UNIVERSITI
TEKNOLOGI
PETRONAS

FINAL EXAMINATION
JANUARY 2024 SEMESTER

COURSE	**:**	**YBB1023 - PHYSICAL CHEMISTRY I**
DATE	**:**	**4 APRIL 2024 (THURSDAY)**
TIME	**:**	**9:00 AM - 12:00 NOON (3 HOURS)**

INSTRUCTIONS TO CANDIDATES

1. Answer **ALL** questions in the Answer Booklet.
2. Begin **EACH** answer on a new page in the Answer Booklet.
3. Indicate clearly answers that are cancelled, if any.
4. Where applicable, show clearly steps taken in arriving at the solutions and indicate **ALL** assumptions, if any.
5. **DO NOT** open this Question Booklet until instructed.

Note :

i. There are **ELEVEN (11)** pages in this Question Booklet including the cover page .

ii. **DOUBLE-SIDED** Question Booklet.

1. a. Use the kinetic model of gases to explain why light gases, such as He, are rare in the Earth's atmosphere but heavier gases, such as O_2 and N_2, once formed remain abundant.

[5 marks]

b. A vessel of volume 22.4 dm^3 contains gases mixture of 2.0 mol H_2 and 1.0 mol N_2 at 273.15 K initially. All the H_2 then reacts with sufficient N_2 to form NH_3. Calculate:

i. Partial pressures of the gases in the final mixture

[4 marks]

ii The total pressure of the mixture

[2 marks]

c. At 300 K and 20 atm, the compression factor of a gas, Z is 0.86. Calculate:

i. The volume occupied by 8.2 mmol of the gas molecules under these conditions

[4 marks]

ii. The molar volume, V_m of the gas and the approximate value of second virial coefficient, B at 300 K

[5 marks]

2. a. Explain the difference between the change in internal energy and the change in enthalpy accompanying a process.

[4 marks]

b. A sample of argon with a mass of 6.56 g occupies 18.5 dm^3 at 305 K.

i. Calculate the work done when the gas expands isothermally against a constant external pressure of 7.7 kPa until its volume has increased by 2.5 dm^3.

[3 marks]

ii. Determine the work that would be done if the same expansion occurred reversibly.

[3 marks]

c. The heat capacity of air is much smaller than liquid water, and relatively modest amounts of heat are required to change the temperature of air. This is one of the reasons why desert regions very hot during the day and cold at night. The molar heat capacity of air at 298 K and 1.00 atm is approximately 21 J/ K. mol.

i. Estimate how much energy is required to raise the temperature of the air in a room with dimensions 4.5 m × 5.5 m × 3.5 m by 10°C.

[5 marks]

ii. If losses are neglected, predict the duration it takes for a heater rated at 1.25 kW to achieve that increase, given that 1 W = 1 J/s.

[3 marks]

d. The cold sink is at 0°C in an ideal heat engine. If 15.00 kJ of heat is withdrawn from the hot source and 4.00 kJ of work is generated, calculate the temperature of the hot source.

[2 marks]

3. a. Discuss the concept of ideal engine in Carnot Cycle with a diagram by including its **FOUR (4)** successive operations.

[5 marks]

b. A sample consisting of 0.40 mol of perfect gas molecules is held by a piston inside a 1.5 dm^3 cylinder with constant external pressure and temperature at 2.5 bar and 40°C, respectively. The piston is released so that the gas can expand. Calculate:

i. The volume of the gas when the expansion is completed.

[2 marks]

ii. The work done when the gas expands, and the heat absorbed by the systems.

[3 marks]

iii. The change in total entropy surrounding, ΔS_{tot}.

[5 marks]

c. Explain how planes in a lattice are labelled and state the Miller indices of the planes that intersect the crystallographic axes at the distances (a, 3b, −2c).

[5 marks]

4. a. **Figure Q4** shows the phase diagram for two partially miscible liquids, water (A) and 2-methylpropanol (B). Describe what will be observed when a mixture of composition $x_B = 0.3$ is heated, at each stage giving the number, composition, and relative amounts of the phases present.

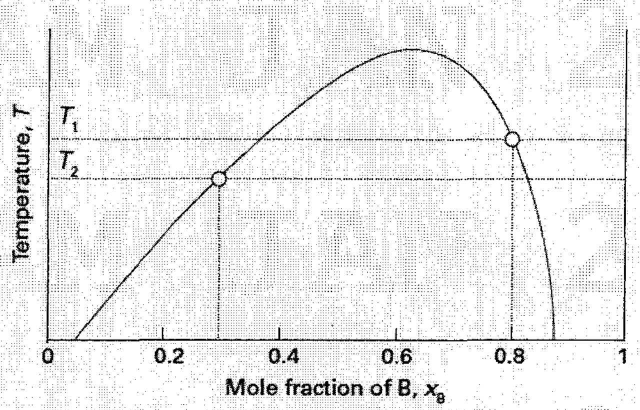

Figure Q4: The phase diagram for two partially miscible liquids.

[6 marks]

b. Aniline, $C_6H_5NH_2$, and hexane, C_6H_{14}, form partially miscible liquid–liquid mixtures at temperatures below 69.1°C. When 42.8 g of aniline and 75.2 g of hexane are mixed at a temperature of 67.5°C, two separated liquid phases are formed, with mole fractions of aniline of 0.308 and 0.618.

i. Determine the overall mole fraction of aniline in the mixture.

[4 marks]

ii. Use the lever rule to determine the relative amounts of the two phases.

[4 marks]

c. It was found that $x_A = 0.220$ when $y_A = 0.314$ by measuring the equilibrium between liquid and vapour phases of a solution at 30°C and 1.00 atm. Calculate the activities and activity coefficients of both components in this solution using Raoult's law.

Given: $P^*_A = 73.0$ kPa; $P^*_B = 92.1$ kPa; x_A = mole fraction in the liquid and y_A = mole fraction in the vapour.

[6 marks]

5. a. An electrochemical reaction has a standard Gibbs energy of −200 kJ/mol and a second reaction of electroplating has a standard Gibbs energy of +30 kJ/mol, both at 300 K. Determine the ratio of their equilibrium constants at 300 K.

[4 marks]

b. The equilibrium pressure of H_2 over solid uranium and solid uranium hydride, UH_3, at 500 K is 139 Pa. Assume activity of solid, a_{solid} = 1. Calculate the standard Gibbs energy of formation of UH_3(s) at 500 K if the initial condition at atmospheric pressure, 1.01 x 10^5 Pa.

[4 marks]

c. Consider the cell:

$$Zn(s) \mid ZnSO_4(aq) \parallel AgNO_3(aq) \mid Ag(s)$$

i. Write the half and overall cell reactions and calculate the standard potential of the cell, $E°$.

[4 marks]

ii. Predict the spontaneity of this electrochemical cell by calculating the equilibrium constant, K for the electrochemical system.

[4 marks]

d. Determine the cell potential change when Q is increased by a factor of 5 for a reaction in which stoichiometric coefficient of the electrons in the half-reactions, v = 3 at 298 K.

[4 marks]

-END OF PAPER-

APPENDIX I

PHYSICAL CONSTANTS

Atomic mass unit	1 amu	= 1.661×10^{-24} g
	1 g	= 6.022×10^{23} amu
Avogadro's number	N_A	= 6.022×10^{23} / mol
Boltzmann's constant	k	= 1.381×10^{-23} J/K
Electron charge	e	= 1.602×10^{-19} C
Faraday's constant	$F = Ne$	= 9.649×10^{4} C/mol
Gas constant	R	= 8.314 J/mol-K
		= 0.08206 L-atm/mol-K
Mass of electron	m_e	= 9.110×10^{-31} kg
Mass of neutron	m_n	= 1.675×10^{-27} kg
Mass of proton	m_p	= 1.673×10^{-27} kg
Atomic mass constant	m_u	= 1.660×10^{-27} kg
Pi	π	= 3.142
Planck's constant	h	= 6.626×10^{-34} J-s
Speed of light	c	= 2.998×10^{8} m/s
Rydberg constant	R_H	= 1.097×10^{7} m^{-1}
	hcR_H	= 2.179×10^{-18} J

APPENDIX II

CONVERSION FACTORS

Length: SI unit: meter (m)

1 km	= 0.62137 mi
1 mi	= 5280 ft
	= 1.6093 km
1 m	= 1.0936 yd
1 in.	= 2.54 cm
1 cm	= 0.39370 in.
1 Å	= 10^{-10} m

Pressure: SI unit : Pascal (Pa)

1 Pa	= 1 N m^{-2}
	= 1 kg $m^{-1}s^{-2}$
1 atm	= 101325 Pa
	= 760 torr
	= 760 mmHg
	= 14.70 lb in^{-2} (or psi)
1 bar	= 10^5 Pa
	= 750 torr
	= 750 mmHg

Mass: SI unit: kilogram (kg)

1 kg	= 2.2046 lb
1 lb	= 453.59 g
	= 16 oz
1 amu	= 1.66054 x 10^{-24} g

Volume: SI unit: cubic meter (m^3)

1 L	= 10^{-3} m^3
	= 1 dm^3
	= 10^3 cm^3
	= 1.0567 qt
1 gal	= 4 qt
	= 3.7854 L
1 cm^3	= 1 mL
1 in^3	= 16.39 cm^3

APPENDIX III

FORMULAS

$$PV = nRT$$

$$P_i = X_i P$$

$$Z = \frac{V_m}{V_m^0}$$

$$V_m = \frac{ZRT}{p}$$

$$P = \frac{RT}{V_m - b} - \frac{a}{V_m^2}$$

$$pV_m = RT(1 + \frac{B}{V_m})$$

$$q = mC\Delta T$$

$$\Delta U = q + w$$

$$w = C_v \Delta T$$

$$C_v = C_p - R$$

$$H = U + pV$$

$$e = 1 - \frac{T_c}{T_h}$$

$$Q_h = \frac{W}{e}$$

$$Q_c = Q_h - W$$

$$K_p = \frac{Q_h}{W} = \frac{T_h}{T_h - T_c}$$

$$w = -nRT \ln \frac{V_f}{V_i}$$

$$w = -P_{ext} \Delta V$$

$$\Delta_{vap} S = \frac{\Delta_{vap} H}{T_b}$$

$$\Delta S_{sys} + \Delta S_{sur} = 0$$

$$\Delta U = nC_{v,m}(T_2 - T_1)$$

$$\ln \frac{P_2}{P_1} = \frac{-\Delta H_a}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

$$2\theta = 2x\sin^{-1}(\frac{\lambda}{2d})$$

$$n_B l_B = n_a l_a$$

$$a_J = \frac{p_J}{p_j^*}$$

$$p_J = \gamma_J p_{tot}$$

$$\gamma_B = \frac{a_B}{x_B}$$

$$\Delta_r G^\Theta = -RT\ln K$$

$$\frac{K_1}{K_2} = e(-\frac{\Delta_r G^\Theta{}_1 - \Delta_r G^\Theta{}_2}{RT})$$

$$Q = \frac{p_{product}}{p_{reactant}}$$

$$\Delta_r G = \Delta_r G^\Theta + RT\ln Q$$

$$E_{Cell} = E^\circ_{Cell} - \frac{0.0592\ \text{V}}{n} \log Q$$

$$E^\circ_{cell} = E^\circ_{cathode} - E^\circ_{anode}$$

$$E^\circ_{cell} = \frac{RT}{nF} \ln K$$

Molar heat capacity at constant pressure, $C_{p,m} = \frac{5}{2}R$

Molar heat capacity at constantvolume, $C_{v,m} = \frac{3}{2}R$

APPENDIX IV

ELECTROCHEMISTRY TABLE

Standard Reduction Potentials at 25°C (298 K) for Many Common Half-reactions

Half-reaction	$\mathscr{E}°$ (V)	Half-reaction	$\mathscr{E}°$ (V)
$F_2 + 2e^- \rightarrow 2F^-$	2.87	$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$	0.40
$Ag^{2+} + e^- \rightarrow Ag^+$	1.99	$Cu^{2+} + 2e^- \rightarrow Cu$	0.34
$Co^{3+} + e^- \rightarrow Co^{2+}$	1.82	$Hg_2Cl_2 + 2e^- \rightarrow 2Hg + 2Cl^-$	0.27
$H_2O_2 + 2H^+ + 2e^- \rightarrow 2H_2O$	1.78	$AgCl + e^- \rightarrow Ag + Cl^-$	0.22
$Ce^{4+} + e^- \rightarrow Ce^{3+}$	1.70	$SO_4^{2-} + 4H^+ + 2e^- \rightarrow H_2SO_3 + H_2O$	0.20
$PbO_2 + 4H^+ + SO_4^{2-} + 2e^- \rightarrow PbSO_4 + 2H_2O$	1.69	$Cu^{2+} + e^- \rightarrow Cu^+$	0.16
$MnO_4^- + 4H^+ + 3e^- \rightarrow MnO_2 + 2H_2O$	1.68	$2H^+ + 2e^- \rightarrow H_2$	0.00
$IO_4^- + 2H^+ + 2e^- \rightarrow IO_3^- + H_2O$	1.60	$Fe^{3+} + 3e^- \rightarrow Fe$	−0.036
$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$	1.51	$Pb^{2+} + 2e^- \rightarrow Pb$	−0.13
$Au^{3+} + 3e^- \rightarrow Au$	1.50	$Sn^{2+} + 2e^- \rightarrow Sn$	−0.14
$PbO_2 + 4H^+ + 2e^- \rightarrow Pb^{2+} + 2H_2O$	1.46	$Ni^{2+} + 2e^- \rightarrow Ni$	−0.23
$Cl_2 + 2e^- \rightarrow 2Cl^-$	1.36	$PbSO_4 + 2e^- \rightarrow Pb + SO_4^{2-}$	−0.35
$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$	1.33	$Cd^{2+} + 2e^- \rightarrow Cd$	−0.40
$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$	1.23	$Fe^{2+} + 2e^- \rightarrow Fe$	−0.44
$MnO_2 + 4H^+ + 2e^- \rightarrow Mn^{2+} + 2H_2O$	1.21	$Cr^{3+} + e^- \rightarrow Cr^{2+}$	−0.50
$IO_3^- + 6H^+ + 5e^- \rightarrow \frac{1}{2}I_2 + 3H_2O$	1.20	$Cr^{3+} + 3e^- \rightarrow Cr$	−0.73
$Br_2 + 2e^- \rightarrow 2Br^-$	1.09	$Zn^{2+} + 2e^- \rightarrow Zn$	−0.76
$VO_2^+ + 2H^+ + e^- \rightarrow VO^{2+} + H_2O$	1.00	$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$	−0.83
$AuCl_4^- + 3e^- \rightarrow Au + 4Cl^-$	0.99	$Mn^{2+} + 2e^- \rightarrow Mn$	−1.18
$NO_3^- + 4H^+ + 3e^- \rightarrow NO + 2H_2O$	0.96	$Al^{3+} + 3e^- \rightarrow Al$	−1.66
$ClO_2 + e^- \rightarrow ClO_2^-$	0.954	$H_2 + 2e^- \rightarrow 2H^-$	−2.23
$2Hg^{2+} + 2e^- \rightarrow Hg_2^{2+}$	0.91	$Mg^{2+} + 2e^- \rightarrow Mg$	−2.37
$Ag^+ + e^- \rightarrow Ag$	0.80	$La^{3+} + 3e^- \rightarrow La$	−2.37
$Hg_2^{2+} + 2e^- \rightarrow 2Hg$	0.80	$Na^+ + e^- \rightarrow Na$	−2.71
$Fe^{3+} + e^- \rightarrow Fe^{2+}$	0.77	$Ca^{2+} + 2e^- \rightarrow Ca$	−2.76
$O_2 + 2H^+ + 2e^- \rightarrow H_2O_2$	0.68	$Ba^{2+} + 2e^- \rightarrow Ba$	−2.90
$MnO_4^- + e^- \rightarrow MnO_4^{2-}$	0.56	$K^+ + e^- \rightarrow K$	−2.92
$I_2 + 2e^- \rightarrow 2I^-$	0.54	$Li^+ + e^- \rightarrow Li$	−3.05
$Cu^+ + e^- \rightarrow Cu$	0.52		

APPENDIX V

LIST OF ELEMENTS

Name	Symbol	Atomic number	Atomic weight	Name	Symbol	Atomic number	Atomic weight
actinium	Ac	89	227.03[a]	mendelevium	Md	101	258.10[a]
aluminium	Al	13	26.98	mercury	Hg	80	200.59
americium	Am	95	243.06[a]	molybdenum	Mo	42	95.94
antimony	Sb	51	121.75	neodymium	Nd	60	144.24
argon	Ar	18	39.95	neon	Ne	10	20.18
arsenic	As	33	74.92	neptunium	Np	93	237.05[a]
astatine	At	85	209.99[a]	nickel	Ni	28	58.69
barium	Ba	56	137.33	niobium	Nb	41	92.91
berkelium	Bk	97	247.07[a]	nitrogen	N	7	14.01
beryllium	Be	4	9.01	nobelium	No	102	259.10[a]
bismuth	Bi	83	208.98	osmium	Os	76	190.23
bohrium	Bh	107	264.12[a]	oxygen	O	8	16.00
boron	B	5	10.81	palladium	Pd	46	106.40
bromine	Br	35	79.90	phosphorus	P	15	30.97
cadmium	Cd	48	112.41	platinum	Pt	78	195.08
calcium	Ca	20	40.08	plutonium	Pu	94	244.06[a]
californium	Cf	98	251.08[a]	polonium	Po	84	208.98[a]
carbon	C	6	12.01	potassium	K	19	39.10
cerium	Ce	58	140.12	praseodymium	Pr	59	140.91
cesium	Cs	55	132.91	promethium	Pm	61	145.00[a]
chlorine	Cl	17	35.45	protactinium	Pa	91	231.04
chromium	Cr	24	52.00	radium	Ra	88	226.03[a]
cobalt	Co	27	58.93	radon	Rn	86	222.02[a]
copper	Cu	29	63.55	rhenium	Re	75	186.21
curium	Cm	96	247.07[a]	rhodium	Rh	45	102.91
dubnium	Db	105	262.11[a]	rubidium	Rb	37	85.47
dysprosium	Dy	66	162.50	ruthenium	Ru	44	101.07
einsteinium	Es	99	252.08[a]	rutherfordium	Rf	104	261.11[a]
erbium	Er	68	167.26	samarium	Sm	62	150.35
europium	Eu	63	151.96	scandium	Sc	21	44.96
fermium	Fm	100	257.10[a]	seaborgium	Sg	106	266.00[a]
fluorine	F	9	19.00	selenium	Se	34	78.96
francium	Fr	87	223.02[a]	silicon	Si	14	28.09
gadolinium	Gd	64	157.25	silver	Ag	47	107.87
gallium	Ga	31	69.72	sodium	Na	11	23.00
germanium	Ge	32	72.61	strontium	Sr	38	87.62
gold	Au	79	196.97	sulfur	S	16	32.07
hafnium	Hf	72	178.49	tantalum	Ta	73	180.95
hassium	Hs	108	269.13[a]	technetium	Tc	43	98.00[a]
helium	He	2	4.00	tellurium	Te	52	127.60
holmium	Ho	67	164.93	terbium	Tb	65	158.93
hydrogen	H	1	1.01	thallium	Tl	81	204.37
indium	In	49	114.82	thorium	Th	90	232.04
iodine	I	53	126.90	thulium	Tm	69	168.93
iridium	Ir	77	192.22	tin	Sn	50	118.71
iron	Fe	26	55.85	titanium	Ti	22	47.90
krypton	Kr	36	83.80	tungsten	W	74	183.84
lanthanum	La	57	138.91	uranium	U	92	238.03
lawrencium	Lr	103	262.11[a]	vanadium	V	23	50.94
lead	Pb	82	207.19	xenon	Xe	54	131.30
lithium	Li	3	6.94	ytterbium	Yb	70	173.04
lutetium	Lu	71	174.97	yttrium	Y	39	88.91
magnesium	Mg	12	24.31	zinc	Zn	30	65.39
manganese	Mn	25	54.94	zirconium	Zr	40	91.22
meitnerium	Mt	109	268.14[a]				

[a]Mass of longest-lived or most important isotope