University College Dublin
An Coláiste Ollscoile, Baile Átha Cliath

SEMESTER I EXAMINATIONS - 2012/2013

School of Mechanical and Materials Engineering

MEEN10050 Energy Engineering

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Time Allowed: 2 Hours

Instructions for Candidates

50 Marks (out of 100) are allocated for Section A (MCQ), based on all 20 Questions.

- Questions A1 to A20 carry equal marks (+2.5 marks each).
- Negative marks apply for incorrect answers (-0.625 marks each).
- Zero mark applies for a blank answer on any question.

Please complete **MULTIPLE CHOICE "ANSWER SHEET"** *using* ***HB Pencil.***

50 Marks (out of 100) are allocated for Section B are based on any 2 Questions (25 marks each). Numbers in ( ) brackets indicate marks allocated to each part of a question.

Fluid Property Data and Formulae are included at the end of this document.

Instructions for Invigilators

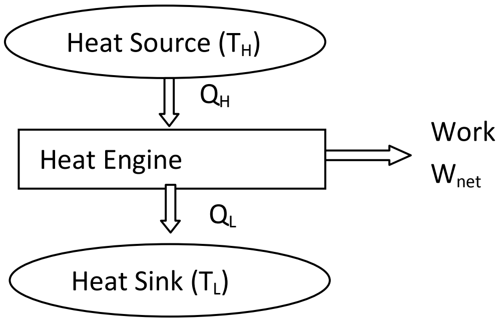
Please supply one Answer Book and one MULTIPLE CHOICE "ANSWER SHEET" to each candidate.

Non-programmable calculators are permitted.
No rough-work paper is to be provided for candidates.

50 Marks are allocated for Section A (MCQ), based on all 20 Questions.

Question A1.

Which of the following quantities could correctly represent the heat engine shown below?



(A) T_H = 500 °C, T_L = 500 °C, Q_H = 100 J, Q_L = 70 J, W_{net} = 30 J

(B) T_H = 500 °C, T_L = 100 °C, Q_H = 100 J, Q_L = 70 J, W_{net} = 30 J

(C) T_H = 100 °C, T_L = 500 °C, Q_H = 100 J, Q_L = 70 J, W_{net} = 30 J

(D) T_H = 100 °C, T_L = 500 °C, Q_H = 70 J, Q_L = 30 J, W_{net} = 100 J

Question A2.

Cooling of an electronic power transistor is assisted by attaching it to an aluminium heat sink. The electrical power to be dissipated is 0.3 watts, the exposed surface area of the heat sink is 0.001m^2, the convection heat transfer coefficient is 6.0 W•m^{-2}•.K^{-1} and the ambient temperature is 20°C. Assuming steady state conditions and ignoring radiation effects, the surface temperature of the heat sink will be

(A) 20°C

(B) 25°C

(C) 50°C

(D) 70°C

Question A3.

The units for heat flux are

(A) W

(B) W•m^{-2}

(C) W•m^{-1}•K^{-1}

(D) W•m^{-2}•K^{-1}

Question A4.

A triple glazed window consists of 3 clear glass panes of 3 mm thickness each, separated by air cavities of 12 mm each.

The window area is 1.0 m^2. If the thermal conductivity of the glass panes is 0.8 W•m^{-1}•K^{-1} and of the air cavities is 0.028 W•m^{-1}•K^{-1} what is the total thermal resistance of the window? (The interior convection coefficient is 9 W•m^{-2}•.K^{-1} and the exterior convection coefficient is 35 W•m^{-2}•.K^{-1})

(A) 0.85 K•W^{-1}

(B) 1.0 K•W^{-1}

(C) 2.5 K•W^{-1}

(D) 10 K•W^{-1}

Question A5.

If for the window of Question A4 the ambient air temperature is –10 °C and the room air temperature is 20 °C what will be the inside surface temperature of the inner glass layer?

(A) -10.67 °C

(B) 11.33 °C

(C) 16.67 °C

(D) 21.33 °C

Question A6.

The absorptivity of an opaque surface is 0.6. What is its reflectivity?

(A) 0.4

(B) 0.6

(C) 1.6

(D) 1.4

Question A7.

A tank has two separate internal chambers (“A” and “B”) which are initially separated by a membrane. Chamber “A” has a volume of 1 m^3 and contains 1.0 kg of air. Chamber “B” has a volume of 1.0 m^3 and contains air at a specific volume of 4.0 m^3•kg^{-1}. If the membrane is broken and mixing occurs until a uniform state is achieved, the final specific volume of the air will be

(A) 1.2 m^3•kg^{-1}

(B) 1.6 m^3•kg^{-1}

(C) 5.0 m^3•kg^{-1}

(D) 8.0 m^3•kg^{-1}

Question A8.

Air is trapped in a rigid vessel, the internal volume of which remains constant. The initial temperature and absolute pressure are 250^{o}C and 250 kPa respectively. Heat loss occurs such that the air temperature reduces to 100^{o}C. The new air pressure in the vessel will be

(A) 406.5 kPa

(B) 300 kPa

(C) 221.5 kPa

(D) 178.3 kPa

Question A9.

H_2O is stored in a rigid vessel at 1.0 MPa, 100^{o}C. Is this

(A) Superheated vapour ?

(B) Sub-cooled liquid

(C) Saturated vapour ?

(D) Saturated liquid ?

Question A10.

An engine crankshaft rotates at 3000 rev•min^{-1} and transmits a torque of 31.83 N•m to its load. The engine power output is

(A) 1.0 kW

(B) 10 kW

(C) 60.0 kW

(D) 600 kW

Question A11.

An ideal gas undergoes a polytropic compression process where the absolute pressure increases from 132kPa to 365kPa whilst volume reduces from 1.75m^3 to 0.75m^3. The polytropic index *n* is

(A) 1.751

(B) 1.0

(C) 2.73

(D) 1.2

Question A12.

Water at a temperature of 125^{o}C and a pressure of 232.1 kPa is at a state such that its specific enthalpy is 1619.2 kJ•kg^{-1}. Which of the following could also be correct?

(A) v = 0.7706 m^3•kg^{-1}

(B) x = 0.5

(C) v = 0.001065 m^3•kg^{-1}

(D) x = 1.0

Question A13.

The correct operating sequence of a 4-stroke cycle internal combustion engine is

(A) Intake, Compression, Combustion, Expansion, Exhaust

(B) Compression, Expansion, Intake, Exhaust

(C) Throttling, Intake, Exhaust, Combustion

(D) Compression, Expansion, Throttling, Combustion, Exhaust

Question A14.

The pressure of an ideal gas drops significantly as it flows under steady state conditions through an insulated throttle valve. Which of the following does not remain constant?

(A) Temperature

(B) Specific internal energy

(C) Specific enthalpy

(D) Specific entropy

Question A15.

1.725 kg of liquid water at atmospheric pressure is heated electrically in an insulated kettle from 17.5 to 75^{o}C over a time period of 138.2 seconds. The average electric power is

(A) 3.0 kW

(B) 2.0 kW

(C) 1.0 kW

(D) 0.5 kW

Question A16.

A closed Thermodynamic System

(A) Always contains heat

(B) Always contains work

(C) Always has a constant volume

(D) Always has a constant mass

Question A17.

Heat is added to a closed cylinder of constant pressure containing 0.718 kg of air. What will be the heat input needed to increase the temperature of the air from 20^{o}C to 120^{o}C?

(A) 0.139 kJ

(B) 51.55 kJ

(C) 72.16 kJ

(D) 100.5 kJ

Question A18.

Condensing of a refrigerant in the ideal vapour compression refrigeration cycle occurs at constant

(A) Pressure

(B) Temperature

(C) Specific enthalpy

(D) Specific entropy

Question A19.

A domestic refrigerator with a coefficient of performance of 2.25 is being used to cool 30.2 kg of apples from 25.1 ^oC down to 3 ^oC. The specific heat of apples is 3.65 $kJ•kg^{-1}•K^{-1}$ and the cost of electricity is €0.20 per kWh. The estimated total cost of electricity required for the refrigerator to cool the apples is

(A) € 0.0003

(B) € 0.06

(C) € 0.36

(D) € 1.2

Question A20.

Saturated liquid R134a refrigerant at 0.770 MPa, 30^{o}C (h_f = 91.49 $kJ•kg^{-1}$) is throttled to 0.20 MPa in a steady state, steady flow process. At this exit condition T_{sat} = -10.09^{o}C, h_f = 36.84 $kJ•kg^{-1}$, h_g = 241.30 $kJ•kg^{-1}$. Is the dryness fraction at exit

(A) 0.447

(B) 0.379

(C) 0.226

(D) 0.267

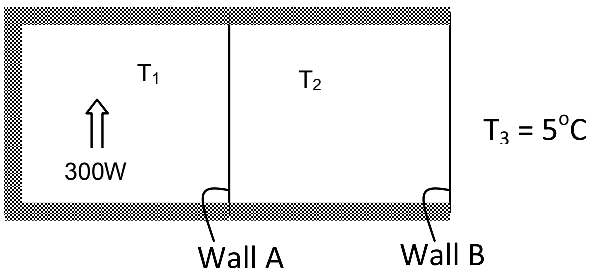
<u>SECTION B</u> **(50 Marks)** (please use an Answer Book)
Marks for Section B are based on <u>any two</u> Questions (25 marks each)

<u>Question B1 (25 Marks)</u>

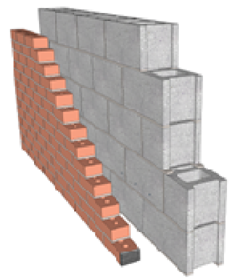
A heater provides 300 W of heating in the space shown on the left hand side of the Figure a. This space has one wall which is adjacent to an unheated space which itself has only one external wall. All the surfaces except walls A and B are adiabatic. Steady state conditions apply. The overall U value for wall A is 2.4 $W \cdot m^{-2} \cdot K^{-1}$.

Wall B is constructed of face brick (10 cm thickness) and concrete block (30 cm thickness) with an air-filled cavity (5 cm thickness) as shown in Figure b. The interior and exterior convection coefficients are 8.3 $W \cdot m^{-2} \cdot K^{-1}$, and 34 $W \cdot m^{-2} \cdot K^{-1}$, respectively. The brick thermal conductivity is 0.86 $W \cdot m^{-1} \cdot K^{-1}$, the concrete block thermal conductivity 1.5 $W \cdot m^{-1} \cdot K^{-1}$, and the air cavity thermal conductivity is 0.25 $W \cdot m^{-1} \cdot K^{-1}$.

The surface areas of walls A and B are both equal at 25 m^2. Assume that the rooms are perfectly air tight. The external ambient temperature T_3 is 5^oC.



<u>Figure a</u>.



<u>Figure b</u>.

(a) What is the U-value of the wall B? (7 marks)

(b) What is the temperature T_2 of the air in the unheated room? (14 marks)

(c) What is the temperature T_1 of the air in the heated room? (4 marks)

<u>Question B2 (25 Marks)</u>

(A) A gas is compressed from state (P_1, V_1) to (P_2, V_2) via two alternative paths, A and B:

- Path A: a polytropic process in which PV^n = Constant.
- Path B: an isobaric process to (P_1, V_2) followed by an isochoric process to (P_2, V_2).

(i) Derive an expression for the work done during compression along path A (10 marks)

(ii) Derive an expression for the work done during compression along path B (7 marks)

(B) A mass of 0.12 kg of air undergoes a polytropic compression in a piston–cylinder assembly from an initial P_1 = 100 kPa and temperature T_1 = 17^oC to a final pressure P_2 = 800 kPa. Assuming ideal gas behaviour and a polytropic index *n* = 1.35, determine the final temperature (^oC). (8 marks)

<u>Question B3 (25 Marks)</u>

A pumped domestic shower unit incorporates an electrical resistance heater to increase the temperature of liquid water before it is directed towards the shower head. The heater in a specific model draws 7.2 kW of electric power and operates in a steady state with an inlet water supply temperature of 5^oC during cold weather.

(A) What inlet water flow rate (in *litres* per minute) can be sustained if the outlet water temperature is to be 50^oC at the exit from the heater? (12 marks)

(B) What exit temperature (^oC) would be achieved if this water flow rate were increased by 60%? (8 marks)

In working through your answers, write down any equation used, explain why you are using it and note any simplifying assumptions made in the course of your analysis.

(5 marks)

Properties of H_2O

Table 1: Saturated Water & Steam

Pressure	Saturation Temp. (°C)	Specific Volume ($m^3 \cdot kg^{-1}$)		Specific Internal Energy ($kJ \cdot kg^{-1}$)			Specific Enthalpy ($kJ \cdot kg^{-1}$)			Specific Entropy ($kJ \cdot kg^{-1} \cdot K^{-1}$)		
P	$T_{sat.}$	v_f	v_g	u_f	u_{fg}	u_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
0.87 kPa	5.00	0.001000	147.01	21.0	2360.8	2381.8	21.02	2489.1	2510.1	0.0763	8.9585	9.0248
2.0 kPa	17.50	0.001001	67.00	73.48	2326.0	2399.5	73.48	2460.0	2533.5	0.2607	8.4629	8.7237
10 kPa	45.81	0.001010	14.67	191.8	2246.1	2437.9	191.8	2392.8	2584.7	0.6493	7.5009	8.1502
12.35 kPa	50.0	0.001012	12.03	209.3	2233.4	2442.7	209.34	2382.0	2591.3	0.7038	7.3710	8.0748
20 kPa	60.06	0.001017	7.649	251.38	2205.4	2456.7	251.40	2358.3	2609.7	0.8320	7.0766	7.9085
38.60 kPa	75.00	0.001030	4.1289	313.99	2161.2	2475.2	314.0	2320.6	2634.6	1.0158	6.6654	7.6812
100 kPa	99.63	0.001043	1.6940	417.4	2088.7	2506.1	417.5	2258.0	2675.5	1.3026	6.0568	7.7394
101.325 kPa	100.00	0.001044	1.6729	418.94	2087.6	2506.5	419.04	2257.0	2676.1	1.3069	6.0480	7.3549
200 kPa	120.23	0.001061	0.8857	504.49	2025.0	2529.5	504.7	2201.9	2706.7	1.5301	5.5970	7.1271
232.1 kPa	125.00	0.001065	0.7706	524.74	2009.9	2534.6	524.99	2188.5	2713.5	1.5813	5.4962	7.0775
500 kPa	151.86	0.001093	0.3749	639.68	1921.6	2561.2	640.23	2108.5	2748.7	1.8607	4.9606	6.8213
1.0 MPa	179.91	0.001127	0.19444	761.7	1822.0	2583.6	762.8	2015.3	2778.1	2.1387	4.4478	6.5865
10 MPa	311.06	0.001452	0.018026	1393.0	1151.4	2544.4	1407.7	1317.1	2724.7	3.3596	2.2544	5.6141
14 MPa	336.75	0.001611	0.011485	1548.6	928.2	2476.8	1571.1	1066.5	2637.6	3.6232	1.7485	5.3717
15 MPa	342.24	0.001658	0.010337	1585.6	869.8	2455.5	1610.5	1000.0	2610.5	3.6848	1.6249	5.3098

Table 2: Superheated Steam

Pressure	Temp. (°C)	Specific Volume ($m^3 \cdot kg^{-1}$)	Specific Internal Energy ($kJ \cdot kg^{-1}$)	Specific Enthalpy ($kJ \cdot kg^{-1}$)	Specific Entropy ($kJ \cdot kg^{-1} \cdot K^{-1}$)
P	T	v	u	h	s
10 kPa	500	35.679	3132.3	3489.1	9.8978
100 kPa	500	3.565	3131.6	3488.1	8.8342
200 kPa	500	1.7814	3130.8	3487.1	8.5133
1.0 MPa	500	0.3541	3124.4	3478.5	7.7622
10 MPa	500	0.03279	3045.8	3373.7	6.5966
15.0 MPa	500	0.02080	2996.6	3308.6	6.3443

MEEN 10050 - Energy Engineering Formulae

Heat Transfer

Conduction: $\boxed{\dot{Q}_{\text{conduction}} = -k.A.\frac{dT}{dX}}$ Convection: $\boxed{\dot{Q}_{conv} = h.A.(T_{surface} - T_{fluid})}$

Radiation: $\boxed{\dot{Q}_{\text{radiation-net}} = \varepsilon_s.\sigma.A_s.\left(T_{\text{s}}^{\ 4} - T_{\text{surr}}^{\ 4}\right)}$ Stefan-Boltzmann Const. $\sigma = 5.67\text{X}10^{-8}\ \text{W.m}^{-2}\text{K}^{-4}$

Thermal Resistances (K•W^{-1}): $\boxed{R_{cond} = \frac{L}{k.A}}$ $\boxed{R_{conv} = \frac{1}{h.A}}$

Resistances in Series: $\boxed{R_{total} = R_1 + R_2 = \sum R}$ In Parallel: $\boxed{\frac{1}{R_{total}} = \left(\frac{1}{R_1} + \frac{1}{R_2}\right) = \frac{R_1.R_2}{R_1 + R_2}}$

Overall: $\boxed{\dot{Q} = U.A.\Delta T_{overall}}$ $\boxed{\dot{Q} = \frac{\Delta T_{overall}}{R_{total}}}$ $\boxed{U.A = 1/R_{total}}$

Single-Layer Plane Wall: $\boxed{\dot{Q} = \frac{(T_i - T_o)}{\left(\frac{1}{h_i.A} + \frac{\Delta x}{k_w.A} + \frac{1}{h_o.A}\right)}}$ $\boxed{\frac{1}{U_A} = \frac{1}{h_i} + \frac{\Delta x}{k_w} + \frac{1}{h_o}}$

Multi-Layered Plane Wall: $\boxed{R_{total} = R_{conv,1} + R_{wall,1} + R_{wall,2} + R_{conv,2} = \frac{1}{h_1.A} + \frac{L_1}{k_1.A} + \frac{L_2}{k_2.A} + \frac{1}{h_2.A}}$

Ideal Gases: $\boxed{P.v = R.T}$ $\boxed{P.V = m.R.T}$ $\boxed{C_{P_0} = C_{v_0} + R}$ $\boxed{du = C_{v_0}.dT}$ $\boxed{dh = C_{P_0}.dT}$ $\boxed{u = \int_0^T C_{v_o} dT = C_{v_o}.T}$

Specific Heats: $\boxed{C_{v_0} = \left(\frac{\partial u}{\partial T}\right)_{v=\text{const}}}$ $\boxed{C_{P_0} = \left(\frac{\partial h}{\partial T}\right)_{P=\text{const}}}$

Mixtures of Liquid & Vapour:

Specific Volume $\boxed{v_{mix} = v_f + x.v_{fg}}$ $\boxed{v_{fg} = v_g - v_f}$ $\boxed{V = m.v}$

Specific Internal Energy $\boxed{u_{mix} = u_f + x.u_{fg}}$ $\boxed{u_{fg} = u_g - u_f}$ $\boxed{U = m.u}$

Specific Enthalpy $h = u + P.v$ $\boxed{h_{mix} = h_f + x.h_{fg}}$ $\boxed{h_{fg} = h_g - h_f}$ $\boxed{H = m.h}$

Specific Entropy $\boxed{s_{mix} = s_f + x.s_{fg}}$ $\boxed{s_{fg} = s_g - s_f}$ $\boxed{S = m.s}$ $\boxed{dS = \left(\frac{\delta Q}{T}\right)_{\text{int. rev}}}$

$\boxed{x = (m_{vapour})/(m_{total})}$

Work: $\boxed{\delta W = \int P.dV \quad (rev)}$ $\boxed{{}_1W_2 = \int_1^2 \delta W = \int_1^2 P.dV}$ $\boxed{{}_1W_2 = P(V_2 - V_1)}$ {constant P}

$\boxed{{}_1W_2 = \dfrac{P_2.V_2 - P_1V_1}{1-n}}$ {polytropic: $P.V^n = \text{constant}$, $n \neq 1.0$ } $\boxed{{}_1\mathrm{W}_2 = \mathrm{P}_1\mathrm{V}_1 \cdot \ln\left(\dfrac{\mathrm{V}_2}{\mathrm{V}_1}\right)}$ {P.V=constant}

$\boxed{W_{\text{net cycle}} = \oint_{cycle} P.dV}$ $\boxed{P = \omega.T = 2.\pi.N.T}$

First Law: $\boxed{\oint \delta Q = \oint \delta W}$ (cycle) $\boxed{\delta Q = dE + \delta W}$ (process)

First Law - System: $\boxed{{}_1Q_2 = U_2 - U_1 + \dfrac{m(\overline{V}_2^2 - \overline{V}_1^2)}{2} + m.g.(Z_2 - Z_1) + {}_1W_2}$ $\boxed{\dot{Q} = \dfrac{dE}{dt} + \dot{W}}$

First Law - Control Volume:

$$\dot{Q}_{cv} + \sum \dot{m}_i (h_i + \overline{V_i^2}/2 + gZ_i) = \sum \dot{m}_e (h_e + \overline{V_e^2}/2 + gZ_e) + \dot{W}_{cv} + \frac{d}{dt}\left(U + m.\overline{V}^2/2 + m.g.Z\right)$$

SSSF: $$\dot{Q}_{cv} + \sum \dot{m}_i (h_i + \overline{V_i^2}/2 + gZ_i) = \sum \dot{m}_e (h_e + \overline{V_e^2}/2 + gZ_e) + \dot{W}_{cv}$$

$\boxed{\dot{m} = \rho.A.\overline{V}_{average}}$ **SSSF** $\boxed{q_{cv} + h_i + \overline{V_i^2}/2 + gZ_i = h_e + \overline{V_e^2}/2 + gZ_e + w_{cv}}$

Heat Engines: 1st Law: $\boxed{W_{net,out} = Q_{in} - Q_{out}}$ Efficiency: $\boxed{\eta_{th} = \dfrac{\dot{W}_{net,out}}{\dot{Q}_{in}} = \dfrac{W_{net,out}}{Q_{in}} = \dfrac{Q_{in} - Q_{out}}{Q_{in}} = 1 - \dfrac{Q_{out}}{Q_{in}}}$

I.C. Engine $\boxed{\dot{W} = \omega.T = 2.\pi.N.T \ \{N \text{ in rev.s}^{-1}\}}$ $\boxed{i.m.e.p = \dfrac{\oint_{cycle} P.dV}{V_d}}$ $\boxed{i.m.e.p = \dfrac{P_i}{\left(N/n_r\right)V_d}}$

Refrigeration: $\boxed{C.O.P._R = \dfrac{\dot{Q}_L}{\dot{W}_{in}}}$ **Heat Pump**: $\boxed{C.O.P._{HP} = \dfrac{\dot{Q}_H}{\dot{W}_{in}}}$

***Additional Data** which may or may not be required.* (Sections A and B)

0^oC	= 273.15 K
R_u	= 8314.5 J•kg^{-1}•K^{-1}
R_{air}	= 287.0 J•kg^{-1}•K^{-1}
$R_{nitrogen}$	= 296.8 J•kg^{-1}•K^{-1}
$R_{water\ vapour}$	= 461.9 J•kg^{-1}•K^{-1}
$R_{carbon\ dioxide\ (CO2)}$	= 189 J•kg^{-1}•K^{-1}
M_{air}	= 28.96 kg•kmol^{-1}
$M_{oxygen\ (O2)}$	= 32.0 kg•kmol^{-1}
$M_{nitrogen\ (N2)}$	= 28.0 kg•kmol^{-1}
$M_{carbon\ dioxide\ (CO2)}$	= 44.0 kg•kmol^{-1}
$M_{water\ vapour\ (H2O)}$	= 18.0 kg•kmol^{-1}

C_p for air	= 1005 J•kg^{-1}•K^{-1}
C_v for air	= 718 J•kg^{-1}•K^{-1}
C_p for liquid water	= 4180 J•kg^{-1}•K^{-1}
C_p for nitrogen	= 1039 J•kg^{-1}•K^{-1}
C_v for nitrogen	= 743 J•kg^{-1}•K^{-1}
C_p for carbon dioxide	= 846 J•kg^{-1}•K^{-1}
C_v for carbon dioxide	= 657 J•kg^{-1}•K^{-1}

Acceleration due to gravity g = 9.81 m.s^{-2}
Standard Atmospheric Press.
= 101.325 kPa (760 mm Hg)
Approx. composition of air:
3.76 kmol N_2 : 1 kmol O_2