

Subject Name & Code:
PHYSICS- BE01R00021

Experiment – 1

EXERCISE 1

General Classification of Errors

Errors in experimental measurements are generally classified into three types:

- **Instrumental Errors**
 - **Definition:** Errors arising from the inherent limitations of the measuring instrument (e.g., its finite resolution).
 - **Example:** Using a ruler graduated in 1 mm increments to measure an object; the precise position between marks must be estimated.
 - **How they are taken care of:** The uncertainty is quantified as the instrument's **least count** (often taken as \pm half the smallest division). Using more precise instruments reduces, but does not eliminate, this error.

- **Systematic Errors**
 - **Definition:** Consistent, repeatable deviations from the true value due to flaws in the experimental setup, calibration, or procedure. They affect **accuracy**.
 - **Example:** A stopwatch that runs consistently 2% fast, or a thermometer not calibrated at the ice point, leading to all temperature readings being offset.
 - **How they are taken care of:** Identified through calibration against known standards, control experiments, or by changing the experimental method. Once identified, a correction factor can be applied to the data.

- **Random Errors**
 - **Definition:** Unpredictable, fluctuating variations in measurements caused by uncontrollable environmental changes, observer judgment, or minor instrumental variations. They affect **precision**.
 - **Example:** Slight variations in the starting angle when releasing a pendulum, causing small differences in the measured period for repeated trials.
 - **How they are taken care of:** Reduced by taking multiple measurements and using statistical analysis (calculating the mean and standard deviation/uncertainty in the mean). The effects of random errors tend to average out over many trials.

EXERCISE 2

Sources of Error in a Simple Pendulum Experiment

In the simple pendulum experiment to determine gravitational acceleration g using $T = 2\pi\sqrt{\frac{l}{g}}$, potential sources of error include:

- **Systematic Errors:**
 - **Length Measurement:** Incorrect measurement of the effective length l from the pivot point to the **center of mass** of the bob. Parallax error while using a ruler, or not accounting for the finite radius of the bob, introduces a consistent offset.
 - **Zero Error in Timer:** A stopwatch that is not calibrated or has a consistent lag/advance in the experimenter's reaction time when starting/stopping.
 - **Finite Amplitude:** The formula $T = 2\pi\sqrt{\frac{l}{g}}$ assumes small angles ($\theta \approx 0$). Using a large amplitude ($> 5^\circ$) makes the period longer, leading to an underestimation of g if not corrected.
 - **Air Resistance & Friction:** Neglecting damping effects at the pivot can cause the measured period to be slightly longer than the theoretical ideal.
- **Random Errors:**
 - **Timing Uncertainty:** Slight variations in judging the start and end of a complete oscillation cycle, especially when determining the "extreme point" of the swing.
 - **Environmental Fluctuations:** Small air currents, vibrations of the support, or temperature changes affecting the length of the pendulum string.
 - **Measurement Scatter:** Slight inconsistencies in measuring the length l for each trial or in counting the number of oscillations.
- **How to Minimize:**
 - Measure length carefully using a Vernier caliper for the bob and a meter tape for the string, reducing parallax.
 - Use a small amplitude ($< 5^\circ$) and time over multiple oscillations (e.g., 20 oscillations) to reduce the impact of timing reaction errors.
 - Repeat measurements several times and use statistical analysis (mean and uncertainty in the mean) to account for random errors.
 - Apply theoretical corrections (e.g., for finite amplitude) if necessary.

EXERCISE 3

Why Uncertainty Decreases with Averaging

- Random errors cause individual measurements to scatter around the true value, some being higher and some lower.

- The **mean** (average) of several measurements provides a better estimate of the true value than any single measurement, as the random fluctuations partially cancel each other out.
- While the spread or range of the data (related to the uncertainty of a single measurement, Δx) may remain similar, the **uncertainty in the mean** (Δx_{avg}) quantifies how close the average is likely to be to the true value.
- Statistically, $\Delta x_{\text{avg}} = \Delta x / \sqrt{N}$, where N is the number of measurements. As N increases, \sqrt{N} increases, so the uncertainty in the mean decreases. For example, averaging 4 measurements reduces the uncertainty in the mean by half compared to a single measurement.
- Therefore, averaging does not change the precision of individual readings but improves the reliability and confidence in the final reported average value.

EXERCISE 4

Difference Between Accuracy and Precision

- **Accuracy** refers to how close a measured value is to the **true or accepted value** of the quantity. It indicates the correctness of a measurement and is affected primarily by **systematic errors**.
 - *Example:* If the true length of an object is 10.00 cm, a set of measurements reading 10.02 cm, 10.01 cm, and 10.03 cm is **accurate** (close to the true value).
- **Precision** refers to how close **repeated measurements** of the same quantity are to each other. It indicates the reproducibility or consistency of measurements and is affected primarily by **random errors**.
 - *Example:* Repeated measurements of 9.85 cm, 9.86 cm, and 9.85 cm are **precise** (tightly clustered), even if they are not accurate (far from 10.00 cm).

Key Analogy: Imagine throwing darts at a target.

- **High Accuracy, Low Precision:** Darts are scattered but centered around the bullseye (average is correct, but individual results vary widely).
- **Low Accuracy, High Precision:** Darts are tightly clustered together, but away from the bullseye (consistent but systematically off-target).
- **High Accuracy, High Precision:** All darts are tightly clustered in the bullseye (ideal scenario).

In experimental reporting, both concepts are essential: **precision** is reflected in the size of the uncertainty (e.g., ± 0.02 cm), while **accuracy** is assessed by comparing the final reported value (mean \pm uncertainty) to the accepted standard.

EXERCISE 5

Significant Figures

Quantities	Number of significant figures
12.74	4
11.5	3
1.50	3 (Trailing zero after decimal is significant)
1.5	2
12.25345	7
0.8	1 (Leading zeros are not significant)
0.05	1 (Leading zeros are not significant)

EXERCISE 6

Reporting Value with Uncertainty

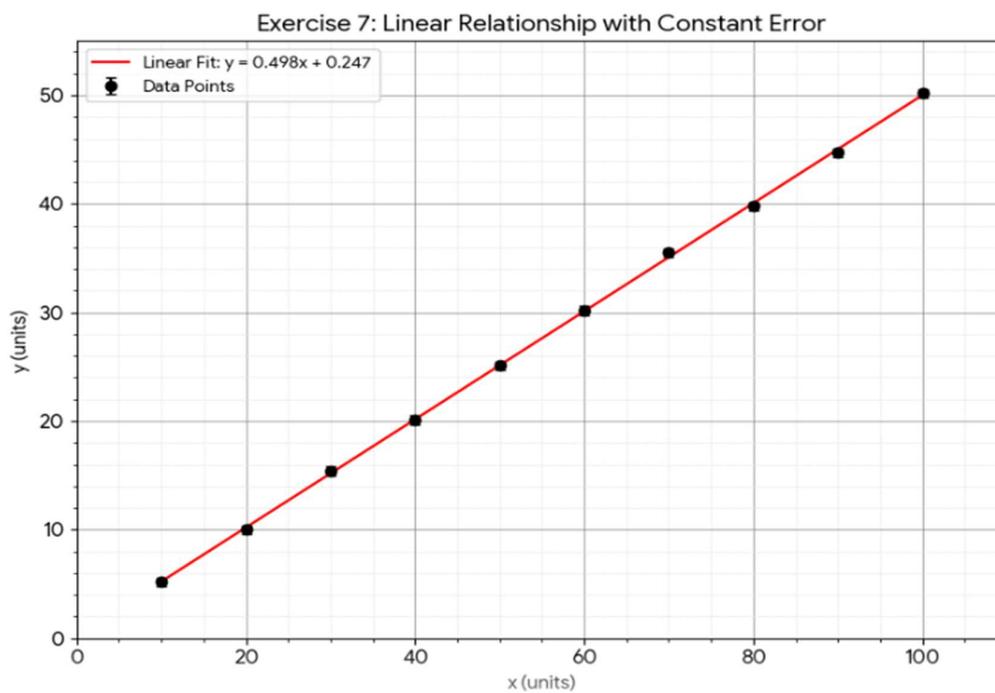
- The uncertainty **0.1247** has four significant figures. We need to round it to **two**.
- The first two digits are '12'. The next digit is '4', which is less than 5. Therefore, we round down.
- The uncertainty becomes **0.12**.
- The measured value **1.25578** must then be rounded to the same decimal place as the uncertainty (two decimal places).
- The digit in the third decimal place of the value is '5', and the preceding digit ('5') is odd. Following the rule for rounding when the remainder is exactly 5, we round the last retained digit to the nearest even number. The '5' in the hundredths place is odd, so we round it up to '6'.
- **Final Answer:**
 $t = 1.26 \pm 0.12 \text{ s}$

EXERCISE 7

Plot a graph for following data.

x	y	Δy
10	5.2	0.4
20	10	0.4
30	15.4	0.4
40	20.1	0.4
50	25.1	0.4
60	30.2	0.4
70	35.5	0.4
80	39.8	0.4
90	44.7	0.4
100	50.2	0.4

Graph:

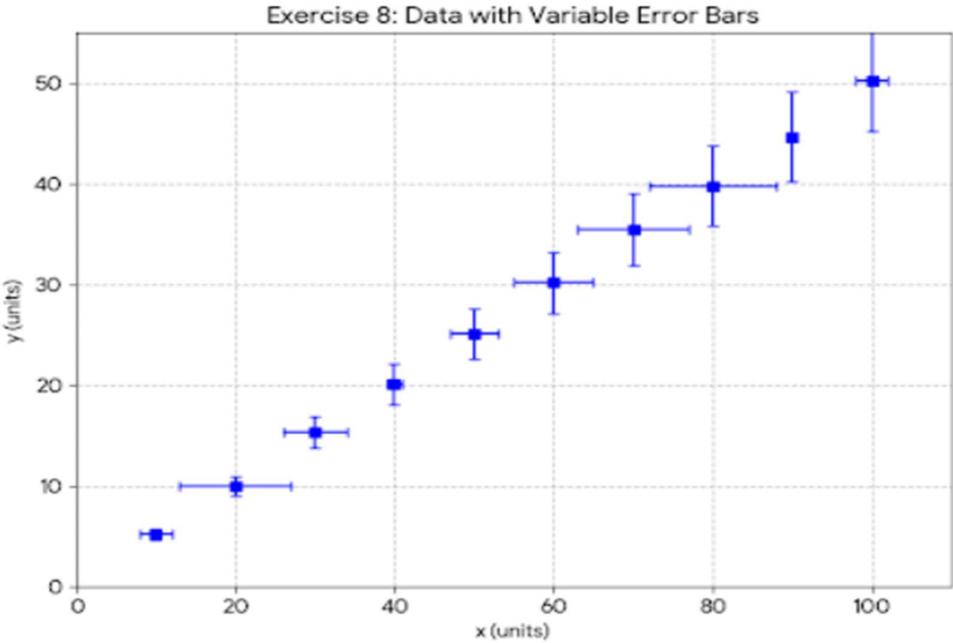


EXERCISE 8

Plot a graph for following data.

x	Δx	y	Δy
10	2	5.2	10%
20	7	10	10%
30	4	15.4	10%
40	1	20.1	10%
50	3	25.1	10%
60	5	30.2	10%
70	7	35.5	10%
80	8	39.8	10%
90	0.5	44.7	10%
100	2	50.2	10%

Graph:



EXPERIMENT-4 QUESTIONS: ANSWERS

(a) Explanation of Resonance and Pressure Node/Antinode Positions

- **Resonance:** A phenomenon where an external vibrating force (tuning fork) matches the natural frequency of a system (air column), causing a large increase in amplitude due to constructive interference. In this experiment, it is heard as a pronounced increase in sound intensity.
- **Pressure Antinode at Closed End (Water Surface):**
 - The water surface is a rigid boundary where air particle displacement is zero.
 - This point experiences maximum pressure variation (from compression to rarefaction) during wave reflection.
 - Therefore, it is a **pressure antinode** (and a displacement node).
- **Pressure Node near Open End:**
 - The open end is a free boundary where air particles can move freely.
 - The pressure here remains nearly constant, equalizing with atmospheric pressure.
 - Therefore, it is a **pressure node** (and a displacement antinode). The exact node lies slightly outside the tube, accounted for by the end correction.

(b) Relationship Between Tube Length and Wavelength (Fundamental Mode)

- For the **first resonance** (fundamental mode), the effective length of the air column ($l_1 + x$), where x is the end correction, is approximately **one-quarter of the wavelength** (λ).
- Formula:

$$l_1 + x \approx \frac{\lambda}{4}$$

(c) Relationship Between Velocity V , Frequency f , and Length l

- The velocity of sound V at room temperature is calculated using the frequency f of the tuning fork and the difference between the second (l_2) and first (l_1) resonant lengths.
- Formula:

$$V = 2f(l_2 - l_1)$$

- Here, $(l_2 - l_1) = \frac{\lambda}{2}$, so $V = f\lambda$.

(d) Shape of Graph: Wavelength λ vs. Frequency f

- The relationship is $\lambda = \frac{V}{f}$, where V is constant for a given medium and temperature.
- This is an inverse relationship, so a plot of λ versus f yields a **rectangular hyperbola** (a decreasing curve).
- Alternatively, plotting λ versus $\frac{1}{f}$ would give a straight line through the origin with slope V .

EXPERIMENT-5: I-V CHARACTERISTIC OF PN DIODE - QUESTIONS & ANSWERS

1. List types of diodes.

- **PN Junction Diode** – Standard diode formed by joining P-type and N-type semiconductors.
 - **Zener Diode** – Operates in reverse breakdown region for voltage regulation.
 - **Light Emitting Diode (LED)** – Emits light when forward biased.
 - **Photodiode** – Generates current when exposed to light (operates in reverse bias).
 - **Schottky Diode** – Metal-semiconductor junction with low forward voltage drop and fast switching.
 - **Varactor Diode (Varicap)** – Capacitance varies with reverse bias voltage; used in tuning circuits.
 - **Tunnel Diode** – Exhibits negative resistance region for high-frequency applications.
 - **PIN Diode** – Intrinsic layer between P and N regions for RF switching and photodetection.
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2. Give applications of PN diode.

- **Rectification** – Converting AC to DC in power supplies (half-wave and full-wave rectifiers).
 - **Clipping and Clamping Circuits** – Shaping waveforms and setting DC levels.
 - **Voltage Protection** – Preventing reverse polarity damage in circuits.
 - **Switching** – Fast on/off switching in digital and RF circuits.
 - **Logic Gates** – Basic implementation in diode logic circuits (e.g., AND, OR gates).
 - **Demodulation** – Extracting audio signals in AM radio receivers.
 - **Solar Cells** – Converting light energy into electrical energy (photovoltaic effect).
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3. What are P & N type Semiconductors?

- **P-type Semiconductor:**
 - Created by doping an intrinsic semiconductor (e.g., Silicon) with **acceptor impurities** (e.g., Boron, group III elements).
 - Contains an excess of **holes** (positive charge carriers) as majority carriers.
 - Electrons are minority carriers.

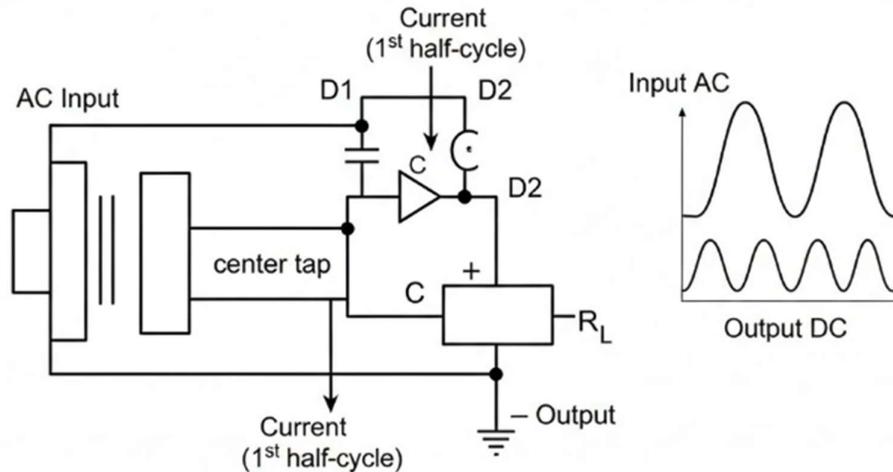
- Overall electrically neutral.
- **N-type Semiconductor:**
 - Created by doping an intrinsic semiconductor with **donor impurities** (e.g., Phosphorus, group V elements).
 - Contains an excess of **free electrons** (negative charge carriers) as majority carriers.
 - Holes are minority carriers.
 - Overall electrically neutral.

4. Distinguish between Drift and Diffusion currents in a PN junction diode.

Feature	Drift Current	Diffusion Current
Cause	Due to movement of charge carriers under the influence of an electric field (applied voltage).	Due to movement of charge carriers from a region of higher concentration to a region of lower concentration .
Carriers Involved	Both electrons and holes contribute.	Both electrons and holes contribute.
Direction	For electrons: opposite to electric field; for holes: along the electric field.	Electrons diffuse from N-side to P-side; holes diffuse from P-side to N-side.
Dominant Region	Dominant in reverse bias and in the depletion region under bias.	Dominant in forward bias and during junction formation without bias.
Relation with Bias	Increases with applied voltage (in both forward and reverse bias, but small in forward).	Increases exponentially with forward voltage; negligible in reverse bias.

5. Explain how a PN diode can be used as a full-wave rectifier with an appropriate diagram.

Diagram:



Explanation:

- **Circuit:** The center-tapped transformer provides two equal but opposite-phase AC voltages.
- **Operation during Positive Half-Cycle (top terminal positive):**
 - D1 is forward biased and conducts. Current flows through D1, R_L , and back to the center tap.
 - D2 is reverse biased and blocks current.
- **Operation during Negative Half-Cycle (bottom terminal positive):**
 - D2 is forward biased and conducts. Current flows through D2, R_L , and back to the center tap.
 - D1 is reverse biased and blocks current.
- **Result:** Current flows through R_L in the **same direction** during both halves of the input AC cycle, producing a pulsating DC output with double the frequency of the input.
- **Smoothing:** The capacitor (C) filters the pulsations to produce a smoother DC voltage.
- **Advantages:** Higher efficiency and better transformer utilization compared to a half-wave rectifier.

EXPERIMENT-6: V-I CHARACTERISTIC OF ZENER DIODE - QUESTIONS & ANSWERS

1. What do you mean by Zener breakdown voltage?

- The **Zener breakdown voltage (V_z)** is the specific reverse bias voltage at which a Zener diode undergoes **avalanche or Zener breakdown**, allowing a large increase in reverse current while maintaining an almost constant voltage across its terminals.
- It is a **controlled and non-destructive** breakdown, designed into the diode during manufacturing.
- Below V_z , the diode blocks current like a regular PN diode. At and above V_z , it conducts heavily in reverse bias, and the voltage across it remains approximately equal to V_z even with significant changes in current.
- It is a key parameter for voltage regulation and protection applications.

2. Distinguish between Avalanche and Zener breakdown mechanism.

Feature	Zener Breakdown	Avalanche Breakdown
Mechanism	Caused by high electric field ($\geq 10^6$ V/cm) tunneling valence electrons directly from the P-side to the conduction band on the N-side (Quantum Tunneling).	Caused by high-energy charge carriers (electrons/holes) gaining enough kinetic energy to ionize other atoms upon collision, creating an electron-hole pair multiplication effect (Impact Ionization).
Doping Level	Occurs in heavily doped PN junctions (narrow depletion region).	Occurs in lightly doped PN junctions (wide depletion region).
Breakdown Voltage	Occurs at lower voltages (typically below 5V for Silicon).	Occurs at higher voltages (typically above 7V for Silicon).
Temperature Coefficient	Has a negative temperature coefficient (V_z decreases with increase in temperature).	Has a positive temperature coefficient (Breakdown voltage increases with increase in temperature).

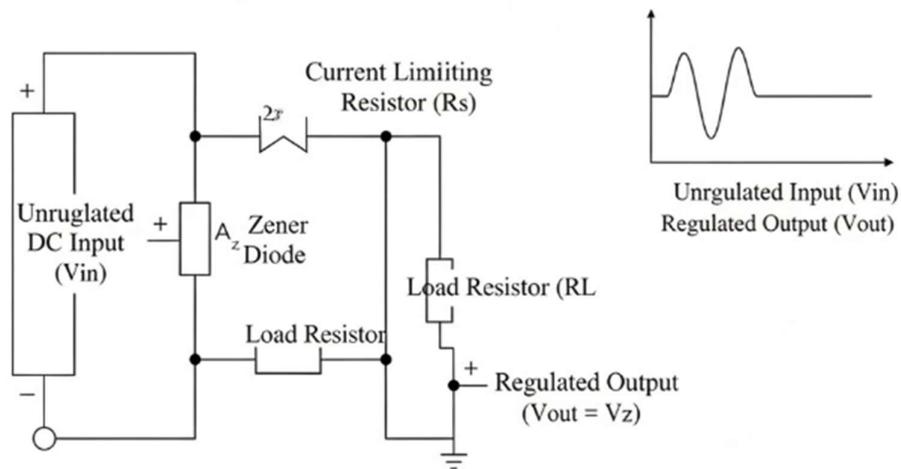
Feature	Zener Breakdown	Avalanche Breakdown
Dominance	Predominant mechanism for diodes with low $V_Z (< 5V)$.	Predominant mechanism for diodes with high $V_Z (> 7V)$. For mid-range (5-7V), both effects coexist.

3. Distinguish between PN diode and Zener diode.

Feature	PN Junction Diode	Zener Diode
Primary Function	Allows current flow in one direction only (forward bias). Used for rectification, switching.	Designed to operate in reverse breakdown region . Used for voltage regulation, protection.
Reverse Bias Operation	Blocks current until reverse voltage exceeds peak inverse voltage (PIV), leading to destructive breakdown .	Conducts heavily at a specific non-destructive reverse breakdown voltage (V_Z) .
Doping Level	Moderately doped.	Heavily doped to achieve a sharp breakdown.
Symbol	Standard diode symbol (arrow + bar).	Diode symbol with a bent "Z"-shaped line at the cathode bar.
I-V Characteristic	Forward: Exponential current rise. Reverse: Negligible current until destructive breakdown.	Forward: Similar to PN diode. Reverse: Sharp, controlled breakdown at V_Z with nearly constant voltage.
Applications	Rectifiers, clippers, clampers, logic gates.	Voltage regulators, voltage reference, surge protectors, clippers.

4. Explain application of Zener diode as a voltage regulator with circuit diagram.

Diagram:



Explanation:

- **Purpose:** To provide a **constant output voltage (V_{out})** to a load (R_L) from an unregulated or fluctuating DC input voltage (V_{in}), even when the load current or input voltage changes.
- **Operating Principle:**
 - The Zener diode is reverse-biased and operates in its breakdown region.
 - The resistor R_s limits the current through the diode to a safe value.
 - As long as V_{in} is greater than V_z , the voltage across the Zener diode (and hence across R_L) remains **fixed at V_z** , its breakdown voltage.
 - Any increase in V_{in} or decrease in load current causes an increase in current through the Zener diode (I_z), but V_{out} remains V_z .
 - Any decrease in V_{in} or increase in load current causes a decrease in I_z , but V_{out} still remains V_z , provided the minimum Zener current (I_{zmin}) is maintained.
- **Regulation Action:** The Zener diode **shunts** excess current away from the load when necessary, maintaining a constant voltage. The current I_z adjusts automatically to compensate for changes in input voltage or load resistance, keeping $V_{out} = V_z$ stable.
- **Limitations:** Efficiency is low for large voltage drops ($V_{in} \gg V_z$). Suitable for low-power, fixed-voltage applications.

EXPERIMENT-7: V-I CHARACTERISTIC OF LIGHT EMITTING DIODE - QUESTIONS & ANSWERS

1. Can LEDs be made of silicon or Germanium? Why?

- **No**, practical LEDs are not made from pure silicon (Si) or germanium (Ge).
 - **Reason:** Both silicon and germanium are **indirect bandgap semiconductors**. In these materials, when an electron recombines with a hole (releasing energy as a photon), the process requires a change in momentum. This makes the probability of radiative recombination (light emission) very low. Most of the energy is released as **heat (phonons)** instead of light, making them extremely inefficient for light emission.
 - LEDs require **direct bandgap semiconductors** (like Gallium Arsenide - GaAs), where electron-hole recombination occurs directly without a momentum change, resulting in efficient photon emission.
-

2. What are the materials used in the fabrication of LEDs?

LEDs are fabricated using **compound semiconductors** (mostly III-V group elements) that are direct bandgap materials. The specific material determines the color/wavelength of the emitted light.

- **Infrared (IR):**
 - Gallium Arsenide (GaAs) – ~870-950 nm
 - Aluminum Gallium Arsenide (AlGaAs) – Adjustable IR range
- **Red & Orange:**
 - Gallium Arsenide Phosphide (GaAsP) – ~630-660 nm (Red)
 - Aluminum Gallium Indium Phosphide (AlGaInP) – High-brightness red, orange, yellow
- **Yellow & Green:**
 - Gallium Phosphide (GaP) – ~555 nm (Green, also used for yellow with doping)
 - Indium Gallium Nitride (InGaN) – High-efficiency green
- **Blue, Violet, & Ultraviolet (UV):**
 - Gallium Nitride (GaN) – ~450 nm (Blue)
 - Indium Gallium Nitride (InGaN) – Adjustable blue to green
 - Aluminum Gallium Nitride (AlGaN) – UV LEDs

- **White LEDs:** Typically a **blue LED** (InGaN) coated with a **yellow phosphor** (e.g., Yttrium Aluminum Garnet doped with Cerium - YAG:Ce), which converts some blue light to yellow, resulting in white light.
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3. Can a reading lamp be made of an LED? Why?

- **Yes**, absolutely. Modern reading lamps and general-purpose lighting are widely made using LEDs.
 - **Reasons:**
 - **High Efficiency (Lumens/Watt):** LEDs convert a high percentage of electrical energy into visible light, making them more energy-efficient than incandescent or fluorescent bulbs.
 - **Long Lifespan:** LEDs last tens of thousands of hours (25,000-50,000 hrs), reducing replacement frequency.
 - **Durability:** Solid-state construction makes them robust and resistant to shock/vibration.
 - **Low Heat Emission:** They emit very little infrared radiation, making them cooler to the touch compared to incandescent bulbs.
 - **Design Flexibility:** Available in various color temperatures (warm white, cool white) and can be dimmable.
 - **Instant On:** No warm-up time, unlike some CFLs.
 - **Environmental Benefits:** Contain no mercury (unlike CFLs) and have a smaller carbon footprint due to lower energy consumption.
-

4. List some applications of LED.

- **Lighting:**
 - Residential, commercial, and industrial lighting.
 - Street lights, parking lot lights.
 - Automotive lighting (headlights, brake lights, indicators).
 - Flashlights and emergency lights.
- **Displays:**
 - Full-color video screens (LED billboards, stadium displays).
 - TV and monitor backlighting.
 - Seven-segment displays, alphanumeric displays.
- **Indicators & Signals:**

- Power/status indicators on electronic devices.
- Traffic signal lights.
- Aviation and nautical navigation lights.
- **Communications:**
 - Infrared remote controls.
 - Optical fiber communication (as a light source).
 - Li-Fi (Light Fidelity) for wireless data transmission.
- **Sensing & Medical:**
 - Optical sensors (proximity, ambient light).
 - Pulse oximeters.
 - Phototherapy for neonatal jaundice.
- **Consumer Electronics:**
 - Backlighting for keyboards, phones, etc.
 - Decorative and mood lighting.
- **Horticulture:** Grow lights for indoor farming (specific wavelengths for plant growth).

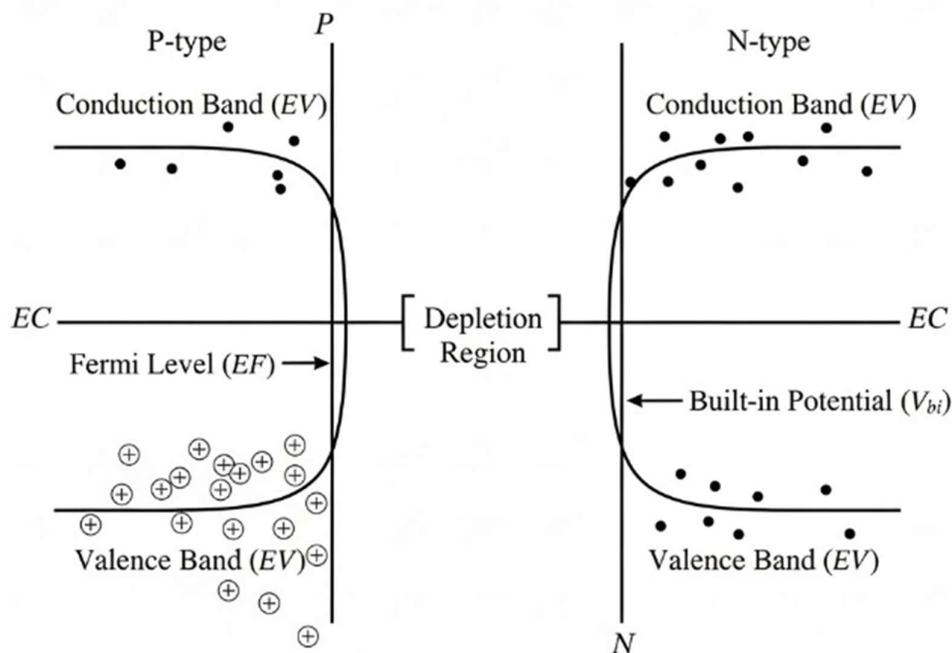
EXPERIMENT-8: SOLAR CELL CHARACTERISTICS - QUESTIONS & ANSWERS

1. Why a PN junction is required for the operation of a solar cell?

- The PN junction is fundamental because it creates an **internal electric field** across the depletion region.
- This built-in electric field acts as a **charge separator**. When light (photons) with energy greater than the bandgap of the semiconductor strikes the cell, it generates electron-hole pairs.
- The electric field sweeps the electrons toward the N-side and holes toward the P-side, preventing them from recombining immediately.
- This separation of charges creates a **potential difference (photo-voltage)** across the junction. If an external circuit is connected, this voltage drives a current, enabling electrical power generation.
- Without the PN junction and its built-in field, the generated electron-hole pairs would quickly recombine, producing no net electrical output.

2. Draw the energy band diagram of a P-N junction.

Diagram:



3. Explain how photo-voltage is generated across a PN junction diode when illuminated by light.

- **Step 1 – Photon Absorption:** When light of sufficient energy ($h\nu \geq E_g$, the bandgap energy) strikes the solar cell, photons are absorbed, primarily in the depletion region and the neutral regions close to it.
- **Step 2 – Electron-Hole Pair Generation:** This absorption excites electrons from the valence band to the conduction band, creating **electron-hole pairs**.
- **Step 3 – Charge Separation by Built-in Field:** The **built-in electric field** in the depletion region acts on these carriers. It exerts a force that **drives electrons toward the N-side** and **holes toward the P-side**.
- **Step 4 – Charge Accumulation & Voltage Buildup:** Electrons accumulate on the N-side, and holes accumulate on the P-side. This creates an excess of negative charge on the N-side and positive charge on the P-side, establishing a **photo-voltage** across the terminals.
- **Step 5 – External Current Flow:** When a load is connected, this photo-voltage drives electrons from the N-side through the external circuit to the P-side to recombine with holes, generating an electric current.

4. What are solar parameters? Define I_{sc} , V_{oc} & fill factor.

- **Solar Parameters** are key electrical characteristics that define the performance and quality of a photovoltaic (PV) solar cell or module under standard test conditions (STC).
- **Short Circuit Current (I_{sc}):**
 - The maximum current delivered by the solar cell when its terminals are short-circuited ($V=0$).
 - It depends directly on the intensity of incident light and the area of the cell.
- **Open Circuit Voltage (V_{oc}):**
 - The maximum voltage available from the solar cell when no current is drawn (open circuit, $I=0$).
 - It is determined by the semiconductor material's bandgap and is logarithmically dependent on light intensity.
- **Fill Factor (FF):**
 - A measure of the "squareness" of the I-V curve and the quality of the solar cell.
 - It is the ratio of the **maximum power output ($P_{max} = V_{mp} * I_{mp}$)** to the product of V_{oc} and I_{sc} .

- **Formula:** $FF = \frac{P_{max}}{V_{oc} \times I_{sc}} = \frac{V_{mp} \times I_{mp}}{V_{oc} \times I_{sc}}$
- A higher FF (closer to 1) indicates a more efficient cell with lower internal losses. Typical values range from 0.7 to 0.85.

5. What are different losses in solar cells? Enlist them.

Solar cell efficiency is reduced by various loss mechanisms:

- **Optical Losses:**
 - **Reflection Loss:** Incident light reflected from the cell surface.
 - **Shading Loss:** Due to front contact gridlines blocking light.
 - **Transmission Loss:** Light passing through the cell without being absorbed (if cell is too thin or photon energy < bandgap).
- **Recombination Losses (Carrier Loss):**
 - **Radiative Recombination:** Electron-hole pairs recombine, emitting a photon (inverse of absorption).
 - **Auger Recombination:** Energy from recombination is transferred to a third carrier (electron or hole) as kinetic energy.
 - **Shockley-Read-Hall (SRH) Recombination:** Occurs via defect states (traps) in the forbidden gap, dominant in imperfect crystals.
 - **Surface Recombination:** At the exposed surfaces of the semiconductor where many dangling bonds (defects) exist.
- **Resistive Losses:**
 - **Series Resistance (Rs):** Resistance due to semiconductor bulk, contacts, and interconnects. It reduces FF and I_{sc} .
 - **Shunt Resistance (Rsh):** Due to leakage paths (e.g., crystal defects, moisture). It reduces FF and V_{oc} .
- **Thermodynamic & Spectral Losses:**
 - **Sub-bandgap Loss:** Photons with energy less than the bandgap ($h\nu < E_g$) are not absorbed.
 - **Excess Energy Loss (Thermalization):** Photons with energy greater than the bandgap ($h\nu > E_g$) excite electrons high into the conduction band, which then relax to the band edge, losing excess energy as heat.
 - **Carnot & Ultimate Efficiency Limit:** Fundamental thermodynamic limit for any energy conversion device.

EXPERIMENT-9: RIGIDITY MODULUS USING TORSIONAL PENDULUM - VIVA ANSWERS

1. What is Modulus of Rigidity?

- The **Modulus of Rigidity (η or G)** is an **elastic constant** that measures a material's resistance to deformation under **shear stress**.
 - It is defined as the ratio of **shear stress** to the corresponding **shear strain** within the material's elastic limit.
 - **Formula:** $\eta = \frac{\text{Shear Stress}}{\text{Shear Strain}} = \frac{F/A}{\Delta x/L}$
Where:
 F = Tangential force,
 A = Area over which force is applied,
 Δx = Transverse displacement,
 L = Original length.
 - It quantifies the **stiffness** of a material when subjected to twisting or shearing forces. Higher rigidity modulus means greater resistance to angular deformation.
 - **SI Unit:** Pascal (Pa) or N/m^2 .
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2. Define stress.

- **Stress** is defined as the **internal restoring force per unit area** developed within a material when an external force is applied to it.
 - It is a measure of the intensity of the internal forces that particles of a material exert on each other when subjected to external loads.
 - **Formula:** $\text{Stress}(\sigma) = \frac{\text{Internal Restoring Force}(F)}{\text{Cross-sectional Area}(A)}$
 - **SI Unit:** Pascal (Pa) or N/m^2 .
 - **Types:** Normal stress (tensile/compressive) and shear stress (tangential).
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3. Define strain.

- **Strain** is the **dimensional change (deformation) per unit original dimension** of a material when subjected to external forces.
- It is a dimensionless measure of the relative deformation of the material.
- **Formula:** $\text{Strain}(\epsilon) = \frac{\text{Change in Dimension}(\Delta L)}{\text{Original Dimension}(L)}$
- It has **no units** (a pure ratio).

- **Types:** Longitudinal (linear) strain, shear strain, and volumetric strain.
-

4. Define time period. What are factors that influence the time period of a torsional pendulum?

- **Time Period (T):** The time taken to complete **one full oscillation** (e.g., from one extreme angular position, through the mean, to the other extreme, and back to the starting point). For the torsional pendulum, it is the time for one complete rotational to-and-fro motion.
- **Factors influencing the time period of a torsional pendulum:**
 - **Moment of Inertia (I) of the disc:** $T \propto \sqrt{I}$. A disc with larger mass or larger radius has a larger I and hence a longer time period.
 - **Length of the suspension wire (l):** $T \propto \sqrt{l}$. A longer wire offers less restoring torque, resulting in a longer period.
 - **Radius of the wire (r):** $T \propto \frac{1}{r^2}$. A thicker wire (larger r) is stiffer and provides a greater restoring torque, leading to a shorter period.
 - **Rigidity Modulus (η) of the wire material:** $T \propto \frac{1}{\sqrt{\eta}}$. A wire made of a material with a higher rigidity modulus is stiffer, resulting in a shorter period.
 - **Amplitude of oscillation:** For a perfectly elastic wire and small angular displacements (within the elastic limit), the time period is **independent of amplitude**. This is an example of **isochronous oscillations**.
 - **External damping:** Air resistance and friction at the supports can slightly affect the period if damping is significant.

EXPERIMENT-10:**Question 1: Searle's Experiment – Maximum Percentage Error in Young's Modulus****Given:**

- Initial Vernier reading: Zero between $3.20 \times 10^{-2} \text{ m}$ and $3.25 \times 10^{-2} \text{ m}$; 20th division coincides.
- After load: Zero between same main scale marks; 45th division coincides.
- Additional load, $\Delta F = 2 \text{ kg} \times g$ ($g \approx 9.8 \text{ m/s}^2$, but may cancel in % error).
- Length $L = 2 \text{ m}$
- Area $A = 8 \times 10^{-7} \text{ m}^2$
- Least count of Vernier = $1.0 \times 10^{-5} \text{ m}$

To find: Maximum percentage error in Young's modulus Y .

Formula:

$$Y = \frac{FL}{Al}$$

Relative error:

$$\frac{\Delta Y}{Y} = \frac{\Delta F}{F} + \frac{\Delta L}{L} + \frac{\Delta A}{A} + \frac{\Delta l}{l}$$

Here $F = mg$, $\Delta F/F$ negligible if mass known exactly.

Given:

ΔL from meter scale? Not given, but likely negligible compared to Δl .

$\Delta A/A = 2 \frac{\Delta d}{d}$, but d not given directly; area given, so ΔA from area measurement?

Possibly $\Delta A = 0$ if area exact? But area given as constant.

For maximum error, focus on extension l measurement error from Vernier.

Finding extension l :

Vernier reading = Main scale reading (MSR) + (Vernier division \times Least count)

Initial:

MSR lower limit = $3.20 \times 10^{-2} \text{ m}$

MSR upper limit = $3.25 \times 10^{-2} \text{ m}$

Vernier coincidence = 20

$$\begin{aligned} \text{Reading } R_1 &= 3.20 \times 10^{-2} + 20 \times (1.0 \times 10^{-5}) \\ &= 3.20 \times 10^{-2} + 2.0 \times 10^{-4} = 0.03200 + 0.00020 = 0.03220 \text{ m} \end{aligned}$$

Or from upper: $3.25 \times 10^{-2} - (\text{total divisions} - \text{coincidence}) \times LC$? Wait: Main scale divisions: 0.05 m apart? Actually 3.20 to 3.25 is 0.05 m range, so each main scale division = 0.05/?? *unclear*. Better:

Given least count = $1.0 \times 10^{-5} m$, so 1 MSD – 1 VSD = LC.

Let 1 MSD = x , not needed directly.

Actually simpler:

Extension l = difference in readings after – before.

Initial reading R_1 = (some MSR) + $20 \times LC$

Final reading R_2 = (same MSR range) + $45 \times LC$

Since zero lies in same interval, MSR same in both. So change in reading:

$$l = (45 - 20) \times LC = 25 \times (1.0 \times 10^{-5}) = 2.5 \times 10^{-4} m$$

Uncertainty in l : Least count of Vernier = $1.0 \times 10^{-5} m$.

Error in difference: $\Delta l = \sqrt{2} \times LC \approx 1.414 \times 10^{-5} m$, but max error = $2 \times LC$ if worst case?

For max % error, take $\Delta l = LC = 1.0 \times 10^{-5} m$ as error in each reading, so error

in $l = 2 \times LC$? Actually, for difference:

$\Delta l = \sqrt{(\Delta R_1)^2 + (\Delta R_2)^2} = \sqrt{2} \times LC \approx 1.4 \times 10^{-5}$. But “maximum percentage error” usually uses max possible error: $\Delta l = 2 \times LC = 2.0 \times 10^{-5} m$.

Take $\Delta l = 2.0 \times 10^{-5} m$.

Relative error in l :

$$\frac{\Delta l}{l} = \frac{2.0 \times 10^{-5}}{2.5 \times 10^{-4}} = 0.08$$

Other errors: ΔL ? If meter scale L.C. = $0.1 \text{ cm} = 10^{-3} m$, $\Delta L/L \approx 0.001/2 = 0.0005$ small.

$\Delta A/A$: given $A = 8 \times 10^{-7}$ exactly? No error given, so ignore.

$\Delta F/F$: mass exact? If mass exact, zero error.

Max relative error in Y :

$$\frac{\Delta Y}{Y} \approx \frac{\Delta l}{l} = 0.08$$

Percentage error = 8%.

Final Answer:

$$\boxed{8\%}$$

Question 2: Maximum Error in Young's Modulus

Given:

- Diameter $d = 0.050 \text{ cm}$, L.C. of screw gauge = 0.001 cm

- Length $L = 110.0 \text{ cm}$, L.C. of scale = 0.1 cm
- Load $F = 50 \text{ N}$ (exact)
- Extension $l = 0.125 \text{ cm}$, L.C. of micrometer = 0.001 cm
- $Y = \frac{4FL}{\pi d^2 l}$

Find: Maximum error in Y .

Relative error formula:

$$\frac{\Delta Y}{Y} = \frac{\Delta L}{L} + 2 \frac{\Delta d}{d} + \frac{\Delta l}{l}$$

($\Delta F = 0$ since given exactly.)

Uncertainties:

- $\Delta L = 0.1 \text{ cm}$
- $\Delta d = 0.001 \text{ cm}$
- $\Delta l = 0.001 \text{ cm}$

Relative errors:

$$\begin{aligned} \frac{\Delta L}{L} &= \frac{0.1}{110.0} \approx 0.000909 \\ 2 \frac{\Delta d}{d} &= 2 \times \frac{0.001}{0.050} = 2 \times 0.02 = 0.04 \\ \frac{\Delta l}{l} &= \frac{0.001}{0.125} = 0.008 \end{aligned}$$

Sum for max error:

$$\frac{\Delta Y}{Y} = 0.000909 + 0.04 + 0.008 \approx 0.048909$$

Absolute error: First find Y :

$$F = 50 \text{ N}, L = 1.100 \text{ m}, d = 5.0 \times 10^{-4} \text{ m}, l = 1.25 \times 10^{-3} \text{ m}$$

$$Y = \frac{4 \times 50 \times 1.100}{\pi \times (5.0 \times 10^{-4})^2 \times 1.25 \times 10^{-3}}$$

$$\text{Denominator: } \pi \times 25 \times 10^{-8} \times 1.25 \times 10^{-3} = \pi \times 31.25 \times 10^{-11}$$

$$\text{Numerator: } 4 \times 50 \times 1.100 = 220$$

$$\text{So } Y = \frac{220}{\pi \times 31.25 \times 10^{-11}} \approx \frac{220}{98.174 \times 10^{-11}} \approx 2.241 \times 10^{11} \text{ Pa}$$

$$\Delta Y = Y \times 0.048909 \approx 2.241 \times 10^{11} \times 0.0489 \approx 1.096 \times 10^{10} \text{ Pa}$$

Final Answer:

$$\Delta Y \approx 1.1 \times 10^{10} \text{ N/m}^2$$

(or $\frac{\Delta Y}{Y} \approx 4.89\%$).

Question 3: Young's Modulus from Graph

Given: Graph of Δl vs. W , length $L = 1 \text{ m}$, area $A = 10^{-6} \text{ m}^2$.

From graph: slope = $\Delta l/W$? Actually graph shows Δl increases with W , likely straight line. Pick points: At $W = 20 \text{ N}$ (say), $\Delta l \approx 2 \times 10^{-4} \text{ m}$? But graph not fully clear—text shows 4 at top maybe $\Delta l = 4 \times 10^{-4} \text{ m}$ at $W = 40 \text{ N}$? Need more data.

From given graph in your doc: max $\Delta l \approx 4 \times 10^{-4} \text{ m}$ at $W = 20 \text{ N}$? Wait, maybe scale: on y-axis 4 means $4 \times 10^{-4} \text{ m}$, x-axis unlabeled. Likely slope $\frac{\Delta l}{W} = \frac{4 \times 10^{-4}}{20} = 2 \times 10^{-5} \text{ m/N}$.

$$\text{Then } Y = \frac{WL}{A\Delta l} = \frac{L}{A \times (\Delta l/W)}$$

$$Y = \frac{1}{10^{-6} \times 2 \times 10^{-5}} = \frac{1}{2 \times 10^{-11}} = 5 \times 10^{10} \text{ N/m}^2?$$

But options: 2×10^{11} , 2×10^{-11} , 3×10^{12} , 3×10^{-12} . Closest is 2×10^{11} if slope is $5 \times 10^{-6} \text{ m/N}$:

$$Y = 1/(10^{-6} \times 5 \times 10^{-6}) = 2 \times 10^{11}.$$

Given typical steel $Y \approx 2 \times 10^{11}$, so likely slope is $5 \times 10^{-6} \text{ m/N}$.

Final Answer:

$$2 \times 10^{11} \text{ N/m}^2$$

Question 4: Elastic Limit of Steel vs. Rubber

Answer:

The statement means that steel can withstand a **greater stress** (force per unit area) than rubber before it undergoes **permanent deformation**. The elastic limit is the maximum stress up to which a material returns to its original shape when the stress is removed. Steel, being a much stiffer and stronger material, has a higher elastic limit compared to rubber, which can be stretched easily but reaches its elastic limit at a much lower stress. This makes steel suitable for structural applications where high loads are involved without permanent bending, while rubber is used where large elastic deformation is needed at low stress.



EXPERIMENT-11: DETERMINATION OF LASER WAVELENGTH USING DIFFRACTION GRATING – QUIZ ANSWERS

1. Give the full form of LASER.

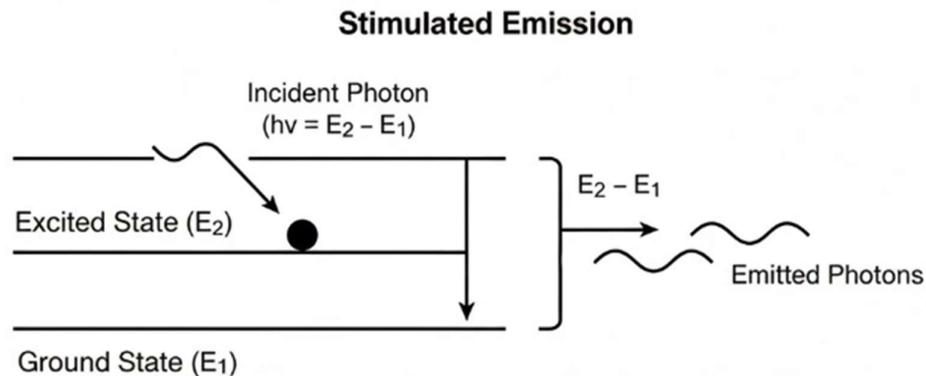
Answer:

Light Amplification by Stimulated Emission of Radiation.

2. Explain stimulated emission of radiation with a diagram.

Answer:

- **Stimulated emission** is a quantum process where an incoming photon of a specific frequency interacts with an already excited atom or molecule, causing it to drop to a lower energy state and emit a **second photon**.
- The emitted photon is **identical** to the incident photon in terms of **wavelength, phase, polarization, and direction**. This results in **coherent** and **amplified** light output.
- **Diagram:**



An incident photon stimulates an excited electron to drop,
producing two coherent photons.

3. How does laser differ from ordinary light source?

Answer:

Feature	Laser Light	Ordinary Light (e.g., bulb, sun)
Coherence	High temporal & spatial coherence (waves are in phase).	Incoherent (waves out of phase).

Feature	Laser Light	Ordinary Light (e.g., bulb, sun)
Monochromaticity	Highly monochromatic (very narrow wavelength band).	Polychromatic (broad spectrum of wavelengths).
Directionality	Highly directional (low divergence, forms a narrow beam).	Omnidirectional (radiates in all directions).
Intensity / Brightness	Very high intensity (energy concentrated in a small area/frequency).	Lower intensity (energy spread over broad area/spectrum).
Underlying Process	Stimulated emission (dominant).	Spontaneous emission & thermal radiation.

4. Define (i) diffraction (ii) interference & (iii) diffraction grating.

Answer:

- **(i) Diffraction:**
The **bending and spreading of waves** (e.g., light) as they pass through an aperture or around an obstacle whose size is comparable to the wavelength of the wave. It is a direct consequence of the wave nature of light.
- **(ii) Interference:**
The phenomenon where **two or more coherent waves** superimpose to form a resultant wave of greater, lower, or the same amplitude. It produces a pattern of **bright (constructive interference)** and **dark (destructive interference)** fringes.
- **(iii) Diffraction Grating:**
An optical component with a **regular, periodic structure** of closely spaced parallel slits or lines. It works by causing diffraction and interference of light, thereby dispersing it into its constituent wavelengths (spectrum). The key parameter is the **grating element (a+b)**, the distance between corresponding points on adjacent slits.

5. Mention a few important applications of laser.

Answer:

- **Medicine:** Laser surgery (LASIK, skin treatment), cancer therapy, dental procedures, endoscopy.

- **Industry & Manufacturing:** Cutting, welding, drilling, engraving, 3D printing (stereolithography), barcode scanners.
- **Communications:** Optical fiber communication (high-speed data transmission).
- **Metrology & Sensing:** LIDAR (Light Detection and Ranging), interferometry for precise measurements, environmental monitoring.
- **Information Technology:** CD/DVD/Blu-ray reading and writing, laser printers.
- **Scientific Research:** Spectroscopy, nuclear fusion (inertial confinement), atomic cooling (optical molasses).
- **Military & Defense:** Target designation, rangefinders, directed-energy weapons.
- **Entertainment & Display:** Laser light shows, holography, projectors.

EXPERIMENT-12: MELDE'S APPARATUS – QUIZ ANSWERS

1. What is the use of Melde's apparatus?

- To **demonstrate the formation of standing waves** in a stretched string.
 - To **determine the frequency** of an electrically maintained tuning fork.
 - To study standing waves in both **transverse** and **longitudinal** vibration modes.
 - To verify the relationship between wave speed, tension, linear density, and frequency in a string ($v = \sqrt{T/\mu}$ and $f = v/\lambda$).
-

2. What is the longitudinal position in Melde's experiment?

- The tuning fork is oriented so its **prongs vibrate parallel to the length** of the string.
 - This creates periodic **tension variations** in the string, generating standing waves.
 - In this mode, **one complete vibration of the string corresponds to two vibrations of the tuning fork**.
 - Therefore, the **tuning fork frequency is twice the string's frequency**: $f_{\text{fork}} = 2f_{\text{string}}$.
-

3. What is the transverse position in Melde's experiment?

- The tuning fork is oriented so its **prongs vibrate perpendicular to the length** of the string.
 - This directly drives the string **up and down**, generating transverse standing waves.
 - In this mode, the string vibrates **once for each vibration of the tuning fork**.
 - Therefore, the **tuning fork frequency equals the string's frequency**: $f_{\text{fork}} = f_{\text{string}}$.
-

4. The points where the amplitude of the wave is maximum and the strain is least are called Antinodes. True or false?

- **True.**
 - **Antinodes** are positions in a standing wave where the **amplitude of vibration is maximum**.
 - At these points, the **particles oscillate with maximum displacement**, but the **strain (deformation per unit length) is minimum** (or zero at the extreme positions).
-

5. The length of the fundamental wave is equal to $\frac{\lambda}{2}$ is true or false?

- **False.**
- For a **string fixed at both ends**, the **fundamental mode (first harmonic)** has a **wavelength λ that is twice the length L of the string: $\lambda = 2L$.**
- Therefore, the **length L of the string** is equal to **half the wavelength** ($L = \lambda/2$), not the other way around.
- The statement as written ("length of the fundamental wave is equal to $\lambda/2$ ") is ambiguous but generally incorrect; the correct relationship is $L = \lambda/2$ for the fundamental mode.

EXPERIMENT-14: ULTRASONIC INTERFEROMETER – QUIZ ANSWERS

1. Define acoustic grating.

- An **acoustic grating** is formed when **ultrasonic waves** are passed through a liquid medium, creating a periodic variation in the density (and hence refractive index) of the medium.
 - This periodic variation acts like a **diffraction grating** for a beam of light passed through the same medium, causing the light to diffract into multiple orders.
 - It is used in **acoustic-optic devices** and to determine the velocity of ultrasound in liquids (Debye-Sears effect).
-

2. State the examples of piezoelectric materials.

- **Natural Crystals:** Quartz (SiO_2), Rochelle salt, Tourmaline.
 - **Ceramics:** Lead Zirconate Titanate (PZT), Barium Titanate (BaTiO_3).
 - **Polymers:** Polyvinylidene Fluoride (PVDF).
 - **Other Materials:** Gallium Orthophosphate (GaPO_4), Lithium Niobate (LiNbO_3).
-

3. Explain piezoelectric effect.

- The **piezoelectric effect** is the ability of certain materials to generate an **electric charge** in response to applied **mechanical stress** (direct effect).
 - Conversely, these materials undergo **mechanical deformation** (strain) when an external **electric field** is applied (inverse/converse effect).
 - **Mechanism:** In piezoelectric crystals, the **asymmetric arrangement** of positive and negative ions in the unit cell causes a displacement of charges (dipole moment) under stress, producing a voltage across the crystal.
 - **Applications:** Used in ultrasonic generators, sensors, actuators, transducers, quartz watches, and microphone pickups.
-

4. Using the device ultrasonic interferometer, calculate the adiabatic compressibility of water, castor oil, and glycerin. Compare the results and comment.

- **General Calculation (for any liquid):**
 - **Given/Measured:** Frequency f (e.g., 2 MHz), density ρ of liquid, distance D between n successive maxima in micrometer readings.
 - **Wavelength:** $\lambda = \frac{2D}{n-1}$

- **Velocity:** $v = \lambda f = \frac{2Df}{n-1}$
- **Adiabatic Compressibility:** $\beta = \frac{1}{\rho v^2}$
- **Typical Comparison (Order of Magnitude):**
 - **Water** ($\rho \approx 1000 \text{ kg/m}^3$, $v \approx 1500 \text{ m/s}$):

$$\beta \approx \frac{1}{1000 \times (1500)^2} \approx 4.44 \times 10^{-10} \text{ Pa}^{-1}$$
 - **Castor Oil** (denser, higher viscosity): Lower velocity ($\sim 1500\text{-}1700 \text{ m/s}$), higher density ($\sim 960 \text{ kg/m}^3$).
 β slightly lower than water.
 - **Glycerin** (very viscous, high density $\sim 1260 \text{ kg/m}^3$): Higher velocity ($\sim 1900\text{-}2000 \text{ m/s}$).

$$\beta \approx \frac{1}{1260 \times (1900)^2} \approx 2.2 \times 10^{-1} \text{ Pa}^{-1}$$
- **Comparison & Comment:**
 - **Glycerin** has the **lowest adiabatic compressibility** (most difficult to compress) due to its high density and strong intermolecular forces.
 - **Water** has a **moderate compressibility**.
 - **Castor Oil** has compressibility between water and glycerin.
 - **Trend:** Compressibility decreases with increasing density and sound velocity. More viscous, dense liquids tend to be less compressible.
 - **Verification:** Experimental values should follow $\beta_{\text{glycerin}} < \beta_{\text{castor oil}} < \beta_{\text{water}}$.

5. State any five applications of ultrasound.

- **Medical Imaging:** Ultrasonography (e.g., fetal imaging, organ examination).
- **Non-Destructive Testing (NDT):** Detecting flaws, cracks, or voids in metals, welds, and composites.
- **Cleaning:** Ultrasonic cleaners for delicate instruments, jewelry, and electronic parts.
- **Industrial Processing:** Emulsification, homogenization, welding of plastics, and sonochemistry.
- **Distance & Flow Measurement:** Sonar (underwater navigation), rangefinders, and Doppler flow meters for fluids.

EXPERIMENT-15: NEWTON'S RINGS – VIVA ANSWERS

1. What is Interference?

- **Interference** is a wave phenomenon where **two or more coherent waves** superimpose to form a resultant wave.
 - The resultant wave's amplitude (and hence intensity) is determined by the **phase difference** between the overlapping waves.
 - **Constructive Interference:** Waves in phase (path difference = $n\lambda$) → amplitude adds → bright fringes.
 - **Destructive Interference:** Waves out of phase (path difference = $(2n + 1)\lambda/2$) → amplitude cancels → dark fringes.
-

2. How Newton's rings are formed?

- Newton's rings are formed due to **interference of light** between two reflected beams.
 - A **plano-convex lens** is placed on a **flat glass plate**, creating a thin air wedge of varying thickness.
 - Monochromatic light (e.g., sodium light) is shone onto the setup.
 - Light reflects from:
 1. The **bottom surface of the lens** (glass-to-air boundary).
 2. The **top surface of the glass plate** (air-to-glass boundary).
 - These two reflected beams are **coherent** and interfere with each other.
 - The **path difference** depends on the thickness of the air gap at each point.
 - Where the path difference satisfies conditions for **destructive interference**, **dark rings** appear; for **constructive interference**, **bright rings** appear, forming concentric circular fringes.
-

3. What is the least count of a travelling microscope?

- The **least count (L.C.)** of a travelling microscope is the **smallest length it can accurately measure**.
- It is calculated as:

$$\text{L.C.} = \frac{\text{Pitch of the screw}}{\text{Number of divisions on the circular scale}}$$

- **Pitch:** Distance moved by the screw per one full rotation (often 1 mm or 0.5 mm).

- **Example:** If pitch = 1 mm and circular scale has 100 divisions,

$$\text{L.C.} = \frac{1 \text{ mm}}{100} = 0.01 \text{ mm} = 10^{-5} \text{ m.}$$

4. Why is the central spot dark?

- The central spot is dark because at the point of contact between the lens and the glass plate, the **thickness of the air film is zero**.
- The **path difference** between the two interfering beams arises from:
 1. **Twice the thickness** of the air film ($2t$).
 2. An **additional phase shift of π (or $\lambda/2$)** because the reflection at the **glass-to-air** boundary (bottom of lens) occurs at a rarer medium, causing a phase change, while reflection at the **air-to-glass** boundary (top of plate) does not.
- At the center ($t = 0$), the **net path difference = $\lambda/2$** , which satisfies the condition for **destructive interference**.
- Therefore, a **dark spot** is observed at the center.
