12.1 Magnetic Fields

Imagine reaching a speed of 431 km/h on your way to the airport. The Maglev train in Shanghai, China (**Figure 1**), can do just that. "Maglev" is short for magnetic levitation. Magnets are used to apply a force to the train to lift or "levitate" it against the force of gravity. The train is then able to float above the tracks, not making physical contact. This greatly reduces friction, so the train is able to travel at very high speeds. This technology would not have been possible without an understanding of magnetism and magnetic fields.

Figure 1 This train uses magnetic levitation to float above the tracks and avoid friction.

magnetic field a region of space around a magnet that causes a magnetic force on magnetic objects

What Are Fields?

You may have heard of force fields in science-fiction games, shows, or movies. These force fields are generally invisible areas that prevent a character from entering a place or prevent weapons from harming a person or a ship. These science-fiction force fields do not exist. However, force fields are all around us. A field is a region of space surrounding an object that can cause another object to experience a force. For example, a **magnetic field** is the three-dimensional region of space surrounding a magnet that will exert a force on magnetic objects. The magnetic field exists around the magnet whether the magnetic field is causing a force or not.

Earth has a magnetic field that exists both inside and surrounding it (**Figure 2**). Other types of fields also exist in nature. A gravitational field exists around Earth because of Earth's mass, and it causes objects with mass to be attracted toward Earth's centre. Electric fields surround charged particles such as protons and electrons. The electric fields cause charged particles to experience forces of attraction or repulsion. For example, an electron has an electric field around it that will cause a force of attraction to a positively charged particle. All fields have specific properties and point in specific directions, governing how objects are affected within those fields.

Figure 2 A magnetic force field exists both inside and surrounding Earth.

Magnetic Field Properties

There is a story about a shepherd named Magnes, who lived in the area of Magnesia, Greece, over 4000 years ago. He was surprised one day when he stepped on a rock and the iron nails in his sandals stuck to it. This type of rock came to be known as magnetite.

After more observations of magnetite, it was found that certain ends of pieces of magnetite would attract each other, while others would repel each other. This became more obvious if the magnetite was split into small slivers. When a magnetite sliver is suspended on a string, it orients itself with Earth's magnetic field. Since these slivers had two magnetic ends, they were labelled poles. This discovery led to the invention of the compass, a very useful navigational tool. The compass needle is a permanent magnet. The pole of a magnet that points toward Earth's north magnetic pole is labelled north. The other pole is labelled south. Unlike poles (north and south) attract each other, and like poles (north and north or south and south) repel each other. The force of repulsion or attraction increases as the magnets get closer to one another.

Since the north pole of the compass needle points north, it means that Earth's north pole must actually be a south magnetic pole. Similarly, Earth's south pole must actually be a north magnetic pole. In fact, Earth's magnetic poles have actually flipped directions in the past. Approximately 780 000 years ago, the north pole slowly moved toward the south pole until the poles changed over. Today, scientists have noticed a steady decline in the strength of Earth's magnetic field. Some scientists believe that another flip is coming soon, perhaps in the next 1000 years.

Magnetic Field Lines

Magnetic fields exist in three dimensions surrounding a magnet and are more intense at the poles. Magnetic fields are invisible, but can be represented in diagrams with magnetic field lines. Magnetic field lines

- point from the north pole to the south pole outside a magnet, and from the south pole to the north pole inside a magnet
- never cross one another
- are closer together where the magnetic field is stronger

Drawing Field Lines

A compass can be used to map the direction of the field lines around a magnet. The compass needle will align itself along the direction of the field. **Figure 3** shows the field lines around different magnets.

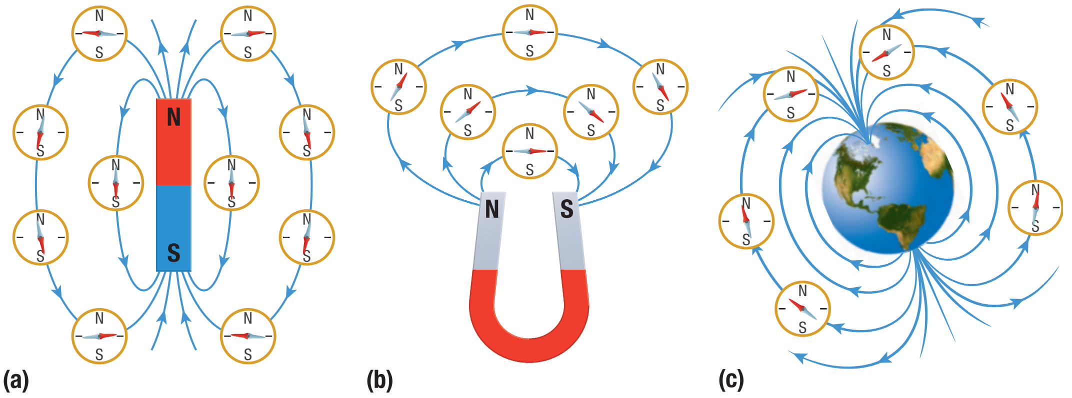

Figure 3 (a) A magnetic field around a bar magnet with mini compasses on the field lines
(b) A magnetic field around a horseshoe magnet with mini compasses on the field lines
(c) A magnetic field around Earth with mini compasses on the field lines

When the north pole of a magnet is brought near the south pole of another magnet, the two magnets attract each other. This happens because of the way the magnetic field of one magnet interacts with the magnetic field of the other magnet. The field lines appear as shown in **Figure 4**.

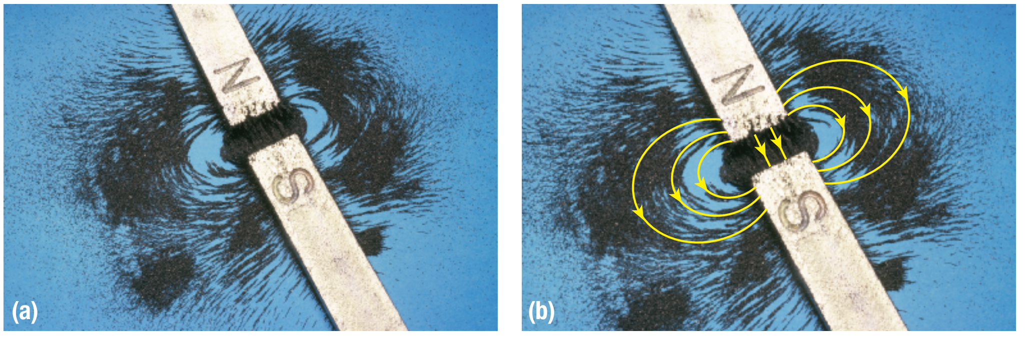

Figure 4 (a) The magnetic fields around these magnets are shown using iron filings, which line up with the field lines. (b) The direction of the magnetic field lines

When two like magnetic poles (north and north or south and south) are brought close to one another, the magnets repel each other. This happens because of the way the magnetic fields of the magnets interact. The magnetic fields appear as shown in **Figure 5**.

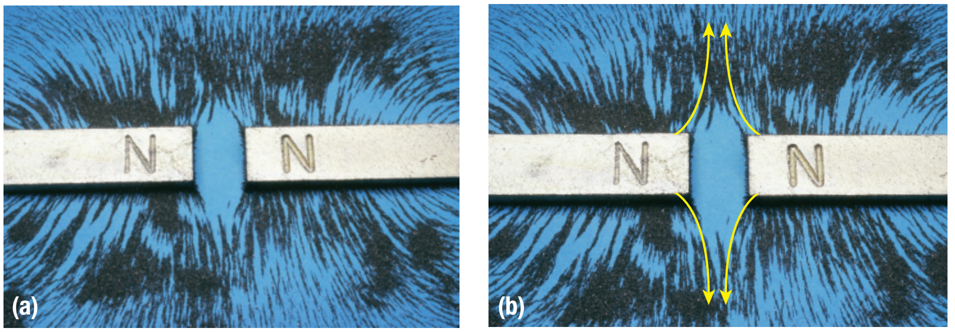

Figure 5 (a) The magnetic fields around these magnets are shown using iron filings, which line up with the field lines. (b) The direction of the magnetic field lines

Investigation 12.1.1

Properties of Magnetic Fields (p. 574)

In this investigation, you will observe the properties of the magnetic fields around permanent magnets.

Magnetic Fields at Work

Many technologies, such as Maglev trains, particle accelerators, and magnetic resonance imaging (MRI) systems, use magnetic fields. The Maglev train discussed in the opening paragraph uses magnetic fields for both levitation and forward motion. The type of Maglev train used in Shanghai is based on a German design that uses magnetic fields that cause the train to levitate based on attraction. The bottom of the train is attracted upward toward the bottom of the track (**Figure 6**). The forward motion is caused by both attraction and repulsion forces between the track and the train. Attraction forces between the front of the train and the track immediately in front of it pull the train forward. At the same time, repulsion forces at the back of the train push it forward.

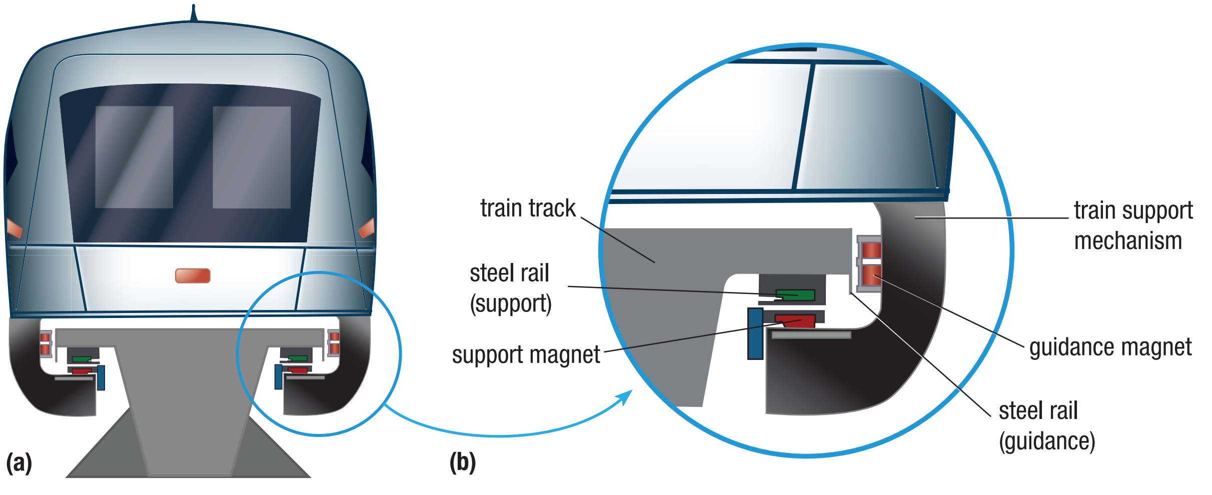

Figure 6 (a) The Maglev train support mechanism (b) The red support magnet attracts upward toward the bottom of the steel rail. This levitates the train at all times. The guidance magnet is used to keep the train along a specific path as it moves above the track.

Particle accelerators are machines that accelerate subatomic particles, such as electrons and protons, to speeds approaching the speed of light, making them collide with a target or with other particles. The results of the collisions are analyzed to possibly find new particles. The Large Hadron Collider (LHC) is a particle accelerator in Europe that uses magnetic fields to control the path and speed of protons. Scientists force the protons to collide with each other. One of the aims of the LHC is to detect a special particle called the Higgs boson, which is believed to be responsible for the mass of all particles.

CAREER LINK

To learn more about becoming a particle physicist,

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A magnetic resonance imaging (MRI) system uses incredibly strong magnetic fields to produce very detailed images of the inside of the human body. These detailed images provide doctors with important information that can be used to diagnose a disease or provide information for surgery. MRI scans can even detect cancerous cells before they become tumours. Early detection and diagnosis of problems can help save many lives.

These amazing technologies use magnetic fields, but magnetic fields are also found in many technologies that we use daily. Magnetic fields are present wherever there is a magnet. Magnets can hold pictures on the side of a refrigerator, or in your locker at school; magnets inside electric motors help the motors spin; electric bells use magnets to ring at the end of your physics class; and the hard drive in your computer stores information using magnetic fields.

In the northern parts of the northern hemisphere, magnetic fields cause beautiful displays of light in the night sky called northern lights or aurora borealis (**Figure 7**). Charged particles from the Sun travel through space and interact with Earth's magnetic field, which is strongest at the poles. The shape of the field directs these charged particles toward the ground. These downward-travelling particles collide with oxygen or other gases in the atmosphere, transforming kinetic energy into light.

Figure 7 Northern lights produced as a result of Earth's magnetic field interacting with charged particles from the Sun in the atmosphere. The different colours result from collisions with oxygen, nitrogen, hydrogen, and helium at different altitudes.

Even living creatures can use magnetic fields to their benefit. Spiny lobsters navigate their way through long migrations over hundreds of kilometres. Scientists suspected that the spiny lobsters used Earth's magnetic field to guide their way. They removed some lobsters and placed them in a tank where the scientists could slightly change the magnetic field. With the magnetic field changed, the lobsters changed their path. Other animals, like birds, also use the magnetic field of Earth to help navigate while migrating.

WEB LINK

To find out more about how living creatures use magnetic fields,

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Research This

The Maglev Train

Skills: Researching, Analyzing, Communicating — SKILLS HANDBOOK A5.1

Mass transit is one solution that has been recommended to lessen the amount of greenhouse gases we emit by reducing the number of cars and trucks on the road. High-speed mass transit could reduce the use of airplanes, which also emit greenhouse gases. The Maglev train is one option.

1. Research the operational Maglev train in Shanghai and collect information on the benefits and disadvantages.
2. Research conventional trains and collect information on the benefits and disadvantages.
3. Research future projects that plan to use Maglev technology.

A. What is the main advantage of Maglev technology? T/I
B. What are some reasons why Maglev train technology is not more commonly used? T/I
C. Compare conventional train technology to Maglev technology using a graphic organizer. T/I C A
D. How has Maglev technology affected the people who use the Maglev train in Shanghai? How has its use affected the environment? T/I A

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12.1 Summary

- Magnetic fields cause forces on objects that can be affected by magnets.
- Magnetic fields are three-dimensional.
- Magnetic forces increase as magnetic objects get closer to each other.
- Magnetic fields cause attraction between unlike poles and repulsion between like poles.
- Magnetic field lines represent what a magnetic field looks like around a magnetic object.
- Magnetic field lines point from the magnetic north pole to the magnetic south pole outside a magnet and from south to north inside a magnet.
- Magnetic field lines never cross one another.
- Magnetic field lines are closer together where the magnetic field is stronger.

12.1 Questions

1. Describe the importance of the compass to navigation. K/U C A
2. How would moving the magnetic north pole of Earth to a point on the equator change navigation using a compass? K/U
3. You come across a piece of magnetite in Ontario. Describe how you could use the magnetite to help you determine the orientation of magnetic north and magnetic south. Will you be able to determine which way is magnetic north using the magnetite? Explain your answer. K/U C A
4. Suppose Earth had no magnetic field. K/U A
   (a) How would the northern lights be affected?
   (b) What would happen to animal navigation?
5. Copy the diagrams in **Figure 8** into your notebook and show the directions that the compass needles would point. K/U T/I C

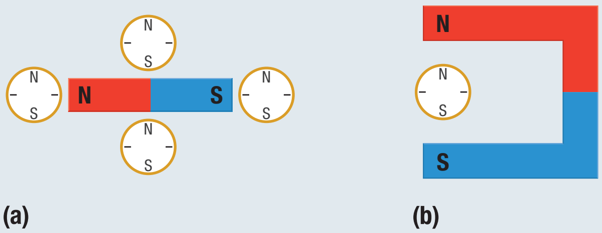

Figure 8

6. Copy the diagrams in **Figure 9** into your notebook and show the field lines. K/U T/I C

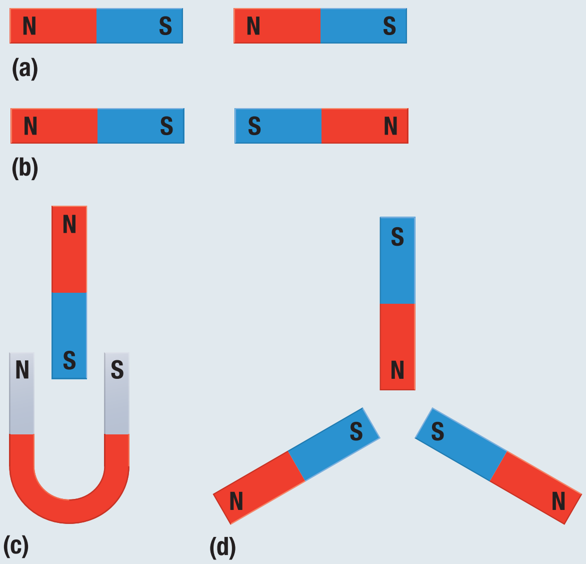

Figure 9

7. Choose one application of magnetic fields and research how they are used. Prepare a brief summary of your findings in a short report or poster. C A

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