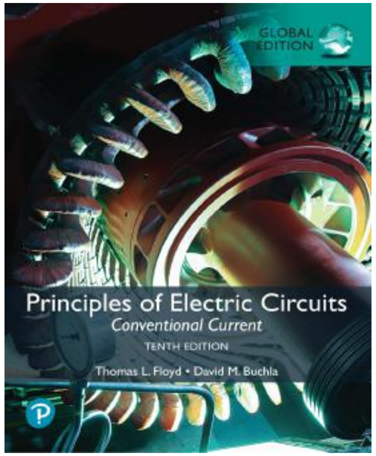
Principles of Electric Circuits: Conventional Current

Tenth Edition, Global Edition

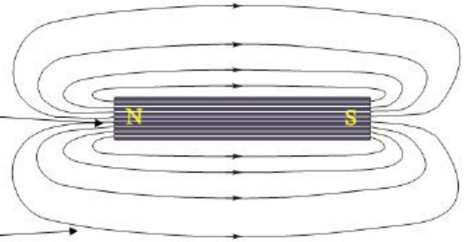


Chapter 10

Magnetism and Electromagnetism

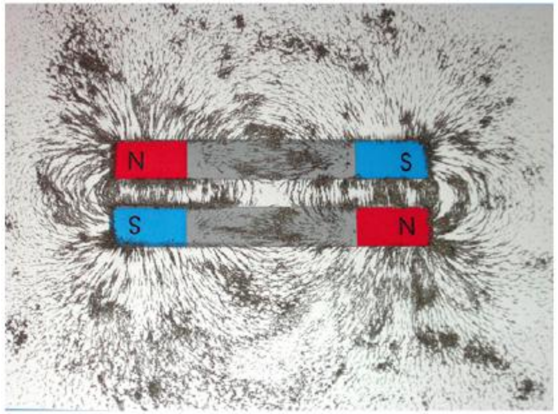
Summary: Magnetic Quantities (1 of 12)

Magnetic fields are described by drawing flux lines that represent the magnetic field. By convention, lines are drawn from the North magnetic pole to the South magnetic pole.



Summary: Magnetic Quantities (2 of 12)

Magnetic flux lines are invisible, but the effects can be visualized with iron filings sprinkled in a magnetic field.



Summary: Magnetic 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.

Summary: Magnetic Quantities (3 of 12)

The unit of flux is the weber. A measure of flux density is the weber/square meter, which defines the unit **tesla**, (T), which is a very large unit.

Flux density is given by the equation

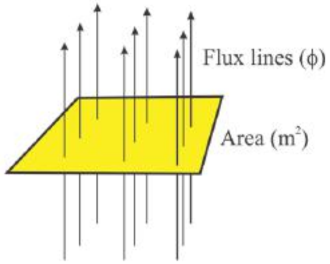
$$B = \frac{\phi}{A}$$

where

B = flux density (T)

ϕ = flux (Wb)

A = area (m^2)



Summary: Magnetic Quantities (4 of 12)

It is common for flux density to also be measured in Gauss (G), a much smaller unit than the Tesla (10^4 G = 1.0 T). This is the reason meters to measure flux density are referred to as *gaussmeters*.

(Integrity Model IDR-329 distributed by Less EMF Inc.)

Summary: Magnetic Quantities (5 of 12)

Example:

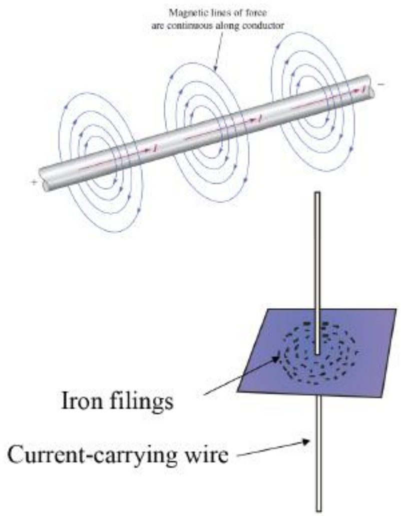
What is the flux density in a rectangular core that is 8.0 mm by 10 mm if the flux is 4.0 mWb?

$$B = \frac{\phi}{A}$$

$$B = \frac{4.0\times10^{-3}\ \text{Wb}}{(8.0\times10^{-3}\ \text{m})(10\times10^{-3}\ \text{m})} = 50\ \text{Wb/m}^2 = 50\ \text{T}$$

Summary: Magnetic Quantities (6 of 12)

- Magnetic flux lines surround a current carrying wire in the form of concentric circles.
- As in the case of bar magnets, the effects of electrical current can be visualized with iron filings around the wire – the current must be large to see this effect.



Summary: Magnetic Quantities (7 of 12)

- **Permeability** (μ) defines the ease with which a magnetic field can be established in a given material. It is measured in units of the weber per ampere-turn meter (Wb/At-m).
- The permeability of a vacuum (μ_0) is $4\pi \times 10^{-7}$ (Wb/At-m), which is used as a reference.
- **Relative Permeability** (m_r) is the ratio of the absolute permeability to the permeability of a vacuum.

$$\mu_r = \frac{\mu}{\mu_0}$$

Pearson

Summary: Magnetic Quantities (8 of 12)

- **Reluctance** (**R**) is the opposition to the establishment of a magnetic field in a material.

$$\mathcal{R} = \frac{l}{\mu A}$$

R= reluctance in At/Wb

l = length of the path

μ = permeability (Wb/At m).

A = area in m^2

Pearson

Summary: Magnetic Quantities (9 of 12)

- Recall that magnetic flux lines surround a current-carrying wire. A coil reinforces and intensifies these flux lines.
- The *cause* of magnetic flux is called magnetomotive force (mmf), which is related to the current and number of turns of the coil.

$$F_m = NI$$

F_m = magnetomotive force (At)

N = number of turns of wire in a coil

I = current (A)

Pearson

Summary: Magnetic Quantities (10 of 12)

- Ohm's law for magnetic circuits is

$$\phi = \frac{F_m}{\mathcal{R}}$$

- flux (ϕ) is analogous to current
- magnetomotive force (F_m) is analogous to voltage
- reluctance (**R**) is analogous to resistance.

Example:

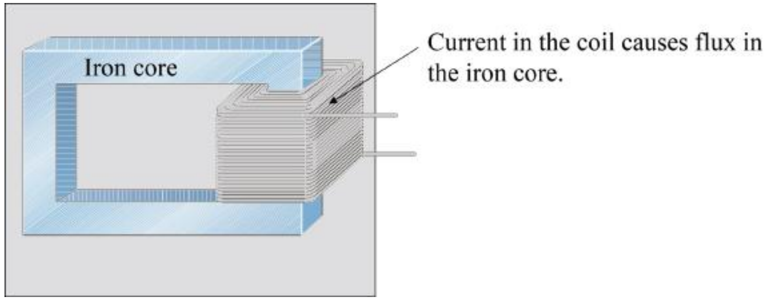
What flux is in a core that is wrapped with a 300 turn coil with a current of 100 mA if the reluctance of the core is 1.5 × 10^7 A-t/Wb ?

$$\phi = \frac{F_m}{\mathcal{R}} = \frac{(0.10\ \text{A})(300\ \text{t})}{1.5 \times 10^7\ \text{A-t/Wb}} = 2.0\ \mu\text{Wb}$$

Pearson

Summary: Magnetic Quantities (11 of 12)

- The magnetomotive force (mmf) is not a true force in the physics sense, but can be thought of as a *cause* of flux in a core or other material.

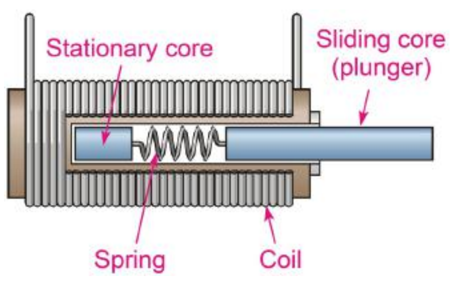


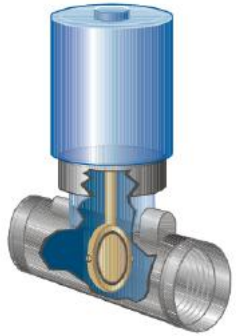
Question:

What is the mmf if a 250 turn coil has 3.0 A of current? 750 At

Summary: Solenoids

- A **solenoid** converts an electrical signal to mechanical motion.

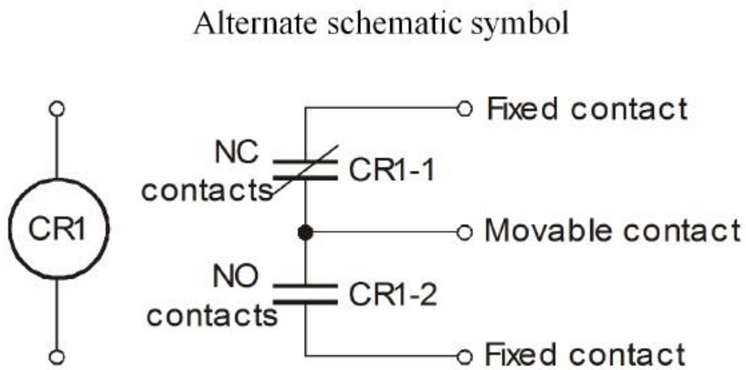




One application is valves that can remotely control a fluid in a pipe, such as in sprinkler systems.

Summary: Relays

- A **relay** is an electrically controlled switch; a small control voltage on the coil can control a large current through the contacts.



Summary (1 of 3)

- **Magnetic field intensity** is the magnetomotive force per unit length of a magnetic path.

$$H = \frac{F_m}{l} \quad \text{or} \quad H = \frac{NI}{l}$$

H= Magnetic field intensity (At/m)
F_m = magnetomotive force (At)
l = average length of the path (m)
N = number of turns
I = current (A)

- Magnetic field intensity represents the effort that a given current must put into establishing a certain flux density in a material.

Summary : Magnetic Quantities (12 of 12)

- If a material is permeable, ~~then a given~~ then a given magnetic field intensity will establish a greater flux density within the material. The relation between *B* (flux density) and *H* (the effort to establish the field) is

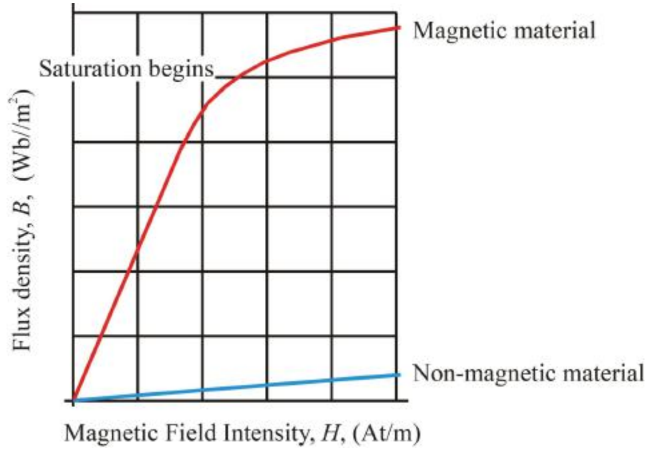
$$B = \mu H$$

  μ = permeability (Wb/At-m).
  H= Magnetic field intensity (At/m)

- This relation between *B* and *H* is valid up to saturation, when further increase in *H* has no affect on *B*.

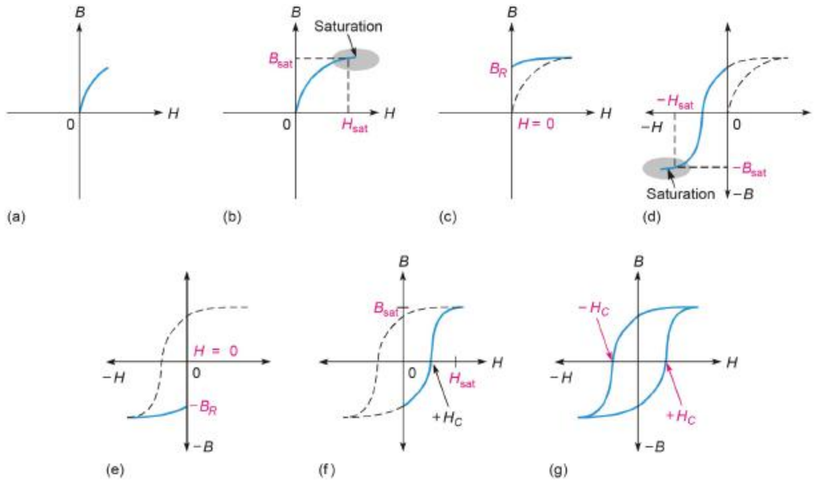
Summary (2 of 3)

- As the graph shows, the flux density depends on both the material and the magnetic field intensity.



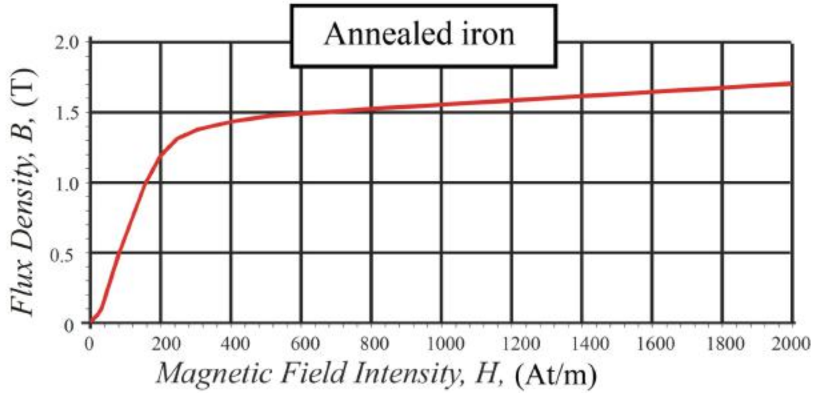
Summary (3 of 3)

As *H* is varied, the magnetic hysteresis curve is developed.



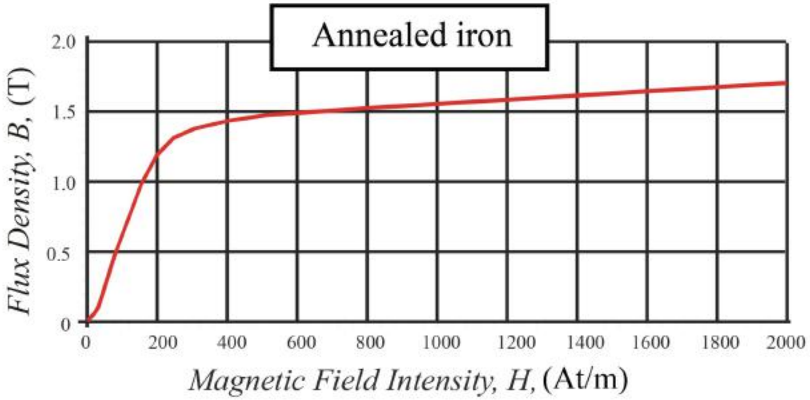
Summary: Magnetization Curve (1 of 3)

A *B-H* curve is referred to as a **magnetization curve** for the case where the material is initially unmagnetized.



Summary: Magnetization Curve (2 of 3)

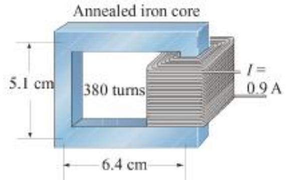
A *B-H* curve can be read to determine the flux density in a given core. The next slide shows how to read the graph to determine the flux density in an annealed iron core.



Summary: Magnetization Curve (3 of 3)

Example:

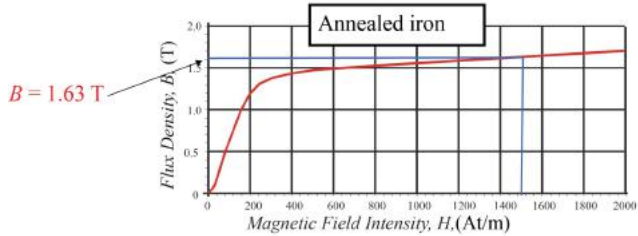
What is B for the core?



Solution:

$$H = \frac{NI}{l} = \frac{(380\ \text{t})(0.9\ \text{A})}{0.23\ \text{m}} = 1487\ \text{At/m}$$

Reading the graph,

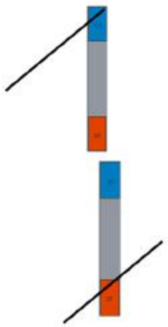


Summary: Relative motion

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 in the wire.



Summary: Induced voltage

The induced voltage due to the relative motion between the conductor and the magnetic field when the motion is perpendicular to the field is given by

$$v_{ind} = Blv$$

B = flux density in T

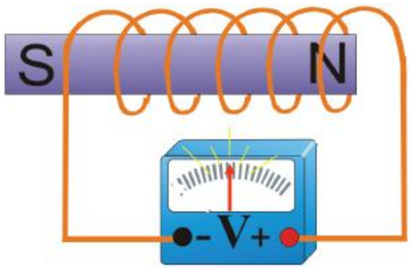
l = length of the conductor in the magnetic field in m

v = relative velocity in m/s (motion that is perpendicular)

Summary: Faraday's law (1 of 2)

Faraday experimented with generating current by relative motion between a magnet and a coil of wire. The amount of voltage induced across a coil is determined by two factors:

1. The rate of change of the magnetic flux with respect to the coil.

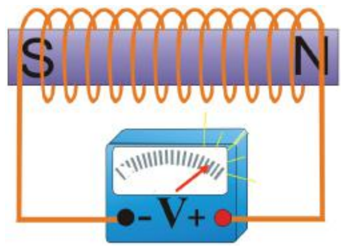


Voltage is indicated only when magnet is *moving*.

Summary: Faraday's law (2 of 2)

Faraday experimented with generating current by relative motion between a magnet and a coil of wire. The amount of voltage induced across a coil is determined by two factors:

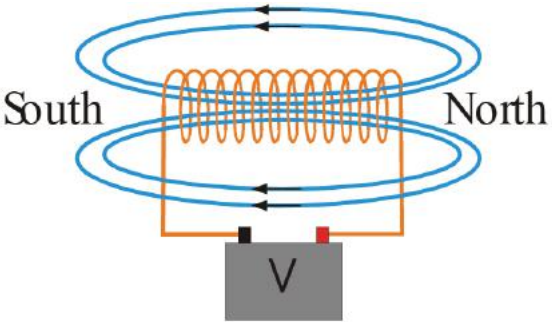
1. The rate of change of the magnetic flux with respect to the coil.
2. The number of turns of wire in the coil.



Voltage is indicated only when magnet is *moving*.

Summary: Magnetic field around a coil

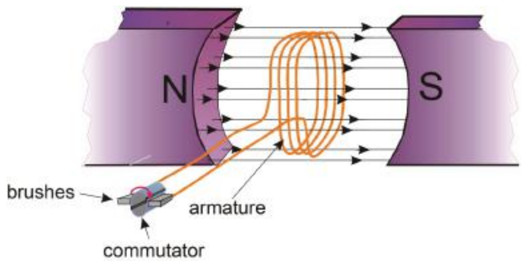
Just as a moving magnetic field induces a voltage, current in a coil causes a magnetic field. The coil acts as an electromagnet, with a north and south pole as in the case of a permanent magnet.



Summary: DC Motor

A dc motor includes a rotating coil, which receives current through a split ring, called the commutator. The commutator is connected to fixed brushes, which are connected to an external circuit. The magnetic core is not shown for simplicity.

Small motors may use a fixed magnet, as shown.



Summary: Brushless DC Motor

Brushless dc motors use an electronic controller to periodically reverse the field in the stator windings. This causes the stator field to rotate, and the permanent magnet rotor moves in the same direction as the rotating field.

A cutaway view of a brushless motor is shown.

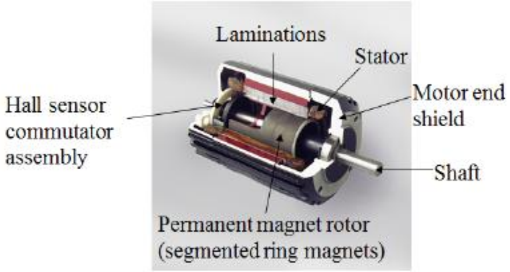


Photo courtesy of Bodine Electric Company, used with permission.

Magnetic units

It is useful to review the key magnetic units from this chapter:

Quantity	Symbol	Unit	Symbol
Magnetic field intensity	H	Ampere-turns/meter	At/m
Magnetic flux	ϕ	Weber	Wb
Magnetic flux density	B	Tesla	T
Magnetomotive force	F_m	Ampere-turn	At
Permeability	μ	Webers/ampere-turns-meter	Wb/At·m
Reluctance	R	Ampere-turns/weber	At/Wb

Selected Key Terms (1 of 3)

Magnetic field A force field radiating from the north pole to the south pole of a magnet.

Magnetic flux The lines of force between the north pole and south pole of a permanent magnet or an electromagnet.

Weber (Wb) The SI unit of magnetic flux, which represents 10^8 lines.

Permeability The measure of ease with which a magnetic field can be established in a material.

Reluctance The opposition to the establishment of a magnetic field in a material.

Selected Key Terms (2 of 3)

Magnetomotive force (mmf) The cause of a magnetic field, measured in ampere-turns (At).

Solenoid An electromagnetically controlled device in which the mechanical movement of a shaft or plunger is activated by a magnetizing current.

Hysteresis A characteristic of a magnetic material whereby a change in magnetism lags the application of the magnetic field intensity.

Retentivity The ability of a material, once magnetized, to maintain a magnetized state without the presence of a magnetizing current.

Selected Key Terms (3 of 3)

Induced voltage (v_{ind}) Voltage produced as a result of a changing magnetic field.

Faraday's law A law stating that 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.

Lenz's law A law stating that when the current through a coil changes, the polarity of the induced voltage created by the changing magnetic field is such that it always opposes the change in the current that caused it. The current cannot change instantaneously.

Quiz (1 of 11)

1. A unit of flux density that is the same as a Wb/m^2 is the
   a. ampere-turn
   b. ampere-turn/weber
   c. ampere-turn/meter
   d. tesla

Quiz (2 of 11)

2. If one magnetic circuit has a larger flux than a second magnetic circuit, then the first circuit has
   a. a higher flux density
   b. the same flux density
   c. a lower flux density
   d. answer depends on the particular circuit.

Quiz (3 of 11)

3. The *cause* of magnetic flux is
   a. magnetomotive force
   b. induced voltage
   c. induced current
   d. hysteresis

Quiz (4 of 11)

4. The measurement unit for permeability is
   a. weber/ampere-turn
   b. ampere-turn/weber
   c. weber/ampere-turn-meter
   d. dimensionless

Quiz (5 of 11)

5. The measurement unit for *relative* permeability is
   a. weber/ampere-turn
   b. ampere-turn/weber
   c. weber/ampere-turn meter
   d. dimensionless

Quiz (6 of 11)

6. The property of a magnetic material to behave as if it had a memory is called
   a. remembrance
   b. hysteresis
   c. reluctance
   d. permittivity

Quiz (7 of 11)

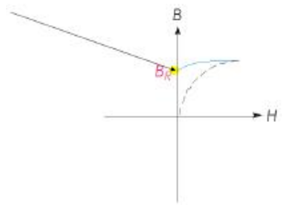
7. Ohm's law for a magnetic circuit is
   a. $F_m = NI$
   b. $B = \mu H$
   c. $\phi = \frac{F_m}{R}$
   d. $R = \frac{l}{\mu A}$

Quiz (8 of 11)

8. The control voltage for a relay is applied to the
    a. normally-open contacts
    b. normally-closed contacts
    c. coil
    d. armature

Quiz (9 of 11)

9. A partial hysteresis curve is shown. At the point indicated, magnetic flux
    a. is zero
    b. exists with no magnetizing force
    c. is maximum
    d. is proportional to the current



Quiz (10 of 11)

10. When the current through a coil changes, the induced voltage across the coil will
    a. oppose the change in the current that caused it
    b. add to the change in the current that caused it
    c. be zero
    d. be equal to the source voltage

Quiz (11 of 11)

Answers:

1. d
2. d
3. a
4. c
5. d
6. b
7. c
8. c
9. b
10. a