CONFIDENTIAL

UNIVERSITI KUALA LUMPUR
Malaysian Institute of Marine Engineering Technology

FINAL EXAMINATION
OCTOBER 2025 SEMESTER SESSION

SUBJECT CODE	:	**LGD21002**
SUBJECT TITLE	:	**FUNDAMENTAL THERMODYNAMICS**
PROGRAMME NAME (FOR MPU: PROGRAMME LEVEL)	:	**DIPLOMA OF ENGINEERING TECHNOLOGY IN SHIP CONSTRUCTION AND MAINTENANCE**
TIME / DURATION	:	**2.00 PM - 4.00 PM (2 HOURS)**
DATE	:	**28 JANUARY 2026**

INSTRUCTIONS TO CANDIDATES

1. Please read **CAREFULLY** the instructions given in the question paper.
2. This question paper has information printed on both sides of the paper.
3. This question paper consists of **TWO (2)** sections; Section A and Section B.
4. Answer **ALL** questions in Section A. For Section B, answer TWO **(2)** questions with at least ONE (1) question from 4 or question 5.
5. Please write your answer on the answer booklet provided.
6. Answer **ALL** questions in English language **ONLY**.
7. The formulae sheet has been appended for your reference. Steam Tables will be provided.

THERE ARE 6 PAGES OF QUESTIONS, EXCLUDING THIS COVER PAGE.

SECTION A (Total: 60 marks)

INSTRUCTION: Answer ALL questions. Please use the answer booklet provided.

Question 1

(a) Define the following:

(i) Equilibrium

(ii) Thermal equilibrium

(iii) Chemical equilibrium

(iv) Phase equilibrium

(v) Mechanical equilibrium

(10 marks)

(b) Draw an illustration to show a closed system reaching thermal equilibrium.

(4 marks)

(c) Explain the zeroth law of thermodynamics and its significance in defining temperature.

(4 marks)

(d) Illustrate the zeroth law of thermodynamics of two bodies in an isolated enclosure.

(2 marks)

Question 2

(a) Define the following:

(i) macroscopic forms of energy

(ii) microscopic forms of energy

(4 marks)

(b) State TWO (2) examples of macroscopic forms of energy.

(2 marks)

(c) Draw SIX (6) various forms of microscopic energies (state their names) that make up sensible energy.

(6 marks)

(d) Describe the following internal energies:

(i) nuclear energy

(ii) latent energy

(iii) chemical energy

(iv sensible energy

(8 marks)

Question 3

(a) Describe the arrangement of atoms in solid, liquid and gas phase.

(6 marks)

(b) Figure 1 shows a phase diagram of a critical point separating two regions.

(i) Describe the physical meaning of the critical point.

(2 marks)

(ii) Explain how the properties and phase behavior of a substance below and above the critical point differ.

(4 marks)

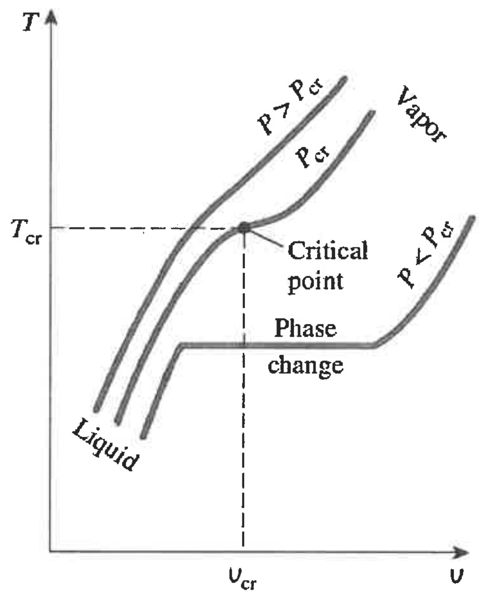

Figure 1

(c) A pure substance can change from the solid phase to the vapor phase through different thermodynamic pathways.

(i) Explain two distinct ways by which a substance can change from the solid phase to the vapor phase, with reference to the energy interactions involved.

(4 marks)

(ii) Identify the names of the phase-change processes described in part (a).

(2 marks)

(iii) Illustrate these two phase-change pathways on a P-T diagram, clearly indicating the phase boundaries crossed.

(2 marks)

SECTION B (Total: 40 marks)

INSTRUCTION: Answer TWO (2) questions only. Please use the answer booklet provided.

Question 4

(a) Complete Table 1 below using the conservation of energy principle for a closed system. Show all the necessary calculations.

Table 1

Q_{in} (J)	W_{OUT} (J)	E_1(J)	E_2 (J)	m (kg)	$e_2 - e_1$ (J/kg)
350	910	(i)	2100	2.5	(ii)
-480	(iii)	1600	950	4	(iv)
(v)	120	800	(vi)	1.2	-250

(12 marks)

(b) A mass of 6 kg of saturated water vapor at 400 kPa is heated at constant pressure until its temperature reaches 250°C. Using the steam tables,

(i) Calculate the boundary work done during the process in kJ

(ii) Draw the P–v diagram for the process, clearly showing the initial and final states.

(8 marks)

Question 5

(a) Complete Table 2 below based on the conservation of mass principle for air that flows steadily in a pipe. Show all the necessary calculations that are involved.

Table 2

Pressure	Temperature	Volume flow rate	Mass Flow rate	Specific volume	Area	Diameter
P (kPa)	T (°C)	V (m/s)	$\dot{m}$ (kg/s)	v (m³/kg)	A (m²)	D (m)
500	200	30	0.45	(i)	(ii)	(iii)
(iv)	350	18	(v)	0.3120	0.0045	(iv)

(12 marks)

(b) Steam enters a horizontal pipe of constant diameter 0.12 m at 2 MPa and 300°C with a velocity of 40 m/s and exits at 1.8 MPa and 400°C. Using the steam tables, calculate:

(i) The cross-sectional area of the tube in m^2

(ii) The mass flow rate of the steam in kg/s

(ii) The exit velocity of the steam in m/s

(iv) The volume flow rate at the inlet in m^3/s

(8 marks)

Question 6

(a) Complete Table 3 below based on the conservation of mass principle for air that flows steadily in a pipe. Show all the necessary calculations that are involved.

Table 3

	$\dot{W}_{net,out}$ (kW)	$\dot{W}_{net,in}$ (kW)	$\dot{Q}_H$ (kW)	$\dot{Q}_L$ (kW)	η_{th}	COP_R	COP_{HP}
Heat Engine	(i)	-	80	50	(ii)	-	-
Refrigerator	-	(iii)	(iv)	10	-	1.2	-
Heat Pump	-	(v)	20	(vi)	-	-	2.5

(12 marks)

(b) A Carnot heat engine receives heat from a reservoir at 1000°C at a rate of 840 kJ/min and rejects the waste heat to the ambient air at 25°C. The entire work output of the heat engine is used to drive a refrigerator that removes heat from the refrigerated space at –5°C and transfers it to the same ambient air at 25°C. Calculate the maximum rate of heat removal from the refrigerated space in kJ/s.

(8 marks)

END OF EXAMINATION PAPER

THERMODYNAMICS FORMULA

First Law of Thermodynamics
Density, $\rho = \frac{m}{V}$
Specific Gravity, $SG = \frac{\rho}{\rho_{H_2O}}$
Specific Weight, $\gamma_s = \rho g$
Gage Pressure, $P_{gage} = P_{abs} - P_{atm}$
Vacuum Pressure, $P_{vac} = P_{atm} - P_{abs}$
Kinetic Energy, $KE = \frac{mV^2}{2}$
Potential Energy, $PE = mgz$
Total energy, $E = U + KE + PE$
Heat transfer, $Q = \dot{Q}\Delta t$
Work, $W = Fs$
Force, $F = PA$
Spring Force, $F = kx$
Electrical work, $W_e = VI\Delta t$
Shaft work, $W_{sh} = 2\pi nT$
Shaft power, $\dot{W}_{sh} = 2\pi\dot{n}T$
Spring Work, $W_{spring} = \frac{1}{2}k(x_2^{\ 2} - x_1^{\ 2})$
Enthalpy, $H = U + PV$
Quality, $x = \frac{m_g}{m_{total}}$ $x = \frac{y - y_f}{y_{fg}}$ $where\ y = v, u\ or\ h$
Mass total $m_{total} = m_f + m_g$
Ideal gas equation $PV = mRT$
$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

General Energy Balance $E_{in} - E_{out} = \Delta E_{system}$
$\Delta E_{system} = \Delta U + \Delta KE + \Delta PE$
Energy Balance for a closed system $\Delta Q - \Delta W = \Delta U + \Delta KE + \Delta PE$
Energy Balance for a constant pressure process $W_b + \Delta U = \Delta H$ $Q - W_{other} = \Delta H + \Delta KE + \Delta PE$
Conservation of mass and energy equations for steady-flow process $\sum \dot{m}_{in} = \sum \dot{m}_{out}$ $\dot{Q} - \dot{W} = \sum_{out} \dot{m}[h + \frac{V^2}{2} + gz] - \sum_{in} \dot{m}[h + \frac{V^2}{2} + gz]$
Boundary work (P = constant), $W_b = mP_0(v_2 - v_1)$
Boundary work (T = constant), $W_b = P_1 V_1 \ln\left(\frac{V_2}{V_1}\right)$
Energy balance for a steady-flow process $\dot{E}_{in} - \dot{E}_{out} = \frac{dE_{system}}{dt} = 0$ $\dot{E}_{in} = \dot{E}_{out}$
Mass flow rate, $\dot{m} = \rho A V = \rho \dot{V} = \frac{\dot{V}}{v}$
Volume flow rate, $\dot{V} = VA = \frac{\dot{m}}{\rho}$
Thermal efficiency of a Heat Engine $\eta_{th} = \frac{W_{net,out}}{Q_H} = 1 - \frac{Q_L}{Q_H}$
Coefficient of performance $COP_R = \frac{Q_L}{W_{net,in}} = \frac{q_L}{w_{net,in}} = \frac{Q_L}{Q_H - Q_L} = \frac{h_1 - h_4}{h_2 - h_1}$ $COP_{HP} = \frac{Q_H}{W_{net,in}} = \frac{q_H}{w_{net,in}} = \frac{Q_H}{Q_H - Q_L} = \frac{h_2 - h_3}{h_2 - h_1}$
Carnot Heat Engine
$\eta_{th,Carnot} = \eta_{th,rev} = 1 - \frac{T_L}{T_H}$

Carnot Refrigerators and Heat Pumps
$COP_R, carnot = \frac{1}{T_H / T_L - 1}$
$COP_R, carnot = \frac{1}{1 - T_L / T_H}$
Entropy
$S_{gen} = \Delta S_{total} = \Delta S_{sys} + \Delta S_{surr} \geq 0$
$\Delta S = m(s_2 - s_1)$
The Entropy Change of Ideal Gases
Constant Specific Heats (Approximate Analysis)
$s_2 - s_1 = c_{v,avg} \ln\frac{T_2}{T_1} + R \ln\frac{v_2}{v_1}$
$s_2 - s_1 = c_{p,avg} \ln\frac{T_2}{T_1} - R \ln\frac{P_2}{P_1}$
Variable Specific Heats (Exact Analysis)
$s_2 - s_1 = s_2^o - s_1^o - R \ln\frac{P_2}{P_1}$
Isentropic Processes of Ideal Gases
Constant Specific Heats (Approximate Analysis)
$\left(\frac{T_2}{T_1}\right) = \left(\frac{v_1}{v_2}\right)^{k-1}$
$\left(\frac{T_2}{T_1}\right) = \left(\frac{P_2}{P_1}\right)^{(k-1)/k}$
$\left(\frac{P_2}{P_1}\right) = \left(\frac{v_1}{v_2}\right)^{k}$
Variable Specific Heats (Exact Analysis)
$\left(\frac{P_2}{P_1}\right) = \frac{P_{r2}}{P_{r1}}$
$\left(\frac{v_2}{v_1}\right) = \frac{v_{r2}}{v_{r1}}$
Isentropic Efficiency of Turbine, $\eta_T = \frac{w_a}{w_s} \cong \frac{h_1 - h_{2a}}{h_1 - h_{2s}}$
Isentropic Efficiency of Compressors, $\eta_C = \frac{w_s}{w_a} \cong \frac{h_{2s} - h_1}{h_{2a} - h_1}$
Isentropic Efficiency of Pump, $\eta_P = \frac{w_s}{w_a} \cong \frac{v(P_2 - P_1)}{h_{2a} - h_1}$

Isentropic Efficiency of Nozzle, $\eta_N = \frac{V_{2a}^2}{V_{2s}^2} \cong \frac{h_1 - h_{2a}}{h_1 - h_{2s}}$
Gas Power Cycle
Compression ratio, $r = \frac{V_{max}}{V_{min}} = \frac{V_{BDC}}{V_{TDC}} = \frac{V_1}{V_2} = \frac{v_1}{v_2}$
Mean Effective Pressure, $MEP = \frac{W_{net}}{V_{max} - V_{min}} = \frac{w_{net}}{v_{max} - v_{min}}$
Otto Cycle
$q_{in} = u_3 - u_2 = c_v(T_3 - T_2)$
$q_{out} = u_4 - u_1 = c_v(T_4 - T_1)$
$\eta_{th,Otto} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{T_4 - T_1}{T_3 - T_2} = 1 - \frac{T_1(T_4/T_1 - 1)}{T_2(T_3/T_2 - 1)}$
$\eta_{th,Otto} = 1 - \frac{1}{r^{k-1}}$
Diesel Cycle
$q_{in} - w_{b,out} = u_3 - u_2 \rightarrow q_{in} = P_2(v_3 - v_2) + (u_3 - u_2) = h_3 - h_2 = c_p(T_3 - T_2)$
$-q_{out} = u_1 - u_4 \rightarrow q_{out} = u_4 - u_1 = c_v(T_4 - T_1)$
$\eta_{th,Diesel} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{T_4 - T_1}{k(T_3 - T_2)} = 1 - \frac{T_1(T_4/T_1 - 1)}{kT_2(T_3/T_2 - 1)}$
$\eta_{th,Diesel} = 1 - \frac{1}{r^{k-1}}\left[\frac{r_c^k - 1}{k(r_c - 1)}\right]$
$r_c = \frac{V_3}{V_2} = \frac{v_3}{v_2}$
Rankine Cycle
$Pump\ (q = 0): w_{pump,in} = h_2 - h_1 \quad where\ h_1 = h_{f@P_1}$
$or \quad w_{pump,in} = v(P_2 - P_1) \quad where\ v \cong v_1 = v_{f@P_1}$
$Boiler\ (w = 0): q_{in} = h_3 - h_2$
$Turbine\ (q = 0): w_{turb,out} = h_3 - h_4$
$Condenser\ (w = 0): q_{out} = h_4 - h_1$
$w_{net} = q_{in} - q_{out} = w_{turb,out} - w_{pump,in}$
Isentropic Efficiencies for Pumps and Turbines
$\eta_P = \frac{w_s}{w_a} = \frac{h_{2s} - h_1}{h_{2a} - h_1}$
$\eta_T = \frac{w_a}{w_s} = \frac{h_3 - h_{4a}}{h_3 - h_{4s}}$

Ideal Reheat Rankine Cycle
$q_{in} = q_{primary} + q_{reheat} = (h_3 - h_2) + (h_5 - h_4)$
$w_{turb,out} = w_{turb,I} + w_{turb,II} = (h_3 - h_4) + (h_5 - h_6)$
Partial Pressure of Dry Air and Water vapor
$P = P_a + P_v$
Enthalpy of Dry Air and Water vapor
$h_{dry\ air} = c_p T = (1.005 kJ/kg.^o C)T$
$\Delta h_{dry\ air} = c_p \Delta T = (1.005 kJ/kg.^o C)\Delta T$
$h_v(T, low\ P) \cong h_g(T)$
$h_g(T) \cong 2500.9 + 1.82T$
Specific and Relative Humidity of Air
$\omega = \frac{m_v}{m_a} = \frac{P_v V/R_v T}{P_a V/R_a T} = \frac{P_v/R_v}{P_a/R_a} = 0.622\frac{P_v}{P_a} = \frac{0.622 P_v}{P - P_v}$
$\emptyset = \frac{m_v}{m_g} = \frac{P_v V/R_v T}{P_g V/R_g T} = \frac{P_v}{P_g} \quad where\ P_g = P_{sat@T}$
$\emptyset = \frac{\omega P}{(0.622 + \omega)P_g}$
$\omega = \frac{0.622\emptyset P_g}{P - \emptyset P_g}$
$\omega_1 = \frac{c_p(T_2 - T_1) + \omega_2 h_{fg_2}}{h_{g_1} - h_{f_2}}$
$\omega_2 = \frac{0.622 P_{g_2}}{P_2 - P_{g_2}}$
Total Enthalpy of Atmospheric Air
$H = H_a + H_v = m_a h_a + m_v h_v$
$h = h_a + \omega h_g$
Dew Point Temperature
$T_{dp} = T_{sat@P_v}$

Conversion Factors

DIMENSION	METRIC	METRIC/ENGLISH
Acceleration	1 m/s^2 = 100 cm/s^2	1 m/s^2 = 3.2808 ft/s^2 1 ft/s^2 = 0.3048* m/s^2
Area	1 m^2 = 10^4 cm^2 = 10^6 mm^2 = 10^{-6} km^2	1 m^2 = 1550 in^2 = 10.764 ft^2 1 ft^2 = 144 in^2 = 0.09290304* m^2
Density	1 g/cm^3 = 1 kg/L = 1000 kg/m^3	1 g/cm^3 = 62.428 lbm/ft^3 = 0.036127 lbm/in^3 1 lbm/in^3 = 1728 lbm/ft^3 1 kg/m^3 = 0.062428 lbm/ft^3
Energy, heat, work, internal energy, enthalpy	1 kJ = 1000 J = 1000 N · m = 1 kPa · m^3 1 kJ/kg = 1000 m^2/s^2 1 kWh = 3600 kJ 1 cal† = 4.184 J 1 IT cal† = 4.1868 J 1 Cal† = 4.1868 kJ	1 kJ = 0.94782 Btu 1 Btu = 1.055056 kJ = 5.40395 psia · ft^3 = 778.169 lbf · ft 1 Btu/lbm = 25,037 ft^2/s^2 = 2.326* kJ/kg 1 kJ/kg = 0.430 Btu/lbm 1 kWh = 3412.14 Btu 1 therm = 10^5 Btu = 1.055 × 10^5 kJ (natural gas)
Force	1 N = 1 kg · m/s^2 = 10^5 dyne 1 kgf = 9.80665 N	1 N = 0.22481 lbf 1 lbf = 32.174 lbm · ft/s^2 = 4.44822 N
Heat flux	1 W/cm^2 = 10^4 W/m^2	1 W/m^2 = 0.3171 Btu/h · ft^2
Heat transfer coefficient	1 W/m^2 · °C = 1 W/m^2 · K	1 W/m^2 · °C = 0.17612 Btu/h · ft^2 · °F
Length	1 m = 100 cm = 1000 mm = 10^6 μm 1 km = 1000 m	1 m = 39.370 in = 3.2808 ft = 1.0926 yd 1 ft = 12 in = 0.3048* m 1 mile = 5280 ft = 1.6093 km 1 in = 2.54* cm
Mass	1 kg = 1000 g 1 metric ton = 1000 kg	1 kg = 2.2046226 lbm 1 lbm = 0.45359237* kg 1 ounce = 28.3495 g 1 slug = 32.174 lbm = 14.5939 kg 1 short ton = 2000 lbm = 907.1847 kg
Power, heat transfer rate	1 W = 1 J/s 1 kW = 1000 W = 1.341 hp 1 hp† = 745.7 W	1 kW = 3412.14 Btu/h = 737.56 lbf · ft/s 1 hp = 550 lbf · ft/s = 0.7068 Btu/s = 42.41 Btu/min = 2544.5 Btu/h = 0.74570 kW 1 boiler hp = 33,475 Btu/h 1 Btu/h = 1.055056 kJ/h 1 ton of refrigeration = 200 Btu/min
Pressure	1 Pa = 1 N/m^2 1 kPa = 10^3 Pa = 10^{-3} MPa 1 atm = 101.325 kPa = 1.01325 bars = 760 mm Hg at 0°C = 1.03323 kgf/cm^2 1 mm Hg = 0.1333 kPa	1 Pa = 1.4504 × 10^{-4} psia = 0.020886 lbf/ft^2 1 psi = 144 lbf/ft^2 = 6.894757 kPa 1 atm = 14.696 psia = 29.92 in Hg at 30°F 1 in Hg = 3.387 kPa
Specific heat	1 kJ/kg · °C = 1 kJ/kg · K = 1 J/g · °C	1 Btu/lbm · °F = 4.1868 kJ/kg · °C 1 Btu/lbmol · R = 4.1868 kJ/kmol · K 1 kJ/kg · °C = 0.23885 Btu/lbm · °F = 0.23885 Btu/lbm · R

*Exact conversion factor between metric and English units.

†Calorie is originally defined as the amount of heat needed to raise the temperature of 1 g of water by 1°C, but it varies with temperature. The international steam table (IT) calorie (generally preferred by engineers) is exactly 4.1868 J by definition and corresponds to the specific heat of water at 15°C. The thermochemical calorie (generally preferred by physicists) is exactly 4.184 J by definition and corresponds to the specific heat of water at room temperature. The difference between the two is about 0.06 percent, which is negligible. The capitalized Calorie used by nutritionists is actually a kilocalorie (1000 IT calories).

DIMENSION	METRIC	METRIC/ENGLISH
Specific volume	1 m^3/kg = 1000 L/kg = 1000 cm^3/g	1 m^3/kg = 16.02 ft^3/lbm 1 ft^3/lbm = 0.062428 m^3/kg
Temperature	T(K) = T(°C) + 273.15 ΔT(K) = ΔT(°C)	T(R) = T(°F) + 459.67 = 1.8T(K) T(°F) = 1.8 T(°C) + 32 ΔT(°F) = ΔT(R) = 1.8 ΔT(K)
Thermal conductivity	1 W/m · °C = 1 W/m · K	1 W/m · °C = 0.57782 Btu/h · ft · °F
Velocity	1 m/s = 3.60 km/h	1 m/s = 3.2808 ft/s = 2.237 mi/h 1 mi/h = 1.46667 ft/s 1 mi/h = 1.6093 km/h
Volume	1 m^3 = 1000 L = 10^6 cm^3 (cc)	1 m^3 = 6.1024 × 10^4 in^3 = 35.315 ft^3 = 264.17 gal (U.S.) 1 U.S. gallon = 231 in^3 = 3.7854 L 1 fl ounce = 29.5735 cm^3 = 0.0295735 L 1 U.S. gallon = 128 fl ounces
Volume flow rate	1 m^3/s = 60,000 L/min = 10^6 cm^3/s	1 m^3/s = 15,850 gal/min (gpm) = 35.315 ft^3/s = 2118.9 ft^3/min (cfm)

[1]Mechanical horsepower. The electrical horsepower is taken to be exactly 746 W

Some Physical Constants

Universal gas constant	R_u = 8.31447 kJ/kmol · K = 8.31447 kPa · m^3/kmol · K = 0.0831447 bar · m^3/kmol · K = 82.05 L · atm/kmol · K = 1.9858 Btu/lbmol · R = 1545.37 ft · lbf/lbmol · R = 10.73 psia · ft^3/lbmol · R
Standard acceleration of gravity	g = 9.80665 m/s^2 = 32.174 ft/s^2
Standard atmospheric pressure	1 atm = 101.325 kPa = 1.01325 bar = 14.696 psia = 760 mm Hg (0°C) = 29.9213 in Hg (32°F) = 10.3323 m H_2O (4°C)
Stefan–Boltzmann constant	σ = 5.6704 × 10^{-8} W/m^2 · K^4 = 0.1714 × 10^{-8} Btu/h · ft^2 · R^4
Boltzmann's constant	k = 1.380650 × 10^{-23} J/K
Speed of light in vacuum	c_o = 2.9979 × 10^8 m/s = 9.836 × 10^8 ft/s
Speed of sound in dry air at 0°C and 1 atm	c = 331.36 m/s = 1089 ft/s
Heat of fusion of water at 1 atm	h_{if} = 333.7 kJ/kg = 143.5 Btu/lbm
Enthalpy of vaporization of water at 1 atm	h_{fg} = 2256.5 kJ/kg = 970.12 Btu/lbm