DEPARTMENT OF CHEMICAL & PROCESS ENGINEERING

University of Strathclyde Engineering

Degree of BEng/MEng in Chemical Engineering

CP203/CP211 Thermodynamics and Chemical Principles

Date: Friday 7th May 2021 **Time: 14:00-17:00**
Duration: 3 hours

Answer All Questions

The paper is divided into TWO sections

Answer each section in a separate booklet

There are 100 marks available in each section of the paper

Calculators must not be used to store text and/or formulae nor be capable of communication. Invigilators may require calculators to be re-set.

Remember to clearly state any assumptions you make when solving each question.

Equation sheets and periodic table are provided at the end of the paper.

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Section A: Answer All Questions

QA1. Methane gas is continually fed into a steady-state isothermal compressor at an inlet absolute pressure of 500 bar and temperature of 200 K. The gas exits the compressor at an absolute pressure of 750 bar. The compressibility factor of methane in this range of conditions obeys the following equation:

$$\boldsymbol{Z = a + bP}$$

with the constants taking the values a = 0.28 and b = 0.00208 bar^{-1}.

Calculate the final volume of the gas in cm^3 and the molar work of compression in kJ/mol.

[16 marks]

QA2. Calculate the value of the Joule-Thomson coefficient for a gas that is described by the following equation of state:

$$\boldsymbol{P = \frac{RT}{v - b}}$$

where b is a constant with the value 0.03 m^3 mol^{-1}. The constant pressure heat capacity of the gas is c_P = 21 J mol^{-1} K^{-1}.

[16 marks]

QA3. A thermodynamic cycle is composed of four steps: **i)** reversible isothermal expansion at 130 °C; **ii)** irreversible adiabatic expansion to a temperature of 20 °C; **iii)** reversible isothermal compression at 20 °C; **iv)** reversible adiabatic compression back to the initial state at 130 °C. The entropy change in the first step of the process is Δs_1 = 18 J mol^{-1} K^{-1} and the entropy change in step **ii)** is Δs_2 = 3 J mol^{-1} K^{-1}.

Choose the correct sketch of the cyclic process on a temperature-entropy (TS) diagram (among 4 options).

Calculate the efficiency of the real heat engine, as well as the efficiency of a Carnot engine operating between the same two temperatures.

[20 marks]

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QA4. A vapour mixture composed of 75% of heptane and 25% of octane (molar basis), at a temperature of 100 °C, is in equilibrium with a liquid mixture of the same components. The vapour phase can be assumed to be an ideal gas and the liquid phase can be assumed to form an ideal mixture. Making use of the data presented in **Table QA4**, calculate the pressure in bar and the mole fraction of heptane in the liquid phase.

[18 marks]

***Table QA4**: Physical data for pure heptane and octane.*

Component	**heptane**	**octane**
Enthalpy of Vaporisation at 100 °C (kJ mol^{-1})	36	41
Boiling Temperature at 1 bar (°C)	98.5	125.7

QA5. An ideal gas, initially at 25 °C, is compressed adiabatically so that its final pressure is three times its initial pressure. The constant volume heat capacity of the gas is c_V = 18.5 J mol^{-1} K^{-1}.

Calculate the ratio of heat capacities, γ, and the final temperature of the gas in °C.

[12 marks]

QA6. An adiabatic turbine operates with an inlet stream of air at 6 bar and 400 K. The air leaves the turbine at 2 bar and 330 K. Over this range of conditions, you can assume that air behaves as an ideal gas, with a constant pressure heat capacity of c_P = 30 J mol^{-1} K^{-1}.

Calculate the entropy change during operation of the turbine in J mol^{-1} K^{-1}.

Calculate the efficiency of the turbine relative to its isentropic mode of operation at the same inlet conditions and outlet pressure.

[18 marks]

[PLEASE TURN OVER]

Section B: Answer All Questions

QB1. Given that the insertion of a tube (0.34 mm bore) into bulk water results in the rise of a column of water above the incident bulk liquid surface to a height of 6.1 mm, at 325 K, determine the surface tension of water at this temperature. [10 marks]

QB2. Data for the surface tension of an uncharged surfactant, measured with increasing concentration at 25 °C, is analysed using the Gibbs equation, giving a gradient of -9.475 x 10^{-3} N m^{-1}, from a plot of γ against log(concentration).

i) Calculate Γ for the system studied.

ii) Calculate the area occupied by one molecule of the surfactant.

iii) Discuss what change would be expected in the area occupied per molecule if the surfactant were charged.

[15 marks]

QB3. An adsorption surface experiences 9.83 x 10^{26} collisions per square metre per second from a pure diatomic gas at 0.35 atm and 323 K. Determine the gas present.

[10 marks]

QB4. Using the Antoine equation:

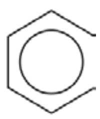
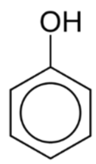
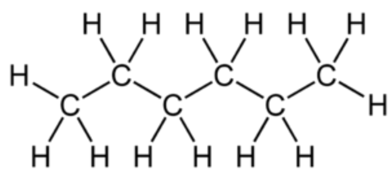
$$log\,P = A - \frac{B}{T + C}$$

where T is temperature in °C and P is pressure in Torr, and the data provided in **Table QB4**:

i) Calculate the boiling points of phenol, hexane and benzene.

ii) Explain the trend in boiling points for these three molecules.

Table QB4: Antoine constants and chemical structures of chemicals in QB4

Chemical	benzene	phenol	hexane
Chemical structure			
Temperature range/°C	8 to 103	107 to 182	-29 to 92
A	6.90565	7.1330	6.87601
B	1211.033	1516.79	1171.17
C	220.790	174.95	224.41

[14 marks]

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QB5. **a)** What assumptions are made in the derivation of the Langmuir equation? Use a diagram to illustrate your answer.

b) A material has a monolayer capacity of 12.30 mmol g^{-1} for nitrogen adsorption at 77 K. Given that the area occupied by 1 molecule of nitrogen is 1.62 x 10^{-15} cm^2, what is the surface area of the material? Comment on the answer obtained in the context of your understanding of this parameter.

[16 marks]

QB6. Define the term 'equilibrium vapour pressure' and discuss:

i) the molecular basis of this physical quantity

ii) the effect of temperature

iii) the effect of surface area.

[14 marks]

QB7. Using an appropriate sketch, explain the expected trend in the surface tension of benzene with increasing temperature.

[8 marks]

QB8. Given the data in **Table QB8** for adsorption of ethanol on a mesoporous carbon at 28 °C, at which temperature the saturated vapour pressure for ethanol is 70.9 mbar, and that the molar heat of condensation for ethanol is -38.56 kJ mol^{-1}, determine:

i) the monolayer coverage

ii) the value of the C constant for the process

iii) the heat of adsorption

Note that you may use graph paper or software to plot your graphs.

Table QB8: Molar uptakes for adsorption of ethanol on mesoporous carbon

p/p^o	$p/n(p^o-p)$ / g $mmol^{-1}$
0.05	0.0077
0.15	0.0179
0.25	0.0284
0.35	0.0392

[13 marks]

Information:

g = 9.81 m s^{-2}

R = 8.314 J K^{-1} mol^{-1}

Avogadro's number = 6.023 x 10^{23} molecule mol^{-1}

Boltzmann Constant = 1.38 x 10^{-23} J K^{-1} $molecule^{-1}$

1 atm = 101325 Pa

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Thermodynamics Equation Sheet

All symbols have the same meaning as given in class materials.

First Law (general)

$$\Delta U = Q + W - \Delta\left(\frac{1}{2}mv^2\right) - \Delta(mgz)$$

Gibbs phase rule

$$F = 2 - \pi + N$$

Thermal expansion coefficient

$$\alpha = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_{P,m}$$

Isothermal compressibility

$$\beta = -\frac{1}{V}\left(\frac{\partial V}{\partial P}\right)_{T,m}$$

Heat capacities

$$C_V = \left(\frac{\partial U}{\partial T}\right)_V = T\left(\frac{\partial S}{\partial T}\right)_V$$

$$C_P = \left(\frac{\partial H}{\partial T}\right)_P = T\left(\frac{\partial S}{\partial T}\right)_P$$

$$C_P - C_V = T\left(\frac{\partial V}{\partial T}\right)_P\left(\frac{\partial P}{\partial T}\right)_V$$

Van der Waals equation of state

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

Virial equation of state

$$Z = 1 + \frac{B}{v} + \frac{C}{v^2} + \frac{D}{v^3} + ...$$

Thermodynamic potentials

$$H = U + PV$$
$$A = U - TS$$
$$G = H - TS$$

Fundamental thermodynamic relations

$$\mathrm{d}U = T\mathrm{d}S - P\mathrm{d}V$$
$$\mathrm{d}H = T\mathrm{d}S + V\mathrm{d}P$$
$$\mathrm{d}A = -S\mathrm{d}T - P\mathrm{d}V$$
$$\mathrm{d}G = -S\mathrm{d}T + V\mathrm{d}P$$

Maxwell equations

$$\left(\frac{\partial T}{\partial V}\right)_S = -\left(\frac{\partial P}{\partial S}\right)_V$$

$$\left(\frac{\partial T}{\partial P}\right)_S = \left(\frac{\partial V}{\partial S}\right)_P$$

$$\left(\frac{\partial S}{\partial P}\right)_T = -\left(\frac{\partial V}{\partial T}\right)_P$$

$$\left(\frac{\partial S}{\partial V}\right)_T = \left(\frac{\partial P}{\partial T}\right)_V$$

Internal energy and enthalpy

$$\left(\frac{\partial U}{\partial V}\right)_T = T\left(\frac{\partial P}{\partial T}\right)_V - P$$

$$\left(\frac{\partial U}{\partial P}\right)_T = -T\left(\frac{\partial V}{\partial T}\right)_P - P\left(\frac{\partial V}{\partial P}\right)_T$$

$$\left(\frac{\partial H}{\partial V}\right)_T = T\left(\frac{\partial P}{\partial T}\right)_V + V\left(\frac{\partial P}{\partial V}\right)_T$$

$$\left(\frac{\partial H}{\partial P}\right)_T = -T\left(\frac{\partial V}{\partial T}\right)_P + V$$

Carnot relationship

$$\left|\frac{Q_1}{Q_2}\right| = \frac{T_1}{T_2}$$

Entropy

$$\Delta S = \int_1^2 \frac{\mathrm{d}Q_{\mathrm{rev}}}{T}$$

$$\mathrm{d}S = \frac{C_P}{T}\mathrm{d}T - \left(\frac{\partial V}{\partial T}\right)_P \mathrm{d}P$$

$$\Delta S_{\mathrm{IG}} = C_P \ln\frac{T_2}{T_1} - nR\ln\frac{P_2}{P_1}$$

Thermodynamics Equation Sheet

Joule-Thomson coefficient

$$\left(\frac{\partial T}{\partial P}\right)_H = \frac{V}{C_P}\left(\alpha \mathrm{T} - 1\right)$$

Phase equilibrium

$$\frac{\mathrm{d}P^{sat}}{\mathrm{d}T_b} = \frac{\Delta h}{T_b \Delta v}$$

$$\frac{\mathrm{d}P^{sat}}{\mathrm{d}T_b} = \frac{\Delta h P^{sat}}{R T_b^{\ 2}}$$

$$\ln P^{sat} = A - \frac{B}{T_b + C}$$

Multi-component systems (*m* or *M* stand for any extensive property)

$$\mathrm{d}U = T\mathrm{d}S - P\mathrm{d}V + \sum_{i=1} \mu_i \,\mathrm{d}n_i$$

$$\mu_i = \left(\frac{\partial G}{\partial n_i}\right)_{T,P,nj}$$

$$m = \sum_i x_i \overline{m}_i$$

$$\Delta M_{\mathrm{Mix}} = \sum_i n_i \overline{m}_i - \sum_i n_i m_i^0$$

$$\sum_i x_i \mathrm{d}\overline{m}_i = 0$$

Ideal mixture

$$\mu_i = \mu_i^0 + RT \ln x_i$$

$$U = \sum_i n_i u_i^0$$

$$H = \sum_i n_i h_i^0$$

$$V = \sum_i n_i v_i^0$$

$$S = \sum_i n_i s_i^0 - nR \sum_i x_i \ln x_i$$

$$G = \sum_i n_i \mu_i^0 + nRT \sum_i x_i \ln x_i$$

$$P y_i = P_i^{\mathrm{sat}} x_i$$

Relative volatility

$$\alpha_{ij} = \frac{P_i^{\mathrm{sat}}}{P_j^{\mathrm{sat}}}$$

Chemical Principles Equation Sheet

All symbols have the same meaning as given in class materials.

$$V = -\frac{\mu_A \mu_B}{4\pi\varepsilon R^3}\left[-2\cos\theta_A \cos\theta_B + \sin\theta_A \sin\theta_B \cos(\phi_B - \phi_A)\right]$$

$$\frac{M_t}{M_e} = A_1\left[1 - e^{-(k_1 t)^{\beta_1}}\right] + A_2\left[1 - e^{-(k_2 t)^{\beta_2}}\right]$$

$$F_{electrostatic} = -k\,\frac{q_1 \cdot q_2}{r^2}$$

$$E_{electrostatic} = k\,\frac{q_1 \cdot q_2}{r}$$

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_o}$$

$$E_{electrostatic} = \frac{q_1 \cdot q_2}{4\pi\varepsilon_r r}$$

$$K.E. = ½mv^2$$

$$\langle v^2 \rangle^{\frac{1}{2}} = \left(\frac{3RT}{M}\right)^{\frac{1}{2}}$$

Error! Bookmark not defined. $\frac{\left({}^{3RT}/_{M_A}\right)^{\frac{1}{2}}}{\left({}^{3RT}/_{M_B}\right)^{\frac{1}{2}}} = \left(\frac{M_B}{M_A}\right)^{\frac{1}{2}}$

$$d^2 = 2Dt$$

$$D = \frac{\lambda^2}{2\tau}$$

$$D = D_0 e^{-\frac{E_a}{RT}}$$

$$D = \frac{k_B T}{6\pi\eta a}$$

$$\eta = \eta_0 e^{\frac{E_a}{RT}}$$

$$V = -\frac{\mu Q \cos\theta}{4\pi\varepsilon R^2}$$

$$V = -\frac{\alpha Q^2 e^2}{32\pi^2\varepsilon^2 R^4}$$

$$V = -\frac{\alpha_B \mu_A^2 (3\cos^2\theta_A + 1)}{32\pi^2\varepsilon^2 R^6}$$

$$V = -\frac{3h(v_A v_B)\alpha_A \alpha_B}{512(v_A + v_B)\pi^4\varepsilon^4 R^6}$$

$$p = p^* e^{\frac{V_m \Delta P}{RT}}$$

$$p = p^* e^{\frac{2\gamma V_m}{rRT}}$$

$$p_{in} = p_{out} + \frac{2\gamma}{r}$$

$$p_{in} = p_{out} + \frac{4\gamma}{r}$$

$$\gamma = \frac{F}{L}$$

$$\frac{2\gamma}{r} = \rho g h$$

Chemical Principles Equation Sheet

$$\gamma = \frac{rh\rho g}{2\cos\theta}$$

$$ratio = \frac{V}{A \cdot L}$$

$$PV = nRT$$

$$\left(p + \frac{n^2 a}{V^2}\right)(V - nb) = nRT$$

$$\Gamma = \frac{-1}{RT}\left(\frac{d\gamma}{dlnc}\right)_{p,T}$$

$$\Gamma = \frac{-1}{2.303RT}\left(\frac{d\gamma}{dlogc}\right)_{p,T}$$

$$A = \frac{1}{N_A \Gamma}$$

$$\Delta \mathrm{G} = \Delta \mathrm{H} - T\Delta S$$

$$Z = \frac{P}{(2\pi m k_B T)^{\frac{1}{2}}}$$

$$T = \frac{Number\ of\ sites}{Collision\ rate}$$

$$\frac{P}{n_{ads}} = \frac{1}{Kn_m} + \frac{P}{n_m}$$

$$s = n_m A_m L$$

$$\frac{dlnK}{dT} = \frac{\Delta_f H^{\circ}}{RT^2}$$

$$\left(\frac{dlnp}{d\left(\frac{1}{T}\right)}\right)_{\theta} = \frac{\Delta_{ad} H^{\circ}}{R}$$

$$\Delta \mathrm{G} = -RTlnK$$

$$\frac{p}{n(p^o - p)} = \frac{1}{n_m c} + \frac{(c-1)}{n_m c} \cdot \frac{p}{p^o}$$

$$c = exp\left(\frac{|\Delta H_A| - |\Delta H_L|}{RT}\right)$$

$$\theta = c_1 ln(c_2 p)$$

$$\theta = c_1 p^{\frac{1}{c_2}}$$

$$\theta_A = \frac{B_A P_A}{1 + \sum_i B_i P_i}$$

$$V_{ads} = \frac{(K \cdot p)^{\frac{1}{2}} \cdot V_m}{\left[1 + (K \cdot p)^{\frac{1}{2}}\right]}$$

$$logw = logw_o - Dlog_{10}^2\left(\frac{p^o}{p}\right)$$

$$D = B\left(\frac{T}{\beta}\right)^2$$

$$\frac{M_t}{M_e} = 1 - e^{-kt}$$

$$k = Ae^{-\frac{E_a}{RT}}$$

Periodic Table

Group	1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Period																			
1	1 **H** 1.008																		2 **He** 4.003
2	3 **Li** 6.941	4 **Be** 9.012												5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
3	11 **Na** 22.99	12 **Mg** 24.31												13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.07	17 **Cl** 35.45	18 **Ar** 39.95
4	19 **K** 39.10	20 **Ca** 40.08		21 **Sc** 44.96	22 **Ti** 47.87	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.41	31 **Ga** 69.72	32 **Ge** 72.64	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
5	37 **Rb** 85.47	38 **Sr** 87.62		39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 **Tc** 98	44 **Ru** 101.1	45 **Rh** 102.9	46 **Pd** 106.4	47 **Ag** 107.9	48 **Cd** 112.4	49 **In** 114.8	50 **Sn** 118.7	51 **Sb** 121.8	52 **Te** 127.6	53 **I** 126.9	54 **Xe** 131.3
6	55 **Cs** 132.9	56 **B** 137.3	*	71 **Lu** 175.0	72 **Hf** 178.5	73 **Ta** 180.9	74 **W** 183.8	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.1	79 **Au** 197.0	80 **Hg** 200.6	81 **Tl** 204.4	82 **Pb** 207.2	83 **Bi** 209.0	84 **Po** 209	85 **At** 210	86 **Rn** 222
7	87 **Fr** 223	88 **Ra** 226	†	103 **Lr** 260	104 **Rf** 267	105 **Db** 268	106 **Sg** 271	107 **Bh** 272	108 **Hs** 270	109 **Mt** 276	110 **Ds** 281	111 **Rg** 280	112 **Uub** 285	113 **Uut** 284	114 **Uuq** 289	115 **Uup** 288	116 **Uuh** 293	117 **Uus** —	118 **Uuo** 294
*Lanthanoids			*	57 **La** 138.9	58 **Ce** 140.1	59 **Pr** 140.9	60 **Nd** 144.2	61 **Pm** 145	62 **Sm** 150.3	63 **Eu** 151.9	64 **Gd** 157.2	65 **Tb** 158.9	66 **Dy** 132.5	67 **Ho** 164.9	68 **Er** 167.2	69 **Tm** 168.9	70 **Yb** 173.0		
†Actinoids			†	89 **Ac** 227	90 **Th** 232.0	91 **Pa** 231.0	92 **U** 238.0	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		

Thermodynamics Steam Tables

P/kPa (t^{sat}/°C)		sat. liq.	sat. vap.	TEMPERATURE: t °C (TEMPERATURE: T kelvins) 150 (423.15)	175 (448.15)	200 (473.15)	220 (493.15)	240 (513.15)	260 (533.15)	280 (553.15)	300 (573.15)
325 (136.29)	V	1.076	561.75	583.58	622.41	660.33	690.22	719.81	749.18	778.39	807.47
	U	572.847	2545.7	2568.7	2609.6	2649.6	2681.2	2712.7	2744.0	2775.3	2806.6
	H	573.197	2728.3	2758.4	2811.9	2864.2	2905.6	2946.6	2987.5	3028.2	3069.0
	S	1.7004	6.9640	7.0363	7.1592	7.2729	7.3585	7.4400	7.5181	7.5933	7.6657
350 (138.87)	V	1.079	524.00	540.58	576.90	612.31	640.18	667.75	695.09	722.27	749.33
	U	583.892	2548.2	2567.1	2608.3	2648.6	2680.4	2712.0	2743.4	2774.8	2806.2
	H	584.270	2731.6	2756.3	2810.3	2863.0	2904.5	2945.7	2986.7	3027.6	3068.4
	S	1.7273	6.9392	6.9982	7.1222	7.2366	7.3226	7.4045	7.4828	7.5581	7.6307
375 (141.31)	V	1.081	491.13	503.29	537.46	570.69	596.81	622.62	648.22	673.64	698.94
	U	594.332	2550.6	2565.4	2607.1	2647.7	2679.6	2711.3	2742.8	2774.3	2805.7
	H	594.737	2734.7	2754.1	2808.6	2861.7	2903.4	2944.8	2985.9	3026.9	3067.8
	S	1.7526	6.9160	6.9624	7.0875	7.2027	7.2891	7.3713	7.4499	7.5254	7.5981
400 (143.62)	V	1.084	462.22	470.66	502.93	534.26	558.85	583.14	607.20	631.09	654.85
	U	604.237	2552.7	2563.7	2605.8	2646.7	2678.8	2710.6	2742.2	2773.7	2805.3
	H	604.670	2737.6	2752.0	2807.0	2860.4	2902.3	2943.9	2985.1	3026.2	3067.2
	S	1.7764	6.8943	6.9285	7.0548	7.1708	7.2576	7.3402	7.4190	7.4947	7.5675
425 (145.82)	V	1.086	436.61	441.85	472.47	502.12	525.36	548.30	571.01	593.54	615.95
	U	613.667	2554.8	2562.0	2604.5	2645.7	2678.0	2709.9	2741.6	2773.2	2804.8
	H	614.128	2740.3	2749.8	2805.3	2859.1	2901.2	2942.9	2984.3	3025.5	3066.6
	S	1.7990	6.8739	6.8965	7.0239	7.1407	7.2280	7.3108	7.3899	7.4657	7.5388
450 (147.92)	V	1.088	413.75	416.24	445.38	473.55	495.59	517.33	538.83	560.17	581.37
	U	622.672	2556.7	2560.3	2603.2	2644.7	2677.1	2709.2	2741.0	2772.7	2804.4
	H	623.162	2742.9	2747.7	2803.7	2857.8	2900.2	2942.0	2983.5	3024.8	3066.0
	S	1.8204	6.8547	6.8660	6.9946	7.1121	7.1999	7.2831	7.3624	7.4384	7.5116
475 (149.92)	V	1.091	393.22	393.31	421.14	447.97	468.95	489.62	510.05	530.30	550.43
	U	631.294	2558.5	2558.6	2601.9	2643.7	2676.3	2708.5	2740.4	2772.2	2803.9
	H	631.812	2745.3	2745.5	2802.0	2856.5	2899.1	2941.1	2982.7	3024.1	3065.4
	S	1.8408	6.8365	6.8369	6.9667	7.0850	7.1732	7.2567	7.3363	7.4125	7.4858
500 (151.84)	V	1.093	374.68	....	399.31	424.96	444.97	464.67	484.14	503.43	522.58
	U	639.569	2560.2	....	2600.6	2642.7	2675.5	2707.8	2739.8	2771.7	2803.5
	H	640.116	2747.5	....	2800.3	2855.1	2898.0	2940.1	2981.9	3023.4	3064.8
	S	1.8604	6.8192	....	6.9400	7.0592	7.1478	7.2317	7.3115	7.3879	7.4614
525 (153.69)	V	1.095	357.84	....	379.56	404.13	423.28	442.11	460.70	479.11	497.38
	U	647.528	2561.8	....	2599.3	2641.6	2674.6	2707.1	2739.2	2771.2	2803.0
	H	648.103	2749.7	....	2798.6	2853.8	2896.8	2939.2	2981.1	3022.7	3064.1
	S	1.8790	6.8027	....	6.9145	7.0345	7.1236	7.2078	7.2879	7.3645	7.4381
550 (155.47)	V	1.097	342.48	....	361.60	385.19	403.55	421.59	439.38	457.00	474.48
	U	655.199	2563.3	....	2598.0	2640.6	2673.8	2706.4	2738.6	2770.6	2802.6
	H	655.802	2751.7	....	2796.8	2852.5	2895.7	2938.3	2980.3	3022.0	3063.5
	S	1.8970	6.7870	....	6.8900	7.0108	7.1004	7.1849	7.2653	7.3421	7.4158
575 (157.18)	V	1.099	328.41	....	345.20	367.90	385.54	402.85	419.92	436.81	453.56
	U	662.603	2564.8	....	2596.6	2639.6	2672.9	2705.7	2738.0	2770.1	2802.1
	H	663.235	2753.6	....	2795.1	2851.1	2894.6	2937.3	2979.5	3021.3	3062.9
	S	1.9142	6.7720	....	6.8664	6.9880	7.0781	7.1630	7.2436	7.3206	7.3945
600 (158.84)	V	1.101	315.47	....	330.16	352.04	369.03	385.68	402.08	418.31	434.39
	U	669.762	2566.2	....	2595.3	2638.5	2672.1	2705.0	2737.4	2769.6	2801.6
	H	670.423	2755.5	....	2793.3	2849.7	2893.5	2936.4	2978.7	3020.6	3062.3
	S	1.9308	6.7575	....	6.8437	6.9662	7.0567	7.1419	7.2228	7.3000	7.3740
625 (160.44)	V	1.103	303.54	....	316.31	337.45	353.83	369.87	385.67	401.28	416.75
	U	676.695	2567.5	....	2593.9	2637.5	2671.2	2704.2	2736.8	2769.1	2801.2
	H	677.384	2757.2	....	2791.6	2848.4	2892.3	2935.4	2977.8	3019.9	3061.7
	S	1.9469	6.7437	....	6.8217	6.9451	7.0361	7.1217	7.2028	7.2802	7.3544
650 (161.99)	V	1.105	292.49	....	303.53	323.98	339.80	355.29	370.52	385.56	400.47
	U	683.417	2568.7	....	2592.5	2636.4	2670.3	2703.5	2736.2	2768.5	2800.7
	H	684.135	2758.9	....	2789.8	2847.0	2891.2	2934.4	2977.0	3019.2	3061.0
	S	1.9623	6.7304	....	6.8004	6.9247	7.0162	7.1021	7.1835	7.2611	7.3355
675 (163.49)	V	1.106	282.23	....	291.69	311.51	326.81	341.78	356.49	371.01	385.39
	U	689.943	2570.0	....	2591.1	2635.4	2669.5	2702.8	2735.6	2768.0	2800.3
	H	690.689	2760.5	....	2788.0	2845.6	2890.1	2933.5	2976.2	3018.5	3060.4
	S	1.9773	6.7176	....	6.7798	6.9050	6.9970	7.0833	7.1650	7.2428	7.3173
700 (164.96)	V	1.108	272.68	....	280.69	299.92	314.75	329.23	343.46	357.50	371.39
	U	696.285	2571.1	....	2589.7	2634.3	2668.6	2702.1	2735.0	2767.5	2799.8
	H	697.061	2762.0	....	2786.2	2844.2	2888.9	2932.5	2975.4	3017.7	3059.8
	S	1.9918	6.7052	....	6.7598	6.8859	6.9784	7.0651	7.1470	7.2250	7.2997
725 (166.38)	V	1.110	263.77	....	270.45	289.13	303.51	317.55	331.33	344.92	358.36
	U	702.457	2572.2	....	2588.3	2633.2	2667.7	2701.3	2734.3	2767.0	2799.3
	H	703.261	2763.4	....	2784.4	2842.8	2887.7	2931.5	2974.6	3017.0	3059.1
	S	2.0059	6.6932	....	6.7404	6.8673	6.9604	7.0474	7.1296	7.2078	7.2827

Note: *u* and *h* are in units of kJ kg^{-1}; s in units of kJ kg^{-1} K^{-1}; v is in units of cm^3 g^{-1}