APPLIED MARINE ENGINEERING

Attempt ALL questions
Marks for each part question are shown in brackets

1. Detail the changes in the properties of steel by the addition of EACH of the following elements:

    (a)   nickel;

    (2)

    (b)   chromium;

    (2)

    (c)   molybdenum;

    (2)

    (d)   silicon;

    (2)

    (e)   manganese.

    (2)

2. With reference to the heat treatment of steel:

    (a)   explain which steels this process is best suited to;

    (2)

    (b)   explain EACH of the following processes, making reference to mechanical properties and internal structure:

        (i)   hardening;

        (4)

        (ii)   tempering.

        (4)

3. With reference to the installation of copper pipes in engine cooling systems:

    (a)   describe THREE possible causes for their premature failure;

    (6)

    (b)   outline FOUR recommendations for the installation of copper pipes.

    (4)

4. With reference to the attachment of aluminium superstructures to a steel hull:

    (a)   explain why it is not normal practice to join the two components using conventional welding techniques;

    (2)

    (b)   state the particular problems associated with the aluminium superstructure where it is bonded to a steel hull;

    (2)

    (c)   outline the maintenance that should be carried out to ensure the continued structural integrity of the vessel;

    (2)

    (d)   sketch a typical transition joint that could be utilised to attach an aluminium superstructure to a steel hull.

    (4)

5. (a) Describe the problems associated with two dissimilar metals in contact in the presence of sea water. (4)

   (b) Describe THREE different methods that may be used to reduce the problems described in part (a). (6)

6. (a) Explain, with the aid of a sketch, the design and operation of a thermocouple. (8)

   (b) State ONE limitation of the thermocouple, stating how this is overcome in practice. (2)

7. (a) Describe, with the aid of a sketch, how a Bourdon Tube can be utilised to measure temperature. (8)

   (b) State a typical application and location for this type of device. (2)

8. (a) Define EACH of the following terms:

   (i) cascade control; (4)

   (ii) split range control. (3)

   (b) Describe possible problems associated with *split range control* used for the control of a main engine cooling system. (3)

(9) The figure shows a tank filling with fluid at a variable rate, and an output regulated manually by an operator controlling a value.

Explain, with the aid of a control block diagram, the control process taking place that enables the operator to maintain a constant tank level. 'h' for varying rates of fluid flow input.

Note: fluid flow in will always be less than the maximum flow out with the valve full open.
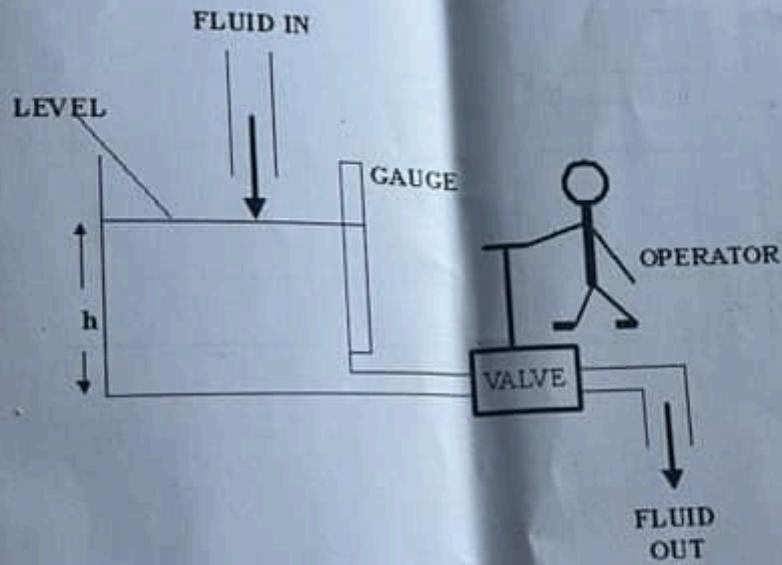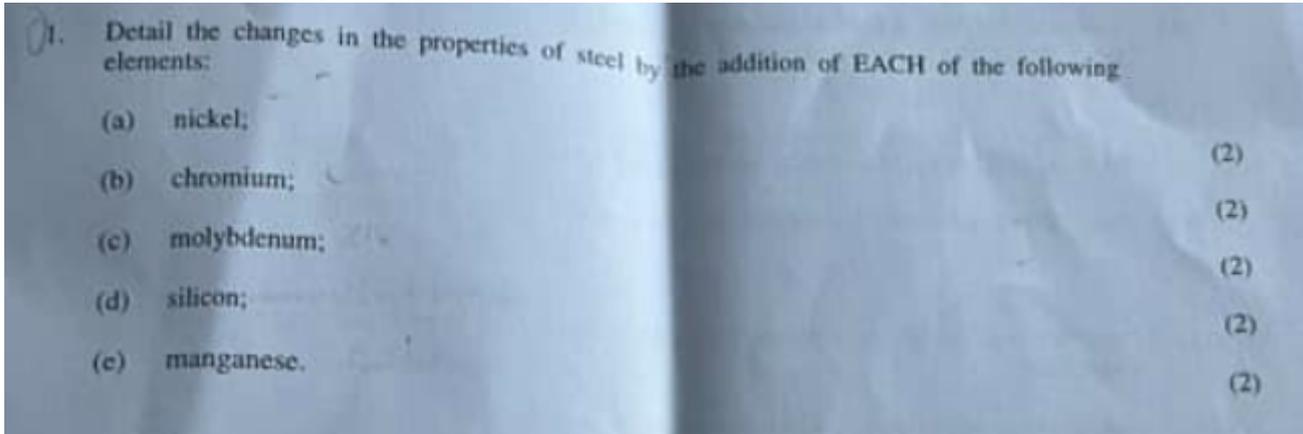
(10)

Fig Q9

1. Detail the changes in the properties of steel by the addition of EACH of the following elements:

   (a)   nickel;

   (b)   chromium;   (2)

   (c)   molybdenum;   (2)

   (d)   silicon;   (2)

   (e)   manganese.   (2)

                                                                                                        (2)

(a) Nickel (2 marks)

- Increases **toughness and strength**, even at low temperatures.

- Improves **corrosion resistance** (key in stainless steels).

(b) Chromium (2 marks)

- Greatly improves **hardness and wear resistance**.

- Provides **corrosion and oxidation resistance** (forms stainless steel when ≥12%).

(c) Molybdenum (2 marks)

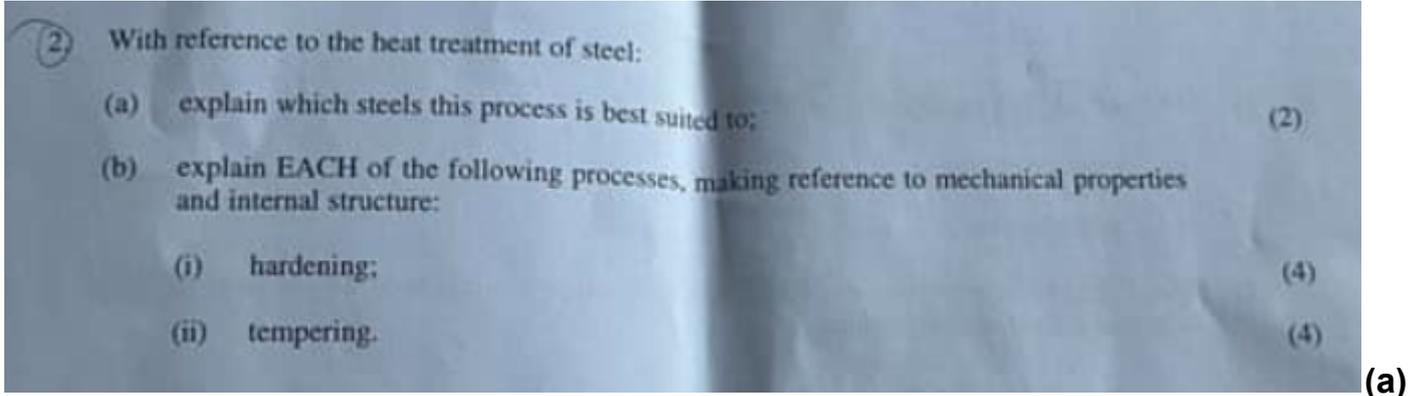- Increases **strength at high temperatures**.

- Improves **creep resistance** and resistance to **pitting corrosion** (important in marine steels).

(d) Silicon (2 marks)

- Improves **strength and hardness**.

- Increases **resistance to oxidation** at high temperatures.

- Also acts as a **deoxidiser** during steelmaking.

(e) Manganese (2 marks)

- Increases **strength, toughness, and wear resistance**.

- Helps remove oxygen and sulphur during steelmaking (deoxidiser and desulphuriser).

> (2) With reference to the heat treatment of steel:
>
> (a) explain which steels this process is best suited to; (2)
>
> (b) explain EACH of the following processes, making reference to mechanical properties and internal structure:
>
>   (i) hardening; (4)
>
>   (ii) tempering. (4)

(a)

Which steels this process is best suited to (2 marks)

- Heat treatment is most effective for **medium- and high-carbon steels** (≥0.3% carbon).

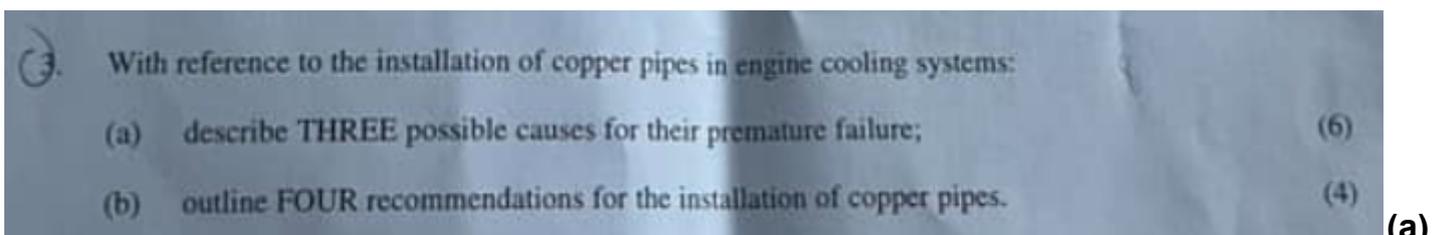- Low-carbon steels (<0.25% C) do not harden significantly because they cannot form sufficient martensite.

(b) Processes

(i) Hardening (4 marks)

- **Process:** Steel is heated to above the critical temperature (~800–900 °C) until it becomes **austenitic**, then rapidly quenched in water, oil, or air.

- **Internal structure:** Austenite transforms into **martensite**, a very hard but brittle structure.

- **Mechanical properties:** Hardness and strength increase greatly, but toughness and ductility are reduced.

(ii) Tempering (4 marks)

- **Process:** Hardened steel is reheated to a temperature below the critical point (~150–650 °C), held, then cooled slowly.

- **Internal structure:** Martensite partially decomposes to **tempered martensite** (fine ferrite + carbide structure).

- **Mechanical properties:** Some hardness is sacrificed, but **toughness and ductility are restored**, reducing brittleness.

> 3. With reference to the installation of copper pipes in engine cooling systems:
>
> (a) describe THREE possible causes for their premature failure; (6)
>
> (b) outline FOUR recommendations for the installation of copper pipes. (4)

(a)

Three possible causes of premature failure (6 marks)

1. **Erosion–corrosion**

- ○ High-velocity seawater or turbulence (especially at bends or restrictions) strips away the protective oxide film.

  - ○ Leads to localised thinning and perforation.

2. **Galvanic corrosion**

  - ○ Occurs when copper pipes are connected to dissimilar metals (e.g., steel or aluminium) in seawater.

  - ○ Copper acts as the cathode, accelerating attack on the less noble metal.
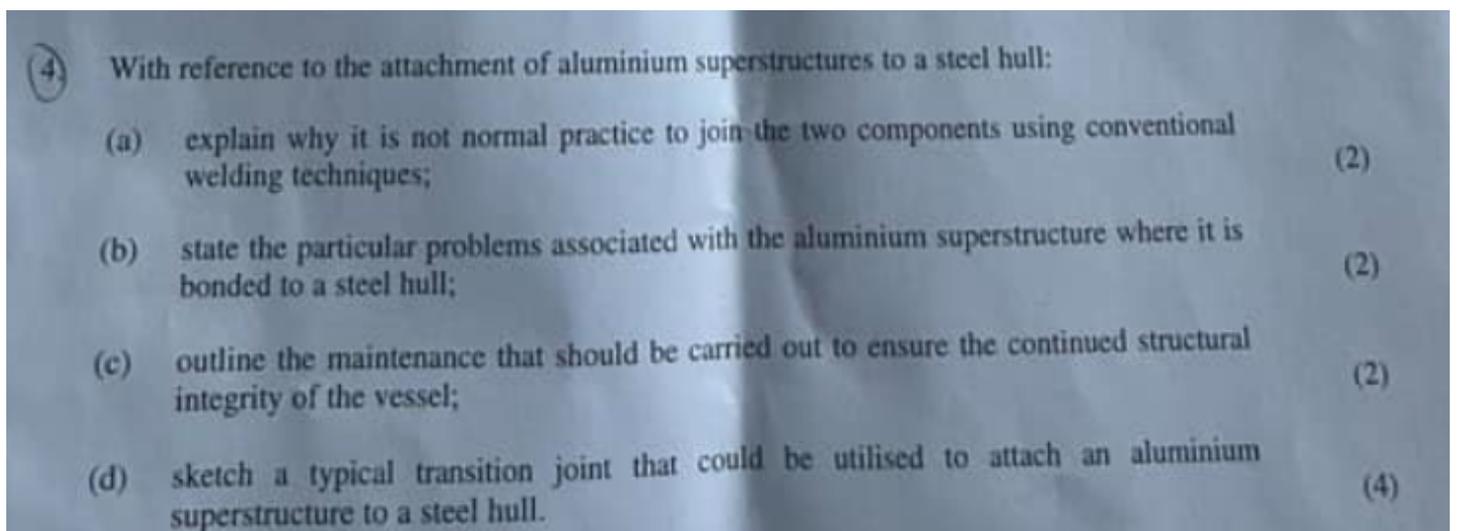
3. **Dezincification (in brass alloys)**

  - ○ If brass pipes are used, zinc is selectively leached, leaving a porous copper-rich structure that is weak.

  - ○ Can cause leaks and mechanical failure.

(Other acceptable answers: pitting from deposits, stress corrosion cracking, or poor water treatment.)

(b) Four recommendations for installation (4 marks)

1. **Use proper material selection** – preferably 90/10 or 70/30 cupro-nickel alloys instead of pure copper, as they are far more resistant to seawater corrosion.

2. **Maintain correct water velocity** – keep seawater flow rates moderate (not exceeding design velocity, typically 1.5–2.5 m/s for copper alloys) to prevent erosion–corrosion.

3. **Avoid direct contact with dissimilar metals** – use insulating flanges, sleeves, or non-conductive couplings to minimise galvanic action.

4. **Ensure good installation practices** – smooth bends, proper supports to avoid vibration, and clean, well-flushed systems to reduce deposit build-up.

(4) With reference to the attachment of aluminium superstructures to a steel hull:

(a) explain why it is not normal practice to join the two components using conventional welding techniques; (2)

(b) state the particular problems associated with the aluminium superstructure where it is bonded to a steel hull; (2)

(c) outline the maintenance that should be carried out to ensure the continued structural integrity of the vessel; (2)

(d) sketch a typical transition joint that could be utilised to attach an aluminium superstructure to a steel hull. (4)

(a) Why conventional welding is not used (2 marks)

- Aluminium and steel have **widely differing melting points** (Al ~660 °C, steel ~1500 °C), making fusion welding impractical.

- They also form **brittle intermetallic compounds** at the joint, leading to cracks and weak welds.

(b) Problems with aluminium superstructure bonded to steel hull (2 marks)

1. **Galvanic corrosion** – aluminium is anodic to steel in seawater, leading to rapid wastage at the joint.

2. **Differential thermal expansion** – aluminium expands almost twice as much as steel when heated, leading to stress, distortion, and possible cracking.
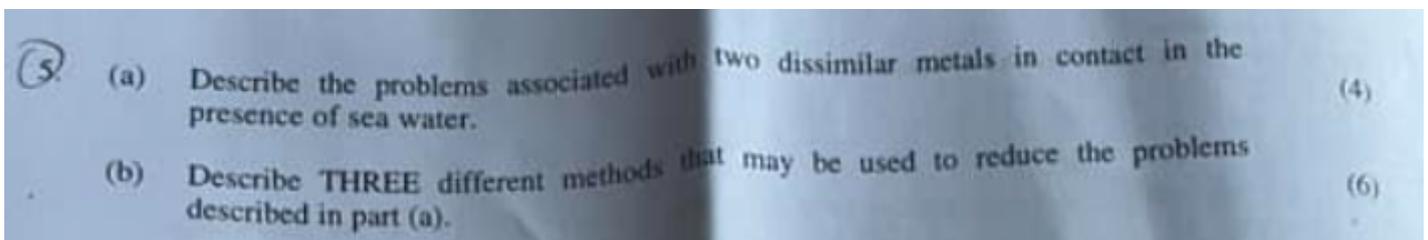

(c) Maintenance required (2 marks)

- **Regular inspection** of the joint area for signs of corrosion, cracking, or distortion.

- **Protective coatings and sealants** should be maintained to prevent galvanic action.

- **Anode systems** and insulation barriers should be checked to ensure continued protection.

(d) Typical transition joint (4 marks)

- Use an **explosion-bonded bimetallic strip** (aluminium on one side, steel on the other).

- The **steel face** is welded to the steel hull using normal steel welding techniques.

- The **aluminium face** is welded to the aluminium superstructure using aluminium welding methods.

- This ensures a strong, corrosion-resistant connection between the dissimilar metals.

(In an exam sketch: draw steel plate at bottom, Al superstructure at top, with a bimetallic strip in between, showing welds on each side.)

5. (a) Describe the problems associated with two dissimilar metals in contact in the presence of sea water. (4)

(b) Describe THREE different methods that may be used to reduce the problems described in part (a). (6)

(a) Problems with dissimilar metals in seawater (4 marks)

- When two dissimilar metals are in electrical contact and immersed in seawater, a **galvanic cell** is formed.

- The **less noble (anodic) metal** corrodes preferentially, while the more noble (cathodic) metal is protected.

- This leads to **accelerated wastage** of the anodic material.

- Severe problems occur at joints, fittings, and fasteners where the contact area ratio is small (e.g., small anodic area coupled to a large cathodic area).

(b) Three methods to reduce the problems (6 marks)

1. **Electrical insulation**

   - Use insulating gaskets, sleeves, or coatings to break the galvanic path between dissimilar metals.
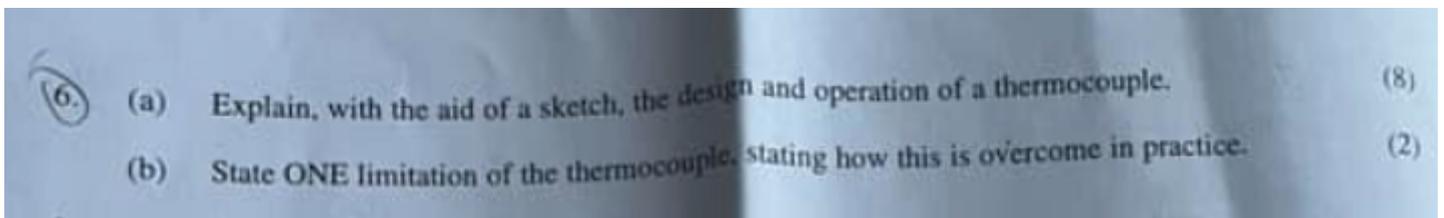
2. **Use of sacrificial anodes**

   - Fit zinc, aluminium, or magnesium anodes near the joint to act as the preferential anode and protect both metals.

3. **Protective coatings**

   - Apply paint, epoxy, or other protective coatings to one or both metals to reduce seawater exposure and current flow.

   - Priority is to coat the more noble (cathodic) metal, so the anodic one is not exposed to full current demand.

(Other acceptable answers: selecting metals close in the galvanic series, impressed current cathodic protection, or controlling seawater chemistry.)

6. (a) Explain, with the aid of a sketch, the design and operation of a thermocouple. (8)

   (b) State ONE limitation of the thermocouple, stating how this is overcome in practice. (2)

(a) Design and operation of a thermocouple (8 marks)

Design:

- A thermocouple consists of **two dissimilar metal wires** (e.g., copper–constantan, iron–constantan, chromel–alumel).

- The wires are joined at one end (the **measuring or hot junction**).

- The other ends (the **reference or cold junction**) are connected to a measuring instrument (millivoltmeter, indicator, or controller).

Operation (Seebeck effect):

1. When the hot junction is exposed to a temperature different from the reference junction, a **thermoelectric voltage (EMF)** is generated.

2. This EMF is proportional to the **temperature difference** between the two junctions.

3. The small voltage is measured by an electronic device, calibrated to show temperature directly.

4. By maintaining the reference junction at a known temperature (or compensating electronically), the actual temperature at the hot junction can be accurately determined.

(In an exam sketch: draw two dissimilar wires joined at hot junction → connected to a voltmeter at cold junction → show temperature difference producing EMF.)
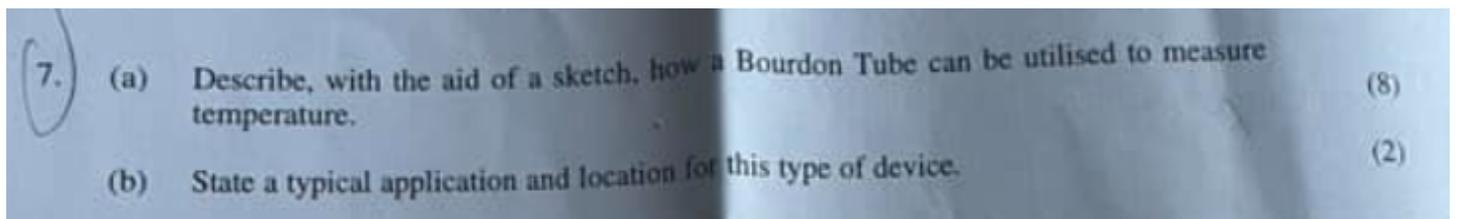

(b) Limitation of the thermocouple and how it is overcome (2 marks)

Limitation:

- The EMF produced is **very small** (in the millivolt range), so readings can be affected by electrical noise or resistance in the leads.

Overcome in practice:

- Use **sensitive electronic amplifiers and compensating circuits** to boost and stabilise the signal.

- Alternatively, use **cold junction compensation** in modern digital instruments to correct for ambient temperature variations.
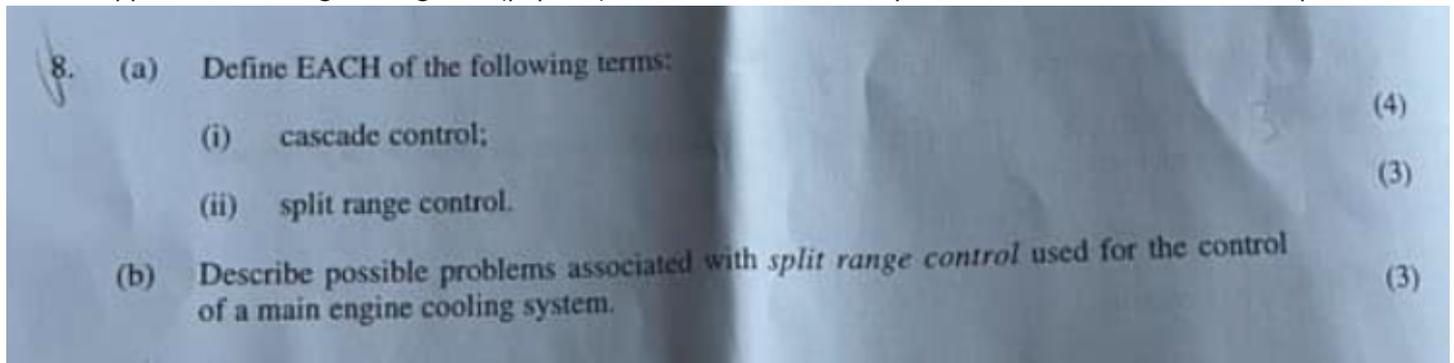
> 7. (a) Describe, with the aid of a sketch, how a Bourdon Tube can be utilised to measure temperature. (8)
>
> (b) State a typical application and location for this type of device. (2)

(a) Description with sketch (8 marks)

- A **Bourdon tube** is a curved, hollow, elliptical metal tube that tends to straighten when internal pressure increases.

- To measure **temperature**, the tube is connected to a sealed **bulb** filled with a thermally sensitive liquid or vapour.

- As the bulb is exposed to a temperature change, the liquid or vapour inside expands or contracts, causing the **pressure inside the Bourdon tube** to change.

- This pressure change makes the tube flex or straighten slightly.

- The end of the tube is linked by a system of levers and gears to a pointer moving over a calibrated scale.

- The scale is graduated in **temperature units (°C or °F)**, giving a direct reading.

(In the sketch: show a bulb → capillary tube → Bourdon tube → linkage → pointer on dial.)

(b) Typical application and location (2 marks)

- Commonly used for **measuring cooling water, lubricating oil, or steam temperature** on board ships.

- A typical location: **engine room cooling water system** or **boiler temperature gauge**.

8. (a) Define EACH of the following terms:

    (i)   cascade control;   (4)

    (ii) split range control.   (3)

    (b) Describe possible problems associated with *split range control* used for the control of a main engine cooling system.   (3)

(a) Definitions

(i) Cascade control (4 marks)

- Cascade control uses **two controllers** arranged in a hierarchy (a master and a slave).

- The **primary (master) controller** measures and controls the main process variable (e.g., jacket water temperature).

- Its output sets the **setpoint** of the **secondary (slave) controller**, which controls a faster-acting variable (e.g., cooling water flow).

- Advantage: disturbances in the secondary loop are corrected before they affect the main process, improving stability and accuracy.

(ii) Split range control (3 marks)

- A single controller output signal is divided to operate **two or more final control elements** (e.g., valves).

- Each element responds to a different portion of the controller's output range.

- Example: in a cooling system, one valve may open to admit seawater when the signal is 0–50%, while another valve may bypass the cooler when the signal is 50–100%.

- This allows **one controller to manage multiple actuators** in sequence.

(b) Problems with split range control in main engine cooling systems (3 marks)

1. **Valve overlap or deadband** – if the changeover between valves is not perfectly tuned, there may be a temperature overshoot, undershoot, or hunting.

2. **Non-linear response** – one valve may be more sensitive than the other, giving uneven control.

3. **Maintenance and calibration issues** – sticking, leakage, or poor calibration of valves can cause poor temperature regulation.

(9) The figure shows a tank filling with fluid at a variable rate, and an output regulated manually by an operator controlling a value.

Explain, with the aid of a control block diagram, the control process taking place that enables the operator to maintain a constant tank level. 'h' for varying rates of fluid flow input.

Note: fluid flow in will always be less than the maximum flow out with the valve full open.

(10)
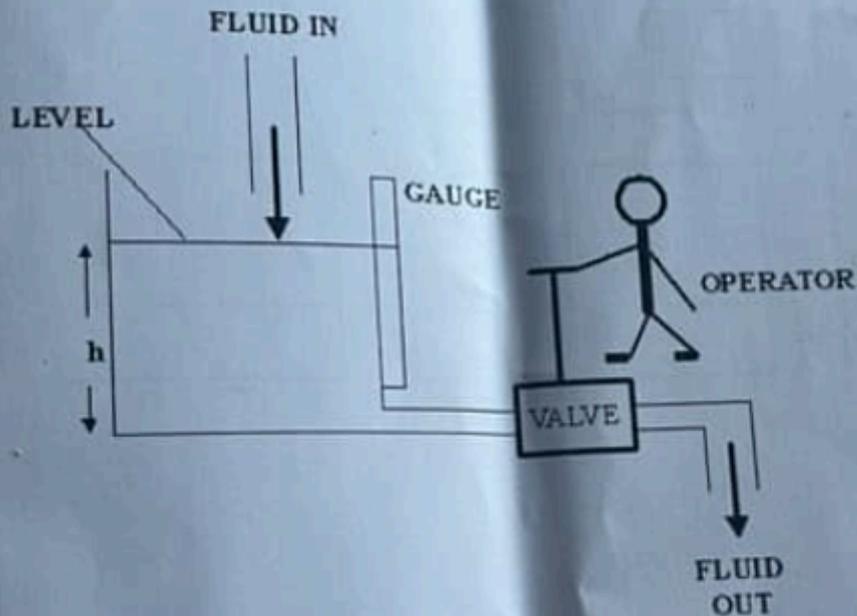
FLUID IN

LEVEL

GAUGE

OPERATOR

h

VALVE

FLUID OUT

Fig Q9

Explanation of the Control Process (10 marks)

- The system is an example of **manual feedback control**.

- The **process** is the tank in which liquid level h must be kept constant.

- The **disturbance** is the variable inflow of fluid.

- The **measured variable** is the liquid level h, read on a level gauge.

- The **operator** continuously monitors the gauge (the feedback signal).

- If the level rises above setpoint, the operator adjusts the **valve** to increase outflow; if the level falls, the operator reduces outflow.

- In this way, the operator acts as the **controller**, maintaining balance between inflow and outflow.

- Because inflow is always less than the maximum outflow when the valve is full open, the operator can always achieve control by adjustment.

Control Block Diagram (manual feedback loop)

1. **Setpoint (desired level h)** → compared with →

2. **Process variable (actual tank level, via gauge)** → generates →

3. **Error (difference between setpoint and actual level)** → operator observes →

4. **Operator (controller)** → adjusts →

5. **Final control element (valve)** → regulates →

6. **Process (tank outflow)** → affects →

7. **Controlled variable (tank level)**, which is fed back to the operator.

Key Points for Marks

- Correct identification of process (tank & level).

- Inflow disturbance.

- Valve as final control element.

- Gauge as feedback element.

- Operator as controller.

- Explanation that operator keeps level steady by balancing inflow and outflow.

- Block diagram showing feedback loop.