Exercise walk-through

Electromagnetic induction ▪ 20.5

eXercise

You must be able to

- use **magnetic flux** $\Phi = BA$ and **flux linkage** $N\Phi$
- apply **Faraday's** and **Lenz's** laws

Method — Flux and flux linkage

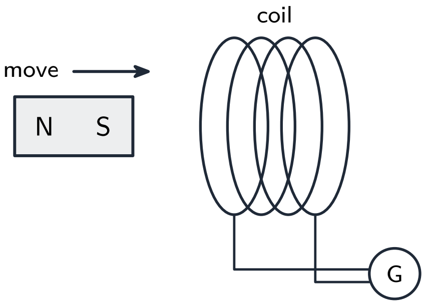
$$\Phi = BA \quad (\text{weber, Wb}), \qquad \text{flux linkage} = N\Phi = NBA.$$

Method — Induction

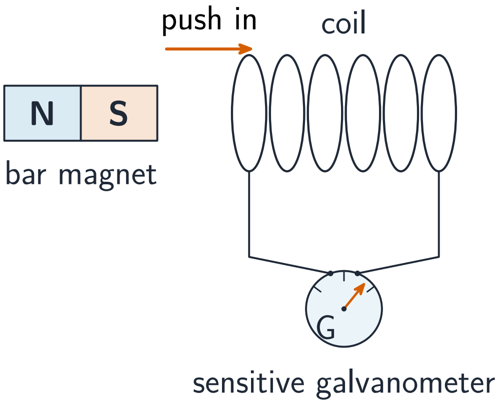
A **changing** flux linkage induces an e.m.f.:

- **Faraday's law:** the induced e.m.f. $\propto$ the **rate of change of flux linkage**: $E = \dfrac{\Delta(N\Phi)}{\Delta t}$.
- **Lenz's law:** the induced e.m.f. **opposes the change** producing it (from conservation of energy).

Worked example. $N = 200$ turns, $A = 0.010\ \mathrm{m}^2$, B changes from 0.10 to 0.30 T in 0.50 s: $E = N\dfrac{A\Delta B}{\Delta t} = 200 \times \dfrac{0.010 \times 0.20}{0.50} = 0.80$ V.



Method — Induction



Inducing an EMF by changing flux

Method — A moving conductor (motional e.m.f.)

A straight conductor of length L moving at speed v **perpendicular** to a field B **cuts** field lines, sweeping out area at the rate Lv. So flux is cut at the rate $B\,Lv$, inducing:

$$E = BLv.$$

The flux **cut** in a time Δt is then $\Phi = E\Delta t$ (since $E = \Delta\Phi/\Delta t$).
Worked example. A rod of length 0.30 m moves at 5.0 m s^{-1} across a 0.40 T field: $E = BLv = 0.40 \times 0.30 \times 5.0 = 0.60$ V.

Practice 2.1 ▪ 1 mark

Define **magnetic flux**.

Solution 2.1

Worked steps

The product of the **magnetic flux density** and the **area perpendicular** to it ($\Phi = BA$) **B1**.

Practice 2.2 ▪ 2 marks

Write $\Phi = BA$ and the **flux linkage** for a coil of N turns.

Solution 2.2

Method: Induction

Worked steps

$\Phi = BA$; flux linkage $= N\Phi = NBA$ **B1** **B1**.

Practice 2.3 ▪ 1 mark

State **Faraday's law**.

Solution 2.3

Worked steps

The induced e.m.f. is **proportional to the rate of change of flux linkage** B1.

Practice 2.4 ▪ 1 mark

State **Lenz's law**.

Solution 2.4

Worked steps

The induced e.m.f. (or current) is in a direction that **opposes the change** that produces it **B1**.

Exam-style 3.1 ▪ 1 mark

The induced e.m.f. in a coil is proportional to the:

A magnetic flux

B rate of change of flux linkage

C area of the coil

D current in the coil

Solution 3.1

Method: Induction

A magnetic flux

B rate of change of flux linkage ✓

C area of the coil

D current in the coil

Worked steps

B — rate of change of flux linkage.

Exam-style 3.2 ▪ 3 marks

A coil of 200 turns and area 0.010 m^2 is in a field that changes from 0.10 T to 0.30 T in 0.50 s. Calculate the induced **e.m.f.**

Solution 3.2

Method: Induction

Worked steps

$$E = N\frac{\Delta\Phi}{\Delta t} = N\frac{A\Delta B}{\Delta t} = 200 \times \frac{0.010 \times (0.30 - 0.10)}{0.50} \quad \boxed{\textbf{M1}}\boxed{\textbf{M1}} = 0.80\ \text{V} \quad \boxed{\textbf{A1}}.$$

Exam-style 3.3 ▪ 3 marks

State **Lenz's law** and explain how it follows from **conservation of energy**.

Solution 3.3

Method: Induction

Worked steps

The induced e.m.f./current **opposes the change** producing it B1; if it aided the change, the current would grow without an energy source — impossible B1; so opposing it conserves energy (work must be done against the force) B1.

Exam-style 3.4 ▪ 2 marks

Describe an experiment to show that a **changing magnetic flux** induces an e.m.f.

Solution 3.4

Method: Induction

Worked steps

Move a **magnet into a coil** connected to a galvanometer B1; the galvanometer **deflects** while the flux changes (and reads zero when the magnet is still) B1.

Exam-style 3.5 ▪ 2 marks

An aircraft of wingspan 30 m flies horizontally at 250 m s^{-1} through the vertical component of the Earth's magnetic field, $B = 4.5 \times 10^{-5}$ T.

(a) Calculate the e.m.f. induced between the wingtips.

(b) Calculate the magnetic flux **cut** by the wings in 15 s.

Solution 3.5

Method: Induction

Worked steps

(b) $\Phi = E\Delta t = 0.34 \times 15$ M1 $= 5.1$ Wb A1.

Exam-style 3.6 ▪ 2 marks

An aircraft with a wingspan of 34 m flies horizontally through the Earth's magnetic field. The **vertical** component of the field is 4.4×10^{-5} T. An e.m.f. of 0.55 V is induced between the wingtips P and Q.

(a) **State** Faraday's law of electromagnetic induction.

(b) **Calculate** the magnetic flux cut by the wings in 15 s. Give a **unit** with your answer.

(c) **Determine** the area swept by the wings in that time.

(d) Hence **determine** the speed of the aircraft.

(e) Use **Lenz's law** to explain how you would decide which wingtip is at the higher potential.

(f) **State and explain** what happens to the induced e.m.f. if the aircraft flies at the same speed directly over the magnetic **equator**, where the field is horizontal.

Solution 3.6

Method: Induction

Worked steps

(a) The magnitude of the induced e.m.f. is **proportional to the rate of change of magnetic flux linkage** **B1**; the flux linkage is the flux through the circuit multiplied by the number of turns **B1**.

(b) $\Phi = \varepsilon t = 0.55 \times 15$ **M1** $= 8.25$ Wb — the weber, equal to a volt second **A1**.

(c) $\Phi = BA$, so $A = \dfrac{\Phi}{B} = \dfrac{8.25}{4.4 \times 10^{-5}}$ **M1** $= 1.9 \times 10^{5}$ m^2 **A1**.

(d) The wings sweep an area $A =$ (span) $\times$ (distance), so distance $= \dfrac{1.875 \times 10^{5}}{34} = 5.5 \times 10^{3}$ m **M1**; $v = \dfrac{5515}{15} = 3.7 \times 10^{2}$ m s^{-1} **A1**.

Solution 3.6

(e) The induced e.m.f. drives a current in the direction that **opposes the change producing it** B1. Imagine completing the circuit: the induced current must create a magnetic field opposing the change in flux through it B1, and the wingtip that the conventional current flows **towards** inside the wing is the one at the higher potential — apply the right-hand rule to the field direction and the aircraft's velocity to decide which B1.

(f) The e.m.f. becomes **zero** B1. Only the component of the field **perpendicular** to the swept area cuts through it, and a horizontal field is parallel to the area a horizontally-flying wing sweeps out, so no flux is cut B1.