Cambridge

A2 Level

Physics

CODE: (9702)

Chapter 28

Chapter 28: Electromagnetic induction

Observing induction

Factors affecting induced current

For a straight wire, the induced current or e.m.f. depends on:

■ ■ the magnitude of the magnetic flux density

■ ■ the length of the wire in the field

■ ■ the speed of movement of the wire.

For a coil of wire, the induced current or e.m.f. depends on:

■ ■ the magnitude of the magnetic flux density

■ ■ the cross-sectional area of the coil

■ ■ the number of turns of wire

■ ■ the rate at which the coil turns in the field

Explaining electromagnetic induction

Cutting magnetic field lines

Start by thinking about a simple bar magnet. It has a magnetic field in the space around it. We represent this field by magnetic field lines. Now think about what happens when a wire is moved into the magnetic field (Figure 28.5). As it moves, it cuts across the magnetic field. Remove the wire from the field, and again it must cut across the field lines, but in the opposite direction.

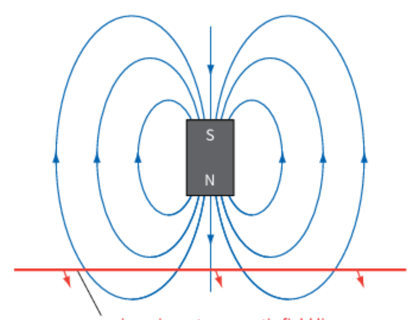

Figure 28.5 Inducing a current by moving a wire through a magnetic field.

Figure 28.6 shows a coil near a magnet. When the coil is outside the fi eld, there are no magnetic fi eld lines linking the coil. When it is inside the fi eld, fi eld lines link the coil. Moving the coil into or out of the fi eld changes this linkage, and this induces an e.m.f. across the ends of the coil.

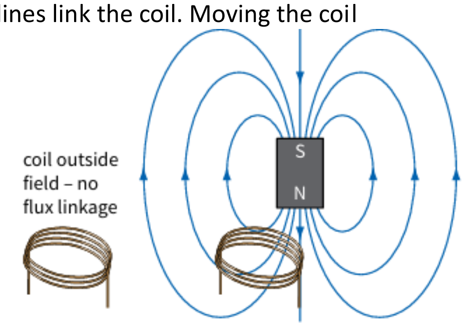

Figure 28.6 The flux passing through a coil changes as it is moved into and out of a magnetic field.

Current direction

Instead of a current producing a force on a current-carrying conductor in a magnetic fi eld, we provide an external force on a conductor by moving it through a magnetic field and this induces a current in the conductor. So you should not be too surprised to find that we use the mirror image of the left - hand rule: Fleming's right-hand (generator) rule.

T h e three fingers represent the same things again (Figure 28.8):

■ ■ thuMb – direction of Motion

■ ■ First finger – direction of external magnetic Field

■ ■ seCond finger – direction of (conventional) induced Current

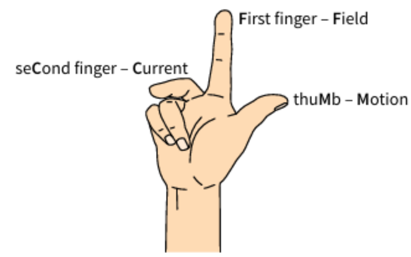

Figure 28.8 Fleming's right-hand (generator) rule.

Induced e.m.f.

When a conductor is not part of a complete circuit, there cannot be an induced current. Instead, negative charge will accumulate at one end of the conductor, leaving the other end positively charged. We have induced an e.m.f. across the ends of the conductor.

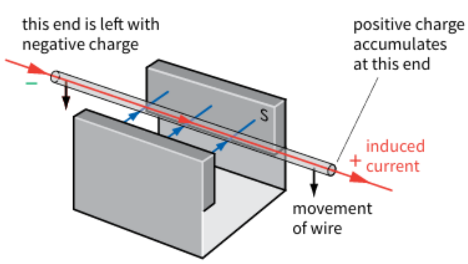

Figure 28.10 An e.m.f. is induced across the ends of the conductor.

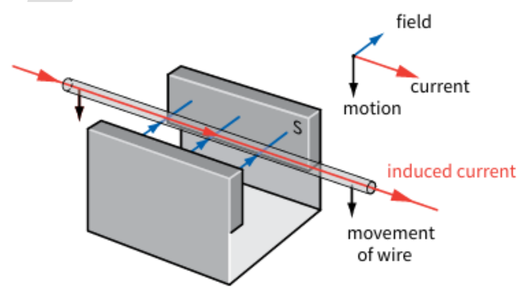

Figure 28.9 Deducing the direction of the induced current using Fleming's right-hand rule.

Magnetic flux and magnetic flux linkage

Now we can go on to define **magnetic flux** as a quantity. We picture **magnetic flux density** B as the number of magnetic fi eld lines passing through a region **per unit area.**

For a coil with N turns, the magnetic flux linkage is defined as the product of the magnetic flux and the number of turns; that is:

$$\text{magnetic flux linkage} = N\Phi$$

or

$$\text{magnetic flux linkage} = BAN\cos\theta$$

The unit for magnetic flux or flux linkage is the weber (Wb).

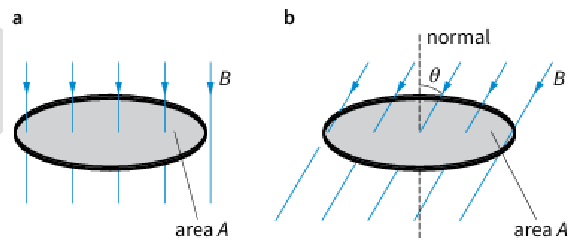

Figure 28.12 **a** The magnetic flux is equal to *BA* when the field is normal to the area. **b** The magnetic flux becomes *BA* cos *θ* when the field is at an angle *θ* to the normal of the area.

One weber (1 Wb) is the flux that passes through an area of 1 m^2 when the magnetic flux density is 1 T.
1 Wb = 1 T m^2.

An e.m.f. is induced in a circuit whenever there is a change in the magnetic fl ux linking the circuit. Since magnetic fl ux is equal to BA cos θ, there are three ways an e.m.f. can be induced:

■ ■ changing the magnetic flux density B
■ ■ changing the area A of the circuit
■ ■ changing the angle θ

Lenz's law

We use Faraday's law to calculate the magnitude of an induced e.m.f. Now we can go on to think about the direction of the e.m.f. – in other words, which end of a wire or coil moving in a magnetic field becomes positive, and which becomes negative.

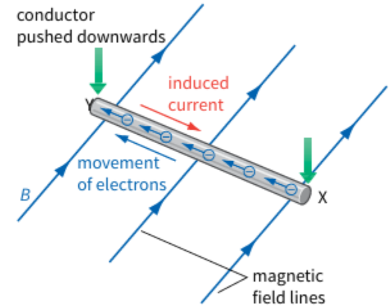

Figure 28.20 Showing the direction of the induced current.

The origin of electromagnetic induction

Figure 28.20 gives an explanation. A straight wire XY is being pushed downwards through a horizontal magnetic field of flux density B. Now, think about the free electrons in the wire. They are moving downwards, so they are in effect an electric current. Of course, because electrons are negatively charged, the conventional current is flowing upwards.

In Figure 28.20, electrons are found to accumulate at Y. T his end of the wire is thus the negative end of the e.m.f. and X is positive. If the wire was connected to an external circuit, electrons would flow out of Y, round the circuit, and back into X. Figure 28.21 shows how the moving wire is equivalent to a cell (or any other source of e.m.f.).

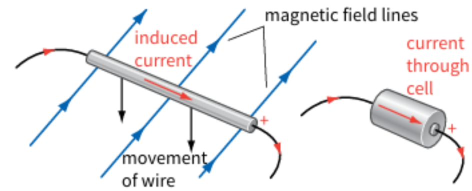

Figure 28.21 A moving conductor in a magnetic field is a source of e.m.f., equivalent to a cell.

Forces and movement

Figure 28.22 shows one of the experiments from earlier in this chapter. The north pole of a magnet is being pushed towards a coil of wire. There is an induced current in the coil, but what is its direction? The diagram shows the two possibilities.

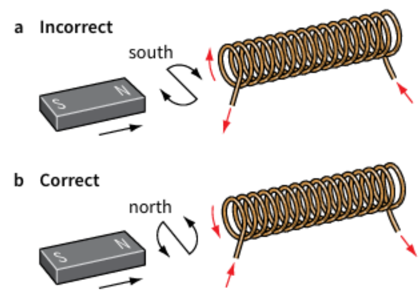

Figure 28.22 Moving a magnet towards a coil: the direction of the induced current is as shown in **b**, not **a**.

Figure 28.23 shows how we can apply the same reasoning to a straight wire being moved in a downward direction through a magnetic fi eld. Th ere will be an induced current in the wire, but in which direction? Since this is a case of a current across a magnetic fi eld, a force will act on it (the motor effect), and we can use Fleming's left -hand rule to deduce its direction.

A general law for induced e.m.f.

Lenz's law summarises this general principle of energy conservation. If the direction of the current were opposite to this, we would be getting energy for nothing. Here is a statement of Lenz's law:

> Any induced current or induced e.m.f. will be established in a direction so as to produce effects which oppose the change that is producing it.

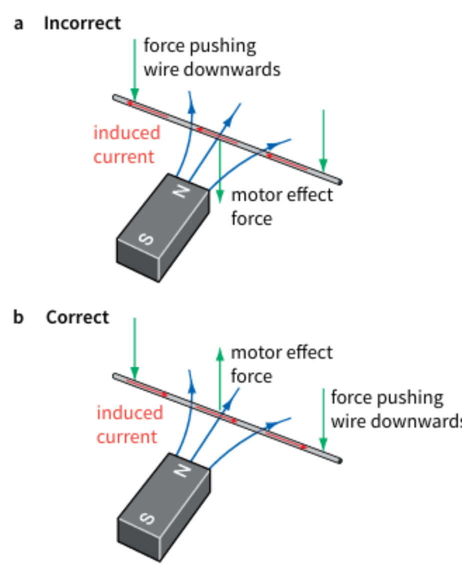

Figure 28.23 Moving a conductor through a magnetic field: the direction of the induced current is as shown in **b**, not **a**.

Using induction: eddy currents, generators and transformers

An induced e.m.f. can be generated in a variety of ways. What they all have in common is that a conductor is cutting across magnetic field lines (in some cases, the conductor moves; in others, the field lines move).

Eddy currents

Induced e.m.f.s are formed in some unexpected places. Consider the demonstration shown in Figure 28.25. A metal disc on the end of a rod swings freely between two opposite magnetic poles

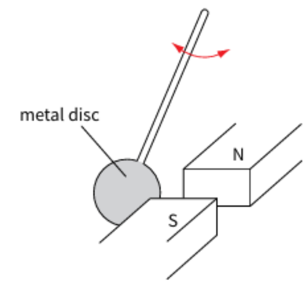

Figure 28.25 Demonstrating eddy current damping.

Generators

We can generate electricity by spinning a coil in a magnetic field. This is equivalent to using an electric motor backwards. Figure 28.26 shows such a coil in three different orientations as it spins

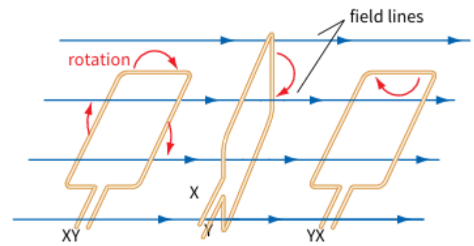

Figure 28.26 A coil rotating in a magnetic field.

Figure 28.27 shows how the flux linkage varies with time for a rotating coil. According to Faraday's law, the induced e.m.f. is equal to minus the gradient of the flux linkage against time graph.

■ ■ When the flux linking the coil is maximum, the rate of change of flux is zero and hence the induced e.m.f. is zero.

■ ■ When the flux linking the coil is zero, the rate of change of flux is maximum (the graph is steepest) and hence the induced e.m.f. is also maximum.

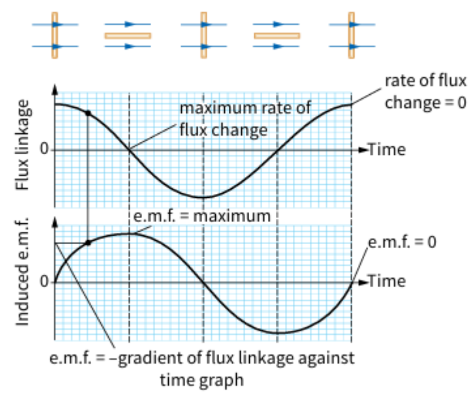

Figure 28.27 The magnetic flux linking a rotating coil as it changes. This gives rise to an alternating e.m.f. The orientation of the coil is shown above the graphs.

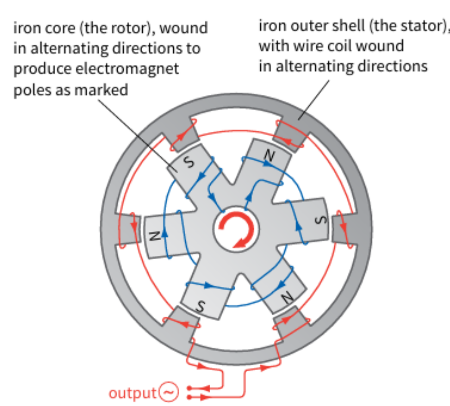

Figure 28.28 In a generator, an electromagnet rotates inside a coil.

Transformers

Another use of electromagnetic induction is in transformers. An alternating current is supplied to the primary coil and produces a varying magnetic field in the soft iron core (Figure 28.30). The secondary coil is also wound round this core, so the magnetic flux linking the secondary coil is constantly changing.

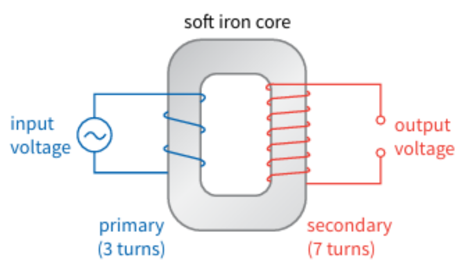

Figure 28.30 The construction of a transformer.