UNIVERSITI KUALA LUMPUR
MALAYSIAN INSTITUTE OF CHEMICAL AND BIOENGINEERING TECHNOLOGY

FINAL EXAMINATION
OCTOBER 2025 SEMESTER

COURSE CODE	:	CCB21002
COURSE NAME	:	ENERGY BALANCE
PROGRAMME NAME	:	BACHELOR OF CHEMICAL ENGINEERING WITH HONOURS
DATE	:	29 JANUARY 2026
TIME	:	9.00 AM – 12.00 PM
DURATION	:	3 HOURS

INSTRUCTIONS TO CANDIDATES

1. Please read the instructions given in the question paper CAREFULLY.
2. This question paper has information printed on both sides of the paper.
3. This question paper contains a total of THREE (3) questions. Answer ALL questions.
4. Please write your answers on the answer booklet provided.
5. Answer all questions in English language ONLY.

THERE ARE 14 PAGES OF QUESTIONS AND APPENDICES, EXCLUDING THIS PAGE.

(Total: 100 marks)

INSTRUCTION: Answer ALL questions

Question 1

A continuous condenser is used to cool benzene vapour at 580°C until it is completely condensed and exits the unit as a liquid at 25°C. The condensed benzene is continuously collected in drums, each with a volume of 1.75 m^3. Each drum is filled in 2 minutes. Assuming negligible kinetic and potential energy effects and steady-state conditions, calculate the rate of heat removal (in kW) from the benzene in the condenser.

(25 Marks)

Question 2

A pure carbon monoxide stream enters a steady-state continuous reactor at 25°C and 1 atm with a molar flow rate of 65.0 mol/h. The carbon monoxide reacts with an excess amount of steam supplied at 250°C and 1 atm according to the following reaction:

$$CO\,(g) + H_2O\,(v) \rightarrow CO_2(g) + H_2(g)$$

The reactor outlet stream leaves the system at 400°C and 1 atm. Analysis of the outlet stream shows that it contains 30.0 mole% hydrogen, 30.0 mole% carbon dioxide and the remaining fraction is water vapor.

(a) Using the extent of reaction method, calculate the total molar flow rate of the outlet stream.

(7 marks)

(b) Taking elemental species [C(s), O_2(g), H_2(g)] at 25°C, 1 atm as reference for enthalpy calculations, calculate the rate of heat (kW) to or from the reactor.

(23 marks)

Question 3

Sulfur dioxide (SO_2) is oxidized to sulfur trioxide (SO_3) in a small pilot-plant reactor. Sulfur dioxide and 100% excess air are fed to the reactor at 450°C. A sulfur dioxide conversion of 65% is obtained and the products leave the reactor at 550°C. The production rate of sulfur trioxide is 1.00×10^2 kg/min. The reactor is surrounded by water jackets, into which cooling water at 25°C is supplied.

(a) Determine the sulfur dioxide and air feed rates (in standard cubic meters per second) and the extent of reaction.

(13 marks)

(b) Measure the standard heat of reaction for the oxidation of sulfur dioxide.

(7 marks)

(c) Evaluate the rate of heat transfer (in kW) from the reactor to the cooling water and determine the minimum cooling-water flow rate if the allowable temperature rise of the water is limited to 15°C.

(25 marks)

END OF EXAMINATION PAPER

APPENDIX A

$$n_{Aout} = n_{Ain} \pm \nu_A \xi$$

$$\xi = \frac{|n_{Aout} - n_{Ain}|}{\nu_A} = \frac{n_{A,r}}{\nu_A}$$

$$\Delta \boldsymbol{H} = \frac{\Delta \hat{\mathrm{H}}_{\boldsymbol{r}(\boldsymbol{T_O P_o})}}{|\boldsymbol{\nu_A}|} \boldsymbol{n_{A,r}}$$

$$\Delta H = \xi \Delta \hat{H}_{r\,(T_0, P_0)}$$

$$\Delta \dot{H} = \xi \Delta \hat{H}_r^{\circ} + \sum_{out} \dot{n}_o \hat{H}_o - \sum_{in} \dot{n}_i \hat{H}_i$$

$$\Delta \dot{H} = \sum_{out} \dot{n}_o \hat{H}_o - \sum_{in} \dot{n}_i \hat{H}_i$$

$$\dot{Q} = \sum \left(\dot{n}\hat{\mathrm{H}}\right)_{out} - \sum \left(\dot{n}\hat{\mathrm{H}}\right)_{in}$$

$$Q = \Delta U = \sum_{out} n_o \hat{U}_o - \sum_{in} n_i \hat{U}_i$$

$$\dot{Q} = \Delta \dot{H} = \sum_{out} \dot{n}_{out} \hat{H}_{out} - \sum_{in} \dot{n}_i \hat{H}_i$$

$$\Delta \hat{\mathrm{H}} = \int_{T_1}^{T_2} C_P(T)\, dT$$

$$\Delta \hat{H} = \hat{V} \Delta P + \int_{T_1}^{T_2} C_p(T) dT$$

$$\Delta \hat{H}_r^o = -\sum_i \nu_i \left(\Delta \hat{H}_c^o\right)_i = -\left\{ \sum_{\text{products}} |\nu_i| \left(\Delta \hat{H}_c^o\right)_i - \sum_{\text{reactants}} |\nu_i| \left(\Delta \hat{H}_c^o\right)_i \right\}$$

$$\sigma \hat{H}_r^o \, \mathrm{o} \, \chi \overline{\nu_i} \left(\varpi \hat{H}_c^o\right)_i \Big) \quad \mathfrak{l}_{\text{reactants}} \left|\nu i\right| \left(\iota \hat{H}_c^o\right)_i \chi \, \mathrm{H}_{\text{products}} \left|\nu i\right| \left(\rho \hat{H}_c^o\right)_i$$

$$\phi \hat{H}_r^o \, \mathrm{o} \, \varpi \nu_i \iota \hat{H}_{fi}^o \, \mathrm{o} \, \underset{\text{products}}{\tau} \left|\nu i\right| \pi \hat{H}_{fi}^o \, \mathrm{o} \, \underset{\text{reactants}}{\tau} \left|\nu i\right| \tau \hat{H}_{fi}^o$$

APPENDIX B

PERIODIC TABLE

1 H 1.00794																	2 He 4.002602
3 Li 6.941	4 Be 9.012182											5 B 10.811	C 12.0107	7 N 14.00674	8 O 15.9994	9 F 18.9984032	10 Ne 20.1797
11 Na 22.989770	12 Mg 24.3050											13 Al 26.581538	14 Si 28.0855	15 P 30.973761	16 S 32.066	17 Cl 35.4527	18 Ar 39.948
19 K 39.0983	20 Ca 40.078	21 Sc 44.955910	22 Ti 47.867	23 V 50.9415	24 Cr 51.9961	25 Mn 54.938049	26 Fe 55.845	27 Co 58.933200	28 Ni 58.6534	29 Cu 63.545	30 Zn 65.39	31 Ga 69.723	32 Ge 72.61	33 As 74.92160	34 Se 78.96	35 Br 79.504	36 Kr 83.80
37 Rb 85.4678	38 Sr 87.62	39 Y 88.90585	40 Zr 91.224	41 Nb 92.90638	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.90550	46 Pd 106.42	47 Ag 196.56655	48 Cd 112.411	49 In 114.818	50 Sn 118.710	51 Sb 121.760	52 Te 127.60	53 I 126.90447	54 Xe 131.29
55 Cs 132.90545	56 Ba 137.327	57 La 138.9055	72 Hf 178.49	73 Ta 180.94.79	74 W 183.84	75 Re 186.207	76 Os 190.23	77 Ir 192.217	78 Pt 195.078	79 Au 196.56655	80 Hg 200.59	81 Tl 204.3833	82 Pb 207.2	83 Bi 208.58038	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	89 Ac (227)	104 Rf (261)	105 Db (262)	106 Sg (263)	107 Bh (262)	108 Hs (265)	109 Mt (266)	110 (269)	111 (272)	112 (277)		114 (289) (287)		116 (289)		118 (293)

58 Ce 140.116	59 Pr 140.50765	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.964	64 Gd 157.25	65 Tb 158.92534	66 Dy 162.50	67 Ho 164.93032	68 Er 167.26	69 Tm 168.93421	70 Yb 173.04	71 Lu 174.967
90 Th 232.0381	91 Pa 231.035888	92 U 238.0289	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

APPENDIX C

Quantity	Equivalent Values
Mass	1 kg = 1000 g = 0.001 metric ton = 2.20462 lb_m = 35.27392 oz 1 lb_m = 16 oz = 5 x 10^{-4} ton = 453.593 g = 0.453593 kg
Length	1 m = 100 cm = 1000 mm = 10^6 microns (μm) = 10^{10} angstroms ($\overset{0}{A}$) = 39.37 in = 3.2808 ft = 1.0936 yd = 0.0006214 mile 1 ft = 12 in = 1/3 yd = 0.3048 m = 30.48 cm
Volume	1 m^3 = 1000 liters = 10^6 cm^3 = 10^6 ml = 35.3145 ft^3 = 220.83 imperial gallons = 264.17 gal = 1056.68 qt 1ft^3 = 1728 in^3 = 7.4805 gal = 0.028317 m^3 = 28.317 liters = 28 317 cm^3
Force	1 N = 1 kg.m/s^2 = 10^5 dynes = 10^5 g.cm/s^2 = 0.22481 lb_f 1 lb_f = 32.174 lb_m.ft/s^2 = 4.4482 N = 4.4482 x 10^5 dynes
Pressure	1 atm = 1.01325 x 10^5 N/m^2 (Pa) = 101.325 kPa = 1.01325 bars = 1.01325 x 10^6 dynes/cm^2 = 760 mm Hg at 0°C (torr) = 10.333 m H_2O at 4°C = 14.696 lb_f/in^2 (psi) = 33.9 ft H_2O at 4°C = 29.921 in Hg at 0°C
Energy	1 J = 1 N.m = 10^7 ergs = 10^7 dyne.cm = 2.778 x 10^{-7} kW.h = 0.23901 cal = 0.7376 ft-lb_f = 9.486 x 10^{-4} Btu
Power	1 W = 1 J/s = 0.23901 cal/s = 0.7376 ft.lb_f/s = 9.486 x 10^{-4} Btu/s = 1.341 x 10^{-3} hp

Gas Constant = 0.082 L atm K^{-1} mol^{-1}
= 8.314 L kPa K^{-1} mol^{-1}
= 8.314 m^3 Pa K^{-1} mol^{-1}
= 8.314 J mol^{-1} K^{-1}

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)
										−438.15(g)	−919.73(g)
Acetone	C_3H_6O	58.08	0.791	−95.0	5.69	56.0	30.2	508.0	47.0	−248.2(l)	−1785.7(l)
										−216.7(g)	−1821.4(g)
Acetylene	C_2H_2	26.04	—	—	—	−81.5	17.6	309.5	61.6	+226.75(g)	−1299.6(g)
Ammonia	NH_3	17.03	—	−77.8	5.653	−33.43	23.351	405.5	111.3	−67.20(l)	
										−46.19(g)	−382.58(g)
Ammonium hydroxide	NH_4OH	35.03	—	—	—	—	—	—	—	−366.48(aq)	—
Ammonium nitrate	NH_4NO_3	80.05	$1.725^{25°}$	169.6	5.4		Decomposes at 210°C			−365.14(c)	—
										−399.36(aq)	
Ammonium sulfate	$(NH_4)_2SO_4$	132.14	1.769	513	—		Decomposes at 513°C after melting			−1179.3(c)	
										−1173.1(aq)	
Aniline	C_6H_7N	93.12	1.022	−6.3	—	184.2	—	699	52.4	—	—
Benzaldehyde	C_6H_5CHO	106.12	1.046	−26.0	—	179.0	38.40	—	—	−88.83(l)	−3520.0(l)
										−40.04(g)	—
Benzene	C_6H_6	78.11	0.879	5.53	9.837	80.10	30.765	562.6	48.6	+48.66(l)	−3267.6(l)
										+82.93(g)	−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)
										−124.7(g)	−2878.5(g)
Isobutane	C_4H_{10}	58.12	—	−159.6	4.540	−11.73	21.292	408.1	36.0	−158.4(l)	−2849.0(l)
										−134.5(g)	−2868.8(g)
1-Butene	C_4H_8	56.10	—	−185.3	3.8480	−6.25	21.916	419.6	39.7	+1.17(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)	—

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)	−1075.2(l)
										+115.3(g)	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)	−352.2(l)
										−106.7(g)	−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 $44.01n_w$ 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*)

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)
										—	−6171.0(g)
n-Octane	C_8H_{18}	114.22	0.703	−57.0	—	125.5	—	568.8	24.5	−249.9(l)	−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)	

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
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*)

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

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

Table B.8 Specific Enthalpies of Selected Gases: SI Units

	$\hat{H}$(kJ/mol) Reference state: Gas, P_{ref} = 1 atm, T_{ref} = 25°C						
T	Air	O_2	N_2	H_2	CO	CO_2	H_2O
0	−0.72	−0.73	−0.73	−0.72	−0.73	−0.92	−0.84
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100	2.19	2.24	2.19	2.16	2.19	2.90	2.54
200	5.15	5.31	5.13	5.06	5.16	7.08	6.01
300	8.17	8.47	8.12	7.96	8.17	11.58	9.57
400	11.24	11.72	11.15	10.89	11.25	16.35	13.23
500	14.37	15.03	14.24	13.83	14.38	21.34	17.01
600	17.55	18.41	17.39	16.81	17.57	26.53	20.91
700	20.80	21.86	20.59	19.81	20.82	31.88	24.92
800	24.10	25.35	23.86	22.85	24.13	37.36	29.05
900	27.46	28.89	27.19	25.93	27.49	42.94	33.32
1000	30.86	32.47	30.56	29.04	30.91	48.60	37.69
1100	34.31	36.07	33.99	32.19	34.37	54.33	42.18
1200	37.81	39.70	37.46	35.39	37.87	60.14	46.78
1300	41.34	43.38	40.97	38.62	41.40	65.98	51.47
1400	44.89	47.07	44.51	41.90	44.95	71.89	56.25
1500	48.45	50.77	48.06	45.22	48.51	77.84	61.09

Table B.9 Specific Enthalpies of Selected Gases: American Engineering Units

	$\hat{H}$(Btu/lb-mole) Reference state: Gas, P_{ref} = 1 atm, T_{ref} = 77°F						
T	Air	O_2	N_2	H_2	CO	CO_2	H_2O
32	−312	−315	−312	−310	−312	−394	−361
77	0	0	0	0	0	0	0
100	160	162	160	159	160	206	185
200	858	875	857	848	859	1132	996
300	1563	1602	1558	1539	1564	2108	1818
400	2275	2342	2265	2231	2276	3129	2652
500	2993	3094	2976	2925	2994	4192	3499
600	3719	3858	3694	3621	3720	5293	4359
700	4451	4633	4418	4319	4454	6429	5233
800	5192	5418	5150	5021	5195	7599	6122
900	5940	6212	5889	5725	5945	8790	7025
1000	6695	7015	6635	6433	6702	10015	7944
1100	7459	7826	7399	7145	7467	11263	8880
1200	8230	8645	8151	7861	8239	12533	9831
1300	9010	9471	8922	8581	9021	13820	10799
1400	9797	10304	9699	9306	9809	15122	11783
1500	10590	11142	10485	10035	10606	16436	12783
1600	11392	11988	11278	10769	11409	17773	13798
1700	12200	12836	12080	11509	12220	19119	14831
1800	13016	13691	12888	12254	13036	20469	15877
1900	13837	14551	13702	13003	13858	21840	16941
2000	14663	15415	14524	13759	14688	23211	18019