

**UNIVERSITY COLLEGE TATI (UC TATI)****FINAL EXAMINATION QUESTION BOOKLET**

COURSE CODE	: BCE1113
COURSE	: ELEMENTARY PRINCIPLES IN CHEMICAL ENGINEERING
SEMESTER/SESSION	: 2 - 2023/2024
DURATION	: 3 HOURS

**Instructions:**

1. This booklet contains **5** questions. Answer **ALL** questions.
2. All answers should be written in answer booklet.
3. Write legibly and draw sketches wherever required.
4. If in doubt, raise up your hands and ask the invigilator.

**DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO**

**THIS BOOKLET CONTAINS 7 PRINTED PAGES INCLUDING COVER PAGE**

## ELEMENTARY PRINCIPLES IN CHEMICAL ENGINEERING (BCE 1113)

**QUESTION 1**

- (a)
- i. Indicate is the SI unit for force? (2 marks)
  - ii. Convert 2000 mm to meters. (2 marks)
  - iii. Clarify is the difference between weight and mass? (2 marks)
  - iv. Convert 5 kg to pounds. (2 marks)
  - v. Give the SI unit for energy? (2 marks)
- (b) A pound-force is the force required to accelerate a mass of 1 slug at a rate of  $1 \text{ ft/s}^2$ , and a pound-mass is the mass that will experience an acceleration of  $32.2 \text{ ft/s}^2$  when subjected to a force of 1 lbf. Solve the following:
- i. Calculate the weight of a 65-pound-mass object on earth and on Mars, where the acceleration due to gravity is  $3.71 \text{ m/s}^2$ . (4 marks)
  - ii. A 10-pound-force is applied to a 5-pound-mass object. Estimate the resulting acceleration of the object in  $\text{ft/s}^2$ ? (4 marks)

## ELEMENTARY PRINCIPLES IN CHEMICAL ENGINEERING (BCE 1113)

**QUESTION 2**

- (a) A slurry of silica particles in water flow through a pipe. To determine both the flow rate and the composition of the slurry, a sample is collected in a measuring cylinder for 2.5 minutes. The following data is collected:

Mass of empty cylinder: 45.0 g

Mass of cylinder + collected slurry: 470.0 g

Volume collected: 300 ml

Mass of cylinder + dried solids: 89.0 g.

Find:

- i. The volumetric flow rate and mass flow rate of the slurry (3 marks)
  - ii. The density of the slurry (3 marks)
  - iii. The mass fraction of silica in the slurry (3 marks)
- (b) A mixture is 15.0 mole % n-pentane ( $C_5H_{12}$ ), 25.0 mole % n-hexane ( $C_6H_{14}$ ), and 60.0 mole % n-heptane ( $C_7H_{16}$ ). Solve the following:
- i. The mass fraction of each compound in the mixture. (3 marks)
  - ii. The average molecular weight of the mixture. (3 marks)
  - iii. The mass (kg) of a sample containing 15.0 kmol of n-heptane. (3 marks)

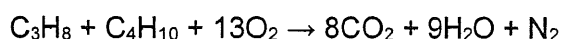
**QUESTION 3**

(a) A chemical solution of hydrochloric acid (HCl) is contained in two separate flasks. The first solution contains 15 wt% HCl, and the second solution contains 30 wt% HCl. If 300 g of the first solution is combined with 250 g of the second solution, calculate the mass and composition of the resulting mixture. Sketch the schematic diagram of the process. (10 marks)

(b) A liquid mixture containing 45.0 mole % ethanol (E), 30.0 mole % water (W), and 25.0 mole % isopropyl alcohol (I) is fed to a distillation column. The bottoms product contains 98.0 mole % W and no E, and 97.0% of the E in the feed is recovered in the overhead product. The overhead product is fed to a second column. The overhead product from the second column contains 90.0% of the I in the feed to this column. The composition of this stream is 60.0 mole % I and the balance W.

- i. Draw and label a flowchart of this process. (3 marks)
- ii. Show the molar ratio of the isopropyl alcohol at the overhead product of the second column to the feed of the first column. (7 marks)

(c) A mixture of propane (C<sub>3</sub>H<sub>8</sub>) and butane (C<sub>4</sub>H<sub>10</sub>) is burned with air to produce carbon dioxide (CO<sub>2</sub>), water (H<sub>2</sub>O), and nitrogen (N<sub>2</sub>) according to the following reaction:



- i. If the propane and butane mixture has a molar ratio of 2:1 and 10 kmol of the mixture is burned with 60 kmol of air, compute the limiting reactant and the theoretical yield of CO<sub>2</sub> in kmol. (3 marks)
- ii. If the actual yield of CO<sub>2</sub> is 70% of the theoretical yield, show the percent yield. (4 marks)

**QUESTION 4**

- (a) Oxygen at 200K and 35 atm has a tabulated specific volume of 3.294 cm<sup>3</sup>/g and a specific internal energy of 1920 J/mol. Calculate the specific enthalpy of O<sub>2</sub> in this state. (4 marks)
- (b) A piston-cylinder device initially contains 0.5 kg of nitrogen gas at 200 kPa and 400 K. The piston is resting on stops, and the volume of the gas is 0.5 m<sup>3</sup>. Heat is now added to the gas until the piston moves to the end of the cylinder and the volume is 1 m<sup>3</sup>. The pressure inside the cylinder is maintained constant during the process. The nitrogen gas can be assumed to behave as an ideal gas with constant specific heat. Calculate:
- The final temperature of the gas (3 marks)
  - The heat added to the gas. (2 marks)
- (c) Use the data in Table B.2 to solve the following:
- The heat capacity (C<sub>p</sub>) of liquid benzene at 40 °C (2 marks)
  - The heat capacity at constant pressure of benzene vapor at 40 °C (2 marks)
  - The heat capacity at constant pressure of solid carbon at 40 °C (2 marks)
- (d) Estimate the specific enthalpy of steam (kJ/kg) at 500 K and 20 bar relative to steam at 300 K and 1 atm using:
- Steam table (2 marks)
  - Table B.2 and assuming ideal gas behavior (2 marks)

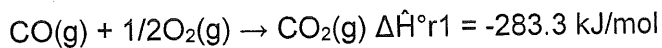
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**QUESTION 5**

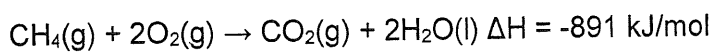
(a) Determine the standard heat of reaction for the following reaction:



if the standard heat of reaction:



(b) For the reaction: (4 marks)

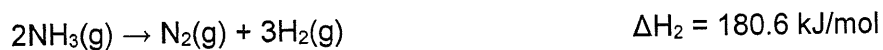


If 10 moles of methane are combusted per second at constant pressure and temperature of 25°C, calculate the rate of heat released in kJ/s.

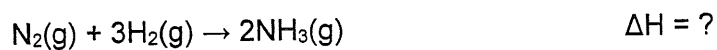
(c) The reaction between nitrogen and hydrogen to form ammonia can be represented as follows: (6 marks)



The decomposition of ammonia into nitrogen and hydrogen can be represented as follows:



Using the above reactions and the heat of reaction values, determine the heat of reaction for the following reaction:



## APPENDIX

## A. Factor for unit conversion

Quantity	Equivalent Values
<b>Mass</b>	1 kg = 1000 g = 0.001 metric ton = 2.20462 lb <sub>m</sub> = 35.27392 oz 1 lb <sub>m</sub> = 16 oz = 5 × 10 <sup>-4</sup> ton = 453.593 g = 0.453593 kg
<b>Length</b>	1 m = 100 cm = 1000 mm = 10 <sup>6</sup> microns (μm) = 10 <sup>10</sup> angstroms (Å) = 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
<b>Volume</b>	1 m <sup>3</sup> = 1000 L = 10 <sup>6</sup> cm <sup>3</sup> = 10 <sup>6</sup> mL = 35.3145 ft <sup>3</sup> = 220.83 imperial gallons = 264.17 gal = 1056.68 qt 1 ft <sup>3</sup> = 1728 in. <sup>3</sup> = 7.4805 gal = 0.028317 m <sup>3</sup> = 28.317 L = 28,317 cm <sup>3</sup>
<b>Force</b>	1 N = 1 kg·m/s <sup>2</sup> = 10 <sup>5</sup> dynes = 10 <sup>5</sup> g·cm/s <sup>2</sup> = 0.22481 lb <sub>f</sub> 1 lb <sub>f</sub> = 32.174 lb <sub>m</sub> ·ft/s <sup>2</sup> = 4.4482 N = 4.4482 × 10 <sup>5</sup> dynes
<b>Pressure</b>	1 atm = 1.01325 × 10 <sup>5</sup> N/m <sup>2</sup> (Pa) = 101.325 kPa = 1.01325 bar = 1.01325 × 10 <sup>6</sup> dynes/cm <sup>2</sup> = 760 mm Hg at 0°C (torr) = 10.333 m H <sub>2</sub> O at 4°C = 14.696 lb <sub>f</sub> /in. <sup>2</sup> (psi) = 33.9 ft H <sub>2</sub> O at 4°C = 29.921 in. Hg at 0°C
<b>Energy</b>	1 J = 1 N·m = 10 <sup>7</sup> ergs = 10 <sup>7</sup> dyne·cm = 2.778 × 10 <sup>-7</sup> kW·h = 0.23901 cal = 0.7376 ft·lb <sub>f</sub> = 9.486 × 10 <sup>-4</sup> Btu
<b>Power</b>	1 W = 1 J/s = 0.23901 cal/s = 0.7376 ft·lb <sub>f</sub> /s = 9.486 × 10 <sup>-4</sup> Btu/s = 1.341 × 10 <sup>-3</sup> hp

Example: The factor to convert grams to lb<sub>m</sub> is  $\left(\frac{2.20462 \text{ lb}_m}{1000 \text{ g}}\right)$ .

## B. Atomic weight of atom:

C=12 g/mol H=1 g/mol O=16 g/mol N=14 g/mol Cl=35.5 g/mol

----- End of questions -----

SUPPLEMENTARY DATA	
COURSE CODE	: BCE1113
COURSE	: ELEMENTARY PRINCIPLES IN CHEMICAL ENGINEERING

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	$C_9H_{12}$	120.19	g	1	°C	139.2	53.76	-39.79	120.5	0-1200
(Isopropyl benzene)										
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	$C_2H_5OH$	46.07	l	1	°C	103.1				0
(Ethanol)						158.8				100
Ethylene	$C_2H_4$	28.05	g	1	°C	61.34	15.72	-8.749	19.83	0-1200
Ferric oxide	$Fe_2O_3$	159.70	g	1	°C	+40.75	11.47	-6.891	17.66	0-1200
Formaldehyde	$CH_2O$	30.03	c	2	K	103.4	6.711	$-17.72 \times 10^{10}$	—	273-1097
Helium	He	4.00	g	1	°C	34.28	4.268	0.0000	-8.694	0-1200
<i>n</i> -Hexane	$C_6H_{14}$	86.17	l	1	°C	20.8				0-1200
						216.3				20-100
						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	$-8.732 \times 10^{10}$		273-2073
Methane	$CH_4$	16.04	g	1	°C	34.31	5.469	0.3661	-11.00	0-1200
						19.87	5.021	1.268	-11.00	273-1500
Methyl alcohol	$CH_3OH$	32.04	l	1	°C	75.86	16.83			0-65
(Methanol)						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

Table B.2 Heat Capacities<sup>a</sup>

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 <sub>3</sub> COCH <sub>3</sub>	58.08	l	1	°C	123.0	18.6	-12.78	34.76	-30-60
Acetylene	C <sub>2</sub> H <sub>2</sub>	26.04	g	1	°C	71.96	20.10	-5.033	18.20	0-1200
		29.0	g	1	°C	42.43	6.053	0.3191	-1.965	0-1500
Air			g	1	°C	28.94	0.4147	0.4799	-1.965	273-1800
Ammonia	NH <sub>3</sub>	17.03	g	1	K	28.09	0.1965	0.4421	-6.686	0-1200
		132.15	g	1	°C	35.15	2.954			275-328
Ammonium sulfate	(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	132.15	c	1	K	215.9				6-67
Benzene	C <sub>6</sub> H <sub>6</sub>	78.11	l	1	°C	126.5	23.4	-25.20	77.57	0-1200
Isobutane	C <sub>4</sub> H <sub>10</sub>	58.12	g	1	°C	74.06	32.95	-18.91	49.87	0-1200
		58.12	g	1	°C	89.46	30.13	-15.47	34.98	0-1200
<i>n</i> -Butane	C <sub>4</sub> H <sub>10</sub>	58.12	g	1	°C	92.30	27.88	-17.27	50.50	0-1200
Isobutene	C <sub>4</sub> H <sub>8</sub>	56.10	g	1	°C	82.88	25.64	-8.66 × 10 <sup>10</sup>		298-720
Calcium carbide	CaC <sub>2</sub>	64.10	c	2	K	68.62	1.19	-12.87 × 10 <sup>10</sup>		273-1033
Calcium carbonate	CaCO <sub>3</sub>	100.09	c	2	K	82.34	4.975			276-373
Calcium hydroxide	Ca(OH) <sub>2</sub>	74.10	c	1	K	89.5				273-1173
Calcium oxide	CaO	56.08	c	2	K	41.84	2.03	-4.52 × 10 <sup>10</sup>		273-1373
Carbon	C	12.01	c	2	K	11.18	1.095	-4.891 × 10 <sup>10</sup>		0-1500
Carbon dioxide	CO <sub>2</sub>	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 <sub>4</sub>	153.84	l	1	K	93.39	12.98			273-343
Chlorine	Cl <sub>2</sub>	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

<sup>a</sup> 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)

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

Table B.5 Properties of Saturated Steam: Temperature Table<sup>a</sup>

T(°C)	P(bar)	$\hat{V}$ (m <sup>3</sup> /kg)		$\hat{U}$ (kJ/kg)		$\hat{H}$ (kJ/kg)		
		Water	Steam	Water	Steam	Water	Evaporation	Steam
0.01	0.00611	0.001000	206.2	zero	2375.6	+0.0	2501.6	2501.6
2	0.00705	0.001000	179.9	8.4	2378.3	8.4	2496.8	2505.2
4	0.00813	0.001000	157.3	16.8	2381.1	16.8	2492.1	2508.9
6	0.00935	0.001000	137.8	25.2	2383.8	25.2	2487.4	2512.6
8	0.01072	0.001000	121.0	33.6	2386.6	33.6	2482.6	2516.2
10	0.01227	0.001000	106.4	42.0	2389.3	42.0	2477.9	2519.9
12	0.01401	0.001000	93.8	50.4	2392.1	50.4	2473.2	2523.6
14	0.01597	0.001001	82.9	58.8	2394.8	58.8	2468.5	2527.2
16	0.01817	0.001001	73.4	67.1	2397.6	67.1	2463.8	2530.9
18	0.02062	0.001001	65.1	75.5	2400.3	75.5	2459.0	2534.5
20	0.0234	0.001002	57.8	83.9	2403.0	83.9	2454.3	2538.2
22	0.0264	0.001002	51.5	92.2	2405.8	92.2	2449.6	2541.8
24	0.0298	0.001003	45.9	100.6	2408.5	100.6	2444.9	2545.5
25	0.0317	0.001003	43.4	104.8	2409.9	104.8	2442.5	2547.3
26	0.0336	0.001003	41.0	108.9	2411.2	108.9	2440.2	2549.1
28	0.0378	0.001004	36.7	117.3	2414.0	117.3	2435.4	2552.7
30	0.0424	0.001004	32.9	125.7	2416.7	125.7	2430.7	2556.4
32	0.0475	0.001005	29.6	134.0	2419.4	134.0	2425.9	2560.0
34	0.0532	0.001006	26.6	142.4	2422.1	142.4	2421.2	2563.6
36	0.0594	0.001006	24.0	150.7	2424.8	150.7	2416.4	2567.2
38	0.0662	0.001007	21.6	159.1	2427.5	159.1	2411.7	2570.8
40	0.0738	0.001008	19.55	167.4	2430.2	167.5	2406.9	2574.4
42	0.0820	0.001009	17.69	175.8	2432.9	175.8	2402.1	2577.9
44	0.0910	0.001009	16.04	184.2	2435.6	184.2	2397.3	2581.5
46	0.1009	0.001010	14.56	192.5	2438.3	192.5	2392.5	2585.1
48	0.1116	0.001011	13.23	200.9	2440.9	200.9	2387.7	2588.6
50	0.1234	0.001012	12.05	209.2	2443.6	209.3	2382.9	2592.2
52	0.1361	0.001013	10.98	217.7	2446	217.7	2377	2595
54	0.1500	0.001014	10.02	226.0	2449	226.0	2373	2599
56	0.1651	0.001015	9.158	234.4	2451	234.4	2368	2602
58	0.1815	0.001016	8.380	242.8	2454	242.8	2363	2606
60	0.1992	0.001017	7.678	251.1	2456	251.1	2358	2609
62	0.2184	0.001018	7.043	259.5	2459	259.5	2353	2613
64	0.2391	0.001019	6.468	267.9	2461	267.9	2348	2616
66	0.2615	0.001020	5.947	276.2	2464	276.2	2343	2619
68	0.2856	0.001022	5.475	284.6	2467	284.6	2338	2623

<sup>a</sup>From R. W. Haywood, *Thermodynamic Tables in SI (Metric) Units*, Cambridge University Press, London, 1968.  $\hat{V}$  = specific volume,  $\hat{U}$  = specific internal energy, and  $\hat{H}$  = specific enthalpy. Note: kJ/kg  $\times$  0.4303 = Btu/lb<sub>m</sub>.

(continued)

Table B.5 (Continued)

$T(^{\circ}\text{C})$	$P(\text{bar})$	$\hat{V}(\text{m}^3/\text{kg})$		$\hat{U}(\text{kJ}/\text{kg})$		$\hat{H}(\text{kJ}/\text{kg})$		
		Water	Steam	Water	Steam	Water	Evaporation	Steam
70	0.3117	0.001023	5.045	293.0	2469	293.0	2333	2626
72	0.3396	0.001024	4.655	301.4	2472	301.4	2329	2630
74	0.3696	0.001025	4.299	309.8	2474	309.8	2323	2633
76	0.4019	0.001026	3.975	318.2	2476	318.2	2318	2636
78	0.4365	0.001028	3.679	326.4	2479	326.4	2313	2639
80	0.4736	0.001029	3.408	334.8	2482	334.9	2308	2643
82	0.5133	0.001030	3.161	343.2	2484	343.3	2303	2646
84	0.5558	0.001032	2.934	351.6	2487	351.7	2298	2650
86	0.6011	0.001033	2.727	360.0	2489	360.1	2293	2653
88	0.6495	0.001034	2.536	368.4	2491	368.5	2288	2656
90	0.7011	0.001036	2.361	376.9	2493	377.0	2282	2659
92	0.7560	0.001037	2.200	385.3	2496	385.4	2277	2662
94	0.8145	0.001039	2.052	393.7	2499	393.8	2272	2666
96	0.8767	0.001040	1.915	402.1	2501	402.2	2267	2669
98	0.9429	0.001042	1.789	410.6	2504	410.7	2262	2673
100	1.0131	0.001044	1.673	419.0	2507	419.1	2257	2676
102	1.0876	0.001045	1.566	427.1	2509	427.5	2251	2679

Table B.6 Properties of Saturated Steam: Pressure Table

P (bar)	T (°C)	$\hat{V}$ (m <sup>3</sup> /kg)		$\hat{U}$ (kJ/kg)		$\hat{H}$ (kJ/kg)		
		Water	Steam	Water	Steam	Water	Evaporation	Steam
0.00611	0.01	0.001000	206.2	zero	2375.6	+0.0	2501.6	2501.6
0.008	3.8	0.001000	159.7	15.8	2380.7	15.8	2492.6	2508.5
0.010	7.0	0.001000	129.2	29.3	2385.2	29.3	2485.0	2514.4
0.012	9.7	0.001000	108.7	40.6	2388.9	40.6	2478.7	2519.3
0.014	12.0	0.001000	93.9	50.3	2392.0	50.3	2473.2	2523.5
0.016	14.0	0.001001	82.8	58.9	2394.8	58.9	2468.4	2527.3
0.018	15.9	0.001001	74.0	66.5	2397.4	66.5	2464.1	2530.6
0.020	17.5	0.001001	67.0	73.5	2399.6	73.5	2460.2	2533.6
0.022	19.0	0.001002	61.2	79.8	2401.7	79.8	2456.6	2536.4
0.024	20.4	0.001002	56.4	85.7	2403.6	85.7	2453.3	2539.0
0.026	21.7	0.001002	52.3	91.1	2405.4	91.1	2450.2	2541.3
0.028	23.0	0.001002	48.7	96.2	2407.1	96.2	2447.3	2543.6
0.030	24.1	0.001003	45.7	101.0	2408.6	101.0	2444.6	2545.6
0.035	26.7	0.001003	39.5	111.8	2412.2	111.8	2438.5	2550.4
0.040	29.0	0.001004	34.8	121.4	2415.3	121.4	2433.1	2554.5
0.045	31.0	0.001005	31.1	130.0	2418.1	130.0	2428.2	2558.2
0.050	32.9	0.001005	28.2	137.8	2420.6	137.8	2423.8	2561.6
0.060	36.2	0.001006	23.74	151.5	2425.1	151.5	2416.0	2567.5
0.070	39.0	0.001007	20.53	163.4	2428.9	163.4	2409.2	2572.6
0.080	41.5	0.001008	18.10	173.9	2432.3	173.9	2403.2	2577.1
0.090	43.8	0.001009	16.20	183.3	2435.3	183.3	2397.9	2581.1
0.10	45.8	0.001010	14.67	191.8	2438.0	191.8	2392.9	2584.8
0.11	47.7	0.001011	13.42	199.7	2440.5	199.7	2388.4	2588.1
0.12	49.4	0.001012	12.36	206.9	2442.8	206.9	2384.3	2591.2
0.13	51.1	0.001013	11.47	213.7	2445.0	213.7	2380.4	2594.0
0.14	52.6	0.001013	10.69	220.0	2447.0	220.0	2376.7	2596.7

0.15	54.0	0.001014	10.02	226.0	2448.9	226.0	2373.2	2599.2
0.16	55.3	0.001015	9.43	231.6	2450.6	231.6	2370.0	2601.6
0.17	56.6	0.001015	8.91	236.9	2452.3	236.9	2366.9	2603.8
0.18	57.8	0.001016	8.45	242.0	2453.9	242.0	2363.9	2605.9
0.19	59.0	0.001017	8.03	246.8	2455.4	246.8	2361.1	2607.9
0.20	60.1	0.001017	7.65	251.5	2456.9	251.5	2358.4	2609.9
0.22	62.2	0.001018	7.00	260.1	2459.6	260.1	2353.3	2613.5
0.24	64.1	0.001019	6.45	268.2	2462.1	268.2	2348.6	2616.8
0.26	65.9	0.001020	5.98	275.6	2464.4	275.6	2344.2	2619.9
0.28	67.5	0.001021	5.58	282.7	2466.5	282.7	2340.0	2622.7
0.30	69.1	0.001022	5.23	289.3	2468.6	289.3	2336.1	2625.4
0.35	72.7	0.001025	4.53	304.3	2473.1	304.3	2327.2	2631.5
0.40	75.9	0.001027	3.99	317.6	2477.1	317.6	2319.2	2636.9
0.45	78.7	0.001028	3.58	329.6	2480.7	329.6	2312.0	2641.7
0.50	81.3	0.001030	3.24	340.5	2484.0	340.6	2305.4	2646.0
0.55	83.7	0.001032	2.96	350.6	2486.9	350.6	2299.3	2649.9
0.60	86.0	0.001033	2.73	359.9	2489.7	359.9	2293.6	2653.6
0.65	88.0	0.001035	2.53	368.5	2492.2	368.6	2288.3	2656.9
0.70	90.0	0.001036	2.36	376.7	2494.5	376.8	2283.3	2660.1
0.75	91.8	0.001037	2.22	384.4	2496.7	384.5	2278.6	2663.0
0.80	93.5	0.001039	2.087	391.6	2498.8	391.7	2274.1	2665.8
0.85	95.2	0.001040	1.972	398.5	2500.8	398.6	2269.8	2668.4
0.90	96.7	0.001041	1.869	405.1	2502.6	405.2	2265.6	2670.9
0.95	98.2	0.001042	1.777	411.4	2504.4	411.5	2261.7	2673.2
1.00	99.6	0.001043	1.694	417.4	2506.1	417.5	2257.9	2675.4
1.01325 (1 atm)	100.0	0.001044	1.673	419.0	2506.5	419.1	2256.9	2676.0

\*From R. W. Haywood, *Thermodynamic Tables in SI (Metric) Units*, Cambridge University Press, London, 1968.  $\hat{v}$  = specific volume,  $\hat{U}$  = specific internal energy, and  $\hat{H}$  = specific enthalpy. Note:  $\text{kJ/kg} \times 0.4303 = \text{Btu/lb}_m$ .

(continued)

Table B.6 (Continued)

P(bar)	T(°C)	$\hat{V}$ (m <sup>3</sup> /kg)		$\hat{U}$ (kJ/kg)		$\hat{H}$ (kJ/kg)		
		Water	Steam	Water	Steam	Water	Evaporation	Steam
1.1	102.3	0.001046	1.549	428.7	2509.2	428.8	2250.8	2679.6
1.2	104.8	0.001048	1.428	439.2	2512.1	439.4	2244.1	2683.4
1.3	107.1	0.001049	1.325	449.1	2514.7	449.2	2237.8	2687.0
1.4	109.3	0.001051	1.236	458.3	2517.2	458.4	2231.9	2690.3
1.5	111.4	0.001053	1.159	467.0	2519.5	467.1	2226.2	2693.4
1.6	113.3	0.001055	1.091	475.2	2521.7	475.4	2220.9	2696.2
1.7	115.2	0.001056	1.031	483.0	2523.7	483.2	2215.7	2699.0
1.8	116.9	0.001058	0.977	490.5	2525.6	490.7	2210.8	2701.5
1.9	118.6	0.001059	0.929	497.6	2527.5	497.8	2206.1	2704.0
2.0	120.2	0.001061	0.885	504.5	2529.2	504.7	2201.6	2706.3
2.2	123.3	0.001064	0.810	517.4	2532.4	517.6	2193.0	2710.6
2.4	126.1	0.001066	0.746	529.4	2535.4	529.6	2184.9	2714.5
2.6	128.7	0.001069	0.693	540.6	2538.1	540.9	2177.3	2718.2
2.8	131.2	0.001071	0.646	551.1	2540.6	551.4	2170.1	2721.5
3.0	133.5	0.001074	0.606	561.1	2543.0	561.4	2163.2	2724.7
3.2	135.8	0.001076	0.570	570.6	2545.2	570.9	2156.7	2727.6
3.4	137.9	0.001078	0.538	579.6	2547.2	579.9	2150.4	2730.3
3.6	139.9	0.001080	0.510	588.1	2549.2	588.5	2144.4	2732.9
3.8	141.8	0.001082	0.485	596.4	2551.0	596.8	2138.6	2735.3
4.0	143.6	0.001084	0.462	604.2	2552.7	604.7	2133.0	2737.6
4.2	145.4	0.001086	0.442	611.8	2554.4	612.3	2127.5	2739.8
4.4	147.1	0.001088	0.423	619.1	2555.9	619.6	2122.3	2741.9
4.6	148.7	0.001089	0.405	626.2	2557.4	626.7	2117.2	2743.9
4.8	150.3	0.001091	0.389	633.0	2558.8	633.5	2112.2	2745.7
5.0	151.8	0.001093	0.375	639.6	2560.2	640.1	2107.4	2747.5
5.5	155.5	0.001097	0.342	655.2	2563.3	655.8	2095.9	2751.7
6.0	158.8	0.001101	0.315	669.8	2566.2	670.4	2085.0	2755.5
6.5	162.0	0.001105	0.292	683.4	2568.7	684.1	2074.7	2758.9
7.0	165.0	0.001108	0.273	696.3	2571.1	697.1	2064.9	2762.0

7.5	167.8	0.001112	0.2554	708.5	2573.3	709.3	2055.5	2764.8
8.0	170.4	0.001115	0.2403	720.0	2575.5	720.9	2046.5	2767.5
8.5	172.9	0.001118	0.2268	731.1	2577.1	732.0	2037.9	2769.9
9.0	175.4	0.001121	0.2148	741.6	2578.8	742.6	2029.5	2772.1
9.5	177.7	0.001124	0.2040	751.8	2580.4	752.8	2021.4	2774.2
10.0	179.9	0.001127	0.1943	761.5	2581.9	762.6	2013.6	2776.2
10.5	182.0	0.001130	0.1855	770.8	2583.3	772.0	2005.9	2778.0
11.0	184.1	0.001133	0.1774	779.9	2584.5	781.1	1998.5	2779.7
11.5	186.0	0.001136	0.1700	788.6	2585.8	789.9	1991.3	2781.3
12.0	188.0	0.001139	0.1632	797.1	2586.9	798.4	1984.3	2782.7
12.5	189.8	0.001141	0.1569	805.3	2588.0	806.7	1977.4	2784.1
13.0	191.6	0.001144	0.1511	813.2	2589.0	814.7	1970.7	2785.4
14	195.0	0.001149	0.1407	828.5	2590.8	830.1	1957.7	2787.8
15	198.3	0.001154	0.1317	842.9	2592.4	844.7	1945.2	2789.9
16	201.4	0.001159	0.1237	856.7	2593.8	858.6	1933.2	2791.7
17	204.3	0.001163	0.1166	869.9	2595.1	871.8	1921.5	2793.4
18	207.1	0.001168	0.1103	882.5	2596.3	884.6	1910.3	2794.8
19	209.8	0.001172	0.1047	894.6	2597.3	896.8	1899.3	2796.1
20	212.4	0.001177	0.0995	906.2	2598.2	908.6	1888.6	2797.2
21	214.9	0.001181	0.0949	917.5	2598.9	920.0	1878.2	2798.2
22	217.2	0.001185	0.0907	928.3	2599.6	931.0	1868.1	2799.1
23	219.6	0.001189	0.0868	938.9	2600.2	941.6	1858.2	2799.8
24	221.8	0.001193	0.0832	949.1	2600.7	951.9	1848.5	2800.4
25	223.9	0.001197	0.0799	959.0	2601.2	962.0	1839.0	2800.9
26	226.0	0.001201	0.0769	968.6	2601.5	971.7	1829.6	2801.4
27	228.1	0.001205	0.0740	978.0	2601.8	981.2	1820.5	2801.7
28	230.0	0.001209	0.0714	987.1	2602.1	990.5	1811.5	2802.0
29	232.0	0.001213	0.0689	996.0	2602.3	999.5	1802.6	2802.2
30	233.8	0.001216	0.0666	1004.7	2602.4	1008.4	1793.9	2802.3
32	237.4	0.001224	0.0624	1021.5	2602.5	1025.4	1776.9	2802.3
34	240.9	0.001231	0.0587	1037.6	2602.5	1041.8	1760.3	2802.1
36	244.2	0.001238	0.0554	1053.1	2602.2	1057.6	1744.2	2801.7
38	247.3	0.001245	0.0524	1068.0	2601.9	1072.7	1728.4	2801.1

(continued)

Table B.6 (Continued)

P(bar)	T(°C)	$\hat{V}$ (m <sup>3</sup> /kg)		$\hat{U}$ (kJ/kg)		$\hat{H}$ (kJ/kg)		
		Water	Steam	Water	Steam	Water	Evaporation	Steam
40	250.3	0.001252	0.0497	1082.4	2601.3	1087.4	1712.9	2800.3
42	253.2	0.001259	0.0473	1096.3	2600.7	1101.6	1697.8	2799.4
44	256.0	0.001266	0.0451	1109.8	2599.9	1115.4	1682.9	2798.3
46	258.8	0.001272	0.0430	1122.9	2599.1	1128.8	1668.3	2797.1
48	261.4	0.001279	0.0412	1135.6	2598.1	1141.8	1653.9	2795.7
50	263.9	0.001286	0.0394	1148.0	2597.0	1154.5	1639.7	2794.2
52	266.4	0.001292	0.0378	1160.1	2595.9	1166.8	1625.7	2792.6
54	268.8	0.001299	0.0363	1171.9	2594.6	1178.9	1611.9	2790.8
56	271.1	0.001306	0.0349	1183.5	2593.3	1190.8	1598.2	2789.0
58	273.3	0.001312	0.0337	1194.7	2591.9	1202.3	1584.7	2787.0
60	275.6	0.001319	0.0324	1205.8	2590.4	1213.7	1571.3	2785.0
62	277.7	0.001325	0.0313	1216.6	2588.8	1224.8	1558.0	2782.9
64	279.8	0.001332	0.0302	1227.2	2587.2	1235.7	1544.9	2780.6
66	281.8	0.001338	0.0292	1237.6	2585.5	1246.5	1531.9	2778.3
68	283.8	0.001345	0.0283	1247.9	2583.7	1257.0	1518.9	2775.9
70	285.8	0.001351	0.0274	1258.0	2581.8	1267.4	1506.0	2773.5
72	287.7	0.001358	0.0265	1267.9	2579.9	1277.6	1493.3	2770.9
74	289.6	0.001364	0.0257	1277.6	2578.0	1287.7	1480.5	2768.3
76	291.4	0.001371	0.0249	1287.2	2575.9	1297.6	1467.9	2765.5
78	293.2	0.001378	0.0242	1296.7	2573.8	1307.4	1455.3	2762.8
80	295.0	0.001384	0.0235	1306.0	2571.7	1317.1	1442.8	2759.9
82	296.7	0.001391	0.0229	1315.2	2569.5	1326.6	1430.3	2757.0
84	298.4	0.001398	0.0222	1324.3	2567.2	1336.1	1417.9	2754.0
86	300.1	0.001404	0.0216	1333.3	2564.9	1345.4	1405.5	2750.9
88	301.7	0.001411	0.0210	1342.2	2562.6	1354.6	1393.2	2747.8
90	303.3	0.001418	0.02050	1351.0	2560.1	1363.7	1380.9	2744.6
92	304.9	0.001425	0.01996	1359.7	2557.7	1372.8	1368.6	2741.4
94	306.4	0.001432	0.01945	1368.2	2555.2	1381.7	1356.3	2738.0

96	308.0	0.001439	0.01897	1376.7	2552.6	1390.6	1344.1	2734.7
98	309.5	0.001446	0.01849	1385.2	2550.0	1399.3	1331.9	2731.2
100	311.0	0.001453	0.01804	1393.5	2547.3	1408.0	1319.7	2727.7
105	314.6	0.001470	0.01698	1414.1	2540.4	1429.5	1289.2	2718.7
110	318.0	0.001489	0.01601	1434.2	2533.2	1450.6	1258.7	2709.3
115	321.4	0.001507	0.01511	1454.0	2525.7	1471.3	1228.2	2699.5
120	324.6	0.001527	0.01428	1473.4	2517.8	1491.8	1197.4	2689.2
125	327.8	0.001547	0.01351	1492.7	2509.4	1512.0	1166.4	2678.4
130	330.8	0.001567	0.01280	1511.6	2500.6	1532.0	1135.0	2667.0
135	333.8	0.001588	0.01213	1530.4	2491.3	1551.9	1103.1	2655.0
140	336.6	0.001611	0.01150	1549.1	2481.4	1571.6	1070.7	2642.4
145	339.4	0.001634	0.01090	1567.5	2471.0	1591.3	1037.7	2629.1
150	342.1	0.001658	0.01034	1586.1	2459.9	1611.0	1004.0	2615.0
155	344.8	0.001683	0.00981	1604.6	2448.2	1630.7	969.6	2600.3
160	347.3	0.001710	0.00931	1623.2	2436.0	1650.5	934.3	2584.9
165	349.8	0.001739	0.00883	1641.8	2423.1	1670.5	898.3	2568.8
170	352.3	0.001770	0.00837	1661.6	2409.3	1691.7	859.9	2551.6
175	354.6	0.001803	0.00793	1681.8	2394.6	1713.3	820.0	2533.3
180	357.0	0.001840	0.00750	1701.7	2378.9	1734.8	779.1	2513.9
185	359.2	0.001881	0.00708	1721.7	2362.1	1756.5	736.6	2493.1
190	361.4	0.001926	0.00668	1742.1	2343.8	1778.7	692.0	2470.6
195	363.6	0.001977	0.00628	1763.2	2323.6	1801.8	644.2	2446.0
200	365.7	0.00204	0.00588	1785.7	2300.8	1826.5	591.9	2418.4
205	367.8	0.00211	0.00546	1810.7	2274.4	1853.9	532.5	2386.4
210	369.8	0.00220	0.00502	1840.0	2242.1	1886.3	461.3	2347.6
215	371.8	0.00234	0.00451	1878.6	2198.1	1928.9	366.2	2295.2
220	373.7	0.00267	0.00373	1952	2114	2011	185	2196
221.2	374.15	0.00317	0.00317	2038	2038	2108	0	2108

(Critical point)

**Table B.7** Properties of Superheated Steam<sup>a</sup>

P(bar) (T <sub>sat.</sub> °C)	Sat'd Water	Sat'd Steam	Temperature (°C) →								
			50	75	100	150	200	250	300	350	
0.0 (—)	$\hat{H}$	—	2595	2642	2689	2784	2880	2978	3077	3177	
	$\hat{U}$	—	2446	2481	2517	2589	2662	2736	2812	2890	
	$\hat{V}$	—	—	—	—	—	—	—	—	—	
0.1 (45.8)	$\hat{H}$	191.8	2584.8	2593	2640	2688	2783	2880	2977	3077	3177
	$\hat{U}$	191.8	2438.0	2444	2480	2516	2588	2661	2736	2812	2890
	$\hat{V}$	0.00101	14.7	14.8	16.0	17.2	19.5	21.8	24.2	26.5	28.7
0.5 (81.3)	$\hat{H}$	340.6	2646.0	209.3	313.9	2683	2780	2878	2979	3076	3177
	$\hat{U}$	340.6	2484.0	209.2	313.9	2512	2586	2660	2735	2811	2889
	$\hat{V}$	0.00103	3.24	0.00101	0.00103	3.41	3.89	4.35	4.83	5.29	5.75
1.0 (99.6)	$\hat{H}$	417.5	2675.4	209.3	314.0	2676	2776	2875	2975	3074	3176
	$\hat{U}$	417.5	2506.1	209.2	313.9	2507	2583	2658	2734	2811	2889
	$\hat{V}$	0.00104	1.69	0.00101	0.00103	1.69	1.94	2.17	2.40	2.64	2.87
5.0 (151.8)	$\hat{H}$	640.1	2747.5	209.7	314.3	419.4	632.2	2855	2961	3065	3168
	$\hat{U}$	639.6	2560.2	209.2	313.8	418.8	631.6	2643	2724	2803	2883
	$\hat{V}$	0.00109	0.375	0.00101	0.00103	0.00104	0.00109	0.425	0.474	0.522	0.571
10 (179.9)	$\hat{H}$	762.6	2776.2	210.1	314.7	419.7	632.5	2827	2943	3052	3159
	$\hat{U}$	761.5	2582	209.1	313.7	418.7	631.4	2621	2710	2794	2876
	$\hat{V}$	0.00113	0.194	0.00101	0.00103	0.00104	0.00109	0.206	0.233	0.258	0.282
20 (212.4)	$\hat{H}$	908.6	2797.2	211.0	315.5	420.5	633.1	852.6	2902	3025	3139
	$\hat{U}$	906.2	2598.2	209.0	313.5	418.4	603.9	850.2	2679	2774	2862
	$\hat{V}$	0.00118	0.09950	0.00101	0.00102	0.00104	0.00109	0.00116	0.111	0.125	0.139
40 (250.3)	$\hat{H}$	1087.4	2800.3	212.7	317.1	422.0	634.3	853.4	1085.8	2962	3095
	$\hat{U}$	1082.4	2601.3	208.6	313.0	417.8	630.0	848.8	1080.8	2727	2829
	$\hat{V}$	0.00125	0.04975	0.00101	0.00102	0.00104	0.00109	0.00115	0.00125	0.0588	0.0665
60 (275.6)	$\hat{H}$	1213.7	2785.0	214.4	318.7	423.5	635.6	854.2	1085.8	2885	3046
	$\hat{U}$	1205.8	2590.4	208.3	312.6	417.3	629.1	847.3	1078.3	2668	2792
	$\hat{V}$	0.00132	0.0325	0.00101	0.00103	0.00104	0.00109	0.00115	0.00125	0.0361	0.0422
80 (295.0)	$\hat{H}$	1317.1	2759.9	216.1	320.3	425.0	636.8	855.1	1085.8	2787	2990
	$\hat{U}$	1306.0	2571.7	208.1	312.3	416.7	628.2	845.9	1075.8	2593	2750
	$\hat{V}$	0.00139	0.0235	0.00101	0.00102	0.00104	0.00109	0.00115	0.00124	0.0243	0.0299
100 (311.0)	$\hat{H}$	1408.0	2727.7	217.8	322.9	426.5	638.1	855.9	1085.8	1343.4	2926
	$\hat{U}$	1393.5	2547.3	207.8	311.7	416.1	627.3	844.4	1073.4	1329.4	2702
	$\hat{V}$	0.00145	0.0181	0.00101	0.00102	0.00104	0.00109	0.00115	0.00124	0.00140	0.0224
150 (342.1)	$\hat{H}$	1611.0	2615.0	222.1	326.0	430.3	641.3	858.1	1086.2	1338.2	2695
	$\hat{U}$	1586.1	2459.9	207.0	310.7	414.7	625.0	841.0	1067.7	1317.6	2523
	$\hat{V}$	0.00166	0.0103	0.00101	0.00102	0.00104	0.00108	0.00114	0.00123	0.00138	0.0115
200 (365.7)	$\hat{H}$	1826.5	2418.4	226.4	330.0	434.0	644.5	860.4	1086.7	1334.3	1647.1
	$\hat{U}$	1785.7	2300.8	206.3	309.7	413.2	622.9	837.7	1062.2	1307.1	1613.7
	$\hat{V}$	0.00204	0.005875	0.00100	0.00102	0.00103	0.00108	0.00114	0.00122	0.00136	0.00167
221.2(P <sub>c</sub> ) (374.15)(T <sub>c</sub> )	$\hat{H}$	2108	2108	228.2	331.7	435.7	645.8	861.4	1087.0	1332.8	1635.5
	$\hat{U}$	2037.8	2037.8	206.0	309.2	412.8	622.0	836.3	1060.0	1302.9	1600.3
	$\hat{V}$	0.00317	0.00317	0.00100	0.00102	0.00103	0.00108	0.00114	0.00122	0.00135	0.00163
250 (—)	$\hat{H}$	—	—	230.7	334.0	437.8	647.7	862.8	1087.5	1331.1	1625.0
	$\hat{U}$	—	—	205.7	308.7	412.1	620.8	834.4	1057.0	1297.5	1585.0
	$\hat{V}$	—	—	0.00100	0.00101	0.00103	0.00108	0.00113	0.00122	0.00135	0.00160
300 (—)	$\hat{H}$	—	—	235.0	338.1	441.6	650.9	865.2	1088.4	1328.7	1609.9
	$\hat{U}$	—	—	205.0	307.7	410.8	618.7	831.3	1052.1	1288.7	1563.3
	$\hat{V}$	—	—	0.0009990	0.00101	0.00103	0.00107	0.00113	0.00121	0.00133	0.00155
500 (—)	$\hat{H}$	—	—	251.9	354.2	456.8	664.1	875.4	1093.6	1323.7	1576.3
	$\hat{U}$	—	—	202.4	304.0	405.8	611.0	819.7	1034.3	1259.3	1504.1
	$\hat{V}$	—	—	0.0009911	0.00100	0.00102	0.00106	0.00111	0.00119	0.00129	0.00144
1000 (—)	$\hat{H}$	—	—	293.9	394.3	495.1	698.0	903.5	1113.0	1327.7	1550.5
	$\hat{U}$	—	—	196.5	295.7	395.1	594.4	795.3	999.0	1207.1	1419.0
	$\hat{V}$	—	—	0.0009737	0.0009852	0.001000	0.00104	0.00108	0.00114	0.00122	0.00131

<sup>a</sup>Adapted from R. W. Haywood, *Thermodynamic Tables in SI (Metric) Units*, Cambridge University Press, London, 1968. Water is a liquid in the enclosed region between 50°C and 350°C.  $\hat{H}$  = specific enthalpy (kJ/kg),  $\hat{U}$  = specific internal energy (kJ/kg),  $\hat{V}$  = specific volume (m<sup>3</sup>/kg). Note: kJ/kg × 0.4303 = Btu/lb<sub>m</sub>.

(continued)

Table B.7 (Continued)

$P(\text{bar})$ ( $T_{\text{sat.}}^{\circ}\text{C}$ )		Temperature ( $^{\circ}\text{C}$ )							
		400	450	500	550	600	650	700	750
0.0 (—)	$\hat{H}$	3280	3384	3497	3597	3706	3816	3929	4043
	$\hat{U}$	2969	3050	3132	3217	3303	3390	3480	3591
	$\hat{V}$	—	—	—	—	—	—	—	—
0.1 (45.8)	$\hat{H}$	3280	3384	3489	3596	3706	3816	3929	4043
	$\hat{U}$	2969	3050	3132	3217	3303	3390	3480	3571
	$\hat{V}$	21.1	33.3	35.7	38.0	40.3	42.6	44.8	47.2
0.5 (81.3)	$\hat{H}$	3279	3383	3489	3596	3705	3816	3929	4043
	$\hat{U}$	2969	3049	3132	3216	3302	3390	3480	3571
	$\hat{V}$	6.21	6.67	7.14	7.58	8.06	8.55	9.01	9.43
1.0 (99.6)	$\hat{H}$	3278	3382	3488	3596	3705	3816	3928	4042
	$\hat{U}$	2968	3049	3132	3216	3302	3390	3479	3570
	$\hat{V}$	3.11	3.33	3.57	3.80	4.03	4.26	4.48	4.72
5.0 (151.8)	$\hat{H}$	3272	3379	3484	3592	3702	3813	3926	4040
	$\hat{U}$	2964	3045	3128	3213	3300	3388	3477	3569
	$\hat{V}$	0.617	0.664	0.711	0.758	0.804	0.850	0.897	0.943
10 (179.9)	$\hat{H}$	3264	3371	3478	3587	3697	3809	3923	4038
	$\hat{U}$	2958	3041	3124	3210	3296	3385	3475	3567
	$\hat{V}$	0.307	0.330	0.353	0.377	0.402	0.424	0.448	0.472
20 (212.4)	$\hat{H}$	3249	3358	3467	3578	3689	3802	3916	4032
	$\hat{U}$	2946	3031	3115	3202	3290	3379	3470	3562
	$\hat{V}$	0.151	0.163	0.175	0.188	0.200	0.211	0.223	0.235
40 (250.3)	$\hat{H}$	3216	3331	3445	3559	3673	3788	3904	4021
	$\hat{U}$	2922	3011	3100	3188	3278	3368	3460	3554
	$\hat{V}$	0.0734	0.0799	0.0864	0.0926	0.0987	0.105	0.111	0.117
60 (275.6)	$\hat{H}$	3180	3303	3422	3539	3657	3774	3892	4011
	$\hat{U}$	2896	2991	3083	3174	3265	3357	3451	3545
	$\hat{V}$	0.0474	0.0521	0.0566	0.0609	0.0652	0.0693	0.0735	0.0776
80 (295.0)	$\hat{H}$	3142	3274	3399	3520	3640	3759	3879	4000
	$\hat{U}$	2867	2969	3065	3159	3252	3346	3441	3537
	$\hat{V}$	0.0344	0.0382	0.0417	0.0450	0.0483	0.0515	0.0547	0.0578
100 (311.0)	$\hat{H}$	3100	3244	3375	3500	3623	3745	3867	3989
	$\hat{U}$	2836	2946	3047	3144	3240	3335	3431	3528
	$\hat{V}$	0.0264	0.0298	0.0328	0.0356	0.0383	0.0410	0.0435	0.0461
150 (342.1)	$\hat{H}$	2975	3160	3311	3448	3580	3708	3835	3962
	$\hat{U}$	2744	2883	2999	3105	3207	3307	3407	3507
	$\hat{V}$	0.0157	0.0185	0.0208	0.0229	0.0249	0.0267	0.0286	0.0304
200 (365.7)	$\hat{H}$	2820	3064	3241	3394	3536	3671	3804	3935
	$\hat{U}$	2622	2810	2946	3063	3172	3278	3382	3485
	$\hat{V}$	0.009950	0.0127	0.0148	0.0166	0.0182	0.197	0.211	0.0225
221.2( $P_c$ ) (374.15)( $T_c$ )	$\hat{H}$	2733	3020	3210	3370	3516	3655	3790	3923
	$\hat{U}$	2553	2776	2922	3045	3157	3265	3371	3476
	$\hat{V}$	0.008157	0.0110	0.0130	0.0147	0.0162	0.0176	0.0190	0.0202
250 (—)	$\hat{H}$	2582	2954	3166	3337	3490	3633	3772	3908
	$\hat{U}$	2432	2725	2888	3019	3137	3248	3356	3463
	$\hat{V}$	0.006013	0.009174	0.0111	0.0127	0.0141	0.0143	0.0166	0.0178
300 (—)	$\hat{H}$	2162	2826	3085	3277	3443	3595	3740	3880
	$\hat{U}$	2077	2623	2825	2972	3100	3218	3330	3441
	$\hat{V}$	0.002830	0.006734	0.008680	0.0102	0.0114	0.0126	0.0136	0.0147
500 (—)	$\hat{H}$	1878	2293	2723	3021	3248	3439	3610	3771
	$\hat{U}$	1791	2169	2529	2765	2946	3091	3224	3350
	$\hat{V}$	0.001726	0.002491	0.003882	0.005112	0.006112	0.007000	0.007722	0.008418
1000 (—)	$\hat{H}$	1798	2051	2316	2594	2857	3105	3324	3526
	$\hat{U}$	1653	1888	2127	2369	2591	2795	2971	3131
	$\hat{V}$	0.001446	0.001628	0.001893	0.002246	0.002668	0.003106	0.003536	0.003953

