DEPARTMENT OF CHEMICAL & PROCESS ENGINEERING

University of Strathclyde Engineering

Degree of BEng/MEng in Chemical Engineering

CP203 Thermodynamics and Chemical Principles

Date: Monday 9th May 2016 **Time: 09:30-12:30**
Duration: 3 hours

<u>Answer All Questions</u>

<u>Answer each section in a separate booklet</u>

There are 200 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.

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Section A: Answer All Questions

QA1. An ideal gas is expanded isothermally in a closed and frictionless piston/cylinder apparatus to 2.5 times its initial volume, producing in the process 2.4 kJ mol^{-1} of work. Calculate the temperature of the gas inside the cylinder. [10 marks]

QA2. 7 moles of methane are initially at a pressure of 2 bar and a temperature of 290 K. Calculate the enthalpy change of a process after which the gas has a pressure of 6 bar and a temperature of 420 K. You can make use of the fact that the enthalpy is a function of state to define a convenient path for the process. You can also assume that under these conditions methane behaves ideally and has heat capacities of c_P = 35.7 J mol^{-1} K^{-1} and c_V = 27.4 J mol^{-1} K^{-1}. [20 marks]

QA3. 42 moles of pure hydrogen gas and 17 moles of pure oxygen gas are first mixed at a constant temperature of 60°C and a constant pressure of 2 bar. The mixture is then cooled isobarically to a temperature of 25°C. Calculate the total entropy change for the process of mixing and cooling.

You can assume ideal mixture behaviour. Heat capacities for the gases are c_P (H_2) = 29.2 J mol^{-1} K^{-1} and c_P (O_2) = 29.7 J mol^{-1} K^{-1}.

[25 marks]

QA4. Derive an expression for the change in molar enthalpy with molar volume at constant temperature of a gas described by the van der Waals equation of state. [20 marks]

QA5. A heat pump uses an ideal gas to keep an exam venue warm (at 25°C) during a typical Scottish summer (outside temperature of 0°C). The following facts are known about the four-step cycle of operation of the heat pump:

i) The first and third steps are adiabatic and involve gas expansion and gas compression, respectively;

ii) During the second step, involving isothermal expansion, the entropy of the gas increases by 50 J K^{-1};

iii) The fourth step involves isothermal gas compression, and consumes 20 kJ of work.

Calculate the coefficient of performance of the heat pump and compare it to the corresponding coefficient of performance for a Carnot heat pump operating between the same two temperatures.

[30 marks]

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QA6. A liquid mixture of acetone (component 1) and acetonitrile (component 2) is in equilibrium with its vapour in a closed vessel at 60°C. If the mole fraction of acetone in the vapour is 0.35, calculate the composition of the liquid phase, assuming that the mixture behaves ideally.

Pure component equilibrium for the each of the two species is given by the following Antoine equations, where pressure is in kPa and temperature is in °C:

$$\ln\left(P_1^{sat}\right) = 14.5463 - \frac{2940.46}{T + 237.22}$$

$$\ln\left(P_2^{sat}\right) = 14.2724 - \frac{2945.47}{T + 224.00}$$

[20 marks]

QA7. Integrate the Clapeyron equation for vapour-liquid equilibrium assuming that the liquid molar volume is negligible compared to the vapour molar volume, and that the vapour is well described by the virial expansion below, with coefficient B = −0.045 bar^{-1}:

$$Z = 1 + BP$$

Use the expression you obtained to estimate the boiling temperature of water at 7 bar, making use of the fact that water boils at T = 99.6°C at P = 1 bar. The enthalpy of vapourisation of water over the relevant range of conditions can be considered constant and equal to 38.9 kJ mol^{-1}.

[30 marks]

QA8. A stream of pure carbon dioxide gas initially at T = 300 K and P = 8 bar is throttled adiabatically through a valve, such that its pressure drops by 6 bar. Calculate the temperature of the stream after passing the valve, assuming that there is no work done in the throttling process and that the molar volume is inversely proportional to the pressure with constant a = 2500 J mol^{-1}:

$$v = \frac{a}{P}$$

Within the relevant range of pressure and temperature, you may assume that c_P = 37.5 J/molK and α = 0.0035 K^{-1} are constants. [25 marks]

QA9. A reversible adiabatic turbine accepts steam at 5 bar and 280°C. The steam leaves the turbine at 3.5 bar. Using the steam tables provided, calculate the molar work produced by the turbine and the outlet temperature of the steam. You may ignore kinetic and potential energy changes during the process.

[20 marks]

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NUMERICAL SOLUTIONS

QA1. 315 K

QA2. 32.5 kJ

QA3. 102.4 J/K

QA4. $\left(\frac{\partial h}{\partial v}\right)_T = \frac{2a}{v^2} - \frac{RTb}{(v-b)^2}$

QA5. β = 3.15; β_{ID} = 11.93

QA6. x_1 = 0.202

QA7. 430.2 K

QA8. 296 K

QA9. -1.55 kJ/mol; 236 ºC

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Thermodynamics Equation Sheet

All symbols have the 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

$$\alpha = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P$$

Isothermal compressibility

$$\beta = -\frac{1}{V}\left(\frac{\partial V}{\partial P}\right)_T$$

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

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

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

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

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

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

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Thermodynamics Equation Sheet

Joule-Thomson coefficient

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

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)

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

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

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

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

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

Ideal mixture

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

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

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

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

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

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

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

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Thermodynamics Steam Tables

P/kPa (t^{sat}/°C)		sat. liq.	sat. vap.	TEMPERATURE: t °C (TEMPERATURE: T kelvins) 75 (348.15)	100 (373.15)	125 (398.15)	150 (423.15)	175 (448.15)	200 (473.15)	225 (498.15)	250 (523.15)
	V	1.000	129200.	160640.	172180.	183720.	195270.	206810.	218350.	229890.	241430.
1	U	29.334	2385.2	2480.8	2516.4	2552.3	2588.5	2624.9	2661.7	2698.8	2736.3
(6.98)	H	29.335	2514.4	2641.5	2688.6	2736.0	2783.7	2831.7	2880.1	2928.7	2977.7
	S	0.1060	8.9767	9.3828	9.5136	9.6365	9.7527	9.8629	9.9679	10.0681	10.1641
	V	1.010	14670.	16030.	17190.	18350.	19510.	20660.	21820.	22980.	24130.
10	U	191.822	2438.0	2479.7	2515.6	2551.6	2588.0	2624.5	2661.4	2698.6	2736.1
(45.83)	H	191.832	2584.8	2640.0	2687.5	2735.2	2783.1	2831.2	2879.6	2928.4	2977.4
	S	0.6493	8.1511	8.3168	8.4486	8.5722	8.6888	8.7994	8.9045	9.0049	9.1010
	V	1.017	7649.8	8000.0	8584.7	9167.1	9748.0	10320.	10900.	11480.	12060.
20	U	251.432	2456.9	2478.4	2514.6	2550.9	2587.4	2624.1	2661.0	2698.3	2735.8
(60.09)	H	251.453	2609.9	2638.4	2686.3	2734.2	2782.3	2830.6	2879.2	2928.0	2977.1
	S	0.8321	7.9094	7.9933	8.1261	8.2504	8.3676	8.4785	8.5839	8.6844	8.7806
	V	1.022	5229.3	5322.0	5714.4	6104.6	6493.2	6880.8	7267.5	7653.8	8039.7
30	U	289.271	2468.6	2477.1	2513.6	2550.2	2586.8	2623.6	2660.7	2698.0	2735.6
(69.12)	H	289.302	2625.4	2636.8	2685.1	2733.3	2781.6	2830.0	2878.7	2927.6	2976.8
	S	0.9441	7.7695	7.8024	7.9363	8.0614	8.1791	8.2903	8.3960	8.4967	8.5930
	V	1.027	3993.4	....	4279.2	4573.3	4865.8	5157.2	5447.8	5738.0	6027.7
40	U	317.609	2477.1	....	2512.6	2549.4	2586.2	2623.2	2660.3	2697.7	2735.4
(75.89)	H	317.650	2636.9	....	2683.8	2732.3	2780.9	2829.5	2878.2	2927.2	2976.5
	S	1.0261	7.6709	....	7.8009	7.9268	8.0450	8.1566	8.2624	8.3633	8.4598
	V	1.030	3240.2	....	3418.1	3654.5	3889.3	4123.0	4356.0	4588.5	4820.5
50	U	340.513	2484.0	....	2511.7	2548.6	2585.6	2622.7	2659.9	2697.4	2735.1
(81.35)	H	340.564	2646.0	....	2682.6	2731.4	2780.1	2828.9	2877.7	2926.8	2976.1
	S	1.0912	7.5947	....	7.6953	7.8219	7.9406	8.0526	8.1587	8.2598	8.3564
	V	1.037	2216.9	....	2269.8	2429.4	2587.3	2744.2	2900.2	3055.8	3210.9
75	U	384.374	2496.7	....	2509.2	2546.7	2584.2	2621.6	2659.0	2696.7	2734.5
(91.79)	H	384.451	2663.0	....	2679.4	2728.9	2778.2	2827.4	2876.6	2925.8	2975.3
	S	1.2131	7.4570	....	7.5014	7.6300	7.7500	7.8629	7.9697	8.0712	8.1681
	V	1.043	1693.7	....	1695.5	1816.7	1936.3	2054.7	2172.3	2289.4	2406.1
100	U	417.406	2506.1	....	2506.6	2544.8	2582.7	2620.4	2658.1	2695.9	2733.9
(99.63)	H	417.511	2675.4	....	2676.2	2726.5	2776.3	2825.9	2875.4	2924.9	2974.5
	S	1.3027	7.3598	....	7.3618	7.4923	7.6137	7.7275	7.8349	7.9369	8.0342
	V	1.044	1673.0	....	1673.0	1792.7	1910.7	2027.7	2143.8	2259.3	2374.5
101.325	U	418.959	2506.5	....	2506.5	2544.7	2582.6	2620.4	2658.1	2695.9	2733.9
(100.00)	H	419.064	2676.0	....	2676.0	2726.4	2776.2	2825.8	2875.3	2924.8	2974.5
	S	1.3069	7.3554	....	7.3554	7.4860	7.6075	7.7213	7.8288	7.9308	8.0280
	V	1.049	1374.6	....	....	1449.1	1545.6	1641.0	1735.6	1829.6	1923.2
125	U	444.224	2513.4	....	....	2542.9	2581.2	2619.3	2657.2	2695.2	2733.3
(105.99)	H	444.356	2685.2	....	....	2724.0	2774.4	2824.4	2874.2	2923.9	2973.7
	S	1.3740	7.2847	....	....	7.3844	7.5072	7.6219	7.7300	7.8324	7.9300
	V	1.053	1159.0	....	....	1204.0	1285.2	1365.2	1444.4	1523.0	1601.3
150	U	466.968	2519.5	....	....	2540.9	2579.7	2618.1	2656.3	2694.4	2732.7
(111.37)	H	467.126	2693.4	....	....	2721.5	2772.5	2822.9	2872.9	2922.9	2972.9
	S	1.4336	7.2234	....	....	7.2953	7.4194	7.5352	7.6439	7.7468	7.8447
	V	1.057	1003.34	....	....	1028.8	1099.1	1168.2	1236.4	1304.1	1371.3
175	U	486.815	2524.7	....	....	2538.9	2578.2	2616.9	2655.3	2693.7	2732.1
(116.06)	H	487.000	2700.3	....	....	2719.0	2770.5	2821.3	2871.7	2921.9	2972.0
	S	1.4849	7.1716	....	....	7.2191	7.3447	7.4614	7.5708	7.6741	7.7724
	V	1.061	885.44	....	....	897.47	959.54	1020.4	1080.4	1139.8	1198.9
200	U	504.489	2529.2	....	....	2536.9	2576.6	2615.7	2654.4	2692.9	2731.4
(120.23)	H	504.701	2706.3	....	....	2716.4	2768.5	2819.8	2870.5	2920.9	2971.2
	S	1.5301	7.1268	....	....	7.1523	7.2794	7.3971	7.5072	7.6110	7.7096
	V	1.064	792.97	....	....	795.25	850.97	905.44	959.06	1012.1	1064.7
225	U	520.465	2533.2	....	....	2534.8	2575.1	2614.5	2653.5	2692.2	2730.8
(123.99)	H	520.705	2711.6	....	....	2713.8	2766.5	2818.2	2869.3	2919.9	2970.4
	S	1.5705	7.0873	....	....	7.0928	7.2213	7.3400	7.4508	7.5551	7.6540
	V	1.068	718.44	....	....	....	764.09	813.47	861.98	909.91	957.41
250	U	535.077	2536.8	....	....	....	2573.5	2613.3	2652.5	2691.4	2730.2
(127.43)	H	535.343	2716.4	....	....	....	2764.5	2816.7	2868.0	2918.9	2969.6
	S	1.6071	7.0520	....	....	....	7.1689	7.2886	7.4001	7.5050	7.6042
	V	1.071	657.04	....	....	....	693.00	738.21	782.55	826.29	869.61
275	U	548.564	2540.0	....	....	....	2571.9	2612.1	2651.6	2690.7	2729.6
(130.60)	H	548.858	2720.7	....	....	....	2762.5	2815.1	2866.8	2917.9	2968.7
	S	1.6407	7.0201	....	....	....	7.1211	7.2419	7.3541	7.4594	7.5590
	V	1.073	605.56	....	....	....	633.74	675.49	716.35	756.60	796.44
300	U	561.107	2543.0	....	....	....	2570.3	2610.8	2650.6	2689.9	2729.0
(133.54)	H	561.429	2724.7	....	....	....	2760.4	2813.5	2865.5	2916.9	2967.9
	S	1.6716	6.9909	....	....	....	7.0771	7.1990	7.3119	7.4177	7.5176

V = SPECIFIC VOLUME $\mathrm{cm^3\ g^{-1}}$

U = SPECIFIC INTERNAL ENERGY $\mathrm{kJ\ kg^{-1}}$

H = SPECIFIC ENTHALPY $\mathrm{kJ\ kg^{-1}}$

S = SPECIFIC ENTROPY $\mathrm{kJ\ kg^{-1}\ K^{-1}}$

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)
	V	1.076	561.75	583.58	622.41	660.33	690.22	719.81	749.18	778.39	807.47
325	U	572.847	2545.7	2568.7	2609.6	2649.6	2681.2	2712.7	2744.0	2775.3	2806.6
(136.29)	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
	V	1.079	524.00	540.58	576.90	612.31	640.18	667.75	695.09	722.27	749.33
350	U	583.892	2548.2	2567.1	2608.3	2648.6	2680.4	2712.0	2743.4	2774.8	2806.2
(138.87)	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
	V	1.081	491.13	503.29	537.46	570.69	596.81	622.62	648.22	673.64	698.94
375	U	594.332	2550.6	2565.4	2607.1	2647.7	2679.6	2711.3	2742.8	2774.3	2805.7
(141.31)	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
	V	1.084	462.22	470.66	502.93	534.26	558.85	583.14	607.20	631.09	654.85
400	U	604.237	2552.7	2563.7	2605.8	2646.7	2678.8	2710.6	2742.2	2773.7	2805.3
(143.62)	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
	V	1.086	436.61	441.85	472.47	502.12	525.36	548.30	571.01	593.54	615.95
425	U	613.667	2554.8	2562.0	2604.5	2645.7	2678.0	2709.9	2741.6	2773.2	2804.8
(145.82)	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
	V	1.088	413.75	416.24	445.38	473.55	495.59	517.33	538.83	560.17	581.37
450	U	622.672	2556.7	2560.3	2603.2	2644.7	2677.1	2709.2	2741.0	2772.7	2804.4
(147.92)	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
	V	1.091	393.22	393.31	421.14	447.97	468.95	489.62	510.05	530.30	550.43
475	U	631.294	2558.5	2558.6	2601.9	2643.7	2676.3	2708.5	2740.4	2772.2	2803.9
(149.92)	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
	V	1.093	374.68	....	399.31	424.96	444.97	464.67	484.14	503.43	522.58
500	U	639.569	2560.2	....	2600.6	2642.7	2675.5	2707.8	2739.8	2771.7	2803.5
(151.84)	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
	V	1.095	357.84	....	379.56	404.13	423.28	442.11	460.70	479.11	497.38
525	U	647.528	2561.8	....	2599.3	2641.6	2674.6	2707.1	2739.2	2771.2	2803.0
(153.69)	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
	V	1.097	342.48	....	361.60	385.19	403.55	421.59	439.38	457.00	474.48
550	U	655.199	2563.3	....	2598.0	2640.6	2673.8	2706.4	2738.6	2770.6	2802.6
(155.47)	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
	V	1.099	328.41	....	345.20	367.90	385.54	402.85	419.92	436.81	453.56
575	U	662.603	2564.8	....	2596.6	2639.6	2672.9	2705.7	2738.0	2770.1	2802.1
(157.18)	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
	V	1.101	315.47	....	330.16	352.04	369.03	385.68	402.08	418.31	434.39
600	U	669.762	2566.2	....	2595.3	2638.5	2672.1	2705.0	2737.4	2769.6	2801.6
(158.84)	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
	V	1.103	303.54	....	316.31	337.45	353.83	369.87	385.67	401.28	416.75
625	U	676.695	2567.5	....	2593.9	2637.5	2671.2	2704.2	2736.8	2769.1	2801.2
(160.44)	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
	V	1.105	292.49	....	303.53	323.98	339.80	355.29	370.52	385.56	400.47
650	U	683.417	2568.7	....	2592.5	2636.4	2670.3	2703.5	2736.2	2768.5	2800.7
(161.99)	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
	V	1.106	282.23	....	291.69	311.51	326.81	341.78	356.49	371.01	385.39
675	U	689.943	2570.0	....	2591.1	2635.4	2669.5	2702.8	2735.6	2768.0	2800.3
(163.49)	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
	V	1.108	272.68	....	280.69	299.92	314.75	329.23	343.46	357.50	371.39
700	U	696.285	2571.1	....	2589.7	2634.3	2668.6	2702.1	2735.0	2767.5	2799.8
(164.96)	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
	V	1.110	263.77	....	270.45	289.13	303.51	317.55	331.33	344.92	358.36
725	U	702.457	2572.2	....	2588.3	2633.2	2667.7	2701.3	2734.3	2767.0	2799.3
(166.38)	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