Alternating Current

Multiple Choice Questions

Choose and write the correct option(s) in the following questions.

1. **If the *rms* current in a 50 Hz *ac* circuit is 5 A, the value of the current 1/300 seconds after its value becomes zero is** [*NCERT Exemplar*]

   (*a*) $5\sqrt{2}$ A (*b*) $5\sqrt{\frac{3}{2}}$ A (*c*) 5/6 A (*d*) $5/\sqrt{2}$ A

2. **An alternating current generator has an internal resistance R_g and an internal reactance X_g. It is used to supply power to a passive load consisting of a resistance R_g and a reactance X_L. For maximum power to be delivered from the generator to the load, the value of X_L is equal to** [*NCERT Exemplar*]

   (*a*) zero (*b*) X_g (*c*) $-X_g$ (*d*) R_g

3. **When a voltage measuring device is connected to *ac* mains, the meter shows the steady input voltage of 220 V. This means** [*NCERT Exemplar*]

   (*a*) input voltage cannot be *ac* voltage, but a *dc* voltage.
   (*b*) maximum input voltage is 220 V.
   (*c*) the meter reads not V but $<V^2>$ and is calibrated to read $\sqrt{<V^2>}$.
   (*d*) the pointer of the meter is stuck by some mechanical defect.

4. **To reduce the resonant frequency in an *LCR* series circuit with a generator** [*NCERT Exemplar*]

   (*a*) the generator frequency should be reduced.
   (*b*) another capacitor should be added in parallel to the first.
   (*c*) the iron core of the inductor should be removed.
   (*d*) dielectric in the capacitor should be removed.

5. **Electrical energy is transmitted over large distances at high alternating voltages. Which of the following statements is (are) correct?** [*NCERT Exemplar*]

   (*a*) For a given power level, there is a lower current.
   (*b*) Lower current implies less power loss.
   (*c*) Transmission lines can be made thinner.
   (*d*) It is easy to reduce the voltage at the receiving end using step-down transformers.

6. **In a pure inductive circuit, the current**

   (*a*) lags behind the applied emf by an angle π
   (*b*) lags behind the applied emf by an angle $\pi/2$
   (*c*) leads the applied emf by an angle $\pi/2$
   (*d*) and applied emf are in same phase

7. **When an *ac* voltage of 220 V is applied to the capacitor *C*** [*NCERT Exemplar*]

   (*a*) the maximum voltage between plates is 220 V.
   (*b*) the current is in phase with the applied voltage.
   (*c*) the charge on the plates is in phase with the applied voltage.
   (*d*) power delivered to the capacitor is zero.

8. **In an *ac* circuit, voltage V and current i are given by**

   $V = 100 \sin 100\,t$ **volt**

   $i = 100 \sin (100t + \pi/3)$ **mA**

   The power dissipated in the circuit is

   (*a*) 10^4W (*b*) 10 W (*c*) 2.5 W (*d*) 5 W

9. **Which of the following combinations should be selected for better tuning of an LCR circuit used for communication?** [*NCERT Exemplar*]

(*a*) $R = 20\ \Omega, L = 1.5$ H, $C = 35\ \mu$F (*b*) $R = 25\ \Omega, L = 2.5$ H, $C = 45\ \mu$F

(*c*) $R = 15\ \Omega, L = 3.5$ H, $C = 30\ \mu$F (*d*) $R = 25\ \Omega, L = 1.5$ H, $C = 45\ \mu$F

10. **The output of a step-down transformer is measured to be 24 V when connected to a 12 watt light bulb. The value of the peak current is** [*NCERT Exemplar*]

(*a*) $1/\sqrt{2}$ A (*b*) $\sqrt{2}$ A (*c*) 2 A (*d*) $2\sqrt{2}$ A

11. **The selectivity of a series LCR ac circuit is large, when** [*CBSE 2020 (55/5/1*]

(*a*) L is large and R is large (*b*) L is small and R is small

(*c*) L is large and R is small (*d*) $L = R$

12. **The phase difference between the current and the voltage in series LCR circuit at resonance is** [*CBSE 2020 (55/5/2*]

(*a*) π (*b*) $\pi/2$ (*c*) $\pi/3$ (*d*) zero

13. **An alternating current is given by $i = i_1 \cos \omega t + i_2 \sin \omega t$. The rms current is given by**

(*a*) $\dfrac{i_1 + i_2}{\sqrt{2}}$ (*b*) $\dfrac{i_1 - i_2}{\sqrt{2}}$ (*c*) $\sqrt{\dfrac{i_1^2 + i_2^2}{2}}$ (*d*) $\dfrac{i_1 i_2}{\sqrt{2}}$

14. **An alternating voltage source of variable angular frequency 'ω' and fixed amplitude 'V' is connected in series with a capacitance C and electric bulb of resistance R (inductance zero). When 'ω' is increased** [*CBSE Sample Paper-2022, Term-1*]

(*a*) the bulb glows dimmer

(*b*) the bulb glows brighter

(*c*) net impedance of the circuit remains unchanged

(*d*) total impedance of the circuit increases

15. **The rms current in a circuit connected to a 50 Hz ac source is 15A. The value of the current in the circuit $\left(\dfrac{1}{600}\right)$s after the instant the current is zero, is** [*CBSE 2022 (55/2/4), Term-1*]

(*a*) $\dfrac{15}{\sqrt{2}}$A (*b*) $15\sqrt{2}$A (*c*) $\dfrac{\sqrt{2}}{15}$A (*d*) 8 A

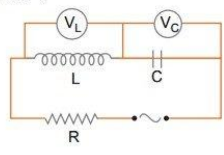
16. **When an alternating voltage $E = E_o \sin \omega t$ is applied to a circuit, a current $I = I_o \sin\left(\omega t + \dfrac{\pi}{2}\right)$ flows through it. The average power dissipated in the circuit is** [*CBSE 2022 (55/2/4), Term-1*]

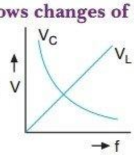
(*a*) $E_{rms} \cdot I_{rms}$ (*b*) $E_o I_o$ (*c*) $\dfrac{E_o I_o}{\sqrt{2}}$ (*d*) zero

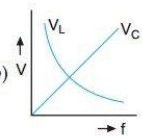
17. **The voltage across a resistor, an inductor, and a capacitor connected in series to an ac source are 20 V, 15 V and 30 V respectively. The resultant voltage in the circuit is** [*CBSE 2022 (55/2/4), Term-1*]

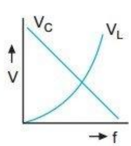
(*a*) 5 V (*b*) 20 V (*c*) 25 V (*d*) 65 V

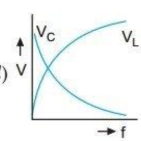
18. **A series LCR circuit is shown in figure. The source frequency f is varied, but the current is kept unchanged. Which of the curves shows changes of V_C and V_L with frequency?**



(*a*)


(*b*)


(*c*)


(*d*)


19. **A 300 Ω resistor and a capacitor of $\left(\frac{25}{\pi}\right)$μF are connected in series to a 200 V – 50 Hz *ac* source. The current in the circuit is** *[CBSE 2022 (55/2/4), Term-1]*

(*a*) 0.1 A (*b*) 0.4 A (*c*) 0.6 A (*d*) 0.8 A

20. **The core of a transformer is laminated to reduce the effect of**

[CBSE Sample Paper-2022, Term-1]

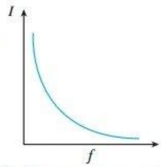
(*a*) flux leakage (*b*) copper loss (*c*) hysteresis loss (*d*) eddy current

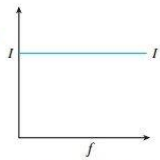
21. **Which among the following is not a cause for power loss in a transformer?**

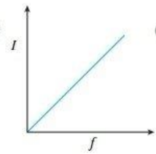
[CBSE Sample Paper-2022, Term-1)]

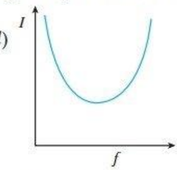
(*a*) Eddy currents are produced in the soft iron core of a transformer.
(*b*) Electric flux sharing is not properly done in primary and secondary coils.
(*c*) Humming sound produced in the transformers due to magnetostriction.
(*d*) Primary coil is made up of a very thick copper wire.

22. **Which of the following graphs represent the variation of current (*I*) with frequency (*f*) in an AC circuit containing a pure capacitor?** *[CBSE Sample Paper-2022, Term-1]*

(*a*)


(*b*)


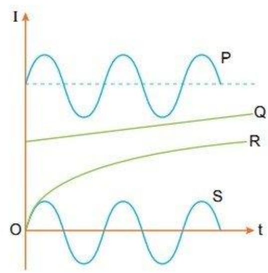
(*c*)


(*d*)


23. **An inductor, a capacitor and a resistor are connected in series across an ac source of voltage. If the frequency of the source is decreased gradually the reactance of** *[CBSE 2023 (55/3/1)]*

(*a*) both the inductor and the capacitor decreases.
(*b*) inductor decreases and the capacitor increases.
(*c*) both the inductor and the capacitor increases.
(*d*) inductor increases and the capacitor decreases.

24. **The figure shows variation of current (*I*) with time (*t*) in four devices *P*, *Q*, *R* and *S*. The device in which an alternating current flows is** *[CBSE 2023 (55/4/1)]*



(*a*) *P* (*b*) *Q* (*c*) *R* (*d*) *S*

25. **An *ac* voltage $v = v_0 \sin \omega t$ is applied to a series combination of a resistor *R* and an element *X*. The instantaneous current in the circuit is $I = I_0 \sin\left(\omega t + \frac{\pi}{4}\right)$. Then which of the following is correct?** *[CBSE 2023 (55/4/1)]*

(*a*) *X* is a capacitor and $X_C = \sqrt{2}\ R$ (*b*) *X* is an inductor and $X_L = R$
(*c*) *X* is an inductor and $X_L = \sqrt{2}\ R$ (*d*) *X* is a capacitor and $X_C = R$

26. **The instantaneous values of EMF and the current in a series AC circuit are $E = E_0 \sin \omega t$ and $I = I_0 \sin (\omega t + \pi/3)$ respectively, then it is** **[*CBSE Sample Paper-2022, Term-1*]**

(*a*) necessarily a *RL* circuit
(*b*) necessarily a *RC* circuit
(*c*) necessarily a *LCR* circuit
(*d*) can be *RC* or *LCR* circuit

Answers

1. (*b*)	**2.** (*c*)	**3.** (*c*)	**4.** (*b*)	**5.** (*a*), (*b*), (*d*)	**6.** (*b*)	**7.** (*c*), (*d*)
8. (*c*)	**9.** (*c*)	**10.** (*a*)	**11.** (*c*)	**12.** (*d*)	**13.** (*c*)	**14.** (*b*)
15. (*a*)	**16.** (*d*)	**17.** (*c*)	**18.** (*a*)	**19.** (*b*)	**20.** (*d*)	**21.** (*d*)
22. (*c*)	**23.** (*b*)	**24.** (*a*)	**25.** (*d*)	**26.** (*d*)		

Assertion-Reason Questions

In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.

(*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 and R is also false.***

1. **Assertion(*A*)** : An alternating current of frequency 50 Hz becomes zero, 100 times in one second.
Reason (*R*) : Alternating current changes direction and becomes zero twice in a cycle.

2. **Assertion(*A*)** : Capacitor serves as a block for *DC* and offers an easy path to *AC*.
Reason (*R*) : Capacitive reactance is inversely proportional to frequency.

3. **Assertion(*A*)** : When capacitive reactance is smaller than the inductive reactance in *LCR* circuit, *emf* leads the current.
Reason (*R*) : The phase angle is the angle between the alternating *emf* and alternating current of the circuit.

4. **Assertion(*A*)** : Transformers are used only in alternating current source not in direct current.
Reason (*R*) : Only a.c. can be stepped up or down by means of transformers. [*AIIMS 2009*]

5. **Assertion(*A*)** : An inductance and a resistance are connected in series with an AC circuit. In this circuit the current and the potential difference across the resistance lags behind potential difference across the inductance by an angle $\pi/2$.
Reason (*R*) : In *LR* circuit voltage leads the current by phase angle which depends on the value of inductance and resistance both.

6. **Assertion(*A*)** : In series *LCR* resonance circuit, the impedance is equal to the ohmic resistance.
Reason (*R*) : At resonance, the inductive reactance exceeds the capacitive reactance.

7. **Assertion(*A*)** : An alternating current does not show any magnetic effect.
Reason (*R*) : Alternating current does not vary with time.

8. **Assertion(*A*)** : In series *LCR*-circuit, the resonance occurs at one frequency only.
Reason (*R*) : At resonance, the inductive reactance is equal and opposite to the capacitive reactance.

9. **Assertion(*A*)** : A step-up transformer cannot be used as a step-down transformer.
Reason (*R*) : A transformer works only in one direction. [*CBSE 2022 (55/2/4), Term-1*]

10. **Assertion** (*A*) : It is advantageous to transmit electric power at high voltage.
Reason (*R*) : High voltage implies high current. [*AIIMS 2010*]

Answers

1. (*a*) 2. (*a*) 3. (*b*) 4. (*a*) 5. (*b*) 6. (*c*) 7. (*d*)
8. (*a*) 9. (*d*) 10. (*b*)

Case-based/Passage-based Questions

Read the paragraph given below and answer the questions that follow:

Electrical Energy Transmission and Distribution:

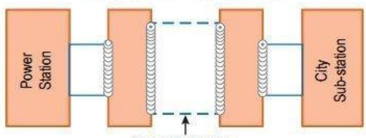


Figure: Long distance power transmissions

The large-scale transmission and distribution of electrical energy over long distances is done with the use of transformers. The voltage output of the generator is stepped-up. It is then transmitted over long distances to an area sub-station near the consumers. There the voltage is stepped down. It is further stepped down at distributing sub-stations and utility poles before a power supply of 240 V reaches our homes. [***CBSE Sample Paper-2022, Term-I, Modified***]

(*i*) **Which of the following statement is true?**
(*a*) Energy is created when a transformer steps up the voltage.
(*b*) A transformer is designed to convert an AC voltage to DC voltage.
(*c*) Step–up transformer increases the power for transmission.
(*d*) Step–down transformer decreases the AC voltage.

(*ii*) **If the secondary coil has a greater number of turns than the primary,**
(*a*) the voltage is stepped-up ($V_s > V_p$) and arrangement is called a step-up transformer
(*b*) the voltage is stepped-down ($V_s < V_p$) and arrangement is called a step-down transformer
(*c*) the current is stepped-up ($I_s > I_p$) and arrangement is called a step-up transformer
(*d*) the current is stepped-down ($I_s < I_p$) and arrangement is called a step-down transformer

OR

We need to step-up the voltage for power transmission, so that
(*a*) the current is reduced and consequently, the I^2R loss is cut down
(*b*) the voltage is increased , the power losses are also increased
(*c*) the power is increased before transmission is done
(*d*) the voltage is decreased so V^2/R losses are reduced

(*iii*) **A power transmission line feeds input power at 2300 V to a step down transformer with its primary windings having 4000 turns. The number of turns in the secondary in order to get output power at 230 V are**
(*a*) 4 (*b*) 40
(*c*) 400 (*d*) 4000

(*iv*) **The metal/alloy that is more suitable for making cores of transformers is**

(*a*) steel (*b*) soft iron (*c*) copper (*d*) brass

Explanations

(*i*) (*d*) In step down transformer,

$$V_S < V_P \quad \text{and} \quad I_S > I_P.$$

So, step-down transformer decreases the *ac* voltage.

(*ii*) (*a*) In step up transformer,

$$V_S > V_P \quad \text{and} \quad I_P > I_S$$

and, $$\frac{N_S}{N_P} = \frac{V_S}{V_P} = \frac{I_P}{I_S} > 1$$

i.e., if number of turns in secondary coil are more than the number of turns in primary coil, then voltage is increased, and hence they are called step-up transformers.

OR

(*a*) Current is reduced if voltage is stepped up so consequently I^2R (copper losses) are cut down.

(*iii*) (*c*) Given, $E_P = 2300$ V

$E_S = 230$ V

$N_P = 4000$

then, $$\frac{E_P}{E_S} = \frac{N_P}{N_S}$$

$$\Rightarrow \quad \frac{2300}{230} = \frac{4000}{N_S}$$

$$\Rightarrow \quad N_S = 400$$

So, number of turns in secondary are 400.

(*iv*) (*b*) Soft iron because it reduced the hysteresis loss.

CONCEPTUAL QUESTIONS

Q. 1. Define capacitor reactance. Write its SI units? [*CBSE Delhi 2015*]

Ans. The imaginary/virtual resistance offered by a capacitor to the flow of an alternating current is called capacitor reactance, $X_C = \frac{1}{\omega C}$. Its SI unit is ohm.

Q. 2. Explain why current flows through an ideal capacitor when it is connected to an *ac* source but not when it is connected to a *dc* source in a steady state. [*CBSE (East) 2016*]

Ans. For *ac* source, circuit is complete due to the presence of displacement current in the capacitor. For steady *dc*, there is no displacement current, therefore, circuit is not complete.

Mathematically, Capacitive reactance $X_C = \frac{1}{2\pi\nu C} = \frac{1}{\omega C}$

So, capacitor allows easy path for *ac* source.

For *dc*, $\nu = 0$, so X_c = infinity,

So capacitor blocks *dc*.

Q. 3. Define 'quality factor' of resonance in series *LCR* circuit. What is its SI unit? [*CBSE Delhi 2016*]

Ans. The quality factor (Q) of series *LCR* circuit is defined as the ratio of the resonant frequency to frequency band width of the resonant curve.

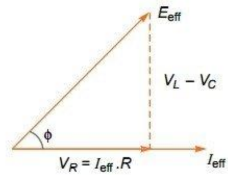
$$Q = \frac{\omega_r}{\omega_2 - \omega_1} = \frac{\omega_r L}{R}$$

Clearly, smaller the value of R, larger is the quality factor and sharper the resonance. Thus quality factor determines the nature of sharpness of resonance.
It has no units.

Q. 4. In a series *LCR* circuit, $V_L = V_C \neq V_R$.
What is the value of power factor for this circuit? [*CBSE Panchkula 2015*]

Ans. Power factor,

$$\cos\phi = \frac{V_R}{\sqrt{V_R^2 + (V_L - V_C)^2}}$$



Since $V_L = V_C$; $\cos\phi = \frac{V_R}{V_R} = 1$

The value of power factor is 1.

Q. 5. The power factor of an *ac* circuit is 0.5. What is the phase difference between voltage and current in this circuit? [*CBSE (F) 2015, (South) 2016*]

Ans. Power factor between voltage and current is given by $\cos\phi$, where ϕ is phase difference

$$\cos\phi = 0.5 = \frac{1}{2} \Rightarrow \phi = \cos^{-1}\left(\frac{1}{2}\right) = \frac{\pi}{3}$$

Q. 6. What is wattless current? [*CBSE Delhi 2011, Chennai 2015*]

Ans. When pure inductor and/or pure capacitor is connected to ac source, the current flows in the circuit, but with no power loss; the phase difference between voltage and current is $\frac{\pi}{2}$. Such a current is called the wattless current.

Q. 7. What is the impedance of a capacitor of capacitance *C* in an *ac* circuit using source of frequency *n* Hz? [*CBSE 2020 (55/2/1)*]

Ans.

Impedance of a capacitor of capacitance $C = \frac{1}{\omega C}$.
$\omega = 2\pi n$.
$\therefore$ impedance $= \frac{1}{2\pi n C}$.

[*Topper's Answer 2020*]

Q. 8. A light bulb and a solenoid are connected in series across an ac source of voltage. Explain, how the glow of the light bulb will be affected when an iron rod is inserted in the solenoid. [*CBSE (F) 2017*]

Ans. When iron rod is inserted in the coil, the inductance of coil increases; so impedance of circuit increases and hence, current in circuit $I = \frac{V}{\sqrt{R^2 + (\omega L)^2}}$ decreases. Consequently, the glow of bulb decreases.

Q. 9. Why is the use of *ac* voltage preferred over *dc* voltage? Give two reasons. [*CBSE (AI) 2014*]

Ans. (*i*) The generation of *ac* is more economical than *dc*.

(*ii*) Alternating voltage can be stepped up or stepped down as per requirement during transmission from power generating station to the consumer.

(*iii*) Alternating current in a circuit can be controlled by using wattless devices like the choke coil.

(*iv*) Alternating voltages can be transmitted from one place to another, with much lower energy loss in the transmission line.

Q. 10. What is the average value of *ac* voltage

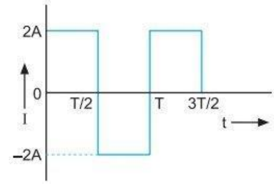
$$V = V_0 \sin \omega t$$

over the time interval $t = 0$ to $t = \frac{\pi}{\omega}$. [*HOTS*]

Ans. $V_{av} = \dfrac{\int_0^{\pi/\omega} V dt}{\int_0^{\pi/\omega} dt} = \dfrac{\int_0^{\pi/\omega} V_0 \sin \omega t \, dt}{[t]_0^{\pi/\omega}} = \dfrac{V_0\left\{-\dfrac{\cos\omega t}{\omega}\right\}_0^{\pi/\omega}}{\pi/\omega} = -\dfrac{V_0}{\pi}[\cos\pi - \cos 0] = \dfrac{2V_0}{\pi}$

Q. 11. What is the rms value of alternating current shown in figure? [*HOTS*]

Ans. In given *ac*, there are identical positive and negative half cycles, so the mean value of current is zero; but the rms value is not zero.



$$(I^2)_{mean} = \frac{\int_0^T I^2 dt}{\int_0^T dt} = \frac{\int_0^{T/2} (2)^2 dt + \int_{T/2}^{T} (-2)^2 dt}{T} = \frac{\int_0^T 4 dt}{T} = 4$$

$$I_{rms} = \sqrt{4} = \mathbf{2\ A}$$

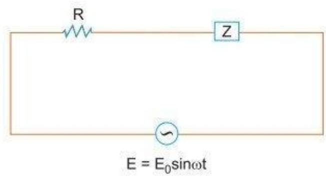
Very Short Answer Questions

Each of the following questions are of 2 marks.

Q. 1. An alternating voltage $E = E_0 \sin \omega t$ is applied to a circuit containing a resistor R connected in series with a black box. The current in the circuit is found to be $I = I_o \sin(\omega t + \pi/4)$.

(*i*) State whether the element in the black box is a capacitor or inductor.

(*ii*) Draw the corresponding phasor diagram and find the impedance in terms of *R*.



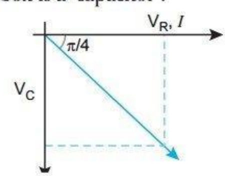
Ans. (*i*) As the current leads the voltage by $\dfrac{\pi}{4}$, the element used in black box is a 'capacitor'.

(*ii*) Here, $\tan\dfrac{\pi}{4} = V_C/V_R \quad \Rightarrow \quad 1 = \dfrac{V_C}{V_R}$

$\Rightarrow \quad V_C = V_R \quad \Rightarrow \quad X_C = R$

$\therefore$ Impedance $Z = \sqrt{(X_C)^2 + R^2} = \sqrt{R^2 + R^2} = \sqrt{2R^2}$

$\therefore \ Z = \sqrt{2}\,\boldsymbol{R}$



Q.2. The coil of an ac generator consists of 100 turns of wire, each of area 0.5m². The resistance of the wire is 100 Ω. The coil is rotating in a magnetic field of 0.8 T perpendicular to its axis of rotation, at a constant angular speed of 60 radian per second. Calculate the maximum emf generated and power dissipated in the coil. [*CBSE 2023 (55/2/1)*]

Ans. Given, $N = 100, A = 0.5 \text{ m}^2, R = 100\ \Omega, B = 0.8\text{T}, \omega = 60 \text{ rad } s^{-1}$

εmf generate,

$$\varepsilon_0 = NA\omega B = 100 \times 0.5 \times 60 \times 0.8$$
$$= 2400 \text{ volt}$$

Power dissipated, $P = \dfrac{\varepsilon_{rms}^2}{R} = \dfrac{\left(\dfrac{2400}{\sqrt{2}}\right)^2}{100} = \mathbf{28.8\ kW}$

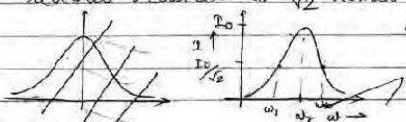
Q. 3. (a) Explain the term 'sharpness of resonance' in *ac* circuit.

(b) In a series *LCR* circuit, $V_L = V_C \neq V_R$. What is the value of power factor for this circuit?

[*CBSE 2020 (55/2/1)*]

Ans.

(a) • Sharpness of resonance or Q-factor of AC circuit is defined as the ratio of the resonant angular frequency to the difference in angular frequencies of two sides in which the current in the circuit reduces to $\frac{1}{\sqrt{2}}$ times its maximum value.



∴ by the figure, sharpness of resonance $= \frac{\omega_r}{\omega_2 - \omega_1}$

(b) In a series LCR circuit, $V_L = V_C \neq V_R$.

∴ power factor = 1

[*Topper's Answer 2020*]

Q. 4. A circular coil of radius 10 cm and 20 turns is rotated about its vertical diameter with angular speed of 50 rad s^{-1} in a uniform horizontal magnetic field of $3{\cdot}0 \times 10^{-2}$ T.

(i) Calculate the maximum and average emf induced in the coil.

(ii) If the coil forms a closed loop of resistance 10 Ω, calculate the maximum current in the coil and the average power loss due to Joule heating. [*CBSE 2019 (55/4/1)*]

Ans. (i) Here, $r = 10$ cm, N = 20 turns, $\omega = 50$ rad s^{-1}

$B = 3.0 \times 10^{-2}$ T

$\varepsilon_0 = NBA\omega$

$= 20 \times 3 \times 10^{-2} \times \pi (10 \times 10^{-2})^2 \times 50$ ½

$= 0.942$ volt

$\varepsilon_{AV} = 0$, over a cycle ½

(ii) $i_0 = \frac{e_0}{R} = \frac{0.942}{10}$

$= 0.094$ A ½

$P = \frac{1}{2}\varepsilon_0 \times I_0$

$= \frac{1}{2} \times 0.942 \times 0.094$

$= 0.045$ watt. ½

[*CBSE Marking Scheme 2019 (55/4/1)*]

Q. 5. Calculate the quality factor of a series *LCR* circuit with $L = 2.0$ H, $C = 2$ μF and $R = 10$ Ω. Mention the significance of quality factor in *LCR* circuit. [*CBSE (F) 2012*]

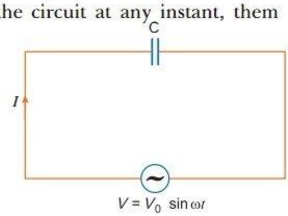
Ans. We have, $Q = \frac{1}{R}\sqrt{\frac{L}{C}} = \frac{1}{10}\sqrt{\frac{2}{2 \times 10^{-6}}} = \mathbf{100}$

It signifies the sharpness of resonance.

Q. 6. An *ac* source of emf $V = V_0 \sin \omega t$ is connected to a capacitor of capacitance *C*. Deduce the expression for the current (*I*) flowing in it. Plot the graph of (i) *V* vs. ωt, and (ii) *I* vs. ωt.

[*CBSE 2020 (55/2/1), 2023 (55/3/1)*]

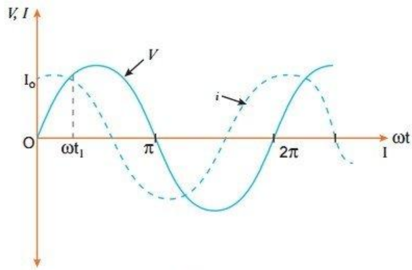
Ans. Let q be the charge on capacitor (C) and I, the current in the circuit at any instant, them instantaneous current is given by



$$I = \frac{dq}{dt} = \frac{d}{dt} CV_0 \sin \omega t = \omega CV_0 \cos \omega t$$

$$= I_0 \cos \omega t = I_0 \sin\left(\omega t + \frac{\pi}{2}\right) \quad \text{where, } I_0 = \frac{V_0}{(1/\omega C)}$$

Graphs for (i) and (ii)



Q. 7. Both alternating current and direct current are measured in amperes. But how is the ampere defined for an alternating current? **[*NCERT Exemplar*]**

Ans. An *ac* current changes direction with the source frequency and the attractive force would average to zero. Thus, the *ac* ampere must be defined in terms of some property that is independent of the direction of current. Joule's heating effect is such property and hence it is used to define rms value of *ac*.

Q. 8. A 60 W load is connected to the secondary of a transformer whose primary draws line voltage. If a current of 0.54 A flows in the load, what is the current in the primary coil? Comment on the type of transformer being used. **[*NCERT Exemplar*]**

Ans. Here, $P_L = 60$ W, $I_L = 0.54$ A

$$V_L = \frac{60}{0.54} = 111.1 \text{ V}$$

The transformer is step-down and have $\frac{1}{2}$ input voltage. Hence

$$I_P = \frac{1}{2} \times I_L = \frac{1}{2} \times 0.54 = \mathbf{0.27\ A.}$$

Q. 9. Explain why the reactance provided by a capacitor to an alternating current decreases with increasing frequency. **[*NCERT Exemplar*]**

Ans. A capacitor does not allow flow of direct current through it as the resistance across the gap is infinite. When an alternating voltage is applied across the capacitor plates, the plates are alternately charged and discharged. The current through the capacitor is a result of this changing voltage (or charge). Thus, a capacitor will pass more current through it if the voltage is changing at a faster rate, *i.e.*, if the frequency of supply is higher. This implies that the reactance offered by a capacitor is less with increasing frequency; it is given by $1/\omega C$.

Q. 10. Explain why the reactance offered by an inductor increases with increasing frequency of an alternating voltage. **[*NCERT Exemplar*]**

Ans. An inductor opposes flow of current through it by developing an induced emf according to Lenz's law. The induced voltage has a polarity so as to maintain the current at its present value. If the current is decreasing, the polarity of the induced emf will be so as to increase the current and vice versa. Since the induced emf is proportional to the rate of change of current, it will provide greater reactance to the flow of current if the rate of change is faster, *i.e.*, if the frequency is higher. The reactance of an inductor, therefore, is proportional to the frequency, being given by ωL.

Q. 11. (a) A 44 mH inductor is connected to 220 V, 50 Hz *ac* supply. Determine the rms value of current in the circuit. [*NCERT*] [*CBSE (AI) 2013, 2012*]

(b) What is the net power absorbed by the circuit in a complete cycle?

Ans. (a) Given $L = 44$ mH$= 44 \times 10^{-3}$ H, $V_{rms} = 220$ V, $\nu = 50$ Hz

Inductive reactance of current $X_C = \omega L$

$\therefore$ RMS value of current,

$$I_{rms} = \frac{V_{rms}}{\omega L} = \frac{V_{rms}}{2\pi\nu L}$$

$$= \frac{220}{2 \times \left(\frac{22}{7}\right) \times 50 \times 44 \times 10^{-3}}$$

$$= \frac{220 \times 7 \times 10^3}{2 \times 22 \times 50 \times 44} = \frac{700}{44} = \mathbf{15.9\ A}$$

(b) We know, $P = V_{rms} \cdot I_{rms} \cdot \cos\phi$

In pure inductor circuit $\phi = \frac{\pi}{2}$ radians

$\Rightarrow \quad \cos\frac{\pi}{2} = 0$

As such net power consumed $= V_{rms} I_{rms} \cos\frac{\pi}{2} = \mathbf{0}$

Short Answer Questions

Each of the following questions are of 3 marks.

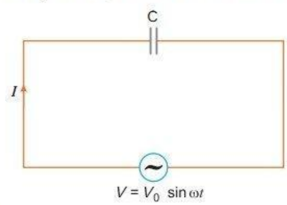
Q. 1. Show that the current leads the voltage in phase by $\pi/2$ in an *ac* circuit containing an ideal capacitor. [*CBSE (F) 2014*]

Ans. The instantaneous voltage,

$$V = V_0 \sin \omega t \qquad ...(i)$$

Let q be the charge on capacitor and I, the current in the circuit at any instant, then instantaneous potential difference,

$$V = \frac{q}{C} \qquad ...(ii)$$



From (*i*) and (*ii*), we get

$$\frac{q}{C} = V_0 \sin\omega t \Rightarrow q = CV_0 \sin\omega t$$

The instantaneous current,

$$I = \frac{dq}{dt} = \frac{d}{dt}(CV_0 \sin\omega t) = CV_0 \frac{d}{dt}(\sin\omega t) = CV_0 \omega \cos\omega t$$

$$I = \frac{V_0}{1/\omega C} \cos\omega t$$

$$I = I_0 \sin\left(\omega t + \frac{\pi}{2}\right)$$

Hence, the current leads the applied voltage in phase by $\pi/2$.

Q. 2. In a series LCR circuit, obtain the conditions under which (*i*) the impedance of the circuit is minimum, and (*ii*) wattless current flows in the circuit. [*CBSE (F) 2014*]

Ans. (*i*) Impedance of series LCR circuit is given by

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

For the impedance, Z to be minimum,

$$X_L = X_C$$

(*ii*) Power, $P = V_{rms} I_{rms} \cos \phi$

When $\phi = \frac{\pi}{2}$

Power $= V_{rms} I_{rms} \cos \frac{\pi}{2} = 0$

Therefore, wattless current flows when the impedance of the circuit is purely inductive or purely capacitive.

In another way we can say, for wattless current to flow, circuit should not have any ohmic resistance ($R = 0$).

Q. 3. State the underlying principle of a transformer. How is the large scale transmission of electric energy over long distances done with the use of transformers? [*CBSE (AI) 2012*]

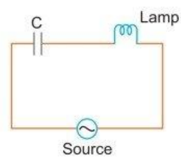
Ans. The principle of transformer is based upon the principle of mutual induction which states that due to continuous change in the current in the primary coil an emf gets induced across the secondary coil. At the power generating station, the step up transformers step up the output voltage which reduces the current through the cables and hence reduce resistive power loss. Then, at the consumer end, a step down transformer steps down the voltage.

Hence, the large scale transmission of electric energy over long distances is done by stepping up the voltage at the generating station to minimise the power loss in the transmission cables.

Q. 4. An electric lamp connected in series with a capacitor and an *ac* source is glowing with of certain brightness. How does the brightness of the lamp change on reducing the (*i*) capacitance and (*ii*) frequency? [*CBSE Delhi 2010, (North) 2016*]

Ans. (*i*) When capacitance is reduced, capacitive reactance $X_C = \frac{1}{\omega C}$ increases, hence impedance of circuit

$$Z = \sqrt{R^2 + X_C^2}$$



increases and so current $I = \frac{V}{Z}$ decreases. As a result the brightness of the bulb is reduced.

(*ii*) When frequency decreases; capacitive reactance $X_C = \frac{1}{2\pi\nu C}$ increases and hence impedance of circuit increases, so current decreases. As a result brightness of bulb is reduced.

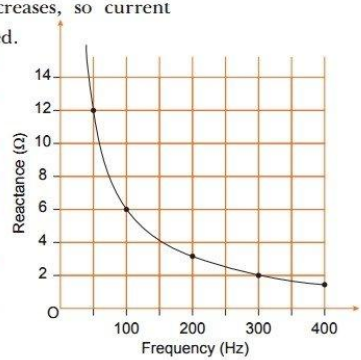
Q. 5. The figure shows the graphical variation of the reactance of a capacitor with frequency of ac source.

(*a*) Find the capacitance of the capacitor.

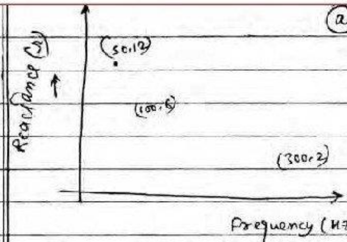
(*b*) An ideal inductor has the same reactance at 100 Hz frequency as the capacitor has at the same frequency. Find the value of inductance of the inductor.

(*c*) Draw the graph showing the variation of the reactance of this inductor with frequency.

[*CBSE 2020 (55/2/1)*]



Ans.

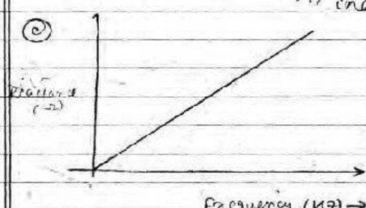


(a) We know, for AC source,
capacitor reactance, $X_C = \frac{1}{\omega C}$
$\Rightarrow X_C = \frac{1}{2\pi f C}$.
f = Frequency (in Hz)

Here, a point on the graph is (100, 6).
$\therefore$ when $f = 100$, $X_C = 6$.
$\Rightarrow 6 = \frac{1}{2\pi \times 100 \times C} \Rightarrow 2\pi \times 100 \times C = \frac{1}{6}$
$\Rightarrow C = \frac{1}{1200\pi}$
$\therefore C = \frac{7}{1200 \times 22}$ F $= 0.0265 \times 10^{-2}$ F
$= 2.65 \times 10^{-4}$ F.
$\therefore$ required capacitance $= 2.65 \times 10^{-4}$ F. (Ans)

(b) At 100 Hz, ~~frequen~~ ~~inductance~~ reactance of inductor = 6 Ω.
We know, reactance $X_L = \omega L$
L is inductance of inductor.
$\therefore 6 = 2\pi \times 100 \times L \Rightarrow L = \frac{6}{200\pi}$ H
$\therefore L = \frac{3 \times 7}{100 \times 22} = \frac{21}{22 \times 100}$ H $= 0.954 \times 10^{-2}$ H.
$\therefore$ inductance $= 0.954 \times 10^{-2}$ H (Ans)

(c)



$\because X_L = \omega L = 2\pi f L$.
$\therefore X_L = f \cdot 2\pi L$.
$\therefore$ the graph is a straight line passing through origin.

[*Topper's Answer 2020*]

Q. 6. A capacitor of unknown capacitance, a resistor of 100 Ω and an inductor of self inductance $L = \left(\frac{4}{\pi^2}\right)$ henry are connected in series to an *ac* source of 200 V and 50 Hz. Calculate the value of the capacitance and impedance of the circuit when the current is in phase with the voltage. Calculate the power dissipated in the circuit. **[*CBSE South 2016*]**

Ans. Capacitance, $C = \frac{1}{L\omega^2} = \frac{1}{\frac{4}{\pi^2}(2\pi \times 50)^2}\text{F} = \frac{1}{40000}\text{F} = \mathbf{2.5 \times 10^{-5}\ F}$

Since V and I are in same phase. then $Z = R = \mathbf{100\ \Omega}$

Power dissipated $= \frac{E_{rms}^2}{2} = \frac{(200)^2}{100}\text{W} = \mathbf{400\ W}$

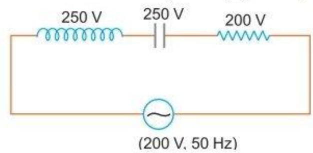
Q. 7. A series *LCR* circuit is connected to an *ac* source (200 V, 50 Hz). The voltages across the resistor, capacitor and inductor are respectively 200 V, 250 V and 250 V.

(*i*) The algebraic sum of the voltages across the three elements is greater than the voltage of the source. How is this paradox resolved?

(*ii*) Given the value of the resistance of *R* is 40 Ω, calculate the current in the circuit.

[*CBSE (F) 2013*]

Ans. (*i*) From given parameters



$V_R = 200\text{ V}, V_L = 250\text{ V}$ and $V_C = 250\text{ V}$

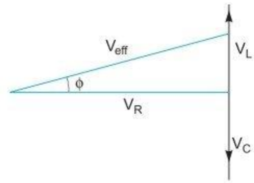
V_{eff} should be given as

$V_{eff} = V_R + V_L + V_C = 200\text{ V} + 250\text{ V} + 250\text{ V}$

$= 700\text{ V}$

However, $V_{eff} > 200\text{ V}$ of the *ac* source.

This paradox can be solved only by using phaser diagram, as given below:



$$(V_{eff}) = \sqrt{V_R^2 + (V_L - V_C)^2}$$

Since $V_L = V_C$ so $V_{eff} = V_R = 200\text{ V}$

(*ii*) Given $R = 40\ \Omega$, so current in the *LCR* circuit.

$$I_{eff} = \frac{V_{eff}}{R} \qquad [X_L = X_C \quad \text{or} \quad Z = R]$$

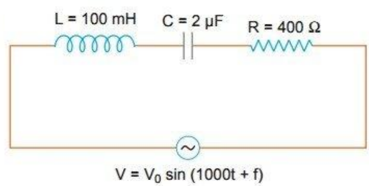
$$= \frac{200}{40} = \mathbf{5\ A}$$

Q. 8. (*i*) Find the value of the phase difference between the current and the voltage in the series *LCR* circuit shown below. Which one leads in phase: current or voltage?

(*ii*) Without making any other change, find the value of the additional capacitor, C_1, to be connected in parallel with the capacitor *C*, in order to make the power factor of the circuit unity.

[*CBSE Delhi 2017, Allahabad 2015*]

Ans. (*i*) Inductive reactance,



$$X_L = \omega L = (1000 \times 100 \times 10^{-3})\ \Omega = 100\ \Omega$$

Capacitive reactance,

$$X_C = \frac{1}{\omega C} = \left(\frac{1}{1000 \times 2 \times 10^{-6}}\right) \Omega = 500\ \Omega$$

Phase angle,

$$\tan\phi = \frac{X_L - X_C}{R}$$

$$\tan\phi = \frac{100 - 500}{400} = -1$$

$$\phi = -\frac{\pi}{4}$$

As $X_C > X_L$, (phase angle is negative), hence current leads voltage.

(*ii*) To make power factor unity

$X_{C'} = X_L$ (where C' = net capacitance of parallel combination)

$$\frac{1}{\omega C'} = 100$$

$\therefore \quad C' = 10 \times 10^{-6}\text{ F} = 10\ \mu\text{F}$

$\because \quad C' = C + C_1$

$\Rightarrow \quad 10 = 2 + C_1 \qquad \Rightarrow C_1 = \mathbf{8\ \mu F}$

Q. 9. A series *LCR* circuit with $R = 20\ \Omega$, $L = 2\ H$ and $C = 50\ \mu F$ is connected to a 200 volts ac source of variable frequency. What is (*i*) the amplitude of the current, and (*ii*) the average power transferred to the circuit in one complete cycle, at resonance? (*iii*) Calculate the potential drop across the capacitor. [*CBSE 2023 (55/4/1)*]

Ans. (*i*) At resonance, $Z = R$

$$I_{rms} = \frac{V_{rms}}{Z} = \frac{200}{20} = 10\text{ A}$$

Amplitude of the current, $I_0 = \sqrt{2} \times I_{rms}$

$$= 1.414 \times 10 = \mathbf{14.14\ A}$$

(*ii*) Average power transferred to the circuit in one complete cycle at resonance,

$$P = I_{rms}^2 R = (10)^2 \times 20$$

$$= \mathbf{2000\ W}$$

(*iii*) Resonant frequency,

$$\omega_r = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{2 \times 50 \times 10^{-6}}} = 100\text{ rad/s}$$

$$X_C = \frac{1}{\omega_r C} = \frac{1}{100 \times 50 \times 10^{-6}}$$

Voltage across capacitor,

$$V_C = I_{rms} X_C = 10 \times \frac{1}{100 \times 50 \times 10^{-6}} = \mathbf{2000\ V}$$

Q. 10. A series *CR* circuit with $R = 200\ \Omega$ and $C = (50/\pi)\ \mu F$ is connected across an ac source of peak voltage $\varepsilon_0 = 100$ V and frequency $\nu = 50$ Hz. Calculate (*a*) impedance of the circuit (*Z*), (*b*) phase angle (ϕ), and (*c*) voltage across the resistor. [*CBSE 2023 (55/2/1)*]

Ans. (*a*) Given, $R = 200\ \Omega$,

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi\nu C} = \frac{1}{2\pi \times 50 \times \frac{50}{\pi} \times 10^{-6}} = 200\ \Omega$$

Impudence, $Z = \sqrt{R^2 + X_C^2}$

$$Z = \sqrt{(200)^2 + (200)^2} = \mathbf{200\sqrt{2}\ \Omega}$$

(*b*) Phase angle, $\tan\phi = \frac{X_C}{R} = \frac{200}{200} = 1 \quad \Rightarrow \quad \phi = 45°$ or $\frac{\pi}{4}$ **rad**

(*c*) $\varepsilon_{rms} = \frac{\varepsilon_0}{\sqrt{2}} = \frac{100}{\sqrt{2}}\text{V}$

and $I_{rms} = \frac{\varepsilon_{rms}}{Z} = \frac{\frac{100}{\sqrt{2}}}{200\sqrt{2}} = \frac{1}{4}\text{A}$

So, $V_R = I_{rms} R = \frac{1}{4} \times 200 = \mathbf{50\ V.}$

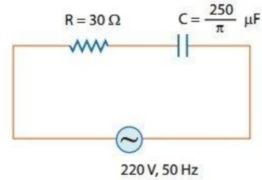
Q. 11. A resistor of 30 Ω and a capacitor of $\frac{250}{\pi}\ \mu F$ are connected in series to a 200 V, 50 Hz *ac* source. Calculate (*i*) the current in the circuit, and (*ii*) voltage drops across the resistor and the capacitor (*iii*) Is the algebraic sum of these voltages more than the source voltage? If yes, solve the paradox. [*CBSE 2023 (55/4/1)*]

Ans. (*i*) capacitive reactant,

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi\nu C}$$

$$= \frac{1}{2\pi \times 50 \times \frac{250}{\pi} \times 10^{-6}}$$

$$= 40\ \Omega$$



Impedance of the circuit, $Z = \sqrt{R^2 + X_C^2}$

$$= \sqrt{(30)^2 + (40)^2} = 50\ \Omega$$

So, current in the circuit, $I_{\text{rms}} = \frac{E_{rms}}{Z} = \frac{200}{50} = \mathbf{4\ A}$

(*ii*) Voltage across resistor, $V_R = I_{\text{rms}} R = 4 \times 30 = \mathbf{120\ V}$

Voltage across capacitor, $V_C = I_{\text{rms}} X_C = 4 \times 40 = \mathbf{160\ V}$

(*iii*) The algebraic sum of voltages across the combination is

$$V_{rms} = V_R + V_C = 120 + 160 = 280\ \text{V}$$

While V_{rms} of the source is 200 V. Yes, the voltages across the combination is more than the voltage of the source. The voltage across the resistor and capacitor are not in phase.

This paradox can be resolved as when the current passes through the capacitor, it leads the voltage V_C by phase $\frac{\pi}{2}$. So voltage of the source can be given as,

$$V_{rms} = \sqrt{V_R^2 + V_C^2} = \sqrt{(120)^2 + (160)^2}$$

$$= \sqrt{14400 + 25600} = 200\ \text{V.}$$

Q. 12. The primary coil of an ideal step up transformer has 100 turns and transformation ratio is also 100. The input voltage and power are 220 V and 1100 W respectively. Calculate

(*a*) the number of turns in the secondary coil.

(*b*) the current in the primary coil.

(*c*) the voltage across the secondary coil.

(*d*) the current in the secondary coil.

(*e*) the power in the secondary coil. [*CBSE Delhi 2016*]

Ans. (*a*) Transformation ratio $r = \frac{\text{Number of turns in secondary coil}\ (N_S)}{\text{Number of turns in primary coil}\ (N_P)}$

Given $N_P = 100$, $r = 100$

$\therefore$ Number of turns in secondary coil, $N_S = rN_P = 100 \times 100 = \mathbf{10{,}000}$

(*b*) Input voltage $V_P = 220$ V, Input power $P_{in} = 1100$ W

Current in primary coil $I_p = \frac{P_{in}}{V_P} = \frac{1100}{220} = \mathbf{5\ A}$

(*c*) Voltage across secondary coil (V_S) is

$\therefore$ $V_S = rV_P = 100 \times 220 = 22{,}000\ \text{V} = \mathbf{22\ kV}$ $\left(r = \frac{V_S}{V_P}\right)$

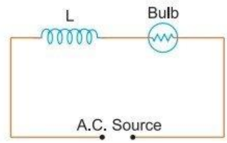
(*d*) Current in secondary coil (I_S),

$\therefore$ $I_S = \frac{I_P}{r} = \frac{5}{100} = \mathbf{0.05\ A}$ $\left(r = \frac{I_P}{I_S}\right)$

(*e*) Power in secondary coil, $P_{out} = V_S I_S = 22 \times 10^3 \times 0.05 = \mathbf{1100\ W}$

Obviously power in secondary coil is same as power in primary. This means that the transformer is ideal, *i.e.*, there are no energy losses.

Q. 13. An inductor L of reactance X_L is connected in series with a bulb B to an *ac* source as shown in figure. Explain briefly how does the brightness of the bulb change when (*i*) number of turns of the inductor is reduced (*ii*) an iron rod is inserted in the inductor and (*iii*) a capacitor of reactance $X_C = X_L$ is included in the circuit.



[*CBSE Delhi 2014, 2015*]

Ans. Brightness of the bulb depends on square of the I_{rms} (*i.e.*, I^2_{rms})

Impedance of the circuit, $Z = \sqrt{R^2 + (\omega L)^2}$ and

Current in the circuit, $I = \frac{V}{Z}$

(*i*) When the number of turns in the inductor is reduced, the self inductance of the coil decreases; so impedance of circuit reduces and so current in the circuit $\left(I = \frac{E}{Z}\right)$ increases. Thus, the brightness of the bulb increases.

(*ii*) When iron (being a ferromagnetic substance) rod is inserted in the coil, its inductance increases and in turn, impedance of the circuit increases. As a result, a larger fraction of the applied ac voltage appears across the inductor, leaving less voltage across the bulb. Hence, brightness of the bulb decreases.

(*iii*) When capacitor of reactance $X_C = X_L$ is introduced, the net reactance of circuit becomes zero, so impedance of circuit decreases; it becomes $Z = R$; so current in circuit increases; hence brightness of bulb increases. Thus brightness of bulb in both cases increases.

Q. 14. A capacitor (C) and resistor (R) are connected in series with an *ac* source of voltage of frequency 50 Hz. The potential difference across C and R are respectively 120 V, 90 V, and the current in the circuit is 3 A. Calculate (*i*) the impedance of the circuit (*ii*) the value of the inductance, which when connected in series with C and R will make the power factor of the circuit unity.

[*CBSE 2019 (55/2/1)*]

Ans. As from relation,

$$R = \frac{V_R}{I_R} = \frac{90}{3} = 30\ \Omega$$

$$X_C = \frac{V_C}{I_C} = \frac{120}{3} = 40\ \Omega$$

(*i*) Impedance, $Z = \sqrt{R^2 + X_C^2}$

$$= \sqrt{30^2 + 40^2} = \mathbf{50\ \Omega}$$

(*ii*) As power factor = 1

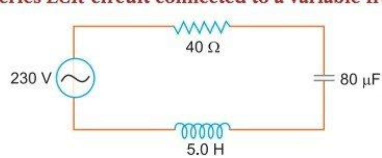
Now, $X_L = X_C$

$$2\pi\nu L = 40$$

$$100\pi L = 40$$

$$\therefore \quad L = \frac{\mathbf{2}}{\mathbf{5\pi}}\ \mathbf{H}.$$

Q. 15. The figure shows a series *LCR* circuit connected to a variable frequency 230 *V* source.



(*a*) Determine the source frequency which drives the circuit in resonance.

(*b*) **Calculate the impedance of the circuit and amplitude of current at resonance.**

(*c*) **Show that potential drop across *LC* combination is zero at resonating frequency.**

[*CBSE 2019 (55/2/1)*]

Ans. (*a*) $\omega = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{5\times80\times10^{-6}}} = \frac{1}{\sqrt{400\times10^{-6}}}$

$\omega = \frac{1000}{20} = 50 \text{ rad/s} \Rightarrow f = \frac{\omega}{2\pi} = \frac{50}{2\pi} = \mathbf{\frac{25}{\pi} \text{ Hz}}$

(*b*) At resonance, $Z = R = \mathbf{40\ \Omega}$

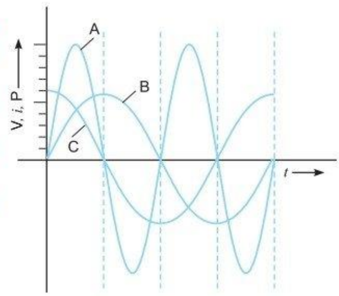
$I_{max} = \frac{230\sqrt{2}}{R} = \frac{230\sqrt{2}}{40} = \mathbf{8.1\ A}$

(*c*) $V_C = I_{max}X_C = \frac{230\sqrt{2}}{40} \times \frac{1}{50\times80\times10^{-6}} = 2025 \text{ V}$ $\quad [\because X_C = \frac{1}{\omega C}]$

$V_L = I_{max}X_L = \frac{230\sqrt{2}}{40} \times 50\times5 = 2025 \text{ V}$ $\quad [\because X_L = \omega L]$

Hence, $V_C - V_L = 0$

Q. 16. A device '*X*' is connected to an *ac* source. The variation of voltage, current and power in one complete cycle is shown in the figure.



(*a*) **Which curve shows power consumption over a full cycle?**

(*b*) **What is the average power consumption over a cycle?**

(*c*) **Identify the device '*X*'.** **[*NCERT Exemplar*]**

Ans. (*a*) *A*

(*b*) Zero

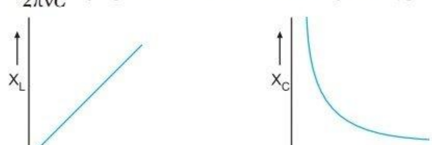
(*c*) *L* or *C* or *LC* Series combination of *L* and *C*

Q. 17. (*i*) **Draw the graphs showing variation of inductive reactance and capacitive reactance with frequency of applied *ac* source.**

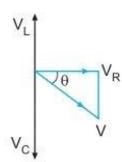
(*ii*) **Can the voltage drop across the inductor or the capacitor in a series *LCR* circuit be greater than the applied voltage of the *ac* source? Justify your answer.** **[*HOTS*]**

Ans. (*i*) (*a*) $X_L = \omega L = 2\pi\nu L$; graph of X_L and ν is a straight line

(*b*) $X_C = \frac{1}{\omega C} = \frac{1}{2\pi\nu C}$, graph of X_C and ν is a rectangular hyperbola as shown in fig.



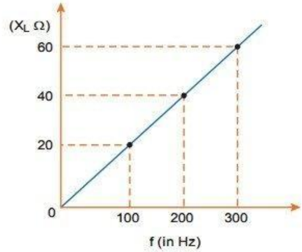
(*ii*) Yes; because $V = \sqrt{V_R^2 + (V_C - V_L)^2}$;



As V_C and V_L have opposite faces, V_C or V_L may be greater than V.

The situation may be as shown in figure where $V_C > V$.

Q. 18. The variation of inductive reactance (X_L) of an inductor with the frequency (f) of the *ac* source of 100 V and variable frequency is shown in the fig.



(*i*) **Calculate the self-inductance of the inductor.**

(*ii*) **When this inductor is used in series with a capacitor of unknown value and a resistor of 10 Ω at 300 s^{-1}, maximum power dissipation occurs in the circuit. Calculate the capacitance of the capacitor.** [*CBSE 2020 (55/5/1)*]

Ans. As we know, $X_L = 2\pi fL$ ½

$$L = \frac{X_L}{2\pi f} = \frac{40}{2\pi \times 200} = 0.1/\pi \text{ henry} = 0.032\text{H}$$ ½

Maximum power dissipation takes place at resonance, ½

$$\nu = \frac{1}{2\pi\sqrt{LC}}$$ ½

$$\Rightarrow \quad C = \frac{1}{L \times 300^2 \times 4\pi^2}\text{F}$$ ½

$$\therefore \quad C = \frac{\pi}{0.1 \times 9 \times 10^4 \times 4\pi^2}\text{F} = 8.8\mu\text{F}$$ ½

[*CBSE Marking Scheme 2020 (55/5/1)*]

Long Answer Questions

Each of the following questions are of 5 marks.

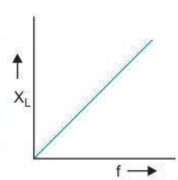
Q. 1. Explain the term inductive reactance. Show graphically the variation of inductive reactance with frequency of the applied alternating voltage.

An *ac* voltage $V = V_0 \sin \omega t$ is applied across a pure inductor of inductance *L*. Find an expression for the current *i*, flowing in the circuit and show mathematically that the current flowing through it lags behind the applied voltage by a phase angle of $\frac{\pi}{2}$. Also draw (*i*) phasor diagram (*ii*) graphs of *V* and *i* versus ωt for the circuit. [*CBSE East 2016*]

Ans. Inductive Reactance: The opposition offered by an inductor to the flow of alternating current through it is called the inductive reactance. It is denoted by X_L. Its value is $X_L = \omega L = 2\pi fL$ where *L* is inductance and *f* is the frequency of the applied voltage.

Obviously $\quad X_L \propto f$

Thus, the graph between X_L and frequency *f* is linear (as shown in fig.).



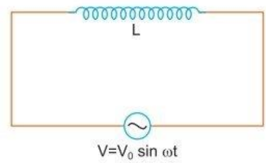
Phase Difference between Current and Applied Voltage in Purely Inductive circuit :

AC circuit containing pure inductance: Consider a coil of self-inductance *L* and negligible ohmic resistance. An alternating potential difference is applied across its ends. The magnitude and direction of *ac* changes periodically, due to which there is a continual change in magnetic flux linked with the coil. Therefore according to Faraday's law, an induced emf is produced in the coil, which opposes the applied voltage. As a result the current in the circuit is reduced. That is ***inductance acts like a resistance in ac circuit***. The instantaneous value of alternating voltage applied

$$V = V_0 \sin \omega t \quad \ldots(i)$$

If i is the instantaneous current in the circuit and $\frac{di}{dt}$ the rate of change of current in the circuit at that instant, then instantaneous induced emf

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



(a)

According to Kirchhoff's loop rule

$$V + \varepsilon = 0 \Rightarrow V - L\frac{di}{dt} = 0$$

or $$V = L\frac{di}{dt} \text{ or } \frac{di}{dt} = \frac{V}{L}$$

or $$\frac{di}{dt} = \frac{V_0 \sin \omega t}{L} \text{ or } di = \frac{V_0 \sin \omega t}{L} dt$$

Integrating with respect to time 't',

$$i = \frac{V_0}{L}\int \sin \omega t\, dt = \frac{V_0}{L}\left\{-\frac{\cos \omega t}{\omega}\right\} = -\frac{V_0}{\omega L}\cos \omega t = -\frac{V_0}{\omega L}\sin\left(\frac{\pi}{2} - \omega t\right)$$

or $$i = \frac{V_0}{\omega L}\sin\left(\omega t - \frac{\pi}{2}\right) \quad \ldots(ii)$$

This is required expression for current

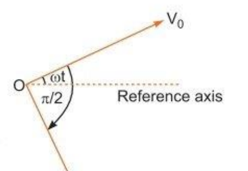
or $$i = i_0 \sin\left(\omega t - \frac{\pi}{2}\right) \quad \ldots(iii)$$

where $$i_0 = \frac{V_0}{\omega L}$$

is the peak value of alternating current

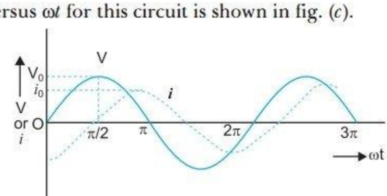
Also comparing (*i*) and (*iii*), we note that current lags behind the applied voltage by an angle $\frac{\pi}{2}$ (Fig. *b*).

Phasor diagram: The phasor diagram of circuit containing pure inductance is shown in Fig. (*b*).



(b) Phasor diagram

Graphs of V and I versus ωt for this circuit is shown in fig. (*c*).



(c)

Q. 2. (*a*) What is impedance?

(*b*) A series *LCR* circuit is connected to an *ac* source having voltage $V = V_0 \sin \omega t$. Derive expression for the impedance, instantaneous current and its phase relationship to the applied voltage. Find the expression for resonant frequency.

[*CBSE Delhi 2010, 2023(55/1/1)*]

OR

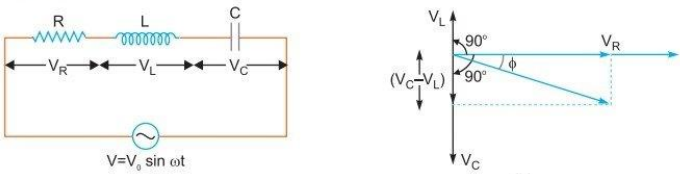
(a) An *ac* source of voltage $V = V_0 \sin \omega t$ is connected to a series combination of *L*, *C* and *R*. Use the phasor diagram to obtain expressions for impedance of the circuit and phase angle between voltage and current. Find the condition when current will be in phase with the voltage. What is the circuit in this condition called?

(b) In a series *LR* circuit $X_L = R$ and power factor of the circuit is P_1. When capacitor with capacitance *C* such that $X_L = X_C$ is put in series, the power factor becomes P_2. Calculate $\frac{P_1}{P_2}$. **[*CBSE Delhi 2016*]**

Ans. **Impedance:** The opposition offered by the combination of a resistor and reactive component to the flow of ac is called impedance. Mathematically it is the ratio of rms voltage applied and rms current produced in circuit *i.e.*, $Z = \frac{V}{I}$.

Its unit is ohm (Ω).

Expression for Impedance in *LCR* series circuit: Suppose resistance *R*, inductance *L* and capacitance *C* are connected in series and an alternating source of voltage $V = V_0 \sin \omega t$ is applied across it (fig. a). On account of being in series, the current (i) flowing through all of them is the same.



(a) (b)

Suppose the voltage across resistance *R* is V_R voltage across inductance *L* is V_L and voltage across capacitance *C* is V_C. The voltage V_R and current i are in the same phase, the voltage V_L will lead the current by angle 90° while the voltage V_C will lag behind the current by angle 90° (fig. *b*). Clearly V_C and V_L are in opposite directions, therefore their resultant potential difference = $V_C - V_L$ (if $V_C > V_L$).

Thus V_R and $(V_C - V_L)$ are mutually perpendicular and the phase difference between them is 90°. As applied voltage across the circuit is *V*, the resultant of V_R and $(V_C - V_L)$ will also be *V*. From fig.

$$V^2 = V_R^2 + (V_C - V_L)^2 \Rightarrow V = \sqrt{V_R^2 + (V_C - V_L)^2}$$

But $V_R = R\,i$, $V_C = X_C\, i$ and $V_L = X_L\, i$

where $X_C = \frac{1}{\omega C}$ = capacitance reactance and $X_L = \omega L$ = inductive reactance

$$V = \sqrt{(Ri)^2 + (X_C i - X_L i)^2}$$

Impedance of circuit, $Z = \frac{V}{i} = \sqrt{R^2 + (X_C - X_L)^2}$

i.e., $$Z = \sqrt{R^2 + (X_C - X_L)^2} = \sqrt{R^2 + \left(\frac{1}{\omega C} - \omega L\right)^2}$$

Instantaneous current $$I = \frac{V_0 \sin(\omega t + \phi)}{\sqrt{R^2 + \left(\frac{1}{\omega C} - \omega L\right)^2}}$$

The phase difference (ϕ) between current and voltage is given by, $\tan \phi = \frac{X_C - X_L}{R}$

Resonant Frequency: For resonance $\phi = 0$, so $X_C - X_L = 0$

$$\frac{1}{\omega C} = \omega L \Rightarrow \omega^2 = \frac{1}{LC}$$

$\therefore$ Resonant frequency $\omega_r = \frac{1}{\sqrt{LC}}$

Phase difference (ϕ) in series LCR circuit is given by

$$\tan\phi = \frac{V_C - V_L}{V_R} = \frac{i_m(X_C - X_L)}{i_m R} = \frac{(X_C - X_L)}{R}$$

When current and voltage are in phase

$$\phi = 0 \quad \Rightarrow \quad X_C - X_L = 0 \Rightarrow \quad X_C = X_L$$

This condition is called resonance and the circuit is called resonant circuit.

Case I: $X_L = R$

$$\therefore \quad Z = \sqrt{R^2 + X_L^2} = \sqrt{R^2 + R^2} = \sqrt{2}R$$

Power factor, $P_1 = \cos\phi = \frac{R}{Z} = \frac{R}{\sqrt{2}R} = \frac{1}{\sqrt{2}}$

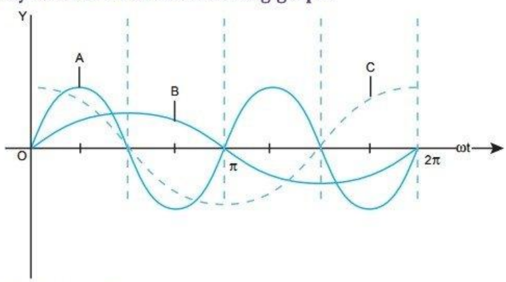
Case II: $X_L = X_C$

$$\therefore \quad Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{R^2} = R$$

Power factor, $P_2 = \frac{R}{Z} = \frac{R}{R} = 1$

$$\therefore \quad \frac{P_1}{P_2} = \frac{\mathbf{1}}{\sqrt{\mathbf{2}}}$$

Q. 3. A device 'X' is connected to an ac source $V = V_0 \sin \omega t$. The variation of voltage, current and power in one cycle is show in the following graph:



(a) Identify the device 'X'.

(b) Which of the curves, A, B and C represent the voltage, current and the power consumed in the circuit? Justify your answer.

(c) How does its impedance vary with frequency of the *ac* source? Show graphically.

(d) Obtain an expression for the current in the circuit and its phase relation with *ac* voltage.

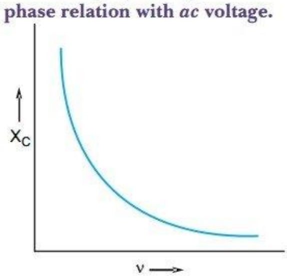
Ans. (a) The device 'X' is a capacitor.

(b) Curve B : Voltage

Curve C : Current

Curve A : Power consumed in the circuit

Reason : This is because current leads the voltage in phase by $\frac{\pi}{2}$ for a capacitor.



(c) Impedance:

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi\nu C}$$

$\Rightarrow \quad X_C \propto \frac{1}{\nu}$

(*d*) Voltage applied to the circuit is

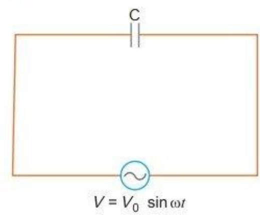
$$V = V_0 \sin \omega t$$

Due to this voltage, a charge will be produced which will charge the plates of the capacitor with positive and negative charges.

$$V = \frac{Q}{C} \qquad \Rightarrow \qquad Q = CV$$

Therefore, the instantaneous value of the current in the circuit is

$$I = \frac{dQ}{dt} = \frac{d(CV)}{dt} = \frac{d}{dt}(CV_0 \sin \omega t)$$



$$\therefore \quad I = \omega C V_0 \cos \omega t = \frac{V_0}{\frac{1}{\omega C}} \sin\left(\omega t + \frac{\pi}{2}\right)$$

$$I = I_0 \sin\left(\omega t + \frac{\pi}{2}\right)$$

where, $I_0 = \frac{V_0}{\frac{1}{\omega C}}$ = Peak value of current

Hence, current leads the voltage in phase by $\frac{\pi}{2}$.

Q. 4. (*a*) An alternating voltage $V = V_m \sin \omega$ applied to a series *LCR* circuit drives a current given by $i = i_m \sin (\omega t + \phi)$. Deduce an expression for the average power dissipated over a cycle.

(*b*) For circuits used for transporting electric power, a low power factor implies large power loss in transmission. Explain. **[*CBSE (F) 2011*]**

OR

A voltage $V = V_0 \sin \omega t$ is applied to a series *LCR* circuit. Derive the expression for the average power dissipated over a cycle.

Under what condition is (*i*) no power dissipated even though the current flows through the circuit, (*ii*) maximum power dissipated in the circuit? **[*CBSE (AI) 2014*]**

Ans. (*a*) We have, $V = V_m \sin \omega t$ and $i = i_m \sin (\omega t + \phi)$

and instantaneous power, $P = Vi$

$$= V_m \sin \omega t \,.\, i_m \sin (\omega t + \phi)$$

$$= V_m i_m \sin \omega t \sin (\omega t + \phi)$$

$$= \frac{1}{2} V_m i_m 2 \sin \omega t . \sin (\omega t + \phi)$$

From trigonometric formula

$$2 \sin A \sin B = \cos (A - B) - \cos (A + B)$$

$$\therefore \quad \text{Instantaneous power, } P = \frac{1}{2} V_m i_m [\cos (\omega t - \omega t - \phi) - \cos (\omega t + \phi + \omega t)]$$

$$= \frac{1}{2} V_m i_m [\cos \phi - \cos (2\omega t + \phi)]$$

Average power for complete cycle,

$$\overline{P} = \frac{1}{2} V_m i_m [\cos \phi - \overline{\cos (2\omega t + \phi)}]$$

where $\overline{\cos (\omega t + \phi)}$ is the mean value of $\cos (2\omega t + \phi)$ over complete cycle. But for a complete cycle, $\cos (2\omega t + \phi) = 0$.

∴ Average power, $\overline{P} = \frac{1}{2} V_m i_m \cos\phi = \frac{V_0}{\sqrt{2}} \frac{i_0}{\sqrt{2}} \cos\phi$

$$\overline{P} = V_{rms} i_{rms} \cos\phi$$

(i) If phase angle $\phi = 90°$ (resistance R is not used in the circuit) then no power dissipated.

(ii) If phase angle $\phi = 0°$ or circuit is pure resistive (or $X_L = X_C$) at resonance then

Max power, $P = V_{rms} \times I_{rms} = \frac{V_0 I_0}{2}$

(b) The power is $P = V_{rms} I_{rms} \cos\phi$. If $\cos\phi$ is small, then current considerably increases when voltage is constant. Power loss, we know is I^2R. Hence, power loss increases.

Q. 5. Find the condition for resonance in a series *LCR* circuit connected to a source $V = V_m \sin \omega t$, where ω can be varied. Give the factors on which the resonant frequency of a series *LCR* circuit depends. Plot a graph showing the variation of electric current with frequency in a series *LCR* circuit. [*CBSE 2023 (55/1/1)*]

Ans. Condition for resonance to occur in series *LCR ac* circuit:

For resonance the current produced in the circuit and emf applied must always be in the same phase. Phase difference (ϕ) in series *LCR* circuit is given by

$$\tan\phi = \frac{X_C - X_L}{R}$$

For resonance $\phi = 0 \quad \Rightarrow \quad X_C - X_L = 0$

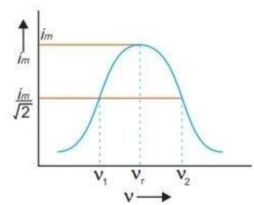
or $\quad X_C = X_L$

If ω_r is resonant frequency, then $X_C = \frac{1}{\omega_r C}$

and $\quad X_C = \omega_r L$

$$\frac{1}{\omega_r C} = \omega_r L \Rightarrow \omega_r = \frac{1}{\sqrt{LC}}$$

Linear resonant frequency, $\nu_r = \frac{\omega_r}{2\pi} = \frac{1}{2\pi\sqrt{LC}}$



Factors on which resonant frequency depends:

(i) Inductance, *i.e.*, $\left(\nu_r \propto \frac{1}{\sqrt{L}}\right)$

(ii) Capacitance, *i.e.*, $\left(\nu_r \propto \frac{1}{\sqrt{C}}\right)$

The graph of variation of peak current i_m with frequency is shown above in fig. Half power frequencies are the frequencies on either side of resonant frequency for which current reduces to half of its maximum value. In fig., ν_1 and ν_2 are half power frequencies.

Q. 6. Explain with the help of a labelled diagram, the principle and working of an *ac* generator. Write the expression for the emf generated in the coil in terms of speed of rotation. Can the current produced by an *ac* generator be measured with a moving coil galvanometer?

OR

Describe briefly, with the help of a labelled diagram, the basic elements of an *ac* generator. State its underlying principle. Show diagrammatically how an alternating emf is generated by a loop of wire rotating in a magnetic field. Write the expression for the instantaneous value of the emf induced in the rotating loop. [*CBSE 2023 (55/2/1)*]

OR

State the working of ac generator with the help of a labelled diagram.

The coil of an *ac* generator having *N* turns, each of area *A*, is rotated with a constant angular velocity ω. Deduce the expression for the alternating emf generated in the coil.

What is the source of energy generation in this device? [*CBSE (AI) 2011*]

Ans. **AC generator:** A dynamo or generator is a device which converts mechanical energy into electrical energy.

Principle: It works on the principle of electromagnetic induction. When a coil rotates continuously in a magnetic field, the effective area of the coil linked normally with the magnetic field lines, changes continuously with time. This variation of magnetic flux with time results in the production of an alternating emf in the coil.

Construction: It consists of the four main parts:

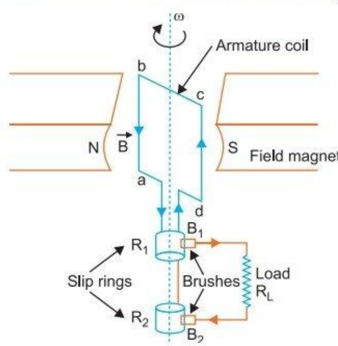
(*i*) **Field Magnet:** It produces the magnetic field. In the case of a low power dynamo, the magnetic field is generated by a permanent magnet, while in the case of large power dynamo, the magnetic field is produced by an electromagnet.

(*ii*) **Armature:** It consists of a large number of turns of insulated wire in the soft iron drum or ring. It can revolve round an axle between the two poles of the field magnet. The drum or ring serves the two purposes: (*a*) It serves as a support to coils and (*b*) It increases the magnetic field due to air core being replaced by an iron core.

(*iii*) **Slip Rings:** The slip rings R_1 and R_2 are the two metal rings to which the ends of armature coil are connected. These rings are fixed to the shaft which rotates the armature coil so that the rings also rotate along with the armature.

(*iv*) **Brushes:** These are two flexible metal plates or carbon rods (B_1 and B_2) which are fixed and constantly touch the revolving rings. The output current in external load R_L is taken through these brushes.

Working: When the armature coil is rotated in the strong magnetic field, the magnetic flux linked with the coil changes and the current is induced in the coil, its direction being given by Fleming's right hand rule. Considering the armature to be in vertical position and as it rotates in clockwise direction, the wire *ab* moves downward and *cd* upward, so that the direction of induced current is shown in fig. In the external circuit, the current flows along $B_1 R_L B_2$. The direction of current remains unchanged during the first half turn of armature. During the second half revolution, the wire *ab* moves upward and *cd* downward, so the direction of current is reversed and in external circuit it flows along $B_2 R_L B_1$. Thus the direction of induced emf and current changes in the external circuit after each half revolution.



Expression for Induced emf: When the coil is rotated with a constant angular speed ω , the angle θ between the magnetic field vector *B* and the area vector *A* of the coil at any instant *t* is $\theta = \omega t$ (assuming $\theta = 0°$ at $t = 0$). As a result, the effective area of the coil exposed to the magnetic field lines changes with time, the flux at any time *t* is

$$\phi_B = BA \cos \theta = BA \cos \omega t$$

From Faraday's law, the induced emf for the rotating coil of N turns is then,

$$\varepsilon = -N\frac{d\phi_B}{dt} = -NBA\frac{d}{dt}(\cos \omega t)$$

Thus, the instantaneous value of the emf is

$$\varepsilon = NBA\ \omega \sin \omega t$$

where $NBA\omega = 2\pi\upsilon NBA$ is the maximum value of the emf, which occurs when $\sin \omega t = \pm 1$. If we denote $NBA\omega$ as ε_0, then

$$\varepsilon = \varepsilon_0 \sin \omega t \quad \Rightarrow \quad \varepsilon = \varepsilon_0 \sin 2\pi\nu t$$

where ν is the frequency of revolution of the generator's coil.

Obviously, the emf produced is alternating and hence the current is also alternating.

Current produced by an *ac* generator cannot be measured by moving coil ammeter; because the average value of *ac* over full cycle is zero.

The source of energy generation is the mechanical energy of rotation of armature coil.

Q. 7. (*a*) Describe briefly, with the help of a labelled diagram, the working of a step up transformer.

(*b*) Write any two sources of energy loss in a transformer. **[*CBSE (F) 2012*]**

(*c*) A step up transformer converts a low voltage into high voltage. Does it not violate the principle of conservation of energy? Explain. **[*CBSE Delhi 2011, 2009*]**

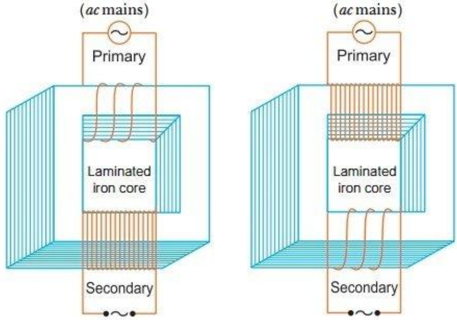
OR

Draw a schematic diagram of a step-up transformer. Explain its working principle. Deduce the expression for the secondary to primary voltage in terms of the number of turns in the two coils. In an ideal transformer, how is this ratio related to the currents in the two coils?

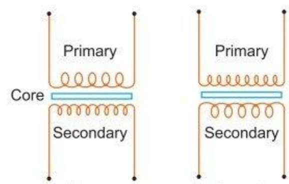
How is the transformer used in large scale transmission and distribution of electrical energy over long distances? **[*CBSE (AI) 2010, (East) 2016*]**

Ans. (*a*) **Transformer:** A transformer converts low voltage into high voltage *ac* and vice-versa.

Construction: It consists of laminated core of soft iron, on which two coils of insulated copper wire are separately wound. These coils are kept insulated from each other and from the iron-core, but are coupled through mutual induction. The number of turns in these coils are different. Out of these coils one coil is called *primary coil* and other is called the *secondary coil*. The terminals of primary coils are connected to *ac* mains and the terminals of the secondary coil are connected to external circuit in which alternating current of desired voltage is required. Transformers are of two types:



(a) Step up Transformer (b) Step down Transformer



(a) Step up (b) Step down

1. **Step up Transformer:** It transforms the alternating low voltage to alternating high voltage and in this the number of turns in secondary coil is more than that in primary coil (*i.e.*, $N_S > N_P$).
2. **Step down Transformer:** It transforms the alternating high voltage to alternating low voltage and in this the number of turns in secondary coil is less than that in primary coil (*i.e.*, $N_S < N_P$).

Working Principle: When alternating current source is connected to the ends of primary coil, the current changes continuously in the primary coil; due to which the magnetic flux linked with the secondary coil changes continuously, therefore the alternating emf of same frequency is developed across the secondary.

Let N_P be the number of turns in primary coil, N_S the number of turns in secondary coil and ϕ the magnetic flux linked with each turn. ***We assume that there is no leakage of flux so that the flux linked with each turn of primary coil and secondary coil is the same.*** According to Faraday's laws the emf induced in the primary coil

$$\varepsilon_P = -N_P \frac{\Delta\phi}{\Delta t} \qquad ...(i)$$

and emf induced in the secondary coil

$$\varepsilon_S = -N_S \frac{\Delta\phi}{\Delta t} \qquad ...(ii)$$

From (*i*) and (*ii*)

$$\frac{\varepsilon_S}{\varepsilon_P} = \frac{N_S}{N_P}$$

If the resistance of primary coil is negligible, the emf (ε_P) induced in the primary coil, will be equal to the applied potential difference (V_P) across its ends. Similarly if the secondary circuit is open, then the potential difference V_S across its ends will be equal to the emf (ε_S) induced in it; therefore

$$\frac{V_S}{V_P} = \frac{\varepsilon_S}{\varepsilon_P} = \frac{N_S}{N_P} = r(\text{say})$$

where $r = \frac{N_S}{N_P}$ is called the transformation ratio. If i_P and i_S are the instantaneous currents in primary and secondary coils and there is no loss of energy; then

For about 100% efficiency, Power in primary = Power in secondary

$$V_P\, i_P = V_S\, i_S$$

$$\therefore \quad \frac{i_S}{i_P} = \frac{V_P}{V_S} = \frac{N_P}{N_S} = \frac{1}{r}$$

In step up transformer, $N_S > N_P \rightarrow r > 1$;

So $\quad V_S > V_P$ and $i_S < i_P$

i.e., step up transformer increases the voltage, but decreases the current.

In step down transformer, $N_S < N_P \rightarrow r < 1$

so $\quad V_S < V_P$ and $i_S > i_P$

i.e., step down transformer decreases the voltage, but increases the current.

Laminated core: The core of a transformer is laminated to reduce the energy losses due to eddy currents, so that its efficiency may remain nearly 100%.

In a transformer with 100% efficiency (say),

Input power = output power (*i.e.*, $V_P I_P = V_S I_S$)

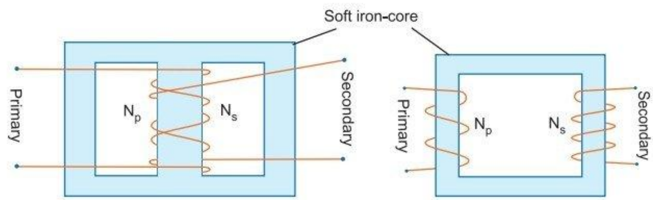
(b) The sources of energy loss in a transformer are (i) eddy current losses due to iron core (ii) flux leakage losses. (iii) copper losses due to heating up of copper wires (iv) hysteresis losses due to magnetisation and demagnetisation of core.

(c) When output voltage increases, the output current automatically decreases to keep the power same. Thus, there is no violation of conservation of energy in a step up transformer.

Q. 8. With the help of a diagram, explain the principle of a device which changes a low voltage into a high voltage but does not violate the law of conservation of energy. Give any one reason why the device may not be 100% efficient. **[*CBSE Sample Paper 2018*]**

Ans. Transformer changes a low voltage into a high voltage without voilating the law of conservation of energy.

Principle: When alternating current source is connected to the ends of primary coil, the current changes continuously in the primary coil; due to which the magnetic flux linked with the secondary coil changes continuously, therefore the alternating emf of same frequency is developed across the secondary.



(a) Two coils on top of each other

(b)Two coils on separate limbs of the core

The device may not be 100% efficient due to following energy losses in a transformer:

(i) Joule Heating: Energy is lost due to heating of primary and secondary windings as heat (I^2Rt).

(ii) Flux Leakage: Energy is lost due to coupling of primary and secondary coils not being perfect, *i.e.*, whole of magnetic flux generated in primary coil is not linked with the secondary coil.

Q. 9. (a) Draw the diagram of a device which is used to decrease high *ac* voltage into a low *ac* voltage and state its working principle. Write four sources of energy loss in this device.

(b) A small town with a demand of 1200 kW of electric power at 220 V is situated 20 km away from an electric plant generating power at 440 V. The resistance of the two wire line carrying power is 0.5 Ω per km. The town gets the power from the line through a 4000-220 V step-down transformer at a sub-station in the town. Estimate the line power loss in the form of heat. **[*CBSE 2019 (55/1/2)*]**

Ans. (a) Refer to Q. 7, Long Answer Questions

(b) Demand of electric power = 1200 kW

Distance of town from power station = 20 km

Two wire = 20 × 2 = 40 km

Total resistance of line = 40 × 0.5 = 20 Ω

The town gets a power of 4000 volts

Power = voltage × current

$$I = \frac{1200 \times 10^3}{4000} = \frac{1200}{4} = 300 \text{ A}$$

The line power loss in the form of heat $= I^2 \times R$

$= (300)^2 \times 20 = 9000 \times 20 = \mathbf{1800\ kW}$

Q. 10. A 2 μF capacitor, 100 W resistor and 8 H inductor are connected in series with an ac source.

(*i*) What should be the frequency of the source such that current drawn in the circuit is maximum? What is this frequency called?

(*ii*) If the peak value of emf of the source is 200 V, find the maximum current.

(*iii*) Draw a graph showing variation of amplitude of circuit current with changing frequency of applied voltage in a series *LRC* circuit for two different values of resistance R_1 and R_2 ($R_1 > R_2$).

(*iv*) Define the term 'Sharpness of Resonance'. Under what condition, does a circuit become more selective? [*CBSE (F) 2016*]

Ans. (*i*) For maximum frequency

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

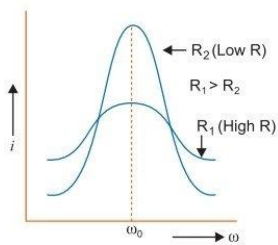
$$\Rightarrow \quad 2\pi\nu \times 8 = \frac{1}{2\pi\nu \times 2 \times 10^{-6}} \Rightarrow (2\pi\nu)^2 = \frac{1}{16 \times 10^{-6}}$$

$$\Rightarrow \quad 2\pi\nu = \frac{1}{4 \times 10^{-3}} \quad \Rightarrow \nu = \frac{250}{2\pi} = \mathbf{39.80\ s^{-1}}$$

This frequency is called resonance frequency.

(*ii*) Maximum current, $I_0 = \frac{E_0}{R} = \frac{200}{100} = \mathbf{2\ A}$ [E_0 maximum emf]

(*iii*)



(*iv*) $\frac{\omega_0}{2\Delta\omega}$ is measure of sharpness of resonance, where ω_0 is the resonant frequency and $2\Delta\omega$ is the bandwidth.

Circuit is more selective if it has greater value of sharpness. The circuit should have smaller bandwidth $\Delta\omega$.

Q. 11. (*i*) Draw a labelled diagram of *ac* generator. Derive the expression for the instantaneous value of the emf induced in the coil. [*CBSE Sample Paper 2021*]

(*ii*) A circular coil of cross-sectional area 200 cm² and 20 turns is rotated about the vertical diameter with angular speed of 50 rad s⁻¹ in a uniform magnetic field of magnitude 3.0 × 10⁻² T. Calculate the maximum value of the current in the coil. [*CBSE Delhi 2017*]

Ans. (*i*) Refer to Q. 6, Long Answer Questions.

(*ii*) Given,

$N = 20,\ A = 200\ \text{cm}^2 = 200 \times 10^{-4}\ \text{m}^2,\ B = 3.0 \times 10^{-2}\ \text{T}$

$\omega = 50\ \text{rad s}^{-1}$

EMF induced in the coil

$\varepsilon = NBA\omega \sin \omega t$

Maximum emf induced

$$\varepsilon_{max} = NBA\omega = 20 \times 3.0 \times 10^{-2} \times 200 \times 10^{-4} \times 50 = 600 \text{ mV}$$

Maximum value of current induced

$$I_{max} = \frac{\varepsilon_{max}}{R} = \frac{\mathbf{600}}{\boldsymbol{R}} \textbf{ mA}$$

Q. 12. (*i*) Draw a labelled diagram of a step-up transformer. Obtain the ratio of secondary to primary voltage in terms of number of turns and currents in the two coils.

(*ii*) A power transmission line feeds input power at 2200 V to a step-down transformer with its primary windings having 3000 turns. Find the number of turns in the secondary to get the power output at 220 V. **[*CBSE Delhi 2017*]**

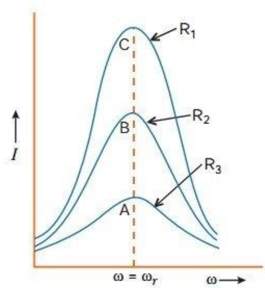
Ans. (*i*) Refer to Q. 7, Long Answer Questions.

(*ii*) Given, $V_P = 2200$ V, $N_P = 3000$ turns, $V_S = 220$ V

We have, $\dfrac{V_S}{V_P} = \dfrac{N_S}{N_P}$

$$\Rightarrow N_S = \frac{V_S}{V_P} \times N_P = \frac{220}{2200} \times 3000 = \mathbf{300 \ turns}$$

Q 13. (*a*) What do you understand by 'sharpness of resonance' for a series *LCR* resonant circuit? How is it related with the quality factor '*Q*' of the circuit? Using the graphs given in the diagram, explain the factors which affect it. For which graph is the resistance (*R*) minimum?



(*b*) A 2 μF capacitor , 100 Ω resistor and 8 H inductor are connected in series with an *ac* source. Find the frequency of the *ac* source for which the current drawn in the circuit is maximum.

If the peak value of emf of the source is 200 V, calculate the (*i*) maximum current, and (*ii*) inductive and capacitive reactance of the circuit at resonance. **[*CBSE 2019 (55/4/1)*]**

Ans. (*a*) The circuit would be set to have a high Sharpness of Resonance, if the current in the circuit drops rapidly as the frequency of the applied AC source shifts from its resonant value. (Also accept sharpness of resonance = $\omega_0 / 2\Delta\omega$). ½

Sharpness of Resonance is measured by the quality factor, $Q = \dfrac{1}{R}\sqrt{\dfrac{L}{C}}$ ½

Note: Accept the answer if the student write sharpness of resonance = Q – factor. ½

Sharpness of resonance for given value L and C / value of ω, depends on R. R is minimum for circuit C. ½

(*b*) Resonant frequency, $\nu = \dfrac{1}{2\pi\sqrt{LC}}$ ½

$$= \frac{1}{2 \times 3.14\sqrt{8 \times 2 \times 10^{-6}}}$$

$$= \frac{1000}{8 \times 3.14}$$

= 39.81 or 40 Hz (Approximately) ½

(*i*) Here, $V_0 = 200$ V

$$i_0 = \frac{V_0}{Z} = \frac{V_0}{R} \qquad (\because\ Z = R \text{ at resonance}) \qquad ½$$

$$= \frac{200}{100} = 2 \text{ Ampere}$$

(*ii*) At resonance, ½

$$X_L = X_C$$

Now, $X_L = \omega L = 2\pi\nu L$ ½

$$= 2\pi \times 39.81 \times 8$$

$$= 2000\ \Omega \qquad ½$$

So, $X_C = X_L = 2000\ \Omega$ [*CBSE Marking Scheme 2019 (55/4/1)*]

Questions for Practice

1. Choose and write the correct option in the following questions.

(*i*) The power factor of a series *LCR* circuit at resonance will be [*CBSE 2020 (55/5/1)*]

(*a*) 1 (*b*) 0 (*c*) 1/2 (*d*) $1/\sqrt{2}$

(*ii*) The electric current in a circuit is given by $I = I_0\left(\frac{t}{T}\right)$ for some time. The rms value of current for the period $t = 0$ to $t = T$ is

(*a*) $\frac{I_0}{\sqrt{2}}$ (*b*) $\sqrt{2}I_0$ (*c*) $\frac{I_0}{\sqrt{3}}$ (*d*) $\sqrt{3}I_0$

(*iii*) A 15 Ω resistor, an 80 mH inductor and a capacitor of capacitance *C* are connected in series with a 50 Hz *ac* source. If the source voltage and current in the circuit are in phase, then the value of capacitance is [*CBSE 2022 (55/2/4), Term-1*]

(*a*) 100 μF (*b*) 127 μF (*c*) 142 μF (*d*) 160 μF

(*iv*) A voltage signal is described by :

$$V = V_0 \text{ for } 0 \le t \le \frac{T}{2}$$

$$= 0 \text{ for } \frac{T}{2} \le t \le T$$

for a cycle. Its rms value is [*CBSE 2023 (55/3/1)*]

(*a*) $\frac{V_0}{\sqrt{2}}$ (*b*) V_0

(*c*) $\frac{V_0}{2}$ (*d*) $\sqrt{2}\,V_0$

(*v*) An inductor of reactance 1 Ω and a resistor of 2 Ω are connected in series to the terminals of a 6 V (rms) ac source. The power dissipated in the circuit is [*NCERT Exemplar*]

(*a*) 8 W (*b*) 12 W (*c*) 14.4 W (*d*) 18 W

(*vi*) A choke coil is a coil having

(*a*) low inductance and high resistance

(*b*) low inductance and low resistance

(*c*) high inductance and high resistance

(*d*) high inductance and negligible or small resistance (*vii*) The potential differences across the resistance, capacitance and inductance are 80 V, 40 V and 100 V respectively in an *L-C-R* circuit, the power factor for this circuit is

(*a*) 0.4 (*b*) 0.5

(*c*) 0.8 (*d*) 1.0

(*viii*) A 20 volt AC is applied to a circuit consisting of a resistance and a coil with negligible resistance. If the voltage across the resistance is 12 volt, the voltage across the coil is

[CBSE Sample Paper-2022), Term-1]

(*a*) 16 V (*b*) 10 V

(*c*) 8 V (*d*) 6 V

2. ***In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.***

(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 and R is also false.

Assertion (*A*) : The quantity L/R possesses the dimension of time.

Reason (*R*) : In order to reduce the rate of increase of current through a solenoid, we should increase the time constant.

3. An alternating current from a source is given by $i = 10 \sin 314\, t$. What is the effective value of current and frequency of source?

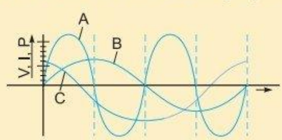
4. Draw a graph to show variation of capacitive-reactance with frequency in an *ac* circuit.

5. (*a*) The peak voltage of an ac supply is 300 V. What is the rms voltage?

(*b*) The rms value of current in an ac circuit is 10 A. What is the peak current? *[NCERT]*

6. Mention the two characteristic properties of the material suitable for making core of a transformer. *[CBSE (AI) 2012]*

7. A device '*X*' is connected to an ac source $V = V_0 \sin \omega t$. The variation of voltage, current and power in one complete cycle is shown in the following figure.



(*i*) Which curve shows power consumption over a full cycle?

(*ii*) Identify the device '*X*'.

8. How does the resistance differ from impedance? With the help of a suitable phasor diagram, obtain an expression for impedance of a series *LCR* circuit, connected to a source $V = V_m \sin \omega t$. *[CBSE 2023 (55/1/1)]*

9. A 15.0 μF capacitor is connected to 220 V, 50 Hz source. Find the capacitive reactance and the rms current.

10. How much current is drawn by the primary coil of a transformer which steps down 220 V to 22 V to operate a device with an impedance of 220 Ω?

11. Define power factor. State the conditions under which it is (*i*) maximum and (*ii*) minimum. *[CBSE Delhi 2010]*

12. When an ac source is connected to an ideal inductor show that the average power supplied by the source over a complete cycle is zero. *[CBSE (Central) 2016]*

13. When an *ac* source is connected to an ideal capacitor, show that the average power supplied by the source over a complete cycle is zero. *[CBSE (North) 2016]*

14. The current flowing through a pure inductor of inductance 2 mH is $i = 15 \cos 300t$ ampere. What is the (*i*) rms and (*ii*) average value of current for a complete cycle? *[CBSE (F) 2011]*

15. In a series *LCR* circuit with an ac source of effective voltage 50 V, frequency $\nu = 50/\pi$ Hz, $R = 300\ \Omega$, $C = 20\ \mu F$ and $L = 1.0$ H. Find the *rms* current in the circuit. *[CBSE (F) 2014]*

16. (*a*) A 60 μF capacitor is connected to a 110 V, 60 Hz *ac* supply. Determine the rms value of current in the circuit.

    (*b*) What is the net power absorbed by the circuit in a complete cycle? *[NCERT]*

17. A series *LCR* circuit with $R = 20\ \Omega$, $L = 1.5$ H and $C = 35\ \mu F$ is connected to a variable frequency 200 V *ac* supply. When the frequency of the supply equals the natural frequency of the circuit, what is the average power transferred to the circuit in one complete cycle? *[NCERT]*

18. You are given three circuit elements *X*, *Y* and *Z*. When the element *X* is connected across an *ac* source of a given voltage, the current and the voltage are in the same phase. When the element *Y* is connected in series with *X* across the source, voltage is ahead of the current in phase by $\pi/4$. But the current is ahead of the voltage in phase by $\pi/4$ when *Z* is connected in series with *X* across the source. Identify the circuit elements *X*, *Y* and *Z*.

    When all the three elements are connected in series across the same source, determine the impedance of the circuit.

    Draw a plot of the current versus the frequency of applied source and mention the significance of this plot.

19. A resistor *R* and an inductor *L* are connected in series to a source $V = V_0 \sin \omega t$. Find the

    (*a*) peak value of the voltage drops across *R* and across *L*,

    (*b*) phase difference between the applied voltage and current. Which of them is ahead? *[CBSE 2020 (55/1/2)]*

20. An ac source $V = V_m \sin \omega t$ connected across an ideal capacitor. Derive the expression for the (*i*) current flowing in the circuit, and (*ii*) rectance of the capacitor. Plot a graph of current *i* versus ωt. *[CBSE 2023 (55/3/1)]*

21. A series combination of an inductor *L*, a capacitor *C* and a resistor *R* is connected across an *ac* source of voltage in a circuit. Obtain an expression for the average power consumed by the circuit. Find power factor for (*i*) purely inductive circuit, and (*ii*) purely resistive circuit. *[CBSE 2023 (55/3/1)]*

22. A resistor of 100 Ω and a capacitor of $100/\pi\ \mu F$ are connected in series to a 220 V, 50 Hz ac supply.

    (*a*) Calculate the current in the circuit.

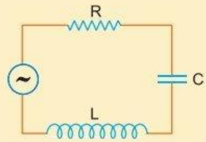
    (*b*) Calculate the (rms) voltage across the resistor and the capacitor. Do you find the algebraic sum of these voltages more than the source voltage? If yes, how do you resolve the paradox? *[CBSE Chennai 2015]*

23. A 100 Ω resistor is connected to a 220 V, 50 Hz ac supply:

    (*a*) What is the rms value of current in the circuit?

    (*b*) What is the net power consumed over a full cycle? *[NCERT]*

24. The figure shows a series *LCR* circuit with $L = 5.0$ H, $C = 80\ \mu$F, $R = 40\ \Omega$ connected to a variable frequency 240 V source. Calculate.



(*i*) The angular frequency of the source which drives the circuit at resonance.

(*ii*) The current at the resonating frequency.

(*iii*) The rms potential drop across the capacitor at resonance. **[*CBSE Delhi 2012*]**

25. (*a*) For a given *ac*, $i = i_m \sin \omega t$, show that the average power dissipated in a resistor *R* over a complete cycle is $\frac{1}{2} i_m^2 R$.

(*b*) A light bulb is rated at 100 W for a 220 V *ac* supply. Calculate the resistance of the bulb. **[*CBSE (AI) 2013*]**

26. Determine the current and quality factor at resonance for a series *LCR* circuit with $L = 1.00$ mH, $C = 1.00$ nF and $R = 100\ \Omega$ connected to an *ac* source having peak voltage of 100 V. **[*CBSE (F) 2011*]**

27. A circuit is set up by connecting inductance $L = 100$ mH, resistor $R = 100\ \Omega$ and a capacitor of reactance $200\ \Omega$ in series. An alternating emf of $150\sqrt{2}$ V, $500/\pi$ Hz is applied across this series combination. Calculate the power dissipated in the resistor. **[*CBSE (F) 2014*]**

28. (*a*) State the condition for resonance to occur in series *LCR ac* circuit and derive an expression for resonant frequency. **[*CBSE Delhi 2010*]**

(*b*) Draw a plot showing the variation of the peak current (i_m) with frequency of the *ac* source used. Define the quality factor *Q* of the circuit.

29. (*a*) Derive the expression for the current flowing in an ideal capacitor and its reactance when connected to an *ac* source of voltage $V = V_0 \sin \omega t$.

(*b*) Draw its phasor diagram.

(*c*) If resistance is added in series to capacitor, what changes will occur in the current flowing in the circuit and phase angle between voltage and current? **[*CBSE Sample Paper 2021*]**

30. A circuit containing a 80 mH inductor and a 60 μF capacitor in series is connected to a 230 V, 50 Hz supply. The resistance of the circuit is negligible.

(*a*) Obtain the current amplitude and rms values.

(*b*) Obtain the rms values of potential drops across each element. **[*NCERT*]**

Answers

1. (*i*) (*a*) (*ii*) (*c*) (*iii*) (*b*) (*iv*) (*a*) (*v*) (*c*) (*vi*) (*d*) (*vii*) (*c*) (*viii*) (*a*)

2. (*b*) **3.** 50 Hz **9.** 212.31 Ω, 1.03 A **10.** 0.1 A, 0.01 A **14.** (*i*) $7.5\sqrt{2}$ A (*ii*) 0

15. 0.1 A **16.** (*a*) 2.49 A (*b*) 0 **17.** 2 kW

21. (*a*) 1.56 A (*b*) 156 V , 156 V

23. (*a*) 2.2 A (*b*) 484 W **24.** (*i*) 50 rads^{-1} (*ii*) 6 A (*iii*) 1500 V **25.** 484 Ω

26. 0.707 A, 10 **27.** 225 W **30.** (*a*) 11.6 A, 8.23 A (*b*) 207 V, 237 V