UNIVERSITY OF SWAZILAND

FACULTY OF SCIENCE

DEPARTMENT OF PHYSICS

MAIN EXAMINATION	:	**2009/2010**
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

Universal gas constant, R	$= 8.31\ J\ mol^{-1}K^{-1}$
Specific heat of water, c_w	$= 4186\ J\ kg^{-1}K^{-1}$
Density of water, ρ	$= 10^3\ kg.m^{-3}$
Latent heat of fusion for ice, L_f	$= 3.33 \times 10^5\ Jkg^{-1}$
Specific heat of iron, c_i	$= 448\ J\ kg^{-1}K^{-1}$
Avogadro's number, N_A	$= 6.02 \times 10^{23}$ molecules.mol^{-1}
Boltzmann constant, k_B	$= 1.38 \times 10^{-23}\ JK^{-1}$
Stefan-Boltzmann constant, σ	$= 5.67 \times 10^{-8}\ Wm^{-2}K^{-4}$
1 atmosphere	$= 1.013 \times 10^5 Nm^{-2}$
Thermal conductivity of gold, k_{gold}	$= 314\ Wm^{-1}K^{-1}$
Thermal conductivity of silver, k_{silver}	$= 427\ Wm^{-1}K^{-1}$

QUESTION 1

(a) Show, mathematically, that for a given mass of an ideal gas and for an adiabatic process,

$$p = kV^{-\gamma}$$

where k and γ are constants. The other symbols have the usual meaning. (11 marks)

(b) Two moles of an ideal gas ($\gamma = 1.40$) expands slowly and adiabatically from a pressure of 5.00 atm and a volume of 12.0 liters to a final volume of 30.0 liters.

(i) What is the final pressure of the gas? (3 marks)

(ii) What are the initial and final temperatures? (4 marks)

(c) During the compression stroke of a certain gasoline engine, the pressure increases from 1.00 am to 20.0 atm. Assuming that the process is adiabatic and reversible and the gas is ideal with $\gamma = 1.40$,

(i) By what factor does the volume change and (3 marks)
(ii) By what factor does the temperature change? (3 marks)
(iii) What is the compression ratio? (1 mark)

QUESTION 2

(a) Consider the van der Waals equation below:

$$\left(p + \frac{a}{v^2}\right)(v - b = RT)$$

(i) Expand this equation in virial form and show that

$$pv + \frac{a}{v} = \frac{RT}{\left(1 - \frac{b}{v}\right)}$$ (4 marks)

(ii) Determine the first three virial constants. (7 marks)

(b) The constant b that appears in van der Waals' equation of state for oxygen is measured to be 31.8 cm^3/mol. Assuming a spherical shape, estimate the diameter of the oxygen molecule. (6 marks)

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

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

Show that the average speed of a gas molecule is given by

$$\bar{v} = 1.59\sqrt{\frac{k_B T}{m}}$$

Note: $\int_0^\infty v^3 \exp(-\lambda v^2)dv = \frac{1}{2\lambda^2}$, where the symbols have the usual meaning. (8 marks)

QUESTION 3

(a) State two factors that affect the efficiency of automobile engines?

(2 marks)

(b) In practical heat engines such as the automobile engine, which of the following do we have more control of: (i) the temperature of the hot reservoir or (ii) the temperature of the cold reservoir? Explain.

(4 marks)

(c) An ideal heat pump absorbs heat Q_C from a cold reservoir and rejects heat Q_H to a hot reservoir. With the aid of Fig. 1 , derive the expression below, which represents the amount of work required to run the pump:

$$|W| = \frac{T_H - T_C}{T_C}|Q_C|$$ (13 marks)

(d) One of the most efficient engines ever built has an efficiency of 42% and operates between 430°C and 1870°C.

(i) What is its maximum theoretical efficiency? (3 marks)

(ii) How much power does the engine deliver if it absorbs 1.4×10^5 J of the thermal energy each second? (3 marks)

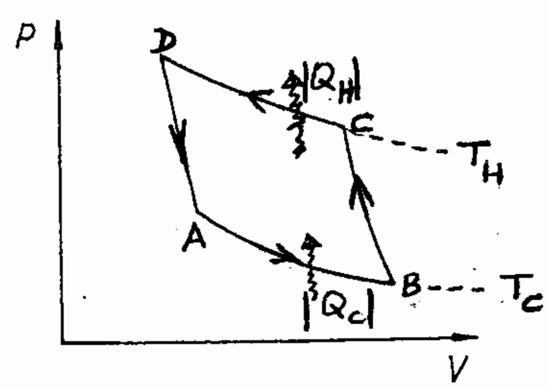

Fig. 1

QUESTION 4

(a) Fig. 2 shows a schematic diagram of a solar water heating panel system. Explain how the system works. Comment on the properties of the materials used to make the panel, with the aid of a detailed diagram (of the panel). Label the diagram. (12 marks)

(b) The surface of the Sun has a temperature of about 5800 K. Taking the radius of the Sun to be 6.96×10^8 m, calculate the total energy radiated by the Sun each day. (Assume $e = 1$).

(4 marks)

(c) A bar of gold is in thermal contact with a bar of silver of the same length and area. One end of the compound bar (double slab) is maintained at 80.0˚C while the opposite end is at 30.0˚C.

Find the temperature at the junction of the two metals when the heat flow reaches steady state. (9 marks)

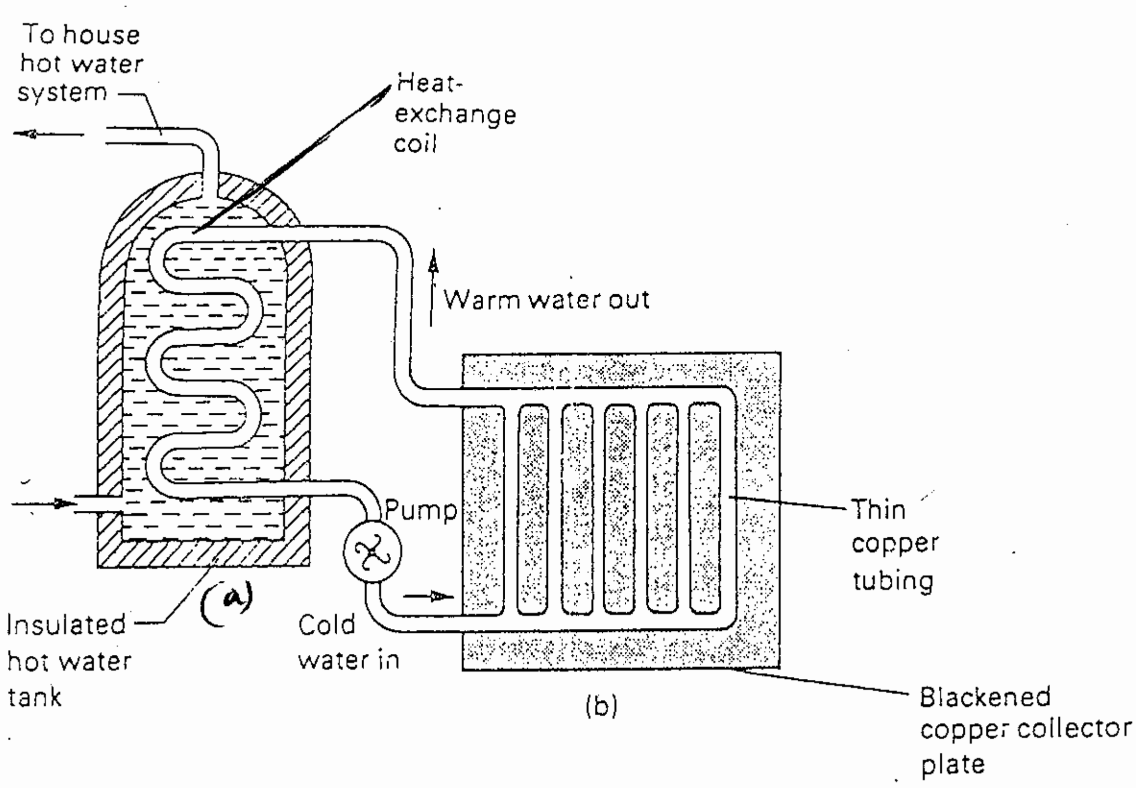

Fig. 2

QUESTION 5

(a) State the Clausius theorem in thermodynamics. (2 marks)

(b) Discuss two common examples of natural processes that involve an increase in entropy. Be sure to account for all parts of each system under consideration. (4 marks)

(c) A thermodynamic process occurs in which the entropy of a system changes by - 8.0 J/K. According to the second law of thermodynamics, what can you conclude about the entropy change of the environment? (2 marks)

(d) A 1.5 kg iron horseshoe initially at 600°C is dropped into a bucket containing 20 kg of water at 25°C.

- (i) What is the final temperature? (Neglect the heat capacity of the container) (4 marks)
- (ii) Find the change in entropy of the water, iron and universe (7 marks)

(e) Using an ideal Carnot refrigerator, how much work is required to change 0.50 kg of tap water at 10°C into ice at -20°C? Assume that the freezer compartment is held at -20 °C and the refrigerator exhausts heat into a room at 20°C. (6 marks)