Exercise walk-through

Electromagnetic effects ▪ 4.5

eXercise

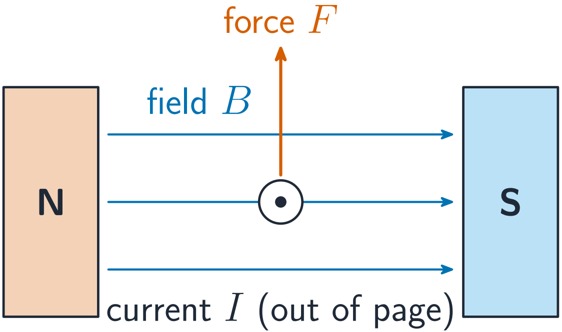
You must be able to

- describe the force on a current-carrying wire (and how to reverse it)
- describe electromagnetic induction and the a.c. generator
- use $\dfrac{V_p}{V_s} = \dfrac{N_p}{N_s}$ for a transformer

Method — Motor effect & transformer

$N_p = 1200$, $N_s = 100$, $V_p = 240$ **V:** $V_s = 240 \times \dfrac{100}{1200} = 20$ V (step-down).

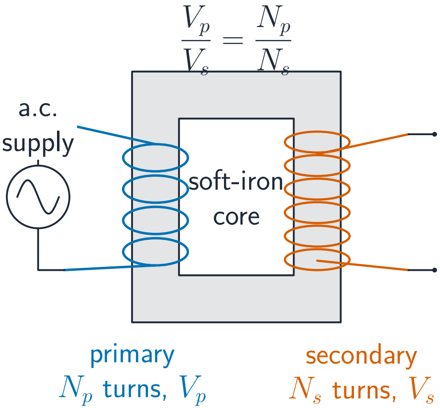
Method — Motor effect & transformer



F, B and I are all at 90° (Fleming's left-hand rule)

A current-carrying wire in a field feels a force at right angles

Method — Motor effect & transformer



A transformer: primary and secondary coils on a soft-iron core

Method — Induction, the generator and the transformer

An e.m.f. is **induced 感应** whenever a conductor cuts across a magnetic field or the field through a coil changes. The induced e.m.f. is larger with a **stronger magnet**, a **faster movement**, or **more turns** on the coil, and it always opposes the change causing it. Find the direction of the induced current with **Fleming's right-hand rule 弗莱明右手定则** (thumb = motion, first finger = field, second finger = current); for the force on a current-carrying wire use the left-hand rule instead.

In an **a.c. generator 交流发电机** a coil spins in a magnetic field, and **slip rings 滑环** with brushes carry the current out. The e.m.f. is largest when the coil is flat, because its sides then cut the field fastest, and zero when the coil is upright, because its sides move along the field. So the e.m.f.-time graph is a sine curve: peak, zero, opposite peak, zero for each turn.

A **transformer 变压器** has a **primary coil 原线圈** and a **secondary coil 副线圈** wound on a laminated **soft-iron core 软铁芯**. The a.c. in the primary makes a changing field

Method — Induction, the generator and the transformer

in the core; the core carries that field to the secondary, where it induces an alternating e.m.f. It works only on a.c., because a steady current makes no change of field.

$$\frac{V_p}{V_s} = \frac{N_p}{N_s} \qquad I_p V_p = I_s V_s \text{ (at 100\% efficiency)}$$

Worked example (transmission). A power station sends 2.0 MW along cables of total resistance $5.0\ \Omega$. Compare the loss at 10 kV and at 400 kV.

1. At 10 kV: $I = \dfrac{P}{V} = \dfrac{2.0 \times 10^6}{10\,000} = 200$ A, so the loss is $I^2 R = 200^2 \times 5.0 = 200\,000$ W, a tenth of the power sent.
2. At 400 kV: $I = \dfrac{2.0 \times 10^6}{400\,000} = 5.0$ A, so the loss is $5.0^2 \times 5.0 = 125$ W.

Method — Induction, the generator and the transformer

That is why a step-up transformer raises the voltage for transmission and a step-down transformer lowers it again for homes: the same power at a higher voltage needs a smaller current, and the heating loss I^2R falls with the square of the current.

Practice 2.1 ▪ 2 marks

State two ways to increase the force on a current-carrying wire in a magnetic field.

Solution 2.1

Worked steps

increase the current; use a stronger magnetic field B1 B1.

Practice 2.2 ▪ 1 mark

State what a step-up transformer does to the voltage.

Solution 2.2

Worked steps

it increases (steps up) the voltage **B1**.

Practice 2.3 ▪ 3 marks

State three ways to increase the e.m.f. induced in a coil by a moving magnet.

Solution 2.3

Method: Induction, the generator and the transformer

Worked steps

Any three of: use a stronger magnet; move the magnet or coil faster; use more turns on the coil; use a coil of larger area B3.

Practice 2.4 ▪ 2 marks

State the two parts that carry the current out of a spinning generator coil, and state where in the turn the e.m.f. is zero.

Solution 2.4

Method: Induction, the generator and the transformer

Worked steps

Slip rings and carbon brushes **B1**. The e.m.f. is zero when the coil is upright, so its sides move along the field instead of cutting across it **B1**.

Practice 2.5 ▪ 3 marks

Describe the construction of a simple transformer.

Solution 2.5

Worked steps

Two coils, a primary and a secondary **B1**, wound on a soft-iron core **B1** that links the coils magnetically but is not electrically connected to them **B1**.

Exam-style 3.1 ▪ 1 mark

Reversing the current in a wire in a magnetic field:

- **A** removes the force
- **B** reverses the force
- **C** doubles the force
- **D** has no effect

Solution 3.1

A removes the force

B reverses the force ✓

C doubles the force

D has no effect

Worked steps

B. Reversing the current reverses the direction of the force.

Exam-style 3.2 ▪ 3 marks

A transformer has 200 turns on the primary and 1000 turns on the secondary. The primary voltage is 12 V.

(a) Find the secondary voltage.

(b) State whether this is a step-up or step-down transformer.

Solution 3.2

Worked steps

(a) $\dfrac{V_p}{V_s} = \dfrac{N_p}{N_s}$: $\dfrac{12}{V_s} = \dfrac{200}{1000}$ **M1**; $V_s = 12 \times 5$ **M1**; $= 60$ V **A1**.

(b) step-up (more turns on the secondary) **B1**.

Exam-style 3.3 ▪ 3 marks

Describe how an e.m.f. is induced when a magnet is moved into a coil, and state two ways to make the induced e.m.f. larger.

Solution 3.3

Method: Induction, the generator and the transformer

Worked steps

(a) $I = \dfrac{P}{V} = \dfrac{2.0 \times 10^6}{400\,000}$ **M1** $= 5.0$ A **A1**.
(b) $P = I^2 R = 5.0^2 \times 5.0$ **M1** $= 125$ W **A1**.
(c) At 10 kV the current would be 200 A, forty times larger **B1**; the loss is $I^2 R$, so it would be about 1600 times larger, roughly 200 kW **B1**.
(d) $\dfrac{V_p}{V_s} = \dfrac{N_p}{N_s}$ **M1**; $\dfrac{20\,000}{400\,000} = \dfrac{500}{N_s}$ **M1**; $N_s = 10\,000$ turns **A1**.
(e) A direct current gives a steady magnetic field in the core, and a field that does not change induces no e.m.f. in the secondary **B1**.

Exam-style 3.3 ▪ 2 marks

A power station generates 2.0 MW of electrical power, transmitted through cables of total resistance $5.0\ \Omega$.

(a) A step-up transformer raises the voltage to 400 kV. Calculate the current in the cables.

(b) Calculate the power wasted as heat in the cables.

(c) Explain why much more power would be wasted if the voltage were only 10 kV.

(d) The step-up transformer has 500 turns on its primary and the generator supplies 20 kV. Calculate the number of turns on the secondary.

(e) Explain why a transformer cannot be used with a direct current.

Solution 3.3

Method: Induction, the generator and the transformer

Worked steps

(a) $I = \dfrac{P}{V} = \dfrac{2.0 \times 10^6}{400\,000}$ **M1** $= 5.0$ A **A1**.

(b) $P = I^2 R = 5.0^2 \times 5.0$ **M1** $= 125$ W **A1**.

(c) At 10 kV the current would be 200 A, forty times larger **B1**; the loss is $I^2 R$, so it would be about 1600 times larger, roughly 200 kW **B1**.

(d) $\dfrac{V_p}{V_s} = \dfrac{N_p}{N_s}$ **M1**; $\dfrac{20\,000}{400\,000} = \dfrac{500}{N_s}$ **M1**; $N_s = 10\,000$ turns **A1**.

(e) A direct current gives a steady magnetic field in the core, and a field that does not change induces no e.m.f. in the secondary **B1**.

Exam-style 3.4 ▪ 2 marks

A student spins a coil between the poles of a magnet and connects it to an oscilloscope.
(a) Sketch the e.m.f. against time for two complete turns of the coil.
(b) Explain, by referring to the position of the coil, why the e.m.f. is zero twice in each turn.
(c) The student spins the coil faster. State two changes to the trace.

Solution 3.4

Method: Induction, the generator and the transformer

Worked steps

(a) A sine-shaped curve **B1** crossing zero twice per turn, with two complete cycles shown **B1**.
(b) The e.m.f. is zero when the coil is upright **B1**, because its sides are then moving parallel to the field lines and cut none of them **B1**.
(c) The peaks are higher **B1** and the cycles are closer together, so the frequency is higher **B1**.