UNIVERSITY OF RUHUNA

BACHELOR OF SCIENCE GENERAL DEGREE LEVEL II(SEMESTER I) EXAMINATION JULY 2015

Subject:PHYSICS
Course Unit: PHY2114

Time: Two hours & 30 minutes

Part II

Answer FIVE(05) questions only
At least 01(ONE) question from Part B should be answered.

All symbols have their usual meaning

Part A

1. (a) The temperatures of the inner and outer surfaces of a spherical shell having respective inner and outer radii a and b are maintained at temperatures T_1 and T_2 $(T_1 > T2)$, respectively. Thermal conductivity of the shell material is k.

   i. Show that the rate of radial heat transfer through the shell is given by

$$\frac{dQ}{dT} = \frac{4\pi kab(T_1 - T_2)}{(b-a)}.$$

   ii. If $k = 0.7W\,\mathrm{m^{-1}\,K^{-1}}$, $a = 0.1\,\mathrm{m}$ and $b = 0.3\,\mathrm{m}$, calculate the rate of radial heat transfer through the shell.

   (b) Explain following physical phenomena, briefly.

   i. Many motor cycle engines don't have a radiator.

   ii. Radiator is mounted in the front side of most vehicles.

   iii. Usually the boiling point of water in Nuwaraeliya is less than that in Matara.

2. (a) Write down the first law in thermodynamics describing each term.

   (b) Show that the slope of adiabatics is γ times the slope of isothermals.

   (c) One mole of an ideal gas $(\gamma = \frac{5}{3})$ at (1.5 atm, V, 300 K) is capable of executing following processes.

   $A \longrightarrow B$: the gas expands isothermally until its volume becomes $1.5V$.
   $B \longrightarrow C$: pressure of the gas increases up to 1.25 atm through an isochoric process.
   $C \longrightarrow D$: the gas undergoes an adiabatic process.
   $D \longrightarrow A$: the gas comes back to the initial state through an isobaric process.

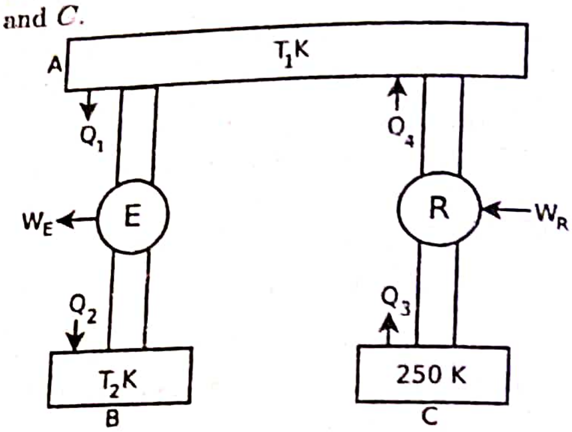
   i. Draw a $P - V$ diagram for the above cyclic process.

   ii. Find volume at state D in terms of V.

   iii. Find the pressure at state B.

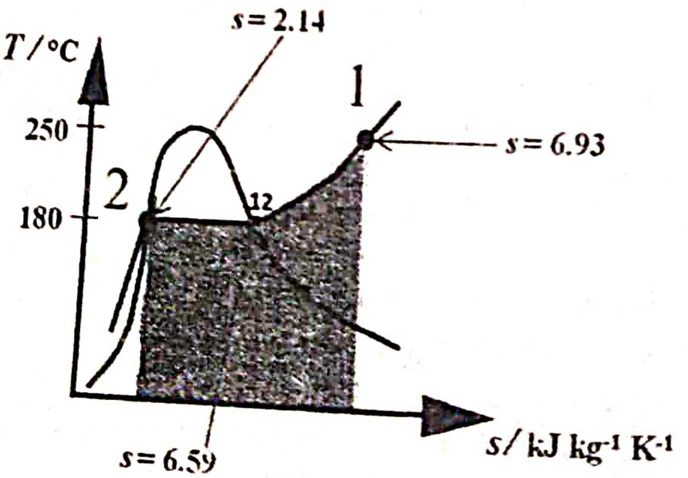
   iv. If $V = 0.1\,\mathrm{m^3}$, find the work done by the gas during the above cyclic process. [When 1 mole of an ideal gas changes its state from (P_1, V_1, T_1) to (P_2, V_2, T_2), the work done by the gas during isothermal and adiabatic processes are given by $W = RT\ln\frac{V_2}{V_1}$ and $W = \frac{(P_2V_2 - P_1V_1)}{(1-\gamma)}$, respectively. Universal gas constant $(R) = 8.314\,\mathrm{J\,K^{-1}\,mol^{-1}}$, $1\,\mathrm{atm} = 1 \times 10^5\,\mathrm{N\,m^{-2}}$]

3. (a) What is meant by a heat reservoir?
   (b) Write down differences between internal and external combustion engines.
   (c) Define the efficiency (η) of an engine and the coefficient of performance (K) of a refrigerator.
   (d) Show that $K = \frac{T_C}{T_H - T_C}$.
   (e) Following figure shows a reversible engine and a reversible refrigerator operating among three reservoirs A, B and C.



      i. If the coefficient of performance of the refrigerator is 1.0, calculate T_1.
      ii. If the maximum efficiency of a hypothetical engine operating between the reservoirs B and C is 50%, calculate T_2.
      iii. If $W_E = 300\,\text{J}$ and $W_R = 400\,\text{J}$ calculate Q_1, Q_2, Q_3 and Q_4.

4. (a) Sketch a Carnot cycle in a $T-S$ diagram and describe the processes, briefly.
   (b) A piston/cylinder combination has 1 kg water in a superheated vapor state at 1000 kPa, 250 °C with specific volume (v), 0.23 m^3 kg^{-1} and entropy (s), 6.93 kJ kg^{-1} K^{-1}. This system is now cooled with a constant-loading to a final temperature of 180 °C as shown in the $T-s$ diagram below. This isobaric process ends when the water has reached a state of saturated liquid water with specific volume (v_f), 0.001 m^3 kg^{-1}, and entropy(s_f), 2.14 kJ kg^{-1} K^{-1}. During this process the water goes through an intermediate stage (i.e. state-12 in diagram) of saturated water vapour, and the entropy of the water vapour state (s_g) is 6.59 kJ kg^{-1} K^{-1}. (Any lowercase symbol for volume or entropy indicates that it is a specific property and represents the property value per unit mass.)



      i. If the process is reversible, then estimate the heat transfer using the area in the $T-s$ diagram. (Assume that the entropy changes linearly with temperature in the superheated region of water-vapor.)

ii. If the process is irreversible and the water is let to cool down to a ambient temperature of 180 °C under constant-loading, then find the total entropy generation in the process.

5. (a) Use the expression $Tds = C_p dT - vdP$ to show that, for an ideal gas the change in entropy per unit mass can be given by $s_2 - s_1 = C_p \ln(T_2/T_1) - R\ln(P_2/P_1)$.
Where C_p is the specific heat capacity at constant pressure.
(Any lowercase symbol for volume or entropy indicates that it is a specific property and represents the property value per unit mass).

(b) Using above expression of $(s_2 - s_1)$ and assuming C_p is constant in temperature, show that for an ideal gas that undergoes a constant entropy (isentropic)process is

$$T_2/T_1 = (P_2/P_1)^{(k-1)/k},$$

where $k = C_p/C_v$, C_v is the specific heat capacity at constant volume, and $R = C_p - C_v$.

(c) Helium contained in a cylinder at ambient conditions of, 100 kPa, and 20 °C, is compressed to 600 kPa in a reversible isothermal process. (Assume helium behaves as an ideal gas and for helium $C_p = 5.19\,\mathrm{kJkg^{-1}K^{-1}}$, $C_v = 3.12\,\mathrm{kJkg^{-1}K^{-1}}$ and individual gas constant $(R) = 2.077\,\mathrm{kJkg^{-1}K^{-1}}$.)
Using expression derived in part (a), find the change in entropy per kilogram of helium during this isothermal process. Hence, find the heat-transfer per kilogram of helium.

6. (a) You are given the expression $dh = Tds + vdP$.
i. Using $C_v = T(\partial s/\partial T)_v$, find an expression for $(\partial h/\partial T)_v$ in terms of P, v, T and C_v. Using this result show that, $C_p - C_v = R$ for an ideal gas.
(Any lowercase symbol for volume, entropy or enthalpy indicates that it is a specific property and represents the property value per unit mass).
ii. Using Maxwell's relation $(\partial s/\partial P)_T = -(\partial v/\partial T)_P$, derive an expression for $(\partial h/\partial P)_T$ in terms of P, v and T.
iii. Using the result in part (ii) above, find $(\partial h/\partial P)_T$ for an ideal gas. what can you say about the shape of an $h - P$ diagram during an isothermal process of an ideal gas?

(b) i. Using $dh = (\partial h/\partial T)_P dT + (\partial h/\partial P)_T dP$ and the expression you got in part (a) (ii), show that the change in enthalpy per unit mass of a simple compressible substance can be written as,

$$h_2 - h_1 = \int_1^2 C_p dT + \int_1^2 [v - T(\partial v/\partial T)_P] dP.$$

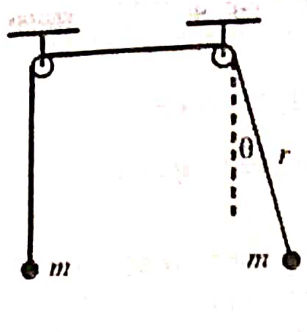
(Any lowercase symbol for volume, entropy or enthalpy indicates that it is a specific property and represents the property value per unit mass.)
ii. Using the expression in part (b) (i), show that for an ideal gas the enthalpy is only a function of temperature.

Part B

7. Two equal masses, m, connected by a string, hang over two pulleys of negligible size, as shown in the figure. The left one moves in a vertical line, but the right one is free to swing to the sides in the plane of the masses and pulleys.

   (a) Write down the Lagrangian for the system.

   (b) Determine the equations of motion for r and θ.



8. Potential energy function between two atoms in a diatomic molecule can be expressed as follows:

$$V(x) = \frac{a}{x^{12}} - \frac{b}{x^6}$$

where a and b are positive constants and x is the distance between atoms.

   (a) For which values of x, is $V(x)$ equal to zero?

   (b) For which values of x, is $V(x)$ a minimum?

   (c) Derive an expression for the force between two atoms. Show that the two atoms repel each other for x less than a value x_0. What is the value of x_0?

9. A particle moves in a circular orbit of radius r under the influence of an attractive central force.

   (a) Show that this orbit is stable if $f(r) > -\frac{r}{3}\frac{\partial f}{\partial r}|_r$, where $f(r)$ is the magnitude of the force as a function of the distance r from the center.

   (b) If the attractive central force is $f(r) = \frac{k_2}{r^2} + \frac{k_4}{r^4}$, where k_2 and k_4 are constants, show that a stable circular orbit with radius r_0 is possible only if $r_0^2 k_2 > k_4$.