# Electronics Engineering

# Basic Electrical Engineering

Comprehensive Theory

*with* **Solved Examples** and **Practice Questions**

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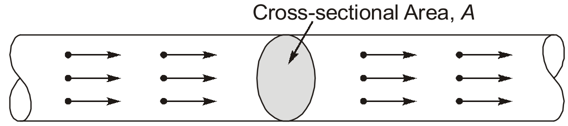
CHAPTER 1

# Electromagnetism

## 1.1 Electric Current

Electric current may be defined as the time rate of net motion of an electric charge across a cross-sectional area. A random motion of electrons in a metal does not constitute a current unless there is a net transfer of charge with time




i.e., electric current, $i$ = Rate of transfer of electric charge

$$= \frac{\text{Quantity of electric charge transferred during a given time duration}}{\text{Time duration}}$$

$$= \frac{dQ}{dt}$$

Coulomb is the practical as well as SI unit for measurement of electric charge. One coulomb is approximately equal to sum of $624 \times 10^{16}$ electrons charge.

Since current is the rate of flow of electric charge through a conductor and coulomb is the unit of electric charge, the current may be specified in coulombs per second or Ampere.

## 1.2 Electromotive Force and Potential Difference

Electromotive force (emf) is the force that causes an electric current to flow in an electric circuit while the potential difference between two points in an electric circuit is that difference in their electrical state which tends to cause flow of electric current between them.

Volt is a unit of electromotive force as well as potential difference in practical as well as in SI system of units.

The volt is defined as that potential difference between two points of a conductor carrying a current of one ampere when the power dissipated between these points is equal to one watt.

## 1.3 Resistance

Resistance may be defined as that property of a substance which opposes (or restricts) the flow of an electric current (or electrons) through it.

The SI unit of resistance is ohm (Ω), which is defined as resistance between two points of a conductor when a potential difference of one volt, applied between these points, produces in this conductor a current of one ampere, the conductor not being a source of any emf.

For insulators having high resistance, much bigger units kilo ohm or kΩ($10^3$ ohm) and mega ohm or MΩ ($10^6$ ohm) are used. In case of very small resistances smaller units like milli-ohm ($10^{-3}$ ohm) or micro ohm ($10^{-6}$ ohm) are employed.

## 1.4 OHM's Law

The current flowing through a conductor is directly proportional to the potential difference across the ends of the conductor and inversely proportional to the conductor resistance. This relation was discovered by German physicist George Simon Ohm and so it is known as Ohm's law.

If $I$ is the current flowing through a conductor of resistance $R$ across which a potential difference $V$ is applied then according to Ohm's law

$$I \propto V \text{ and } I \propto \frac{1}{R} \text{ or } I \propto \frac{V}{R} \text{ or } I = \frac{V}{R}$$

where $V$ is in volt. $R$ is in ohm and $I$ is in ampere.

**Ohm's law may be defined as follows:**

Physical state i.e., temperature etc. remaining the same, the current flowing through a conductor is directly proportional to the potential difference applied across its ends.

or

The ratio of potential difference applied across a conductor and current flowing through it remains constant provided physical state i.e., temperature etc. of the conductor remains unchanged.

i.e. $$\frac{V}{I} = \text{constant} = R$$

where $R$ is known as the resistance of the conductor.

Ohm's law may be alternatively expressed as

$$V = IR$$

Ohm's law cannot be applied to circuits consisting of electronic tubes or transistors because such elements are not bilateral i.e., they behave in different way when the direction of flow of current is reversed as in case of a diode. Ohm's law also cannot be applied to circuits consisting of nonlinear elements such as powdered carbon, thyrite, electric arc etc. For example, for silicon carbide, the relationship between applied voltage (for potential difference) $V$ and current flowing $I$ is given as $V = KI^m$ where $K$ and $m$ are constants and $m$ is less than unity.

## 1.5 SI System of Units

SI stands for "System International d' Unites" in French. This abbreviation is now adopted by the International Standardising Organization as the abbreviated name of this new system of units in all languages.

The SI system is a comprehensive, logical and coherent system, designed for use in all branches of science, engineering and technology.

This system derives all the units from the following seven base units.

| Quantity | Unit | Symbol |
|---|---|---|
| Length | metre | m |
| Mass | kilogram | kg |
| Time | second | s |
| Intensity of electric current | ampere | A |
| Thermodynamic temperature | Kelvin | K |
| Luminous intensity | candela | cd |
| Amount of substance | mole | mol |

The SI system besides seven base units, has following supplementary units.

| Quantity | Unit | Symbol |
|---|---|---|
| Plane angle | radian | rad |
| Solid angle | steradian | sr |

Recommended prefixes for formation of multiples and submultiples of units are given below:

| Multiple | Prefix | Multiple | Prefix |
|---|---|---|---|
| 10 | deca | $10^{-1}$ | deci |
| $10^2$ | hecto | $10^{-2}$ | centi |
| $10^3$ | kilo (K) | $10^{-3}$ | milli (*m*) |
| $10^6$ | mega (M) | $10^{-6}$ | micro ($\mu$) |
| $10^9$ | giga (G) | $10^{-9}$ | nano (*n*) |
| $10^{12}$ | tera (T) | $10^{-12}$ | pico (*p*) |

## 1.6 Work, Power and Energy

**Work :** Work is said to be done by or against a force, when its point of application moves in or opposite to the direction of the force and is measured by the product of the force and the displacement of the point of application in the direction of force.

i. e., Work done, $W = \text{Force } [F] \times \text{distance } [d]$

The SI or MKS unit of work is the joule, which is defined as the work done when a force of one newton acts through a distance of one metre in the direction of the force. Hence, if a force $F$ acts through distance $d$ in its own direction,

$$W = F\,[\text{newtons}] \times d\,[\text{metres}] = Fd \text{ joules}$$

**Power :** Power is defined as the rate of doing work or the amount of work done in unit time.

The MKS or SI unit of power is the joule/second or watt. In practice, the watt is often found to be inconveniently small and so a bigger unit, the kilowatt is frequently used.

$$1 \text{ kilowatt} = 1{,}000 \text{ watts}$$

**Energy :** Energy is defined as the capacity of doing work. Its units are same as those of work, mentioned above. If a body having mass $m$, in kg, is moving with velocity $v$, in metres/second,

$$\text{Kinetic energy} = \frac{1}{2}mv^2 \text{ J}$$

If a body having mass $m$, in kg, is lifted vertically through height $h$, in metres, and if $g$ is the gravitational acceleration, in metres/second$^2$ in that region, potential energy acquired by the body

= Work done in lifting the body = $mgh$ joule

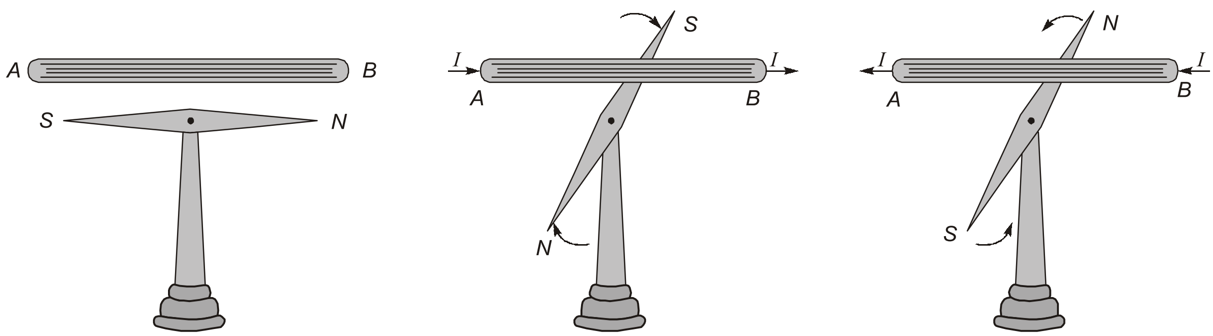
As already stated, in SI system the unit of energy of all forms is joule. Bigger unit of energy is mega joules (MJ) where 1 MJ = $10^6$ J.

**Calorie :** It is the amount of heat required to raise the temperature of one gram of water through 1°C.

1 calorie = 4.18 J = 4.2 J

## 1.7 Magnetic Field due to a Current Carrying Conductor

In 1819 it was discovered by a Danish Physicist, Hans Christian Oersted that an electric current is always accomplished by certain magnetic effects.

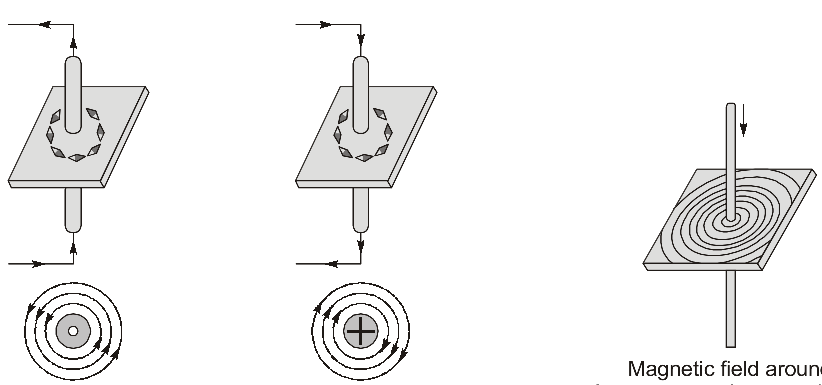



**(a) No current flow** **(b) Current flowing from *A* to *B*** **(c) Current flowing from *B* to *A***

**Oersted** found that when current is passed through a conductor placed above the magnetic needle, the needle turns in a certain direction, as shown in figures above. He also found that when the direction of flow of current is reversed the magnetic needle also deflects in opposite direction.

Further investigation showed that the field around the current carrying conductor consists of lines of force, which encircles the conductor. It can be proved experimentally by passing a current carrying conductor AB in the card board and plotting the field with the help of magnetic needle on it, as shown in figures below.

It is observed that when the current is passed through conductor in upward direction, the direction of lines of force is counterclockwise direction (observed from the top of the conductor) and when the current is passed through the conductor in downward direction, the direction of lines of force is clockwise (observed from the top of the conductor).



**(d)** **(e)** Magnetic field around A current carrying counductor

The properties of the lines of magnetic induction around a current carrying conductor are summarized as below:

(i) Lines of magnetic induction are circles, symmetrical about, and concentric with, the axis of the conductor.

(ii) The spacing between the lines of induction decreases as we move closer to the conductor.

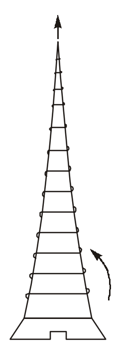
(iii) The direction of lines of magnetic induction depends on the direction of flow of current through the conductor.

(iv) Magnetic induction or flux density depends upon the strength (or magnitude) of the current flowing through the conductor.

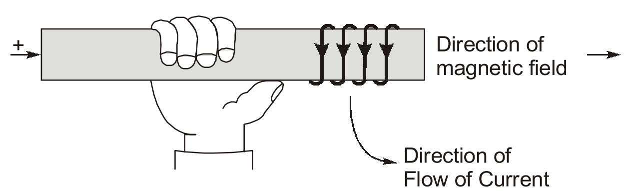
## 1.8 Determination of Direction of Magnetic Field Around a Current Carrying Conductor

The direction of lines of force (magnetic field) around a straight current carrying conductor may be determined by any of the following rules :

1. **Corkscrew Rule :** If the right handed corkscrew is held with its axis parallel to the conductor pointing the direction of flow of current and the head of the screw is rotated in such a direction that the screw moves in the direction of flow of current then the direction in which the head of screw is rotated, will be the direction of magnetic lines of force.
2. **Right Hand Rule :** If the current carrying conductor is held in right hand by the observer so that it is encircled by fingers stretching the thumb at right angle to the fingers in the direction of flow of current then finger tips will point the direction of magnetic lines of force, as shown in figure (b).



(a) Corkscrew Rule




(b) Right hand rule

## 1.9 Magnetic Field due to a Circular Loop

If a single turn wire carrying current is bent in the form of a loop (or ring) as shown in figure. The lines of magnetic induction around it will be concentric circles, leaving the plane of the loop (or ring) on one side and entering on the other. The loop acts as the true magnet having north and south poles.

The direction of magnetic field may be determined by applying either of the two rules namely (i) right hand rule or (ii) corkscrew rule.

**Example 1.1** A laminated soft iron ring of relative permeability 1000 has a mean circumference of 800 mm and a cross-sectional area 500 mm$^2$. A radial air-gap of 1 mm width is cut in the ring which is wound with 1000 turns. Calculate the current required to produce an air-gap flux of 0.5 mWb if leakage factor is 1.2 and stacking factor 0.9. Neglect fringing.

***Solution:***

$$\text{Total AT reqd.} = \Phi_g S_g + \Phi_i S_i = \frac{\Phi_g l_g}{\mu_0 A_g} + \frac{\Phi_i l_i}{\mu_0 \mu_r A_i B}$$

Now, air-gap flux $\Phi_s = 0.5\text{ mWb} = 0.5\times 10^{-3}\text{ Wb}$, $l_g = 1\text{ mm} = 1\times 10^{-3}\text{ m}$; $A_g = 500\text{ mm}^2 = 500\times 10^{-6}\text{ m}^2$

Flux in the iron ring, $\Phi_i = 1.2 \times 0.5 \times 10^{-3}$ Wb

Net cross-sectional area $= A_i \times \text{stacking factor} = 500 \times 10^{-6} \times 0.9\text{ m}^2$

$$\therefore \quad \text{Total AT reqd.} = \frac{0.5\times 10^{-3}\times 1\times 10^{-3}}{4\pi\times 10^{-7}\times 500\times 10^{-6}} + \frac{1.2\times 0.5\times 10^{-3}\times 800\times 10^{-3}}{4\pi\times 10^{-7}\times 1000\times(0.9\times 500\times 10^{-6})}$$

$$\therefore \quad I = \frac{1644}{1000} = 1.64\text{ A}$$

**Example 1.2** A ring has a diameter of 21 cm and a cross-sectional area of 10 cm$^2$. The ring is made up of semicircular sections of cast iron and cas steel, with each joint having a reluctance equal to an air-gap of 0.2 mm. Find the ampere-turns required to produce a flux of $8 \times 10^{-4}$ Wb. The relative permeability of cast steel and cast iron are 800 and 166 respectively. Neglect fringing and leakage effects.

***Solution:***

$$\Phi = 8 \times 10^{-4}\text{ Wb}$$

$$A = 10\text{ cm}^2 = 10^{-3}\text{ m}^2$$

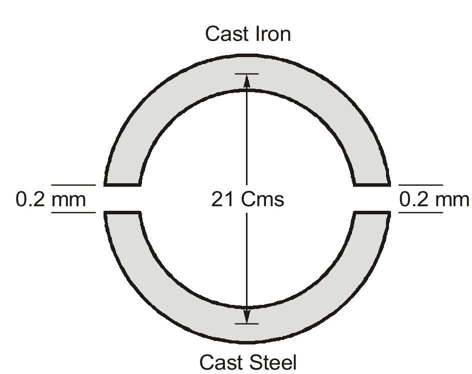
$$B = 8 \times 10^{-4}/10^{-3} = 0.8\text{ Wb/m}^2$$

Air gap $\quad H = B/\mu_0 = 0.8/4\pi \times 10^{-7} = 6.366 \times 10^5$ AT/m

Total air-gap length $= 2 \times 0.2 = 0.4\text{ mm} = 4 \times 10^{-4}$ m

$\therefore \quad$ AT required $= H \times l = 6.366 \times 10^5 \times 4 \times 10^{-4} = 255$

Cast Steel Path



$$H = \frac{B}{\mu_0\mu_r} = \frac{0.8}{4\pi\times10^{-7}\times800} = 796 \text{ AT/m}$$

$$\text{Path} = \pi\frac{D}{2} = 21\frac{\pi}{2} = 33 \text{ cm} = 0.33 \text{ m}$$

$$\text{AT required} = H\times l = 796\times0.33 = 263$$

Cast Iron Path,

$$H = \frac{0.8}{4\pi\times10^{-7}\times166} = 3835 \text{ AT/m; path} = 0.33 \text{ m}$$

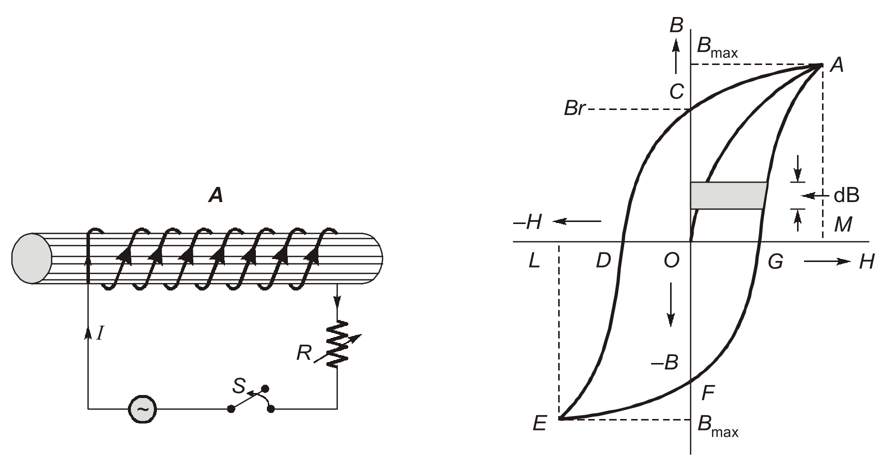
$$\text{At required} = 3835\times0.33 = 1265$$

$$\text{Total At required} = 255+263+1265 = \mathbf{1783\ AT}$$

## 1.20 Magnetic Hysteresis

It may be defined as the lagging of magnetisation or induction flux density ($B$) behind the magnetising force ($H$). Alternatively, it may be defined as that quality of a magnetic substance, due to which energy is dissipated in it, on the reversal of its magnetism.

Let us take an unmagnetised bar of iron $AB$ and magnetise it by placing it within the field of a solenoid, shown in figure (a). The field $H$ (= $NI/l$) produced by the solenoid is called the magnetising force. The value of $H$ can be increased or decreased by increasing or decreasing current through the coil. Let $H$ be increased in steps from zero up to a certain maximum value and the corresponding values of flux density ($B$) be noted. If we plot the relation between $H$ and $B$, a curve like $OA$, as shown in figure, is obtained. The material becomes magnetically saturated for $H = OM$ and has at that time a maximum flux density of $B_{max}$ established through it.




(a) (b)

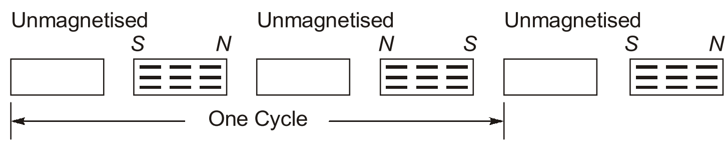
If $H$ is now decreased gradually (by decreasing solenoid current), flux density $B$ will not decrease along $AO$, as might be expected, but will decrease less rapidly along $AC$. When $H$ is zero, $B$ is not but has a definite value $B_r = OC$. It means that on removing the magnetising force $H$, the iron bar is not completely demagnetised. This value of $B$ (= $OC$) measures the **retentivity** or **remanence** of the material and is called the **remanent** or **residual flux density** $B_r$.

To demagnetise the iron bar, we have to apply the magnetising force in the reverse direction. When $H$ is reversed (by reversing current through the solenoid), then $B$ is reduced to zero at point $D$ where $H = OD$. This value of $H$ required to wipe off residual magnetism is known as coercive force ($H_c$) and is a measure of the coercivity of the material.

If, after the magnetisation has been reduced to zero, value of $H$ is further increased in the 'negative' i.e. reversed direction, the iron bar again reaches a state of magnetic saturation, represented by point $L$. By taking $H$ back from its value corresponding to negative saturation, (= $OL$) to its value for positive saturation (= $OM$), a similar curve $EFGA$ is obtained.

It is seen that $B$ always lag behind $H$. The two never attain zero value simultaneously. This lagging of $B$ behind $H$ is given the name 'hysteresis' which literally means **to lag behind**. The closed loop $ACDEFGA$ which is obtained when iron bar is taken through one complete cycle of magnetisation is known as **hysteresis loop**.

By one cycle of magnetisation of a magnetic material is meant its being carried through one reversal of magnetisation, as shown in figure below.




## 1.21 **Area of Hysteresis Loop (**This derivation is not Important)

According to **Weber's Molecular Theory** of magnetism, when a magnetic material is magnetised, its molecules are forced along a straight line. So, energy is spent in this process. Now, if iron has no retentivity, then energy spent in straightening the molecules could be recovered by reducing $H$ to zero in the same way as the energy stored up in a spring can be recovered by allowing the spring to release its energy by driving some kind of load. Hence, in the case of magnetisation of a material of **high retentivity**, all the energy put into it originally for straightening the molecules is not recovered when $H$ is reduced to zero. We will now proceed to find this loss of energy per cycle of magnetisation.

Let $l$ = mean length of the iron bar ; $A$ = its area of cross-section; $N$ = No. of turns of wire of the solenoid.

If $B$ is the flux density at any instant, then $\Phi = BA$.

When current through the solenoid changes, then flux also changes and so produces an induced e.m.f. whose value is

$$e = N\frac{d\Phi}{dt}\text{ volt} = N\frac{d}{dt}(BA) = NA\frac{dB}{dt}\text{ volt} \qquad \text{(neglecting –ve sign)}$$

Now $$H = \frac{NI}{l}$$

or $$I = \frac{Hl}{N}$$

The power or rate of expenditure of energy in maintaining the current $I$ against induced e.m.f. $e$ is

$$= eI\text{ watt} = \frac{Hl}{N}\times NA\frac{dB}{dt} = AlH\frac{dB}{dt}\text{ watt}$$

Energy spent in time, $$dt = Al.H\times\frac{dB}{dt}\times dt = Al.H.dB\text{ joule}$$

Total net work done for one cycle of magnetisation is $W = Al\oint H\,dB$ joule

where $\oint$ stands for integration over the whole cycle. Now, $H\,dB$ represents the shaded area in hysteresis curve.

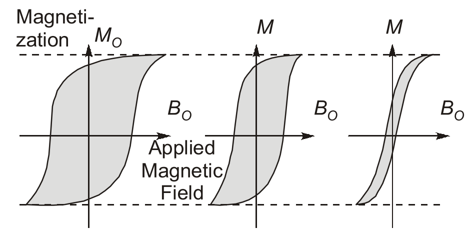
Hence, $\oint H dB$ = area of the loop i.e. the area between the $B$–$H$ curve and the $B$-axis

$\therefore$ work done/cycle = $A_1 \times$ (area of the loop) joule. Now $Al$ - volume of the material

$\therefore$ net work done/cycle/m$^3$ = (loop area) joule, or $W_h$ = (Area of $B$–$H$ loop) joule m$^3$/cycle

As seen from above, hysteresis loop measures the energy dissipated due to hysteresis which appears in the form of heat and so raises the temperature of that portion of the magnetic circuit which is subjected to magnetic reversal.

The shape of the hysteresis loop depends on the nature of the magnetic material.




**Loop 1** is for **hard steel**. Due to its high retentivity, it is well suited for making permanent magnets. But due to large hysteresis loss (as shown by large loop area) it is not suitable for rapid reversals of magnetisation. Certain alloys of aluminium, nickel and steel called **Alnico** alloys have been found extremely suitable for making permanent magnets.

**Loop 2** is for **wrought iron and cast steel**. It shows that these materials have high permeability and fairly good coercivity, hence making them suitable for cores of electromagnets.

**Loop 3** is for **alloyed sheet steel** and it shows high permeability and low hysteresis loss. Hence, such materials are most suited for making armature and transformer cores which are subjected to rapid reversals of magnetisation.

**NOTE**

Ferromagnetic materials having low retentivities are widely used in power communication apparatus. Since silicon iron has high permeability and saturation flux density, it is extensively used in the magnetic circuits of electrical machines and heavy current apparatus where a high flux density is desirable in order to limit the cross-sectional area and therefore, the weight and cost.

## 1.22 Permanent Magnet Materials

Permanent magnets find wide application in electrical measuring instruments, small DC motors, headphones, magnetic chucks and moving-coil loudspeakers etc. In permanent magnets, high retentivity as well as high coercivity are most desirable in order to resist demagnetisation. In fact, the product $B_rH_c$ is the best criterion for the merit of a permanent magnet. The material commonly used for such purposes are carbon-free iron-nickel-aluminium copper-cobalt alloys which are made anisotropic by heating to a very high temperature and then cooling in a strong magnetic field.

## 1.23 Steinmetz Hysteresis Law

It was experimentally found by Steinmetz that hysteresis loss per m$^3$ per cycle of magnetisation of a magnetic material depends on (i) the maximum flux density established in it i.e. $B_{max}$ and (ii) the magnetic quality of the material.

$\therefore$ Hysteresis loss $W_h \propto B_{max}^{1.6}$ Joule/m$^3$/cycle

$$\therefore \quad W_h = \eta B_{max}^{1.6} fV \text{ J/s or watt}$$

where $f$ is frequency of reversals of magnetisation and $V$ is the volume of the magnetic material. The armature of electric motors and generators and transformer cores etc. which are subjected to rapid reversals of magnetisation should, obviously, be made of substances having low hysteresis coefficient in order to reduce the hysteresis loss.

## 1.24 Energy Stored in a Magnetic Field

For establishing a magnetic field, energy must be spent, though no energy is required to maintain it. Take the example of the exciting coils of an electromagnet. The energy supplied to it is spent in two ways (i) part of it goes to meet $I^2R$ loss and is lost once for all (ii) part of it goes to create flux and is stored in the magnetic field as potential energy and is similar to the potential energy of a raised weight. When a weight $W$ is raised through a height of $h$, the potential energy stored in it is $W_h$. Work is done in raising this weight but once raised to a certain height, no further expenditure of energy is required to maintain it at that position. This mechanical potential energy can be recovered, so can be the electrical energy stored in the magnetic field.

When current through an inductive coil is gradually changed from zero to maximum value $I$ then every change of it is opposed by the self-induced e.m.f. produced due to this change. Energy is needed to overcome this opposition. This energy is stored in the magnetic field of the coil and is, later on, recovered when that field collapses.

Let, at any instant,

$i$ = instantaneous value of current ; $e$ = induced e.m.f. at that instant = $L \,.\, di/dt$

Then, work done in time $dt$ in overcoming this opposition is

$$dW = ei\,dt = L.\frac{di}{dt} \times i \times dt = Li\,di$$

Total work done in establishing the maximum steady current of $I$ is

$$\int_0^W dW = \int_0^1 Li\,di = \frac{LI^2}{2}$$

or $$W = \frac{1}{2}LI^2$$

This work is stored as the energy of the magnetic field

∴ $$E = \frac{1}{2}LI^2 \text{ joules}$$

## 1.25 Rate of Change of Stored Energy

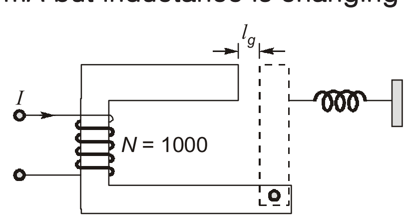
As seen from $E = 1/2\, LI^2$. The rate of change of energy can be found by differentiating the above equation

$$\frac{dE}{dt} = \frac{1}{2}\left[L.2.I.\frac{dI}{dt} + I^2\frac{dL}{dt}\right] = LI.\frac{dI}{dt} + \frac{1}{2}I^2\frac{dL}{dt}$$

**Example 1.3** A relay (Given below) has a coil of 1000 turns and an air-gap of area 10 cm$^2$ and length 1.0 mm. Calculate the rate of change of stored energy in the air-gap of the relay when

(a) Armature is stationary at 1.0 mm from the core and current is 10 mA but is increasing at the rate of 25 A/s.

(b) Current is constant at 20 mA but inductance is changing at the rate of 100 H/s.



***Solution:***

$$L = \frac{\mu_0 N^2 A}{l_g} = \frac{4\pi\times10^{-7}\times(10^3)^2\times10\times10^{-4}}{1\times10^{-3}} = 1.26 \text{ H}$$

(i) Here, $dI/dt$ = 25 A/s, $dL/dt$ = 0 because armature is stationary.

$$\therefore \quad \frac{dE}{dt} = LI\frac{dI}{dt} = 1.26 \times 10 \times 10^{-3} \times 15 = 0.315 \text{ W}$$

(ii) Here, $dL/dt$ = 100 H/s, $dI/dt$ = 0 because current is constant

$$\therefore \quad \frac{dE}{dt} = \frac{1}{2}I^2\frac{dL}{dt} = \frac{1}{2}(20\times10^{-3})^2\times100 = 0.02 \text{ W}$$

## Student's Assignment

**Q.1** **Assertion (A) :** In an electric circuit, the current is due to the presence of electromotive force.
**Reason (R) :** In a magnetic circuit, the magnetic flux is due to the presence of a magnetomotive force.
(a) Both A and R are true and R is a correct explanation of A.
(b) Both A and R are true but R is not a correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.

**Q.2** **Assertion (A):** Leakage flux has a path dominated through the surrounding air.
**Reason (R):** Leakage flux may be defined as that flux which does not follow the intended path in a magnetic circuit.
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

**Q.3** A conductor 20 cm long moves at right angle to its length at a constant speed of 30 m/s in a uniform magnetic field of flux density 1.2 T. The emf induced in case the conductor motion is normal to the field flux is
(a) 0 volt (b) 28.8 volt
(c) 7.2 volt (d) 14.4 volt

**Q.4** A magnetic circuit with relative permeability of 100 has a core cross-sectional area of 5 cm$^2$ and mean core length of 25 cm. The coil has 120 turns with an mmf of 1000 AT. The magnetic core flux is
(a) 0.75 mWb (b) 1 mWb
(c) 0.05 mWb (d) 0.25 mWb

**Q.5** Match **List-I** (Magnetic quantities) with **List-II** (Units) and select the correct answer using the codes given below the lists:

| List-I | List-II |
|---|---|
| A. Permeability | 1. Wb |
| B. Magnetic field intensity | 2. Wb/m$^2$ |
| C. Magnetic flux | 3. H/m |
| D. Magnetic flux density | 4. Amp.-turns/m |

**Codes:**

| | A | B | C | D |
|---|---|---|---|---|
| (a) | 4 | 3 | 1 | 2 |
| (b) | 3 | 4 | 1 | 2 |
| (c) | 4 | 2 | 3 | 1 |
| (d) | 3 | 1 | 2 | 4 |

**Q.6** "In all cases of electromagnetic induction, an induced voltage will cause a current to flow in a closed circuit in such a direction that the magnetic field which is caused by that current will oppose the change that produces the current", is the original statement of

(a) Lenz's Law
(b) Fleming's law of induction
(c) Ampere's circuital law
(d) Faraday's law of magnetic induction

**Q.7** Match **List-I (Electric Circuit)** with **List-II (Magnetic Circuit)** and select the correct answer using the codes given below the lists:

| | List-I | | List-II |
|---|---|---|---|
| A. | Current | 1. | Magnetic flux density |
| B. | Conductivity | 2. | Magnetic field intensity |
| C. | Electric field intensity | 3. | Magnetic flux |
| D. | Current density | 4. | Permeability |

**Codes:**

| | A | B | C | D |
|---|---|---|---|---|
| (a) | 2 | 4 | 3 | 1 |
| (b) | 3 | 4 | 2 | 1 |
| (c) | 2 | 3 | 4 | 1 |
| (d) | 3 | 1 | 2 | 4 |

**Q.8** One 800-turn flat coil with an area of $5 \times 10^{-2}$ m$^2$ is rotating in a magnetic field of flux density 60 mWb/m$^2$ at 1500 rpm. The value of induced emf in the coil if the plane of the coil is parallel to the field is

(a) 375 V
(b) 288 V
(c) 392 V
(d) 377 V

***Answer Key :***

**1.** (b) **2.** (a) **3.** (c) **4.** (d) **5.** (b)
**6.** (a) **7.** (b) **8.** (d)

## Student's Assignments Explanations

**1. (b)**

$$I = \frac{\text{EMF}}{R} \text{ ( for an electric circuit)}$$

$$\phi = \frac{\text{MMF}}{\text{Redactance}}$$

( for a magnetic circuit)

**2. (a)**

**3. (c)**

Given, $\theta = 90°$

$\therefore$ emf induced $= B\,l\,v \sin\theta$

$= 1.2 \times 0.2 \times 30 \times \sin 90°$

$= 7.2$ volt

**4. (d)**

Given, $\mu_r = 100$, $a = 5$ cm$^2$, $l = 25$ cm, $N = 120$ turns, $NI$ = MMF = 1000 AT

We know that,

$$\text{Flux} = \frac{\text{MMF}}{Rl}$$

$$= \frac{NI}{\left(\frac{l}{\mu_0 \mu_r A}\right)} = \frac{NI \cdot \mu_0 \mu_r A}{l}$$

or, $$\text{Flux} = \frac{1000 \times 4\pi \times 10^{-7} \times 100 \times 5 \times 10^{-4}}{25 \times 10^{-2}}$$

$$= \frac{4\pi}{5} \times 10^{-4} = 0.25 \text{ mWb}$$

**5. (b)**

$$H = \frac{NI}{l}\left(\frac{\text{Ampere-turn}}{\text{metre}}\right)$$

$$\phi = B.A.$$

or, $$B = \frac{\phi}{A} \text{ (Wb/m}^2\text{)}$$

$\phi$ has a unit of Wb; permeability, $\mu$ has unit of Henry/m.

**6. (a)**

**7. (b)**

**8. (d)**

Emf induced, $e = N\phi\omega$

Here, $\phi = B \times A$

$= 60 \times 10^{-3} \times 5 \times 10^{-2}$

$= 3 \times 10^{-3}$ Wb

And, $$\omega = \frac{2\pi}{60}N = \frac{2\pi \times 1500}{60} = 50\,\pi \text{ rad/s}$$

Given, $N$ = Number of turns = 800

So, emf induced,

$$e = 800 \times 3 \times 10^{-3} \times 50\,\pi = 377 \text{ volt}$$

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