JARAMOGI OGINGA ODINGA UNIVERSITY OF SCIENCE AND TECHNOLOGY

SCHOOL OF BIOLOGICAL AND PHYSICAL SCIENCES

UNIVERSITY EXAMINATION FOR THEDEGREE OF BACHELOR OF EDUCATION (SCIENCE)

3RD YEAR 1ST SEMESTER

MAIN

REGULAR

COURSE CODE: SPH 302

COURSE TITLE: THERMODYNAMICS

EXAM VENUE: **STREAM: (BED SCI)**

DATE: **EXAM SESSION:**

TIME: 2:00HRS

Instructions:

1. **Answer question 1 (Compulsory) and ANY other 2 questions.**
2. **Candidates are advised not to write on the question paper.**
3. **Candidates must hand in their answer booklets to the invigilator while in the examination room.**

Take the Ideal-gas constant,R to be 8.3145J/(mol.K)

QUESTION ONE (30 Marks)

(a) For an ideal monatomic gas of one mole, calculate the heat capacity at a constant pressure, C_p (2 marks)

(b) Show that, for an ideal gas

(i) $\frac{R}{C_v} = \gamma - 1$ (2 marks)

(ii) $\frac{R}{C_P} = \frac{\gamma - 1}{\gamma}$ where R is an ideal-gas constant, C_v and C_p are the heat capacities per mole and γ is the adiabatic index. (2 marks)

(c) Use thermodynamic arguments to obtain the general result that, for any gas at temperature T, the pressure is given by

$P = T\left(\frac{\partial P}{\partial T}\right)_V - \left(\frac{\partial U}{\partial V}\right)_T$, where U is the total energy of the gas. (3 marks)

(d) In an adiabatic change, show that

$$\left(\frac{\partial p}{\partial V}\right)_{\text{adiabatic}} = \gamma \left(\frac{\partial p}{\partial V}\right)_T,$$

$$\left(\frac{\partial V}{\partial T}\right)_{\text{adiabatic}} = \frac{1}{1-\gamma} \left(\frac{\partial V}{\partial T}\right)_p;$$

$$\left(\frac{\partial p}{\partial T}\right)_{\text{adiabatic}} = \frac{\gamma}{\gamma - 1} \left(\frac{\partial p}{\partial T}\right)_V$$

(6 marks)

(e) What is the maximum possible efficiency of an engine operating between two thermal reservoirs, one at 100 ˚C and the other at 0 ˚C? (2 marks)

(f) What is the change of entropy in the gas, surroundings and Universe during a Joule expansion? (2 marks)

(g) Suppose 1.00 kg of water at 100°C is placed in thermal contact with 1.00 kg of water at 0°C. Find the approximate total change in entropy when the hot water cools to 99°C and the cold water warms to 1°C. Assume that the specific heat capacity of water is constant at over the given temperature range. (3 marks)

(h) Summarize **three** main consequences of the third law of thermodynamics and explain how it casts a shadow of doubt on some of the conclusions from various thermodynamic models. (6 marks)

(i) Show that in phase equilibrium, each coexisting phase has the same **chemical potential** $\mu_1 = \mu_2$ (2 marks)

QUESTION TWO (20 Marks)

(a) One mole of ideal monatomic gas is confined in a cylinder by a piston and is maintained at a constant temperature 80^{o}c by thermal contact with a heat reservoir. The gas slowly expands from V to 2V while being held at the same temperature.

(i) Explain why does the internal energy of the gas not change? (2 marks)

(ii) Calculate the work done by the gas (3 marks)

(iii) The heat flow into the gas. (3 marks)

(b) For an ideal monatomic gas of one mole

(i) Show that for, the gas constant, R at constant pressure is given by $R = P\left(\frac{\partial V}{\partial T}\right)_p$ where p, V and T have their usual meanings. (3 marks)

(ii) Calculate the molar heat capacity of the gas at a constant volume C_V. (3 marks)

(c) Calculate the adiabatic index γ of the gas. (3 marks)

(d) Derive change in internal energy dU in terms of heat capacity at constant volume C_v and change in temperature dT for an deal gas. (3 marks)

QUESTION THREE (20 Marks)

(a) In general, the internal energy is a function of temperature and volume, so that we can write U = U(T,V). Using this reasoning, show that $C_p - C_V = R$ for a mole of ideal gas. (4 marks)

(b) Calculate the change of entropy

(i) of a bath containing water, initially at 20 ˚C, when it is placed in thermal contact with a very large heat reservoir at 80˚C. (3 marks)

(ii) of the reservoir when process (i) occurs. The bath and its contents have total heat capacity 10^4 JK^{-1}. (3 marks)

(c) Show that another expression for the entropy per mole of an ideal gas is (3 marks)

$$S = C_p \ln T - R \ln p + \text{constant}.$$

(d) If the substance is an ideal monatomic gas, then $C_P = \frac{5}{2} R$. From this Calculate $S_2 - S_1$

(3 marks)

(e) The work done by a mole of an ideal gas in a reversible adiabatic expansion from (P_1, V_1) to (P_2, V_2): can be calculated by determining the area under the PV curve. Show that this work is given by $W = \frac{R(T_1 - T_2)}{\gamma - 1}$.

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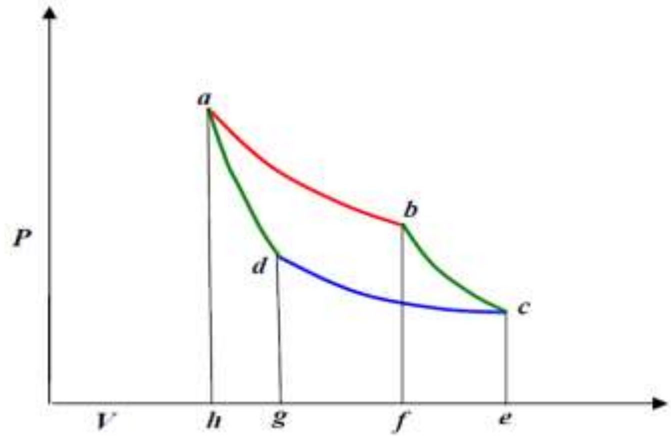
(4 marks)

QUESTION FOUR (20 Marks)

(a) (i) Figure below shows a Carnot cycle. Derive the expression for the heat exhausted

$$Q_C = nRT_C \ln \frac{V_a}{V_b}$$

(3 marks)



(ii) For a Carnot Cycle, the ratio of heat input to heat output is equal to the ratio of the highest absolute temperature to the lowest absolute temperature. Show that the work done for the Carnot cycle above is given by $W = \left(1 - \frac{T_C}{T_H}\right) Q_H$. (3 marks)

(b) A gasoline engine in a large truck takes in 2500 J of heat and delivers 500 J of mechanical work per cycle. The heat is obtained by burning gasoline with heat of combustion $L_V = 5\times10^4$ J/g.

(i) What is the thermal efficiency of this engine? (3 marks)

(ii) How much heat is discarded in each cycle? (3 marks)

(iii) How much gasoline is burned during each cycle? (3 marks)

(iv) If the engine goes through 100 cycles per second, what is its power output in watts? (3 marks)

(v) How much gasoline is burned per second? (2 marks)

QUESTION FIVE (20 Marks)

(a) Using the first law dU = TdS − pdV, derive the **four** thermodynamic potentials U, H, F, G (in terms of U, S, T, p, V), and give dU, dH, dF, dG in terms of T, S, p, V and their derivatives. (4 marks)

(b) Derive all the Maxwell relations. (8 marks)

(c) Given $dQ = C_p dT + Adp$ and $dQ = C_V dT + BdV$ where A and B are constants

(i) Explain why we can write $dQ = C_p dT + Adp$ and $dQ = C_V dT + BdV$. (2 marks)

(ii) Show that $(C_p - C_V)dT = BdV - Adp$ (3 marks)

(iii) Also show that at constant temperature $\left(\frac{\partial p}{\partial V}\right)_T = \frac{B}{A}$ (3 marks)