1. With reference to EACH of the following materials, explain their properties and name an engineering shipboard component that benefits from these properties:

(a) cast iron; (3) 3

(b) cast steel; (2) 0

(c) alloyed steel; (3) 0

(d) wrought iron. (2) 0

1. With reference to EACH of the following materials, explain their properties and name an engineering shipboard component that benefits from these properties:

(a) Cast Iron (3)

Properties:

- High compressive strength.
- Good wear resistance.
- Excellent vibration damping.
- Good castability for complex shapes.
- Relatively brittle with low tensile strength.

Shipboard component:

- **Pump casing** (or engine bedplate, valve body, cylinder liner).

(b) Cast Steel (2)

Properties:

- Higher tensile strength and toughness than cast iron.
- Good impact resistance and ductility.
- Can be cast into complex shapes while retaining strength.

Shipboard component:

- **Propeller hub** (or valve body, stern frame, rudder casting).

(c) Alloyed Steel (3)

Properties:

- Enhanced strength and hardness due to alloying elements such as chromium, nickel, molybdenum, or vanadium.
- Improved wear, corrosion, and fatigue resistance.
- Good toughness at high stresses.

Shipboard component:

- **Crankshaft** (or gears, turbine shafts, propeller shafts, connecting rods).

(d) Wrought Iron (2)

Properties:

- Tough and ductile.
- Good corrosion resistance.
- Easily forged and welded.
- Good resistance to shock loading.

Shipboard component:

- **Chain links, shackles, or decorative fittings** (historically also used for rivets and handrails).

Exam-style Answers

Material	Properties	Shipboard Component
Cast Iron	High compressive strength, wear resistant, good damping	Pump casing
Cast Steel	Strong, tough, impact resistant	Propeller hub
Alloyed Steel	High strength, fatigue and wear resistant	Crankshaft
Wrought Iron	Tough, ductile, corrosion resistant	Chain link or shackle

These answers are at the level typically expected for a marine engineering materials question worth **10 marks**.

2. (a) Explain how the properties of steel are modified by its carbon content. (2)

(b) Explain EACH of the following terms:

(i) annealing; (3)

(ii) normalising; (3)

(iii) hardening. (2)

2 (a) Explain how the properties of steel are modified by its carbon content. (2)

The properties of steel change as the **carbon content increases**:

- **Higher carbon content** increases **hardness, strength, and wear resistance**.
- However, it decreases **ductility, toughness, and weldability**, making the steel more brittle.

Conversely, **low-carbon steels** are softer, more ductile, and easier to form and weld.

---

2 (b) Explain EACH of the following terms:

(i) Annealing (3)

Annealing is a heat-treatment process in which steel is:

1. Heated to a suitable temperature above its critical range.
2. Held at that temperature for a specified period.
3. Cooled **slowly**, usually in the furnace.

Purpose:

- Relieves internal stresses.
- Increases ductility and toughness.
- Softens the material for machining or forming.

(ii) Normalising (3)

Normalising is a heat-treatment process in which steel is:

1. Heated above its critical temperature.
2. Soaked at that temperature.
3. Removed from the furnace and cooled in **still air**.

Purpose:

- Refines the grain structure.
- Improves mechanical properties.
- Produces a stronger and more uniform structure than annealing.

(iii) Hardening (2)

Hardening is a heat-treatment process in which steel is:

1. Heated above its critical temperature.
2. Rapidly cooled (quenched) in water, oil, or another quenching medium.

Purpose:

- Increases hardness and strength.
- Improves wear resistance, although brittleness is increased.

Exam-style Answers

(a) Increasing carbon content increases hardness and strength but reduces ductility and toughness.

(b)(i) Annealing: Heat steel, soak, and cool slowly to soften it and relieve stresses.

(b)(ii) Normalising: Heat steel above the critical temperature and cool in air to refine grain structure and improve strength.

(b)(iii) Hardening: Heat steel above the critical temperature and quench rapidly to increase hardness and wear resistance.

3. Explain EACH of the following engineering terms, stating ONE material that exhibits EACH property:

(a) brittleness; (2)

(b) ductility; (2)

(c) hardness; (2)

(d) malleability; (2)

(e) toughness. (2)

3.
Explain EACH of the following engineering terms, stating ONE material that exhibits EACH property:

(a) Brittleness (2)

Brittleness is the property of a material whereby it fractures with **little or no plastic deformation** when subjected to stress.

Example material: Cast iron (or glass).

(b) Ductility (2)

Ductility is the ability of a material to be **drawn into wire** or to undergo significant plastic deformation in tension before fracture.

Example material: Copper (or mild steel, aluminium).

(c) Hardness (2)

Hardness is the ability of a material to **resist indentation, scratching, abrasion, or wear**.

Example material: Hardened steel (or tungsten carbide).

(d) Malleability (2)

Malleability is the ability of a material to be **hammered, rolled, or pressed into thin sheets** without cracking.

Example material: Gold (or lead, aluminium).

(e) Toughness (2)

Toughness is the ability of a material to **absorb energy and withstand shock or impact loading without fracturing**.

Example material: Mild steel (or wrought iron).

Exam-style Answers

Property	Definition	Example Material
Brittleness	Fractures with little plastic deformation	Cast iron
Ductility	Can be drawn into wire	Copper
Hardness	Resists wear, scratching and indentation	Hardened steel
Malleability	Can be formed into thin sheets	Gold
Toughness	Resists shock and absorbs energy before fracture	Mild steel

4. With reference to joining a steel hull to an aluminium superstructure:

(a) explain, with the aid of a sketch, the process of *explosion welding*; (6)

(b) explain why this joint is superior to an insulated bolt joint. (4)

4. With reference to joining a steel hull to an aluminium superstructure:

(a) Explain, with the aid of a sketch, the process of explosion welding. (6)

Explosion welding is a solid-state welding process used to join two dissimilar metals, such as steel and aluminium, without melting them.

Process

1. A plate of aluminium is positioned above a steel plate with a small gap between them.
2. A layer of explosive material is placed on top of the aluminium plate.
3. The explosive is detonated from one end.
4. The explosion drives the aluminium plate towards the steel plate at very high velocity.
5. The impact produces extremely high local pressure, causing plastic deformation at the interface.
6. Surface oxides and contaminants are expelled as a jet, leaving clean metal surfaces.
7. A strong metallurgical bond is formed between the two metals without significant melting.

The resulting product is often called a **transition joint**, which can then be welded conventionally:

- Steel side → welded to the steel hull.
- Aluminium side → welded to the aluminium superstructure.

```
Before Detonation

   Explosive Layer
   ================

   Aluminium Plate
   ----------------

        Gap

   ----------------
      Steel Plate


After Detonation

   Aluminium
   -----------------
      ~~~~~~~
      Wavy Bond
      ~~~~~~~
   -----------------
        Steel
```

- The characteristic **wavy interface** is a typical feature of explosion-welded joints.

(b) Explain why this joint is superior to an insulated bolt joint. (4)

An explosion-welded transition joint is superior because:

1. **Permanent metallurgical bond**
   - Produces a stronger and more reliable connection than bolted joints.
2. **Watertight and continuous**
   - No bolt holes or gaskets that may leak or loosen in service.
3. **Reduced galvanic corrosion**
   - The transition joint provides a controlled interface between steel and aluminium, minimising direct dissimilar-metal contact.
4. **Better fatigue resistance**
   - Handles vibration and cyclic loading more effectively than bolted connections, which may loosen over time.
5. **Lower maintenance**
   - No insulation washers, bolts, or fasteners requiring periodic inspection and replacement.

Exam-style Answer

(a) Explosion welding joins steel and aluminium by accelerating one plate into the other using explosives. The high-velocity impact removes surface oxides and creates a metallurgical bond without melting the metals. The resulting transition joint can then be welded to the steel hull and aluminium superstructure.

(b) It is superior because it provides a strong permanent bond, reduces galvanic corrosion, is watertight, resists fatigue and vibration, and requires less maintenance than an insulated bolted joint.

-

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

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

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

When two **dissimilar metals** are in electrical contact and immersed in seawater, a **galvanic cell** is formed because seawater acts as an electrolyte.

- The more **active (anodic)** metal corrodes preferentially.
- The more **noble (cathodic)** metal is protected.
- Corrosion of the anodic metal can be rapid, especially if there is a large cathode-to-anode area ratio.
- The result is accelerated material loss, weakening of the structure, leakage, increased maintenance, and possible failure of components.

Example: Aluminium in contact with steel in seawater will tend to corrode more rapidly than if it were isolated.

---

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

1. Electrical Insulation

- Separate the two metals using insulating materials such as gaskets, sleeves, bushes, washers, or non-conductive coatings.
- This breaks the electrical circuit and prevents galvanic action.

2. Protective Coatings

- Apply paint, epoxy, or other protective coatings to prevent seawater from reaching the metals.
- Ideally both metals should be coated, particularly the cathodic metal, to reduce galvanic effects.

3. Cathodic Protection

- Fit sacrificial anodes (zinc or aluminium) or use an impressed-current system.
- The sacrificial anode corrodes instead of the protected structure.

Other acceptable methods:

- Use metals that are close together in the galvanic series.
- Employ explosion-welded transition joints between steel and aluminium structures.
- Reduce exposure to seawater and maintain coatings regularly.

Exam-style Answer

(a) Two dissimilar metals in contact in seawater form a galvanic cell. The less noble metal becomes the anode and corrodes, while the more noble metal becomes the cathode and is protected. This can cause rapid localised corrosion and structural weakening.

(b)

1. Electrically insulate the metals with non-conductive gaskets or bushes.
2. Apply protective coatings to isolate the metals from seawater.
3. Use cathodic protection such as sacrificial anodes or impressed-current systems.

6. (a) Explain how *osmosis* may occur in a fibre glass hull.

   (b) Explain how the likelihood of *osmosis* occuring in the future can be reduced during the manufacturing process of the hull.

   (c) Explain how *osmosis* may be detected in service.

6

(a) Explain how osmosis may occur in a fibreglass hull. (4)

Osmosis in a fibreglass (GRP) hull occurs when water penetrates through the gel coat and enters the laminate.

- Small amounts of water diffuse through the gel coat.
- The water reacts with soluble chemicals or uncured materials within the laminate.
- This creates a concentrated solution beneath the gel coat.
- Due to osmotic action, more water is drawn into the laminate, increasing pressure.
- The pressure eventually causes the formation of **blisters** on the hull surface, which may contain acidic fluid.

(b) Explain how the likelihood of osmosis occurring in the future can be reduced during the manufacturing process of the hull. (4)

The risk of osmosis can be reduced by:

1. **Ensuring correct resin mixing and curing**
   - Proper catalyst ratios and curing reduce the amount of unreacted chemicals remaining in the laminate.
2. **Using high-quality resins and gel coats**
   - Modern isophthalic or vinyl ester resins have better water resistance than standard polyester resins.
3. **Avoiding air pockets and voids**
   - Good lamination techniques ensure complete wetting of the glass fibres and minimise trapped air.
4. **Applying an impermeable barrier coat**
   - An epoxy barrier coat provides additional protection against water penetration.

(c) Explain how osmosis may be detected in service. (2)

Osmosis may be detected by:

- **Visual inspection** revealing blisters or bubbles on the underwater hull surface.
- Opening a blister may release a liquid with a **vinegar-like or acidic smell**.
- Moisture meters or hull surveys can be used to confirm moisture ingress within the laminate.

Exam-style Answer

(a) Osmosis occurs when water passes through the gel coat and reacts with soluble substances in the laminate. This creates an osmotic solution that draws in more water, producing pressure and causing blisters.

(b)

- Ensure correct resin mixing and curing.
- Use water-resistant resins and gel coats.
- Eliminate voids and air pockets during lamination.
- Apply an epoxy barrier coat.

(c)

- Detect by blistering of the hull surface.
- Confirm by the presence of acidic fluid in blisters or by moisture testing.

Short Exam Answers

(a) Water passes through the gel coat and reacts with soluble materials in the laminate, forming a concentrated solution. More water is drawn in by osmosis, causing pressure and blister formation.

(b) Use quality resins, ensure complete curing, eliminate voids, and apply an effective gel coat or epoxy barrier coating.

(c) Detect by blistering of the hull surface and by acidic fluid found inside the blisters.

7. With reference to the flowrate measuring device shown in the figure, describe the principle of operation, explaining how an analogue remote reading may be obtained.

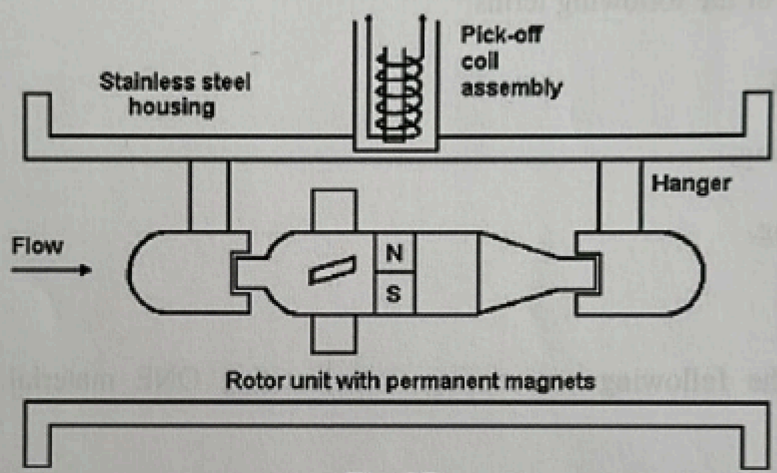

Fig Q7

7. With reference to the flowrate measuring device shown in Fig. Q7, describe the principle of operation, explaining how an analogue remote reading may be obtained. (10)

The device shown is a **variable-area flowmeter (rotameter) with magnetic coupling and inductive pick-off coils** for remote indication.

Principle of Operation

1. Fluid enters the meter and flows from left to right.
2. The flow causes the **rotor (float)** to move along the flow tube.
3. The rotor finds a position where:
    - The upward force due to fluid flow balances
    - The downward force due to its weight.
4. As the flow rate increases, the rotor moves further along the tube.
5. Therefore, the rotor position is directly related to the flow rate.

Magnetic Transmission

- The rotor contains **permanent magnets**.
- As the rotor moves, the magnetic field moves with it.
- The magnets can be detected through the stainless-steel housing without mechanical linkage, preventing leakage and wear.

Obtaining an Analogue Remote Reading

1. A **pick-off coil assembly** is mounted outside the flow tube.
2. As the magnetised rotor moves, the magnetic flux linking the coils changes.
3. This change produces a varying electrical signal (voltage, current, or inductance change).
4. Electronic circuitry converts this signal into a standard analogue output, such as:
    - **4–20 mA current signal**, or
    - **0–10 V voltage signal**.
5. The analogue signal is transmitted to a remote indicator, recorder, PLC, or control system.
6. The remote instrument is calibrated so that the electrical signal corresponds directly to the flow rate.

```
              Pick-off Coils
             ┌──────────────┐
             │              │
             └──────┬───────┘
                    │
    Stainless Steel Housing
   ┌───────────────────────────┐
   │                           │
   │     N      S              │
   │   [ Permanent Magnet ]    │
   │       Rotor/Float         │
   │                           │
   └───────────────────────────┘
              ↑
        Position varies
        with flow rate

  Flow ──────────────────────►

 Magnetic movement
         ↓
 Electrical signal
         ↓
 4-20 mA Output
         ↓
 Remote Flow Indicator
```

Exam Answer (10 Marks)

The instrument operates on the variable-area principle. Fluid flow moves the rotor to a position where the fluid force balances the rotor weight. As flow increases, the rotor moves further along the tube. Permanent magnets contained within the rotor produce a magnetic field that passes through the non-magnetic stainless-steel housing. A pick-off coil assembly detects changes in magnetic flux as the rotor moves. The coil output is converted into a proportional analogue signal, typically 4–20 mA, which can be transmitted to a remote indicator or control system. The remote reading therefore provides a continuous indication of flow rate without any direct mechanical connection to the measuring element.

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

(b) State a typical application and location for this type of device. 8

(a) Describe, with the aid of a sketch, how a Bourdon Tube can be utilised to measure temperature. (6)

A **Bourdon tube temperature gauge** uses a sealed bulb, capillary tube, and Bourdon tube filled with a liquid, gas, or vapour.

Principle of Operation

1. The **temperature-sensing bulb** is placed in the medium whose temperature is to be measured.
2. The bulb, capillary tube, and Bourdon tube form a sealed system filled with a fluid.
3. As temperature increases, the fluid expands and its pressure increases.
4. The increased pressure causes the **Bourdon tube** to straighten slightly.
5. The movement of the free end of the Bourdon tube is transmitted through a linkage and gear mechanism.
6. The pointer moves across a calibrated temperature scale, indicating the temperature directly.

When the temperature falls, the pressure decreases and the Bourdon tube returns towards its original shape.

```
Temperature
    Bulb
     |
     |
     | Capillary Tube
     |
     ▼
  _______________
 /               \
|  C-shaped       |---- Linkage ---- Pointer
| Bourdon Tube    |                   /
 \_______________/                   /
                                 Temperature
                                    Scale
```

Advantages

- No electrical supply required.
- Suitable for remote temperature indication.

- Robust and reliable for marine use.

(b) State a typical application and location for this type of device. (4)

Typical applications:

- Main engine jacket cooling water temperature.
- Lubricating oil temperature.
- Fuel oil temperature.
- Boiler water temperature.

Typical location:

- The sensing bulb is fitted in the pipeline, tank, cooler outlet, or machinery being monitored.
- The gauge is mounted remotely on an engine control console, local machinery panel, or engine room bulkhead.

Exam Answer

(a) A temperature bulb, capillary tube, and Bourdon tube are filled with a fluid and sealed. Temperature changes alter the fluid pressure, causing the Bourdon tube to move. This movement is transmitted through a linkage to a pointer, which indicates temperature on a calibrated scale.

(b) Example: Main engine lubricating oil temperature measurement. The bulb is fitted in the lubricating oil line, and the gauge is mounted on the engine room control panel.

9. (a) Explain EACH of the following control terms:

(i) proportional bandwidth; (2)

(ii) integral action; (2)

(iii) derivative action. (2)

(b) Describe a 3-step method for tuning a PID controller. (4)

9 (a)

Explain EACH of the following control terms:

(i) Proportional bandwidth (2)

Proportional bandwidth (PB) is the range of measured variable values over which the controller output changes from **0% to 100%**.

- It is usually expressed as a **percentage of the measurement range**.
- A narrow proportional band gives a higher controller gain and a more sensitive response.
- A wide proportional band gives a lower controller gain and a less sensitive response.

Relationship:

$$PB(\%) = \frac{100}{Gain}$$

(ii) Integral action (2)

Integral action (reset action) continuously changes the controller output in proportion to the **magnitude and duration of the error**.

- It eliminates **offset (steady-state error)**.
- The longer the error exists, the greater the corrective action applied.

(iii) Derivative action (2)

Derivative action (rate action) produces a controller output proportional to the **rate of change of the error**.

- It anticipates future changes.
- It improves stability and reduces overshoot.
- It has little effect when the error is constant.

---

9 (b) Describe a 3-step method for tuning a PID controller. (4)

A common manual tuning procedure is:

Step 1 – Adjust Proportional Action

- Set integral and derivative actions to zero.
- Gradually increase controller gain (or reduce proportional band) until the process begins to oscillate steadily.
- Reduce the gain slightly until stable operation is achieved.

Step 2 – Adjust Integral Action

- Introduce integral action gradually.
- Increase it until any offset is removed and the process reaches the set point without excessive oscillation.

Step 3 – Adjust Derivative Action

- Add derivative action slowly.
- Increase it until overshoot and oscillations are reduced and a stable, responsive control is obtained.

Exam-style Answer

(a)

- **Proportional bandwidth:** The percentage range of measured value required to move the controller output from 0% to 100%.
- **Integral action:** Controller action proportional to the magnitude and duration of the error; removes offset.
- **Derivative action:** Controller action proportional to the rate of change of error; anticipates changes and reduces overshoot.

(b)

1. Adjust proportional gain until the system is close to continuous oscillation.
2. Add integral action to eliminate steady-state error.
3. Add derivative action to improve stability and reduce overshoot.

10. Explain, with the aid of a diagram, the principle of a cascade control method for regulating the freshwater coolant temperature of a diesel engine. (10)

10. Explain, with the aid of a diagram, the principle of a cascade control method for regulating the freshwater coolant temperature of a diesel engine. (10)

A **cascade control system** uses **two controllers** arranged in series:

- A **master (primary) controller** controls the engine jacket water temperature.
- A **slave (secondary) controller** controls the cooling water flow through the freshwater cooler.

The secondary loop responds quickly to disturbances, while the primary loop maintains the required engine temperature.

Diagram

```
                 Set Point
                     |
                     ▼
          ┌──────────────────┐
          | Master Temp.     |
          | Controller       |
          └────────┬─────────┘
                   |
         Set Point |
         to Slave  ▼
          ┌──────────────────┐
          | Slave Temp.      |
          | Controller       |
          └────────┬─────────┘
                   |
                   ▼
            Control Valve
                   |
                   ▼
  Sea Water ──► Fresh Water Cooler
                   |
                   ▼
            To Diesel Engine
                   |
                   ▼
        Jacket Water Temperature
                   |
                   └───────────────┐
                                   |
                     Temperature Sensor
                                   |
                                   ▼
                       Master Controller
```

```
     Cooler Outlet Temperature
                ▲
                |
       Temperature Sensor
                |
                └──────────► Slave Controller
```

Principle of Operation

1. The **master controller** measures the engine jacket-water outlet temperature.
2. It compares the measured temperature with the desired set point (e.g. 80–85°C).
3. The master controller does not operate the valve directly. Instead, it sends a set point to the **slave controller**.
4. The slave controller measures the temperature of the cooling water leaving the cooler.
5. The slave controller compares this value with its set point received from the master controller.
6. It then adjusts the seawater control valve to regulate cooling through the freshwater cooler.

7. If engine temperature rises:
    - The master controller increases the cooling demand.
    - The slave controller opens the valve further.
    - More seawater flows through the cooler, reducing freshwater temperature.
8. If engine temperature falls:
    - The master controller reduces the cooling demand.
    - The slave controller closes the valve slightly.
    - Cooling is reduced and engine temperature rises back to normal.

Advantages of Cascade Control

- Faster response to disturbances.
- Improved temperature stability.
- Reduced overshoot and hunting.
- Better control when seawater temperature changes rapidly.
- Protects the engine from excessive temperature fluctuations.

Exam-Style Answer (10 Marks)

Cascade control uses two controllers: a master controller sensing engine jacket-water temperature and a slave controller sensing cooler outlet temperature. The master controller compares engine temperature with the set point and sends a demand signal to the slave controller. The slave controller adjusts the seawater control valve to regulate cooling through the freshwater cooler. The secondary loop responds quickly to changes in cooling conditions, while the primary loop maintains the correct engine operating temperature. This provides faster response, improved stability, and more accurate temperature control than a single-loop system.