

Magnets, motors, generators and transformers

Physics grades 9-10 (GCSE · IGCSE · O Level · Class 9-10) · Lesson

Quick answer: Electromagnetism links electricity and magnetism: a current produces a magnetic field, a current-carrying wire in a field feels a force $F = B I L$, and a changing magnetic field induces a voltage. These effects drive motors, generators and transformers.

Level: Physics grades 9-10 (GCSE · IGCSE · O Level · Class 9-10) · **Curriculum:** HS-PS2-5, GCSE P7

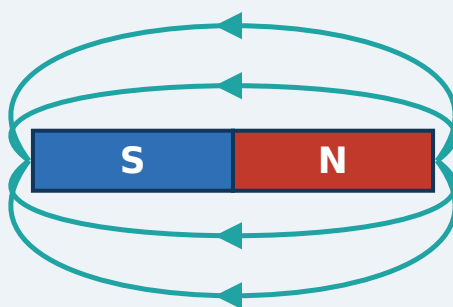
What is a magnetic field and how do magnets behave?

Every magnet has two poles, north and south. Like poles repel and unlike poles attract. Around a magnet there is a **magnetic field**, which you can map with plotting compasses or iron filings.

Definition

A magnetic field is a region in which a magnet, a piece of magnetic material or a current-carrying wire feels a force. Its strength B is measured in tesla (T).

Field lines show the direction a free north pole would move: they leave the north pole and enter the south pole. Where the lines are crowded together the field is strong, as at the poles.

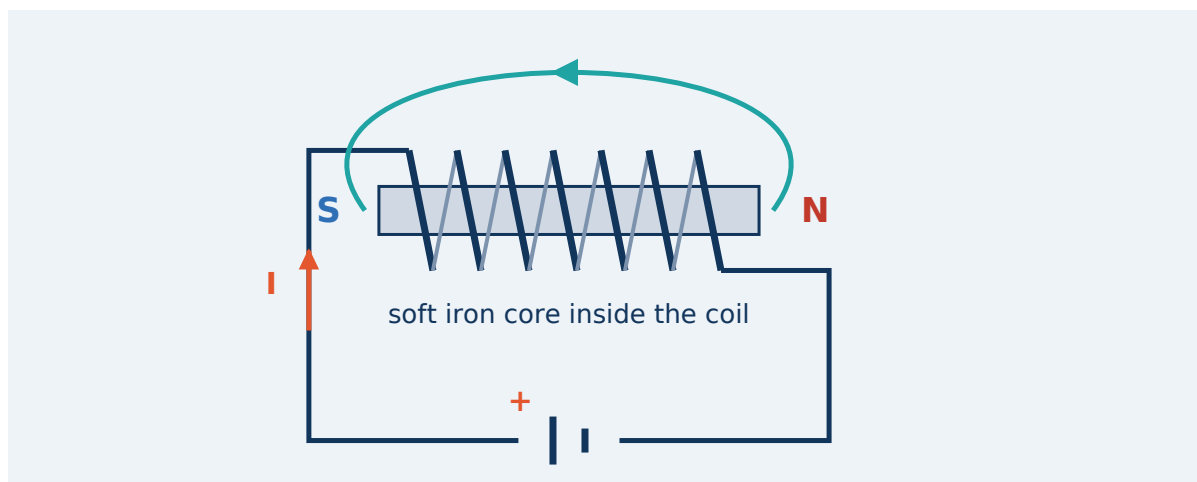


Field lines run from N to S outside the magnet and are closest at the poles

Magnetic field of a bar magnet: the lines leave the north pole and enter the south pole.

How does an electric current make a magnet?

A current in a straight wire is surrounded by circular field lines. Grip the wire with your right hand with the thumb along the conventional current: your fingers curl in the direction of the field. Winding the wire into a coil, called a **solenoid**, makes the fields of all the turns add up. The result looks like a bar magnet with a strong, nearly uniform field inside.



An electromagnet: a current in the coil makes a field like a bar magnet's, strengthened by a soft iron core.

An electromagnet gets stronger with a larger current, more turns of wire, and a core of soft iron. Unlike a permanent magnet it can be switched off, which is why scrapyard cranes use them.

What is the motor effect and how do you calculate the force?

When a wire carrying a current lies across a magnetic field, its own field interacts with the magnet's field and the wire feels a force. This is the **motor effect**. The force is greatest when the wire is at right angles to the field and zero when the wire is parallel to it.

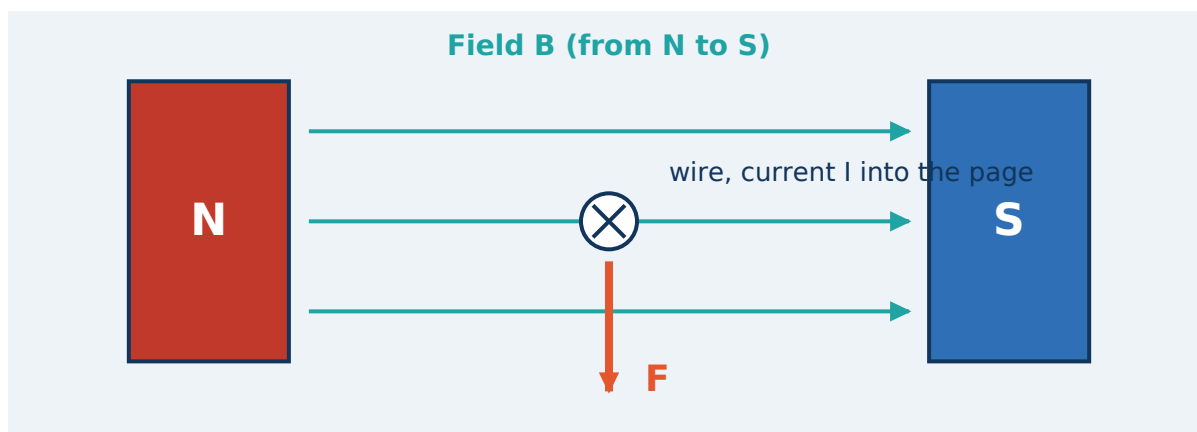
Formula

$$F = B I L$$

F is the force in newtons (N), B is the magnetic field strength in tesla (T), I is the current in amperes (A) and L is the length of wire in the field in metres (m).

Key law: Fleming's left-hand rule

Hold your left hand with the first finger, second finger and thumb at right angles. The first finger points along the field (N to S), the second finger along the current, and the thumb shows the direction of the force or motion.



A wire carrying current into the page between two poles feels a downward force.

Worked example 1: force

A 0.15 m length of wire carries 4.0 A at right angles to a field of 0.20 T. Find the force.

$$F = B I L = 0.20 \times 4.0 \times 0.15 = \mathbf{0.12 \text{ N}}.$$

Worked example 2: field strength

A 0.060 m wire carrying 2.5 A feels a force of 0.030 N. Find the field.

$$B = F \div (I L) = 0.030 \div (2.5 \times 0.060) = 0.030 \div 0.15 = \mathbf{0.20 \text{ T}}.$$

In an electric motor a coil sits in the field. The forces on its two sides point in opposite directions and turn the coil. A split-ring commutator reverses the current every half turn so that the coil keeps turning the same way.

How do generators produce a voltage?

If a wire cuts across magnetic field lines, or the magnetic field through a coil changes, a voltage is **induced**. If the circuit is complete, a current flows. This is electromagnetic induction. The induced voltage is bigger when the magnet moves faster, the magnet is stronger, or the coil has more turns. No movement and no change in the field means no voltage. A generator spins a coil in a field, so the voltage rises, falls and reverses with each half turn: this is alternating current.

Device	Energy in	Energy out	Key idea
Motor	electrical	kinetic	force on a current in a field
Generator	kinetic	electrical (a.c.)	induction in a spinning coil
Transformer	a.c. at one voltage	a.c. at another voltage	changing field in an iron core

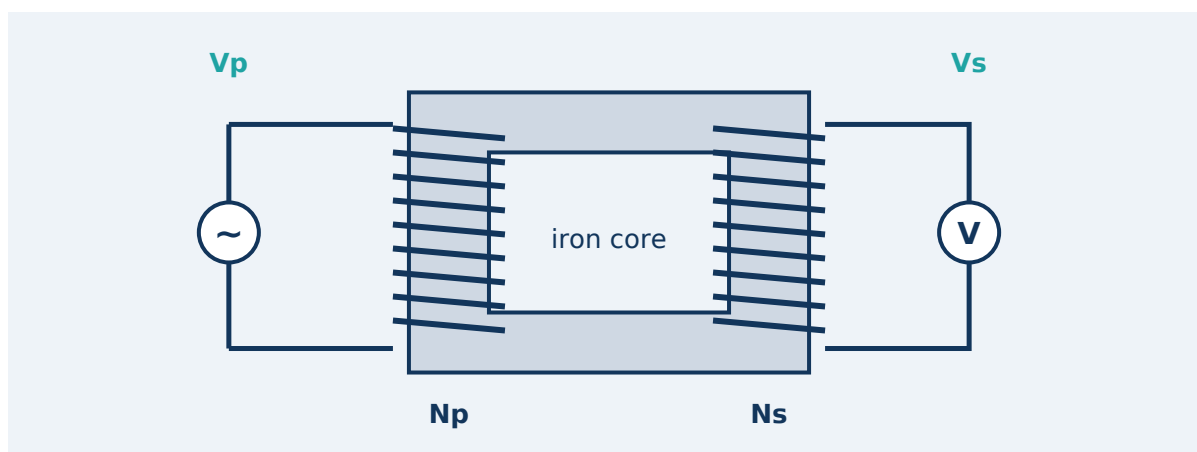
How does a transformer change voltage?

A transformer has two coils wound on one iron core. An alternating current in the **primary** coil makes a changing field in the core, which induces an alternating voltage in the **secondary** coil. More turns on the secondary give a higher voltage (step-up), fewer turns a lower one (step-down). Power stations use step-up transformers to send electricity along cables at very high voltage and low current, and step-down transformers near homes.

Formula

$$V_p \div V_s = N_p \div N_s \text{ and, for an ideal transformer, } V_p I_p = V_s I_s$$

V is the voltage in volts (V), N the number of turns, I the current in amperes (A). The letters p and s mean primary and secondary.



Transformer: two coils on a laminated iron core. The primary coil is on the left, the secondary on the right.

Worked example 3: transformer

A phone charger steps 230 V down to 12 V. The primary has 2300 turns.

$$N_s = N_p \times V_s \div V_p = 2300 \times 12 \div 230 = \mathbf{120 \text{ turns.}}$$

If the output is 12 V at 2.0 A, the power is 24 W, so $I_p = 24 \div 230 = 0.10 \text{ A}$.

Common mistake

A transformer does not make energy. A step-up transformer raises the voltage but lowers the current by the same factor. It also needs alternating current: a battery gives a steady field and no induced voltage.

Lina's tip

Remember "left hand for motors": first finger = Field, second finger = Current, thumb = Motion. For a transformer, put the larger number of turns with the larger voltage.

Key points to remember

- Field lines run from north to south outside a magnet; strength B is in tesla (T).
- Motor effect: $F = B I L$, direction from Fleming's left-hand rule.
- Induction needs a changing field: faster, stronger or more turns means more voltage.
- Transformer: $V_p \div V_s = N_p \div N_s$, and ideally $V_p I_p = V_s I_s$.
- Transformers work only with alternating current.

Magnets, motors, generators and transformers: frequently asked questions

What is the difference between a motor and a generator?

A motor transfers electrical energy to movement using the force on a current in a field. A generator does the opposite, using movement to induce a voltage.

Why does a transformer not work on direct current?

A steady current makes a steady field, so the field through the secondary coil does not change

and no voltage is induced. Only a changing field induces a voltage.

How can you make an electromagnet stronger?

Increase the current, add more turns of wire, or put a soft iron core inside the coil. The iron becomes magnetised and strengthens the field.

What does the tesla measure?

The tesla measures magnetic field strength. One tesla is the field that exerts a force of 1 N on 1 m of wire carrying 1 A at right angles to the field.

Why do power lines use very high voltage?

For the same power, a higher voltage means a smaller current. Heating losses in the cables depend on the square of the current, so far less energy is wasted.