UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF PHYSICS

SUPPLEMENTARY EXAMINATION 2010

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,	$\gamma = 5/3$ and $C_v = 3R/2$
Universal gas constant, R	= 8.31 J $mol^{-1}K^{-1}$
Specific heat of iron, c_{iron}	= 448 J $kg^{-1}K^{-1}$
Specific heat of copper, c_{copper}	= 420 J $kg^{-1}K^{-1}$
Specific heat of water, c_{water}	= 4200 J $kg^{-1}K^{-1}$
Density of water, ρ	= 10^3 $kg.m^{-3}$
Thermal conductivity of copper, k_{copper}	= 385 $Wm^{-1}K^{-1}$
Thermal conductivity of steel, k_{steel}	= 50.2 $Wm^{-1}K^{-1}$
Stefan-Boltzmann constant, σ	= 5.67×10^{-8} $Wm^{-2}K^{-4}$
Latent heat of fusion for ice, L_f	= 3.33×10^5 Jkg^{-1}
Avogadro's number, N_A	= 6.02×10^{23} $molecules.mol^{-1}$
Boltzmann constant, k_B	= 1.38×10^{-23} JK^{-1}
1 atmosphere	= $1.013 \times 10^5 Nm^{-2}$

QUESTION 1

(a) The following terms are associated with radiation. Explain what they mean?

(i) emissivity (2 marks)

(ii) radiant emittance (2 marks)

(b) Imagine a steam pipe, 2 m long, with an outer radius of 5 cm. The surface of the pipe is 80 °C and the pipe is exposed to a room at 20 °C. Find the rate at which energy is radiated from the surface of the pipe. Assume that the emissivity of the pipe is 0.90.

(4 marks)

(c) Consider a water pipe of internal radius r_1, external radius r_2 and length L. The inner and outer cylinders are at temperatures T_1 and T_2, respectively (where $T_1 > T_2$). The thermal conductivity of the pipe is k.

Show that the rate at which heat flows through the wall of the pipe is given by

$$\frac{dQ}{dt} = \frac{2\pi k\left(T_1 - T_2\right).L}{\log_e\left(\frac{r_2}{r_1}\right)}$$ (10 marks)

(d) A bar, 1.0 m long and 8.0 cm in diameter, is made by joining a piece of copper and a piece of steel together, as shown in Fig. 1.1. The outside of the bar is insulated. When the furnace temperature reaches 600 °C, the other end of the bar is immersed in a reservoir of ice-water at 0 °C.

Find the temperature at the interface of the copper and steel sections. (7 marks)

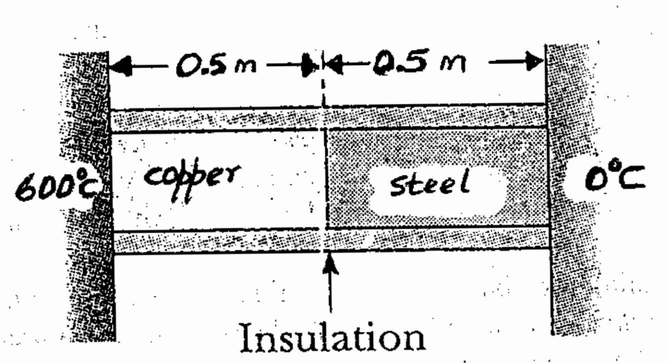

Fig. 1.1

QUESTION 2

(a) With the aid of an equation, explain briefly how you would determine the efficiency of a Carnot engine. (3 marks)

(b) Fig. 2.1 represents a schematic p-V diagram of a four-stroke internal combustion engine. Show, by mathematical analysis, that the thermal efficiency, η of the engine is given by:

$$\eta = 1 - \frac{(T_4 - T_1)}{(T_3 - T_2)}$$

and then demonstrate that

$$\eta = 1 - \frac{1}{r^{\gamma - 1}}$$

where r is the compression ratio and the other symbols have the usual meaning. (11 marks)

(c) Imagine a Carnot engine which absorbs 5000 J of heat during each cycle, from the high-temperature reservoir at 300 K, and rejects 3500 J.

(i) Calculate the temperature of the low-temperature reservoir. (4 marks)
(ii) What is the thermal efficiency of the engine? (2 marks)

(d) Consider a freezer in a room at 25 °C. The temperature of the compartment inside the freezer is -10 °C. How much work would be required to extract 2500 joules of heat from the freezer. Assume that the freezer behaves like a Carnot refrigerator? (5 marks)

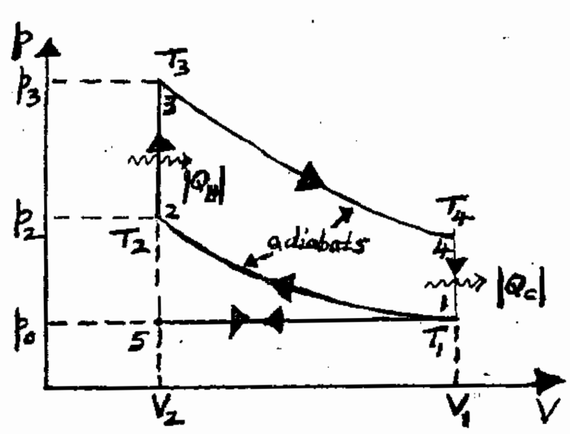

Fig. 2.1

QUESTION 3

(a) An ideal gas is made to move through a cycle which consists of three steps. In Step 1-2, the pressure increases at constant volume; in Step 2-3, the volume decreases at constant pressure; Step 3-1 is an isothermal process, the volume increases.

(i) Draw the cycle and label it. (3 marks)

(ii) **For each step** of the cycle, considering the gas to be the system, determine whether the change in entropy is positive, negative or zero. Give reasons for your answer. (9 marks)

(b) A 10 kg block of copper at 700 °C is immersed in water initially at 30 °C. The volume of water is 0.05 m^3. Heat exchange takes place during the thermodynamic process. Calculate the change in entropy of each of the following and assume that there are no heat losses during the process:

(i) the block of copper (8 marks)

(ii) the water (3 marks)

(iii) the universe (2 marks)

QUESTION 4

(a) C_p and C_v represent molar heat capacities at constant pressure and constant volume, respectively. Show that for an ideal gas $C_v = C_p - R$. (5 marks)

(b) Two thousand moles of a monatomic, ideal gas is taken through the following cycle: (1) An adiabatic compression from 4.6 m^3 to 2 m^3. (2) An isobaric expansion from 2 m^3 to 4.6 m^3 at a pressure of 4×10^6 Pa: (3) An isochoric decrease in pressure from 4×10^6 Pa to 1×10^6 Pa.

(i) Show the p-V diagram for this thermodynamic process. (3 marks)

(ii) Calculate the work done during each step and the net work for the cycle. (4 marks)

(iii) Calculate the heat exchanged during each step of the cycle and the net heat for the cycle. (10 marks)

(iv) Calculate the change in internal energy during each step of the cycle and the change in internal energy of the cycle. (3 marks)

QUESTION 5

(a) Consider an ideal gas in a rectangular box consisting of sides of lengths A, B and C. The pressure, p exerted by the gas onto the wall with cross-sectional area AB is given by the following equation:

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

where v_x represents the speed of any of the gas molecules in the x-direction. The other symbols have the usual meaning.

Show that the root-mean-square speed, v_{rms} of the gas molecules is $(3p/\rho)^{½}$, where ρ is the density of the gas. (9 marks)

(b) The van der Waals equation of state is given by

$\left[p + \frac{a}{v^2}\right]\left[v - b\right] = RT$, where the symbols have the usual meaning.

Explain the meaning of this equation with reference to the ideal gas law. (6 marks)

(c) Explain how you would determine the thermal conductivity of a conductor, with the aid of a suitable diagram. (10 marks)