UNIVERSITY OF SWAZILAND

57

FACULTY OF SCIENCE

DEPARTMENT OF PHYSICS

MAIN EXAMINATION	:	**2010/2011**
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.

DO NOT OPEN THE PAPER UNTIL PERMISSION HAS BEEN GIVEN BY THE INVIGILATOR.

INFORMATION

58

Universal gas constant, R	$= 8.314\ J\ mol^{-1}K^{-1}$
Specific heat of water, c_w	$= 4186\ J\ kg^{-1}K^{-1}$
Density of water, ρ	$= 10^3\ kg.m^{-3}$
Latent heat of fusion for ice, L_f	$= 3.33 \times 10^5\ Jkg^{-1}$
Specific heat of iron, c_i	$= 448\ J\ kg^{-1}K^{-1}$
Avogadro's number, N_A	$= 6.02 \times 10^{23}$ molecules.mol^{-1}
Boltzmann constant, k_B	$= 1.38 \times 10^{-23}\ JK^{-1}$
Stefan-Boltzmann constant, σ	$= 5.67 \times 10^{-8}\ Wm^{-2}K^{-4}$
1 atmosphere	$= 1.013 \times 10^5 Nm^{-2}$
Thermal conductivity of gold, k_{gold}	$= 314\ Wm^{-1}K^{-1}$
Thermal conductivity of silver, k_{silver}	$= 427\ Wm^{-1}K^{-1}$

For a monatomic gas, $\gamma = 5/3$; $C_v = 3R/2$, where $R = 8.314\ Jmol^{-1}\ K^{-1}$.

QUESTION 1

(a) What is meant by the following terms:

(i) Isochoric process (2 marks)

(ii) reversible process (2 marks)

(iii) adiabatic process (2 marks)

(b) One mole of an ideal, monatomic gas is initially at a pressure of 1.0×10^5 Pa and a temperature of 300 K. Suppose that the gas expands to twice the initial volume, by each of the following processes:

(i) isobaric, (5 marks)

(ii) isothermal, and (3 marks)

(iii) adiabatic (8 marks)

[**For each of the three** processes, determine the work done and the heat absorbed (or rejected) by the gas].

(iv) Sketch a p-V diagram which represents the three processes mentioned in (b)(i), (ii) and (iii) and label the diagram. (3 marks)

QUESTION 2

(a) An 80.0 g piece of metal at 100°C is dropped into an insulated container with 400 g of water at 18°C.

(i) If the final temperature of the system is 23.1°C, what is the specific heat of the metal? (3 marks)

(ii) Find the change in entropy of the water. (3 marks)

(iii) What is the change in entropy of the metal. (3 marks)

(iv) Calculate the change in entropy of the universe. (2 marks)

(b) Fig. 2.1 shows the p-V diagram of a Carnot cycle. Use the diagram to complete Table 2.1 for each step by indicating whether W, ΔT, Q and ΔS are positive, negative or zero. *Show how you arrived at each solution with the aid of appropriate equations based largely on thermodynamic processes.* (14 marks)

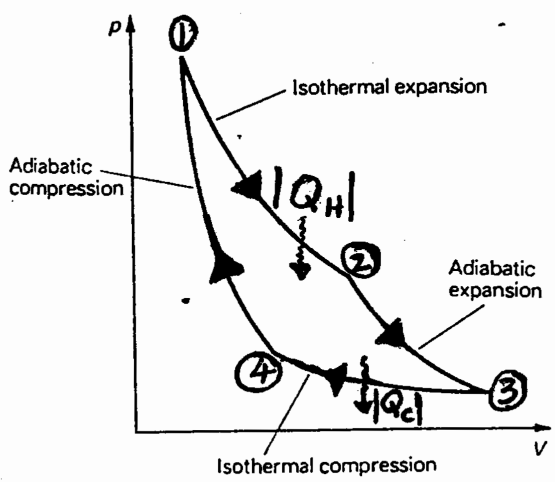

Figure 2.1

Table 2.1

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*				

<u>Note</u>: You are requested to complete the table provided on page 8 of this paper and submit it together with your answer book(s).

QUESTION 3

61

(a) Define the terms listed below:

(i) Radiant emittance (2 marks)

(ii) Isotropic radiation (2 marks)

(iii) Absorptivity (2 marks)

(b) (i) Derive an expression for the radial rate of heat flow through a vessel in the form of a spherical shell, as shown in Fig. 3.1. The inner and outer radii of the shell are 'a' and 'b', respectively. Assume that the temperatures of the inner and outer spheres are respectively T_a and T_b, where $T_a > T_b$. (7 marks)

(ii) Explain what the expression for the rate of heat flow derived in (b) means in practice, that is, intepret the expression. (4 marks)

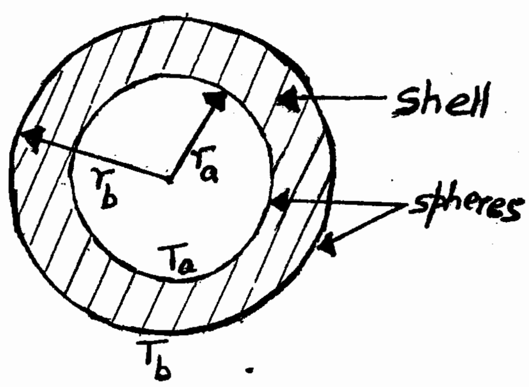

Figure 3.1

(c) Consider the sun to behave like a spherical black body of radius R. The temperature at the surface of the sun is T_0. Determine an expression for the power flux, that is, the energy radiated by the sun per unit time onto another spherical surface distance d away from the centre of the sun. (4 marks)

(d) The approximate surface temperature of the sun is 6000 K. Taking the sun to be a sphere with radius 7×10^8 m and assuming an emissivity of 0.93. Calculate the energy radiated by the sun per second and mention any assumptions made in the calculation. (4 marks)

QUESTION 4

(a) The thermodynamic cycle of the modern internal combustion engine can be reasonably approximated as consisting of two adiabatic and two isochoric processes as shown in Fig. 4.1. Processes *ab* and *cd* are adiabatic. The volume compression ratio of the engine is V_a/V_b.

Using the basic definition of efficiency, analyse this cycle and show that the efficiency of the engine can be expressed as

$$Efficiency = 1 - \left(\frac{V_b}{V_a}\right)^{\gamma - 1}$$ (10 marks)

(b) Imagine that the working medium of the internal combustion engine is one mole of an ideal gas for which $C_p = 29.20$ Jmol^{-1} K^{-1} and $C_v = 20.88$ Jmol^{-1} K^{-1}. The pressure at points 'a' and 'b' are 1.0×10^5 Pa and 1.5×10^6 Pa, respectively. The temperature at point 'a' is 330 K whilst at point 'c' it is as high as 2450 K.

Calculate the temperature at points 'b' and 'd'. (8 marks)

(c) A Carnot engine takes 6300 J of heat each cycle from the high-temperature reservoir at 500 K and gives out 3780 J to the low-temperature reservoir.

(i) Calculate the temperature of the low-temperature reservoir. (3 marks)

(ii) Calculate the efficiency of the Carnot engine. (2 marks)

(iii) How much work is done during each cycle? (2 marks)

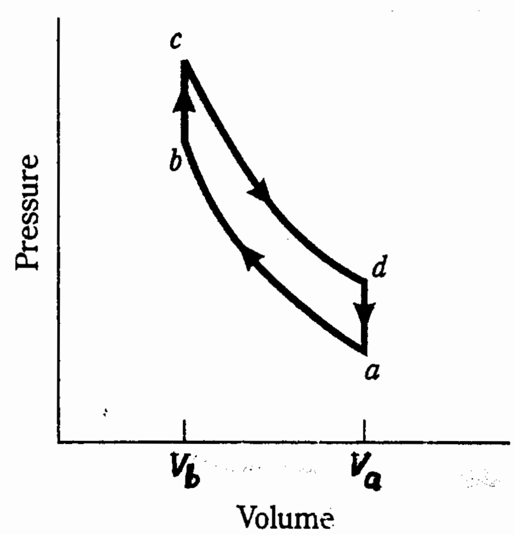

Figure 4.1

QUESTION 5 63

(a) Derive the equation below to show that the pressure exerted by an ideal gas in a container depends on the mass, m of the molecules, the number of molecules, N the volume, V occupied by the molecules and their root-mean-square speed, v_{rms}

$$p = \frac{Nm(v_{rms})^2}{3V}$$ (14 marks)

(b) Calculate the mean free path and collision frequency for nitrogen molecules at 20°C and 1 atm. The number of molecules per unit volume is 2.5×10^{25} and their average speed at 20°C is 511 ms^{-1}. Assume a molecular diameter of 2×10^{-10} m. (6 marks)

(c) A vessel contains H_2 at a temperature of 137°C. The molal specific volume is 0.07 m^3mol^{-1} whilst the van der Waals' constants for the gas are 2.5×10^{-2} Nm^4mol^{-2} and 2.7×10^{-5} m^3mol^{-1}, respectively. Compute the pressure exerted by the gas using the following equations:

(i) the ideal gas equation, (2 marks)

(ii) the van der Waals equation. (3 marks)

64

CANDIDATE'S EXAMINATION NUMBER:...

USE THE TABLE BELOW TO ANSWER QUESTION 2(b)(i)

Table 2.1. 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(s).