BINDURA UNIVERSITY OF SCIENCE EDUCATION

FACULTY OF SCIENCE

CHEMISTRY DEPARTMENT

JAN 2025

HBScED and HBSc CHT

COURSE: **CH101:** **PHYSICAL CHEMISTRY I**

TIME: **2 HOURS**

Answer **QUESTION ONE (1)** and **FOUR (4) OTHERS.** Each question carries **20 marks.**

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1. a) Calculate w for the adiabatic expansion of one mole of an ideal gas at an initial pressure of 2.00 bar from an initial temperature of 450 K to a final temperature of 300 K. [4 marks]

   b) Write an expression for the work done in the isothermal reversible expansion of the gas at 300 K from an initial pressure of 2.00 bar. What value of the final pressure would give the same value of w as in (a)? [4 marks]

   [Assume that $C_{P,m} = 5/2\ R$.]

   c) For one mole of an ideal gas, $P_{external} = P = 200 \times 10^3$ Pa. The temperature is changed from 100°C to 25.0°C at constant pressure. $C_{V,m} = 3/2\ R$. Calculate ΔU, ΔH, q, and w. [6 marks]

   d) Classify the following processes as spontaneous or not spontaneous and explain your answer.

      (i) The vaporization of superheated water at 102°C and 1 bar.

      (ii) The constant pressure melting of ice at its normal freezing point by the addition of an infinitesimal quantity of heat.

      (iii) The adiabatic expansion of a gas into a vacuum. [6 marks]

SECTION A: Answer **TWO (2)** questions from this section.

2. a) An electric motor produces 96 kJ of energy each second as mechanical work and loses 8 kJ as heat to the surroundings. What is the change in the internal energy of the motor each second? [4 marks]

   b) Calculate the work done when 50 g of iron reacts with hydrochloric acid to produce $FeC1_2$(aq) and hydrogen in: [4 marks]

      (i) a closed vessel of fixed volume,

      (ii) an open beaker at 25°C [6 marks]

   c) Calculate the solar energy required to produce 5255 g of $C_6H_{12}O_6$ given the thermochemical equation for photosynthesis:

$$6H_2O_{(l)} + 6CO_{2(g)} \rightarrow C_6H_{12}O_{6(s)} + 6O_{2(g)} \qquad \Delta H = +2803 kJ/mol$$

   d) What mass of iron must be in a hot pack to provide 335 kJ of heat when the iron reacts with oxygen and is converted to iron (III) oxide according to the following thermochemical equation? [6 marks]

$$2\,Fe(s) + \frac{3}{2}O_2(g) \rightarrow Fe_2O_3(s); \qquad \Delta H^o = -824.2\ kJ/mol$$

3. Consider a 20 L sample of moist air at 60°C and 1 atm in which the partial pressure of water vapor is 0.120 atm. Assume that dry air has the composition 78.0 mole percent N_2, 21.0 mole percent O_2, and 1.00 mole percent Ar.

   a) What are the mole percentages of each of the gases in the sample? [8 marks]

   b) The percent relative humidity is defined as % RH = $\frac{P_{H_2O}}{P^*_{H_2O}}$ where P_{H_2O} is the partial pressure of water in the sample and $P^*_{H_2O}$ = 0.197 atm is the equilibrium vapor pressure of water at 60°C. The gas is compressed at 60°C until the relative humidity is 100%. What volume does the mixture now occupy? [6 marks]

   c) What fraction of the water will be condensed if the total pressure of the mixture is isothermally increased to 200 atm? [6 marks]

4. a) Real walls are never totally adiabatic. Order the following walls in increasing order with respect to being diathermal: 1 cm-thick concrete, 1 cm-thick vacuum, 1 cm-thick copper and 1 cm-thick cork. [4 marks]

   b) The location of the boundary between the system and the surroundings is a choice that must be made by the thermodynamicist. Consider a beaker of boiling water in an airtight room.

(i) Is the system open or closed if you place the boundary just outside the liquid water? [3 marks]

(ii) Is the system open or closed if you place the boundary just inside the walls of the room? [3 marks]

c) Calculate the amount of heat required to heat 1.01 kg of water from 0.05°C to 35.81°C. [4 marks]

d) Draw a clearly labeled phase diagram for carbon dioxide. [6 marks]

SECTION B: Answer **TWO (2)** questions from this section.

5. a) A pellet of Zn of mass 10.0 g is dropped into a flask containing dilute H_2SO_4 at a pressure $P = 1.00$ bar and temperature $T = 298$ K. What is the reaction that occurs? Calculate w for the process. [4 marks]

b) (i) Under what conditions is $dA \leq 0$ a condition that defines the spontaneity of a process? [2 marks]

(ii) Under what conditions is $dG \leq 0$ a condition that defines the spontaneity of a process? [2 marks]

c) Consider the equilibrium $C_2H_6(g) \leftrightarrow C_2H_4(g) + H_2(g)$. At 1000 K and a constant total pressure of 1 bar, $C_2H_6(g)$ is introduced into a reaction vessel. At equilibrium, the composition of the mixture in mole percent is $H_2(g)$: 26%, $C_2H_4(g)$: 26%, and $C_2H_6(g)$: 48%.

(i) Calculate K_P at 1000 K. [3 marks]

(ii) If $\Delta H^{\circ}_{reaction} = 137.0$ kJ mol^{-1}, calculate the value of K_P at 298.15K. [3 marks]

(iii) Calculate $\Delta G^{\circ}_{reaction}$ for this reaction at 298.15 K. [2 marks]

d) Define the following terms:

(i) Adiabatic process
(ii) State function
(iii) Eutectic
(iv) Super critical fluid [4 marks]

6. a) Why is $\Delta H_{sublimation} = \Delta H_{fusion} + \Delta H_{vaporization}$? [4 marks]

b) For water, $\Delta H_{vaporization}$ is 40.65 kJ mol^{-1}, and the normal boiling point is 373.15 K. Calculate the boiling point for water on the top of a mountain of height 5500 m, where the normal barometric pressure is 380 Torr. [6 marks]

c) The phase diagram of NH_3 can be characterized by the following information. The normal melting and boiling temperatures are 195.2

and 239.82 K, respectively, the triple point pressure and temperature are 6077 Pa and 195.41 K, respectively. The critical point parameters are 112.8×10^5 Pa and 405.5 K. Make a sketch of the *P-T* phase diagram (not necessarily to scale) for NH_3. State which and how many phases are present. [10 marks]

7. a) A chemical reaction occurs under isochoric conditions, in a container with diathermic walls. Will the temperature of the surroundings increase, decrease, or remain same in this process? Explain. [4 marks]

b) 3.00 moles of an ideal gas at 27.0°C expands isothermally from an initial volume of 20.0 dm^3 to a final volume of 60.0 dm^3. Calculate *w* for this process [8 marks]

i. for expansion against a constant external pressure of 1.00×10^5 Pa, and
ii. for a reversible expansion.

c) Calculate the standard enthalpy of formation of $FeS_2(s)$ at 300°C from the data below at 25°C and from the information that for the reaction.

$$2FeS_{2(s)} + \frac{11}{2}O_{2(g)} \rightarrow Fe_2O_{3(s)} + 4\ SO_{2(g)}, \quad \Delta H^\circ_{reaction} = 1655\ \text{kJ mol}^{-1}.$$

Assume that the heat capacities are independent of temperature.

Substance	Fe(*s*)	$FeS_2(s)$	$Fe_2O_3(s)$	S(rhombic)	$SO_2(g)$
ΔH°_f (kJ mol^{-1})			–824.2		–296.81
$C_{P,m}/R$	3.02	7.48		2.72	

[6 marks]

d) Under what conditions are ΔH and ΔU for a reaction involving gases and/or liquids or solids identical? [2 marks]

END OF PAPER