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UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF PHYSICS

MAIN EXAMINATION 2005

TITLE OF PAPER	:	THERMODYNAMICS
COURSE NUMBER	:	P242
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 8 PAGES, INCLUDING THIS PAGE.

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INFORMATION

For a monatomic gas: $\gamma = \frac{5}{3}$ and $C_V = \dfrac{3}{2}R$

Universal gas constant	$= 8.31\ J\ mol^{-1}K^{-1}$
Specific heat of water	$= 4200\ J\ kg^{-1}K^{-1}$
Density of water	$= 10^3 kg.m^{-3}$
Latent heat of fusion of ice	$= 3.34 \times 10^5\ J\ kg^{-1}$
Avogadro's number	$= 6.02 \times 10^{23}$ molecules.mol^{-1}

QUESTION 1

(a) What is meant by the following terms:

(i) radiant emittance (2 marks)
(ii) isotropic radiation (2 marks)
(iii) absorptivity (2 marks)
(iv) black body (2 marks)

(b) Fig. 1.1 represents the cross-section of a hot water pipe of external radius "a" and internal radius "b". The length of the pipe is "c". The temperature of the hot water is T_1 and that of the surroundings is T_2, where $T_2 < T_1$.

Show that the rate at which heat flows through the walls of the pipe is given by the following equation:

$$\frac{dQ}{dt} = \frac{2\pi k(T_1 - T_2)}{\left[\log_e(a/b)\right]/c}$$

(9 marks)

(c) A solid bar, 4.0 metres long and 0.1 metre in diameter, is made by joining a piece of steel and a piece of copper together end-to-end, as shown in Fig. 1.2. When the furnace temperature reaches 600°C, the other end of the bar is immersed in a reservoir of ice-water at 0°C. The bar is insulated except for the ends which are exposed to the furnace and ice-water.

Find the temperature at the interface of the copper and steel sections.
[$k_{steel} = 50.2\ Wm^{-1}(C^{\circ})^{-1}$; $k_{copper} = 385\ Wm^{-1}(C^{\circ})^{-1}$] (8 marks)

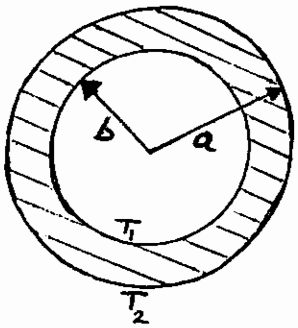

Fig. 1.1

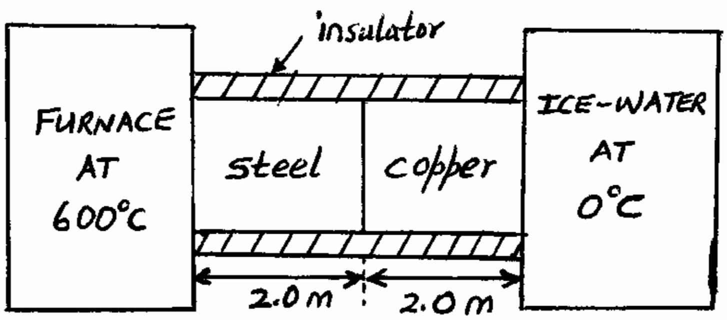

Fig. 1.2

QUESTION 2

(a) What is meant by the following processes?

(i) an isobaric process; (2 marks)

(ii) a quasi-static process. (2 marks)

(b) 500 moles of a ideal, monatomic gas is taken through the following thermodynamic cycle: (1) An adiabatic compression from 1 x 10^6 Pa to 4 x 10^6 Pa; (2) An isobaric expansion from $2 m^3$ to 6 m^3 at a pressure of 4 x 10^6 Pa; (3) An isochoric decrease in pressure back to the initial state.

(i) Show the p-V diagram for this cyclic process; (4 marks)

(ii) Calculate the work done during each step and the net work for the cycle. (10 marks)

(iii) Calculate the heat exchanged during each step of the cycle and the net heat for the cycle. (7 marks)

QUESTION 3

(a) Explain, briefly, the meaning of entropy. (1 mark)

(b) The p-V diagram shown in Fig. 3.1 represents a Carnot cycle. With reference to this cycle,

(i) complete Table 3.1, indicating whether W, ΔT, Q and ΔS are positive, negative or zero (*Refer also to page 8*);

(8 marks)

(ii) use the results obtained in (b)(i) to draw a T-S diagram. Label it. (3 marks)

(c) A 100 kg piece of iron at 750°C is cooled by submerging it in cold water. The original temperature of water, 0.5 m^3 in volume, is 10°C. Assuming that there are no heat losses during the thermodynamic process and that no steam emerges from the water, calculate the entropy change of

(i) the iron (10 marks)

(ii) the water (3 marks)

[The specific heat of iron is 470 J $kg^{-1}K^{-1}$]

Fig. 3.1

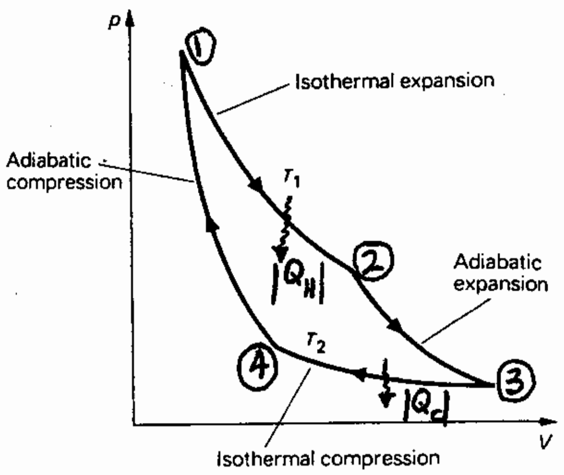

Table 3.1. Summary of the entropy changes associated with each thermodynamic process

Step or Leg	Thermodynamic Process	W	ΔT	Q	ΔS
1 → 2	Isothermal expansion				
2 → 3	Adiabatic expansion				
3 → 4	Isothermal compression				
4 → 1	Adiabatic compression				

QUESTION 4

(a) Discuss the principle of operation of an internal combustion engine with the aid of the Otto cycle illustrated in Fig. 4.1. (7 marks)

(b) Derive an expression for the thermal efficiency of a reversible heat engine operating on the Otto cycle in terms of the temperatures at points 1, 2, 3, and 4 (see Fig. 4.1). Consider the working medium to be one mole of an ideal gas of constant heat capacity.

(9 marks)

(c) Imagine an ice-cube maker in a room at 30°C. The maker is designed to freeze ice cubes at the rate of 0.01 kg per second, starting with water at the freezing point. If the system behaves like an ideal Carnot refrigerator,

(i) At what rate would the heat be given off to the room? (5 marks)

(ii) What would be the power rating of the refrigerator's electric motor? (2 marks)

(iii) What would be the coefficient of performance of the refrigerator? (2 marks)

[Note that W, Q_c, and Q_H may also be expressed in J/s].

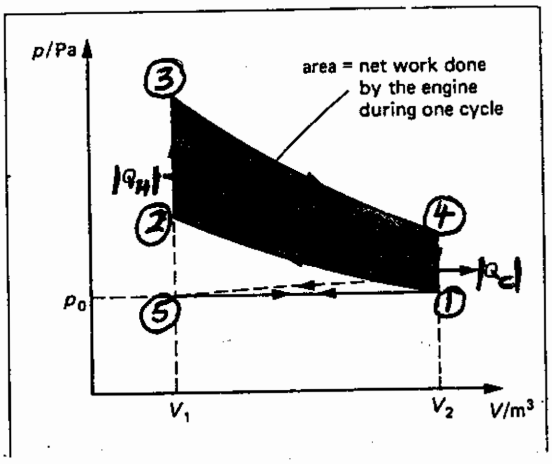

Fig. 4.1

QUESTION 5

(a) Write down the van der Waals' equation of state. (2 marks)

(b) Discuss, briefly, the meaning of van der Waals' equation with reference to the ideal gas law. (7 marks)

(c) The constant 'b' in van der Waals' equation, for a nitrogen gas, is 3.9×10^{-5} m^3/mol. Estimate the diameter of a nitrogen molecule. (4 marks)

(d) Imagine a CO_2 gas in a rigid vessel. The temperature of the gas is 80°C and its molal specific volume is 0.18 m^3/mol. The van der Waals' constants 'a' and 'b' for CO_2 are 3.6×10^{-1} Nm^4/mol^2 and 4.3×10^{-5} m^3/mol, respectively.

Estimate the pressure exerted by the gas onto the walls of the vessel using

(i) the van der Waals' equation (4 marks)

(ii) the ideal gas equation (3 marks)

(e) Consider air molecules at a temperature and pressure equal to 273 K and 10^5 Pa, respectively. The concentration of the molecules is estimated to be 3×10^{25} per cubic metre and they travel at an average speed of about 10^7 ms^{-1}. The effective diameter of each molecule is 2 Å. Find

(i) the magnitude of the mean free path of a molecule. (3 marks)

(ii) the collision frequency of the air molecules. (2 marks)

CANDIDATE'S EXAMINATION NUMBER:..

USE THE TABLE BELOW TO ANSWER QUESTION 3(b)(i)

Table 3.1. Summary of the entropy changes associated with each thermodynamic process

Step or Leg	**Thermodynamic Process**	**W**	**ΔT**	**Q**	**ΔS**
1 → 2	Isothermal expansion				
2 → 3	Adiabatic expansion				
3 → 4	Isothermal compression				
4 → 1	Adiabatic compression				

The completed table should be handed in together with your answer book.