

# Magnet

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## Key Concepts

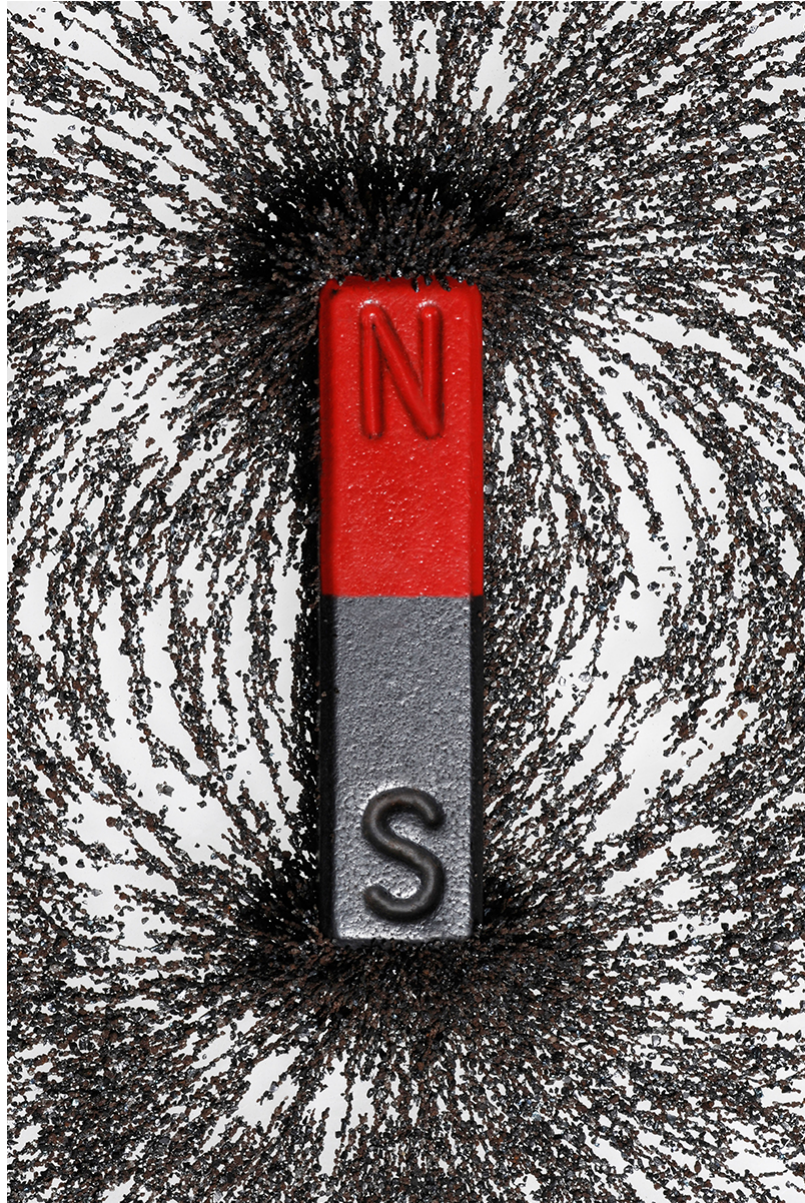
- A magnet is a physical object that creates a magnetic field and exerts forces on other magnets and on moving charged particles.
- Four types of magnets are permanent magnets, induced magnets, electromagnets, and induced electromagnets.
- Most magnetic materials can be classified as ferromagnetic, paramagnetic, or diamagnetic.

**A physical object that creates a magnetic field through which the object exerts forces on other magnets and on moving charged particles.** A magnet creates a magnetic field in the space surrounding the magnet. This magnetic field exerts forces on other magnets and on particles with electric charge if the particles are in motion. These magnetic forces can be attractive or repulsive and can also generate electric currents. The simplest magnet is a magnetic dipole, which consists of a north magnetic pole and a south magnetic pole (Fig. 3). Fundamentally, magnetic monopoles do not exist. A magnet always occurs as a magnetic dipole or as a collection of magnetic dipoles; even if a permanent magnet is cut in half, the two halves will each be magnetic dipoles. Magnetism is a component of electromagnetism, which is one of the four fundamental interactions of the universe. *See also:* DIPOLE; ELECTRIC CHARGE; ELECTRIC CURRENT; ELECTROMAGNETIC FIELD; ELECTROMAGNETISM; FUNDAMENTAL INTERACTIONS; MAGNETIC MONOPOLES; MAGNETISM.

## Types of magnets

### Permanent magnets

A permanent magnet continually creates a magnetic field without the assistance of an external agent. This type of magnet consists of a magnetic material that has been permanently magnetized; that is, the magnetic dipoles of the material's atoms are aligned with each other. Examples of permanent magnets include bar magnets, refrigerator magnets, and compass needles.



**Fig. 3** A magnetic dipole, consisting of a north magnetic pole (red "N") and a south magnetic pole (silver "S"). Iron filings affected by the magnet reveal magnetic field lines, which converge at the poles. (Credit: Alchemy/Alamy Stock Photo)

## Induced magnets

An induced magnet is similar to a permanent magnet in that an induced magnet consists of a magnetized material, but it is different in that the magnetization is not permanent. Such a material acts as a magnet only in the presence of other magnets. Examples of induced magnets include steel paperclips attracted to a bar magnet and screws attracted to a permanently magnetized screwdriver.

## Electromagnets

An electromagnet is a temporary magnet that consists of freely traveling electric currents rather than magnetized materials. Technically, an electric current always produces a magnetic field. However, this magnetic field is often too weak to be significant. Electromagnets are designed to produce significant magnetic fields. In practice, this is usually accomplished by sending an electric current through a wire that has been wound tightly into a helical coil. This configuration is known as a solenoid. To a good approximation, a simple solenoidal electromagnet generates a magnetic field that has the same pattern as the field generated by a small bar magnet. Therefore, a simple solenoidal electromagnet can be treated mathematically as a bar magnet. The only difference is that an electromagnet can be turned on and off. This makes electromagnets ideal for situations where the magnetic force needs to be switched on and off, such as in electric motors and audio speakers. *See also:* AUDIO AMPLIFIER; ELECTROMAGNET; LOUDSPEAKER; MOTOR; SOLENOID (ELECTRICITY).

A solenoid usually has a rod of magnetic material at its core to boost the strength of the solenoid's magnetic field. Therefore, the object that is commonly called an "electromagnet" is actually an electromagnet plus an induced magnet working together. The strength of the magnetic field  $B$  produced inside a solenoidal electromagnet is given by the expression:  $B = \mu NI/L$ . In this equation,  $\mu$  is the magnetic permeability of the rod (the potential change in the magnetic field of a material given another magnetic field it is located within),  $N$  is the number of windings in the coil,  $I$  is the electric current in the wire, and  $L$  is the length of the solenoid.

## Induced electromagnets

The electric current in an electromagnet is usually supplied by an external electric circuit. However, in some cases, the electric current is instead generated by a changing magnetic field according to Faraday's law of induction. For instance, when a bar magnet moves toward a block of copper, the changing magnetic field associated with the movement of the magnet induces circulating electric currents in the block. These eddy currents then act as an induced electromagnet which repels the bar magnet. The key point is that the force between a magnet and an induced electromagnet is due to the induced electric currents and not an induced magnetization. This means that any electrically conductive material can become an induced electromagnet, even if it does not have significant magnetic properties. When the purpose of the induction is to collect and use the induced electric current, the device is called a generator. When the purpose is to create a force between the magnet and the induced electromagnet, the device is called a magnetic brake. Generators and magnetic brakes are found in power plants, cars, and rollercoasters.

## ***Magnetic materials***

All materials can become induced magnets. In other words, all materials exhibit a magnetic response in the presence of other magnets. In most situations, however, the magnetic response is too weak to be noticeable. The magnetic response becomes noticeable only if the material has particularly strong magnetic properties (such as

iron) or if the magnetic material is near an extremely strong magnet (such as during magnetic levitation demonstrations). *See also:* IRON; MAGNETIC LEVITATION.

Fundamentally, the magnetization of a material arises from the intrinsic and orbital magnetic dipole moments of its electrons because magnetic fields are created by the movement of charged particles. In most cases, the small magnetic fields generated by the motion and intrinsic spin of orbital electrons are pointed in different directions and cancel each other out. In a magnetized material, these small magnetic fields line up in small regions or domains that reinforce each other, leading to a stronger magnetic field throughout and around the material. *See also:* ELECTRON.

Most magnetic materials can be classified into three main categories: ferromagnetic, paramagnetic, and diamagnetic.

## Ferromagnetic materials

Ferromagnetism is the strongest magnetic material response. Most permanent magnets and induced magnets encountered in everyday life are ferromagnetic. Non-permanently magnetized ferromagnetic objects such as screws are always attracted to magnets, regardless of their orientation. Ferromagnetic materials are nonlinear and experience hysteresis effects, meaning that their current state depends on their history. This is what allows some ferromagnetic materials to be made into permanent magnets. Examples of ferromagnetic materials include iron, steel, and nickel. *See also:* FERROMAGNETISM; MAGNETIC FERROELECTRICS; NICKEL; STEEL.

## Paramagnetic materials

Paramagnetism is similar to ferromagnetism in that paramagnetic materials are always attracted to magnets. However, paramagnetism is much weaker than ferromagnetism. Also, unlike ferromagnetism, paramagnetism is a linear material response that does not experience hysteresis effects. Examples of paramagnetic materials include molecular oxygen and aluminum. *See also:* PARAMAGNETISM.

## Diamagnetic materials

Diamagnetism is the weakest material response. All materials (except monatomic hydrogen) display some amount of diamagnetism. However, a material is classified as diamagnetic only if the other types of magnetic response are not present. Diamagnetic materials are always repelled from magnets. Like paramagnetism, diamagnetism is a linear material response. Examples of diamagnetic materials include water, wood, bismuth, and pyrolytic carbon. *See also:* DIAMAGNETISM.

## ***Forces between magnets***

In general, the manner in which two magnets exert forces on each other is complex. However, for two simple magnets, the forces can be determined according to a few rules:

Only the magnetic poles that are closest to each other experience a significant force. The other magnetic poles can be ignored.

Opposites attract, meaning that if the north pole of one magnet is close to the south pole of the other magnet, then the magnets exert an attractive force on each other.

Likes repel, meaning that if the north pole of one magnet is close to the north pole of the other magnet, then the magnets exert a repulsive force on each other. Similarly, if the south pole of one magnet is close to the south pole of the other magnet, then the magnets exert a repulsive force on each other.

For a ferromagnetic or paramagnetic material near another magnet, the induced magnet of the material has its closest pole as the opposite type of pole as that of the other magnet. The end result is that non-permanently magnetized ferromagnetic and paramagnetic materials are always attracted to other magnets.

For a diamagnetic material near another magnet, the induced magnet has its closest pole as the same type of pole as that of the other magnet. The end result is that diamagnetic materials are always repelled away from other magnets.

For an electromagnet, the location of its north pole is found using the so-called right-hand rule. With the fingers of the right hand curled in the direction of the electric current, the tip of the extended thumb marks the approximate location of the electromagnet's north pole. The electromagnet's south pole is located at the opposite end of the electromagnet.

For an induced electromagnet, the poles are always orientated such that the force between the original magnet and the induced electromagnet is repulsive when the magnet and induced electromagnet are moving toward each other and attractive when they are moving away from each other. In each case, the force opposes the motion. Therefore, this effect is conceptually similar to friction. For this reason, this effect is called magnetic braking. *See also:* FRICTION

## ***History and applications***

Permanent magnets have been in use for millennia. The ancient Greeks discovered that an iron ore called lodestone (Fig. 2) naturally contains a permanent magnetization and can attract other objects. Additionally, the Chinese have used magnets in compasses for over a thousand years. In 1820, French physicists Jean-Baptiste Biot and Félix Savart developed the equation for the magnetic field generated by a current-carrying wire, enabling the systematic design of electromagnets. In the mid-nineteenth century, English physicist and chemist Michael Faraday discovered Faraday's law of induction and used this law to invent the generator and the magnetic brake.



**Fig. 2** A lodestone attracting a metal paperclip. (Credit: neal and molly jansen/Alamy)

Modern applications of magnets include a wide range of devices such as hard disks, credit cards, generators, electric motors, audio speakers, and microphones. Today, magnets are found in virtually every vehicle, household appliance, and electronic device. *See also:* AMPÈRE'S LAW; BIOT-SAVART LAW; ELECTRONICS.

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## Keywords

magnet; magnetism; permanent magnet; like charges repel; opposite charges attract; fridge magnet; electromagnetism

## Bibliography

A. A. N. El Islam, A. Abdelghani, and B Houari, Electromagnet separator of different particles, *Int. J. Eng. Manu.*, 8(5):22, 2018 DOI: <http://doi.org/10.5815/ijem.2018.05.03>

## Additional Readings

K. Krauskopf and A. Beiser, *The Physical Universe*, 17th ed., McGraw-Hill, 2020