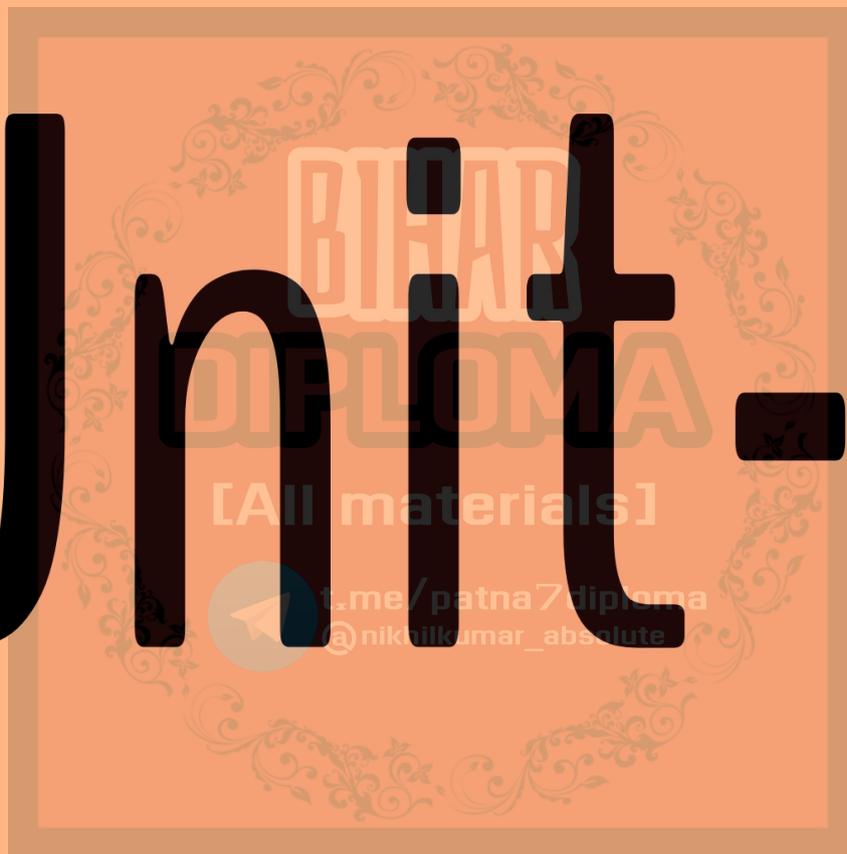


Unit-1



Wave Motion:

- Waves involve the transfer of energy through a medium without the transfer of matter
- Waves have crests (high points) and troughs (low points)
- Characteristics of waves include wavelength, frequency, period, amplitude, and speed

Transverse Waves:

- Definition: Waves where the particles of the medium vibrate perpendicular/transverse to the direction of wave travel
- Examples:
 - Water waves - the surface of the water moves up and down perpendicular to the wave direction
 - Electromagnetic waves like light, radio waves - the electric and magnetic fields oscillate perpendicular to the direction of travel
 - Seismic S-waves - particles of the ground vibrate perpendicular to the wave direction

Longitudinal Waves:

- Definition: Waves where the particles of the medium vibrate parallel/longitudinal to the direction of wave travel
- Examples:
 - Sound waves in air/solids/liquids - particles vibrate parallel to the wave direction creating compressions and rarefactions
 - Seismic P-waves - particles of the ground vibrate parallel to the wave direction

Wave Velocity:

- Definition: The speed at which the wave disturbance propagates through the medium
- Depends on properties of the medium like elasticity and density
- Different types of waves travel at different speeds in a given medium
- Wave velocity (v) = Wavelength (λ) x Frequency (f)

Frequency and Wavelength:

- Frequency (f) = number of wave cycles that pass a point per unit of time (usually seconds), units are Hertz (Hz)
- Wavelength (λ) = distance between corresponding points on adjacent waves, units are typically meters (m)
- Relationship: Wave velocity (v) = Frequency (f) x Wavelength (λ) $v = f * \lambda$
- Higher frequency means shorter wavelength and vice versa for a wave of fixed velocity

Sound Waves:

- Longitudinal mechanical waves that propagate through a medium by particle vibration parallel to wave direction
- Need a material medium to travel through (cannot travel through vacuum)
- Properties:
 - Frequency determines pitch (high frequency = high pitch)
 - Amplitude determines loudness/intensity
 - Speed depends on properties of medium (faster in solids, slower in gases)
 - Can exhibit reflection, refraction, diffraction, interference

Light Waves:

- Transverse electromagnetic waves that can travel through vacuum at speed of light ($c = 3 \times 10^8 \text{ m/s}$)
- Do not require a medium, can travel through vacuum
- Properties:
 - Range of wavelengths from radio waves (long) to gamma rays (short)
 - Visible light is a small part of the electromagnetic spectrum
 - Exhibits properties of both waves and particles (wave-particle duality)
 - Can exhibit reflection, refraction, diffraction, interference

Both are forms of wave motion that transfer energy, but sound requires a medium while light can travel through vacuum. Their properties like frequency, wavelength, and speed impact how they behave and are perceived.

Wave Equation:

- The general equation for a traveling wave is: $y = A \sin(\omega t - kx + \phi)$
- y is the displacement of the wave from equilibrium position
- A is the amplitude (maximum displacement)
- ω is the angular frequency ($\omega = 2\pi f$, where f is frequency)
- k is the wave number ($k = 2\pi/\lambda$, where λ is wavelength)
- ϕ is the phase constant/angle
- For a simple sine wave: $y = A \sin(\omega t)$, where $r = A$ is amplitude

[All materials]

Amplitude (A):



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- The maximum displacement of the wave from its resting position
- Larger amplitude means more energy in the wave

Amplitude (A):

- The maximum displacement of the wave from its resting position
- Larger amplitude means more energy in the wave

Phase ($\omega t - kx + \phi$):

- Specifies the position in the wave cycle at a given point in time
- Determines the shape of the wave pattern

Phase Difference:

- The difference in phase between two waves of same frequency
- Causes constructive or destructive interference patterns

Principle of Superposition:

- When two or more waves occupy the same region, the resulting disturbance is the vector sum of the individual waves
- Allows waves to interfere constructively (amplify) or destructively (cancel out)

Beat Formation:

- Occurs due to interference of two waves with slightly different frequencies
- The amplitude varies periodically from a maximum to a minimum value
- The frequency of the beats is: $f_{\text{beat}} = |f_1 - f_2|$
- Causes periodic variations in intensity that can be heard/observed

This covers the key concepts related to wave equations, properties like amplitude and phase, superposition principles, and the phenomenon of beat formation when waves interfere.

Simple Harmonic Motion (SHM):

- **Definition:** The periodic motion of an object where the restoring force is directly proportional to the displacement from an equilibrium position and acts in the opposite direction.
- **Examples:** Mass on a spring, simple pendulum

Displacement (x):

- The position of the object relative to its equilibrium position at any time t
- **Expression:** $x = A \cos(\omega t + \varphi)$
 - A is the amplitude (maximum displacement)
 - ω is the angular frequency ($\omega = 2\pi/T$)
 - φ is the phase constant

Velocity (v):

- Rate of change of displacement
- **Expression:** $v = -A\omega \sin(\omega t + \varphi)$

Acceleration (a):

- Rate of change of velocity
- Expression: $a = -Aw^2 \cos(\omega t + \varphi) = -(\omega^2)x$

Time Period (T):

- Time taken for one complete oscillation cycle
- Related to angular frequency ω by: $\omega = 2\pi/T$

Frequency (f):

- Number of oscillations per unit time
- $f = 1/T$

Other properties:

- Restoring force $F = -kx$ (Hooke's Law), where k is the force constant
- Total energy is constant and given by: $E = (1/2)kA^2$ [All materials]
- Simple Harmonic Motion has a constant amplitude and period
- Velocity is maximum at equilibrium, acceleration is maximum at extreme positions

Simple Harmonic Progressive Wave and Energy Transfer:

- A simple harmonic progressive wave is a traveling wave where the disturbance is a simple harmonic motion
- It transfers energy from one point to another without transferring matter
- Examples: water waves, sound waves, electromagnetic waves
- The energy is carried by the wave and gets transferred along the direction of wave propagation
- No net transfer of particles in the medium takes place, only the energy transfers

Vibration of a Cantilever and Determination of Time Period:

- A cantilever is a beam that is fixed at one end and free at the other
- It can vibrate in different modes (fundamental, overtones) depending on the driving force
- The time period (T) of vibration depends on factors like length (L), mass per unit length (m), and flexural rigidity (EI)
- For the fundamental mode: $T = 2\pi(mL^4/3EI)^{1/2}$
- The time period can be determined experimentally by measuring the oscillation time for a known number of cycles

Free, Forced, and Resonant Vibrations:

- **Free Vibrations:** System oscillates at its natural frequency after being disturbed from equilibrium
 - Example: A plucked guitar string vibrating freely
- **Forced Vibrations:** External periodic force drives the vibration at its frequency
 - Example: A child pushing a swing periodically
- **Resonance:** When the driving frequency equals the natural frequency, amplitude increases greatly
 - Example: Shattering glass with intense sound at its resonant frequency
- Damping reduces amplitude over time in free/forced vibrations unless energy is continuously supplied

Free vibrations occur naturally, forced vibrations require an external driving force, and resonance leads to maximum amplitude when the frequencies match, which can cause damage if too extreme.

Acoustics of Buildings:

- Deals with the study of sound propagation, reflection, and absorption within enclosed spaces like auditoriums, concert halls, classrooms, etc.

Reverberation:

- The persistence of sound in an enclosed space due to multiple reflections from surfaces after the sound source has stopped
- Caused by the reflections gradually decreasing in intensity as sound energy is absorbed by surfaces

Reverberation Time (RT):

- The time required for the sound pressure level to decrease by 60 dB (decibels) after the sound source has stopped
- Depends on the room volume, surface areas, and sound absorption coefficients of materials
- Too short RT causes acoustical dryness, too long causes blurring of sounds

Echo:

- The distinct repetition of a sound caused by the reflection of sound waves from a surface some distance away
- Occurs when the reflected sound arrives at the listener's ear after a delay of at least $1/15$ of a second from the direct sound
- Can be reduced by using sound-absorbing materials or irregularly shaped surfaces

Noise:

- Unwanted or excessive sound that is unpleasant or disruptive
- Can come from external sources (traffic, construction) or internal sources (HVAC systems, equipment)
- Can be controlled by using sound insulation materials, barriers, and proper room design

Coefficient of Sound Absorption:

- Measure of how much sound energy a material can absorb upon striking its surface
- Ranges from 0 (perfectly reflective) to 1 (perfectly absorptive)
- Depends on material properties like porosity, density, thickness, and frequency of sound
- Materials with higher absorption coefficients are better at absorbing sound energy

Methods to Control Reverberation Time:

1. Sound-absorbing materials:

- Adding materials with high absorption coefficients like acoustical tiles, carpets, curtains
- Effective at absorbing reflected sound energy and reducing reverberation
- Applications: auditoriums, concert halls, recording studios

2. Diffusion/scattering techniques:

- Using irregularly shaped surfaces or diffusers to scatter sound waves in different directions
- Prevents flutter echoes and excessive reflections
- Applications: concert halls, home theaters, recording studios

3. Room volume and surface area

adjustments:

- Increasing or decreasing room volume and surface areas to achieve desired reverberation time
- Larger volumes and more absorptive surfaces lead to shorter reverberation times
- Applications: auditoriums, places of worship, classrooms

4. Electroacoustic techniques:

- Using microphones and loudspeakers with signal processing to adjust reverberation electronically
- Allows for variable reverberation control based on requirements
- Applications: performance venues, recording studios, concert halls

Ultrasonic Waves - Introduction and

Properties:

- Ultrasonic waves are sound waves with frequencies above the upper audible limit for humans (>20 kHz)
- They propagate as mechanical vibrations in elastic media like solids, liquids, or gases
- Properties:
 - High frequencies allow shorter wavelengths for better resolution
 - Can propagate over long distances with little attenuation in some media
 - Interact with matter through reflection, refraction, scattering, and absorption
 - Non-ionizing radiation, considered safe for most applications

Engineering Applications of Ultrasonic

Waves:

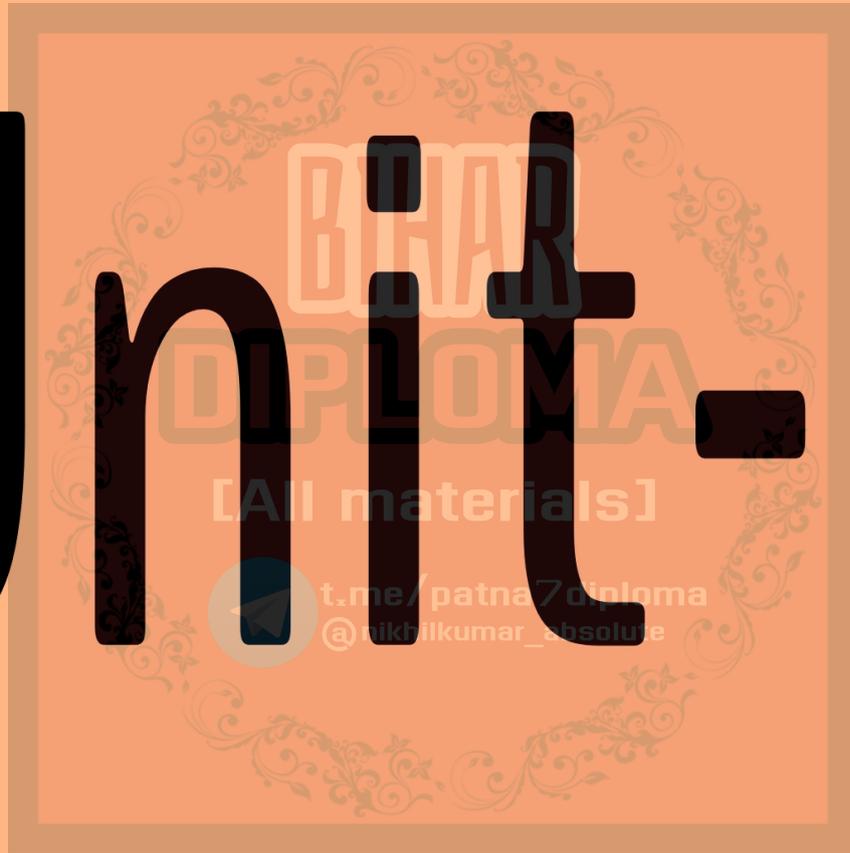
- **Non-Destructive Testing (NDT):** Used to detect flaws, cracks, or defects in materials like metals, composites, and structures without damaging them
- **Level Measurement:** Ultrasonic waves are used to measure the level of liquids or solids in tanks or silos
- **Cleaning:** High-intensity ultrasound can be used for cleaning surfaces, tools, or components through cavitation
- **Welding:** Ultrasonic welding uses high-frequency vibrations to join materials like plastics or metals
- **Ranging and Detection:** Used in sonar systems for underwater ranging, detection, and imaging

Medical Applications of Ultrasonic Waves:

- **Diagnostics:** Ultrasound imaging (sonography) uses high-frequency sound waves to visualize internal body structures and organs for diagnosis
- **Therapy:** High-intensity focused ultrasound (HIFU) can be used for targeted heating and destruction of tissues for treating certain conditions
- **Fetal Monitoring:** Doppler ultrasound is used to monitor fetal heartbeat and movement during pregnancy
- **Lithotripsy:** Ultrasonic shock waves are used to break up kidney stones or gallstones in the body
- **Dental Cleaning:** Ultrasonic scalers use high-frequency vibrations for removing plaque and tartar from teeth

Ultrasonic waves find diverse applications in engineering and medicine due to their unique properties, ability to penetrate and interact with materials, and their non-invasive and non-destructive nature in many cases.

Unit-2



Basic Optical Laws

- Laws of Reflection
 - Angle of incidence equals angle of reflection
 - Incident ray, reflected ray, and normal lie in the same plane
- Laws of Refraction (Snell's Law)
 - Relationship between angles of incidence, refraction, and refractive indices

Reflection and Refraction

- Reflection - bouncing off a surface
- Refraction - bending of light as it passes from one medium to another

Refractive Index

- Measure of how much the speed of light is reduced in a medium
- Absolute refractive index = $\frac{\text{speed of light in vacuum}}{\text{speed in medium}}$
- Used in Snell's law to predict refraction angles

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Images and Image Formation by Mirrors

- Plane mirrors produce virtual, upright, same-size images
- Concave mirrors can produce real, inverted, smaller or larger images
- Convex mirrors always produce virtual, upright, smaller images

Lens and Thin Lenses

- Converging (convex) lenses cause parallel rays to converge
- Diverging (concave) lenses cause parallel rays to diverge
- Thin lens approximation ignores lens thickness

Lens Formula

- $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$
 - f is focal length, u is object distance, v is image distance

Power of Lens

- Power = $1/\text{focal length (in meters)}$
- Unit is diopters (D)

Magnification

- Ratio of image height to object height
- For lenses: $m = v/u$
- For mirrors: $m = v/u$ (real images), $m = -v/u$ (virtual images)

Defects

- Spherical aberration - edges of lenses/mirrors focus differently
- Coma - off-axis rays not focusing properly
- Astigmatism - different foci for different planes
- Chromatic aberration - different wavelengths focusing differently
- Distortion - image appearing curved/stretched



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[All materials]

Total Internal Reflection

- Phenomenon where light traveling from a denser medium to a rarer medium is completely reflected back into the denser medium
- Occurs when the angle of incidence exceeds the critical angle

Critical Angle

- Angle of incidence in the denser medium beyond which total internal reflection occurs
- Defined by: $\sin(\text{critical angle}) = n_2/n_1$
 - n_1 is refractive index of denser medium
 - n_2 is refractive index of rarer medium
- Total internal reflection only occurs if $n_1 > n_2$

Conditions for Total Internal Reflection

1. Light must travel from a denser to rarer medium
2. Angle of incidence must exceed the critical angle
3. Boundary between mediums must be very smooth/unobstructed

Applications in Optical Fibers

- Optical fibers rely on repeated total internal reflection to transmit light signals over long distances
- Fiber core has higher refractive index than cladding layer
- Light is injected into the core at an acceptable angle
- Total internal reflection "traps" and guides light down fiber with minimal loss
- Used for telecommunications, internet, cable TV, computer networks, sensors, etc.

Key Points:

- Cladding refractive index must be lower than core
- Signals can travel long distances with little attenuation
- Bending must be gentle to maintain acceptable angles
- Higher refractive index difference gives more efficient guiding

Simple Microscope

- Uses a single convex lens to magnify small objects
- Lens is placed close to the object, within its focal length
- Gives an upright, virtual, and magnified image

Compound Microscope

- Uses two lens systems - objective and eyepiece
- Objective forms a real, inverted, and magnified image
- Eyepiece further magnifies the real image from objective
- Final image is inverted and virtual



Astronomical Telescope in Normal Adjustment

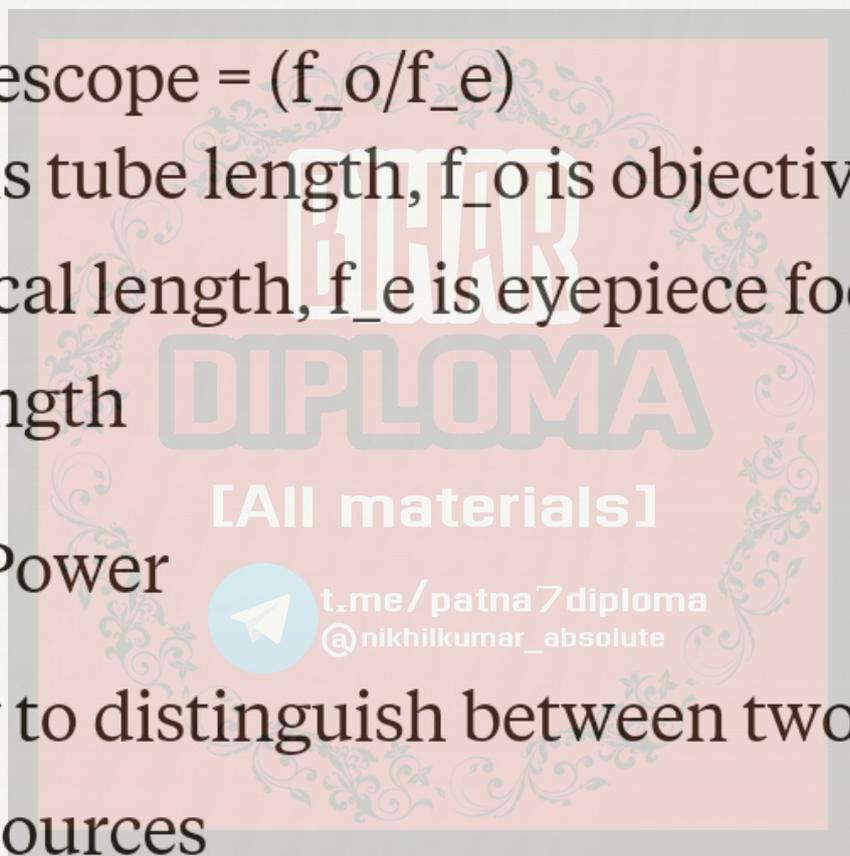
- Objective (large lens) forms real, inverted image of distant object
- Eyepiece magnifies and renders the final virtual image upright
- Large objective gathers more light for better resolution

Magnifying Power

- For microscope = $(L/f_o) * (1/f_e)$
- For telescope = (f_o/f_e)
 - L is tube length, f_o is objective focal length, f_e is eyepiece focal length

Resolving Power

- Ability to distinguish between two close point sources
- Higher for larger diameter objective lens/mirror



Uses of Microscope

- Study micro organisms, biological specimens
- Examine micro-structures of materials
- Quality control, failure analysis

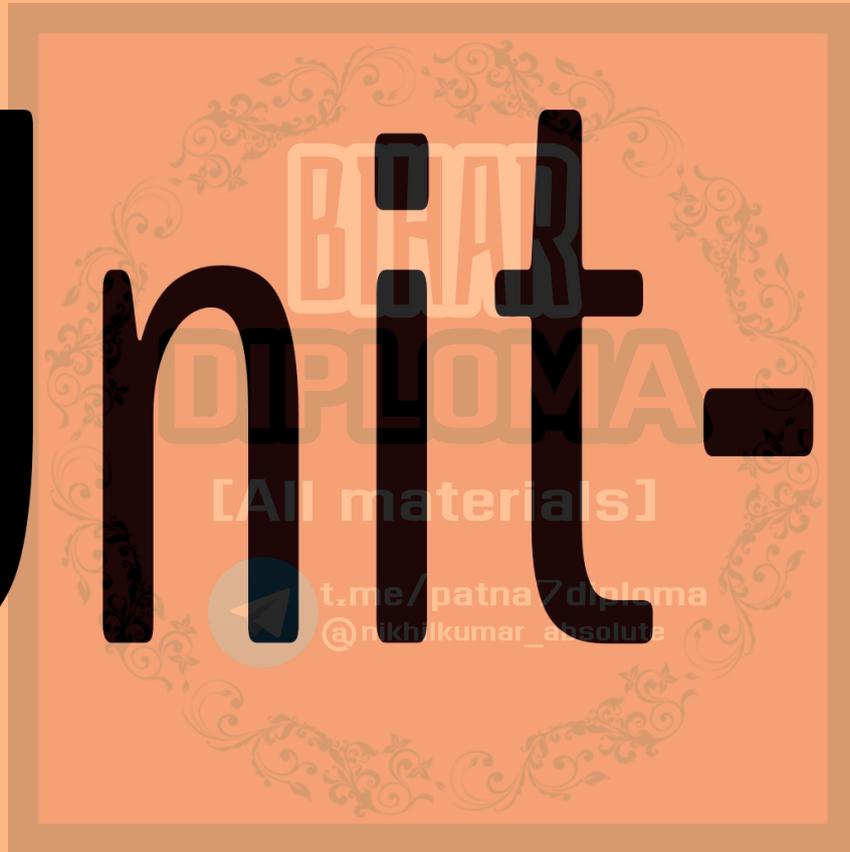
Uses of Telescope

- View celestial objects like planets, stars, galaxies
- Earth observation from satellites
- Track objects in space

Optical Projection Systems

- Project real images from slides/films onto screens
- Use condenser lens to focus light through slide
- Projection lens forms enlarged real image on screen
- Used in projectors, opaque projectors, overhead projectors

Unit-3



Coulomb's Law:

- Describes the electrostatic force between two charged particles
- Force is directly proportional to the product of the charges and inversely proportional to the square of the distance between them
- $F = k(q_1q_2)/r^2$
- k is the Coulomb constant

Unit of Charge:

- The fundamental unit of charge is the coulomb (C)
- $1\text{ C} = \text{charge of } 6.24 \times 10^{18} \text{ electrons}$ (approx)
- Charge is quantized, existing as integral multiples of electron charge ($1.6 \times 10^{-19}\text{ C}$)

Electric Field:

- The region around a charged particle where electric force can be experienced
- At any point, electric field strength is force per unit charge
- $E = F/q$
- Field lines point away from positive charges, towards negative charges
- Units are N/C

Electric Lines of Force and Properties:

- Visualization of electric field, tangential to field at each point
- Properties:
 - Originate from positive charges, terminate on negative charges
 - Never cross each other
 - Closer together where field is stronger
 - Perpendicular to any equipotential surface
- Electric field is strongest where lines are most dense

Electric Flux:

- Amount of electric field passing through a given area
- Defined mathematically as the electric field integrated over the area
- Units are Nm^2/C
- Related to the number of electric field lines passing through area
- Gauss's Law relates flux to enclosed charge

Electric Potential:

- Potential energy per unit charge associated with the electric field
- Measured in volts ($V = \text{J}/\text{C}$)
- Potential due to a point charge is kQ/r
- Equipotential surfaces are surfaces with the same potential value
- Potential is highest nearest positive charges, lowest nearest negative charges

Potential Difference:

- Work required to move a unit charge between two points, against/along electric field
- Voltage is another term for potential difference
- Caused by separation of positive and negative charges
- Measured in volts (V)
- Can be calculated by path integral of $E \cdot dl$ between the two points
- Allows electrical energy to be stored/converted in a circuit

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Gauss Law Application:

1. Straight Charged Conductor:

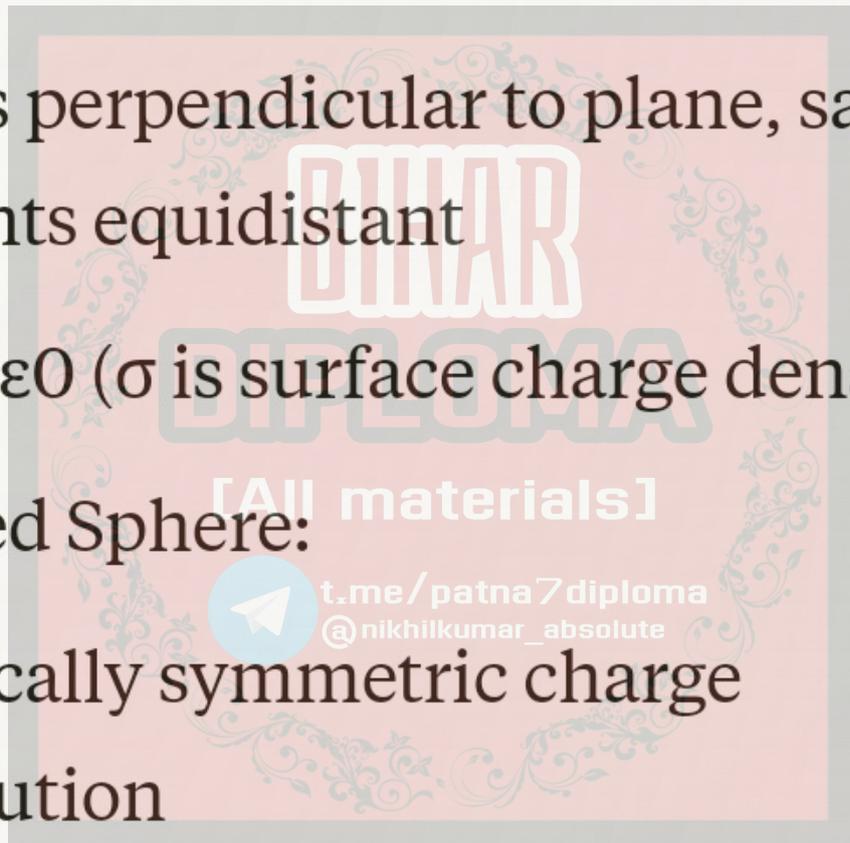
- Infinite line of uniform charge density
- Field at any point is perpendicular to the line
- $E = \lambda/2\pi\epsilon_0 r$ (λ is linear charge density)

2. Infinite Plane Sheet:

- Infinite planar sheet with uniform surface charge density
- Field is perpendicular to plane, same at all points equidistant
- $E = \sigma/2\epsilon_0$ (σ is surface charge density)

3. Charged Sphere:

- Spherically symmetric charge distribution
- Field outside is kQ/r^2 (Coulomb's law)
- Field inside is zero by Gauss's law



Capacitors and Working:

- Capacitor stores electric charge and energy in electric field
- Formed by two conductors separated by insulator (dielectric)
- Capacitance $C = Q/V$ (ratio of charge to potential difference)
- Parallel plate capacitor: $C = \epsilon_0 A/d$
- When charged, electric field between plates is $E = \sigma/\epsilon_0$
- Dielectric increases capacitance by factor k (relative permittivity)
- Energy stored in capacitor is $U = 1/2 QV$
 $= 1/2 CV^2$

Types of Capacitors:

- Parallel plate
- Cylindrical
- Spherical
- Electrolytic
- Ceramic
- Paper
- Mica

Capacitance and Units:

- Capacitance (C) is the ability to store charge
- Unit is Farad (F) = Coulomb/Volt
- 1F = Charge of 1C at 1V potential difference

Parallel Plate Capacitor Capacitance:

- $C = \epsilon_0 \epsilon_r A/d$ [All materials]
- ϵ_0 = permittivity of free space
- ϵ_r = relative permittivity of dielectric
- A = area of plates
- d = separation between plates

Series Combination:

- $1/C_{eq} = 1/C_1 + 1/C_2 + 1/C_3 + \dots$
- Works like resistors in parallel

Parallel Combination:

- $C_{eq} = C_1 + C_2 + C_3 + \dots$
- Works like resistors in series

Dielectric and Effect:

- Dielectric increases capacitance by factor $k = \epsilon_r$
- Polarized molecules slightly cancel internal E-field
- More charge can be stored at same voltage

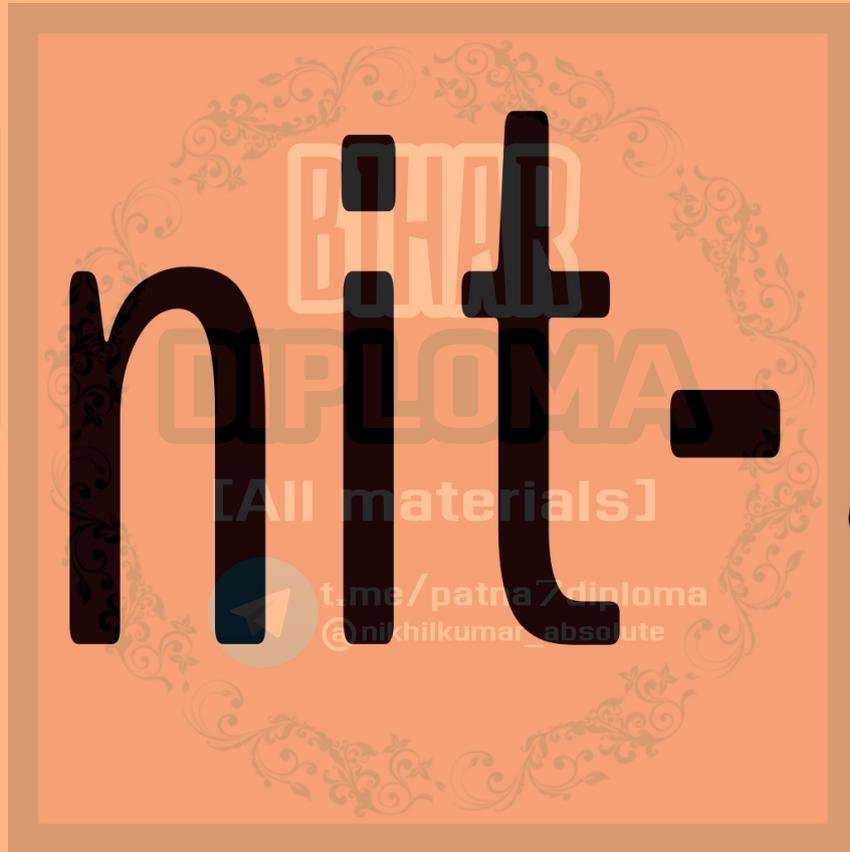
Dielectric Breakdown:

- At high fields, dielectric ionizes and allows discharge
- Breakdown voltage depends on dielectric material
- Causes arcing, damages capacitor

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Electric Current and its Units:

- Electric current is the flow of electric charge carriers (electrons) through a conductor
- Unit of electric current is the ampere (A)
- 1 ampere = flow of 1 coulomb of charge per second

Direct and Alternating Current:

- Direct Current (DC):
 - Electrons flow in one constant direction
 - Examples: batteries, DC power supplies
- Alternating Current (AC):
 - Electrons periodically reverse direction
 - Examples: household outlets, power grids t.me/patna7diploma @nikhilkumar_absolute
 - AC changes direction following a sine wave
 - Frequency of AC is measured in Hertz (Hz)

Resistance and its Units:

- Resistance is the opposition to the flow of electric current in a conductor
- Unit of resistance is the ohm (Ω)
- Higher resistance allows less current flow
- Resistance depends on material properties and geometry of the conductor
- Ohm's Law: $V = IR$ (Voltage = Current * Resistance)



Specific Resistance:

- Specific resistance (resistivity) is the resistance to current flow for a given material
- Unit is ohm-meter ($\Omega\text{-m}$)
- Depends on the atomic structure and temperature of the material
- Higher specific resistance means lower conductivity

Conductance:

- Conductance is the inverse of resistance
- Unit is Siemens (S)
- Conductance = $1/\text{Resistance}$

Specific Conductance:

- Specific conductance is the conductance of a 1 meter cube of a material
- Unit is Siemens/meter (S/m)
- Specific conductance = $1 / \text{Specific resistance}$

Series Combination of Resistances:

- In a series circuit, the total resistance is the sum of the individual resistances
- $R_T = R_1 + R_2 + R_3 + \dots$

Parallel Combination of Resistances:

- In a parallel circuit, the total conductance is the sum of the individual conductances
- $1/R_T = 1/R_1 + 1/R_2 + 1/R_3 + \dots$
- Equivalent to resistors combining as $1/(1/R_1 + 1/R_2 + \dots)$

Factors Affecting Resistance of a Wire:

- Material of the wire (resistivity)
- Length of the wire (longer = more resistance)
- Cross-sectional area of the wire (smaller area = more resistance)
- Temperature (resistance increases as temperature increases for most materials)

Carbon Resistances:

- Made from a compact cylindrical rod of carbon composition
- Carbon is a good resistor material due to its high resistivity
- Value is determined by the ratio of carbon and insulating binder
- Not as stable or precise as metal film resistors

Resistor Color Coding:

- Resistors have colored bands that represent their resistance value
- Color code (4-band example): Brown-Black-Red-Gold
 - Brown=1, Black=0, Red= 2×100 , Gold= $\pm 5\%$ tolerance
 - Value = $12 \times 100 \Omega = 1200 \Omega \pm 5\%$
- Other colors: Orange, Yellow, Green, Blue, Violet, Gray, White
- More bands can represent more precise values and temperature coefficients

Ohm's Law and its Verification:

- Ohm's Law: $V = IR$ (Voltage = Current * Resistance)
- Can be verified experimentally by measuring V, I, and calculating R
- Hold two variables constant and vary the third to see relationship

Kirchhoff's Laws:

- Kirchhoff's Current Law (KCL):
 - Sum of currents entering a node equals sum of currents leaving the node
 - Useful for analyzing circuit junctions
- Kirchhoff's Voltage Law (KVL):
 - Sum of voltage drops around a closed loop equals the voltage source
 - Useful for analyzing voltage drops across components

Wheatstone Bridge and its Applications:

- Used to measure unknown electrical resistance
- Compares unknown resistance to known resistor values
- Made of four resistors with a galvanometer to detect zero current
- To balance, $R_x/R_1 = R_2/R_3$ (resistance ratio balanced)

Slide Wire Bridge:

- Special type of Wheatstone bridge
- One resistance is a uniform wire over a meter stick
- Unknown resistance balanced by sliding contact position on the wire
- Useful for showing resistance proportional to wire length



Applications:

- Measuring unknown resistor values
- Testing materials/conductors
- Strain gauge sensors (small resistance changes)
- Thermistors (temperature sensing)

Concept of Terminal Potential Difference and Electromotive Force (EMF):

- Terminal Potential Difference: Voltage across the terminals of a source when no current is flowing
- Electromotive Force (EMF): The force that drives electric current to flow in a circuit
- EMF is the work done to move a unit charge around the complete circuit
- EMF is a property of the source, while terminal potential difference depends on the load

Heating Effect of Current:

- Current flowing through a resistance generates heat (thermal energy)
- Caused by collisions of electrons with atoms in the conductor
- Amount of heat produced is proportional to: current squared x resistance x time
- Can be useful (heaters, filaments) or problematic (overheating)

Electric Power:

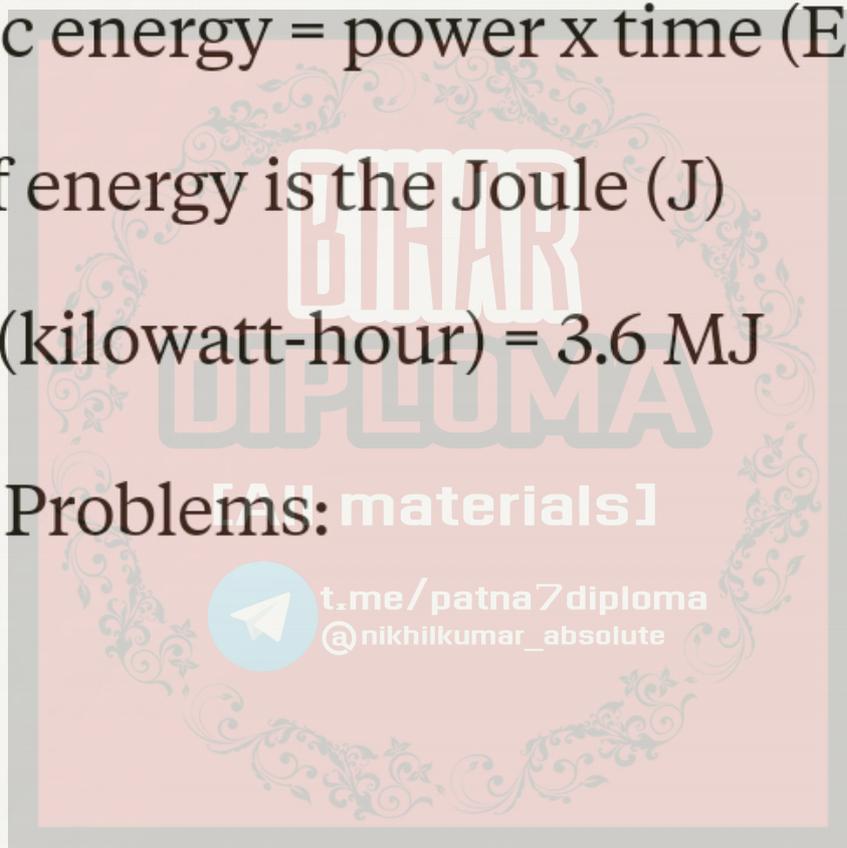
- Power is the rate of energy conversion/transfer
- Electric power = current x voltage ($P = IV$)
- Unit of power is the Watt (W)

Electric Energy and Units:

- Energy is the capacity to do work
- Electric energy = power x time ($E = Pt$)
- Unit of energy is the Joule (J)
- 1 kWh (kilowatt-hour) = 3.6 MJ

Numerical Problems:

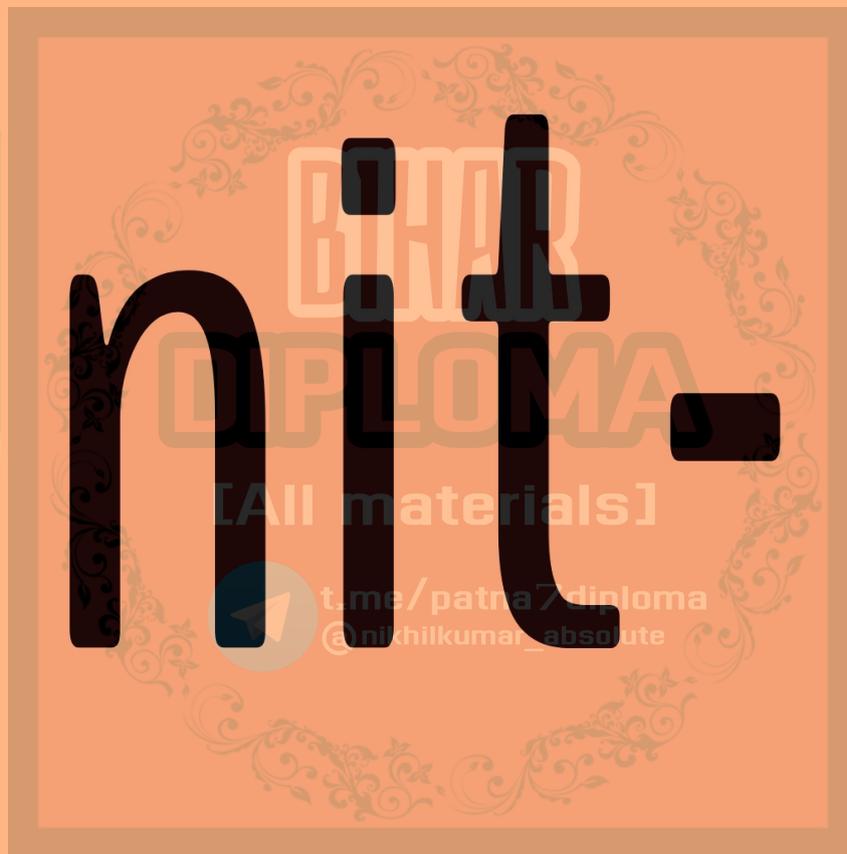
- $P = IV$
- $E = Pt$
- Substitute and solve for unknown quantity



Advantages of Electric Energy:

- Can be transmitted efficiently over long distances
- Pollution-free at the point of use
- Can be converted easily to other forms (heat, light, motion)
- Available through renewable (hydro, solar, wind) and non-renewable sources

Unit-5



Types of Magnetic Materials:

1. Diamagnetic Materials:

- Properties:
 - They are weakly repelled by an external magnetic field.
 - They have a relative magnetic permeability slightly less than 1 ($\mu_r < 1$).
 - They exhibit a negative magnetic susceptibility ($\chi < 0$).
- Examples: Copper, gold, silver, water, and most organic compounds.

2. Paramagnetic Materials:

- Properties:
 - They are weakly attracted to an external magnetic field.
 - They have a relative magnetic permeability slightly greater than 1 ($\mu_r > 1$).
 - They exhibit a small positive magnetic susceptibility ($\chi > 0$).
 - The magnetic moment is induced by an external magnetic field and disappears when the field is removed.
 - Examples: Aluminum, platinum, oxygen, and materials containing transition metal ions.

3. Ferromagnetic Materials:

- Properties:

- They exhibit strong attraction to an external magnetic field.
- They have a large positive magnetic susceptibility ($\chi \gg 0$).
- They possess a spontaneous magnetization even in the absence of an external magnetic field (due to the parallel alignment of atomic magnetic moments).
- They can be permanently magnetized and retain their magnetization after the removal of an external magnetic field.
- They exhibit magnetic hysteresis, which means that the magnetization depends on the magnetic field history.
- Examples: Iron, nickel, cobalt, and some alloys (e.g., alnico, permalloy).

Magnetic Field and Units

- Magnetic field is the region around a magnet or current-carrying conductor where magnetic force exists
- Measured in teslas (T) in SI units or gauss (G) in CGS units
- $1\text{ T} = 10,000\text{ G}$

Magnetic Intensity (H)

- The magnetic field strength inside a magnetic material
- Measured in amperes per meter (A/m)
- Related to the magnetic field B by the equation: $B = \mu_0(H + M)$ where M is the magnetization

Magnetic Lines of Force

- Imaginary lines used to visualize the magnetic field
- Come out of N-pole and enter into S-pole of a magnet
- Never cross each other
- More concentrated where the magnetic field is stronger

Magnetic Flux (Φ) and Units

- The total magnetic field passing through a given area
- Units are webers (Wb) or tesla-meter² (T.m²)
- Calculated by $\Phi = B.A.\cos\theta$ where B is field, A is area, θ is angle between B and area

Magnetization (M)

- The vector field that expresses the density of permanent or induced magnetic dipole moments in a magnetic material
- Measured in amperes per meter (A/m)

Concept of Electromagnetic Induction

- Principle of production of electromotive force due to changing magnetic flux linkage
- Established by Michael Faraday's experiments

Concept of Electromagnetic Induction

- Principle of production of electromotive force due to changing magnetic flux linkage
- Established by Michael Faraday's experiments
- Underlies the operation of generators, inductors, transformers
- Faraday's Law: The induced EMF is directly proportional to the rate of change of magnetic flux

Faraday's Laws

Faraday's Law of Electromagnetic Induction:

- States that the induced EMF in a conductor is equal to the rate of change of magnetic flux linkage
- Mathematically: $EMF = -N(d\Phi/dt)$
Where N is number of turns, Φ is magnetic flux
- Underlies the operation of generators, inductors, transformers

Lenz's Law:

- States that the direction of induced current is so as to oppose the change in magnetic flux causing it
- Used to determine the direction of induced current

Lorentz Force

- The force experienced by a charged particle moving in a magnetic field
- Combines both electric and magnetic forces on the particle
- Given by the Lorentz force equation: $F = q(E + v \times B)$ Where q is charge, E is electric field, v is velocity, B is magnetic field
- The magnetic force component is: $F = qvB\sin\theta$ Where θ is the angle between v and B
- Causes charged particles to experience a force perpendicular to their velocity and the B field
- Underlies the operation of particle accelerators, mass spectrometers, TV tubes, etc.
- The magnetic force does no work (always perpendicular to v), but can cause circular motion

Force on Current-Carrying Conductor

- A current-carrying conductor experiences a force when placed in a magnetic field
- The force is given by: $F = BIL \sin\theta$ Where
B is the magnetic field strength I is the current L is the length of the conductor
 θ is the angle between B and the conductor
- The force is perpendicular to both the field B and the current I
- It follows the Fleming's left-hand rule
- Used in motors, loudspeakers, meters to measure current

Force on a Rectangular Coil in a Magnetic Field

- A rectangular coil with N turns carrying current I in a magnetic field B experiences a net force
- The net force is the sum of forces on the two longer straight sections of the coil
- Force on each side = $BNIZ \sin \theta$ Where N is number of turns I is current Z is length of side θ is angle between side and B field
- The net force is: $F = 2NBIAZ \sin \theta$ Where A is the area of the coil
- The force tries to rotate the coil to align its area vector parallel to B
- Basis of operation of electric motors and galvanometers
- Also used to define one tesla unit of magnetic field strength

Moving Coil Galvanometer

Principle:

- It works on the principle of electromagnetic induction
- A small coil of wire suspended between the poles of a permanent magnet experiences a torque when current flows through it

Construction:

- Cylindrical coil of many turns of insulated wire
- The coil is suspended between curved pole pieces of a permanent magnet by a thin phosphor-bronze strip
- A spiral spring provides the restoring torque
- A lightweight aluminum pointer attached to the coil moves over a calibrated scale

Working:

- When current flows through the coil, it experiences a torque proportional to the current
- Torque = $NBIA \sin\theta$ Where N = number of turns, B = magnetic field, A = area of coil, I = current, θ = angle between B and A
- The coil rotates until the restoring torque of the spring balances the electromagnetic torque
- Angle of rotation is proportional to the current, giving a current measurement

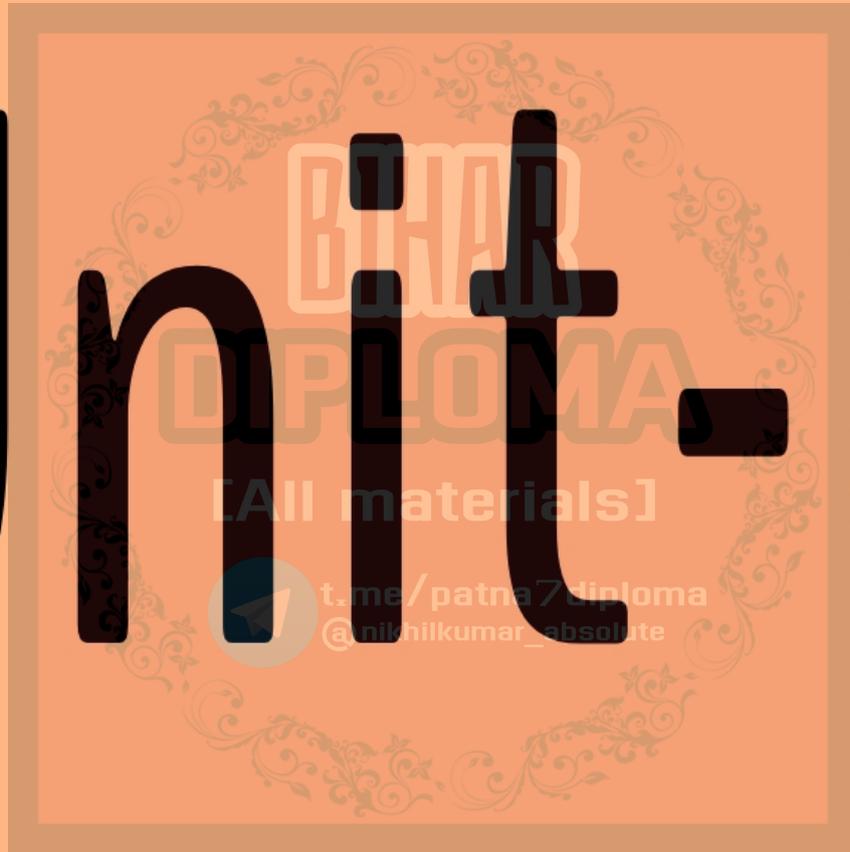
Conversion to Ammeter:

- A small resistance R_s is connected in parallel with the coil
- Most of the current passes through R_s , small fraction through coil
- Scale is calibrated to measure larger currents based on R_s value

Conversion to Voltmeter:

- A high resistance R_{sh} is connected in series with the coil
- This limits the full current through the coil for higher voltage measurements
- Scale is calibrated to measure voltages across R_{sh} based on $I = V/R_{sh}$

Unit-6



Energy Bands in Solids:

- In solid materials, the atomic orbitals of individual atoms combine and form energy bands.
- The highest range of energy levels occupied by electrons is called the valence band.
- The higher energy level above the valence band is called the conduction band.
- In conductors, the valence and conduction bands overlap, allowing electrons to flow freely.
- In insulators, there is a large energy gap between the valence and conduction bands, preventing electron flow.
- In semiconductors, the energy gap is smaller, allowing some electron excitation and conduction at higher temperatures.

Types of Materials:

1. Insulators

- Have a large energy gap (>4 eV) between valence and conduction bands
- Electrons cannot easily gain enough energy to jump the gap
- Poor conductors of electricity and heat (e.g. rubber, glass, plastics)

2. Semiconductors

- Have a smaller energy gap (0.5 - 3 eV)
- Some electrons can gain enough thermal energy to jump the gap
- Their conductivity can be controlled by doping with impurities
- Examples: silicon, germanium, gallium arsenide

3. Conductors

- Valence and conduction bands overlap with no energy gap
- Electrons can flow freely, enabling good electrical and thermal conductivity
- Examples: metals like copper, aluminum, gold

Intrinsic and Extrinsic Semiconductors:

- Intrinsic semiconductors are extremely pure with no doping agents added.
- Extrinsic semiconductors are doped by adding impurities to create n-type or p-type regions.
- N-type: Doped with pentavalent impurities (e.g. phosphorus in silicon) that provide extra free electrons.
- P-type: Doped with trivalent impurities (e.g. boron in silicon) that create electron deficiencies or "holes".

P-N Junction:

- Formed when p-type and n-type semiconductor regions are joined together.
- Holes from the p-side diffuse into the n-region and combine with electrons (forming a depletion region).
- Prevents further diffusion of charge carriers, creating a potential barrier.
- Acts as an insulator with no bias voltage applied.

Junction Diode and V-I Characteristics:

- A p-n junction forms a simple semiconductor diode.
- Under forward bias (p-side positive), electrons are repelled from n-region and holes from p-region, allowing current flow.
- Under reverse bias (n-side positive), the depletion region widens, preventing current flow (except for a small leakage current).
- V-I Characteristics:
 - Forward Biased: Exponential increase in current with voltage (ohmic at high voltages).
 - Reverse Biased: Very small leakage current (until breakdown voltage).

Applications of Junction Diodes:

- Used for rectification of AC to DC.
- LED operation (by forward biasing to allow recombination of electrons/holes).
- Used in circuits like clippers, clampers, voltage multipliers.

Types of Junction Diodes:

1. Signal Diode (e.g. 1N914, 1N4148)

- Used for small signal applications like rectification, clamping, clipping
- Low reverse breakdown voltage and current

2. Power Diode (e.g. 1N4001, 1N5408)

- Can handle higher currents and reverse voltages
- Used for power supplies, motor controls

3. Zener Diode

- Designed for operating in reverse breakdown region
- Used for voltage regulation and protection circuits

4. Light Emitting Diode (LED)

- Emits light when forward biased due to electron-hole recombination

5. Photodiode

- Generates current when exposed to light (photovoltaic mode)

6. Schottky Diode

- Forms a metal-semiconductor junction
- Has lower forward voltage drop and faster switching

Diodes as Rectifiers:

Half-Wave Rectifier

- Uses a single diode to convert AC to pulsating DC
- During positive half-cycle, diode is forward biased and conducts
- During negative half-cycle, diode is reverse biased and blocks current
- Output is a half-wave rectified voltage

Full-Wave Rectifier

- Uses two diodes (or four arranged as a bridge)
- For center-tapped full-wave: AC supplied to center tap of transformer
- One diode conducts during positive half-cycle
- Other diode conducts during negative half-cycle
- Output is a full-wave rectified voltage (smoother than half-wave)

The rectified outputs still have AC ripples which can be smoothed out using filtering capacitors to get steady DC.

Transistor:

- A three-terminal semiconductor device used to amplify or switch electronic signals and electrical power.
- Three terminals: Base (B), Collector (C), Emitter (E)
- Controls the flow of current/carriers between C and E by varying the base current/voltage

Types:

1. N-P-N Transistor

- Formed by sandwiching a thin p-type region between two n-type regions
- Electrons are the majority carriers

2. P-N-P Transistor

- Formed by sandwiching a thin n-type region between two p-type regions
- Holes are the majority carriers

Electronic Applications (listed):

- Amplifiers (audio, RF, operational)
- Switching circuits (digital logic gates)
- Voltage regulators
- Oscillators
- Power control (motor drives, power supplies)
- Pulse generators and timers
- Radio transmitters and receivers
- Memory and storage devices
- Signal modulation/demodulation
- Analog and digital computation circuits

In both n-p-n and p-n-p transistors, a small base current controls a much larger collector-emitter current, enabling amplification and switching functions.

Transistors are fundamental building blocks in modern electronics.

Photocells (Photodiodes/Photoconductors):

Working Principle:

- Made of semiconductor materials like silicon, germanium, etc.
- Absorb photons from incident light, creating electron-hole pairs
- The electron-hole pairs are separated by an internal electric field
- This generates a flow of current, proportional to the light intensity

Applications:

- Light sensors and detectors
- Optical communications (fiber optics)
- Night vision devices
- Burglar alarm systems
- Automatic lighting controls
- Scanning and imaging devices

Solar Cells:

Working Principle:

- Based on the photovoltaic effect
- Made of p-n junction semiconductor materials (silicon, gallium arsenide, etc.)
- Photons from sunlight are absorbed, creating electron-hole pairs
- The built-in electric field of the p-n junction separates the charges
- This generates a voltage/current, converting solar energy to electrical energy

Applications:

- Photovoltaic (PV) systems for electricity generation
- Solar panels for residential, commercial and utility-scale power plants
- Solar-powered devices (calculators, watches, lighting, etc.)
- Space satellites and spacecraft
- Solar water heating systems
- Building-integrated photovoltaics (BIPV)

Unit-7



Lasers:

Energy Levels:

- Atoms/molecules have discrete energy levels they can occupy
- An electron can absorb a photon and jump to a higher energy level (excitation)
- Or it can drop to a lower level by emitting a photon

Ionization and Excitation Potentials:

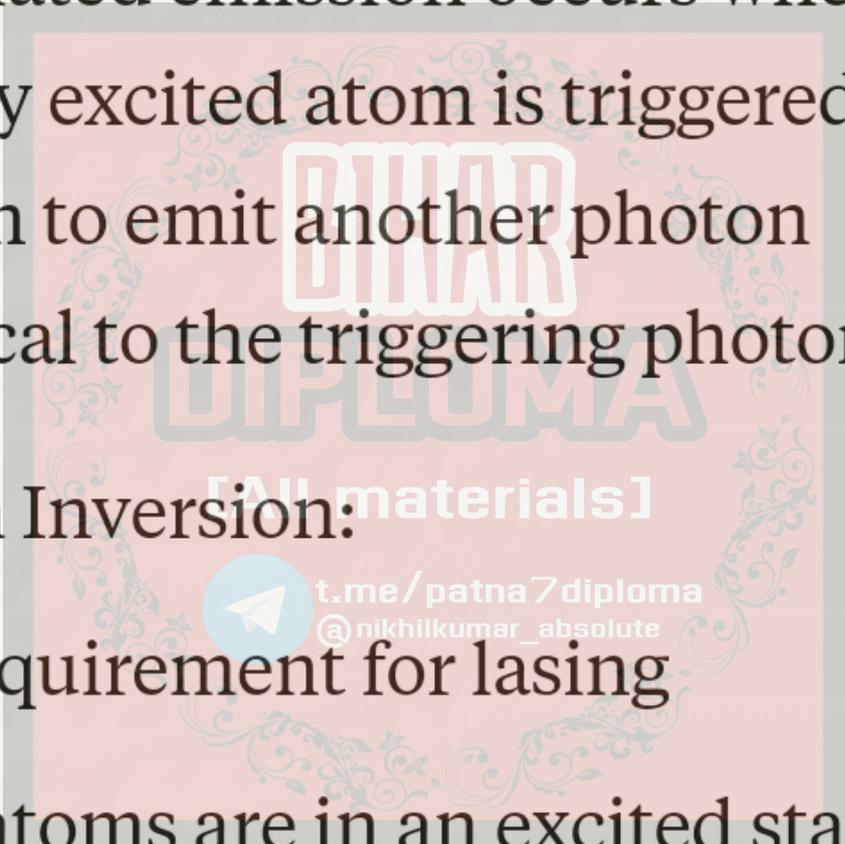
- Ionization potential is the minimum energy needed to remove an electron from an atom
- Excitation potential is the energy needed to move an electron to a higher bound state

Spontaneous and Stimulated Emission:

- Spontaneous emission occurs when an excited electron drops to a lower level, emitting a photon randomly
- Stimulated emission occurs when an already excited atom is triggered by a photon to emit another photon identical to the triggering photon

Population Inversion:

- Key requirement for lasing
- More atoms are in an excited state than in the ground state
- Achieved through pumping methods



Pumping Methods:

- Optical pumping (using another laser)
- Electrical discharge (in gas lasers)
- Injection pumping (in semiconductor lasers)

Optical Feedback:

- Photons from stimulated emission are reflected back into the laser medium by mirrors
- Triggers more stimulated emission and amplification of coherent light

Types of Lasers:

Ruby Laser

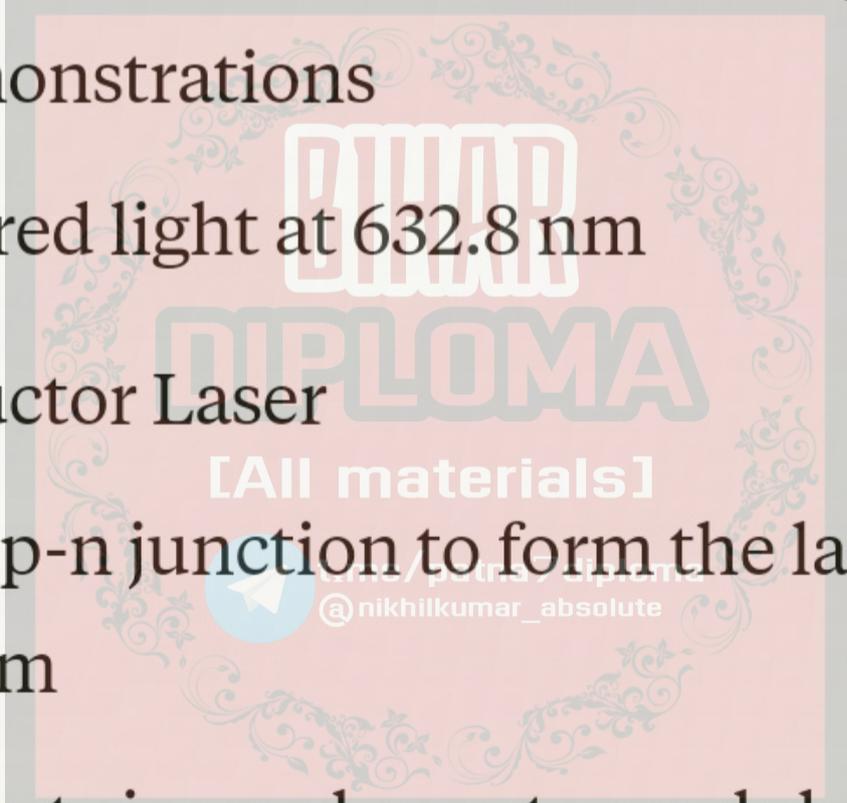
- One of the first lasers demonstrated in 1960
- Lasing medium is a synthetic ruby crystal
- Optically pumped by a xenon flash lamp

He-Ne Laser

- Gas laser with a mixture of helium and neon
- Continuous wave laser commonly used in demonstrations
- Emits red light at 632.8 nm

Semiconductor Laser

- Uses a p-n junction to form the lasing medium
- Compact size and easy to modulate
- Used in CD/DVD players, laser pointers, fiber optics



Laser Characteristics:

- Monochromatic (single wavelength)
- Coherent (waves have a fixed phase relationship)
- Highly collimated beam (low divergence)

Engineering Applications:

- Surveying and leveling instruments
- Laser cutting, welding, and drilling of materials
- Data transmission over fiber optic cables
- Laser printing and scanning (e.g. barcode scanners)
- Laser shows and holography

Medical Applications:

- Laser surgery (e.g. LASIK eye surgery, tumor removal)
- Laser treatments (e.g. skin resurfacing, hair removal)
- Photodynamic therapy for cancer
- Vision correction (e.g. LASIK, PRK)
- Diagnostic tools like laser Doppler
- Laser capture microdissection

Fiber Optics:

Introduction to Optical Fibers

- Thin strands of transparent material (glass/plastic) used to guide light
- Consist of core and cladding layers with different refractive indices

Light Propagation

- Light is propagated by total internal reflection at the core-cladding interface
- Allows very low optical loss over long distances

Acceptance Angle and Numerical Aperture

- Acceptance angle is the maximum angle that light can enter the fiber core
- Numerical aperture (NA) defines the light gathering ability of the fiber
- $NA = n_0 * \sin(\theta_{max})$ [n_0 = core refractive index, θ_{max} = max acceptance angle]

Fiber Types

- Step-index (sharp refractive index change at core-clad boundary)
- Graded-index (refractive index gradually decreases from core to cladding)
- Single-mode (thin core, one propagation path)
- Multi-mode (larger core, multiple propagation paths)

[All materials]

Telecommunication Applications

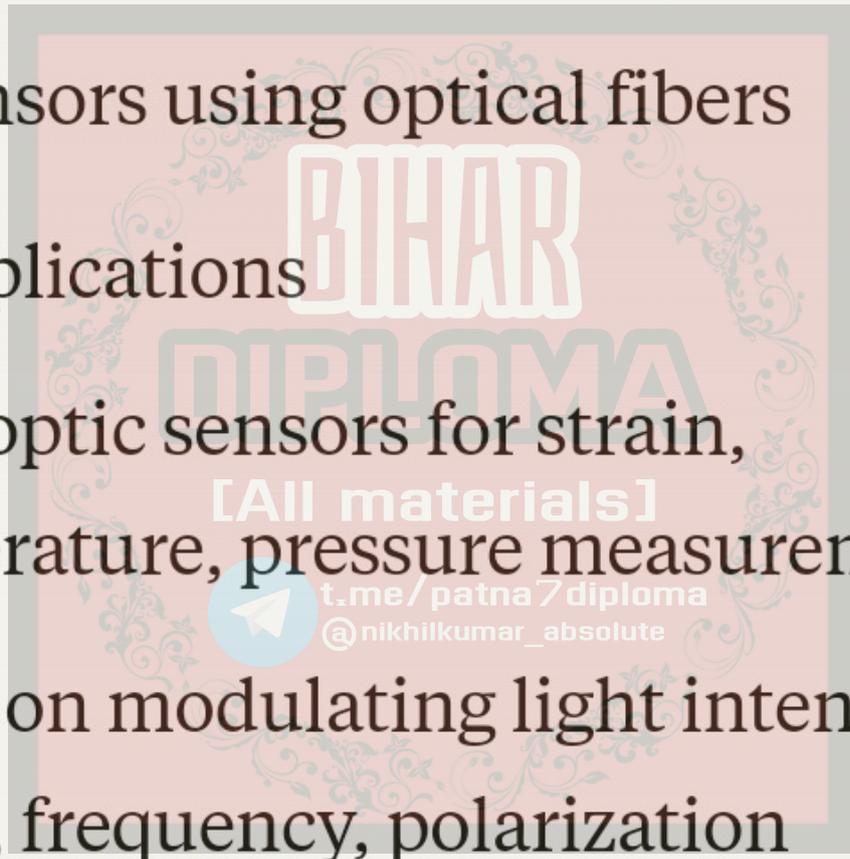
- Long-distance voice/data transmission over optical fiber networks
- High bandwidth, low loss allows faster data rates over long distances

Medical Applications

- Endoscopic imaging using fiber optic cables
- Laser delivery for surgical procedures
- Biosensors using optical fibers

Sensor Applications

- Fiber optic sensors for strain, temperature, pressure measurements
- Based on modulating light intensity, phase, frequency, polarization
- Used in structural monitoring, oil/gas, aerospace industries



Nanoscience and Nanotechnology:

Introduction

- Study and manipulation of matter on the nanoscale (1-100 nm)
- Emergence of unique optical, electrical, chemical properties at the nanoscale
- Combines principles from physics, chemistry, biology, materials science

Nanoparticles

- Particles with dimensions between 1-100 nm
- Can be composed of metals, semiconductors, oxides, carbon etc.
- High surface area to volume ratio leads to novel properties

Metallic Nanoparticles

- Gold, silver nanoparticles exhibit strong surface plasmon resonance
- Applications in sensing, imaging, photonics, catalysis

Semiconductor Nanoparticles (Quantum Dots)

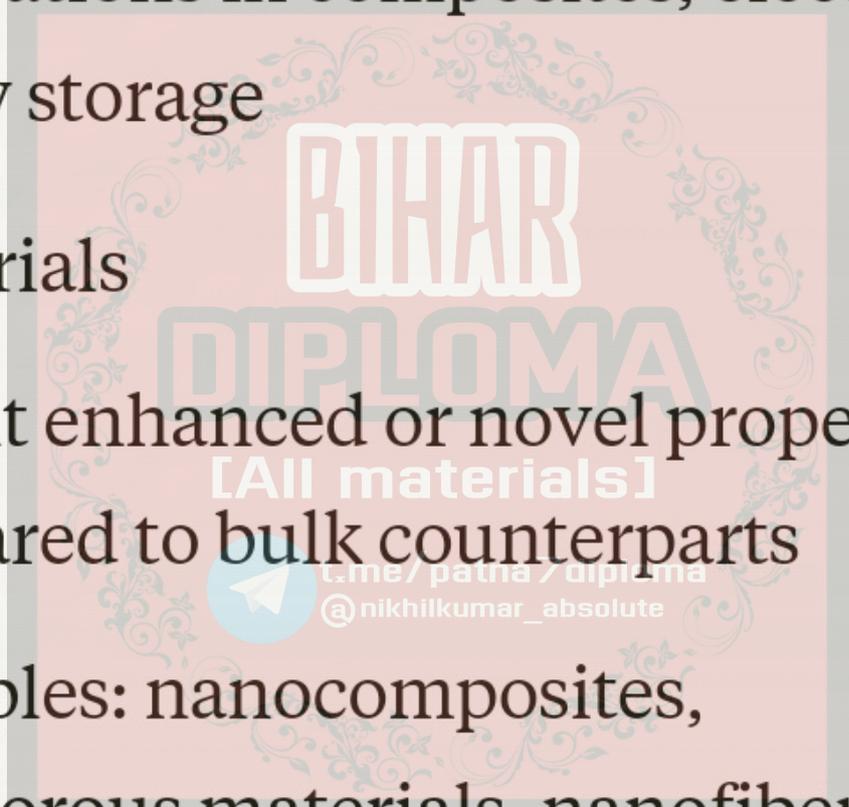
- Quantum confinement effects tune optical and electronic properties
- Size-dependent light emission, used in LEDs, solar cells, biolabeling

Carbon Nanomaterials

- Fullerenes, carbon nanotubes, graphene
- High mechanical strength, thermal/electrical conductivity
- Applications in composites, electronics, energy storage

Nanomaterials

- Exhibit enhanced or novel properties compared to bulk counterparts
- Examples: nanocomposites, nanoporous materials, nanofibers
- Applications in catalysis, sensors, coatings, biomaterials



Characterization Techniques

- Electron microscopy (SEM, TEM), scanning probe microscopy (AFM, STM)
[All materials]
- X-ray diffraction, dynamic light scattering
- UV-Vis, IR, Raman spectroscopy

Properties at Nanoscale

- Quantum confinement effects dominate material properties
- Increased surface area to volume ratio
- High surface energy and reactivity
- Size-dependent optical, electronic, magnetic, thermal properties

Nanotechnology

- Design, production and application of structures/devices at nanoscale
- Top-down approach (lithography, etching)
- Bottom-up approach (self-assembly, molecular manufacturing)
- Enabling precise control over fundamental building blocks of matter

[All materials]

Nanotech-Based Devices

Nanoelectronics

- Transistors, integrated circuits with nanoscale features
- High performance, low power devices

Nanophotonics

- Lasers, LEDs, optical fibers, waveguides
- Enhanced light-matter interactions

Nanobiosensors

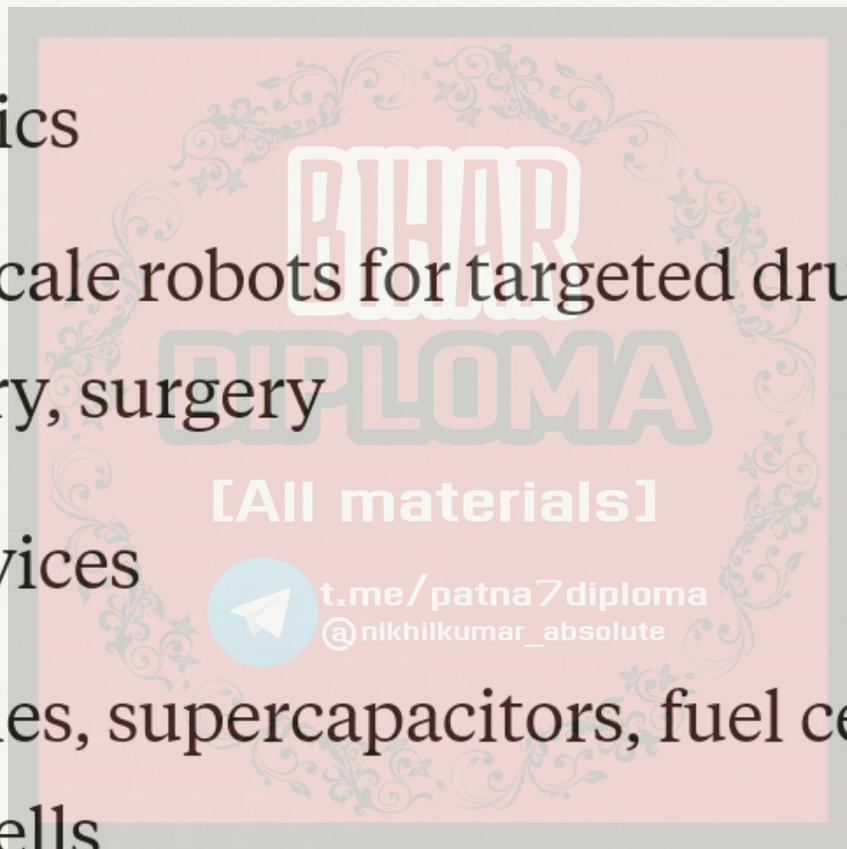
- Highly sensitive detection of biomolecules
- Based on optical, electrochemical, mass-based transduction

Nanorobotics

- Nanoscale robots for targeted drug delivery, surgery

Energy Devices

- Batteries, supercapacitors, fuel cells, solar cells
- Improved energy density, efficiency using nanomaterials



Applications of Nanotechnology

Electronics/Optoelectronics

- Faster computing, higher data storage densities

Materials

- Harder, tougher, self-cleaning coatings
- Stronger, lighter structural composites

Environmental

- Catalysts for reducing emissions, remediation
- Water purification membranes

Biomedical

- Tissue engineering, targeted drug delivery
- Bioimaging, biosensing, nanomedicine

Energy

- Improved solar cells, fuel cells, batteries
- Hydrogen storage, thermal insulation

