Modern Physics (DI01000061) - Winter 2024 Solution

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Question 1 [14 marks]

Fill in the blanks / MCQs

Solution

Table 1. MCQ Answers

No.	Answer	No.	Answer
(1)	(a) Si	(8)	(b) 0.5 Hz
(2)	(a) 1.50	(9)	(a) 300000 km/s
(3)	(b) greater than	(10)	(b) solid
(4)	(c) 4	(11)	(a) crest and trough
(5)	(d) Total internal reflection	(12)	(b) monochromatic
(6)	(d) frequency	(13)	(a) Single mode
(7)	(a) Coulomb	(14)	(b) 45°

Mnemonic

"Silicon Glass Bridge Optic Frequency Coulomb Hz Solid Crest Mono Single 45"

Question 2(A) [6 marks]

Attempt any two

Question 2(A)(1) [3 marks]

Differentiate between accuracy and precision.

Solution

Table 2. Accuracy vs Precision

Parameter	Accuracy	Precision
Definition	Closeness to true value	Consistency of repeated measurements
Focus	Correctness	Reproducibility
Error Type	Systematic error	Random error
Example	Hitting bullseye	Hitting same spot repeatedly

- **Accuracy**: How close measurement is to actual value
- **Precision**: How close repeated measurements are to each other

Mnemonic

"Accurate Aims Actual, Precise Repeats Reliably"

Question 2(A)(2) [3 marks]

Determine the diameter of a sphere measured by micrometer screw, main scale reading is 5 mm and 50th division of circular scale is coinciding with base line. The least count of this instrument is 0.01 mm.

Solution

Given:
- Main Scale Reading (MSR) = 5 mm
- Circular Scale Reading (CSR) = 50 divisions
- Least Count (LC) = 0.01 mm

Formula:

$$\text{Total Reading} = \text{MSR} + (\text{CSR} \times \text{LC})$$

Calculation:

$$\begin{aligned}\text{Total Reading} &= 5 + (50 \times 0.01)\\ &= 5 + 0.5\\ &= 5.5 \text{ mm}\end{aligned}$$

Diameter of sphere = 5.5 mm

Mnemonic

"Main Scale Reading + Circular * Least Count"

Question 2(A)(3) [3 marks]

Calculate the amount of electric charge stored on either plate of a capacitor of capacitance 4 μF when connected across 12 volt battery.

Solution

Given:
- Capacitance (C) = 4 μF = 4×10^{-6} F
- Voltage (V) = 12 V

Formula:

$$Q = CV$$

Calculation:

$$\begin{aligned}Q &= 4 \times 10^{-6} \times 12\\ Q &= 48 \times 10^{-6} \text{ C}\\ Q &= 48\ \mu\text{C}\end{aligned}$$

Electric charge stored = 48 μC

Mnemonic

"Charge equals Capacitance times Voltage"

Question 2(B) [8 marks]

Attempt any two

Question 2(B)(1) [4 marks]

Draw a sketch of micrometer screw gauge with proper nomenclature.

Solution

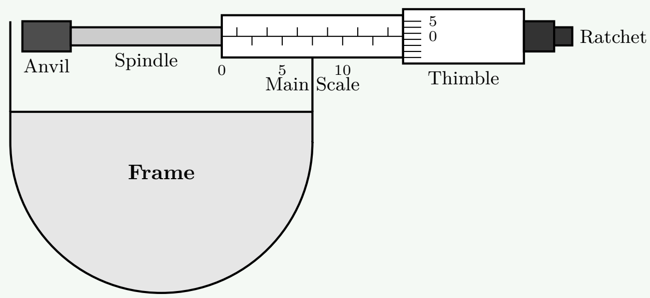


Figure 1. Micrometer Screw Gauge

Main Components:

- **Frame**: U-shaped structure providing support
- **Anvil**: Fixed jaw for placing object
- **Spindle**: Movable screw mechanism
- **Thimble Scale**: Circular scale with 50 divisions
- **Main Scale**: Linear scale in mm
- **Ratchet**: For consistent pressure application

Mnemonic

"Frame Anvil Spindle Thimble Main Ratchet"

Question 2(B)(2) [4 marks]

Explain the zero, positive and negative errors for vernier calipers with proper diagram and list necessary steps to remove these types of errors.

Solution

Types of Errors:

Table 3. Vernier Caliper Errors

Error Type	Condition	Reading
Zero Error	Zero line of vernier doesn't coincide with main scale zero	Non-zero reading when jaws closed
Positive Error	Vernier zero is right of main scale zero	Add correction
Negative Error	Vernier zero is left of main scale zero	Subtract correction

Diagrams:

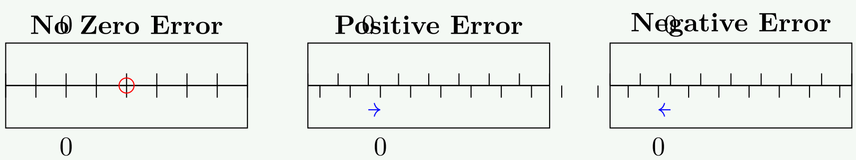


Figure 2. Vernier Caliper Zero Errors

Steps to Remove Errors:

- **Check zero error** before measurement
- **Apply correction** to final reading
- **Clean jaws** regularly to prevent debris
- **Handle carefully** to avoid mechanical damage

Mnemonic

"Check Clean Correct Carefully"

Question 2(B)(3) [4 marks]

In an experiment of finding the periodic time of a simple pendulum, the observations are 1.96 s, 1.98 s, 2.00 s, 2.02 s, 2.04 s. Calculate absolute error, mean absolute error, relative error and percentage error.

Solution

Data: 1.96, 1.98, 2.00, 2.02, 2.04 s

Calculations:

1. **Mean value**:

$$\bar{x} = \frac{1.96 + 1.98 + 2.00 + 2.02 + 2.04}{5} = \frac{10.00}{5} = 2.00 \text{ s}$$

2. **Absolute errors** ($|\Delta x_i| = |x_i - \bar{x}|$):

- $|1.96 - 2.00| = 0.04$ s
- $|1.98 - 2.00| = 0.02$ s
- $|2.00 - 2.00| = 0.00$ s
- $|2.02 - 2.00| = 0.02$ s
- $|2.04 - 2.00| = 0.04$ s

3. **Mean absolute error**:

$$\overline{\Delta x} = \frac{0.04 + 0.02 + 0.00 + 0.02 + 0.04}{5} = \frac{0.12}{5} = 0.024 \text{ s}$$

4. **Relative error**:

$$\delta x = \frac{\overline{\Delta x}}{\bar{x}} = \frac{0.024}{2.00} = 0.012$$

5. **Percentage error**:

$$\% \text{ Error} = 0.012 \times 100 = 1.2\%$$

Results: Mean absolute error = 0.024 s, Relative error = 0.012, Percentage error = 1.2%

Mnemonic

"Mean Absolute Relative Percentage"

Question 3(A) [6 marks]

Attempt any two

Question 3(A)(1) [3 marks]

Define: Electric flux, Electric field, Potential Difference

Solution

Table 4. Definitions

Term	Definition	Unit	Formula
Electric Flux	Number of electric field lines passing through a surface	Nm^2/C	$\Phi = E \cdot A$
Electric Field	Force per unit positive charge	N/C	$E = F/q$
Potential Difference	Work done per unit charge between two points	Volt	$V = W/q$

- **Electric flux**: Measure of field lines penetrating surface
- **Electric field**: Region where electric force acts on charges
- **Potential difference**: Energy difference per unit charge

Mnemonic

"Flux Field Force, Work Watts Volts"

Question 3(A)(2) [3 marks]

Derive the formula for equivalent capacitance when three different capacitors are connected in series with necessary circuit diagram.

Solution

Circuit Diagram:

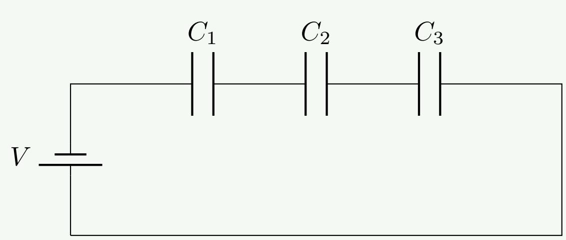


Figure 3. Capacitors in Series

Derivation:

- **Same charge** Q flows through each capacitor.
- **Voltage divides**: $V = V_1 + V_2 + V_3$
- For each capacitor: $V_1 = Q/C_1, V_2 = Q/C_2, V_3 = Q/C_3$

- Total voltage:

$$V = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3} = Q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$$

- For equivalent capacitor C_s: $V = Q/C_s$
- Comparing equations:

$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Formula:

$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Mnemonic

"Series Sums reciprocals, Same charge Splits voltage"

Question 3(A)(3) [3 marks]

Define: Infrasonic sound, Audible Sound, Ultrasonic sound

Solution

Table 5. Sound Classifications

Sound Type	Frequency Range	Characteristics	Applications
Infrasonic	Below 20 Hz	Inaudible to humans	Earthquake detection
Audible	20 Hz to 20 kHz	Audible to humans	Communication, music
Ultrasonic	Above 20 kHz	Inaudible to humans	Medical imaging, SONAR

- **Infrasonic**: Low frequency sounds below human hearing
- **Audible**: Normal hearing range for humans
- **Ultrasonic**: High frequency sounds above human hearing

Mnemonic

"Infra-Below, Audible-Between, Ultra-Above"

Question 3(B) [8 marks]

Attempt any two

Question 3(B)(1) [4 marks]

Prove $C = \epsilon_0 A/d$ for parallel plate capacitor.

Solution

Diagram:

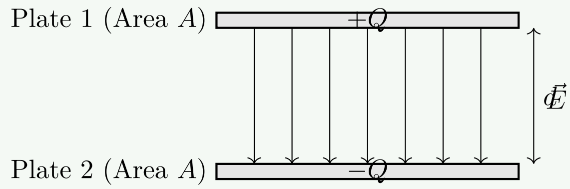


Figure 4. Parallel Plate Capacitor

Derivation:

- **Electric field** between plates: $E = \sigma/\epsilon_0 = Q/(\epsilon_0 A)$
- **Potential difference**: $V = E \times d = Qd/(\epsilon_0 A)$
- **Capacitance definition**: $C = Q/V$
- Substituting V:

$$C = \frac{Q}{Qd/(\epsilon_0 A)} = \frac{\epsilon_0 A}{d}$$

Final Formula:

$$C = \frac{\epsilon_0 A}{d}$$

Where:

- ϵ_0: Permittivity of free space
- A: Area of plates
- d: Distance between plates

Mnemonic

"Capacitance equals epsilon-zero Area over distance"

Question 3(B)(2) [4 marks]

List the characteristics of electric field lines.

Solution

Key Characteristics:

1. **Direction**: Start from positive charge and end at negative charge.
2. **Density**: The closeness of lines indicates field strength (denser = stronger).
3. **Continuous**: They are continuous curves without breaks in a charge-free region.
4. **Non-intersecting**: Two field lines never cross each other (otherwise there would be two directions of field at one point).
5. **Perpendicular**: They are always normal to the surface of a charged conductor.
6. **Closed loops**: They do not form closed loops (electrostatic field is conservative).
7. **Tangent**: Tangent to the line at any point gives the direction of the electric field.

Mnemonic

"Positive to Negative, Dense means Strong, Never cross, Always perpendicular"

Question 3(B)(3) [4 marks]

Describe working and construction of magnetostriction method used for production of ultrasonic waves.

Solution

Construction:

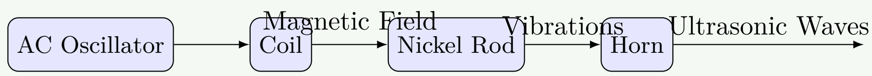


Figure 5. Magnetostriction Oscillator Block Diagram

Components:

- **Nickel rod**: Ferromagnetic material showing magnetostriction effect.
- **Coil**: Solenoid wrapped around the rod to produce magnetic field.
- **AC oscillator**: Source of high-frequency alternating current.
- **Horn**: To transmit acoustic energy efficiently.

Working Principle:

- When **AC current** flows through the coil, a rapidly changing **magnetic field** is produced.
- The ferromagnetic rod undergoes **magnetostriction** (change in length) at twice the frequency of the applied AC.
- This produces **mechanical vibrations** in the rod.
- If the frequency matches the natural frequency of the rod, resonance occurs, producing high-intensity **ultrasonic waves**.

Mnemonic

"AC Coil Makes Nickel vibrate, Creates Ultrasonic"

Question 4(A) [6 marks]

Attempt any two

Question 4(A)(1) [3 marks]

A radio station broadcasts its radio signals at 9.26×10^7 Hz. Find the wavelength if the waves travel at a speed of 3.00×10^8 m/s.

Solution

Given:

- Frequency $(f) = 9.26 \times 10^7$ Hz
- Speed $(c) = 3.00 \times 10^8$ m/s

Formula:

$$c = f\lambda \implies \lambda = \frac{c}{f}$$

Calculation:

$$\lambda = \frac{3.00 \times 10^8}{9.26 \times 10^7}$$
$$\lambda = \frac{300}{92.6} \times 10^0$$
$$\lambda \approx 3.24 \text{ m}$$

Wavelength = 3.24 m

Mnemonic

"Speed equals frequency times wavelength"

Question 4(A)(2) [3 marks]

State the Snell's law and explain refractive index of media.

Solution

Snell's Law: The ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant value for a given pair of media.

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Where:

- n_1, n_2: Refractive indices of medium 1 and 2
- θ_1, θ_2: Angles of incidence and refraction

Refractive Index:

Table 6. Refractive Index Types

Type	**Definition**	**Formula**
Absolute	Speed of light in vacuum to medium	$n = c/v$
Relative	Ratio of speeds in two media	$n_{21} = v_1/v_2$

Higher refractive index means an optically denser medium where light travels slower.

Mnemonic

"Snell Says Sine ratio constant, Dense slows Down light"

Question 4(A)(3) [3 marks]

Compare: Ordinary light and LASER

Solution

Table 7. Ordinary Light vs LASER

Property	**Ordinary Light**	**LASER**
Coherence	Incoherent	Coherent
Color	Polychromatic	Monochromatic
Direction	Divergent	Parallel beam
Intensity	Low	Very high
Phase	Random	Fixed phase relationship
Wavelength	Multiple wavelengths	Single wavelength

Mnemonic

"LASER: Coherent Monochromatic Parallel Intense"

Question 4(B) [8 marks]

Attempt any two

Question 4(B)(1) [4 marks]

Demonstrate the structure of an optical fiber with necessary diagram.

Solution

Optical Fiber Structure:

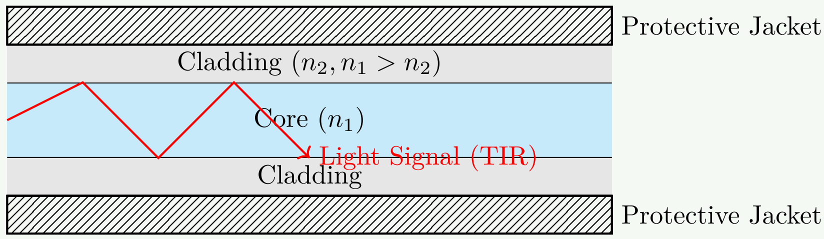


Figure 6. Structure of Optical Fiber

Components:

Table 8. Fiber Components

Component	Material	Function	Refractive Index
Core	Glass/Plastic	Light transmission	Higher (n_1)
Cladding	Glass	Total internal reflection	Lower (n_2)
Jacket	Plastic	Protection	-

Working Principle: Light travels through the core via **Total Internal Reflection (TIR)** because $n_1 > n_2$.

Mnemonic

"Core Cladding Jacket, Higher Lower Protection"

Question 4(B)(2) [4 marks]

List applications of LASER in engineering and medical field.

Solution

Engineering Applications:
- **Cutting and welding**: Precision metal cutting.
- **3D printing**: Laser sintering.
- **Measurement**: Distance measuring and surveying (LIDAR).
- **Communication**: Optical fiber systems.
- **Material processing**: Surface hardening.
- **Barcode scanning**: Retail and inventory.

Medical Applications:
- **Surgery**: Precise tissue cutting (bloodless surgery).
- **Eye treatment**: LASIK corrective surgery.
- **Cancer treatment**: Tumor destruction.
- **Diagnostics**: Spectroscopy.
- **Dentistry**: Cavity treatment.
- **Skin treatment**: Cosmetic procedures (hair removal).

Mnemonic

"Engineering: Cut Weld Measure Communicate, Medical: Surgery Eye Cancer Diagnose"

Question 4(B)(3) [4 marks]

Explain P-type and N-type semiconductors.

Solution

Table 9. N-type vs P-type Semiconductors

Property	**N-type**	**P-type**
Dopant	Phosphorus, Arsenic (Pentavalent)	Boron, Aluminum (Trivalent)
Majority Carriers	Electrons	Holes
Minority Carriers	Holes	Electrons
Charge	Electrically Neutral	Electrically Neutral
Formation	Donor impurity adds electrons	Acceptor impurity creates holes

Both types are formed by **doping** intrinsic semiconductors (like Si or Ge) with specific impurities to increase conductivity.

Mnemonic

"N-type Negative electrons, P-type Positive holes"

Question 5(A) [6 marks]

Attempt any two

Question 5(A)(1) [3 marks]

Classify conductors, semiconductors and insulators based on energy band gap.

Solution

Table 10. Material Classification

Material	**Energy Band Gap**	**Characteristics**
Conductor	No gap (0 eV)	Valence and conduction bands overlap
Semiconductor	Small gap (1-3 eV)	Moderate band gap
Insulator	Large gap (>3 eV)	Wide band gap

Energy Band Diagram:

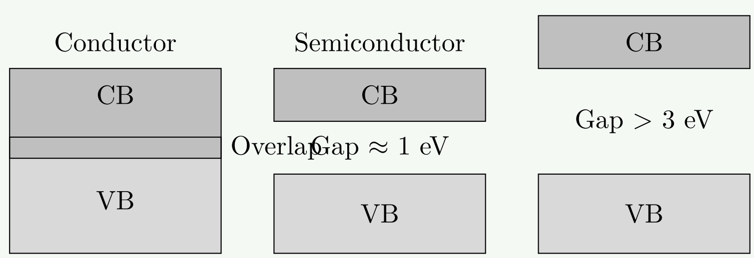


Figure 7. Energy Band Diagrams

Mnemonic

"No gap Conducts, Small gap Semi, Large gap Insulates"

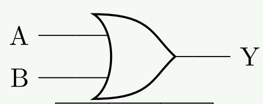
Question 5(A)(2) [3 marks]

Explain OR and AND logic gates with necessary truth table.

Solution

OR Gate

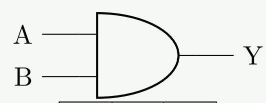
$$Y = A + B$$



A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

AND Gate

$$Y = A \cdot B$$



A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

Mnemonic

"OR: Any high makes high, AND: All high makes high"

Question 5(A)(3) [3 marks]

Describe the use of Zener diode as a voltage regulator.

Solution

Circuit Diagram:

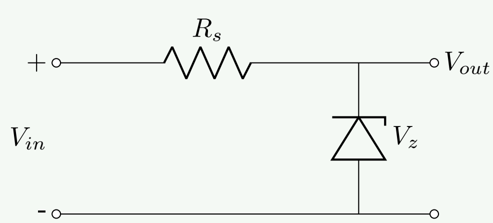


Figure 8. Zener Voltage Regulator

Working Principle:

- **Reverse Bias**: Zener diode is connected in reverse bias.
- **Breakdown**: When V_{in} exceeds Zener voltage V_z, the diode conducts deeply in breakdown region.
- **Regulation**: Voltage across Zener remains constant (V_z) despite changes in input voltage or load current.
- **Series Resistor** (R_s): Limits the current to protect the Zener diode.

Mnemonic

"Zener Zealously maintains Voltage despite Variations"

Question 5(B) [8 marks]

Attempt any two

Question 5(B)(1) [4 marks]

Explain full wave rectifier with necessary circuit and draw input and output waveforms.

Solution

Circuit Diagram (Center-Tapped):

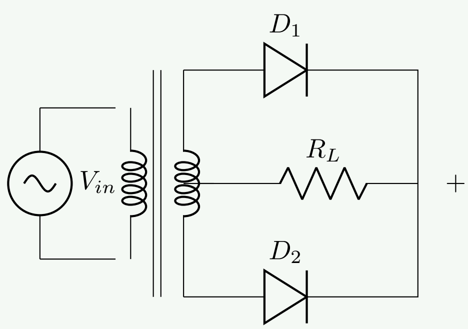


Figure 9. Full Wave Rectifier

Waveforms:

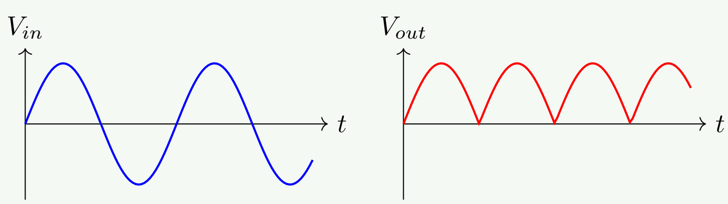


Figure 10. Input and Output Waveforms

Mnemonic

"Full wave uses Full cycle, Better efficiency Better output"

Question 5(B)(2) [4 marks]

Demonstrate forward and reverse characteristics of P-N junction diode.

Solution

I-V Characteristic Curve:

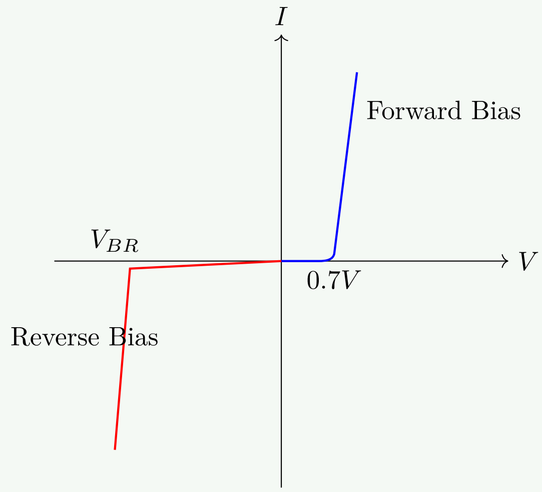


Figure 11. PN Junction Diode Characteristics

Characteristics:

- **Forward Bias**: Diode conducts current significantly after cut-in voltage (0.7V for Si).
- **Reverse Bias**: Negligible leakage current until breakdown voltage.
- **Cut-in Voltage**: The voltage at which current starts increasing rapidly.
- **Breakdown**: Sharp increase in reverse current at high reverse voltage.

Mnemonic

"Forward Flow, Reverse Resist"

Question 5(B)(3) [4 marks]

Write the principle of LED and explain its construction and working.

Solution

Principle: Electroluminescence - Conversion of electrical energy into light energy during carrier recombination.
Construction:

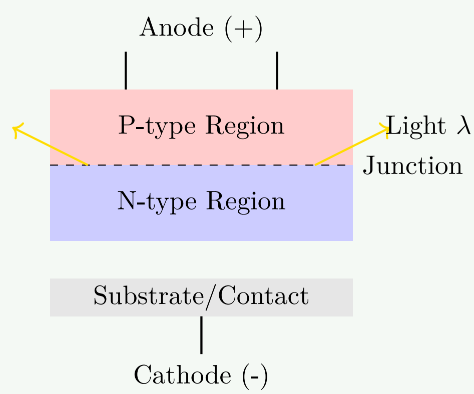


Figure 12. LED Construction

Working:

- It operates in **Forward Bias**.
- Electrons from N-region cross into P-region and recombine with holes.
- Energy is released in the form of **photons** (light).
- The color depends on the **band gap** of the semiconductor material (e.g., GaAs for Red).

Mnemonic

"LED: Light Emitting Diode, Electrons and holes Dance to make Light"