UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF PHYSICS

SUPPLEMENTARY EXAMINATION	:	**JULY 2009**
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 $C_V = \frac{3R}{2}$

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

Universal gas constant, R = 8.31 $J.mol^{-1}K^{-1}$

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

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

QUESTION 1

(a) The overall volume expansion ratio of a Carnot cycle shown in Fig. 1.1 is $V_C/V_A = 15$. The temperature limits of the cycle are 21°C (step C-D) and 260°C (step A-B). Determine the volume ratios of the isothermal and adiabatic processes, that is, V_D/V_A and V_C/V_D.

[$\gamma = C_p/C_v = 1.4$] (10 marks)

(b) A real engine takes in 120 kJ of heat at 500 K and expels 50% of the heat at 200 K. If the engine is replaced by a Carnot engine working between the same two temperatures

(i) How much heat would be expelled from the Carnot engine (3 marks)

(ii) How much work would the Carnot engine do? (2 marks)

(iii) Assume that the Carnot engine were used as a refrigerator betweej the same two temperatures. What would be its performance coefficient? (5 marks)

(c) A Carnot engine takes in 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. (3 marks)

(ii) What is the thermal efficiency of the cycle? (2 marks)

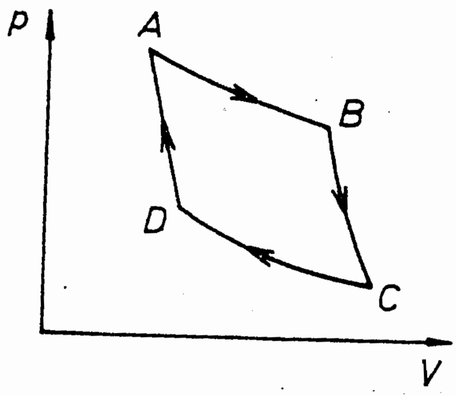

Fig. 1.1

QUESTION 2

(a) Calculate the magnitude of the mean free path and the collision frequency of air molecules at 0°C and 1 atmosphere pressure. Note that the effective molecular radius is 2 Å. For the conditions stated, the average speed of air molecules is about 1×10^7 m/s and there are about 3×10^{25} molecules/m^3. (6 marks)

(b) The atmospheric pressure on the Earth's surface is found to be about 90 times less than the pressure near the surface of the planet Venus. On the other hand, the temperature of the planet Venus is 500°C in comparison with typical temperatures on Earth of 10°C.

Determine the ratio of the speed of an average CO_2 molecule on Earth to that of an average CO_2 molecule on Venus. (3 marks)

(c) With reference to the kinetic theory of an ideal gas, show that the root-mean-square speed, V_{rms} of the gas molecules is given by $(3p/\rho)^{½}$, where p represents the gas pressure and ρ is the density of the gas. (16 marks)

QUESTION 3

(a) Imagine an ideal gas that obeys a p-V cycle XYZX. X to Y is an isochoric process, Y to Z is an isothermal expansion, and Z to X is an isobaric process.

(i) For each step of the cycle XYZX, determine whether the following quantities are positive, negative or zero: change in temperature, heat absorbed, work done by the gas, change in internal energy and change in entropy. Take the gas to be the system. (12 marks)

(ii) For the whole cycle — X to Y to Z to X — answer the same questions. (3 marks)

(b) Consider 200 g of water at 40°C. A heat reservoir at 300°C is used to evaporate the water completely.

(i) How much energy should the reservoir supply in order to evaporate the water completely? (6 marks)

(ii) Calculate the entropy change of the water (4 marks)

QUESTION 4

(a) Consider a spherical object, 2.5 m in radius. The surface temperature of the object is 800°C. The object is surrounded by a spherical shell with an inner radius of 2.5 m and an outer radius of 5.0 m. The thermal conductivity of the shell is 35 W/m.K The outer surface of the shell is exposed to room temperature (25°C).

Calculate the rate of heat flow through the spherical shell. (6 marks)

(b) Consider a water pipe of internal radius "a", external radius "b" and length L. 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

$$\frac{dQ}{dt} = \frac{2\pi k(T_1 - T_2)L}{\ln\left(\frac{b}{a}\right)}$$

[k is the thermal conductivity of the pipe].

(9 marks)

(c) The surface temperature of a sphere of radius R is T_0. The sphere radiates like a black body.

(i) Determine the power radiated by the sphere. (3 marks)

(ii) Determine the radiant emittance at a distance d >> R from the centre of the sphere. (4 marks)

(iii) Determine the power incident on a small sphere of radius r placed a distance d away from the centre of the sphere of radius R. (3 marks)

QUESTION 5

(a) Two moles of a monatomic ideal gas are initially at 600 K and 3×10^5 Nm^{-2} pressure. Calculate the work done, the heat transferred, and the change in internal energy of the gas when

(i) the gas expands along an isothermal path to twice its original volume;

(4 marks)

(ii) the gas expands along an adiabatic path to twice its original volume.

(9 marks)

State whether each of the values calculated in (i) and (ii) is positive or negative.

(b) The change in internal energy of an ideal gas undergoing an adiabatic process is given by the following equation:

$$dU = nC_v dT$$

where the symbols have the usual meaning.

Show that

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}}$$

(12 marks)