THE UNIVERSITY OF NEW SOUTH WALES

SCHOOL OF PHYSICS

MIDSESSION TEST – SEPTEMBER 2009

PHYS2060 – THERMAL PHYSICS

Time allowed – 50 minutes

Total number of questions – 3

Attempt **ALL** questions

Attempt **ALL** parts

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

Specific heat of liquid H_2O = 4.18 J/gK
Latent heat of the liquid-solid transition for H_2O = 333 J/g
Latent heat of the liquid-gas transition for H_2O = 2270 J/g
Adiabatic constant for N_2 g = 1.4
Specific heat at constant pressure for N_2 C_P = 29.12 J mol^{-1} K^{-1}
Specific heat at constant pressure for N_2 C_V = 20.8 J mol^{-1} 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

$$\kappa_T = \frac{-1}{V}\left(\frac{\partial V}{\partial P}\right)_T$$ Isothermal compressibility

$$\beta = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P$$ Expansivity

$$\kappa_S = \frac{-1}{V}\left(\frac{\partial V}{\partial P}\right)_S$$ Adiabatic compressibility

$$c_V = \frac{1}{n}\left(\frac{\partial U}{\partial T}\right)_V$$

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

Thermodynamic potentials

F=U-TS	*dF=-SdT-PdV*	Helmholtz Free Energy
H=U+PV	*dH=TdS+VdP*	Enthalpy
G=U-TS+PV	*dG=-SdT+VdP*	Gibbs Free Energy

Ideal gas

PV=NkT

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

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

Efficiency of Carnot cycle

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

QUESTION 1 (5 marks)

(i) Explain the difference between extensive parameters and intensive parameters, giving examples of each.

You are given the following thermodynamic parameters: P, S, T, V, μ, U, N

(ii) Draw a table with two columns, one labelled "Extensive", the other labelled "Intensive". Enter the parameters into your table in the appropriate column and place conjugate parameters adjacent to each other (in the same row), linked by a line or arrow.

(iii) What is meant by a "state variable" or "state parameter"? Give examples of parameters that are state variables. Given examples of parameters that are NOT state variables.

(iv) How do state variables differ from other properties of a system during a thermodynamic process?

(v) What is a quasi-static process? Why is it important in thermodynamics?

QUESTION 2 (5 marks)

PART A

(i) Show that for an ideal gas, the specific heat at constant pressure is given by:

$$c_P = \frac{\gamma}{\gamma - 1} R$$

where γ is the adiabatic constant and R is the universal gas constant.

PART B

The fundamental equation for a single component system can be expressed by the first order homogeneous equation:

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

where first order homogeneous implies that for any λ:

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

(ii) Using this property, show that for a single component system, the fundamental equation can be written in terms of specific values as:

$$u = u(s, v)$$

QUESTION 3 (10 marks)

A heat engine is based on a Joule or Brayton cycle, A→B→C→D→A where:

A→B is an isobaric compression at low pressure P_L
B→C is an adiabatic compression where the pressure increases to P_H
C→D is an isobaric expansion at high pressure P_H
D→A is an adiabatic expansion where the pressure drops to P_L

This heat engine uses an ideal gas (adiabatic constant γ) as the working substance.

(i) Draw the Joule/Brayton cycle on a P-V diagram, marking the points A, B, C and D and labelling the pressures P_H and P_L.
(ii) On your diagram, mark steps where heat enters or leaves the system.
(iii) Derive an expression for the amount of heat that enters the system (per cycle) in terms of γ and the pressures and volumes of the appropriate end states.
(iv) Derive an expression for the amount of heat that leaves the system (per cycle) in terms of γ and the pressures and volumes of the appropriate end states.
(v) Hence (or otherwise) determine the work produced by the Joule/Brayton cycle engine (per cycle).
(vi) Show that the efficiency of the Joule/Brayton cycle is given by:

$$\eta = 1 - \left(\frac{P_L}{P_H}\right)^{\frac{\gamma-1}{\gamma}}$$