Principles of Electrical machines

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Introduction

Electric Machine:

Is a device that convert either mechanical energy to electrical energy or vice versa. Electrical machines also include transformers, which do not actually make conversion between mechanical and **electrical** form but they convert AC current from one voltage level to another voltage level.

A generator :

converts mechanical energy to electrical energy.

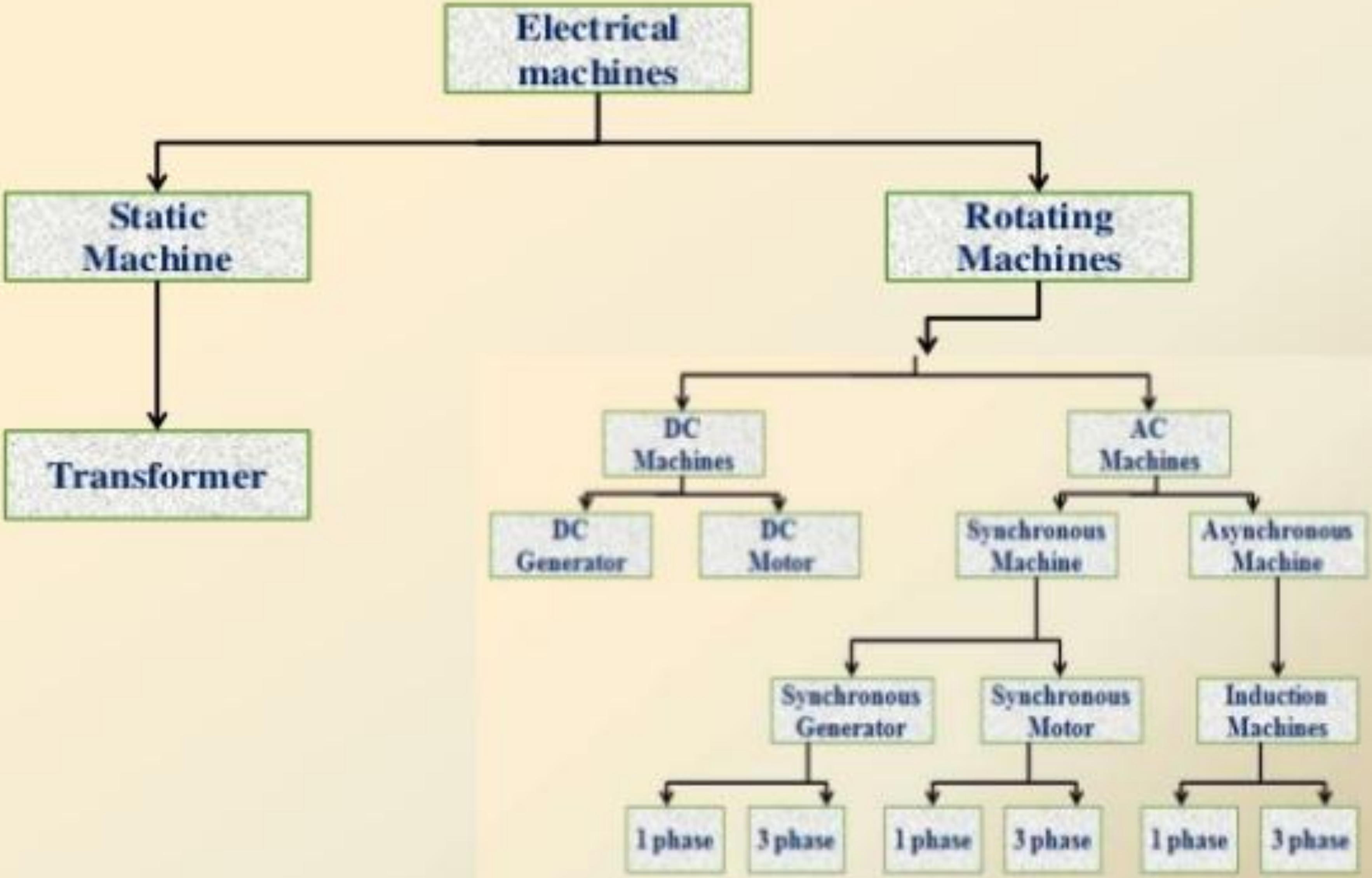
A motor:

converts electrical energy to mechanical energy.

A transformer:

is a device that converts an A.C. electrical energy at one voltage level to an A.C. electrical energy at another voltage level, but with the same frequency.

Classification of electrical machines



Electric Machines

- These three types of electric devices are found everywhere in modern daily life.
- Electric motors in the home run refrigerators, freezers, vacuum cleaners, blenders, air conditioners, fans, and many similar appliances.
- In the workplace, motors provide the motive power for almost all tools. Of course, generators are necessary to supply the power used by all these motors.

Chapter One

Electromagnetism

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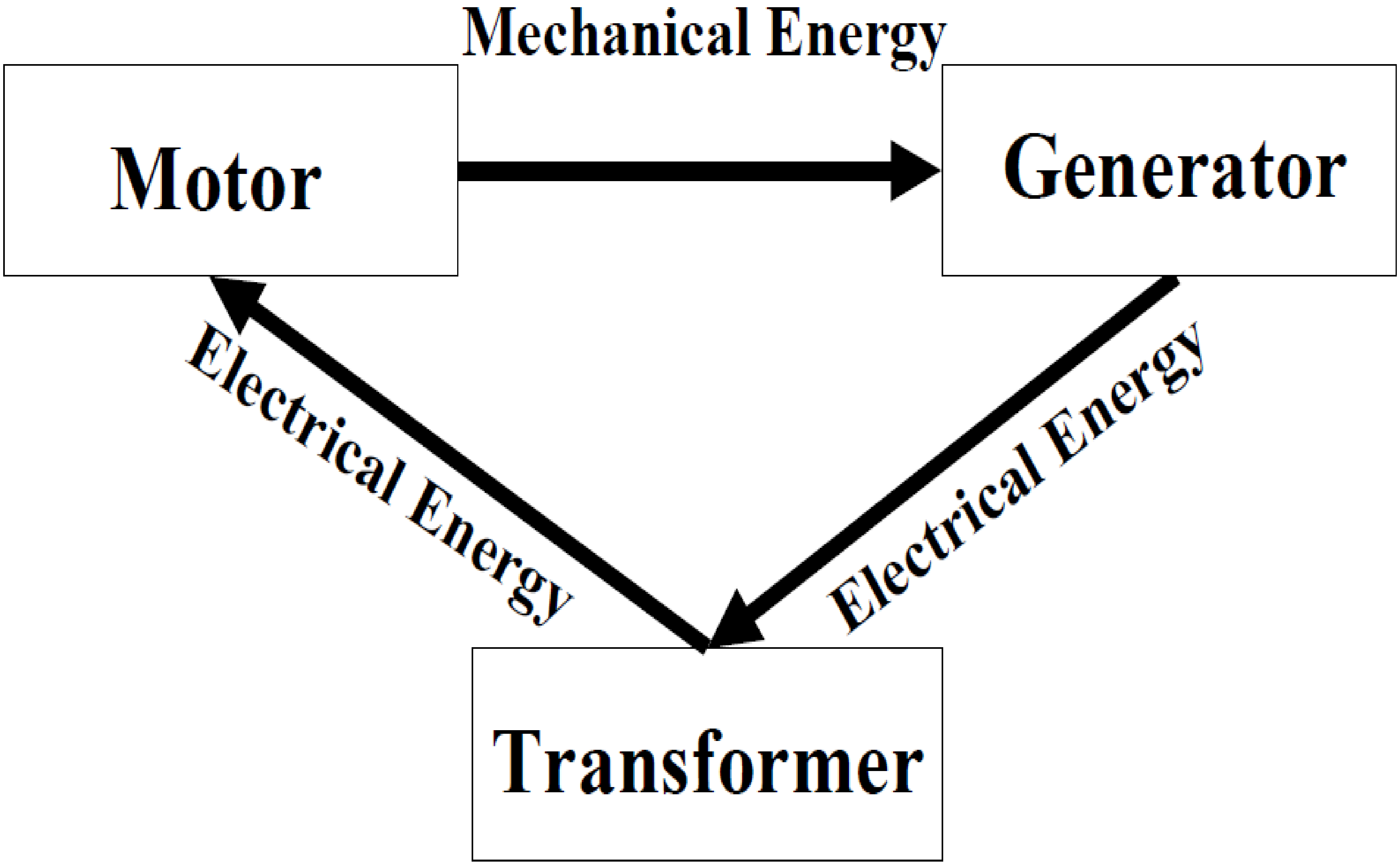
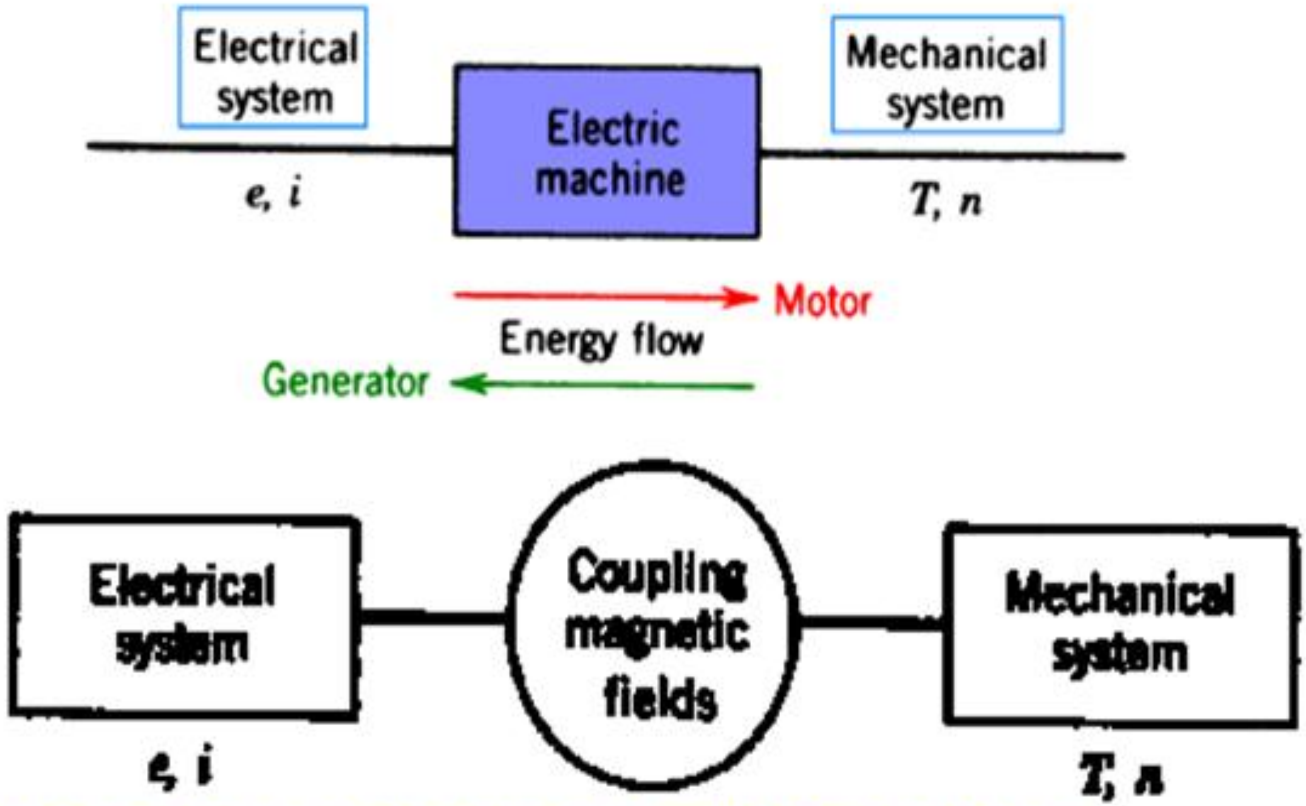
Energy conversion process



Energy conversion process

- Energy is needed in different forms:



- Continuous energy converter = electrical machines
    - Motors and generators
    - Operate in both modes

INTRODUCTION

- **The electromagnetic system is a necessary element of all rotating, static electric machinery and electromechanical devices.**
- **Electromechanical devices** include [Synchronous motors, Stepper motors. assemblies like switches, solenoids, electric valve actuators. servomechanisms like servomotors, positioning devices, chart recorders and power meter& Automatic controls like relays, thermostats, heating/cooling controls]
- **The role of electromagnetic system is to establish and control electromagnetic fields for carrying out conversion of energy, and transfer.**
- **Practically all motors and generators, depend upon the magnetic field as the coupling medium allowing interchange of energy in either direction between electrical and mechanical systems.**
- **A transformer though not an electromechanical conversion device, provides a means of transferring electrical energy between two electrical ports via the medium of a magnetic field.**
- **It is, therefore, seen that all electric machines including transformers use the medium of magnetic field for energy conversion and transfer.**

What is Magnetism?

- In physics, **magnetism** **is a force that can attract (pull closer) or repel (push away) objects that have a magnetic material** like iron.
- **Magnetic Elements: Metals like Iron, nickel and cobalt are strongly attracted to magnets.**
- A **magnet** **is a material or object that produces a magnetic field.**
- **This magnetic field is invisible but is responsible for the most notable property of a magnet: a force that pulls on other ferromagnetic materials and attracts or repels other magnets.**

Magnetic Field

- **A magnetic field can be represented by lines of induction or flux lines.**
- **These lines are invisible and are produced by magnetized material or by electrical currents. Magnetic fields are electrical in nature, and the magnetic field caused by a long straight line of current is simulated in Figure 1.**

Magnetic Fields

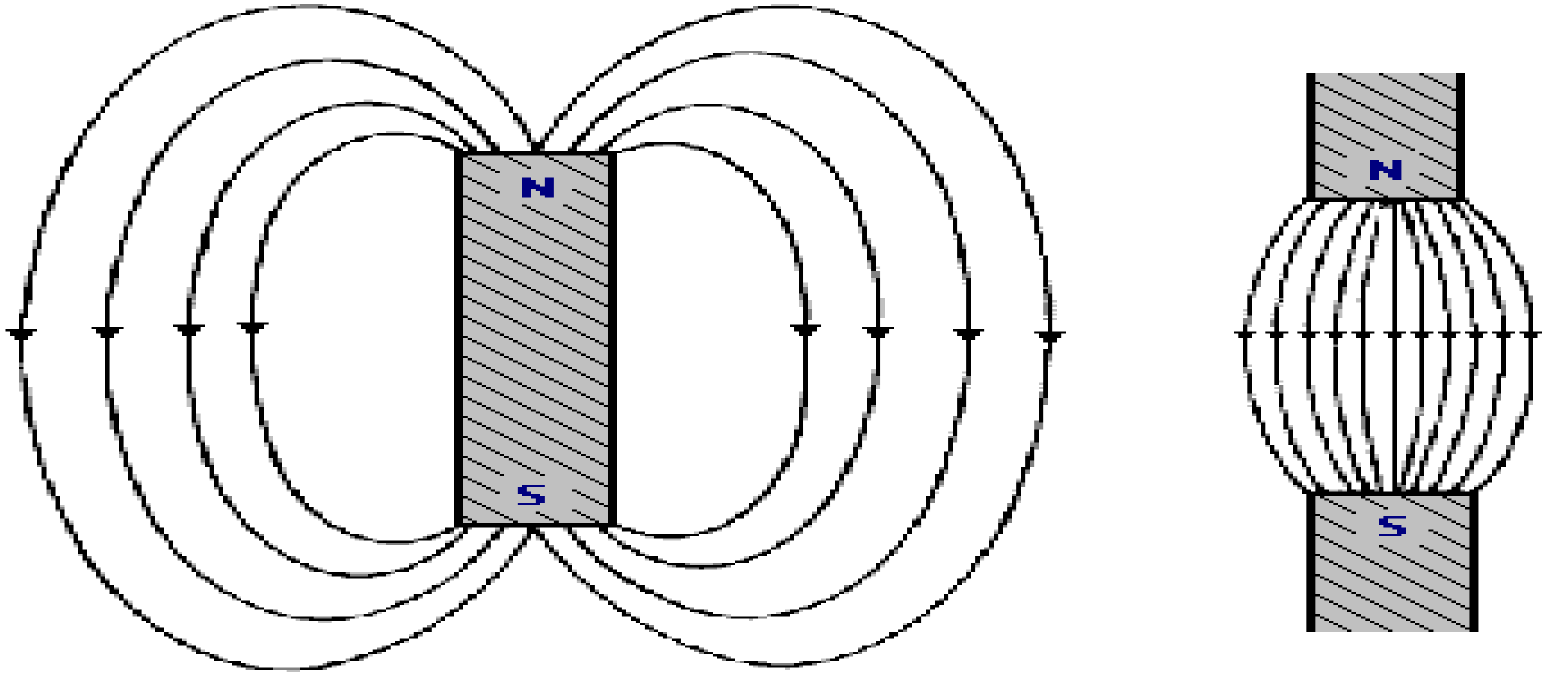
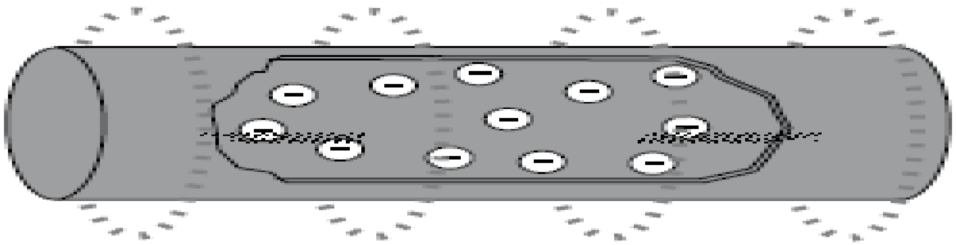
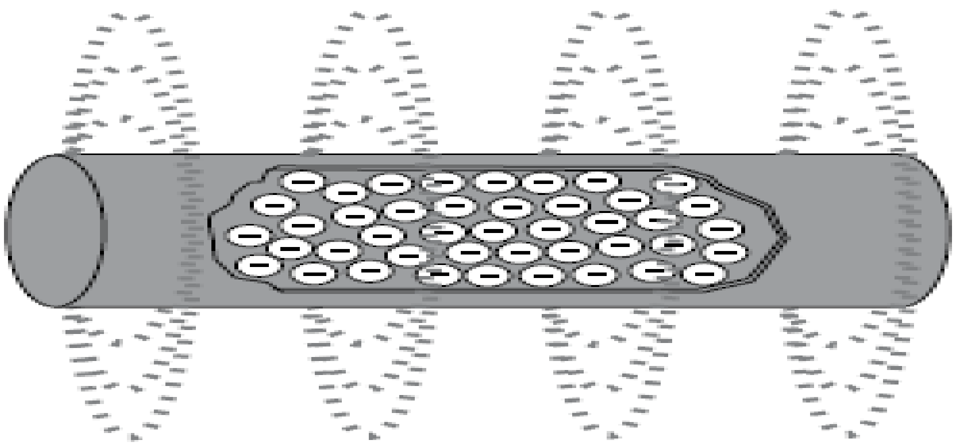


Fig.1 Representation of magnetic field

When current flows through a conductor, it produces a <u>magnetic field</u> around the conductor. The strength of the magnetic field <u>is proportional to the amount of current.</u>





Magnetic Flux Density (B)

Flux density is the measure of the number of magnetic lines of **force per unit of cross-sectional area.**

The relationship between total flux and flux density is given by the following equation:

$$B = \varphi / A$$

Where

B=flux density in Tesla

φ=total magnetic flux in weber

A= cross-sectional area in square meter

Ampere-turns of Magnetomotive Force (mmf)

-The force produced by current through a coil of wire is called magnetomotive force (mmf).

– The strength of a coil's magnetic field is proportional to the amount of current flowing through the coil and the number of turns per given length of coil.

– Ampere-turns = I × N = mmf

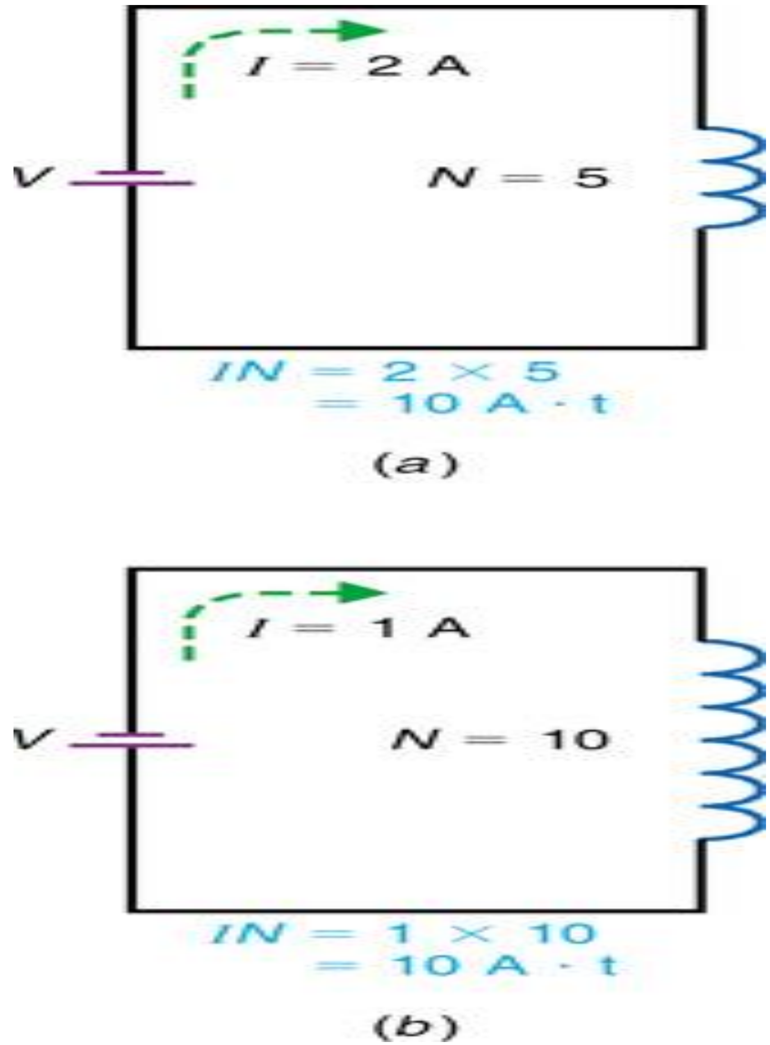
– I is the amount of current flowing through N turns of wire.

– This formula specifies the amount of magnetizing force or magnetic potential (mmf).

Ampere-turns of Magneto motive Force (mmf)

- The SI abbreviation for ampere-turn is A · t.

Fig. 2: Two examples of equal ampere-turns for the same mmf. (*a*) IN is 2 × 5 = 10. (*b*) *IN* is 1 × 10 = 10.

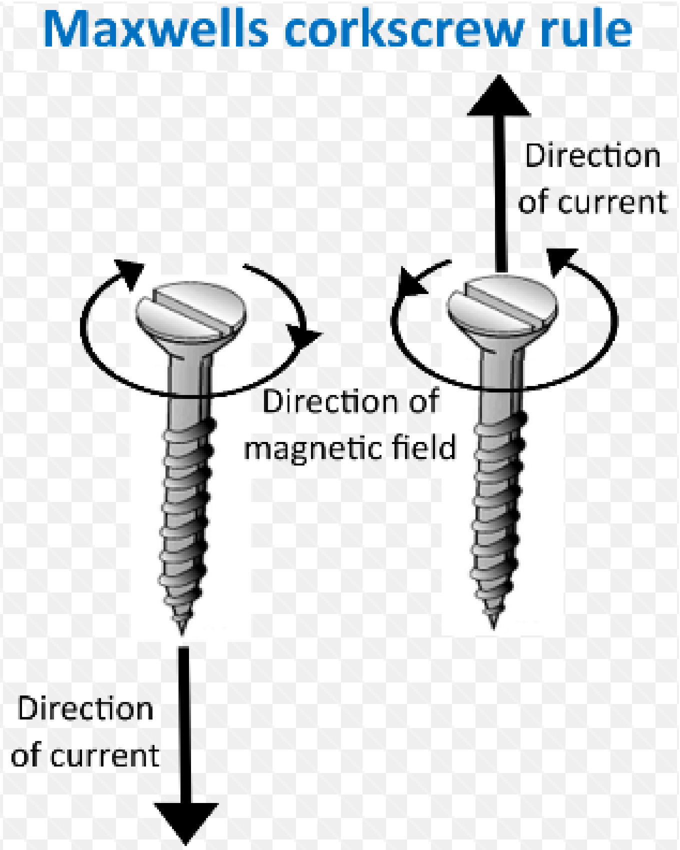


Field Intensity (*H*)

- Is also known as the **magnetizing force.**
- **The length of a coil influences the intensity of a magnetic field.** Intensity is different from m.m.f.
- Equation: H = m.m.f./length = N . I / L
- m.m.f. = H . L
- Units: A·t/m
  ampere-turns per meter
- **Shorter magnetic circuits produce a greater field intensity**

Magnetic field direction

- The following illustration shows that, when the current is passed through this conductor, a circular shape magnetic field shown by dotted lines is setup in a plane perpendicular to the current flow. A circular field can have any one of the two circular directions namely clockwise or anticlockwise.



For **an outward flow of current direction** which is shown by dot mark, the magnetic field takes **anticlockwise direction**.

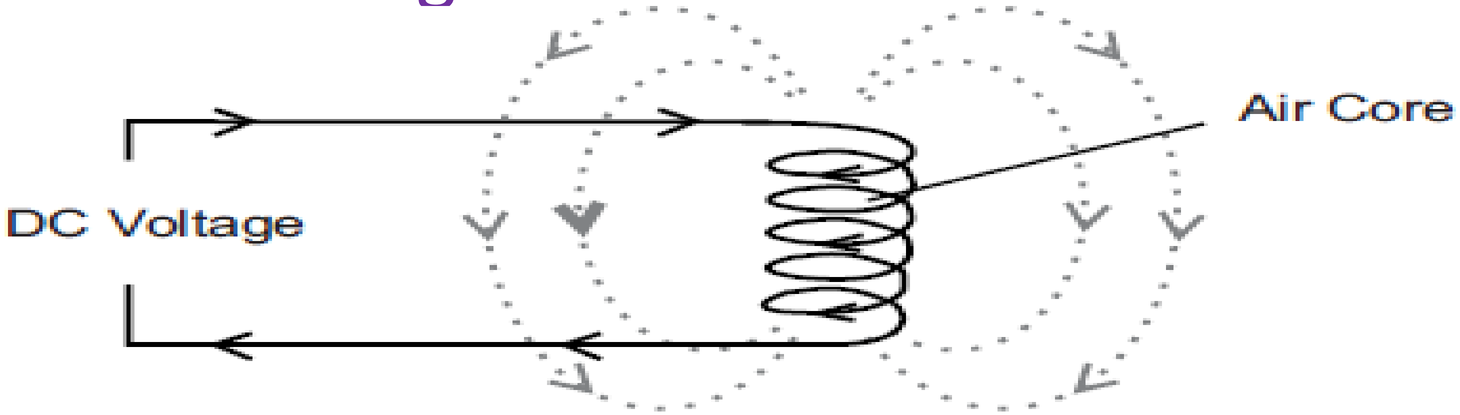
The direction of magnetic field can be determined by:

1-Right hand corkscrew rule

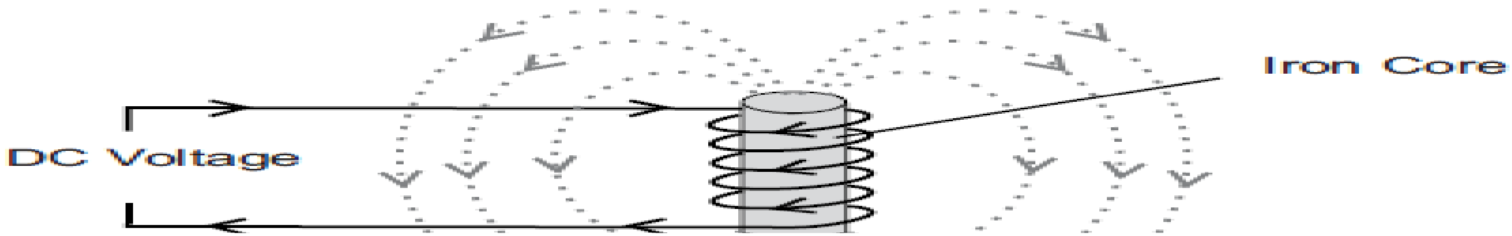
2-Right hand grip rule

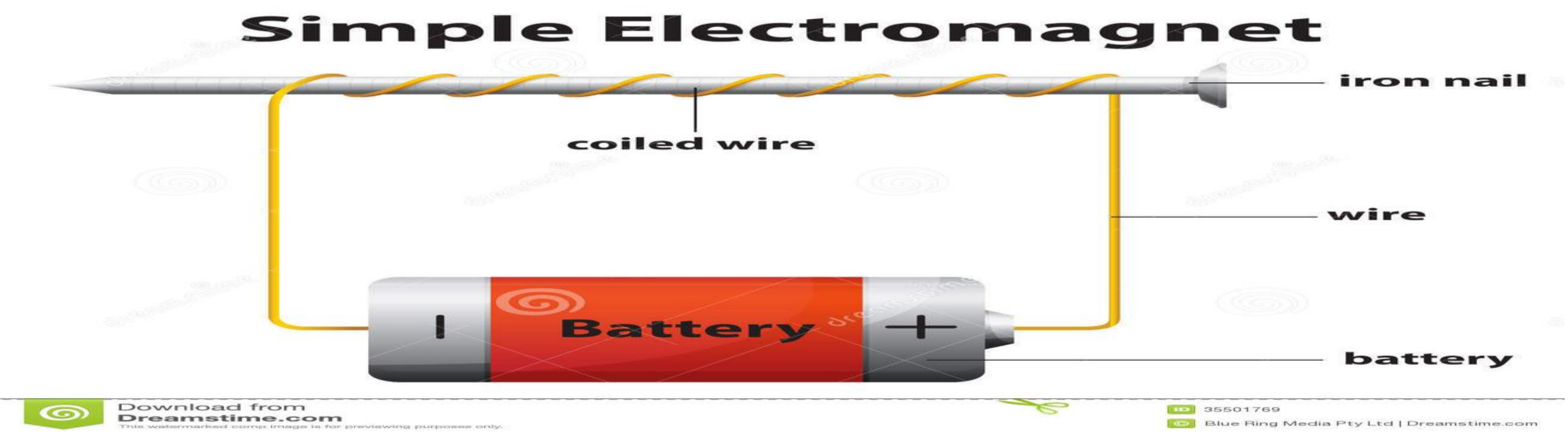
Electromagnet

- An **electromagnet can be made by winding a conductor into a coil** and **applying a DC voltage**. The lines of flux, formed by current flow through the conductor, combine to produce a larger and stronger magnetic field.
- The center of the coil is known as the core. This simple electromagnet has an air core.

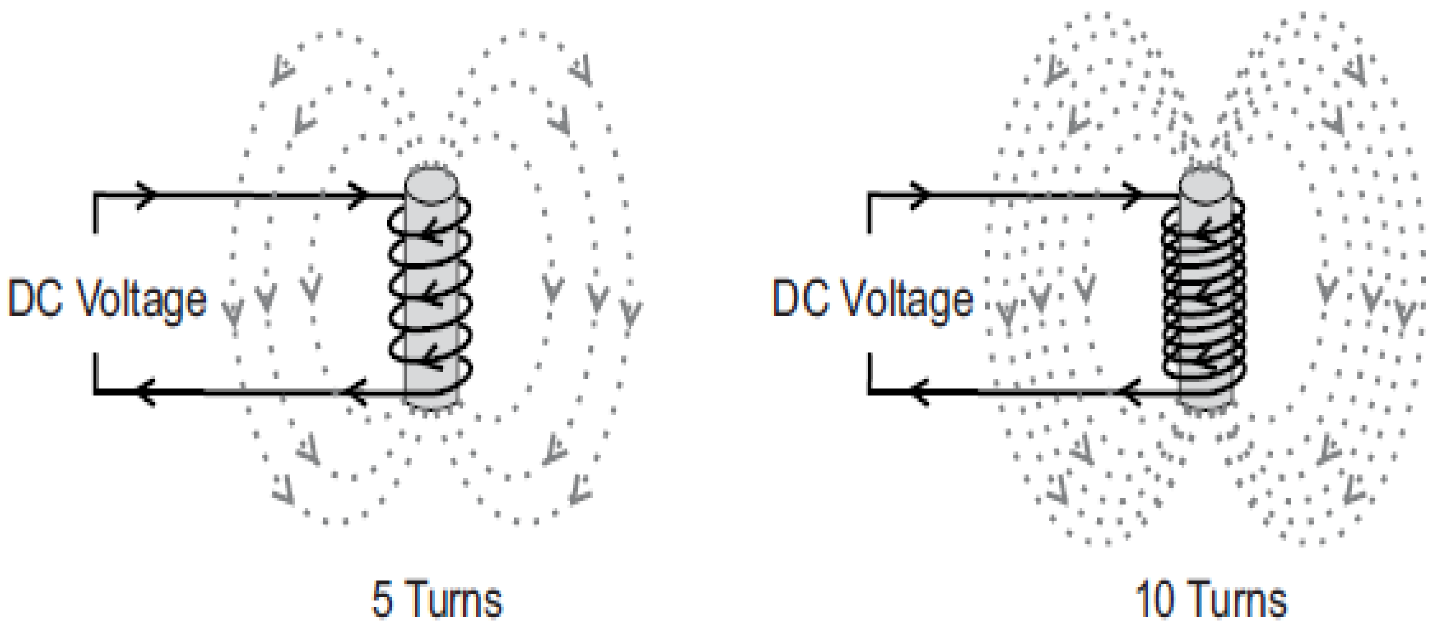


- **Adding an Iron Core Iron conducts magnetic flux more easily than air.** When an <u>insulated conductor</u> is wound around an iron core, a stronger magnetic field is produced for the same level of current.



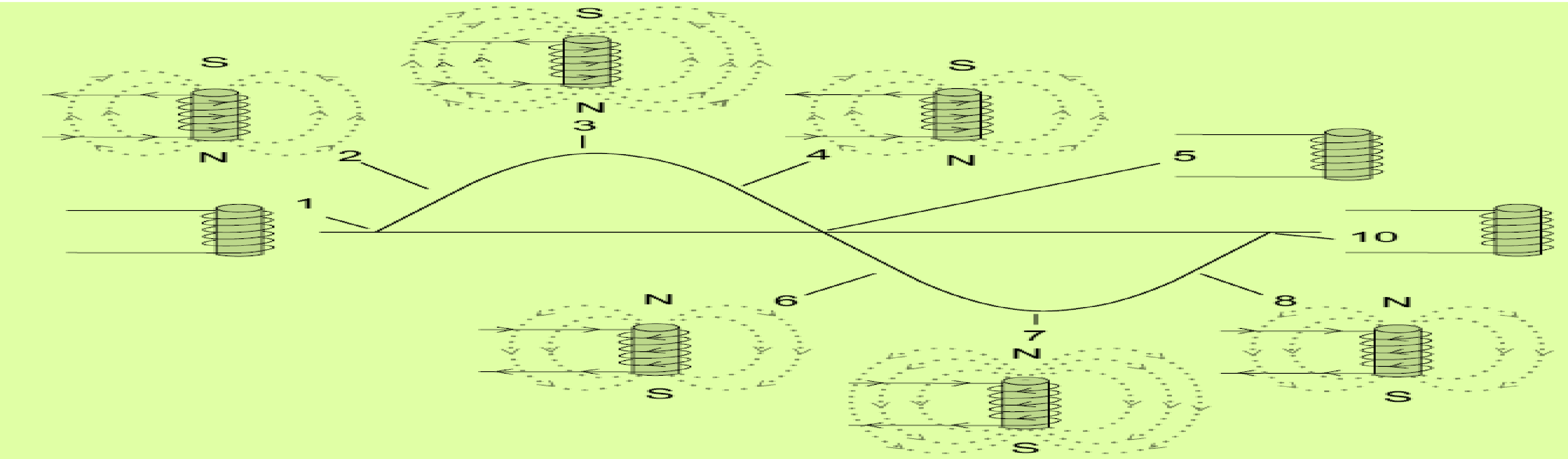


- **The strength of the magnetic field** created by the electromagnet can be increased further by increasing the number of **turns in the coil. The greater the number of turns the** stronger the magnetic field for the same level of current.



Changing Polarity

- The magnetic field of an **electromagnet** has the same characteristics as a **natural magnet**, including a north and south pole. However, when the direction of current flow through the electromagnet changes, the polarity of the electromagnet changes.
- The polarity of an electromagnet connected to an AC source changes at the frequency of the AC source. This is demonstrated in the following illustration.

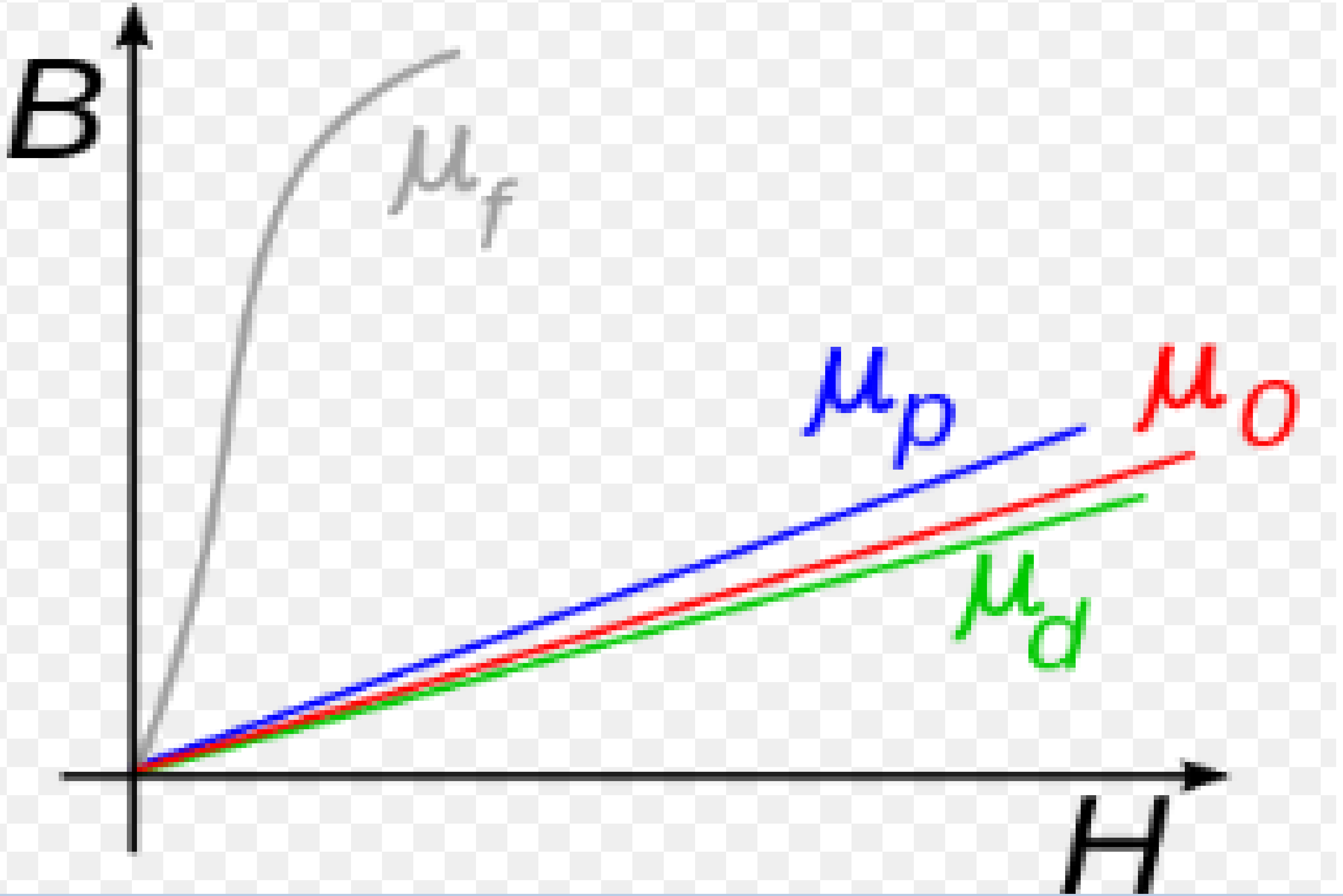


Permeability

- Permeability (μ) is a measure of the ability to concentrate magnetic fields.
- Materials with high permeability can concentrate flux, and produce large values of flux density *B* for a specified *H*.
- The amount of flux produced by *H* depends on the material in the field.
- These factors are reflected in the formulas:
  - $B = \mu \times H$
  - $\mu = B / H$
- The unit of μ is henrys per meter or **weber per ampere-turn meter**
- A flux density **of** one Wb/m^2 (one **weber** per square metre) **is** one **tesla (T)**.

Relative Permeability

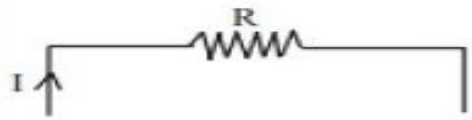
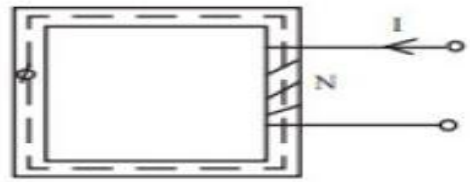
- Relative Permeability (μ_r) is the ratio of the absolute permeability to the permeability of a vacuum.
- **Ferromagnetic materials** have high values of relative permeability (as high as 10,000). such as iron, steel, cobalt and their alloys
- **Paramagnetic materials** The relative permeability is slightly more than 1. such as aluminum and air.
- **Diamagnetic materials** The relative permeability is less than 1. such as gold, silver, copper, and carbon
- **Non-magnetic materials** The relative permeability is approximately 1.

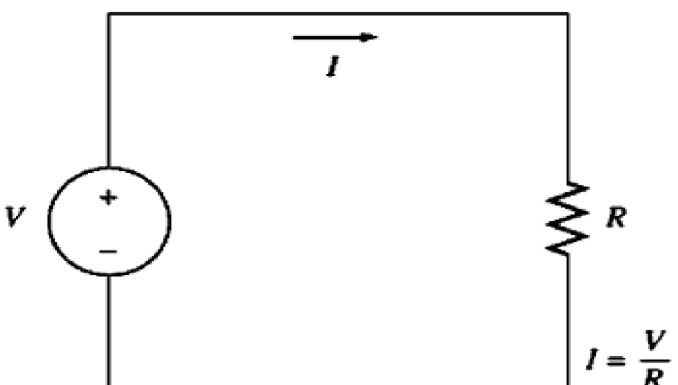


Permeability for: Ferromagnets (μ_f), Paramagnets(μ_p), free space (μ_0) and Diamagnets (μ_d)

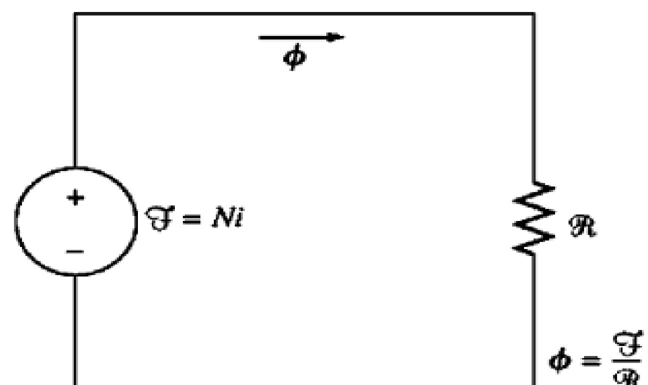
Medium	Permeability, μ (H/m)	Relative permeability, max., μ/μ_0
Metglas 2714A (annealed)	1.26×10^{0}	1 000 000[7]
Iron (99.95% pure Fe annealed in H)	2.5×10^{-1}	200 000[8]
NANOPERM®	1.0×10^{-1}	80 000[9]
Mu-metal	2.5×10^{-2}	20 000[10]
Mu-metal	6.3×10^{-2}	50 000[11]
Cobalt-iron (high permeability strip material)	2.3×10^{-2}	18 000[12]
Permalloy	1.0×10^{-2}	8000[10]
Iron (99.8% pure)	6.3×10^{-3}	5000[8]
Electrical steel	5.0×10^{-3}	4000[10][not in citation given]
Ferritic stainless steel (annealed)	1.26×10^{-3} – 2.26×10^{-3}	1000 – 1800[13]
Martensitic stainless steel (annealed)	9.42×10^{-4} – 1.19×10^{-3}	750 – 950[13]
Ferrite (manganese zinc)	$>8.0 \times 10^{-4}$	640 (or more)
Ferrite (nickel zinc)	2.0×10^{-5} – 8.0×10^{-4}	16 – 640
Carbon steel	1.26×10^{-4}	100[10]
Nickel	1.26×10^{-4} – 7.54×10^{-4}	100[10] – 600
Martensitic stainless steel (hardened)	5.0×10^{-5} – 1.2×10^{-4}	40 – 95[13]
Austenitic stainless steel	1.260×10^{-6} – 8.8×10^{-6}	1.003 – 7[13][14][note 1]
Neodymium magnet	1.32×10^{-6}	1.05[15]
Platinum	$1.256\,970 \times 10^{-6}$	1.000 265
Aluminum	$1.256\,665 \times 10^{-6}$	1.000 022
Wood	$1.256\,637\,60 \times 10^{-6}$	1.000 000 43[16]

Difference between Electric Circuit & Magnetic Circuit

Electric Circuit	Magnetic Circuit
	
2)E.M.F is the source to pass current	2) MMF is the source to pass flux (MMF is caused by flow of current)
3) Current in Amperes; current density in A/m²	3) ϕ is in webbers; flux density wb/m²
4) current $\dfrac{EMF}{\text{Resistance}}$	4) Flux = $\dfrac{\text{MMF}}{\text{Reluctance}}$
5) Resistance = R = $\dfrac{\delta l}{a}$ and is constant	5) Reluctance = $\dfrac{L}{\mu_0 \mu_r A}$ It veries as μ_r is variable



(a) A simple electric circuit.



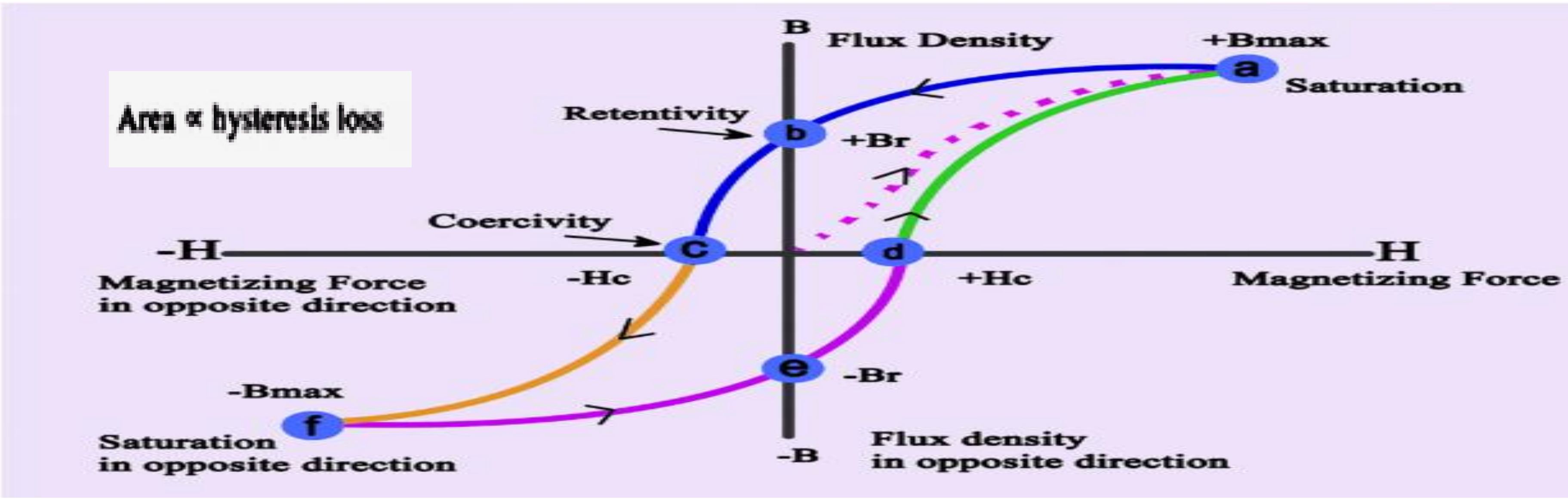
(b) The magnetic circuit analog to a transformer core.

Comparison between materials

PROPERTIES	FERROMAGNETIC MATERIALS	PARAMAGNETIC MATERIALS	DIAMAGNETIC
State	They are solid.	They can be solid, liquid or gas.	They can be solid, liquid or gas.
Effect of Magnet	Strongly attracted by a magnet.	Weakly attracted by a magnet.	Weakly repelled by a magnet.
Behavior under non-uniform field	tend to move from low to high field region.	tend to move from low to high field region.	tend to move from high to low region.
Behavior under external field	They preserve the magnetic properties after the external field is removed.	They do not preserve the magnetic properties once the external field is removed.	They do not preserve the magnetic properties once the external field is removed.
Effect of Temperature	Above curie point, it becomes a paramagnetic.	With the rise of temperature, it becomes a diamagnetic.	No effect.
Permeability	Very high	Little greater than unity	Little less than unity
Susceptibility	Very high and positive	Little greater than unity and positive	Little less than unity and negative
Examples	Iron, Nickel, Cobalt	Lithium, Tantalum,	Copper, Silver, Gold

Hysteresis Loop | Magnetization Curve

- A curve, or loop, plotted on B-H coordinates showing how the magnetization of a ferromagnetic material varies when subjected to a periodically reversing magnetic field, is known as Hysteresis Loop. Hysteresis is the lagging of the magnetization of a ferromagnetic material behind the magnetizing force H.



Hysteresis Loop | Magnetization Curve

- From the hysteresis loop, we can conclude different magnetic properties of a material such as:
- **Reluctance**– The opposition that a magnetic circuit presents to the passage of magnetic lines through it.
- **Retentivity**– The ability of a ferromagnetic material to retain residual magnetism is termed its retentivity.
- **Residual Magnetism**– The magnetism remaining after the external magnetizing force is removed.
- **Coercive Force** – The magnetic field strength required to reduce the residual magnetism to zero is termed the coercive force.
- **Permeability**– Permeability is the measure of the ease, with which magnetic lines of force pass through a given material.

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.

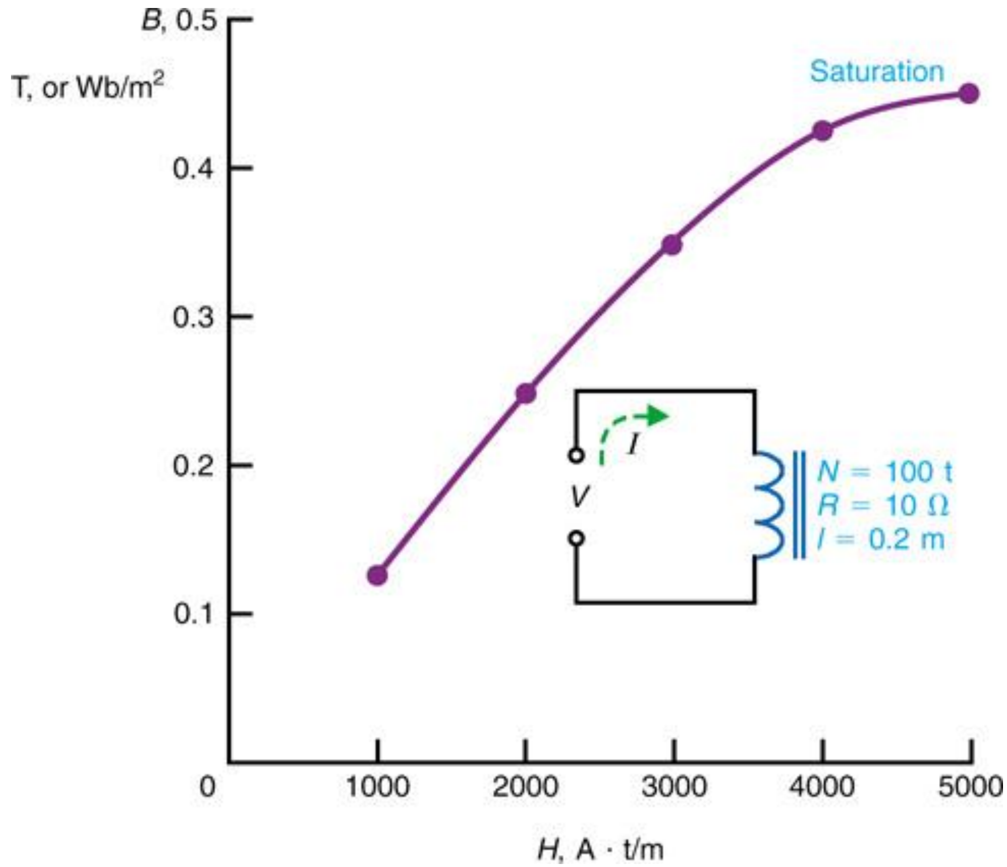


Fig. : *B-H* magnetization curve for soft iron. No values are shown near zero, where μ may vary with previous magnetization.

Magnetic Hysteresis

- Hysteresis Loop
  - B_R is due to **retentivity (memory),** 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 $B = 0$)

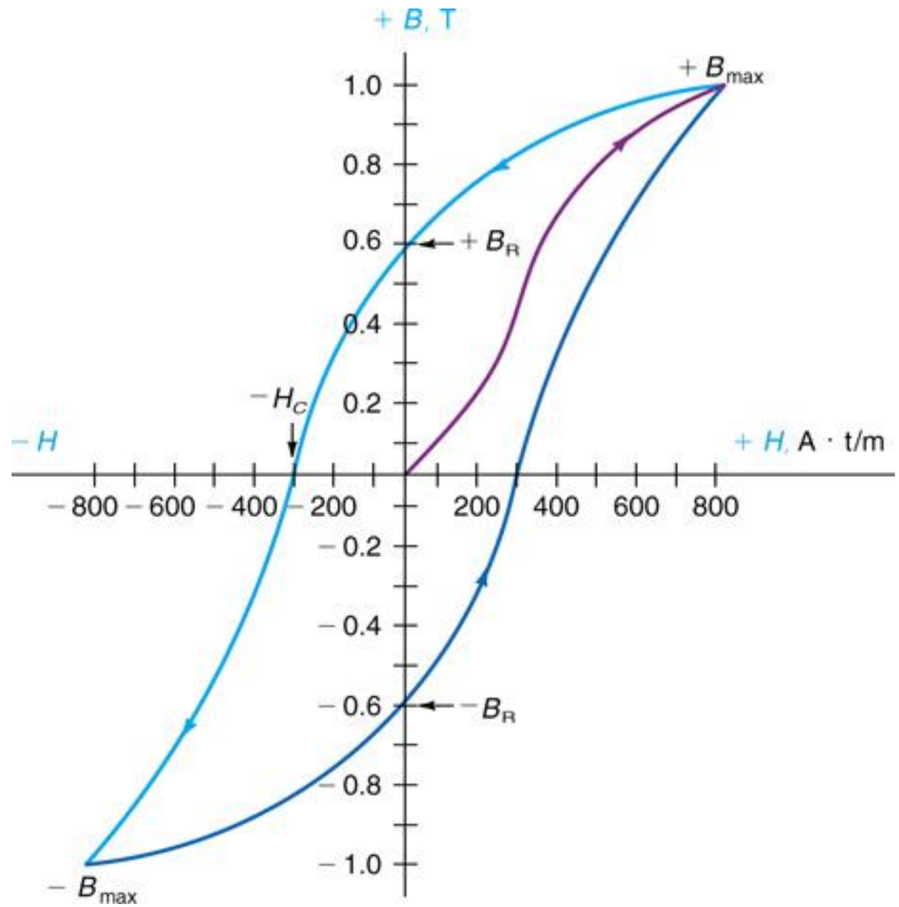


Fig. 3: Hysteresis loop for magnetic materials. This graph is a *B-H* curve like Fig. 2, but *H* alternates in polarity with alternating current.

H.W.

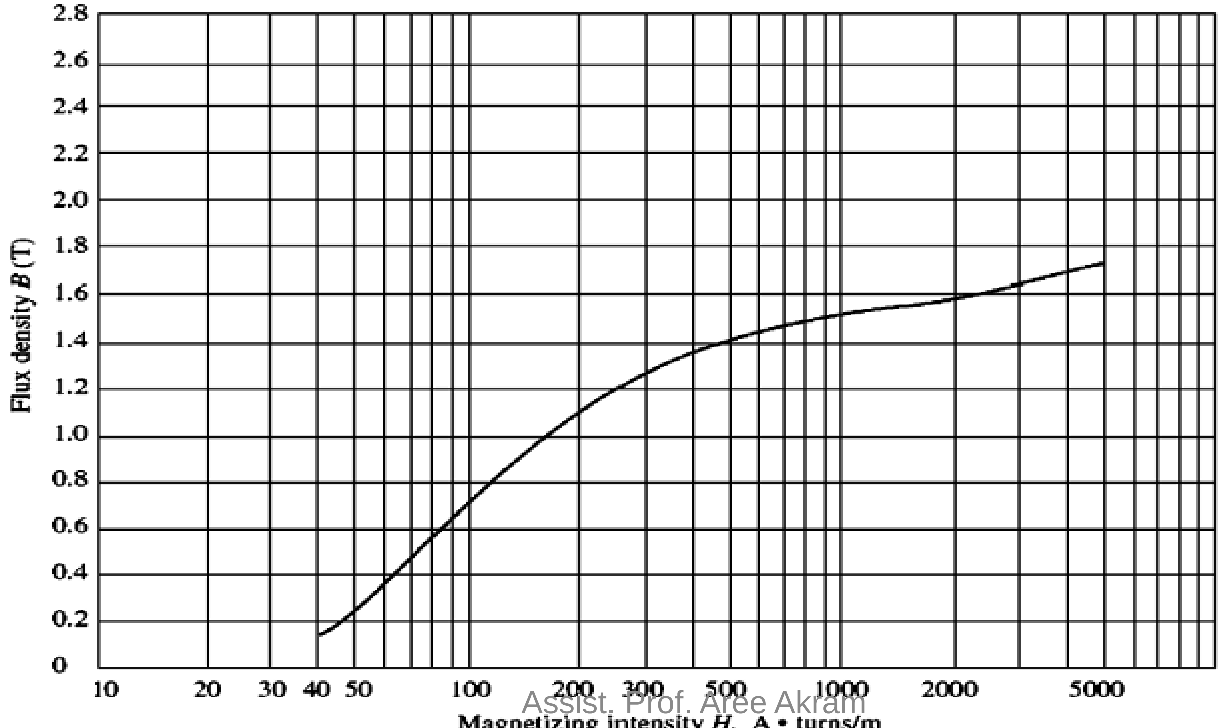
Example

A square magnetic core has a mean path length of 55 cm and a cross sectional area of150 cm^2.A 200 tum coil of wire is wrapped around one leg of the core. The core is made of a material having the magnetization curve shown in figure below.

(a) How much current is required to produce 0.012 Weber of flux in the core?

(b) What is the core's relative permeability at that current level?

(c) What is its reluctance?



Laws of electromagnetism

There are four laws of electromagnetism

- Faraday`s Law.
- Lenz`s Law.
- The Biot-Savart law.
- Ampere's law.

Electromagnetic induction

- 1819 **Oersted's experiment** that when an electric current is passed through a conducting wire, a magnetic field is produced around it
- 1831 Faraday experiment.
- Electromagnetic induction.

"**An electric field can be produced by <u>changing</u> magnetic field**"

Lenz law " current **opposes** the change in magnetic field"