GUJARAT TECHNOLOGICAL UNIVERSITY

BE-4 SEMESTER – OLD PAPER – S22 TO W25 – QUESTION BANK SOLUTION

Subject Name & Code:
Mechanical Measurement and Metrology- 3141901

Unit 4: Measurement Systems and Basic Concepts of Measurement Methods

Repeated Questions:

1. **Explain the principle of Electrical Strain Gauges.**

Appeared in: **W23 (Q5b OR, 04 marks)**, **W24 (Q5b, 04 marks)**, **S25 (Q5b, 04 marks)**, S22 (Q5b OR, 04 marks)

Answer:

- **Principle**: **Piezoresistive effect** – when a conductor is stretched, its length (L) increases and cross-sectional area (A) decreases, causing an increase in electrical resistance $R = \rho L/A$.
- **Mathematical relation**:

$$\frac{\Delta R}{R} = GF \times \varepsilon$$

where GF = gauge factor (≈ 2 for metal foil), ε = strain = $\Delta L/L$.

- **Construction**: Thin constantan foil etched into a grid pattern, mounted on a flexible polyimide backing. Bonded to the test specimen with special adhesive.
- **Working**: When specimen deforms, foil deforms proportionally → resistance change measured by **Wheatstone bridge** (quarter, half, or full bridge). Output voltage proportional to strain.
- **Application**: Load cells, pressure transducers, torque sensors, structural health monitoring.

2. **Explain the construction and working of a Thermocouple with a neat sketch. / Write a short note on Thermocouple.**

Appeared in: **W24 (Q4b, 04 marks)**, **W22 (Q3c, 07 marks)**, **S25 (Q5c, 07 marks)**, S23 (Q2c OR, 07 marks)

Answer:

- **Thermocouple** is a temperature sensor based on Seebeck effect (voltage generated at junction of two dissimilar metals when heated).
- **Construction**:
  - Two dissimilar metal wires (e.g., Chromel–Alumel, Iron–Constantan, Copper–Constantan).
  - Welded or twisted at one end – **hot junction** (measuring junction).
  - Other ends (cold junction) kept at reference temperature (0°C or ice bath) or compensated.
  - Voltage measured by millivoltmeter.

- **Working**:
  - Temperature difference between hot and cold junctions generates EMF (Seebeck voltage).
  - EMF ∝ ΔT for small ranges, but usually polynomial for wide range.
  - Cold junction compensation needed if reference not 0°C.
- **Types**: Type K (Chromel–Alumel), Type J, T, E, R, S, B for different ranges.
- **Laws of thermocouples**:
  - Law of homogeneous circuit
  - Law of intermediate metals
  - Law of intermediate temperatures
- **Advantages**: Wide range (-200 to 2000°C), rugged, inexpensive.
- **Limitations**: Non-linear, low voltage output, needs cold junction compensation.
- **[DG]**

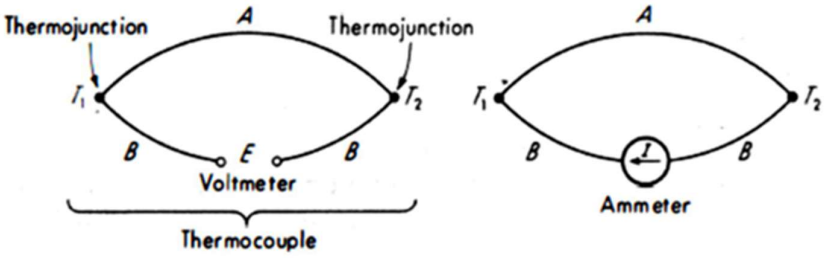

Fig.5.37 - Thermocouple

(Highest weightage: 7 marks – appears in 4+ papers)

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3. **Explain the construction and working of an Optical Pyrometer.**

Appeared in: **W25 (Q5c OR, 07 marks)**, **W24 (Q4c OR, 07 marks)**, W25 (Q4b OR, 04 marks - how to measure)

Answer:

- **Optical pyrometer** measures high temperatures (700°C to 3000°C) by comparing brightness of hot object with that of a calibrated lamp filament.
- **Construction**:
  - Lens focusing target image onto a lamp filament (tungsten).
  - Variable resistor to vary lamp current (hence brightness).
  - Red filter (to make monochromatic).
  - Eyepiece for viewing.
  - Ammeter calibrated in temperature (or potentiometer).
- **Working** (disappearing filament method):
  - Operator looks through eyepiece at glowing target.
  - Adjust lamp current until filament brightness matches target; the filament "disappears" against the background.
  - Read temperature from ammeter calibration.
- **Advantages**: Non-contact, measures moving objects, high range.
- **Limitations**: Needs clear line of sight, emissivity error, operator dependency.

(Highest weightage: 7 marks)

4. **Write a short note on Coordinate Measuring Machine (CMM). / List advantages and applications of CMM.**

Appeared in: **W25 (Q5b, 04 marks)**, **W23 (Q5c, 07 marks)**, **S25 (Q4b OR, 04 marks)**, S23

(Q5c OR, 07 marks)

Answer:

- **CMM** is a device for measuring geometric features of an object by touching its surface with a probe and recording 3D coordinates.
- **Construction**:
  - Bridge or gantry structure with three axes (X, Y, Z).
  - Electronic touch-trigger probe.
  - Air bearings for low friction.
  - Computer controller and metrology software.
- **Types**: Bridge (most common), Gantry (large parts), Horizontal arm (automotive), Cantilever.
- **Probe types**: Touch trigger, scanning, optical, laser.
- **Working**:
  - Part placed on table.
  - Probe moves to contact points; coordinates recorded.
  - Software computes dimensions, form, position, orientation.
- **Advantages**:
  - High accuracy (±0.5 μm).
  - Complex shape measurement.
  - Automated inspection.
- **Limitations**: Expensive, temperature controlled environment needed.
- **Applications**: Automotive, aerospace, tooling, reverse engineering.

5. **Explain the working of a McLeod Gauge for pressure measurement with a diagram.**

Appeared in: **W23 (Q3c OR, 07 marks)**, **W24 (Q5c OR, 07 marks)**

Answer:

- **McLeod Gauge** is a mercury-based compression vacuum gauge, measures absolute pressure from 10 Pa down to 10^-4 Pa.
- **Construction**:
  - Glass assembly: capillary tube (closed top), reference capillary, bulb, cut-off valve.
  - Mercury reservoir to compress gas.
  - Manometer scale.
- **Working**:
  - Connect unknown pressure gas to gauge.
  - Raise mercury until the gas in bulb is compressed into the capillary.
  - Boyle's law: $P_1V_1 = P_2V_2$.
  - After compression, measure height difference h between mercury levels in two capillaries.
  - Initial pressure $P_{\text{unknown}} = (a/h) \times$ scale factor (derived from geometry).
  - Calculation uses: $P = (A_c/V_b) \times h^2$ (for small h), where A_c = area of capillary, V_b = bulb volume.
- **Advantages**: Absolute measurement, independent of gas composition.
- **Limitations**: Mercury hazardous, not continuous reading, condensing vapors interfere.
- **[DG]**

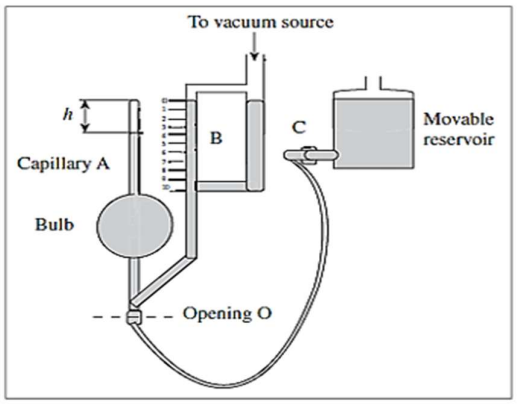

Fig.5.55 - McLeod gauge

6. **Define and explain: Sensitivity, Hysteresis, Range & Span, Accuracy & Precision, Threshold, Calibration, Linearity, etc.**

Appeared in: **S25 (Q1a, 03 marks)**, **W24 (Q3b OR, 04 marks)**, W23 (Q1a, 03 marks)

Answer:
(all terms in one answer, concise):

Term	Definition & Explanation
Sensitivity	Ratio of change in output to change in input. $S = \Delta O/\Delta I$. High sensitivity = small input gives large output.
Hysteresis	Maximum difference in output for the same input when input is approached from opposite directions (increasing vs decreasing). Caused by backlash, friction.
Range	Limits within which instrument can measure (e.g., 0–100°C).
Span	Algebraic difference between max and min of range (e.g., 100°C).
Accuracy	Closeness of measured value to true value. Expressed as % of full scale or reading.
Precision	Closeness of repeated measurements to each other (scatter). High precision ≠ high accuracy if systematic error present.
Threshold	The smallest input change that produces a detectable output. Below threshold, instrument does not respond.
Calibration	Comparing instrument output against a known standard to determine errors and make adjustments. Ensures traceability.
Linearity	Maximum deviation of calibration curve from a straight line, as % of full scale. Ideal instrument has perfect linearity.

For 4 marks: provide one example for each term (e.g., thermometer sensitivity 1°C/mm, hysteresis 0.5°C, etc.)

7. **What is a Transducer? Classify transducers. / Explain different types of transducers.**
Appeared in: **S25 (Q4a, 03 marks)**, S22 (Q1c, 07 marks)

Answer:
Classification (as earlier in Unit 1). Brief:

- **Active vs Passive**
- **Analog vs Digital**
- **Resistive, Inductive, Capacitive, Piezoelectric, Photoelectric, Thermoelectric**
  Examples: Thermocouple (active), LVDT (passive inductive), strain gauge (passive resistive).

8. **Explain Cathode Ray Oscilloscope (CRO) / Oscillographs.**
Appeared in: **S25 (Q4c OR, 07 marks)**

Answer:

- **CRO** (Cathode Ray Oscilloscope) is an electronic instrument that displays electrical signals as waveforms.
- **Construction**:
  - Cathode ray tube (CRT) – electron gun, deflection plates, phosphor screen.
  - Vertical amplifier (Y-input).
  - Horizontal time base (sweep generator).
  - Power supply.
- **Working**:
  - Electron beam emitted from cathode, accelerated to screen.
  - Input voltage applied to vertical deflection plates → beam moves up/down.
  - Time base applies sawtooth voltage to horizontal plates → beam sweeps left to right.
  - Result: signal amplitude vs time display.
- **Applications in metrology**:
  - Displaying transducer outputs (pressure, vibration).
  - Analyzing dynamic strain signals.
  - Checking LVDT output waveform.
  - Measuring frequency and phase.
- **[DG]**

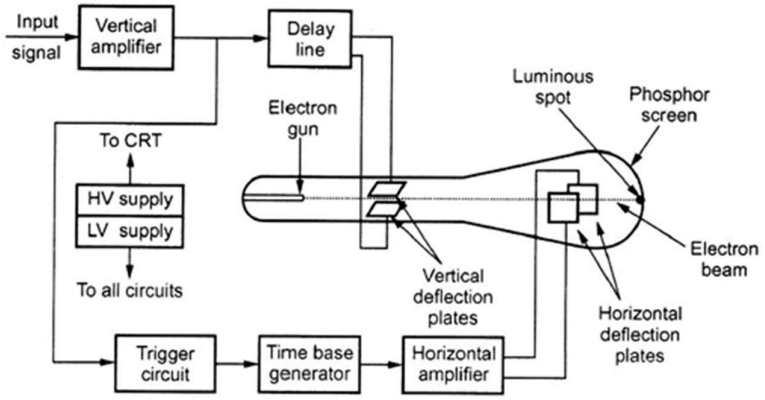

Fig.4.9 – Block diagram of CRO

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Other Important Questions:

1. **Explain the working principle of a Bimetallic Strip.**

Appeared in: W24 (Q4a, 03 marks)

Answer:

- **Principle**: Two metals with different coefficients of thermal expansion bonded together. When temperature changes, differential expansion causes bending.
- **Working**:
  - High expansion metal on one side (e.g., brass), low expansion (invar) on other.
  - On heating, brass expands more → strip bends toward invar side.
- **Applications**: Thermometers (dial type), thermostats, thermal switches.

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2. **Describe the construction and working of a Resistance Temperature Detector (RTD).**

Appeared in: W24 (Q4c, 07 marks)

Answer:

- **RTD** is a temperature sensor using the principle that electrical resistance of pure metal increases with temperature (positive temperature coefficient).
- **Construction**:
  - Sensing element: platinum (most stable), nickel, copper wire wound around a ceramic former (or thin film).
  - Leads connected in Wheatstone bridge.
  - Sheathed in stainless steel or glass for protection.
- **Working**:
  - Resistance $R_t = R_0(1 + \alpha t)$ (for small range).
  - For platinum: α ≈ 0.00385 Ω/Ω/°C (DIN 43760).
  - Standard: Pt100 (100 Ω at 0°C).
  - Bridge output converted to temperature.
- **Advantages**: High accuracy, stability, wide range (-200 to 850°C).
- **Limitations**: Slower than thermocouple, self-heating error, expensive.
- **Applications**: Precision laboratory measurements, industrial control (engine exhaust, HVAC).

(For numerical example – see separate section below)

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3. **Explain the principle of a Thermocouple. State the laws of thermocouples.**

Appeared in: W23 (Q3b, 04 marks)

Answer:

- **Principle**: Seebeck effect – a temperature difference between two junctions of dissimilar metals generates EMF.
- **Laws**:
  1. **Law of homogeneous circuit**: A thermocouple of a single homogeneous metal produces no EMF even with temperature gradient.
  2. **Law of intermediate metals**: Inserting a third metal into the circuit does not affect EMF if both junctions are at same temperature.
  3. **Law of intermediate temperatures**: EMF generated with junctions at T1 and T3 equals EMF(T1,T2) + EMF(T2,T3).

- **Application**: Cold junction compensation and extension wires.

4. **Explain application of series and parallel connection in thermocouple.**

Appeared in: W24 (Q4b, 04 marks)

Answer:

- **Series connection (Thermopile)**:
  - Many thermocouples connected in series (alternating junctions).
  - Total EMF = sum of individual EMFs → increases sensitivity.
  - Used for radiation detection (solar radiometers).
- **Parallel connection**:
  - Several identical thermocouples connected in parallel with same hot and cold junction temperatures.
  - Output EMF equals average EMF.
  - Used for averaging temperature over a surface (e.g., furnace wall).

5. **Explain Liquid-in-Glass Thermometer.**

Appeared in: W24 (Q4b OR, 04 marks)

Answer:

- **Construction**: Sealed glass capillary tube with a bulb at bottom, filled with mercury or alcohol. Above liquid, vacuum or inert gas.
- **Working**: Liquid expands with temperature; height of column proportional to temperature. Scale calibrated.
- **Advantages**: Simple, no power, low cost.
- **Limitations**: Fragile, slow response, not remote reading, limited range (mercury -30 to 500°C).

6. **Explain the International Temperature Scale with all the important standard points.**

Appeared in: S22 (Q4a, 03 marks)

Answer:

- **ITS-90** is the current international calibration standard.
- **Fixed points** (triple points or freezing points):
  - Hydrogen (–259.35°C)
  - Oxygen (–182.96°C)
  - Water (0.01°C triple point)
  - Gallium (29.7646°C)
  - Indium (156.5985°C)
  - Tin (231.928°C)
  - Zinc (419.527°C)
  - Aluminum (660.323°C)
  - Silver (961.78°C)
  - Gold (1064.18°C)
- Used to calibrate PRTs and thermocouples.

7. **Define Temperature Compensation. Explain temperature compensation in liquid-filled**

thermometer.
Appeared in: S22 (Q4a OR, 03 marks)

Answer:
- **Temperature compensation**: Technique to eliminate error caused by ambient temperature change.
- **In liquid-in-glass thermometer**:
  - The stem and bulb both expand with temperature; if uncompensated, reading error occurs.
  - Compensation: use a secondary bulb at the top (expansion chamber) or use external compensation with a bimetallic strip adjusting scale position.
  - Mercury-in-glass with compensation has a varying bore cross-section.
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8. **Explain the Wheatstone bridge circuit for strain measurement.**
Appeared in: (From syllabus)

Answer:
- **Wheatstone bridge** is used to convert small resistance change (ΔR) of strain gauge into voltage output.
- **Circuit**: Four resistances (R1, R2, R3, R4) arranged in a diamond; excitation voltage V_in across one diagonal; output V_out across other diagonal.
- **For quarter bridge** (one active strain gauge R_g, three fixed resistances):

$$V_{out} = \frac{V_{in}}{4} \cdot \frac{\Delta R_g}{R_g} = \frac{V_{in}}{4} \cdot GF \cdot \varepsilon$$

- **Balanced condition**: V_out = 0 when ΔR = 0.
- **Advantages**: Amplifies small ΔR, cancels temperature effects if dummy gauges used.
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9. **What is Gauge Factor? Explain its importance.**
Appeared in: S25 (Q5a, 03 marks)

Answer:
- **Gauge factor (GF)** = $\frac{\Delta R/R}{\varepsilon}$ where ε = strain (ΔL/L).
- **Importance**:
  - Indicates sensitivity of strain gauge.
  - Metal foil gauges have GF ≈ 2; semiconductor gauges have GF up to 150.
  - Used to determine strain from measured ΔR.
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10. **Explain Strain Gauge Sensitivity Factor with its significance.**
Appeared in: S22 (Q3a, 03 marks)

Answer:
- Same as gauge factor.
- **Significance**:
  - Higher GF means larger output for same strain → better resolution.
  - But non-linearity and temperature sensitivity increase with higher GF.
  - Metal gauges provide linear response, semiconductors offer high sensitivity for small strains.

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11. **State desirable characteristics of a strain gauge.**
Appeared in: W22 (Q4a, 03 marks)

Answer:
1. High gauge factor (sensitivity).
2. Low temperature coefficient of resistance.
3. Low hysteresis.
4. High linearity.
5. Small size and low mass.
6. Good fatigue life.
7. Easy to bond.

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12. **List types of strain gauge and explain working of any one with neat sketch.**
Appeared in: W22 (Q4b OR, 04 marks)

Answer:
Types:
- Metal foil strain gauge (most common)
- Wire strain gauge
- Semiconductor (piezoresistive)
- Thin-film

Foil strain gauge working:
- Photographically etched constantan foil on polyimide backing.
- Bonded to specimen surface.
- Specimen deforms → foil deforms → $\Delta R/R = GF \times \varepsilon$.
- Measured via Wheatstone bridge.

[DG]

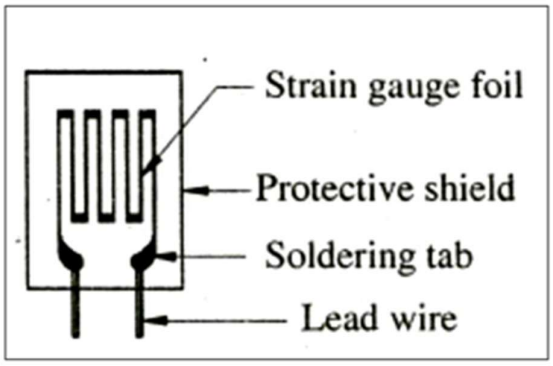

Fig.5.21 - Etched foil type bounded strain gauge

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13. **Explain the principle of LASER. State the advantages of LASER.**
Appeared in: S25 (Q4a OR, 03 marks), S22 (Q4b, 04 marks)

Answer:
- **Principle**: **Light Amplification by Stimulated Emission of Radiation** – electrons in active medium (ruby, He-Ne) are pumped to excited state; stimulated emission produces coherent, monochromatic, collimated light.

- **Advantages**:
- **High coherence** – enables interferometry.
- **Low divergence** (near parallel beam) – long range measurement.
- **High intensity** – visible even at long distance.
- **Monochromatic** – single wavelength, precise.
- **Non-contact measurement** – no mechanical loading.
- **Fast response** – suitable for dynamic events.

14. **Explain the principle of LASER-based Interferometer.**
Appeared in: S22 (Q4b, 04 marks)

Answer:

- **Principle**: Two coherent laser beams (one from reference, one from measurement path) interfere. Path difference causes fringe shift. Each fringe shift = λ/2 displacement.
- **Working**:
  - Laser beam split into two by a beam splitter.
  - One beam goes to fixed mirror, other to movable mirror (attached to object).
  - Beams recombine; interference fringes detected by photodiode.
  - Counting fringes gives displacement (resolution λ/2 ~ 0.3 μm for He-Ne).
  - Using phase interpolation, resolution < 1 nm possible.
- **Applications**: Calibration of CMMs, length metrology, vibration measurement.

15. **Explain with a neat sketch the working of any one interferometer.**
Appeared in: W23 (Q5c OR, 07 marks), W22 (Q2c OR, 07 marks)

Answer:

- A thermometer measures temperature by using a **thermometric property** that changes linearly with temperature.
- **Common principles**:
  - **Expansion of liquids** (mercury/alcohol in glass) – volume change.
  - **Expansion of solids** (bimetallic strip) – differential expansion.
  - **Change in electrical resistance** (RTD, thermistor) – resistance vs temperature.
  - **Thermoelectric EMF** (thermocouple) – Seebeck effect.
  - **Pressure of gas** (gas thermometer) – ideal gas law.
- **Working (e.g., liquid-in-glass)**: Liquid expands in capillary; height ∝ temperature. Calibrated at fixed points (ice/steam).

16. **Explain advances in metrology (related to LASER and CMM).**
Appeared in: (From syllabus)

Answer:

Advances include:

- **Laser interferometers** for sub-nanometer accuracy.
- **Laser trackers** for large-volume metrology (aircraft assembly).
- **CMM with laser scanning** (non-contact, millions of points).
- **White light interferometry** for surface finish.

- **Machine vision** using structured light.
- **On-machine probing** with wireless probes.
- **Digital twins** and metrology software integration.

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17. **Explain different types of amplifiers (Optical, Electronic).**
Appeared in: W23 (Q5a, 03 marks - Optical Amplifier)

Answer:

- **Optical amplifier** (in metrology): Uses lever of light – a mirror attached to a moving element deflects a light beam; displacement magnified on a scale. Example: Zeiss optimeter gives magnification up to 4000×.
- **Electronic amplifier**: Uses operational amplifiers to increase voltage/current from transducers (e.g., strain gauge bridge output). Provides high gain, filtering, linearization.
- In comparators, optical amplifiers are frictionless; electronic amplifiers enable remote display and data logging.

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18. **Mention any three advantages of electrical intermediate modifying devices.**
Appeared in: W23 (Q5a OR, 03 marks)

Answer:

1. **High sensitivity** – can detect very small signals (μV, pA).
2. **Remote transmission** – signals can be sent long distances without loss.
3. **Easy processing** – amplification, filtering, digitization, display.
4. **Integration with data acquisition** – computer interface for analysis.

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19. **Define and explain: Threshold, Calibration, Hysteresis.**
Appeared in: S25 (Q1a, 03 marks)

Answer:

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20. **What is the function of a Radiation Pyrometer?**
Appeared in: S23 (Q5b, 04 marks)

Answer:

- **Function:** To measure high temperatures (500°C to 3000°C) without contact by detecting the thermal radiation emitted from a hot object.
- **Unlike optical pyrometer** (which uses filament matching), radiation pyrometer collects total radiation (IR + visible) using a thermopile or bolometer.
- **Working**: Radiation from target focused on a thermopile; output EMF calibrated to temperature.
- **Applications**: Furnaces, molten metals, moving parts.

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21. **Enlist the temperature measuring instruments.**
Appeared in: S23 (Q5a, 03 marks)

Answer:

1. Liquid-in-glass thermometer
2. Bimetallic strip thermometer
3. RTD (Resistance Temperature Detector)
4. Thermocouple
5. Thermistor
6. Optical pyrometer
7. Radiation pyrometer
8. Infrared thermal imager