

Exercise walk-through

20.5.1

Induced e.m.f. from a graph: gradients, the rotating coil and Lenz in action

A-Level Physics

Four patterns you must recognise

bar magnet

curved $N \rightarrow S$ outside; strongest near the poles

straight wire

circles; **right-hand grip** :
thumb = current, fingers = field

flat coil

field through the centre is at right angles; acts like a small bar magnet

solenoid

nearly **uniform** inside along the axis; outside falls off fast

Faraday and Lenz

Faraday : the induced e.m.f. equals the rate of change of flux linkage

$$|\varepsilon| = N \frac{d\Phi}{dt}$$

Lenz : the induced e.m.f. **opposes the change** that makes it – conservation of energy. Combined:

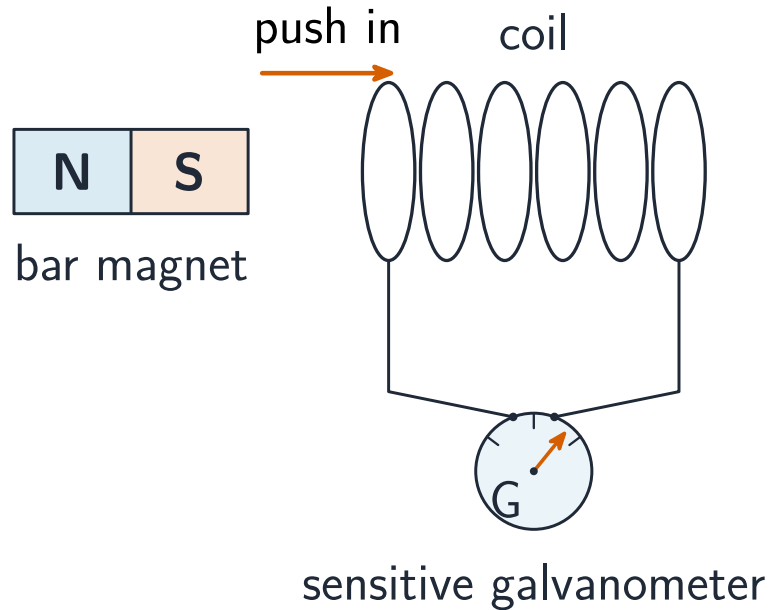
$$\varepsilon = - \frac{d(N\Phi)}{dt}$$

$N = 200$, $A = 0.010 \text{ m}^2$, B falls from 0.50 T to 0 in 0.20 s

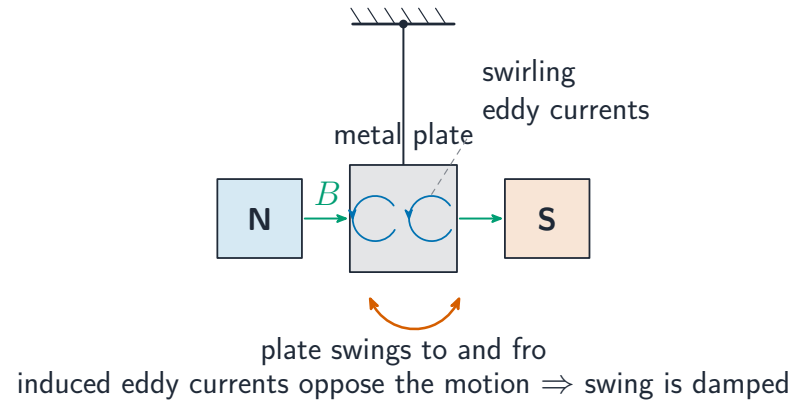
$$\Delta(N\Phi) = NBA = 1.0 \text{ Wb}$$

$$|\varepsilon| = \frac{1.0}{0.20} = 5.0 \text{ V}$$

Seeing induction happen



Faster motion, bigger deflection; reverse the motion, reverse the needle.



Eddy currents in the plate oppose its motion, so it stops quickly.

Exercises 2.1·2.2

2.1 A coil of 150 turns and cross-sectional area $4.0 \times 10^{-3} \text{ m}^2$ has its plane perpendicular to a uniform field of flux density 0.25 T. Calculate the flux linkage. [2]

2.2 The flux density in **2.1** then falls steadily to zero in 0.20 s. Calculate the magnitude of the induced e.m.f. [2]

Exercises 2.1·2.2

2.1 A coil of 150 turns and cross-sectional area $4.0 \times 10^{-3} \text{ m}^2$ has its plane perpendicular to a uniform field of flux density 0.25 T. Calculate the flux linkage. [2]

2.1

- the plane is perpendicular to the field, so the full area links the flux

$$N\Phi = NBA = 150 \times 0.25 \text{ T} \times 4.0 \times 10^{-3} \text{ m}^2 = \mathbf{0.15 \text{ Wb}}$$

2.2 The flux density in **2.1** then falls steadily to zero in 0.20 s. Calculate the magnitude of the induced e.m.f. [2]

2.2

- divide the change in flux linkage by the time

$$|E| = \frac{\Delta(N\Phi)}{\Delta t} = \frac{0.15 \text{ Wb}}{0.20 \text{ s}} = \mathbf{0.75 \text{ V}}$$

Exercises 2.3·2.4

2.3 The flux linkage through a coil rises steadily for 2.0 s, stays constant for 1.0 s, and then falls to zero in 1.0 s. Sketch a graph of the induced e.m.f. against time for these 4.0 s. [3]

2.4 A magnet is dropped through a coil connected to a datalogger. Explain why the trace shows two pulses of **opposite sign**. [2]

Exercises 2.3·2.4

2.3 The flux linkage through a coil rises steadily for 2.0 s, stays constant for 1.0 s, and then falls to zero in 1.0 s. Sketch a graph of the induced e.m.f. against time for these 4.0 s. [3]

2.3

- from 0 to 2.0 s: a **constant** e.m.f., of one sign
- from 2.0 to 3.0 s: **zero**
- from 3.0 to 4.0 s: **constant**, of the **opposite** sign and **twice** the earlier magnitude, because the same flux change happens in half the time

2.4 A magnet is dropped through a coil connected to a datalogger. Explain why the trace shows two pulses of **opposite sign**. [2]

2.4

- as the magnet enters, the flux linkage through the coil **increases**; as it leaves, the flux linkage **decreases**
- the gradient $\frac{d(N\Phi)}{dt}$ therefore has **opposite signs**, so the induced e.m.f. does too

Exercises 2.5·2.6

2.5 Explain why the second pulse is **taller and narrower** than the first.

[2]

2.6 A coil rotates at a steady rate in a uniform magnetic field. State the position of the coil at which the induced e.m.f. is **zero**, and explain why.

[2]

Exercises 2.5·2.6

2.5 Explain why the second pulse is **taller and narrower** than the first. [2]

2.5

- the magnet **accelerates** under gravity, so it is moving faster as it leaves than as it entered
- the same change of flux linkage therefore happens in a **shorter time**, giving a **larger** e.m.f. that lasts for **less** time – the two areas remain equal

2.6 A coil rotates at a steady rate in a uniform magnetic field. State the position of the coil at which the induced e.m.f. is **zero**, and explain why. [2]

2.6

- when the **plane of the coil is perpendicular to the field** – that is, when the flux linkage is a **maximum**
- at that instant the flux linkage is momentarily **not changing**, so $\frac{d(N\Phi)}{dt} = 0$ and the induced e.m.f. is zero

Exercise 3.1

3.1 A coil rotates at a steady rate in a uniform magnetic field. At the instant when the **plane of the coil is perpendicular to the field**, the flux linkage and the induced e.m.f. are [1]

☐

A flux linkage maximum, e.m.f. maximum

B flux linkage maximum, e.m.f. zero

C flux linkage zero, e.m.f. maximum

D flux linkage zero, e.m.f. zero

Exercise 3.1

3.1 A coil rotates at a steady rate in a uniform magnetic field. At the instant when the **plane of the coil is perpendicular to the field**, the flux linkage and the induced e.m.f. are [1]

- ☐ **A** flux linkage maximum, e.m.f. maximum
B flux linkage maximum, e.m.f. zero
C flux linkage zero, e.m.f. maximum
D flux linkage zero, e.m.f. zero

3.1 B

- with the plane of the coil perpendicular to the field, the full area links the flux, so the flux linkage is at its **maximum**
- a maximum is a turning point, so the flux linkage is momentarily constant and the e.m.f. is **zero**. **A** is the standard error: the e.m.f. follows the *rate of change*, not the flux

Exercise 3.2 (a)

3.2 A strong bar magnet is dropped down a long vertical **copper** tube. It takes several seconds to fall through. The same magnet dropped down an identical **plastic** tube falls through in a fraction of a second.

(a) Explain, in terms of flux, induced current and force, why the magnet falls slowly down the copper tube.

[4]

Exercise 3.2 (a)

3.2 A strong bar magnet is dropped down a long vertical **copper** tube. It takes several seconds to fall through. The same magnet dropped down an identical **plastic** tube falls through in a fraction of a second.

(a) Explain, in terms of flux, induced current and force, why the magnet falls slowly down the copper tube. [4]

(a)

- as the magnet falls, the magnetic flux linking each part of the copper tube **changes**
- an e.m.f. is induced, and because copper is a conductor a current – an **eddy current** – flows in the tube wall
- by **Lenz's law** the current is in the direction that **opposes the change** producing it
- so the tube exerts an **upward force** on the falling magnet, which nearly balances its weight, and the magnet falls slowly at almost constant speed

Exercise 3.2 (b)

3.2 A strong bar magnet is dropped down a long vertical **copper** tube. It takes several seconds to fall through. The same magnet dropped down an identical **plastic** tube falls through in a fraction of a second.

(b) Explain why the magnet falls freely down the plastic tube.

[2]

Exercise 3.2 (b)

3.2 A strong bar magnet is dropped down a long vertical **copper** tube. It takes several seconds to fall through. The same magnet dropped down an identical **plastic** tube falls through in a fraction of a second.

(b) Explain why the magnet falls freely down the plastic tube. [2]

(b)

- an e.m.f. is still induced in the plastic, because the changing flux does not care what the material is
- but plastic is an **insulator**, so no current flows, there is no opposing force, and the magnet falls freely under gravity

Exercise 3.3 (a)

3.3 A flat coil of 250 turns and area $1.8 \times 10^{-3} \text{ m}^2$ rotates at 50 revolutions per second about an axis perpendicular to a uniform magnetic field of flux density 85 mT.

(a) Calculate the maximum flux linkage through the coil.

[2]

Exercise 3.3 (a)

3.3 A flat coil of 250 turns and area $1.8 \times 10^{-3} \text{ m}^2$ rotates at 50 revolutions per second about an axis perpendicular to a uniform magnetic field of flux density 85 mT.

(a) Calculate the maximum flux linkage through the coil. [2]

(a)

- the maximum flux linkage is NBA , with the plane of the coil perpendicular to the field

$$N\Phi_{\max} = NBA = 250 \times 85 \times 10^{-3} \text{ T} \times 1.8 \times 10^{-3} \text{ m}^2 = \mathbf{3.8 \times 10^{-2} \text{ Wb}}$$

Exercise 3.3 (b)

3.3 A flat coil of 250 turns and area $1.8 \times 10^{-3} \text{ m}^2$ rotates at 50 revolutions per second about an axis perpendicular to a uniform magnetic field of flux density 85 mT.

(b) State the orientation of the coil when the flux linkage is a maximum, and state the induced e.m.f. at that instant. [2]

Exercise 3.3 (b)

3.3 A flat coil of 250 turns and area $1.8 \times 10^{-3} \text{ m}^2$ rotates at 50 revolutions per second about an axis perpendicular to a uniform magnetic field of flux density 85 mT.

(b) State the orientation of the coil when the flux linkage is a maximum, and state the induced e.m.f. at that instant. [2]

(b)

- the **plane of the coil is perpendicular to the field** (the normal to the coil is along the field)
- at that instant the induced e.m.f. is **zero**

Exercise 3.3 (c)

3.3 A flat coil of 250 turns and area $1.8 \times 10^{-3} \text{ m}^2$ rotates at 50 revolutions per second about an axis perpendicular to a uniform magnetic field of flux density 85 mT.

(c) On the same time axis, sketch the flux linkage and the induced e.m.f. against time, for one complete rotation. [3]

Exercise 3.3 (c)

3.3 A flat coil of 250 turns and area $1.8 \times 10^{-3} \text{ m}^2$ rotates at 50 revolutions per second about an axis perpendicular to a uniform magnetic field of flux density 85 mT.

(c) On the same time axis, sketch the flux linkage and the induced e.m.f. against time, for one complete rotation. [3]

(c)

- flux linkage: a **cosine** curve, starting at its maximum $3.8 \times 10^{-2} \text{ Wb}$, through zero, to $-3.8 \times 10^{-2} \text{ Wb}$ and back
- e.m.f.: a **sine** curve of the same period
- the e.m.f. curve is a **quarter of a cycle** ahead: its zeros are at the peaks of the flux-linkage curve, and its peaks are at the zeros

Exercise 3.3 (d)

3.3 A flat coil of 250 turns and area $1.8 \times 10^{-3} \text{ m}^2$ rotates at 50 revolutions per second about an axis perpendicular to a uniform magnetic field of flux density 85 mT.

(d) The peak e.m.f. is given by $E_0 = 2\pi f NBA$. Calculate it. [2]

Exercise 3.3 (d)

3.3 A flat coil of 250 turns and area $1.8 \times 10^{-3} \text{ m}^2$ rotates at 50 revolutions per second about an axis perpendicular to a uniform magnetic field of flux density 85 mT.

(d) The peak e.m.f. is given by $E_0 = 2\pi f NBA$. Calculate it. [2]

(d)

- substitute into $E_0 = 2\pi f NBA$, using the flux linkage from part (a)

$$E_0 = 2\pi f NBA = 2\pi \times 50 \text{ Hz} \times 3.8 \times 10^{-2} \text{ Wb} = \mathbf{12 \text{ V}}$$

Exercise 3.3 (e)

3.3 A flat coil of 250 turns and area $1.8 \times 10^{-3} \text{ m}^2$ rotates at 50 revolutions per second about an axis perpendicular to a uniform magnetic field of flux density 85 mT.

(e) The coil is now rotated at 100 revolutions per second. State the effect on the peak e.m.f. and on the period, and explain both. [2]

Exercise 3.3 (e)

3.3 A flat coil of 250 turns and area $1.8 \times 10^{-3} \text{ m}^2$ rotates at 50 revolutions per second about an axis perpendicular to a uniform magnetic field of flux density 85 mT.

(e) The coil is now rotated at 100 revolutions per second. State the effect on the peak e.m.f. and on the period, and explain both. [2]

(e)

- the peak e.m.f. **doubles**, to about 24 V, because $E_0 = 2\pi f NBA$ is proportional to f
- the period **halves**, to $1.0 \times 10^{-2} \text{ s}$, because $T = 1/f$; both changes follow from the same doubling of f