University College Dublin
An Coláiste Ollscoile, Baile Átha Cliath

SEMESTER II 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.

Section A Multiple Choice - (please use MCQ Answer Sheet)

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

Question A1.

The thermal conductivity of an expanded polystyrene insulating board of 1 m^2 surface area is 0.03 W•m^{-1}•K^{-1}. If the surface temperatures of the board are 20ºC and –1ºC what thickness would be required to limit the heat flow to 15 W?

(A) 0.038 m

(B) 0.042 m

(C) 0.08 m

(D) 0.8 m

Question A2.

Which of the following statements about a material is true?

(A) A high U-value is a good insulator, and a high R-value is a good conductor.

(B) A high U-value is a good conductor, and a high R-value is a good insulator.

(C) A high U-value is a good insulator, and a high R-value is a good insulator.

(D) A high U-value is a good conductor, and a high R-value is a good conductor.

Question A3.

Considering heat losses from a building, which of the following is affected by changes in wind speed?

(A) Radiation heat losses from the roof

(B) Radiation heat losses from the walls

(C) Convection heat losses from windows

(D) Conduction heat losses from the floor to the ground

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 2.0 m^2. The thermal conductivity of each of the glass panes is 0.9 W•m^{-1}•K^{-1} and of the air cavities is 0.032 W•m^{-1}•K^{-1}. The interior and exterior convection coefficients are 8 W•m^{-2}•K^{-1} and 25 W•m^{-2}•K^{-1}. What is the U-value of the window?

(A) 0.46 W•m^{-2}•K^{-1}

(B) 1.08 W•m^{-2}•K^{-1}

(C) 1.32 W•m^{-2}•K^{-1}

(D) 2.16 W•m^{-2}•K^{-1}

Question A5.

A well insulated external wall has a U-value of 0.265 W•m^{-2}•K^{-1}. The ambient air temperature is –10^{o}C and the room air temperature is 20^{o}C? The interior convection coefficient is 8 W•m^{-2}•K^{-1} and exterior convection coefficient is 25 W•m^{-2}•K^{-1}. What is the temperature of the interior surface?

(A) –10.5^{o}C

(B) 12^{o}C

(C) 19^{o}C

(D) 22^{o}C

Question A6.

A window with a surface area of 2.0 m^2 receives solar radiation of 800 W•m^{-2}. If the absorptivity of the glazing is 0.1 and the reflectivity is 0.3, what will be the solar radiation entering the room?

(A) 160 W

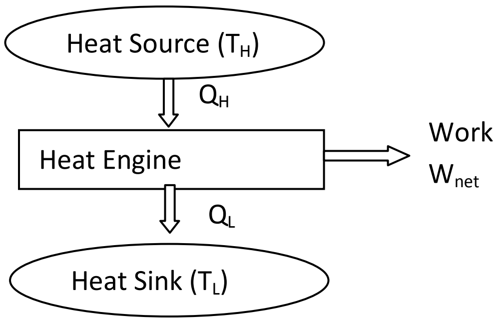
(B) 240 W

(C) 480 W

(D) 960 W

Question A7.

Which of the following quantities correspond to the heat engine shown below?



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

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

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

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

Question A8.

Air is trapped in a closed cylinder at an initial temperature of 426.85°C. The pressure is held constant whilst the volume is halved. The final temperature of the gas is;

(A) 213.4°C

(B) 853.7°C

(C) 76.85°C

(D) 426.85°C

Question A9.

A closed cylinder with an internal volume of 0.292 m^3 contains Carbon Dioxide (CO_2) gas at 18.9°C and at an absolute pressure of 189 kPa. Assuming ideal gas behaviour, the mass of CO_2 will be;

(A) 0.001 kg

(B) 0.0155 kg

(C) 1.0 kg

(D) 15.45 kg

Question A10.

The units of enthalpy H are

(A) J

(B) $J.kg^{-1}$

(C) $J.K^{-1}$

(D) $W.m^{-1}K^{-1}$

Question A11.

0.1944 kg of H_2O is stored in a rigid vessel at 1.0 MPa, 100°C. Is this?

(A) Superheated vapour ?

(B) Sub-cooled liquid ?

(C) Saturated vapour ?

(D) Saturated liquid ?

Question A12.

A rigid tank contains a saturated mixture of liquid and vapour water at 500 kPa. The dryness fraction *x* is 0.10. What is the specific volume of the mixture?

(A) 0.03749 $m^3\bullet kg^{-1}$

(B) 0.3541 $kg\bullet m^{-3}$

(C) 3.565 $m^3\bullet kg^{-1}$

(D) 0.03847 $m^3\bullet kg^{-1}$

Question A13.

The atmospheric pressure levels at the top floor and the bottom floor of a tall building were measured using a barometer at 98.03 and 99.20 kPa respectively. The density of air was determined as 1.193 $kg\bullet m^{-3}$. What is the height of the building?

(A) 981 m

(B) 119 m

(C) 100m

(D) 12.7 m

Question A14.

0.5 kg of water is contained in a rigid vessel at a temperature of 125°C and a pressure of 232.1 kPa. The specific enthalpy is 1050 $kJ\bullet kg^{-1}$. Which of the following could also be correct?

(A) v = 0.001065 $m^3\bullet kg^{-1}$

(B) v = 0.7706 $m^3\bullet kg^{-1}$

(C) x = 0.5

(D) x = 0.24

Question A15.

The specific enthalpy of 3.0 kg of water contained in a volume of 2.4 m^3 at 200 kPa is

(A) 504.7 $kJ\bullet kg^{-1}$

(B) 2493.3 $kJ\bullet kg^{-1}$

(C) 2706.7 $kJ\bullet kg^{-1}$

(D) 0.8 $m^3\bullet kg^{-1}$

Question A16.

Heat is added to a closed cylinder of constant volume containing 0.718 kg of air. What will be the heat input needed to increase the temperature of the air from 20°C to 100°C?

(A) 41.24 kJ

(B) 72.16 kJ

(C) 57.73 kJ

(D) 57.44 kJ

Question A17.

The quality of a liquid-vapour mixture in equilibrium is?

(A) The volume fraction in vapour form (%)

(B) The volume fraction in liquid form (%)

(C) The mass fraction in liquid form (%)

(D) The mass fraction in vapour form (%)

Question A18.

0.8 kg of liquid water at atmospheric pressure is heated electrically in an insulated kettle from 17.5 to 75°C over a time period of 80.1 seconds. What average electric power is required?

(A) 1.2 kW

(B) 1.8 kW

(C) 2.4 kW

(D) 3.0 kW

Question A19.

Which of the following is not a component of a vapour compression refrigeration machine?

(A) Compressor

(B) Evaporator

(C) Condenser

(D) Turbine

Question A20.

A domestic refrigerator with a coefficient of performance of 2.25 is being used to cool 30.2 kg of apples from 25.1°C down to 3°C. Estimate the total cost of electricity required for the refrigerator to cool the apples. The specific heat of apples is 3.65 kJ•kg^{-1}•K^{-1} and the cost of electricity is €0.2 per kWh.

(A) €0.0003

(B) €0.06

(C) €0.36

(D) €1.20

SECTION B (50 Marks) (please use an Answer Book)

Marks for Section B are based on any two Questions (25 marks each)

Question B1 (25 Marks)

A heater provides 400 W of heating in the space shown on the left hand side of **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.

Wall B of 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 8.6 W•m^{-2}•K^{-1}, and 35 W•m^{-2}•K^{-1}, respectively. The brick thermal conductivity is 0.85 W•m^{-1}•K^{-1}, the concrete block thermal conductivity 1.25 W•m^{-1}•K^{-1}, and the air cavity thermal effective conductivity is equivalent to 0.25 W•m^{-1}•K^{-1}.

Wall A is constructed by a single layer of brick (the same face brick as that in wall B) and the interior convection coefficients may be assumed to be all equal.

The surface areas of walls A and B are both equal at 20 m^2. Assume that the rooms are perfectly air tight. The external ambient temperature is 0°C.

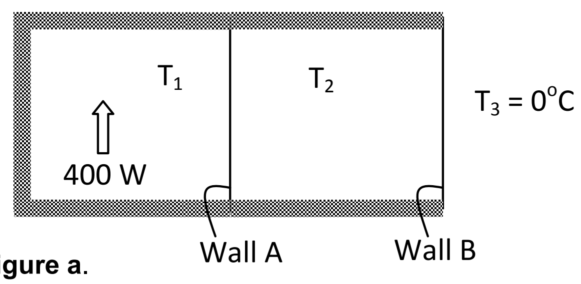


Figure a.

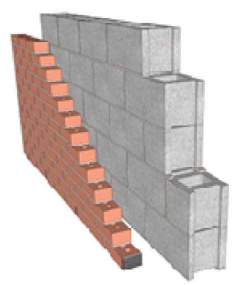


Figure b.

(a) What are the U-values of the two walls? (8 marks)

(b) What is the temperature T_2 of the air in the unheated room? (12 marks)

(c) What is the temperature T_1 of the air in the heated room? (5 marks)

Question B2 (25 Marks)

Explain briefly what is meant by the term “Ideal Gas” and give an appropriate equation of state, indicating clearly the units used for each property.

(5 marks)

Also for ideal gases, draw sketches illustrating;

(i) the shape of a line of constant pressure on plot of temperature as a function of specific volume (T-v) for an ideal gas, and

(4 marks)

(ii) the shape of a line of constant temperature on a plot of pressure against specific volume (P-v), also for an ideal gas.

(4 marks)

Specific volume data for H_2O vapour is available from Thermodynamic property data tables. Estimates may also be made by assuming ideal gas behaviour.

For H_2O at each of two states (1 & 2) given below, find

(a) the specific volume from the data tables, (4 marks)
(b) the specific volume calculated using the ideal gas equation and, (4 marks)
(c) the percentage error involved in assuming ideal gas behaviour. (4 marks)

State 1: 200 kPa, 120.23°C
State 2: 10 MPa, 500°C

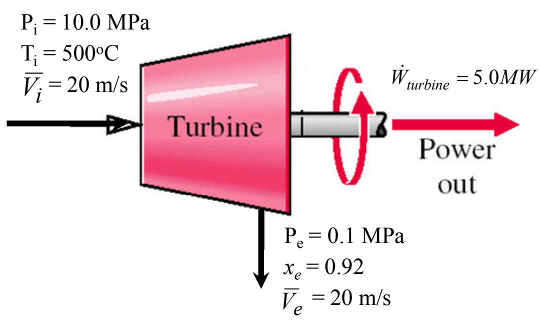
Question B3 (25 Marks)

List the conditions to be met for a thermodynamic process to be accurately described as a steady state, steady flow process. Write down a mathematical expression for the First Law of Thermodynamics as applied to such a process, explaining clearly the notation and sign conventions used.

(8 marks)

Consider steady state, steady flow of steam through a turbine used for electricity generation. You may assume that the process is adiabatic. The steam inlet and exit conditions are listed below;

	Inlet	Exit
Pressure (MPa)	10.0	0.1
Temperature (°C)	500	
Velocity (m/s)	20	20
Dryness Fraction		0.92



Making use of the Data Tables given at the end of this paper, determine;

(i) The outlet temperature of the steam (°C), (5 marks)

(ii) The change in specific enthalpy of the steam (kJ/kg), (5 marks)

(iii) The mass flow rate of steam required to yield a turbine mechanical power output of 5.0 MW (Neglecting potential energy changes and any mechanical friction losses in the turbine).

(7 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	0.00103	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: $\dot{Q}_{\text{conduction}} = -k.A.\dfrac{dT}{dX}$ Convection: $\dot{Q}_{conv} = h.A.(T_{surface} - T_{fluid})$

Radiation: $\dot{Q}_{\text{radiation-net}} = \varepsilon_s.\sigma.A_s.\left(T_{\text{s}}^{4} - T_{\text{surr}}^{4}\right)$ Stefan-Boltzmann Const. σ = 5.67X10^{-8} W.m^{-2}K^{-4}

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

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

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

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

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

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

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

Mixtures of Liquid & Vapour:

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

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

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

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

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

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: $P.V^n = \text{constant}$, $n \neq 1.0$ } $\boxed{{}_1W_2 = P_1V_1 \cdot \ln\left(\dfrac{V_2}{V_1}\right)}$ {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:

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

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

$\boxed{\dot{m} = \rho.A.\overline{V}_{average}}$ **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 $J \cdot kg^{-1} \cdot K^{-1}$
R_{air}	= 287.0 $J \cdot kg^{-1} \cdot K^{-1}$
$R_{nitrogen}$	= 296.8 $J \cdot kg^{-1} \cdot K^{-1}$
$R_{water\ vapour}$	= 461.9 $J \cdot kg^{-1} \cdot K^{-1}$
$R_{carbon\ dioxide\ (CO2)}$	= 189 $J \cdot kg^{-1} \cdot K^{-1}$
M_{air}	= 28.96 $kg \cdot kmol^{-1}$
$M_{oxygen\ (O2)}$	= 32.0 $kg \cdot kmol^{-1}$
$M_{nitrogen\ (N2)}$	= 28.0 $kg \cdot kmol^{-1}$
$M_{carbon\ dioxide\ (CO2)}$	= 44.0 $kg \cdot kmol^{-1}$
$M_{water\ vapour\ (H2O)}$	= 18.0 $kg \cdot kmol^{-1}$

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

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