

1

BASIC ELECTRONICS
FOR +2 SC STUDENTS OF ELECTRONICS



**SADASIVA
BISWAL**



BASIC ELECTRONICS

FOR +2 SC STUDENTS OF ELECTRONICS

VOLUME 1



ATLANTIC

SADASIVA BISWAL

Published by

ATLANTIC

PUBLISHERS & DISTRIBUTORS (P) LTD

7/22, Ansari Road, Darya Ganj, New Delhi-110002

Phones : +91-11-40775252, 40775214, 23273880, 23275880

Fax : +91-11-23285873

Web : www.atlanticbooks.com

E-mail : orders@atlanticbooks.com

Branch Office: Chennai

Phones : +91-44-48531784, 28291383

E-mail : chennai@atlanticbooks.com

Copyright © The Author, 2008, 2021

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, transmitted or utilized in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior permission of the copyright owner. Application for such permission should be addressed to the publisher.

Disclaimer

- The author and the publisher have taken every effort to the maximum of their skill, expertise and knowledge to provide correct material in the book. Even then if some mistakes persist in the content of the book, the publisher does not take responsibility for the same. The publisher shall have no liability to any person or entity with respect to any loss or damage caused, or alleged to have been caused directly or indirectly, by the information contained in this book.
- The author has fully tried to follow the copyright law. However, if any work is found to be similar, it is unintentional and the same should not be used as defamatory or to file legal suit against the author.
- If the readers find any mistakes, we shall be grateful to them for pointing out those to us so that these can be corrected in the next edition.
- All disputes are subject to the jurisdiction of Delhi courts only.

Printed & bound in India by Atlantic Print Services

*DEDICATED
TO
MY PUPILS*

Now, the resistance across AB is R which is the series combination of 1Ω , $R_4\Omega$ and 1Ω . So,

$$R = 1 + R_4 + 1$$

$$= 1 + \frac{5}{4} + 1 = 2 + \frac{5}{4} = \frac{13}{4}$$

$$= 3.25 \text{ ohms}$$

Thus, the effective resistance across AB is 3.25 ohms.



2

Capacitors

Q. 1. What is a capacitor?

Ans. Capacitor : Capacitor is a device which stores electrical charge.

The function of the capacitor is to store a large amount of charge for a given potential difference or to store a given charge at low potential difference. The relation of charge and potential difference in a capacitor is used to define capacitance.

Q. 2. Define capacitance. Mention its MKSa Unit.

Ans. Capacitance : The capacitance of a capacitor is defined as the ratio of the charge transferred from one plate to the other of the capacitor, to the potential difference produced between the plates. Mathematically we can write :

$$C = \frac{Q}{V} \quad \dots(16)$$

where C is the capacitance of the capacitor, Q is the amount of charge transferred from one plate to the other and V is the potential difference between the two plates.

Units. The MKS unit of capacitance is farad.

$$1 \text{ Farad} = 1 \text{ coul/1 volt}$$

Other units used for capacitance are micro farad (μF) and pico farad (PF)

$$1 \mu\text{F} = 10^{-6} \text{ F}$$

$$1 \text{ PF} = 10^{-12} \text{ F}$$

Defn. of Farad. A farad is the capacitance of a capacitor which acquires a potential difference of 1 volt when it receives a charge of 1 coulomb.

Q. 3. How can a capacitor be formed? Give its symbols.

Ans. Formation of a capacitor : A simple capacitor can be formed by taking two separate metallic plates with a non-conducting substance (Dielectric) placed in the space between them (fig. 2.1).

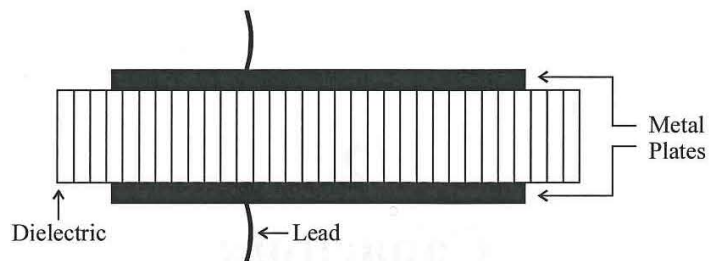


Fig. 2.1

Symbols of capacitor

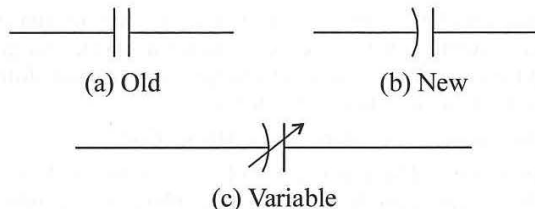


Fig. 2.2

Q. 4. Describe the function of material dielectrics in a capacitor ?

Ans. *Function of material dielectrics in a capacitor :* Air is used as a medium between the two plates of many types of capacitors. Like those in other capacitors, solid and liquid materials such as mica, paraffined paper or oil are used as the material medium between the plates. These materials have good insulating properties as well as they also respond to the presence of the electric field between the plates of the capacitor. As a result of which, the capacitance increases largely. These substances introduced in between the two plates of a capacitor are called dielectrics. The presence of a dielectric between the two plates of a capacitor increases the capacitance of the capacitor.

Q. 5. Deduce the capacitance of a parallel plate capacitor ?

Ans. *Capacitance of a parallel plate capacitor :* Let us consider a parallel plate capacitor whose two plates are charged uniformly to $+Q$ and $-Q$ and separated by a dielectric. The potential difference developed between the two plates is 'V'. Each plate has a surface area 'A'.

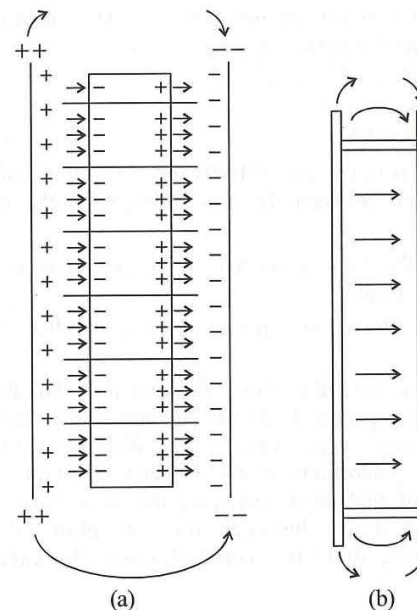


Fig. 2.3. Parallel plate capacitor.

If the plates are large and their separation small, the electric field intensity between them is every where uniform. The electric field intensity is given by

$$E = \frac{\Psi}{\epsilon q} = \frac{Q}{\epsilon A} \quad \dots(17)$$

[$\because \Psi = Q$, i.e., the total no. of lines of force emerging from charge is equal to the charge itself.]

From the definition of electric field intensity we have $E = \frac{F}{q}$

The potential difference between the two plates is given by,

$$\begin{aligned} V &= \frac{W}{q} = \frac{FS}{q} = \frac{Eq}{q} S = ES \\ &= \frac{Q}{\epsilon A} S \quad \dots(18) \end{aligned}$$

where S is the separation between the two plates. Now, the capacitance ' C ' of the capacitor is given by

$$C = \frac{Q}{V} = \frac{Q}{\frac{Q}{\epsilon_r \epsilon_0 A} S} = \epsilon_r \epsilon_0 \frac{A}{S} \quad \dots(19)$$

where ϵ_r is the relative permittivity or dielectric constant of the dielectric employed between the two plates, ϵ_0 is the permittivity of empty space.

Q. 6. Describe the factors on which the capacitance of a parallel plate capacitor depends.

Ans. Factors on which the capacitance of a parallel plate capacitor depends.

It is now clear from the above equation (19) that the capacitance of a parallel plate capacitor is directly proportional to the area of each plate, ' A '; inversely proportional to the distance between the two plates, ' S '; directly proportional to the dielectric constant, ' ϵ_r '. This shows that as the area of each plate increases, the capacitance will increase. Increasing the distance between the two plates decreases the capacitance. As the dielectric constant rises, the capacitance also increases.

Q. 7. What are commercial capacitors ?

Ans. *Commercial capacitors* : A multi plate capacitor is formed by joining a number of parallel plate capacitors. That means a large number of plates, each of large area are used to make a commercial capacitor. This capacitor has large capacitance. In such high grade capacitors mica is used as dielectric. Low cost capacitors of capacitance upto $10 \mu\text{F}$ are usually made of alternate layers of tin or aluminium foil and waxed paper. These are frequently wound into rolls under pressure and sealed into moisture-resisting metal containers. A multi plate capacitor is shown in fig. 2.4.

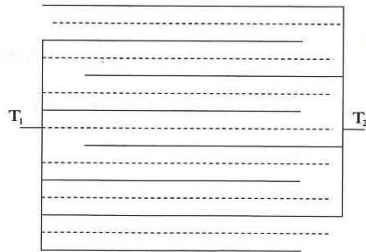


Fig. 2.4. Commercial Capacitor

Q. 8. What do you mean by dielectric strength ?

Ans. *Dielectric strength* : The dielectric strength or breakdown voltage is really a measure of the insulating quality of the material. Dielectric strength is defined as that property of the insulator which determines the maxm. potential gradient which can be applied to the material before its insulating properties are destroyed by a disruptive discharge of electricity through the insulator. The capacitor will withstand certain voltage or potential gradient. After a critical potential gradient, the dielectric strength will breakdown and the capacitor will be destroyed with sparks through the dielectric material. The dielectric strength is always measured in terms of Kilo-volt/centimeter.

TABLE

Dielectric Strength (Average values)

Dielectric material	Breakdown voltage in KV/cm
Air	30
Transformer oil	75
Turpentine	110
Paraffin oil	160
Kerosene	160
Paraffin, solid	250-450
Paraffined paper	300-500
Polystyrene	250-1500
Mica	300-700
Ebonite	300-1000
Glass	300-1600
Vacuum	> 4000

Q. 9. Derive expressions for energy stored in a capacitor ?

Ans. *Energy stored in a capacitor* : When a capacitor is charged energy is stored in the capacitor. When the capacitor is discharged, the energy is released from the capacitor. Therefore during charging of a capacitor, the current in the circuit falls and during discharging of the capacitor, the current in the circuit rises.

Let's consider one uncharged capacitor. This capacitor is gradually charged by transferring small charges ' dq ' from one plate to the other. This is done continuously by steps. So, at each step the work done is vdq . Since, initially the potential difference between the two plates is zero (uncharged capacitor) and the potential increases uniformly to a final value ' v ' (fully charged capacitor), the average

potential difference between the two plates of the capacitor is thus $\frac{Q+V}{2} = \frac{V}{2}$. Hence the work done in transferring the total charge Q from one plate to the other is given by

$$W = FS = EQS = \frac{\bar{V}}{S} QS = \frac{1}{2} VQ \quad \dots(20)$$

From the definition of capacitance we have

$$Q = CV$$

Substituting this value of Q in eqn. (20) we have,

$$W = \frac{1}{2} V(CV) = \frac{1}{2} CV^2 \quad \dots(21)$$

Substituting the value of V in eqn. (20) we have,

$$W = \frac{1}{2} \left(\frac{Q}{C} \right) \times Q = \frac{1}{2} \frac{Q^2}{C} \quad \dots(22)$$

In the above relations ' C ' is measured in Farads, ' V ' in volts and Q in coulombs and hence the energy is in joules.

Q. 10. What is power factor in capacitors ?

Ans. *Power factor in capacitors* : Power factor of a capacitor represents its percentage rating of losses.

$$\text{Power Factor} = \frac{\text{loss of energy}}{\text{energy supplied}} \times 100\%$$

With little or no leakage or losses, a capacitor has zero power factor.

Q. 11. What is inductance in capacitors ?

Ans. *Inductance in capacitors* : In all capacitors there is a small value of inductance from the counter emf developed in the leads of the capacitor and the current travelling along the plates. In low frequency this inductance is negligible. In high frequency above 10MHz, the inductance can be taken into account.

Q. 12. What do you mean by variable capacitors ? Where such capacitors are used ?

Ans. *Variable capacitors* : Two types of capacitors are there which can be adjusted or varied. These adjustable capacitors are generally constructed of two or more flat metal plates separated by sheets of mica or plastic. The adjustable capacitors are also called padders or trimmers. These capacitors have capacitance from 30 PF to 1000 PF. The working voltage ranges from 100 to 600 volts.

Variable capacitors are formed of two sets of plates, one stator or stationary plates and the other rotor or rotatable plates. In these capacitors, air is usually used as dielectric. Sometimes mica sheet, plastic or ceramic metals are also used as dielectric. When the shafts are rotated the rotor plates mesh into the spaces between stator plates, without touching. Consequently, the area of the plates vary and hence the capacitance changes. Some special variable capacitors are also available which are called vacuum-dielectric variable capacitors. These capacitors are used in tuning circuits of radio receivers.

Q. 13. Discuss various types of capacitors.

Ans. *Types of capacitors* : Various types of capacitors are in use. These are :

- (a) Vacuum capacitor
- (b) Air capacitor
- (c) Mica capacitor
- (d) Ceramic capacitor
- (e) Paper capacitor
- (f) Plastic capacitor
- (g) Electrolytic capacitor
- (h) Oil-filled capacitor

(a) Vacuum capacitor. These capacitors are available in both fixed and variable type. They have no leakage. They are used in 5000-50,000 volt service. They have capacitances ranging from 5 to 250 PF. They are efficient for frequency 1000 MHz. These capacitors are used in transmitters.

(b) Air capacitor. These capacitors are made in fixed, adjustable and variable type. They have little leakage except through insulators. They are used in both low and high voltage applications. Specifically these capacitors are suitable for receivers and transmitters. Fixed and variable type of air capacitors have capacitance below 500 PF.

(c) Mica capacitor. These capacitors are available as fixed and adjustable type. They have little leakage except through some material between the plates. The working voltage for them ranges from 350 to several thousand volts. Their capacitance varies from 1.5 PF to 0.1 μ F. Fixed types are used as RF by pass capacitors. They are used in the frequency 300 MHz and more. The efficiency decreases as the frequency drops to 10MHz. Adjustable types are used as padders and trimmers.

(d) Ceramic capacitor. Both fixed type and adjustable types are available. They have more low leakage. Their capacitance ranges from

1.5 PF to 0.01 μF for fixed types and upto 100 PF for adjustable types. Their working voltage is about 500 volt and frequency is 300 MHz or more.

(e) **Paper capacitor.** Paper covered with oil, wax, poly chlorinated. Biphenyl (PCB) or Ester is used. They have low leakage. This leakage becomes very high with old once due to contamination with moisture. Fixed types of these paper capacitors have frequencies from 10 PF to 10 μF . Working voltage ranges from 150 to several thousand volts. They are useful in the frequency 1 or 2 MHz . Beyond this frequency, they are less effective because there will be dielectric fatigue and hysteresis loss.

(f) **Plastic capacitor.** Instead of paper sheets, plastics are also used as dielectrics. These capacitors are available in tubular forms. They work effectively in high frequencies. Their capacitance is about 2 μF . Their working voltage ranges from 200 volt to 600 volt.

(g) **Electrolytic capacitors.** They are available in fixed types only. They have leakage if used beyond rated voltage. They work in the frequency range from few μF to 50,000 μF or even more. The working voltage is 6 to about 700 volts. These are useful only in d.c. circuits. Tantalum electrolytic capacitors operate at a higher temperatures and hence are used the most. An electrolytic capacitor consists of an Aluminium foil emersed in a solution of electrolyte. The Aluminium-foil serves as the +ve plate and the electrolyte as the -ve plate. To make an electrical connection with the liquid, another Aluminium foil is placed in the solution. To prevent the two foils from touching each other, a piece of gauze is placed between them. Then the combination is rolled into tubular shape and sealed to make air tight. A wire lead from one end connected to one of the foil plates and a wire lead from the other end connected to the other foil plate serve as the connecting leads of the capacitor.

The electrolytic capacitors are normally polarised. A special type of non-polarised electrolytic capacitor may be used during starting periods in a.c. electric motors. These capacitors are relatively small and less expensive in regard to the high value of capacitance.

(h) **Oil filled capacitor.** In these capacitors, insulating oil is used as the dielectric.

Q. 14. Discuss on the colour code for capacitance.

Ans. *Capacitance colour code :* The colour codes for capacitance are same as for resistors, i.e., 0, 1, 2....9 are represented by the colours black, brown, red, orange... etc. The capacitance obtained from colour code is always in pico farad. In some capacitors, colours

are printed and in some other capacitors numbers are printed. In fixed capacitors, however, their capacitance and working voltage are printed.

There are different types of codes, namely :

- Three-dot code
- Six-dot code
- Marked with number of coloured dots or bands.

(a) **Three-dot code.** This is the simplest code used with 500 volt mica capacitors with a tolerance 20%. A 580 PF colour-coded mica capacitor is shown below in fig. 2.5.

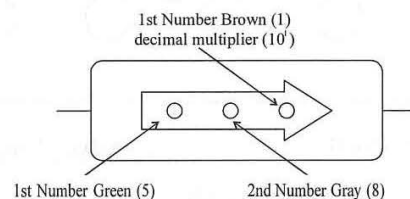


Fig. 2.5. Three-dot code.

(b) **Six-dot code.** A six-dot coded capacitor is shown in fig. 2.6. There are six-dots which are read clockwise from top left. White indicates mica, the next two dots indicate capacitance numbers, the fourth dot is the capacitance multiplier, the fifth dot gives the tolerance and the sixth dot gives the temperature co-efficient in parts per million (ppm). This increases as the numbers decrease from four. Such type of capacitor has voltage ratings from 300 volt to 500 volt.

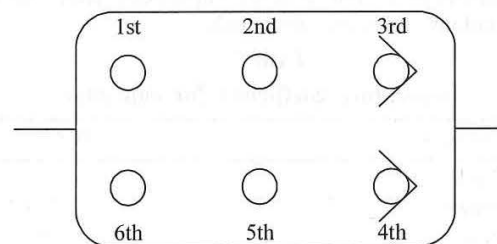


Fig. 2.6. Six-dot code.

Note. The three-dot and six-dot coded capacitors are known as EIA (Electronic Industries Association) code.

The military standard is similar to EIA except that a black first dot indicates a mica dielectric and silver a paper dielectric.

(c) **A capacitor having a series of colour dots.** There are some ceramic capacitors which are cylindrical in shape and are marked with a number of coloured dots or bands. One example of such a colour coded capacitor are shown below in fig. 2.7.

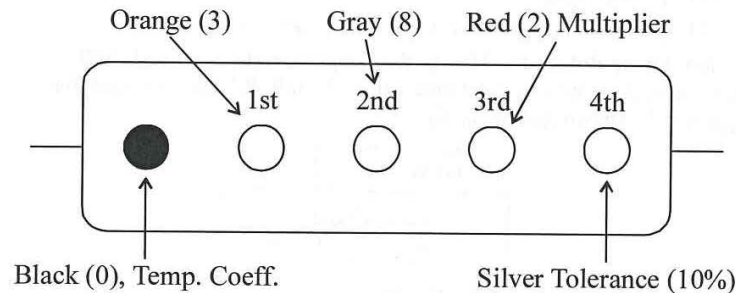


Fig. 2.7

The capacitance of the capacitor is $3800 \pm 10\%$.

Q. 15. What is temperature co-efficient of capacitance ? Explain.

Ans. *Temperature co-efficient of capacitance* : The temperature co-efficient of capacitance is the degree by which the capacitor will change its capacitance with a change in temperature. A capacitance has zero temperature coefficient if it doesn't change with temperature. If the capacitance decreases with temperature it has negative temperature co-efficient. If the temp. co-efficient is -220 , then the capacitance will be decreased by 220 ppm per degree centigrade increase in temperature. For ceramic capacitors, temp. co-efficients according to colour codes are given below :

TABLE

Temperature coefficient for capacitor

Colour	TC/°C
Black	0
Brown	- 33
Red	- 75
Orange	- 150
Yellow	- 220

Colour	TC/°C
Green	- 330
Blue	- 470
Violet	- 750
Gray	+ 30
White	+ 500

Q. 16. Derive the laws of series and parallel combination of capacitors.

Ans. *Combinations of capacitors* : Two or more capacitors can be combined in two ways :

- In series
- In parallel

(a) Series combination of capacitors

Let's consider three capacitors joined in series. A potential difference ' V ' is applied across the group of the capacitors. Let C_1 , C_2 , C_3 be the individual capacitances of the capacitors and V_1 , V_2 and V_3 represent the potential differences over the capacitors. Each of these capacitors, holds the same quantity of electricity. This follows from the fact that if the capacitors are initially uncharged, a charge upon one plate always attracts upon the other plate, a charge equal in magnitude and opposite in size.

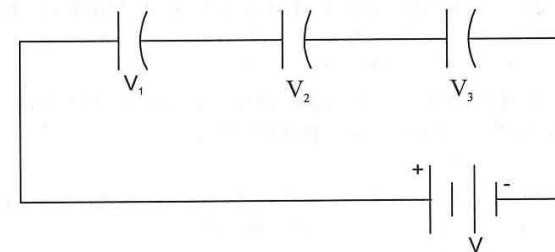


Fig. 2.8. Capacitors in series.

For the series connection it follows that :

$$V = V_1 + V_2 + V_3$$

If we substitute in this equation the various values,

$$V = \frac{Q}{C}, \quad V_1 = \frac{Q}{C_1}, \quad V_2 = \frac{Q}{C_2}, \quad V_3 = \frac{Q}{C_3}$$

We have

$$\frac{Q}{C} = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}$$

Dividing both sides of the equation by Q , we get

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \quad \dots(23)$$

That is, for capacitors connected in series, the reciprocal of the joint capacitance is equal to the sum of the reciprocals of the several capacitances.

(b) Parallel combination of capacitors

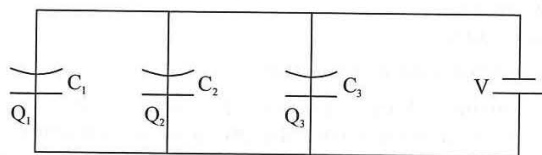


Fig. 2.9. Capacitors in parallel.

In fig. 2.9 are shown three capacitors of separate capacitances, C_1 , C_2 and C_3 , connected in parallel and joined to a device for establishing a potential difference, such as a cell. Obviously all the capacitors are charged to the same potential, since they are all connected directly to the same source of potential difference. By defn. of capacitance, the charge on each capacitor is,

$$Q_1 = C_1 V, \quad Q_2 = C_2 V, \quad Q_3 = C_3 V$$

the potential difference over each being the same. The total charge Q is equal to the sum of the separate charges,

$$Q = Q_1 + Q_2 + Q_3$$

If ' C ' represents the joint capacitance, $Q = CV$ and therefore by substitution for Q , Q_1 , Q_2 and Q_3 we get

$$CV = C_1 V + C_2 V + C_3 V$$

Dividing both sides of the equation by V , we obtain

$$C = C_1 + C_2 + C_3 \quad \dots(24)$$

That is, for capacitors connected in parallel, the joint capacitance is the sum of several capacitances.

Q. 17. How can the capacitors be selected ?

Ans. *Selection of capacitors* : Capacitors can be selected by considering the following factors :

(i) **Capacitance.** A capacitor can be replaced by another having the same capacitance.

(ii) **Working voltage.** A capacitor can be chosen considering its working voltage. The rated voltage should be 10 to 20% higher than the max^m voltage of the circuit.

(iii) **Type of dielectric.** For radio frequency, the capacitors having mica, air, vacuum or ceramic dielectric should be used. For audio frequency, capacitors having mica, ceramic, paper or plastic dielectric should be used. For d.c. filter circuits, electrolytic capacitors are commonly used.

(iv) **Variable, adjustable or fixed.** A similar capacitor is chosen as the original one.

(v) **Physical size.** Ceramic capacitors are generally smaller than equivalent mica and paper capacitors. Electrolytic capacitors are much smaller than paper capacitors.

(vi) **Cost.** Probable cost per μF increases in the order of electrolytic, ceramic, paper, plastic, mica air, and vacuum capacitors.

Q. 18. What do you mean by a.c. and d.c. resistance of a capacitor ?

Ans. *A.C. and d.c. resistance of a capacitor* : When a capacitor is connected in a d.c. circuit, the plate gets charged up and the electron current drops to zero. The capacitor, thereafter, acts as though it had an infinite resistance.

When a capacitor is connected to an alternating source of emf, its action is different. The reversing of emf reverses the flow of electrons to and from the plates of the capacitor and the alternating flow of charge builds an alternating current. The resistance offered by the capacitor is called capacitive reactance. In an a.c. circuit, it is given by,

$$X_c = \frac{1}{j\omega C}$$

Where ' C ' is the capacity of the capacitor ' ω ' is the angular frequency given by $\omega = 2\pi f$, f is the frequency, X_c is the capacitive reactance of the capacitor and j is the imaginary quantity. The

magnitude of X_c is $\frac{1}{\omega C}$. The capacitive reactance in an a.c. circuit plays the role of resistance in d.c. circuit. The current in an a.c. circuit having capacitance C only is given by

$$i = \frac{E_0}{X_c} e^{j\omega t} \quad \dots(25)$$

where $X_c = \frac{1}{j\omega C}$ is called the capacitive reactance of the circuit.

Q. 19. How does capacitance vary with a.c. emf ?

Ans. Variation of capacitance with a.c. emf :

In an a.c. circuit

$$E = E_0 e^{j\omega t} \quad \dots(26)$$

$$\text{Where } E = q/C \quad \dots(27)$$

$$\text{Then, we have } C = q/E \quad \dots(28)$$

It shows that as a.c. emf increases the capacitance 'C' falls keeping q, the instantaneous charge on the capacitor constant.

EXERCISES

Numerical problems with Solutions

1. Represent the colour code for the following capacitors :

- (a) 470 pf $\pm$ 10%
- (b) 620 pf $\pm$ 20%
- (c) 33 pf $\pm$ 5%
- (d) 66 pf $\pm$ 20%
- (e) 82 pf $\pm$ 5%

Solution

- (a) 470 pf = 47×10^1 pf
The colour code of 4 is Yellow
The colour code of 7 is Violet
The colour code of 1 is Brown
The colour code of 10% tolerance is Silver
So, the colour code of the capacitor is Yellow, Violet, Brown, Silver.
- (b) 620 pf = 62×10^1 pf
The colour code of 6 is Blue
The colour code of 2 is Red
The colour code of 1 is Brown
The colour code of 20% tolerance is No colour
So, the colour code of the capacitor is Blue, Red, Brown.
- (c) 33 pf = 33×10^0 pf
The colour code of 3 is Orange

The colour code of 3 is Orange

The colour code of 0 is Black

The colour code of 5% tolerance is Gold

So, the colour code of the capacitor is Orange, Orange, Black, Gold.

(d) 66 pf = 66×10^0 pf

The colour code of 6 is Blue

The colour code of 6 is Blue

The colour code of 0 is Black

The colour code of 20% tolerance is No colour

So, the colour code of the capacitor is Blue, Blue, Black.

(e) 82 pf = 82×10^0 pf

The colour code of 8 is Grey

The colour code of 2 is Red

The colour code of 0 is Black

The colour code of 5% tolerance is Gold

So, the colour code of the capacitor is Grey, Red, Black, Gold.

2. Find the value of the capacitance from the following colour code of the capacitors :

- (a) Green, Grey, Brown
- (b) Red, Green, Red, Silver
- (c) Orange, Grey, Red, Silver
- (d) Red, Red, Brown, Gold
- (e) Violet, Orange, Black

Solution

(a) Green, Grey, Brown

First colour Green represents the number 5, second colour Grey represents the number 8, third colour Brown represents 10^1 . As there is no fourth colour, tolerance is 20%.

Hence, the capacitance is 58×10^1 pf $\pm$ 20%
= 580 pf $\pm$ 20%

(b) Red, Green, Red, Silver

First colour Red represents the number 2

Second colour Green represents the number 5

Third colour Red represents 10^2

Fourth colour Silver represents 10% tolerance

Hence, the capacitance is

$$25 \times 10^2 \text{ pf} \pm 10\%$$

$$= 2500 \text{ pf} \pm 10\%$$

(c) Orange, Grey, Red, Silver

First colour Orange represents the number 3

Second colour Grey represents the number 8

Third colour Red represents 10^2

Fourth colour silver represents 10% tolerance

Hence, the capacitance is

$$38 \times 10^2 \text{ pf} \pm 10\% \\ = 3800 \text{ pf} \pm 10\%$$

(d) Red, Red, Brown, Gold

First colour Red represents the number 2

Second colour Red represents the number 2

Third colour Brown represents 10^1

Fourth colour Gold represents 5% tolerance

Hence, the capacitance is

$$22 \times 10^1 \text{ pf} \pm 5\% \\ = 220 \text{ pf} \pm 5\%$$

(e) Violet, Orange, Black

First colour violet represents the number 7

Second colour Orange represents the number 3

Third colour Black represents 10^0

As there is no fourth colour, the tolerance is 20%.

Hence, the capacitance is

$$73 \times 10^0 \text{ of} \pm 20\% \\ = 73 \text{ pf} \pm 20\%$$

3. Three capacitors have capacitances 0.5, 0.3 and 0.2 μf . What is their joint capacitance when arranged to give (a) a minimum capacitance and (b) a maximum capacitance?

Solution

In series,

$$\frac{1}{C} = \frac{1}{0.5\mu\text{f}} + \frac{1}{0.3\mu\text{f}} + \frac{1}{0.2\mu\text{f}} \\ = \frac{10}{5} + \frac{10}{3} + \frac{10}{2} \\ = 2 + 3.33 + 5 \\ = 10.33$$

$$C = \frac{1}{10.33} = 0.0968 \mu\text{f}$$

In parallel,

$$C = C_1 + C_2 + C_3 \\ = (0.5 + 0.3 + 0.2) \mu\text{f} \\ = 1.0 \mu\text{f}$$

4. Six $1/2 \mu\text{f}$ capacitors are connected first in series and then in parallel. What are the respective joint capacitances of the combination.

Solution

In series,

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_1} + \frac{1}{C_1} + \frac{1}{C_1} + \frac{1}{C_1} + \frac{1}{C_1} \\ = \frac{6}{C_1} = \frac{6}{1/2\mu\text{f}} = \frac{12}{\mu\text{f}} \text{ or } C = \frac{1}{12} \mu\text{f} = 0.083 \mu\text{f}$$

In parallel,

$$C = C_1 + C_1 + C_1 + C_1 + C_1 + C_1 = 6C_1$$

$$C = 6 \times \frac{1}{2} = 3\mu\text{f}$$

5. Three capacitors of capacitance 0.1, 0.2, and 0.5 μf , respectively, are connected in parallel and the group then connected in series with another group of 0.1, 0.2 and 0.5 μf , respectively, connected in series. Calculate the total capacitance.

Solution

In parallel,

$$C = C_1 + C_2 + C_3 \\ = (0.1 + 0.2 + 0.5) \mu\text{f} \\ = 0.8 \mu\text{f}$$

In series,

$$\frac{1}{C^1} = \frac{1}{C} + \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \\ = \frac{1}{0.8} + \frac{1}{0.1} + \frac{1}{0.2} + \frac{1}{0.5} \\ = \frac{10}{8} + \frac{10}{1} + \frac{10}{2} + \frac{10}{5} \\ = \frac{5}{4} + 10 + 5 + 2 \\ = 17 + \frac{5}{4} = \frac{73}{4} \\ \therefore C^1 = \frac{4}{73} \mu\text{f} = 0.054 \mu\text{f}$$

6. A conductor is charged to a potential of 100 volts and has the electrical capacity of 2 microfarad (μf). What is the charge on the conductor?

Solution

$$\begin{aligned} V &= 100 \text{ volts,} & C &= 2 \mu f \\ C &= Q/V & \Rightarrow & Q = CV \\ & & & = 2 \times 100 \mu C \\ & & & = 200 \mu C \end{aligned}$$

7. Find the capacity of a spherical charged conductor in vacuum whose radius is equal to the radius of the earth.

Solution

$$\begin{aligned} \epsilon_0 &= 8.85 \times 10^{-12} \text{ coul}^2/\text{N.m}^2, \quad r = 6.5 \times 10^6 \text{ m} \\ C &= 4\pi\epsilon_0 r \\ &= 4 \times 3.142 \times 8.85 \times 10^{-12} \times 6.5 \times 10^6 \\ &= 723.17 \times 10^{-6} \text{ farad} \\ &= 723.17 \mu f \end{aligned}$$

8. A capacitor is charged to 100 V. What is charge on its positive plate if its capacitance is 2 μf ?

Solution

$$\begin{aligned} C &= 2 \mu f, \quad V = 100 \text{ V} \\ Q &= CV = 2 \mu f \times 100 \text{ V} \\ &= 200 \mu C \end{aligned}$$

9. ' n ' identical oil drops, each of capacity ' C ' are charged to a potential of V volts each. The radius of each drop is ' R ', and the charge of each drop is ' Q ' coulomb. These ' n ' oil drops are merged to form a bigger drop of radius ' R_1 '. Find the capacitance of this bigger drop.

Solution

$$\text{Volume of bigger drop} = \frac{4}{3}\pi R_1^3$$

$$\text{Volume of small drops} = n \times \frac{4}{3}\pi R^3$$

$$\text{So, } \frac{4}{3}\pi R_1^3 = n \times \frac{4}{3}\pi R^3$$

$$\text{or, } R_1 = n^{1/3} R$$

We know that the capacity of a sphere is proportional to its radius.

$$\text{Hence, } \frac{C_1}{C} = \frac{n^{1/3} R}{R} = n^{1/3}$$

$$\text{or, } C_1 = n^{1/3} C$$

10. The area of each plate of a capacitor is 1 m^2 and are separated by 0.1 cm. Find the capacitance considering air as the dielectric.

Solution

$$\begin{aligned} A &= 1 \text{ m}^2, \quad S = 0.1 \times 10^{-2} \text{ m} \\ C &= \epsilon_0 A/S \\ &= \frac{8.85 \times 10^{-12} \times 1}{0.1 \times 10^{-2}} \\ &= 8.85 \times 10^{-9} \text{ f} \end{aligned}$$

11. A multiplate commercial capacitor is made of 350 plates separated by fine sheets of mica ($\epsilon_r = 2.5$) of thickness 10^{-5} m . The effective area of the plates is $45 \times 10^{-3} \text{ m}^2$. Find the capacitance.

Solution

$$\begin{aligned} 2N &= 350 \text{ plates} \\ \epsilon_r &= 2.5 \\ t &= 10^{-5} \text{ m}, \quad S = 10^{-5}/350 \text{ m} \\ A_{\text{eff}} &= 45 \times 10^{-3} \text{ m}^2, \quad A = \frac{45 \times 10^{-3}}{350} \text{ m}^2 \\ C_{\text{eff}} &= ? \\ C &= \epsilon_r \epsilon_0 \times A/S \end{aligned}$$

$$\begin{aligned} &= \frac{2.5 \times 8.85 \times 10^{-12} \times 45 \times 10^{-3}}{350 \times 10^{-5} / 350} \\ &= 2.5 \times 8.85 \times 45 \times 10^{-10} = 995.625 \times 10^{-10} \text{ f} \\ C_{\text{eff}} &= (2N - 1) C \\ &= (350 - 1) \times 995.625 \times 10^{-10} \text{ f} \\ &= 349 \times 995.625 \times 10^{-10} \text{ f} \\ &= 347473 \times 10^{-10} \text{ f} \\ &= 34.7473 \times 10^{-6} \text{ f} \\ &= 34.7473 \mu f \\ &\approx 35 \mu f \end{aligned}$$

12. A $10\ \mu\text{f}$ capacitor is charged to a potential of 400 volts and is then discharged through a conductor. Find the energy given to the conductor due to discharge of the capacitor.

Solution

$$C = 10\ \mu\text{f}$$

$$V = 400\ \text{volts}$$

Energy of the charged capacitor

$$= \frac{1}{2} CV^2$$

Energy given to the conductor

$$= \frac{1}{2} \times 10 \times 10^{-6} \times (4 \times 10^2)^2\ \text{Joule}$$

$$= \frac{1}{2} \times 10^{-5} \times 16 \times 10^4\ \text{Joule}$$

$$= 8 \times 10^{-1}\ \text{Joule}$$

$$= 0.8\ \text{Joule.}$$

13. A $2000\ \mu\text{f}$ capacitor is charged at a steady rate of $25\ \mu\text{C}$ per second. After what time the P.D. across the capacitor plates shall be 20 volts.

Solution

Total charge on the capacitor plates,

$$Q = CV$$

$$= 2000\ \mu\text{f} \times 20\ \text{volts}$$

$$= 4 \times 10^4\ \mu\text{C}$$

Time needed for charging the capacitor to 20 volts is

$$t = \frac{4 \times 10^4}{25} = 1600\ \text{S}$$



3

Inductors

Q. 1. What is an Inductor ?

Ans. Inductor : Inductor is a device that stores energy in the form of magnetic field. A straight wire bent into the form of a coil possesses inductance which is known as self inductance of the coil.

Q. 2. How does an inductor act ?

Ans. Function : An inductor offers resistance to the flow of a.c. through it. A pure inductance doesn't offer any resistance to the flow of d.c. through it.

Q. 3. Discuss on various types of inductors.

Ans. Types of inductors : Different types of inductors are :

- (a) An air core inductor
- (b) Iron core inductor
- (c) A special type of inductor called toroid

(a) An air core inductor. In most electronic applications of inductance where space is limited, wire is wound into either single-layer or multi-layer coils with air. Such an inductor is known as air core inductor.

(b) Iron core inductor. When an inductor has core made of powdered-iron compound (Ferrite) or laminated (thin iron sheet) cores, it is called an iron core inductor. Ferrite materials like zinc or manganese-iron oxides have magnetic permeability but are insulators. Therefore a coil with a ferrite core makes an inductor of inductance many times more than that of an air core inductor. In many applications, coils are wound around a ferrite cylinder that can be screwed into or out of the core space of the coil. This results in a controlled variations of inductance. The inductor has maxm. inductance when the iron core (slug) is screwed into the coil and the inductance is minimum when the slug is backed out.

(c) **A special type of inductor or toroid.** A special type of inductor called toroid which consists of a doughnut-shaper ferrite core, either single-layer-wound as shown in the figure below or multi-layer-wound. Such an inductor has high values of inductance with less wire and therefore little resistance in the coil. Moreover all the lines of force remain in the core. As a result of which, no shielding is required to prevent its field from surrounding circuits or electrical appliances. Even two toroids very close to each other will have no interaction between them.

Q. 4. Give the symbols of inductors.

Ans. Inductor symbols :

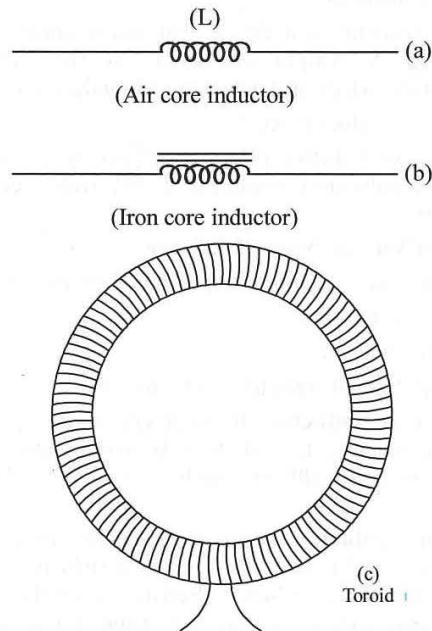


Fig. 3.1. (a) Air core inductor, (b) Iron core inductor, (c) A special type of inductor or toroid.

Q. 5. What are variable inductors ?

Ans. Variable inductors : There are some inductors, mainly iron core inductors whose inductance is required to be varied in accordance

with the need of the applications. In such inductors, coils are wound around a ferrite cylinder which is screwed into or out of the core space of the coil. Consequently, there is a controlled variations of inductance. In such cases, the inductance may be maximum or minimum depending upon the position of the "slug".

Q. 6. Deduce the law of combination of inductors in series and in parallel.

Ans. Combination of inductors : Inductors can be combined in two ways.

- (a) In series
- (b) In parallel

Self-inductances combine like the series and parallel combinations of resistances.

(a) Inductors in series. When inductances are placed in series. The total induced emf is the sum of the separate emf's. Hence, if 'i' is the current flowing through the inductances and 'L' is the resultant or equivalent inductance of the series, then

$$L \frac{di}{dt} = L_1 \frac{di}{dt} + L_2 \frac{di}{dt} + \dots + L_n \frac{di}{dt}$$

Since,

$$i_1 = i_2 = \dots = i_n = i$$

$$\text{So, } L = \sum_{j=1}^n L_j \quad \dots(29)$$

Where $j = 1, 2, 3, \dots, n$

Expanding eqn. (29) we have,

$$L = L_1 + L_2 + L_3 + \dots + L_n \quad \dots(30)$$

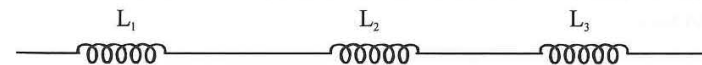


Fig. 3.2. Inductors in series

(b) Inductors in parallel : When inductors are joined in parallel the induced emf across each inductor is the same as the induced emf across the combination. But the currents are different in different inductors. Let the current in each inductor be $i_1, i_2, \dots, i_n$ respectively and the current across the combination is i . Then $i = i_1 + i_2 + i_3 + \dots + i_n = \text{total current}$

$$\text{Thus, } L \frac{di}{dt} = L_1 \frac{di_1}{dt} = L_2 \frac{di_2}{dt} = \dots = L_n \frac{di_n}{dt} \quad \dots(31)$$

From the above equation we get

$$\begin{aligned} \frac{di_1}{dt} &= \frac{L}{L_1} \frac{di}{dt} \\ \frac{di_2}{dt} &= \frac{L}{L_2} \frac{di}{dt} \\ &\vdots \\ \frac{di_n}{dt} &= \frac{L}{L_n} \frac{di}{dt} \end{aligned}$$

Adding the above relations we get,

$$\left(\frac{L}{L_1} + \frac{L}{L_2} + \frac{L}{L_3} + \dots + \frac{L}{L_n} \right) \frac{di}{dt} = \frac{di_1}{dt} + \frac{di_2}{dt} + \frac{di_3}{dt} + \dots + \frac{di_n}{dt}$$

$$\text{But } \frac{di}{dt} = \frac{di_1}{dt} + \frac{di_2}{dt} + \dots + \frac{di_n}{dt}$$

$$\text{So, we have, } \frac{L}{L_1} + \frac{L}{L_2} + \frac{L}{L_3} + \dots + \frac{L}{L_n} = 1$$

$$\text{or, } \frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \dots + \frac{1}{L_n} \quad \dots(32)$$

$$\text{or, } \frac{1}{L} = \sum_{j=1}^n \frac{1}{L_j} \quad \dots(33)$$

Where, $j = 1, 2, 3, 4 \dots n$.

Therefore, the sum of the reciprocals of individual inductance is equal to the reciprocal of the combined inductance of all inductors joined in parallel.

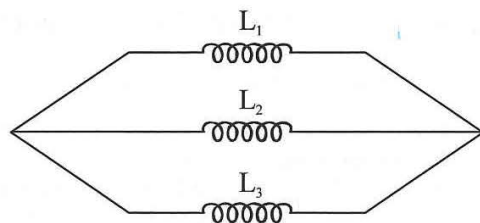


Fig. 3.3. Inductors in parallel

Q. 7. Define Inductance. Mention its units.

Ans. *Inductance* : A coil which produces induction effect in itself by a current flowing through it has co-efficient of self-induction or inductance L .

Definition of L : Self-inductance L of an inductor is defined as the magnetic flux linked with it when a unit current flows through it. Mathematically, it is given by

$$L = \frac{\phi}{i} \quad \dots(34)$$

$$\text{When } i = 1, \phi = L \quad \dots(35)$$

where ϕ is the flux linked with the coil when the current is unity.

Units of inductance

MKS — Henry

$$1 \text{ Henry} = \frac{1 \text{ volt}}{1 \text{ amp./sec.}}$$

CGS — Emu of inductance

$$1 \text{ Emu of inductance} = \frac{1 \text{ emu of potential difference}}{1 \text{ emu of current / sec.}}$$

Relation between Henry and emu of inductance

$$1 \text{ Henry} = 10^9 \text{ emu of inductance.}$$

Q. 8. Derive an expression for the energy stored in an inductor.

Ans. *Energy stored in an inductor* : When current through an inductor changes, the flux linked with inductor also changes. The rate of change of flux induces an emf in the inductor which opposes the inducing current. To increase the current in the inductor energy must be spent externally. This energy gets stored in the inductor.

From Faraday's law of electro magnetic induction, we have,

$$e = -\frac{d\phi}{dt}$$

$$\text{But } \phi = Li$$

$$\text{Hence } e = -\frac{d(Li)}{dt}$$

$$= -L \frac{di}{dt}$$

Electrical work done by the field = $ei \, dt$

$$= L \frac{di}{dt} (idt)$$

$$dw = Lidi$$

Total work done by a current i_0 in the inductor is given by

$$\int_0^w dw = \int_0^{i_0} Lidi$$

$$w = L \int_0^{i_0} idi$$

$$= L \left(\frac{i^2}{2} \right)_0^{i_0}$$

$$w = \frac{1}{2} Li_0^2 \quad \dots(36)$$

where 'L' is the self-inductance of the inductor and w is the total energy stored in the inductor.

Q. 9. What do you mean by d.c. and a.c. resistance of an inductor?

Ans. A.C. and D.C. resistance : As the inductor has negligible resistance it doesn't oppose the flow of d.c. But when alternating current passes through an inductor, induced emf is set up, which opposes the a.c. This opposition to a.c. is measured by inductive reactance X_L or a.c. resistance of an inductor.

$$X_L = \omega L = 2 \pi fL \quad \dots(37)$$

where 'L' is the self-inductance of the coil measured in Henry and 'f' is the frequency of applied a.c. measured in Hertz.

Q. 10. How does inductance vary with emf ?

Ans. Variation of L with emf : In an inductive circuit, the current is given by,

$$i = i_0 \sin \left(\omega t - \frac{\pi}{2} \right)$$

$$\text{where } i_0 = \frac{E_0}{\omega L}$$

$$\text{or, } L = \frac{E_0}{\omega i_0}$$

where E_0 is the peak value of alternating emf applied across L and i_0 is the peak value of alternating current flowing through L . ω is the angular frequency given by

$$\omega = 2 \pi f$$

where f is the frequency of the applied a.c. emf.

Thus inductance of the coil varies with the emf.

Q. 11. Write down the uses of an inductor.

Ans. Application of inductor : An inductor is generally used as a choke. An air core inductor maintains constant inductance even at a very high current while an iron core loses its ability to smooth out variations beyond that current. To prevent this, a small air gap may be left in the iron core to introduce sufficient reluctance in the magnetic circuit.

Q. 12. What is a choke coil? Mention various types of chokes.

Ans. Types of chokes : An inductor is known as a choke coil since it chokes out variation of amplitudes. There are different types of choke coils depending upon the reactances. These are :

- (a) Radio frequency choke (RFC)
- (b) Audio frequency choke (AFC)
- (c) Power frequency choke (PFC)

(a) Radio frequency choke (RFC)

For radio frequency applications (20 KHz to 500 MHz), an air-core coil with low value of inductance is used as RFC.

(b) Audio frequency choke (AFC)

In case of lower frequency circuits, coils having greater inductance are required. For this reason iron core choke coils with higher inductance are used as AFC. Here the frequency is limited to 20 KHz.

A laminated iron core choke :

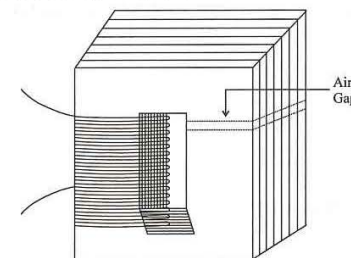


Fig. 3.4

(c) Power frequency choke (PFC)

The power frequency is about 50 Hz. Therefore inductors having still higher inductances are required for chokes.

EXERCISES**Numerical problems with solutions**

1. Find out the self-inductance of a coil of 100 turns when a current of 5 amp passing through it produces a magnetic flux of 0.5×10^{-14} weber.

Solution

$$N = 100 \text{ turns}$$

$$I = 5 \text{ amp}$$

$$\phi = 0.5 \times 10^{-14} \text{ weber}$$

$$\text{Here, } N\phi = LI$$

$$\text{or, } L = \frac{N\phi}{I}$$

$$= \frac{100 \times 0.5 \times 10^{-14}}{5}$$

$$= 1000 \times 10^{-5} \text{ henry}$$

$$= 1000 \times 10^{-6} \text{ henry}$$

$$= 1000 \text{ } \mu\text{H}$$

2. Find out the co-efficient of self-inductance of a coil of 500 turns when a change of current of 1.25 amperes produces a magnetic flux of one microweber.

Solution

$$N = 500 \text{ turns}$$

$$dI = 1.25 \text{ amps}$$

$$d\phi = 1 \text{ } \mu\text{ weber} = 1 \times 10^{-6} \text{ weber}$$

$$L = ?$$

$$\text{Here, } Nd\phi = LdI$$

$$\text{or, } L = \frac{Nd\phi}{dI}$$

$$= \frac{500 \times 10^{-6}}{1.25}$$

$$= 400 \times 10^{-6} \text{ henry}$$

$$= 0.4 \times 10^{-3} \text{ henry}$$

$$= 0.4 \text{ millihenry}$$

3. The current in a circuit drops from 10A to 2A in 0.1S. An average emf of 32 V is induced in the circuit while this happens. Find the inductance of the circuit.

Solution

$$I_1 = 10A, I_2 = 2A$$

$$dI = I_2 - I_1 = 2 - 10 = -8A$$

$$\text{Induced emf.} = 32 \text{ V, } t = 0.1 \text{ S}$$

$$e = -L \frac{dI}{dt}$$

$$32 = -L \left(\frac{-8}{0.1} \right)$$

$$= L (80)$$

$$L = \frac{32}{80} = \frac{2}{5} = 0.4 \text{ henry}$$

4. Two coils are coupled together. When current in one of the coils decays from 1A to Zero in 0.12S, emf of 1V is induced across the second. Find the co-efficient of mutual induction.

Solution

$$dI = -1A$$

$$dt = 0.12 \text{ S}$$

$$e = 1V, M = ?$$

$$\text{Here, } e = -M \frac{dI}{dt}$$

$$1 = -M \left(-\frac{1}{0.12} \right)$$

$$= \frac{M}{.12}$$

$$\text{or, } M = 0.12 \text{ henry}$$

5. A circuit in which there is a current of 5A is changed so that the current falls to Zero in 0.1 S. If an average emf of 200 V is induced, what is the self-inductance of the circuit ?

Solution

$$\begin{aligned} dI &= -5 \text{ A} \\ dt &= 0.1 \text{ s} \\ e &= 200 \text{ V} \\ L &= ? \end{aligned}$$

$$\text{Here, } e = -L \frac{dI}{dt}$$

$$\begin{aligned} 200 &= -L \left(\frac{-5}{0.1} \right) \\ &= L (50) \end{aligned}$$

$$\text{or, } L = \frac{200}{50} = 4 \text{ henry}$$

6. The current in a coil of 325 turns is changed from zero to 6.32 A, thereby producing a flux of 8.46×10^{-4} wb. What is the self-inductance of this coil ?

Solution

$$\begin{aligned} N &= 325 \text{ turns} \\ I &= 6.32 \text{ Amps} \\ \phi &= 8.46 \times 10^{-4} \text{ wb} \\ L &= ? \end{aligned}$$

$$\text{Here, } N\phi = LI$$

$$\begin{aligned} \text{or, } L &= \frac{N\phi}{I} \\ &= \frac{325 \times 8.46 \times 10^{-4}}{6.32} \text{ henry} \\ &= 435 \times 10^{-4} \text{ henry} \\ &= 43.5 \times 10^{-3} \text{ henry} \\ &= 43.5 \text{ millihenry} \\ &= 43.5 \text{ mH} \end{aligned}$$

7. An air-core solenoid is 50 cm long and has 120 turns per centimeter and a diameter of 12 cm. What is the self-inductance of the solenoid ?

Solution

$$l = 50 \text{ cm}$$

$$n = 120 \text{ turns/cm, } N = 50 \times 120 \text{ turns}$$

$$d = 12 \text{ cm, } r = \frac{d}{2} = 6 \text{ cm}$$

$$\begin{aligned} L &= ?, \mu_0 = 4\pi \times 10^{-7} \text{ wb/A.m} \\ &= 4\pi \times 10^{-9} \text{ wb/A.cm} \end{aligned}$$

$$\begin{aligned} \text{Here, } L &= \frac{\mu_0 N^2 A}{l} = \frac{4\pi \times 10^{-9} \times (6000)^2 \pi (6)^2}{50} \\ &= \frac{4\pi^2 \times 36 \times 36 \times 10^6 \times 10^{-9}}{50} = \frac{4 \times 9.87 \times 1296 \times 10^{-4}}{5} \end{aligned}$$

$$\begin{aligned} L &= 10233 \times 10^{-4} \text{ henry} \\ &= 1023.3 \times 10^{-3} \text{ henry} \\ &= 1023.3 \text{ millihenry} \\ &= 1023.3 \text{ mH} \end{aligned}$$

8. Two coils A and B are placed near each other. A current change of 6A in A produces a flux change of 12×10^{-4} Wb in B, which has 2000 turns. What is the mutual inductance of the system.

Solution

$$\begin{aligned} dI &= 6A, \quad d\phi = 12 \times 10^{-4} \text{ wb} \\ N &= 2000 \text{ turns, } M = ? \end{aligned}$$

$$\text{Here, } Nd\phi = MdI$$

$$\begin{aligned} \text{or, } M &= \frac{Nd\phi}{dI} = \frac{2 \times 10^3 \times 12 \times 10^{-4}}{6} \\ &= 400 \times 10^{-3} \text{ henry} \\ &= 400 \text{ mH} \end{aligned}$$

9. In an inductor, a current of 5A is maintained. If the self-inductance of the inductor is 100 mH, find the energy stored in the inductor.

Solution

$$\begin{aligned} I &= 5A, \quad L = 100 \text{ mH} = 100 \times 10^{-3} \text{ H} \\ E &= ? \end{aligned}$$

$$\text{Here, } E = \frac{1}{2} LI^2$$

$$= \frac{1}{2} \times 100 \times 10^{-3} \times (5)^2$$

$$= \frac{1}{2} \times 10^{-1} \times 25$$

$$= 12.5 \times 10^{-1} \text{ Joules}$$

$$= 1.25 \text{ Joules.}$$

10. What will be the self-inductance of an inductor if it stores up 20 joules for a current 4 A in it ?

Solution

$$E = 20 \text{ Joules, } I = 4 \text{ A}$$

$$L = ?$$

$$\text{Here, } E = \frac{1}{2} LI^2$$

$$\text{or, } L = \frac{2E}{I^2} = \frac{2 \times 20}{(4)^2} = \frac{40}{16} H$$

$$= \frac{5}{2} H = 2.5 H$$



4

Electromagnetic Induction

Q. 1. What do you mean by electromagnetic induction ? Explain.

Ans. When there is a relative motion between a coil and a magnet, there is change in magnetic flux which causes a current in the coil. This phenomenon is called electromagnetic induction. This was discovered by Faraday in 1831.

Definition of electromagnetic induction :

The process of producing electric current or emf by the relative motion between a coil and a magnet is known as electromagnetic induction. In this process the electric current is produced by the magnetic field. The current so produced is called induced current and the emf which causes induced current is called induced emf.

Experimental remonstration of the phenomenon of electromagnetic induction :

Michael Faraday of England and Joseph Henry of America independently demonstrated that the change of magnetic flux linked with a coil induces an emf in the coil. The induced emf is found to oppose the inducing emf by Lenz.

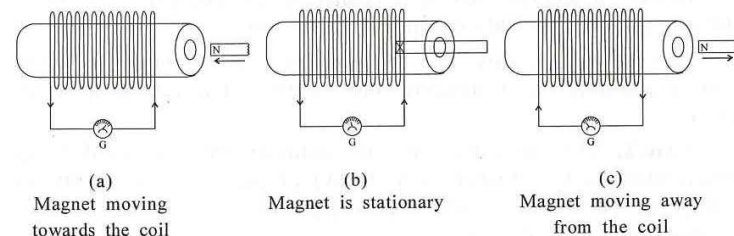


Fig. 4.1

The above figure 4.1 represents a coil of wire connected to a sensitive galvanometer 'G'. If the north pole of a bar magnet is moved towards the coil, there is deflection in the galvanometer indicating a momentary current in the coil in the anti clockwise direction [fig. 4.1(a)]. This current which is set up in the coil due to the change of flux linked with the coil is known as the induced current and the process of generating the induced emf is known as electromagnetic induction.

When the bar magnet remains at rest within the coil, no current is induced so there is no deflection by the galvanometer [fig. 4.2(b)]. When the magnet is quickly removed from the coil, the galvanometer will indicate a current in the direction opposite to that observed in the 1st case. This current is in clockwise direction.

Conclusion. By conducting a series of such experiments, Faraday found that an emf is induced in a coil (conductor) when there is any change of magnetic flux linked with the conductor.

Note

- (i) In the above experiments, magnet is moved towards or away from the coil and induction effect is noticed. The same effect can also be produced by moving the coil (conductor) towards a fixed magnet.
- (ii) An emf may also be induced in a coil by the change in the magnetic field association with a change in current in a near by circuit. This is due to the fact that the change in current in a coil or in a circuit produces a magnetic field. In this magnetic field, if a conductor is moved, a current is set up in the conductor. This is nothing but the induced current.

Q. 2. State and explain Faraday's laws of electromagnetic induction.

Ans. Faraday's laws of electromagnetic induction :

Law-1. Whenever there is a change in the magnetic flux linked through the coil, an induced current flows through it.

Increase in magnetic flux produced an inverse (opposite sense) current and decrease in magnetic flux produces a direct (same sense) current.

Law-2. The magnitude of the induced emf 'E' is directly proportional to the number of turns (N) of the coil and the rate of change of flux ($d\phi/dt$) linked through the coil.

Mathematically, $E \propto N$

$$E \propto \frac{d\phi}{dt}$$

$$\therefore E \propto N \frac{d\phi}{dt}$$

$$\text{or, } E = KN \frac{d\phi}{dt} = N \frac{d\phi}{dt} \quad \dots(38)$$

where K = constant of proportionality = 1, using suitable units. ' $d\phi$ ' is the change in flux linked through the coil in time interval ' dt '. In M.K.S. system ' $d\phi$ ' is expressed in webers, ' dt ' in seconds and ' E ' in volt.

Q. 3. State and explain Lenz's Law.

Ans. Lenz's Law : This law states that whenever an emf is induced, the induced current is in such a direction as to oppose (by its magnetic action) the change inducing the current.

Lenz's law and the principle of conservation of energy

Lenz's law is a particular example of the principle of conservation of energy. An induced current can produce heat to do chemical or mechanical work. The energy must come from the work done in inducing the current. When induction is due to motion of a magnet or a coil, work is done; therefore the motion must be resisted by a force. This opposing force comes from the action of the magnetic field of the induced current. When a change in current in a primary coil induces an emf in a neighbouring secondary coil, the current in the secondary will be in such a direction as to require the expenditure of additional energy in the primary to maintain the current.

Q. 4. How can Lenz's law be verified experimentally ? Describe.

Ans. Experimental verification of Lenz's law :

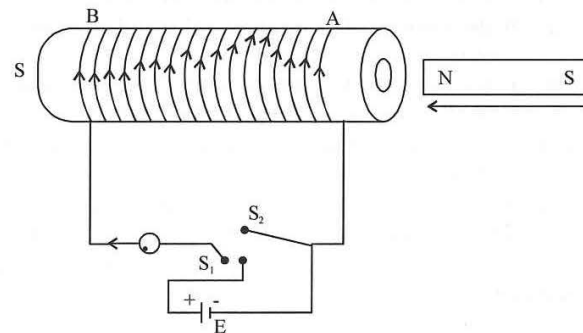


Fig. 4.2

Components

- (i) Coil AB
- (ii) Hollow wooden cylinder
- (iii) Galvanometer (G)
- (iv) Battery (E)
- (v) Switches (S_1, S_2)

Procedure

The circuit is completed as shown in fig. 4.2. Gap 1 is closed by S_1 keeping gap 2 open. Consequently the source of emf E sends a current through the circuit in the direction as shown in the figure. The direction in which the pointer of galvanometer moves is noted. Let us say, it moves towards right. The direction of this current, when looked into face 'A' of the coil is anticlockwise. So we conclude that a current which appears anticlockwise from face 'A', gives a deflection toward right in galvanometer. Now gap 2 is closed by S_2 keeping gap 1 open, so that battery goes out of circuit. A magnet N-S towards the end 'A' of the coil is moved. It will be observed that if north pole, 'N' of the magnet approaches the coil, the current set up in the coil produces a deflection towards right indicating that the direction of induced current must be anticlockwise as seen through the face 'A'. According to the rule of magnetic effects of currents, face 'A' should develop a north polarity due to magnetic field of induced current. The approaching north pole of the magnet is opposed by this north polarity *i.e.*, the cause which produces induced emf. Hence Lenz's Law is verified.

Q. 5. What are the consequences of Lenz's law?

Ans. *Consequences of Lenz's law* : The following results are observed from the electromagnetic induction and Lenz's law :

- (i) If the magnetic flux linked with a coil increases, the induced current set up in the coil rises.
- (ii) If the magnetic flux linked with a coil decreases, the induced current produced in the coil also decreases.
- (iii) Any change of magnetic flux through the coil causes induced current in the coil.
- (iv) The induced current or the induced emf is always in a direction opposite to the very cause from which it is due.

In the light of Lenz's law, the final expression for induced emf is modified as :

$$E = -N \frac{d\phi}{dt} \quad \dots(39)$$

Q. 6. What do you mean by self-induction ?

Ans. *Self-induction* : Self-induction is the property of an electric circuit due to which any change in the magnetic flux linked through it, induces an emf in it. The emf induced is called self-induced emf or back emf.

Q. 7. Define self-inductance of a coil. Mention its MKS unit.

Ans. *Self-inductance* : The self-inductance of a coil is equal to the number of flux linkages per unit current.

The magnetic flux linked with the circuit is directly proportional to the flow of current I , *i.e.*, $\phi \propto I$

$$\text{or, } \phi = LI$$

where L the constant of proportionality is called the coefficient of self-induction or self-inductance.

$$\text{When, } I = 1, \text{ then } L = \phi \quad \dots(40)$$

Hence self-inductance of a coil is equal to the magnetic flux linked with it due to flow of unit current through it.

Now from the Faraday's law of electromagnetic induction the induced emf (e) is given by

$$e = -\frac{d\phi}{dt} = -\frac{d}{dt}(LI) = -L \frac{dI}{dt}$$

$$\text{i.e., } L = -\frac{e}{\left(\frac{dI}{dt}\right)} \quad \dots(41)$$

$$\text{When, } \frac{dI}{dt} = 1, \quad L = -e \quad \dots(42)$$

The -ve sign comes from the Lenz's law. Hence from equn. (42), L is numerically equal to ' e '.

Thus, self-inductance of the coil is defined as the ratio of the emf of self-induction to the rate of change of current in the coil.

Units of self-inductance :

MKS_a or SI unit of self-inductance is called Henry.

$$\text{One Henry} = \frac{1 \text{ volt}}{1 \text{ Amp/sec.}}$$

Hence, one Henry is the self-inductance of a coil in which an emf of 1 volt is induced when the current is changing at the rate of 1 Amp/Sec.

Q. 8. Find an expression for the self-inductance of an inductor.

Ans. *Self-inductance of an inductor* : The value of 'L' for a straight wire is negligibly small. But if the same wire is made into the form of a coil, its inductance increases. The value of 'L' of a coil depends upon :

- (i) permeability of the material used in the core of the coil.
- (ii) number of turns in the coil.
- (iii) gap between the two adjacent turns of the coil.
- (iv) the area of each turn of the inductor.

From the above we have

$$L = \frac{\mu N^2 A}{l} \quad \dots(43)$$

where μ = permeability of the magnetic core on which one coil is wound to prepare the inductor.

N = Number of turns.

A = The area of each turn.

l = Total length of the inductor.

Q. 9. What is mutual induction ?

Ans. *Mutual induction* : When there is a current in one of two adjacent circuits, some of the magnetic flux associated with the first or primary circuit 'P' links the near by or secondary circuit 'S' (Fig. 4.3). If the current changes in 'P' there results a change of flux in 'S'. Hence an emf is induced in the secondary circuit. This phenomenon is called mutual induction.

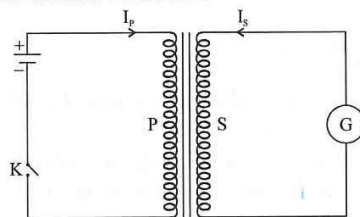


Fig. 4.3

Mutual induction of two circuits is the property by virtue of which a current changing in the first results in the induction of an emf in the second.

Q. 10. Define mutual inductance. Mention its units.

Ans. *Mutual inductance* : Let ϕ be the magnetic flux linked with the coil 'S' due to a current 'I' flowing through 'P'.

$$\phi \propto I$$

$$\text{or, } \phi = MI \quad \dots(44)$$

where M is called the co-efficient of mutual induction of two circuits. If $I = 1$, then $\phi = M$...(45)

Therefore, co-efficient of mutual induction of two circuits or mutual inductance is defined as the magnetic flux linked with the second circuit due to a unit current flowing through the first.

Differentiating equn. (44),

$$\frac{d\phi}{dt} = M \frac{dI}{dt}$$

According to Faraday's law of electromagnetic induction

$$e = - \frac{d\phi}{dt} \quad (\text{if } N \text{ is one})$$

where 'e' is the emf induced in the second circuit

$$\text{Now, } e = - \frac{d(MI)}{dt}$$

$$e = - \frac{MdI}{dt}$$

$$\Rightarrow M = - \frac{e}{\frac{dI}{dt}}$$

$$\text{when } \frac{dI}{dt} = 1, \quad M = -e \quad \dots(46)$$

The -ve sign comes from the Lenz's law. Hence from equn. (46), M is numerically equal to e .

Thus, co-efficient of mutual induction of two circuits or mutual inductance is defined as the emf induced in the second circuit due to current changing at a unit rate in the first.

Units

(i) *SI system* : Unit of co-efficient of mutual induction or mutual inductance in SI unit is 'Henry'.

$$1 \text{ Henry} = \frac{1 \text{ volt}}{1 \text{ amp/sec.}}$$

Coefficient of mutual induction of two circuits is said to be 1 Henry if an emf of 1 volt is induced in the secondary circuit due to a current changing at the rate of 1 amp/sec in the first.

(ii) *CGS system* : Unit of mutual inductance in CGS system is emu of inductance.

Co-efficient of mutual induction of two circuits is equal to 1 emu of inductance, if an emf of 1 emu is induced in the second due to a current changing at the rate of 1 emu in the first.

Q. 11. Discuss on the mutual inductance of two circuits or coils.

Ans. *Mutual inductance of two circuits* : When two circuits or coils are closed to each other and current flowing in one circuit or coil, the mutual inductance 'M' between two circuits or coils is given by,

$$M = \frac{\mu N_1 N_2 A}{l} \quad \dots(47)$$

where μ is the permeability of the cores on which the coils are wound and also the permeability of the medium separating the two coils.

N_1 = number of turns in primary

N_2 = number of turns in the secondary

A = area of the coils of primary and secondary

l = the length of the primary coil.

Thus the mutual inductance between the two coils or circuits depends upon :

- (i) the permeability of the cores on which the coils are wound and also the permeability of the medium separating the two coils.
- (ii) the number of turns of coils in primary and secondary.
- (iii) the area of the coils primary and secondary.
- (iv) the orientation of the two coils.

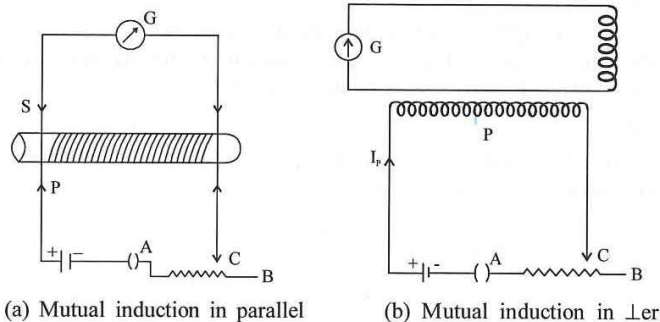


Fig. 4.4

The value of 'M' is maximum when the two coils or circuits are parallel and wound over a single iron core. The value of 'M' is minimum when one coil is $\perp$ er to another. The value of 'M' varies by changing the orientation of one coil with respect to the other when all other factors remain the same.

EXERCISES

Numerical Problems with Solutions

1. Find out the flux linking through a single turn of a coil placed in an uniform magnetic field of induction 8×10^{-5} weber/m². The coil is rectangular of length 50 cm and breadth 20 cm and is so placed that the coil normal makes an angle of 60° to magnetic field direction.

Solution

$$B = 8 \times 10^{-5} \text{ weber/m}^2$$

$$A = 50 \times 10^{-2} \times 20 \times 10^{-2} \text{ m}^2 \\ = 1000 \times 10^{-4} \text{ m}^2 = 10^{-1} \text{ m}^2$$

$$\alpha = 60^\circ, \quad \phi = ?$$

$$\begin{aligned} \text{Here, } \phi &= BA \cos \alpha \\ &= 8 \times 10^{-5} \times 10^{-1} \cos 60^\circ \\ &= 8 \times 10^{-6} \times 1/2 = 4 \times 10^{-6} \text{ weber} \end{aligned}$$

2. The north pole of a bar magnet is moved away from a coil of 400 turns, so that the flux linked through the coil changes from 4×10^{-6} weber to 2×10^{-6} weber in 1 millisecond. What is the average emf in the coil ?

Solution

$$N = 400 \text{ turns}$$

$$\frac{d\phi}{dt} = \frac{4 \times 10^{-6} - 2 \times 10^{-6}}{1 \times 10^{-3}} \text{ weber/second}$$

$$E = ?$$

$$\text{Here, } E = -N \frac{d\phi}{dt}$$

$$= -400 \times \frac{2 \times 10^{-6}}{10^{-3}}$$

$$= -400 \times 2 \times 10^{-3}$$

$$= -800 \times 10^{-3}$$

$$= -0.8 \text{ Volt.}$$

3. A pair of adjacent coils has a mutual inductance of 1 henry. The current in primary changes from 0 to 10 amp in 0.04 second. What is the average emf induced in the secondary ? If the secondary has 400 turns, what is the change in flux linked with the secondary during this time ?

Solution

$$M = 1 \text{ henry}$$

$$\frac{dI}{dt} = \frac{10}{0.04} \text{ amp/Sec} = \frac{10 \times 10^2}{4} = 250 \text{ amp/Sec.}$$

$$E_s = ? \quad N_s = 400 \text{ turns, } d\phi = ?$$

$$\text{Here, } E_s = -M \frac{dI}{dt} = -1 \times 250 = -250 \text{ volts}$$

$$\text{Again, } E_s = -N_s \frac{d\phi}{dt} \text{ or } d\phi = \frac{E_s dt}{N_s}$$

$$\begin{aligned} d\phi &= -\frac{(-250) \times 0.04}{400} = \frac{250 \times 4 \times 10^{-2}}{400} \\ &= \frac{25 \times 4 \times 10^{-1} \times 10^{-2}}{4} \\ &= 25 \times 10^{-3} \text{ weber} \\ &= 0.025 \text{ weber} \end{aligned}$$

4. A coil has an inductance of 10 millihenry. Find the emf induced in the coil when the current flowing through it changes at the rate of 120 amp per second.

Solution

$$L = 10 \times 10^{-3} \text{ henry}$$

$$\frac{dI}{dt} = 120 \text{ amp/Second}$$

$$E = ?$$

$$\begin{aligned} \text{Here, } E &= -L \frac{dI}{dt} = -10 \times 10^{-3} \times 120 \\ &= -12 \times 10^{-1} \text{ volts} \\ &= -1.2 \text{ volts.} \end{aligned}$$

5. The plane of a coil is at right angles to a magnetic field of induction 10^{-12} weber/m². If the flux linkage is 1 weber, what is the area of the coil?

Solution

$$B = 10^{-12} \text{ weber/m}^2$$

$$\phi = 1 \text{ weber}$$

$$A = ?$$

$$\text{Here, } \phi = BA$$

$$\begin{aligned} \text{or, } A &= \frac{\phi}{B} = \frac{1 \text{ weber}}{10^{-12} \text{ weber/m}^2} \\ &= 10^{12} \text{ m}^2 \\ &= 100 \text{ m}^2 \end{aligned}$$

6. Find the flux linking through a coil of single turn of area 100 cm² if it is placed in a magnetic field of induction 5×10^{-2} weber/m², such that the coil normal makes an angle of 60° to field direction.

Solution

$$\begin{aligned} A &= 100 \text{ cm}^2 = 100 \times (10^{-2} \text{ m})^2 \\ &= 10^2 \times 10^{-4} \text{ m}^2 = 10^{-2} \text{ m}^2 \end{aligned}$$

$$B = 5 \times 10^{-2} \text{ weber/m}^2$$

$$\alpha = 60^\circ, \phi = ?$$

$$\begin{aligned} \text{Here, } \phi &= BA \cos \alpha \\ &= 5 \times 10^{-2} \times 10^{-2} \times \cos 60^\circ \\ &= 5 \times 10^{-4} \times \frac{1}{2} = 2.5 \times 10^{-4} \text{ weber} \end{aligned}$$

7. A coil of 500 turns is threaded by a changing magnetic flux, changing at the rate of 0.4×10^{-2} weber/sec. Find the average emf induced in the coil.

Solution

$$N = 500 \text{ turns}$$

$$\frac{d\phi}{dt} = 0.4 \times 10^{-2} \text{ weber/Sec}$$

$$E = ?$$

$$\text{Here, } E = -N \frac{d\phi}{dt}$$

$$= -500 \times 0.4 \times 10^{-2} \text{ volts}$$

$$= -2 \text{ volts}$$

8. A magnetic field of $2 \times 10^{-3} \text{ T}$ produces a flux of $2.4 \times 10^{-5} \text{ Wb}$ in an iron bar of cross-section 0.2 cm^2 . Calculate its permeability.

Solution

$$B = 2 \times 10^{-3}$$

$$\phi = 2.4 \times 10^{-5} \text{ Wb}$$

$$A = 0.2 \text{ cm}^2 = 0.2 \times (10^{-2} \text{ m})^2 = 0.2 \times 10^{-4} \text{ m}^2$$

$$\mu = ?$$

Here, $\mu = \frac{\phi}{\phi_0}$

Where, $\phi_0 = BA = 2 \times 10^{-3} \times 0.2 \times 10^{-4} \text{ Wb}$

$$= 0.4 \times 10^{-7} \text{ Wb}$$

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

So, $\mu = \frac{2.4 \times 10^{-5}}{4 \times 10^{-8}}$

$$= 0.6 \times 10^3$$

$$= 600$$

9. A coil has inductance of 5 mH . Find the emf induced in it when the current is changed in it at the rate of 20 A/Sec .

Solution

$$L = 5 \text{ mH} = 5 \times 10^{-3} \text{ H}$$

$$\frac{dI}{dt} = 20 \text{ Amp/sec.}$$

$$E = ?$$

Here, $E = -L \frac{dI}{dt}$

$$= -5 \times 10^{-3} \times (20)$$

$$= -100 \times 10^{-3} = -10^{-1} \text{ volt}$$

$$= -0.1 \text{ volt}$$

10. The coil of 600 turns is threaded by a flux of $8 \times 10^{-5} \text{ Wb}$. If the flux is reduced to $3 \times 10^{-5} \text{ Wb}$ in 0.015 S , what is the average induced emf ?

Solution

$$N = 600 \text{ turns}$$

$$\frac{d\phi}{dt} = \frac{8 \times 10^{-5} - 3 \times 10^{-5}}{0.015} \text{ Wb/S}$$

$$= \frac{5 \times 10^{-5}}{15 \times 10^{-3}} \text{ Wb/S}$$

$$= \frac{1}{3} \times 10^{-2}$$

$$\bar{E} = ?$$

Here, $\bar{E} = -N \frac{d\phi}{dt}$

$$= -600 \times \frac{1}{3} \times 10^{-2}$$

$$= -2 \text{ volts}$$

11. A wire "cuts" a flux of 0.03 Wb in 0.02 S . What average emf is induced in the wire?

Solution

$$d\phi = 0.03 \text{ Wb, } dt = 0.02 \text{ S}$$

$$\bar{E} = ?$$

Here, $\bar{E} = -\frac{d\phi}{dt} = -\frac{0.03}{0.02} = -\frac{30}{2}$

$$= -15 \text{ volts}$$



5

A.C. Fundamentals

Q. 1. What do you mean by alternating emf and alternating current.

Ans. *Alternating emf* : The emf produced by a coil rotating in a uniform magnetic field is called an alternating emf. This emf is so named because it alternates between the +ve and -ve half cycle after each half time period. This emf alternates reversing direction twice in each rotation of the coil. This emf is periodic in nature. It is given by

$$E = E_0 \sin \omega t$$

where E_0 is the steady values of the emf and ω is the angular velocity of the coil.

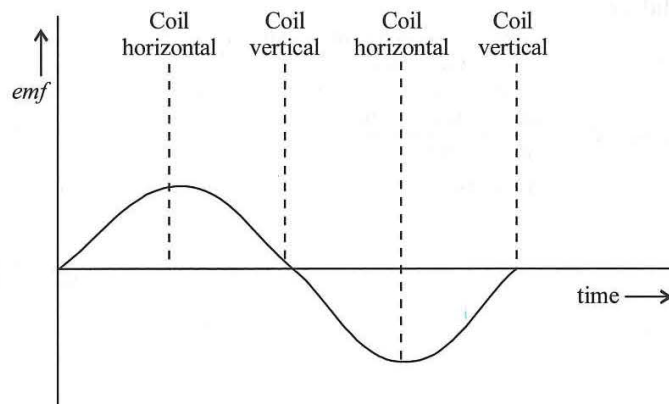


Fig. 5.1

Alternating current : It is the current which, when flowing through a conductor, changes continuously in magnitude and varies periodically in direction.

A graph between instantaneous value of a.c., ' I ' and ' t ' is shown in fig. 5.2. The graph indicates that magnitude of current varies continuously in between ' $+I_0$ ' and ' $-I_0$ '. Its direction also changes after equal intervals of time of $(T/2)$ second where T is the time period of a.c. The curve, ' I ' against ' t ' is a 'sine curve'.

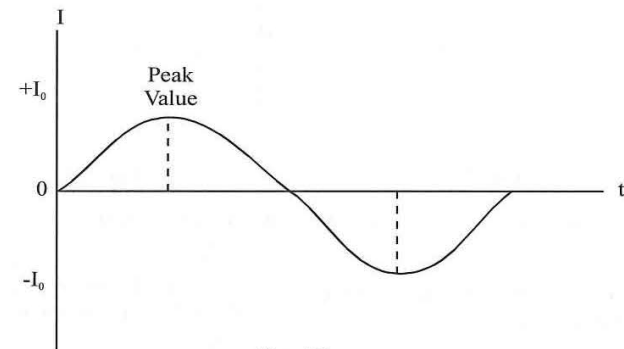


Fig. 5.2

Therefore instantaneous value ' I ' of current is given by

$$I = I_0 \sin \omega t$$

where ' I_0 ' is called the peak value and ' ω ' is the angular velocity of rotation of conductor.

$$\omega = \frac{2\pi}{T} = 2\pi f \quad \left(\because f = \frac{1}{T} \right)$$

' f ' being the frequency of a.c.

$$I = I_0 \sin 2\pi ft.$$

Q. 2. Distinguish between a.c. and d.c.

Ans. *Distinction between a.c. and d.c. :*

Alternating current

1. An alternating current is a current which continuously changes in magnitude and periodically reverses in direction.
2. It fluctuates between +ve & -ve half cycle.

Direct current

1. A direct current changes continuously in magnitude but does not change in direction.
2. It is unidirectional having only +ve or -ve half cycle.

3.

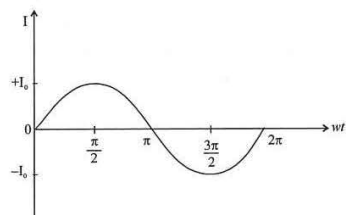


Fig. 5.3

4. Alternating current is given by

$$I = I_0 \sin \omega t$$

5. Alternating current is more dangerous.

3.

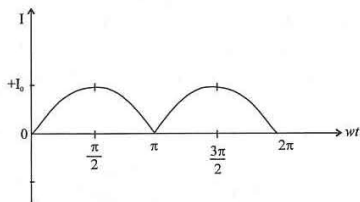


Fig. 5.4

4. Direct current is given by I_0
 $= E_0/R$ where E_0 is the steady emf &
 R is the resistance in the
circuit.5. Direct current is less
dangerous.**Q. 3.** Find the average, mean and rms value of a.c.**Ans.** *Average value of a.c. (for full cycle)* : It is the value of alternating current averaged over a complete cycle. It can be shown that the average value of a.c. is zero. Let 'T' be the time period of a.c. Alternating current is given by

$$I = I_0 \sin \omega t$$

$$I_{av} = \frac{\int_0^T I_0 \sin \omega t \, dt}{\int_0^T dt}$$

$$= \frac{1}{T} I_0 \int_0^T \sin \omega t \, dt$$

$$\text{or, } I_{av} = \frac{I_0}{T} \left[-\frac{\cos \omega t}{\omega} \right]_0^T$$

$$\begin{aligned} &= \frac{I_0}{\omega T} [(-\cos \omega t)]_0^T \\ &= \frac{I_0}{\omega T} [(-\cos \omega T) - (\cos 0)] \\ &= \frac{I_0}{\omega T} (-\cos 2\pi + \cos 0) \quad (\because \omega T = 2\pi) \\ &= \frac{I_0}{\omega T} (-1 + 1) \\ &= \frac{I_0}{\omega T} \times 0 \end{aligned}$$

$$\text{or, } I_{av} = 0$$

Mean value of A.C. or D.C. value of A.C. (for half cycle) : Mean value of a.c. for half cycle is that value of steady current which sends the same charge through a circuit as is done by the a.c. in half cycle i.e., in a time ' $T/2$ '.Let ' dq ' be the charge transferred in a small time ' dt '.

$$dq = I \, dt$$

$$\text{Since, } I = I_0 \sin \omega t$$

$$dq = I_0 \sin \omega t \, dt$$

If ' q ' is the charge transferred in half the cycle of a.c.,

$$q = \int_0^{T/2} dq = \int_0^{T/2} I_0 \sin \omega t \, dt$$

$$\begin{aligned} \text{or, } q &= I_0 \left(-\frac{\cos \omega t}{\omega} \right)_0^{T/2} \\ &= -\frac{I_0}{\omega} \left(\cos \frac{\omega T}{2} - \cos 0 \right) \\ &= -\frac{I_0}{\omega} (\cos \pi - \cos 0) \quad \left(\because \frac{\omega T}{2} = \pi \right) \end{aligned}$$

$$\text{i.e., } q = \frac{-I_0}{\omega} (-1 - 1)$$

$$\text{or, } q = \frac{2I_0}{\omega} \quad \dots(48)$$

If ' I_{mean} ' is the mean value of a.c.,

$$q = I_{\text{mean}} \times \frac{T}{2} \quad \dots(49)$$

From eqns. (48) and (49)

$$I_{\text{mean}} \times \frac{T}{2} = \frac{2I_0}{\omega}$$

$$\therefore I_{\text{mean}} = \frac{4I_0}{\omega T}$$

$$\text{But } \omega T = 2\pi$$

$$\therefore I_{\text{mean}} = \frac{4I_0}{2\pi}$$

$$\text{or, } I_{\text{mean}} = \frac{2I_0}{\pi} \quad \dots(50)$$

R.M.S. value of A.C. or virtual value of A.C. : R.M.S. value of A.C. is that value of steady current which when flowing through a resistance produces same heat as is done by a.c. in half of its cycle flowing through same resistance.

Let ' dH ' be the heat produced by a.c. in a small time ' dt '.

$$dH = I^2 R dt$$

$$\text{or, } dH = I_0^2 R \sin^2 \omega t dt \quad (\text{where } I = I_0 \sin \omega t)$$

Heat produced in half the cycle of a.c. is

$$H = \int_0^H dH = \int_0^{T/2} I_0^2 R \sin^2 \omega t dt$$

$$\begin{aligned} \text{or, } H &= I_0^2 R \int_0^{T/2} \left[\frac{1 - \cos \omega t}{2} \right] dt \\ &= \frac{1}{2} I_0^2 R \left[\int_0^{T/2} dt - \int_0^{T/2} \cos \omega t dt \right] \end{aligned}$$

$$\text{or, } H = \frac{I_0^2 R}{2} \left[t - \frac{\sin 2\omega t}{2\omega} \right]_0^{T/2}$$

$$\text{or, } H = \frac{I_0^2 R}{2} \left[\left(\frac{T}{2} - \frac{\sin \omega T}{2\omega} \right) - \left(0 - \frac{\sin 0}{2\omega} \right) \right]$$

$$\text{or, } H = \frac{I_0^2 R}{2} \times \frac{T}{2} \quad \dots(51)$$

If I_{rms} is the r.m.s. value of a.c.,

$$H = I_{\text{rms}}^2 \times R \times \frac{T}{2} \quad \dots(52)$$

From eqns. (51) & (52)

$$I_{\text{rms}}^2 \times R \times \frac{T}{2} = \frac{I_0^2 R}{2} \times \frac{T}{2}$$

$$I_{\text{rms}}^2 = \frac{I_0^2}{2}$$

$$\text{or, } I_{\text{rms}} = \frac{I_0}{\sqrt{2}} \quad \dots(53)$$

Q. 4. Find the rms value of a.c. emf.

Ans. *R.M.S. value of emf :* The a.c. emf is given by

$$E = E_0 \sin \omega t = E_0 \sin \alpha$$

The limiting value of ' α ' for a complete cycle is 0 to 2π . So the mean square value of a.c. emf is given by

$$\overline{E^2} = \frac{\int_0^{2\pi} E_0^2 \sin^2 \alpha d\alpha}{\int_0^{2\pi} d\alpha}$$

$$= \frac{E_0^2}{2\pi} \int_0^{2\pi} \sin^2 \alpha d\alpha$$

$$= \frac{E_0^2}{2\pi} \int_0^{2\pi} \left[\frac{1 - \cos 2\alpha}{2} \right] d\alpha$$

$$= \frac{E_0^2}{2\pi} \left[\frac{1}{2} \int_0^{2\pi} d\alpha - \frac{1}{2} \int_0^{2\pi} \cos 2\alpha d\alpha \right]$$

$$\begin{aligned}
 &= \frac{E_0^2}{2\pi} \left[\frac{1}{2} \{\alpha\}_0^{2\pi} - \frac{1}{2} \left\{ \frac{\sin 2\alpha}{2} \right\}_0^{2\pi} \right] \\
 &= \frac{E_0^2}{2\pi} \left[\frac{1}{2} 2\pi - \frac{1}{4} \{\sin 4\pi - \sin 0\} \right] \\
 &= \frac{E_0^2}{2\pi} \left(\pi - \frac{1}{4} \times 0 \right) \\
 &= \frac{E_0^2}{2\pi} \cdot \pi \\
 &= \frac{E_0^2}{2} \\
 \text{i.e., } \overline{E^2} &= \frac{E_0^2}{2} \\
 \text{or, } \sqrt{\overline{E^2}} &= \sqrt{\frac{E_0^2}{2}} \\
 \text{i.e., } E_{rms} &= \frac{E_0}{\sqrt{2}} \quad \dots(54)
 \end{aligned}$$

Q. 5. Define virtual emf and virtual current.

Ans. Virtual emf : Virtual emf is defined as that potential difference which when maintained across a resistor produces the same heat as produced by a steady d.c. across the same resistor in the same time interval. The r.m.s. value of emf is the virtual emf.

Virtual current : Virtual current can be defined as that a.c. which produces the same heat as produced by a steady d.c. through the same resistance for the same time interval. The rms value of current is the virtual current.

Q. 6. What are different circuit elements ? Mention their functions.

Ans. Circuit elements and their functions : The circuit elements are :

- (a) Resistance
- (b) Inductance
- (c) Capacitance

(a) Resistance. An electron current flows through a conductor, electrons move forward while they are colliding with each other also. Opposition offered by the conductor due to these collisions is called resistance. Schematic diagram of resistance is shown in fig. 5.5. It is denoted by R. It is equally effective in constant as well as variable currents.

Resistance of a conductor opposes the flow of current in the conductor.



Fig. 5.5

(b) Inductance. Let us consider a wire wound over a wooden cylinder having large number of turns. Let it have a negligible resistance. If a constant current flows through it, it offers no opposition ($\because R = 0$). In case of variable currents an induced emf is set up in such a direction that it opposes the changing current. This opposition to the flow of electricity is called inductive reactance and is denoted by ' X_L '.

$$X_L = \omega L$$

Where $\omega = 2\pi f$, f being frequency of a.c. and
 L = coefficient of self-induction of coil.

Schematic diagram of an inductor is shown in fig. 5.6.

Inductance in an electric circuit plays the role of friction in mechanics. Inductor is called as choking coil as it chokes a.c. The role of inductance in a.c. circuit is same as the role of resistances in d.c. circuit.

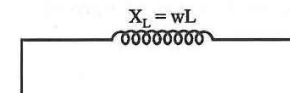


Fig. 5.6

Capacitance. When a condenser is inserted in a d.c. circuit, the plate gets charged up, and the electron current drops to zero. The capacitor (fig. 5.7), thereafter, acts as though it had an infinite resistance, when connected to an alternating source of emf, it acts differently. In reversing of emf reverses the flow of electrons to and from the plates of the capacitor and the alternating flow of charge constitutes an alternating current. The opposition offered by the capacitor to a.c. is called capacitive reactance. It is denoted by ' X_C '.

$$X_C = \frac{1}{\omega C}$$

where C = Capacity of the condenser.

A capacitor allows a.c. to flow and blocks d.c.

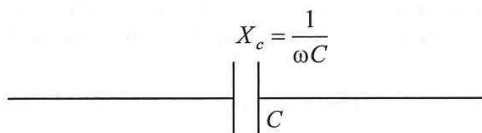


Fig. 5.7

Q. 7. Find current in an a.c. circuit containing pure resistance only. Show by graph the phase relationship between emf and current.

Ans. *Circuit containing pure resistance :* Let us consider a source of a.c. connected in a circuit comprising of pure resistance [fig. 5.8(a)]. If E is the instantaneous voltage of the source,

$$E = E_0 \sin \omega t \quad \dots(55)$$

where E_0 is the peak value of the emf. If ' I ' is the instantaneous value of current, from ohm's law,

$$I = \frac{\text{Instantaneous value of emf}}{\text{resistance}}$$

$$= \frac{E_0 \sin \omega t}{R}$$

$$\text{i.e., } I = I_0 \sin \omega t \quad \dots(56)$$

where $I = +\frac{E_0}{R}$, is the peak value of current.

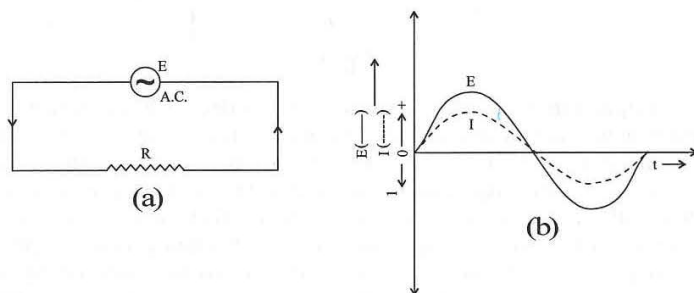


Fig. 5.8

Comparing expressions for ' E ' & ' I ' it is seen that there is no phase difference between emf and current in a circuit containing pure resistance i.e., emf and current are in same phase in a pure resistive a.c. circuit.

A graph between time (along x -axis) and emf (—) and current (--) along y -axis is shown in fig. 5.8 (b).

Q. 8. Find current in an a.c. circuit containing pure inductance only. Show by graph the phase relationship between emf and current.

Ans. *Circuit containing inductance only :* Let a source of a.c. be applied to a circuit containing pure inductance [fig. 5.9(a)]. The instantaneous emf is

$$E = E_0 \sin \omega t \quad \dots(57)$$

If E' is the emf induced in the coil,

$$E' = -L \frac{dI}{dt}$$

where ' L ' is the co-efficient of self-inductance of the coil and ' I ' is the instantaneous current.

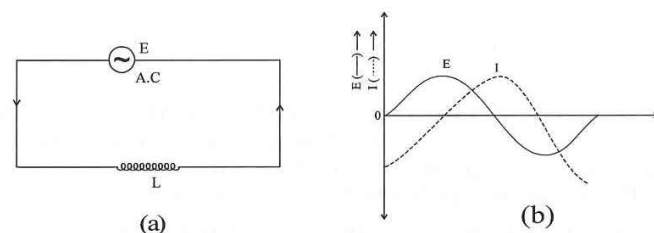


Fig. 5.9

At any instant the current can be in equilibrium if the applied voltage is equal and opposite to the induced voltage.

$$\text{i.e., } E = -E'$$

$$\text{or, } E_0 \sin \omega t = -\left(-L \frac{dI}{dt}\right)$$

$$\text{or, } L \frac{dI}{dt} = E_0 \sin \omega t$$