Section 3.2.1 – Making Electricity

Charge Separation in a Wire

Consider a wire moving downwards within a magnetic field, as shown in **Figure 1**. Using the R.H. slap rule upon both the negatively charged electrons and the positively charged cations, it can be seen that the charges move to opposite ends of the wire.

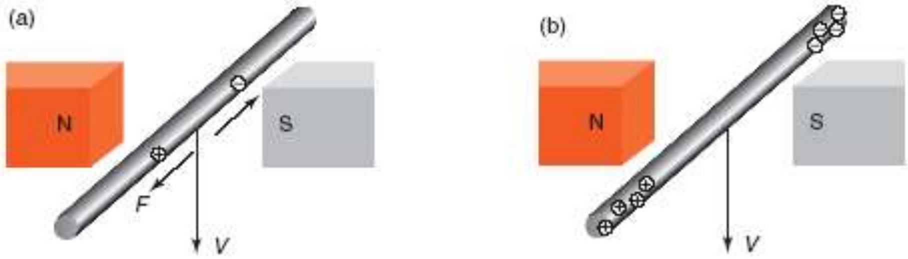


Figure 1

Electrons are free to move and create a negative end. However, cations are fixed within the lattice, but the lack of electrons present result in a positive end.
This charge separation, caused by a magnetic field, results in an **induced voltage** or **EMF.**

NB: As soon as the wire stops moving the magnetic force is reduced to zero.
The wire must remain moving to produce an induced voltage.

The factors that determine the magnitude of the **electromotive force (EMF)** are the **magnetic field strength (B)**, the **velocity** of the rod ***(v)*** and the **length** of the rod (***l***). The equation relating these variables is:

$$\varepsilon = Blv$$

Where ε represents the induced emf (Volts)
B represents the magnetic field strength (T)
l represents the length of the rod in the magnetic field (m)
v represents the speed of the rod (ms-1)

Example 1

A 10.0 cm metal rod moves at right angles across a magnetic field of strength 0.40 T at a speed of 50 cms^{-1}. Calculate the magnitude of the induced emf across the ends of the rod?

ε = ?	ε = B*lv*
l = 10.0 cm	= 0.40 × 0.10 × 0.50
= 0.10 m	= 0.02 Volts
v = 50 cms^{-1}	= <u>20 mV</u>
= 0.50 ms^{-1}	
B = 0.40 T	

Case Study - Slide Rail

Consider the apparatus shown in **Figure 2** below. It consists of a sliding rail of length (*l*) that can slide along a pair of metal strips at points P and Q. The apparatus also contains an ammeter to detect the presence and direction of current and a magnetic field which threads through the entire apparatus.

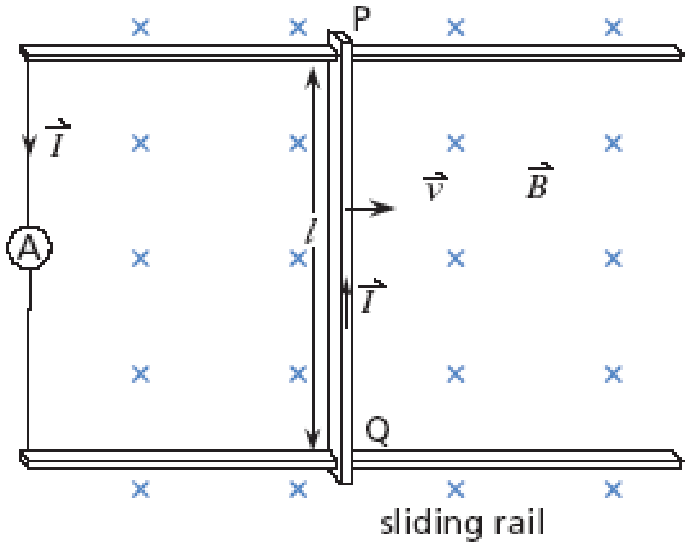


Figure 2

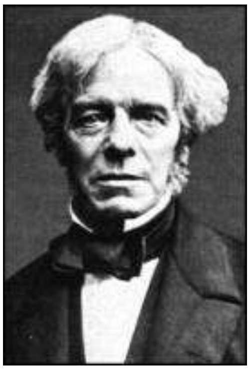
When the sliding rail is moved to the right, the charged particles within it gain a velocity to the right. One can use the RH slap rule upon the charged particles within the slide rail to predict that charge separation will occur an induced current will run from Q to P. This current flows outside of the field and is measured upon the ammeter

This induced current in turns generates its own magnetic field around the sliding rail, which interacts with the existing magnetic field into the page to produce an opposing force to the left (again using the R.H Slap Rule), opposite to the direction of the velocity of the sliding rail.

NB: Electrical energy does not magically appear from nowhere. Work must be done upon the sliding rail in order to generate electricity (ie. oppose the magnetic force).

Electromagnetic Induction

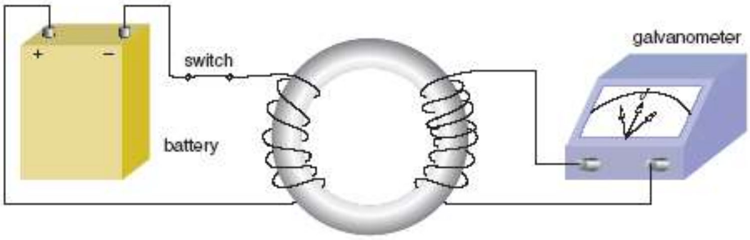
Michael Faraday discovered that **electricity** could be generated within a coil as a result of:



1. Changing the magnetic field, or;
2. Moving the coil within a constant magnetic field

Investigation A

His arrangement was as shown below:



A. Closing the switch

At the instance of closing the switch, the sensitive ammeter displayed a momentary current flow.

B. Opening the switch

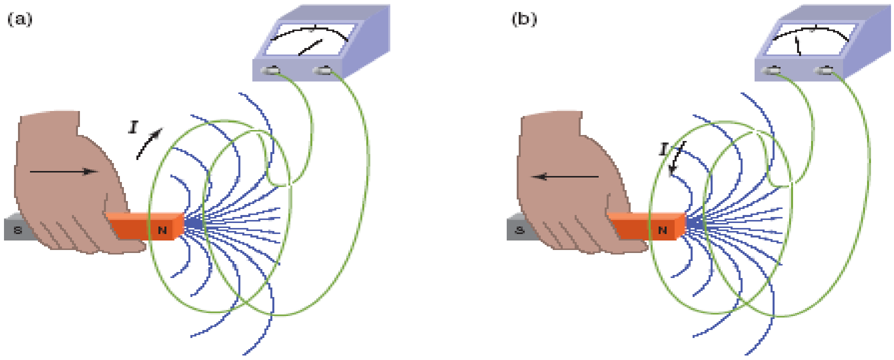
At the instance of opening the switch, the sensitive ammeter displayed a momentary current flow (in the opposite direction).

C. Switch closed or open

When the switch remains open or closed, no current flows.

Investigation B

His arrangement was as shown below:



A. Insert the magnet

Inserting the magnet produced a current.

B. Removing the magnet

Removing the magnet produced a current (in the opposite direction).

C. Stationary Magnet

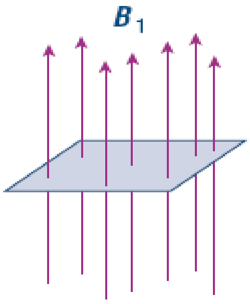
Produced no current at all.

Conclusion

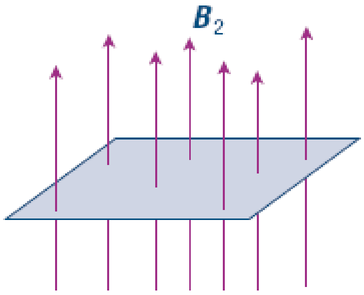
"The changing magnetic field induced an emf"

Magnetic Flux

Magnetic flux (ϕ_B) is defined as the product of the magnetic field strength (B) and the area (A). It is a measure of the amount of magnetic field passing through an area.



Magnetic flux 1
[A strong field]



Magnetic flux 2
[A weaker field, but same amount of flux]

NB: The strength of the magnetic field is represented by the number of field lines per unit area.

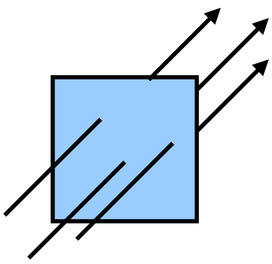
$$\phi_B = BA$$

Where ϕ_B = Magnetic flux (Wb)
B = Magnetic field strength (T)
A = Area (m^2)

NB: Magnetic flux is measured in Weber (Wb) [$1Wb = 1Tm^2$]

Example 2

Calculate the magnetic flux created by a magnetic field strength of 200 mT passing through a square frame, of sides 20 cm.

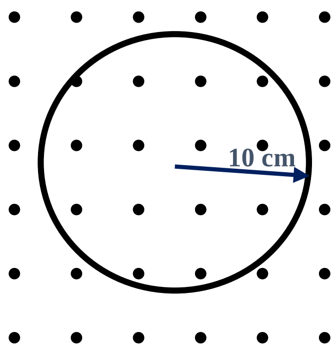


ϕ_B= ?
$B = 200 \times 10^{-3}$ T
$A = .20 \times .20$
$= 4.0 \times 10^{-2}\ m^2$

$\phi_B = BA$
$= 200 \times 10^{-3} \times 4.0 \times 10^{-2}$
= 0.008 Wb
= <u>8 mWb</u>

Example 3

Calculate the magnetic flux created by a magnetic field strength of 400 mT passing through a circular frame of radius of sides 10 cm.
[**NB:** the magnetic field is going out of the page]



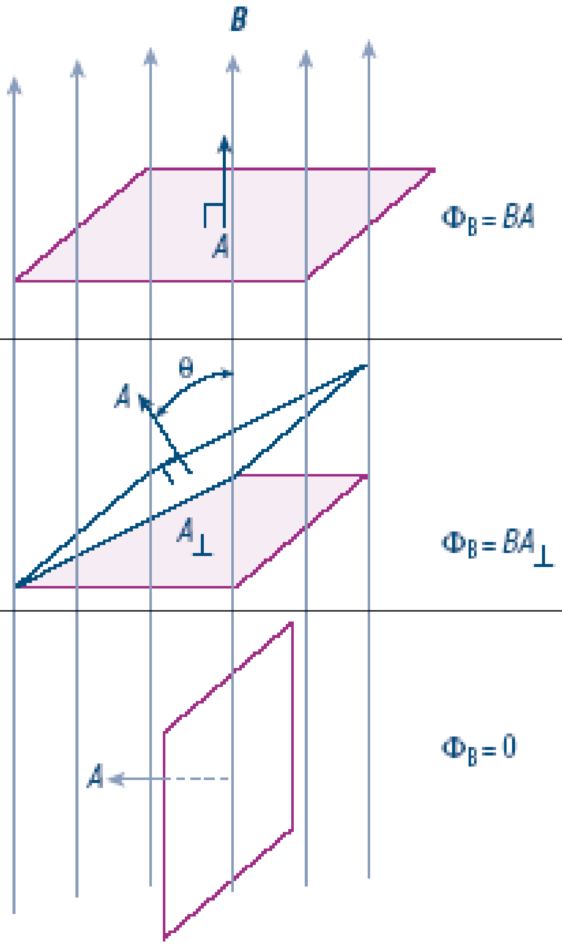
ϕ_B= ?
$B = 400 \times 10^{-3}$ T
r = 10 cm
= 0.10 m
$A = \pi r^2$
$= \pi \times (0.10)^2$
$= 0.0314\ m^2$

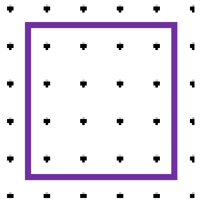
$\phi_B = BA$
$= 400 \times 10^{-3} \times 0.0314$
= 0.0126 Wb
= <u>12.57 mWb</u>

Δ Φ in a rotating coil

As a coil rotates through an originally perpendicular magnetic field (B), the amount of magnetic field lines that threat the coil decreases from a maximum to zero through a 180° rotation.

Side View **Top View**

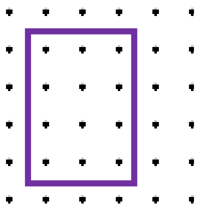




B ⊥ A

When B is perpendicular to A
$\varphi = BA$

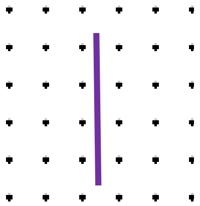
Φ is a maximum value



B ∠ A

When B is at an angle to A
$\Phi = BA \times (\cos\theta)$

$0 < \Phi < \Phi_{max}$

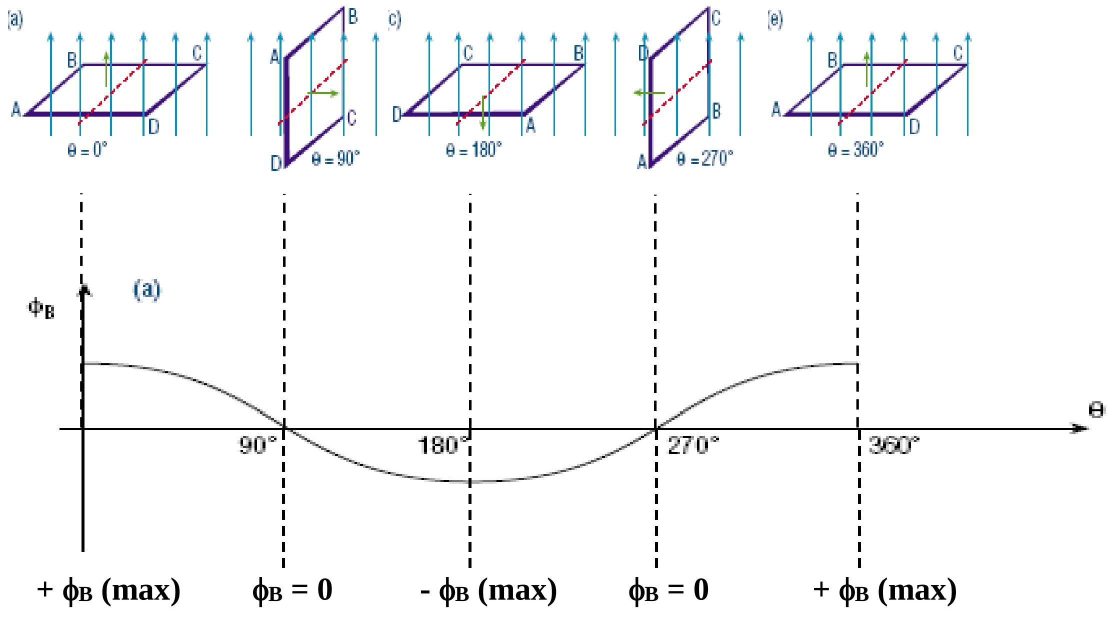


B ∥ A

When B is parallel to A
$\Phi = 0$

Example 4

Consider a square coil rotation 360° through a vertical magnetic field. What would the variation of magnetic flux (Φ) look like?



Exam Styled Questions

Question 1
Figure 1 shows a 50 turn rectangular coil of area 0.020 m^2 that can rotate in a uniform magnetic field of 2.0T. The coil is shown in three different orientations, A, B & C.

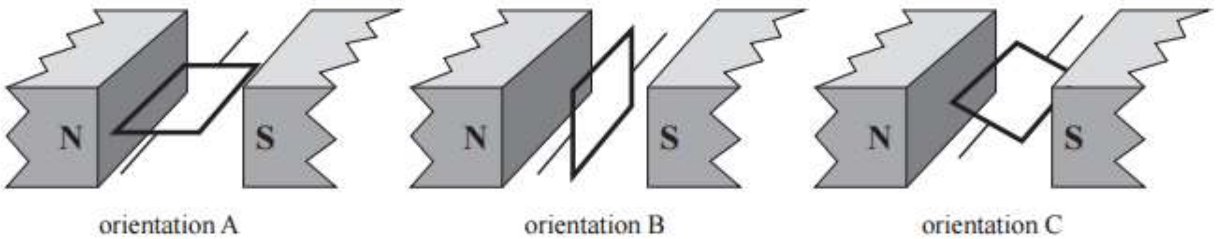


Figure 1

In orientation A the coil is the closest to the value of the magnetic flux through the coil when it is at orientation C?

A. 0 Wb
B. 0.03 Wb
C. 0.04 Wb
D. 1.5 Wb

The maximum flux through the coil is $\Phi = BA = 0.020 \times 2.0 = 0.04$ Wb, but the coil is at an angle so the flux is less, but not zero.
***NB:** The number of turns in the coil has no effect upon the magnetic flux.*

B

Students are experimenting with a simple AC generator, as shown in **Figure 2**. It consists of a rectangular coil of n turns that rotates at a constant speed in a uniform magnetic field.

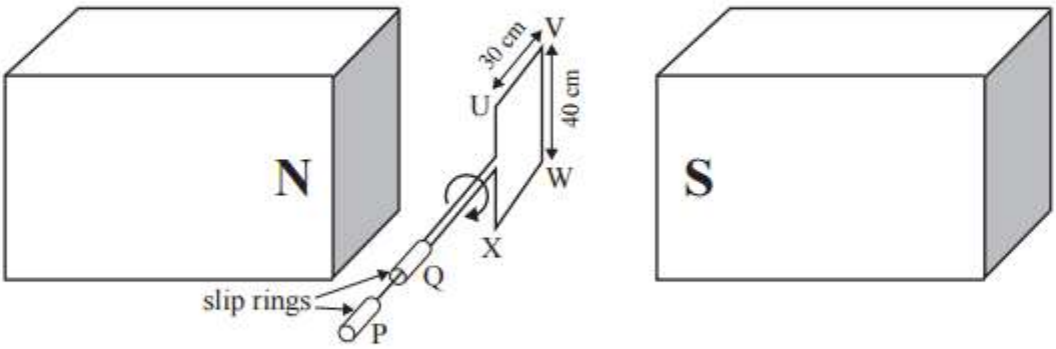


Figure 2

The uniform magnetic fi eld in the region between the magnets is 0.030 T. The dimensions of the rectangular coil are 30 cm × 40 cm. The coil is located completely within the uniform magnetic field of the two magnets.

Question 2

Describe how the magnetic flux through the rotating coil changes as the coil makes a complete rotation. Take the starting point of the rotation to be the position shown in Figure 2. You do not need to include any calculations or numbers in your answer. You may use a sketch in your answer.

Initially the flux through the coil is to the right and at a maximum value.
Over the next quarter turn the amount of flux reduces to zero.
For the next quarter turn, the flux enters from the other side of the coil, starting at zero and building to a maximum value.
For the third quarter turn, the amount of flux reduces to zero.
For the last quarter turn, the flux pass through the coil from the original side increasing back to the starting value. This can be represented as a cos graph with amount of flux to the right as positive.