Chapter 22: Electric motors and electromagnetic induction

The motor effect – movement from electricity

When a current is passed through a wire placed in a magnetic field a force is produced which acts on the wire.

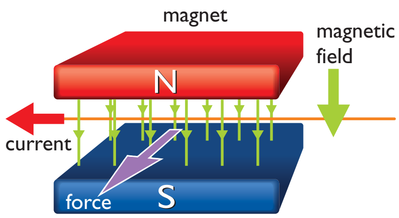
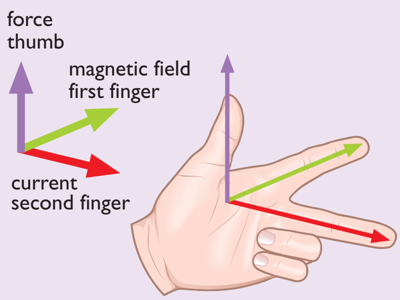


Figure 22.1

Figure 22.1 shows part of a wire carrying a current placed in the magnetic field produced by two strong magnets.

The magnets have opposite poles facing and the field lines point from N to S.

Please see the Appendix for additional information on particle accelerators.



You need to be able to use **Fleming's Left Hand Rule** to work out the direction of the force that acts on the wire.

This is also called the **Motor Rule**.

The force acting upon the wire will make the wire move. The thumb of your left hand may be used to determine the direction of movement caused by the force on the wire. In order to remember what component the direction of the thumb shows remember: thu**m**b shows the direction of **m**ovement caused by the force on the wire.

(Alternatively, **f**umb → **f**orce!!)

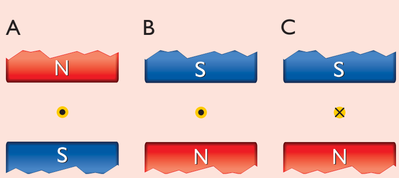
Moving coil loudspeaker

The motor effect is also used in **loudspeakers**: the signal current produced by an amplifier is alternating, and by passing it through a coil in a magnetic field the current results in alternating forces on the coil. The coil is attached to a paper cone and this transfers the vibrations to the air.

Worked Example 2

a) Copy and complete the following diagrams by drawing in magnetic field lines.

b) Use Fleming's Left Hand Rule to work out the direction of the force that will act on the conductors shown in the magnetic fields, below.



a) Field lines should be drawn going from N to S

b) A: → F
B: ← F
C: → F

● Shows a conductor carrying current flowing **out of** the plane of the paper perpendicularly **towards** you.

⊗ Shows a conductor carrying current flowing **into** the plane of the paper perpendicularly **away from** you.

The *size of the force* that acts on a current-carrying conductor placed at right angles to a magnetic field may be increased by either *increasing the strength of the magnetic field* or by *increasing the current* in the wire.

The electric motor

In its simplest form a DC motor consists of a single turn coil of wire that is free to rotate in a magnetic field about an axle, as shown in Figure 22.2. Carbon brushes make contact with the ends of the coil that are connected to a commutator so that a current can be passed through the coil.

The sequence of diagrams in Figure 22.2 show the coil from an end-on view, making it easy to see how the forces acting on each side of the coil produce a turning effect about the axle. Figure 22.2c shows that the turning effect is zero when the coil is parallel to the permanent magnets (because the line of action of the forces passes through the axis of rotation). This might suggest that the coil stops in this position, but it will inevitably overshoot, and as soon as it does so, the commutator will reverse the direction of the current in the coil which means the coil will continue to spin.

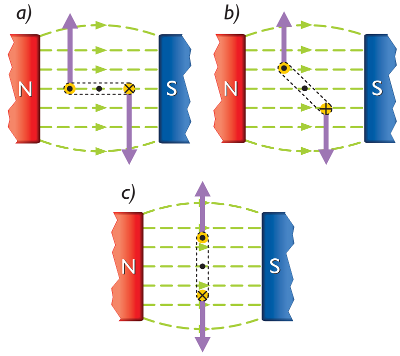


Figure 22.2

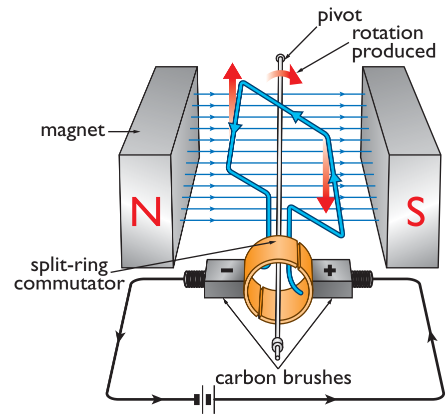


Figure 22.3 *Simple electric motor*

Worked Example 3

State three ways in which you could change the design of a DC motor to make it spin faster for a given load.

Increase the strength of the magnetic field. Put more turns on the coil. Pass a larger current through the coil. (But note that if the maximum design current for a motor is exceeded then the motor is likely to burn out.)

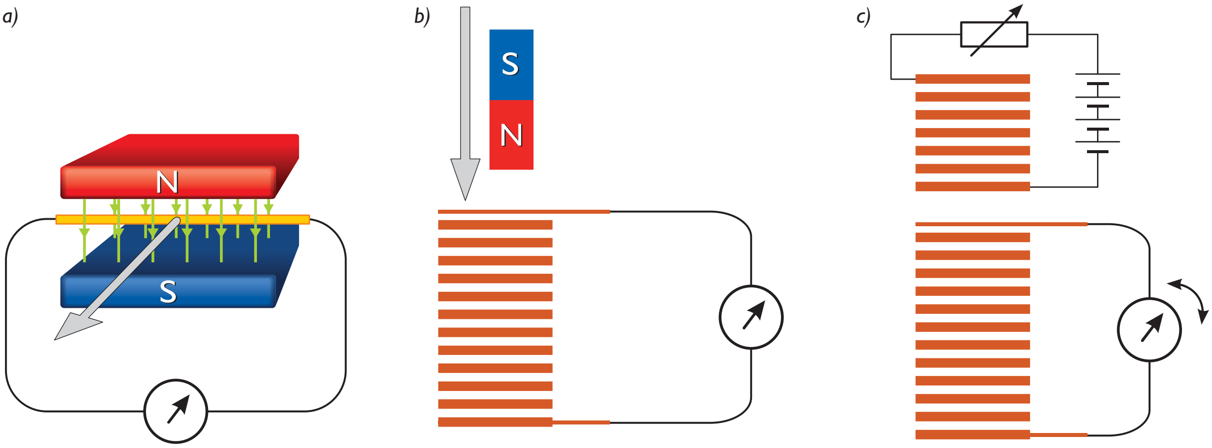
Electromagnetic induction and the generator

When a conductor is in a changing magnetic field a voltage will be induced in the conductor.

The magnetic field can change if:

- the conductor is moving into, or out of, a magnetic field (see Figure 22.4a),
- a magnet is moving towards, or away from, the conductor (see Figure 22.4b) or
- the magnetic field is being varied (see Figure 22.4c).

If the conductor is part of a closed electric circuit then the induced voltage will cause a current to flow.



a) moving a conductor out of (or into) a magnetic field induces a voltage.

b) moving a magnet into (or out of) a long coil induces a voltage.

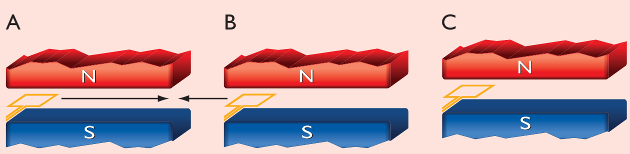
c) varying the current in the top coil induces a voltage in the bottom coil.

Figure 22.4

> The size of the induced voltage in a coil can be increased by increasing the rate of change of the strength of the magnetic field, by having more turns on the coil and by having a coil of greater area.

Worked Example 4

Look at the three situations shown below; in each case a small plane coil is in the field between two permanent magnets:



In **A** the coil is moving horizontally at constant speed between the two magnets.

In **B** the coil is moving horizontally at constant speed out of the gap between the two magnets.

In **C** the coil is stationary between the two magnets.

In which situation, if any, is a voltage induced in the coil?

In **A** the coil is moving in a uniform magnetic field so the amount of magnetic flux cutting the coil is not changing → No induced voltage

In **B** the coil is moving out of a uniform magnetic field so the amount of magnetic flux cutting the coil is decreasing → Voltage induced

In **C** the coil is not moving so the magnetic flux cutting the coil is constant → No induced voltage

Two types of generator

The *bicycle dynamo* consists of a strong, small bar magnet which is spun by the wheel of the bicycle. It spins between the faces of a U-shaped iron core on which a coil of wire is wound. The changing magnetic field induces an alternating voltage in the coil.

Larger *generators* have spinning coils of wire in the magnetic field of strong permanent magnets (or, in large generators, a magnetic field produced by electromagnets). Since the coil in which the voltage is being induced is spinning, the electrical connections are made by brushes which slide over slip rings.

The transformer

The function of a transformer is to change the size of an alternating voltage. This is done by having two separate coils with different numbers of turns.

Transformers consist of a core made from thin sheets of a magnetically soft material clamped together. Two separate coils of wire, insulated from one another, are tightly wound onto the core. Transformers are designed to perform the job of changing voltage with very little power loss → you may **assume that they are 100% efficient**.

$$\frac{\text{input (primary) voltage}}{\text{output (secondary) voltage}} = \frac{\text{primary turns}}{\text{secondary turns}}$$

$$\frac{Vp}{Vs} = \frac{n_1}{n_2}$$

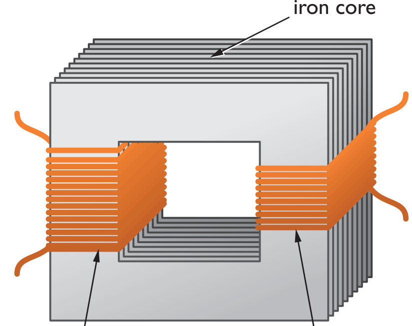


Figure 22.5 *A transformer*

If $n_1 > n_2$ then the transformer *steps down* the input voltage; if $n_2 > n_1$ then the transformer *steps up* the input voltage.

Worked Example 5

A transformer is designed to step down the mains voltage of 230 V to 11.5 V. If there are 1200 turns on the primary coil how many turns should be wound on the secondary coil?

Rearrange $\frac{Vp}{Vs} = \frac{n_1}{n_2}$ to give $n_2 = \frac{Vs}{Vp} \times n_1$

So, $n_2 = \frac{11.5\ \text{V}}{230\ \text{V}} \times 1200$

Therefore, $n_2 = 60$ turns

Transmission of electrical energy

Transformers are used in the transmission of electrical energy over large distances. Transmission lines have low but not zero resistance. Power loss due to this resistance is given by the formula $P = I^2R$, and this means that power losses between the power station and the consumers would be unacceptably large. As transformers are close to 100% efficient

Power input = power output so $Vp \times Ip = Vs \times Is \rightarrow \frac{Vp}{Vs} = \frac{Is}{Ip} \quad \left(= \frac{n_1}{n_2}\right)$

So if a transformer is used to step up the generated alternating voltage 50 times this means the current is stepped down 50 times → $Is = 1/50\ Ip$ The advantage of this is clear, since power loss along the transmission lines is proportional to current squared this will reduce the loss by $(1/50)^2$. The voltage is stepped down using transformers close to the consumers, again with very little power loss because of the near 100% efficiency of the transformer.

Practical work

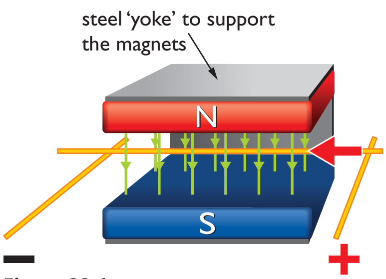


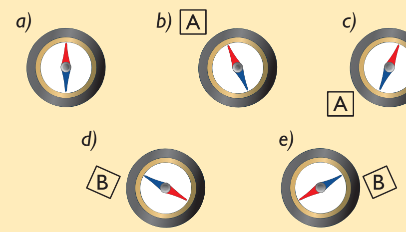
Figure 22.6

You should have practical experience of both the motor and generator effects. A standard experiment to demonstrate that a current in a wire, placed at right angles to a magnetic field, produces a force on the wire is shown here. A short length of copper wire rests on two copper wire 'rails'. When a current is passed through the wire it catapults out of the field sliding along the rails. (The motor effect.)

The generator effect can be demonstrated by thrusting a strong magnet into a long, tightly wound coil connected to a galvanometer (sensitive ammeter). The induced voltage will circulate a detectable current. It can be seen that the induced voltage only occurs when the magnet is moving with respect to the coil. We can also observe that the direction of the induced voltage (and current) depends on the pole of the magnet entering the coil and its direction of travel. Faster movement induces a larger voltage.

Warm-up questions

1 A compass needle points north as shown in a) below.



An unknown object **A** is brought near to the compass and the compass deflects towards it as shown in b) and c). A second unknown object **B** is brought close to the compass and it responds as shown in d) and e). What does this tell you about objects **A** and **B**?

2 Steel is a magnetically hard substance and it is often used for making compass needles. What is meant by the term 'hard' in this context?

3 The magnetic field around a magnet is often represented using *field lines*.

a) What does the spacing of the field lines tell you about the magnetic field?

b) What do the arrows on the field lines tell you about the magnetic field?

4 When a steel paper clip is suspended from a permanent magnet it is then able to pick up a further paper clip and this may be repeated several times to form a chain of paper clips hanging from the magnet. The paper clips have temporary or __________ magnetism. [Supply the missing word.]

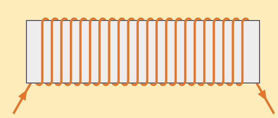
5 *a)* Show, with the aid of a field line sketch, how the magnetic field varies around a single bar magnet.

b) Show how you would position two bar magnets to produce a region of strong and nearly uniform magnetic field. Add field lines to show the magnetic field.

6 Copy and complete the following magnetic field patterns for the three arrangements of current-carrying conductors shown.

A long straight conductor carrying a current into the plane of the paper at 90°.

A section through a plane circular coil carrying a current up out of plane of the paper on the left and down into the plane of the paper on the right.



A long solenoid wound on a cardboard tube. Current flowing in and out as shown by the arrows.

7 State two ways in which the strength of the magnetic field produced by the solenoid in question 6 could be increased.

8 A uniform magnetic field is used in cloud chambers to distinguish between different particles produced by collisions between subatomic particles. It is possible to tell the difference between positively and negatively charged moving particles – how do their paths differ, provided they are not moving parallel to the magnetic field lines?

9 Copy and complete the following paragraph:

Fleming's Left Hand Rule is used to predict the direction of the __________ on a __________ carrying conductor in a __________ __________. The thumb, first finger and second finger are arranged to point in three mutually perpendicular directions; the first finger points in the direction of

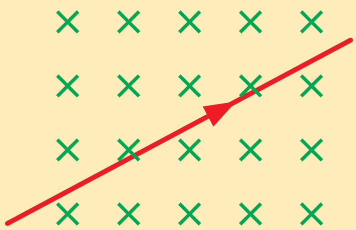
Warm-up questions

the __________ __________, the second finger points in the direction of the __________ and the thumb indicated the direction of the __________ on the conductor. Fleming's Left Hand Rule is also known as the __________ rule.

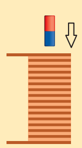
10 Imagine that there is a uniform magnetic field acting over the area of this page directed perpendicularly into the page shown below. A current flows through a wire placed in the field.

a) Copy the drawing and use Fleming's Left Hand Rule to find the direction of the force that acts on the conductor and mark it clearly on your diagram.

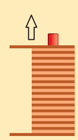
b) State two ways in which the force on the conductor could be made weaker.



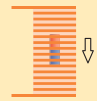
11 In which of the following will there be a voltage induced in the systems of conductors shown?



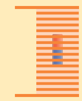
A bar magnet moving into a coil.



A bar magnet moving out of a coil.



A bar magnet moving whilst completely inside a coil.



A bar magnet at rest inside a coil.

12 Show, with the aid of a clear, labelled diagram, the key features of a transformer.

13 A transformer is designed to step a voltage down from 120 V to 6 V. Explain how the design you have shown in question 12 can do this.

14 What is the advantage of stepping up the voltage of electricity generated at a power station to a much higher voltage before transmitting electrical energy via the National Grid?

15 Transformers are assumed to be virtually 100% efficient. What does this mean in terms of electrical power input and output?

16 A generator consists of a coil which is driven mechanically to rotate in a magnetic field. How do the following factors affect the size of the voltage induced in the coil (if at all):

a) The coil has more turns.

b) The coil rotates faster.

c) The magnetic field is made stronger.

Notes