Lesson 1 - Section 1

Theory of Magnetism

To understand the magnetic behavior of materials, it is necessary to take a microscopic view of matter. A suitable starting point is the composition of the atom, which Bohr described as consisting of a heavy nucleus and a number of electrons moving around the nucleus in specific orbits. Closer investigation reveals that the atom of any substance experiences a torque when placed in a magnetic field; this is called a *magnetic moment.* The resultant magnetic moment of an atom depends upon three factors-the positive charge of the nucleus spinning on its axis, the negative charge of the electron spinning on its axis, and the effect of the electrons moving in their orbits. The magnetic moment of the spin and orbital motions of the electron far exceeds that of the spinning proton. However, this magnetic moment can be affected by the presence of an adjacent atom. Accordingly, if two hydrogen atoms are combined to form a hydrogen *molecule,* it is found that the electron spins, the proton spins, and the orbital motions of the electrons of each atom oppose each other so that a resultant magnetic moment of zero should be expected. Although this is almost the case, experiment reveals that the relative permeability of hydrogen is not equal to 1 but rather is very slightly less than unity. In other words, the molecular reaction is such that when hydrogen is the medium there is a slight decrease in the magnetic field compared with free space. This behavior occurs because there is a precessional motion of all rotating charges about the field direction, and the effect of this precession is to set up a field opposed to the applied field regardless of the direction of spin or orbital motion. Materials in which this behavior manifests itself are called *diamagnetic* for obvious reasons. Besides hydrogen, other materials possessing this characteristic are silver and copper.

Continuing further with the hydrogen molecule, let us assume next that it is made to lose an electron, thus yielding the hydrogen ion. Clearly, complete neutralization of the spin and orbital electron motions no longer takes place. In fact, when a magnetic field is applied, the ion is so oriented that its net magnetic moment aligns itself with the field, thereby causing a slight increase in flux density.This behavior is described as p*aramagnetism* and

is characteristic of such materials as aluminum and platinum. Paramagnetic materials have a relative permeability slightly in excess of unity.

So far we have considered those elements whose magnetic properties differ only very slightly from those of free space. As a matter of fact the vast majority of materials fall within this category. However, there is one class of materials-principally iron and its alloys with nickel, cobalt, and alumi- num-for which the relative permeability is very many times greater than that of free space. These materials are called *ferromagnetic* and are of great importance in electrical engineering. We may ask at this point why iron (and its alloys) is so very much more magnetic than other elements. Essentially, the answer is provided by the *domain* theory of magnetism. Like all metals, iron is crystalline in structure with the atoms arranged in a space lattice. However, domains are subcrystalline particles of varying sizes and shapes containing about 10 atoms in a volume of approximately cubic centimeters. *The distinguishing feature of the domain is that the magnetic moments of its constituent atoms are all aligned in the same direction* Thus in a ferromagnetic material, not only must there exist a magnetic moment due to a nonneutralized spin of an electron in an inner orbit, but also the resultant spin of all neighboring atoms in the domain must be parallel.

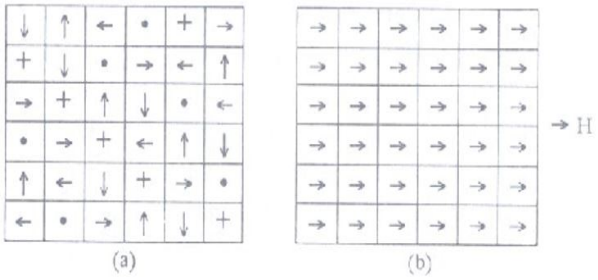

Figure 1-1. Presentation of a Ferromagnetic Crystal: (a) Unmagnetized and (b) Fully Magnetized by the Field *H*.

It would seem by the explanation so far that, if iron is composed of completely magnetized domains, then the iron should be in a state of complete magnetization throughout the body of material even without the application of a magnetizing force. Actually, this is not the case, because the domains act independently of each other, and for a specimen of unmagnetized iron these domains are aligned haphazardly in all directions so that the net magnetic moment is zero over the specimen. Figure 1-1 illustrates the situation diagrammatically in a simplified fashion. Because of the crystal

lattice structure of iron the 'easy' direction of domain alignment can take place in any one of six directions-left, right, up, down, out, or in-depending upon the direction of the applied magnetizing force. Figure l-l(a) shows the unmagnetized configuration. Figure l-l(b) depicts the result of applying a force from left to right of such magnitude as to effect alignment of all the domains. When this state is reached the iron is said to be *saturated-there* is no further increase in flux density over that of free space for further increases in magnetizing force.

Large increases in the temperature of a magnetized piece of iron bring about a decrease in its magnetizing capability. The temperature increase enforces the agitation existing between atoms until at a temperature of 750°C the agitation is so severe that it destroys the parallelism existing between the magnetic moments of the neighboring atoms of the domain and thereby causes it to lose its magnetic property. The temperature at which this occurs is called the *curie point.*

Part I. Comprehension Exercises

A. Put "T" for true and "F" for false statements. Justify your answers.

…….1. With his atomic theory, Bohr contributed to the understanding of the magnetic behavior of materials.

…….2. The atoms of a substance, if placed in a magnetic field, are subject to a torque.

…….3. Platinum is a diamagnetic material.

…….4. In ferromagnetic materials, the magnetic moments of large groups

…….5. In an unagnetized ferromagnetic material, the domains are aligned in different direction.

…….6. The magnetic properties of iron increase with an increase in temperature.

B. Choose a, b, c, or d which best completes each item.

1. Permeability of silver is less than unity ..... .
   a. because of its atoms setting up a field against the applied field
   b. because of its molecules rotating about the applied field
   c. due to the precessional spin of its positive charges
   d. due to the orbital motions of its negative charges

2. It is true that ..... .
   a. paramagnetic materials provide a small penetration of the magnetic field
   b. paramagnetic materials provide a great penetration of the magnetic field
   c. the resultant magnetic moment of an atom depends on its spinning axis
   d. the resultant magnetic moment o f an atom depends on the nucleus spinning on its axis
3. According to the text, ...
   a. two atoms of hydrogen, if combined, pronounce a permeability greater than 1
   b. two atoms of hydrogen, if combined, give rise to a high magnetic moment
   c. diamagnetic materials have magnetic properties more than those of free space
   d. diamagnetic materials have magnetic properties less than those of free space
4. Paramagnetism is based on the fact that the magnetic moment of a paramagnetic material, when placed in a magnetic field, ...
   a. results in a decrease in flux density
   b. lines up with the field
   c. is equal to 1
   d. is low compared with free space
5. The magnetic properties of diamagnetic and paramagnetic materials ..... those of free space.
   a. are greater than
   b. are smaller than
   c. differ slightly from
   d. differ greatly from
6. The abnormal magnetic properties of iron may be caused by ,..... .
   a. the magnetic moment resulting from an inner orbital spin of a nonneutralized electron
   b. the parallelism of the resultant spin of all neighboring atoms in the domain
   c. the domains oriented at random with their axes pointing in various directions
   d. both a and b

C. Answer the following questions orally.

1. What is called a magnetic moment?
2. What does the resultant magnetic moment of an atom depend on?
3. How do adjacent atoms affect the magnetic moment of each other?
4. How does the magnetic behavior of materials differ?
5. Why does platinum have the characteristic of paramagnetism?
6. What forms the domains in a ferromagnetic material?
7. What causes the alignment of the magnetic domains in iron?
8. What is called the curie point?

Part IL Language Practice

A. Choose a, b, c, or d which best completes each item.

1. Copper is ..... material, therefore, it exhibits a relative permeability slightly less than unity.
   a. a paramagnetic b. a diamagnetic
   c. a permeable d. a neutral
2. Iron provides a great penetration of the magnetic field, that is ,its ..... is many times greater than that of free space.
   a. magnetic flux b. atomic composition
   c. relative permeability d. magnetic moment
3. Elements and metals which have slight magnetic properties are called ..... materials.
   a. magnetic b. metallic
   c. diamagnetic d. paramagnetic
4. Iron and some of its alloys have an appreciable magnetic permeability. These materials are called ..... .
   a. ferromagnetic b. diamagnetic
   c. paramagnetic d. magnetic
5. The state of ..... is reached when all the magnetic domains are aligned in one direction.
   a. magnetization b. saturation
   c. flux density d. neutralization

B. Fill in the blanks with the appropriate form of the words given.

1. Magnet

a. Maxwell showed that some of the properties of ..... may be compared to a flow.

b. Lines of flux are conventionally said to leave a ..... material at the north pole and re-enter at the south pole,
c. If the ..... field is produced by a solenoid, we will have the same representation of lines of flux, but with the solenoid taking the place of a ..... .

2. Permeate

a. Relative .....is a pure number that is the same in all unit systems; the value and dimension of absolute .....depend upon the system of units employed.
b. A ..... is an apparatus used for determining corresponding values of magnetizing force and flux density in a test specimen.

3. Move

a. When a conductor is ..... through a magnetic field in such a way as to cut the magnetic lines, an emf is generated in the conductor.
b. A moving - conductor microphone is a microphone the electric output of which results from the ..... of a conductor in a magnetic field.
c. In a moving - conductor loudspeaker, the ..... conductor is in the form of a coil connected to the source of electric energy.

4. Rotate

a. The most important parts of a dc motor are the ....., the stator, and the brushgear .
b. A .....…converter combines both motor and generator action in one armature winding connected to both a commutator and slip rings, and is exited by one magnetic field.
c. A rotary generator is an alternating-current generator adapted to be ..... by a motor or prime mover.

5. Saturate

a. A magnetic-core reactor operating in the region of saturation without independent control means is known as ..... reactor.
b. A ..... sleeve is a flexible tubular product made from cotton and coated with an electrical insulating material.
c. Saturation induction is sometimes referred to as ..... flux density.

C. Fill in the blanks with the following words.

inductance	element	circuit	way
changing	treated	flux	it
discovered	current	from	

Inductance is a characteristic of magnetic fields, and it was first.....by

Faraday in his renowned experiments of 1831. In a general ..... inductance can be characterized as that property of a circuit ..... by which energy is capable of being stored in a magnetic ..... field. A significant and distinguishing feature of inductance, however, is that ..... makes itself fell in a circuit only when there is a/an .....current or flux. Thus, although a circuit element may have .....by virtue of its geometrical and magnetic properties, its presence in the ..... is not exhibited unless there is a time rate of change of ..... .This aspect of inductance is particularly stressed when we consider it ..... the circuit viewpoint. However, for the sake of completeness, inductance is also..... from an energy and a physical view.

D. Put the following sentences in the right order to form a paragraph. Write the corresponding letters in the boxes provided.

a. Trans formers are to be found in such varied applications as radio and television receivers and electrical power distribution circuits.
b. An understanding of electromagnetism is essential to the study of electrical engineering because it is the key to the operation of a great part of the electrical apparatus found in industry as well as the home.
c. Similarly, static transformers provide the means for converting energy from one electrical system to another through the medium of a magnetic field.
d. Other important devices-for example, circuit breakers, automatic switches, relays, and magnetic amplifiers-require the presence of a confined magnetic field for their proper operation.
e. All electric motors and generators, ranging in size from the fractional horsepower units found in home appliances to the 25,000-hp giants used in some industries, depend upon the electromagnetic field as the coupling device permitting interchange of energy between an electrical system and a mechanical system and vice versa.