Lesson 20 Magnetism

0 Introduction
a. The **lodestone**, which contains iron ore, was found more than 2000 years ago in the region of Magnesia in Greece.
b. In the 12th century, the Chinese used them for navigating ships.
c. In 18th century, French physicist Charles Coulomb studied the force between lodestones.
d. In 1820 Danish science professor, Hans Christian Oersted, discovered the relationship between the electricity and magnetism in a class demonstration.

1 Magnetic Poles
a. Magnets are similar to electric charges, for they can both attract and repel without touching, and their interaction depends on the distance of separation between the two magnets. Where as electric charges produce electric force, regions called **magnetic poles** produce magnetic forces.
b. If you suspend a bar magnet from its center by a string, it will act as a compass. The end that points northward is called the **north-seeking pole (north pole)**, and the end that points south is call the **south-seeking pole (south pole)**.
c. All magnets have north and south poles at the two ends. Unlike the electric charges which can be isolated as negatively charged electrons or positively charged protons, the north and south poles of a magnet can never be separated from each other. Even if you break the magnet in half, each half still behaves like a complete magnet.
d. **Like poles repels; opposite poles attract.**

2 Magnetic Fields
a. The space around the magnet is filled with a **magnetic field**. The shape of the field is revealed by **magnetic field lines**. The magnetic field lines spread from the north pole, curve around the magnet, and return to the south pole. Where the lines are closer (at the poles), the field strength is stronger.
b. If we place another magnetic or small compass anywhere in the field, its poles will tend to line up with the field.

3 The Nature of a Magnetic Field
a. Just as electric charge is surrounded by an electric filed, the same charge is surrounded by a magnetic field if it is moving. Magnetism is due to the distortions in the electric field caused by motion, and was explained by Albert Einstein in his theory of special relativity. A magnetic field is a relativistic by-product of the electric field.
b. Although the magnet as a whole may be stationary, it is composed of atoms whose electrons are in constant motion about atomic nuclei. This moving charge constitutes a tiny current and produces a magnetic field. More important, electrons spinning about their own axes constitute a charge in motion and thus creates another magnetic field. In most materials, the field due to spinning predominates over the field due to orbital motion.
c. Every spinning electron is a tiny magnet. A pair of electrons spinning in the same direction makes up a stronger magnet. A pair of electrons spinning in opposite directions work against each other. Their magnetic fields cancel. This is why most of the materials are not magnets.
d. In materials such as iron, nickel, and cobalt, the fields do not cancel one another entirely. Each iron atom, then, is a tiny magnet.

4 Magnetic Domains
a. The magnetic field of individual iron atoms are so strong that interactions among adjacent iron atoms cause large clusters of them to line up with one another. These cluster of aligned atoms are called magnetic domains. Each domain is perfectly magnetized, and is made up of billions of aligned atoms. There are many of them in a crystal iron.
b. The difference between a piece of ordinary iron and an iron magnet is the alignment of domains.

c. When a strong magnet is brought nearby an iron nail, whose domains are randomly oriented, two effects take place.
   i) A growth in the size of the domains that is oriented in the direction of the magnetic field. The growth is at the expanse of domains that are not aligned.
   ii) A rotation of domains as they are brought into alignment.

d. When we remove the magnet, the thermal motion causes the most or all of the domains in the nail return to random arrangement.

e. Permanent magnets are made by simply placing pieces of iron or certain iron alloys in strong magnetic fields. Soft iron is easier to magnetize than steel. Another way of making a permanent magnet is to stroke a piece of iron with a magnet. The stroking motion aligns the domain in the iron. If a permanent magnet is dropped or heated, some of the domains are jostled out of arrangement and the magnet becomes weaker.

5 Electric Currents and Magnetic Fields

a. A moving electron produces a magnetic field. Electric current also produces magnetic field. A current-carrying conductor is surrounded by a magnetic field whose direction can be decided by the right-hand rule. If you grasp a long current-carrying wire with your right hand, and holding your thumb pointing to the direction of the current, then your fingers would curl around the wire in the direction of the magnetic field (from N to S).

b. If the wire is bent into a loop, the magnetic lines become bunched inside the loop. The magnetic field intensity in this region is increased as the number of loops increased. A current-carrying coil of wire with many loops is an electromagnet.

c. Sometimes a piece of iron is placed inside the coil of an electromagnet. The magnetic domains in the iron will be induced into alignment and enhance the magnetic field intensity. Beyond certain limit, the magnetic field in iron saturates, so iron is not used in the strongest superconducting electromagnets.

6 Magnetic Forces on Moving Charged Particles

a. When a charged particle moves in a magnetic field, it will experience a deflecting force \( F \).
   \[
   F = qVB,
   \]
   \( q \) is the electric charge,
   \( v \) is the component of velocity perpendicular to the field
   \( B \) is the magnetic field strength

b. The direction of the force can be decided by the Fleming’s left hand motor rule: If you point your left forefinger in the direction of the magnetic field, and your second finger in the direction of the current flow, then your thumb will point naturally in the direction of the resulting force.

c. This sideway-deflecting force is employed to spread the electron onto the screen of CRT in your TV.

d. Also, this force is working in a larger scale. Earth’s magnetic field will deflect the charged particles from outer space to reduce the cosmic rays striking Earth’s surface.

7 Magnetic Force on Current-Carrying Wires

a. The current-carrying wire will experience the same force as the charged particles. The Fleming’s left hand motor rule will be used to decide the direction of the force.

b. If the direction of the current in the wire is reversed, the deflecting force acts in the opposite direction.

c. The force is maximum when the current is perpendicular to the magnetic field lines.
d. The current-carrying wire deflects a magnetic compass and a magnet deflects a current-carrying wire are different effect of the same phenomena.

8 Meters to Motors

a. A sensitive current-indicating instrument is called a **galvanometer**. The coil is mounted for movement and the magnet is held stationary. The coil turns against a spring, so the greater the current in the loops, the greater its deflection.

b. A galvanometer may be calibrated to measure current, in which case it is called an **ammeter**. When a galvanometer is calibrated to measure electric potential, it is called a **voltmeter**.

c. The design of a galvanometer and a motor is similar. The major difference is that the current is made to change direction every time the coil makes a half revolution. It overshoots just in time for the current to reverse. So, it is forced to make another half revolution, and so on in cyclic rotation.

d. In a motor, the current in the upper and lower sides of the loop is in opposite direction. The current is reversed during each half revolution by means of stationary contacts on the shaft. The parts of the wire that brush against these contacts are called brushes. The forces in the upper and lower regions do not change directions as the loop rotates.

e. Larger motors, the magnet is replaced with electromagnet and many loops of the wire are wound about an iron cylinder called **armature**.

9 Earth’s Magnetic Field

a. Earth itself is a huge magnet. The magnetic poles of Earth do not coincide with the geographic North pole. That is, the compass does not point to the true north. The discrepancy between the orientation of compass and the true north is called **magnetic declination**.

b. Why Earth itself is a magnet? The reason is not exactly known. There are some possible theories:
   
   i) The moving charges looping around within Earth creates its magnetic field.
   
   ii) Convection currents in the molten parts of Earth’s interior may produce Earth’s magnetic field.

c. Based on the analysis of rock strata, the magnetic filed of Earth is not stable. It has changed throughout geologic time. There have been times when magnetic field of Earth diminished to zero and then reverse itself.