CHAPTER 25

Magnetism and Electromagnetism

25.1 INTRODUCTION

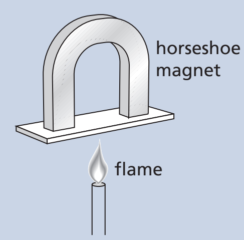
In 1269 a French scholar, Pelerin de Maricourt, also known by his Latin name of Petrus Peregrinus de Maricourt, was taking part in the battle siege of an Italian city. As the action was very slow and dull he wrote a letter to a friend describing his study of magnets. In this letter he described the existence of magnetic poles, regions on the magnets where the force seemed to be most intense, and explained how to determine the north and south pole of magnets, using the fact that the same poles always repelled. He also described how one could not isolate a single pole, for if a magnet were broken in two then each piece would have both a north and a south pole. In the same letter Peregrinus explained that a compass would work better if the magnetic sliver were placed onto a pivot rather than being floated on a cork, and that a graduated scale placed under the sliver would allow more accurate directions to be read. He had described a navigation compass.

Just like Peregrinus way back then, everybody today is fascinated by magnets. In this chapter we will look at the theory and applications of basic magnetism and electromagnetism. These topics were among the earliest scientific investigations and have proven to be extremely valuable areas of research. Some common questions often asked include these:

- Why do compass needles always point north? Have they always done this?
- Why do older recorded tapes always sound worse than brand new ones?
- How do long-distance migrating birds always find their way home?
- Are all metals attracted to magnets or just steel?
- How is it that electric motors are getting smaller but are still getting more powerful?
- Will I lose data from my computer floppy disks if I store them incorrectly?
- Do magnets in pillows and in wristbands really relieve pain and stress?
- Why would you feed a cow a magnet?

NOVEL CHALLENGE

If you heat an iron bar attached to a magnet as shown, at a particular temperature (Curie temperature) the bar falls off. *Why might this be?*

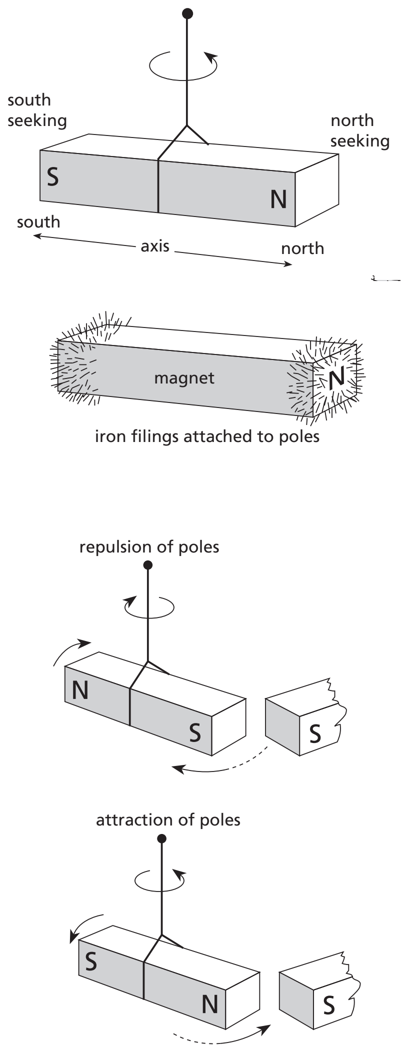


25.2 MAGNETS AND MAGNETIC MATERIALS

Magnetic materials

Magnetic substances are those that can be magnetised. The elements iron (Fe), cobalt (Co) and nickel (Ni), together with certain alloys, display the strongest magnetic properties. Pieces of magnetic mineral ore such as **magnetite** (Fe_3O_4) were probably the earliest magnets discovered and used. In historical times it was recorded that some rocks from a region of Magnesia, now called Turkey, were attracted to each other. These rocks were called magnets. The Chinese used **lodestones** cast in the form of spoons for divination and text from their Han dynasty of about 250 BC describes a south-pointing spoon. In 113 BC details were given on how chess pieces could be made to fight automatically using the lodestone. The term 'lode' seems to refer to the lodestar or guiding star, which refers to how the stone was used in navigation and divination in early Chinese history.

Figure 25.1(a)
Magnetic poles.



Historically, the magnetic phenomenon was regarded as magical, but today we recognise that such forces are due to the fundamental natural force of magnetism. It was in the nineteenth century that it became clear that both electricity and magnetism were related as fundamental forces of nature.

One of the main properties of magnets is their ability to attract objects, chiefly those made of iron. Several naturally occurring minerals are magnetic. Any material able to keep its magnetic properties for a long time is called a **permanent magnet**. The English scientist Michael Faraday showed with sensitive apparatus that, in fact, all substances are influenced by magnets. He classified substances into three types.

- **Diamagnetic** substances, which are very weakly repelled by magnets. This class, in fact, includes most substances. Examples of diamagnetic materials include glass and the metals copper, gold, and bismuth.
- **Paramagnetic** substances, which are very weakly attracted by magnets. Examples include the metals manganese, aluminium and platinum.
- **Ferromagnetic** substances, which are very strongly attracted to magnets. Iron, nickel and cobalt, together with alloys of these metals and aluminium, are the best examples. The majority of small permanent bar magnets used at school are called ALNICO magnets. Can you work out how the name is derived? Ferromagnetic comes from the Latin *ferrum*, meaning 'iron'.

If any magnet is freely suspended by a thread, as shown in Figure 25.1**(a)**, then it will always orient itself so that one of its ends points to the Earth's north pole and one points to the Earth's south pole. Also, as shown in Figure 25.1, if a magnet has small iron filings sprinkled over it then they tend to congregate at both ends where the degree of attraction is strongest.

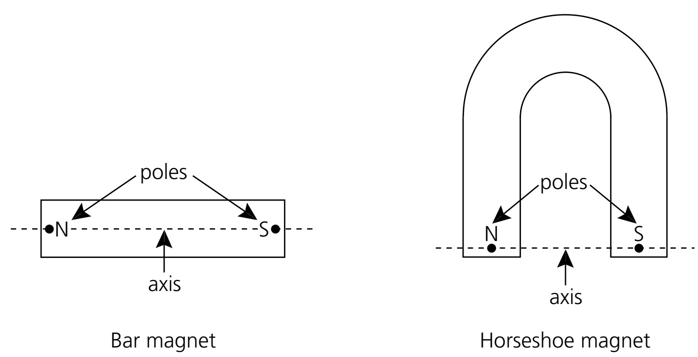
Simple tests between two separate magnets always lead to one of two results — the ends are either attracted together or repelled apart. This is also represented in Figure 25.1. The forces attracting the iron filings or repelling opposite ends of the magnets seem to be strongest at the **magnetic poles** of any magnet. The pole that points north is called the north-seeking pole and is by convention labelled as N, while the pole that points south is called the south-seeking pole and is labelled S. The term north comes from the Italian *nertro*, meaning 'left' because north is to the left when one is facing the rising sun. The line through the poles of a magnet is called the **magnetic axis**. A simple statement of the law of magnetic poles is:

Unlike poles attract while like poles repel.

As seen in Figure 25.1**(b)**, the magnetic axis of a bar magnet passes through the magnetic material itself, whereas in a horseshoe magnet, the bar is bent into a U-shape so that the magnetic axis passes across the gap created between the poles.

The development of magnetic materials has been progressing at a rapid rate since the simplest ferrous magnetics and ALNICO-type alloys of the early twentieth century. Most recently, the development of **rare earth magnets** has occurred, with world leadership roles being taken in research by Australian scientists. In 1992, for example, one of the world's most powerful magnet facilities was opened in Sydney, called the National Pulsed Magnet Laboratory. This facility is used in developing high-tech electronic devices on a sub-atomic level including quantum wires, dots and switches. It houses enormously powerful supercooled magnets capable of producing fields up to a million times stronger than the Earth's magnetism.

Figure 25.1(b)
Magnetic axes.



Rare earth magnets have been produced since about the 1980s, but only recently have become relatively inexpensive to manufacture. The term 'rare earth' is used because they are made from alloys of the rare earth elements or lanthanides. They are mostly made from the alloy **neodymium iron boride** (NdFeB) by a sintering process, meaning they are formed with intense heat and pressure. The element neodymium is found in the mineral sands component called monazite, which is mined in various coastal locations around Australia — a good reason for the environmentally sensitive process of mineral sands mining. After being moulded into various shapes the magnets are coated in zinc to protect against corrosion as the material is highly susceptible to oxidation. One of the big advantages of rare earth permanent magnets over ALNICO alloys is that they retain their full magnetic strength almost indefinitely. The magnetic material, however, will begin to lose magnetisation at high temperatures so these have to be avoided, but their performance is enhanced at very low temperatures. The rare earth super magnets, as they are dubbed, are revolutionising the magnet applications industry. Because rare earth magnets contain much stronger magnetism in smaller volumes of alloy, they are being used in components such as mini hi-fi speakers, mini electric motors and generators, robotics instrumentation, wrist-watches and hearing-aids. In fact, new technology applications are being developed continually. It has been estimated that up to 30 fundamental components in the modern electronically controlled motor vehicle alone will benefit from the use of very small rare earth magnet technology.

NEI Activity 25.1 MAGNETIC MOVES

1. Figure 25.1**(a)** illustrates a magnet sprinkled with iron filings. If you actually did this your teacher would not be pleased — explain why this might be so! Use a magnet placed on the viewing glass of an overhead projector. Place another thin glass plate on top of it and a piece of clear acetate plastic on top of this. Now you can sprinkle iron filings over the magnet, but on to the acetate sheet. Give the sheet a gentle tap and observe the pattern of iron filings produced. Try to explain this to the rest of the class.
2. The *Guinness Book of Records* lists the world's largest magnet and electromagnet. Research these and find out their characteristics as well as what they are used for. In what field of physics–engineering are very large magnets required?

Inducing magnets

If a piece of iron or steel, such as a paper clip, is allowed to come into contact with one of the poles of a permanent magnet then it also will become magnetised and attract iron filings, as shown in Figure 25.2. The paperclip will remain a magnet while in contact with the bar magnet, but once separated will probably lose most of its magnetic attraction properties again. The paperclip has become an **induced magnet**, as opposed to a permanent magnet. Pure iron, or 'soft' iron as it is called, becomes quite a strong induced magnet while in contact with another magnet. The **induced poles** are oriented as shown in Figure 25.2 and this is most easily tested with a third magnet whose poles are marked in some way, using the observed forces of repulsion or attraction.

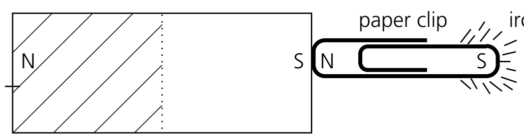
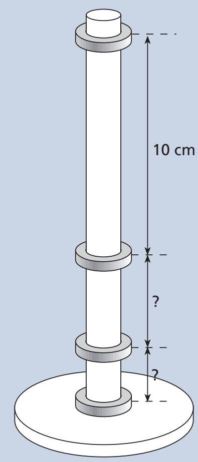


Figure 25.2
Induced magnetism.

NOVEL CHALLENGE

Four ring magnets are placed on a wooden pole as shown.
If the distance between the top two is 10 cm, calculate the other spacings?



PHYSICS UPDATE

In May 1997, using a Ni/Sn coil, scientists at Lawrence Berkeley National Laboratory in California achieved the highest ever magnetic field of 13.5 T. That's big!

Superconducting magnets have become an important tool in the application of nuclear magnetic resonance (NMR) for materials and medical research, especially magnetic resonance imaging (MRI). With increasing magnetic field strengths, scientists are able to view materials with higher clarity and resolution. The National High Magnetic Field Laboratory (NHMFL) in the USA is working on building the largest NMR magnet in the world, capable of field strengths of 25 T. Now that's even bigger!