Module 4

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Syllabus

- Magnetic Measurements: Measurement of flux and permeability - flux meter, BH curve and permeability measurement - hysteresis measurement- ballistic galvanometer – principle- determination of BH curve - hysteresis loop. Lloyd Fisher square — measurement of iron losses.
- Measurement luminous intensity-Photoconductive Transducers-Photovoltaic cells
- Temperature sensors-Resistance temperature detectors-negative temperature coefficient Thermistors-thermocouples-silicon temperature sensors.

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Magnetic Measurements

- The operating characteristics of electrical machines, apparatus and instruments are greatly influenced by the properties of ferromagnetic materials used for their construction.

- Therefore magnetic measurements and a thorough knowledge of characteristics of magnetic materials are of utmost importance in designing and manufacturing electrical equipment.

- The principal requirements in magnetic measurements are

1)The measurement of magnetic field strength(H) and magnetic flux density(B).

2)The determination of B-H curve and hysteresis loop for ferromagnetic materials.

3)The determination of eddy current and hysteresis losses of ferromagnetic materials subjected to alternating magnetic fields .

4)The testing of permanent magnets .

- **Various Tests for Magnetic measurements**

1)DC Tests

2)AC Tests

3)Steady State Tests

1) DC Tests

- These are used to determine B-H curve and hysteresis loop of ferromagnetic materials
- The direct current is used to have variable mmf and flux meter or ballistic galvanometer can be used to measure flux density.
- Such tests are also called ballistic tests.

2) AC tests

- When a ferromagnetic materials is subjected to a cycle of magnetization and demagnetization then the eddy current and hysteresis losses occur.
- Such tests are carried out at power, audio or radio frequencies.

3) Steady State Tests

- The flux in the air gap plays an important role in the operation of various electrical equipments.
- Such a flux is measured using steady state tests.
- Such test give steady state value of the flux in the air gap of a magnetic material .

The inaccuracies in magnetic measurements

Magnetic measurements have some inherent inaccuracies due to which the measured values depart considerably from the true values. The inaccuracies are due to the following reasons

a)The conditions in the magnetic specimen under test are different from those assumed in calculations.

b) The magnetic materials are not homogeneous.

c) There is no uniformity between different batches of test specimens even if such batches are of the same composition.

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Fluxmeter

- The meter which is used for measuring the flux of the permanent magnet, such type of meter is known as the flux meter.
- The fluxmeter is the advanced form of the ballistic galvanometer which has certain advantages like the meter has low controlling torque and heavy electromagnetic damping.

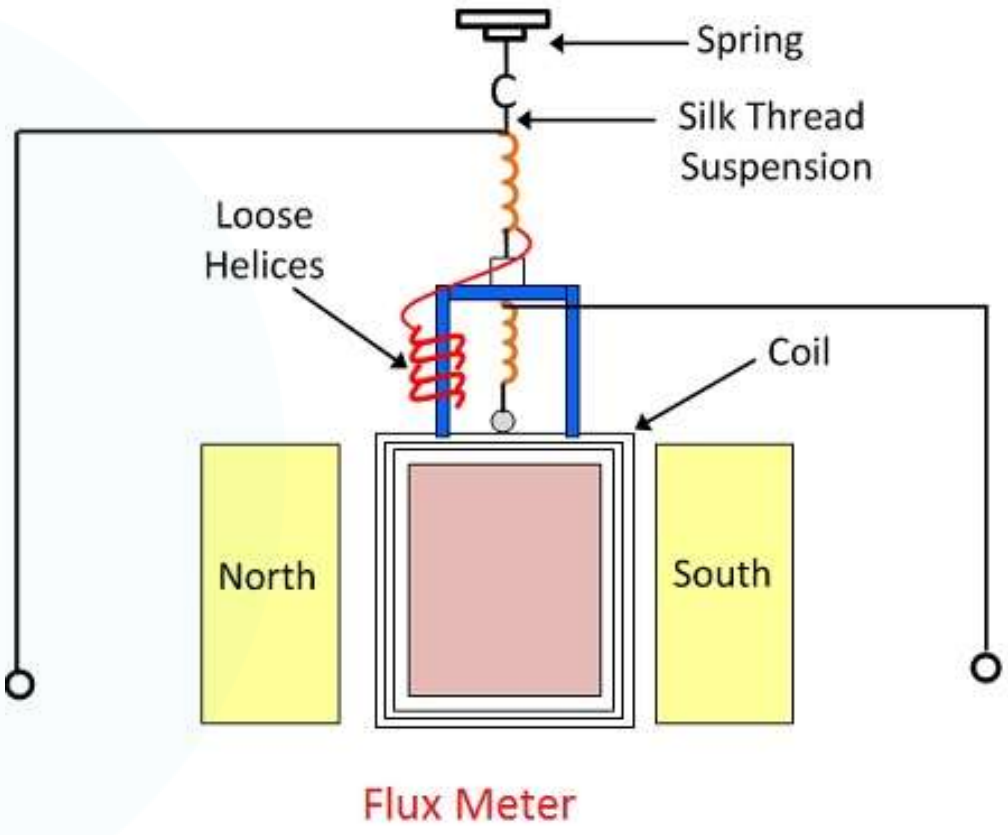
Construction of Flux Meter

The fluxmeter has a coil which is freely suspended by the help of the spring and the single silk thread.

The coil moves freely between the poles of the permanent magnet.

The current enters into the coil with the help of the helices which is very thin and made from the annealed silver strips.

The air friction damping of the coil is negligible.



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Operation of Flux Meter

- The terminals of the fluxmeter are connected across the search coil as shown in the figure below.
- The flux linking with the coil is varied by either removing it from the magnetic field or by reversing the field of the magnet.
- The change of the flux induces the electromotive force in the coil.
- This emf induces the current in the search coil and send it through the flux meter. Because of the current, the pointer of the fluxmeter deflects, and their deflection is directly proportional to the change in the value of flux linkages.

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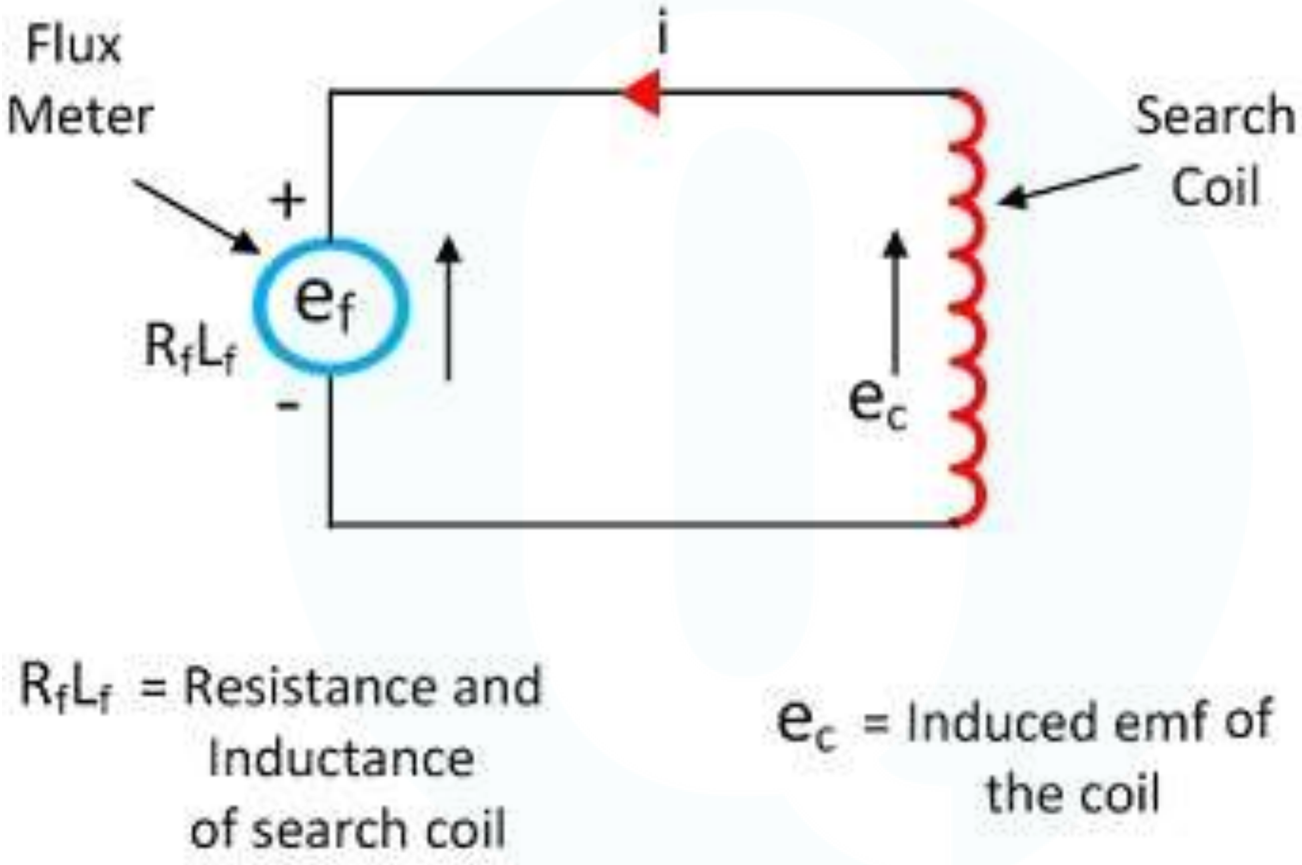

Flux Meter With Search Coil

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- As, the variation of the flux linkages reduces, coil stop moving because of their high electromagnetic damping.
- The high electromagnetic damping is because of the low resistance circuit between the fluxmeter and the search coil.

Advantages of Fluxmeter

- The fluxmeter is portable.
- The scale of the fluxmeter is calibrated in Weber meters.
- The deflection of the coil is free from the time taken by the flux to change.

Disadvantages

- Less sensitive and less accurate

Theory

Let

- R= total resistance of search coil and meter coil.
- L=total inductance of search coil and meter coil.
- N=turns of search coil.
- φ= flux linking with search coil
- i= instantaneous current.

Emf induced in the search coil = N dφ/dt

Emf induced in the fluxmeter coil due to the movement of the coil in permanent magnetic field e_b= K dθ/dt

- dθ/dt – angular velocity of fluxmeter coil

- Emf due to inductance = L di /dt
- Therefore $e = e_b + L\, di/dt$
- $N\, d\varphi/dt = K\, d\theta/dt + L\, di/dt$

$$\int_{\varphi 1}^{\varphi 2} N\, d\varphi/dt\ \ dt = \int_{\theta 1}^{\theta 2} K\, d\theta/dt\ \ dt + \int_{i_1}^{i_2} L\, di/dt\ \ dt$$

Since $i_1 = i_2 = 0$

$N(\varphi_2 - \varphi_1) = K\,(\theta_2 - \theta_1)$

$(\theta_2 - \theta_1) = N(\varphi_2 - \varphi_1)/K$

Deflection is proportional to flux. So the scale is uniform.

Ballistic Galvanometer

- The galvanometer which is used for estimating the quantity of charge flow through it is called the ballistic galvanometer.
- It depends on the deflection of the coil which is directly proportional to the charge passing through it.

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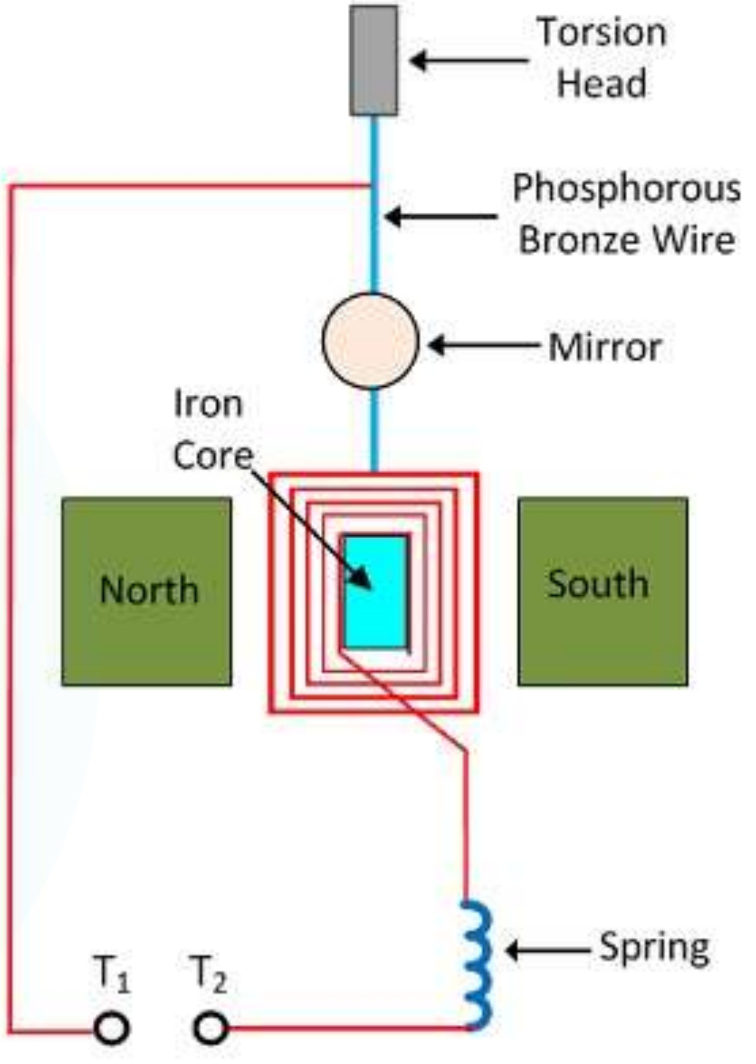
Construction of Ballistic Galvanometer

- The ballistic galvanometer consists of a coil of copper wire which is wound on the non-conducting frame of the galvanometer.
- The phosphorous bronze suspends the coil between the north and south poles of a magnet.
- For increasing the magnetic flux the iron core places within the coil.
- The lower portion of the coil connects with the spring.
- This spring provides the restoring torque to the coil.



Ballistic Galvanometer

- When the charge passes through the galvanometer, their coil starts moving and gets an impulse.
- The impulse of the coil is proportional to the charges passes through it.
- The moving system of a ballistic galvanometer is designed to have a large moment of interia. This is achieved by attaching small weights to the moving system.
- The moment of inertia means the body oppose the angular movement.
- The eddy current damping provided in a ballistic galvanometer is very small. This is achieved by winding the moving coil on a non-magnetic former.
- If the coil has a high moment of inertia, then their oscillations are large. Thus, accurate reading is obtained.

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Theory of Ballistic Galvanometer

In a ballistic Galvanometer damping constant $= 0$

$$G I = \text{Torque} = J \frac{d^2\theta}{dt^2} = \frac{d}{dt}\left(J \frac{d\theta}{dt}\right) = \frac{d}{dt}(\text{angular momentum})$$

$G I(t)\, dt$ = rate of change of angular momentum $\times$ dt

= Total change of angular momentum in dt time

$G Q$.

↑

charge flown in dt time.

Assume the coil was in rest before the impulse current. (Initial angular momentum $= 0$)

$G Q$ = Angular momentum after impulse current immediately

$= J\omega$ [where ω = angular velocity immediately after the impulse current
J = moment of inertia.]

$$\omega = \frac{GQ}{J}$$

kinetic energy immediately after the impulse current $= \frac{1}{2} J\omega^2$

Assume the coil can move upto an angle θ_f with this kinetic energy $\frac{1}{2} J\omega^2$

Final potential energy in spring $\frac{1}{2} k \theta_f^2 = \frac{1}{2} J\omega^2$ = initial kinetic.

k → spring constant

$$\frac{1}{2} k \theta_f^2 = \frac{1}{2} J \omega^2 = \frac{1}{2} J \left(\frac{G\theta}{J}\right)^2$$

$$\Rightarrow k \theta_f^2 = J \left(\frac{G\theta}{J}\right)^2$$

$$\Rightarrow \sqrt{\frac{k}{J}}\ \theta_f = \frac{G\theta}{J}$$

$$\Rightarrow \theta = \sqrt{\frac{k}{J}}\ \frac{J}{G} (\theta_f)$$

unknown $= \frac{\sqrt{kJ}}{G} \theta_f$

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Measurement of flux density

- The measurement of flux density inside a specimen can be done by winding a search coil over the specimen. This search coil is known as a “ B coil” .
- This search coil is then connected to a ballistic galvanometer or to a flux meter.
- Let us consider that we have to measure the flux density in a ring specimen shown in Fig. The ring specimen is wound with a magnetizing winding which carries a current I.
- A search coil of convenient number of turns is wound on the specimen and connected through a resistance and calibrating coil, to a ballistic galvanometer as shown.

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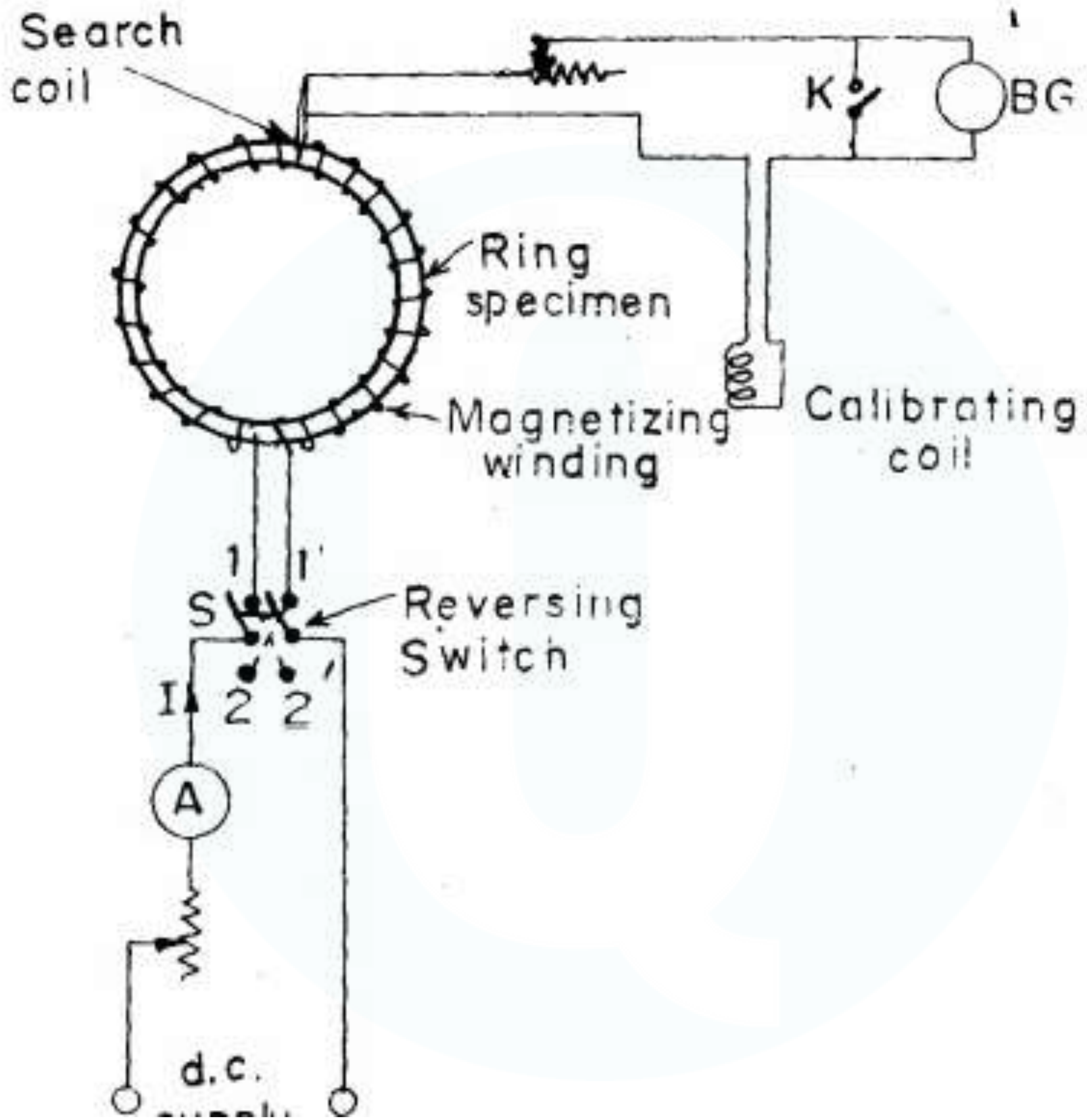

Search coil
K
BG
Ring specimen
Magnetizing winding
Calibrating coil
1
1'
S
Reversing Switch
I
2
2
A
d.c.

- The current through the magnetizing coil is reversed and therefore the flux linkages of the search coil change inducing an emf in it.
- Thus emf sends a current through the ballistic galvanometer causing it to deflect.
- Let

  φ=flux linking the search coil

  R= resistance of the ballistic galvanometer circuit

  N= number of turns in the search coil

  t= time taken to reverse the flux

- Average emf induced in the search coil, $e = Nd\varphi/dt = 2N\varphi/t$
- Average current through the ballistic galvanometer, $I = 2N\varphi / Rt$
- Charge passing is, $Q = I*t = 2N\varphi/R$
- Let θ_1 be the throw of the galvanometer and K_q be the constant of galvanometer expressed in coulomb per unit deflection.
- Charge indicated by ballistic galvanometer $= K_q \theta_1$

$$2N\varphi/R = K_q \theta_1$$

$$\text{Or Flux} = R K_q \theta_1 / 2N$$

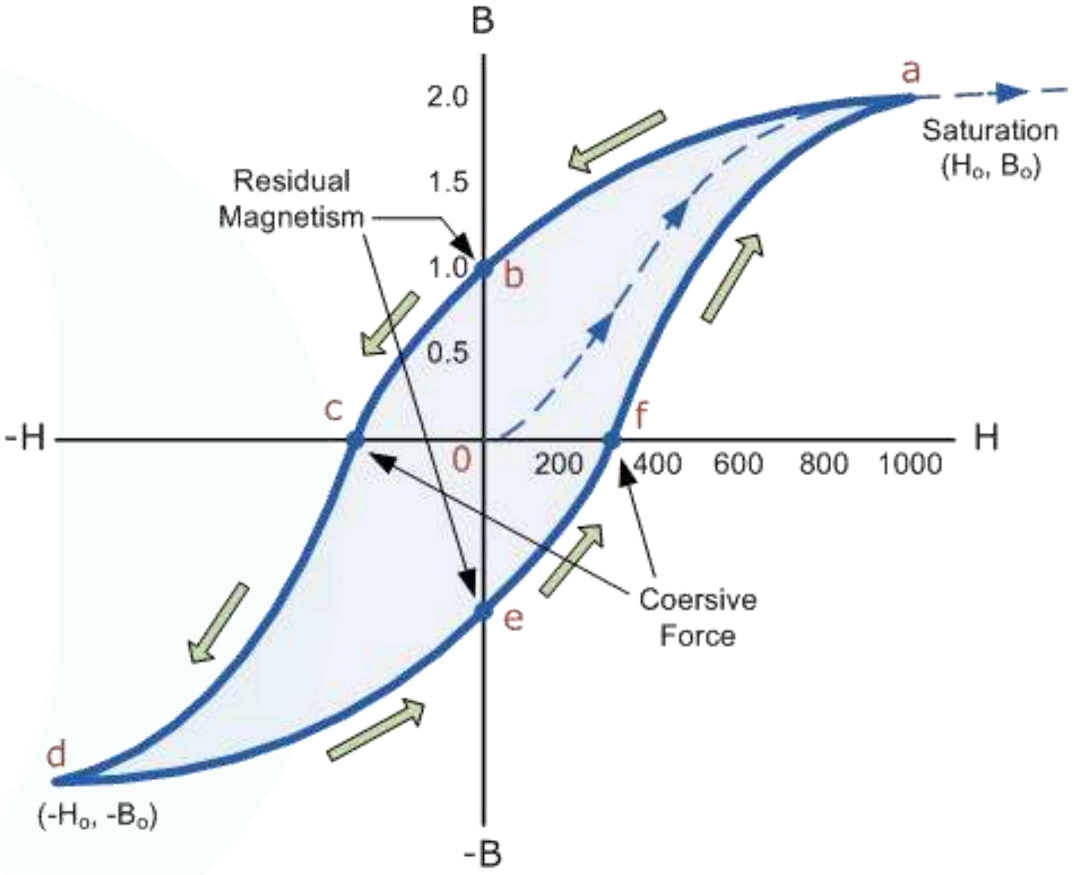
- Flux density, $B = \text{flux}/\text{Area} = R K_q \theta_1 / 2NA_s$
- Where A_s=cross-sectional area of specimen

B-H curve and Hysteresis Loop

- The B-H curve is generally used to describe the nonlinear behavior of magnetization that a ferromagnetic material obtains in response to an applied magnetic field.
- Magnetic soft iron steels are widely used as core materials in motors, transformers, and inductors.
- By plotting values of flux density, (B) against the field strength, (H) we can produce a set of curves called **Magnetisation Curves**, **Magnetic Hysteresis Curves** or more commonly **B-H Curves** for each type of core material.
- Flux density increases in proportion to the field strength until it reaches a certain value where it can not increase any more becoming almost level and constant as the field strength continues to increase.

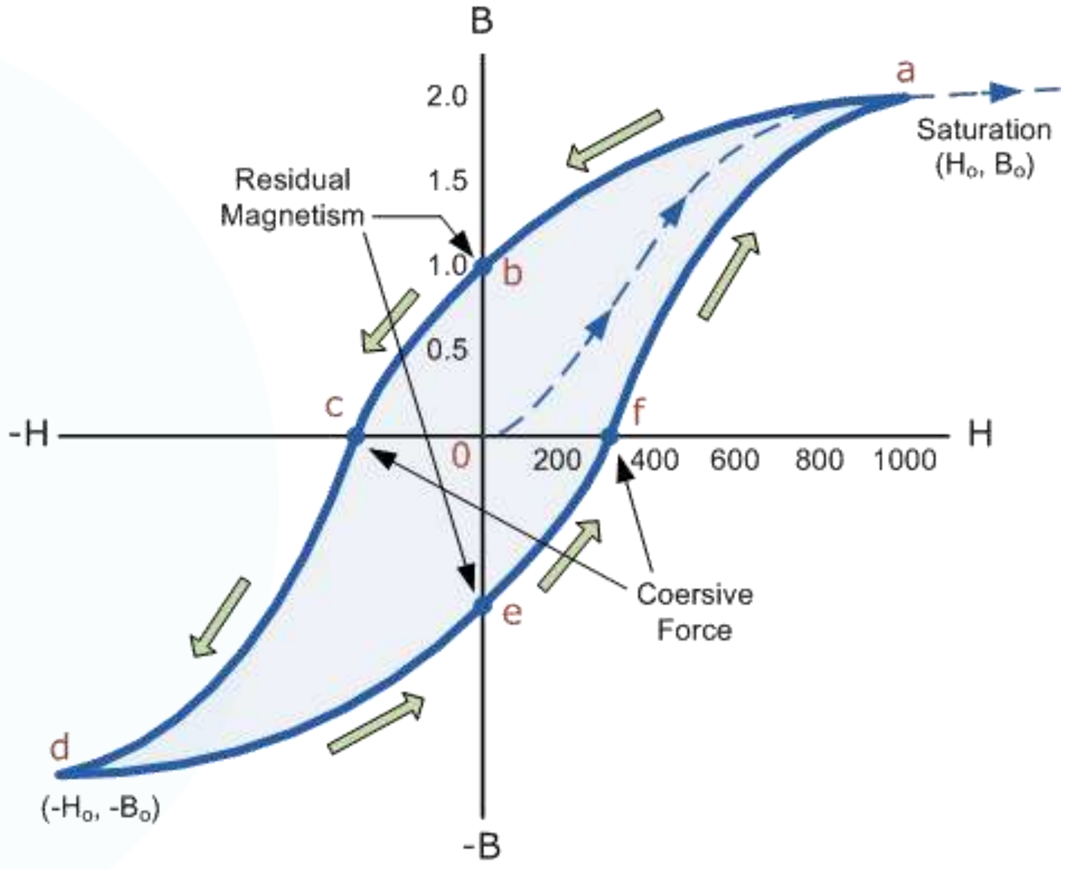
- This is because there is a limit to the amount of flux density that can be generated by the core as all the domains in the iron are perfectly aligned.

- Any further increase will have no effect on the value of B, and the point on the graph where the flux density reaches its limit is called **Magnetic Saturation** also known as **Saturation of the Core** .



- If we now open a switch and remove the magnetising current flowing through the coil we would expect the magnetic field around the coil to disappear as the magnetic flux reduced to zero.

- However, the magnetic flux does not completely disappear as the electromagnetic core material still retains some of its magnetism even when the current has stopped flowing in the coil. This ability of a coil to retain some of its magnetism within the core after the magnetisation process has stopped is called **Retentivity** , while the amount of flux density still remaining in the core is called **Residual Magnetism**, B_R



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- The reason for this is some of the tiny molecular magnets do not return to a completely random pattern and still point in the direction of the original magnetising field giving them a sort of “memory”.
- One way to reduce this residual flux density to zero is by reversing the direction of the current flowing through the coil, thereby making the value of H, the magnetic field strength negative.
- If this reverse current is increased further the flux density will also increase in the reverse direction until the ferromagnetic core reaches saturation again but in the reverse direction from before. Reducing the magnetising current, i once again to zero will produce a similar amount of residual magnetism but in the reverse direction.

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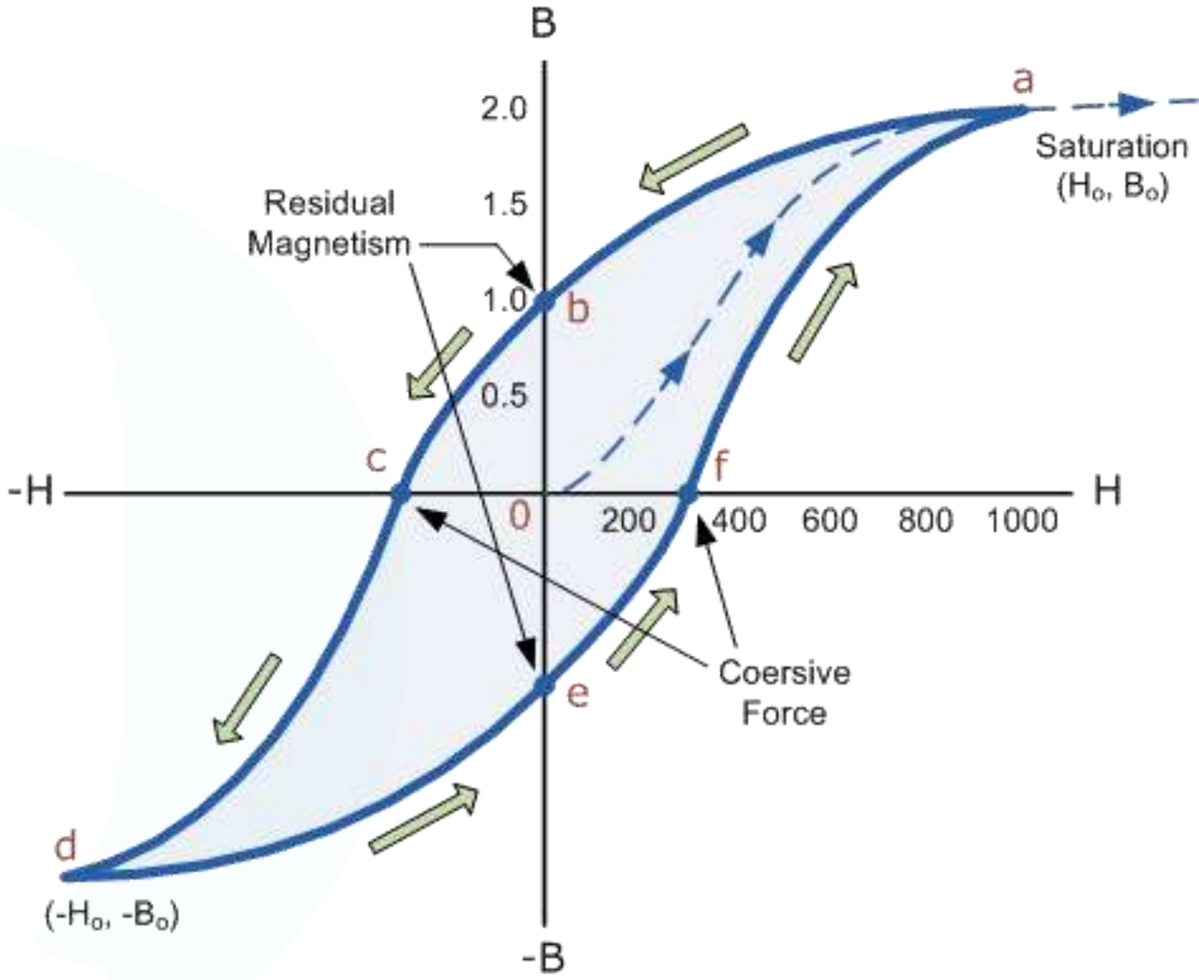
- Then by constantly changing the direction of the magnetising current through the coil from a positive direction to a negative direction, a **Magnetic Hysteresis** loop of the ferromagnetic core can be produced.



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Determination of B-H curve

There are two methods for the determination of B-H curve of a specimen.

Method of reversals

- A ring shaped specimen whose dimensions are known is used for the purpose.
- After demagnetizing the test is started by setting the magnetising current to its lowest test value.
- With galvanometer key K closed, the iron specimen is brought into a ‘ reproducible cyclic magnetic state’ by throwing the reversing switch S backward and forward about twenty times.
- Key K is now opened and the value of flux corresponding to this value of H is measured by noting the throw of galvanometer.

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- The value of flux density corresponding to this H(=N*I/*l*) can be calculated by dividing the flux by the area of the specimen.
- The above procedure is repeated for various values of H up to the maximum testing point.
- The B-H curve may be plotted from the measured values of B corresponding to the various values of H.

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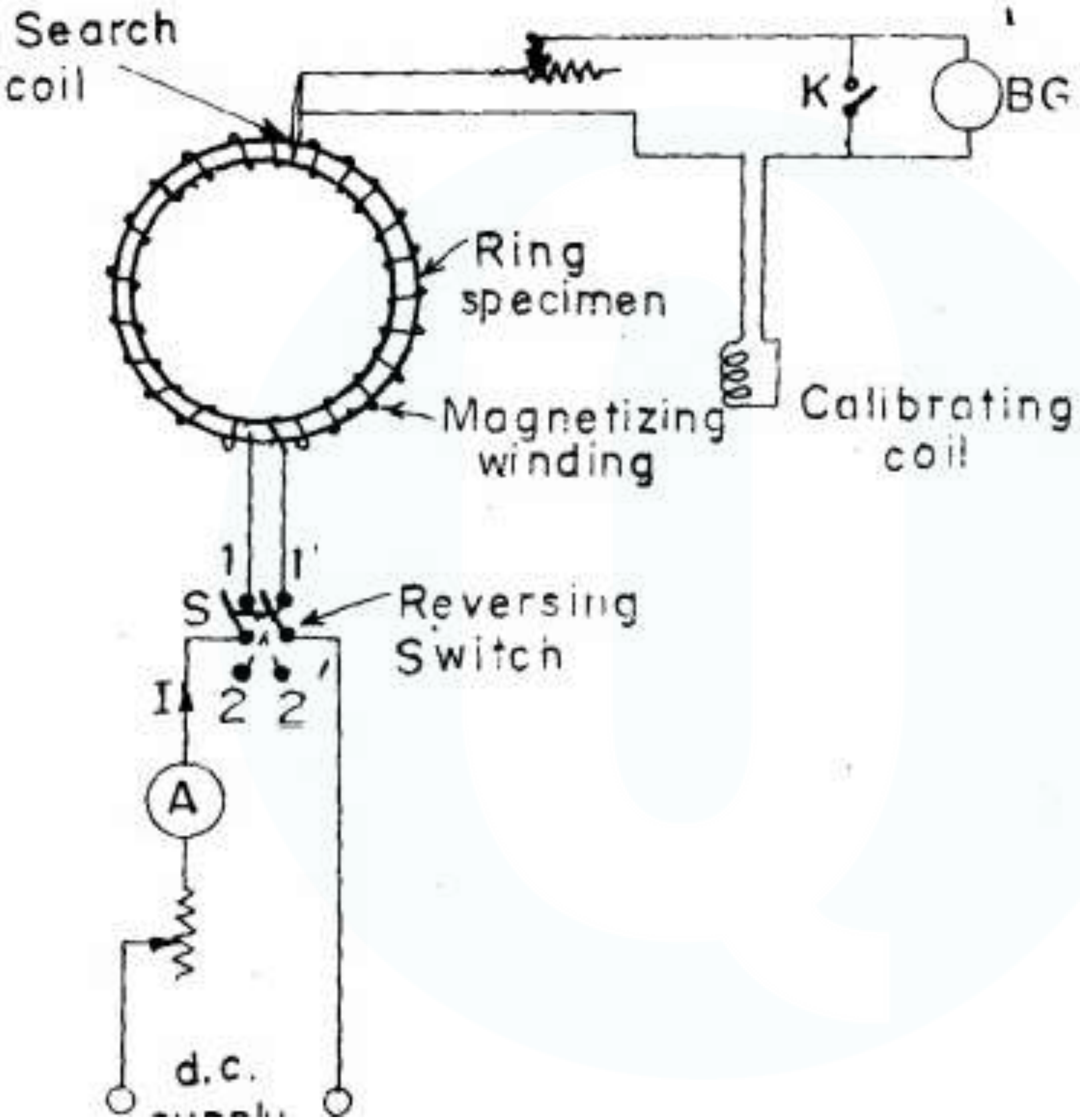

Search coil
K
BG
Ring specimen
Magnetizing winding
Calibrating coil
1
1'
S
Reversing Switch
I
2
2
A
d.c.

Step by step method

- The circuit for this test is shown in Fig.
- The magnetizing winding is supplied through a potential divider having a large number of tapping.
- The tappings are arranged so that the magnetizing force H may be increased, in a number of suitable steps, up to the desired maximum value. The specimen before being tested is demagnetized.
- The tapping switch S is set on tapping 1 and the switch S_1 is closed. The throw of the galvanometer corresponding to this increase in flux density in the specimen, form zero to some value B, is observed.

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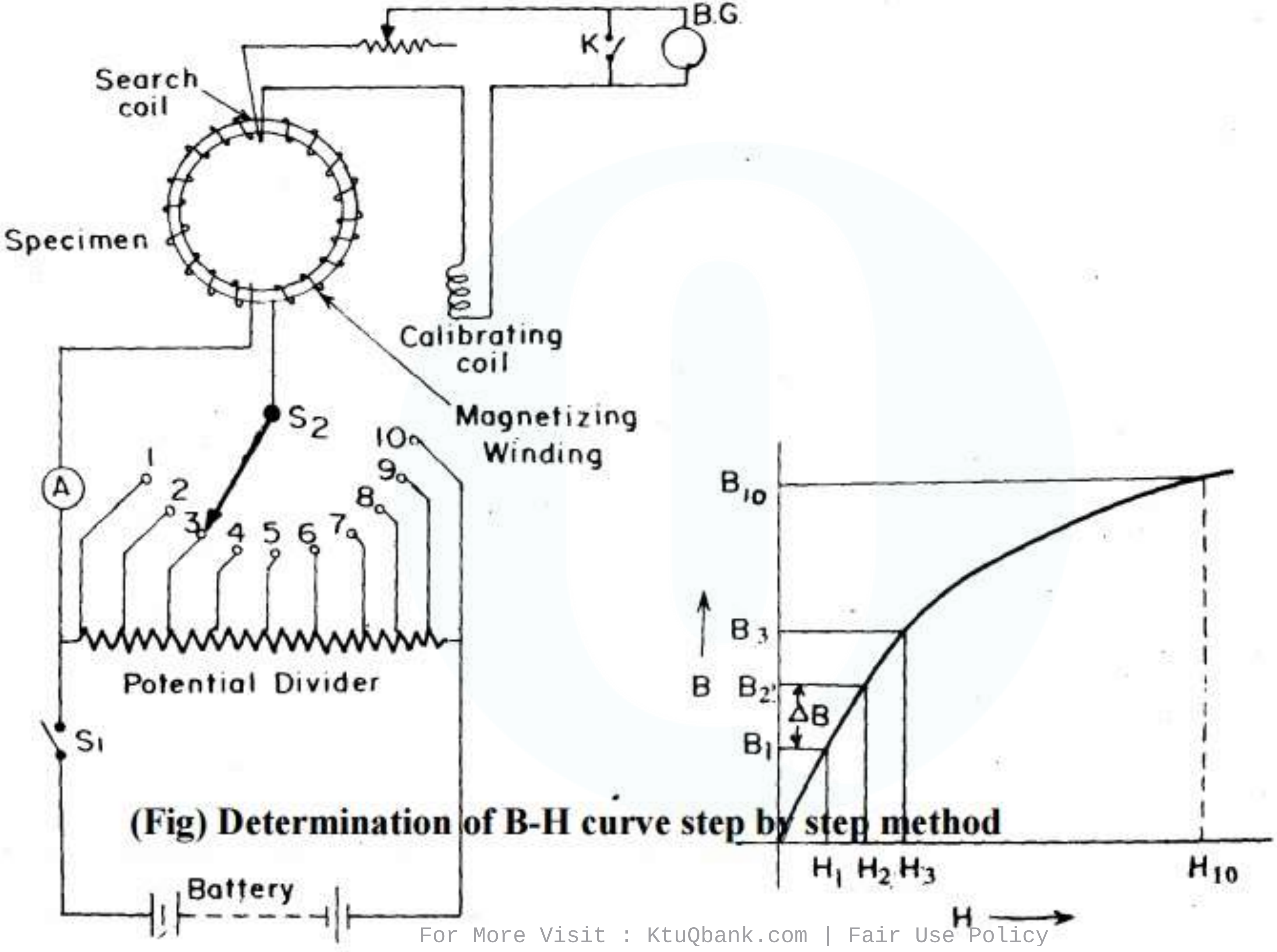

(Fig) Determination of B-H curve step by step method

Determination of Hysteresis Loop

Step by step method

- The determination of hysteresis loop by this method is done by simply continuing the procedure for the determination of B-H curve.
- After reaching the point of maximum H i.e... when switch S is at tapping 10, the magnetizing current is next reduced, in steps to zero by moving switch 2 down through the tapping points 9, 8, 7 …..3, 2, 1.
- After reduction of magnetizing force to zero, negative values of H are obtained by reversing the supply to potential divider and then moving the switch S up again in order 1, 2, 3 ……7, 8. 9, 10.

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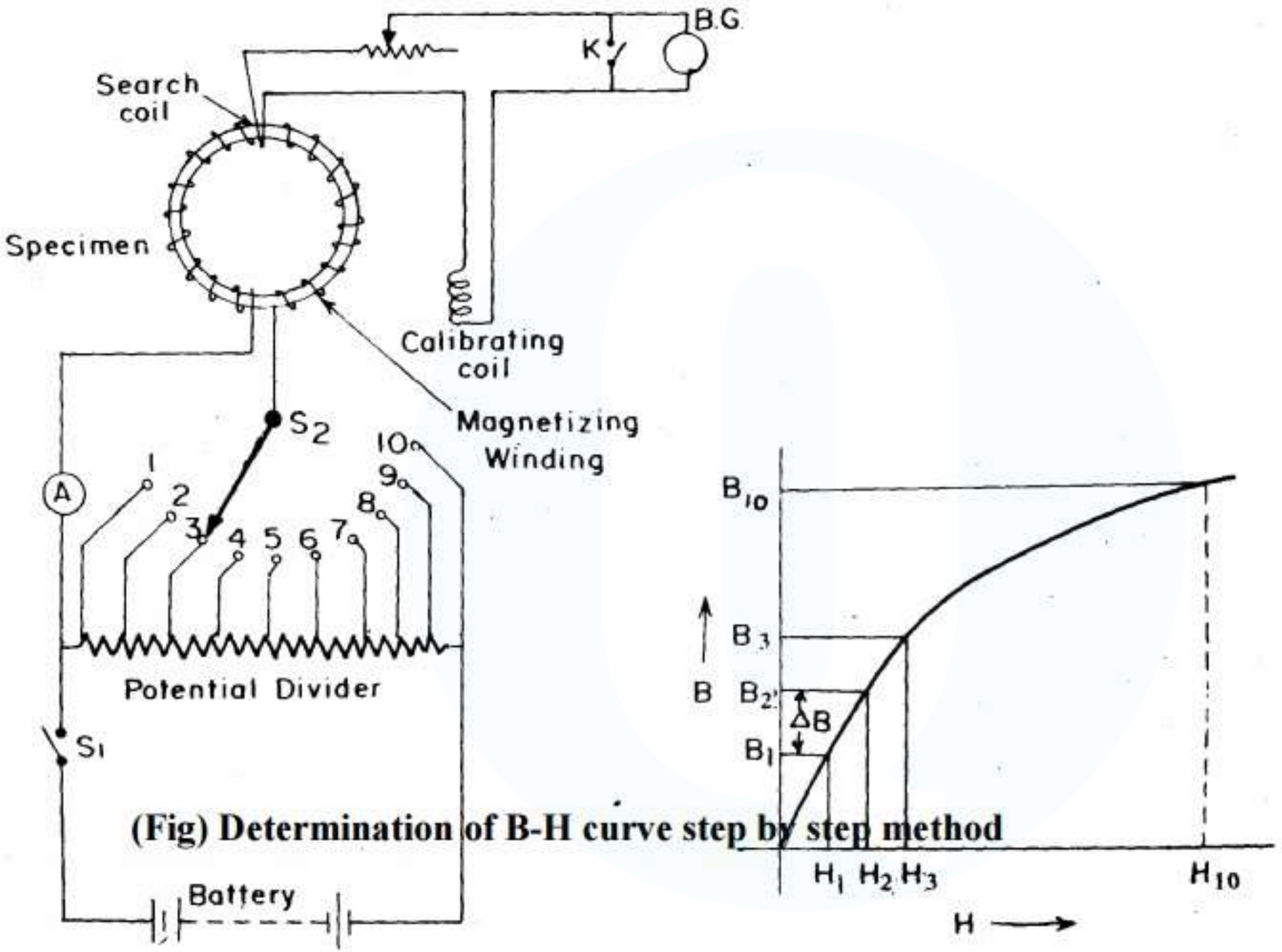


(Fig) Determination of B-H curve step by step method

Magnetic Permeability

- The magnetic permeability is defined as the property of the material to allow the magnetic line of force to pass through it. In other words, the magnetic material can support the development of the magnetic field.

- The magnetic permeability of the material is directly proportional to the number of lines passing through it.

- The permeability of the air or vacuum is represented by μ_0 which is equal to $4\pi\times10^{-7}$ H/m. The permeability of air or vacuum is very poor. μ represents the magnetic permeability.

- The permeability of the material is equal to the ratio of flux density of the material to the field intensity.

$$\mu = \frac{B}{H}$$

Where,

B – magnetic flux density

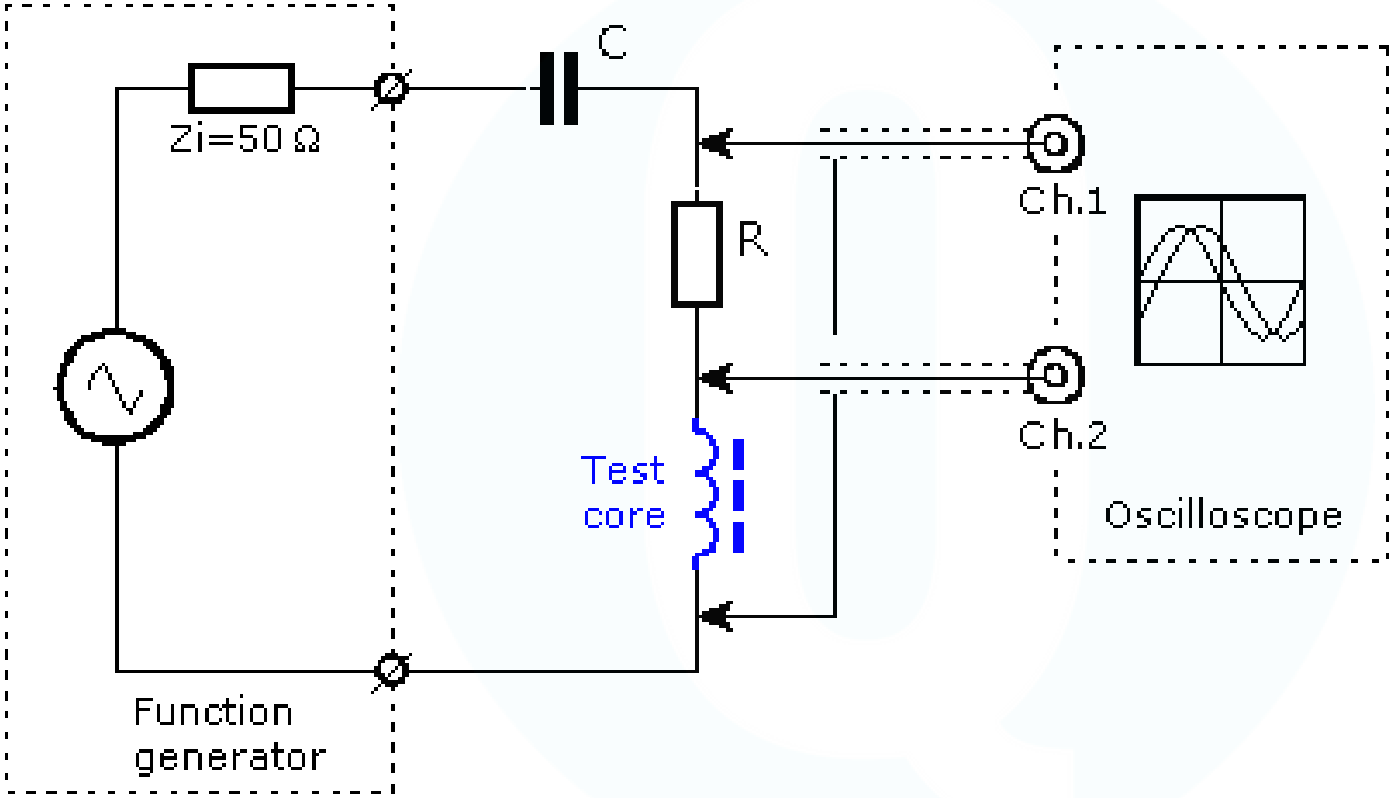
H – magnetic field intensity

- **Relative Permeability** – The relative permeability of the material is the comparison of the permeability concerning the air or vacuum.
- The relative permeability of the material is the ratio of the permeability of any medium to the permeability of air or vacuum.

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

$$\mu = \mu_0 \mu_r$$

Measurement of Magnetic Permeability



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- The coil must have approximately one turn for every millimeter magnetic path length.
- The number of turns N, cross sectional area A_c and the magnetic path length l_c must be known.
- Clean the surfaces of core very carefully.
- The core halves must be clamped straight to each other with a sufficient force.
- The value of capacitor is not very critical but must be large enough to pass the signal without high voltage losses.

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- The resistor must have a value that is suitable for measuring the current.
- Set the function generator to output a sine wave with a frequency between 100 and 1000Hz.
- Adjust the output voltage to large as possible amplitude where there is not any distortion is visible .
- Adjust the frequency so that both the voltage and current can be read with a high accuracy.
- The oscilloscope shows two signals i) The voltage across the inductor V_L ii) and the terminal voltage of the function generator V_K

To obtain the voltage across the resistor V_R these two signals must be subtracted by the oscilloscope and will result in a third waveform that corresponds to the voltage across the resistor R

$$v_R(t) = v_k(t) - v_L(t)$$

With the effective resistor voltage the inductor current *I* can be determinated:

$$I := \frac{V_R}{R}$$

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From this the absolute permeability is calculated:

$$B = \mu H = \frac{\mu N I}{l_c}$$

i.e $$\frac{\phi}{A_c} = \frac{\mu N I}{l_c}$$

$$\phi = \frac{\mu N I}{l_c} \cdot A_c$$

$$L = \frac{N\phi}{I} = \frac{N \mu N I}{l_c \cdot I} \cdot A_c$$

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$$V_L = I \cdot X_L = I \cdot L\omega = I \cdot L \cdot 2\pi f$$

$$= I \cdot \frac{N \mu N I}{l_c \cdot I} \cdot A_c \cdot 2\pi f$$

$$= \frac{N^2 \mu \cdot I \cdot A_c \cdot 2\pi f}{l_c}$$

$$\therefore \mu = \frac{V_L \cdot l_c}{N^2 I A_c \cdot 2\pi f}$$

$$\mu = \mu_0 \mu_r$$

$$\therefore \mu_r = \mu / \mu_0$$

AC test

- This test is done to determine the iron losses in magnetic materials at different values of flux density and frequency and to separate two components of iron losses. i.e eddy current losses and hysteresis losses.
- When a magnetic material is subjected to an alternating field, loss in power occurs due to hysteresis and eddy currents. This loss is called iron loss or core loss.

$$\text{Hysteresis loss} = K_h * B_{max}^{1.6} * f * V$$

- K_h - Hysteresis co-efficient
- B_{max} -Flux density
- f- Frequency
- V-volume

$$\text{Eddy current loss} = K_e * B_{max}^2 * f^2 * t^2 * V$$

- Hysteresis loss is caused by magnetisation and demagnetisation of core as the current flows forward and reverse direction , some amount of power has to be spent for this.
- Eddy currents are loops of currents induced in the core by changing magnetic field according to Faraday's law of electromagnetic induction.

Lloyd Fisher Square-Measurement of Iron Losses

- This is the most common method of measuring the total iron loss in a sheet(strip) material.
- This is also called wattmeter method of measurement of iron losses.
- The sheet material to be tested is arranged in the form of a Lloyd-Fisher magnetic square which is shown in fig.
- They are built up into four bundles and assembled to form a complete magnetic circuit with the aid of bent corner pieces and clamps .
- The strips used are usually 0.25 m long and 50 to 60 mm wide.
- These strips are built up into four stacks.

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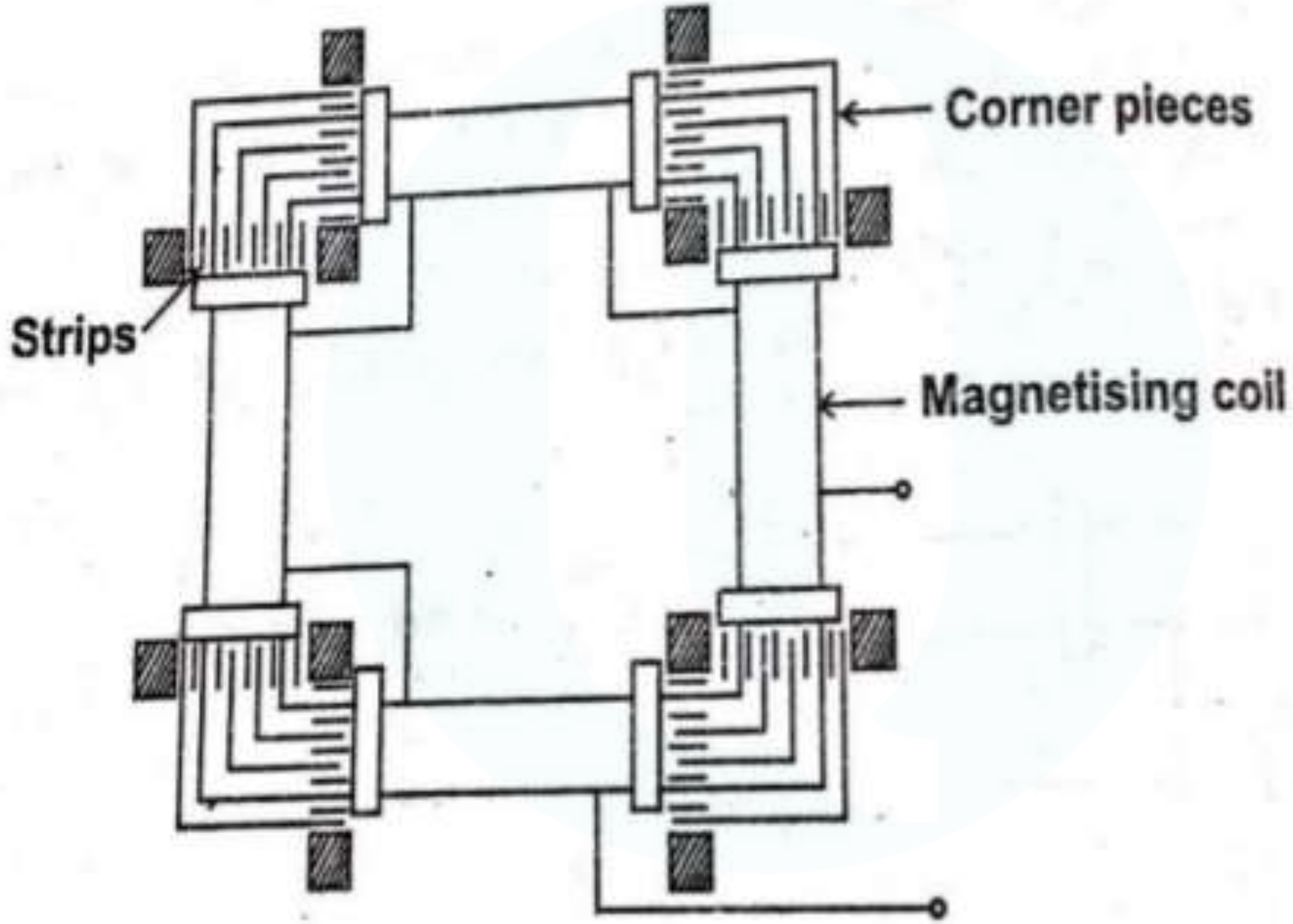
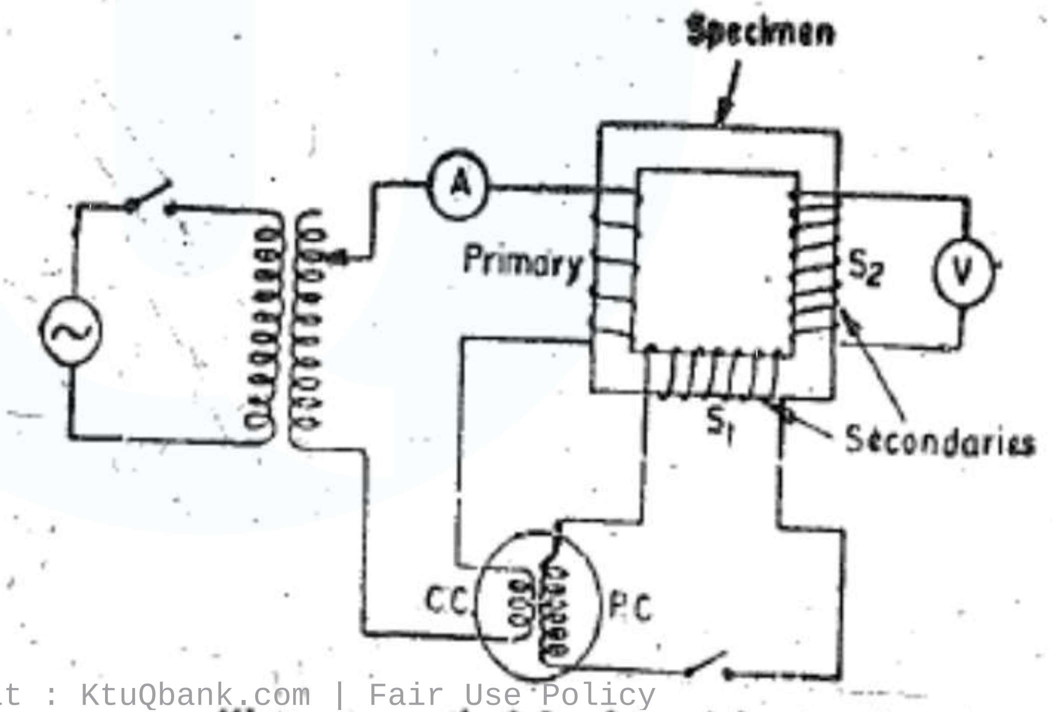

Corner pieces
Strips
Magnetising coil

- Each stack is made up of two types of strips one cut in the direction of rolling and the other cut perpendicular to the direction of rolling.
- The stacks or strips are placed inside four similar magnetizing coils of large cross-sectional area
- These four coils are connected in series to form the primary winding.
- Each magnetizing coils has two similar single layer coils underneath it called secondary coils .Thus in a magnetic square there are eight secondary coils.
- These secondary coils are connected in series in groups of four, one from each core, to form two separate secondary windings.
- The corner joints are made by a set of standard right angled corner pieces.

Test Setup

- The test setup is shown in fig.b. The test specimen is weighed before assembly and its effective cross section is determined.
- The primary winding, formed by connecting the four similar magnetizing coils in series, is connected to ac supply through autotransformer in series with current coil of wattmeter.



Wattmeter method for determining iron loss.

- Across, one of these two secondaries the potential coil of the wattmeter is connected and across the other is connected an electrostatic voltmeter.
- The voltage applied to the primary winding is adjusted till the magnetizing current is adjusted to give required value of B_m.
- The wattmeter and voltmeter readings are noted.
- The rms value of emf induced in the secondary winding S_2

$E = 4\ K_f\, B^1_{max}\, A_s\ f\ N_2$ volts, K_f – form factor (1.11 for sine wave), A_s – cross sectional area of the specimen.

$$B^1_{max} = E / 4\ K_f\, A_s\ f\ N_2$$

- Thus the secondary winding S_2 encloses flux in the air space between specimen and coil in addition to the flux in the specimen. Correction need to be applied for the value of B^1_{max}.

Observed value of flux = true value of flux in the specimen + flux in the air space between specimen and the coil

$$B^1_{max} \; A_s = B_{max} \, A_s + \mu_0 \, H_m \,(A_c – A_s)$$

$$B_{max} = B^1_{max} - \; \mu_0 \, H_m \,(A_c / A_s – 1)$$

A_c - cross sectional area of the coil

B^1_{max} - Observed value of flux density

B_{max} - True value of flux density in the specimen

- We want to find the iron loss of the specimen.
- The wattmeter reading includes the iron loss of specimen and the copper loss of secondary winding ckt.
- The copper loss of secondary ckt can be calculated and it is subtracted from the wattmeter reading.

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- Let P_i = total iron loss

P = wattmeter reading

V=voltage applied to wattmeter pressure coil (pc)

E = voltage reading of voltmeter = voltage induced in S_1 (since no of turns are equal for S_1 and S_2)

r_p= resistance of wattmeter pressure coil

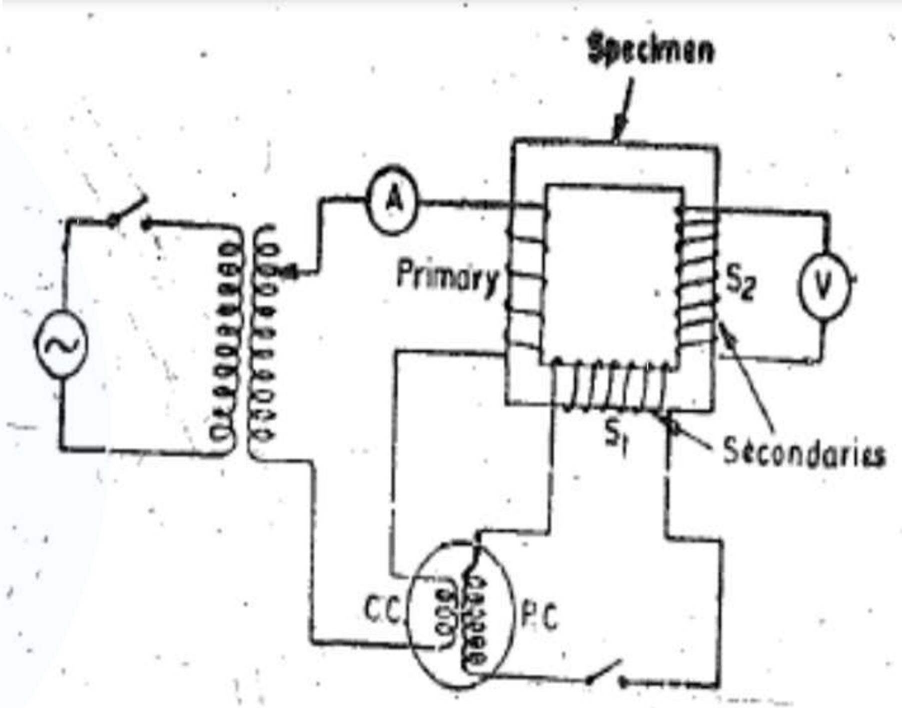
r_c= resistance of coil S_1

I_p= current in pressure coil ckt

Voltage induced in S_1 , $E= I_p(r_p+r_c)$

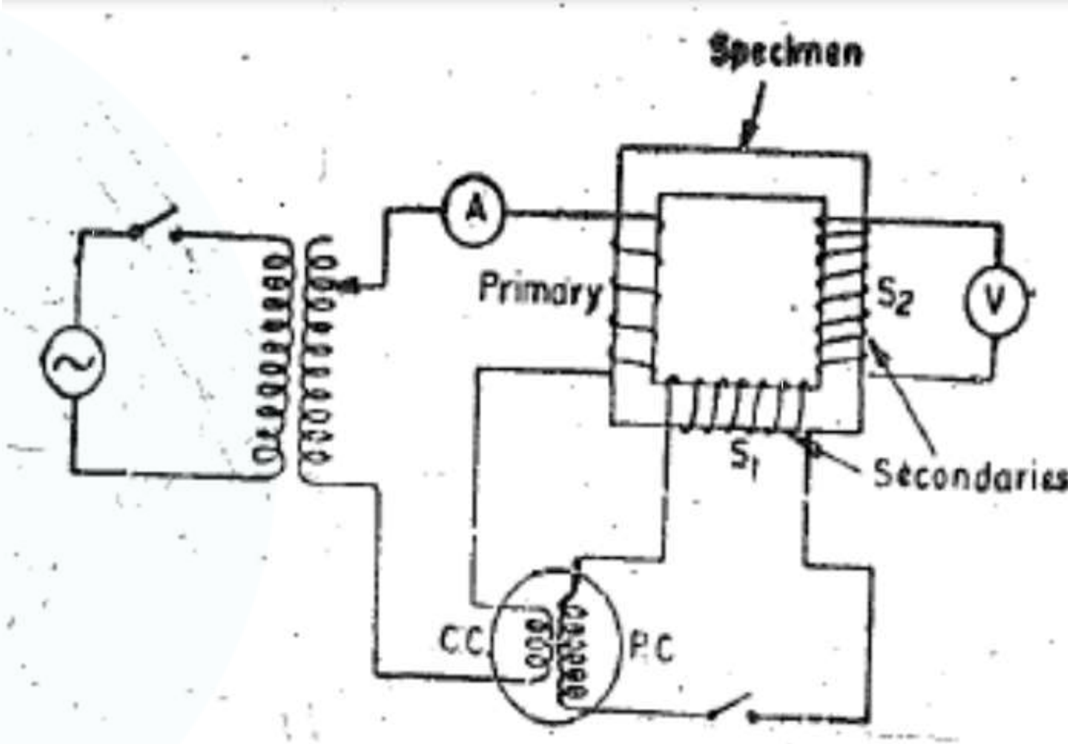
Total copper loss in secondary =

$$E^2 / (r_p+r_c)$$



Wattmeter method for determining iron loss.

Total iron loss in specimen + copper loss in secondary winding = **PE/V** [because, the wattmeter reading is P= (cc current x pc voltage) = I_c x V. The pc voltage is reduced due to the resistance drop of sec coil. It should be actually E to give the correct power loss. Thus, actual loss is I_c x E or (P/V)xE = PE/V]



Wattmeter method for determining iron loss.

Therefore, total iron loss of specimen Pi =

$$(PE/V) - E^2 / (r_p+r_c) \text{ watts}$$

Therefore, total iron loss of specimen Pi = (PE/V) - E ^{2} / (r_p+r_c) watts

$$= \frac{PE}{V} - \frac{E^2}{r_p + r_c}$$

$$= \frac{P.E}{E - I_p r_c} - \frac{E^2}{r_p + r_c}$$

$$= \frac{P.I_p(r_p + r_c)}{I_p(r_p + r_c) - I_p r_c} - \frac{E^2}{r_p + r_c}$$

$$= \frac{P(r_p + r_c)}{r_p} - \frac{E^2}{r_p + r_c}$$

$$= P\left[1 + \frac{r_c}{r_p}\right] - \frac{E^2}{r_p + r_c}$$

- Specific iron loss can be calculated by dividing the total iron loss by weight of the specimen
- The advantages of this method are reliable and superior for testing .

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Measurement luminous intensity

- Luminous intensity is the illuminating power of the source and is measured by units called *candela*.
- Transducers are used for the measurement of luminous intensity.
- The transducer changes the physical quantity into an electrical signal. It is an electronic device which has two main functions, i.e., sensing and transduction. It senses the physical quantity and then converts it into electrical signals.
- The photoelectric transducer converts the light energy into electrical energy. It is made of semiconductor material.

- Photoelectric Transducer Working can be categorized as photo emissive, photo-conductive or photo-voltaic.
- In photo emissive devices, radiation falling on a cathode causes electrons to be emitted from the cathode surface.
- In photo conductive devices, the resistance of a material is changed when it is illuminated.

Photoconductive Cell

- Light striking the surface of a material can provide sufficient energy to cause electrons within the material to break away from their atoms. Thus, free electrons and holes (charge carriers) are created within the material, and consequently its resistance is reduced. This is known as the Photoconductive effect.
- It uses the semiconductor material like cadmium selenide as a photo sensing element.

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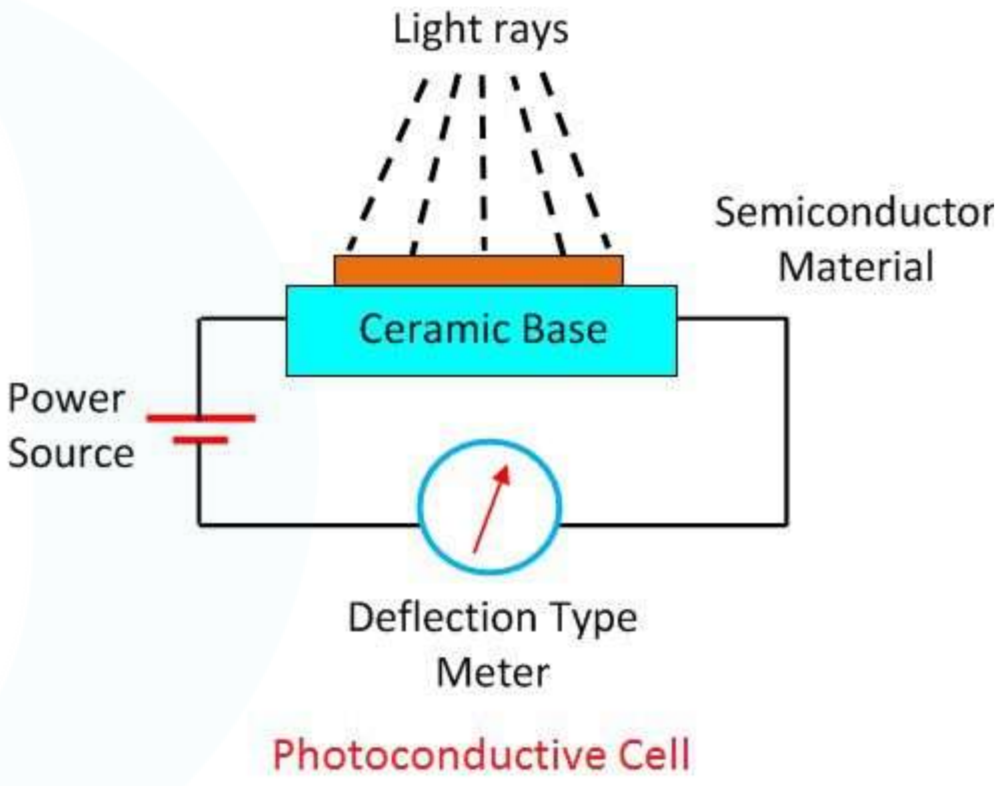
- When the beam of light falls on the semiconductor material, their conductivity increases and the material works like a closed switch.
- The current starts flowing into the material and deflects the pointer of the meter.



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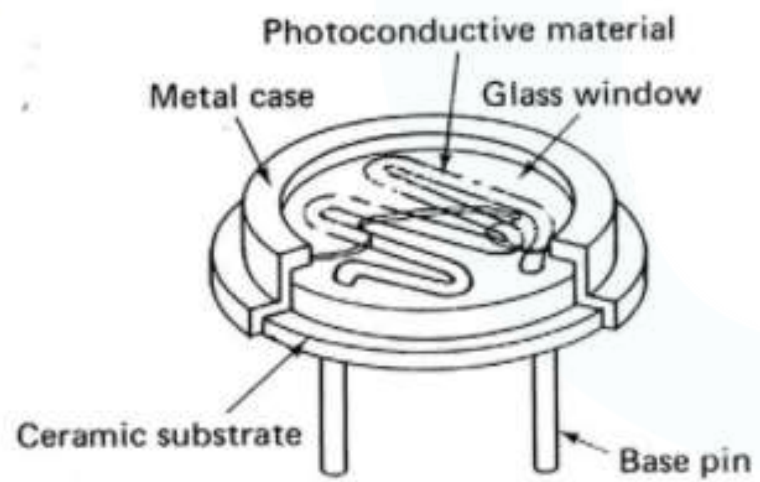
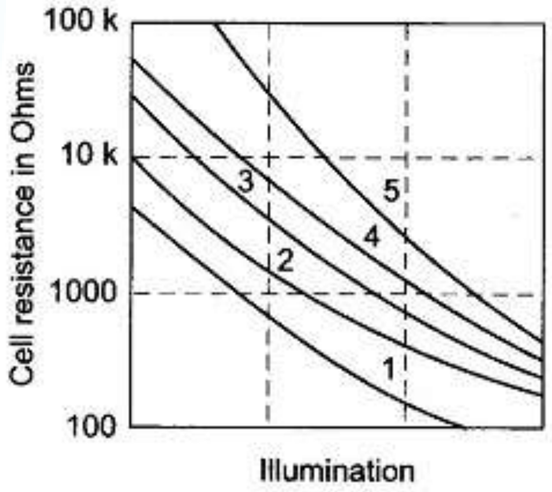
- The photo conductive material, typically Cadium selenide is deposited in a zig zag pattern (to obtain a desired resistance value and power rating) separating two metal coated areas acting as electrodes, all on an insulating base such as ceramic.
- The assembly is enclosed in a metal case with a glass window over the photo conductive material.





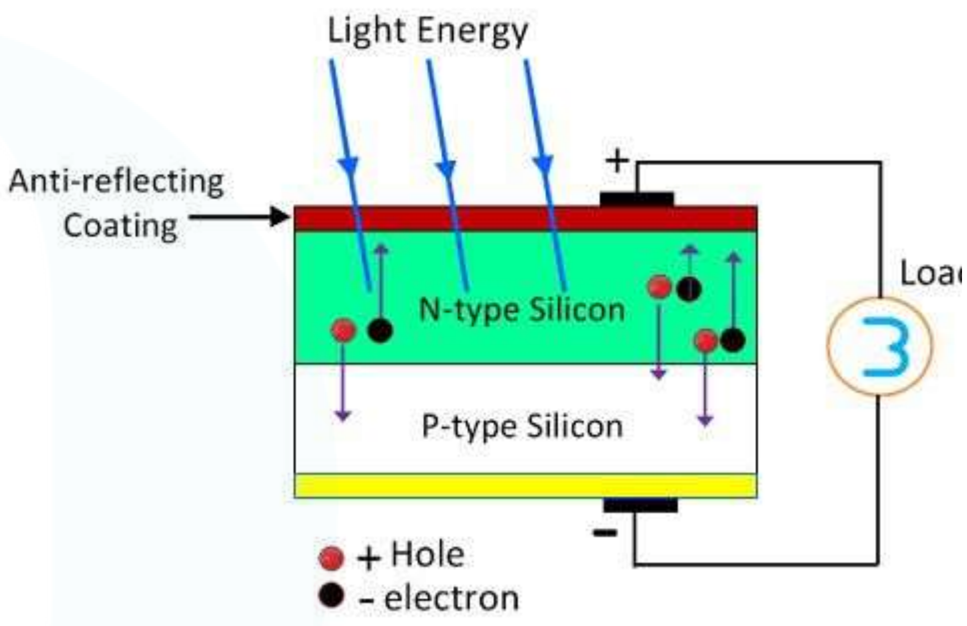
Typical Curves of Resistance vs Illum

Photo-voltaic cell

- The Photo-voltaic effect is a process that generates voltage or electric current in a photovoltaic cell when it is exposed to sunlight.
- Light is composed of photons, which are simply small bundles of electromagnetic radiation or energy.
- When light of a suitable wavelength is incident on these cells, energy from the photon is transferred to electron of the semiconducting material, causing it to jump to a higher energy state known as the conduction band.
- In their excited state in the conduction band, these electrons are free to move through the material, and it is this motion of the electron that creates an electric current in the cell.

- The semiconductor materials like arsenide, indium, cadmium, silicon, selenium and gallium are used for making the PV cells. Mostly silicon and selenium are used for making the cell.

- The output voltage and current obtained from the single unit of the cell is very less. The magnitude of the output voltage is 0.6v, and that of the current is 0.8v.



Photovoltaic Cell

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Temperature Sensor/Temperature transducers

- A Temperature Transducer is a device that converts the thermal quantity into electrical signal.

Main Features of Temperature Transducers

- The input to them are always the thermal quantities
- They generally converts the thermal quantity into electrical quantity
- They are usually used for the measurement of the temperature and heat flow.

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Basic Scheme of Temperature Transducers

The basic element of temperature transducers are

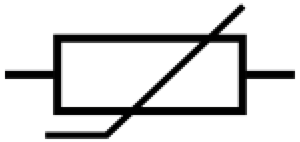
- Sensing Element:-The sensing element in the temperature transducers is the element whose properties change with change in temperature. As the temperature changes the corresponding change occurs in certain property of the element.
- Transduction Element:-It is the element that transforms the output of the sensing element into electrical quantity. The change in the property of the of sensing element acts as the input for it. It measures the change in the property of sensing element. The output is of transduction element is then calibrated to give output which represents the change in the thermal quantity.

- **Types of Temperature Transducers**

There are four commonly used temperature sensor types: RTD, NTC Thermistor, Thermocouples, Semiconductor based temperature sensors.

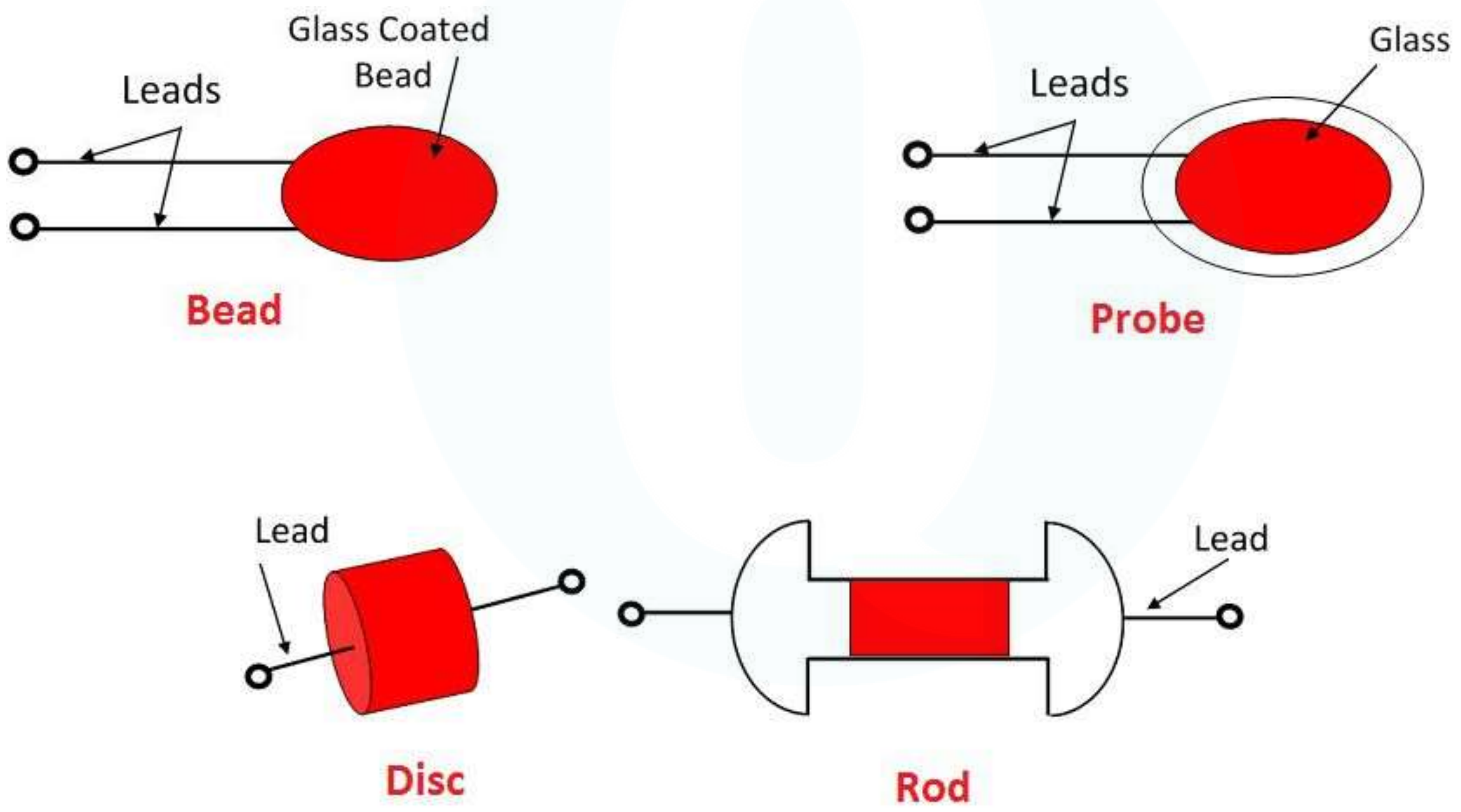
Thermistor

- The word thermistor can be termed as Thermal Resistor.
- As the name indicates it is a device whose resistance changes with the change of the temperature.
- Due to there high sensitivity they are widely used for the measurements of the temperature.
- Thermistors are generally composed of mixture of metallic oxides.
- The circuit symbol for a thermistor is shown below:



- The working principle of a thermistor is that its resistance is dependent on its temperature.
- The resistance of a thermistor is measured using an ohmmeter.
- If we know the exact relationship between how changes in the temperature will affect the resistance of the thermistor, then by measuring the thermistor’s resistance we can derive its temperature.

- It is available in the form of the bead, rod and disc. The different types of the thermistor are shown in the figure below.



Types of Thermistors

- The thermistor is classified into two types. They are the negative temperature coefficient and the positive temperature coefficient thermistor.
- **Negative Temperature Coefficient Thermistor (NTC)** – In this type of thermistor when the temperature increases the resistance decreases.
- **Positive Temperature Coefficient Thermistor** – The resistance of the thermistor increases with the increases in temperature.

Advantages of Thermistor

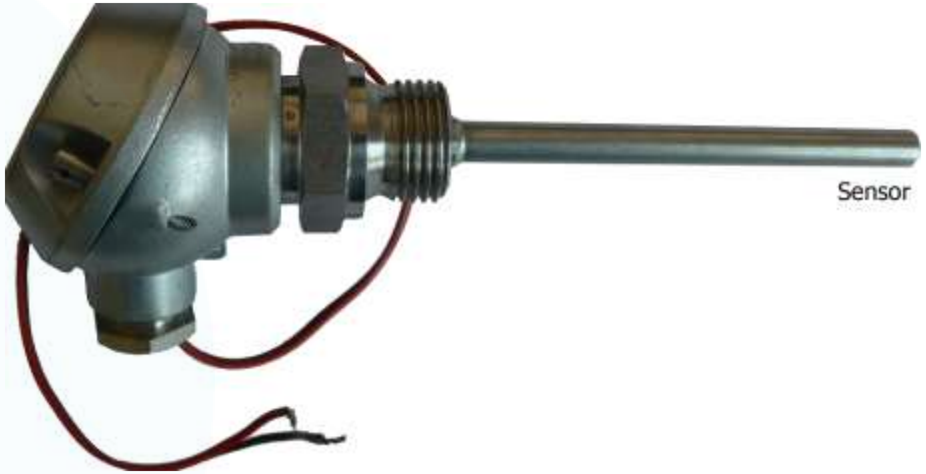
- The thermistor is compact, long durable and less expensive.
- The response time of the thermistor changes from seconds to minutes.

Uses of Thermistors

- Digital thermometers (thermostats)
- Automotive applications (to measure oil and coolant temperatures in cars & trucks)
- Household appliances

Resistance Thermometer or resistance temperature detector (RTD)

- The resistance thermometer or resistance temperature detector (RTD) uses the resistance of electrical conductor for measuring the temperature.
- This conductor is referred to as a temperature sensor.
- The main function of the RTD is to give a positive change in resistance with temperature.
- The metal has a high-temperature coefficient that means their resistance increases with the increase in temperature.



- The resistance thermometer uses a sensitive element made of extremely pure metals like platinum, copper or nickel.
- The resistance of the metal is directly proportional to the temperature. Mostly, platinum is used in resistance thermometer.
- The following are the requirements of the conductor used in the RTDs.

❑ The resistivity of the material is high so that the minimum volume of conductor is used for construction.

❑ The change in resistance of the material concerning temperature should be as high as possible.

❑ The resistance of the material depends on the temperature.

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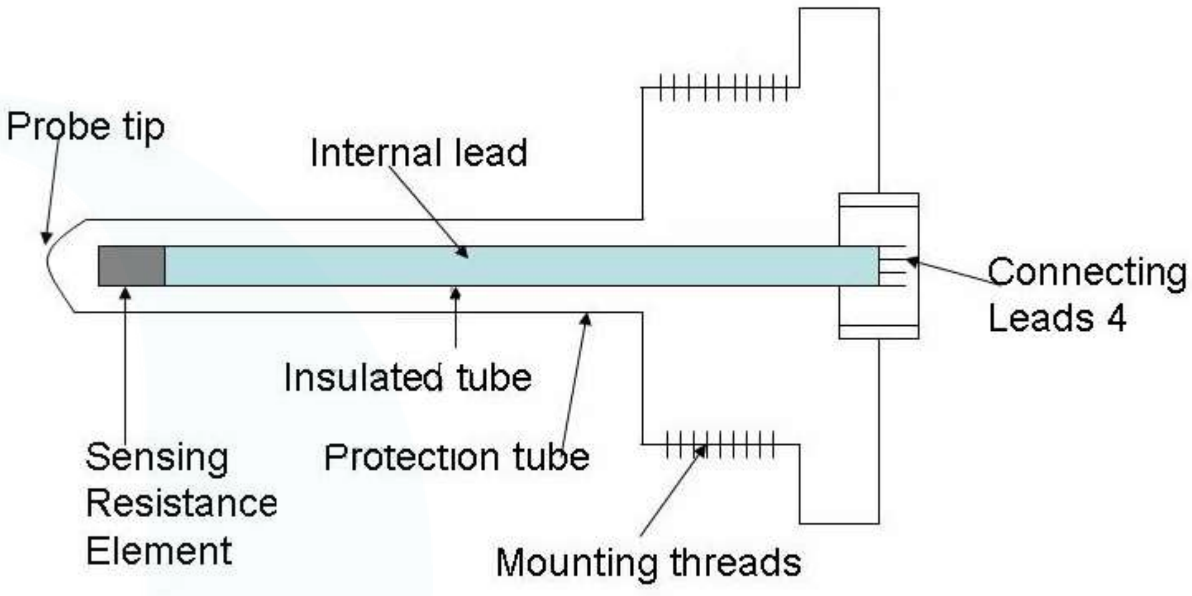
- The resistance element is placed inside the hollow structure called protection tube. It is made up of stainless steel or carbon steel.
- Internally lead wire is used to connect resistance element with external lead terminals. Lead wire covered by insulated tube for short circuit prevention. Fiber glass is used for low and medium temperature and a ceramic insulation for high temperature.

Construction of metal resistance thermometer



- Protection tube is used to protect the resistance element and internal lead wires from ambient conditions.

Operation of RTD

- Initial resistance is measured by using wheatstone bridge. Probe tip of the RTD is placed near the heat source. As the temperature varies, the resistance of the material also varies. Final resistance is again measured.

- From the above measurement, variation in temperature can be calculated as follows,

$$R_t = R_0 (1+\alpha t)$$

$$t = ((R_t / R_0)-1)/\alpha$$

Where, R_t = resistance at t^oC.

R_0 = Resistance at 0^oC.

t = temperature.

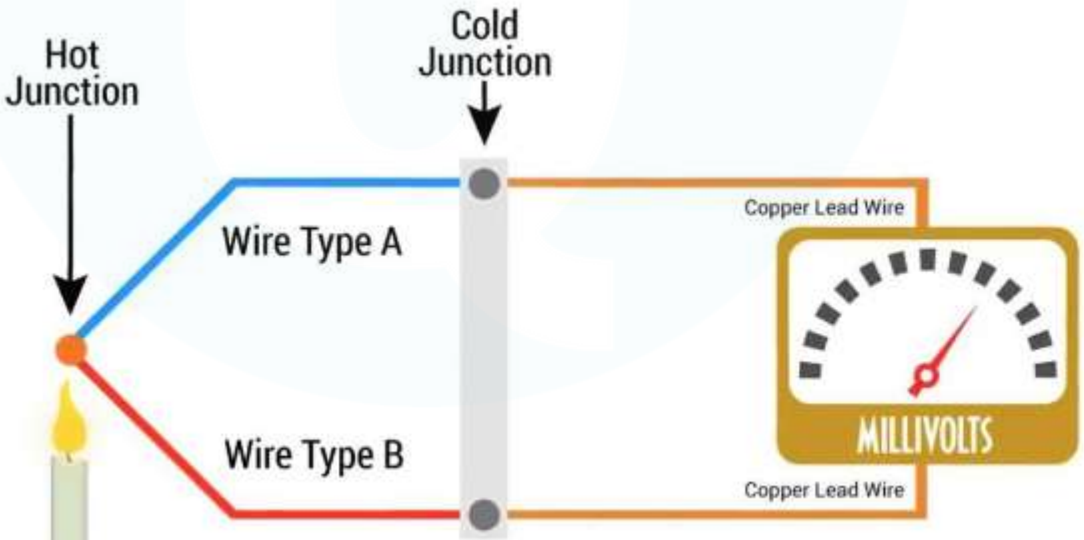
α = Temperature coefficient of RTD material.

Thermocouple

- A thermocouple is a sensor used to measure temperature in a number of processes.
- Thermocouples consist of two wire legs made from dissimilar metals which are fixed together at one end, creating a junction.
- The junction is placed on the element or surface where we want to measure the temperature. This junction is known as a hot junction.
- And the second end of the plate is kept at a lower temperature (room temperature). This junction is known as cold junction or reference junction.

- According to the Seebeck effect, the temperature difference between the two different metals induces the potential differences between two points of the thermocouple plates.

- If the circuit is closed, a very small amount of current will flow through the circuit. A voltmeter is connected in the circuit. The voltage measured by the voltmeter is a function of a temperature difference between two junctions



- A thermocouple can measure a wide range of temperatures.
- It is a simple, robust, and cost-effective temperature sensor used in various industrial applications, home, office, and commercial applications.
- Thomas Johann Seebeck found that a magnetic field is produced when two different metals are connected at one end and create a temperature difference between two ends.

Thermocouple Types

- Thermocouples are available in different combinations of metals. The type of thermocouple is chosen according to the application, ranges.
- Base metal thermocouples or type J, K, T, & E are relatively low cost and therefore the most popular thermocouples. They are commonly used in a broad range of low to medium temperature applications.
- Noble metal thermocouples or type R, S, and B have greater resistance than base metal thermocouples, however they have platinum conductors, making them far more expensive. They are commonly used in high temperature applications.

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Thermocouple Applications

- It is used to monitor the temperature in the steel and iron industries. For, this type of application, type B, S, R, and K thermocouples are used in the electric arc furnace.
- It is used in the temperature sensors in thermostats to measure the temperature of the office, showrooms, and homes.
- It is installed to monitor the temperature while testing the thermal stability of switchgear equipment.
- The number of thermocouples is installed in the chemical production plant and petroleum refineries to measure and monitor temperature at a different stage of the plant.

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RTD Vs Thermocouple

Sensor	Advantages	Disadvantages
RTD Sensor	• Linear output • Repeatability • Better stability	• Self heating • Less sensitive • Cost
Thermocouple	• Fast response • Wider temperature range • Durable	• Less accurate • Wiring is more expensive • Less stable

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Silicon temperature sensors

- They are classified into different types like Voltage output, Current output, Digital output, Resistance output and Diode temperature sensors.
- Modern semiconductor temperature sensors offer high accuracy and high linearity over an operating range of about -55°C to +150°C.
- A silicon temperature sensor is an integrated circuit, and can, therefore, include extensive signal processing circuitry within the same package as the sensor.
- Some of these are analog circuits with either voltage or current output.

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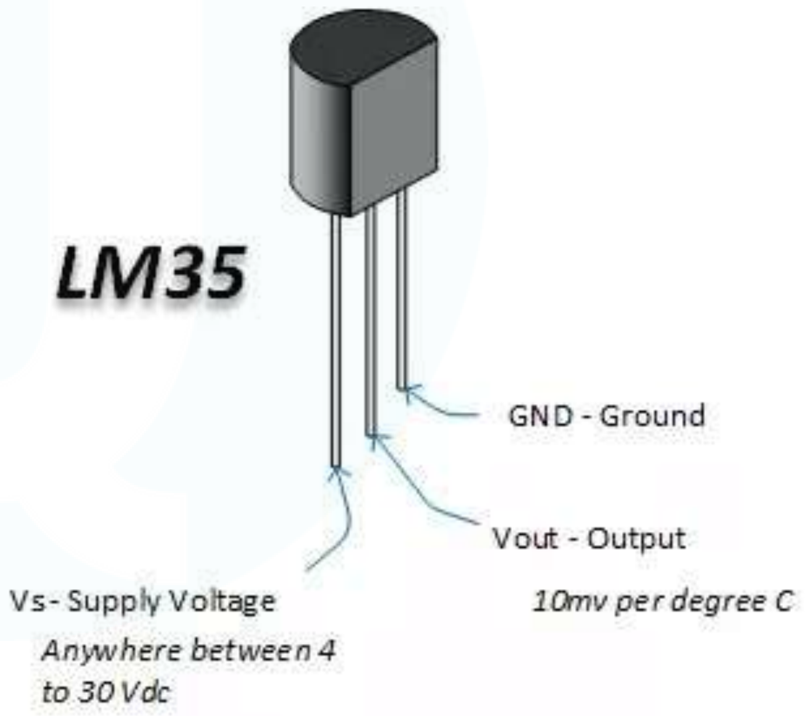
- An example of the temperature sensor is an LM35, it is a precision integrated circuit temperature sensor. The output voltage is linearly proportional to the Celsius temperature and the range of this sensor is -55^{0}C to +120^{0}C.



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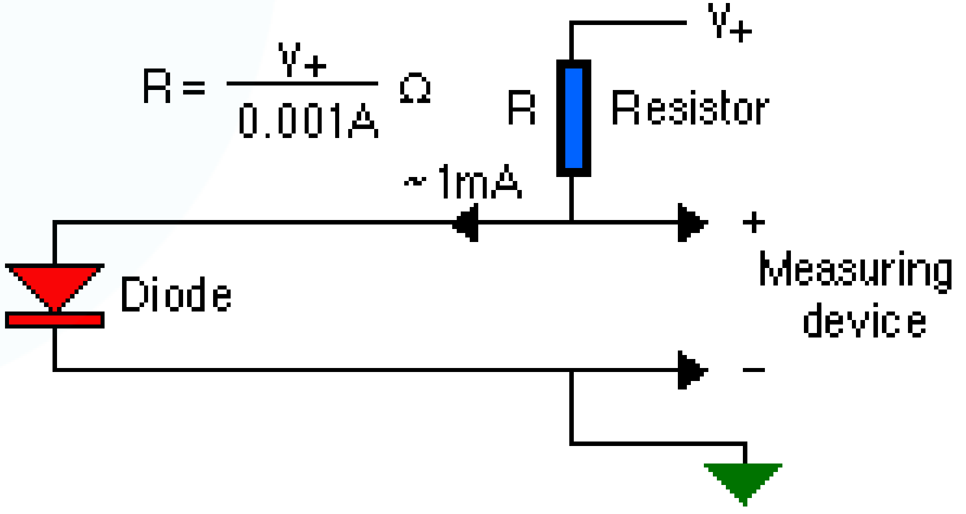
- The ordinary semiconductor diode may be used as a temperature sensor.
- The diode is the lowest cost temperature sensor and can produce satisfactory results if it is well calibrated and provide a stable excitation current.
- Almost any silicon diode can be used.
- The forward biased voltage across a diode has a temperature coefficient of about 2.3mV/°C and is reasonably linear.
- The measuring circuit is simple.



Diode as a Temperature Sensor

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Major characteristics of semiconductor temperature sensors include:

- They provide reasonably linear output.
- They are available in moderately small sizes.
- They are not capable enough to measure high temperatures. Their temperature range is typically limited between -40 to +120°C.
- They give fairly accurate temperature readings if properly calibrated.
- Use of semiconductor temperature sensors enables simple interfacing with other electronic devices like amplifiers, regulators, Digital signal processors, and microcontrollers etc.
- Unlike other temperature sensors like thermocouples and RTDs, their electrical and mechanical performance is not very robust.

Comparison

	Thermocouple	RTD	Thermistor	Silicon
Temperature range	-270 to 1800 C	-250 to 900 C	-100 to 450 C	-55 to 150 C
Accuracy	±0.5 C	±0.01 C	±0.1 C	±0.15 C
Excitation	Not required	Current source	Voltage source	Supply voltage
Output type	Voltage	Resistance	Resistance	Voltage