KENYATTA UNIVERSITY

UNIVERSITY EXAMINATIONS 2011/2012

SECOND SEMESTER EXAMINATION FOR THE DEGREE OF BACHELOR OF SCIENCE (TELECOMMUNICATION AND INFORMATION TECHNOLOGY)

SPH 307: THERMAL PHYSICS II

DATE: WEDNESDAY, 4TH APRIL 2012 **TIME:** 2.00 P.M. – 4.00 P.M.

INSTRUCTIONS

1. Answer question **one** and **any other two** questions. Question one carries two marks While each of the other questions carry 20 marks.

2. Where necessary use the constants
   i). Universal gas constant R = 8.31 J/mol.K
   ii) Specific heat capacity of water C = 4200 J/kg.K
   iii) Latent heat of fusion of water 3.34×10^5 J/kg
   iv) Specific heat capacity of ice = 2000 J/kgK

Q1. a) i) State Kelvin-Planck statement of the second law of thermodynamics [1mark]

ii) Define a reversible process ? [1mark]

iii) Explain what is meant by a quasistatic process [1mark]

iv) State and prove Carnot's theorem for a reversible heat engine [6marks]

b) A Carnot engine working as a refrigerator between the temperatures 260 K and 300 K receives 2100 J of heat from reservoir at the lower temperature.. Calculate :

i) the heat rejected to the sink. [2marks]

ii) the work done in each cycle to operate the refrigerator. [2marks]

iii) the coefficient of performance of the refrigerator. [2marks]

c) Using the first law of thermodynamics, show that the entropy change of an ideal gas which is allowed to expand at constant temperature is

$$S_2 - S_1 = nR\ln\left(\frac{V_2}{V_1}\right)$$

where n is the number of moles and R is the universal gas constant. [4marks]

d) A 0.06kg cube of ice at an initial temperature of -15° C is placed in 0.5kg of water at a temperature of 60° C in an insulated container of negligible mass. Calculate the entropy change of the system. [6marks]

e) Starting from the fundamental thermodynamic relation, and using the appropriate Maxwell relation, show that

$$\left(\frac{\partial U}{\partial P}\right)_T = -T\left(\frac{\partial V}{\partial T}\right)_P - P\left(\frac{\partial V}{\partial P}\right)_T$$ [3marks]

g) Give the characteristics of a first order phase transition. [2marks]

Q2. a) Prove that Clausius statement is equivalent to Kelvin – Planck's statement of the Second law of thermodynamics [5marks]

b) A heat engine operating between two reservoirs has an efficiency of 30 % and does 2500 J of work on the surroundings in each cycle. Calculate the amount of heat absorbed in each cycle from the hot reservoir and the cold reservoir. [3marks]

c) i) Show that for Carnot engine using an ideal gas and operating between reservoirs at temperature T_1 and T_2 ($T_1 > T_2$) the thermal efficiency is given by

$$\eta = \frac{T_1 - T_2}{T_1}$$ [6marks]

ii) Explain why the efficiency of a real engine operating at the same temperature Would be lower than that of Carnot engine. [2marks]

d) A inventor claims to have developed an engine that is said to extract 5000J of heat per cycle from a reservoir at 400 K, and rejects 3500 J of heat per cycle to a reservoir at 300 K and do 1500 J of work per cycle on the surroundings. Comment on this claim [3marks]

Q3. a) i) Clearly distinguish between the critical point and the triple point temperatures of substance. [2marks]

ii) For a typical pure substance, sketch the projection of P-V-T surface in the P-T plane. Label the salient features of the projection. [3marks]

iii) The equations of the sublimation and vaporization curves of a particular material are

$$\ln P = 0.04 - \frac{6}{T} \quad \text{.........Sublimation}$$

$$\ln P = 0.03 - \frac{4}{T} \quad \text{.........Vaporization}$$

where P is the pressure in atmosphere. Find the temperature and pressure at the triple point. [3marks]

b) The equation of state of a real gas is

$$(P + \frac{n^2 a}{V^2})(V - nb) = nRT$$

where a and b are constants and the rest of symbols have their usual meaning. Determine P, V, and T at the critical point. [5marks]

c) i) State the condition for equilibrium between two phases of a one component system maintained at constant pressure and temperature. [1mark]

ii) Use this equilibrium condition to obtain the Causius -Clapeyron equation. [4marks]

iii) Use the Clausius – Clapeyron equation to deduce the conditions for first – order phase transition. [2marks]

Q4. a) i) What is a thermodynamic potential function ? [1mark]

ii) Define four thermodynamic potentials [2marks]

iii) Using the differential forms of the four thermodynamic potential functions derive the four Maxwell relations. [6marks]

b) One mole of ice is converted into liquid water at 273 K and 10^5 Pa. Given that the accompanying change in volume is is 1.64×10^{-6} mol^{-1}. Calculate the change in :

i) Helmholtz free energy [2marks]

ii) Gibbs' free energy [2marks]

c) i) Calculate the thermal efficiency of an engine that operates by taking 2 moles of an ideal gas through the following cycle. Take $C_v = 20.5\ Jmol^{-1}K^{-1}$ [5marks]

ii) Calculate the efficiency of a Carnot engine operating at the same temperature range. (See Fig 4.1)
[2marks]

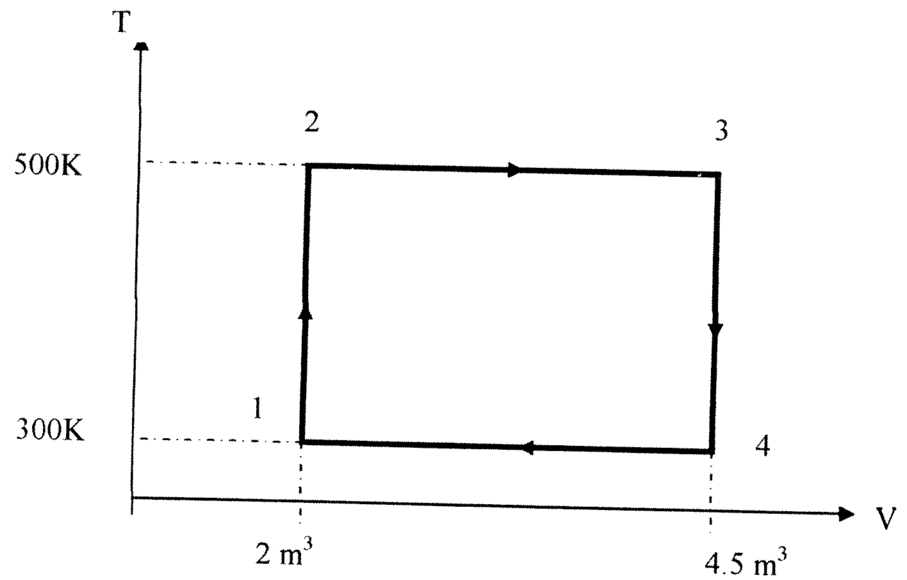

Fig 4.1 TV diagram cycle of an engine.

Q5. a) Briefly discuss the merits and demerits of the throttling process and adiabatic expansion against a restraining force as a method of producing low temperature. [3marks]

b) State the third law of thermodynamics and explain it. [2marks]

c) Use the statement of the third law of thermodynamics to show that at absolute zero temperature, solids and liquids have zero:

a. heat capacity [3marks]
b. thermal expansion coefficient [4marks]

d) i) Draw a PV diagram for the air standard cycle for an Otto engine and name the processes. [3marks]

ii) Show that the thermal efficiency η for air-standard Otto cycle is

$$\eta = 1 - \frac{1}{r_v^{\gamma - 1}}$$

where r_v is volume compression ratio and γ is the ratio of the specific heats. [5marks]
