SENIOR SIX TERM 2

TOPIC 3/5: MAGNETIC EFFECT OF AN ELECTRIC CURRENT

Competency: The learner appreciates that a current carrying conductor in a magnetic field experiences a force and uses this concept to design models of different devices to solve societal needs.

Magnetic flux density, B

Magnetic flux density (B) is defined as the force acting per unit current per unit length on a wire placed at right angle to the magnetic field.

The S.I unit of B is tesla (T)

A tesla is the magnetic flux density in which a straight conductor of length 1m placed across the field and carrying a current of one ampere experiences a magnetic force of one Newton (1N)

$1T = \frac{1N}{1A \times 1N}$

Magnetic flux, ϕ,

Magnetic flux, ϕ, is a measure of the number of magnetic lines passing normally across a given area of space. The strength of the magnetic field around a magnet depends on the number of lines per unit area.

Magnetic flux is thus, a product of magnitude of magnetic flux density and area of projection normal to magnetic field lines

I.e. $\phi = B \times A = BA$

S.I unit of magnetic flux ϕ is Weber (Wb)

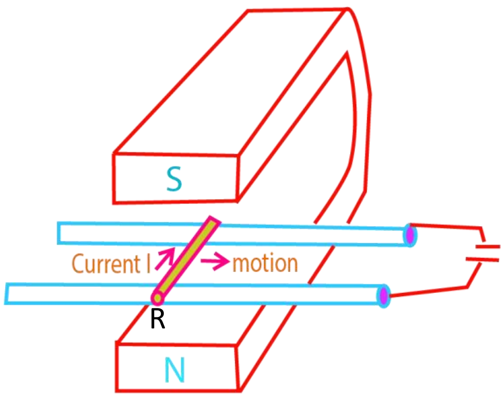
If a magnetic field is at an angle, θ, to the area, A, then

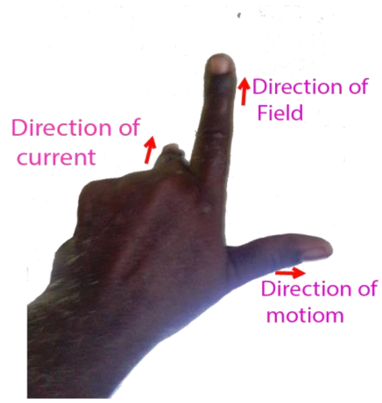
$\phi = BA\cos\theta$

The Magnetic Force on a current carrying conductor placed across a magnetic field and Fleming's Left Hand Rule

A conductor carrying a current I placed in a magnetic field due to some source other than itself, experiences a mechanical force.

Demonstration of a magnetic force on a current carrying conductor





Left hand

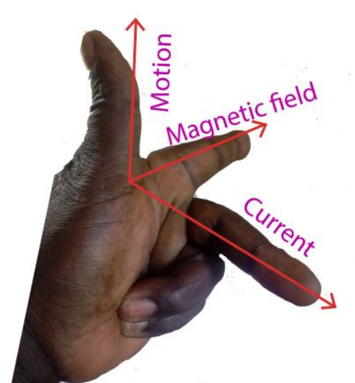
A short brass rod R is connected across a pair of brass rails, as shown in above.

A horseshoe magnet is placed so that the rod lies in the field between its poles.

When current passes through the rod, from an accumulator, the rod rolls along the rails, the direction of rolling is predicted by Fleming's Left Hand rule.

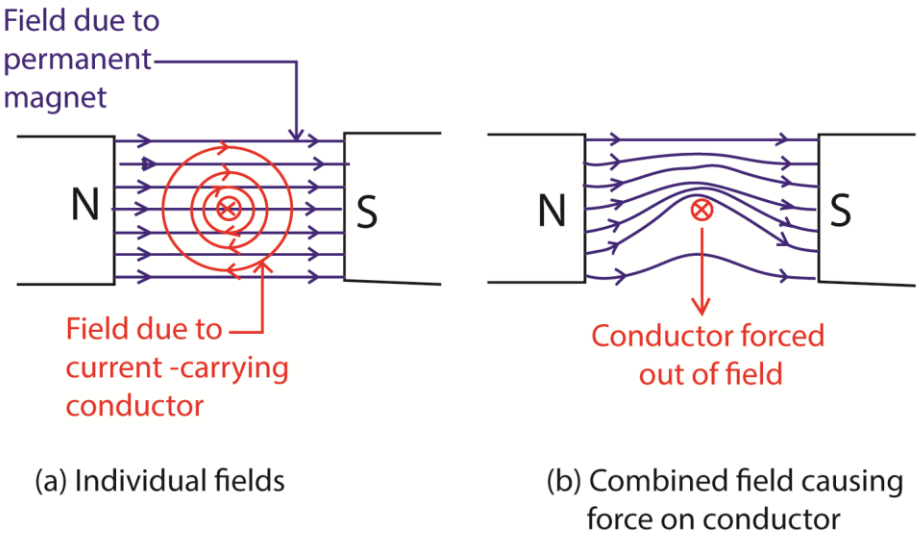
Fleming's Left Hand rule

States that when a straight conductor is placed across a magnetic field and a current is passed through it, the direction of magnetic force is predicted by the thumb when the first two fingers are placed perpendicular to each other. The first finger pointing in magnetic field direction and the second finger in the direction of current.



Flemings' left hand rule

Explanation for the origin of the force of current carrying conductor in a magnetic field



The current in the conductor produces a magnetic field around it.

This magnetic field of the current carrying conductor interacts with the magnetic field of the magnet.

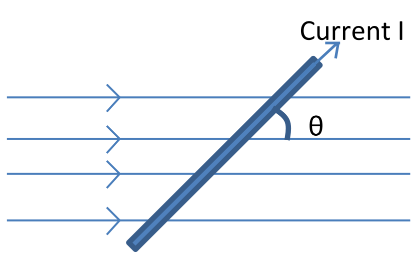
This creates a region of stronger magnetic field on one side of the wire and a weaker magnetic field on the opposite side.

A net force F = BIL then pushes the wire/conductor from the direction of stronger field to that of weaker field as shown above.

Factors affecting the magnitude of force experienced by a current carrying conductor placed across a magnetic field

i. Magnetic field strength or flux density, B; magnetic force increases with magnetic field density.
ii. Size of current, I, flowing through the conductor; the force is directly proportional to the current.
iii. Length L of the conductor; the force is directly proportional to the length of the conductor.
 i.e. $F \propto L$

iv. Angle of inclination of conductor across a magnetic field



$F = BIL\sin\theta$

When $\theta = 90^0$; $F = BIL$

When $\theta = 0$; $F = 0$

It follows that F is zero when the conductor is parallel to the field direction

Magnetic Permeability

Magnetic Permeability is the ability of the material to form an internal magnetic field within itself under the influence of an applied magnetic field.

Or

Magnetic permeability is the ability of a material to become magnetized when exposed to a magnetic field.

The SI unit of magnetic permeability is Henry per meter.

The main application of magnetic permeability is the characterization of magnetic materials such as paramagnetic, diamagnetic or ferromagnetic.

Electromagnets, transformers, and inductors use materials with significantly high magnetic permeability values.

Factors Affecting Magnetic Permeability

Magnetic permeability depends on the nature of the material, humidity, position in the medium, temperature, and frequency of the applied force.

Magnetic Permeability Formula

Magnetic permeability formula is given as;

Magnetic permeability (μ) = B/H

Where B = magnetic intensity and H = magnetizing field.

The SI unit of magnetic permeability is henneries per meter (H/m) or Newton per ampere squared ($N{\cdot}A^{-2}$).

Types of Permeability

The different types of permeability include;

(i) Permeability of Free Space, air or vacuum.

It is represented by $\mu_0 = B_0/H$

The ratio of magnetic intensity in a vacuum and magnetizing field.

(ii) Permeability of Medium

The ratio of magnetic intensity in the medium and magnetizing field.

It is expressed as;

μ = **B/H**

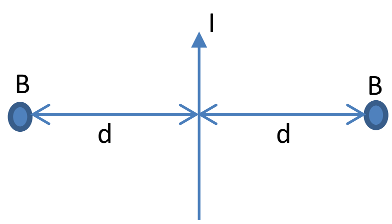
(iii) Relative Permeability

$\boldsymbol{\mu_r = \frac{\mu}{\mu_0}}$

Relative permeability = (number of lines of magnetic induction per unit area in a material)/(number of lines per unit area in a vacuum)

Calculation of magnetic flux density due to a current in straight wire conductor, a solenoid and a plane circular coil

(a) The magnetic field density, B for a point at distance, d, perpendicular to a straight wire carrying a current I in a medium of permeability, μ is obtained as follows.

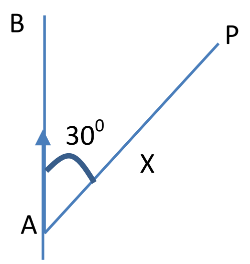


B = $\frac{\mu I}{2\pi d}$

In the vacuum B = $\frac{\mu_0 I}{2\pi d}$ where μ_0 = 4π x $10^{-7}$$Hm^{-1}$

Example 1

Use the diagram below, write down the expression for magnetic flux density at P due to



Solution

The perpendicular distance, d, of P from AB = xsin30^0.

Thus at P, B = $\frac{\mu_0 I}{2\pi\, x\, (x\sin 30)}$

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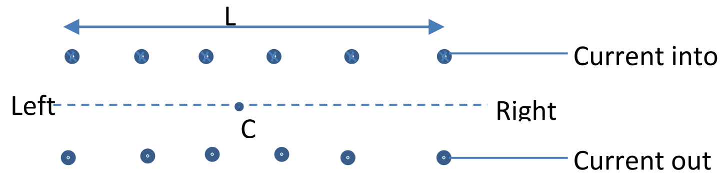
(b)(i) The magnetic flux density experienced at the centre and along the axis of a solenoid of length (L), number of turn (N), and carrying a current (I) is calculated from



At the center and along the axis of the solenoid magnetic flux density in air, B

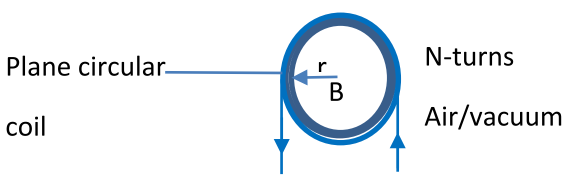
B = $\mu_0 nI$ where n = $\frac{N}{L}$ (number of turns per meter)

Or

B = $\frac{\mu_0 NI}{L}$

(b)(ii) The magnetic flux density experienced at either end of a solenoid of length (L), number of turn (N), and carrying a current (I) in the vacuum is half that in the centre, C and is equal to $\frac{\mu_0 NI}{2L}$

(c) The magnetic flux density B at the center of a plane circular coil of radius, r, and having N-turns of wire each carrying current I in the vacuum.



At the center of the coil, magnetic flux density, B = $\frac{\mu_0 NI}{2r}$ in the vacuum/air

Example 2

Determine the magnetic flux density at the center of plane circular coil of 10 turns each, radius r and currying a current I in a vacuum.

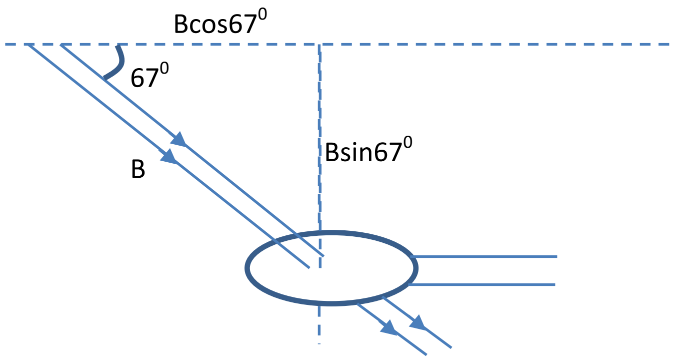
Solution

From B = $\frac{\mu_0 NI}{2r}$

B = $\frac{\mu_0 x\ 10\ x\ I}{2r} = \frac{5\mu_0 NI}{r}$

Example 3

A plane circular coil of 20 turns is placed with its surface flat on a horizontal table. If the plane of the coil is threaded by magnetic field of flux density 3.6x 10^{-5}T at an angle 67^0, find magnetic flux threading the coil of radius 5cm



Magnetic flux threading the plane of the coil normally

ϕ = B'A where B' = Bsin 67^0

= BAsin 67^0

= Bπr^2sin67^0

= 3.6 x 10^{-5} x π x (0.05)2 x sin67^0

= 2.6 x 10^{-7}Wb

Derivation of the formula, F = BIL

Consider a conductor of length L, cross section area A with N free electrons placed across magmetic

Field of magnetic field density B.

When a p.d is applied across its ends, the electrons begin to drift with velocity, V=$\frac{I}{neA}$; where n = $\frac{N}{AL}$ (number of electrons per unit volume.)

When the conductor is placed across an external magnetic field of density B, each electron experiences a force

F_1= BeV

=Be . $\frac{I}{neA}$

= $\frac{BI}{nA}$

Total force on N electrons, F = NF_1 =$\frac{NBI}{nA}$

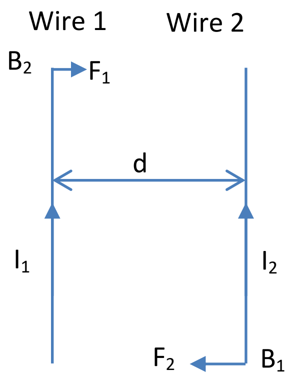
But N = nAL

Thus F = $\frac{(nAL)BI}{nA}$ = BIL

Calculation of magnetic force due to parallel straight wires/conductors carrying currents

(a) Derivation of an expression of attractive force, F, between two parallel wires carrying currents I_1 and I_2 in the same direction

Let $F_1 = B_2I_1L$ be the perpendicular attractive force wire 1 experiences due to magnetic field of wire 2 and $F_2 = B_1I_2L$ be the perpendicular attractive force experienced by wire 2 due to magnetic field of wire 1



Magnetic field due to wire 1 a distance d away = $B_1 = \frac{\mu_0 I_1}{2\pi d}$

Magnetic field due to wire 2, a distance d away = $B_2 = \frac{\mu_0 I_2}{2\pi d}$

Magnetic force acting on wire 1, $F_1 = B_2I_1L_1$

Substituting for B_2; $F_1 = \left(\frac{\mu_0 I_2}{2\pi d}\right) I_1 L_1 = \frac{\mu_0 I_2 I_1 L_1}{2\pi d}$ towards wire 2

Force per unit length, $F = \frac{F_1}{L_1} = \frac{\mu_0 I_2 I_1}{2\pi d}$

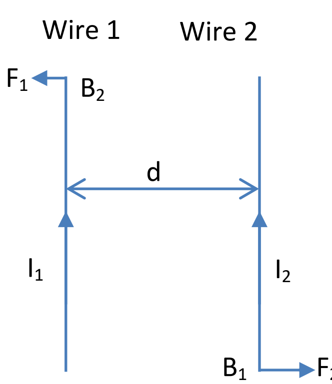
Magnetic force on wire 2, $F_2 = B_1I_2L_2$

Substituting for B_1, $F_2 = \left(\frac{\mu_0 I_1}{2\pi d}\right) I_2 L_2 = \frac{\mu_0 I_2 I_1 L_2}{2\pi d}$ toward wire 1

Force per unit length $F = \frac{F_2}{L_2} = \frac{\mu_0 I_2 I_1}{2\pi d}$

(b) Derivation of an expression of repulsive force, F, between two parallel wires carrying currents I_1 and I_2 in the opposite direction

Let $F_1 = B_2I_1L$ be the perpendicular repulsive force wire 1 experiences due to magnetic field of wire 2 and $F_2 = B_1I_2L$ be the perpendicular repulsive force experienced by wire 2 due to magnetic field of wire 1



Magnetic field due to wire 1 a distance d away = $B_1 = \frac{\mu_0 I_1}{2\pi d}$

Magnetic field due to wire 2, a distance d away = $B_2 = \frac{\mu_0 I_2}{2\pi d}$

Magnetic force acting on wire 1, $F_1 = B_2 I_1 L_1$

Substituting for B_2; $F_1 = \left(\frac{\mu_0 I_2}{2\pi d}\right) I_1 L_1 = \frac{\mu_0 I_2 I_1 L_1}{2\pi d}$ towards wire 2

Force per unit length, $F = \frac{F_1}{L_1} = \frac{\mu_0 I_2 I_1}{2\pi d}$

Magnetic force on wire 2, $F_2 = B_1 I_2 L_2$

Substituting for B_1, $F_2 = \left(\frac{\mu_0 I_1}{2\pi d}\right) I_2 L_2 = \frac{\mu_0 I_2 I_1 L_2}{2\pi d}$ toward wire 1

Force per unit length $F = \frac{F_2}{L_2} = \frac{\mu_0 I_2 I_1}{2\pi d}$

Generally $F_1 = F_2 = F$

When current is flowing in the same direction, the forces between the wires are attractive but in different directions, the forces are repulsive.

Ampere

It is a unit of current.

Definition

An ampere is a steady current which when flowing in each of two straight parallel wires of infinite length and negligible cross section area and placed a distance of 1m apart in a vacuum produce a force of 2×10^{-7}N per meter on each other.

Derivation of an ampere

From expression $\frac{F}{L} = \frac{\mu_0 I_2 I_1}{2\pi d}$

Suppose $I_1 = I_2 = 1A$, d = 1m, $\mu_0 = 4\pi \times 10^{-7}$H/m

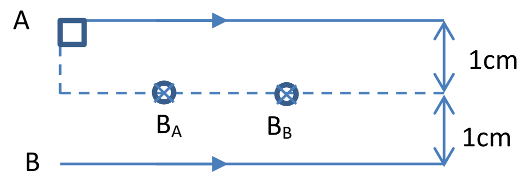
$\frac{F}{L} = \frac{4\pi \times 10^{-7} \times 1 \times 1}{2\pi \times 1} = 2.0 \times 10^{-7}$N/m

Example 4

Two straight wires A and B carry currents 4A and 6A respectively in a vacuum. Given that A and B are parallel to each other and are a distance of 2.0cm apart, calculate the resultant magnetic field mid-way between the wires carrying current in

(a) Opposite direction

Solution

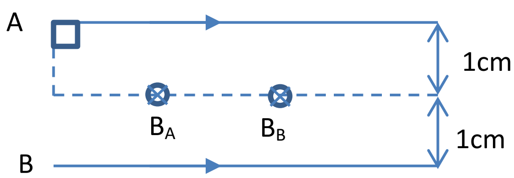


$B_A = \frac{\mu_0 I_A}{2\pi d_A}$; $B_B = \frac{\mu_0 I_B}{2\pi d_B}$

Resultant magnetic field midway, B = $B_A + B_B$; $d_A = d_B$ = 1cm = 0.01m

$B = \frac{\mu_0 x\ 4}{2\pi\ x\ 0.01} + \frac{\mu_0\ x\ 6}{2\pi\ x\ 0.01} = \frac{4\pi\ x\ 10^{-7}}{2\pi\ x\ 0.01}(4+6) = 2 \times 10^{-4}$T perpendicular to the plane of paper

(b) Same direction



Resultant magnetic field midway, B = $B_A + (-B_B)$; $d_A = d_B$ = 1cm = 0.01m

$B = \frac{\mu_0\ x\ 6}{2\pi\ x\ 0.01} - \frac{\mu_0\ x\ 4}{2\pi\ x\ 0.01} + = \frac{4\pi\ x\ 10^{-7}}{2\pi\ x\ 0.01}(6-4) = 4 \times 10^{-5}$T perpendicular to the plane of paper

Example 5

Find the force per unit length of the wires when IA = 8.0A, I_B =11.0A and r = 3.0cm (04marks)

The magnetic flux density which A produces at B is given by

$\frac{\mu_0 I_A}{2\pi r} = \frac{4\pi\ x\ 10^{-7}\ x\ 8}{2\pi\ x\ 3\ x\ 10^{-2}} = 5.30 \times 10^{-5}$T

Force exerted by A on B, F = BI_BL

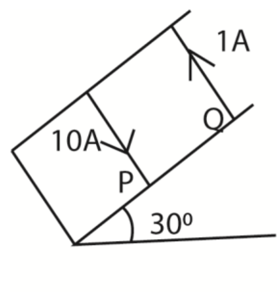
$\frac{F}{L} = BI_B = 5.30 \times 10^{-5} \times 11 = 5.85 \times 10^{-4} Nm^{-1}$.

Or

$\frac{F}{L} = \frac{\mu_0 I_A I_B}{2\pi r} = \frac{4\pi\ x\ 10^{-7} x\ 8\ x\ 11}{2\pi\ x\ 3\ x\ 10^{-2}} = 5.85 \times 10^{-4} Nm^{-1}$

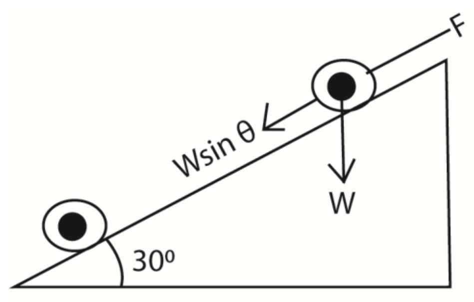
Example 6

Two parallel wires P and Q, each of length 0.2m carry currents of 10A and 1A respectively



The distance between the wires is 0.04m. If both wires remain stationary and the angle of the plane with the horizontal is 30^0. Calculate weight of Q.

Solution



Force F between the two wires is given by

F = $\frac{\mu_0 I_1 I_2 L}{2\pi a} = \frac{4\pi \ x\ 10^{-7} \ x\ 10 \ x\ 1 \ x\ 0.2}{2\pi \ x\ 0.4}$ = 1.0 x 10^{-3}N

But for equilibrium, the component of the weight along the slop is balanced by the magnetic force on the wire i.e. F = Wsinθ

=> W = $\frac{F}{\sin\theta} = \frac{1.0 \ x\ 10^{-3}}{\sin 30}$ = 2 x 10^{-3}N

Example 7

Two parallel wires, P and Q of equal length 0.1m, each carrying a current of 10A are a distance 0.05m apart with P directly above Q. If P remains stationary, find the weight of P. (03marks)

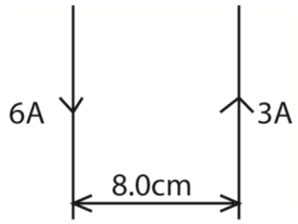
Solution

Force due to magnetic field on P = weight of P, W.

W = $\frac{\mu_0 I_1 I_2 L}{2\pi a} = \frac{4\pi \ x\ 10^{-7} \ x\ 10 \ x\ 10 \ x\ 0.1}{2\pi \ x\ 0.05}$ = 4.0 x 10^{-5}N

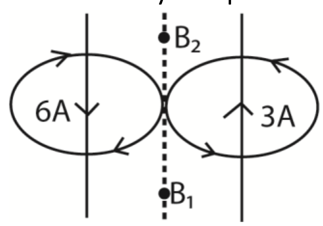
Example 8

Two straight long and straight wires of negligible cross-section area carry currents of 6.0A and 3.0A in opposite direction as shown below



If the wire are separated by a distance of 8.0cm, find the;

(i) Magnetic flux density at a point mid-way between the wires (04marks)



Magnetic flux density midway between the wires.

$B = B_1 + B_2$

$= \frac{\mu_0 I_1}{2\pi R} + \frac{\mu_0 I_2}{2\pi R}$

$= \frac{6 \, x \, 4\pi \, x \, 10^{-7}}{2\pi \, x \, 0.04} + \frac{3 \, x \, 4\pi \, x \, 10^{-7}}{2\pi \, x \, 0.04}$

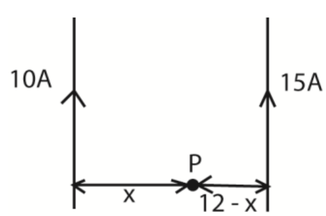
$= 4.5 \text{ x } 10^{-5}\text{T}$

(ii) Force per meter between the wire (03marks)

$\frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi a} = \frac{4\pi \, x \, 10^{-7} \, x \, 6 \, x \, 3}{2\pi \, x \, 0.08} = 4.5 \text{ x } 10^{-5}\text{Nm}^{-1}$

Example 9

Two long parallel wires placed 12cm apart in air carry currents of 10A and 15A respectively in the same direction. Determine the position where the magnetic flux is zero. (04marks)



Let P be the point where the resultant magnetic flux is zero

Then, $\frac{\mu_0 1_1}{2\pi x} = \frac{\mu_0 1_2}{2\pi(12-x)}$

$\frac{10}{x} = \frac{15}{12-x}$

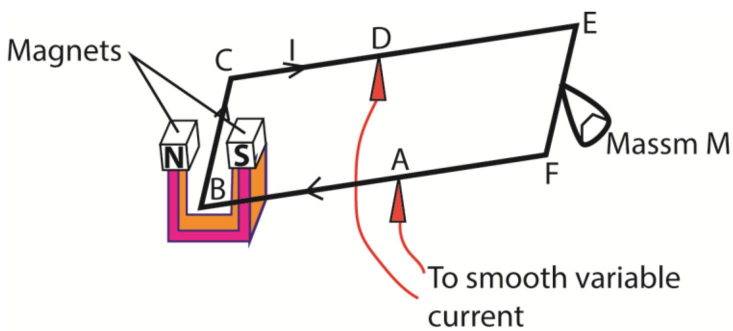
x = 4.8cm

P is 4.8cm from 10A current and 7.2 cm from the 15A current carrying conductor.

Measurements of current using a current balance

The **ampere balance** (also **current balance** or **Kelvin balance**) is an electromechanical apparatus used for the **precise** measurement of the SI unit of Electrical current, the **ampere**. It was invented by Williams Thomson 1st Baron Kelvin.

Set up



AB = AF, length BC = L and the current through the wire is A

The magnets provide a uniform magnetic field, B, perpendicular to wire BC.

At equilibrium when the frame BCEF is balanced

The force exerted on the wire = weight of the mass

$$BIL = Mg$$

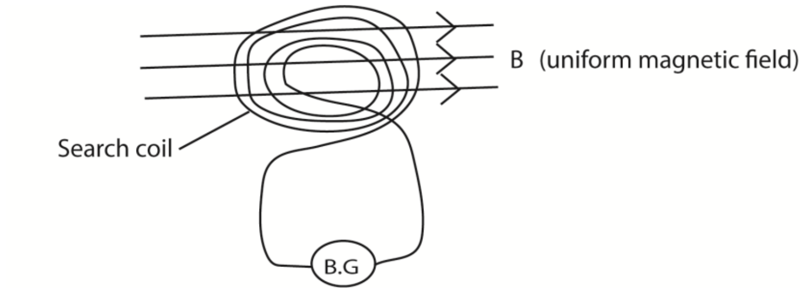
$$I = \frac{Mg}{BL}$$

Sources of error

- Accuracy of length L
- Rigidity of the frame
- To avoid overheating, the current should be switched off as soon as measurements have been taken.
- Shield the set-up from the disturbance of wind.

Experiments to measure magnetic flux density

(a) An experiment to determine the magnetic flux density of a uniform magnetic field using a search coil and ballistic galvanometer



A search coil of cross section area A and number of turn's N is connected in series with ballistic galvanometer. The search coil is then placed in uniform magnetic field such that the plane of the coil is perpendicular to the magnetic field. The coil is then pulled completely out of the field. The first deflection of the ballistic galvanometer noted θ_1.

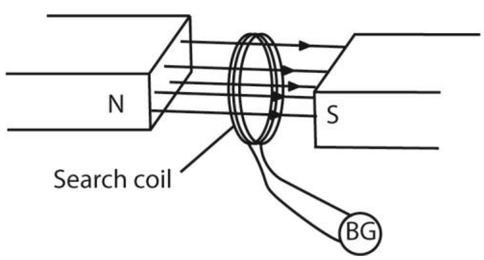
A capacitor of known capacitance C is then charged to a p.d. V and then charged through the ballistic galvanometer, θ_2 is noted

The magnetic flux density of uniform magnetic field is obtained from

B = $\frac{CVR}{AN} x \frac{\theta_1}{\theta_2}$

Where R is the resistance of the whole circuit.

(b) An experiment to measure the magnetic flux density between the poles of pieces of a strong magnet.



A search coil is connected to a ballistic galvanometer. The coil is then placed with its plane normal to the magnetic field whose magnetic flux density, B is required.

The coil is then pulled completely out of the field and deflection θ_1 of ballistic galvanometer is noted

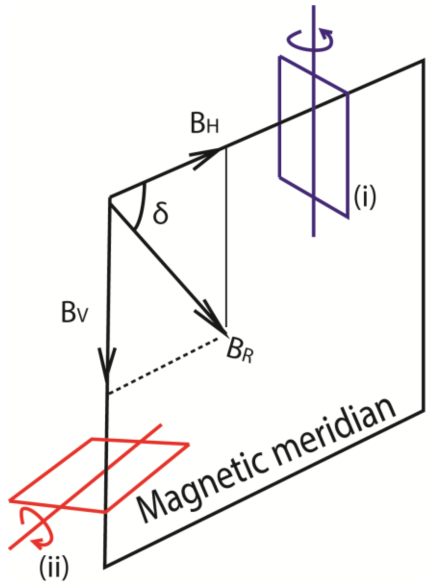
$\frac{NAB}{R} = CQ$, where R = resistance of the coil

A capacitor of known capacitance Q is charged to a p.d. V and is then discharged through the ballistic galvanometer. The deflection θ_2 is noted

CV = $C\theta_2$

The magnetic flux density B is now calculated from B = $\frac{CVR\theta}{NA\theta\prime}$ where A is the area of the coil, N is the number of turns in the coil and R is the resistance of the coil circuit.

(c) An experiment to determine the value of the earth's magnetic flux density at a place, using a search coil.



- A coil of known number of turns, N (about 100) and area A is connected to a calibrated ballistic galvanometer so that the total resistance in the circuit is R.
- The coil is placed in a vertical plane perpendicular to the magnetic meridian of the earth as shown in (i) in figure above. The coil is then rotated through 180^0 about the vertical axis. The maximum throw θ_1 is noted.
- The coil is then placed with its plane in horizontal plane perpendicular to the magnetic meridian of the earth as shown in (ii) in figure above. The coil is then rotated through 180^0 about the horizontal axis. The maximum throw θ_2 is noted.
- Treatment of results

  $B_H = \frac{k\theta_1 R}{2NA}$ and $B_V = \frac{k\theta_2 R}{2NA}$

  k is obtained by charging standard capacitor to a known p.d V and then discharging it through the ballistic galvanometer and the deflection α is noted.

  $k = \frac{CV}{\alpha}$

  Then B is calculated from $b = \sqrt{B_H^2 + B_V^2}$

Magnetic moment

Magnetic moment, also known as magnetic dipole moment, is the measure of the object's tendency to align with a magnetic field.

Magnetic Moment is defined as magnetic strength and orientation of a magnet or other object that produces a magnetic field.

The magnetic moment is a vector quantity. Magnetic moments of two magnets are compared using a deflected magnetometer.

The structure and mode of action of the deflection magnetometer

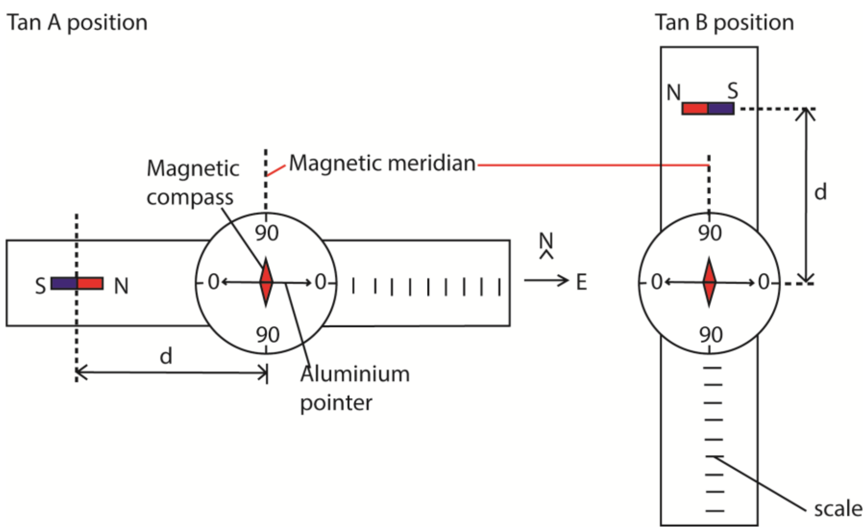
It consists of a small compass needle (small magnet) enclosed in a transparent box which is pivoted on a vertical axis and carries alight aluminium pointer. The pointer can rotate over a circular scale.

The box is fixed in the center of wooden box with two arms of linear scales of 0.5m each that coincide at the center of the magnetic compass.

Deflection magnetometer is used for

- Comparing magnetic moments of two magnets
- Verifying inverse law

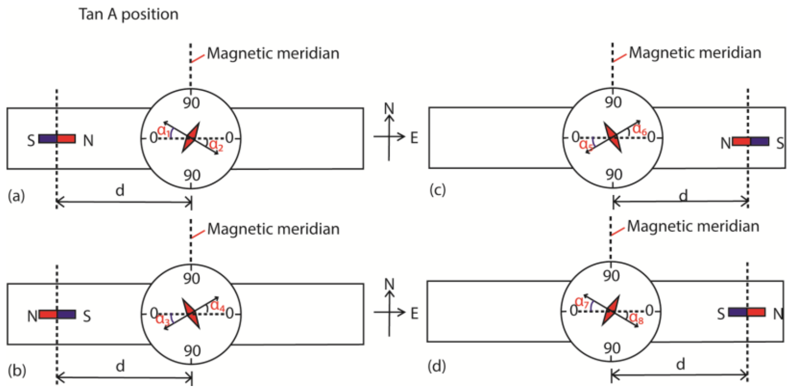
The magnetometer can be used in two positions; i.e. Tan A position and Tan B position



i. Tan A position
   The arms of magnetometer are adjusted to be parallel the aluminium pointer so that they lie in east-west direction and compass pointer adjusted to read zero degrees on the circular scale while the magnetic needle lies in the direction of magnetic meridian
ii. Tan B position

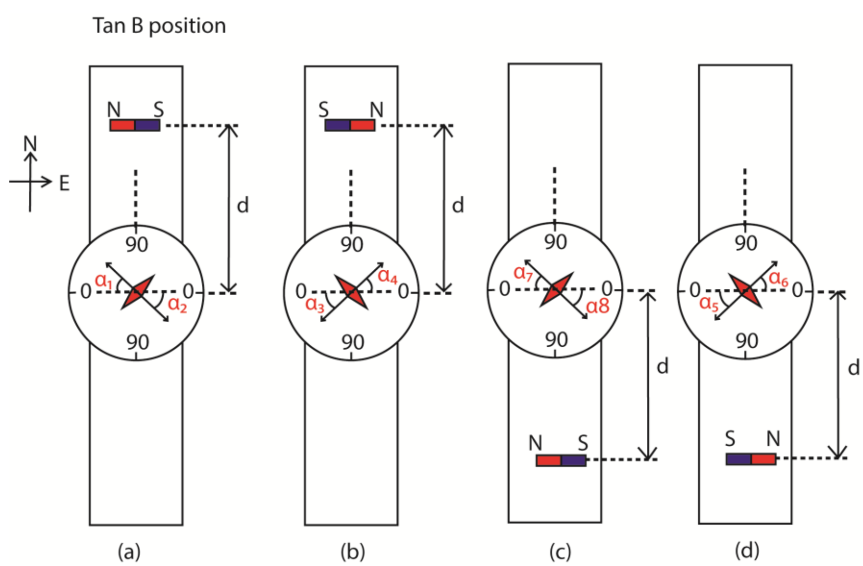
   The arms of magnetometer are adjusted to be parallel the aluminium pointer so that they lie in north-south direction and compass pointer adjusted to read zero degrees on the circular scale while the magnetic needle lies in the direction of magnetic meridian

(i) Comparing magnetic moments of two magnets using a magnetometer at equal distances in Tan A position



(a) The first bar magnet is placed a distance d from the magnetic compass as shown above and angles of deflection of aluminium pointer α_1 and α_2 are noted
(b) The polarity of the bar magnet in (a) is reversed and angles of deflections α_3 and α_4 are noted
(c) The first bar magnet is placed equal distance d from magnetic compass on the opposite arm and angles of deflection of aluminium pointer α_5 and α_6 are noted
(d) The polarity of the bar magnet in (c) is reversed and angles of deflections α_7 and α_8 are noted
(e) Average angle $\theta_1 = \frac{\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 + \alpha_6 + \alpha_7 + \alpha_8}{8}$
(f) Steps (a) to (e) are repeated for the second magnet to obtain average angle θ_2
(g) The ratio of magnetic moments is given by $\frac{M_1}{M_2} = \frac{\tan\theta_1}{\tan\theta_2}$

(ii) Comparing magnetic moments of two magnets using a magnetometer at equal distances in Tan B position



(a) The first bar magnet is placed a distance d from the magnetic compass as shown above and angles of deflection of aluminium pointer α_1 and α_2 are noted
(b) The polarity of the bar magnet in (a) is reversed and angles of deflections α_3 and α_4 are noted
(c) The first bar magnet is placed equal distance d from magnetic compass on the opposite arm and angles of deflection of aluminium pointer α_5 and α_6 are noted
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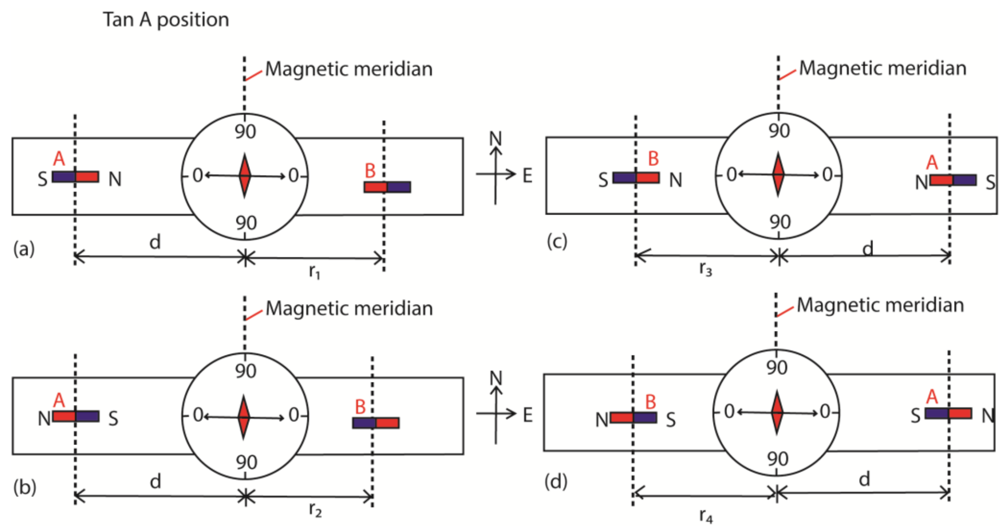
(e) Average angle $\theta_1 = \frac{\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 + \alpha_6 + \alpha_7 + \alpha_8}{8}$

(f) Steps (a) to (e) are repeated for the second magnet to obtain average angle θ_2

(g) The ratio of magnetic moments is given by $\frac{M_1}{M_2} = \frac{\tan\theta_1}{\tan\theta_2}$

Comparing magnetic moments of two magnets using a magnetometer and null method in tan A position



(a) Place one magnet a distance d_1 from the magnetic compass and another on the opposite arm facing each other.

(b) Adjust the second magnet to a distance r_1 until the compass needle shows zero deflection

(c) Reverse the poles of the two magnets keeping the distance d of the first magnet and determine the distance r_2 of the second magnet leading to zero to zero deflection.

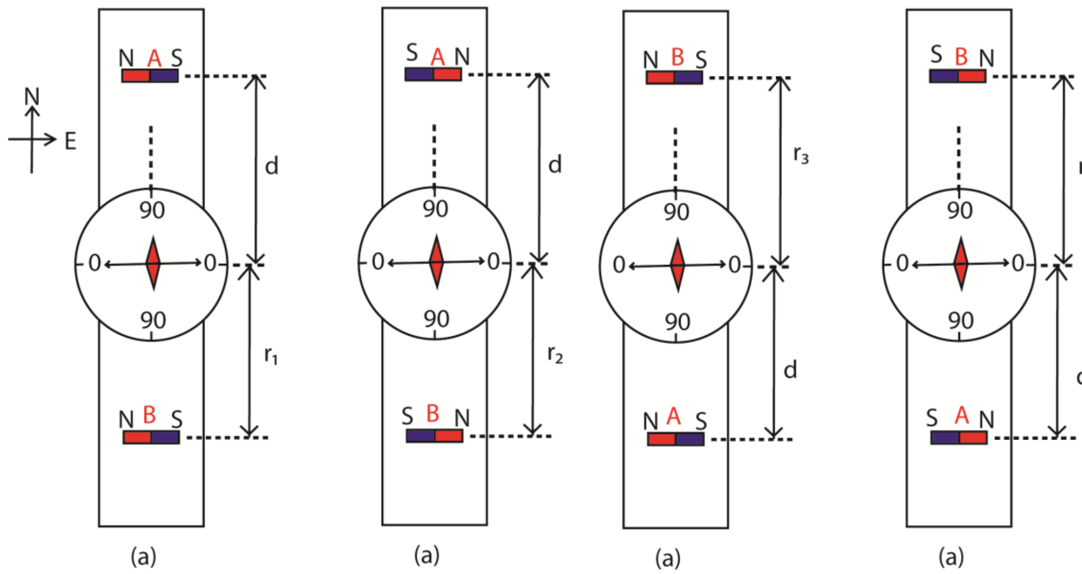
(d) The magnets are interchanged keeping the distance d of first magnet unchanged, procedures (b) and C are repeated for distances r_3 and r_4.

(e) Now $d_2 = \frac{r_1 + r_2 + r_3 + r_4}{4}$

(f) The ratio of magnetic moments is given by $\frac{M_1}{M_2} = \frac{d_1^3}{d_2^3}$

Comparing magnetic moments of two magnets using a magnetometer and null method in tan B position

Tan B position: null mehod



(a) Place one magnet a distance d_1 from the magnetic compass and another on the opposite arm facing each other.

(b) Adjust the second magnet to a distance r_1 until the compass needle shows zero deflection

(c) Reverse the poles of the two magnets keeping the distance d of the first magnet and determine the distance r_2 of the second magnet leading to zero to zero deflection.

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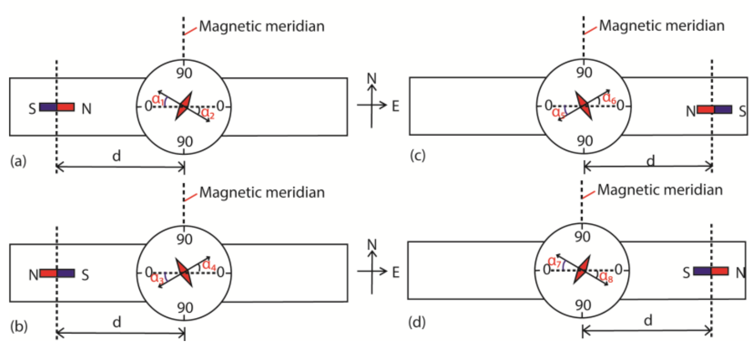
(e) Now $d_2 = \frac{r_1 + r_2 + r_3 + r_4}{4}$

(f) The ratio of magnetic moments is given by $\frac{M_1}{M_2} = \frac{d_1^3}{d_2^3}$

Verifying inverse square law

A. Arrange the magnetometer in tan A position

Tan A position



(a) The first bar magnet is placed a distance d from the magnetic compass as shown above and angles of deflection of aluminium pointer α_1 and α_2 are noted

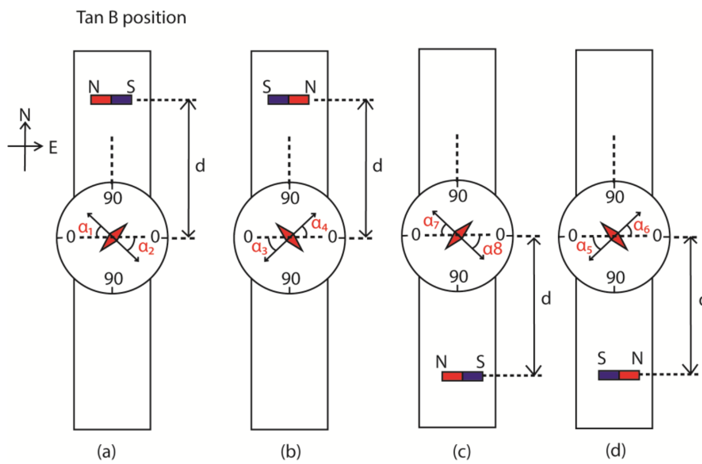
(b) The polarity of the bar magnet in (a) is reversed and angles of deflections α_3 and α_4 are noted

(c) The first bar magnet is placed equal distance d from magnetic compass on the opposite arm and angles of deflection of aluminium pointer α_5 and α_6 are noted

(d) The polarity of the bar magnet in (c) is reversed and angles of deflections α_7 and α_8 are noted

(e) Average angle $\theta_A = \frac{\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 + \alpha_6 + \alpha_7 + \alpha_8}{8}$

B. Arrange the deflection magnetometer in position B



(a) The first bar magnet is placed a distance d from the magnetic compass as shown above and angles of deflection of aluminium pointer α_1 and α_2 are noted

(b) The polarity of the bar magnet in (a) is reversed and angles of deflections α_3 and α_4 are noted

(c) The first bar magnet is placed equal distance d from magnetic compass on the opposite arm and angles of deflection of aluminium pointer α_5 and α_6 are noted

(d) The polarity of the bar magnet in (c) is reversed and angles of deflections α_7 and α_8 are noted

(e) Average angle $\theta_B = \frac{\alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5 + \alpha_6 + \alpha_7 + \alpha_8}{8}$

(f) Inverse square law is verified if $\frac{\tan \theta_A}{\tan \theta_B} = 2$.

Magnetic moment of a coil

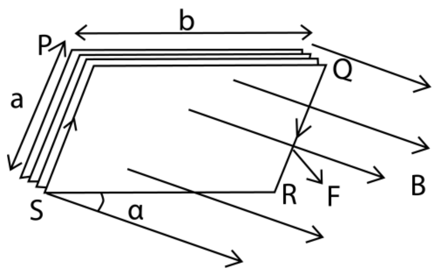
Magnetic moment is torque experienced by the coil per tesla of magnetic field acting along the plane of the coil.

Or

Magnetic moment of a coil is a couple exerted on a coil when it is placed with its plane parallel to a magnetic field of 1T

Derivation of expression for torque on rectangular coil in a magnetic field

Consider a rectangular coil of N turns each of dimensions a x b inclined at an angle α to uniform magnetic field of flux density, B.



- When current, I, flows through the coil, the conductor experiences a magnetic force.
- Force on side PQ = NBIbsinα (downwards) while Force on side RS = NBIbsinsα (upwards). The two forces cancel out due to rigidity of the coil.
- Side PS experiences force NBIacosα perpendicularly into the page while RQ experiences force NBIacosα perpendicularly out of page. The two forces constitute a couple whose moment of force

  $\tau = F \times b$

  $= NBIabcos\alpha$

  $= NBIAcos\alpha$ (where A is the area = a x b)

  If θ is the angle between the field and the normal to the plane of the coil, then θ = 90° - α, and

  $\tau = NBIAsin\theta$

Example 14

A small circular coil of 20 turns of wire lies in a uniform magnetic field of flux density 5.0×10^{-2}T. The normal to the coil makes an angle of 30^0 with the direction of the magnetic field. If the radius of the coil is 4cm and the coil carries a current of 2.0A, find the

(i) Magnetic moment of the coil (02marks)

$M = NIA = 20\pi \times (4 \times 10^{-2})^2 \times 2 = 0.2Am^2$

(ii) Torque on the coil

$T = MBsin\theta = 0.2 \times 5 \times 10^{-2} sin30^0 = 5.0 \times 10^{-3}Nm$

Example 15

Show that when the magnetic flux linking a coil changes, the total charge which passes through is depends only on the resistance of the coil and total flux linking it (05marks).

Consider a coil of N turns each linked by magnetic flux of ϕ_1.

Suppose the magnetic flux changes to ϕ_2.

When the magnetic flux ϕ changes, an e.m.f ε is induced in the coil.

$\varepsilon = \frac{-Nd\phi}{dt}$

$I = \frac{\varepsilon}{R}$; R = the resistance of the coil

$\varepsilon = IR$

Hence IR = $\frac{-Nd\phi}{dt}$

But I =$\frac{dQ}{dt}$; where Q is the induced charge

⇨ $\frac{dQ}{dt} = \frac{-N}{R} \cdot \frac{d\phi}{dt}$

dQ = $\frac{-N}{R}\ d\phi$

The amount of the charge which passes through the coil when

the magnetic flux changes from ϕ_1 to ϕ_2 is

Q = $\frac{-N}{R}\int_{\phi_1}^{\phi_2} d\phi$ = $\frac{-N}{R}(\phi_2 - \phi_1)$

Thank you
Dr. Bbosa Science