CHAPTER 05

ELECTROMAGNETIC INDUCTION

Induction may be defined, the operation of discovering and proving general propositions.

"JOHN STUART MILL"

INTRODUCTION

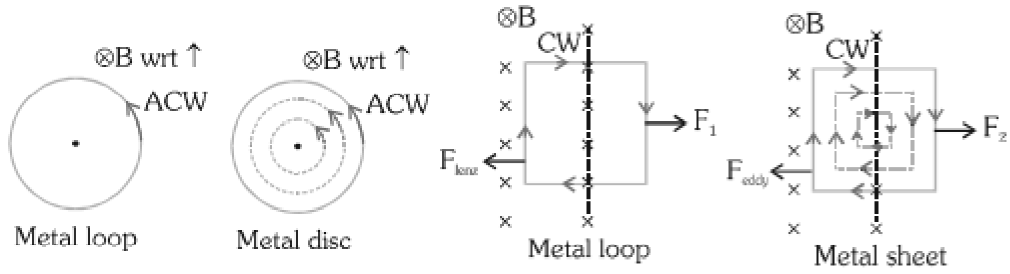
From previous chapters, we know that current produces magnetic field. Is reverse possible i.e. can magnetic field produce electric current ? The answer is 'yes'. It is found that currents were induced in closed coils when subjected to changing magnetic fields.

The phenomenon in which electric current is generated by changing magnetic fields is known as electromagnetic induction. The current so produced is known as induced current.

If current is produced in the circuit, this must be due to some emf produced in the circuit. This emf produced in the circuit. This emf produced as a result of change in magnetic field is known as induced emf.

The phenomenon of electromagnetic induction (EMI) is the basis of working of power generators, dynamos, transformers etc.

Eddy Currents (or Focalt's currents)



($F_1 <<< F_2$)

(i) Eddy currents are basically the induced currents set up inside the body of conductor whenever the magnetic flux linked with it changes.

(ii) Eddy currents tend to follow the path of least resistance inside a conductor. So they from irregularly shaped loops. However, their directions are not random, but guided by Lenz's law.

(iii) Eddy currents have both undesirable effects and practically useful applications.

Applications of eddy currents

(i) Induction furnace
(ii) Electromagnetic damping
(iii) Electric brakes
(iv) Speedometers
(v) Induction motor
(vi) Electromagnetic shielding
(vii) Inductothermy
(viii) Energy meters

ETOOS KEY POINTS

(i) These currents are produced only in closed path within the entire volume and on the surface of metal body. Therefore their measurement is impossible.

(ii) Circulation plane of these currents is always perpendicular to the external field direction.

(iii) Generally resistance of metal bodies is low so magnitude of these currents is very high.

(iv) These currents heat up the metal body and some time body will melt out (Application : Induction furnace)

(v) Due to these induced currents a strong eddy force (or torque) acts on metal body which always apposes the translatory (or rotatory) motion of metal body, according to lenz.

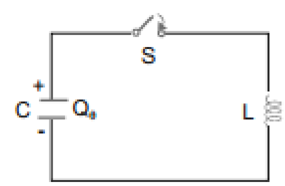
(vi) **Transformer**

Cause : Transformer core is always present in the effect of alternating magnetic field ($B = B_0 \sin\omega t$). Due to this eddy currents are produced in its volume, so a part of magnetic energy of core is wasted as heat.

Remmady : To minimise these losses transformer core should be laminated. with the help of lamination process, circulation path of eddy current is greatly reduced & net resistance of system is greatly increased. So these currents become

LC Oscillations

Consider an LC circuit in which a capacitor is connected to an inductor, as shown in Figure.



Etoos Tips & Formulas

1. **Magnetic Flux :**

$\phi = \vec{B}.\vec{A} = BA\cos\theta$ for uniform $\vec{B}$.

$\phi = \int \vec{B}.d\vec{A}$ = for non uniform $\vec{B}$.

2. **FARADAY'S Laws of Electromagnetic Induction :**

(a) An induced emf is setup whenever the magnetic flux linking that circuit changes.

(b) The magnitude of the induced emf in any circuit is proportional to the rate of change of the magnetic flux linking the circuit, $\varepsilon \propto \frac{d\varphi}{dt}$.

3. **Lenz's Laws :**

The direction of an induced emf is always such as to oppose the cause producing it.

4. **Law of EMI :** $e = -\frac{d\varphi}{dt}$

The negative sign indicates that the induced emf oppose the change of the flux.

5. **EMF Induced in a Straight Conductor in Uniform Magnetic Field :**

$E = BLv\sin\theta$

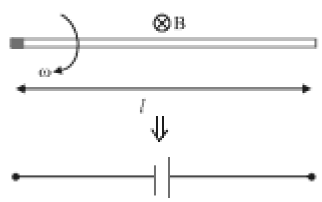
where B = flux density

L = length of the conductor

v = velocity of the conductor

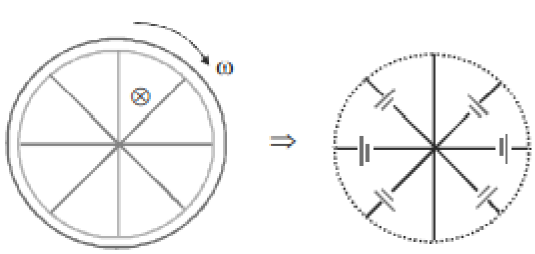
θ = angle between direction of motion of conductor & B.

6. **EMF Induced in a Rod Rotating Perpendicular to Magnetic Field**



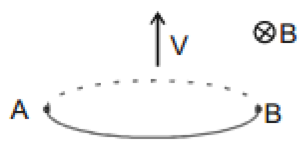
$E = \frac{1}{2}B\omega\ell^2$

For a wheel rotating in a earth magnetic field effective emf induced between the periphery & centre = $\frac{1}{2}B\omega\ell^2$



SOLVED EXAMPLE

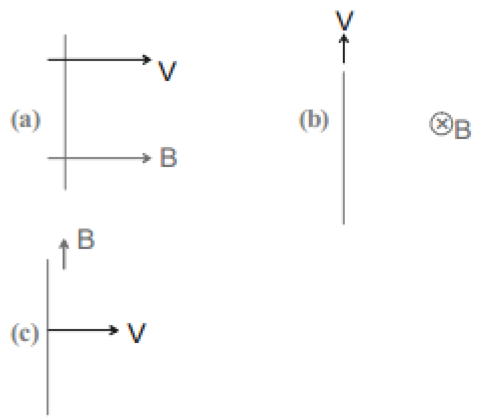
Ex. 1 A circular coil of radius R is moving in a magnetic field **B** with a velocity **v** as shown in the figure.



Find the emf across the diametrically opposite points A and B.

Sol. emf = $BVl_{effective}$ $= 2\,R\,v\,B$

Ex. 2 Find the emf induced in the rod in the following cases. The figures are self explanatory.



Sol. (a) here $\vec{v} \,||\, \vec{B}$ So $\vec{v} \times \vec{B} = 0$

emf = $\vec{\ell} \cdot (\vec{v} \times \vec{B}) = 0$

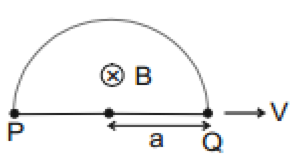
(b) here $\vec{v} \,||\, \vec{\ell}$

So emf = $\vec{\ell} \cdot (\vec{v} \times \vec{B}) = 0$

(c) here $\vec{B} \,||\, \vec{\ell}$

So emf = $\vec{\ell} \cdot (\vec{v} \times \vec{B}) = 0$

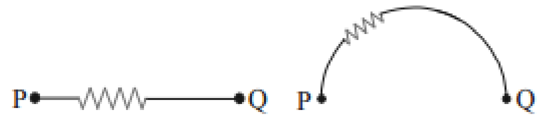
Ex. 3 Find the emf across the points P and Q which are diametrically opposite points of a semicircular closed loop moving in a magnetic field as shown. Also draw the electrical equivalent circuit of each branch.



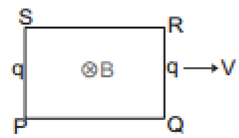
Sol. Here $\vec{v} \,||\, \vec{\ell}$

So emf = $\vec{\ell} \cdot (\vec{v} \times \vec{B}) = 0$

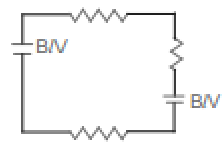
Induced emf = 0



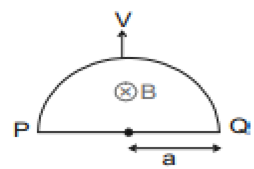
Ex. 4 Figure shows a rectangular loop moving in a uniform magnetic field. Show the electrical equivalence of each branch.



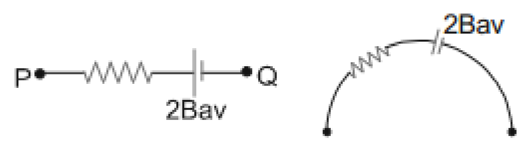
Sol.



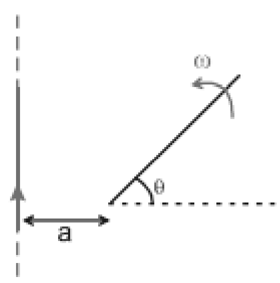
Ex. 5 Find the emf across the points P and Q which are diametrically opposite points of a semicircular closed loop moving in a magnetic field as shown. Also draw the electrical equivalence of each branch.



Sol. Induced emf = 2Bav



Ex. 6 A rod of length l is rotating with an angular speed ω about its one end which is at a distance 'a' from an infinitely long wire carrying current i. Find the emf induced in the rod at the instant shown in the figure.



Exercise # 1 SINGLE OBJECTIVE NEET LEVEL

1. In electromagnetic induction, the induced e.m.f. in a coil is independent of
(A) Change in the flux
(B) Time
(C) Resistance of the circuit
(D) None of the above

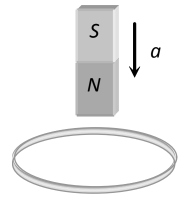
2. Lenz's law is consequence of the law of conservation of
(A) Charge (B) Momentum
(C) Mass (D) Energy

3. In electromagnetic induction, the induced charge in a coil is independent of
(A) Change in the flux
(B) Time
(C) Resistance in the circuit
(D) None of the above

4. The magnetic flux through a circuit of resistance R changes by an amount $\Delta\phi$ in time Δt, Then the total quantity of electric charge Q, which passing during this time through any point of the circuit is given by
(A) $Q = \frac{\Delta\phi}{\Delta t}$ (B) $Q = \frac{\Delta\phi}{\Delta t} \times R$
(C) $Q = -\frac{\Delta\phi}{\Delta t} + R$ (D) $Q = \frac{\Delta\phi}{R}$

5. A cylindrical bar magnet is kept along the axis of a circular coil. If the magnet is rotated about its axis, then
(A) A current will be induced in a coil
(B) No current will be induced in a coil
(C) Only an e.m.f. will be induced in the coil
(D) An e.m.f. and a current both will be induced in the coil

6. A metallic ring is attached with the wall of a room. When the north pole of a magnet is brought near to it, the induced current in the ring will be



(A) First clockwise then anticlockwise
(B) In clockwise direction
(C) In anticlockwise direction
(D) First anticlockwise then clockwise

7. A coil having an area A_0 is placed in a magnetic field which changes from B_0 to $4B_0$ in a time interval *t*. The e.m.f. induced in the coil will be
(A) $\frac{3A_0B_0}{t}$ (B) $\frac{4A_0B_0}{t}$
(C) $\frac{3B_0}{A_0 t}$ (D) $\frac{4B_0}{A_0 t}$

8. The magnetic flux linked with a coil is given by an equation ϕ (in *webers*) = $8t^2 + 3t + 5$. The induced e.m.f. in the coil at the fourth second will be
(A) 16 *units* (B) 39 *units*
(C) 67 *units* (D) 145 *units*

9. The current flowing in two coaxial coils in the same direction. On increasing the distance between the two, the electric current will
(A) Increase
(B) Decrease
(C) Remain unchanged
(D) The information is incomplete

10. A copper ring is held horizontally and a bar magnet is dropped through the ring with its length along the axis of the ring. The acceleration of the falling magnet while it is passing through the ring is
(A) Equal to that due to gravity
(B) Less than that due to gravity
(C) More than that due to gravity
(D) Depends on the diameter of the ring and the length of the magnet

Exercise # 2 SINGLE OBJECTIVE AIIMS LEVEL

1. An inductor coil stores energy U when a current i is passed through it and dissipates heat energy at the rate of P. The time constant of the circuit when this coil is connected across a battery of zero internal resistance is :

(A) $\frac{4U}{P}$ (B) $\frac{U}{P}$

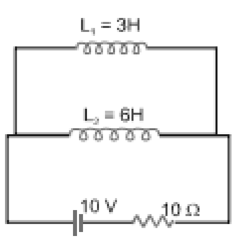
(C) $\frac{2U}{P}$ (D) $\frac{2P}{U}$

2. A metal rod of resistance 20 Ω is fixed along a diameter of conducting ring of radius 0.1 m and lies in x-y plane. There is a magnetic field $\vec{B} = (50T)\hat{k}$. The ring rotates with an angular velocity ω = 20 rad/s about its axis. An external resistance of 10 Ω is connected across the centre of the ring and rim. The current through external resistance is

(A) $\frac{1}{4}$ A (B) $\frac{1}{2}$ A

(C) $\frac{1}{3}$ A (D) zero

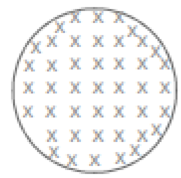
3. Two inductor coils of self inductance 3H and 6H respectively are connected with a resistance 10Ω and a battery 10 V as shown in figure. The ratio of total energy stored at steady state in the inductors to that of heat developed in resistance in 10 seconds at the steady state is(neglect mu
tual inductance between L_1 and L_2):



(A) $\frac{1}{10}$ (B) $\frac{1}{100}$

(C) $\frac{1}{1000}$ (D) 1

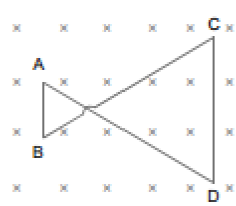
4. A non conducting ring of radius R and mass m having charge q uniformly distributed over its circumference is placed on a rough horizontal surface. A vertical time varying uniform magnetic field B = $4t^2$ is switched on at time t=0. The coefficient of friction between the ring and the table, if the ring starts rotating at t =2 sec, is :



(A) $\frac{4qmR}{g}$ (B) $\frac{2qmR}{g}$

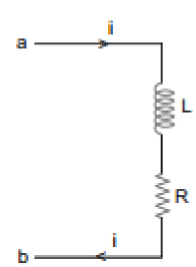
(C) $\frac{8qR}{mg}$ (D) $\frac{qR}{2mg}$

5. A conducting wire frame is placed in a magnetic field which is directed into the paper. The magnetic field is increasing at a constant rate. The directions of induced currents in wires AB and CD are :



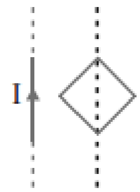
(A) B to A and D to C (B) A to B and C to D
(C) A to B and D to C (D) B to A and C to D

6. When the current in the portion of the circuit shown in the figure is 2A and increasing at the rate of 1 A/s, the measured potential difference $V_a - V_b$ = 8V. However when the current is 2A and decreasing at the rate of 1A/s, the measured potential difference $V_a - V_b$ = 4V. The values of R and L are :



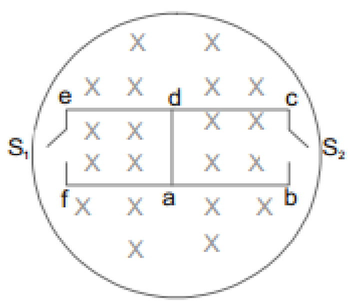
Exercise # 3 PART - 1 MATRIX MATCH COLUMN

1. A square loop of conducting wire is placed symmetrically near a long straight current carrying wire as shown. Match the statements in column-I with the corresponding results in column-II.



Column-I	Column-II
(A) If the magnitude of current I is increased	(P) Current will induce in clockwise direction in the loop
(B) If the magnitude of current I is decreased	(Q) Current will induce in anticlockwise direction in the loop
(C) If the loop is moved away from the wire	(R) wire will attract the loop
(D) If the loop is moved towards the wire	(S) wire will repel the loop
	(T) loop will rotate when current changes.

2. The magnetic field in the cylindrical region shown in figure increases at a constant rate of 10.0 mT/s Each side of the square loop abcd and defa has a length of 2.00 cm and resistance of 2.00 Ω . Correctly match the current in the wire 'ad' in four different situations as listed in column-I with the values given in column-II.



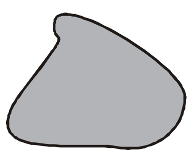
Column-I	Column-II
(A) the switch S_1 is closed but S_2 is open	(P) 5 x 10^{-7} A, d to a
(B) S_1 is open but S_2 is closed	(Q) 5 x 10^{-7} A, a to d
(C) both S_1 and S_2 are open	(R) 2.5 x 10^{-8} A, d to a
(D) both S_1 and S_2 are closed.	(S) 2.5 x 10^{-8} A, a to d
	(T) No current flows

Exercise # 4 PART - 1 PREVIOUS YEAR (NEET/AIPMT)

1. In an inductor of self-inductance L = 2 mH, current changes with time according to relation $i = t^2 e^{-1}$. At what time emf is zero ? [CBSE AIPMT 2001]
(A) 4 s (B) 3 s
(C) 2 s (D) 1 s

2. The magnetic flux through a circuit of resistance R changes by an amount $\Delta\phi$ in a time Δt. Then the total quantity of electric charge q that passes any point in the circuit during the time Δt is represented by [CBSE AIPMT 2004]
(A) $q = \frac{1}{R}\cdot\frac{\Delta\phi}{\Delta t}$ (B) $q = \frac{\Delta\phi}{R}$
(C) $q = \frac{\Delta\phi}{\Delta t}$ (D) $q = R\cdot\frac{\Delta\phi}{\Delta t}$

3. As a result of change in the magnetic flux linked to the closed loop shown in the figure, an emf V volt is induced in the loop. The work done (joule) in taking a charge q coulomb once along the loop is
[CBSE AIPMT 2005]



(A) qV (B) zero
(C) 2 qV (D) $\frac{qV}{2}$

4. Two coils of self-inductances 2 mH and 8 mH are placed so close together that the effective flux in one coil is completely linked with the other. The mutual inductance between these coils is
[CBSE AIPMT 2006]
(A) 10 mH (B) 6 mH
(C) 4 mH (D) 16 mH

5. A long solenoid has 500 turns. When a current of 2 A is passed through it, the resulting magnetic flux linked with each turn of the solenoid is 4×10^{-3} Wb. the self-inductance of the solenoid is
[CBSE AIPMT 2008]
(A) 2.5 H (B) 2 H
(C) 1 H (D) 4 H

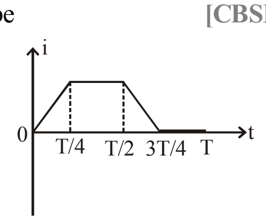
6. A circular disc of radius 0.2 m is placed in ac uniform magnetic field of induction $\frac{1}{\pi}(Wb/m^2)$ in such a way that its axis makes an angle of 60° with B. The magnetic flux linked with the disc is
[CBSE AIPMT 2008]
(A) 0.02 Wb (B) 0.06 Wb
(C) 0.08 Wb (D) 0.01 Wb

7. A conducting circular loop is placed in a uniform magnetic field 0.04 T with its plane perpendicular to the magnetic field. The radius of the loop starts shrinking at 2 mm s^{-1}. The induced emf in the loop when the radius is 2 cm is [CBSE AIPMT 2009]
(A) $3.2\,\pi\,\mu V$ (B) $4.8\,\pi\,\mu V$
(C) $0.8\,\pi\,\mu V$ (D) $1.6\,\pi\,\mu V$

8. A rectangular, a square, a circular and an elliptical loop, all in the x y-plane, are moving out of a uniform magnetic field with a constant velocity, $v = v\hat{i}$. The magnetic field is directed along the during the passage of these loops, out ot the field region, will not remain constant for [CBSE AIPMT 2009]
(A) the rectangular, circular and elliptical loops
(B) the circular and the elliptical loops
(C) only the elliptical loop
(D) any of the four loops

9. A conducting circular loop is placed in a uniform magnetic field, B = 0.025 T with its plane perpendicular to the loop. The radius of the loop is made to shrink at a constant rate of 1 mms^{-1}. The induced emf when the radius is 2 cm, is
[CBSE AIPMT 2010]
(A) $2\,\pi\,\mu V$ (B) $\pi\,\mu V$
(C) $\frac{\pi}{2}\mu V$ (D) $2\,\mu V$

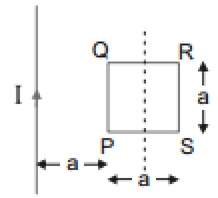
10. The current i in a coil varies with time as shown in the figure. The variation of induced emf with time would be [CBSE AIPMT 2011]



MOCK TEST

STRAIGHT OBJECTIVE TYPE

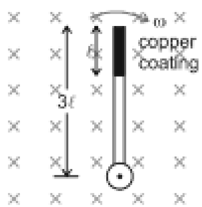
1. In the figure shown a square loop PQRS of side 'a' and resistance 'r' is placed near an infinitely long wire carrying a constant current I. The sides PQ and RS are parallel to the wire. The wire and the loop are in the same plane. The loop is rotated by 180º about an axis parallel to the long wire and passing through the mid points of the side QR and PS. The total amount of charge which passes through any point of the loop during rotation is :



(A) $\frac{\mu_0 Ia}{2\pi r}\ \ell n2$ (B) $\frac{\mu_0 Ia}{\pi r}\ \ell n2$

(C) $\frac{\mu_0 Ia^2}{2\pi r}$ (D) cannot be found because time of rotation not give.

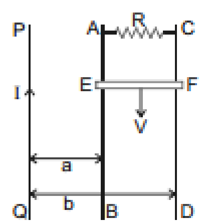
2. A wooden stick of length 3ℓ is rotated about an end with constant angular velocity ω in a uniform magnetic field B perpendicular to the plane of motion. If the upper one third of its length is coated with copper, the potential difference across the whole length of the stick is



(A) $\frac{9B\omega\ell^2}{2}$ (B) $\frac{4B\omega\ell^2}{2}$

(C) $\frac{5B\omega\ell^2}{2}$ (D) $\frac{B\omega\ell^2}{2}$

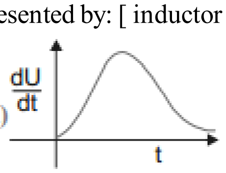
3. PQ is an infinite current carrying conductor. AB and CD are smooth conducting rods on which a conductor EF moves with constant velocity V as shown. The force needed to maintain constant speed of EF is.

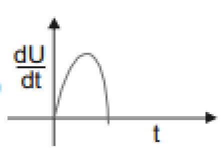


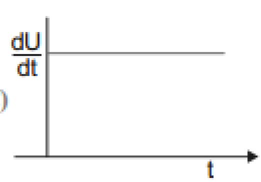
(A) $\frac{1}{VR}\left[\frac{\mu_0 IV}{2\pi}\ell n\left(\frac{b}{a}\right)\right]^2$ (B) $\left[\frac{\mu_0 IV}{2\pi}\ell n\left(\frac{b}{a}\right)\right]\frac{1}{R}$

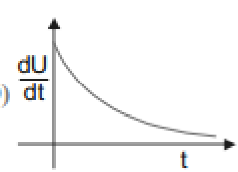
(C) $\left[\frac{\mu_0 IV}{2\pi}\ell n\left(\frac{b}{a}\right)\right]^2\frac{V}{R}$ (D) $\left[\frac{\mu_0 IV}{2\pi}\ell n\left(\frac{b}{a}\right)\right]$

4. Rate of increment of energy in an inductor with time in series LR circuit getting charge with battery of e.m.f. E is best represented by: [inductor has initially zero current]

(A) 

(B) 

(C) 

(D) 

11^{th} Class Modules Chapter Details

Physics
5
Modules

Chemistry
5
Modules

Mathematics
5
Modules

PHYSICS

Module-1

1. Physical World & Measurements
2. Basic Maths & Vector
3. Kinematics

Module-2

1. Law of Motion & Friction
2. Work, Energy & Power

Module-3

1. Motion of system of particles & Rigid Body
2. Gravitation

Module-4

1. Mechanical Properties of Matter
2. Thermal Properties of Matter

Module-5

1. Oscillations
2. Waves

CHEMISTRY

Module-1(PC)

1. Some Basic Conceps of Chemistry
2. Atomic Structure
3. Chemical Equilibrium
4. Ionic Equilibrium

Module-2(PC)

1. Thermodynamics & Thermochemistry
2. Redox Reaction
3. States Of Matter (Gaseous & Liquid)

Module-3(IC)

1. Periodic Table
2. Chemical Bonding
3. Hydrogen & Its Compounds
4. S-Block

Module-4(OC)

1. Nomenclature of Organic Compounds
2. Isomerism
3. General Organic Chemistry

Module-5(OC)

1. Reaction Mechanism
2. Hydrocarbon
3. Aromatic Hydrocarbon
4. Environmental Chemistry & Analysis Of Organic Compounds

BIOLOGY

Module-1

1. Diversity in the Living World
2. Plant Kingdom
3. Animal Kingdom

Module-2

1. Morphology in Flowering Plants
2. Anatomy of Flowering Plants
3. Structural Organization in Animals

Module-3

1. Cell: The Unit of Life
2. Biomolecules
3. Cell Cycle & Cell Division
4. Transport in Plants
5. Mineral Nutrition

Module-4

1. Photosynthesis in Higher Plants
2. Respiration in Plants
3. Plant Growth and Development
4. Digestion & Absorption
5. Breathing & Exchange of Gases

Module-5

1. Body Fluids & Its Circulation
2. Excretory Products & Their Elimination
3. Locomotion & Its Movement
4. Neural Control & Coordination
5. Chemical Coordination and Integration

12th Class Modules Chapter Details

Physics
5
Modules

Chemistry
5
Modules

Mathematics
5
Modules

PHYSICS

Module-1

1. Electrostatics
2. Capacitance

Module-2

1. Current Electricity
2. Magnetic Effect of Current and Magnetism

Module-3

1. Electromagnetic Induction
2. Alternating Current

Module-4

1. Geometrical Optics
2. Wave Optics

Module-5

1. Modern Physics
2. Nuclear Physics
3. Solids & Semiconductor Devices
4. Electromagnetic Waves

CHEMISTRY

Module-1(PC)

1. Solid State
2. Chemical Kinetics
3. Solutions and Colligative Properties

Module-2(PC)

1. Electrochemistry
2. Surface Chemistry

Module-3(IC)

1. P-Block Elements
2. Transition Elements (d & f block)
3. Co-ordination Compound
4. Metallurgy

Module-4(OC)

1. HaloAlkanes & HaloArenes
2. Alcohol, Phenol & Ether
3. Aldehyde, Ketone & Carboxylic Acid

Module-5(OC)

1. Nitrogen & Its Derivatives
2. Biomolecules & Polymers
3. Chemistry in Everyday Life

BIOLOGY

Module-1

1. Reproduction in Organisms
2. Sexual Reproduction in Flowering Plants
3. Human Reproduction
4. Reproductive Health

Module-2

1. Principles of Inheritance and Variation
2. Molecular Basis of Inheritance
3. Evolution

Module-3

1. Human Health and Disease
2. Strategies for Enhancement in Food Production
3. Microbes in Human Welfare

Module-4

1. Biotechnology: Principles and Processes
2. Biotechnology and Its Applications
3. Organisms and Populations

Module-5

1. Ecosystem
2. Biodiversity and Conservation
3. Environmental Issues