Higher Colleges of Technology

DC Electrical Fundamentals

AVT 2103

Magnetism

Module 3.10

Learning Outcomes

CLO 3 – Describe the principle elements of magnetism as it relates to electricity and electrical circuits

Magnetism

- Magnetism is defined as the property of an object to attract certain metallic substances.
- A material possessing this property is known as a **magnet.**
- In general, these substances are ferrous materials; that is, materials composed of iron or iron alloys, such as soft iron, steel, and alnico.
- These materials, sometimes called magnetic materials, today include at least three nonferrous materials: nickel, cobalt, and gadolinium, which are magnetic to a limited degree.

Permeability

- is the degree of magnetization of a material that responds linearly to an applied magnetic field.
- Magnetic permeability is represented by the Greek letter **μ**

  permeability is measured in **Henries** per **metre** (H/m)
  or **Newtons** per **ampere squared** (N/A^2)

  The constant value μ_0 is known as the magnetic constant or the permeability of **free space** (vacuum)

$$\mu_0 = 4\pi \times 10^{-7} \text{ H/m } (1.2566371 \times 10^{-6} \text{ H/m}).$$

Permeability

- **Relative permeability**, sometimes denoted by the symbol μ_r, is the ratio of the permeability of a specific medium to the permeability of free space given by the magnetic constant μ_0.

	Permeability (μ) x10^{-6}
Mu-metal	25,000 H/m
Permalloy	10,000 H/m
Transformer iron	5000 H/m
Steel	875 H/m
Nickel	125 H/m
Platinum	1.2569701 H/m
Aluminium	1.2566650 H/m
Hydrogen	1.2566371 H/m
Vacuum	1.2566371 H/m (μ_0)
Sapphire	1.2566368 H/m
Copper	1.2566290 H/m
Water	1.2566270 H/m

Magnetic Materials

Diamagnetic

- Materials that are said to be diamagnetic are those which are usually considered by non-physicists as "**non-magnetic**", and include water, most organic compounds such as petroleum and some plastics, and many metals including copper, particularly the heavy ones with many core electrons, such as mercury, gold and bismuth.

- Diamagnetic materials have a **relative permeability that is less than 1**, and are therefore repelled by magnetic fields

Paramagnetic

- Paramagnetic materials are attracted to magnetic fields; hence have a **relative permeability greater than one.**

- The force of attraction generated by the applied field is *linear* in the field strength and rather *weak*.

Magnetic Materials

Ferromagnetic

- Ferromagnetism is defined as the phenomenon by which materials, such as iron and steel, in an external magnetic field become magnetized and remain magnetized for a period after the material is no longer in the field.

- All permanent magnets are ferromagnetic, as are the metals that are noticeably attracted to them.

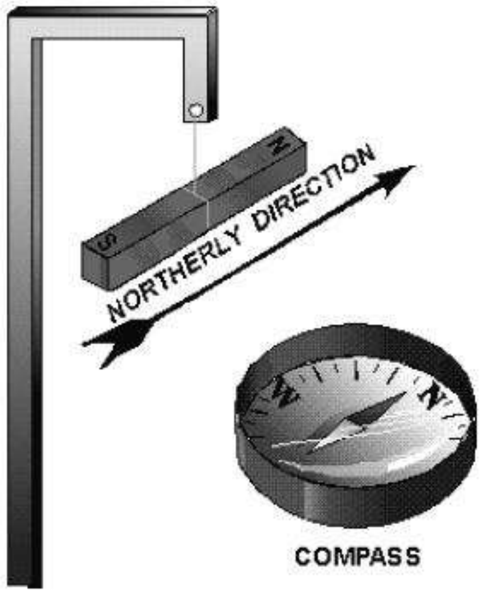
Magnetic Poles

- The magnetic force surrounding a magnet is not uniform.
- There exists a great concentration of force at each end of the magnet and a very weak force at the centre.

- The two ends, which are the regions of concentrated lines of force, are called the **poles** of the magnet.
- Magnets have two magnetic poles and both poles have equal magnetic strength.

Law of Magnetic Poles

If a bar magnet is suspended freely on a string, as shown in figure beside, it will align itself in a north and south direction. When this experiment is repeated, it is found that the same pole of the magnet will always swing toward the north magnetic pole of the earth. Therefore, it is called the north-seeking pole or simply the **north-pole**. The other pole of the magnet is the south-seeking pole or the **south-pole**.



The law for magnetic poles is:

Like poles repel, unlike poles attract

- The north-pole of a magnet will always be attracted to the south-pole of another magnet and will show a repulsion to a north-pole

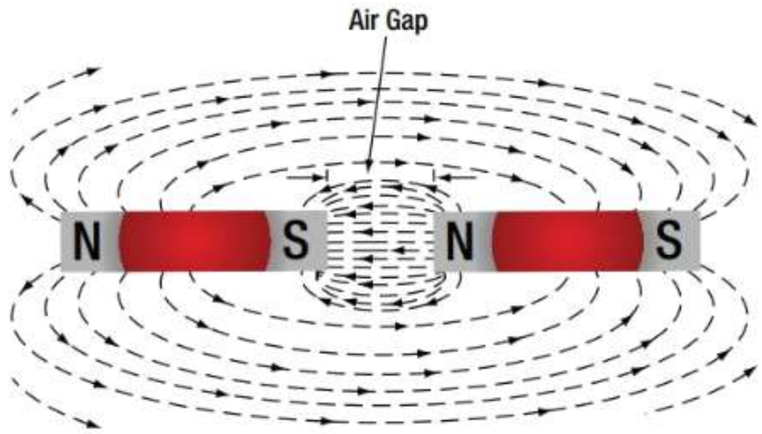


Figure 10-6. Unlike poles attract.

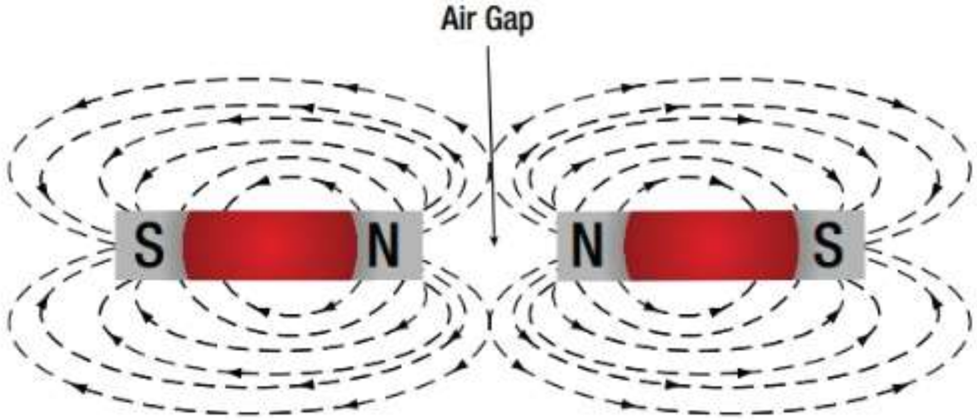
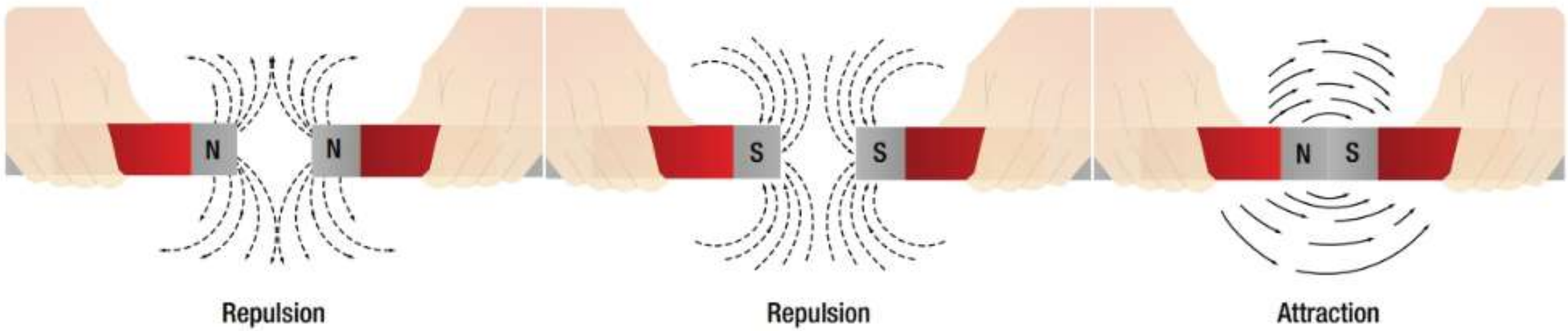


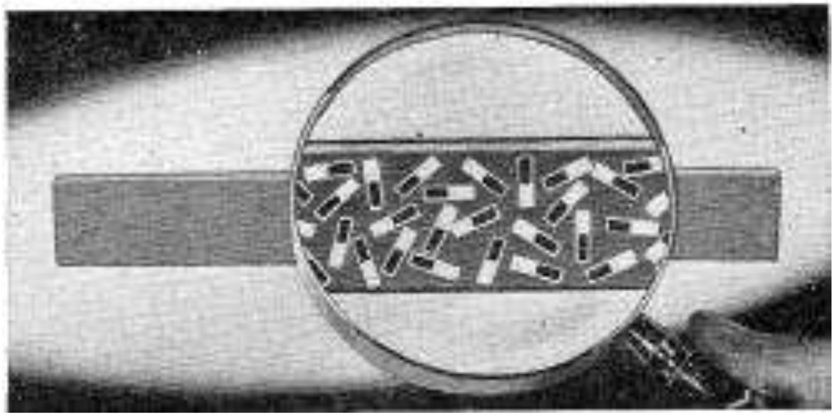
Figure 10-5. Like poles repel.



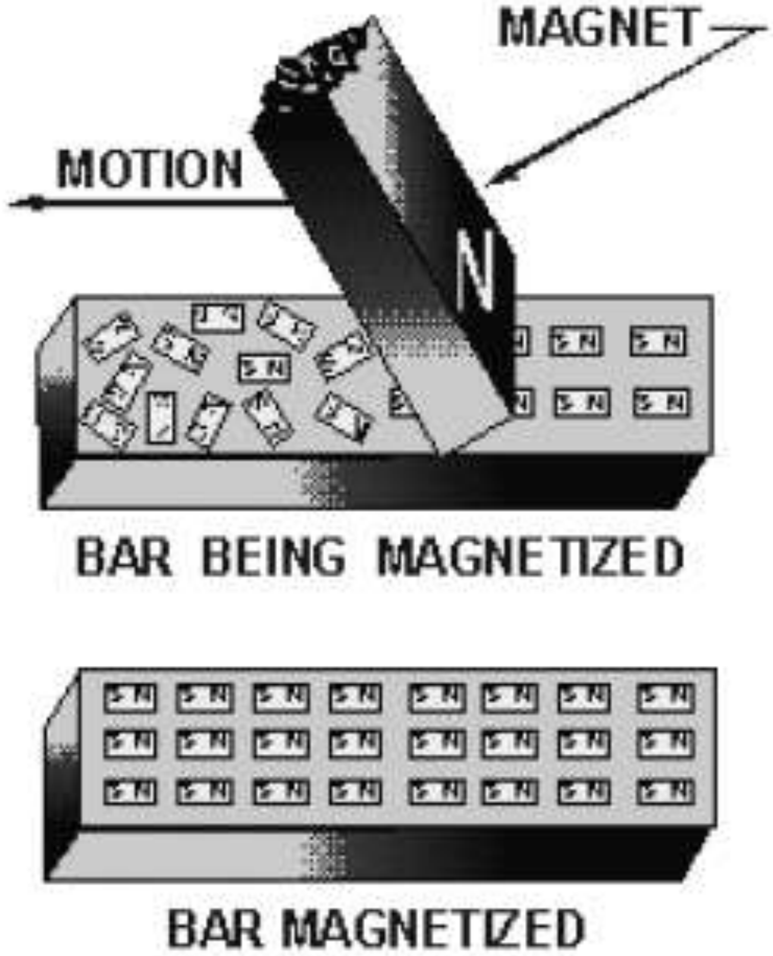
Theories of Magnetism

Weber's Theory

- This theory assumes that all magnetic substances are composed of tiny molecular magnets.



An illustration of Weber's Theory is shown in figure beside, where a steel bar is magnetized by stroking. When a steel bar is stroked several times in the same direction by a magnet, the magnetic force from the north-pole of the magnet causes the molecules to align themselves.



Effect of Breaking a Bar Magnet

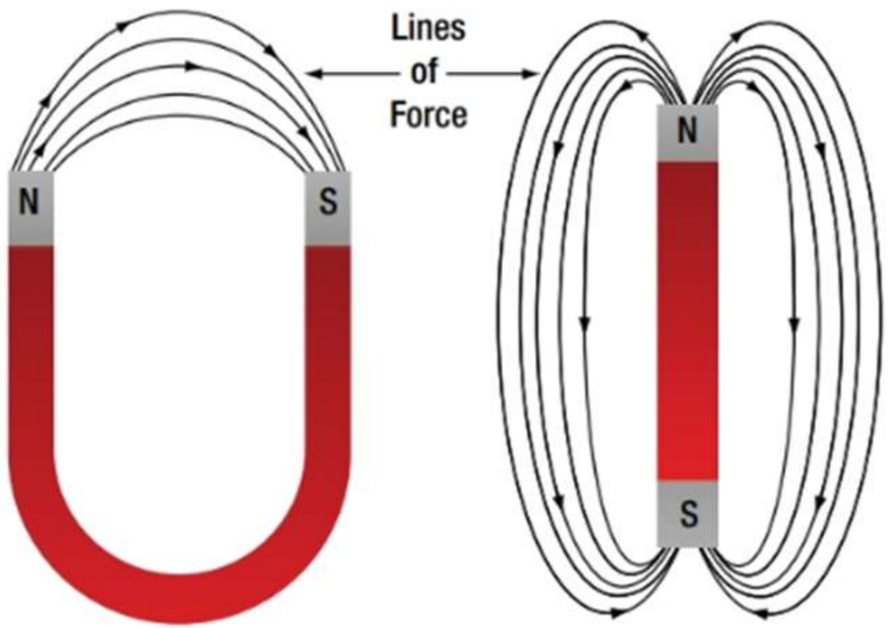
Theoretically, if each piece could be broken up into smaller and smaller pieces until each was a molecule, all would still be individual magnets.

Magnetic Fields

The space surrounding a magnet where magnetic forces act is known as the magnetic field.

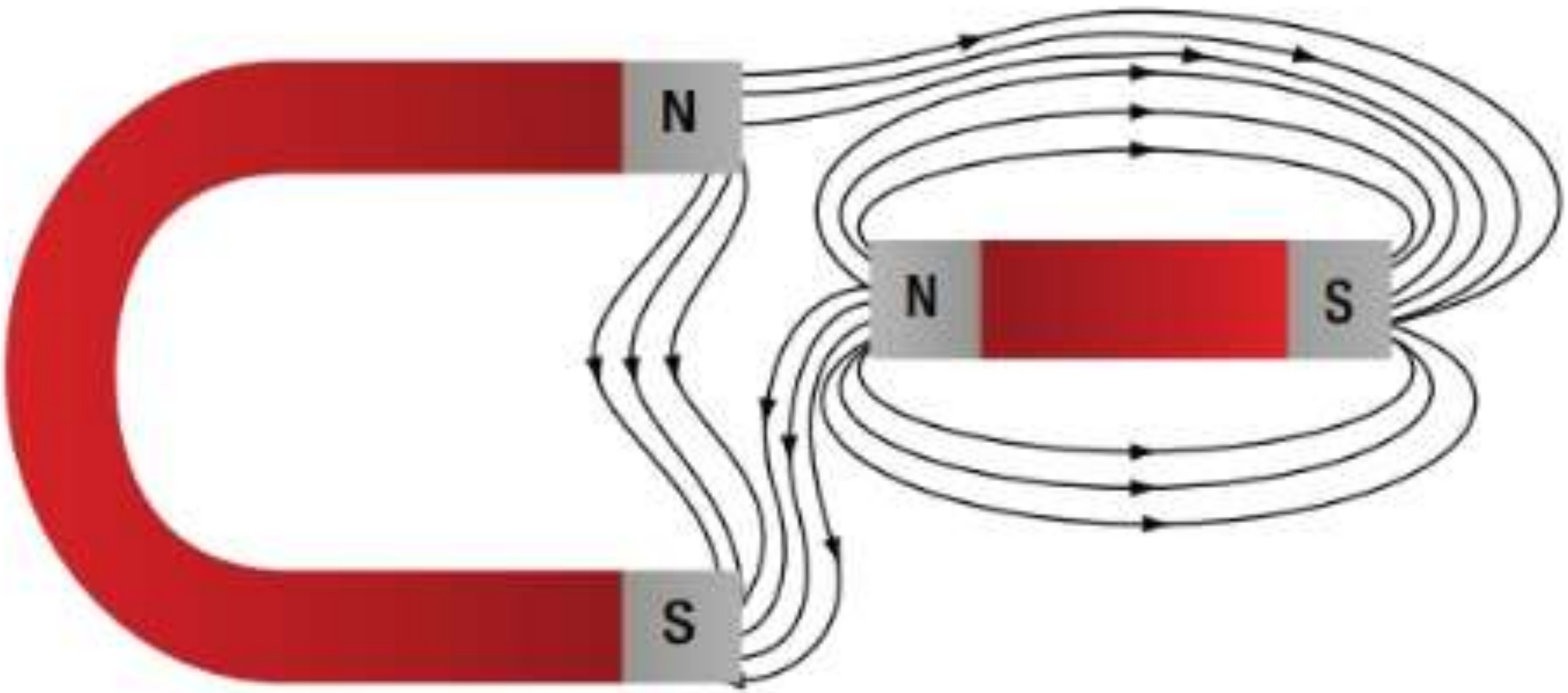
Lines of Force

Lines are used to represent the force existing in the area surrounding a magnet, called **magnetic lines of force**



The characteristics of magnetic lines of force

- Magnetic lines of force are continuous and will always form closed loops.
- Magnetic lines of force will never cross one another.
- Parallel magnetic lines of force travelling in the same direction repel one another. Parallel magnetic lines of force travelling in opposite directions tend to unite with each other and form into single lines travelling in a direction determined by the magnetic poles creating the lines of force.
- Magnetic lines of force tend to shorten themselves. Therefore, the magnetic lines of force existing between two unlike poles cause the poles to be pulled together.
- Magnetic lines of force pass through all materials, both magnetic and nonmagnetic.
- Magnetic lines of force always **enter or leave a magnetic material at right angles to the surface**.



MAGNETIC PROPERTIES AND THE HYSTERESIS LOOP

Magnetic Flux

- The lines of magnetic force previously described, are more properly known as **lines of flux**.
- The unit of magnetic flux is the **Weber** (Wb), *Wilhelm Edouard Weber (1804-91)*
- the symbol for magnetic flux is Φ (Phi)

Flux Density

- The effectiveness of a magnetic field is determined not by the total amount of flux but by the density of flux.
- The flux density (**B**), defined as the flux per unit area of cross-section.
- The unit of flux density is the **Tesla** (T), or Wb/m^2.

MAGNETIC PROPERTIES AND THE HYSTERESIS LOOP

Magnetic Field strength/ Magnetizing Force

- A vector quantity indicating the ability of a magnetic field to exert a force on moving electric charges.
- It is equal to the *magnetic flux density* divided by the *magnetic permeability* of the space where the field exists.
- Also called **magnetic intensity (H)**.
- The unit of Magnetizing Force is **Ampere-turns/Metre** (At/m)

Reluctance

- A measure of the opposition to magnetic flux, analogous to electric resistance.
- The unit of Reluctance is **Ampere-turns/Weber** (At/Wb)

MAGNETIC PROPERTIES AND THE HYSTERESIS LOOP

- When magnetizing a material, there is a direct relationship between the intensity of the magnetizing force and the amount of magnetism developed in a material as demonstrated by the amount of flux (flux density) produced.
- A phenomenon called hysteresis loop.

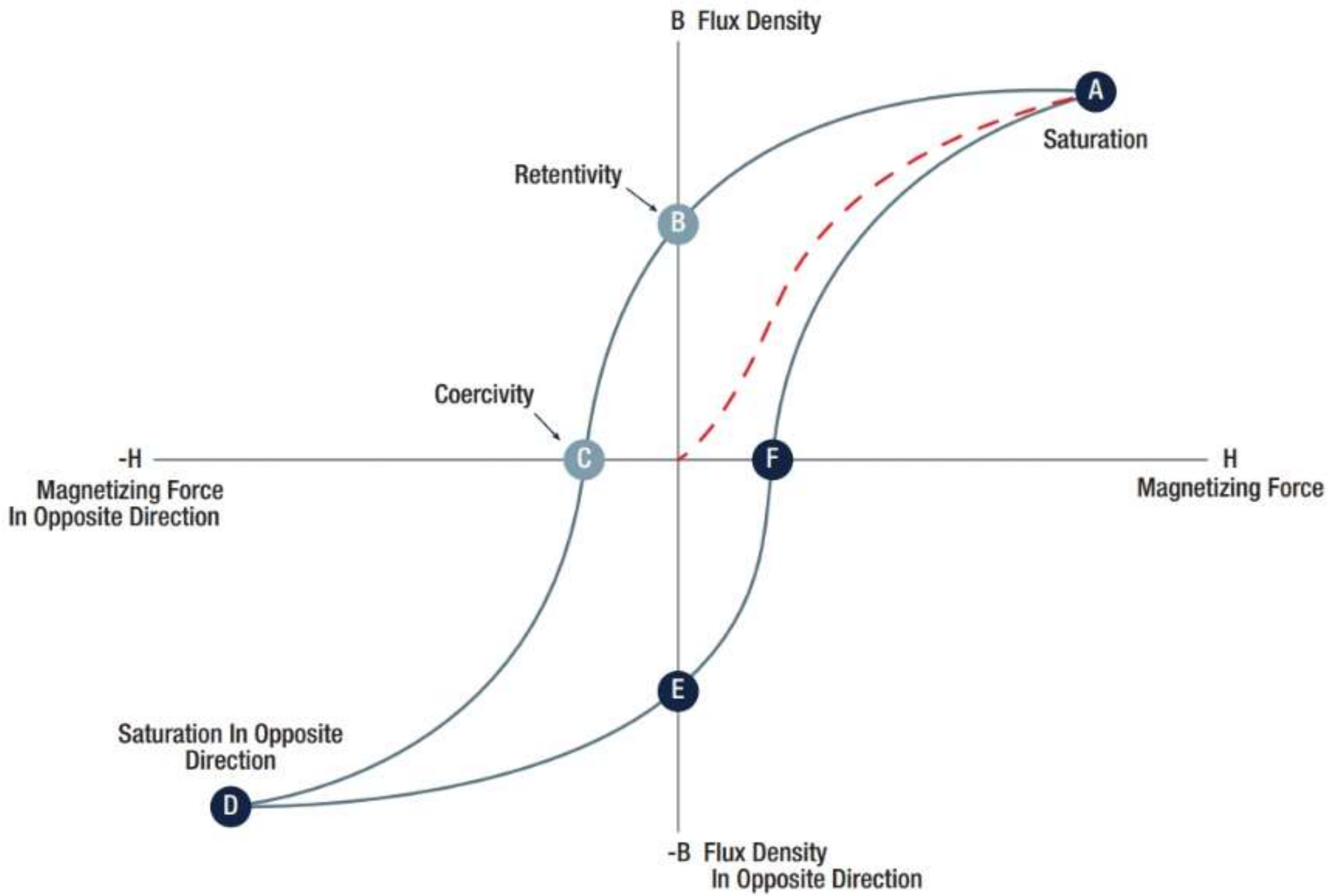


Figure 10-12. The hysteresis loop.

MAGNETIC PROPERTIES AND THE HYSTERESIS LOOP

- Beginning at the origin for a material which is non magnetized or has lost nearly all of its magnetism, as the magnetizing force is increased, the flux density (magnetic field) increases.

- Near point A, increases in magnetizing force produces very little increase in magnetic flux and the material is said to be magnetically saturated.

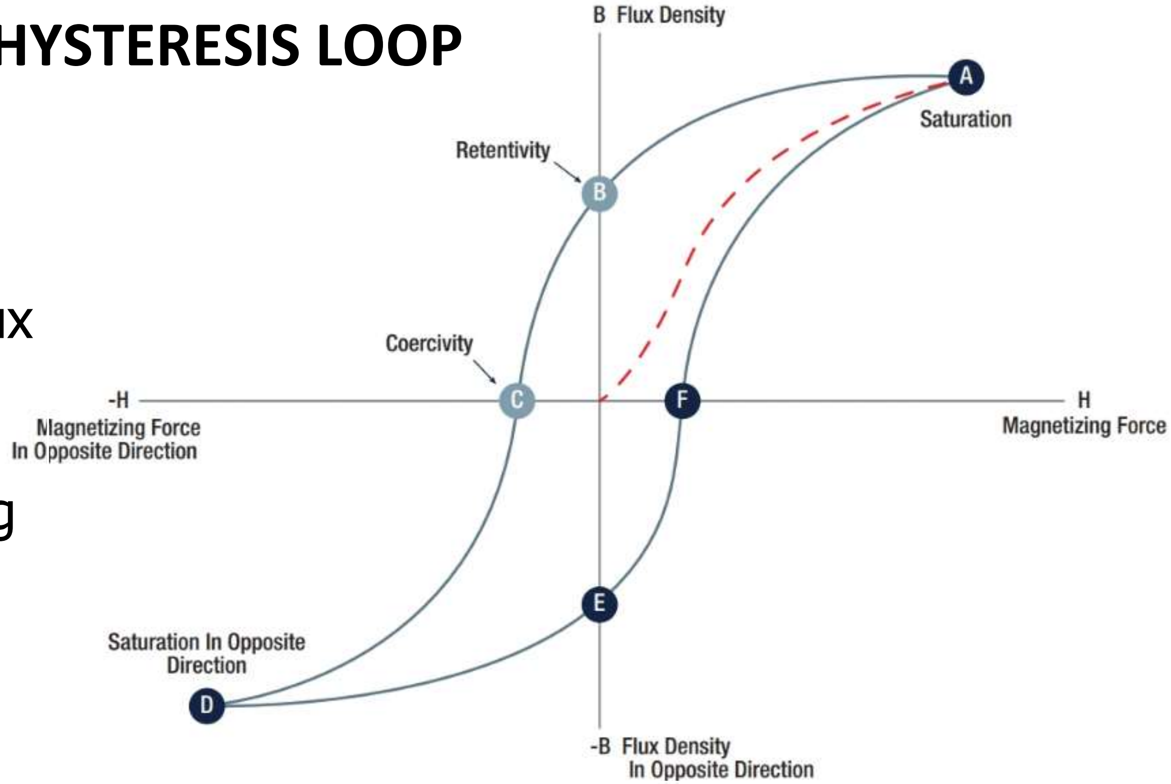


Figure 10-12. The hysteresis loop.

- When the magnetizing force is reduce to zero, some magnetic flux remains in the material (point B). This is referred to as a material's retentivity.

- Application of a reversed magnetizing force removes the flux than remained in the magnetizing material (point C). This is known as coercivity.
- As the reversed magnetizing force is increased, a similar flux build-up related to the intensity of the magnetizing force occurs with polarity opposite to the original (point D). Again, a point of saturation is reached as further increasing the intensity of the magnifying force produces virtually no change in flux density.
- When the magnetizing force is removed, retentivity caused some magnetic flux to remain (point E).

MAGNETIC PROPERTIES AND THE HYSTERESIS LOOP

- Then, as the magnetizing intensity is increased in the original direction, the magnetic flux increases in the original direction once again until saturation is reached.

- Thus, a loop is formed that incorporates the hysteresis of the lingering flux (retentivity) in the magnetized material.

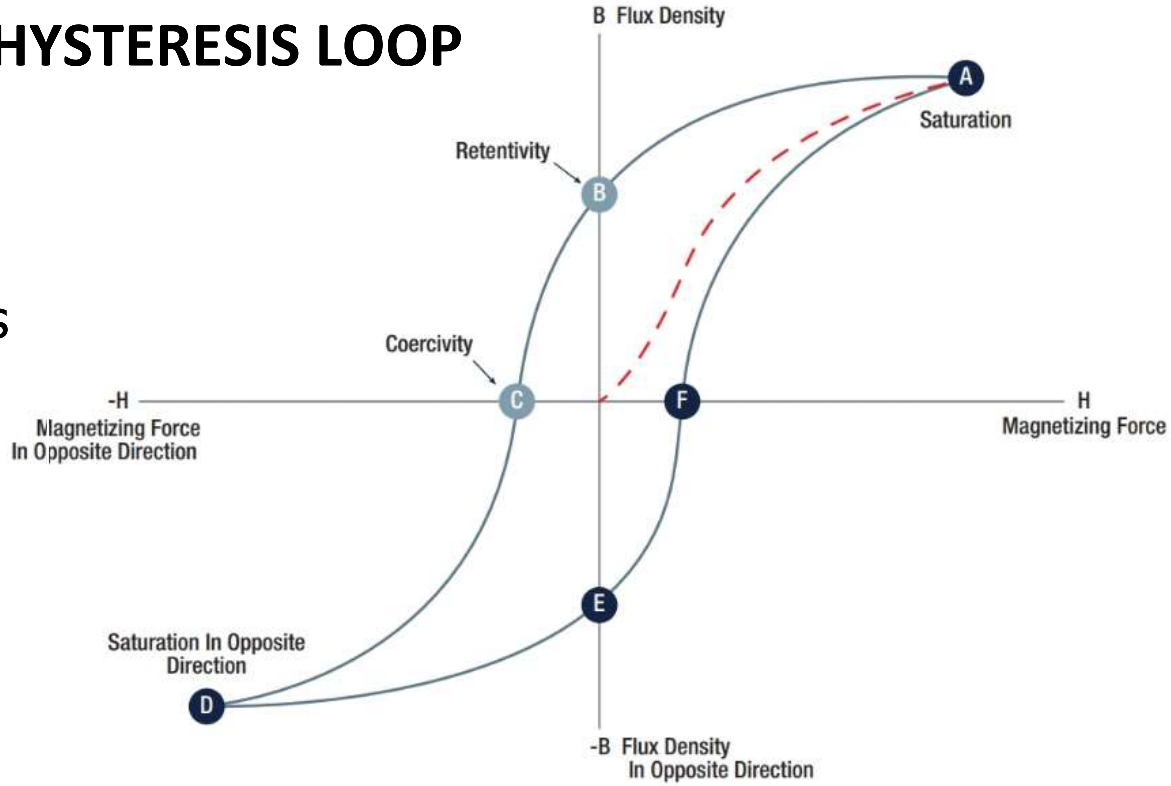


Figure 10-12. The hysteresis loop.

- The coercive force is the magnetizing force in the opposite direction that needs to be applied to remove the retained flux.

- The coercive force reluctance of the material is the opposition to giving up the retained magnetic flux that remains after the magnetizing force is removed.

Saturation point in a material being magnetized is reached when an increase in magnetic field strength produces only a small increase in flux density.

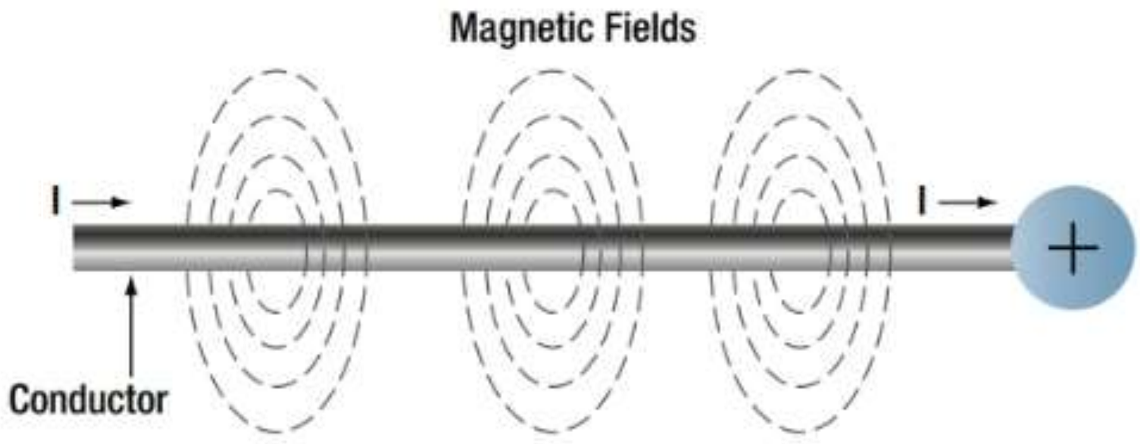
EDDY CURRENTS

- When the magnetic field in a conductor is changed, eddy currents develop.
- The eddy currents induce their own magnetic fields.
- The forces oppose their own development or dissipation as well as the development and dissipation of the conductor's magnetic field.
- The faster the change in the conductor magnetic field, the greater the eddy currents and associated magnetic fields.
- Eddy currents tend to generate heat and reduce the efficiency of devices that rely on changing magnetic fields.

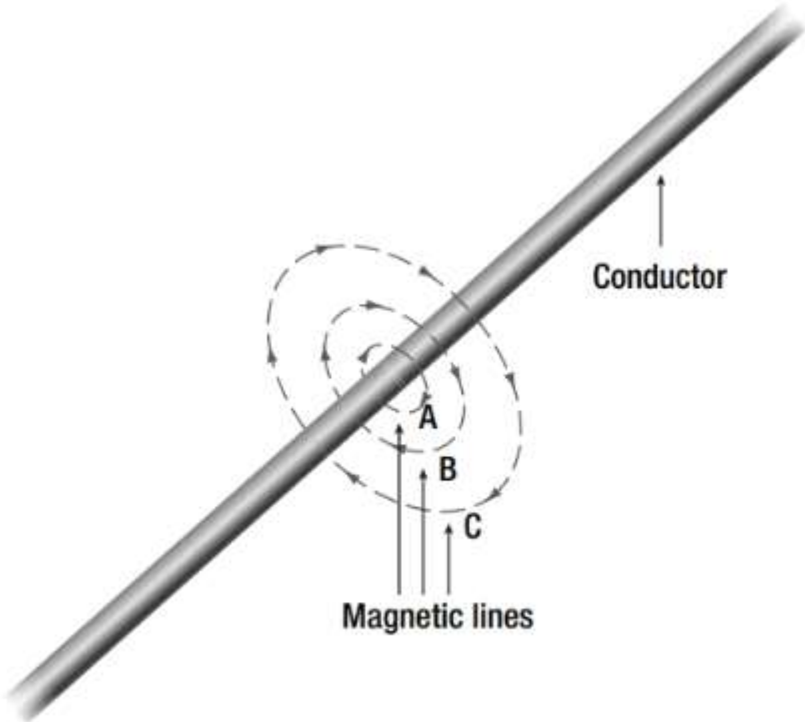
ELECTROMAGNETISM

Danish scientist *Hans Christian Oersted (1770-1851)*

- The electrons moving through the wire created the magnetic field around the conductor.



Magnetic field formed around a conductor in which current is flowing.



Expansion of magnetic field as current increases.

- Since a magnetic field accompanies a charged particle, the greater the current flow, and the greater the magnetic field.

ELECTROMAGNETISM

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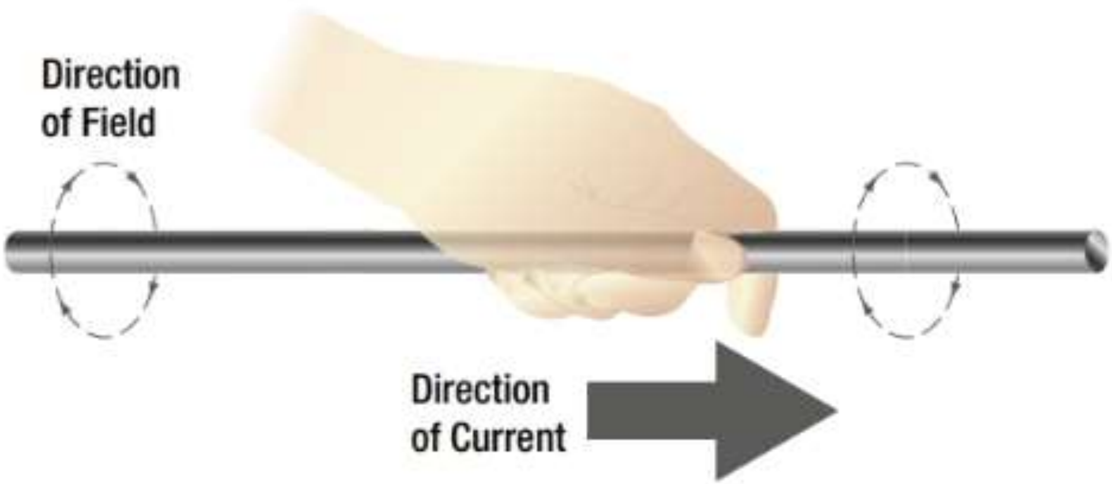
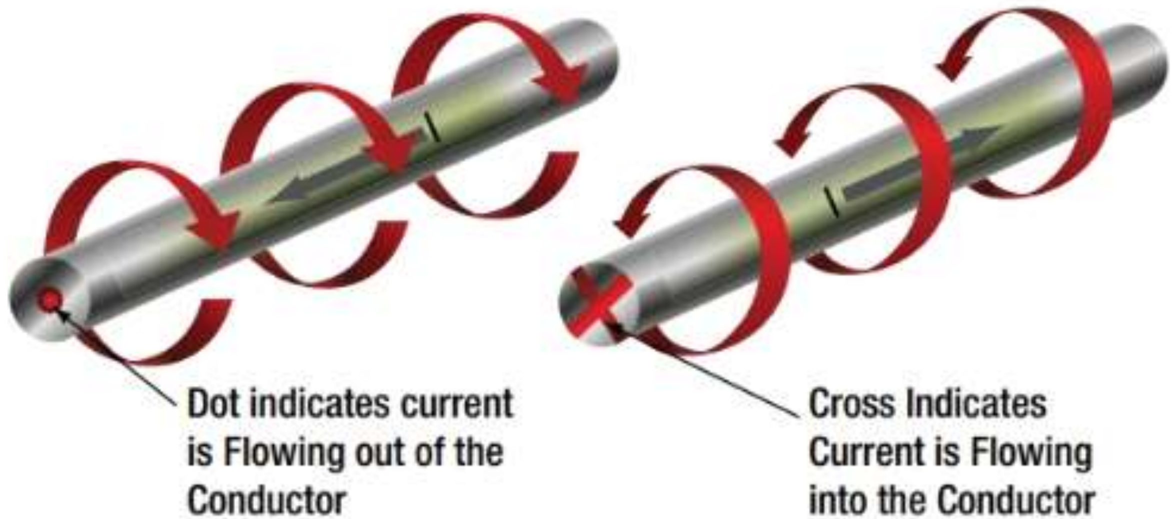
- Direction of electromagnetic fields follow the Left-hand rule.

Left-hand rule.



Direction of current flow in a conductor.



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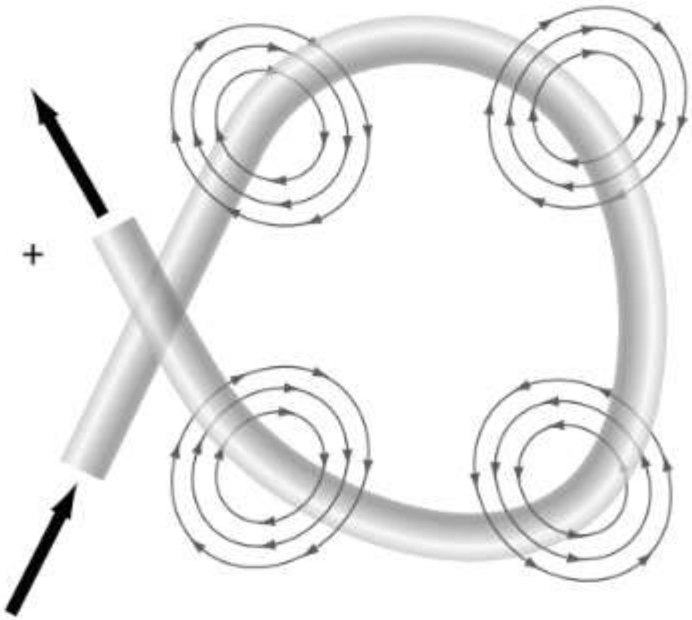

Magnetic field around a looped conductor.

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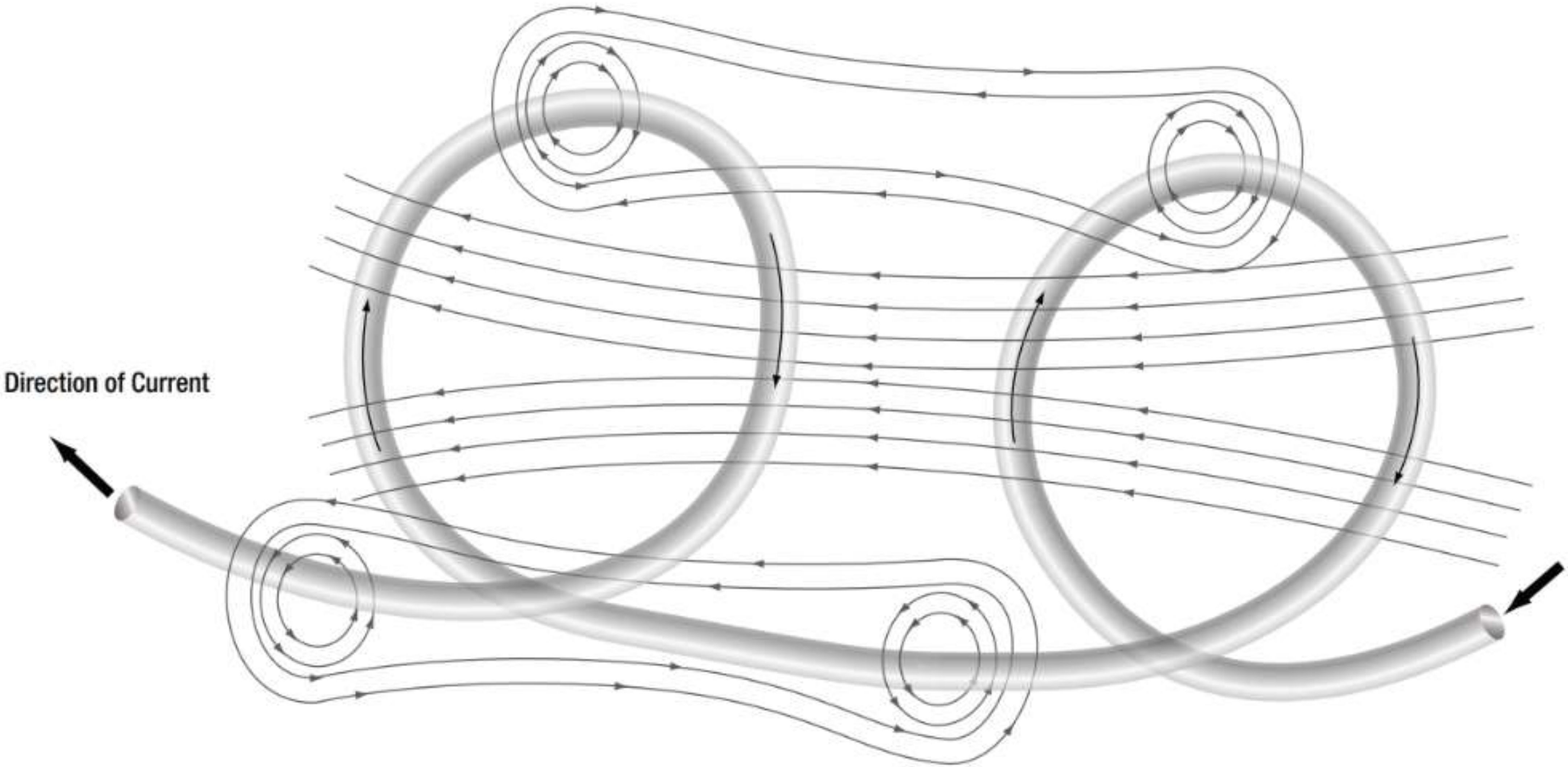
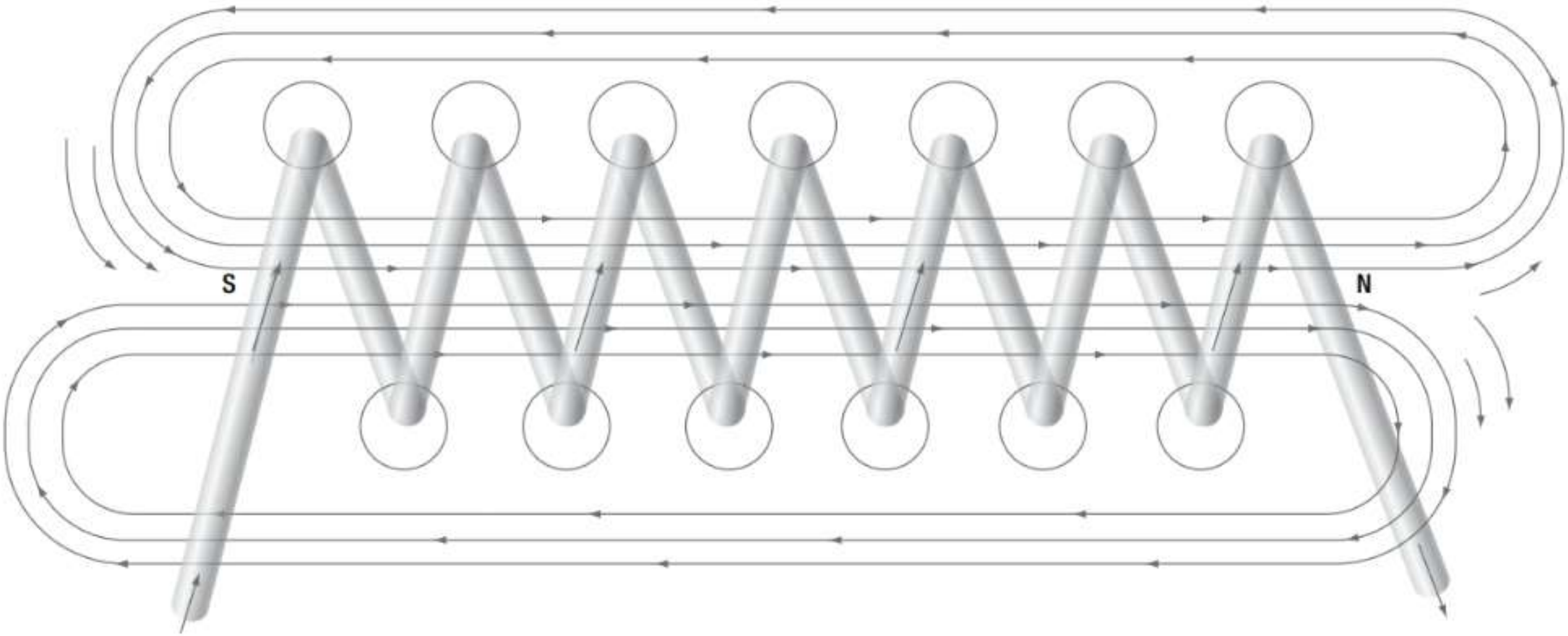


Magnetic field around a conductor with two loops.

ELECTROMAGNETISM

Danish scientist *Hans Christian Oersted (1770-1851)*

- When a wire contains many such loops, it is called a coil.

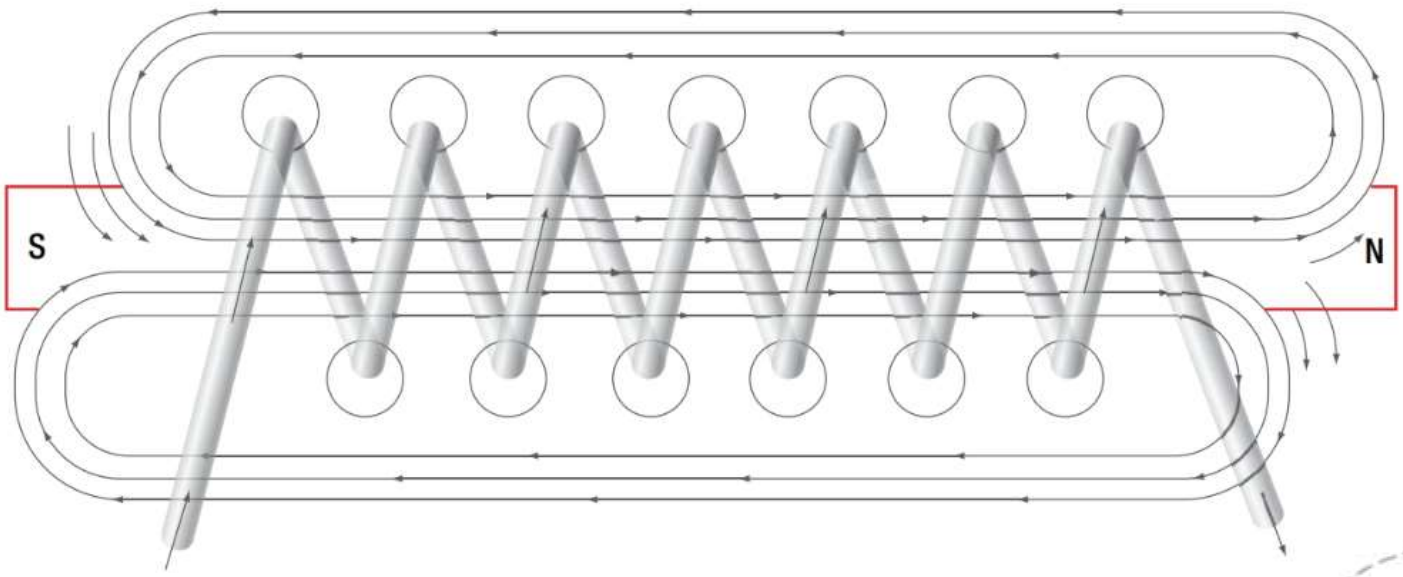


Magnetic field of a coil.

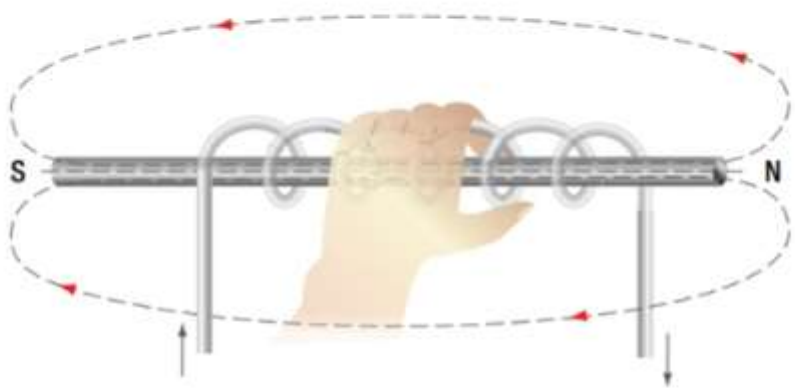
ELECTROMAGNETISM

Danish scientist *Hans Christian Oersted (1770-1851)*

- In a coil made from loops of a conductor, many of the lines of force are dissipated between the loops of the coil.
- By placing a soft iron bar inside the coil, the lines of force will be concentrated in the center of the coil, since soft iron has a greater permeability than air.



Left-hand rule applied to a coil.



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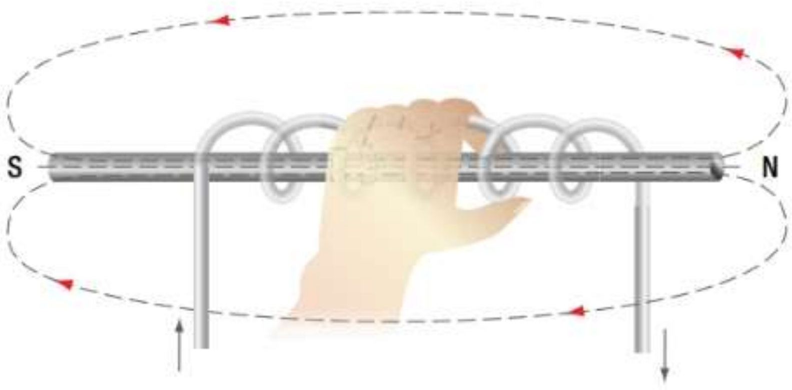

ELECTROMAGNETISM

Danish scientist *Hans Christian Oersted (1770-1851)*

- Electromagnets are used in electrical instruments, motors, generators, relays, and other devices.
- Some electromagnetic devices operate on the principle that an iron core held away from the center of a coil will be rapidly pulled into a center position when the coil is energized.
- This principle is used in the solenoid, also called solenoid switch or relay, in which the iron core is spring-loaded off center and moves to complete a circuit when the coil is energized.

Energized coil with an iron core.