# 19.2 Induction (full D.4, HL)

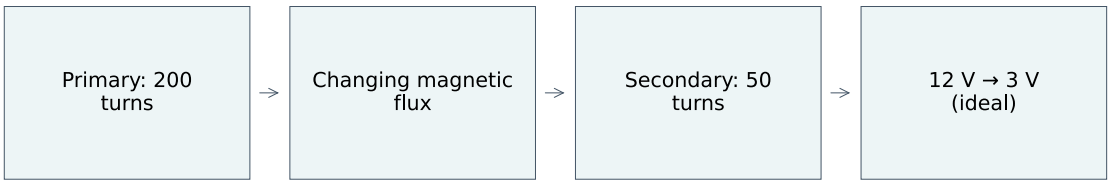
Name: _____ Class: _____ Date: _____ **Total: 24 marks**

**KEY WORDS** magnetic flux • Faraday's law of induction • Lenz's law

## Objective

Practise the full guide D.4 toolkit (HL only): magnetic flux $\Phi = BA\cos\theta$, Faraday's law $\varepsilon = -N\Delta\Phi/\Delta t$, Lenz's law as energy conservation, the moving-conductor emf $\varepsilon = BLv$, the sinusoidal emf of a coil rotating in a uniform field with peak $NBA\omega$, and the effect of rotation frequency on the output. Original practice; not an official IB paper.

## 1 Key knowledge and worked examples




### The D.4 equation set

$$\Phi = BA\cos\theta \qquad \varepsilon = -N\frac{\Delta\Phi}{\Delta t} \qquad \varepsilon = BLv \qquad \varepsilon_0 = NBA\omega$$

Lenz's law: the induced current opposes the change producing it – the minus sign in Faraday's law, and the reason work must be supplied to keep a generator turning.

### Worked example: from flux to emf

A 50-turn coil of area 0.050 m$^2$ sits in a 0.20 T field, its plane tilted 30° from the field-normal: $\Phi = 0.20 \times 0.050 \times \cos 30° = 8.7 \times 10^{-3}$ Wb. If that flux collapses to zero in 0.10 s: $\varepsilon = N\Delta\Phi/\Delta t = 50 \times 8.7 \times 10^{-3}/0.10 = 4.3$ V. Two habits: measure $\theta$ from the normal, not the plane; and check whether the question wants one loop's

emf or the coil's $N$-multiplied total.

## 2 Practice

**2.1** Define magnetic flux and state the angle used in $\Phi = BA\cos\theta$. [2]

**2.2** State Lenz's law and explain why it is a consequence of energy conservation. [2]

**2.3** A rod of length 0.15 m moves at 3.0 m/s perpendicular to a 0.40 T field. Calculate the induced emf. [2]

**2.4** State two changes that increase the peak emf of a coil rotating in a uniform magnetic field. [2]

## 3 Exam-style questions

**3.1** A single loop of area 0.020 $m^2$ lies with its plane perpendicular to a 0.50 T field. Calculate the flux through it; then, if the loop is pulled out of the field in 0.040 s, calculate the average induced emf. [4]

**3.2** A bar magnet hangs on a spring above a coil. The magnet oscillates, and the coil's ends are connected through a small lamp. Explain, using Lenz's law, why the magnet's oscillation dies away faster when the lamp circuit is closed than when it is open. [4]

**3.3** A rectangular coil of 200 turns and area 0.025 $m^2$ rotates at 25 rev/s in a 0.30 T field. Calculate the angular frequency and the peak emf, and describe how the output changes if the rotation rate is doubled. [5]

**3.4** A generator supplies more power when turned faster. Explain this in terms of Faraday's law and the energy the driving source must supply. [3]

## Solutions

Original-task marking: M1 method, A1 accuracy, B1 reasoning.

**2.1** The product of field strength and the perpendicular component of area it crosses: field through the surface; $\theta$ is the angle between the field and the normal to the surface.

**2.2** The induced current's field opposes the change in flux that produces it; the opposition means work must be done to keep the change going, and that work is exactly the electrical energy delivered – without opposition the induced current would create energy from nothing.

**2.3** $\varepsilon = BLv = 0.40 \times 0.15 \times 3.0 = 0.18$ V.

**2.4** Any two of: stronger field $B$; more turns $N$; larger area $A$; faster rotation $\omega$ – since $\varepsilon_0 = NBA\omega$.

**3.1** Plane perpendicular to the field means $\theta = 0$ to the normal: $\Phi = BA = 0.50 \times 0.020 = 1.0 \times 10^{-2}$ Wb; $\varepsilon = \Delta\Phi/\Delta t = 1.0 \times 10^{-2}/0.040 = 0.25$ V.

**3.2** The moving magnet changes the flux through the coil, inducing an emf that drives current through the lamp; by Lenz's law the current's field opposes the magnet's motion, an upward or downward force against it at every phase; the mechanical energy of oscillation converts to electrical energy and then to heat and light in the lamp; with the circuit open no current flows, no opposing force acts, and only the spring's own damping remains.

**3.3** $\omega = 2\pi f = 2\pi \times 25 = 157$ rad/s; $\varepsilon_0 = NBA\omega = 200 \times 0.30 \times 0.025 \times 157 = 236 \approx 240$ V; doubling the rotation rate doubles both the output frequency and the peak emf to about 470 V.

**3.4** Faster rotation raises the rate of flux change, so Faraday's law gives a larger emf and the generator drives more current and power; by Lenz's law the larger current pushes a stronger opposing force on the coils; the source must supply the extra mechanical work against that opposition – energy in equals electrical energy out plus losses.