THE UNIVERSITY OF NEW SOUTH WALES
SCHOOL OF PHYSICS

MIDSESSION TEST – SEPTEMBER 2015

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

Time allowed – 50 minutes

Total number of questions – 2

Attempt **ALL** questions

Attempt **ALL** parts

The questions are 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 $\qquad$ $k_B = 1.38 \times 10^{-23}$ J/K

Avogadro's number $\qquad$ $N_A = 6.022 \times 10^{23}$ mol^{-1}

Real gas constant $\qquad$ $R = 8.314$ 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

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

Thermodynamic quantities

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

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

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

Thermodynamic potentials

$F = U - TS$ $\qquad$ $dF = -SdT - PdV + \mu dN$ $\qquad$ Helmholtz Free Energy

$H = U + PV$ $\qquad$ $dH = TdS + VdP + \mu dN$ $\qquad$ Enthalpy

$G = U - TS + PV$ $\qquad$ $dG = -SdT + VdP + \mu dN$ $\qquad$ Gibbs Free Energy

Ideal gas

$PV = NkT$

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

$PV^\gamma = const$ for Adiabatic process

$$\gamma = \frac{c_P}{c_v} = \frac{f+2}{f}$$

Efficiency of Carnot cycle

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

QUESTION 1

Part A

(i)   What is meant by a quasi-static process? Give an example.

(ii)   How is a reversible process related to a quasi-static process? Give examples.

Part B

For a monatomic ideal gas, the energy of the system is given by:

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

where N is the number of atoms, m is the mass of an atom and v is its velocity.

(iii)   How is this microscopic equation related to the macroscopic equation of state:

$$U = \frac{3}{2} NkT \; ?$$

(iv)   What is the origin of the factor of 3 in the macroscopic equation of state when compared with the microscopic equation?

Part C

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

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

(v)   Show that for a single component system, the fundamental equation can be written in terms of specific values as:

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

(vi)   Explain why the number of variables has been reduced from three in the full fundamental equation to two in the specific value version of the equation.

QUESTION 2

Part A

An Otto cycle engine comprises the following processes:

- A→B – an adiabatic compression from volume V_H to V_L
- B→C – an isochoric pressurization at volume, V_L
- C→D – an adiabatic expansion from volume V_L to V_H
- D→A – an isochoric depressurization at volume, V_H.

Assume that the working fluid for an ideal Otto engine is an ideal gas.

(i)   Sketch the Otto cycle on a P-V diagram. On your diagram indicate: the direction of the cycle; processes where heat enters and leaves the cycle; and the total work done by the cycle.

(ii)   Derive an expression for the total work done by one cycle of the Otto engine in terms of V_H, V_L, P_A, P_B, P_C, P_D and γ.

(iii)   Derive an expression for the heat input into one cycle of the Otto engine in terms of V_H, V_L, P_A, P_B, P_C, P_D and γ.

(iv)   Show that the efficiency of the Otto cycle can be expressed as:

$$\eta = 1 - \frac{T_A}{T_B}$$

where T_A and T_B are the temperatures at points A and B.

(v)   Comment on the similarity between this expression and that for the Carnot cycle efficiency. Are they related or is the form just a coincidence?

Part B

The Otto cycle engine is converted to an Atkinson cycle engine by implementing the following changes to the Otto cycle:

- A→B→C – these processes of the Otto cycle are unchanged.
- C→E – the adiabatic expansion from point C is allowed to continue past volume V_H (point D) to point E where the pressure of the gas is equal to the pressure at point A, P_A.
- E→A – the isochoric depressurisation D→A is replaced by an isobaric compression E→A.

(vi)   Sketch the Atkinson cycle A→B→C→E→A on a new P-V diagram. Mark where heat enters and leaves the Atkinson cycle engine. Indicate the work done by the cycle on your diagram.

(vii)   How does the efficiency of the Atkinson cycle compare with the original Otto cycle on which it is based? (Note: you need NOT derive an expression for efficiency in order to make your comparison).

(viii)   Comment on how the efficiency of the Atkinson cycle engine compares to a Carnot cycle engine.