UNIVERSITY OF SWAZILAND

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FACULTY OF SCIENCE

DEPARTMENT OF PHYSICS

SUPPLEMENTARY EXAMINATION 2012

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 7 PAGES, INCLUDING THIS PAGE.

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INFORMATION

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

For a diatomic gas: $\gamma = \frac{7}{5}$

Universal gas constant, R = 8.31 $Jmol^{-1}K^{-1}$

Specific heat of water = 4190 J $kg^{-1}K^{-1}$

Latent heat of vaporisation of water 2.256 x 10^6 J kg^{-1}

Stefan-Boltzmann constant = 5.67 x 10^{-8} $Wm^{-2}K^{-4}$

QUESTION 1

(a) Consider an ideal gas which is caused to move through a p-V cycle ABCA. A to B is an isochoric process, B to C is an isothermal expansion, and C to A is an isobaric process.

Explain, for each leg or step of the cycle, whether each of the following variables is negative, zero or positive: *temperature change, heat, work done, internal energy change, entropy change.* Consider the gas to be the system. (15 marks)

(b) A heat reservoir at 373 K is used to evaporate 0.2 kg of water originally at 313 K.

(i) How much energy must flow from the reservoir to do this? (6 marks)

(ii) By how much would the entropy of the water change? (4 marks)

QUESTION 2

(a) A rectangular container of dimensions 'a', 'b' and 'c' consists of N particles of an ideal gas. The mass of each particle is m and the density of the gas is ρ. The pressure exerted by the gas onto the area 'ab' is

$$p = \frac{m\left[\left(v_x^2\right)_1 + \left(v_x^2\right)_2 + \ldots\ldots\ldots\ldots\ldots + \left(v_x^2\right)_N\right]}{abc}$$

Show that the root-mean-square speed of the particles is

$$v_{rms} = \sqrt{\overline{v^2}} = \sqrt{\frac{3p}{\rho}}$$ (14 marks)

(b) Measurements by spacecraft have shown that near the surface of the planet Venus the atmospheric pressure is 90 times that on Earth surface, and the temperature is 500°C, compared to typical temperatures on Earth of 10°C. What is the ratio of the speed of an average carbon dioxide molecule on Venus to that of an average carbon dioxide molecule on earth?

Hint: $\frac{1}{2}mv^2 = \frac{3}{2}k_B T$, where the symbols have their usual meanings. (4 marks)

(c) Consider air molecules at 0°C and 1 atmosphere pressure. The molecules collide with each other and the radius of an equivalent molecule is 2 Å. The mean free path of the molecules depends on their size as well as their concentration. For the conditions stated, the average speed of air molecules is about 1×10^7 m/s and there are approximately 3×10^{25} molecules/m^3.

(i) Calculate the mean free path; (4 marks)

(ii) Calculate the collision frequency. (3 marks)

QUESTION 3

(a) For Carnot cycle shown in Fig. 2.1, the ratio V_3/V_1 is 15. Steps 1-2 and 3-4 represent isothermal processes whilst steps 2-3 and 4-1 stand for adiabatic processes. The temperature limits of the cycle are 260°C (step 1-2) and 21°C (step 3-4).

Determine the volume ratios of the isothermal and adiabatic processes, that is, V_4/V_1.and V_3/V_4. Assume that the working medium is a diatomic gas. (10 marks)

(b) Imagine a Carnot engine which takes 5000 J of heat during each cycle from the high-temperature reservoir at 300 K and gives out 3500 J to the low-temperature reservoir.

(i) Calculate the temperature of the low-temperature reservoir. (5 marks)

(ii) What is the thermal efficiency of the cycle? (3 marks)

(c) Consider the temperatures of the hot and cold reservoirs of a real engine to be 600 K and 400 K, respectively.

(i) If the real engine is replaced by a Carnot engine working between the same two temperatures, with an input Q_H of 20 kJ, how much heat would be rejected and how much work would the engine do? (5 marks)

(ii) What would be the co-efficient of performance of the Carnot engine if it were used as a refrigerator between the same two temperatures? (2 marks)

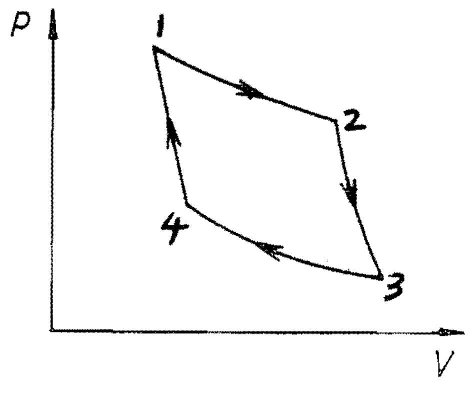

Fig. 2.1

QUESTION 4

(a) Use the ideal gas law and the relationship pV^{γ} = constant to show that for an adiabatic process $TV^{\gamma-1}$ = constant and that $T^{\gamma}p^{1-\gamma}$= constant, where the symbols have their usual meanings.

(7 marks)

(b) Two thousand moles of a monatomic ideal gas is taken through the following cyclic process (1) An isobaric expansion from 2 m^3 to 4.6m^3 at a pressure of 4×10^6 Nm^{-2}; (2) An isochoric decrease in pressure from 4×10^6 Nm^{-2} to 1×10^6 Nm^{-2}; (3) An adiabatic compression back to the initial state.

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

(ii) Find the work done during each step of the cycle and the net work done for the cycle.

(9 marks)

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

QUESTION 5

(a) Consider a water pipe of internal radius x, external radius y and length z. The inside temperature is T_1 while the surroundings are at a temperature of T_2 (where $T_1 > T_2$). Show that heat is conducted through the walls of the pipe at the rate

$$\frac{dQ}{dt} = \frac{2\pi k(T_1 - T_2)z}{\ln\left(\frac{y}{x}\right)}$$

[k is the thermal conductivity of the pipe].

(12 marks)

(b) The surface temperature of a spherical mass of molten metal (the source), 3.0 m in radius, is 1073 K. It is surrounded by a spherical shell with an inside radius of 3.0 m and an outside radius of 6.0 m. The thermal conductivity of the shell is 42 $Wm^{-1}K^{-1}$. If the outside of this spherical shell is exposed to room temperature (298K), what is the rate at which heat flows through the shell?

(7 marks)

(c) Assume that the total surface area of the human body is 2.0 m^2 and that the temperature at the surface of the body is 40°C. How much heat would be lost from the body in 10 min if it is exposed to an environment at 15°C? Assume that the emissivity of the skin is 0.80?

(6 marks)