**UNIVERSITY OF SWAZILAND**

**FACULTY OF SCIENCE**

**DEPARTMENT OF PHYSICS**

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| **MAIN EXAMINATION** | : | **MAY 2008** |
| **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**

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| 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 | $= 448\ J\ kg^{-1}K^{-1}$ |
| Avogadro's number | $= 6.02 \times 10^{23}\ molecules.mol^{-1}$ |
| Boltzmann constant | $= 1.38 \times 10^{-23}\ JK^{-1}$ |
| Stefan-Boltzmann constant | $= 5.67 \times 10^{-8}\ Wm^{-2}K^{-4}$ |
| 1 atmosphere | $= 1.013 \times 10^5 Nm^{-2}$ |
| Thermal conductivity of air | $= 0.0234\ Wm^{-1}K^{-1}$ |
| Thermal conductivity of glass | $= 0.8\ Wm^{-1}K^{-1}$ |

## QUESTION 1

(a) Consider a conductor of unknown thermal conductivity. With the aid of a diagram and a suitable equation, explain how you would measure the thermal conductivity. (10 marks)

(b) Derive an expression for the radial rate of heat flow through a substance between two concentric spheres. The inner sphere has radius $r_1$ and the outer sphere has radius $r_2$. The inside is maintained at a temperature $T_1$ and the outside is at a temperature $T_2$. The thermal conductivity of the substance is $k$. (7 marks)

(c) A Thermopane window of area 6.0 $cm^2$ is constructed of two layers of glass, each 4.0 mm thick separated by an air space of 5.0 mm. If the inside is at 20 °C and the outside is at -30°C, how much heat is lost through the window per second? (4 marks)

(d) A steam pipe has an outer radius of 10 cm and a length of 4.0 m. The surface temperature of the pipe is 95 °C in a room at 23 °C. Assuming an emissivity of 0.80, determine the rate of heat loss in kJ/s due to radiation. (4 marks)

## QUESTION 2

(a) An ideal gas initially at 300 K undergoes an isobaric expansion at 2.50 kPa. If the volume increases from 1.00 $m^3$ to 3.00 $m^3$ and 12.5 kJ of thermal energy is transferred to the gas, find:

(i) the change in its internal energy and (4 marks)

(ii) its final temperature (3 marks)

(b) Calculate the mean free path and collision frequency for nitrogen molecules at 20.0 °C and 1.00 atm. Assume a molecular diameter of 2.00 X $10^{-10}$m. (7 marks)

[***Hint***: The average speed of a nitrogen molecule at 20 °C is about 511 $ms^{-1}$].

(c) With the aid of the equation for $N_v$ below, show that the most probable speed for a gas molecule is $1.73(kT/m)^{-1/2}$ Note that the most probable speed corresponds to the point where the slope of the speed distribution curve, $dN_v/dv$, is zero. (7 marks)

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

[***Hint***: $\int_0^\infty v^4 \exp(-\lambda v^2)dv = \frac{3}{8}\sqrt{\frac{\pi}{\lambda^2}}$ ]

(d) 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 molecule. (4 marks)

## QUESTION 3

(a) A cylinder containing $n$ mol of an ideal gas undergoes a reversible adiabatic process. Show that the work done is

$$W = \left(\frac{1}{\gamma - 1}\right)\left(p_i V_i - p_f V_f\right)$$

where $i$ and $f$ represent the initial and final stages, respectively. (6 marks)

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

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

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

(c) Air in the cylinder of a diesel engine at 20.0 °C is compressed from an initial pressure of 1.00 atm and volume of 800.0 $cm^3$ to a volume of 60.0 $cm^3$. Assuming that air behaves as an ideal gas ($\gamma = 1.40$) and that the compression is adiabatic and reversible, find the final pressure and temperature. (7 marks)

(d) During the compression stroke of a certain gasoline engine, the pressure increases from 1.00 atm to 20.0 atm. Assuming that the process is adiabatic and reversible and the gas is ideal with $\gamma = 1.40$, by what factor does the temperature change? (6 marks)

## QUESTION 4

(a) With the aid of the pV diagram shown in Fig. 4.1 discuss, briefly, the principle of operation of a commercial refrigerator. (8 marks)

(b) An ideal refrigerator is equivalent to a Carnot engine running in reverse, that is, heat $Q_c$ is absorbed from a cold reservoir and heat $Q_h$ is rejected to a hot reservoir. With reference to the Carnot cycle shown in Fig. 4.2, derive the expression below for the coefficient of performance, COP of an ideal refrigerator

$$COP = \frac{T_c}{T_h - T_c}$$ (13 marks)

(c) A refrigerator has a coefficient of performance equal to 5. If the refrigerator absorbs 120 J of thermal energy from a cold reservoir in each cycle, find:

(i) the work done in each cycle and (2 marks)
(ii) the thermal energy expelled to the hot reservoir. (2 marks)

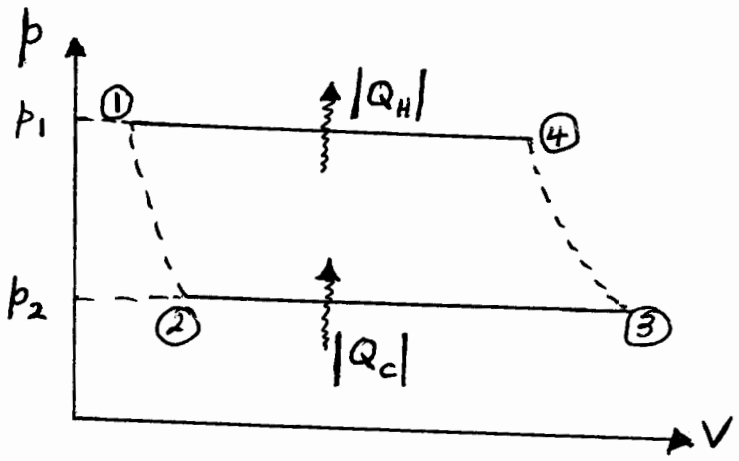


Fig. 4.1

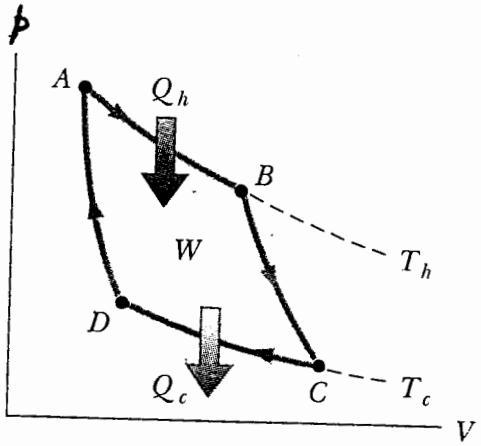


Fig. 4.2

## QUESTION 5

(a) What is meant by the entropy of a system? (2 marks)

(b) There are four points to note about entropy change. Mention them. (4 marks)

(c) State the second law of thermodynamics using the concept of entropy. Explain, briefly, what it means in practice. (4 marks)

(d) A 1.0-kg iron horseshoe is taken from a furnace at 900 °C and dropped into 4.0 kg of water at 10 °C. If no heat is lost to the surroundings, determine the following:

(i) the equilibrium temperature after immersing the iron into the water; (7 marks)

(ii) the change in entropy of the water and the iron; (6 marks)

(iii) the total entropy change. (2 marks)