

Chapter 7

Magnetism and Electromagnetism

Objectives

- Explain the principles of the magnetic field
- Explain the principles of electromagnetism
- Describe the principle of operation for several types of electromagnetic devices
- Explain magnetic hysteresis
- Discuss the principle of electromagnetic induction
- Describe some applications of electromagnetic induction

The Magnetic Field

- A permanent magnet has a magnetic field surrounding it
- A magnetic field is envisioned to consist of lines of force that radiate from the north pole to the south pole and back to the north pole through the magnetic material

Attraction and Repulsion

- Unlike magnetic poles have an attractive force between them
- Two like poles repel each other

Altering a Magnetic Field

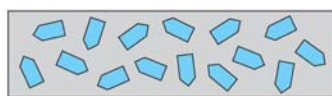
- When nonmagnetic materials such as paper, glass, wood or plastic are placed in a magnetic field, the lines of force are unaltered
- When a magnetic material such as iron is placed in a magnetic field, the lines of force tend to be altered to pass through the magnetic material


Magnetic Flux

- The force lines going from the north pole to the south pole of a magnet are called **magnetic flux** (ϕ); units: **weber** (Wb)
- The **magnetic flux density** (B) is the amount of flux per unit area perpendicular to the magnetic field; units: **tesla** (T)

Magnetizing Materials

- Ferromagnetic materials such as iron, nickel and cobalt have randomly oriented magnetic domains, which become aligned when placed in a magnetic field, thus they effectively become magnets



(a) The magnetic domains (N  S) are randomly oriented in the unmagnetized material.



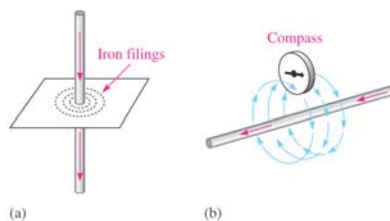
(b) The magnetic domains become aligned when the material is magnetized.

Electromagnetism

- Electromagnetism is the production of a magnetic field by current in a conductor
- Electromagnets are used in devices such as tape recorders, electric motors, speakers, solenoids, and relays

Electromagnetic Field

- When current passes through a conductor, an **electromagnetic field** is created around the conductor
 - Magnetic field is stronger close to the conductor



Direction of Lines of Force

- The direction of the lines of force surrounding a conductor depend upon the direction of current flow
- The **left-hand rule** is used to determine the direction of the lines of force
- If the conductor is grasped in the left hand, with the thumb pointing in the direction of current flow, the fingers of the left hand point in the direction of the magnetic lines of force

Permeability

- Permeability (μ) is the ease with which a magnetic field can be established in a given material
- The higher the permeability, the more easily a magnetic field can be established
- Relative permeability (μ_r) of a material is the ratio of its absolute permeability (μ) to the permeability of a vacuum (μ_0)

Reluctance

- The opposition to the establishment of a magnetic field in a material is called reluctance (\mathfrak{R})
- Reluctance is analogous to resistance in an electric circuit

Magnetomotive Force

- Current in a conductor produces a magnetic field
- The force that produces the magnetic field is called the magnetomotive force (F_m)
- The magnetomotive force (F_m) depends upon the number of turns (N) of wire, and the amount of current (I) through the wire

$$F_m = NI$$

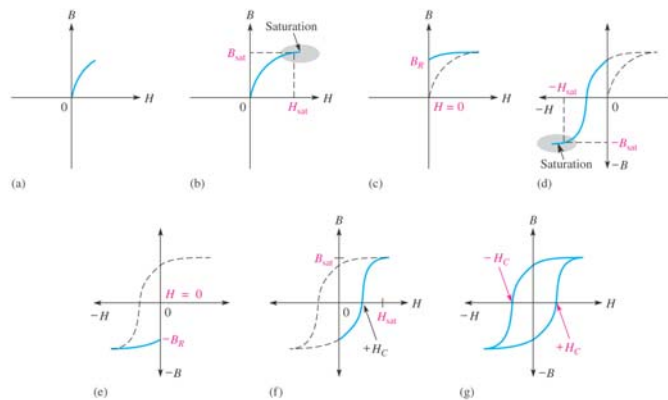
The Electromagnet

- An electromagnet is a coil of wire wound around a core material that can be easily magnetized
- The poles of the magnet depend upon the direction of current flow

Magnetic Hysteresis

- Hysteresis describes the characteristic of a magnetic material that causes the change in magnetization to lag behind the application of a magnetizing force

Magnetic Hysteresis Curve



Magnetizing a Material

- When a magnetic material is exposed to a magnetizing force, it will remain magnetized even with the magnetizing force removed; this is termed retentivity
- Reversal of the magnetizing force will cause the flux density to move toward its negative maximum value

Material Retentivity

- Materials with low retentivity do not retain a magnetic field very well
- Permanent magnets and magnetic tape require high retentivity
- A tape recorder read/write head requires low retentivity
- Low retentivity is desirable in electric motors, since the residual field must be overcome each time the current reverses, thus wasting energy

Electromagnetic Induction

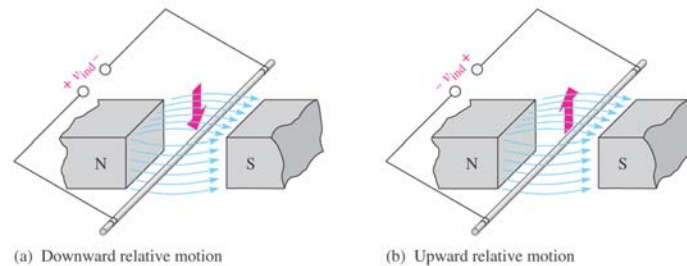
- When a conductor is moved through a magnetic field, a voltage is induced across the conductor
- This principle is known as electromagnetic induction
 - The faster the relative motion, the greater the induced voltage

Relative Motion

- When a wire is moved across a magnetic field, there is a relative motion between the wire and the magnetic field
- When a magnetic field is moved past a stationary wire, there is also relative motion
- In either case, the relative motion results in an induced voltage across the conductor
- The induced voltage depends on the rate of relative motion between the wire and the magnetic field

Polarity of Induced Voltage

- The direction of movement of a wire through a magnetic field will affect the polarity of the induced voltage as indicated below:

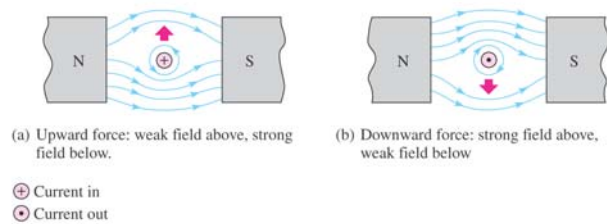


Induced Current

- The voltage induced by the relative motion of a wire through a magnetic field will cause a current in a load connected to the wire
- This current is called an **induced current**
- The concept of induced current is the basis for electric generators

Motor Action

- When a current flows through a wire that is in a magnetic field, the direction of current flow will result in the magnetic field being weakened on one side, and strengthened on the other

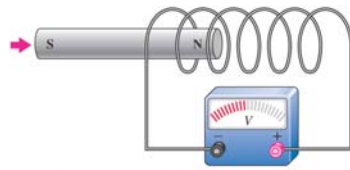


Motor Action

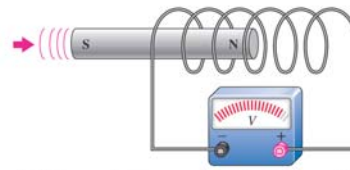
- The result of the weakened and strengthened field is a force on the conductor
- This force is the basis for electric motors

Faraday's Law

- The voltage induced across a coil of wire equals the number of turns in the coil times the rate of change of the magnetic flux



(a) As the magnet moves slowly to the right, its magnetic field is changing with respect to coil, and a voltage is induced.



(b) As the magnet moves more rapidly to the right, its magnetic field is changing more rapidly with respect to coil, and a greater voltage is induced.

Lenz's Law

- When the current through a coil changes, the polarity of an induced voltage created by the changing magnetic field is such that it always opposes the change in current that caused it

Summary

- Unlike magnetic poles attract each other, and like poles repel each other
- Materials that can be magnetized are called ferromagnetic
- When there is current through a conductor, it produces an electromagnetic field around the conductor

Summary

- The left-hand rule can be used to establish the direction of the electromagnetic lines of force around a conductor
- An electromagnet is basically a coil of wire around a magnetic core
- When a conductor moves within a magnetic field, or when a magnetic field moves relative to a conductor, a voltage is induced across the conductor

Summary

- The faster the relative motion between a conductor and a magnetic field, the greater is the induced voltage

SYMBOL	QUANTITY	SI UNIT
B	Magnetic flux density	Tesla (T)
ϕ	Flux	Weber (Wb)
μ	Permeability	Weber/ampere-turn-meter (Wb/At-m)
\mathcal{R}	Reluctance	At/Wb
F_m	Magnetomotive force (mmf)	Ampere-turn (At)
H	Magnetizing force	At/m