

Physics II
ISI B.Math

Mid Semestral Exam : March 4, 2004

Total Marks: 100

Answer all questions.

1. For the following multiple choice questions indicate your answers by the appropriate letters (a), (b), (c) or (d). (15)

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. For each of the following statements indicate whether it is true or false and give a brief explanation. A few lines should suffice.

(20)

- a) For a closed system the value of $\int P dV$ for the change of a gas from one given state to another is a constant regardless of the path, as long as all processes are reversible.
- b) The entropy of an ideal gas is a function of temperature only.
- c) The equation $dH = TdS + pdV$ can be applied only to reversible processes.
- d) The enthalpy of an ideal gas is a function of temperature only.
- e) For any process the second law of thermodynamics requires that the entropy change of the system be zero or positive.
- f) An ideal gas violates the third law of thermodynamics.
- g) The internal energy of an isolated system must be constant.
- h) All ideal gases have the same molar heat capacity at constant pressure.
- i) The Helmholtz free energy of an isolated system must be constant.
- j) A Carnot engine whose thermal efficiency is very high is particularly well suited for a refrigerator, when run in the reeerve direction.

3. A cylindrical container 80 cm long is separated into two compartments by a thin piston, originally clamped in position 30 cm from the left end. The

(15)

left compartment is filled with one mole of helium gas at a pressure of 5 atmospheres; the right compartment is filled with argon gas at 1 atmosphere of pressure. These gases may be considered ideal. The cylinder is submerged in 1 litre of water, and the entire system is initially at the uniform temperature of 25 C. The heat capacities of the cylinder and the piston may be neglected. When the piston is unclamped, a new equilibrium situation is ultimately reached with the piston in a new position.

- a) What is the increase in the temperature of the water?
- b) What is the final position of the piston ?
- c) What is the increase of total entropy of the system?

4. a) Show that in an isobaric isothermal transformation of a system, the Gibb's potential G can never increase. (4)

b) Show that the saturated vapour pressure p_s of a liquid is given by

$$p_s \propto \exp(-L/RT)$$

provided that the temperature is not too close to the critical temperature so that the pressure is sufficiently small and the latent heat L of vaporization may be considered constant over the temperature range of interest.

c) Show that the following processes are irreversible

(i) A gas undergoes a free adiabatic expansion from volume V to $V+dV$, $dV > 0$. (3)

(ii) A gas expands adiabatically by a Joule-Thomson process from a pressure p to $p+dp$, $dp < 0$ (3)

5.(a) For a PVT system show that

$$\left(\frac{\partial U}{\partial V}\right)_P = T \left(\frac{\partial P}{\partial T}\right)_V - P \quad (5)$$

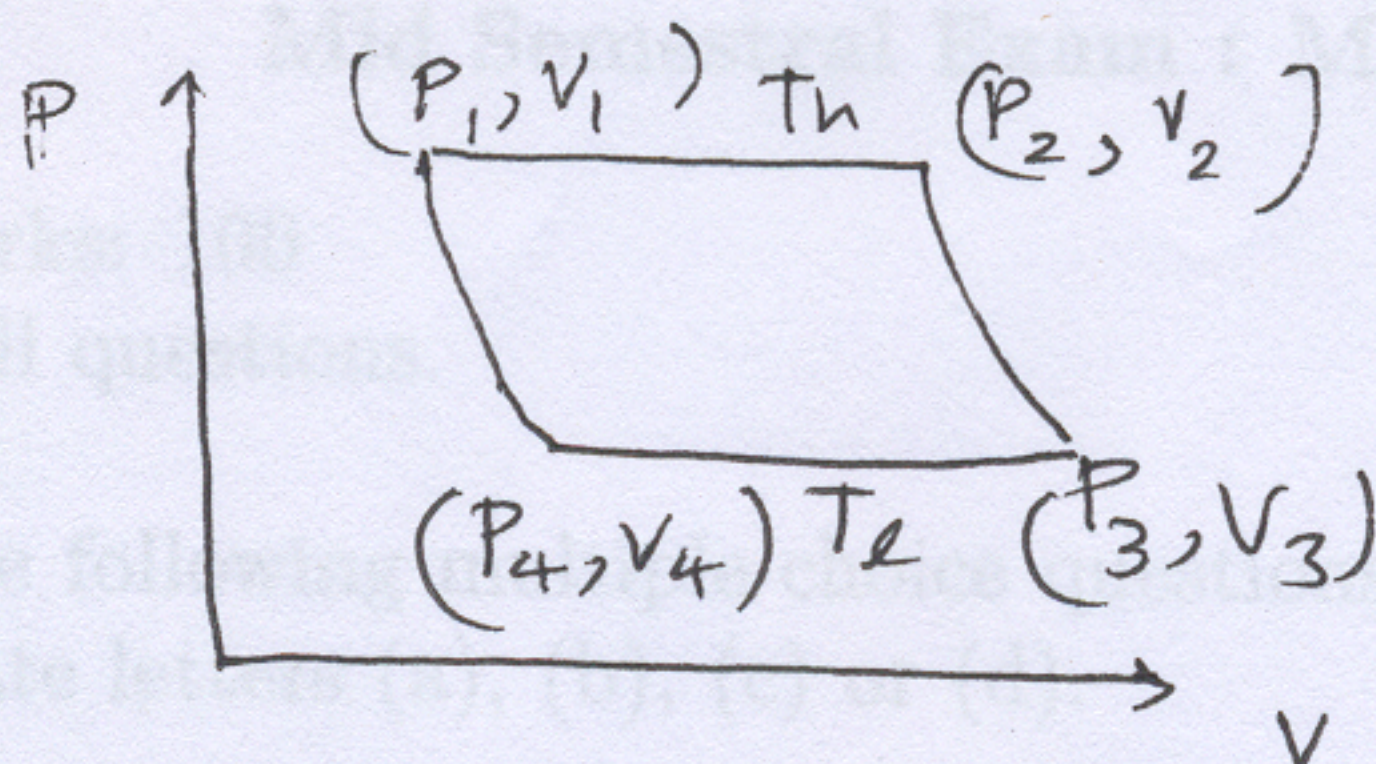
(b) Show that a gas which obeys the van der Waals equation $(p + \frac{a}{V^2}) \times (V - b) = RT$ and whose molar specific heat at constant volume C_V is a constant and independent of temperature, the internal energy (per mole) U is given by (15)

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

and that for an adiabatic quasistatic change

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

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



6. Consider a Carnot engine whose working material is a photon gas or radiation. The internal energy density of this radiation is given by $u = \sigma T^4$ (where $\sigma > 0$ is a constant) and the radiation pressure $p = \frac{1}{3}u$ (15)

(a) Given T_h and T_l (where T_h and T_l are the temperatures of the high and low temperature reservoirs respectively) as well as V_1 and V_2 determine V_3 and V_4 .

(b) What is the heat Q_h taken up and the work done by the gas during its first isothermal expansion? Are they equal to each other, as for an ideal gas?

(c) Do the isentropic stages cancel each other out as in an ideal gas (i.e, is the work done during one isentropic stage equal and opposite to that performed in the other isentropic stage of the cycle?) ?

(d) Calculate the total work done by the gas during one cycle. Compare it with the heat taken up at T_h and show that the energy conversion efficiency is the Carnot efficiency.