UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE & ENGINEERING

DEPARTMENT OF PHYSICS

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MAIN EXAMINATION	:	2013/2014
TITLE OF PAPER	:	THERMODYNAMICS/THERMOFLUIDS
COURSE NUMBER	:	P242/EE202
TIME ALLOWED	:	THREE HOURS
INSTRUCTIONS	:	ANSWER ANY FOUR OUT OF THE 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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ADDITIONAL INFORMATION

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

Stefan-Boltzmann constant, $\sigma = 5.67x10^{-8}\ Wm^{-2}K^{-4}$

For a monatomic gas, $\gamma = 5/3$

For a diatomic gas, $\gamma = 7/5$

1litre $=10^{-3}\ m^3$

QUESTION 1

(a) Consider two slabs connected in series. The slabs have the same cross-section area A, but different thermal conductivities k and thickness L.

Show that the rate of heat flow through the two slabs is given by:

$$\frac{dQ}{dt} = \frac{A(T_1 - T_2)}{\frac{L_1}{k_1} + \frac{L_2}{k_2}}.$$

where T_1 and T_2 are the temperatures at the extreme ends of the double slabs ($T_1 > T_2$). (13 marks)

(b) Sheets of silver and aluminium, each of thickness 0.01 m and of equal cross-sectional area, A = $4x10^{-4}$ m^2, are placed in contact. The outer surface of the brass is kept at 100 °C and the outer surface of the steel is kept at 0 °C. The thermal conductivities of the silver and aluminium are in the ratio 2:1.

(i) With the aid of a diagram, find the temperature of the interface between the two metals. (3 marks)

(ii) Find the rate at which the heat passes through the double slab, at steady state, if the thermal conductivities of silver and aluminium are 406 W/mK and 205 W/mK, respectively. (4 marks)

(c) Consider the total surface area of the human body to be 2.0 m^2 and 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. (5 marks)

QUESTION 2

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(a) (i) Write down the van der Waals equation of state of an imperfect gas. (1 mark)

(ii) Give the physical interpretation of the van der Waals equation of state for one mole of an imperfect gas, with reference to the ideal gas equation. (6 marks)

(b) Consider a three-step p-V cycle EFGE. E to F is an isochoric increase, F to G is an isothermal expansion, and G to E is an isobaric decrease.

For each step of the cycle EFGE, and with the aid of a diagram, determine whether the following quantities are positive, negative or zero: *change in temperature, heat (absorbed or rejected) and change in entropy of the gas.* Take the gas to be the system. (9 marks)

(c) Half a mole of an ideal, diatomic gas is compressed adiabatically and quasi-statically from a volume of 10 litres at 27 °C to 2 litres.

(i) How much work is done on the gas during the compression? (7 marks)

(ii) What is the change in internal energy of the gas? (2 marks)

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QUESTION 3

(a) Describe the principle of operation of an internal combustion engine, with the aid of Otto cycle shown in Fig. 1. (6 marks)

(b) Assume that the working medium in the internal combustion engine is one mole of an ideal, monatomic gas. The engine obeys the Otto cycle shown in Fig. 1. The temperature and pressure at point 1 are $T_1 = 290$ K and $p_1 = 50$ kNm^{-2}. The pressure at point 2 is $p_2 = 1000$ kNm^{-2} and the temperature at point 3 is $T_3 = 2400$ K.

(i) Calculate the temperature values at points 2 and 4. (7 marks)

(ii) Calculate the values of W for step 1-2 and step 3-4. (10 marks)

(iii) What is the thermal efficiency of the engine? (2 marks)

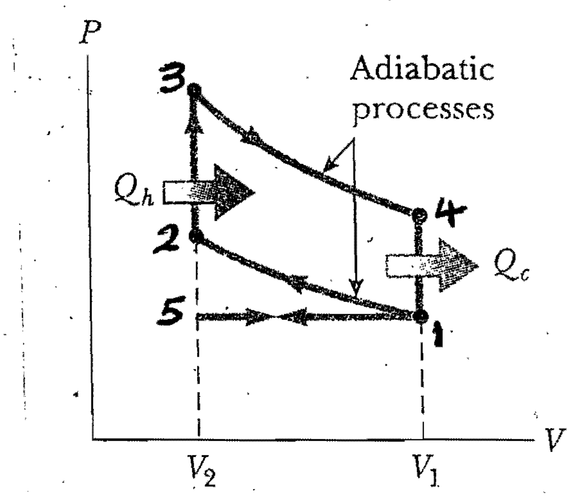

Fig. 1

QUESTION 4

(a) A Carnot refrigerator can be considered to be a Carnot engine operating in reverse. Heat Q_C is absorbed by the refrigerant from the cold reservoir and heat Q_H is rejected to a hot reservoir. With reference to the Carnot cycle provided in Figure 2 (page 7), show that the coefficient of performance of a Carnot refrigerator is given by

$$\omega = \frac{T_C}{T_H - T_C}$$

where the symbols have their usual meanings. (13 marks)

(b) The molecular speed distribution law for a sample of gas containing N molecules is

$$N(v) = 4\pi N\sqrt{\left(\frac{m}{2\pi kT}\right)^3}\, v^2 exp\left(\frac{-mv^2}{2kT}\right),$$

where the symbols have their usual meanings.

Show that the most probable speed, v_P of a gas molecule depends on the temperature of the gas and its mass, as shown below:

$$v_p = \sqrt{\frac{2kT}{m}}$$

(5 marks)

(c) Consider an ideal gas which is caused to move through the following cycle: (i) an isochoric increase in pressure at volume V_1; (ii) an isobaric decrease in volume; (iii) an isothermal expansion to the initial volume, V_1.

For each step of the cycle, taking the gas as the system, determine whether the change in entropy is positive, negative or zero. Give reasons for your answer. (**Hint:** Use the general equation pertaining to entropy change). (7 marks)

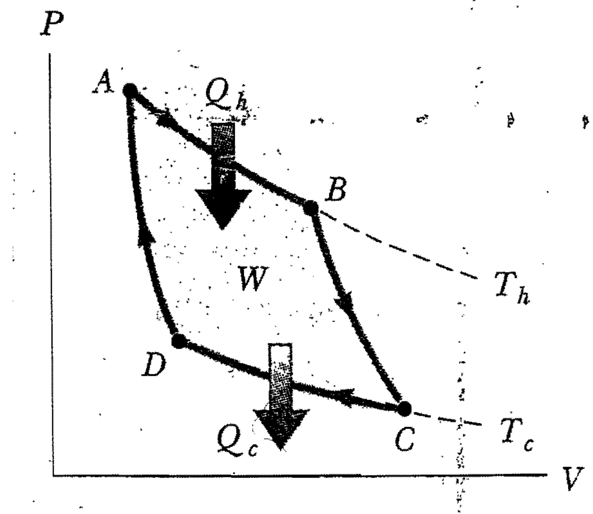

Fig. 2

QUESTION 5

(a) Describe the operation of a thermocouple. Use a suitable graph to illustrate your point. (6 marks)

(b) Fig. 3 shows a flat-plate solar water heating panel and a storage tank. With the aid of a simplified diagram(s), describe the principle of operation of the panel. Comment on the properties of the materials used to make the panel. (15 marks)

(c) A bar of metal X is attached at its end to a metal bar Y twice its length. Bar Y is made of an element whose thermal conductivity is three times that of metal X. Both bars have the same cross-sectional area. If the unattached ends of the metal bars X and Y are kept immersed in water baths at 0 °C and -30 °C, respectively, what will be the temperature at the interface of the two metal bars at steady state? (4 marks)

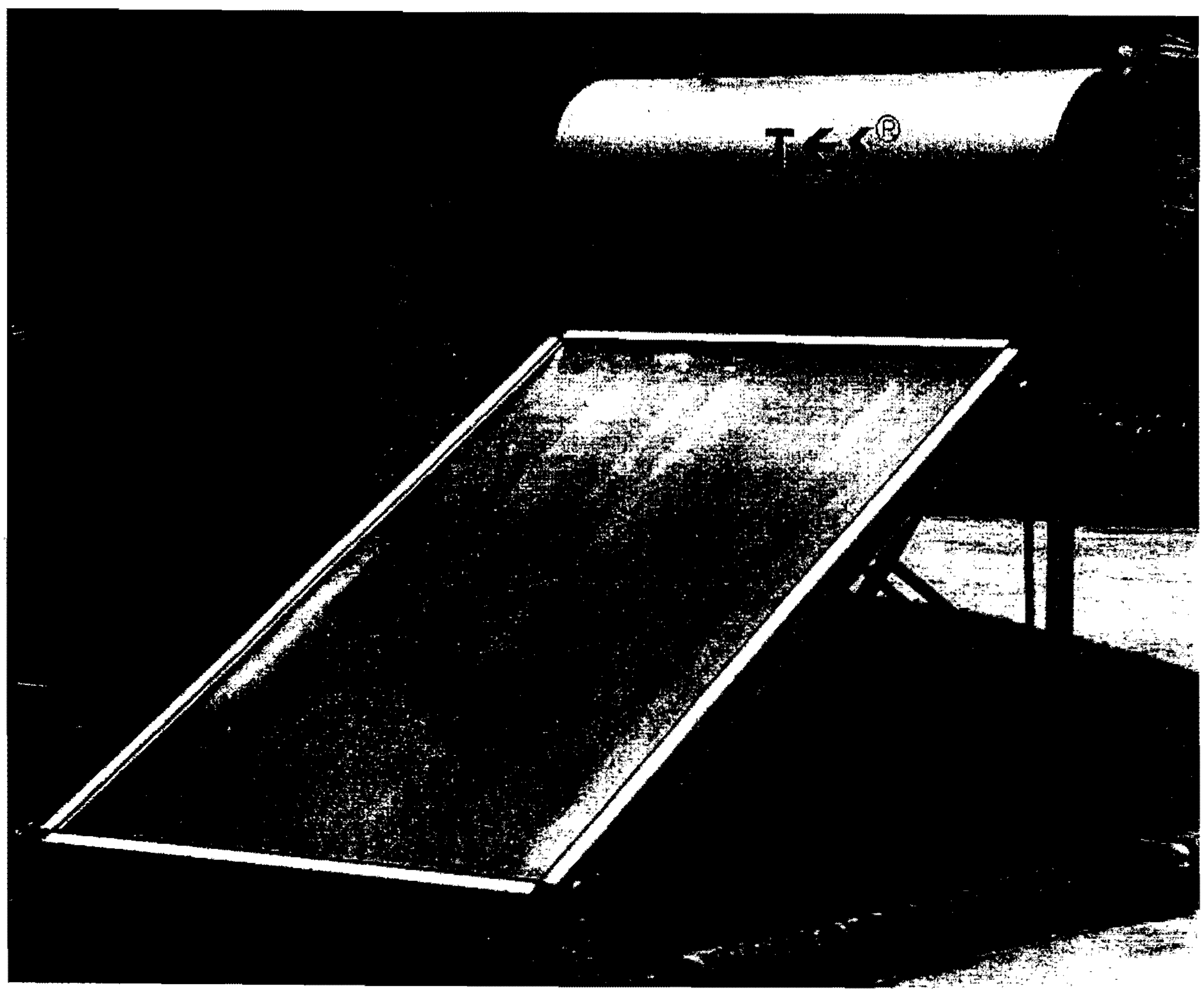

Fig. 3