Physics II
ISI B.Math
Mid Semestral Exam : March 6, 2006

Time: 2 hours
Total Marks: 100
Answer question 1 and any 4 of the rest

1. For the following multiple choice questions indicate your answers by the appropriate letters (a), (b), (c) or (d).

i) A system is changed from an initial equilibrium state to the same final equilibrium state by two different processes - one reversible, and one irreversible. Which of the following is true, where ΔS refers to the system?
(a) $\Delta S_{irr} = \Delta S_{rev}$
(b) $\Delta S_{irr} > \Delta S_{rev}$
(c) $\Delta S_{irr} < \Delta S_{rev}$
(d) No decision is possible with respect to (a), (b) or (c).

ii) An exact differential expression relating thermodynamic variables is given by

$$dB = CdE - FdG + HdJ$$

Which of the following would not be a new thermodynamic potential function consistent with the above expression?
(a) $B - CE$
(b) $B - HJ$
(c) $B - FG - CE$
(d) $B - HJ + FG - CE.$

iii) Given the same exact differential expression as in (ii) we conclude that
(a) $\left(\frac{\partial C}{\partial G}\right)_E = \left(\frac{\partial F}{\partial E}\right)_G$
(b) $\left(\frac{\partial C}{\partial J}\right)_{E,G} = \left(\frac{\partial H}{\partial E}\right)_{J,G}$
(c) $\left(\frac{\partial F}{\partial G}\right)_{E,J} = -\left(\frac{\partial E}{\partial C}\right)_{G,J}$
(d) None of the above.

iv) For a PVT system,

$$T\left(\frac{\partial S}{\partial T}\right)_P - T\left(\frac{\partial S}{\partial T}\right)_V$$

is *always* equal to
(a) zero
(b) $\gamma = \frac{C_P}{C_V}$
(c) R
(d) $T\left(\frac{\partial P}{\partial T}\right)_V \left(\frac{\partial V}{\partial T}\right)_P$

v) The expression $\left(\frac{\partial P}{\partial V}\right)_T \left(\frac{\partial T}{\partial P}\right)_S \left(\frac{\partial S}{\partial T}\right)_P$ is equivalent to

(a) $\left(\frac{\partial S}{\partial V}\right)_T$
(b) $\left(\frac{\partial P}{\partial T}\right)_V$
(c) $\left(\frac{\partial V}{\partial T}\right)_S$
(d) - $\left(\frac{\partial P}{\partial T}\right)_V$

2.(a) Show that if two quasi-static adiabatic curves intersect, the second law of thermodynamics is violated.
(b) Find the efficiency for a reversible engine operating around the cycle

illustrated.
(c) Prove that the slope on a TS diagram of an isochoric (const. volume) curve is T/C_V. Why does an isochoric curve plotted on a TS diagram have a greater slope than an isobaric(const. pressure) curve at the same temperature ?
(d) Two equal volume bulbs containing 1 mole each of a certain ideal gas at the same temperature are connected by a valve. What is the entropy change when the valve is opened ?

3. A room air conditioner operates as a Carnot cycle refrigerator between an outside temperature T_h and a room at lower temperature T_i. The room

gains heat from the outside at the rate $A(T_h - T_i)$; this heat is removed by the air conditioner. The power supplied to the cooling unit is P.
(a)Show that the steady state temperature of the room is

$$T_i = (T_h + P/2A) - [(T_h + P/2A)^2 - {T_h}^2]^{\frac{1}{2}}$$

(b) If the outdoors is at 37 C and the room is maintained at 17 C by a cooling power of 2kW, find the heat loss coefficient of the room in W/K.

4.(a) For a PVT system show that

$$\left(\frac{\partial U}{\partial V}\right)_P = T\left(\frac{\partial P}{\partial T}\right)_V - P$$

(b) Show that a gas which obeys the van der Waals equation $(p + \frac{a}{V^2}) \times (V - b) = RT$ and whose molar specific heat at constant volume C_V is a constant and independent of temperature, the internal energy (per mole) U is given by

$$U = C_V T - \frac{a}{V} + const$$

and that for an adiabatic quasistatic change

$$T(V-b)^\gamma = constant$$

where $\gamma = (C_V + R)/C_V$. Also determine the temperature change when this gas undergoes an adiabatic free expansion in vacuum.

5. (a) By considering a Carnot engine operating in the region of equilibrium coexistence of a liquid and its saturated vapour, derive the Clausius-Clapeyron equation given below. [Hint: On the P-V diagram for this system, draw two neighbouring isothermals at temperatures T and $T + dT$ respectively and operate the engine between these two isothermals by connecting them with adiabatic curves]

$$\left(\frac{dP}{dT}\right) = \frac{\lambda}{T(v_2 - v_1)}$$

where λ is the latent heat of the liquid - vapour phase transition, v_2 , v_1 are the specific volumes of the vapour and water respectively at the transition

temperature.
(b) During the above phase transition, state which of the following quantities remain constant and which change .– molar entropy (s), molar Gibbs potential (g) , molar Helmholtz potential (f) , molar heat capacity (c_p). Give a brief explanation accompanying your answer.
(c) Using the result in part (a) show that the saturated vapour pressure p_s of a liquid is given by

$$p_s \propto \exp(-\lambda M/RT)$$

provided the vapour can be approximated as an ideal gas and the latent heat λ of vaporization may be considered constant over the temperature range of interest. M is the molecular weight of the vapour.

6. (a) Which thermodynamic potential function remains constant during the process of Joule - Thomson expansion ?
(b) Is the Joule - Thomson throttling process a reversible process ? Explain your answer.
(c) Show that in a Joule- Thomson expansion , no temperature change occurs if $\beta = 1/T$ where β is the coeficient of volume expansion of the gas. Hence show that there is no temperature change when an ideal gas undergoes the throttling process.
(d) The Joule- Thomson coefficient μ is a measure of the temperature change during the throttling process. A similar measure of the temperature change produced by an isentropic change of pressure is provided by the coefficient $\mu_S = \left(\frac{\partial T}{\partial P}\right)_S$. Show that

$$\mu_S - \mu = \frac{V}{C_P}$$

7. The lower 10-15 km of the atmosphere – the troposphere - is often in a convective steady state at constant entropy, not constant temperature. Use the condition of mechanical equilibrium in a uniform gravitational field to
(a) Show that $\frac{dT}{dz}$ is a constant, where z is the altitude.
(b) Estimate $\frac{dT}{dz}$ in C/km. Take $\gamma_{air} = 7/5$ and the molecular weight of air $= 29$.
(c) Show that $p \propto \rho^\gamma$ where ρ is the mass density.