UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE & ENGINEERING

DEPARTMENT OF PHYSICS

SUPPLEMENTARY EXAMINATION 2012/2013

TITLE OF PAPER	:	THERMODYNAMICS
COURSE NUMBER	:	P242/EE202
TIME ALLOWED	:	THREE HOURS
INSTRUCTIONS	:	ANSWER ANY FOUR OUT OF FIVE QUESTIONS
		EACH QUESTION CARRIES 25 MARKS
		MARKS FOR DIFFERENT SECTIONS ARE SHOWN IN THE RIGHT-HAND MARGIN.

THIS PAPER HAS 6 PAGES, INCLUDING THIS PAGE.

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QUESTION 1

(a) Explain the meaning of the following processes:

(i) an adiabatic process (3 marks)

(ii) a reversible process (3 marks)

(iii) an isothermal process (2 marks)

(b) Derive the pressure-volume expression given below to show that, for a given mass of an ideal gas in an insulated container,

$$p = KV^{-\gamma}$$

where K is a constant and γ is the ratio of the molar heat capacities at constant pressure and at constant volume.

(10 marks)

(c) Two moles of an ideal gas expand adiabatically in such a way that the volume doubles. The initial pressure and temperature of the gas are 500 Pa and 27 ^{o}C respectively. Calculate

(i) the final temperature of the gas and (4 marks)

(ii) the work done for a reversible expansion. (3 marks)

[The molar heat capacities of the gas are $C_p = 33.44$ $Jmol^{-1}K^{-1}$ and $C_v = 25.12$ $Jmol^{-1}K^{-1}$]

QUESTION 2

(a) With the aid of Fig. 1, derive an expression (at steady state) for the rate at which heat would be transferred through the two slabs made of different materials, slab 1 and slab 2, which have the same cross-sectional area, A. Assume that temperature $T_1 > T_2$.

(12 marks)

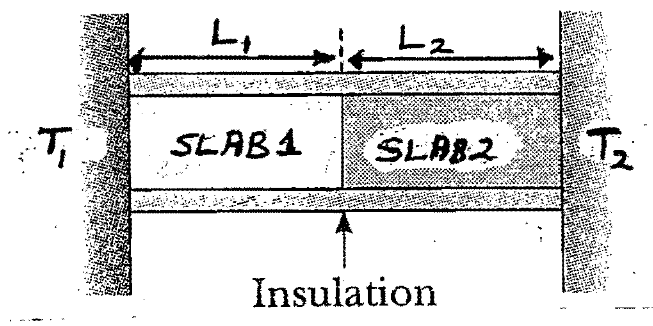

Fig. 1

(b) (i) Find the rate of heat flow through a plaster ceiling having an area of 15 m^2 and a thickness of 15 mm. Consider the direction of heat flow to be perpendicular to this area. The lower and upper surfaces of the ceiling are at the surrounding air temperature of 288 K and 278 K, respectively. (3 marks)

(ii) Find the rate of heat flow when the ceiling is in contact with a 45 mm thick layer of insulating fibre-glass. (5 marks)

[k for plaster = 0.60 $Wm^{-1} K^{-1}$; k for fibre-glass = 0.04 $Wm^{-1} K^{-1}$].

(c) Consider a house without insulation in the ceiling. Analysis shows that the house loses 100 Js^{-1} of heat per square metre of the ceiling, when the temperature inside the house is 333 K and the temperature outside is 293 K. Suppose that glass wool insulation with a thermal conductivity of 0.042 $Wm^{-1}K^{-1}$ is then added to the ceiling. How thick should the insulation be in order to cut the heat loss by 60%. (5 marks)

QUESTION 3

(a) Fig. 2 is a schematic flow diagram of a four-stroke internal combustion engine. Show, by mathematical analysis, that the thermal efficiency, η of the engine is given by:

$$\eta = 1 - \frac{1}{r^{\gamma-1}}$$

where r is called the compression ratio and γ is the ratio of molar heat capacities at constant pressure and at constant volume. Define all symbols used.

(15 marks)

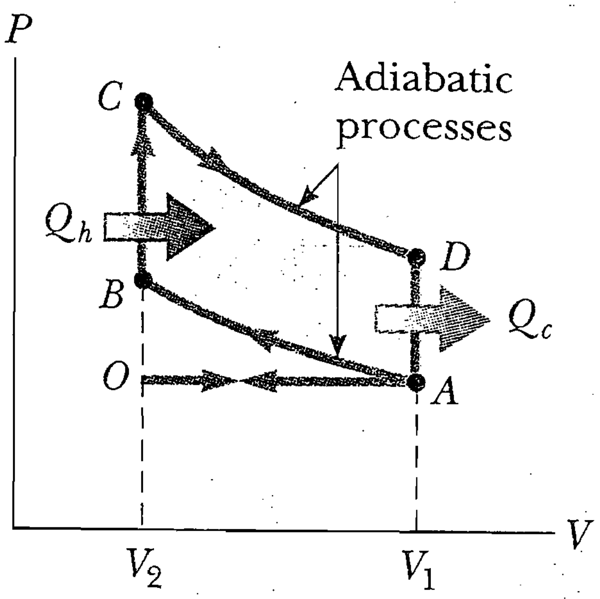

Fig. 2

(b) Consider three heat engines A, B and C. All the engines claim to produce 1000 J of useful output, and all operate between two reservoirs at temperatures 200°C and 0°C. The designers of the heat engines make the following claims:

Engine A requires a 1500 J of heat input;
Engine B requires a 2500 J of heat input;
and Engine C requires a 3000 J of heat input.

Based on your knowledge of the Physics of heat engines, calculate the efficiency claimed by each engine design, and select the most efficient and practical engine. (10 marks)

QUESTION 4

(a) With the aid of a schematic diagram, explain how a solar water heating panel works. Comment on the characteristics of the materials used to construct the panel, as well as their thermal conductivity and absorptivity (where applicable). (12 marks)

(b) Consider an ideal gas in an insulated cylinder. The gas is compressed slowly, and its temperature is observed to rise. Explain briefly why this happens. (3 marks)

(c) Imagine a hot-water pipe 5 m in length and 20 cm in (outer) diameter. The surface temperature of the pipe is 60 °C in a room at 25 °C. If the pipe has an emissivity of 0.60, at what rate would heat be lost by the pipe through radiation? (4 marks)

[Stefan-Boltzmann constant $= 5.67 \times 10^{-8}$ $Wm^{-2}K^{-4}$]

(d) (i) A real engine takes in 210 kJ of heat at 527 °C and expels 143 kJ at 277 °C. What would be the coefficient of performance of this (real) engine when it is operated in reverse? (3 marks)

(ii) Suppose that a Carnot engine is used as a refrigerator between the same two temperatures given in (d)(i). What would be the performance coefficient of the engine? (3 marks)

QUESTION 5

(a) What is an ideal gas? (2 marks)

(b) Show that the pressure of an ideal gas, p, is related to the mean square speed of the gas molecules, $\overline{v^2}$, and the density of the gas, ρ as follows:

$$p = \frac{1}{3}\rho\overline{v^2}$$

(12 marks)

(c) A monatomic ideal gas containing 2×10^3 moles is taken through the following cyclic process: (1) An isobaric expansion from 2 m^3 to 4.6 m^3 at a pressure of 4×10^6 Pa; (2) An isochoric decrease in pressure from 4×10^6 Pa to 1×10^6 Pa; (3) An adiabatic compression back to the initial state.

(i) Show the p-V diagram for this cyclic process; (2 marks)

(ii) Calculate the work done during each step of the cycle and the net work done during the cycle. (9 marks)

[Universal gas constant = 8.31 J $mol^{-1}K^{-1}$].