UNIVERSITI
TEKNOLOGI
PETRONAS

FINAL EXAMINATION
MAY 2024 SEMESTER

COURSE	:	**CFB1043 - PRINCIPLES OF CHEMICAL ENGINEERING**
DATE	:	**5 AUGUST 2024 (MONDAY)**
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 **SIXTEEN (16)** pages in this Question Booklet including the cover page and appendices.

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

1. In a chemical processing plant, sulfur dioxide (SO_2) is to be removed using **TWO (2)** absorption towers in series. The total flow rate of the inlet gas stream entering the first absorption tower is 300 kmol/hour, with a composition of 20 mol% SO_2, 30 mol% CO_2 and the remaining are N_2. The outlet gas stream from the first tower is then directed to the second absorption tower. Pure water is used as the solvent in both absorption towers, with a flow rate of 600 kmol/hour for each tower. It is assumed that the water only absorbs SO_2 and the absorption efficiency for the first and second tower is 60% and 85%, respectively.

   a. Draw the process flow diagram of inlet and outlet streams for the two absorption towers with poper label of all the provided flow rates and component fractions.

   [8 marks]

   b. Calculate the mass composition of all the inlet and outlet streams for the second absorption tower.

   [12 marks]

   c. If the water is not pure due to repeatably use, discuss the consequences to the outlet gas stream in the second tower.

   [4 marks]

2. a. In a combustion process of heptane (C_7H_{16}), 180% of excess air is used to ensure the combustion is complete.

i. Write the chemical reaction for the combustion process.

[4 marks]

ii. Calculate the composition of products in dry and wet basis if the feed of C_7H_{16} is 100 kg/hour.

[12 marks]

b. Moist air at a dry bulb temperature of 323 K and 40% relative humidity enters the cooling coil of a dehumidifying wood dryer and is cooled to 291 K under saturated conditions. If the drying rate of the wood is 3 kg/hour, determine the flow rate of dry air in the system.

[10 marks]

3. A liquid mixture with a composition of 40 mol% acetone (C_3H_6O) and 60 mol% methanol (CH_3OH) is fed into an evaporator at a total flow rate of 100 kmol/hr at 303 K and 5 atm. When the evaporator is operated at 450 K and 1 atm, a substantial amount of the feed is vaporized. The liquid stream discharged from the evaporator contains 78 mol% CH_3OH, while the vapor stream contains 55 mol% C_3H_6O.

a. Determine the heat rate to the evaporator.

[18 marks]

b. If the feed to the evaporator consists of more C_3H_6O than CH_3OH, predict the changes in the heat rate to the evaporator. Justify your answer.

[6 marks]

4. In a new process for the recovery of tin from low-grade ores, it is desired to oxidize stannous oxide (SnO) to stannic oxide (SnO_2), which is then soluble in a caustic solution. Both of the SnO and O_2 enter the reactor at 25°C with 85 % conversion efficiency of SnO according to the chemical reaction below. Additonal data for the heat of formation and heat capacity for different compounds are given in **Table Q4**.

$$SnO + \frac{1}{2}O_2 \longrightarrow SnO_2$$

Table Q4: Respective heat of formation and heat capacity for SnO, SnO_2 and O_2

Compound	ΔH_f (kJ/mol)	C_p (kJ/mol.K), T in kelvin
SnO	-283.3	$39.33+15.15\times10^{-3}T$
SnO_2	-577.8	$73.89+10.04\times10^{-3}T-\frac{2.16\times10^{4}}{T^{2}}$
O_2	0	$29.10+1.158\times10^{-5}T-0.6076\times10^{-8}T^{2}+1.311\times10^{-12}T^{3}$

a. Calculate the heat of reaction at 90°C and 1 atm.

[20 marks]

b. If a catalyst is developed to enhance the reaction conversion efficiency, predict its impact on the mass and energy balance in the reactor. Provide justification for your answer.

[6 marks]

-END OF PAPER-

Table B.1 Selected Physical Property Data[a]

Compound	Formula	Mol. Wt.	SG (20°/4°)	T_m(°C)[b]	$\Delta\hat{H}_m(T_m)$[c,j] kJ/mol	T_b(°C)[d]	$\Delta\hat{H}_v(T_b)$[e,j] kJ/mol	T_c(K)[f]	P_c(atm)[g]	$(\Delta\hat{H}_f°)$[h,j] kJ/mol	$(\Delta\hat{H}_c°)$[i,j] kJ/mol
Acetaldehyde	CH_3CHO	44.05	$0.783^{18°}$	−123.7	—	20.2	25.1	461.0	—	−166.2(g)	−1192.4(g)
Acetic acid	CH_3COOH	60.05	1.049	16.6	12.09	118.2	24.39	594.8	57.1	−486.18(l)	−871.69(l)
Acetone	C_3H_6O	58.08	0.791	−95.0	5.69	56.0	30.2	508.0	47.0	−438.15(g) −248.2(l)	−919.73(g) −1785.7(l)
Acetylene	C_2H_2	26.04	—	—	—	−81.5	17.6	309.5	61.6	−216.7(g) +226.75(g)	−1821.4(g) −1299.6(g)
Ammonia	NH_3	17.03	—	−77.8	5.653	−33.43	23.351	405.5	111.3	−67.20(l)	
Ammonium hydroxide	NH_4OH	35.03	—	—	—	—	—	—	—	−46.19(g) −366.48(aq)	−382.58(g) —
Ammonium nitrate	NH_4NO_3	80.05	$1.725^{25°}$	169.6	5.4	Decomposes at 210°C				−365.14(c)	—
Ammonium sulfate	$(NH_4)_2SO_4$	132.14	1.769	513	—	Decomposes at 513°C after melting				−399.36(aq) −1179.3(c)	
Aniline	C_6H_7N	93.12	1.022	−6.3	—	184.2	—	699	52.4	−1173.1(aq) —	—
Benzaldehyde	C_6H_5CHO	106.12	1.046	−26.0	—	179.0	38.40	—	—	−88.83(l)	−3520.0(l)
Benzene	C_6H_6	78.11	0.879	5.53	9.837	80.10	30.765	562.6	48.6	−40.04(g) +48.66(l) +82.93(g)	— −3267.6(l) −3301.5(g)
Benzoic acid	$C_7H_6O_2$	122.12	$1.266^{15°}$	122.2	—	249.8	—	—	—	—	−3226.7(g)
Benzyl alcohol	C_7H_8O	108.13	1.045	−15.4	—	205.2	—	—	—	—	−3741.8(l)
Bromine	Br_2	159.83	3.119	−7.4	10.8	58.6	31.0	584	102	0(l)	—
1,2-Butadiene	C_4H_6	54.09	—	−136.5	—	10.1	—	446	—	—	—
1,3-Butadiene	C_4H_6	54.09	—	−109.1	—	−4.6	—	425	42.7	—	—
n-Butane	C_4H_{10}	58.12	—	−138.3	4.661	−0.6	22.305	425.17	37.47	−147.0(l)	−2855.6(l)
Isobutane	C_4H_{10}	58.12	—	−159.6	4.540	−11.73	21.292	408.1	36.0	−124.7(g) −158.4(l)	−2878.5(g) −2849.0(l)
1-Butene	C_4H_8	56.10	—	−185.3	3.8480	−6.25	21.916	419.6	39.7	−134.5(g) +1.17(g)	−2868.8(g) −2718.6(g)
Calcium carbide	CaC_2	64.10	$2.22^{18°}$	2300	—	—	—	—	—	−62.76(c)	—
Calcium carbonate	$CaCO_3$	100.09	2.93	Decomposes at 825°C						−1206.9(c)	—
Calcium chloride	$CaCl_2$	110.99	$2.152^{15°}$	782	28.37	>1600	—	—	—	−794.96(c)	—

APPENDIX I: Physical Properties Table (continued)

Calcium hydroxide	$Ca(OH)_2$	74.10	2.24			($-H_2O$ at 580°C)				−986.59(c)	—
Calcium oxide	CaO	56.08	3.32	2570	50	2850	—	—	—	−635.6(c)	—
Calcium phosphate	$Ca_3(PO_4)_2$	310.19	3.14	1670	—	—	—	—	—	−4138(c)	—
Calcium silicate	$CaSiO_3$	116.17	2.915	1530	48.62	—	—	—	—	−1584(c)	—
Calcium sulfate	$CaSO_4$	136.15	2.96	—	—	—	—	—	—	−1432.7(c) −1450.4(aq)	—
Calcium sulfate (gypsum)	$CaSO_4 \cdot 2H_2O$	172.18	2.32		($-1.5\ H_2O$ at 128°C)		—	—	—	−2021(c)	—
Carbon (graphite)	C	12.010	2.26	3600	46.0	4200	—	—	—	0(c)	−393.51(c)
Carbon dioxide	CO_2	44.01	—	−56.6 at 5.2 atm	8.33	(Sublimes at −78°C)		304.2	72.9	−412.9(l) −393.5(g)	— —
Carbon disulfide	CS_2	76.14	$1.261^{22°/20°}$	−112.1	4.39	46.25	26.8	552.0	78.0	+87.9(l) +115.3(g)	−1075.2(l) 1102.6(g)
Carbon monoxide	CO	28.01	—	−205.1	0.837	−191.5	6.042	133.0	34.5	−110.52(g)	−282.99(g)
Carbon tetrachloride	CCl_4	153.84	1.595	−22.9	2.51	76.7	30.0	556.4	45.0	−139.5(l) −106.7(g)	−352.2(l) −385.0(g)
Chlorine	Cl_2	70.91	—	−101.00	6.406	−34.06	20.4	417.0	76.1	0(g)	—
Chlorobenzene	C_6H_5Cl	112.56	1.107	−45	—	132.10	36.5	632.4	44.6	—	—
Chloroethane	C_2H_5Cl	See ethyl chloride									

[a]Adapted in part from D. M. Himmelblau, *Basic Principles and Calculations in Chemical Engineering*, 3rd Edition, ©1974, Tables D.1 and F.1. Adapted by permission of Prentice-Hall, Inc., Englewood Cliffs, NJ.

[b]Melting point at 1 atm.

[c]Heat of fusion at T_m and 1 atm.

[d]Boiling point at 1 atm.

[e]Heat of vaporization at T_b and 1 atm.

[f]Critical temperature.

[g]Critical pressure.

[h]Heat of formation at 25°C and 1 atm.

[i]Heat of combustion at 25°C and 1 atm. Standard states of products are CO_2(g), H_2O(l), SO_2(g), HCl(aq), and N_2(g). To calculate $\Delta \hat{H}_c^\circ$ with H_2O(g) as a product, add $44.01 n_w$ to the tabulated value, where n_w = moles H_2O formed/mole fuel burned.

[j]To convert $\Delta \hat{H}$ to kcal/mol, divide given value by 4.184; to convert to Btu/lb-mole, multiply by 430.28.

(continued)

Table B.1 (Continued)

Compound	Formula	Mol. Wt.	SG (20°/4°)	T_m(°C)[b]	$\Delta\hat{H}_m(T_m)$[c,j] kJ/mol	T_b(°C)[d]	$\Delta\hat{H}_v(T_b)$[e,j] kJ/mol	T_c(K)[f]	P_c(atm)[g]	$(\Delta\hat{H}_f°)$[h,j] kJ/mol	$(\Delta\hat{H}_c°)$[i,j] kJ/mol
Chloroform	$CHCl_3$	119.39	1.489	−63.7	—	61.0		536.0	54.0	−131.8(l)	−373(l)
Copper	Cu	63.54	8.92	1083	13.01	2595	304.6	—		0(c)	—
Cupric sulfate	$CuSO_4$	159.61	$3.606^{15°}$			Decomposes > 600°C				−769.9(c)	—
										−843.1(aq)	
Cyclohexane	C_6H_{12}	84.16	0.779	6.7	2.677	80.7	30.1	553.7	40.4	−156.2(l)	−3919.9(l)
										−123.1(g)	−3953.0(g)
Cyclopentane	C_5H_{10}	70.13	0.745	−93.4	0.609	49.3	27.30	511.8	44.55	−105.9(l)	−3290.9(l)
										−77.2(g)	−3319.5(g)
n-Decane	$C_{10}H_{22}$	142.28	0.730	−29.9	—	173.8	—	619.0	20.8	−249.7(l)	−6778.3(l)
										—	−6829.7(g)
Diethyl ether	$(C_2H_5)_2O$	74.12	$0.708^{25°}$	−116.3	7.30	34.6	26.05	467	35.6	−272.8(l)	−2726.7(l)
Ethane	C_2H_6	30.07	—	−183.3	2.859	−88.6	14.72	305.4	48.2	−84.67(g)	−1559.9(g)
Ethyl acetate	$C_4H_8O_2$	88.10	0.901	−83.8	—	77.0	—	523.1	37.8	−463.2(l)	−2246.4(l)
										−426.8(g)	—
Ethyl alcohol (Ethanol)	C_2H_5OH	46.07	0.789	−114.6	5.021	78.5	38.58	516.3	63.0	−277.63(l)	−1366.91(l)
										−235.31(g)	−1409.25(g)
Ethyl benzene	C_8H_{10}	106.16	0.867	−94.67	9.163	136.2	35.98	619.7	37.0	−12.46(l)	−4564.9(l)
										+29.79(g)	−4607.1(g)
Ethyl bromide	C_2H_5Br	108.98	1.460	−119.1	—	38.2	—	504	61.5	−54.4(g)	—
Ethyl chloride	C_2H_5Cl	64.52	$0.903^{15°}$	−138.3	4.452	13.1	24.7	460.4	52.0	−105.0(g)	—
3-Ethyl hexane	C_8H_{18}	114.22	0.717	—	—	118.5	34.27	567.0	26.4	−250.5(l)	−5407.1(l)
										−210.9(g)	−5509.8(g)
Ethylene	C_2H_4	28.05	—	−169.2	3.350	−103.7	13.54	283.1	50.5	+52.28(g)	−1410.99(g)
Ethylene glycol	$C_2H_6O_2$	62.07	$1.113^{19°}$	−13	11.23	197.2	56.9	—	—	−451.5(l)	−1179.5(l)
Ferric oxide	Fe_2O_3	159.70	5.12			Decomposes at 1560°C				−387.1(g)	—
Ferrous oxide	FeO	71.85	5.7	—	—	—	—	—	—	−822.2(c)	
Ferrous sulfide	FeS	87.92	4.84	1193	—	—	—	—	—	−266.5(c)	—
Formaldehyde	H_2CO	30.03	$0.815^{-20°}$	−92	—	−19.3	24.48	—	—	−95.1(c)	—
Formic acid	CH_2O_2	46.03	1.220	8.30	12.68	100.5	22.25	—	—	−115.90(g)	−563.46(g)
										−409.2(l)	−262.8(l)
Glycerol	$C_3H_8O_3$	92.09	$1.260^{50°}$	18.20	18.30	290.0	—	—	—	−362.6(g)	—
Helium	He	4.00	—	−269.7	0.02	−268.9	0.084	5.26	2.26	−665.9(l)	−1661.1(l)
										0(g)	—

APPENDIX I: Physical Properties Table (continued)

n-Heptane	C_7H_{16}	100.20	0.684	−90.59	14.03	98.43	31.69	540.2	27.0	−224.4(l) −187.8(g)	−4816.9(l) −4853.5(g)
n-Hexane	C_6H_{14}	86.17	0.659	−95.32	13.03	68.74	28.85	507.9	29.9	−198.8(l) −167.2(g)	−4163.1(l) −4194.8(g)
Hydrogen	H_2	2.016	—	−259.19	0.12	−252.76	0.904	33.3	12.8	0(g)	−285.84(g)
Hydrogen bromide	HBr	80.92	—	−86	—	−67	—	—	—	−36.23(g)	—
Hydrogen chloride	HCl	36.47	—	−114.2	1.99	−85.0	16.1	324.6	81.5	−92.31(g)	—
Hydrogen cyanide	HCN	27.03	—	−14	—	26	—	—	—	+130.54(g)	—
Hydrogen fluoride	HF	20.0	—	−83	—	20	—	503.2	—	−268.6(g) −316.9(aq, 200)	— —
Hydrogen sulfide	H_2S	34.08	—	−85.5	2.38	−60.3	18.67	373.6	88.9	−19.96(g)	−562.59(g)
Iodine	I_2	253.8	4.93	113.3	—	184.2	—	826.0	—	0(c)	—
Iron	Fe	55.85	7.7	1535	15.1	2800	354.0	—	—	0(c)	—
Lead	Pb	207.21	$11.337^{20°/20°}$	327.4	5.10	1750	179.9	—		0(c)	—
Lead oxide	PbO	223.21	9.5	886	11.7	1472	213	—	—	−219.2(c)	—
Magnesium	Mg	24.32	1.74	650	9.2	1120	131.8	—	—	0(c)	—
Magnesium chloride	$MgCl_2$	95.23	$2.325^{25°}$	714	43.1	1418	136.8	—	—	−641.8(c)	—
Magnesium hydroxide	$Mg(OH)_2$	58.34	2.4	Decomposes at 350°C				—			—
Magnesium oxide	MgO	40.32	3.65	2900	77.4	3600	—	—	—	−601.8(c)	—
Mercury	Hg	200.61	13.546	−38.87	—	−356.9	—	—	—	0(c)	—
Methane	CH_4	16.04	—	−182.5	0.94	−161.5	8.179	190.70	45.8	−74.85(g)	−890.36(g)
Methyl acetate	$C_3H_6O_2$	74.08	0.933	−98.9	—	57.1	—	506.7	46.30	−409.4(l)	−1595(l)
Methyl alcohol (Methanol)	CH_3OH	32.04	0.792	−97.9	3.167	64.7	35.27	513.20	78.50	−238.6(l) −201.2(g)	726.6(l) −764.0(g)
Methyl amine	CH_5N	31.06	$0.699^{-11°}$	−92.7	—	−6.9	—	429.9	73.60	−28.0(g)	−1071.5(l)
Methyl chloride	CH_3Cl	50.49	—	−97.9	—	−24	—	416.1	65.80	−81.92(g)	—

(continued)

Table B.1 (Continued)

Compound	Formula	Mol. Wt.	SG (20°/4°)	T_m(°C)[b]	$\Delta\hat{H}_m(T_m)$[c,j] kJ/mol	T_b(°C)[d]	$\Delta\hat{H}_v(T_b)$[e,j] kJ/mol	T_c(K)[f]	P_c(atm)[g]	$(\Delta\hat{H}_f°)$[h,j] kJ/mol	$(\Delta\hat{H}_c°)$[i,j] kJ/mol
Methyl ethyl ketone	C_4H_8O	72.10	0.805	−87.1	—	78.2	32.0	—	—	—	−2436(l)
Naphthalene	$C_{10}H_8$	128.16	1.145	80.0	—	217.8	—	—	—	—	−5157(g)
Nickel	Ni	58.69	8.90	1452	—	2900	—	—	—	0(c)	—
Nitric acid	HNO_3	63.02	1.502	−41.6	10.47	86	30.30	—	—	−173.23(l)	—
										−206.57(aq)	
Nitrobenzene	$C_6H_5O_2N$	123.11	1.203	5.5	—	210.7	—	—	—	—	−3092.8(l)
Nitrogen	N_2	28.02	—	−210.0	0.720	−195.8	5.577	126.20	33.5	0(g)	—
Nitrogen dioxide	NO_2	46.01	—	−9.3	7.335	21.3	14.73	431.0	100.0	+33.8(g)	—
Nitric oxide	NO	30.01	—	−163.6	2.301	−151.8	13.78	179.20	65.0	+90.37(g)	—
Nitrogen pentoxide	N_2O_5	108.02	$1.63^{18°}$	30	—	47	—	—	—	—	—
Nitrogen tetraoxide	N_2O_4	92.0	1.448	−9.5	—	21.1	—	431.0	99.0	+9.3(g)	—
Nitrous oxide	N_2O	44.02	$1.226^{-89°}$	−91.1	—	−88.8	—	309.5	71.70	+81.5(g)	—
n-Nonane	C_9H_{20}	128.25	0.718	−53.8	—	150.6	—	595	23.0	−229.0(l)	−6124.5(l)
n-Octane	C_8H_{18}	114.22	0.703	−57.0	—	125.5	—	568.8	24.5	— −249.9(l)	−6171.0(g) −5470.7(l)
										−208.4(g)	−5512.2(g)
Oxalic acid	$C_2H_2O_4$	90.04	1.90		Decomposes at 186°C			—	—	−826.8(c)	−251.9(s)
Oxygen	O_2	32.00	—	−218.75	0.444	−182.97	6.82	154.4	49.7	0(g)	—
n-Pentane	C_5H_{12}	72.15	$0.63^{18°}$	−129.6	8.393	36.07	25.77	469.80	33.3	−173.0(l)	−3509.5(l)
										−146.4(g)	−3536.1(g)
Isopentane	C_5H_{12}	72.15	$0.62^{19°}$	−160.1	—	27.7	—	461.00	32.9	−179.3(l)	−3507.5(l)
							—			−152.0(g)	−3529.2(g)
1-Pentene	C_5H_{10}	70.13	0.641	−165.2	4.94	29.97		474	39.9	−20.9(g)	−3375.8(g)
Phenol	C_6H_5OH	94.11	$1.071^{25°}$	42.5	11.43	181.4	—	692.1	60.5	−158.1(l)	−3063.5(s)
										−90.8(g)	—
Phosphoric acid	H_3PO_4	98.00	$1.834^{18°}$	42.3	10.54	$(-\frac{1}{2}H_2O$ at 213°C)		—	—	−1281.1(c)	—
										−1278.6(aq, $1H_2O$)	—
Phosphorus (red)	P_4	123.90	2.20	$590^{43\ atm}$	81.17	Ignites in air, 725°C		—	—	−17.6(c)	—
										0(c)	

Phosphorus (white)	P_4	123.90	1.82	44.2	2.51	280	49.71	—	—		—
Phosphorus pentoxide	P_2O_5	141.95	2.387	Sublimes at 250°C				—	—	−1506.2(c)	—
Propane	C_3H_8	44.09	—	−187.69	3.52	−42.07	18.77	369.9	42.0	−119.8(l) −103.8(g)	−2204.0(l) −2220.0(g)
Propylene	C_3H_6	42.08	—	−185.2	3.00	−47.70	18.42	365.1	45.4	+20.41(g)	−2058.4(g)
n-Propyl alcohol	C_3H_7OH	60.09	0.804	−127	—	97.04	—	536.7	49.95	−300.70(l) −255.2(g)	−2010.4(l) −2068.6(g)
Isopropyl alcohol	C_3H_7OH	60.09	0.785	−89.7	—	82.24	—	508.8	53.0	−310.9(l)	−1986.6(l)
n-Propyl benzene	C_9H_{12}	120.19	0.862	−99.50	8.54	159.2	38.24	638.7	31.3	−38.40(l) +7.82(g)	−5218.2(l) −5264.48(g)
Silicon dioxide	SiO_2	60.09	2.25	1710	14.2	2230	—	—	—	−851.0(c)	—
Sodium bicarbonate	$NaHCO_3$	84.01	2.20	Decomposes at 270°C				—	—	−945.6(c)	—
Sodium bisulfate	$NaHSO_4$	120.07	2.742	—	—	—	—	—	—	−1126.3(c)	—
Sodium carbonate	Na_2CO_3	105.99	2.533	Decomposes at 854°C				—	—	−1130.9(c)	—
Sodium chloride	NaCl	58.45	2.163	808	28.5	1465	170.7	—	—	−411.0(c)	—
Sodium cyanide	NaCN	49.01	—	562	16.7	1497	155	—	—	−89.79(c)	—
Sodium hydroxide	NaOH	40.00	2.130	319	8.34	1390	—	—	—	−426.6(c) −469.4(aq)	— —
Sodium nitrate	$NaNO_3$	85.00	2.257	310	15.9	Decomposes at 380°C			—	−466.7(c)	—
Sodium nitrite	$NaNO_2$	69.00	2.168^{0°	271	—	Decomposes at 320°C			—	−359.4(c)	—
Sodium sulfate	Na_2SO_4	142.05	2.698	890	24.3	—	—	—	—	−1384.5(c)	—
Sodium sulfide	Na_2S	78.05	1.856	950	6.7	—	—	—	—	−373.2(c)	—
Sodium sulfite	Na_2SO_3	126.05	2.633^{15°	Decomposes				—	—	−1090.3(c)	—

(*continued*)

APPENDIX I: Physical Properties Table (continued)

Table B.1 (Continued)

Compound	Formula	Mol. Wt.	SG (20°/4°)	T_m(°C)[b]	$\Delta\hat{H}_m(T_m)$[c,j] kJ/mol	T_b(°C)[d]	$\Delta\hat{H}_v(T_b)$[e,j] kJ/mol	T_c(K)[f]	P_c(atm)[g]	$(\Delta\hat{H}_f^\circ)$[h,j] kJ/mol	$(\Delta\hat{H}_c^\circ)$[i,j] kJ/mol
Sodium thiosulfate	$Na_2S_2O_3$	158.11	1.667	—	—	—	—	—	—	−1117.1(c)	—
Sulfur (rhombic)	S_8	256.53	2.07	113	10.04	444.6	83.7	—	—	0(c)	—
Sulfur (monoclinic)	S_8	256.53	1.96	119	14.17	444.6	83.7	—	—	+0.30(c)	—
Sulfur dioxide	SO_2	64.07	—	−75.48	7.402	−10.02	24.91	430.7	77.8	−296.90(g)	—
Sulfur trioxide	SO_3	80.07	—	16.84	25.48	43.3	41.80	491.4	83.8	−395.18(g)	—
Sulfuric acid	H_2SO_4	98.08	1.834[18°]	10.35	9.87	Decomposes at 340°C		—	—	−811.32(l) −907.51(aq)	— —
Toluene	C_7H_8	92.13	0.866	−94.99	6.619	110.62	33.47	593.9	40.3	+12.00(l) +50.00(g)	−3909.9(l) −3947.9(g)
Water	H_2O	18.016	1.00[4°]	0.00	6.0095	100.00	40.656	647.4	218.3	−285.84(l) −241.83(g)	— —
m-Xylene	C_8H_{10}	106.16	0.864	−47.87	11.569	139.10	36.40	619	34.6	−25.42(l) +17.24(g)	−4551.9(l) −4594.5(g)
o-Xylene	C_8H_{10}	106.16	0.880	−25.18	13.598	144.42	36.82	631.5	35.7	−24.44(l) +18.99(g)	−4552.9(l) −4596.3(g)
p-Xylene	C_8H_{10}	106.16	0.861	13.26	17.11	138.35	36.07	618	33.9	−24.43(l) 17.95(g)	−4552.91(l) −4595.2(g)
Zinc	Zn	65.38	7.140	419.5	6.674	907	114.77	—	—	0(c)	—

Table B.2 Heat Capacities[a]

Form 1: C_p[kJ/(mol·°C)] or [kJ/(mol·K)] $= a + bT + cT^2 + dT^3$
Form 2: C_p[kJ/(mol·°C)] or [kJ/(mol·K)] $= a + bT + cT^{-2}$

Example: $(C_p)_{\text{acetone(g)}} = 0.07196 + (20.10 \times 10^{-5})T - (12.78 \times 10^{-8})T^2 + (34.76 \times 10^{-12})T^3$, where T is in °C.

Note: The formulas for gases are strictly applicable at pressures low enough for the ideal gas equation of state to apply.

Compound	Formula	Mol. Wt.	State	Form	Temp. Unit	$a \times 10^3$	$b \times 10^5$	$c \times 10^8$	$d \times 10^{12}$	Range (Units of T)
Acetone	CH_3COCH_3	58.08	l	1	°C	123.0	18.6			−30–60
			g	1	°C	71.96	20.10	−12.78	34.76	0–1200
Acetylene	C_2H_2	26.04	g	1	°C	42.43	6.053	−5.033	18.20	0–1200
Air		29.0	g	1	°C	28.94	0.4147	0.3191	−1.965	0–1500
			g	1	K	28.09	0.1965	0.4799	−1.965	273–1800
Ammonia	NH_3	17.03	g	1	°C	35.15	2.954	0.4421	−6.686	0–1200
Ammonium sulfate	$(NH_4)_2SO_4$	132.15	c	1	K	215.9				275–328
Benzene	C_6H_6	78.11	l	1	°C	126.5	23.4			6–67
			g	1	°C	74.06	32.95	−25.20	77.57	0–1200
Isobutane	C_4H_{10}	58.12	g	1	°C	89.46	30.13	−18.91	49.87	0–1200
n-Butane	C_4H_{10}	58.12	g	1	°C	92.30	27.88	−15.47	34.98	0–1200
Isobutene	C_4H_8	56.10	g	1	°C	82.88	25.64	−17.27	50.50	0–1200
Calcium carbide	CaC_2	64.10	c	2	K	68.62	1.19	-8.66×10^{10}	—	298–720
Calcium carbonate	$CaCO_3$	100.09	c	2	K	82.34	4.975	-12.87×10^{10}	—	273–1033
Calcium hydroxide	$Ca(OH)_2$	74.10	c	1	K	89.5				276–373
Calcium oxide	CaO	56.08	c	2	K	41.84	2.03	-4.52×10^{10}		273–1173
Carbon	C	12.01	c	2	K	11.18	1.095	-4.891×10^{10}		273–1373
Carbon dioxide	CO_2	44.01	g	1	°C	36.11	4.233	−2.887	7.464	0–1500
Carbon monoxide	CO	28.01	g	1	°C	28.95	0.4110	0.3548	−2.220	0–1500
Carbon tetrachloride	CCl_4	153.84	l	1	K	93.39	12.98			273–343
Chlorine	Cl_2	70.91	g	1	°C	33.60	1.367	−1.607	6.473	0–1200
Copper	Cu	63.54	c	1	K	22.76	0.6117			273–1357

[a]Adapted in part from D. M. Himmelblau, *Basic Principles and Calculations in Chemical Engineering*, 3rd Edition, © 1974, Table E.1. Adapted by permission of Prentice-Hall, Inc., Englewood Cliffs, NJ.

(*continued*)

APPENDIX II: Heat Capacities (continued)

Table B.2 (Continued)

Compound	Formula	Mol. Wt.	State	Form	Temp. Unit	$a \times 10^3$	$b \times 10^5$	$c \times 10^8$	$d \times 10^{12}$	Range (Units of T)
Cumene (Isopropyl benzene)	C_9H_{12}	120.19	g	1	°C	139.2	53.76	−39.79	120.5	0–1200
Cyclohexane	C_6H_{12}	84.16	g	1	°C	94.140	49.62	−31.90	80.63	0–1200
Cyclopentane	C_5H_{10}	70.13	g	1	°C	73.39	39.28	−25.54	68.66	0–1200
Ethane	C_2H_6	30.07	g	1	°C	49.37	13.92	−5.816	7.280	0–1200
Ethyl alcohol (Ethanol)	C_2H_5OH	46.07	l	1	°C	103.1				0
			l	1	°C	158.8				100
			g	1	°C	61.34	15.72	−8.749	19.83	0–1200
Ethylene	C_2H_4	28.05	g	1	°C	+40.75	11.47	−6.891	17.66	0–1200
Ferric oxide	Fe_2O_3	159.70	c	2	K	103.4	6.711	-17.72×10^{10}	—	273–1097
Formaldehyde	CH_2O	30.03	g	1	°C	34.28	4.268	0.0000	−8.694	0–1200
Helium	He	4.00	g	1	°C	20.8				0–1200
n-Hexane	C_6H_{14}	86.17	l	1	°C	216.3				20–100
			g	1	°C	137.44	40.85	−23.92	57.66	0–1200
Hydrogen	H_2	2.016	g	1	°C	28.84	0.00765	0.3288	−0.8698	0–1500
Hydrogen bromide	HBr	80.92	g	1	°C	29.10	−0.0227	0.9887	−4.858	0–1200
Hydrogen chloride	HCl	36.47	g	1	°C	29.13	−0.1341	0.9715	−4.335	0–1200
Hydrogen cyanide	HCN	27.03	g	1	°C	35.3	2.908	1.092		0–1200
Hydrogen sulfide	H_2S	34.08	g	1	°C	33.51	1.547	0.3012	−3.292	0–1500
Magnesium chloride	$MgCl_2$	95.23	c	1	K	72.4	1.58			273–991
Magnesium oxide	MgO	40.32	c	2	K	45.44	0.5008	-8.732×10^{10}		273–2073
Methane	CH_4	16.04	g	1	°C	34.31	5.469	0.3661	−11.00	0–1200
			g	1	K	19.87	5.021	1.268	−11.00	273–1500
Methyl alcohol (Methanol)	CH_3OH	32.04	l	1	°C	75.86	16.83			0–65
			g	1	°C	42.93	8.301	−1.87	−8.03	0–700
Methyl cyclohexane	C_7H_{14}	98.18	g	1	°C	121.3	56.53	−37.72	100.8	0–1200
Methyl cyclopentane	C_6H_{12}	84.16	g	1	°C	98.83	45.857	−30.44	83.81	0–1200
Nitric acid	NHO_3	63.02	l	1	°C	110.0				25
Nitric oxide	NO	30.01	g	1	°C	29.50	0.8188	−0.2925	0.3652	0–3500

APPENDIX II: Heat Capacities (continued)

Nitrogen	N_2	28.02	g	1	°C	29.00	0.2199	0.5723	−2.871	0–1500
Nitrogen dioxide	NO_2	46.01	g	1	°C	36.07	3.97	−2.88	7.87	0–1200
Nitrogen tetraoxide	N_2O_4	92.02	g	1	°C	75.7	12.5	−11.3		0–300
Nitrous oxide	N_2O	44.02	g	1	°C	37.66	4.151	−2.694	10.57	0–1200
Oxygen	O_2	32.00	g	1	°C	29.10	1.158	−0.6076	1.311	0–1500
n-Pentane	C_5H_{12}	72.15	l	1	°C	155.4	43.68			0–36
			g	1	°C	114.8	34.09	−18.99	42.26	0–1200
Propane	C_3H_8	44.09	g	1	°C	68.032	22.59	−13.11	31.71	0–1200
Propylene	C_3H_6	42.08	g	1	°C	59.580	17.71	−10.17	24.60	0–1200
Sodium carbonate	Na_2CO_3	105.99	c	1	K	121				288–371
Sodium carbonate decahydrate	$Na_2CO_3 \cdot 10H_2O$	286.15	c	1	K	535.6				298
Sulfur	S	32.07	c (Rhombic)	1	K	15.2	2.68			273–368
			c (Monoclinic)	1	K	18.3	1.84			368–392
Sulfuric acid	H_2SO_4	98.08	l	1	°C	139.1	15.59			10–45
Sulfur dioxide	SO_2	64.07	g	1	°C	38.91	3.904	−3.104	8.606	0–1500
Sulfur trioxide	SO_3	80.07	g	1	°C	48.50	9.188	−8.540	32.40	0–1000
Toluene	C_7H_8	92.13	l	1	°C	148.8	32.4			0–110
			g	1	°C	94.18	38.00	−27.86	80.33	0–1200
Water	H_2O	18.016	l	1	°C	75.4				0–100
			g	1	°C	33.46	0.6880	0.7604	−3.593	0–1500

APPENDIX III: Psychrometric Chart