Electromagnetic Induction

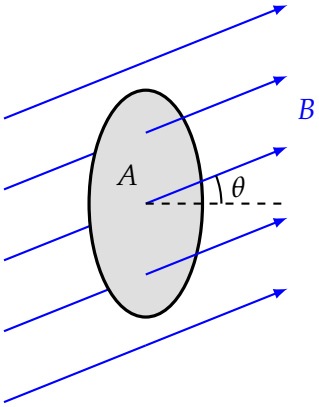
Name _____ Date _____

By the end of this topic I can...

- define magnetic flux and flux linkage
- state and use Faraday's law and Lenz's law
- find the e.m.f. $\mathcal{E} = BLv$ of a conductor cutting field lines
- explain eddy currents, magnetic braking and the a.c. generator

Flux and the laws of induction

Magnetic flux



_____ is the product of a _____ and the _____ through it at right angles:

where θ is the angle between B and the _____ to the area.

- unit: the _____ (Wb), 1 Wb = 1 T m^2
- if B is perpendicular to the area, ϕ = _____
- for a coil of N turns the _____ is

Think of it as the number of field lines passing through the coil.

- flux changes when B, A or θ changes: moving a magnet towards or away from a coil, varying the current in a solenoid, inserting an iron core, pushing a conductor through a field, rotating a coil in a field

Question 27.1 Explain why each process listed above gives a change in magnetic flux.

Faraday's law

Michael Faraday and Heinrich Lenz discovered the laws in the 1830s.

_____: the induced e.m.f. is _____.

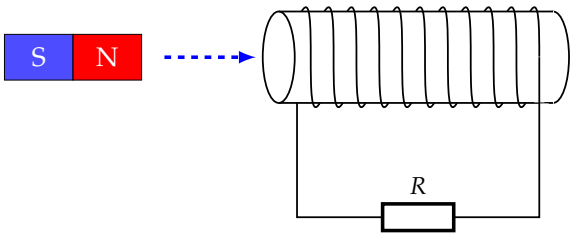
- in SI units:
- it gives the _____ of the e.m.f.; what matters is the _____ in flux. No change means no e.m.f.

Example 27.1 A coil of 80 turns is wound tightly round a solenoid of cross-sectional area 35 cm^2. The flux density at the centre of the solenoid is 75 mT. (a) Find the flux linkage. (b) The solenoid current is reversed in 0.40 s. Find the average induced e.m.f.

Lenz's law

_____: the induced current is in a direction so that its effects _____ that produces it.

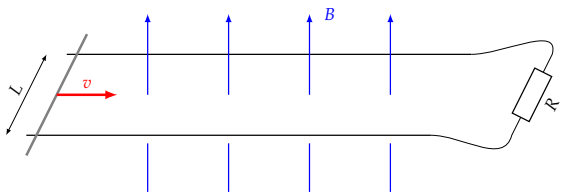
- it gives the _____ (polarity); this is the _____ in Faraday's law
- it follows from _____: induced current produces heat, so work must be done against the opposing force. If a motion causes the change, the magnetic force on the induced current _____ the motion.



Example 27.2 A coil of 200 turns of diameter 10 cm is connected to a resistor $R = 4.0\ \Omega$. A bar magnet far away is pushed (N pole first) into the coil in 2.0 s until the field inside is 0.40 T. (a) Find the average induced e.m.f. (b) Find the average current. (c) In which direction does the current flow through R?

Question 27.2 The magnet is now pulled away. State and explain the direction of the induced current.

Motional e.m.f.



Example 27.3 Two parallel tracks $L = 45$ cm apart are in a uniform field of 0.80 T (upwards), joined by a resistor $R = 6.0\ \Omega$. A metal rod is pushed along the tracks at $v = 3.0\ \text{m s}^{-1}$ towards R. (a) Find the induced current. (b) State its direction (seen from above). (c) Find the external force needed for constant speed.

- for a straight conductor cutting field lines at right angles:

Question 27.3 Find another way to determine the direction of the induced current in the rod above.

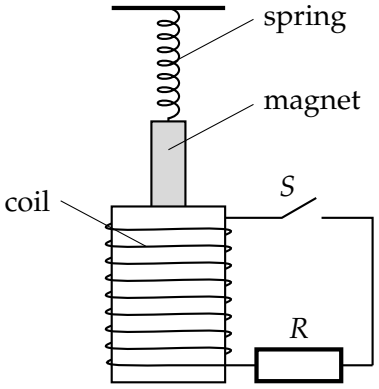
Applications

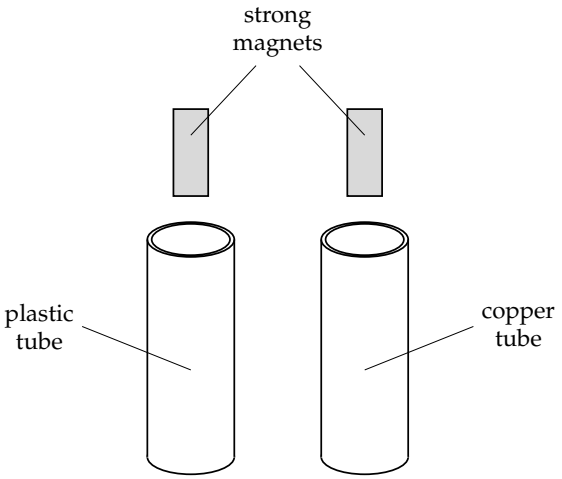
Magnetic braking

• **damped pendulum**: a metal disc swinging between the poles of an electromagnet stops quickly when the magnet is switched on. Different parts of the disc see different rates of change of flux, producing circulating _____.

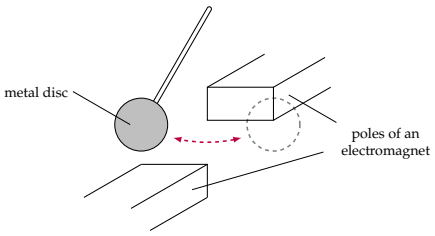
• the eddy currents _____ and the magnetic force on them _____: the oscillation is damped

• **falling magnet**: dropped through a plastic tube the magnet _____ ($a = g$). Through a copper tube _____ are induced and oppose the motion, so $a < g$ and the magnet falls _____.

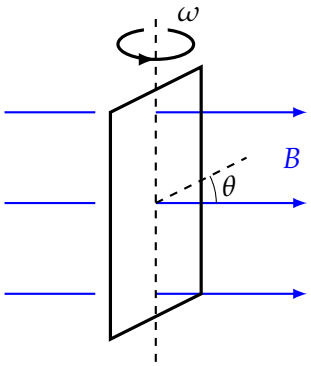




Question 27.4 A magnet hangs from a spring and oscillates in and out of a coil. With switch S open the amplitude hardly changes; with S closed it dies away quickly. Explain.



The generator



A coil of N turns and area A rotates at constant angular speed ω in a uniform field B. Taking $\theta = \omega t$ as the angle between the coil's _____ and the field ($\theta = 0$ at $t = 0$):

$$\Phi = NBA\sin\omega t$$

$$\mathcal{E} = \frac{\mathrm{d}\Phi}{\mathrm{d}t} = \boxed{}$$

a _____ (alternating) e.m.f. with maximum $\mathcal{E}_{\max}$ = _____.

- in practice, a strong electromagnet rotates inside fixed coils

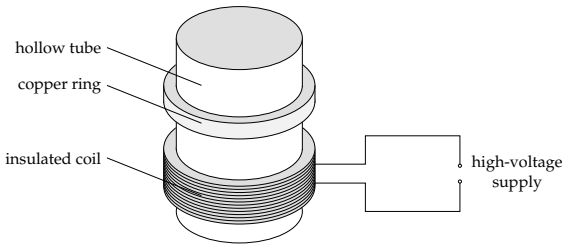
Question 27.5 State and explain the effect on the voltage if the coil rotates faster.

Question 27.6 Is the flux in phase with the e.m.f.? If not, what is the phase difference?

Question 27.7 Is the output maximum when the coil is parallel to the field or at right angles to it?

Electromagnetic gun

A light copper ring sits on a tube wound with a coil. When a high-voltage supply is switched on, the flux in the coil rises very quickly and induces a large _____ and current in the ring. By Lenz's law the force on the ring is _____, much greater than its weight, so the ring jumps up.



Question 27.8 The coil is connected to a steady d.c. supply. An iron core is quickly inserted into the tube. What might happen to the copper ring?

Further applications to research: wireless charging, induction cooking, contactless payment, stylus pens for tablets.