

THE UNIVERSITY OF NEW SOUTH WALES
SCHOOL OF PHYSICS

Midsession Test – SEPTEMBER 2014

PHYS2060 – THERMAL PHYSICS
PHYS2210 – ELECTROMAGNETISM & THERMAL PHYSICS Paper 2

Time allowed – 50 minutes

Total number of questions – 3

Attempt **ALL** questions

The questions are NOT of equal value

This paper may be retained by the candidate

Candidates may not bring their own calculators.

Answers must be written in ink. Except where they are expressly required, pencils may only be used for drawing, sketching or graphical work.

Boltzmann's constant	$k_B = 1.38 \times 10^{-23} \text{ J/K}$
Avogadro's number	$N_A = 6.022 \times 10^{23} \text{ mol}^{-1}$
Real gas constant	$R = 8.314 \text{ J/K.mol}$

Specific heat of liquid H₂O = 4.18 J/gK

Latent heat of the liquid-solid transition for H₂O = 333 J/g

Latent heat of the liquid-gas transition for H₂O = 2270 J/g

Adiabatic constant for N₂ $\gamma = 1.4$

Specific heat at constant pressure for N₂ $C_P = 29.12 \text{ J mol}^{-1} \text{ K}^{-1}$

Specific heat at constant volume for N₂ $C_V = 20.8 \text{ J mol}^{-1} \text{ K}^{-1}$

Molar mass of air = 29 g/mol

Partial derivatives

$$\left(\frac{\partial x}{\partial y}\right)_z \left(\frac{\partial y}{\partial z}\right)_x \left(\frac{\partial z}{\partial x}\right)_y = -1 ; \quad \left(\frac{\partial y}{\partial x}\right)_z = \frac{1}{\left(\frac{\partial x}{\partial y}\right)_z} ; \quad \left(\frac{\partial y}{\partial x}\right)_z = - \frac{\left(\frac{\partial z}{\partial x}\right)_y}{\left(\frac{\partial z}{\partial y}\right)_x}$$

Thermodynamic quantities

$$\kappa_T = \frac{-1}{V} \left(\frac{\partial V}{\partial P}\right)_T \quad \text{Isothermal compressibility} \quad \beta = \frac{1}{V} \left(\frac{\partial V}{\partial T}\right)_P \quad \text{Expansivity}$$

$$\kappa_S = \frac{-1}{V} \left(\frac{\partial V}{\partial P}\right)_S \quad \text{Adiabatic compressibility} \quad c_V = \frac{1}{n} \left(\frac{\partial U}{\partial T}\right)_V$$

$$c_P = \frac{1}{n} \left(\frac{\partial U}{\partial T}\right)_P + \frac{P}{n} \left(\frac{\partial V}{\partial T}\right)_P$$

Thermodynamic potentials

$F = U - TS + \mu N$	$dF = -SdT - PdV + \mu dN$	Helmholtz Free Energy
$H = U + PV + \mu N$	$dH = TdS + VdP + \mu dN$	Enthalpy
$G = U - TS + PV + \mu N$	$dG = -SdT + VdP + \mu dN$	Gibbs Free Energy

Ideal gas

$$PV = NkT$$

$$U = \frac{1}{\gamma - 1} NkT$$

$PV^\gamma = \text{const}$ for Adiabatic process

$$P \partial V = Nk \partial T$$

$$\frac{\partial V}{\partial T} = \frac{Nk}{P}$$

Efficiency of Carnot cycle

$$\eta = \frac{W_{\text{cycle}}}{Q_{\text{in}}} = 1 - \frac{T_c}{T_h}$$

QUESTION 1 (5 marks)

Part A

- (i) Explain the difference between extensive parameters and intensive parameters giving examples of each.
- (ii) Heat flux and work are represented by inexact or improper differentials. What does this mean? How do these parameters differ from the state parameters?
- (iii) What is meant by a quasi-static process and how is it related to a reversible process? Give examples of each.

Part B

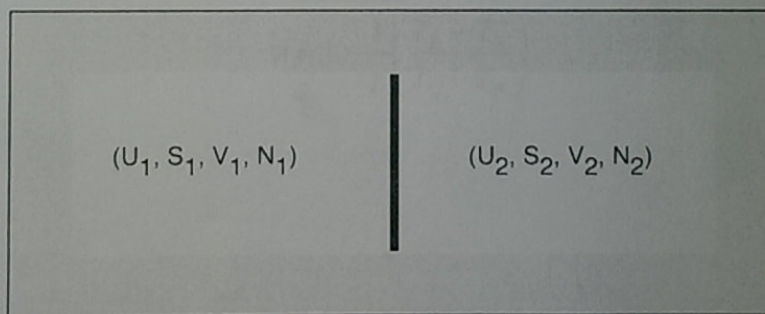
The fundamental equation describing a thermodynamic system consisting of a single type of component is given by

$$U = U(S, V, N)$$

where the total internal energy U is a first order homogenous function of the state parameters S , V and N .

- (iv) Derive an expression for the exact differential, dU , in terms of the partial derivatives of U with respect to the independent variables.
- (v) Use this to obtain expressions for the state parameters T , P and μ in terms of the partial derivatives of the total energy U .

Part C



Two gases, with state parameters (U_1, S_1, V_1, N_1) and (U_2, S_2, V_2, N_2) are placed in an insulated cylinder and separated by a fixed, impermeable diathermal wall. The combined system is initially out of equilibrium. Eventually, the system reaches thermal equilibrium.

- (vi) Using your expression for dU , show that $\left(\frac{\partial U}{\partial S}\right)_{V,N}$ behaves like the temperature when thermal equilibrium is attained.

QUESTION 1 (5 marks)

Part A

- (i) Explain the difference between extensive parameters and intensive parameters giving examples of each.
- (ii) Heat flux and work are represented by inexact or improper differentials. What does this mean? How do these parameters differ from the state parameters?
- (iii) What is meant by a quasi-static process and how is it related to a reversible process? Give examples of each.

Part B

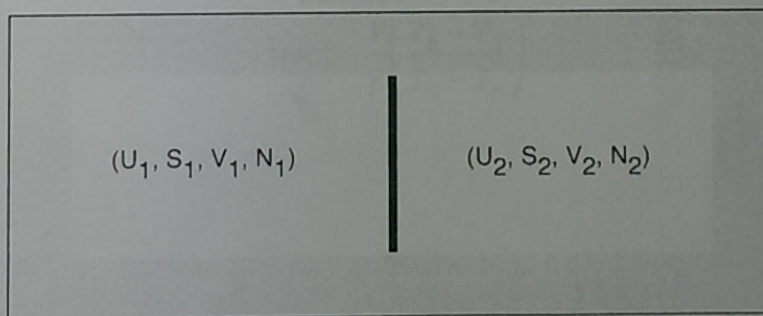
The fundamental equation describing a thermodynamic system consisting of a single type of component is given by

$$U = U(S, V, N)$$

where the total internal energy U is a first order homogenous function of the state parameters S , V and N .

- (iv) Derive an expression for the exact differential, dU , in terms of the partial derivatives of U with respect to the independent variables.
- (v) Use this to obtain expressions for the state parameters T , P and μ in terms of the partial derivatives of the total energy U .

Part C



Two gases, with state parameters (U_1, S_1, V_1, N_1) and (U_2, S_2, V_2, N_2) are placed in an insulated cylinder and separated by a fixed, impermeable diathermal wall. The combined system is initially out of equilibrium. Eventually, the system reaches thermal equilibrium.

- (vi) Using your expression for dU , show that $\left(\frac{\partial U}{\partial S}\right)_{V,N}$ behaves like the temperature when thermal equilibrium is attained.

QUESTION 2 (5 marks)

Part A

For an ideal monatomic gas, one can derive the following relationships:

$$PV = \frac{2}{3} N \left\langle \frac{1}{2} mv^2 \right\rangle$$

$$U = N \left\langle \frac{1}{2} mv^2 \right\rangle$$

- (i) What is the meaning of $\left\langle \frac{1}{2} mv^2 \right\rangle$?
- (ii) Show how these microscopic equations are related to the two equations of state for an ideal monatomic gas.
- (iii) Derive an equation for temperature in terms of the microscopic properties of an ideal monatomic gas.

Part B

An ideal gas changes state under adiabatic conditions.

- (iv) What does it mean for a process to occur under adiabatic conditions?
- (v) By assuming an ideal gas undergoes an adiabatic process, derive the expression:

$$PV^\gamma = \text{constant}$$

QUESTION 3 (10 marks)

A Diesel cycle consists of the following steps:

- A → B – an adiabatic compression
- B → C – an isobaric expansion
- C → D – an adiabatic expansion
- D → A – an isochoric depressurisation.

Assume that the working fluid for the Diesel cycle is an ideal gas, where

$\gamma \equiv \frac{c_p}{c_v}$ is the ratio of the specific heats for the ideal gas.

- (i) Draw a P-V diagram for this cycle. On your diagram, mark where heat enters the cycle and where heat leaves the cycle. Represent the work done by one cycle on your diagram.
- (ii) Derive an expression for the work done by one Diesel cycle in terms of γ , P_A , P_B , P_D , V_A , V_B & V_C .
- (iii) Derive an expression for the heat entering the Diesel motor in terms of γ , P_A , P_B , P_D , V_A , V_B & V_C (note: you may not use all of these parameters).
- (iv) Derive an expression for the heat leaving the Diesel motor in terms of γ , P_A , P_B , P_D , V_A , V_B & V_C (note: you may not use all of these parameters).
- (v) Show that the efficiency of the Diesel cycle is given by:

$$\eta = 1 - \frac{1}{\gamma} \left(\frac{T_D - T_A}{T_C - T_B} \right)$$