CERTIFICATES OF COMPETENCY IN THE MERCHANT NAVY
MARINE ENGINEER OFFICER

STCW 78 as amended CHIEF ENGINEER REG. III/2 - "YACHT 2"
STCW 78 as amended SMALL VESSEL CHIEF ENGINEER <3000 GT, <9000 kW UNLIMITED

058-12 - GENERAL ENGINEERING SCIENCE II

FRIDAY, 06 OCTOBER 2023

1400 - 1600 hrs

Materials to be supplied by examination centres

Candidate's examination workbook Graph paper

Examination Paper Inserts

Notes for the guidance of candidates:

1. Examinations administered by SQA on behalf of the Maritime & Coastguard Agency.
2. Candidates are required to obtain 50% of the total marks allocated to this paper to gain a pass **AND** also obtain a minimum 40% in Sections A and B of the paper.
3. Non-programmable calculators may be used.
4. All formulae used must be stated and the method of working and ALL intermediate steps must be made clear in the answer.

Maritime & Coastguard Agency

SQA

GENERAL ENGINEERING SCIENCE II

Attempt ALL questions

Marks for each question are shown in brackets.

Section A

1. ✓ A stainless steel water vessel has a mass of 3 kg and contains 12 kg of water at a temperature of 22°C. A further 15 kg of water at 70°C is added to the vessel. Assume there are no heat losses.

   Calculate the final equilibrium temperature of the vessel and water. (8)

   Note: the specific heat of stainless steel = 0.5 kJ/kgK
   the specific heat of water = 4.18 kJ/kgK

2. ✓ (a) Define Boyles Law. (2)

   (b) A perfect gas at an initial pressure, temperature and volume of 3.75 bar, 145°C and 280 litres respectively is cooled at constant pressure until its temperature is 10°C.

   Determine EACH of the following:

   (i) the mass of the gas; (3)

   (ii) the final volume in m^3; (3)

   Note: R = 0.29 kJ/kgK

3. ✓ (a) Explain what is meant by the enthalpy of solidification. (2)

   (b) 250 g of ice at -20°C is heated with 120 kJ of energy. Determine the final state and temperature of the resultant. (6)

   Note: Specific heat capacity of ice = 2.11 kJ/kgK,
   Specific heat capacity of water = 4.18 kJ/kgK,
   Enthalpy of fusion of water = 335 kJ/kg.

[OVER

4. An 8 cylinder, 4 stroke diesel engine has a bore of 350 mm and a stroke of 400 mm. Indicator cards were taken and each had a mean effective height of 22 mm. The power of the engine was also tested using a dynamometer which gave a steady state torque reading of 36 kNm at 800 rpm.

Determine EACH of the following:

(a) the brake power; (4)

(b) the indicated power. (4)

Note: Indicator spring constant was 80 $kN/m^2/mm$

5. 1.5 kg of Heptane (C_7H_{16}) is completely burned in air.

Determine EACH of the following:

(a) the stoichiometric mass of air required; (6)

(b) the mass of carbon dioxide in the exhaust gases. (2)

Note: assume air is 23% oxygen by mass

6. Describe the working principles of a vapour compression refrigeration system. Include a basic layout diagram and a corresponding pressure v enthalpy diagram to reference your answer. (10)

Section B

7. (a) Briefly describe the principal molecular characteristic of materials that differentiates those that conduct electricity well from those that do not. (2)

(b) State TWO examples of an electric current being used for EACH of the following:

(i) its magnetic effect; (2)

(ii) chemical effect; (2)

(iii) its heating effect. (2)

8. An electric fire operated from a 230 V supply has a heating element comprising of two 25 Ω coils. The coils may be connected in series to give a low setting, or in parallel to give a high setting.

Determine EACH of the following:

(a) the power output for the low setting; (4)

(b) the power output for the high setting. (4)

9. (a) State how the resistance of metals change as its temperature decreases. (2)

(b) Give an example of where the changing property described in Q9a is used. (2)

(c) Determine the total resistance across a and b in the circuit shown in FIG Q9. (4)

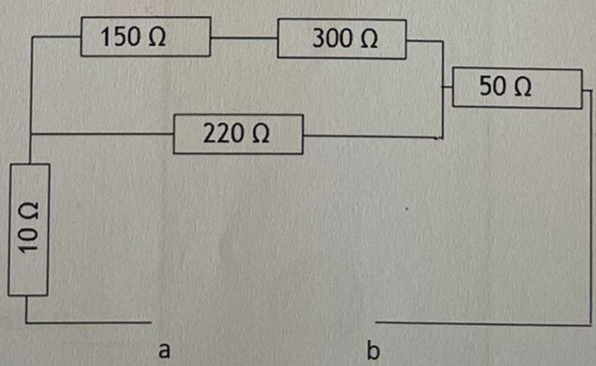


FIG Q9

10. A copper conductor has an effective length of 250 mm and a diameter of 8.5 mm and carries a current of 48 A at right angles to a magnetic field. The force on the conductor is 26 N.

Determine EACH of the following:

(a) the flux density; (4)

(b) the magnetic flux. (4)

11. A tank has an inspection hatch 800 mm diameter situated as shown in FIG Q11. The tank is filled to a height of 7.5 m with seawater.

(a) Determine EACH of the following:

(i) the pressure at the centre of the hatch; (3)

(ii) the thrust on the hatch. (3)

(b) (i) State if the pressure calculated in Q11(a)(i) is an absolute pressure or a gauge pressure; (2)

(ii) Describe the difference between absolute and gauge pressure. (2)

Note: the density of seawater is 1025 kg/m³

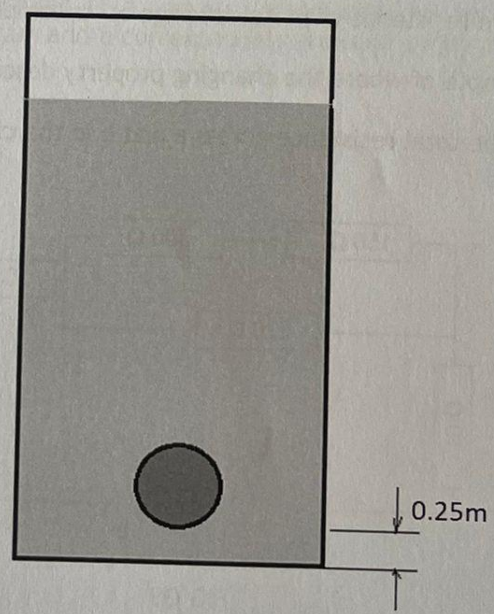


FIG Q11

12. A ship in level trim has a displacement of 23000 tonnes. Before loading a 300 tonne piece of equipment it is decided to move a 90 tonne load already on board off the centreline to heel the ship to an angle.

The 300 tonne equipment load will act at a point 2 m off the centre line to starboard.

Determine EACH of the following:

(a) the distance that the 90 tonne load should be moved away from the centreline so that, on loading the equipment, the ship will become level again; (4)

(b) the heel angle that moving the 90 tonne load will create. (4)

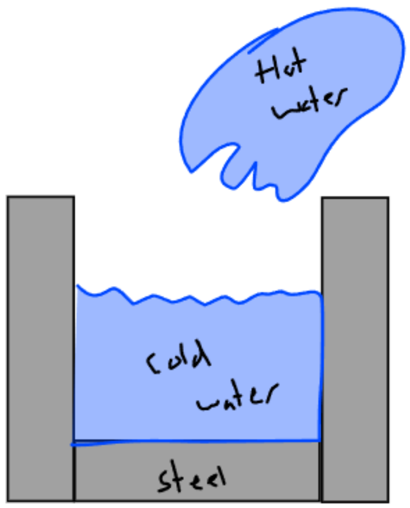
Given $m \times d = \Delta GM \tan\theta$ *and that* $KM = 6m$, *and* $KG = 4.5$ *m.*

Section A

1. ✓ A stainless steel water vessel has a mass of 3 kg and contains 12 kg of water at a temperature of 22°C. A further 15 kg of water at 70°C is added to the vessel. Assume there are no heat losses.

Calculate the final equilibrium temperature of the vessel and water. (8)

Note: the specific heat of stainless steel = 0.5 kJ/kgK
the specific heat of water = 4.18 kJ/kgK



$$Q_{loss} = Q_{gain}$$

$$Q_{Hot\ water} = Q_{cold\ water} + Q_{steel}$$

Name	initial	final	Δt	$Q = mc\Delta t$
Hot water loss	$m = 15$ $c = 4180$ $t = 70$	x	$70 - x$	$Q_{HW} = 15 \times 4180 \times (70 - x)$
Cold water gain	$m = 12$ $c = 4180$ $t = 22$	x	$x - 22$	$Q_{CW} = 12 \times 4180 \times (x - 22)$
Steel gain	$m = 3$ $c = 500$ $t = 22$	x	$x - 22$	$Q_{steel} = 3 \times 500 \times (x - 22)$

$$Q_{\text{Hot water}} = Q_{\text{cold water}} + Q_{\text{steel}}$$

$$15 \times 4180 \times (70 - x) = 12 \times 4180 \times (x - 22) + 3 \times 500 \times (x - 22)$$

$$4{,}389{,}000 - 62700x = 50160x - 1{,}103{,}520 + 1500x - 33{,}000$$

$$5{,}525{,}520 = 114360x$$

$$48.317^\circ C = x$$

Find temp

2. (a) Define Boyles Law. (2)

(b) A perfect gas at an initial pressure, temperature and volume of 3.75 bar, 145°C and 280 litres respectively is cooled at constant pressure until its temperature is 10°C.

Determine EACH of the following:

(i) the mass of the gas; (3)

(ii) the final volume in m^3; (3)

Note: R = 0.29 kJ/kgK

Boyle's law states that a decrease in volume will lead to an increase in pressure, for a perfect gas, at a constant temperature. This is an inversely proportional relationship

$$\frac{P_1V_1}{\cancel{T_1}} = \frac{P_2V_2}{\cancel{T_2}}$$

b) $Pv = mRt$

$P_1 = 3.75 = 375{,}000\ (Pa)$

$v = 280L = 0.28\ m^3$

$m = x$

$R = 290$

$t = 145 + 273 = 418\ K$

$$\frac{375{,}000 \times 0.28}{290 \times 418} = x$$

$0.866194\ kg$

bii) $\frac{\cancel{P_1}V_1}{T_1} = \frac{\cancel{P_2}V_2}{T_2}$

$$\frac{0.28}{418} = \frac{x}{(273+10)}$$

$$\frac{0.28 \times 283}{418} = 0.189569\ m^3$$

3. (a) Explain what is meant by the enthalpy of solidification. (2)

(b) 250 g of ice at -20°C is heated with 120 kJ of energy. Determine the final state and temperature of the resultant. (6)

Note: Specific heat capacity of ice = 2.11 kJ/kgK,
Specific heat capacity of water = 4.18 kJ/kgK,
Enthalpy of fusion of water = 335 kJ/kg.

a) enthalpy of solidification (or fusion) is the amount of energy required to bring about a state change from solid to liquid or vice versa. It's usually given as Joules/Kilograms.

b) ice -20°C —heat ice (1)→ ice 0°C —melt ice (2)→ water 0°C —heat water (3)→ water x°C

(1) heat ice

$Q = mc\Delta t$

$m = 0.25$

$c = 2110$

$\Delta t = 20$

$Q_1 = 0.25 \times 2110 \times 20$

$10{,}550$ J

(2) melt ice

$Q = mL$

$= 0.25 \times 335{,}000$

$Q_L = 83{,}750$ J

(3) Heat water

$120{,}000 - 10{,}550 - 83750 = 25700$

$Q = mc\Delta t$

$25700 = 0.25 \times 4180 \, \Delta t$

$\frac{25700}{0.25 \times 4180} = \Delta t = 24.5933$ °C

Final temp of liquid water 24.5933°C

4. ✓ An 8 cylinder, 4 stroke diesel engine has a bore of 350 mm and a stroke of 400 mm. Indicator cards were taken and each had a mean effective height of 22 mm. The power of the engine was also tested using a dynamometer which gave a steady state torque reading of 36 kNm at 800 rpm.

Determine EACH of the following:

(a) the brake power; (4)

(b) the indicated power. (4)

Note: Indicator spring constant was 80 kN/m²/mm

a) $BP = T 2\pi N$

$$36{,}000 \times 2\pi \times \frac{800}{60}$$

$3{,}015{,}928.947$ Watts

b) $IP = x\ p\ l\ a\ n$

$x = 8$

$p = 22 \times 80{,}000 = 1{,}760{,}000$ (Pa)

$l = 0.4$

$a = \left(\frac{0.35}{2}\right)^2 \pi$

$n = \frac{800}{60} \div 2 = 6.66667$

$$IP = 8 \times 1{,}760{,}000 \times 0.4 \times \left(\frac{0.35}{2}\right)^2 \pi \times 6.66667$$

$\left(\frac{0.35}{2}\right)^2 \pi$ = 0.096211

$= 3{,}612{,}412.673$ watts

5. 1.5 kg of Heptane (C_7H_{16}) is completely burned in air.

Determine EACH of the following:

(a) the stoichiometric mass of air required; (6)

(b) the mass of carbon dioxide in the exhaust gases. (2)

Note: assume air is 23% oxygen by mass

C = 12 H = 1 O = 16

$C_7 = 7 \times 12 = 84$ $H_{16} = 16 \times 1 = 16$ Total = 100

Carbon $1.5 \times \frac{84}{100} = 1.26$ kg

Hydrogen $1.5 \times \frac{16}{100} = 0.24$ kg

Burn Carbon

$C + O_2 = CO_2$

mols = mass / RAM

$\frac{1.26}{12} = \frac{x}{32}$

$\frac{1.26 \times 32}{12} = 3.36$ kg of oxygen

Burn Hydrogen

$H_2 + O = H_2O$

$\frac{0.24}{2} = \frac{x}{16}$

$\frac{0.24 \times 16}{2} = 1.92$ kg of oxygen

Total stoich oxygen Required = 3.36 + 1.92 = 5.28 kg

a) stoich Air $= \frac{5.28}{0.23} =$ **22.957 kg**

b) Mass of CO_2 = Mass of Carbon + Mass of oxygen

1.26 + 3.36 = **4.62 kg**

6. Describe the working principles of a vapour compression refrigeration system. Include a basic layout diagram and a corresponding pressure v enthalpy diagram to reference your answer. (10)

Section B

7. (a) Briefly describe the principal molecular characteristic of materials that differentiates those that conduct electricity well from those that do not. (2)

(b) State TWO examples of an electric current being used for EACH of the following:

(i) its magnetic effect; (2)

(ii) chemical effect; (2)

(iii) its heating effect. (2)

a) conductors usually have a giant lattice structure and valence electrons, the combination of both makes it very easy to pass electrons through the structure as a whole.

Insulators usually do not have a giant lattice structure, and are made from isolated molecules (such as PVC), and they do not have valence electrons. This creates very high internal resistance, which means they are not good conductors.

bi) magnetic effect, Solenoids, electric motor
bii) chemical effect, charging a lead acid battery, anodising a metal, such as chrome or zinc plating
biii) heating effect: electric space heater, shower, kettle, electric fuse.

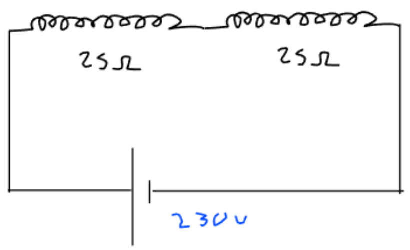
8. ✓ An electric fire operated from a 230 V supply has a heating element comprising of two 25 Ω coils. The coils may be connected in series to give a low setting, or in parallel to give a high setting.

Determine EACH of the following:

(a) the power output for the low setting; (4)

(b) the power output for the high setting. (4)

a)



Res. in Series

$R_T = R_1 + R_2$

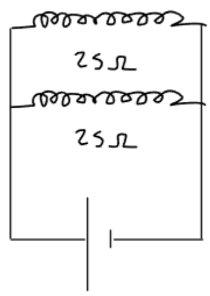
$R_T = 25 + 25 = 50\ \Omega$

current

$I = \frac{V}{R} = \frac{230}{50} = 4.6$ Amps

Power $P = IV = 4.6 \times 230 = 1058$ watts

b)



Res in Parallel

$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$

$\frac{1}{R_T} = \frac{1}{25} + \frac{1}{25}$

$R_T = 12.5\ \Omega$

Current

$I = \frac{V}{R} = \frac{230}{12.5} = 18.4$ Amps

Power $P = IV = 18.4 \times 230 = 4232$ watts

9\. (a) State how the resistance of metals change as its temperature decreases. (2)

(b) Give an example of where the changing property described in Q9a is used. (2)

(c) Determine the total resistance across a and b in the circuit shown in FIG Q9. (4)

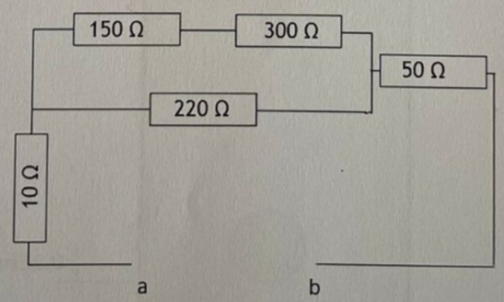
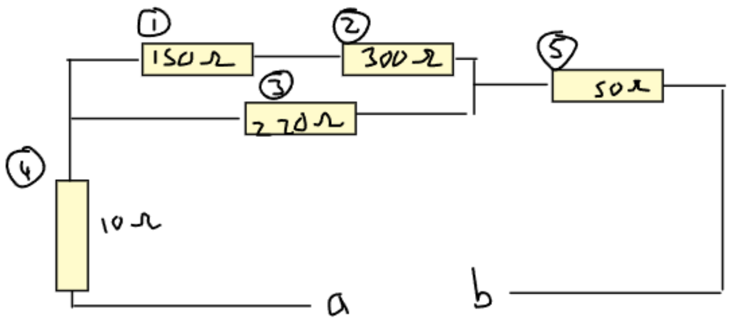


FIG Q9

9a) as the temperature increases, the resistance of a metal usually increases. This is due to more internal resistance, caused by the atoms in the metal vibrating faster, making it harder for the electrons to pass.

b) thermistors, used in electronic thermometers would take advantage of this effect.

c)



Res over Series section ① + ②

$R_6 = R_T = R_1 + R_2 = 150 + 300 = 450$

Res over Parallel section R_6, R_3

$$\frac{1}{R_T} = \frac{1}{R_6} + \frac{1}{R_3}$$

$$\frac{1}{R_T} = \frac{1}{450} + \frac{1}{220}$$

$R_7 = R_T = 147.76\ \Omega$

Res over Series Section $R_4\ R_5\ R_7$

$R_T = R_4 + R_5 + R_7$

$= 10 + 50 + 147.76$

$207.76\ \Omega$

10. A copper conductor has an effective length of 250 mm and a diameter of 8.5 mm and carries a current of 48 A at right angles to a magnetic field. The force on the conductor is 26 N.

Determine EACH of the following:

(a) the flux density; (4)

(b) the magnetic flux. (4)

c) $F = BIL \sin\theta$

$26 = x \cdot 0.25 \times 48$

$\frac{26}{0.25 \times 48} = x$

2.16667 Tesla

b) $B = \frac{\phi}{A}$

$2.166667 \times \pi \left(\frac{0.0085}{2}\right)^2 = \phi$

1.229475×10^{-4} wbs

11. A tank has an inspection hatch 800 mm diameter situated as shown in FIG Q11. The tank is filled to a height of 7.5 m with seawater.

(a) Determine EACH of the following:

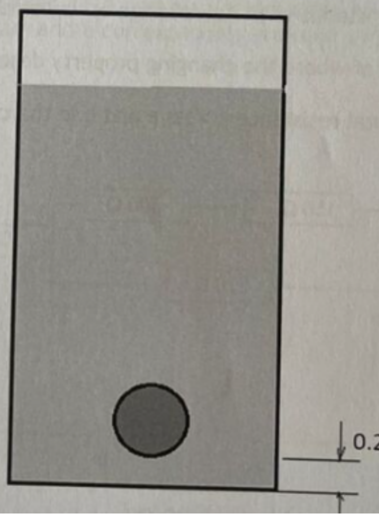
(i) the pressure at the centre of the hatch; (3)

(ii) the thrust on the hatch. (3)

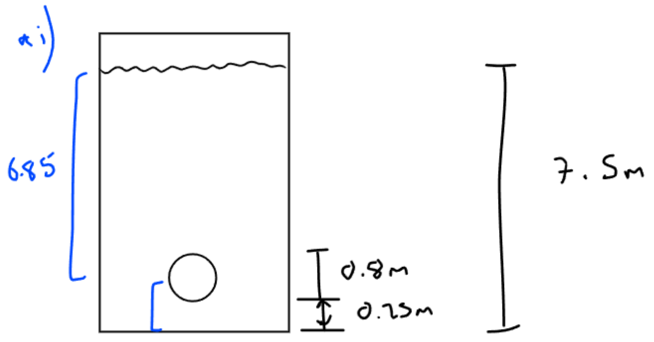
(b) (i) State if the pressure calculated in Q11(a)(i) is an absolute pressure or a gauge pressure; (2)

(ii) Describe the difference between absolute and gauge pressure. (2)

Note: the density of seawater is 1025 kg/m³



a i)



$h = 7.5 - 0.4 - 0.25 = 6.85$

$P = \rho g h = 1025 \times 9.81 \times 6.85$

$= \boxed{68{,}878 \text{ Pa}}$

hydrostatic pressure

ii) $F = \rho g A h$

$F = 1025 \times 9.81 \times \pi (0.4)^2 \times 6.85$

$F = 34{,}622 \text{ N}$

bi) its Gauge Pressure

bii) Absolute pressure would include the atmospheric pressure, as that isn't stated, I cant add it to the calculations.

Gauge pressure compares the pressure within to the pressure on the outside of a container, effectively showing the DIFFERENCE in pressures.

Absolute pressure includes atmospheric pressure, and is a pressure compared to an absolute vacuum.

To get an approximation of absolute pressure from the gauge, I would add another 1 bar, or 100,000 Pa assuming we are at sea level.

12. A ship in level trim has a displacement of 23000 tonnes. Before loading a 300 tonne piece of equipment it is decided to move a 90 tonne load already on board off the centreline to heel the ship to an angle.

The 300 tonne equipment load will act at a point 2 m off the centre line to starboard.

Determine EACH of the following:

(a) the distance that the 90 tonne load should be moved away from the centreline so that, on loading the equipment, the ship will become level again; (4)

(b) the heel angle that moving the 90 tonne load will create. (4)

Given $m \times d = \Delta GM \tan\theta$ *and that* $KM = 6m$, *and* $KG = 4.5$ *m.*

a) clockwise moments = anticlockwise moments

$$md = MD$$

$$90 \times x = 300 \times 2$$

$$x = \frac{300 \times 2}{90}$$

$$x = 6.66667 \text{ m}$$

$$KM - KG = GM$$
$$6 - 4.5 = 1.5$$

b) $md = \Delta GM \tan\theta$

$$90 \times 6.66667 = 23000 \times (1.5) \tan\theta$$

$$\tan^{-1}\left(\frac{90 \times 6.66667}{23000 \times 1.5}\right) = \theta$$

$$0.9963477969^\circ$$