

20.5 Electromagnetic induction

Name: _____ Class: _____ Date: _____

Total: 31 marks

KEY WORDS flux linkage 磁链 • lenz's law 楞次定律 • faraday's law 法拉第定律
 • magnetic field 磁场 • magnetic flux 磁通量

Objective

Build the skills to answer exam questions on **electromagnetic induction**.

You must be able to:

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

1 Worked examples

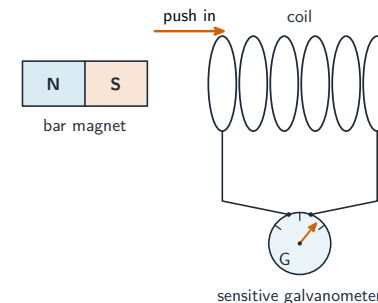
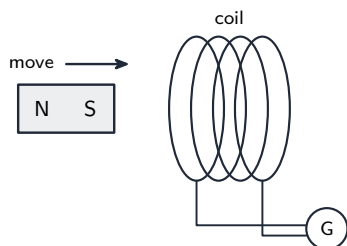
Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ Flux and flux linkage

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

■ Induction

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



Inducing an EMF by changing flux

- **Faraday's law:** the induced e.m.f. $\propto$ the **rate of change of flux linkage**:

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

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

■ 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 BLv , 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: $E = BLv = 0.40 \times 0.30 \times 5.0 = 0.60 \text{ V}.$

2 Practice

Now apply the methods above.

2.1 Define **magnetic flux**.

[1]

2.2 Write $\Phi = BA$ and the **flux linkage** for a coil of N turns. [2]

2.3 State **Faraday's law**. [1]

2.4 State **Lenz's law**. [1]

3 Exam-style questions

3.1 The induced e.m.f. in a coil is proportional to the: [1]

- A magnetic flux
- B rate of change of flux linkage
- C area of the coil
- D current in the coil

3.2 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.** [3]

3.3 State **Lenz's law** and explain how it follows from **conservation of energy**. [3]

3.4 Describe an experiment to show that a **changing magnetic flux** induces an e.m.f. [2]

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

(a) Calculate the e.m.f. induced between the wingtips. [2]

(b) Calculate the magnetic flux **cut** by the wings in 15 s . [2]

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

(a) **State** Faraday's law of electromagnetic induction. [2]

(b) **Calculate** the magnetic flux cut by the wings in 15 s . Give a **unit** with your answer. [2]

(c) **Determine** the area swept by the wings in that time. [2]

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

[2]

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

[3]

(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.

[2]

Solutions

Each answer shows the steps, then the **result**.

2.1

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

2.2

- $\Phi = BA$
- flux linkage $= N\Phi = NBA$

2.3

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

2.4

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

3.1 B

- Faraday: e.m.f. $\propto$ **rate of change of flux linkage**

3.2

- $E = N\Delta\Phi/\Delta t = NA\Delta B/\Delta t$

$$E = 200 \times \frac{(0.010 \text{ m}^2)(0.30 \text{ T} - 0.10 \text{ T})}{0.50 \text{ s}} = \mathbf{0.80 \text{ V}}$$

3.3

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

3.4

- move a **magnet into a coil** connected to a galvanometer
- the galvanometer **deflects** while the flux changes (and reads zero when the magnet is still)

3.5

(a) $E = BLv$

$$E = (4.5 \times 10^{-5} \text{ T})(30 \text{ m})(250 \text{ m s}^{-1}) = \mathbf{0.34 \text{ V}}$$

(b) $\Phi = E\Delta t$

$$\Phi = (0.34 \text{ V})(15 \text{ s}) = \mathbf{5.1 \text{ Wb}}$$

3.6

(a) the magnitude of the induced e.m.f. is **proportional to the rate of change of magnetic flux linkage**

- the flux linkage is the flux through the circuit multiplied by the number of turns

(b) $\Phi = \varepsilon t$

$$\Phi = (0.55 \text{ V})(15 \text{ s}) = \mathbf{8.25 \text{ Wb}}$$

— the weber, equal to a volt second

(c) $\Phi = BA$, so $A = \Phi/B$

$$A = \frac{8.25 \text{ Wb}}{4.4 \times 10^{-5} \text{ T}} = \mathbf{1.9 \times 10^5 \text{ m}^2}$$

(d) the wings sweep an area $A = (\text{span}) \times (\text{distance})$

$$\text{distance} = \frac{1.875 \times 10^5 \text{ m}^2}{34 \text{ m}} = 5.5 \times 10^3 \text{ m}$$

$$v = \frac{5515 \text{ m}}{15 \text{ s}} = \mathbf{3.7 \times 10^2 \text{ m s}^{-1}}$$

(e) the induced e.m.f. drives a current in the direction that **opposes the change producing it**

- imagine completing the circuit: the induced current must create a magnetic field opposing the change in flux through it
- the wingtip that the conventional current flows **towards** inside the wing is the one at the higher potential

(f) the e.m.f. becomes **zero**

- 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