PEARSON NEW INTERNATIONAL EDITION

# Electronics Fundamentals
## Circuits, Devices and Applications

Thomas L. Floyd    David L. Buchla

Eighth Edition

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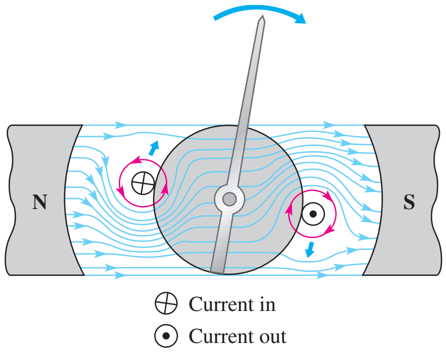
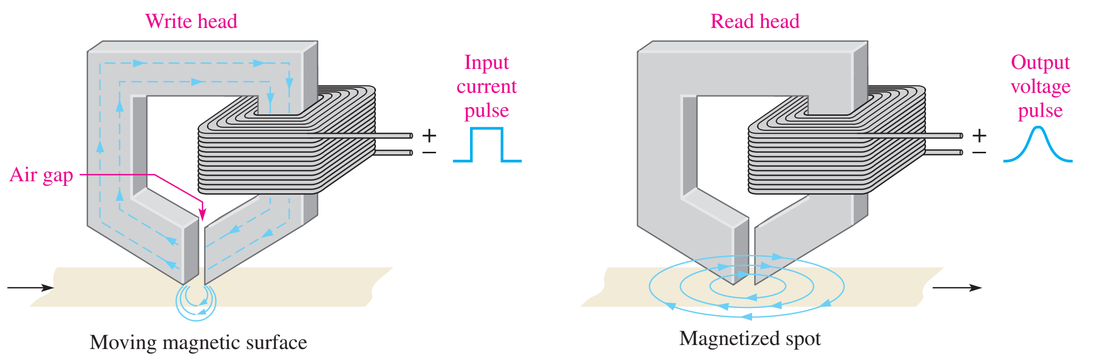



◀ FIGURE 24

When the electromagnetic field interacts with the permanent magnetic field, forces are exerted on the rotating coil assembly, causing it to move clockwise and thus deflecting the pointer.

## Magnetic Disk and Tape Read/Write Head

A simplified diagram of a magnetic disk or tape surface read/write operation is shown in Figure 25. A data bit (1 or 0) is written on the magnetic surface by the magnetization of a small segment of the surface as it moves by the write head. The direction of the magnetic flux lines is controlled by the direction of the current pulse in the winding, as shown in Figure 25(a) for the case of a positive pulse. At the air gap in the write head, the magnetic flux takes a path through the surface of the storage device. This magnetizes a small spot on the surface in the direction of the field. A magnetized spot of one polarity represents a binary 1, and one of the opposite polarity represents a binary 0. Once a spot on the surface is magnetized, it remains until written over with an opposite magnetic field.




(a) The magnetic flux from the write head follows the low reluctance path through the moving magnetic surface.

(b) When read head passes over magnetized spot, an induced voltage appears at the output.

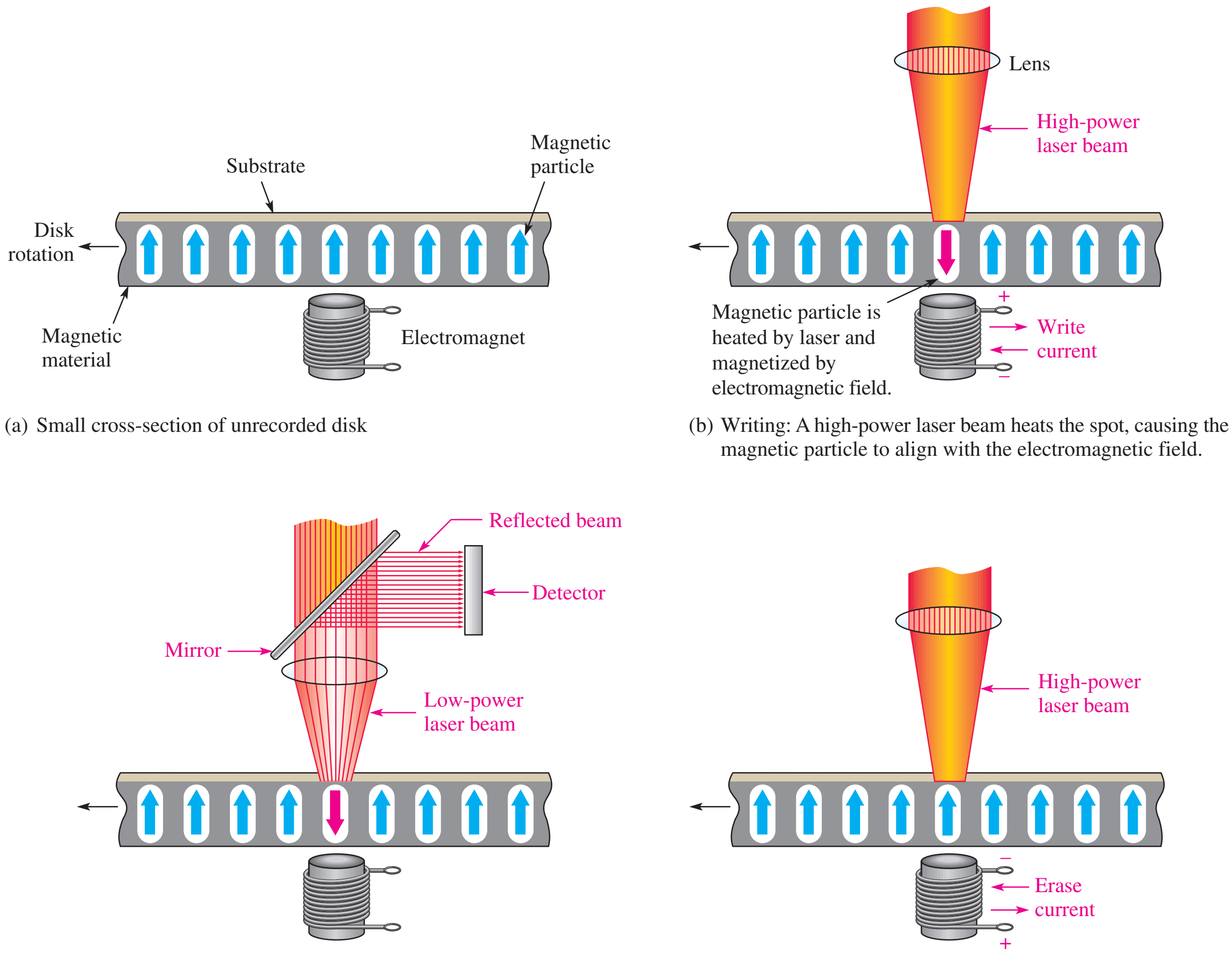
▲ FIGURE 25

Read/write function on a magnetic surface.

When the magnetic surface passes a read head, the magnetized spots produce magnetic fields in the read head, which induce voltage pulses in the winding. The polarity of these pulses depends on the direction of the magnetized spot and indicates whether the stored bit is a 1 or a 0. This process is illustrated in Figure 25(b). Often the read and write heads are combined into a single unit.

## The Magneto-Optical Disk

The magneto-optical disk uses an electromagnet and laser beams to read and write (record) data on a magnetic surface. Magneto-optical disks are formatted in tracks and sectors similar to magnetic floppy disks and hard disks. However, because of the ability of a laser beam to be precisely directed to an extremely small spot, magneto-optical disks are capable of storing much more data than standard magnetic hard disks.




(a) Small cross-section of unrecorded disk

(b) Writing: A high-power laser beam heats the spot, causing the magnetic particle to align with the electromagnetic field.

(c) Reading: A low-power laser beam reflects off of the reversed-polarity magnetic particle and its polarization shifts. If the particle is not reversed, the polarization of the reflected beam is unchanged.

(d) Erasing: The electromagnetic field is reversed as the high-power laser beam heats the spot, causing the magnetic particle to be restored to the original polarity.

▲ FIGURE 26

**Basic concept of the magneto-optical disk.**

Figure 26(a) illustrates a small cross-sectional area of a disk before recording, with an electromagnet positioned below it. Tiny magnetic particles, represented by the arrows, are all magnetized in the same direction.

Writing (recording) on the disk is accomplished by applying an external magnetic field opposite to the direction of the magnetic particles as indicated in Figure 26(b) and then directing a high-power laser beam to heat the disk at a precise spot where a binary 1 is to be stored. The disk material, a magneto-optic alloy, is highly resistant to magnetization at room temperature; but at the spot where the laser beam heats the material, the inherent direction of magnetism is reversed by the external magnetic field produced by the electromagnet. At points where binary 0s are to be stored, the laser beam is not applied and the inherent upward direction of the magnetic particle remains.

As illustrated in Figure 26(c), reading data from the disk is accomplished by turning off the external magnetic field and directing a low-power laser beam at a spot where a bit is to be read. Basically, if a binary 1 is stored at the spot (reversed magnetization), the low-power laser beam is reflected and its polarization is shifted; but if a binary 0 is stored, the polarization of the reflected laser beam is unchanged. A detector senses the difference in the polarity of the reflected laser beam to determine if the bit being read is a 1 or a 0.

Figure 26(d) shows that the disk is erased by restoring the original magnetic direction of each particle by reversing the external magnetic field and applying the high-power laser beam.

**SECTION 3 CHECKUP**

1. Explain the difference between a solenoid and a relay.
2. What is the movable part of a solenoid called?
3. What is the movable part of a relay called?
4. Upon what basic principle is the d'Arsonval meter movement based?

## 4 MAGNETIC HYSTERESIS

When a magnetizing force is applied to a material, the magnetic flux density in the material changes in a certain way.

After completing this section, you should be able to

- **Explain magnetic hysteresis**
  - State the formula for magnetic field intensity
  - Discuss a hysteresis curve
  - Define *retentivity*

### Magnetic Field Intensity ($H$)

The **magnetic field intensity** (also called *magnetizing force*) in a material is defined to be the magnetomotive force ($F_m$) per unit length ($l$) of the material, as expressed by the following equation. The unit of magnetic field intensity ($H$) is ampere-turns per meter (At/m).

$$H = \frac{F_m}{l}$$ **Equation 6**

where $F_m = NI$. Note that the magnetic field intensity ($H$) depends on the number of turns ($N$) of the coil of wire, the current ($I$) through the coil, and the length ($l$) of the material. It does not depend on the type of material.

Since $\phi = F_m/\mathcal{R}$, as $F_m$ increases, the flux increases. Also, the magnetic field intensity ($H$) increases. Recall that the flux density ($B$) is the flux per unit cross-sectional area ($B = \phi/A$), so $B$ is also proportional to $H$. The curve showing how these two quantities ($B$ and $H$) are related is called the $B$-$H$ curve, or the hysteresis curve. The parameters that influence both $B$ and $H$ are illustrated in Figure 27.

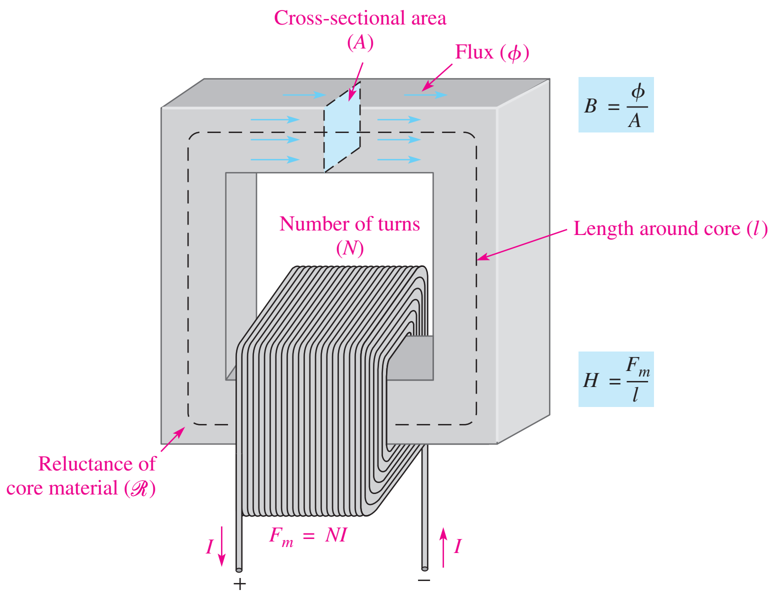
### The Hysteresis Curve and Retentivity

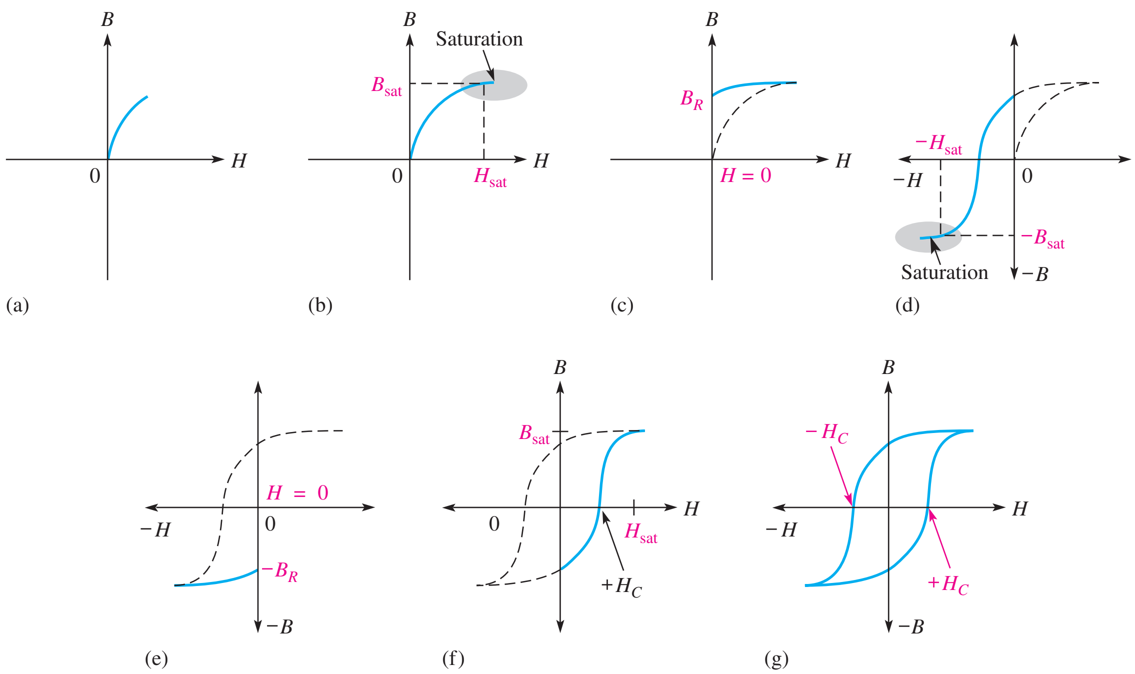
**Hysteresis** is a characteristic of a magnetic material whereby a change in magnetization lags the application of the magnetic field intensity. The magnetic field intensity ($H$) can be readily increased or decreased by varying the current through the coil of wire, and it can be reversed by reversing the voltage polarity across the coil.

Figure 28 illustrates the development of the hysteresis curve. Let's start by assuming a magnetic core is unmagnetized so that $B = 0$. As the magnetic field intensity ($H$) is increased from zero, the flux density ($B$) increases proportionally as indicated by the curve in Figure 28(a). When $H$ reaches a certain value, the value of $B$ begins to level off. As $H$ continues to

**▶ FIGURE 27**

Parameters that determine the magnetic field intensity (*H*) and the flux density (*B*).




**▲ FIGURE 28**

Development of a magnetic hysteresis (*B*-*H*) curve.

increase, $B$ reaches a saturation value ($B_{sat}$) when $H$ reaches a value ($H_{sat}$), as illustrated in Figure 28(b). Once saturation is reached, a further increase in $H$ will not increase $B$.

Now, if $H$ is decreased to zero, $B$ will fall back along a different path to a residual value ($B_R$), as shown in Figure 28(c). This indicates that the material continues to be magnetized even when the magnetic field intensity is removed ($H = 0$). The ability of a material, once magnetized, to maintain a magnetized state without magnetic field intensity is called **retentivity**. The retentivity of a material is indicated by the ratio of $B_R$ to $B_{sat}$.

Reversal of the magnetic field intensity is represented by negative values of $H$ on the curve and is achieved by reversing the current in the coil of wire. An increase in $H$ in the negative direction causes saturation to occur at a value ($-H_{sat}$) where the flux density is at its maximum negative value, as indicated in Figure 28(d).

When the magnetic field intensity is removed ($H = 0$), the flux density goes to its negative residual value ($-B_R$), as shown in Figure 28(e). From the $-B_R$ value, the flux density follows the curve indicated in part (f) back to its maximum positive value when the magnetic field intensity equals $H_{sat}$ in the positive direction.

The complete *B-H* curve is shown in Figure 28(g) and is called the *hysteresis curve.* The magnetic field intensity required to make the flux density zero is called the *coercive force, $H_C$*.

Materials with a low retentivity do not retain a magnetic field very well while those with high retentivities exhibit values of $B_R$ very close to the saturation value of $B$. Depending on the application, retentivity in a magnetic material can be an advantage or a disadvantage. In permanent magnets and memory cores, for example, high retentivity is required. In ac motors, retentivity is undesirable because the residual magnetic field must be overcome each time the current reverses, thus wasting energy.

**SECTION 4 CHECKUP**

1. For a given wirewound core, how does an increase in current through the coil affect the flux density?
2. Define *retentivity.*

## 5 ELECTROMAGNETIC INDUCTION

In this section, you are introduced to electromagnetic induction. Electromagnetic induction is what makes transformers, electrical generators, electrical motors, and many other devices possible.

After completing this section, you should be able to

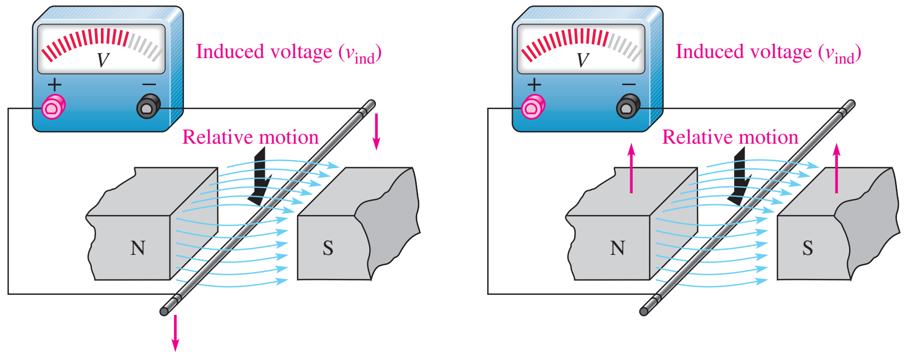
- **Discuss the principle of electromagnetic induction**
  - Explain how voltage is induced in a conductor in a magnetic field
  - Determine polarity of an induced voltage
  - Discuss forces on a conductor in a magnetic field
  - State Faraday's law
  - State Lenz's law
  - Explain how a crankshaft position sensor works

### Relative Motion

When a straight conductor is moved perpendicular to a magnetic field, there is a relative motion between the conductor and the magnetic field. Likewise, when a magnetic field is moved past a stationary conductor, there is also relative motion. In either case, this relative motion results in an **induced voltage ($v_{ind}$)** across the conductor, as Figure 29 indicates. This principle is known as **electromagnetic induction**. The lowercase $v$ stands for instantaneous voltage. The amount of the induced voltage depends on the rate at which the conductor and the magnetic field move with respect to each other: The faster the relative motion, the greater the induced voltage.

▶ **FIGURE 29**

Relative motion between a straight conductor and a magnetic field.

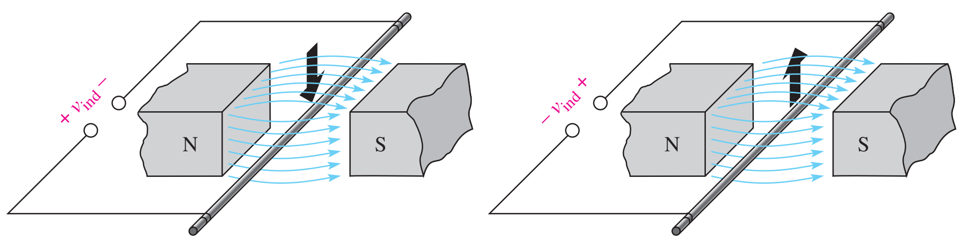



(a) Conductor moving downward

(b) Magnetic field moving upward

## Polarity of the Induced Voltage

If the conductor in Figure 29 is moved first one way and then another in the magnetic field, a reversal of the polarity of the induced voltage will be observed. When the relative motion of the conductor is downward, a voltage is induced with the polarity indicated in Figure 30(a). When the relative motion of the conductor is upward, the polarity is as indicated in part (b) of the figure.




(a) Downward relative motion

(b) Upward relative motion

▲ **FIGURE 30**

Polarity of induced voltage depends on direction of motion of the conductor relative to the magnetic field.

When a straight conductor moves perpendicular to a constant magnetic field, the induced voltage is given by

**Equation 7**

$$v_{ind} = B_{\perp} l v$$

where $v_{ind}$ is the induced voltage in volts, $B_{\perp}$ is the component of the magnetic flux density that is perpendicular to the moving conductor (in teslas), $l$ is the length of the conductor that is exposed to the magnetic field, and $v$ is the velocity of the conductor in m/s.

**EXAMPLE 7**

Assume the conductor in Figure 30 is 10 cm long and the pole face of the magnet is 5.0 cm wide. The flux density is 0.5 T, and the conductor is moved upward at a velocity of 0.8 m/s. What voltage is induced in the conductor?

*Solution* Although the conductor is 10 cm, only 5.0 cm (0.05 m) is in the magnetic field because of the size of the pole faces. Therefore,

$$v_{ind} = B_{\perp} l v = (0.5\text{ T})(0.05\text{ m})(0.8\text{ m/s}) = \mathbf{20\text{ mV}}$$

*Related Problem* What is the induced voltage if the velocity is doubled?