UNIVERSITY OF ABERDEEN SESSION 2010-2011

Degree Examination in EG3020 PROCESS THERMODYNAMICS

Tuesday 25th January 2011 9.00a.m. – 12.00noon

Notes: (i) Candidates ARE permitted to use an approved calculator

(ii) Candidates ARE permitted to use Engineering Mathematics Handbook

(iii) Data sheets are attached to the paper

Candidates should attempt ALL FIVE questions.

PLEASE NOTE THE FOLLOWING

(i) You **must not** have in your possession any material other than that expressly permitted in the rules appropriate to this examination. Where this is permitted, such material **must not** be amended, annotated or modified in any way.

(ii) You **must not** have in your possession any material that could be determined as giving you an advantage in the examination.

(iii) You **must not** attempt to communicate with any candidate during the exam, either orally or by passing written material, or by showing material to another candidate, nor must you attempt to view another candidate's work.

Failure to comply with the above will be regarded as cheating and may lead to disciplinary action as indicated in the Academic Quality Handbook (www.abdn.ac.uk/registry/quality/appendix7x1.pdf) Section 4.14 and 5.

Question 1

In an Otto engine the gas inside the cylinder can be considered as closed system whenever the valves are closed. The initial pressure and temperature conditions of the working fluid air (molar mass M = 28.97 g mol^{-1}, adiabatic coefficient γ = 1.4) are P_1 = 1 atm and T_1 = 25°C. Air can be considered as an ideal gas with constant composition.

In the first step the gas is compressed adiabatically (compression ratio r = 9.8). In the second step the gas is heated in an isochoric process when combustion takes place reaching a temperature T_3 = 2200°C. Then it expands adiabatically to the initial volume. In the last step, the gas returns to its initial conditions.

a) Calculate pressure, temperature and specific volume for all states.

[13 marks]

b) Calculate the efficiency of the cycle.

[5 marks]

c) Sketch the cycle on a *PV* diagram.

[2 marks]

Question 2

In a Rankine cycle power plant the boiler produces superheated water steam at pressure P = 60 bar and temperature T = 600°C. The steam enters a turbine and expands in a reversible and adiabatic process.

a) Determine the exhaust pressure at which saturated steam exits the turbine.

[6 marks]

b) Calculate the vapour quality for an exhaust pressure of 1 bar.

[8 marks]

c) Give advantages and disadvantages of cases a) and b) with respect to a technical process.

[6 marks]

Question 3

Raoult's law and Henry's law are important models to describe the vapour/liquid equilibrium of multiple component mixtures.

a) What are two major assumptions for Raoult's law? When does Henry's law need to be considered?

[4 marks]

b) A gas with an ethane mole fraction of 0.01 is in contact with water at ambient temperature T = 20°C and elevated pressure P = 20 atm inside an isolated cell. Determine the mole fraction of dissolved ethane. Why can Henry's law be applied here?

$$H_{C_2H_6} = 2.63 \times 10^4 \frac{atm}{mole\ fraction}$$

[4 marks]

c) An equimolar liquid mixture of benzene (B) and methyl benzene (M) is in equilibrium with its vapour at T = 30°C. Calculate the system pressure and the composition of the vapour. Why can Raoult's law be applied here?

[8 marks]

d) How is the Gibbs energy defined? Why is it an interesting property in the context of vapour/liquid equilibrium?

[4 marks]

Question 4

A liquid binary mixture is in equilibrium with its vapour at 144°C. The liquid mole fraction of component 1 is $x_1 = 0.6$. In addition, the following information is given:

- $\ln \gamma_1 = Ax_2^2$ and $\ln \gamma_2 = Ax_1^2$
- At 144°C, the saturation pressures are $P_1^{sat} = 75.20$ kPa and $P_2^{sat} = 31.66$ kPa
- The system forms an azeotrope at 144°C for which $x_1^{az} = y_1^{az} = 0.294$

a) Determine the equilibrium pressure of the system.

[9 marks]

b) Determine the composition of the vapour.

[2 marks]

c) Draw a schematic *P-xy* diagram showing the azeotropic behaviour. Indicate how the *P-x* relationship would look like for Raoult's law.

[6 marks]

d) Which is the main problem that is associated with azeotropic mixtures in technical processes? How can it be overcome (give one example)?

[3 marks]

Question 5

The derivative $(\partial U/\partial V)_T$ is sometimes called the internal pressure and the product $T(\partial P/\partial T)_V$ the thermal pressure. These terms appear in the following equation describing the internal energy as a function of *P V T* data:

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

a) Find equations for the internal pressure and thermal pressure for an ideal gas.

[4 marks]

b) Find equations for the internal pressure and thermal pressure for a van der Waals fluid.

[4 marks]

c) What are the main assumptions for an ideal gas? Under which conditions can the ideal gas law be used in practice?

[5 marks]

d) What do the parameters *a* and *b* account for in the van der Waals equation of state?

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

[2 marks]

e) One form of the virial equation is

$$Z = 1 + B'P + C'P^2 + D'P^3 + \cdots$$

What is the physical meaning of the virial coefficients *B', C', D'*? What is the definition of the compressibility factor *Z*, and how can the given virial equation be used to describe an ideal gas?

[5 marks]

Data Sheet

Conversions

1	m	=	3.281	ft					
1	kg	=	2.205	lb					
1	J	=	0.2388	cal					
1	bar	=	100000	$N.m^{-2}$	=	14.50	Psi	=	0.986923 atm
1	bar		750.06	Torr		750.06	mmHg		
1	acre ft	=	43560	ft^3	=	7758	bbl		
1	square mile	=	640	acre					
1	bbl	=	5.615	ft^3	=	0.159	m^3	=	42 US Gal

Temperature Conversions

°R = °F + 460
K = °C + 273
°R = 1.8×K

Universal Gas Constant

8.314 $J.mol^{-1}.K^{-1}$
10.73 $psia.ft^3.lb\text{-}mol^{-1}.°R^{-1}$

Standard Conditions

Stock-tank or Standard Conditions are 60°F and 14.7 psia.

Equations of State

The Generic Cubic Equation of State

$$P = \frac{RT}{V-b} - \frac{a(T)}{(V+\varepsilon b)(V+\sigma b)}$$

$$a(T) = \Psi \frac{\alpha(T_r) R^2 T_c^2}{P_c}$$

$$b = \Omega \frac{RT_c}{P_c}$$

Eq. of State	$\alpha(T_r)$	σ	ε	Ω	Ψ
vdW	1	0	0	1/8	27/64
RK	$T_r^{-0.5}$	1	0	0.08664	0.42748
SRK	$\alpha_{SRK}(T_r;\omega)^{\dagger}$	1	0	0.08664	0.42748
PR	$\alpha_{PR}(T_r;\omega)^{\ddagger}$	$1+\sqrt{2}$	$1-\sqrt{2}$	0.07780	0.30740

† $\alpha_{SRK}(T_r;\omega) = \left[1+\left(0.480+1.574\omega-0.176\omega^2\right)\left(1-T_r^{0.5}\right)\right]^2$

‡ $\alpha_{PR}(T_r;\omega) = \left[1+\left(0.37464+1.54226\omega-0.26992\omega^2\right)\left(1-T_r^{0.5}\right)\right]^2$

Vapour & Vapour–like Roots of The Generic Cubic Equation of State

$$V = \frac{RT}{P} + b - \frac{a(T)}{P}\frac{V-b}{(V+\varepsilon b)(V+\sigma b)}$$

$$Z = 1 + \beta - q\beta\frac{Z-\beta}{(Z+\varepsilon\beta)(Z+\sigma\beta)}$$

$$\beta = \Omega\frac{P_r}{T_r}$$

$$q = \frac{\Psi\alpha(T_r)}{\Omega T_r}$$

Liquid & Liquid–like Roots of The Generic Cubic Equation of State

$$V = b + (V+\varepsilon b)(V+\sigma b)\left[\frac{RT + bP - VP}{a(T)}\right]$$

$$Z = \beta + (Z+\varepsilon\beta)(Z+\sigma\beta)\left(\frac{1+\beta-Z}{q\beta}\right)$$

Raoult's Law

$y_i P = x_i P_i^{SAT} \qquad i = 1,2,3\ldots N$

$y_i P = x_i \gamma_i P_i^{SAT}$

Henry's Law

$x_i H_i = y_i P \qquad i = 1,2,3\ldots N$

Antoine equation

$\log_{10} P^* = A - \frac{B}{T+C}$ $\qquad P^*$ in mm Hg, T in °C

Compound	Formula	*A*	*B*	*C*
Acetone	C3H6O	7.11714	1210.595	229.664
Benzene	C6H6	6.89272	1203.531	219.888
Formaldehyde	CH2O	7.19578	970.595	244.124
Methyl Benzene	C7H8	6.95805	1345.773	219.693

V = SPECIFIC VOLUME $cm^3\ g^{-1}$
U = SPECIFIC INTERNAL ENERGY $kJ\ kg^{-1}$
H = SPECIFIC ENTHALPY $kJ\ kg^{-1}$
S = SPECIFIC ENTROPY $kJ\ kg^{-1}\ K^{-1}$

Table F.1. Saturated Steam, SI Units (Continued)

			SPECIFIC VOLUME V			INTERNAL ENERGY U			ENTHALPY H			ENTROPY S		
t °C	T K	P kPa	sat. liq.	evap.	sat. vap.	sat. liq.	evap.	sat. vap.	sat. liq.	evap.	sat. vap.	sat. liq.	evap.	sat. vap.
75	348.15	38.55	1.026	4133.1	4134.1	313.9	2162.1	2476.0	313.9	2321.5	2635.4	1.0154	6.6681	7.6835
76	349.15	40.19	1.027	3974.6	3975.7	318.1	2159.2	2477.3	318.1	2318.9	2637.1	1.0275	6.6418	7.6693
77	350.15	41.89	1.027	3823.3	3824.3	322.3	2156.3	2478.5	322.3	2316.4	2638.7	1.0395	6.6156	7.6551
78	351.15	43.65	1.028	3678.6	3679.6	326.5	2153.3	2479.8	326.5	2313.9	2640.4	1.0514	6.5896	7.6410
79	352.15	45.47	1.029	3540.3	3541.3	330.7	2150.4	2481.1	330.7	2311.4	2642.1	1.0634	6.5637	7.6271
80	353.15	47.36	1.029	3408.1	3409.1	334.9	2147.4	2482.3	334.9	2308.8	2643.8	1.0753	6.5380	7.6132
81	354.15	49.31	1.030	3281.6	3282.6	339.1	2144.5	2483.5	339.1	2306.3	2645.4	1.0871	6.5123	7.5995
82	355.15	51.33	1.031	3160.6	3161.6	343.3	2141.5	2484.8	343.3	2303.8	2647.1	1.0990	6.4868	7.5858
83	356.15	53.42	1.031	3044.8	3045.8	347.5	2138.6	2486.0	347.5	2301.2	2648.7	1.1108	6.4615	7.5722
84	357.15	55.57	1.032	2933.9	2935.0	351.7	2135.6	2487.3	351.7	2298.6	2650.4	1.1225	6.4362	7.5587
85	358.15	57.80	1.033	2827.8	2828.8	355.9	2132.6	2488.5	355.9	2296.1	2652.0	1.1343	6.4111	7.5454
86	359.15	60.11	1.033	2726.1	2727.2	360.1	2129.7	2489.7	360.1	2293.5	2653.6	1.1460	6.3861	7.5321
87	360.15	62.49	1.034	2628.8	2629.8	364.3	2126.7	2490.9	364.3	2290.9	2655.3	1.1577	6.3612	7.5189
88	361.15	64.95	1.035	2535.4	2536.5	368.5	2123.7	2492.2	368.5	2288.4	2656.9	1.1693	6.3365	7.5058
89	362.15	67.49	1.035	2446.0	2447.0	372.7	2120.7	2493.4	372.7	2285.8	2658.5	1.1809	6.3119	7.4928
90	363.15	70.11	1.036	2360.3	2361.3	376.9	2117.7	2494.6	376.9	2283.2	2660.1	1.1925	6.2873	7.4799
91	364.15	72.81	1.037	2278.0	2279.1	381.1	2114.7	2495.8	381.1	2280.6	2661.7	1.2041	6.2629	7.4670
92	365.15	75.61	1.038	2199.2	2200.2	385.3	2111.7	2497.0	385.4	2278.0	2663.4	1.2156	6.2387	7.4543
93	366.15	78.49	1.038	2123.5	2124.5	389.5	2108.7	2498.2	389.6	2275.4	2665.0	1.2271	6.2145	7.4416
94	367.15	81.46	1.039	2050.9	2051.9	393.7	2105.7	2499.4	393.8	2272.8	2666.6	1.2386	6.1905	7.4291
95	368.15	84.53	1.040	1981.2	1982.2	397.9	2102.7	2500.6	398.0	2270.2	2668.1	1.2501	6.1665	7.4166
96	369.15	87.69	1.041	1914.3	1915.3	402.1	2099.7	2501.8	402.2	2267.5	2669.7	1.2615	6.1427	7.4042
97	370.15	90.94	1.041	1850.0	1851.0	406.3	2096.6	2503.0	406.4	2264.9	2671.3	1.2729	6.1190	7.3919
98	371.15	94.30	1.042	1788.3	1789.3	410.5	2093.6	2504.1	410.6	2262.2	2672.9	1.2842	6.0954	7.3796
99	372.15	97.76	1.043	1729.0	1730.0	414.7	2090.6	2505.3	414.8	2259.6	2674.4	1.2956	6.0719	7.3675
100	373.15	101.33	1.044	1672.0	1673.0	419.0	2087.5	2506.5	419.1	2256.9	2676.0	1.3069	6.0485	7.3554
102	375.15	108.78	1.045	1564.5	1565.5	427.4	2081.4	2508.8	427.5	2251.6	2679.1	1.3294	6.0021	7.3315
104	377.15	116.68	1.047	1465.1	1466.2	435.8	2075.3	2511.1	435.9	2246.3	2682.2	1.3518	5.9560	7.3078
106	379.15	125.04	1.049	1373.1	1374.2	444.3	2069.2	2513.4	444.4	2240.9	2685.3	1.3742	5.9104	7.2845
108	381.15	133.90	1.050	1287.9	1288.9	452.7	2063.0	2515.7	452.9	2235.4	2688.3	1.3964	5.8651	7.2615
110	383.15	143.27	1.052	1208.9	1209.9	461.2	2056.8	2518.0	461.3	2230.0	2691.3	1.4185	5.8203	7.2388
112	385.15	153.16	1.054	1135.6	1136.6	469.6	2050.6	2520.2	469.8	2224.5	2694.3	1.4405	5.7758	7.2164
114	387.15	163.62	1.055	1067.5	1068.5	478.1	2044.3	2522.4	478.3	2219.0	2697.2	1.4624	5.7318	7.1942
116	389.15	174.65	1.057	1004.2	1005.2	486.6	2038.1	2524.6	486.7	2213.4	2700.2	1.4842	5.6881	7.1723
118	391.15	186.28	1.059	945.3	946.3	495.0	2031.8	2526.8	495.2	2207.9	2703.1	1.5060	5.6447	7.1507
120	393.15	198.54	1.061	890.5	891.5	503.5	2025.4	2529.0	503.7	2202.2	2706.0	1.5276	5.6017	7.1293
122	395.15	211.45	1.062	839.4	840.5	512.0	2019.1	2531.1	512.2	2196.6	2708.8	1.5491	5.5590	7.1082
124	397.15	225.04	1.064	791.8	792.8	520.5	2012.7	2533.2	520.7	2190.9	2711.6	1.5706	5.5167	7.0873
126	399.15	239.33	1.066	747.3	748.4	529.0	2006.3	2535.3	529.2	2185.2	2714.4	1.5919	5.4747	7.0666
128	401.15	254.35	1.068	705.8	706.9	537.5	1999.9	2537.4	537.8	2179.4	2717.2	1.6132	5.4330	7.0462
130	403.15	270.13	1.070	667.1	668.1	546.0	1993.4	2539.4	546.3	2173.6	2719.9	1.6344	5.3917	7.0261
132	405.15	286.70	1.072	630.8	631.9	554.5	1986.9	2541.4	554.8	2167.8	2722.6	1.6555	5.3507	7.0061
134	407.15	304.07	1.074	596.9	598.0	563.1	1980.4	2543.4	563.4	2161.9	2725.3	1.6765	5.3099	6.9864
136	409.15	322.29	1.076	565.1	566.2	571.6	1973.8	2545.4	572.0	2155.9	2727.9	1.6974	5.2695	6.9669
138	411.15	341.38	1.078	535.3	536.4	580.2	1967.2	2547.4	580.5	2150.0	2730.5	1.7182	5.2293	6.9475
140	413.15	361.38	1.080	507.4	508.5	588.7	1960.6	2549.3	589.1	2144.0	2733.1	1.7390	5.1894	6.9284
142	415.15	382.31	1.082	481.2	482.3	597.3	1953.9	2551.2	597.7	2137.9	2735.6	1.7597	5.1499	6.9095
144	417.15	404.20	1.084	456.6	457.7	605.9	1947.2	2553.1	606.3	2131.8	2738.1	1.7803	5.1105	6.8908
146	419.15	427.09	1.086	433.5	434.6	614.4	1940.5	2554.9	614.9	2125.7	2740.6	1.8008	5.0715	6.8723
148	421.15	451.01	1.089	411.8	412.9	623.0	1933.7	2556.8	623.5	2119.5	2743.0	1.8213	5.0327	6.8539
150	423.15	476.00	1.091	391.4	392.4	631.6	1926.9	2558.6	632.1	2113.2	2745.4	1.8416	4.9941	6.8358
152	425.15	502.08	1.093	372.1	373.2	640.2	1920.1	2560.3	640.8	2106.9	2747.7	1.8619	4.9558	6.8178
154	427.15	529.29	1.095	354.0	355.1	648.9	1913.2	2562.1	649.4	2100.6	2750.0	1.8822	4.9178	6.8000
156	429.15	557.67	1.098	336.9	338.0	657.5	1906.3	2563.8	658.1	2094.2	2752.3	1.9023	4.8800	6.7823
158	431.15	587.25	1.100	320.8	321.9	666.1	1899.3	2565.5	666.8	2087.7	2754.5	1.9224	4.8424	6.7648
160	433.15	618.06	1.102	305.7	306.8	674.8	1892.3	2567.1	675.5	2081.3	2756.7	1.9425	4.8050	6.7475
162	435.15	650.16	1.105	291.3	292.4	683.5	1885.3	2568.8	684.2	2074.7	2758.9	1.9624	4.7679	6.7303
164	437.15	683.56	1.107	277.8	278.9	692.1	1878.2	2570.4	692.9	2068.1	2761.0	1.9823	4.7309	6.7133
166	439.15	718.31	1.109	265.0	266.1	700.8	1871.1	2571.9	701.6	2061.4	2763.1	2.0022	4.6942	6.6964
168	441.15	754.45	1.112	252.9	254.0	709.5	1863.9	2573.4	710.4	2054.7	2765.1	2.0219	4.6577	6.6796
170	443.15	792.02	1.114	241.4	242.6	718.2	1856.7	2574.9	719.1	2047.9	2767.1	2.0416	4.6214	6.6630
172	445.15	831.06	1.117	230.6	231.7	727.0	1849.5	2576.4	727.9	2041.1	2769.0	2.0613	4.5853	6.6465
174	447.15	871.60	1.120	220.3	221.5	735.7	1842.2	2577.8	736.7	2034.2	2770.9	2.0809	4.5493	6.6302
176	449.15	913.68	1.122	210.6	211.7	744.4	1834.8	2579.3	745.5	2027.3	2772.7	2.1004	4.5136	6.6140
178	451.15	957.36	1.125	201.4	202.5	753.2	1827.4	2580.6	754.3	2020.2	2774.5	2.1199	4.4780	6.5979
180	453.15	1002.7	1.128	192.7	193.8	762.0	1820.0	2581.9	763.1	2013.1	2776.3	2.1393	4.4426	6.5819
182	455.15	1049.6	1.130	184.4	185.5	770.8	1812.5	2583.2	772.0	2006.0	2778.0	2.1587	4.4074	6.5660
184	457.15	1098.3	1.133	176.5	177.6	779.6	1804.9	2584.5	780.8	1998.8	2779.6	2.1780	4.3723	6.5503
186	459.15	1148.8	1.136	169.0	170.2	788.4	1797.3	2585.7	789.7	1991.5	2781.2	2.1972	4.3374	6.5346
188	461.15	1201.0	1.139	161.9	163.1	797.2	1789.7	2586.9	798.6	1984.2	2782.8	2.2164	4.3026	6.5191
190	463.15	1255.1	1.142	155.2	156.3	806.1	1782.0	2588.1	807.5	1976.7	2784.3	2.2356	4.2680	6.5036
192	465.15	1311.1	1.144	148.8	149.9	814.9	1774.2	2589.2	816.5	1969.3	2785.7	2.2547	4.2336	6.4883
194	467.15	1369.0	1.147	142.6	143.8	823.8	1766.4	2590.2	825.4	1961.7	2787.1	2.2738	4.1993	6.4730
196	469.15	1428.9	1.150	136.8	138.0	832.7	1758.6	2591.3	834.4	1954.1	2788.4	2.2928	4.1651	6.4578
198	471.15	1490.9	1.153	131.3	132.4	841.6	1750.6	2592.3	843.4	1946.4	2789.7	2.3117	4.1310	6.4428
200	473.15	1554.9	1.156	126.0	127.2	850.6	1742.6	2593.2	852.4	1938.6	2790.9	2.3307	4.0971	6.4278
202	475.15	1621.0	1.160	121.0	122.1	859.5	1734.6	2594.1	861.4	1930.7	2792.1	2.3495	4.0633	6.4128
204	477.15	1689.3	1.163	116.2	117.3	868.5	1726.5	2595.0	870.5	1922.8	2793.2	2.3684	4.0296	6.3980
206	479.15	1759.8	1.166	111.6	112.8	877.5	1718.3	2595.8	879.5	1914.7	2794.3	2.3872	3.9961	6.3832
208	481.15	1832.6	1.169	107.2	108.4	886.5	1710.1	2596.6	888.6	1906.6	2795.3	2.4059	3.9626	6.3686
210	483.15	1907.7	1.173	103.1	104.2	895.5	1701.8	2597.3	897.7	1898.5	2796.2	2.4247	3.9293	6.3539
212	485.15	1985.2	1.176	99.09	100.26	904.5	1693.5	2598.0	906.9	1890.2	2797.1	2.4434	3.8960	6.3394
214	487.15	2065.1	1.179	95.28	96.46	913.6	1685.1	2598.7	916.0	1881.8	2797.9	2.4620	3.8629	6.3249
216	489.15	2147.5	1.183	91.65	92.83	922.7	1676.6	2599.3	925.2	1873.4	2798.6	2.4806	3.8298	6.3104
218	491.15	2232.4	1.186	88.17	89.36	931.8	1668.0	2599.8	934.4	1864.9	2799.3	2.4992	3.7968	6.2960

Table F.2. Superheated Steam, SI Units (Continued)

P/kPa (t^{sat}/°C)		sat. liq.	sat. vap.	TEMPERATURE: t °C (TEMPERATURE: T kelvins) 450 (723.15)	475 (748.15)	500 (773.15)	525 (798.15)	550 (823.15)	575 (848.15)	600 (873.15)	650 (923.15)
	V	1.312	33.651	54.026	56.357	58.644	60.896	63.120	65.320	67.500	71.807
5800	*U*	1194.7	2591.9	2992.9	3038.8	3084.4	3129.8	3175.2	3220.7	3266.4	3358.5
(273.35)	*H*	1202.3	2787.0	3306.3	3365.7	3424.5	3483.0	3541.2	3599.5	3657.9	3775.0
	S	3.0071	5.9066	6.7416	6.8223	6.8996	6.9740	7.0460	7.1157	7.1835	7.3139
	V	1.315	33.034	53.048	55.346	57.600	59.819	62.010	64.176	66.322	70.563
5900	*U*	1200.3	2591.1	2991.9	3037.9	3083.5	3129.0	3174.4	3220.0	3265.7	3357.9
(274.46)	*H*	1208.0	2786.0	3304.9	3364.4	3423.3	3481.9	3540.3	3598.6	3657.0	3774.3
	S	3.0172	5.8986	6.7322	6.8132	6.8906	6.9652	7.0372	7.1070	7.1749	7.3054
	V	1.319	32.438	52.103	54.369	56.592	58.778	60.937	63.071	65.184	69.359
6000	*U*	1205.8	2590.4	2990.8	3036.9	3082.6	3128.2	3173.7	3219.3	3265.1	3357.4
(275.55)	*H*	1213.7	2785.0	3303.5	3363.2	3422.2	3480.8	3539.3	3597.7	3656.2	3773.5
	S	3.0273	5.8908	6.7230	6.8041	6.8818	6.9564	7.0285	7.0985	7.1664	7.2971
	V	1.322	31.860	51.189	53.424	55.616	57.771	59.898	62.001	64.083	68.196
6100	*U*	1211.2	2589.6	2989.8	3036.0	3081.8	3127.4	3173.0	3218.6	3264.5	3356.8
(276.63)	*H*	1219.3	2783.9	3302.0	3361.9	3421.0	3479.8	3538.3	3596.8	3655.4	3772.8
	S	3.0372	5.8830	6.7139	6.7952	6.8730	6.9478	7.0200	7.0900	7.1581	7.2889
	V	1.325	31.300	50.304	52.510	54.671	56.797	58.894	60.966	63.018	67.069
6200	*U*	1216.6	2588.8	2988.7	3035.0	3080.9	3126.6	3172.2	3218.0	3263.8	3356.3
(277.70)	*H*	1224.8	2782.9	3300.6	3360.6	3419.9	3478.7	3537.4	3595.9	3654.5	3772.1
	S	3.0471	5.8753	6.7049	6.7864	6.8644	6.9393	7.0116	7.0817	7.1498	7.2808
	V	1.328	30.757	49.447	51.624	53.757	55.853	57.921	59.964	61.986	65.979
6300	*U*	1221.9	2588.0	2987.7	3034.1	3080.1	3125.8	3171.5	3217.3	3263.2	3355.7
(278.75)	*H*	1230.3	2781.8	3299.2	3359.3	3418.7	3477.7	3536.4	3595.0	3653.7	3771.4
	S	3.0568	5.8677	6.6960	6.7778	6.8559	6.9309	7.0034	7.0735	7.1417	7.2728
	V	1.332	30.230	48.617	50.767	52.871	54.939	56.978	58.993	60.987	64.922
6400	*U*	1227.2	2587.2	2986.6	3033.1	3079.2	3125.0	3170.8	3216.6	3262.6	3355.2
(279.79)	*H*	1235.7	2780.6	3297.7	3358.0	3417.6	3476.6	3535.4	3594.1	3652.9	3770.7
	S	3.0664	5.8601	6.6872	6.7692	6.8475	6.9226	6.9952	7.0655	7.1337	7.2649
	V	1.335	29.719	47.812	49.935	52.012	54.053	56.065	58.052	60.018	63.898
6500	*U*	1232.5	2586.3	2985.5	3032.2	3078.3	3124.2	3170.0	3215.9	3261.9	3354.6
(280.82)	*H*	1241.1	2779.5	3296.3	3356.8	3416.4	3475.6	3534.4	3593.2	3652.1	3770.0
	S	3.0759	5.8527	6.6786	6.7608	6.8392	6.9145	6.9871	7.0575	7.1258	7.2572
	V	1.338	29.223	47.031	49.129	51.180	53.194	55.179	57.139	59.079	62.905
6600	*U*	1237.6	2585.5	2984.5	3031.2	3077.4	3123.4	3169.3	3215.2	3261.3	3354.1
(281.84)	*H*	1246.5	2778.3	3294.9	3355.5	3415.2	3474.5	3533.5	3592.3	3651.2	3769.2
	S	3.0853	5.8452	6.6700	6.7524	6.8310	6.9064	6.9792	7.0497	7.1181	7.2495
	V	1.342	28.741	46.274	48.346	50.372	52.361	54.320	56.254	58.168	61.942
6700	*U*	1242.8	2584.6	2983.4	3030.3	3076.6	3122.6	3168.6	3214.5	3260.7	3353.5
(282.84)	*H*	1251.8	2777.1	3293.4	3354.2	3414.1	3473.4	3532.5	3591.4	3650.4	3768.5
	S	3.0946	5.8379	6.6616	6.7442	6.8229	6.8985	6.9714	7.0419	7.1104	7.2420
	V	1.345	28.272	45.539	47.587	49.588	51.552	53.486	55.395	57.283	61.007
6800	*U*	1247.9	2583.7	2982.3	3029.3	3075.7	3121.8	3167.8	3213.9	3260.0	3353.0
(283.84)	*H*	1257.0	2775.9	3292.0	3352.9	3412.9	3472.4	3531.5	3590.5	3649.6	3767.8
	S	3.1038	5.8306	6.6532	6.7361	6.8150	6.8907	6.9636	7.0343	7.1028	7.2345
	V	1.351	27.373	44.131	46.133	48.086	50.003	51.889	53.750	55.590	59.217
7000	*U*	1258.0	2581.8	2980.1	3027.4	3074.0	3120.2	3166.3	3212.5	3258.8	3351.9
(285.79)	*H*	1267.4	2773.5	3289.1	3350.3	3410.6	3470.2	3529.6	3588.7	3647.9	3766.4
	S	3.1219	5.8162	6.6368	6.7201	6.7993	6.8753	6.9485	7.0193	7.0880	7.2200
	V	1.358	26.522	42.802	44.759	46.668	48.540	50.381	52.197	53.991	57.527
7200	*U*	1267.9	2579.9	2978.0	3025.4	3072.2	3118.6	3164.9	3211.1	3257.5	3350.7
(287.70)	*H*	1277.6	2770.9	3286.1	3347.7	3408.2	3468.1	3527.6	3586.9	3646.2	3764.9
	S	3.1397	5.8020	6.6208	6.7044	6.7840	6.8602	6.9337	7.0047	7.0735	7.2058
	V	1.364	25.715	41.544	43.460	45.327	47.156	48.954	50.727	52.478	55.928
7400	*U*	1277.6	2578.0	2975.8	3023.5	3070.4	3117.0	3163.4	3209.8	3256.2	3349.6
(289.57)	*H*	1287.7	2768.3	3283.2	3345.1	3405.9	3466.0	3525.7	3585.1	3644.5	3763.5
	S	3.1571	5.7880	6.6050	6.6892	6.7691	6.8456	6.9192	6.9904	7.0594	7.1919
	V	1.371	24.949	40.351	42.228	44.056	45.845	47.603	49.335	51.045	54.413
7600	*U*	1287.2	2575.9	2973.6	3021.5	3068.7	3115.4	3161.9	3208.4	3254.9	3348.5
(291.41)	*H*	1297.6	2765.5	3280.3	3342.5	3403.5	3463.8	3523.7	3583.3	3642.9	3762.1
	S	3.1742	5.7742	6.5896	6.6742	6.7545	6.8312	6.9051	6.9765	7.0457	7.1784
	V	1.378	24.220	39.220	41.060	42.850	44.601	46.320	48.014	49.686	52.976
7800	*U*	1296.7	2573.8	2971.4	3019.6	3066.9	3113.8	3160.4	3207.0	3253.7	3347.4
(293.21)	*H*	1307.4	2762.8	3277.3	3339.8	3401.1	3461.7	3521.7	3581.5	3641.2	3760.6
	S	3.1911	5.7605	6.5745	6.6596	6.7402	6.8172	6.8913	6.9629	7.0322	7.1652
	V	1.384	23.525	38.145	39.950	41.704	43.419	45.102	46.759	48.394	51.611
8000	*U*	1306.0	2571.7	2969.2	3017.6	3065.1	3112.2	3158.9	3205.6	3252.4	3346.3
(294.97)	*H*	1317.1	2759.9	3274.3	3337.2	3398.8	3459.5	3519.7	3579.7	3639.5	3759.2
	S	3.2076	5.7471	6.5597	6.6452	6.7262	6.8035	6.8778	6.9496	7.0191	7.1523