7.1 MAGNETS

7.1.1 Natural Magnets

Magnets are ubiquitous now a days. They are found all around us, in toys, hangers, lifts, door bells, computers, just to name a few items where you can find magnets. Magnets have been around for a long time. Ancient Greeks knew about a rare mineral called **lodestones** found near the city of Magnesia in Asia Minor (present day Turkey) that had a strange power of attracting iron.

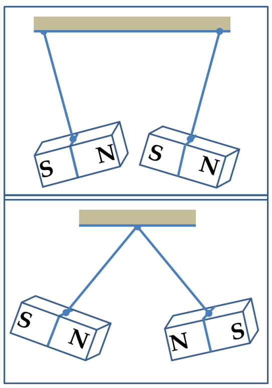

Figure 7.1: Existence of two types of poles of magnets demonstrated by labeling ends and observing attraction between unlike-type ends and repulsion between like-type ends.

Around 1100 AD Chinese discovered that when lodestone placed or iron magnets were placed in floating containers on water, the magnetic pieces always pointed in the North-South direction. This led to the development of **magnetic compass**. The discovery of magnetic compass in China quickly reached Arabs and from there to the Europeans.

Despite its use in navigation, the strange property of magnetism behind the compass remained a mystery until William Gilbert (1544-1603) in England demonstrated with his experiments on a terrella, a spherically shaped magnet, that Earth was actually a giant magnet and magnetic compass responded to Earth's magnetism. Gilbert published his findings in the seminal publication on magnetism called De Magnete in 1600.

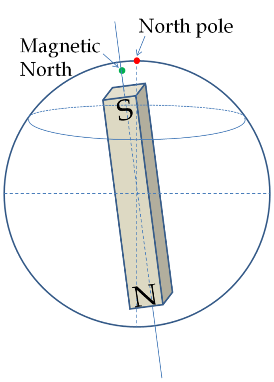

Figure 7.2: Earth as a giant magnet. The South Pole of this magnet is pointed towards Magnetic North Pole, the point on Earth towards a magnetic needle on Earth points.

Uniformly magnetized magnets are polarized in the sense that if one end of a magnet is attracted to one end of another magnet, the other end of the first magnet is then repelled by this same end of the second magnet. This can be demonstrated by marking the ends of two magnets and hanging them from a support as shown in Fig. 7.1. We identify the ends that are attracted as opposite poles.

When magnets are hung from a support so that they can rotate freely about the vertical axis or placed in a fluid so that they can float freely, one of the like-ends of all magnets point towards North pole of Earth. Actually, they point towards a point near the Geographic North Pole, which is called Magnetic North Pole. We mark the end of a magnet that points towards the **Magnetic North Pole**, the North Pole of the magnet. Because opposite poles of magnets attract, we deduce that the Earth as a magnet has its South pole near the Geographic North Pole at the Magnetic North Pole (Fig. 7.2).

The angle between the "magnetic North of compass" at a place and the true geographic North pole of Earth is called declination. Magnetic declination depends on the location on earth. A declination map of Earth is a very useful guide in navigation.

The magnetic south pole of the Earth presently points towards the geographic North pole of the Earth which is defined by the axis of rotation of the Earth. The direction of the magnetism of the Earth has been known to change with time due to the internal magnetohydrodynamics of the molten core of the Earth. There is considerable geological evidence that shows that the magnetic poles of the Earth has actually faced 180° backward from the current direction. That would mean that the magnetic south pole of the Earth was pointed towards the geometric South pole in the past and similarly for the magnetic north pole. The reversals in Earth's magnetic poles come at irregular intervals, averaging about 300,000 years. The last time the reversal happened was 780,000 years ago. NASA scientists in USA keep track of the movement of magnetic North pole, which has been moving between 10 km and 40 km every year in the direction of northwest.

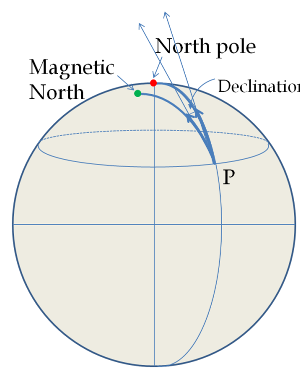

Figure 7.3: Magnetic declination at a place on Earth is the angle between the Geographic North Pole and the Magnetic North towards which a compass points.

7.1.2 Permanent and Temporary Magnets

Magnets come in two varieties - **permanent magnets** and **temporary magnets**. Permanent magnets are magnetized materials that have magnetism already built into them and whose magnetism is not easily destroyed. They apply forces on each other and also on some other materials called magnetizable materials.

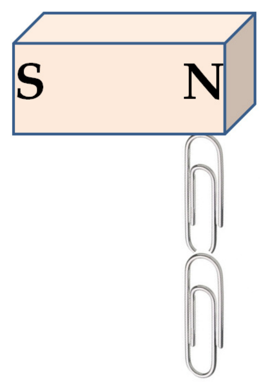

Figure 7.4: Paper-clip made of steel in the middle is temporarily magnetized and attracts another paper clip made of steel.

Temporary magnets are either materials that become magnetized when they are near other magnets. For instance, a paper clip hanging from a magnet attracts other paper clips as illustrated in Fig. 7.4. The first paper clip is an example of a temporary magnet.

Magnetizable materials, such as iron, cobalt and nickel, can be converted into permanent magnets by leaving the material in the same orientation under the influence another magnet. You can also turn a magnetizable material into permanent magnet by stroking the material with a permanent magnet. For instance, place an unmagnetized iron bar on a table. Now, take a permanent magnet and rub the iron bar with the same pole of the magnet along the length of the iron bar in the same direction over and over again as indicated in Fig. 7.5. The iron bar will become permanently magnetized.

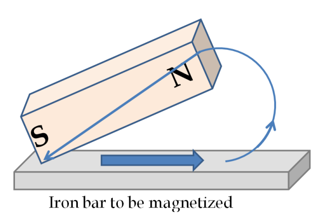

Figure 7.5: Magnetizing an iron bar by stroking with a permanent magnet.

Why do magnetizable materials become magnetized? You can trace the origin of magnetism in materials to the atomic level. Many atoms are tiny magnets themselves. In many materials, called ferromagnets or ferrimagnets, atomic magnets interact with each other such that they tend to align each other's poles. The tendency of alignment and randomization of thermal motion produces domains where atomic magnets are aligned in one direction or another as shown in Fig. 7.6. When the domains are small and randomly oriented, the piece of material does not act as a permanent magnet. However, when the material with atomic magnets is placed near a magnet, say near the South Pole of a permanent magnet, then the force of the external magnet tends to preferentially align the atomic magnets so that North Pole of the atomic magnet faces the South Pole of the external magnet. This leads to growth of **domains** that are aligned with the external magnet and large domains form that are oriented more or less in the direction of the external Poles.

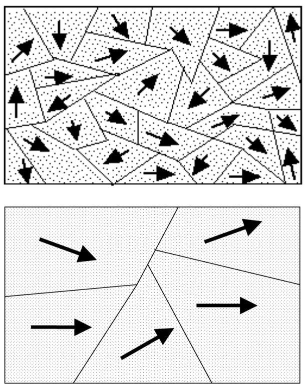

Figure 7.6: A magnetic material consists of domains of aligned magnetic domains. In an unmagnetized sample, the magnets are oriented in random directions. With magnetization, the sizes of the domains increases and they become more aligned.

7.1.3 Electromagnets

In April of 1820 Hans Christian Øersted of the University of Copenhagen (Denmark) made a remarkable discovery by accident that united the subjects of electricity and magnetism. While performing physics demonstrations for students Øersted noticed that, whenever he turned on the current in the wire, a magnetic needle placed nearby also reacted to the current (see Fig. 7.7).

For the next three months Øersted conducted several experiments to understand this new phenomena better and published his findings in leading scientific journals in the summer of 1820.

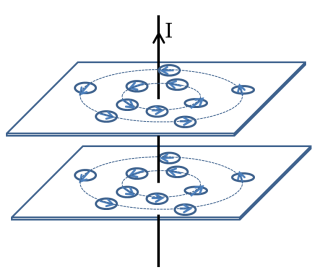

Figure 7.7: The magnetism of a straight-wire carrying a current. The small magnetic needles align around the the current.

In the same year after Øersted's discovery Andre-Marie Ampere in France postulated that if a current carrying wire exerted a magnetic force on the magnetic needle, then two such wires should also exert magnetic force on each other. Ampere conducted experiments and found that two parallel wires carrying current in the same direction attracted each other but if they carried current in opposite directions they repelled. Ampere found that the force between currents was proportional to current in the wire and inversely proportional to the distance between the wires.

Within 10 years of Øersted's discovery, Michael Faraday found that the relative motion of a magnet and a metallic wire induced current in the wire. This showed that, not only a current has a magnetic effect, but a magnet can also generate electric current. We will study Faraday's law in detail in a later chapter.

An electromagnet makes use of the magnetism of moving charges in current carrying wires. The wire carrying a current is wound in loops so that magnetic effect of each loop of current add together to enhance the effect. The magnetic effect of electromagnets can be demonstrated by bringing a permanent magnet near the electromagnet as shown in Fig. 7.8. The electromagnet acts just like a bar magnet with two poles since it attracts the North pole of the suspended permanent magnet when the current is one direction and repels the magnet when the orientation of the current is reversed. Electromagnet is an example of a temporary magnet that acts as a magnet when current through the material is on and as a non-magnet when the current is off.

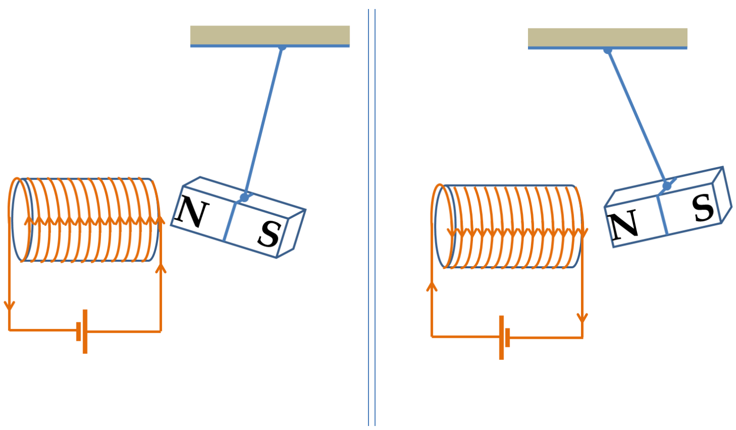

Figure 7.8: Current acts as magnet. When a current flows through a wire, the wire exerts a magnetic force on a magnet. The magnetic force between current carrying wire is attractive if the current flows in one direction and repulsive when the current flows in the opposite direction.

To further enhance the magnetism of an electromagnet, the wire is wound on a magnetizable material. The magnetism of the current then aligns the domains in the material which contributes to the magnetism of the current alone increasing the power of the electromagnet. By placing magnetizable materials in the space of the coils, a material can be made into a permanent magnet if large enough current is delivered for sufficient time to align a significant number of the magnetic domains of the material. This is a preferred method of making new permanent magnets than by stroking the material.