Modern Physics Solutions

DI01000061 – Winter 2024

Semester 1 Study Material

Detailed Solutions and Explanations

Question 1 – Fill in the blanks/MCQs [14 marks]

Solution

Answer Table:

Question	Answer	Question	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) – Attempt any two [6 marks]

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

Differentiate between accuracy and precision.

Solution

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

Key Points:

- **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:

$$\begin{aligned}\text{Main Scale Reading (MSR)} &= 5 \text{ mm}\\ \text{Circular Scale Reading (CSR)} &= 50 \text{ divisions}\\ \text{Least Count (LC)} &= 0.01 \text{ mm}\end{aligned}$$

Formula:

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

Calculation:

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

Answer: 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:

$$\begin{aligned}\text{Capacitance } (C) &= 4\ \mu\text{F} = 4 \times 10^{-6}\ \text{F}\\ \text{Voltage } (V) &= 12\ \text{V}\end{aligned}$$

Key Formula

$$Q = CV$$

Calculation:

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

Answer: Electric charge stored = 48 μC

Mnemonic

"Charge equals Capacitance times Voltage"

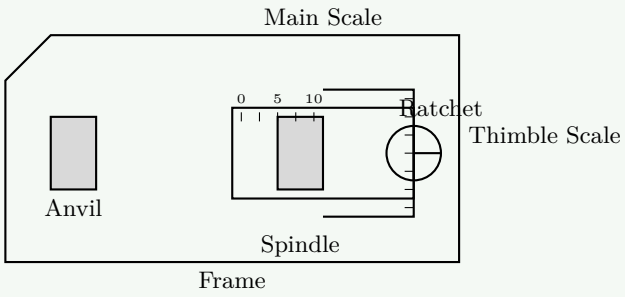
Question 2(B) – Attempt any two [8 marks]

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

Draw a sketch of micrometer screw gauge with proper nomenclature.

Solution

Micrometer Screw Gauge Diagram:



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.

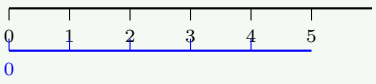
Solution

Types of Errors:

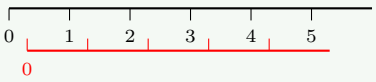
Error Type	Condition	Reading
Zero Error	Zero line of vernier doesn't coincide with main scale zero	Non-zero when jaws closed
Positive Error	Vernier zero is right of main scale zero	Add correction
Negative Error	Vernier zero is left of main scale zero	Subtract correction

Diagrams:

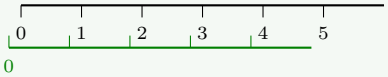
Zero Error:



Positive Error:



Negative Error:



Steps to Remove Errors:

1. **Check zero error** before measurement
2. **Apply correction** to final reading
3. **Clean jaws** regularly to prevent debris
4. **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

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

Mean value:

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

Absolute errors: $|x_i - \bar{x}|$

Observation	Value (s)	Absolute Error (s)
1	1.96	$\|1.96 - 2.00\| = 0.04$
2	1.98	$\|1.98 - 2.00\| = 0.02$
3	2.00	$\|2.00 - 2.00\| = 0.00$
4	2.02	$\|2.02 - 2.00\| = 0.02$
5	2.04	$\|2.04 - 2.00\| = 0.04$

Mean absolute error:

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

Relative error:

$$\text{Relative error} = \frac{\Delta x_{\text{mean}}}{\bar{x}} = \frac{0.024}{2.00} = 0.012$$

Percentage error:

$$\text{Percentage error} = \text{Relative error} \times 100 = 0.012 \times 100 = 1.2\%$$

Results:

- Mean absolute error = 0.024 s
- Relative error = 0.012
- Percentage error = 1.2%

Mnemonic

"Mean Absolute Relative Percentage"

Question 3(A) – Attempt any two [6 marks]

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

Define: Electric flux, Electric field, Potential Difference

Solution

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	$V = W/q$

Key Points:

- **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

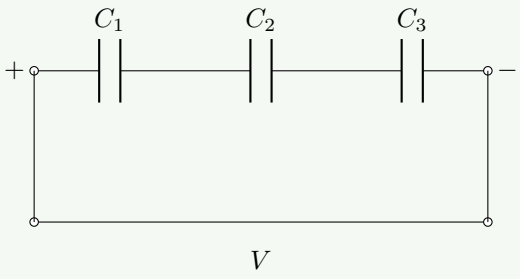
"Flux Field Force, Work Watts Volts"

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:



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**: $V = Q/C_s$
- **Therefore**:

Key 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

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

Key Points:

- **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"

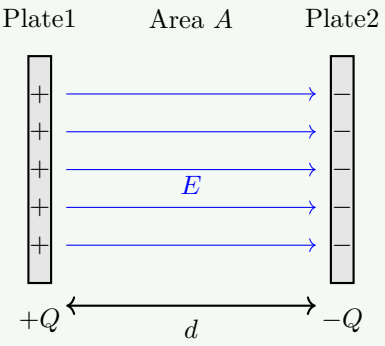
Question 3(B) – Attempt any two [8 marks]

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

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

Solution

Diagram:



Derivation:

- **Electric field** between plates:

$$E = \frac{\sigma}{\epsilon_0} = \frac{Q}{\epsilon_0 A}$$

  where $\sigma = Q/A$ is surface charge density
- **Potential difference**:

$$V = E \times d = \frac{Qd}{\epsilon_0 A}$$

- **Capacitance definition**: $C = Q/V$
- **Substituting**:

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

Key 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**: From positive to negative charge
2. **Density**: Indicates field strength
3. **Continuous**: Never break in free space
4. **Non-intersecting**: No two lines cross
5. **Perpendicular**: To conductor surface
6. **Closed loops**: Only around changing magnetic fields
7. **Tangent**: Gives field direction at any point
8. **Uniform spacing**: In uniform field regions

Properties:

- Start from **positive charges**
- End at **negative charges**
- **Higher density** means stronger field
- **Never intersect** each other

Mnemonic

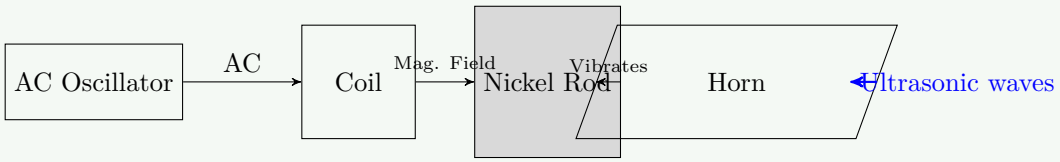
"Positive to Negative, Dense means Strong, Never cross, Always perpendicular"

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

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

Solution

Construction Block Diagram:



Components:

- **Nickel rod**: Magnetostrictive material
- **Coil**: Electromagnet around rod
- **AC oscillator**: High frequency current source
- **Horn**: Sound amplifier and transmitter

Working Principle:

1. **AC current** flows through coil
2. **Magnetic field** changes rapidly
3. **Nickel rod** expands and contracts (magnetostriction effect)
4. **Mechanical vibrations** produced at high frequency
5. **Ultrasonic waves** generated and amplified by horn

Applications: Medical imaging, cleaning, welding, material testing

Mnemonic

"AC Coil Makes Nickel vibrate, Creates Ultrasonic"

Question 4(A) – Attempt any two [6 marks]

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:

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

Key Formula

$$c = f\lambda \quad \Rightarrow \quad \lambda = \frac{c}{f}$$

Calculation:

$$\begin{aligned}\lambda &= \frac{3.00 \times 10^8}{9.26 \times 10^7} \\ &= \frac{3.00}{9.26} \times 10^{8-7} \\ &= 0.324 \times 10^1 \\ &= 3.24 \text{ m}\end{aligned}$$

Answer: 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

Key Formula

Snell's Law:

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

Where: n_1, n_2 = Refractive indices of media 1 and 2, θ_1, θ_2 = Angles of incidence and refraction

Refractive Index:

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

Key Points:

- **Higher refractive index**: Denser medium, slower light
- **Lower refractive index**: Rarer medium, faster light

Mnemonic

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

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

Compare: Ordinary light and LASER

Solution

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

Key Differences:

- **LASER**: Coherent, monochromatic, parallel, intense
- **Ordinary**: Incoherent, polychromatic, divergent, less intense

Mnemonic

"LASER: Coherent Monochromatic Parallel Intense"

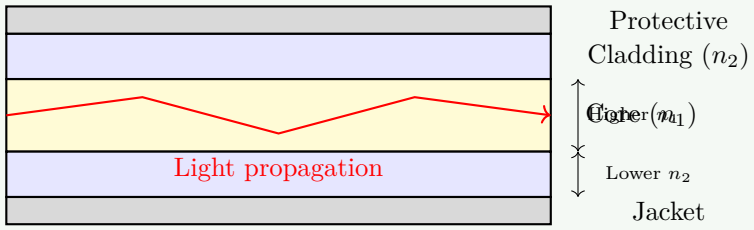
Question 4(B) – Attempt any two [8 marks]

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

Demonstrate the structure of an optical fiber with necessary diagram.

Solution

Optical Fiber Structure:



Components:

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

Working Principle:

- Light enters **core** at acceptance angle
- **Total internal reflection** at core-cladding boundary
- Light travels in **zigzag path** through core
- $n_1 > n_2$ ensures light confinement

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:
1. **Cutting and welding**: Precision metal cutting
2. **3D printing**: Laser sintering
3. **Measurement**: Distance and surveying
4. **Communication**: Optical fiber systems
5. **Material processing**: Surface hardening
6. **Barcode scanning**: Retail and inventory

Medical Applications:
1. **Surgery**: Precise tissue cutting
2. **Eye treatment**: Corrective surgery
3. **Cancer treatment**: Tumor destruction
4. **Diagnostics**: Spectroscopy
5. **Dentistry**: Cavity treatment
6. **Skin treatment**: Cosmetic procedures

Advantages: Precision, non-contact, sterile, minimal damage

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

N-type Semiconductor:

Property	N-type
Dopant	Phosphorus, Arsenic (5 valence electrons)
Majority carriers	Electrons
Minority carriers	Holes
Charge	Negative

P-type Semiconductor:

Property	P-type
Dopant	Boron, Aluminum (3 valence electrons)
Majority carriers	Holes
Minority carriers	Electrons
Charge	Positive

Formation Process:
- **N-type**: Pentavalent atoms donate electrons
- **P-type**: Trivalent atoms accept electrons, create holes
- **Doping**: Controlled addition of impurities
- **Conductivity**: Increases due to free carriers

Mnemonic

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

Question 5(A) – Attempt any two [6 marks]

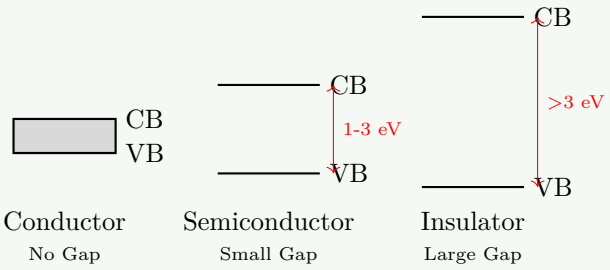
Question 5(A)(1) [3 marks]

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

Solution

Material	Energy Band Gap	Characteristics	Examples
Conductor	No gap (0 eV)	Valence and conduction bands overlap	Copper, Silver
Semiconductor	Small gap (1-3 eV)	Moderate band gap	Silicon, Germanium
Insulator	Large gap (>3 eV)	Wide band gap	Glass, Rubber

Energy Band Diagram:



Key Points:

- **CB**: Conduction Band, **VB**: Valence Band
- **Gap determines** electrical conductivity

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.

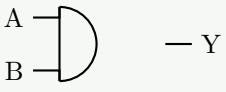
Solution

OR Gate:

A	B	Y = A + B
0	0	0
0	1	1
1	0	1
1	1	1

AND Gate:

A	B	Y = A · B
0	0	0
0	1	0
1	0	0
1	1	1



Key Points:

- **OR**: Output HIGH when any input is HIGH
- **AND**: Output HIGH when all inputs are HIGH

Mnemonic

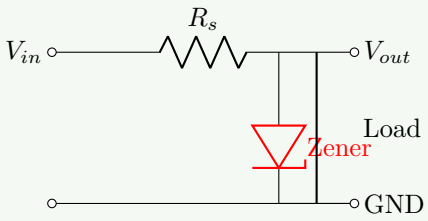
"OR: Any high makes high, AND: All high makes high"

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

Describe the use of Zener diode as a voltage regulator.

Solution

Circuit Diagram:



Working Principle:

- **Forward bias**: Acts like normal diode
- **Reverse bias**: Breaks down at Zener voltage
- **Voltage regulation**: Maintains constant $V_{out} = V_z$
- **Series resistor**: Limits current through Zener

Characteristics:

- **Zener voltage**: Constant breakdown voltage
- **Current range**: Wide operating range
- **Temperature stability**: Good voltage stability
- **Power rating**: Must not exceed maximum power

Applications: Power supplies, voltage references, protection circuits

Mnemonic

"Zener Zealously maintains Voltage despite Variations"

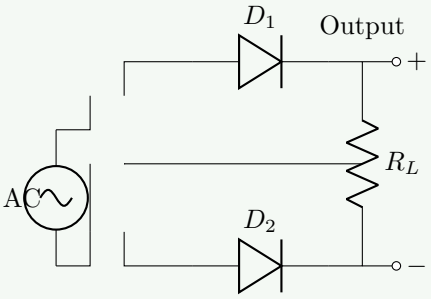
Question 5(B) – Attempt any two [8 marks]

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

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

Solution

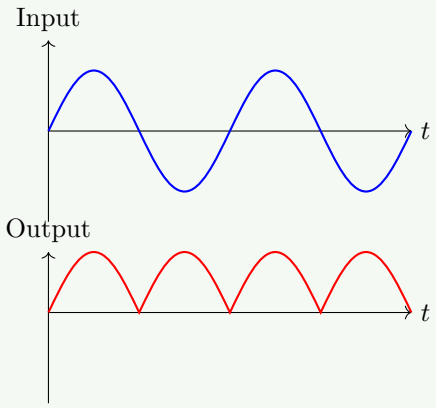
Center-tap Full Wave Rectifier:



Working:

- **Positive half cycle**: D_1 conducts, D_2 off
- **Negative half cycle**: D_2 conducts, D_1 off
- **Both halves**: Current flows through load in same direction

Waveforms:



Advantages: Better efficiency, lower ripple, better transformer utilization

Mnemonic

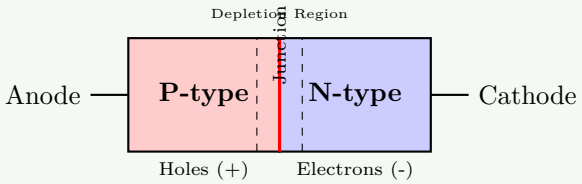
"Full wave uses Full cycle, Better efficiency Better output"

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

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

Solution

P-N Junction Structure:



Forward Bias Characteristics:

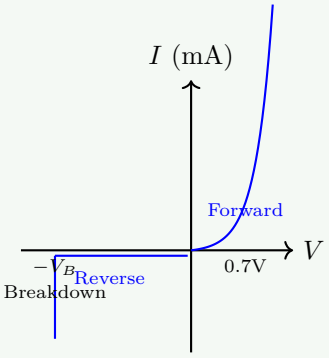
Voltage Range	Current	Behavior
0 to 0.3V (Si)	Very small	Cut-in voltage
Above 0.7V	Exponential increase	Conducting

Reverse Bias Characteristics:

Voltage Range	Current	Behavior
0 to breakdown	Reverse saturation	Leakage current
Breakdown voltage	Sharp increase	Avalanche breakdown

Solution

I-V Characteristic Curve:



Key Points:

- **Forward**: Low resistance, high current
- **Reverse**: High resistance, low current
- **Cut-in voltage**: 0.7V for Silicon, 0.3V for Germanium

Mnemonic

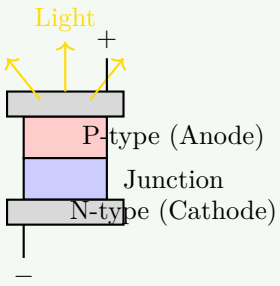
"Forward Flow, Reverse Resist"

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

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

Solution

Principle: **Electroluminescence** – Direct conversion of electrical energy to light energy
Construction:



Materials Used:

Color	Material	Wavelength
Red	GaAs	700 nm
Green	GaP	550 nm
Blue	GaN	470 nm

Solution

Working:

1. **Forward bias**: Electrons and holes recombine at junction
2. **Energy release**: Photons emitted during recombination
3. **Light color**: Depends on band gap energy
4. **Efficiency**: High electrical to optical conversion

Applications: Displays, indicators, lighting, optical communication

Mnemonic

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

— End of Solutions —

Modern Physics (DI01000061) – Winter 2024