Magnetism and magnetic surveys

Magnetised needles have been used to aid navigation for more than a thousand years. The use of magnetic compasses seems to have originated in China in the eighth century and by the twelfth century both floating and pivoted compass needles were used in the West.

What is a magnet?

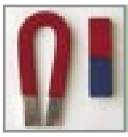


Fig.1 Bar magnet and a 'horseshoe magnet'

A magnet is usually made of iron or *steel*. Individual atoms of iron contain magnetic properties. In an unmagnetised piece of iron these tiny magnets are not all *aligned* in the same direction and therefore there is no net magnetic effect. However, when the iron is placed in a strong *magnetic field* the atoms tend to align in one direction. In a sufficiently strong magnetic field all the atoms point the same way. When this occurs the material cannot be magnetised further and is said to be magnetically *saturated*.

When the external magnetic field is removed some of the atoms may return to their previous *orientation* and the piece of iron loses some of its magnetism. Hard steel (e.g. a sewing needle) is not easily magnetised but it retains its magnetisation much better than soft iron (e.g. nails or pins).

A few other metals (notably nickel and cobalt) exhibit the same kind of magnetism as iron; they are said to be *ferromagnetic*. *Alnico* magnets, which were first produced in the 1930s, are alloys of aluminium, nickel, cobalt and iron mainly.

Ceramic magnets are made of compressed mixtures of iron oxide (Fe_2O_3) and barium or strontium oxide or carbonate (BaO, SrO, $BaCO_3$, $SrCO_3$). They can be manufactured in a variety of shapes and magnetic field orientations and are commonly used, for example, in *DC electric motors* and as 'fridge' magnets.

In recent decades stronger and more expensive magnets have been made from *alloys* of *samarium* or *neodymium* with cobalt and other elements.

Most metals are not ferromagnetic

Some people think that all metals are ferromagnetic; however this is not the case. Familiar examples of non-magnetic metals are aluminium, zinc, copper, brass (an alloy of copper and zinc), lead, silver and gold. Cupro-nickel coins are attracted by a magnet while brass or copper coins are not.

Properties of bar magnets

A bar magnet is one that is magnetised from end to end, and it therefore has two magnetic *poles*. If the magnet is free to rotate (on a thread, a pivot or a float) it acts as a compass – pointing approximately in a north-south direction. To be more precise, it points in the direction of the local *magnetic field*.

The end of the magnet that points roughly north is called the north pole of the magnet.

If a second magnet is brought near a suspended magnet it is found that like poles repel and unlike poles attract one another. A north pole of one magnet is attracted to the south pole of another magnet. The fact that the north pole of a suspended magnet swings towards the North implies that the 'North' geomagnetic pole must be the south pole of the Earth's magnetic field.

The direction of a magnetic field is the direction that a compass needle points, that is, from a north magnetic pole to a south magnetic pole.

The Earth's magnetic field

The Earth has its own magnetic field. Its position and strength change over time and it can even reverse direction; the last reversal occurred 780,000 years ago. The location of the poles changes by between 10 and 40 km a year. At present the 'North' geomagnetic pole is located about 83°N, 115°W and the 'South' pole is about 64°S and 138°E.

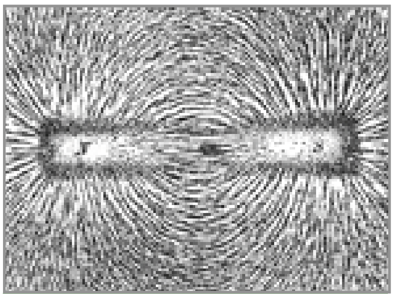


Fig. 2 Pattern produced by iron filings near a bar magnet.

Magnetic flux

If *iron filings* are sprinkled near a magnet, a pattern like that in Fig.2 is produced. Although nothing actually flows from the magnet, the concept of *magnetic flux* is used to describe these lines. The unit of magnetic flux is the *weber* (Wb, pronounced vay-ber). Nearer the poles of a magnet the lines are close together and we can say that the *magnetic flux density* is larger. The strength of a magnetic field (or the magnetic flux density) is measured in webers per square metre. One Wb/m^2 is also called a *tesla* (T).

Comparative values

The list below gives a sense of the magnetic field strength of various magnets

Earth	0.000030 to 0.000060 T (= 30 to 60 μT)
Lodestone	variable, less than 0.1T
Steel magnet	0.1 T
Alnico magnet	0.15 T
Ceramic magnet	0.15 T
Samarium-cobalt	1 T
Neodymium-iron-boron	1.25 T
'Superconducting electromagnets'	20 T

Electromagnetism

When there is an electric current in a coil of wire, the coil becomes a magnet. At the centre of the coil the magnetic field strength (B) is proportional to the electric current (I) and to the number of turns in the coil (N), and is inversely proportional to the radius (r): $B = \mu NI/2r$. The symbol μ represents the magnetic permeability of the material within of the coil.

The permeability of a vacuum, μ_0, has a value of $4\pi\times10^{-7}$ N A^{-2}; the value for a silicon steel it is about 6700 larger.

An air-cored coil of radius 5 mm, with 20 turns and a carrying a current of 1 A would have a maximum field strength of 0.0025 T or 2500 *µT* (microtesla). With a steel core it might be expected to be about 16 T (i.e. 0.0025 × 6700); however steel becomes *magnetically saturated* at about 1 T.

Generating electricity using magnetism.

If a wire is moved across a magnetic field – 'cutting' through magnetic field lines – an electric potential, or *voltage*, is generated between its ends. The faster it cuts the field the greater the voltage. If it cuts through 1 Wb per second then 1 volt is generated while the movement across the magnetic field continues. This phenomenon, which was discovered by Michael Faraday in 1831, is called *electromagnetic induction*.

Measuring variations in geomagnetism

Local magnetic fields result from the combined effect of the Earth's magnetic field and the magnetic field of underlying rock strata and of smaller deposits of magnetic material (usually magnetite). Various types of *magnetometer* have been developed so that magnetic variations can be monitored from fixed or mobile stations. Some measure the overall magnetic field strength at a location but cannot indicate the direction of the field; these are caller *scalar* magnetometers. Others measure both the strength and direction of the field along three axes (*vector* magnetometers).

The Geological Survey of Ireland (GSI)

The Geological Survey of Ireland carry out offshore surveys using a caesium marine magnetometer – a scalar instrument; when towed by a ship this is known as a 'fish'. Some of the results are shown in Fig. 4; the striping on the west (left hand side) is characteristic of magnetic field reversals.

Airborne magnetometers are used over land. These can be trailed behind the plane ('a bird') or fixed to the nose ('a stinger') as shown in Fig. 3. Some of the results are shown in Fig. 5. When interpreted with other geological data such as drill holes, geology, geochemical, geophysical, the data can be used when exploring for mineral or other deposits.

Fig. 3 Magnetometer attached to the front of a plane

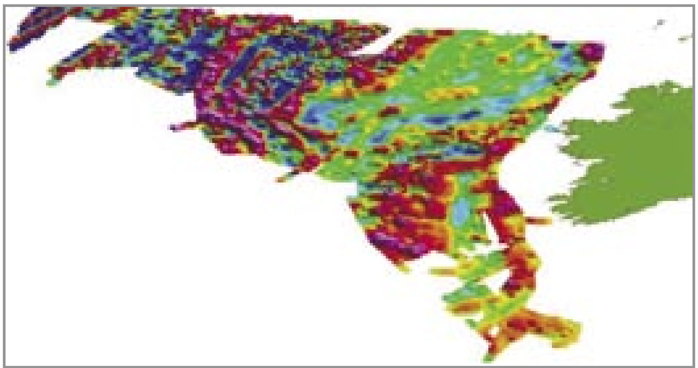


Fig. 4 Marine magnetometry results

The Geological Survey of Ireland (GSI), founded in 1845, is Ireland's **National Earth Science Organisation**. It is responsible for providing geological advice and information, and for the acquisition of data for this purpose. The GSI produces a range of products including maps, reports and databases and acts as a knowledge centre and project partner in all aspects of Irish geology. It functions as a line division of the **Department of Communications, Energy and Natural Resources (DCENR)** with an annual budget in excess of €7 million, and employs approximately 70 staff.

To meet GSI's goals to deliver information and advice to today's society the organisation operates with small teams in specific programme areas. Bedrock, quaternary and offshore mapping produce geological maps which are used by a range of professionals such as geologists, engineers and researchers. In addition these products are further enhanced by the GSI to produce, Groundwater Protection Schemes, Aggregate Potential Maps and Geological Heritage Sites. These works are commonly carried out with Local Authorities and are important planning tools aimed to protect our resources and develop them in a sustainable manner.

The GSI is involved in a large range of projects, these include investigating and cataloguing old mine workings, climate change and carbon sequestration, geological hazards mapping, airborne geophysical surveys and geotourism. A special programme of events is planned for 2008 which is designated by the UN General Assembly as IYPE (International Year of Planet Earth).

In addition the GSI is responsible for Griffith Geoscience Research Awards aimed at building research capacity in the area of Geosciences in Ireland.

For more information on the Geological Survey of Ireland please visit our site at **www.gsi.ie** or **www.sta.ie**

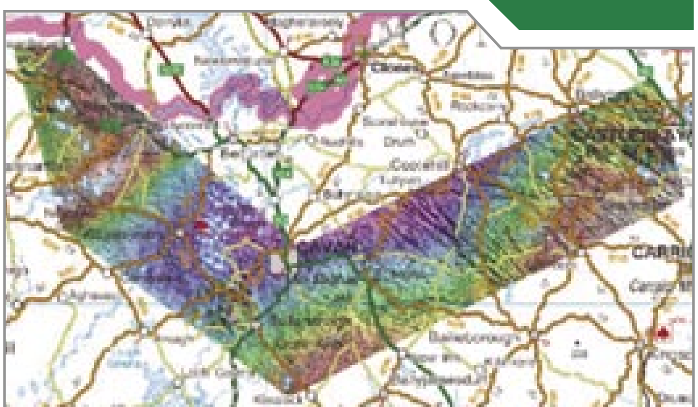


Fig. 5 Airborne magnetometry results

Magnetism and magnetic surveys

Syllabus Reference

Leaving Certificate – Electromagnetism

Magnetism; Magnetic fields; Current in a magnetic field; Electromagnetic induction

Junior Certificate Science

Unit 3C1 Magnetism; 3C2 Static electricity; 3C3 Current electricity and voltage; 3C4 Electric circuits; 3C5 Electricity in mains supply; 3C6 Electronics

Learning Outcomes

On completing this section, the student will be able to:

- Interpret the behaviour of ferromagnets and compasses
- Distinguish between magnetism and gravitation
- Describe what is meant by electromagnetic induction
- Appreciate that the Earth's magnetic field varies over time and from place to place
- Outline some methods used to measure the Earth's magnetism

General Learning Points

- Magnetic compasses can be used for navigation because the Earth has a magnetic field.
- Ordinary bar magnets have poles at each end; unlike poles attract and like poles repel.
- Today magnets can be manufactured with a great variety of magnetic field orientations, including numerous (20+) poles
- Iron, nickel and cobalt are the three main ferromagnetic metals. Most metals are not ferromagnetic
- There are other kinds of magnetism
- The variations in the Earth's magnetic field are measured using a magnetometer.
- An electric potential (voltage) can be generated between the ends of a conductor when it is moved across magnetic field lines.

Student Activity

1. Plotting the magnetic field variations of the classroom. This will require some large sheets of paper – a few square metres if possible and plotting compasses. Spread the paper on a clear area of the ground (classroom floor, hall, school yard); temporarily stick the sheets to the surface. (It is important to keep magnetic material away from the area being surveyed.) Mark points at regular intervals along one edge of the paper (e.g. the South edge). Place the tail of a compass over one of the dots and mark the position of the compass point; then move the compass tail to this dot and repeat until another edge is reached. Join the dots to form a line. This process should be repeated for each of the starting dots. Although the whole procedure is slow it reveals subtle variations in the magnetic field. You may be able to detect the presence of pipes etc. under the floor.
2. More interesting patterns can be obtained by placing a weak bar magnet in the middle of the plotting area; this should be held in place with adhesive. Different orientations of the magnet will give rise to different patterns. Otherwise follow the procedure outlined above.
3. Nickel alloy coins (copper-nickel or silver-nickel) are attracted by a magnet but silver, copper or brass coins are not. Examine a collection of coins (new and old if possible) and classify them by their appearance and magnetic properties.
4. Make a model of the Earth's magnetic field by embedding a bar magnet in a ball of plasticene (or within a globe). Indicate the position of the equator and some meridians. Using compasses investigate the direction of the magnetic field at various points on the surface. Where is the field horizontal (parallel to the surface)? Where is it vertical?
5. Place a neodymium magnet (e.g. 5 mm diameter) in the middle of a shallow dish such as a Petri dish. Add water until the magnet is just covered. Observe the reflections of a square grid or other regular pattern from the surface of the water. How is the water affected by the magnet?

   Refinements: Add a little detergent to the water. Blacken the top surface of the magnet. Cover the bottom of the dish with black paper to eliminate unwanted reflections.

True/False Questions

(a) Compasses were invented by Michael Faraday	**T F**
(b) Lodestone is a naturally occurring magnetic mineral	**T F**
(c) Atoms of iron are magnetic	**T F**
(d) In magnetised steel the atoms are randomly oriented	**T F**
(e) The end of a magnet that points North is called a magnetic field	**T F**
(f) Copper and brass are ferromagnetic	**T F**
(g) Electricity can be generated without a battery	**T F**
(h) The Earth's magnetic field strength is about 1 Wb/m2	**T F**
(i) The unit of magnetic flux density is the tesla	**T F**
(j) There is a limit to the magnetisation of a piece of steel	**T F**
(k) An instrument that measures magnetic fields is called an ammeter	**T F**
(l) Ceramic magnets are made of compressed mixtures of iron oxide with some other materials.	**T F**

Check your answers to these questions on www.sta.ie

Examination Questions

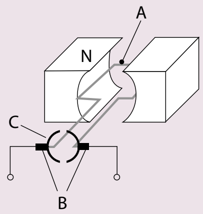
2002 Leaving Certificate Ordinary Level

Describe an experiment to demonstrate that a current-carrying conductor in a magnetic field experiences a force.

The force on a current-carrying conductor in a magnetic field is given by $F = IlB$.

The letter I stands for the current. What do the letters l and B stand for?

The diagram shows a motor.



Name the parts labelled A, B and C.

Explain why A turns when a current flows through it.

Give the function of the parts labelled B.

Give an everyday use of a motor.

Name another device that is based on the same principle as the motor.

For further examples of past paper questions check www.sta.ie

Did You Know?

There are other kinds of magnetism

Paramagnetism and diamagnetism are different from ferromagnetism. Paramagnetic substances are weakly attracted to strong magnetic fields; they include the elements barium, calcium, oxygen and uranium, and the compounds copper (II) sulfate, magnesium chloride and iron (III) chloride.

Diamagnetic substances are weakly repelled by strong magnetic fields; they include: water, most organic compounds, graphite and gold.

Historic developments

The electric battery was invented in by an Alessandro Volta (Italian) in 1800 and it quickly became the focus of much experimentation. In 1820 Hans Christian Ørsted (Danish) discovered that when a conductor carries an electric current a magnetic field forms around it. With the benefit of hindsight it seems surprising that it took twenty years for someone to make this discovery.

Eleven years later (1831) Michael Faraday (English) discovered what is called electromagnetic induction – the fact that a voltage is generated between the ends of a conductor that is moving across a magnetic field. Faraday's work led to the development of electric motors and generators. He also contributed significantly to electrochemistry and to the understanding of the nature of light.

Aurorae

The Sun has an eleven year cycle; this is characterised by a cyclical rise and fall in the number of sunspots. What appear to us as dark specks on the surface of the Sun are in fact gigantic eruptions in which thousands of millions of tonnes of matter (in the form of charged particles) are ejected from the Sun at typically about 500 km/s and sometimes more than 2000 km/s. If an ejection happens to be in our direction then when the charged particles arrive at the Earth (a few days later) they are largely deflected by the Earth's magnetic field. However some may be 'funnelled' in along the field lines towards the magnetic poles. The interaction of the charged particles and the molecules in the upper atmosphere often results in spectacular displays (aurora borealis and aurora australis).

Intense bursts of solar charged particles can occasionally induce damaging voltages in communications satellites and even in national electricity grids.

Biographical Notes

Wilhelm Eduard Weber (1804–1891)

Weber, along with his two brothers, showed an aptitude for science from an early age. On completing his schooling he attended University of Halle where he studied 'natural philosophy.' At the age of 22 he was awarded PhD for his study of reed organ pipes. He taught in Halle until 1831 when he was appointed professor of physics in Göttingen. He believed that if students wished to understand physics it was important that they carry out their own experiments.

Weber carried out much original research himself and contributed to the understanding of areas as diverse as music, acoustics, fluidity, anatomy and electromagnetism. He and C.F. Gauss constructed the first electromagnetic telegraph in 1833.

He pioneered the study of the geomagnetism and produced an Atlas of Geomagnetism. Together with Gauss he published Electrodynamic Proportional Measures in 1864; this laid the foundation for the electrical measurements that are still in use today.

Read more about other famous scientists at www.sta.ie

Revise The Terms

Can you recall the meaning of these terms? Reviewing the terminology is a powerful tool for recall and retention.

aligned; alloys; brass; DC electric motors; ferromagnetic; inversely proportional; iron filings; lodestone ; magnet; magnetic compasses; magnetic field; magnetic field lines; magnetic flux; magnetic flux density; magnetically saturated; magnetometer ; navigation; neodymium; orientation; samarium; scalar ; steel; superconducting magnets; tesla; vector; volt; voltage; weber.

Check the Glossary of Terms for this lesson at www.sta.ie