FSc Part-II · Punjab Board · English Medium

Second Year Physics

Complete Notes

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FSc Part-I Physics — Punjab Board

CHAPTER 12

Electrostatics

Key Concepts · Definitions · Short & Long Questions · MCQs · Diagrams · Exam Tips

This chapter covers Electrostatics from the 2nd Year (FSc Part-II) Physics syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). It studies Coulomb's law, the electric field and field lines, electric flux and Gauss's law, electric potential, capacitors and the energy stored in them. These notes are prepared by freebooks.pk.

Electrostatics is the study of electric charges at rest and the forces, fields and potentials they produce. The same electric force holds atoms and molecules together, so it underlies all of matter.

Learning Objectives

- State and apply Coulomb's law.
- Describe the electric field and electric field lines.
- Define electric flux and state Gauss's law with its applications.
- Define electric potential and relate it to the electric field.
- Explain capacitance and the parallel-plate capacitor.
- Find the energy stored in a capacitor and describe charging through a resistor.

Key Concepts

Coulomb's Law

Coulomb's law states that the electrostatic force between two point charges is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance between them, $F = (1/4 \pi \epsilon_0) q_1 q_2 / r^2$, where ϵ_0 is the permittivity of free space. The force acts along the line joining the charges: like charges repel and unlike charges attract. In a medium other than vacuum the force is reduced by a factor equal to the relative permittivity (dielectric constant) of the medium.

Electric Field and Field Lines

A charge sets up an electric field in the space around it, and any other charge placed in that field experiences a force. The electric field intensity E at a point is the force per unit positive charge placed at that point, $E = F/q$, a vector directed away from a positive charge and towards a negative one. Electric field lines are imaginary lines drawn so that the tangent at any point gives the direction of the field; they start on positive charges and end on negative charges, and where they are closer together the field is stronger.

Electric Flux and Gauss's Law

Electric flux is the number of field lines passing through an area, given by $\Phi = E \cdot A = E A \cos \theta$, where θ is the angle between the field and the normal to the surface. Gauss's law states that the total electric flux through any closed surface is $1/\epsilon_0$ times the total charge enclosed by the surface, $\Phi = Q/\epsilon_0$. Gauss's law makes it easy to find the field for symmetrical charge distributions; for example the field between two oppositely charged parallel plates is $E = \sigma/\epsilon_0$, where σ is the surface charge density.

Electric Potential

The electric potential at a point is the work done in bringing a unit positive charge from infinity to that point against the electric field, V = W/q, measured in volts. The potential due to a point charge q at distance r is V = (1/4 pi epsilon0) q/r. The electric field is related to the potential by E = -delta V / delta r, that is, the field points in the direction of decreasing potential and equals the negative of the potential gradient. A convenient small unit of energy is the electron volt (eV), the energy gained by an electron moving through a potential difference of one volt (1 eV = 1.6 x 10^-19 J).

Capacitors and Capacitance

A capacitor is a device that stores electric charge and energy; it consists of two conductors separated by an insulator. The capacitance is the charge stored per unit potential difference, C = Q/V, measured in farads. For a parallel-plate capacitor with plate area A and separation d, C = epsilon0 A / d in vacuum. Placing a dielectric (insulator) between the plates increases the capacitance, because the dielectric becomes polarised and partly cancels the field; the capacitance increases by the factor of the dielectric constant.

Energy Stored and Charging a Capacitor

A charged capacitor stores energy in the electric field between its plates, given by E = (1/2) C V^2 = (1/2) Q V = Q^2 / (2C). When a capacitor is charged through a resistor R, the charge does not build up instantly but grows gradually; the product RC is called the time constant and measures how quickly the capacitor charges or discharges. After a time equal to the time constant the capacitor reaches about 63% of its final charge.

Important Definitions

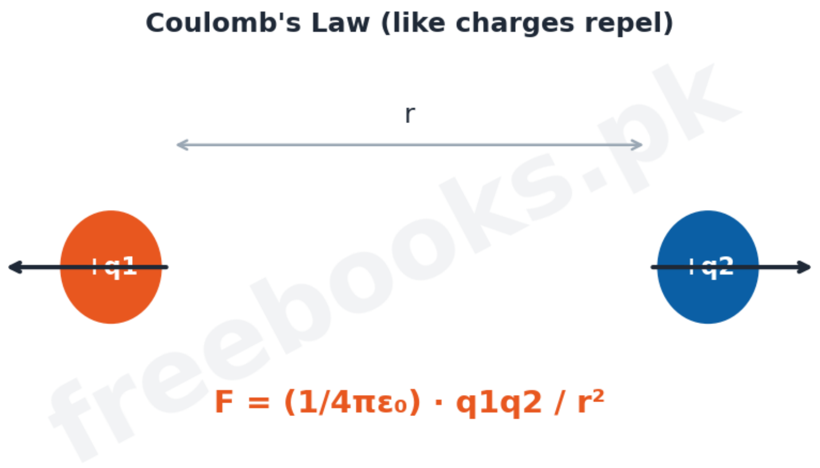
Term	Definition
Coulomb's law	The force between two point charges is proportional to q1q2 and inversely to r^2.
Electric field intensity	The force per unit positive charge at a point, E = F/q.
Electric field lines	Imaginary lines whose tangent gives the direction of the field.
Electric flux	The number of field lines through an area, Phi = E A cos theta.
Gauss's law	Total flux through a closed surface = Q/epsilon0.
Electric potential	Work done in bringing a unit positive charge from infinity to a point, V = W/q.
Capacitance	The charge stored per unit potential difference, C = Q/V.
Time constant	The product RC, the time for a capacitor to reach ~63% of final charge.

Formulas & Rules

Item	Fact
Coulomb's law	F = (1/4 pi epsilon0) q1 q2 / r^2
Electric field intensity	E = F/q
Electric flux	Phi = E A cos theta
Gauss's law	Phi = Q / epsilon0
Field between parallel plates	E = sigma / epsilon0
Potential due to point charge	V = (1/4 pi epsilon0) q / r
Parallel-plate capacitance	C = epsilon0 A / d
Energy stored	E = (1/2) C V^2

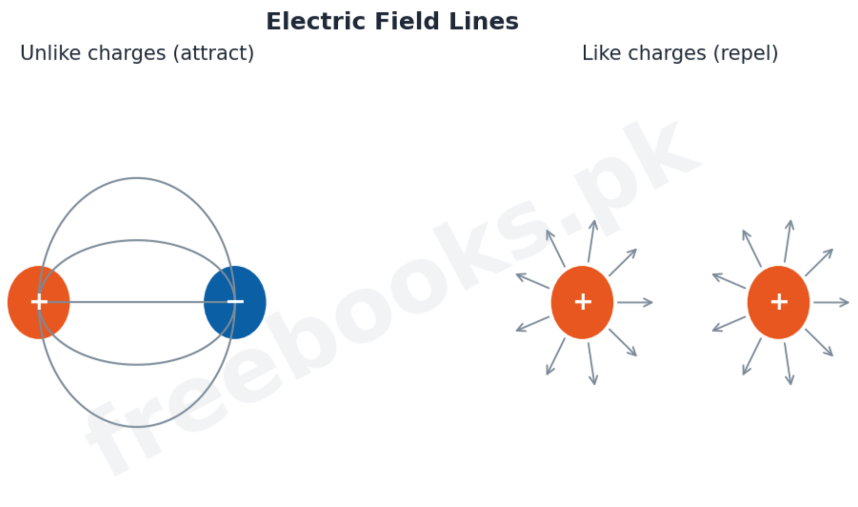
Diagrams & Illustrations

Coulomb's law: two point charges with the electrostatic forces of repulsion acting along the line joining them, separated by a distance r.



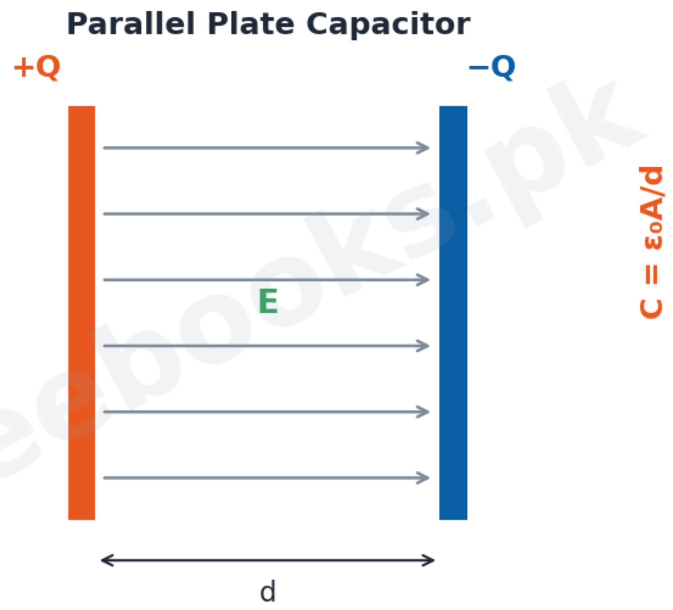
Coulomb's law

Electric field lines: field lines for a pair of unlike charges (attracting) and a pair of like charges (repelling).



Electric field lines

Parallel plate capacitor: a parallel-plate capacitor with charges +Q and -Q on the plates, a uniform field E between them and separation d.



Parallel plate capacitor

Solved Examples & Numericals

Coulomb's law

Two charges of 2 x 10^-6 C and 3 x 10^-6 C are 0.1 m apart. F = 9x10^9 x (2x10^-6 x 3x10^-6)/(0.1)^2 = 9x10^9 x 6x10^-12 / 0.01 = 5.4 N.

Electric field

A charge of 5 x 10^-6 C experiences a force of 0.2 N in a field. The field intensity is E = F/q = 0.2 / 5x10^-6 = 4 x 10^4 N/C.

Capacitance

A capacitor stores 6 x 10^-6 C at 3 V. Its capacitance is C = Q/V = 6x10^-6 / 3 = 2 x 10^-6 F = 2 microfarad.

Energy stored

A 2 microfarad capacitor charged to 100 V stores E = (1/2) C V^2 = 0.5 x 2x10^-6 x (100)^2 = 0.01 J.

Short Questions & Answers

Q1. State Coulomb's law.
Ans. The force between two point charges is proportional to the product of the charges and inversely proportional to the square of the distance, F = (1/4 pi epsilon0) q1 q2 / r^2.

Q2. Define electric field intensity.
Ans. The force per unit positive charge placed at a point, E = F/q; a vector quantity.

Q3. State Gauss's law.
Ans. The total electric flux through any closed surface equals 1/epsilon0 times the charge enclosed.

Q4. What is electric potential?
Ans. The work done in bringing a unit positive charge from infinity to a point against the field, V = W/q.

Q5. Define capacitance.
Ans. The charge stored per unit potential difference, C = Q/V, measured in farads.

Q6. How does a dielectric affect capacitance?
Ans. It increases the capacitance, because the polarised dielectric partly cancels the field between the plates.

Long Questions & Answers

Q1: State Coulomb's law and explain the electric field and electric field lines.

Coulomb's law describes the force between two stationary point charges. It states that this electrostatic force is directly proportional to the product of the magnitudes of the two charges and inversely proportional to the square of the distance between them, so that F = (1/4 pi epsilon0) q1 q2 / r^2, where epsilon0 is the permittivity of free space. The force acts along the straight line joining the charges; like charges (both positive or both negative) repel one another while unlike charges attract. To explain how one charge exerts a force on another without touching it, we use the idea of an electric field: every charge sets up a field in the space around it, and a second charge placed in this field feels a force. The strength of the field, called the electric field intensity, is the force per unit positive charge, E = F/q, and points away from a positive charge and towards a negative one. The field can be pictured using electric field lines, imaginary lines drawn so that the tangent to a line at any point gives the direction of the field there. These lines begin on positive charges and end on negative charges, never cross, and are drawn closer together where the field is stronger, giving a clear picture of both the direction and the strength of the field.

Q2: Define electric flux and state Gauss's law, and use it to find the field between parallel plates.

Electric flux measures the number of electric field lines passing through a given area. For a uniform field E passing through a flat area A, the flux is Phi = E . A = E A cos theta, where theta is the angle between the field lines and the normal (perpendicular) to the surface; the flux is greatest when the field is perpendicular to the surface and zero when it is parallel. Gauss's law relates the total flux through a closed surface to the charge inside it: the total electric flux through any closed surface equals 1/epsilon0 times the net charge enclosed by that surface, Phi = Q/epsilon0. This law is very powerful for charge distributions with symmetry, because it lets us find the field without adding up the contributions of individual charges. Applying it to two large, oppositely charged parallel plates, we find that the field between the plates is uniform and equal to E = sigma/epsilon0, where sigma is the surface charge density (charge per unit area) on the plates. This uniform field is the basis of the parallel-plate capacitor.

Q3: Explain capacitance, derive the capacitance of a parallel-plate capacitor and find the energy stored in a capacitor.

A capacitor is a device for storing electric charge and energy, made of two conductors separated by an insulator. When connected to a battery, equal and opposite charges appear on the two conductors and a potential difference is set up between them. The capacitance is defined as the amount of charge stored per unit potential difference, C = Q/V, and is measured in farads. For a parallel-plate capacitor the plates have area A and are separated by a distance d; the uniform field between them is E = sigma/epsilon0 and the potential difference is V = E d, which on combining with C = Q/V gives the capacitance in vacuum as C = epsilon0 A / d. Thus the capacitance is larger for bigger plates and smaller separation. If a dielectric is inserted between the plates it becomes polarised and reduces the field, so the same charge is held at a lower voltage and the capacitance rises by the dielectric constant. A charged capacitor stores energy in the electric field between its plates; by considering the work done in charging it, this energy is found to be E = (1/2) C V^2, which can also be written as (1/2) Q V or Q^2/(2C). This stored energy is released when the capacitor is discharged.

MCQs with Answers

1. The force between two point charges varies as:
(a) 1/r   (b) 1/r^2   (c) r   (d) r^2
Correct Answer: (b) 1/r^2. Inversely as r^2.

2. Electric field intensity is:

(a) q/F   (b) F/q   (c) F q   (d) F + q

Correct Answer: (b) F/q. E = F/q.

3. The SI unit of capacitance is the:

(a) volt   (b) coulomb   (c) farad   (d) joule

Correct Answer: (c) farad. The farad.

4. Electric flux is given by:

(a) E A cos theta   (b) E/A   (c) A/E   (d) E A tan theta

Correct Answer: (a) E A cos theta. Phi = E A cos theta.

5. Gauss's law gives total flux =

(a) Q epsilon0   (b) Q/epsilon0   (c) epsilon0/Q   (d) Q^2

Correct Answer: (b) Q/epsilon0. Q/epsilon0.

6. The field inside a hollow charged sphere is:

(a) maximum   (b) zero   (c) infinite   (d) negative

Correct Answer: (b) zero. Zero (field-free region).

7. Electric potential is measured in:

(a) newton   (b) volt   (c) farad   (d) tesla

Correct Answer: (b) volt. Volt.

8. The capacitance of a parallel-plate capacitor is:

(a) epsilon0 A/d   (b) epsilon0 d/A   (c) A d/epsilon0   (d) epsilon0 A d

Correct Answer: (a) epsilon0 A/d. C = epsilon0 A/d.

9. Energy stored in a capacitor is:

(a) C V   (b) (1/2) C V^2   (c) C V^2   (d) Q/V

Correct Answer: (b) (1/2) C V^2. (1/2) C V^2.

10. A dielectric between the plates ___ the capacitance:

(a) decreases   (b) increases   (c) zeroes   (d) reverses

Correct Answer: (b) increases. Increases it.

Quick Revision Summary

- Coulomb's law: F = (1/4 pi epsilon0) q1 q2 / r^2; like repel, unlike attract.
- Electric field E = F/q; field lines start on + and end on - charges.
- Electric flux Phi = E A cos theta; Gauss's law: flux = Q/epsilon0.
- Field between parallel plates E = sigma/epsilon0; inside hollow sphere E = 0.
- Potential V = W/q; point charge V = (1/4 pi epsilon0) q/r; E = -delta V/delta r.
- Capacitor: C = Q/V; parallel plate C = epsilon0 A/d; energy = (1/2) C V^2; time constant RC. Notes by freebooks.pk.

Exam Tips

- Write Coulomb's law with the constant 1/4 pi epsilon0.
- Remember E = F/q and its direction rules.
- State Gauss's law as flux = Q/epsilon0.

- Learn E = sigma/epsilon0 for parallel plates.
- Memorise C = epsilon0 A/d and energy = (1/2) C V^2.
- Know that a dielectric increases capacitance and that RC is the time constant.

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FSc Part-I Physics — Punjab Board

CHAPTER 13

Current Electricity

Key Concepts · Definitions · Short & Long Questions · MCQs · Diagrams · Exam Tips

This chapter covers Current Electricity from the 2nd Year (FSc Part-II) Physics syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). It studies electric current and its effects, Ohm's law, resistivity and its temperature dependence, electrical power, electromotive force and potential difference, Kirchhoff's rules, the Wheatstone bridge and the potentiometer. These notes are prepared by freebooks.pk.

Current electricity deals with charges in motion. Every electrical appliance, from a torch to a computer, works because charges flow through circuits, so understanding current, resistance and the rules that govern circuits is essential.

Learning Objectives

- Define electric current and describe its direction and effects.
- State and apply Ohm's law.
- Explain resistivity and how resistance depends on temperature.
- Calculate electrical power and power dissipation in resistors.
- Distinguish electromotive force (EMF) from potential difference.
- State and apply Kirchhoff's two rules.
- Explain the Wheatstone bridge and the potentiometer.

Key Concepts

Electric Current and Its Direction

Electric current is the rate of flow of electric charge through a conductor, $I = Q/t$, and its SI unit is the ampere (A); one ampere is one coulomb per second. In a metallic conductor the current is carried by free electrons, which drift from the negative to the positive terminal. However, by convention the direction of conventional current is taken as the direction in which positive charge would flow, that is, from the positive to the negative terminal in the external circuit, opposite to the electron flow. When a steady current flows, the same charge passes every cross-section of the wire in a given time.

Sources of Current and Effects of Current

A source of current, such as a cell, battery or generator, maintains a potential difference that keeps charges flowing round a circuit by converting some other form of energy (chemical, mechanical, and so on) into electrical energy. An electric current always produces three observable effects: a heating effect (the wire warms up, used in heaters and bulbs), a magnetic effect (a current sets up a magnetic field around it, used in electromagnets and motors) and a chemical effect (a current passing through a solution can cause chemical changes, used in electrolysis and electroplating).

Ohm's Law

Ohm's law states that the current passing through a conductor is directly proportional to the potential difference across its ends, provided the physical conditions such as temperature remain constant. This gives V = I R, where R is the resistance of the conductor, measured in ohms. Conductors that obey Ohm's law are called ohmic (for example metals at constant temperature), while devices such as diodes and filament bulbs are non-ohmic because their resistance changes with the applied voltage or temperature.

Resistivity and Its Temperature Dependence

The resistance of a wire depends on its material, length and thickness: R = rho L / A, where L is the length, A the cross-sectional area and rho the resistivity, a property of the material. A long thin wire has more resistance than a short thick one of the same material. Resistivity itself depends on temperature: for metals the resistivity, and hence the resistance, increases with temperature because the atoms vibrate more and obstruct the electrons, while for semiconductors the resistance decreases with rising temperature. The fractional change per degree is described by the temperature coefficient of resistance.

Electrical Power and Power Dissipation

Electrical power is the rate at which electrical energy is converted into other forms, P = V I. Using Ohm's law this can also be written as P = I^2 R or P = V^2 / R. When current flows through a resistor, electrical energy is dissipated as heat at the rate P = I^2 R; this is why wires and resistors warm up. The energy consumed in time t is W = P t, commonly measured in kilowatt-hours for domestic bills.

Electromotive Force and Potential Difference

The electromotive force (EMF) of a source is the energy it supplies to each unit of charge that passes through it, and equals the potential difference across its terminals when no current flows. Every real source has some internal resistance r, so when it drives a current I the terminal potential difference is less than the EMF: V = E - I r, where E is the EMF. Thus EMF is the total energy per unit charge provided by the source, while potential difference is the energy per unit charge delivered to the external circuit.

Kirchhoff's Rules

Kirchhoff's rules allow the analysis of complicated circuits that cannot be reduced by simple series and parallel combinations. The first rule (junction or current rule) states that the sum of currents flowing into a junction equals the sum flowing out, which is a statement of conservation of charge. The second rule (loop or voltage rule) states that around any closed loop the sum of the EMFs equals the sum of the potential drops (IR terms), which is a statement of conservation of energy. Applying these two rules gives a set of equations that can be solved for the unknown currents.

Wheatstone Bridge and Potentiometer

The Wheatstone bridge is a circuit of four resistances arranged in a diamond with a galvanometer across the middle; it is used to measure an unknown resistance accurately. When the bridge is balanced no current flows through the galvanometer and the resistances satisfy R1/R2 = R3/R4, from which the unknown value is found. The potentiometer is a device that measures potential difference (and EMF) without drawing current from the source at balance, by comparing it against the potential drop along a uniform resistance wire; because it draws no current at balance, it gives more accurate results than a voltmeter.

Important Definitions

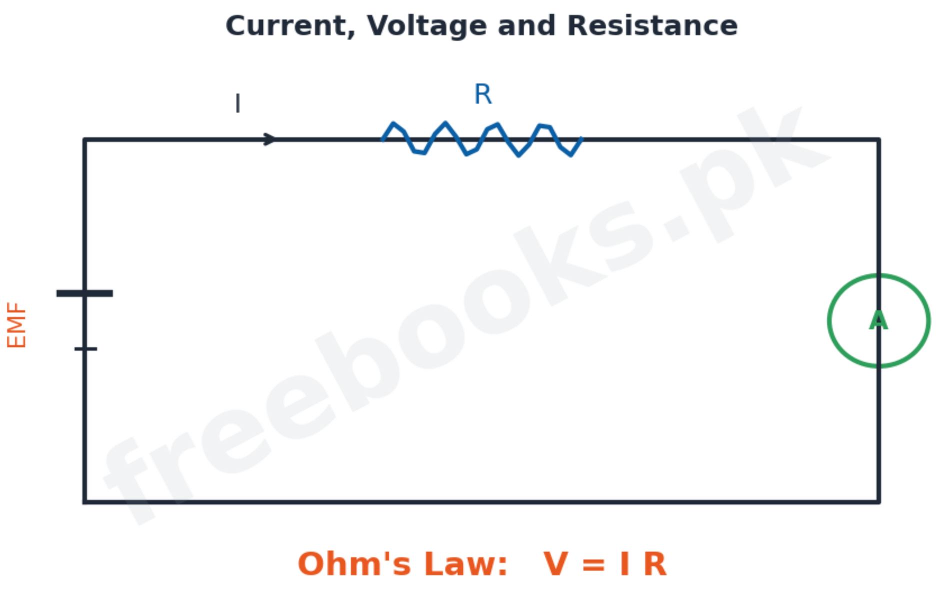
Term	Definition
Electric current	The rate of flow of electric charge, I = Q/t, unit ampere.
Conventional current	The direction in which positive charge would flow, opposite to electron flow.
Ohm's law	Current is proportional to potential difference at constant temperature, V = I R.
Resistivity	A property of a material giving resistance, R = rho L/A.
Electrical power	The rate of conversion of electrical energy, P = V I.
Electromotive force	The energy supplied by a source per unit charge, E.
Kirchhoff's first rule	The sum of currents into a junction equals the sum leaving it.
Wheatstone bridge	A four-resistor circuit used to measure an unknown resistance.

Formulas & Rules

Item	Fact
Electric current	I = Q / t
Ohm's law	V = I R
Resistance of a wire	R = rho L / A
Electrical power	P = V I = I^2 R = V^2 / R
Terminal voltage	V = E - I r
Kirchhoff junction rule	sum I(in) = sum I(out)
Kirchhoff loop rule	sum EMF = sum I R
Wheatstone balance	R1/R2 = R3/R4

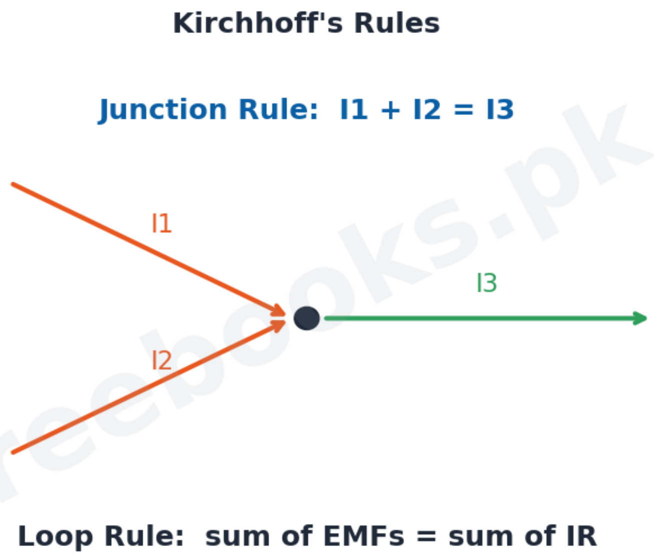
Diagrams & Illustrations

Ohm's law circuit: a simple circuit with a source of EMF, a resistor R and an ammeter, illustrating current I and the relation V = I R.



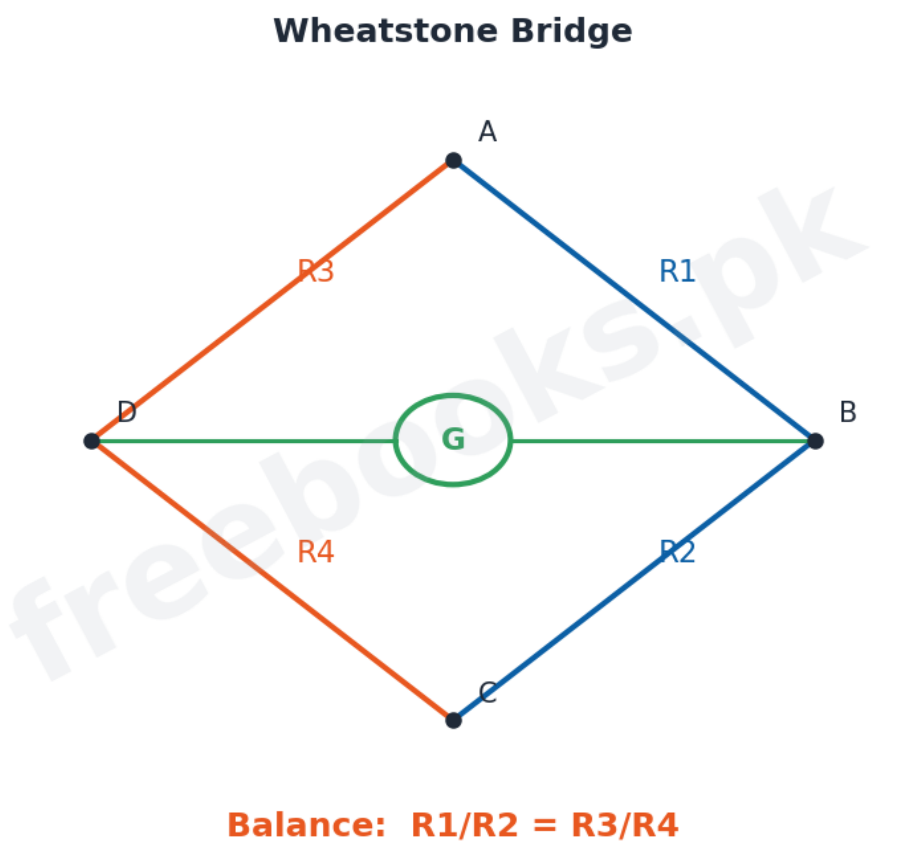
Ohm's law circuit

Kirchhoff's rules: a junction showing currents I1 and I2 entering and I3 leaving, with the junction rule I1 + I2 = I3 and the loop rule.



Kirchhoff's rules

Wheatstone bridge: a Wheatstone bridge of four resistances R1, R2, R3, R4 with a galvanometer, balanced when R1/R2 = R3/R4.



Wheatstone bridge

Solved Examples & Numericals

Ohm's law

A resistor of 20 ohm carries a current of 0.5 A. The potential difference across it is V = I R = 0.5 x 20 = 10 V.

Resistance of a wire

A wire has resistivity 1.7 x 10^-8 ohm m, length 2 m and area 1 x 10^-6 m^2. R = rho L/A = 1.7x10^-8 x 2 / 1x10^-6 = 0.034 ohm.

Electrical power

A bulb draws 0.5 A at 220 V. Its power is P = V I = 220 x 0.5 = 110 W.

Terminal voltage

A cell of EMF 1.5 V and internal resistance 0.5 ohm drives a current of 0.6 A. Its terminal voltage is V = E - I r = 1.5 - 0.6 x 0.5 = 1.2 V.

Wheatstone bridge

In a balanced bridge R1 = 10 ohm, R2 = 20 ohm, R3 = 15 ohm. Then R4 = R3 R2 / R1 = 15 x 20 / 10 = 30 ohm.

Short Questions & Answers

Q1. Define electric current and give its unit.

Ans. The rate of flow of electric charge, I = Q/t; its SI unit is the ampere.

Q2. What is conventional current?

Ans. The direction in which positive charge would flow, taken from + to - in the external circuit, opposite to electron flow.

Q3. State Ohm's law.

Ans. At constant temperature the current through a conductor is directly proportional to the potential difference across it, V = I R.

Q4. How does resistance depend on length and area?

Ans. R = rho L/A: resistance increases with length and decreases with cross-sectional area.

Q5. Differentiate EMF and potential difference.

Ans. EMF is the total energy per unit charge supplied by a source; potential difference is the energy per unit charge delivered to the external circuit, V = E - I r.

Q6. State Kirchhoff's first rule.

Ans. The sum of currents entering a junction equals the sum of currents leaving it (conservation of charge).

Q7. What is the balance condition of a Wheatstone bridge?

Ans. When no current flows through the galvanometer, R1/R2 = R3/R4.

Long Questions & Answers

Q1: State Ohm's law and explain resistivity and its dependence on temperature.

Ohm's law states that the electric current passing through a conductor is directly proportional to the potential difference applied across its ends, provided the temperature and other physical conditions remain constant; this gives the relation V = I R, where the constant of proportionality R is the resistance of the conductor, measured in ohms. Conductors that obey this law, such as metals kept at constant temperature, are called ohmic, whereas devices whose resistance changes with voltage or temperature, such as diodes and filament lamps, are non-ohmic. The resistance of a particular conductor depends not only on the material but also on its dimensions, R = rho L/A, where L is its length, A its cross-sectional area and rho the resistivity, which is a characteristic property of the material. A long, thin wire therefore has greater resistance than a short, thick wire of the same material. Resistivity itself varies with temperature: in metals the free electrons are obstructed more as the atoms vibrate more vigorously at higher temperatures, so the resistivity and hence the resistance increase with temperature; in semiconductors, by contrast, more charge carriers become available as the temperature rises, so their resistance decreases. This temperature behaviour is described by the temperature coefficient of resistance.

Q2: Distinguish between electromotive force and potential difference, and derive the relation for terminal voltage.

The electromotive force (EMF) of a source such as a cell or generator is the amount of energy that the source gives to each unit of charge that passes through it, and it is measured by the potential difference across the terminals of the source when it is not delivering any current. The potential difference, on the other hand, is the energy delivered to each unit of charge as it moves through a part of the external circuit. The two differ because every real source has some internal resistance r of its own. When the source drives a current I round a circuit, part of the energy per unit charge is used up inside the source itself against this internal resistance, an amount equal to I r. Consequently the potential difference available at the terminals, called the terminal voltage, is less than the EMF by this amount, giving $V = E - I r$, where E is the EMF. When no current flows ($I = 0$) the terminal voltage equals the EMF, and the larger the current drawn, the more the terminal voltage falls below the EMF. This explains why the voltage of a battery drops when it supplies a heavy current.

Q3: State Kirchhoff's rules and describe how the Wheatstone bridge is used to find an unknown resistance.

Kirchhoff gave two rules that make it possible to analyse circuits too complicated to be reduced by simple series and parallel combinations. His first rule, the junction (or current) rule, states that the sum of the currents flowing into any junction of a circuit is equal to the sum of the currents flowing out of it; this is a direct consequence of the conservation of electric charge. His second rule, the loop (or voltage) rule, states that around any closed loop in a circuit the algebraic sum of the electromotive forces equals the algebraic sum of the products of current and resistance (the IR drops); this expresses the conservation of energy. By writing down these equations for the junctions and loops of a network and solving them, the unknown currents can be found. An important application is the Wheatstone bridge, which consists of four resistances arranged in a diamond shape with a sensitive galvanometer connected between the two middle points and a battery across the other two. The values of the resistances are adjusted until no current flows through the galvanometer; the bridge is then said to be balanced, and the four resistances satisfy $R1/R2 = R3/R4$. If three of the resistances are known, the fourth (the unknown) can be calculated accurately from this relation. Because the measurement is made at balance, when no current flows through the galvanometer, it does not depend on the exact sensitivity of the galvanometer and is therefore very precise.

MCQs with Answers

1. The SI unit of electric current is the:

(a) volt (b) ampere (c) ohm (d) coulomb

Correct Answer: (b) ampere. The ampere.

2. Conventional current flows from:

(a) - to + outside (b) + to - outside (c) electron direction (d) no direction

Correct Answer: (b) + to - outside. From + to - in the external circuit.

3. Ohm's law is:

(a) V = I/R (b) V = I R (c) I = V R (d) R = V I

Correct Answer: (b) V = I R. V = I R.

4. The resistance of a wire is:

(a) rho A/L (b) rho L/A (c) L/(rho A) (d) rho L A

Correct Answer: (b) rho L/A. R = rho L/A.

5. With rising temperature the resistance of a metal:

(a) decreases (b) increases (c) stays same (d) becomes zero

Correct Answer: (b) increases. Increases.

6. Electrical power is:

(a) V/I (b) V I (c) I/V (d) V + I

Correct Answer: (b) V I. P = V I.

7. Terminal voltage is:

(a) E + I r (b) E - I r (c) I r - E (d) E I

Correct Answer: (b) E - I r. V = E - I r.

8. Kirchhoff's first rule is based on conservation of:

(a) energy (b) charge (c) mass (d) momentum

Correct Answer: (b) charge. Charge.

9. Kirchhoff's loop rule is based on conservation of:

(a) charge (b) energy (c) mass (d) current

Correct Answer: (b) energy. Energy.

10. A balanced Wheatstone bridge satisfies:

(a) R1 R2 = R3 R4 (b) R1/R2 = R3/R4 (c) R1 + R2 = R3 + R4 (d) R1 - R2 = R3 - R4

Correct Answer: (b) R1/R2 = R3/R4. R1/R2 = R3/R4.

Quick Revision Summary

- Current I = Q/t (ampere); conventional current opposite to electron flow.
- Effects of current: heating, magnetic, chemical. Sources maintain potential difference.
- Ohm's law: V = I R (ohmic conductors); R = rho L/A.
- Metals: resistance rises with temperature; semiconductors: falls.
- Power: P = V I = I^2 R = V^2/R; terminal voltage V = E - I r.
- Kirchhoff: junction (charge), loop (energy). Wheatstone balance R1/R2 = R3/R4; potentiometer draws no current at balance. Notes by freebooks.pk.

Exam Tips

- State Ohm's law with the 'constant temperature' condition.
- Learn R = rho L/A and the temperature behaviour of metals vs semiconductors.
- Know all three forms of power: V I, I^2 R, V^2/R.
- Clearly distinguish EMF from terminal voltage (V = E - I r).

- Remember Kirchhoff's rules and what each conserves.
- Memorise the Wheatstone balance condition.

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FSc Part-I Physics — Punjab Board

CHAPTER 14

Electromagnetism

Key Concepts · Definitions · Short & Long Questions · MCQs · Diagrams · Exam Tips

This chapter covers Electromagnetism from the 2nd Year (FSc Part-II) Physics syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). It studies the magnetic field produced by a current, the force on a current-carrying conductor and on a moving charge, magnetic flux and flux density, Ampere's law, the field of a solenoid, e/m of the electron, the cathode ray oscilloscope, torque on a coil and the galvanometer. These notes are prepared by freebooks.pk.

Electromagnetism links electricity and magnetism: a current produces a magnetic field, and a magnetic field exerts a force on a current. These ideas run the motors, meters and measuring instruments we use every day.

Learning Objectives

- Describe the magnetic field produced by a current.
- Find the force on a current-carrying conductor and on a moving charge.
- Define magnetic flux and flux density.
- State Ampere's law and find the field of a solenoid.
- Describe the determination of e/m of an electron and the cathode ray oscilloscope.
- Find the torque on a current-carrying coil and explain the galvanometer.

Key Concepts

Magnetic Field of a Current

Oersted discovered that an electric current produces a magnetic field in the space around it: a compass needle placed near a current-carrying wire is deflected. The magnetic field around a long straight wire forms concentric circles whose direction is given by the right-hand rule (grip the wire with the thumb pointing along the current and the fingers curl in the direction of the field). This link between current and magnetism is the basis of all electromagnetism.

Force on a Current-Carrying Conductor

When a conductor carrying a current is placed in a magnetic field it experiences a force. The magnitude of this force is F = B I L sin theta, where B is the magnetic flux density, I the current, L the length of the conductor in the field and theta the angle between the conductor and the field. The force is greatest when the conductor is perpendicular to the field and zero when it is parallel. Its direction is given by the right-hand rule and is perpendicular to both the current and the field; this force drives electric motors.

Magnetic Flux and Flux Density

The magnetic flux density B (also called the magnetic induction) measures the strength of a magnetic field and has the unit tesla (T). The magnetic flux through an area is the product of the flux density and the area perpendicular to the field, Phi = B . A = B A cos theta, and is measured in webers. Flux density can be thought of as the number of field lines passing through unit area, so a stronger field has more closely packed lines.

Ampere's Law and the Solenoid

Ampere's law provides a way of finding the magnetic field of symmetrical current distributions; it states that the sum of the product of the field and length element around a closed path equals mu0 times the current enclosed. Applying it to a long solenoid (a closely wound coil), the field inside is uniform and directed along the axis, B = mu0 n I, where n is the number of turns per unit length and I the current. A solenoid therefore behaves like a bar magnet and is the basis of the electromagnet.

Force on a Moving Charge

A charge moving through a magnetic field also experiences a force, F = q v B sin theta, where q is the charge, v its speed and theta the angle between the velocity and the field. The force is perpendicular to both the velocity and the field, so it changes the direction of motion but not the speed; a charged particle moving at right angles to a uniform field therefore travels in a circle. This principle is used in devices that control and measure charged particles.

Motion of a Charge in Electric and Magnetic Fields; e/m of the Electron

In an electric field a charge experiences a force qE along the field, while in a magnetic field it experiences the force q v B perpendicular to its motion. By passing a beam of electrons through known electric and magnetic fields and balancing or measuring their deflection, the ratio of the charge to the mass of the electron, e/m, can be determined. This measurement, first made by J. J. Thomson, was an important step in establishing the properties of the electron.

Cathode Ray Oscilloscope

The cathode ray oscilloscope (CRO) is an instrument that displays how a voltage varies with time on a screen. An electron gun produces a fine beam of electrons which is deflected by voltages applied to two pairs of plates (horizontal and vertical) before striking a fluorescent screen, where it makes a bright spot. By feeding the signal to the vertical plates and a time-base to the horizontal plates, the CRO traces the waveform of the signal and can measure voltage, time and frequency.

Torque on a Coil and the Galvanometer

A current-carrying coil placed in a magnetic field experiences a torque that tends to rotate it, given by torque = B I N A, where N is the number of turns and A the area of the coil. This turning effect is used in the galvanometer, a sensitive instrument that detects and measures small currents: the coil rotates against a spring until the torque is balanced, and a pointer shows the current. A galvanometer can be converted into an ammeter by connecting a low resistance (shunt) in parallel, or into a voltmeter by connecting a high resistance in series.

Important Definitions

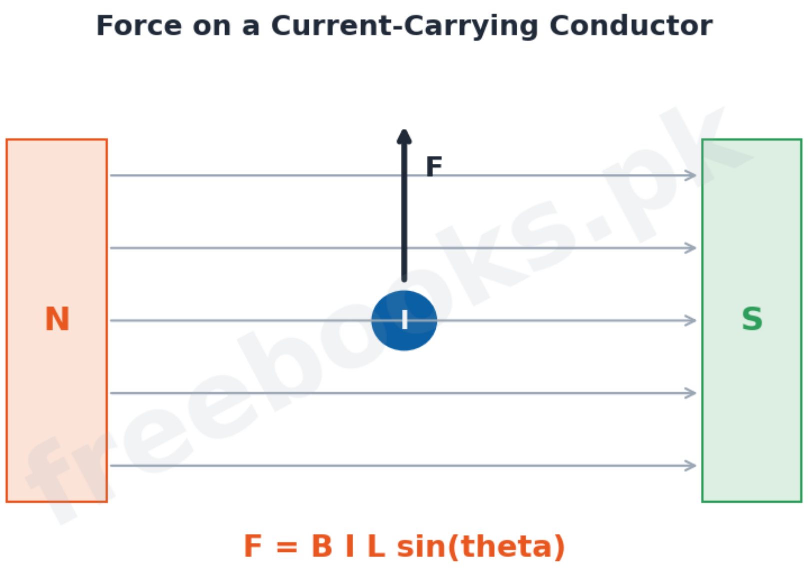
Term	Definition
Magnetic flux density	The strength of a magnetic field, B, measured in tesla.
Magnetic flux	The product of flux density and perpendicular area, Phi = B A cos theta.
Ampere's law	The sum of B times length around a closed path = mu0 times the current enclosed.
Tesla	The SI unit of magnetic flux density.
Force on a conductor	F = B I L sin theta on a current in a field.
Force on a moving charge	F = q v B sin theta on a charge moving in a field.
e/m of electron	The ratio of the charge to the mass of the electron.
Galvanometer	A sensitive instrument that detects and measures small currents.

Formulas & Rules

Item	Fact
Force on a conductor	F = B I L sin theta
Force on a moving charge	F = q v B sin theta
Magnetic flux	Phi = B A cos theta
Field of a solenoid	B = mu0 n I
Torque on a coil	torque = B I N A
Ammeter from galvanometer	low shunt resistance in parallel
Voltmeter from galvanometer	high resistance in series

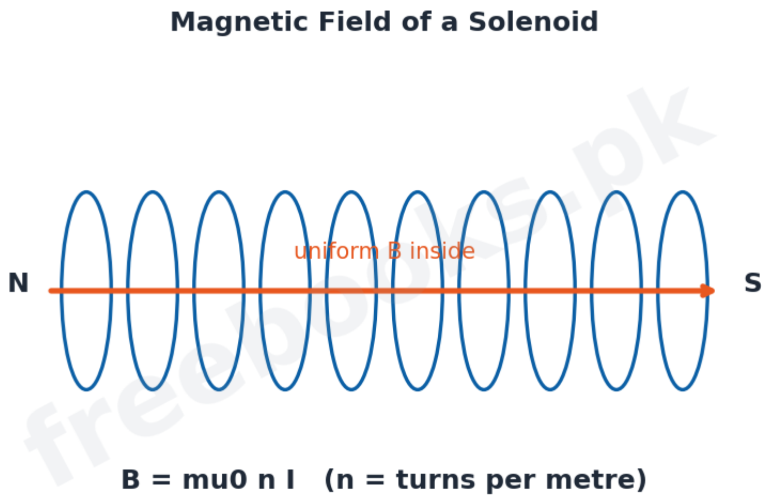
Diagrams & Illustrations

Force on a conductor: a current-carrying conductor between the poles of a magnet, experiencing a force F = B I L sin theta perpendicular to both the current and the field.



Force on a conductor

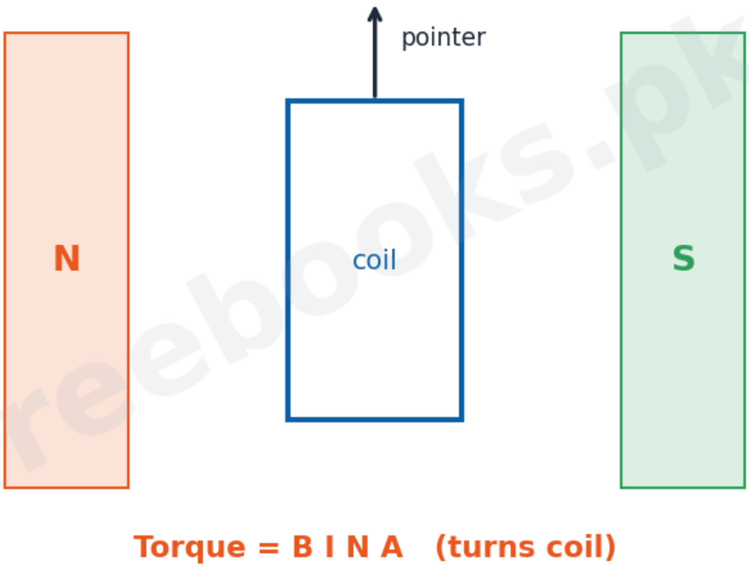
Magnetic field of a solenoid: a solenoid carrying a current with a uniform magnetic field along its axis, B = mu0 n I, behaving like a bar magnet.



Magnetic field of a solenoid

Galvanometer: a coil between the poles of a magnet experiencing a torque B I N A that rotates it against a spring, the principle of the galvanometer.

Galvanometer / Torque on a Coil



Galvanometer

Solved Examples & Numericals

Force on a conductor

A wire of length 0.2 m carrying 5 A lies perpendicular to a field of 0.4 T. F = B I L = 0.4 x 5 x 0.2 = 0.4 N.

Force on a moving charge

An electron (q = 1.6x10^-19 C) moves at 2x10^6 m/s perpendicular to a 0.5 T field. F = q v B = 1.6x10^-19 x 2x10^6 x 0.5 = 1.6x10^-13 N.

Solenoid field

A solenoid has 1000 turns per metre and carries 2 A. B = mu0 n I = 4 pi x 10^-7 x 1000 x 2 = 2.5x10^-3 T.

Torque on a coil

A coil of 50 turns and area 0.01 m^2 carries 0.2 A in a 0.3 T field. Torque = B I N A = 0.3 x 0.2 x 50 x 0.01 = 0.03 N m.

Short Questions & Answers

Q1. What did Oersted discover?
Ans. That an electric current produces a magnetic field around it, deflecting a nearby compass needle.

Q2. Write the force on a current-carrying conductor.

Ans. F = B I L sin theta, perpendicular to both the current and the field.

Q3. Define magnetic flux density.

Ans. The strength of a magnetic field, B, measured in tesla; flux per unit perpendicular area.

Q4. Write the field inside a solenoid.

Ans. B = mu0 n I, where n is the number of turns per unit length and I the current.

Q5. Why does a magnetic force not change a charge's speed?

Ans. Because it acts perpendicular to the velocity, so it changes only the direction of motion, not the speed.

Q6. How is a galvanometer converted into an ammeter?

Ans. By connecting a low resistance (shunt) in parallel with it.

Long Questions & Answers

Q1: Describe the force on a current-carrying conductor in a magnetic field and explain how it depends on the quantities involved.

When a conductor carrying an electric current is placed in a magnetic field, the moving charges in the conductor experience forces, and their combined effect is a force on the whole conductor. Experiment shows that the magnitude of this force is F = B I L sin theta, where B is the magnetic flux density of the field, I is the current in the conductor, L is the length of the conductor lying in the field and theta is the angle between the direction of the current and the direction of the field. The force is therefore directly proportional to the flux density, the current and the length, and depends on the orientation through sin theta: it is a maximum when the conductor is perpendicular to the field (theta = 90 degrees) and zero when it is parallel to the field (theta = 0). The direction of the force is perpendicular to the plane containing both the current and the field and is found using the right-hand rule. This force is the operating principle of the electric motor, in which a current-carrying coil in a magnetic field is made to rotate, and of moving-coil meters.

Q2: State Ampere's law and use it to describe the magnetic field of a solenoid, and explain its uses.

Ampere's law is a general relation for the magnetic field produced by currents; it states that when we take the sum of the product of the magnetic field and the small length element along any closed path, the result equals mu0 (the permeability of free space) times the total current enclosed by that path. This law is especially useful for current distributions that have symmetry, because it lets us find the field without adding up the contributions of each part of the current. Applying it to a long solenoid, which is a wire wound into a large number of closely spaced turns, shows that the magnetic field inside the solenoid is uniform, directed along the axis, and given by B = mu0 n I, where n is the number of turns per unit length and I the current; the field outside a long solenoid is very weak. A solenoid therefore behaves like a bar magnet, with a north pole at one end and a south pole at the other, and forms the basis of the electromagnet. Electromagnets made from solenoids are used in relays, electric bells, cranes for lifting scrap iron and in many other devices, and the strength of the field can be controlled simply by changing the current.

Q3: Explain the torque on a current-carrying coil and describe how a galvanometer works and is adapted into an ammeter and voltmeter.

When a coil carrying a current is placed in a magnetic field, the two sides of the coil that are perpendicular to the field carry currents in opposite directions and therefore experience equal and opposite forces; these forces form a couple that produces a torque tending to rotate the coil. The magnitude of this torque is torque = B I N A, where B is the flux density, I the current, N the number of turns and A the area of the coil, so a coil with many turns and a large area gives a large turning effect. This is the principle of the moving-coil galvanometer, a sensitive instrument used to detect and measure small currents: the coil is pivoted between the poles of a magnet and rotates until the magnetic torque is balanced by the restoring torque of a spring, and a pointer attached to the coil moves over a scale to indicate the current. A galvanometer can be adapted to measure larger currents by connecting a small resistance, called a shunt, in parallel with it so that most of the current bypasses the coil; it then acts as an ammeter. It can be adapted to measure potential difference by connecting a high resistance in series with it, so that only a small current flows for a given voltage; it then acts as a voltmeter. In this way a single basic instrument becomes the heart of the multi-purpose AVO meter.

MCQs with Answers

1. A current produces around it a:
(a) gravitational field (b) magnetic field (c) sound field (d) no field
Correct Answer: (b) magnetic field. A magnetic field (Oersted).

2. The force on a conductor is:
(a) B I L sin theta (b) B I L tan theta (c) B/(I L) (d) I L / B
Correct Answer: (a) B I L sin theta. F = B I L sin theta.

3. The SI unit of magnetic flux density is the:
(a) weber (b) tesla (c) henry (d) farad
Correct Answer: (b) tesla. The tesla.

4. Magnetic flux is:
(a) B A cos theta (b) B/A (c) A/B (d) B A tan theta
Correct Answer: (a) B A cos theta. Phi = B A cos theta.

5. The field inside a long solenoid is:
(a) zero (b) mu0 n I (c) mu0 I/n (d) n I/mu0
Correct Answer: (b) mu0 n I. B = mu0 n I.

6. The force on a moving charge is:
(a) q v B sin theta (b) q/vB (c) vB/q (d) q + v + B
Correct Answer: (a) q v B sin theta. F = q v B sin theta.

7. A magnetic force on a charge changes its:

(a) speed (b) direction (c) mass (d) charge
Correct Answer: (b) direction. Direction only.

8. The torque on a coil is:
(a) B I N A (b) B I/N A (c) N A/B I (d) B/(I N A)
Correct Answer: (a) B I N A. torque = B I N A.

9. A galvanometer becomes an ammeter with a:
(a) high series R (b) low parallel shunt (c) capacitor (d) diode
Correct Answer: (b) low parallel shunt. Low shunt in parallel.

10. A galvanometer becomes a voltmeter with a:
(a) low parallel R (b) high series R (c) shunt (d) inductor
Correct Answer: (b) high series R. High resistance in series.

Quick Revision Summary

- Oersted: current produces a magnetic field (right-hand rule).
- Force on conductor F = B I L sin theta; drives motors.
- Flux density B (tesla); flux Phi = B A cos theta (weber).
- Ampere's law -> solenoid field B = mu0 n I (like a bar magnet).
- Force on moving charge F = q v B sin theta (perpendicular; circular path).
- Torque on coil = B I N A; galvanometer -> ammeter (shunt) or voltmeter (series R). Notes by freebooks.pk.

Exam Tips

- Remember Oersted's discovery links current and magnetism.
- Learn F = B I L sin theta and F = q v B sin theta and when each is maximum/zero.
- State units: tesla (B) and weber (flux).
- Memorise B = mu0 n I for a solenoid.
- Torque on a coil = B I N A.
- Know how a galvanometer is converted to an ammeter and a voltmeter.

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CHAPTER 15

Electromagnetic Induction

Key Concepts · Definitions · Short & Long Questions · MCQs · Diagrams · Exam Tips

This chapter covers Electromagnetic Induction from the 2nd Year (FSc Part-II) Physics syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). It studies induced EMF, motional EMF, Faraday's law, Lenz's law, mutual and self induction, energy stored in an inductor, the A.C. and D.C. generators, the D.C. motor, back EMF and the transformer. These notes are prepared by freebooks.pk.

Electromagnetic induction is the reverse of electromagnetism: a changing magnetic field produces an electric current. This single idea gives us generators, transformers and the entire electrical power supply.

Learning Objectives

- Explain how a changing magnetic flux induces an EMF.
- Derive and use the expression for motional EMF.
- State Faraday's law and Lenz's law.
- Explain mutual and self induction and energy stored in an inductor.
- Describe the A.C. and D.C. generators and the D.C. motor with back EMF.
- Explain the working of a transformer.

Key Concepts

Induced EMF and Induced Current

Faraday found that whenever the magnetic flux linking a coil changes, an electromotive force is set up in the coil, and if the circuit is closed an induced current flows. The change of flux can be produced by moving a magnet towards or away from the coil, by moving the coil, or by changing the current in a nearby coil. No EMF is induced while the flux is steady; an EMF appears only while the flux is changing. This is the phenomenon of electromagnetic induction.

Motional EMF

When a straight conductor of length L moves with speed v at right angles to a magnetic field of flux density B, the free charges in it experience a force and an EMF is induced across its ends, given by EMF = v B L. This motional EMF arises because the moving conductor sweeps through magnetic flux; it is the basis of the electric generator, in which conductors are moved through a magnetic field to generate electricity.

Faraday's Law

Faraday's law of electromagnetic induction states that the magnitude of the induced EMF is equal to the rate of change of magnetic flux linkage, EMF = -N (delta Phi / delta t), where N is the number of turns and Phi the flux through each turn. The faster the flux changes, or the more turns the coil has, the greater the induced EMF. The minus sign indicates the direction of the induced EMF, which is given by Lenz's law.

Lenz's Law

Lenz's law states that the direction of the induced current is always such as to oppose the change that produces it. For example, when a north pole is pushed towards a coil the induced current flows so as to make the near face of the coil a north pole, which repels the approaching magnet and opposes its motion. Lenz's law is a direct consequence of the conservation of energy, because the work done against this opposition is what appears as electrical energy.

Mutual and Self Induction

Mutual induction occurs when a changing current in one coil induces an EMF in a neighbouring coil because the changing flux of the first coil links the second; this is the principle of the transformer. Self induction occurs when a changing current in a coil induces an EMF in the same coil that opposes the change of current. The property of a coil to oppose changes in current is called its inductance L, measured in henries; a coil with inductance is called an inductor.

Energy Stored in an Inductor

Because an inductor opposes changes in the current through it, work has to be done to establish a current, and this energy is stored in the magnetic field of the inductor. The energy stored is $E = (1/2) L I^2$, where L is the inductance and I the final current. This stored magnetic energy is released when the current is switched off, which is why breaking an inductive circuit can produce a spark.

Generators and the D.C. Motor

A generator converts mechanical energy into electrical energy using electromagnetic induction: a coil is rotated in a magnetic field so that the flux through it changes continuously, inducing an EMF. In the A.C. generator the coil is connected to slip rings and the output is alternating; in the D.C. generator a split-ring commutator reverses the connections each half turn so that the output is direct. The D.C. motor is the reverse device: it uses the force on a current-carrying coil in a magnetic field to convert electrical energy into mechanical rotation.

Back EMF and the Transformer

As the coil of a running motor rotates it also acts as a generator and produces an EMF that opposes the applied voltage; this is called the back EMF, and it limits the current drawn by the motor. The transformer is a device that changes the size of an alternating voltage using mutual induction between two coils wound on a common iron core. The voltages are related to the numbers of turns by $V_s/V_p = N_s/N_p$: a step-up transformer has more turns on the secondary and raises the voltage, while a step-down transformer has fewer and lowers it. Transformers make the efficient transmission of electrical power possible.

Important Definitions

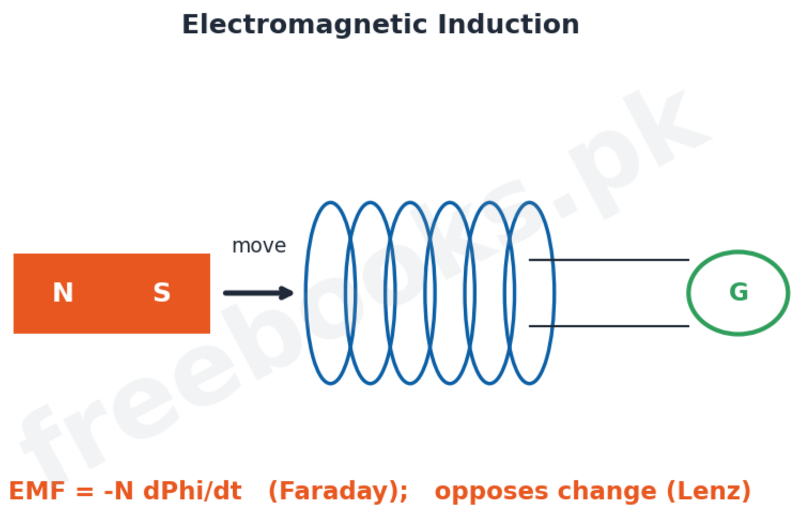
Term	Definition
Electromagnetic induction	The production of an EMF by a changing magnetic flux.
Motional EMF	The EMF induced in a conductor moving through a field, EMF = v B L.
Faraday's law	Induced EMF = rate of change of flux linkage, EMF = -N delta Phi/delta t.
Lenz's law	The induced current opposes the change that produces it.
Mutual induction	EMF induced in one coil by a changing current in a neighbouring coil.
Self induction	EMF induced in a coil by a change of its own current.
Inductance	The property of a coil to oppose changes in current, unit henry.
Transformer	A device that changes an alternating voltage using mutual induction.

Formulas & Rules

Item	Fact
Motional EMF	EMF = v B L
Faraday's law	EMF = -N (delta Phi / delta t)
Energy in an inductor	E = (1/2) L I^2
Transformer relation	Vs/Vp = Ns/Np
Ideal transformer power	Vp Ip = Vs Is

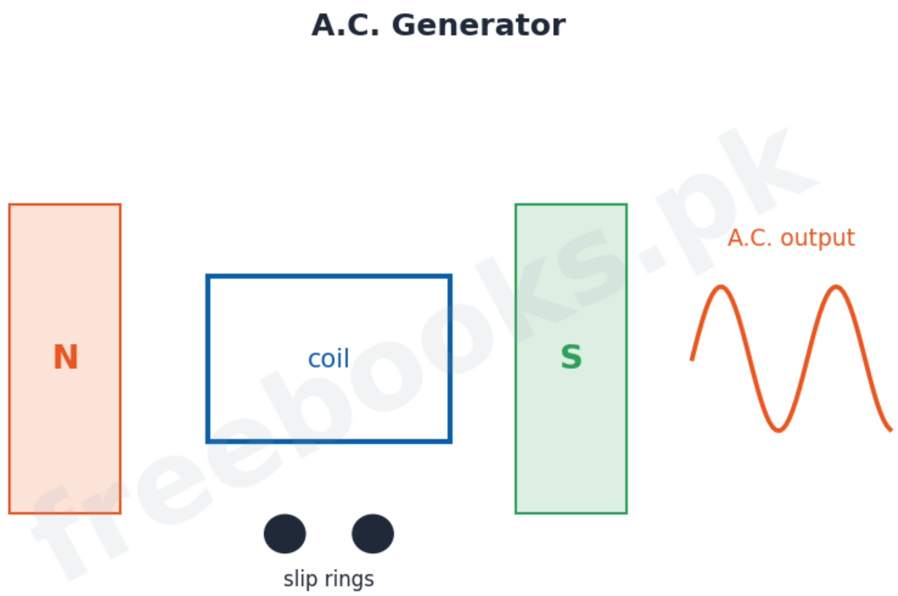
Diagrams & Illustrations

Electromagnetic induction: a bar magnet moved towards a coil connected to a galvanometer, inducing a current whose direction opposes the change (Faraday's and Lenz's laws).



Electromagnetic induction

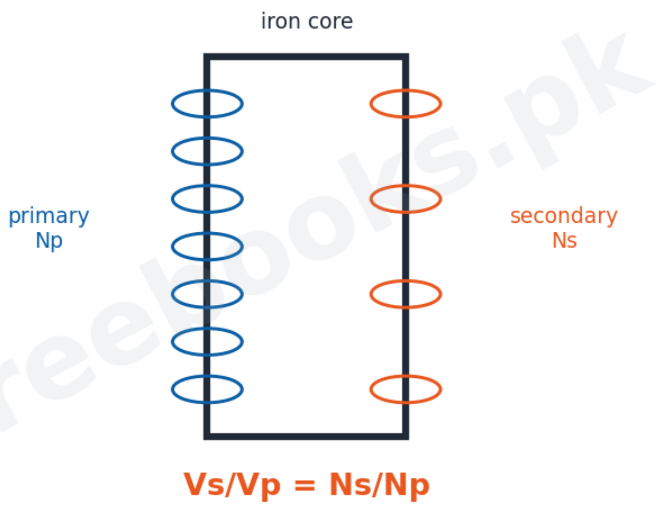
A.C. generator: a coil rotating between magnetic poles with slip rings, producing an alternating output voltage.



A.C. generator

Transformer: primary and secondary coils wound on a common iron core, with Vs/Vp = Ns/Np.

Transformer



Transformer

Solved Examples & Numericals

Motional EMF

A rod 0.5 m long moves at 4 m/s perpendicular to a 0.2 T field. EMF = v B L = 4 x 0.2 x 0.5 = 0.4 V.

Faraday's law

A coil of 100 turns has its flux changing by 2x10^-3 Wb in 0.1 s. EMF = N delta Phi/delta t = 100 x 2x10^-3 / 0.1 = 2 V.

Energy in an inductor

An inductor of 0.5 H carries 2 A. Energy stored = (1/2) L I^2 = 0.5 x 0.5 x 4 = 1 J.

Transformer

A transformer has Np = 100, Ns = 500 and Vp = 220 V. Then Vs = Vp x Ns/Np = 220 x 5 = 1100 V (step-up).

Short Questions & Answers

Q1. What is electromagnetic induction?
Ans. The production of an EMF (and current, if the circuit is closed) by a changing magnetic flux.

Q2. Write the expression for motional EMF.
Ans. EMF = v B L for a conductor of length L moving at speed v perpendicular to a field B.

Q3. State Faraday's law.

Ans. The induced EMF equals the rate of change of magnetic flux linkage, EMF = -N delta Phi/delta t.

Q4. State Lenz's law.

Ans. The induced current always flows in a direction that opposes the change producing it (conservation of energy).

Q5. What is self induction?

Ans. The induction of an EMF in a coil by a change of its own current, opposing that change.

Q6. Write the transformer turns relation.

Ans. Vs/Vp = Ns/Np, relating the voltages to the numbers of turns.

Long Questions & Answers

Q1: State Faraday's law and Lenz's law and explain how they describe electromagnetic induction.

Electromagnetic induction is the production of an electromotive force whenever the magnetic flux linking a circuit changes. Faraday's law gives the size of this induced EMF: it states that the magnitude of the induced EMF is equal to the rate of change of the magnetic flux linkage of the coil, EMF = -N (delta Phi / delta t), where N is the number of turns in the coil and Phi is the flux threading each turn. Thus the induced EMF is large when the flux changes rapidly and when the coil has many turns, and it is zero when the flux is steady. Lenz's law gives the direction of the induced effect: it states that the induced current always flows in such a direction as to oppose the very change that is producing it, which is the reason for the minus sign in Faraday's law. For instance, when the north pole of a magnet is pushed towards a coil, the induced current makes the near face of the coil into a north pole so as to repel the magnet and oppose its approach; if the magnet is pulled away, the induced current reverses so as to attract it and oppose its withdrawal. Lenz's law is really a statement of the conservation of energy, because the mechanical work done against this opposition is exactly what is converted into electrical energy in the coil.

Q2: Describe the construction and working of an A.C. generator.

An alternating-current generator converts mechanical energy into electrical energy by electromagnetic induction. It consists of a coil of many turns of wire, called the armature, which is free to rotate in the magnetic field produced by a permanent magnet or electromagnet. The two ends of the coil are connected to two separate slip rings, against which carbon brushes press to carry the current to the external circuit. When the coil is rotated (by a turbine, engine or other prime mover), the magnetic flux passing through it changes continuously: as the coil turns, the flux linkage rises and falls, so by Faraday's law an EMF is induced in it. During one half of each revolution the flux is increasing and the induced EMF acts one way, and during the other half the flux is decreasing and the EMF reverses, so the output is an alternating voltage that rises and falls in the shape of a sine curve, reversing its direction twice in every complete rotation. The slip rings keep each end of the coil permanently connected to the same brush, so the alternating nature of the current is delivered unchanged to the circuit. This is the principle used in the huge generators of power stations that supply mains electricity.

Q3: Explain the working of a transformer and state how it changes voltage, and why it is used in power transmission.

A transformer is a device that increases or decreases the size of an alternating voltage by means of mutual induction. It consists of two coils, a primary and a secondary, wound on a common core of soft iron. When an alternating voltage is applied to the primary coil, it drives an alternating current that sets up a continually changing magnetic flux in the iron core; the core guides almost all of this flux through the secondary coil, so a changing flux links the secondary and, by Faraday's law, induces an alternating EMF in it. Because the same flux links each turn of both coils, the induced voltages are proportional to the numbers of turns, giving the relation Vs/Vp = Ns/Np, where the subscripts p and s refer to the primary and secondary. If the secondary has more turns than the primary it is a step-up transformer and raises the voltage; if it has fewer, it is a step-down transformer and lowers the voltage. In an ideal transformer no energy is lost, so the power on the two sides is equal, Vp Ip = Vs Is, which means that stepping the voltage up steps the current down and vice versa. Transformers are essential in the transmission of electrical power: electricity is generated at moderate voltage, stepped up to a very high voltage for transmission over long distances (which greatly reduces the current and hence the energy wasted as heat in the cables), and then stepped down again to safe values for use in homes and factories.

MCQs with Answers

1. An EMF is induced in a coil only when the flux is:
(a) steady (b) zero (c) changing (d) maximum
Correct Answer: (c) changing. Changing.

2. Motional EMF is:
(a) v B L (b) B L/v (c) v/BL (d) B/vL
Correct Answer: (a) v B L. EMF = v B L.

3. Faraday's law gives EMF equal to the rate of change of:
(a) current (b) charge (c) flux linkage (d) resistance
Correct Answer: (c) flux linkage. Flux linkage.

4. Lenz's law is a consequence of conservation of:
(a) charge (b) energy (c) mass (d) momentum
Correct Answer: (b) energy. Energy.

5. The unit of inductance is the:
(a) tesla (b) henry (c) weber (d) farad
Correct Answer: (b) henry. The henry.

6. Energy stored in an inductor is:
(a) (1/2) L I^2 (b) L I (c) (1/2) L I (d) L I^2
Correct Answer: (a) (1/2) L I^2. (1/2) L I^2.

7. An A.C. generator uses:

(a) a commutator (b) slip rings (c) a battery (d) a diode

Correct Answer: (b) slip rings. Slip rings.

8. A split-ring commutator is used in a:

(a) A.C. generator (b) D.C. generator (c) transformer (d) voltmeter

Correct Answer: (b) D.C. generator. D.C. generator.

9. The transformer works on:

(a) self induction only (b) mutual induction (c) electrostatics (d) resistance

Correct Answer: (b) mutual induction. Mutual induction.

10. A step-up transformer has more turns on the:

(a) primary (b) secondary (c) core (d) brush

Correct Answer: (b) secondary. Secondary.

Quick Revision Summary

- Induction: changing flux induces EMF (and current if circuit closed).
- Motional EMF = v B L; Faraday: EMF = -N delta Phi/delta t.
- Lenz's law: induced current opposes the change (energy conservation).
- Mutual/self induction; inductance L (henry); energy = (1/2) L I^2.
- A.C. generator (slip rings) vs D.C. generator (commutator); motor has back EMF.
- Transformer: Vs/Vp = Ns/Np; Vp Ip = Vs Is; used in power transmission. Notes by freebooks.pk.

Exam Tips

- Stress that only a changing flux induces an EMF.
- Learn EMF = v B L and Faraday's law EMF = -N delta Phi/delta t.
- State Lenz's law and link it to energy conservation.
- Remember energy in an inductor = (1/2) L I^2.
- Distinguish A.C. (slip rings) and D.C. (commutator) generators.
- Memorise the transformer turns and power relations.

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CHAPTER 16

Alternating Current

Key Concepts · Definitions · Short & Long Questions · MCQs · Diagrams · Exam Tips

This chapter covers Alternating Current from the 2nd Year (FSc Part-II) Physics syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). It studies alternating current and its peak and rms values, A.C. through a resistor, capacitor and inductor, reactance and impedance, R-C and R-L circuits, power in A.C. circuits, series and parallel resonance, the choke and electromagnetic waves with their transmission and modulation. These notes are prepared by freebooks.pk.

Alternating current reverses direction many times each second and is the form in which electricity is generated and supplied. Understanding how it behaves in resistors, capacitors and inductors explains radios, tuning circuits and the whole of A.C. technology.

Learning Objectives

- Define alternating current and its peak and rms values.
- Describe A.C. through a resistor, a capacitor and an inductor.
- Define reactance and impedance.
- Analyse R-C and R-L series circuits and power in A.C. circuits.
- Explain series and parallel resonance.
- Describe electromagnetic waves and modulation.

Key Concepts

Alternating Current and Its Values

An alternating current (A.C.) is one that reverses its direction periodically, usually varying sinusoidally with time as i = Io sin(2 pi f t), where Io is the peak (maximum) value and f the frequency. The instantaneous value changes from moment to moment. Because the current is sometimes positive and sometimes negative, its average over a cycle is zero, so its effective size is described by the root-mean-square (rms) value, Irms = Io / sqrt 2, which is the steady direct current that would produce the same heating effect. Mains voltage quoted as 220 V is an rms value.

A.C. Through a Resistor

When an alternating voltage is applied across a pure resistor, the current is in phase with the voltage, meaning both reach their peaks and zeros at the same instants. Ohm's law holds at every instant, so the peak current is Io = Vo / R and the rms current is Vrms / R. A resistor dissipates energy as heat in an A.C. circuit just as it does with direct current.

A.C. Through a Capacitor

When an alternating voltage is applied across a capacitor, the current leads the voltage by 90 degrees (a quarter cycle), because the capacitor must charge before a voltage appears across it. The capacitor opposes the flow of A.C. through its capacitive reactance, Xc = 1 / (2 pi f C), which is measured in ohms. The reactance is large at low frequency (so a capacitor blocks direct current, for which f = 0) and small at high frequency.

A.C. Through an Inductor

When an alternating voltage is applied across a pure inductor, the current lags the voltage by 90 degrees, because the induced back EMF opposes changes in current. The inductor opposes A.C. through its inductive reactance, $X_L = 2 \pi f L$, also measured in ohms. Unlike the capacitor, the inductive reactance is small at low frequency and large at high frequency, so an inductor readily passes direct current but impedes high-frequency A.C.

Impedance and R-C, R-L Circuits

In a circuit containing resistance and reactance together, the combined opposition to alternating current is called the impedance Z, measured in ohms, and the current is $I_{rms} = V_{rms} / Z$. For a series circuit containing resistance R, inductive reactance XL and capacitive reactance XC, the impedance is $Z = \sqrt{R^2 + (X_L - X_C)^2}$. In an R-L or R-C circuit the current and voltage are out of phase by an angle phi given by the impedance triangle, where $\tan \phi = (X_L - X_C)/R$.

Power in A.C. Circuits

In an A.C. circuit the average power delivered is $P = V_{rms} I_{rms} \cos \phi$, where cos phi is called the power factor and phi is the phase angle between current and voltage. In a pure resistor $\phi = 0$ and $\cos \phi = 1$, so all the power is dissipated; in a pure capacitor or inductor $\phi = 90$ degrees and $\cos \phi = 0$, so on average no power is consumed. Real circuits lie between these extremes, and a good power factor is desirable for efficient use of electrical energy.

Resonance

In a series R-L-C circuit the inductive and capacitive reactances cancel at a particular frequency called the resonant frequency, $f_0 = 1 / (2 \pi \sqrt{L C})$. At resonance the impedance is minimum (equal to R alone) and the current is maximum. A parallel resonance circuit behaves in the opposite way, offering maximum impedance and minimum current at resonance. Resonance circuits are used to tune radios and televisions to a chosen station by selecting the frequency at which the response is greatest.

Electromagnetic Waves and Modulation

Accelerating charges, such as those in an aerial carrying a high-frequency alternating current, radiate electromagnetic waves, which consist of oscillating electric and magnetic fields travelling through space at the speed of light and needing no medium. To carry information, a low-frequency signal (such as speech or music) is combined with a high-frequency carrier wave in a process called modulation: in amplitude modulation (AM) the amplitude of the carrier is varied in step with the signal, while in frequency modulation (FM) its frequency is varied. The modulated wave is transmitted from an aerial, received by another aerial and then demodulated to recover the original signal.

Important Definitions

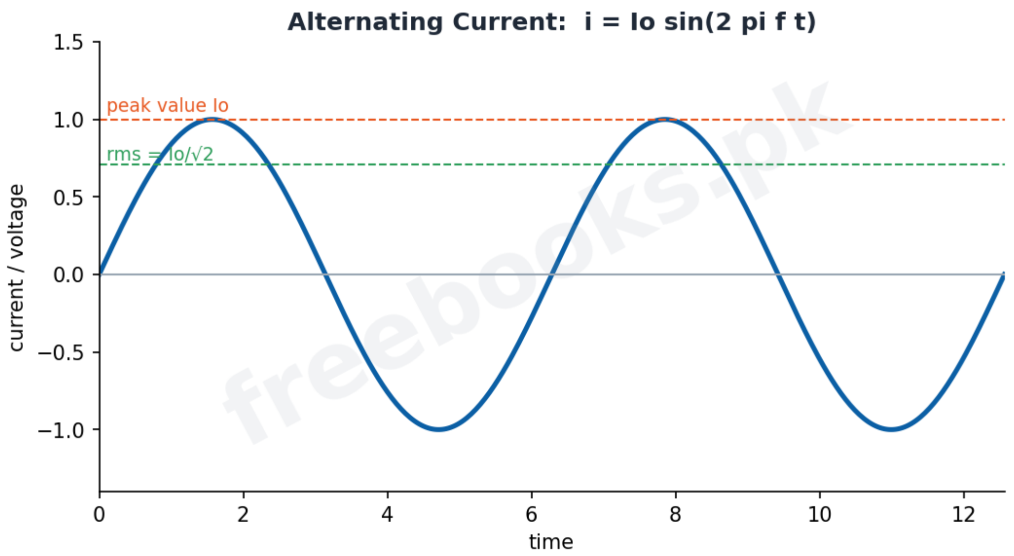
Term	Definition
Alternating current	A current that reverses direction periodically, i = Io sin(2 pi f t).
Peak value	The maximum value of an alternating current or voltage, Io.
Rms value	The effective value, Irms = Io / sqrt 2, giving the same heating as a D.C.
Capacitive reactance	The opposition of a capacitor to A.C., Xc = 1/(2 pi f C).
Inductive reactance	The opposition of an inductor to A.C., XL = 2 pi f L.
Impedance	The total opposition to A.C., Z = sqrt(R^2 + (XL - XC)^2).
Power factor	cos phi, the cosine of the phase angle between current and voltage.
Resonant frequency	The frequency at which XL = XC, f0 = 1/(2 pi sqrt(L C)).

Formulas & Rules

Item	Fact
Instantaneous current	i = Io sin(2 pi f t)
Rms value	Irms = Io / sqrt 2
Capacitive reactance	Xc = 1 / (2 pi f C)
Inductive reactance	XL = 2 pi f L
Impedance	Z = sqrt(R^2 + (XL - XC)^2)
Power in A.C.	P = Vrms Irms cos phi
Resonant frequency	f0 = 1 / (2 pi sqrt(L C))

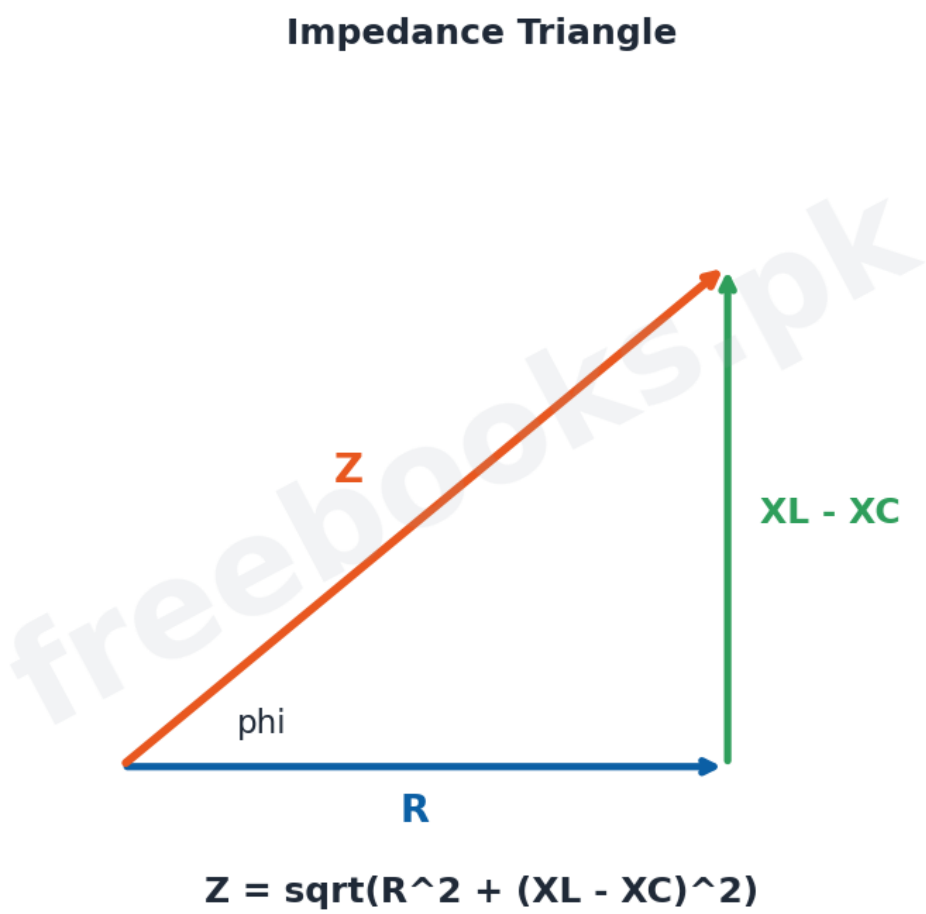
Diagrams & Illustrations

Alternating current: a sine graph of alternating current against time, marking the peak value Io and the rms value Io/sqrt 2.



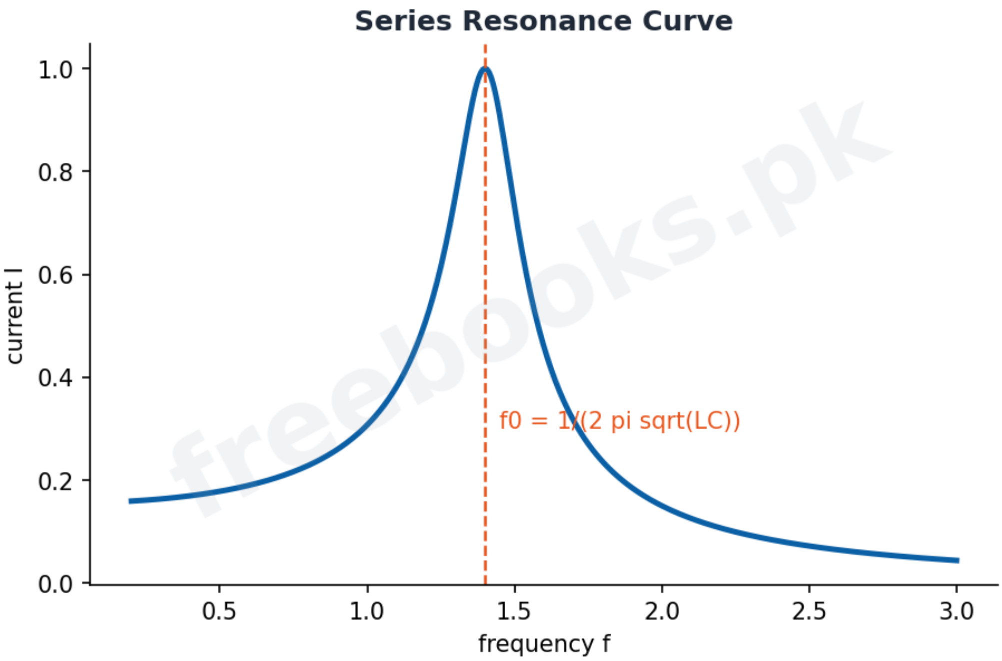
Alternating current

Impedance triangle: an impedance triangle with resistance R, net reactance (XL - XC) and impedance Z, showing the phase angle phi.



Impedance triangle

Series resonance curve: a graph of current against frequency for a series R-L-C circuit, peaking at the resonant frequency f0.



Series resonance curve

Solved Examples & Numericals

Rms value

An alternating current has a peak value of 10 A. Its rms value is Irms = Io/sqrt 2 = 10/1.414 = 7.07 A.

Capacitive reactance

A 10 microfarad capacitor is used at 50 Hz. Xc = 1/(2 pi f C) = 1/(2 pi x 50 x 10x10^-6) = 318 ohm.

Inductive reactance

A 0.2 H inductor is used at 50 Hz. XL = 2 pi f L = 2 pi x 50 x 0.2 = 63 ohm.

Impedance

A series circuit has R = 30 ohm, XL = 80 ohm, XC = 40 ohm. Z = sqrt(30^2 + (80-40)^2) = sqrt(900 + 1600) = 50 ohm.

Resonant frequency

For L = 0.1 H and C = 10 microfarad, f0 = 1/(2 pi sqrt(0.1 x 10x10^-6)) = 1/(2 pi x 10^-3) = 159 Hz.

Short Questions & Answers

Q1. What is alternating current?

Ans. A current that periodically reverses its direction, usually varying sinusoidally, i = Io sin(2 pi f t).

Q2. Define the rms value of A.C.

Ans. The steady direct current that would produce the same heating effect, Irms = Io/sqrt 2.

Q3. Write the capacitive reactance.

Ans. Xc = 1/(2 pi f C); it is large at low frequency and small at high frequency.

Q4. Write the inductive reactance.

Ans. XL = 2 pi f L; it is small at low frequency and large at high frequency.

Q5. What is the power factor?

Ans. cos phi, the cosine of the phase angle between current and voltage; it determines the power consumed.

Q6. Write the resonant frequency of a series circuit.

Ans. f0 = 1/(2 pi sqrt(L C)), where XL = XC and the current is maximum.

Long Questions & Answers

Q1: Describe the behaviour of alternating current through a resistor, a capacitor and an inductor.

The way an alternating current behaves depends on the circuit element it passes through. In a pure resistor the current is exactly in phase with the applied voltage, so both reach their maximum and zero values at the same instants; Ohm's law holds at every moment and the resistor simply dissipates energy as heat, with peak current Io = Vo/R. In a capacitor the situation is different: the current leads the voltage by a quarter of a cycle (90 degrees), because current must flow to charge the plates before a voltage can build up across them. A capacitor opposes alternating current through its capacitive reactance Xc = 1/(2 pi f C), which is large at low frequencies and becomes infinite for direct current (f = 0), so a capacitor blocks D.C. but passes high-frequency A.C. In a pure inductor the current lags the voltage by a quarter cycle, because the self-induced back EMF opposes any change in the current; the inductor opposes A.C. through its inductive reactance XL = 2 pi f L, which is small at low frequencies and large at high frequencies, so an inductor passes D.C. easily but chokes off high-frequency A.C. These phase relationships and reactances are the key to understanding all A.C. circuits.

Q2: Define impedance and power in an A.C. circuit and explain the power factor.

When a circuit contains resistance together with capacitance and/or inductance, the total opposition it offers to alternating current is called the impedance Z, measured in ohms, and the rms current is given by Irms = Vrms/Z. For a series circuit the impedance combines the resistance and the net reactance at right angles, Z = sqrt(R^2 + (XL - XC)^2), and the current and voltage are out of step by a phase angle phi such that tan phi = (XL - XC)/R; this relationship is conveniently shown by the impedance triangle. The average power actually consumed in the circuit is not simply Vrms Irms, but P = Vrms Irms cos phi, where the factor cos phi is called the power factor. Its value depends on the phase angle: in a purely resistive circuit phi = 0 and cos phi = 1, so the whole of the apparent power is dissipated as heat; in a purely inductive or purely capacitive circuit phi = 90 degrees and cos phi = 0, so on average no power is consumed even though a current flows, because energy is alternately stored and returned by the reactive element. Practical circuits lie between these extremes, and electrical engineers aim for a power factor close to one so that electrical energy is used efficiently and cables do not have to carry unnecessarily large currents.

Q3: Explain resonance in a series R-L-C circuit and describe electromagnetic waves and modulation.

In a series circuit containing resistance, inductance and capacitance, the inductive reactance XL increases with frequency while the capacitive reactance XC decreases, so at one particular frequency the two become equal and cancel each other; this frequency is the resonant frequency, f0 = 1/(2 pi sqrt(L C)). At resonance the net reactance is zero, the impedance falls to its smallest value (equal to the resistance alone) and the current in the circuit reaches its maximum. This sharp increase in response at a chosen frequency is exactly what is needed to tune a radio or television to one station out of many, by adjusting L or C so that the resonant frequency matches that of the desired broadcast. Broadcasting itself relies on electromagnetic waves, which are produced when charges accelerate, for example in the high-frequency alternating current of a transmitting aerial; these waves consist of oscillating electric and magnetic fields at right angles to each other and to the direction of travel, and they move through empty space at the speed of light without needing any medium. To carry sound or other information, the low-frequency signal is combined with a high-frequency carrier wave in a process called modulation: in amplitude modulation the amplitude of the carrier is varied in step with the signal, and in frequency modulation its frequency is varied. The modulated carrier is radiated by the transmitting aerial, picked up by a receiving aerial, and then demodulated in the receiver to recover the original signal.

MCQs with Answers

1. The rms value of an A.C. is:
(a) Io (b) Io/2 (c) Io/sqrt 2 (d) 2 Io
Correct Answer: (c) Io/sqrt 2. Irms = Io/sqrt 2.

2. In a resistor, current and voltage are:
(a) 90 out of phase (b) in phase (c) 180 apart (d) random
Correct Answer: (b) in phase. In phase.

3. In a capacitor the current ___ the voltage:
(a) lags (b) leads (c) equals (d) opposes
Correct Answer: (b) leads. Leads by 90 degrees.

4. Capacitive reactance is:
(a) 2 pi f C (b) 1/(2 pi f C) (c) 2 pi f L (d) f/C
Correct Answer: (b) 1/(2 pi f C). Xc = 1/(2 pi f C).

5. Inductive reactance is:

(a) 1/(2 pi f L)   (b) 2 pi f L   (c) 2 pi f C   (d) L/f

Correct Answer: (b) 2 pi f L. XL = 2 pi f L.

6. The total opposition to A.C. is called:

(a) resistance   (b) reactance   (c) impedance   (d) conductance

Correct Answer: (c) impedance. Impedance.

7. The power factor is:

(a) sin phi   (b) cos phi   (c) tan phi   (d) 1/phi

Correct Answer: (b) cos phi. cos phi.

8. At series resonance the current is:

(a) minimum   (b) maximum   (c) zero   (d) infinite

Correct Answer: (b) maximum. Maximum.

9. The resonant frequency is:

(a) 1/(2 pi sqrt(LC))   (b) 2 pi sqrt(LC)   (c) sqrt(LC)   (d) LC

Correct Answer: (a) 1/(2 pi sqrt(LC)). f0 = 1/(2 pi sqrt(LC)).

10. Electromagnetic waves travel at the speed of:

(a) sound   (b) light   (c) a bullet   (d) zero

Correct Answer: (b) light. Light.

Quick Revision Summary

- A.C.: i = Io sin(2 pi f t); rms Irms = Io/sqrt 2 (same heating as D.C.).
- Resistor: in phase. Capacitor: current leads 90, Xc = 1/(2 pi f C). Inductor: current lags 90, XL = 2 pi f L.
- Impedance Z = sqrt(R^2 + (XL - XC)^2); Irms = Vrms/Z.
- Power P = Vrms Irms cos phi; power factor cos phi.
- Series resonance f0 = 1/(2 pi sqrt(LC)): Z minimum, I maximum (tuning).
- EM waves from accelerating charges; modulation AM/FM to carry signals. Notes by freebooks.pk.

Exam Tips

- Remember rms = peak/sqrt 2 and that mains values are rms.
- Learn the phase relations: resistor in phase, capacitor leads, inductor lags.
- Memorise Xc = 1/(2 pi f C) and XL = 2 pi f L and their frequency behaviour.
- Impedance Z = sqrt(R^2 + (XL - XC)^2); power = Vrms Irms cos phi.
- Resonance: XL = XC, f0 = 1/(2 pi sqrt(LC)), current maximum.
- Distinguish AM (amplitude varied) from FM (frequency varied).

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CHAPTER 17

Physics of Solids

Key Concepts · Definitions · Short & Long Questions · MCQs · Diagrams · Exam Tips

This chapter covers Physics of Solids from the 2nd Year (FSc Part-II) Physics syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). It studies the classification of solids, their mechanical properties (stress, strain, Young's modulus and elasticity), their electrical properties and energy bands, superconductors and the magnetic properties of solids. These notes are prepared by freebooks.pk.

Solids are all around us, from metals and glass to plastics and magnets. This chapter explains how their internal structure gives them their mechanical, electrical and magnetic properties.

Learning Objectives

- Classify solids as crystalline, amorphous and polymeric.
- Define stress, strain and Young's modulus and describe elastic behaviour.
- Explain the electrical properties of solids using energy bands.
- Distinguish conductors, insulators and semiconductors.
- Describe superconductors.
- Explain the magnetic properties of solids and the hysteresis loop.

Key Concepts

Classification of Solids

Solids are classified by the arrangement of their particles. In crystalline solids (such as metals, diamond and common salt) the atoms are arranged in a regular, repeating three-dimensional pattern and the solid has a definite melting point. In amorphous or glassy solids (such as glass and plastic) the atoms have no long-range order, so these solids soften gradually rather than melting sharply. Polymeric solids (such as rubber and polythene) are made of very long chain molecules formed by joining many small units, and their properties lie between those of crystalline and amorphous solids.

Stress and Strain

When a force is applied to a solid it tends to change its shape or size. Stress is the force acting per unit area of the body, stress = F/A, measured in pascals, and strain is the fractional change produced, for example the change in length divided by the original length; strain has no units. Stress and strain describe how a material responds to applied forces and are the starting point for studying elasticity.

Elasticity, Hooke's Law and Young's Modulus

A body is elastic if it returns to its original shape when the deforming force is removed. Within a limit called the elastic limit, Hooke's law holds: the strain is directly proportional to the stress. The ratio of stress to strain within this limit is a constant of the material called Young's modulus, Y = stress/strain, which measures the stiffness of the material; a large

Young's modulus means the material is hard to stretch. Beyond the elastic limit the material is permanently deformed and eventually reaches its breaking point.

Electrical Properties and Energy Bands

The electrical behaviour of a solid is explained by the energy band theory. In a solid the allowed energies of the electrons form bands separated by forbidden gaps. The highest filled band is the valence band and the next higher band is the conduction band. Whether a solid conducts depends on the gap between these bands and whether the conduction band contains electrons free to move.

Conductors, Insulators and Semiconductors

In a conductor (a metal) the valence and conduction bands overlap or the conduction band is partly filled, so there are many free electrons and the material conducts well. In an insulator the two bands are separated by a large energy gap that electrons cannot normally cross, so there are no free electrons and the material does not conduct. In a semiconductor the gap is small, so at ordinary temperatures a few electrons cross into the conduction band; its conductivity lies between that of conductors and insulators and increases with temperature. Semiconductors are the basis of all modern electronics.

Superconductors

Some materials, when cooled below a certain very low temperature called the critical (or transition) temperature, lose all their electrical resistance and become superconductors. A current once set up in a superconducting ring continues to flow indefinitely without any energy loss. Superconductors also expel magnetic fields from their interior. They are used to make very powerful electromagnets, for example in magnetic resonance imaging (MRI) machines.

Magnetic Properties of Solids

Solids are classified magnetically by how they respond to a magnetic field. Diamagnetic substances are weakly repelled by a field, paramagnetic substances are weakly attracted, and ferromagnetic substances (such as iron, nickel and cobalt) are strongly attracted and can be permanently magnetised. In ferromagnetic materials the atoms group into small regions called domains, each strongly magnetised; when the material is magnetised these domains line up with the field.

Hysteresis

When a ferromagnetic material is taken through a cycle of magnetisation, the magnetisation lags behind the magnetising field; this lagging is called hysteresis. If the magnetisation is plotted against the magnetising field, a closed loop called the hysteresis loop is obtained. The magnetisation that remains when the field is removed is the retentivity, and the reverse field needed to remove it is the coercivity. The area of the loop represents the energy lost as heat in each cycle, which is important when choosing materials for transformer cores and permanent magnets.

Important Definitions

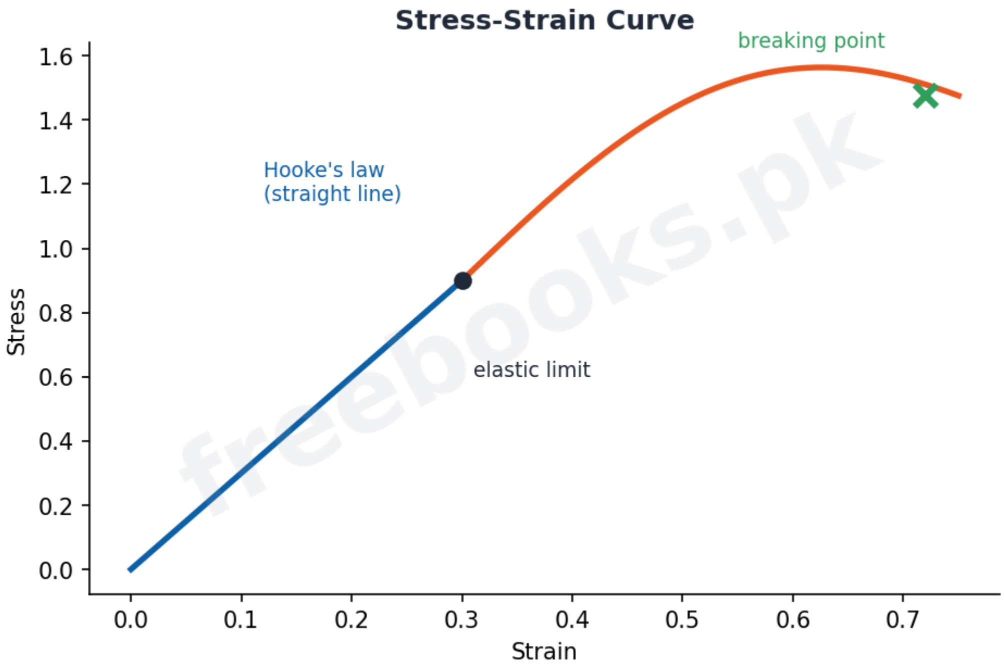
Term	Definition
Crystalline solid	A solid whose atoms are arranged in a regular repeating pattern.
Amorphous solid	A solid with no long-range order in its atoms (e.g. glass).
Stress	The force per unit area on a body, stress = F/A.
Strain	The fractional change in size or shape produced by stress.
Young's modulus	The ratio of stress to strain within the elastic limit, Y = stress/strain.
Semiconductor	A material whose conductivity lies between conductors and insulators.
Superconductor	A material with zero electrical resistance below a critical temperature.
Hysteresis	The lagging of magnetisation behind the magnetising field.

Formulas & Rules

Item	Fact
Stress	stress = F / A
Strain (longitudinal)	strain = change in length / original length
Young's modulus	Y = stress / strain
Hooke's law	stress is proportional to strain (within elastic limit)

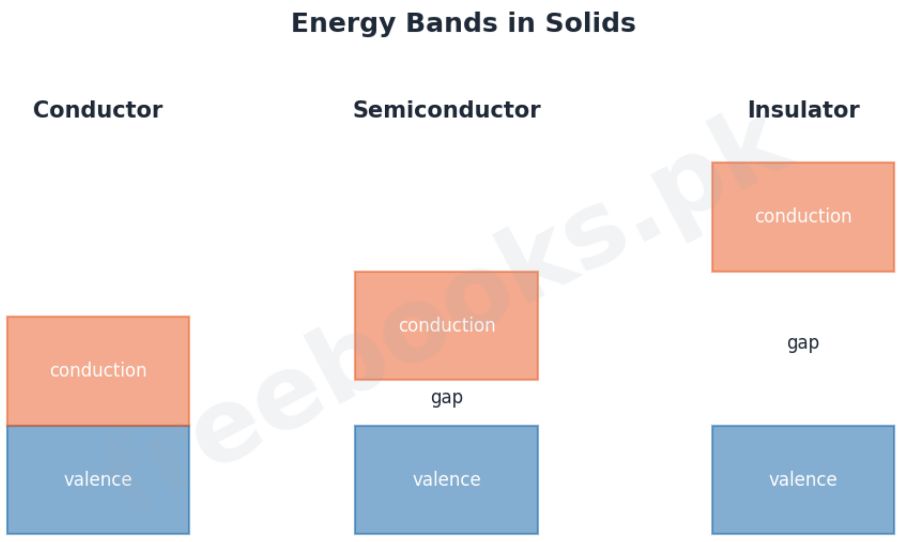
Diagrams & Illustrations

Stress-strain curve: a stress-strain graph showing the straight-line Hooke's law region, the elastic limit and the breaking point.



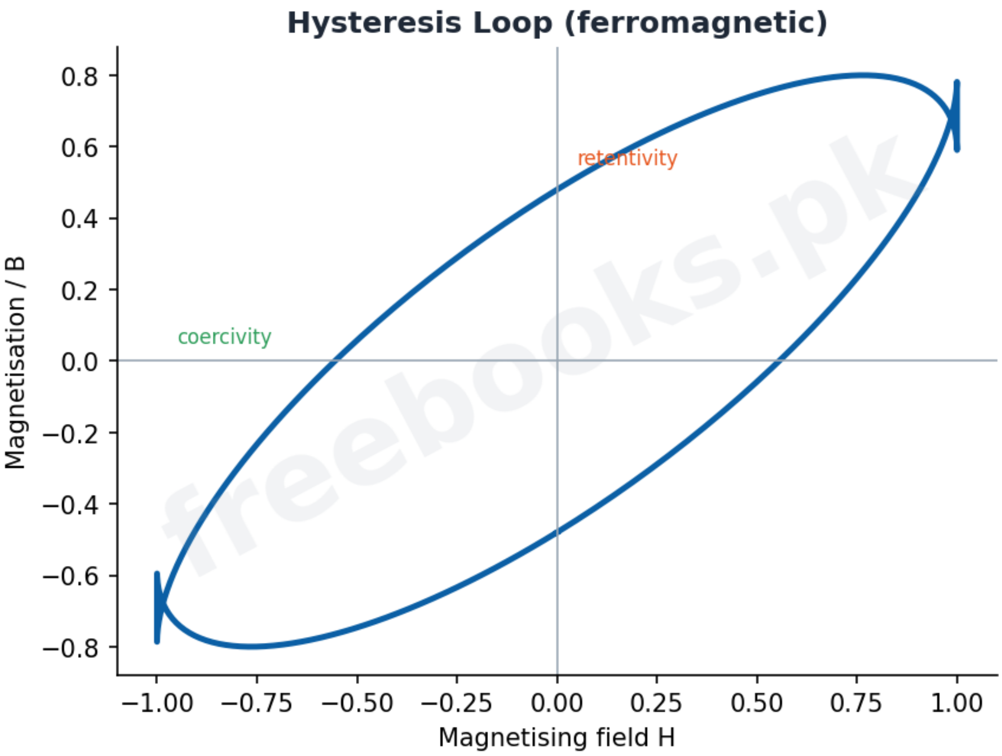
Stress-strain curve

Energy bands: the valence and conduction bands for a conductor (overlapping), a semiconductor (small gap) and an insulator (large gap).



Energy bands

Hysteresis loop: a hysteresis loop of a ferromagnetic material, marking the retentivity and coercivity.



Hysteresis loop

Solved Examples & Numericals

Stress

A wire of area 2 x 10^-6 m^2 carries a load of 40 N. Stress = F/A = 40 / 2x10^-6 = 2 x 10^7 Pa.

Strain

A wire 2 m long stretches by 1 mm. Strain = 1x10^-3 / 2 = 5 x 10^-4 (no units).

Young's modulus

For the wire above, Y = stress/strain = 2x10^7 / 5x10^-4 = 4 x 10^10 Pa.

Semiconductor

As temperature rises, more electrons cross the small band gap of a semiconductor, so its resistance decreases (unlike a metal).

Short Questions & Answers

Q1. Distinguish crystalline and amorphous solids.
Ans. Crystalline solids have a regular repeating atomic arrangement and a sharp melting point; amorphous solids have no long-range order and soften gradually.

Q2. Define stress and strain.

Ans. Stress is the force per unit area (F/A) and strain is the fractional change in size or shape; strain has no units.

Q3. What is Young's modulus?

Ans. The ratio of stress to strain within the elastic limit, Y = stress/strain; it measures stiffness.

Q4. Differentiate a conductor and an insulator using bands.

Ans. In a conductor the valence and conduction bands overlap giving free electrons; in an insulator a large gap separates them so there are no free electrons.

Q5. What is a superconductor?

Ans. A material that loses all electrical resistance below a critical temperature.

Q6. What is hysteresis?

Ans. The lagging of the magnetisation of a ferromagnetic material behind the magnetising field.

Long Questions & Answers

Q1: Define stress, strain and Young's modulus, and describe the elastic behaviour of a solid using the stress-strain curve.

When a solid is subjected to external forces, two quantities describe its response. Stress is the internal restoring force set up per unit area of cross-section and is equal in magnitude to the applied force per unit area, stress = F/A, measured in pascals. Strain is the resulting fractional deformation, for example the increase in length divided by the original length, and being a ratio it has no units. A body is said to be elastic if it regains its original shape and size once the deforming force is removed. If we gradually increase the stress on a wire and plot stress against strain, the graph is at first a straight line through the origin: in this region the strain is directly proportional to the stress, which is Hooke's law, and the constant ratio of stress to strain is Young's modulus, Y = stress/strain, a measure of the stiffness of the material. This straight-line behaviour continues up to a point called the elastic limit; up to this point the wire returns to its original length when unloaded. Beyond the elastic limit the material no longer obeys Hooke's law and is permanently stretched even after the load is removed, and if the stress is increased still further the wire finally reaches its breaking point and snaps. Young's modulus and the position of the elastic limit therefore tell engineers how stiff a material is and how much load it can safely bear.

Q2: Explain the electrical properties of solids using the energy band theory and distinguish conductors, insulators and semiconductors.

The wide range of electrical behaviour of solids is explained by the energy band theory. In an isolated atom the electrons can have only certain discrete energies, but when a very large number of atoms come together to form a solid these levels broaden into ranges of allowed energies called energy bands, which are separated by forbidden gaps in which no electron can exist. The highest band that is normally filled with electrons is called the valence band, and the next allowed band above it is the conduction band; only electrons in the conduction band (or in a partly filled band) are free to move through the solid and carry a current. Whether a solid conducts therefore depends on the arrangement of these bands. In a conductor, such as a metal, the valence and conduction bands overlap, or the highest band is only partly filled, so there are always plenty of free electrons and the material conducts electricity readily. In an insulator the valence band is completely filled and is separated from the empty conduction band by a large energy gap that electrons cannot ordinarily cross, so there are no free electrons and the material does not conduct. In a semiconductor the forbidden gap is quite small, so at room temperature the thermal energy is enough to lift a few electrons across into the conduction band, giving a conductivity between that of conductors and insulators; because more electrons cross the gap as the temperature rises, the conductivity of a semiconductor increases with temperature, the opposite of a metal. This controllable conductivity makes semiconductors the foundation of diodes, transistors and all modern electronics.

Q3: Describe the magnetic properties of solids and explain the hysteresis loop of a ferromagnetic material.

Solids differ greatly in how they respond to a magnetic field, and they are classified accordingly. Diamagnetic substances are very weakly repelled by a magnetic field. Paramagnetic substances are very weakly attracted by a field but lose their magnetism as soon as the field is removed. Ferromagnetic substances, such as iron, nickel and cobalt, are strongly attracted and can be made into permanent magnets; in these materials the atoms group themselves into small regions called domains, within each of which the atomic magnets are already aligned, and magnetising the material consists of lining up these domains with the applied field. When a ferromagnetic material is carried through a complete cycle of magnetisation, first magnetised in one direction, then demagnetised, then magnetised in the opposite direction and back again, its magnetisation always lags behind the magnetising field; this lagging is called hysteresis, and a graph of the magnetisation against the magnetising field forms a closed curve called the hysteresis loop. When the magnetising field is reduced to zero some magnetisation remains, called the retentivity, and a reverse field, called the coercivity, must be applied to remove it. The area enclosed by the loop represents the energy dissipated as heat in the material during each cycle. This is why soft magnetic materials with a thin loop and small energy loss are chosen for transformer cores, while hard materials with a large loop are used for permanent magnets.

MCQs with Answers

1. A solid with a regular repeating atomic pattern is:
(a) amorphous (b) crystalline (c) polymeric (d) liquid
Correct Answer: (b) crystalline. Crystalline.

2. Stress is:
(a) F A (b) F/A (c) A/F (d) F + A
Correct Answer: (b) F/A. Force per unit area, F/A.

3. Strain has the unit:

(a) pascal (b) newton (c) no unit (d) metre

Correct Answer: (c) no unit. It is a ratio (no unit).

4. Young's modulus is:

(a) strain/stress (b) stress/strain (c) stress x strain (d) stress + strain

Correct Answer: (b) stress/strain. Y = stress/strain.

5. Hooke's law holds up to the:

(a) breaking point (b) elastic limit (c) band gap (d) domain

Correct Answer: (b) elastic limit. The elastic limit.

6. In a conductor the valence and conduction bands:

(a) are far apart (b) overlap (c) are empty (d) do not exist

Correct Answer: (b) overlap. Overlap (many free electrons).

7. A semiconductor has a ___ energy gap:

(a) large (b) small (c) zero (d) infinite

Correct Answer: (b) small. Small.

8. With rising temperature a semiconductor's resistance:

(a) increases (b) decreases (c) stays same (d) is infinite

Correct Answer: (b) decreases. Decreases.

9. A superconductor has ___ resistance below its critical temperature:

(a) high (b) zero (c) infinite (d) negative

Correct Answer: (b) zero. Zero.

10. The lagging of magnetisation behind the field is:

(a) resonance (b) hysteresis (c) induction (d) polarisation

Correct Answer: (b) hysteresis. Hysteresis.

Quick Revision Summary

- Solids: crystalline (regular), amorphous (glassy), polymeric (long chains).
- Stress = F/A; strain = fractional change; Young's modulus Y = stress/strain.
- Hooke's law up to the elastic limit; then permanent deformation and breaking point.
- Energy bands: conductor (overlap), semiconductor (small gap), insulator (large gap).
- Superconductor: zero resistance below critical temperature.
- Magnetism: dia (repelled), para (weakly attracted), ferro (strong, domains); hysteresis loop, retentivity, coercivity. Notes by freebooks.pk.

Exam Tips

- Classify solids with an example of each type.
- Learn stress = F/A, strain (no units) and Y = stress/strain.
- Link Hooke's law to the straight part of the stress-strain curve.
- Explain conductor/insulator/semiconductor with band gaps.
- Remember a semiconductor's resistance falls with temperature.

- Define retentivity and coercivity on the hysteresis loop.

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FSc Part-I Physics — Punjab Board

CHAPTER 18

Electronics

Key Concepts · Definitions · Short & Long Questions · MCQs · Diagrams · Exam Tips

This chapter covers Electronics from the 2nd Year (FSc Part-II) Physics syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). It studies the p-n junction and its use in rectification, special diodes, the transistor as an amplifier and switch, the operational amplifier, digital systems and logic gates. These notes are prepared by freebooks.pk.

Electronics is built on semiconductor devices such as diodes and transistors. This chapter explains how these small components rectify current, amplify signals, switch circuits and carry out logic, forming the basis of every electronic device.

Learning Objectives

- Describe the p-n junction and its forward and reverse characteristics.
- Explain rectification using diodes.
- Describe specially designed diodes such as the LED and photodiode.
- Explain the transistor as an amplifier and as a switch.
- Describe the operational amplifier and its uses.
- Explain digital systems and the fundamental logic gates.

Key Concepts

The p-n Junction

A p-n junction is formed when a p-type semiconductor (with positive charge carriers called holes) is joined to an n-type semiconductor (with free electrons). At the junction electrons and holes combine, leaving a thin depletion region with a potential barrier. When the junction is forward biased (p connected to + and n to -) the barrier is lowered and a current flows easily; when it is reverse biased the barrier is raised and almost no current flows. A p-n junction therefore conducts in only one direction and acts as a diode.

Rectification

Rectification is the process of converting alternating current into direct current, and it makes use of the one-way conduction of a diode. In half-wave rectification a single diode allows only one half of each A.C. cycle to pass, giving a pulsating one-directional output. In full-wave rectification an arrangement of diodes (such as a bridge of four diodes) uses both halves of the cycle, giving a smoother, more efficient direct output. Rectifiers are used in the power supplies of nearly all electronic equipment.

Specially Designed Diodes

Some p-n junctions are designed for special purposes. A light-emitting diode (LED) gives out light when it is forward biased and is used in displays and indicators. A photodiode does the reverse: it conducts more when light falls on it, and is used to detect light. A photovoltaic (solar) cell converts light energy directly into electrical energy. These devices show the close link between electricity and light in semiconductors.

The Transistor

A transistor is a semiconductor device with three regions, either n-p-n or p-n-p, called the emitter, base and collector. A small current fed into the base controls a much larger current flowing between the collector and emitter. This ability of a small signal to control a large one makes the transistor the key active component of modern electronics.

Transistor as an Amplifier and Switch

Because a small base current controls a large collector current, a transistor can be used as an amplifier: a weak input signal applied to the base produces a much stronger copy of it in the collector circuit, as in radios and audio systems. A transistor can also be used as a switch: a small base voltage can turn the large collector current fully on or completely off, so the transistor acts like an electrically controlled switch, which is the basis of digital circuits.

The Operational Amplifier

The operational amplifier (op-amp) is a high-gain amplifier with two inputs, an inverting input and a non-inverting input, and one output; it amplifies the difference between the two inputs. With suitable external resistors it can be connected as an inverting amplifier (output inverted and scaled), a non-inverting amplifier (output in phase and scaled) or a comparator (which compares two voltages and switches its output high or low according to which is larger). Op-amps are versatile building blocks used throughout analogue electronics.

Digital Systems and Logic Gates

In a digital system information is handled using just two states, usually written 1 (high) and 0 (low), rather than a continuously varying signal. The basic building blocks that process these binary signals are logic gates. The three fundamental gates are the AND gate (output 1 only when all inputs are 1, $Y = A.B$), the OR gate (output 1 when any input is 1, $Y = A + B$) and the NOT gate or inverter (output the opposite of the input). Combining these gives all the logic needed for computers and digital devices.

Other Logic Gates

From the fundamental gates other useful gates are built. The NAND gate is an AND gate followed by a NOT, and the NOR gate is an OR gate followed by a NOT; these two are called universal gates because any logic function can be made from them alone. The XOR (exclusive-OR) gate gives an output of 1 only when its two inputs are different. Networks of such gates are used in control systems, for example to switch a device on automatically when certain conditions are met.

Important Definitions

Term	Definition
p-n junction	The boundary formed when p-type and n-type semiconductors are joined; acts as a diode.

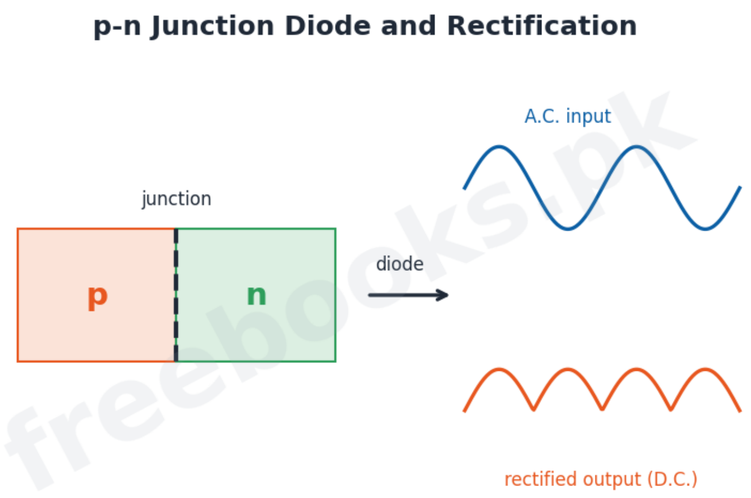
Term	Definition
Forward bias	Connecting a diode so that it conducts (p to +, n to -).
Rectification	The conversion of alternating current into direct current using diodes.
LED	A diode that emits light when forward biased.
Transistor	A three-region semiconductor device in which a small base current controls a large current.
Operational amplifier	A high-gain amplifier that amplifies the difference between its two inputs.
Logic gate	A circuit that processes binary (1/0) signals.
Universal gate	A gate (NAND or NOR) from which any logic function can be made.

Formulas & Rules

Item	Fact
AND gate	Y = A . B
OR gate	Y = A + B
NOT gate	Y = complement of A
NAND gate	Y = complement of (A . B)
NOR gate	Y = complement of (A + B)

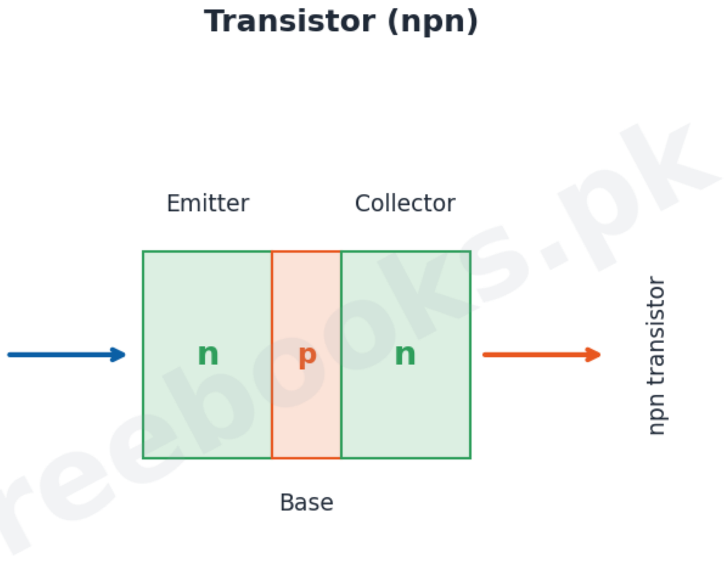
Diagrams & Illustrations

p-n junction diode: a p-n junction diode with p and n regions and the junction, converting an alternating input into a rectified one-directional output.



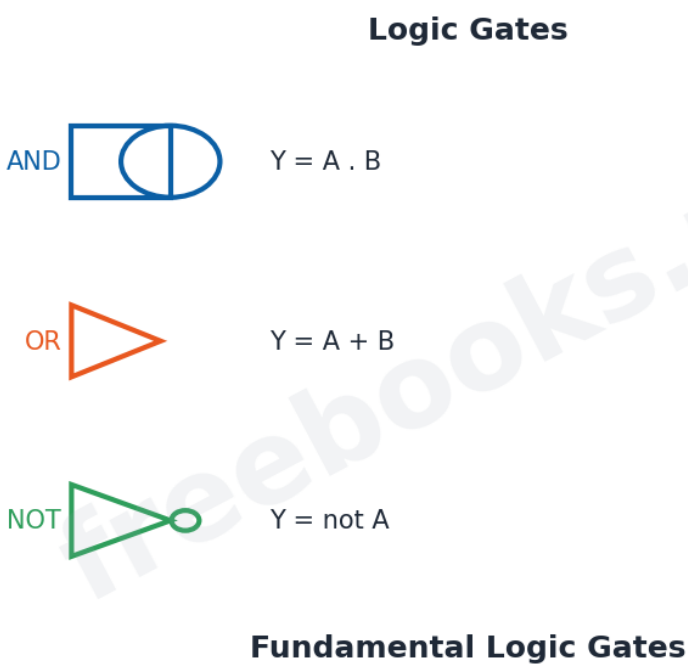
p-n junction diode

Transistor: an n-p-n transistor showing the emitter, base and collector regions, where a small base current controls a large collector current.



Transistor

Logic gates: the symbols of the three fundamental logic gates: AND (Y = A.B), OR (Y = A + B) and NOT (inverter).



Logic gates

Solved Examples & Numericals

Diode conduction

A diode conducts when forward biased (p to +, n to -) and blocks when reverse biased, so it passes current in only one direction.

Half-wave rectifier

In half-wave rectification a single diode passes only one half of each A.C. cycle, giving a pulsating direct output.

AND gate

For an AND gate with inputs A = 1 and B = 0, the output is Y = A.B = 1.0 = 0.

OR gate

For an OR gate with inputs A = 1 and B = 0, the output is Y = A + B = 1 + 0 = 1.

Short Questions & Answers

Q1. What is a p-n junction?
Ans. The boundary formed when p-type and n-type semiconductors are joined; it conducts in only one direction and acts as a diode.

Q2. What is rectification?
Ans. The conversion of alternating current into direct current using the one-way conduction of a diode.

Q3. What is an LED?
Ans. A light-emitting diode, which gives out light when it is forward biased.

Q4. How does a transistor amplify?
Ans. A small base current controls a much larger collector current, so a weak input signal produces a stronger output.

Q5. What is an operational amplifier?
Ans. A high-gain amplifier that amplifies the difference between its inverting and non-inverting inputs.

Q6. Why are NAND and NOR called universal gates?
Ans. Because any logic function can be built using only NAND gates or only NOR gates.

Long Questions & Answers

Q1: Describe the p-n junction and explain how it is used for rectification.

A p-n junction is formed by joining a piece of p-type semiconductor, in which the majority charge carriers are positive holes, to a piece of n-type semiconductor, in which the majority carriers are free electrons. Where they meet, electrons from the n-side and holes from the p-side combine, leaving behind a thin region free of mobile carriers called the depletion region, across which a small potential barrier is set up. The behaviour of the junction depends on how it is connected to a battery. When it is forward biased, with the p-side joined to the positive terminal and the n-side to the negative, the applied voltage lowers the barrier and a current flows easily across the junction. When it is reverse biased, the barrier is raised and only an extremely small current flows. A p-n junction therefore allows current to pass in one direction only and is called a diode. This one-way property is used for rectification, the process of turning alternating current into direct current. In a half-wave rectifier a single diode conducts during only one half of each cycle, so the output is a series of one-directional pulses; in a full-wave rectifier a bridge of four diodes makes use of both halves of the cycle, giving a steadier direct output. Rectifiers of this kind are found in the power supply of almost every piece of electronic equipment, converting the mains A.C. into the D.C. that the circuits need.

Q2: Explain the action of a transistor and describe how it works as an amplifier and as a switch.

A transistor is a semiconductor device made of three regions arranged as either n-p-n or p-n-p; the three regions are called the emitter, the base and the collector, and the base in the middle is very thin and lightly doped. In normal operation the emitter-base junction is forward biased and the collector-base junction is reverse biased. Under these conditions a small current fed into the base controls a much larger current flowing from the collector to the emitter, so that a tiny change in the base current produces a large change in the collector current. This control of a large current by a small one is the key property of the transistor and leads to two very important uses. As an amplifier, a weak signal (for example from a microphone or radio aerial) is applied to the base; the corresponding large variations produced in the collector current are passed through a resistor to give an output signal that is a much stronger copy of the input, so the transistor magnifies the signal. As a switch, the base is used simply to turn the collector current fully on or completely off: a small voltage on the base can drive the transistor into full conduction (on) or cut it off entirely (off), so it behaves like an electrically operated switch with no moving parts. This switching action is the basis of the digital circuits used in computers.

Q3: Explain digital systems and describe the fundamental and other logic gates.

In a digital system, information is represented not by a continuously varying (analogue) signal but by just two distinct states, conventionally written as 1 for a high voltage and 0 for a low voltage. Circuits that process such binary signals are called logic gates, and each gate gives an output that depends in a fixed way on its inputs. There are three fundamental gates. The AND gate gives an output of 1 only when all of its inputs are 1, expressed as $Y = A.B$; if any input is 0 the output is 0. The OR gate gives an output of 1 when any one or more of its inputs is 1, expressed as $Y = A + B$, and gives 0 only when all inputs are 0. The NOT gate, or inverter, has a single input and gives an output that is the opposite of the input, turning 1 into 0 and 0 into 1. From these three, other gates are constructed: the NAND gate is an AND gate followed by a NOT, the NOR gate is an OR gate followed by a NOT, and because any logical operation whatever can be built out of NAND gates alone or NOR gates alone, these two are called universal gates. The XOR (exclusive-OR) gate gives an output of 1 only when its two inputs differ. By connecting such gates together, designers build the counters, memories and processors of computers, as well as automatic control systems that switch equipment on or off when chosen conditions are satisfied.

MCQs with Answers

1. A p-n junction conducts easily when it is:

(a) reverse biased (b) forward biased (c) unbiased (d) heated

Correct Answer: (b) forward biased. Forward biased.

2. A diode allows current in:

(a) both directions (b) one direction (c) no direction (d) random

Correct Answer: (b) one direction. One direction.

3. Converting A.C. to D.C. is called:

(a) amplification (b) rectification (c) modulation (d) induction

Correct Answer: (b) rectification. Rectification.

4. An LED emits light when:

(a) reverse biased (b) forward biased (c) unbiased (d) cooled

Correct Answer: (b) forward biased. Forward biased.

5. A transistor has ___ regions:

(a) two (b) three (c) four (d) five

Correct Answer: (b) three. Three (emitter, base, collector).

6. In a transistor a small ___ current controls a large collector current:

(a) base (b) emitter (c) collector (d) gate

Correct Answer: (a) base. Base current.

7. An op-amp amplifies the ___ of its two inputs:

(a) sum (b) product (c) difference (d) ratio

Correct Answer: (c) difference. Difference.

8. The AND gate gives 1 only when:

(a) any input is 1 (b) all inputs are 1 (c) all inputs are 0 (d) inputs differ

Correct Answer: (b) all inputs are 1. All inputs are 1.

9. The OR gate output is Y =

(a) A . B (b) A + B (c) not A (d) A xor B

Correct Answer: (b) A + B. A + B.

10. Universal gates are:

(a) AND and OR (b) NAND and NOR (c) NOT and OR (d) XOR and AND

Correct Answer: (b) NAND and NOR. NAND and NOR.

Quick Revision Summary

- p-n junction = diode; forward bias conducts, reverse bias blocks.
- Rectification: A.C. to D.C. (half-wave one diode, full-wave bridge).
- Special diodes: LED (emits light), photodiode (detects light), solar cell.
- Transistor (npn/pnp): small base current controls large collector current.
- Uses: amplifier (magnifies signal) and switch (on/off); op-amp amplifies difference of inputs.
- Digital: gates AND (A.B), OR (A+B), NOT; NAND and NOR are universal. Notes by freebooks.pk.

Exam Tips

- Explain forward vs reverse bias of a diode.
- Describe half-wave and full-wave rectification.
- State the three transistor regions and the base-control idea.
- Give both transistor uses: amplifier and switch.
- Learn the three fundamental gates and their expressions.
- Remember NAND and NOR are universal gates.

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CHAPTER 19

Dawn of Modern Physics

Key Concepts · Definitions · Short & Long Questions · MCQs · Diagrams · Exam Tips

This chapter covers the Dawn of Modern Physics from the 2nd Year (FSc Part-II) Physics syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). It studies frames of reference, the special theory of relativity, black body radiation and Planck's quantum, the photoelectric and Compton effects, pair production and annihilation, and the wave nature of particles. These notes are prepared by freebooks.pk.

Around the year 1900 two great ideas, relativity and the quantum, transformed physics. This chapter introduces these ideas, which reveal that at very high speeds and very small scales nature behaves quite differently from everyday experience.

Learning Objectives

- Explain frames of reference and the postulates of special relativity.
- State the results of relativity: time dilation, length contraction and mass-energy equivalence.
- Explain black body radiation and Planck's quantum hypothesis.
- Describe the photoelectric and Compton effects.
- Explain pair production and annihilation.
- State de Broglie's hypothesis of the wave nature of particles.

Key Concepts

Frames of Reference and Relativity

A frame of reference is a coordinate system with respect to which positions and motions are measured. An inertial frame is one moving at constant velocity, in which Newton's laws hold. Einstein's special theory of relativity is based on two postulates: (1) the laws of physics are the same in all inertial frames, and (2) the speed of light in vacuum has the same value for all observers, regardless of the motion of the source or observer. These simple postulates lead to surprising conclusions about space and time.

Consequences of Special Relativity

From the postulates of relativity it follows that measurements of time and length depend on the relative motion of the observer. A moving clock runs slow compared with one at rest, an effect called time dilation, and a moving object is measured to be shorter in the direction of motion, called length contraction. These effects become noticeable only at speeds approaching the speed of light and have been confirmed experimentally.

Mass-Energy Equivalence

One of the most famous results of relativity is that mass and energy are equivalent and interchangeable, expressed by $E = m c^2$, where c is the speed of light. This means that a small amount of mass is equivalent to an enormous amount of energy, since c^2 is very large. Mass-energy equivalence explains the huge energy released in nuclear reactions, where a tiny loss of mass appears as energy.

Black Body Radiation and Planck's Quantum

A black body is an ideal object that absorbs and emits all radiation falling on it. The way the intensity of black body radiation varies with wavelength could not be explained by classical physics. Planck solved the problem by proposing that energy is emitted or absorbed not continuously but in tiny discrete packets called quanta, each of energy $E = h f$, where h is Planck's constant and f the frequency. This quantum hypothesis was the birth of quantum theory.

The Photoelectric Effect

The photoelectric effect is the emission of electrons from a metal surface when light of high enough frequency falls on it. Einstein explained it by treating light as a stream of photons, each carrying energy h f. When a photon strikes the metal it gives all its energy to one electron; part is used to free the electron (the work function W) and the rest becomes its kinetic energy, so $h f = W + (1/2) m v^2$. Below a certain threshold frequency no electrons are emitted, however bright the light, which shows that light behaves as particles.

Compton Effect

In the Compton effect, X-rays scattered by matter are found to have a slightly longer wavelength than the incident X-rays. This is explained by treating the X-ray as a photon that collides with an electron like two particles: the photon gives some of its energy and momentum to the electron, so the scattered photon has less energy and therefore a longer wavelength. The Compton effect is further strong evidence that electromagnetic radiation has a particle nature and that photons carry momentum.

Pair Production and Annihilation

Pair production is a process in which a high-energy photon, passing near a nucleus, disappears and its energy is converted into a particle and its antiparticle, for example an electron and a positron; this shows energy being turned into matter. The reverse process is annihilation, in which a particle and its antiparticle meet and destroy each other, their mass being converted entirely into energy in the form of photons. Both processes are direct illustrations of the equivalence of mass and energy.

Wave Nature of Particles

Just as light shows both wave and particle behaviour, de Broglie proposed that particles of matter also have a wave nature, with a wavelength $\lambda = h / p$, where p is the momentum of the particle and h Planck's constant. This wavelength is extremely small for ordinary objects but significant for tiny particles such as electrons, whose wave nature has been demonstrated by diffraction experiments and is used in the electron microscope. This wave-particle duality is a central idea of modern physics.

Important Definitions

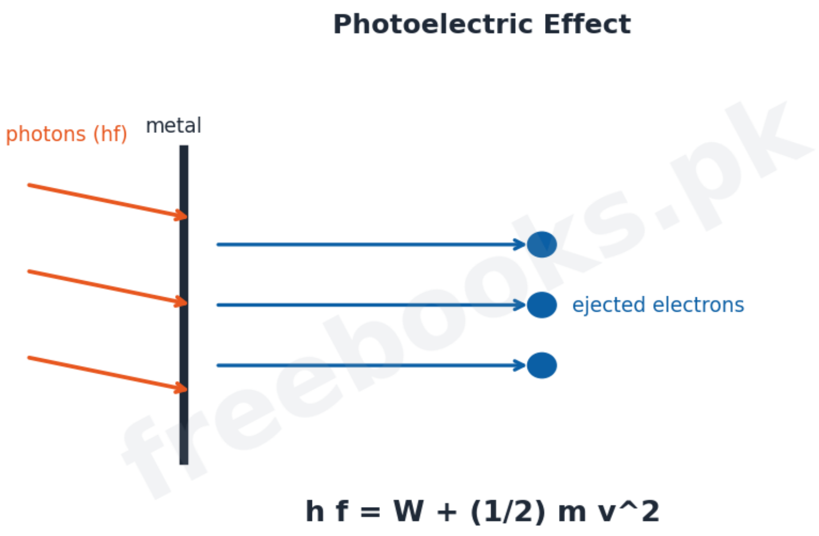
Term	Definition
Frame of reference	A coordinate system with respect to which motion is measured.
Postulates of relativity	Physics is the same in all inertial frames, and light speed is constant for all observers.
Time dilation	A moving clock runs slow compared with one at rest.
Mass-energy equivalence	Mass and energy are interchangeable, E = m c^2.
Quantum	A discrete packet of energy, E = h f.
Photoelectric effect	The emission of electrons from a metal when light of sufficient frequency falls on it.
Pair production	Conversion of a high-energy photon into a particle-antiparticle pair.
de Broglie wavelength	The wavelength of a moving particle, lambda = h/p.

Formulas & Rules

Item	Fact
Quantum energy	E = h f
Mass-energy equivalence	E = m c^2
Photoelectric equation	h f = W + (1/2) m v^2
de Broglie wavelength	lambda = h / p
Threshold frequency	W = h f0

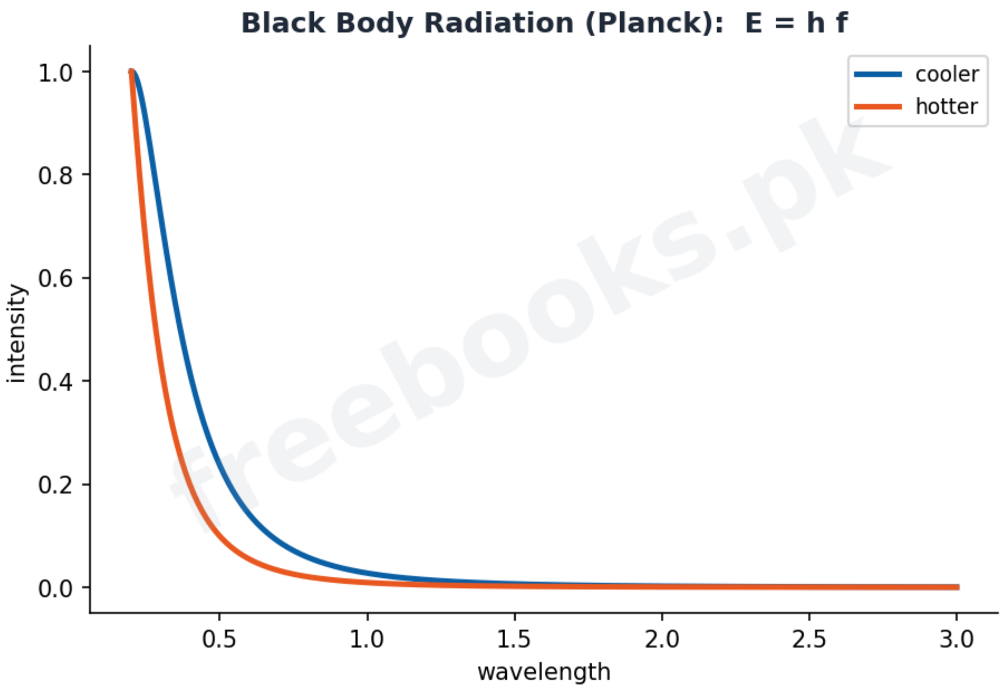
Diagrams & Illustrations

Photoelectric effect: photons of energy h f striking a metal surface and ejecting electrons, with the equation h f = W + (1/2) m v^2.



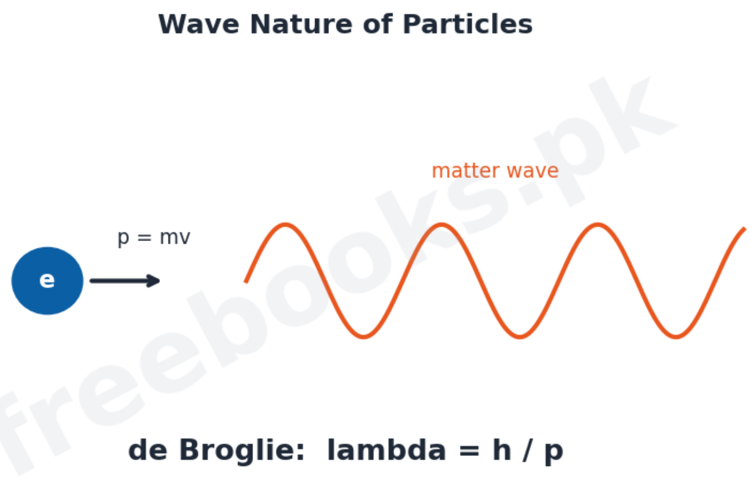
Photoelectric effect

Black body radiation: intensity-wavelength curves of black body radiation for a cooler and a hotter body, explained by Planck's quantum E = h f.



Black body radiation

Wave nature of particles: a moving electron of momentum p associated with a matter wave of wavelength lambda = h/p (de Broglie).



Wave nature of particles

Solved Examples & Numericals

Quantum energy

A photon has frequency 5×10^{14} Hz. Its energy is $E = h f = 6.63 \times 10^{-34} \times 5 \times 10^{14} = 3.3 \times 10^{-19}$ J.

Mass-energy

A mass of 1 g (10^{-3} kg) is equivalent to $E = m c^2 = 10^{-3} \times (3 \times 10^{8})^2 = 9 \times 10^{13}$ J.

Photoelectric effect

Light of energy 5 eV strikes a metal of work function 2 eV. The maximum kinetic energy of the electrons is 5 - 2 = 3 eV.

de Broglie wavelength

An electron has momentum 2×10^{-24} kg m/s. $\lambda = h/p = 6.63 \times 10^{-34} / 2 \times 10^{-24} = 3.3 \times 10^{-10}$ m.

Short Questions & Answers

Q1. State the postulates of special relativity.

Ans. (1) The laws of physics are the same in all inertial frames; (2) the speed of light in vacuum is the same for all observers.

Q2. What is time dilation?

Ans. The slowing down of a moving clock as measured by an observer at rest.

Q3. Write the mass-energy relation.

Ans. $E = m c^2$, showing mass and energy are equivalent.

Q4. State Planck's quantum hypothesis.

Ans. Energy is emitted or absorbed in discrete packets called quanta, each of energy E = h f.

Q5. Write Einstein's photoelectric equation.

Ans. h f = W + (1/2) m v^2, where W is the work function.

Q6. State de Broglie's hypothesis.

Ans. A moving particle has a wave associated with it of wavelength lambda = h/p.

Long Questions & Answers

Q1: State the postulates of the special theory of relativity and describe its main consequences.

The special theory of relativity, put forward by Einstein in 1905, is built on two simple but far-reaching postulates. The first is that the laws of physics have the same form in all inertial frames of reference, that is, in all frames moving with constant velocity relative to one another, so that no experiment can single out one such frame as being at absolute rest. The second is that the speed of light in vacuum has the same value for every observer, whatever the motion of the source of the light or of the observer. Although these postulates seem harmless, taken together they force us to abandon the everyday belief that time and length are the same for everyone. Three important consequences follow. First, time dilation: a clock moving relative to an observer is found to run slow compared with an identical clock at rest beside the observer, so moving clocks tick more slowly. Second, length contraction: an object moving relative to an observer is measured to be shorter in the direction of its motion than when it is at rest. Third, and most famous, mass and energy are shown to be equivalent, related by E = m c^2, so that mass can be converted into energy and energy into mass. All these effects are negligible at everyday speeds but become large as the speed approaches that of light, and they have been confirmed by many experiments.

Q2: Explain black body radiation and the photoelectric effect and show how they led to the quantum theory of light.

Towards the end of the nineteenth century, classical physics failed to explain two experiments involving light, and their resolution gave birth to quantum theory. The first was black body radiation. A black body absorbs and re-emits all the radiation that falls on it, and the way the intensity of its radiation is distributed among the different wavelengths could not be accounted for by classical ideas, which wrongly predicted an infinite emission at short wavelengths. Planck solved this by making the bold assumption that energy is not emitted or absorbed continuously but only in tiny discrete packets, or quanta, each of energy E = h f, where h is Planck's constant and f the frequency; with this assumption the observed radiation curve was correctly reproduced. The second experiment was the photoelectric effect, the emission of electrons from a metal surface illuminated by light. It was found that electrons are emitted only if the frequency of the light exceeds a certain threshold, no matter how bright the light, and that the energy of the emitted electrons depends on the frequency but not on the intensity. Einstein explained this by extending Planck's idea: light itself consists of quanta, or photons, each carrying energy h f. When a photon strikes the metal it gives all its energy to a single electron; part of this energy, the work function W, is used to free the electron from the metal and the rest appears as the electron's kinetic energy, giving Einstein's photoelectric equation h f = W + (1/2) m v^2. Together, black body radiation and the photoelectric effect established that light has a particle nature and that energy is quantised.

Q3: Explain the wave-particle duality of matter, including de Broglie's hypothesis, and mention pair production and annihilation.

The early quantum experiments showed that light, long regarded as a wave, also behaves as a stream of particles called photons, each carrying energy h f and momentum. In 1924 de Broglie made the bold suggestion that this duality is not confined to light but is a property of all matter: every moving particle, he proposed, has a wave associated with it, whose wavelength is given by lambda = h/p, where p is the momentum of the particle and h Planck's constant. For ordinary objects this wavelength is far too small to notice, but for very light particles such as electrons it is comparable with atomic spacings, and the wave nature of electrons was soon confirmed by experiments in which beams of electrons were diffracted just like waves; this principle is used in the electron microscope. Matter therefore shows wave-particle duality, behaving as a wave in some experiments and as a particle in others. The interchange between matter and energy is further shown by two processes. In pair production, a high-energy photon passing close to a nucleus vanishes and its energy is turned into a particle and its antiparticle, such as an electron and a positron, so pure energy becomes matter. In the reverse process, annihilation, a particle meets its antiparticle and the two are destroyed, their entire mass reappearing as energy in the form of photons. Both processes are striking confirmations of Einstein's relation E = m c^2 and of the deep unity of matter and energy in modern physics.

MCQs with Answers

1. The speed of light is the same for:
(a) only the source (b) all observers (c) only fast observers (d) no one
Correct Answer: (b) all observers. All observers (postulate 2).

2. A moving clock runs:
(a) fast (b) slow (c) stops (d) normally
Correct Answer: (b) slow. Slow (time dilation).

3. The mass-energy relation is:
(a) E = m c (b) E = m c^2 (c) E = m/c^2 (d) E = c/m
Correct Answer: (b) E = m c^2. E = m c^2.

4. Planck's quantum of energy is:
(a) h/f (b) h f (c) f/h (d) h c
Correct Answer: (b) h f. E = h f.

5. The photoelectric equation is:
(a) h f = W - KE (b) h f = W + KE (c) h f = W x KE (d) h f = KE/W
Correct Answer: (b) h f = W + KE. h f = W + (1/2) m v^2.

6. Below the threshold frequency, electrons are:

(a) always emitted (b) not emitted (c) emitted faster (d) doubled
Correct Answer: (b) not emitted. Not emitted.

7. In the Compton effect the scattered X-ray has a ___ wavelength:
(a) shorter (b) longer (c) zero (d) same
Correct Answer: (b) longer. Longer.

8. Pair production converts energy into:
(a) heat (b) matter (c) sound (d) light only
Correct Answer: (b) matter. Matter (particle-antiparticle).

9. The de Broglie wavelength is:
(a) h p (b) h/p (c) p/h (d) h c
Correct Answer: (b) h/p. lambda = h/p.

10. Wave-particle duality applies to:
(a) light only (b) matter only (c) both light and matter (d) neither
Correct Answer: (c) both light and matter. Both light and matter.

Quick Revision Summary

- Relativity postulates: physics same in all inertial frames; light speed constant.
- Consequences: time dilation, length contraction, $E = m c^2$.
- Planck: energy in quanta $E = h f$ (black body radiation).
- Photoelectric effect: $h f = W + (1/2) m v^2$; threshold frequency; light as photons.
- Compton effect and pair production/annihilation: photons carry momentum; energy <-> matter.
- de Broglie: particles have waves lambda = h/p; wave-particle duality. Notes by freebooks.pk.

Exam Tips

- Learn the two postulates of special relativity.
- Remember $E = m c^2$ and what time dilation/length contraction mean.
- State Planck's $E = h f$ as the start of quantum theory.
- Write Einstein's photoelectric equation and mention the threshold frequency.
- Give de Broglie's lambda = h/p for the wave nature of particles.
- Link pair production and annihilation to $E = m c^2$.

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FSc Part-I Physics — Punjab Board

CHAPTER 20

Atomic Spectra

Key Concepts · Definitions · Short & Long Questions · MCQs · Diagrams · Exam Tips

This chapter covers Atomic Spectra from the 2nd Year (FSc Part-II) Physics syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). It studies line spectra, Bohr's model of the hydrogen atom and its energy levels, inner-shell transitions and characteristic X-rays, the uncertainty principle and the laser. These notes are prepared by freebooks.pk.

The light given out by atoms comes in sharp, definite colours rather than a continuous range. Explaining these atomic spectra led Bohr to his model of the atom and confirmed that energy inside the atom is quantised.

Learning Objectives

- Explain the line spectrum of atoms.
- Describe Bohr's model of the hydrogen atom and its energy levels.
- Explain how spectral lines arise from energy-level transitions.
- Describe inner-shell transitions and characteristic X-rays.
- State Heisenberg's uncertainty principle.
- Explain the working of a laser.

Key Concepts

Atomic (Line) Spectra

When an element is heated or an electric discharge is passed through its vapour, it gives out light of only certain definite wavelengths, producing a line spectrum of separate coloured lines rather than a continuous band. Each element has its own characteristic set of lines, so a line spectrum acts like a fingerprint that can be used to identify the element. The line spectrum of hydrogen, the simplest atom, was studied in detail and became the key to understanding atomic structure.

Bohr's Model of the Hydrogen Atom

Bohr proposed that in a hydrogen atom the electron moves around the nucleus only in certain allowed circular orbits, in each of which it does not radiate energy; these are called stationary states or energy levels. The electron can only occupy these fixed orbits and not any orbit in between, so its energy is quantised. The allowed orbits are those in which the angular momentum of the electron is a whole-number multiple of h/(2 pi). This bold combination of classical and quantum ideas successfully explained the hydrogen spectrum.

Energy Levels and Spectral Lines

Each allowed orbit corresponds to a definite energy, given for hydrogen by $E_n = -13.6 / n^2$ electron volts, where n = 1, 2, 3, ... is the quantum number; n = 1 is the lowest (ground) state and the levels get closer together as n increases. Normally the electron stays in the lowest level, but if it is given energy it jumps to a higher level. When it falls back to a lower level it emits a photon whose energy equals the difference between the two levels, h f =

E_higher - E_lower. Because only certain energy differences are possible, only certain photon frequencies are emitted, which is why the spectrum consists of sharp lines.

Hydrogen Spectral Series

The spectral lines of hydrogen fall into groups called series, each corresponding to transitions that end on a particular level. Transitions ending on n = 1 give the Lyman series (in the ultraviolet), those ending on n = 2 give the Balmer series (in the visible region) and those ending on n = 3 give the Paschen series (in the infrared). The excellent agreement between the wavelengths predicted by Bohr's model and those measured experimentally was a great triumph of the theory.

Inner-Shell Transitions and Characteristic X-rays

When fast electrons strike a metal target, they can knock electrons out of the inner shells of the target atoms. An electron from a higher shell then falls into the vacancy, and because inner-shell energy differences are very large, the emitted photon is highly energetic and lies in the X-ray region. These X-rays have definite wavelengths characteristic of the target element and are therefore called characteristic X-rays, used to identify elements and in X-ray analysis.

Heisenberg's Uncertainty Principle

Heisenberg's uncertainty principle states that it is impossible to measure both the position and the momentum of a particle exactly at the same time: the more precisely one is known, the less precisely the other can be known, with the product of the uncertainties at least of the order of Planck's constant. A similar relation links energy and time. This principle is a fundamental feature of the quantum world and sets a natural limit on the precision of measurements at the atomic scale.

The Laser

A laser is a device that produces an intense, narrow and highly coherent beam of single-colour light. It works by stimulated emission: an excited atom, struck by a photon of the right energy, is stimulated to emit a second identical photon, so the two travel together in step. To keep this going, most of the atoms must be raised to the excited state, a condition called population inversion, and the light is reflected back and forth between two mirrors to build up a strong beam, one mirror being partly transparent to let the beam out. Lasers are used in surgery, communication, CD and DVD players, cutting and welding, and many other applications.

Important Definitions

Term	Definition
Line spectrum	A spectrum of separate lines of definite wavelength characteristic of an element.
Stationary state	An allowed orbit or energy level in which the electron does not radiate.

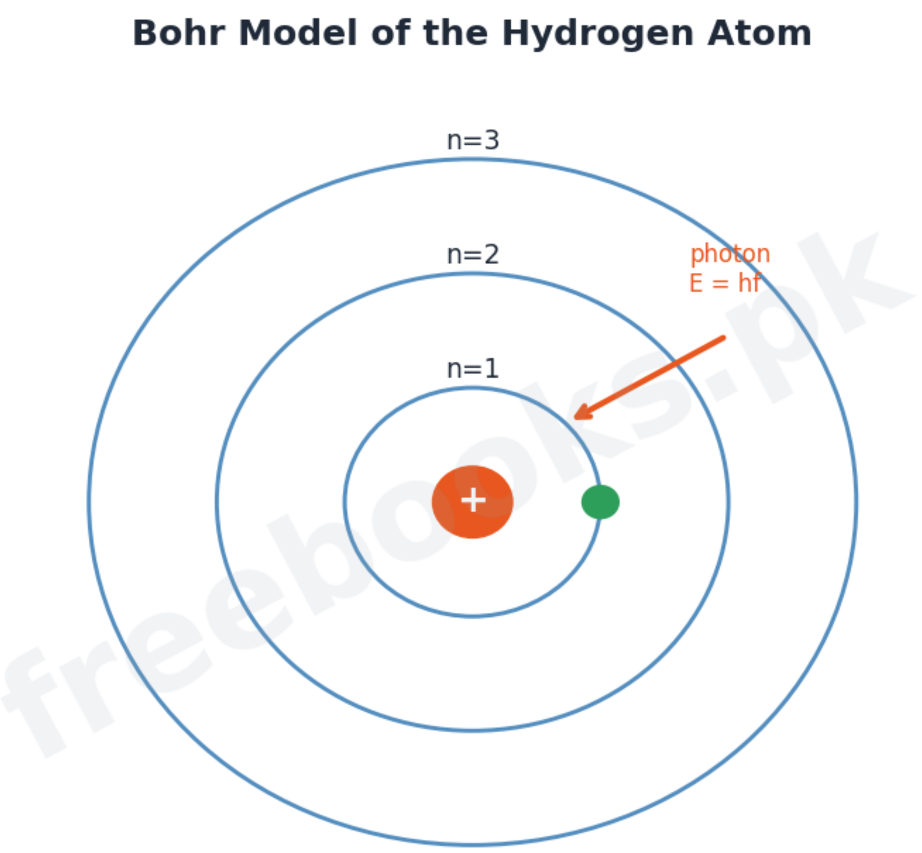
Term	Definition
Energy level	A definite allowed energy of the electron, E_n = -13.6/n^2 eV for hydrogen.
Ground state	The lowest energy level (n = 1).
Characteristic X-rays	X-rays of definite wavelength emitted in inner-shell transitions of an element.
Uncertainty principle	Position and momentum cannot both be measured exactly at once.
Stimulated emission	Emission of a photon caused by another photon of the same energy.
Laser	A device giving an intense coherent single-colour beam by stimulated emission.

Formulas & Rules

Item	Fact
Energy levels of hydrogen	E_n = -13.6 / n^2 eV
Photon of a transition	h f = E_higher - E_lower
Ground state energy	E_1 = -13.6 eV
Uncertainty principle	(delta x)(delta p) is at least of the order of h

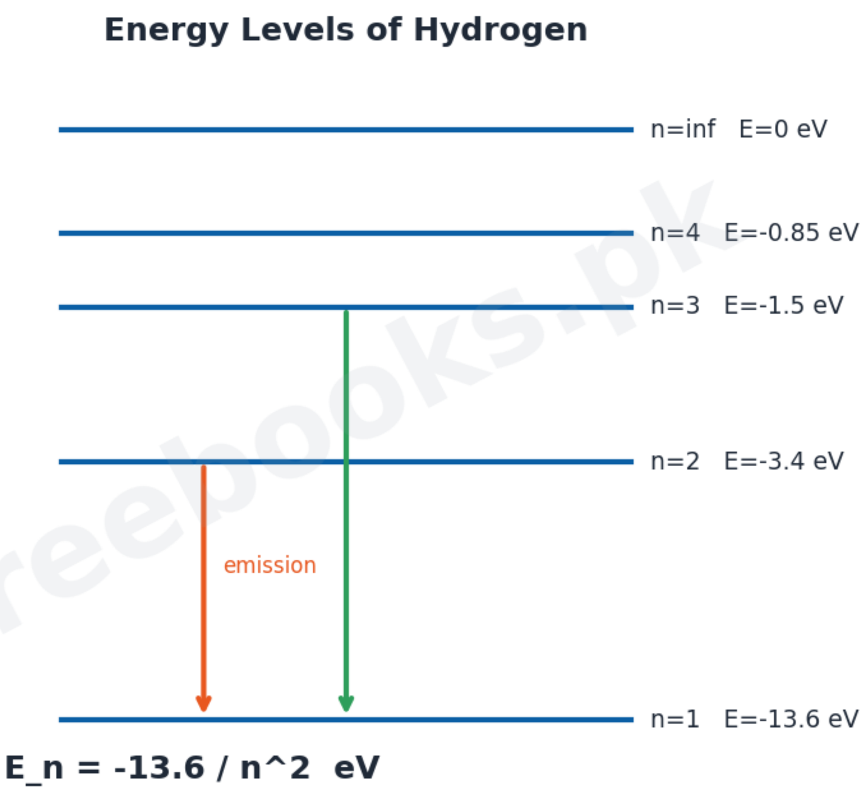
Diagrams & Illustrations

Bohr model of the hydrogen atom: the Bohr model with the electron in allowed circular orbits (n = 1, 2, 3) around the nucleus, emitting a photon when it jumps to a lower orbit.



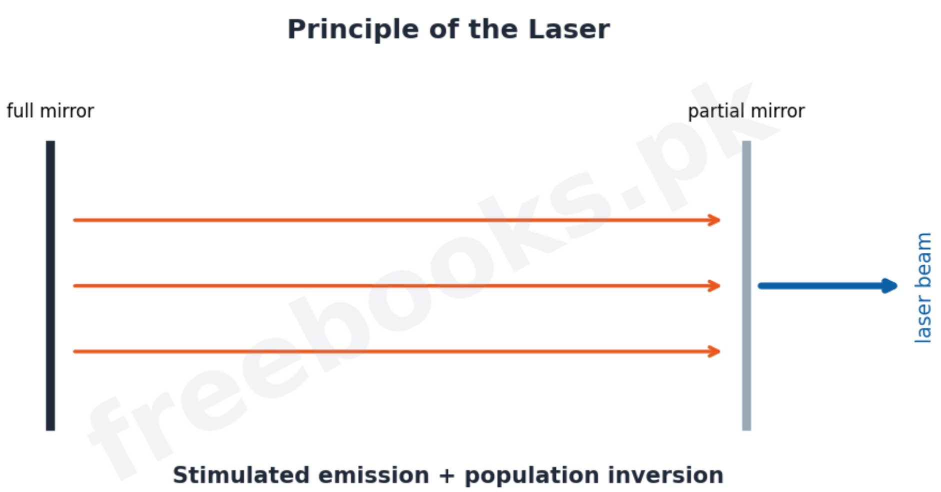
Bohr model of the hydrogen atom

Energy levels of hydrogen: the energy-level diagram of hydrogen with E_n = -13.6/n^2 eV and downward transitions emitting photons.



Energy levels of hydrogen

Principle of the laser: light bouncing between two mirrors and being amplified by stimulated emission to form a laser beam.



Principle of the laser

Solved Examples & Numericals

Ground state energy

For hydrogen with n = 1, E_1 = -13.6/1^2 = -13.6 eV.

Second level

For $n = 2$, $E_2 = -13.6/4 = -3.4$ eV.

Transition energy

An electron falling from $n = 2$ to $n = 1$ emits a photon of energy $E_2 - E_1 = -3.4 - (-13.6) = 10.2$ eV.

Ionisation energy

The energy needed to remove the electron from the ground state ($n = 1$ to infinity) is 13.6 eV, the ionisation energy of hydrogen.

Short Questions & Answers

Q1. What is a line spectrum?
Ans. A spectrum consisting of separate lines of definite wavelength, characteristic of each element.

Q2. State a main postulate of Bohr's model.
Ans. The electron moves only in certain allowed orbits (stationary states) in which it does not radiate energy.

Q3. Write the energy of the nth level of hydrogen.
Ans. $E_n = -13.6/n^2$ eV, with $n = 1$ the ground state.

Q4. How is a spectral line produced?
Ans. When an electron falls from a higher to a lower level it emits a photon of energy $h f = E_{higher} - E_{lower}$.

Q5. What are characteristic X-rays?
Ans. X-rays of definite wavelength emitted when electrons fall into inner-shell vacancies of an element.

Q6. State Heisenberg's uncertainty principle.
Ans. The position and momentum of a particle cannot both be measured exactly at the same time.

Long Questions & Answers

Q1: Describe Bohr's model of the hydrogen atom and explain how it accounts for the line spectrum.

Bohr put forward a model of the hydrogen atom that combined classical mechanics with new quantum ideas. He proposed that the single electron of the hydrogen atom moves around the nucleus only in certain allowed circular orbits, and that while it is in one of these orbits it does not radiate energy, contrary to classical expectation; these allowed orbits are called stationary states or energy levels. The orbits that are permitted are those for which the angular momentum of the electron is a whole-number multiple of $h/(2\pi)$, so the electron's energy can take only certain discrete values and is said to be quantised. For hydrogen these energies are given by $E_n = -13.6/n^2$ electron volts, where $n = 1, 2, 3, \ldots$ is the quantum number; the level $n = 1$ is the lowest, called the ground state, and the levels crowd closer together as n increases towards zero. Normally the electron occupies the ground state, but if the atom absorbs energy the electron is raised to a higher level. When the electron later falls back to a lower level, the atom emits a photon whose energy is exactly equal to the difference between the two levels, $h f = E_{higher} - E_{lower}$. Because only certain energy differences are possible, only photons of certain definite frequencies (and hence wavelengths) can be emitted, and these appear as the sharp bright lines of the line spectrum. In this way Bohr's model explained not only why atomic spectra consist of discrete lines but also predicted their wavelengths for hydrogen with remarkable accuracy.

Q2: Explain how the spectral series of hydrogen arise and describe how characteristic X-rays are produced.

The many lines in the spectrum of hydrogen are not scattered at random but fall into distinct groups called spectral series, each of which corresponds to electron transitions that finish on a particular energy level. Transitions in which the electron falls to the level $n = 1$ form the Lyman series, whose lines lie in the ultraviolet; transitions ending on $n = 2$ form the Balmer series, whose lines lie in the visible part of the spectrum and were the first to be studied; and transitions ending on $n = 3$ form the Paschen series, in the infrared. Since the energy of each level is fixed by $E_n = -13.6/n^2$ eV, the energy, and therefore the wavelength, of every line can be calculated, and the close agreement between these calculated wavelengths and those measured in the laboratory was one of the great successes of Bohr's theory. The same idea of transitions between levels explains characteristic X-rays. When very fast electrons strike a metal target, they can knock an electron out of one of the inner shells of a target atom, leaving a vacancy. An electron from a higher shell immediately falls into this vacancy, and because the energy difference between the inner shells is very large, the photon that is emitted is extremely energetic and lies in the X-ray region of the spectrum. These X-rays have sharply defined wavelengths that are characteristic of the particular target element, which is why they are called characteristic X-rays; they are widely used to identify elements and in X-ray spectroscopy.

Q3: State Heisenberg's uncertainty principle and explain the working of a laser.

Heisenberg's uncertainty principle is a fundamental limitation of the quantum world. It states that it is impossible, even in principle, to determine both the exact position and the exact momentum of a particle at the same instant: the more accurately the position is known, the less accurately the momentum can be known, and vice versa, the product of the two uncertainties being at least of the order of Planck's constant. A similar relation connects the uncertainty in the energy of a state with the uncertainty in the time for which it exists. This principle does not arise from imperfect instruments but is built into nature at the atomic scale. A very different but equally important application of quantum ideas is the laser, a device that produces an intense, narrow, single-colour and highly coherent beam of light. Its action depends on stimulated emission: when an atom is already in an excited state and is struck by a photon whose energy matches the energy the atom is about to release, the atom is stimulated to emit a second photon that is identical to the first and travels in step with it. For this to build up into a strong beam, most of the atoms in the material must first be raised to the excited state, a situation called population inversion, achieved by an external energy source. The light is then reflected many times between two parallel mirrors so that it passes repeatedly through the material and is amplified at each pass; one of the mirrors is made partly transparent so that a portion of this intense, coherent beam emerges as the laser output. Because the beam is so narrow, intense and pure in colour, lasers are used in eye and other surgery, in optical-fibre communication, in reading CDs and DVDs, in cutting and welding metals, and in many measuring instruments.

MCQs with Answers

1. The spectrum of an element consists of:
(a) a continuous band (b) separate lines (c) only one colour (d) no light
Correct Answer: (b) separate lines. Separate lines (line spectrum).

2. In Bohr's model the electron in an allowed orbit:
(a) radiates energy (b) does not radiate (c) gains mass (d) stops
Correct Answer: (b) does not radiate. Does not radiate.

3. The energy of the nth level of hydrogen is:
(a) -13.6 n^2 (b) -13.6/n^2 (c) 13.6 n (d) -13.6 n
Correct Answer: (b) -13.6/n^2. E_n = -13.6/n^2 eV.

4. The ground state energy of hydrogen is:
(a) -3.4 eV (b) -13.6 eV (c) 0 eV (d) +13.6 eV
Correct Answer: (b) -13.6 eV. -13.6 eV.

5. A photon is emitted when the electron:
(a) stays put (b) jumps to a higher level (c) falls to a lower level (d) is removed
Correct Answer: (c) falls to a lower level. Falls to a lower level.

6. The Balmer series lies in the ___ region:
(a) ultraviolet (b) visible (c) infrared (d) X-ray
Correct Answer: (b) visible. Visible.

7. Characteristic X-rays come from ___ transitions:
(a) outer-shell (b) inner-shell (c) nuclear (d) molecular
Correct Answer: (b) inner-shell. Inner-shell.

8. The uncertainty principle links position and:
(a) charge (b) momentum (c) mass (d) colour
Correct Answer: (b) momentum. Momentum.

9. A laser works by:
(a) spontaneous emission (b) stimulated emission (c) absorption only (d) reflection only
Correct Answer: (b) stimulated emission. Stimulated emission.

10. A laser beam is:

(a) incoherent (b) coherent (c) many colours (d) weak

Correct Answer: (b) coherent. Coherent (and monochromatic).

Quick Revision Summary

- Line spectra are characteristic of each element (a fingerprint).
- Bohr: electron in fixed orbits (stationary states); energy quantised.
- E_n = -13.6/n^2 eV; ground state -13.6 eV; photon h f = E_higher - E_lower.
- Series: Lyman (UV, to n=1), Balmer (visible, to n=2), Paschen (IR, to n=3).
- Characteristic X-rays from inner-shell transitions; uncertainty principle limits position and momentum.
- Laser: stimulated emission + population inversion + mirrors; coherent monochromatic beam. Notes by freebooks.pk.

Exam Tips

- State that line spectra identify elements.
- Give Bohr's key postulate (allowed non-radiating orbits).
- Memorise E_n = -13.6/n^2 eV and the transition photon relation.
- Match the series (Lyman/Balmer/Paschen) to their regions.
- State the uncertainty principle in words.
- Explain the laser using stimulated emission and population inversion.

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CHAPTER 21

Nuclear Physics

Key Concepts · Definitions · Short & Long Questions · MCQs · Diagrams · Exam Tips

This chapter covers Nuclear Physics from the 2nd Year (FSc Part-II) Physics syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). It studies the atomic nucleus and isotopes, mass defect and binding energy, radioactivity and half-life, radiation detectors, nuclear reactions, fission and fusion, the biological effects and medical uses of radiation and the basic building blocks of matter. These notes are prepared by freebooks.pk.

The nucleus at the heart of the atom is tiny but holds enormous energy. Nuclear physics explains radioactivity, nuclear reactors, the energy of stars and the uses of radiation in medicine.

Learning Objectives

- Describe the nucleus, nucleons and isotopes.
- Explain mass defect and binding energy.
- Describe radioactivity and define half-life.
- Describe radiation detectors and nuclear reactions.
- Explain nuclear fission and fusion and their applications.
- Describe the biological effects and medical uses of radiation and the building blocks of matter.

Key Concepts

The Atomic Nucleus and Isotopes

The nucleus of an atom is made up of protons, which carry positive charge, and neutrons, which are uncharged; together these are called nucleons. The number of protons is the atomic number Z, and the total number of nucleons is the mass number A, so the number of neutrons is A - Z. Isotopes are atoms of the same element (same Z) that have different numbers of neutrons and therefore different mass numbers; for example hydrogen has the isotopes protium, deuterium and tritium. Isotopes have the same chemical properties but different masses.

Mass Defect and Binding Energy

The mass of a nucleus is always found to be slightly less than the total mass of the separate protons and neutrons that make it up; this difference is called the mass defect. According to Einstein's relation E = m c^2, this missing mass has been converted into the energy that binds the nucleons together, called the binding energy. The binding energy is the energy that would be needed to break the nucleus into its separate nucleons, and the binding energy per nucleon measures how tightly a nucleus is held together; it is greatest for nuclei of medium mass, which are the most stable.

Radioactivity

Radioactivity is the spontaneous breakdown of unstable nuclei with the emission of radiation. There are three main types: alpha particles (helium nuclei, positively charged, weakly penetrating), beta particles (fast electrons, negatively charged, more penetrating) and gamma rays (high-energy electromagnetic radiation, uncharged, very penetrating). When a nucleus emits an alpha or beta particle it changes into the nucleus of a different element, a process called radioactive decay or transmutation.

Half-Life

Radioactive decay is a random process, but for a large number of nuclei it follows a definite pattern. The half-life of a radioactive substance is the time taken for half of the nuclei present to decay. After one half-life half the original nuclei remain, after two half-lives one quarter remain, and so on. Different isotopes have very different half-lives, from fractions of a second to billions of years, and the half-life is used to date rocks and archaeological remains.

Radiation Detectors and Nuclear Reactions

Radiation cannot be seen directly, so special detectors are used. The Geiger-Muller counter detects individual particles of radiation by the ionisation they cause in a gas, giving a click or a count for each particle, while a cloud chamber shows the tracks of ionising particles as trails of tiny droplets. A nuclear reaction is one in which the nucleus of an atom is changed, for example by bombarding it with a particle; in such reactions the total charge and the total number of nucleons are conserved, and energy is released or absorbed according to $E = m c^2$.

Nuclear Fission and Fusion

In nuclear fission a heavy nucleus such as uranium splits into two lighter nuclei when it absorbs a neutron, releasing a great deal of energy and two or three more neutrons; these neutrons can split further nuclei, giving a chain reaction. A controlled chain reaction in a nuclear reactor is used to generate electricity. In nuclear fusion two light nuclei, such as those of hydrogen, join to form a heavier nucleus, again releasing energy; fusion is the source of the energy of the Sun and stars. Both processes release energy because the products are more tightly bound (have greater binding energy per nucleon) than the starting nuclei.

Effects and Uses of Radiation

Radiation ionises the atoms of any material it passes through, and in living tissue this can damage cells and cause harm, so exposure to radiation must be limited and controlled. However, radiation also has many valuable uses. In medicine, radioactive tracers are used to study the working of organs, gamma rays are used to destroy cancer cells (radiotherapy) and to sterilise instruments, and X-rays and gamma rays are used in imaging. In industry radiation is used to detect flaws in metals and to control thickness.

Building Blocks of Matter

Matter is built from a small number of fundamental particles, and four basic forces act between them: the strong nuclear force (which holds the nucleus together), the electromagnetic force, the weak nuclear force (responsible for beta decay) and gravity. The fundamental particles are grouped into leptons, such as the electron, which are truly elementary, and hadrons, such as the proton and neutron, which are made of still smaller particles called quarks. This picture of quarks and leptons is the modern understanding of the ultimate building blocks of matter.

Important Definitions

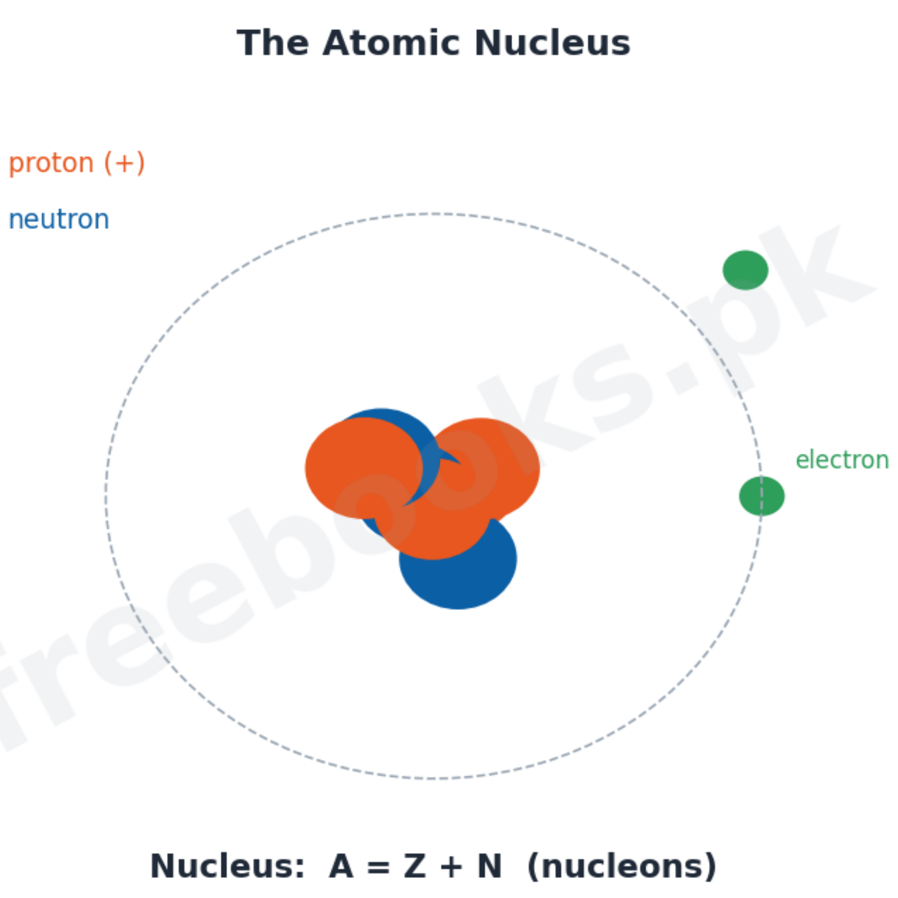
Term	Definition
Nucleon	A proton or a neutron in the nucleus.
Atomic number Z	The number of protons in the nucleus.
Mass number A	The total number of nucleons (protons + neutrons).
Isotopes	Atoms of the same element with different numbers of neutrons.
Mass defect	The difference between the mass of a nucleus and its separate nucleons.
Binding energy	The energy equivalent of the mass defect, holding the nucleus together.
Half-life	The time for half the nuclei of a radioactive sample to decay.
Nuclear fission	The splitting of a heavy nucleus into lighter ones with release of energy.

Formulas & Rules

Item	Fact
Number of neutrons	N = A - Z
Mass-energy relation	E = m c^2
Binding energy	E = (mass defect) x c^2
Half-life decay	after n half-lives, fraction remaining = (1/2)^n

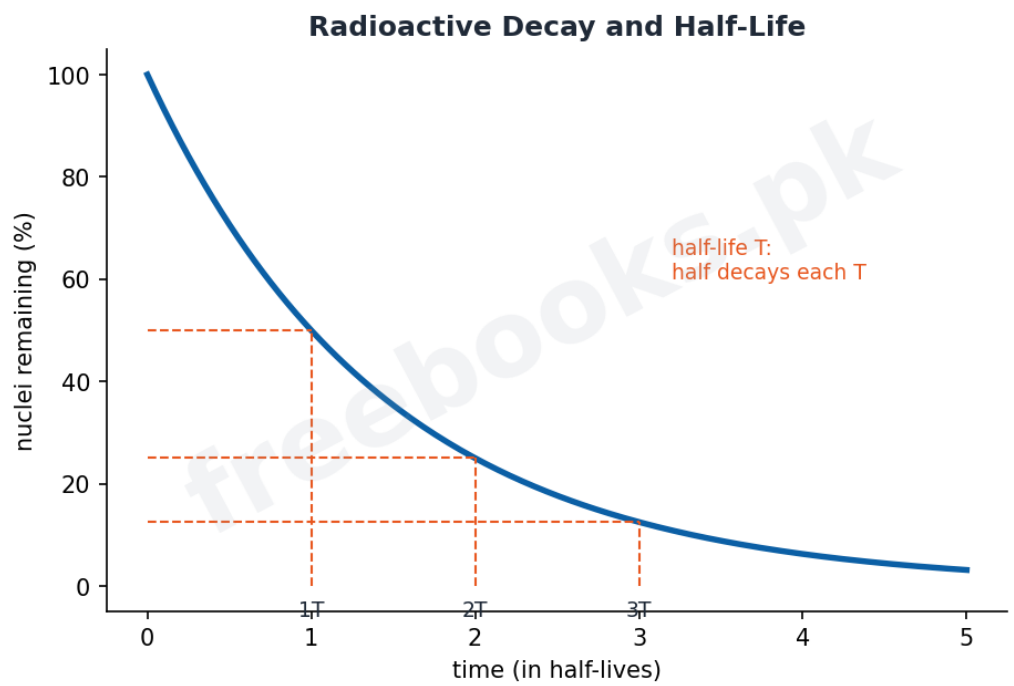
Diagrams & Illustrations

The atomic nucleus: the nucleus made of protons and neutrons (nucleons) with A = Z + N, surrounded by orbiting electrons.



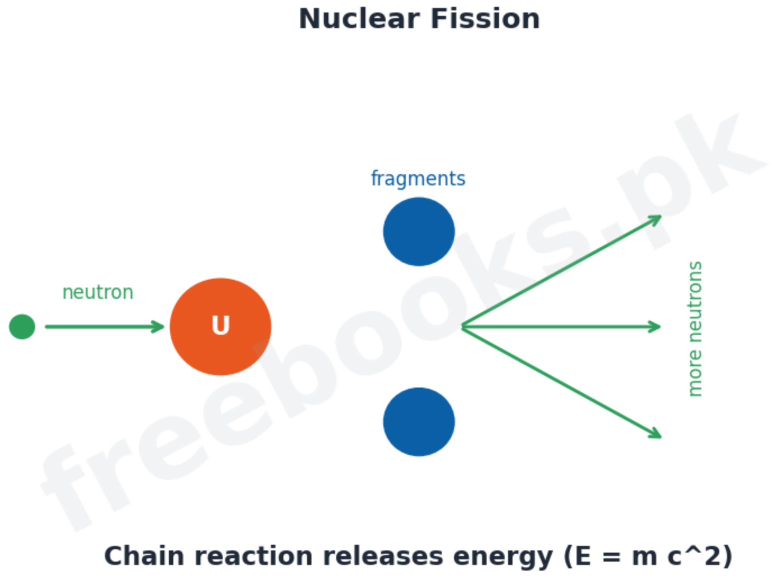
The atomic nucleus

Radioactive decay and half-life: a decay curve showing the number of radioactive nuclei halving after each half-life T.



Radioactive decay and half-life

Nuclear fission: a neutron splitting a uranium nucleus into fragments and releasing more neutrons, starting a chain reaction.



Nuclear fission

Solved Examples & Numericals

Number of neutrons

A nucleus has mass number A = 235 and atomic number Z = 92. Its number of neutrons is N = A - Z = 235 - 92 = 143.

Half-life

A sample has a half-life of 5 years. After 15 years (3 half-lives) the fraction remaining is (1/2)^3 = 1/8 of the original.

Binding energy

If the mass defect of a nucleus is 0.03 u (1 u gives about 931 MeV), its binding energy is about 0.03 x 931 = 28 MeV.

Fission energy

When a uranium nucleus undergoes fission, a small loss of mass appears as a large amount of energy through E = m c^2.

Short Questions & Answers

Q1. What are nucleons?

Ans. The particles in the nucleus, that is, protons and neutrons.

Q2. What are isotopes?

Ans. Atoms of the same element (same atomic number) that have different numbers of neutrons and hence different mass numbers.

Q3. Define mass defect.

Ans. The difference between the total mass of the separate nucleons and the actual mass of the nucleus.

Q4. Define half-life.

Ans. The time taken for half the nuclei of a radioactive sample to decay.

Q5. What is nuclear fission?

Ans. The splitting of a heavy nucleus into two lighter nuclei, with the release of energy and neutrons.

Q6. What is nuclear fusion?

Ans. The joining of two light nuclei to form a heavier nucleus, releasing energy; the source of the Sun's energy.

Long Questions & Answers

Q1: Explain mass defect and binding energy and their significance for nuclear stability.

When the mass of any nucleus is measured, it is found to be a little less than the sum of the masses of the individual protons and neutrons that make it up. This difference in mass is called the mass defect. The explanation lies in Einstein's mass-energy relation E = m c^2: when the separate nucleons come together to form a nucleus, some of their mass is converted into energy, which is released, and this same amount of energy would have to be supplied again to pull the nucleus apart into its separate nucleons. This energy is called the binding energy of the nucleus, and it is a measure of how strongly the nucleons are held together. A more useful quantity is the binding energy per nucleon, obtained by dividing the total binding energy by the number of nucleons. When the binding energy per nucleon is plotted against mass number, it rises steeply for light nuclei, reaches a maximum for nuclei of medium mass (around iron), and then falls slowly for the heaviest nuclei. Nuclei with the greatest binding energy per nucleon are the most stable. This curve explains why energy is released both when a very heavy nucleus splits into medium-sized fragments (fission) and when very light nuclei join together (fusion): in both cases the products are more tightly bound than the starting materials, so energy is given out.

Q2: Describe radioactivity, the three types of radiation, and the meaning of half-life.

Radioactivity is the spontaneous disintegration of unstable atomic nuclei, accompanied by the emission of radiation. It happens without any external cause and is not affected by ordinary chemical or physical conditions such as temperature or pressure. There are three main kinds of radiation. Alpha particles are helium nuclei, consisting of two protons and two neutrons; they carry a positive charge, are relatively heavy and slow, and are easily stopped, for example by a sheet of paper. Beta particles are fast-moving electrons emitted from the nucleus; they carry a negative charge and are more penetrating than alpha particles, being stopped by a few millimetres of aluminium. Gamma rays are very high-energy electromagnetic radiation, carry no charge, and are the most penetrating, requiring thick lead or concrete to reduce them. When a nucleus emits an alpha or beta particle it turns into the nucleus of a different element, a process called radioactive decay or transmutation. Although the decay of any single nucleus is entirely random and cannot be predicted, a large sample decays in a regular way described by the half-life, which is the time taken for half of the nuclei present to decay. After one half-life half the original nuclei remain, after two half-lives a quarter, after three an eighth, and so on. Half-lives range from tiny fractions of a second to billions of years, and measuring them allows scientists to date rocks and ancient remains.

Q3: Explain nuclear fission and fusion and describe the biological effects and medical uses of radiation.

Nuclear fission and fusion are two processes that release the enormous energy stored in the nucleus. In fission, a heavy nucleus such as uranium-235 captures a slow neutron and becomes so unstable that it splits into two lighter nuclei, releasing a large amount of energy together with two or three fresh neutrons. These neutrons can go on to split further uranium nuclei, so that the process multiplies rapidly in a chain reaction. If the chain reaction is allowed to run freely it produces the explosive energy of an atomic bomb, but if it is carefully controlled, by absorbing surplus neutrons, it becomes the steady, useful source of heat in a nuclear reactor, which is used to generate electricity. In fusion, the opposite happens: two very light nuclei, such as those of hydrogen isotopes, are made to join together to form a heavier nucleus, again releasing energy; this is the process that powers the Sun and the other stars. Both processes give out energy because the products are more tightly bound than the original nuclei. The radiation from nuclear processes ionises the matter it passes through, and in living tissue this ionisation can damage or kill cells, so exposure must be kept low and shielding and safety precautions are essential. At the same time, radiation is extremely useful in medicine: small amounts of radioactive substances are used as tracers to follow the working of organs and detect disease, carefully aimed beams of gamma rays are used to destroy cancerous tumours in radiotherapy, gamma radiation is used to sterilise surgical instruments, and X-rays and gamma rays are used to form images of the inside of the body. Thus the same nuclear radiation that can be harmful, when properly controlled, saves many lives.

MCQs with Answers

1. The particles in the nucleus are called:
(a) ions (b) nucleons (c) photons (d) quanta
Correct Answer: (b) nucleons. Nucleons (protons and neutrons).

2. The atomic number is the number of:
(a) neutrons (b) protons (c) electrons only (d) nucleons
Correct Answer: (b) protons. Protons.

3. Isotopes have the same number of ___ but different neutrons:

(a) protons (b) nucleons (c) neutrons (d) mass

Correct Answer: (a) protons. Protons (same element).

4. The missing mass of a nucleus is the:

(a) binding energy (b) mass defect (c) half-life (d) isotope

Correct Answer: (b) mass defect. Mass defect.

5. Binding energy comes from the mass defect via:

(a) V = IR (b) E = m c^2 (c) F = ma (d) PV = nRT

Correct Answer: (b) E = m c^2. E = m c^2.

6. The most penetrating radiation is:

(a) alpha (b) beta (c) gamma (d) all equal

Correct Answer: (c) gamma. Gamma rays.

7. After 2 half-lives the fraction remaining is:

(a) 1/2 (b) 1/4 (c) 1/8 (d) 0

Correct Answer: (b) 1/4. 1/4.

8. Splitting a heavy nucleus is called:

(a) fusion (b) fission (c) decay (d) ionisation

Correct Answer: (b) fission. Fission.

9. The Sun's energy comes mainly from:

(a) fission (b) fusion (c) combustion (d) friction

Correct Answer: (b) fusion. Fusion.

10. A Geiger-Muller counter detects radiation by:

(a) heating (b) ionisation (c) reflection (d) refraction

Correct Answer: (b) ionisation. Ionisation of a gas.

Quick Revision Summary

- Nucleus = protons + neutrons (nucleons); Z = protons, A = nucleons, N = A - Z.
- Isotopes: same Z, different N; mass defect -> binding energy (E = m c^2).
- Radioactivity: alpha (He nucleus), beta (electron), gamma (EM, most penetrating).
- Half-life = time for half the nuclei to decay; (1/2)^n remain after n half-lives.
- Fission (heavy nucleus splits, chain reaction, reactor); fusion (light nuclei join, powers the Sun).
- Radiation ionises tissue (harmful) but is used in tracers, radiotherapy and imaging; matter = quarks + leptons, four basic forces. Notes by freebooks.pk.

Exam Tips

- Define nucleon, Z, A and N = A - Z.
- Explain mass defect and binding energy with E = m c^2.
- List the three radiations in order of penetrating power.
- Use (1/2)^n for the fraction remaining after n half-lives.
- Distinguish fission (splitting) from fusion (joining).

- Give both the dangers and medical uses of radiation.