of little change in flux density when the field intensity increases.

B-H magnetization curve for soft iron. No values are shown near zero, where *μ* may vary with previous magnetization.



Magnetic Hysteresis

- **Hysteresis** refers to a situation where the magnetic flux lags the increases or decreases in magnetizing force.
- **Hysteresis loss** is energy wasted in the form of heat when alternating current reverses rapidly and molecular dipoles lag the magnetizing force.
- For steel and other hard magnetic materials, **hysteresis losses** are much higher than in soft magnetic materials like iron.

Magnetic Hysteresis

- Hysteresis Loop
  - B_R is due to **retentivity,** which is the flux density remaining after the magnetizing force is reduced to zero.
  - Note that $H = 0$ but $B > 0$.
  - H_C is the coercive force (needed to make $B = 0$)

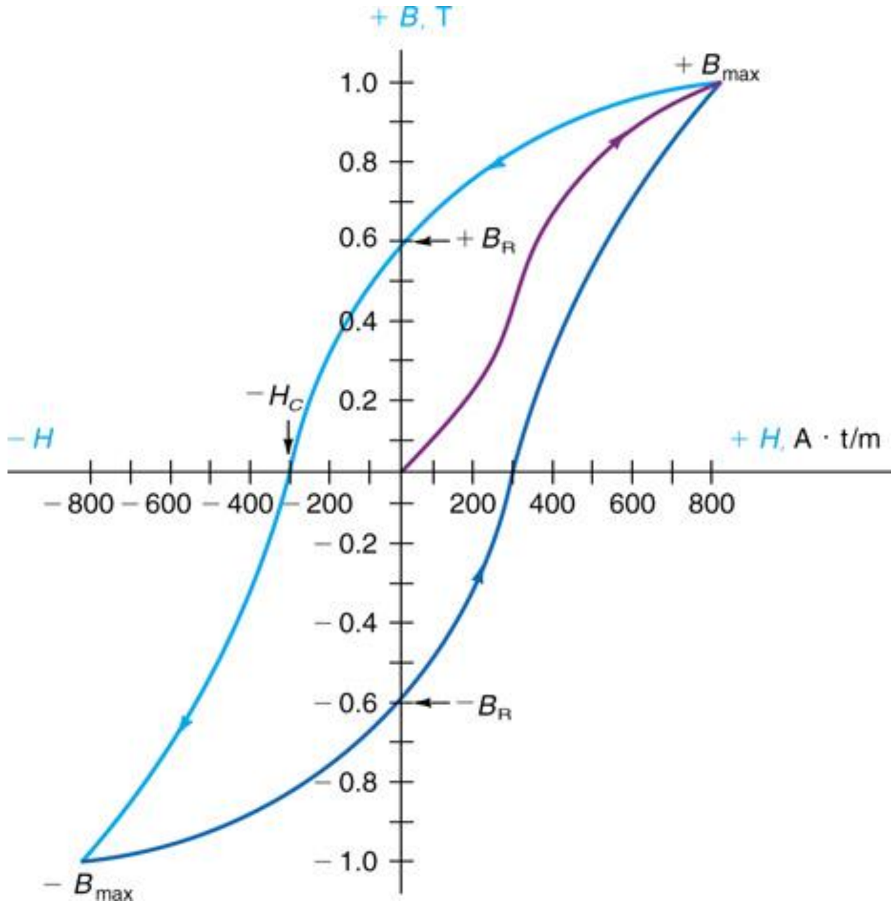


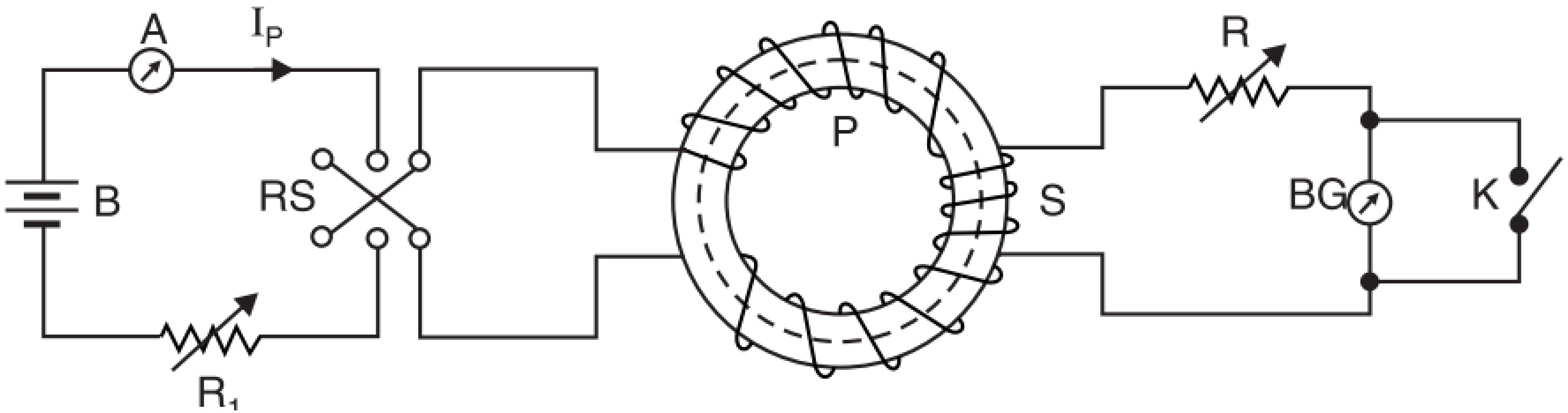
Fig. 14-4: Hysteresis loop for magnetic materials. This graph is a *B*-*H* curve , but *H* alternates in polarity with alternating current.

Magnetic Hysteresis

- Demagnetization (Also Called Degaussing)
  - This method of demagnetization is called **degaussing**.
  - Applications of degaussing include:
    - Metal electrodes in a color picture tube
    - Erasing the recorded signal on magnetic tape.

Determination of B/H or Magnetisation Curve

- ballistic galvanometer
- fluxmeter



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Joseph Henry

- 1797 – 1878
- American physicist
- First director of the Smithsonian
- Improved design of electromagnet
- Constructed one of the first motors
- Discovered self-inductance
- Unit of inductance is named in his honor

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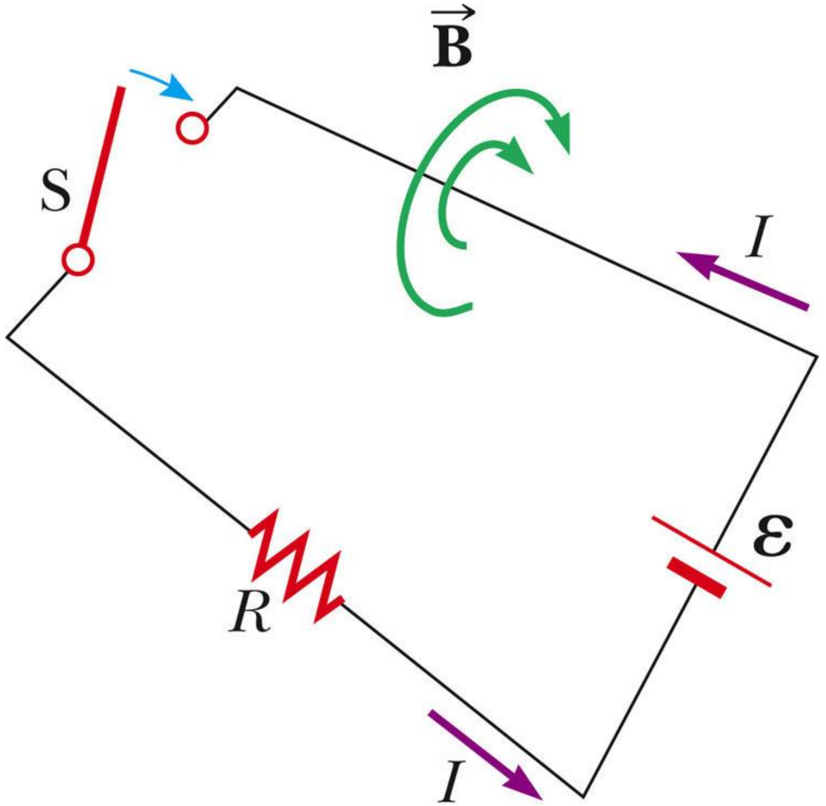
Some Terminology

- Use *emf* and *current* when they are caused by batteries or other sources
- Use *induced emf* and *induced current* when they are caused by changing magnetic fields
- When dealing with problems in electromagnetism, it is important to distinguish between the two situations

Self-Inductance

- When the switch is closed, the current does not immediately reach its maximum value
- Faraday's law can be used to describe the effect ε / R



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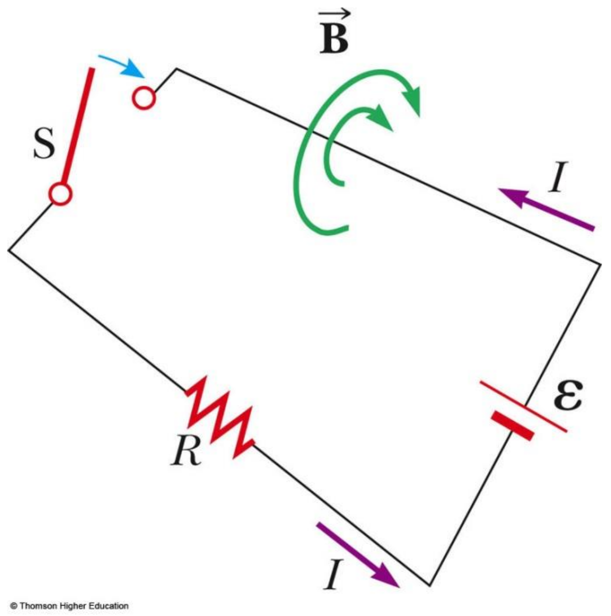
Self-Inductance

- As the current increases with time, the magnetic flux through the circuit loop due to this current also increases with time
- This increasing flux creates an *induced emf* in the circuit



Self-Inductance

- This effect is called ***self-inductance***
  - Because the changing flux through the circuit and the resultant *induced emf* arise from the circuit itself
- The emf $\boldsymbol{\varepsilon_L}$ is called a ***self-induced emf***

Self-Inductance

- An *induced emf* is always proportional to the time rate of change of the current
  - The *emf* is proportional to the flux, which is proportional to the field and the field is proportional to the current

$$\boxed{\varepsilon_L = -L\frac{dI}{dt}}$$

- ***L*** is a constant of proportionality called the ***inductance*** of the coil and it depends on the geometry of the coil and other physical characteristics

Inductance of a Coil

- A closely spaced coil of **N** turns carrying current ***I*** has an inductance of

$$\boxed{L = \frac{N\Phi_B}{I} = -\frac{\varepsilon_L}{dI/dt}}$$

- The inductance is a measure of the opposition to a change in current

Inductance Units

- The SI unit of inductance is the ***henry*** (**H**)

$$\boxed{1\text{H} = 1\frac{\text{V}\cdot\text{s}}{\text{A}}}$$

- Named for Joseph Henry

Inductance of a Solenoid

- Assume a uniformly wound solenoid having ***N*** turns and length ***ℓ***
  - Assume ***ℓ*** is much greater than the radius of the solenoid
- The flux through each turn of area ***A*** is

$$\boxed{\Phi_B = BA = \mu_o n I A = \mu_o \frac{N}{\ell} I A}$$

Inductance of a Solenoid

- The inductance is

$$\boxed{L = \frac{N\Phi_B}{I} = \frac{\mu_o N^2 A}{\ell}}$$

- This shows that **L** depends on the geometry of the object

An inductor in the form of a solenoid contains **420 turns**, is **16.0 cm** in length, and has a cross-sectional area of **3.00 cm^2**. What uniform rate of decrease of current through the inductor induces an emf of **175 μV**?

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$$L = \frac{\mu_0 N^2 A}{\ell} = \frac{\mu_0 (420)^2 (3.00 \times 10^{-4})}{0.160} = 4.16 \times 10^{-4}\ \mathrm{H}$$

$$\varepsilon = -L\frac{dI}{dt} \rightarrow \frac{dI}{dt} = \frac{-\varepsilon}{L} = \frac{-175 \times 10^{-6}\ \mathrm{V}}{4.16 \times 10^{-4}\ \mathrm{H}} = \boxed{-0.421\ \mathrm{A/s}}$$

The current in a **90.0-mH** inductor changes with time as $I = 1.00t^2 - 6.00t$ (in SI units). Find the magnitude of the induced emf at (a) $t = 1.00$ **s** and (b) $t = 4.00$ **s.** (c) At what time is the emf zero?

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$$|\varepsilon| = L\frac{dI}{dt} = \left(90.0\times10^{-3}\right)\frac{d}{dt}\left(t^2 - 6t\right)\ \mathrm{V}$$

(a) **At , t=1s** $\varepsilon = \boxed{360\ \mathrm{mV}}$

(b) **At , t= 4s** $\varepsilon = \boxed{180\ \mathrm{mV}}$

(c)

when t = 3 sec .

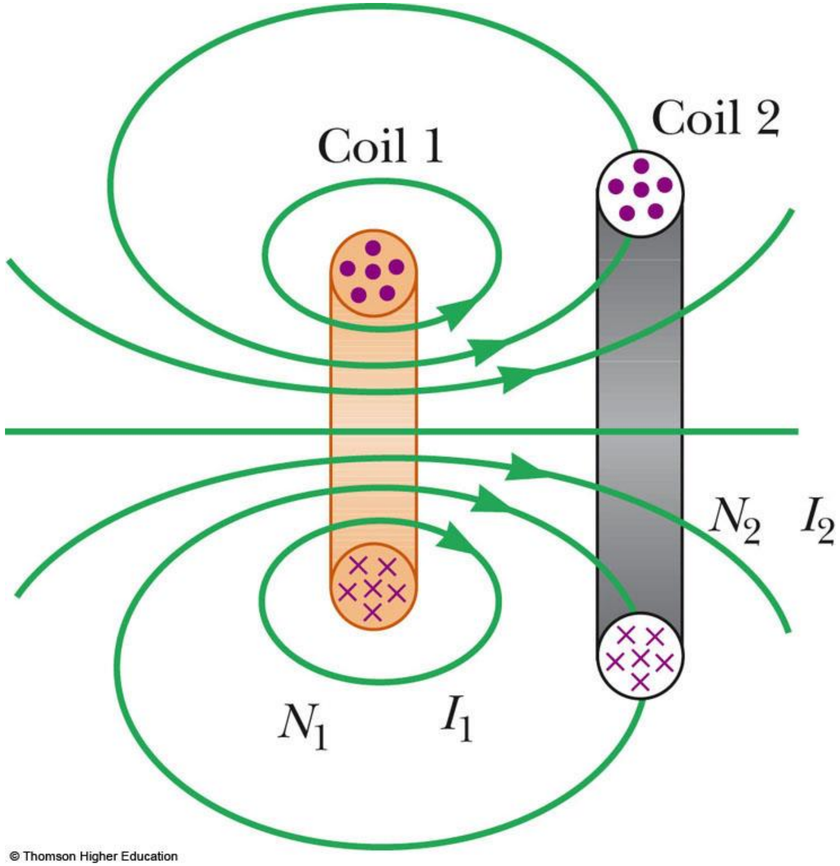
$$\varepsilon = \left(90.0\times10^{-3}\right)\left(2t - 6\right) = 0$$

Mutual Inductance

- The magnetic flux through the area enclosed by a circuit often varies with time because of time-varying currents in nearby circuits
- This process is known as *mutual induction* because it depends on the interaction of two circuits

Mutual Inductance

- The current in *coil 1* sets up a magnetic field
- Some of the magnetic field lines pass through *coil 2*
- Coil 1 has a current I_1 and N_1 turns
- Coil 2 has N_2 turns



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Mutual Inductance

- The **mutual inductance M$_{12}$** of *coil 2* with respect to *coil 1* is

$$\boxed{M_{12} \equiv \frac{N_2 \Phi_{12}}{I_1}}$$

- Mutual inductance depends on the geometry of both circuits and on their orientation with respect to each other

Induced emf in Mutual Inductance

- If current I_1 varies with time, the emf induced by *coil 1* in *coil 2* is

$$\boxed{\varepsilon_2 = -N_2 \frac{d\Phi_{12}}{dt} = -M_{12} \frac{dI_1}{dt}}$$

- If the current is in *coil 2*, there is a mutual inductance M_{21}
- If *current 2* varies with time, the emf induced by *coil 2* in *coil 1* is

$$\boxed{\varepsilon_1 = -M_{21} \frac{dI_2}{dt}}$$

Mutual Inductance

- In mutual induction, the emf induced in one coil is always proportional to the rate at which the current in the other coil is changing
- The mutual inductance in one coil is equal to the mutual inductance in the other coil
  - **$M_{12} = M_{21} = M$**
- The induced emf's can be expressed as

$$\boxed{\varepsilon_1 = -M\frac{dI_2}{dt} \quad \text{and} \quad \varepsilon_2 = -M\frac{dI_1}{dt}}$$

Two coils are close to each other. The first coil carries a time-varying current given by $I(t) = (5.00\ \mathrm{A})\, e^{-0.0250\ t} \sin(377t)$. At $t = 0.800\ \mathrm{s}$, the emf measured across the second coil is $-3.20\ \mathrm{V}$. What is the mutual inductance of the coils?

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$$I_1(t) = I_{max} e^{-\alpha t} \sin \omega t \qquad I_{max} = 5.00\ \text{A} \qquad \alpha = 0.0250\ \text{s}^{-1}$$

$$\omega = 377\ \text{rad/s} \qquad \frac{dI_1}{dt} = I_{max} e^{-\alpha t}\left(-\alpha \sin \omega t + \omega \cos \omega t\right)$$

At $t = 0.800$ s

$$\frac{dI_1}{dt} = (5.00\ \text{A/s})\, e^{-0.0200}\left[-(0.0250)\sin(0.800(377)) + 377\cos(0.800(377))\right]$$

$$\frac{dI_1}{dt} = 1.85 \times 10^{3}\ \text{A/s}$$

$$\varepsilon_2 = -M\frac{dI_1}{dt} \qquad M = \frac{-\varepsilon_2}{dI_1/dt} = \frac{+3.20\ \text{V}}{1.85 \times 10^{3}\ \text{A/s}} = \boxed{1.73\ \text{mH}}$$

Relationship between self and mutual inductance

$$k = \frac{M}{\sqrt{L_1 L_2}} = \frac{\text{Actual mutual inductance}}{\text{Max. possible mutual inductance}}$$

- *The coefficient of coupling (k) between two coils is defined as the fraction of magnetic flux produced by the current in one coil that links the other.*

Thank you