UNIVERSITY OF FORT HARE

University of Fort Hare
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THERMAL PHYSICS (PHY 312)

MAIN EXAMINATION

DATE: MAY 2023

DURATION: 3 HOURS

MARKS: 100

INTERNAL EXAMINER
Mr N. Shambira

EXTERNAL EXAMINER
Dr. I Mabuda

THIS PAPER CONSISTS OF 7 PAGES INCLUDING COVER PAGE

INSTRUCTIONS:

1. Answer all the questions.
2. Write neatly and legibly.
3. Unless otherwise stated, all symbols retain their usual meanings.
4. Values of constants appear at end of the question paper

QUESTION 1 [20 MARKS]

1.1 State the zeroth law of thermodynamics. (2)

1.2 What is the difference between intensive property and extensive property? Give an example of each property. (4)

1.3 The volume expansivity β is defined by $\beta = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P$ where V is volume, T is temperature, and P is pressure. The bulk modulus K is defined by

$$K = -V\left(\frac{\partial P}{\partial V}\right)_T .$$

Calculate values of β and K for an ideal gas, with an equation of state $PV = nRT$, where n is the number of moles of gas and R is the universal gas constant. (6)

1.4 A block of copper at a pressure of 1 atm and a temperature of 5°C is kept at constant volume. The temperature is then raised to 10°C. Assume isothermal compressibility κ and volume expansivity β to be constant within the temperature range 0 to 20°C at values of $6.17\times10^{-5}\,\mathrm{Pa}^{-1}$ and $4.95\times10^{-5}\,\mathrm{K}^{-1}$.

1.4.1 Show that $\mathrm{d}P = \frac{\beta}{\kappa}\mathrm{d}T$, where all symbols have their usual meaning. (5)

1.4.2 Hence calculate the final pressure. (3)

QUESTION 2 [20 MARKS]

2.1 Define a reversible process. (2)

2.2 An adiabatic chamber with rigid walls consists of two compartments, one containing a gas and the other evacuated, the partition between the two compartments is suddenly removed.

Is the work done during an infinitesimal portion of this process (called an adiabatic free expansion) equal to PdV?. (3)

2.3 Show that the work done by an ideal gas during a quasi-static, isothermal expansion from initial pressure P_i to a final pressure P_f is given by

$$W = nRT \ln\left(\frac{P_f}{P_i}\right)$$

(5)

2.4 During a quasi-static expansion of a gas in an adiabatic container, the pressure at any moment is given by the equation $PV^{\gamma} = c$ where γ and c are constants.

2.41 Show that the work done in expanding from a state (P_i, V_i) to a state (P_f, V_f) is $W = -\frac{P_i V_i - P_f V_f}{\gamma - 1}$, where all symbols have their usual meaning. (7)

2.4.2 If the initial pressure and volume are 10^6 Pa and 10^{-3} m^3, respectively, and the final values are 2×10^5 Pa and $3,16 \times 10^{-3}$ m^3 respectively, how much work is done on a gas having $\gamma = 1,4$? (3)

QUESTION 3 [20 MARKS]

3.1 State the First Law of Thermodynamics and name the physical quantity that remains conserved in this law? (3)

3.2 Regarding the internal energy of a hydrostatic system to be a function of T and P, derive the following equations.

3.2.1 $$\mathrm{d}Q=\left[\left(\frac{\partial U}{\partial T}\right)_P+\mathrm{P}\left(\frac{\partial V}{\partial T}\right)_P\right]\mathrm{dT}+\left[\left(\frac{\partial U}{\partial P}\right)_T+P\left(\frac{\partial V}{\partial P}\right)_T\right]dP$$ (6)

3.2.2 $$\left(\frac{\partial U}{\partial T}\right)_P=C_P-PV\beta$$ (5)

3.2.3 $$\left(\frac{\partial U}{\partial P}\right)_T=PV\kappa-\left(C_P-C_V\right)\frac{\kappa}{\beta}$$ (6)

QUESTION 4 [20 MARKS]

4.1 Differentiate between the Kelvin-Planck and Clausius statements of the second law of thermodynamics. (4)

4.2 State the Carnot theorem. (2)

4.3 A Carnot engine works at high temperature 600 K with the efficiency of 40%. If the efficiency of the engine increases to 75% and the low temperature kept constant, find the high temperature at 75% efficiency? (4)

4.4 Consider an idealised Otto cycle for gasoline engines as shown in Figure 1

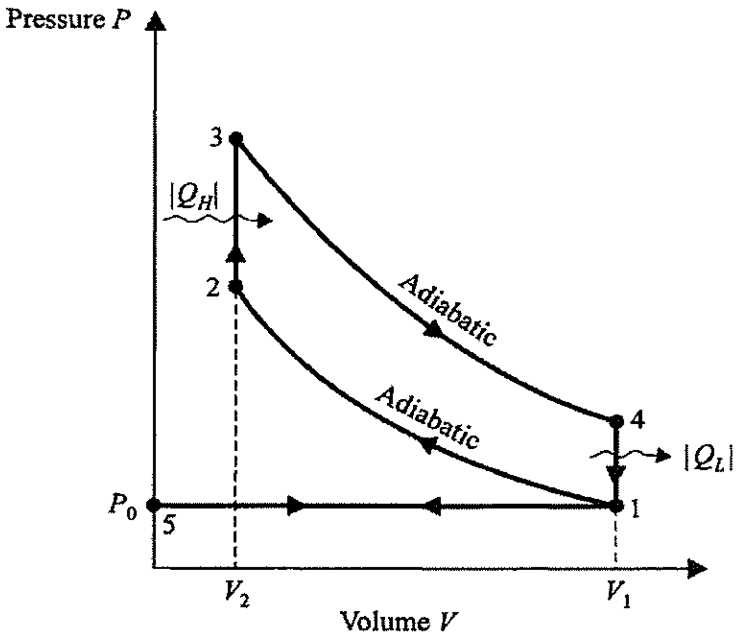

Figure 1. Idealised Otto cycle for gasoline engines

4.4.1 Show that the thermal efficiency of the gasoline engines is given by $\eta = 1 - \frac{1}{r_c^{\gamma-1}}$, where $\gamma = \frac{C_p}{C_V}$ and $r_c = \frac{V_1}{V_2}$ is the compression ratio for the gasoline engine. (10)

QUESTION 5 [20 MARKS]

5.1 State the principle of increasing entropy. (2)

5.2 Show that the entropy of an ideal gas is given as follows:

$$S = C_P \ln T - nR\ln P + \left(S_r - C_p \ln T_r + nR\ln P_r\right)$$ (6)

5.3 A body of constant heat capacity C_P and a temperature T_i is put into contact with a reservoir at temperature T_f. Equilibrium between the body and the reservoir is established at constant pressure.

Determine the total entropy change. (6)

5.4 Given that the equation of state of the Gibbs function is defined as

$G = H - TS$

Show that $V = \left(\frac{\partial G}{\partial P}\right)_T$ and $S = -\left(\frac{\partial G}{\partial T}\right)_P$. (6)

Values of physical constants

Quantity	Symbol	Value
Molar gas constant	$R = N_A k$	8.315 J/mol.K
Avogadro's number	N_A	6.022 x 10^{23} particles/mol
Boltzmann's constant	K	1.381 x 10^{23} J/K
Stefan-Boltzmann constant	σ	5.671 x 10^{-8} W/m^2 K^4
Faraday's constant	N_F	96485 C/mol
Elementary charge	e	1.602 x 10^{-19} C
Electron mass	m_e	9.109 x 10^{-31} kg
Speed of light in vacuum	C	2.998 x 10^{8} m/s
Permeability of vacuum	μ_0	1.257 x 10^{-6} H/m
Permittivity of vacuum	ϵ_0	8.854 x 10^{-12} F/m
Planck's constant	h	6.626 x 10^{-34} JS
Bohr magneton	μ_B	9.274 x 10^{-24} J/T
Nuclear magneton	μ_N	5.051 x 10^{-27} J/T
Proton mass	m_P	1.673 x 10^{-27} kg
Electron-volt	1 eV	1.602 x 10^{-29} J
Atomic mass unit	m_u	1.661 x 10^{-27} kg
Atmosphere of pressure	1 atm	1.013 x 10^{5} Pa
One millimeter of mercury	1 mm Hg	133.3 Pa
C_V of monoatomic gas	$\frac{3R}{2}$	
C_P of monoatomic gas	$\frac{5R}{2}$	