UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF PHYSICS

MAIN EXAMINATION 2006/2007

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

Universal gas constant	= 8.31 J $mol^{-1}K^{-1}$
Specific heat of water	= 4190 J $kg^{-1}K^{-1}$
Density of water	= 10^3 kgm^{-3}
Specific heat of iron	= 470 J $kg^{-1}K^{-1}$
Avogadro's number	= 6.02 x 10^{23} mol^{-1}
Boltzmann constant	= 1.38 x 10^{-23} JK^{-1}
Stefan-Boltzmann constant	= 5.67 x 10^{-8} $Wm^{-2}K^{-4}$
1 atmosphere	= 1.013 x 10^5 Nm^{-2}

QUESTION 1

(a) Draw a schematic diagram which represents an internal combustion engine (or a gasoline engine). Explain, clearly, how the engine works, with the aid of the Otto cycle shown in Fig. 1.1 (12 marks)

(b) An idealised Diesel engine operates in a cycle known as the *air-standard Diesel cycle*, shown in Fig. 1.2. Fuel is sprayed into the cylinder at the point of maximum compression, *B*. Combustion occurs during the expansion $B \rightarrow C$, which is approximated as an isobaric process. The rest of the cycle is the same as in the gasoline engine, described in Fig. 1.1 Show that the efficiency of an engine operating in this idealised Diesel cycle is

$$e = 1 - \frac{1}{\gamma}\left(\frac{T_D - T_A}{T_C - T_B}\right)$$

(13 marks)

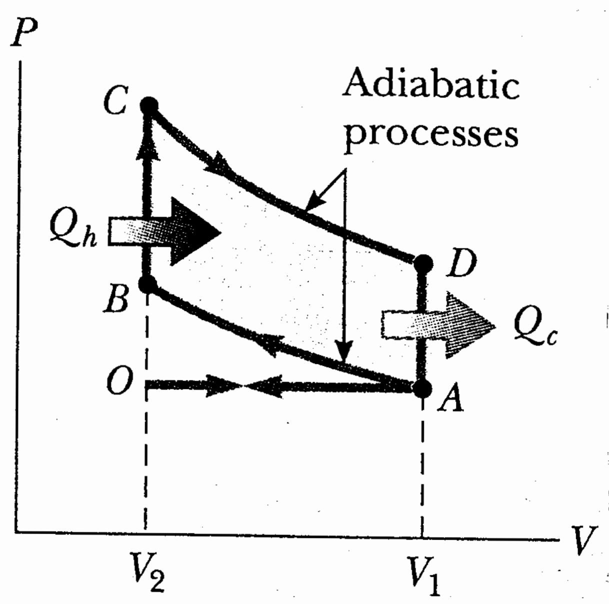

Fig. 1.1

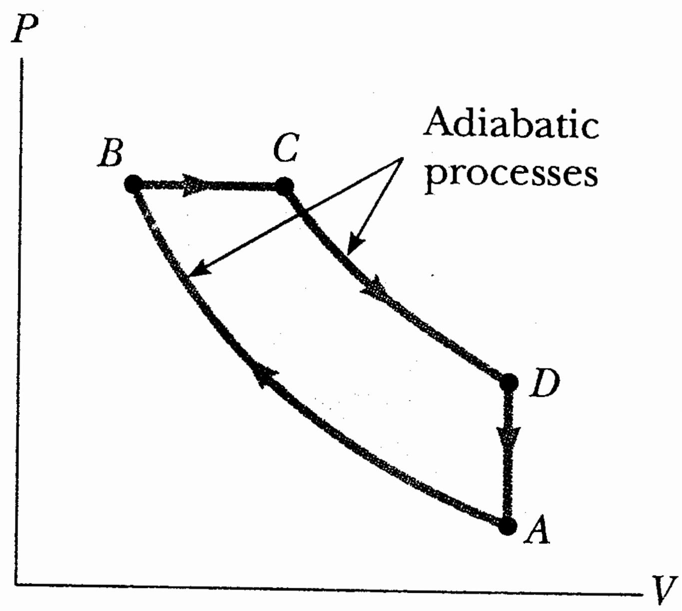

Fig. 1.2

QUESTION 2

(a) What is meant by emissivity? (2 marks)

(b) Assume that the total surface area of the human body is 1.5 m^2 and that the temperature at the surface of the body is 37°C. If the body is in a room at 20°C, how much heat would be lost from it in 10 min, assuming that the emissivity of the skin is 0.90? (4 marks)

(c) Show that the rate of heat flow through any number, i, of slabs in series, having the same cross-sectional area A, but different thermal conductivities k_i and thicknesses L_i, is given by

$$\frac{dQ}{dt} = \frac{A(T_1 - T_i)}{\sum\left(\frac{L_i}{k_i}\right)}$$

where T_1 and T_i are the temperatures at the extreme ends of the i slabs ($T_1 > T_i$). (14 marks)

(d) A bar of gold is in thermal contact with a bar of silver of the same length and area (Fig. 2.1). One end of the compound bar is maintained at 80°C while the opposite end is at 30°C. Find the temperature at the junction when the heat flow reaches steady state.

[The thermal conductivities of gold and silver are 314 W/m.°C and 427 W/m.°C, respectively]. (5 marks)

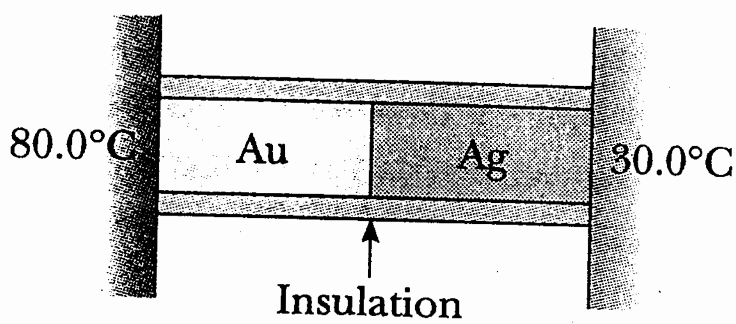

Fig. 2.1

QUESTION 3

(a) What is meant by entropy? (2 marks)

(b) Use the concept of entropy to state the second law of thermodynamics. (2 marks)

(c) Suppose that 1 kg of water at 100°C is mixed with 1 kg of water at 0°C. After equilibrium is reached, the mixture has a uniform temperature of 50°C.

What is the total change in entropy of the system? (8 marks)

(d) A 20 kg piece of iron at 1000°C is cooled by submerging it in 0.2 m^3 of water originally at 25°C.

(i) Find the final temperature of the water; (5 marks)

(ii) Calculate the entropy change of the iron, water and the universe. (8 marks)

Assume that there are no heat losses and ignore the temperature dependence of the specific heat of water.

QUESTION 4

(a) With the aid of the pV diagram shown in Fig. 4.1, discuss the principle of operation of a commercial refrigerator.

(10 marks)

(b) With reference to the ideal cycle for a refrigerator shown in Fig. 4.2, derive an expression to show that the performance coefficient, ω of a Carnot refrigerator is given by

$$\omega = \frac{T_C}{T_H - T_C}$$ (10 marks)

(c) Consider a refrigerator in a room at 25°C. If the temperature of the freezer of a refrigerator is -3°C, how much electrical energy would be required to remove $6x10^5$ J of heat from the freezer operating at its maximum coefficient of performance?

(5 marks)

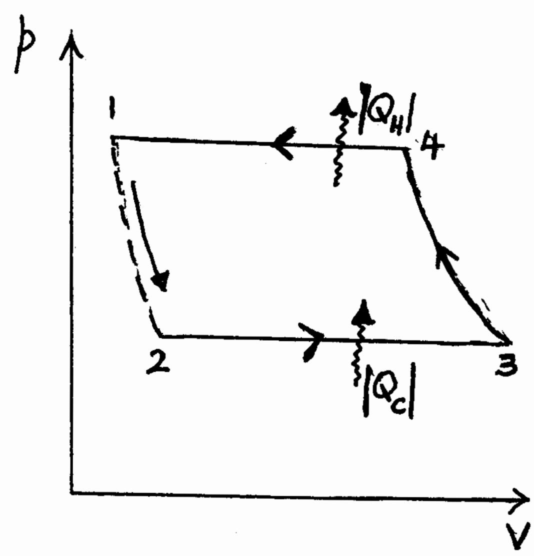

Fig. 4.1

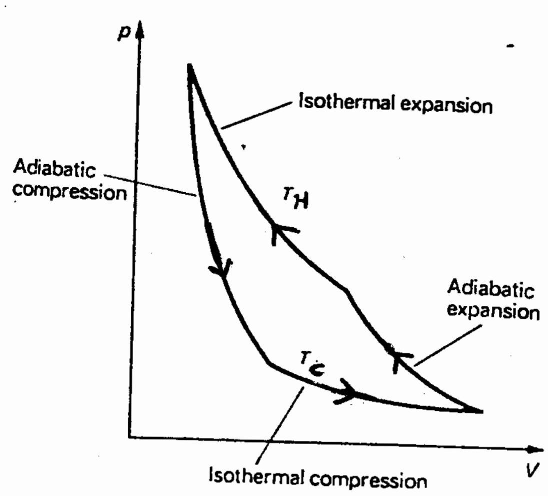

Fig. 4.2

QUESTION 5

(a) Derive an expression which shows the relationship between the average distance, l, a molecule travels between collisions in a gas, the density of molecules, n and the molecular diameter, d. Use appropriate diagram(s) for illustration.

(12 marks)

(b) The molecular diameters of different kinds of gas molecules can be found experimentally by measuring the rates at which the molecules diffuse in the gas. The diameter d = 3.15 x 10^{-10} m has been reported for nitrogen.

Determine the mean free path of a nitrogen molecule at room temperature and at normal atmospheric pressure.

(4 marks)

(c) Fig. 5.1 represents n mol of an ideal monatomic gas being taken through a reversible cycle consisting of two isothermal processes at temperatures $3T_o$ and T_o and two constant-volume processes.

(i) Determine the work done during each step in terms of n, R, and T_o;

(6 marks)

(ii) The net work done by the gas.

(3 marks)

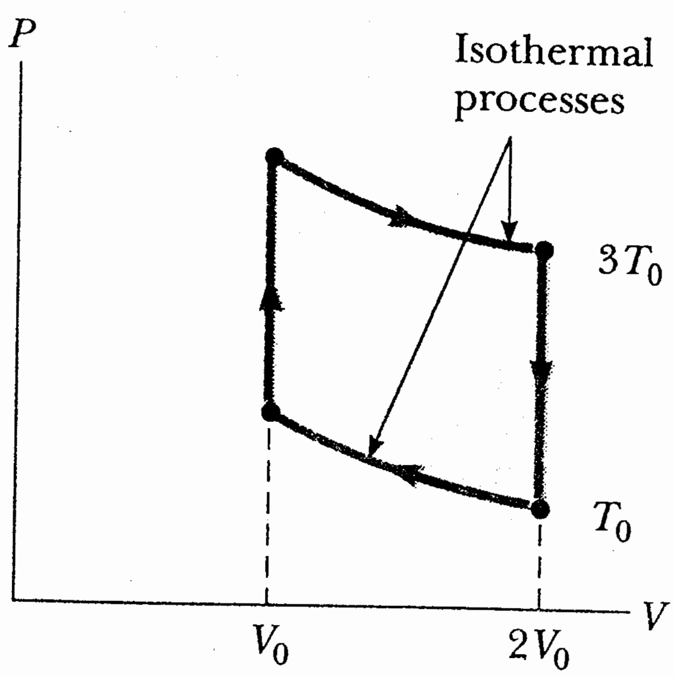

Fig. 5.1