UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2011/2012 Academic Session

June 2012

EKC 222 – Chemical Engineering Thermodynamics
[Termodinamik Kejuruteraan Kimia]

Duration : 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains SEVEN printed pages and TEN printed pages of Appendix before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi TUJUH muka surat yang bercetak dan SEPULUH muka surat Lampiran sebelum anda memulakan peperiksaan ini.]

Instruction: Answer **ALL** questions.

*[**Arahan:** Jawab **SEMUA** soalan.]*

In the event of any discrepancies, the English version shall be used.

[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah digunapakai].

Answer ALL questions.
Jawab SEMUA soalan.

1. [a] The greenhouse effect is a process by which thermal radiation from a planetary surface is absorbed by atmospheric greenhouse gases, and is re-radiated in all direction. Since part of this re-radiation is back towards the surface, energy is transferred to the surface and lower atmosphere. As a result, the average surface temperature is higher than it would be if direct heating by solar radiation were the only warming mechanism. However, the greenhouse gases are normally residing in the stratosphere of earth with temperature at around -60 °C which is much cooler than the earth surface. Do you think the greenhouse theory violates 2^{nd} law of Thermodynamics (Yes/No)? Sketch out your Thermodynamic analysis with justifications.

Kesan rumah hijau adalah satu proses di mana sinaran haba dari permukaan bumi diserapkan oleh gas rumah hijau dalam atmosfera, dan kemudiannya dipancarkan semula ke semua arah. Sebahagian daripada sinaran ini dipancarkan kembali ke arah permukaan bumi, tenaga turut dipindahkan ke permukaan bumi pada suhu yang lebih rendah. Hasilnya, purata suhu permukaan bumi menjadi lebih tinggi daripada pemanasan oleh sinaran terus. Walaubagaimanapun, gas rumah hijau yang bertapak dalam lapisan stratosfera bumi dengan suhu sekitar -60 ° C yang lebih sejuk daripada permukaan bumi. Adakah anda fikir teori rumah hijau melanggar Hukum Termodinamik Kedua (Ya / Tidak)? Lakarkan analisis termodinamik anda beserta dengan keterangan.

[12 marks/markah]

[b] Steam enters a turbine at 4000 kPa and 500°C and leaves as shown in Figure Q.1.[b]. For an inlet velocity of 200 m/s calculate the turbine power output. Neglect any heat transfer. Show that the kinetic energy change is negligible. Given $W_s = \dot{m}\,(h_2 - h_1)$.

Stim memasuki sebuah turbin pada 4000 kPa, suhu 500°C dan keluar dari turbin tersebut seperti yang ditunjukkan dalam Rajah S.1.[b]. Bagi kadar kemasukan stim pada 200 m/s kirakan kuasa turbin tersebut. Abaikan pemindahan tenaga. Tunjukkan bahawa perubahan tenaga kinetik boleh diabaikan.

Diberi $W_s = \dot{m}\,(h_2 - h_1)$.

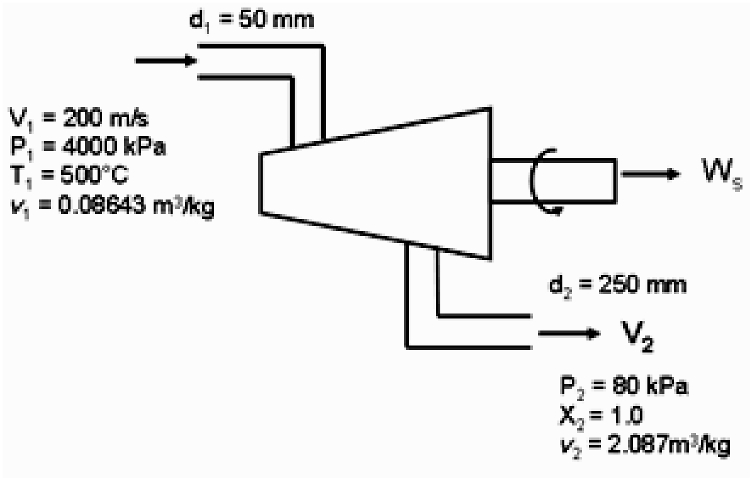

Figure Q.1.[b]. Sketch of the turbine and fluid properties
Rajah S.1.[b]. Lakaran turbin dan sifat bendalir

[13 marks/markah]

2. [a] An electrical refrigerator is supplied with 120 W of electricity while it cools food at the rate of 300 W. What is the rate of heat rejection from the device assuming that it operates cyclically? If the heat rejection is to the room air, what is the rate of energy input to the air?

Sebuah peti sejuk elektrik dibekalkan dengan 120 W elektrik semasa penyejukan makanan dijalankan dengan kuasa sebanyak 300 W. Apakah kadar penolakan haba dari peti sejuk ini dengan anggapan bahawa ia beroperasi secara berkitar? Sekirannya haba disalurkan ke dalam udara bilik, apakah kadar kemasukan tenaga ke udara?

[5 marks/markah]

[b] Calculate the volume of water using ideal gas model under the following conditions. What is the percent error when compared to the values reported in steam tables, discussed what you have learned from this comparison (Ideal gas constant, R = 0.08314 L·bar/mol·K, 1.01 bar = 101 kPa).

Kira isipadu air dengan menggunakan model gas unggul di bawah syarat-syarat berikut. Kemudian kira perbezaan peratus diantara jawapan anda dengan nilai yang dilaporkan dalam jadual stim dan bincangkan apa yang anda telah belajar dari perbandingan ini (pemalar gas unggul, R = 0,08314 L • bar / mol • K, 1,01 Bar = 101 kPa).

[i] P = 1.01 bar; T = 500 °C

[ii] P = 100 bar; T = 500 °C

[5 marks/markah]

[c] JK Lim Super Gas Limited cooperation is about to kick-off for business. You're the newly appointed Chief-Engineer in this company and your first task is to calculate the annual gross sales (in RM) of the superpure-grade nitrogen (N_2). The total gas sales of nitrogen (N_2) is 30,000 units. Take the volume of the cylinder to be 43 L, the pressure to be 12,400 kPa, temperature at 22 ºC, and the cost to be RM6.1/kg. Use Redlich-Kwong EOS and ideal gas model for your analysis and compared the results you have obtained. (Nitrogen (N_2) T_c = 126.2 K, P_c = 33.84 bar).

Syarikat JK Lim Super Gas Sdn. Bhd. akan memulakan perniagaannya. Anda telah dilantik sebagai ketua jurutera baru dalam syarikat ini dan tugas pertama anda adalah untuk mengira jualan tahunan kasar (dalam Ringgit Malaysia) untuk gas nitrogen tulen. Jualan gas nitrogen adalah 30,000 unit. Andaikan isipadu silinder ialah 43 L, tekanan pada 12,400 kPa dan kos satu silinder ialah RM 6.1/kg. Gunakan Redlich-Kwong EOS dan model gas unggul untuk analisis anda dan bandingkan keputusan yang anda perolehi. (Andaikan suhu pada 22 º C, nitrogen T_c = 126.2 K, P_c = 33.84 bar).

Given: Redlich-Kwong EOS, $P = \frac{RT}{v-b} - \frac{a}{T^{1/2}v(v+b)}$ where

Diberi: Redlich-Kwong EOS, *dimana*

$$a = \frac{0.42748R^2T_c^{2.5}}{P_c}[=]\frac{\text{J}\cdot\text{m}^3\cdot\text{K}^{1/2}}{\text{mol}^2} \text{ and } b = \frac{0.08664RT_c}{P_c}[=]\frac{\text{m}^3}{\text{mol}}$$

dan

[15 marks/markah]

3. [a] The theory of *incompressible fluid* can be modelled using the thermodynamic properties of the fluid itself. This is based on the equation of state given by;

Teori ketakbolehmampatan bendalir boleh dimodel dengan menggunakan ciri-ciri termodinamik sesuatu bendalir. Hal ini berdasarkan persamaan keadaan diberi oleh;

$$dV = \left(\frac{\partial V}{\partial T}\right)_P dT + \left(\frac{\partial V}{\partial P}\right)_T dP$$

where,
dimana,

$$\beta = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P \text{ and } \kappa = -\frac{1}{V}\left(\frac{\partial V}{\partial P}\right)_T$$

which simplify the equation into;
yang boleh dimudahkan kepada persamaan;

$$\frac{dV}{V} = \beta dT - \kappa dP$$

and for an *incompressible fluid*, $\beta = \kappa = 0$.
dan bagi bendalir ketakbolehmampatan, $\beta = \kappa = 0$.

By using the above definition of volume expansivity, β and isothermal compressibility, κ and that the relationships given by the Maxwell equations, show that for an *incompressible fluid*, the heat capacities at constant pressure and volume are given by;

Dengan menggunakan definisi pengembangan isipadu, β *dan pemampatan isoterma,* κ *dan seterusnya perkaitan-perkaitan yang diberi oleh persamaan-persamaan Maxwell bagi bendalir ketakbolehmampatan, tunjukkan haba pendam pada tekanan dan isipadu malar adalah seperti berikut;*

$$C_P = C_V$$

[10 marks/markah]

[b] A Carnot engine operates between two temperature reservoirs at 200 °C and 20 °C. If the desired output of the engine is 15kW, determine the heat transfer from the high temperature reservoir and the heat transfer from the low temperature reservoir.

Satu jentera Carnot beroperasi di antara dua takungan suhu pada 200 °C dan 20 °C. Jika pengeluaran jentera yang dikehendaki adalah 15 kW, tentukan pemindahan haba daripada suhu takungan yang tinggi dan pemindahan haba daripada suhu takungan yang rendah.

[5 marks/markah]

[c] Two Carnot engines operate in series between two reservoirs maintained at 600 °F and 100 °F respectively. The energy rejected by the first engine is input into the second engine. If the first engine's efficiency is 20% greater than that of the second engine, calculate the intermediate temperature between the first and the second engines.

Dua jentera Carnot yang beroperasi secara bersiri di antara dua takungan ditetapkan masing-masing pada suhu 600 °F dan 100 °F. Tenaga yang dikeluar daripada jentera pertama disalurkan kepada jentera kedua. Jika jentera pertama mempunyai kecekapan 20% lebih besar berbanding jentera kedua, kirakan suhu perantaraan di antara jentera pertama dan jentera kedua.

These temperature equivalents may be used;
Persamaan penukaran suhu di bawah mungkin boleh digunakan;

$$T(K) = T(°C) + 273.15$$

$$T(°F) = 1.8T(°C) + 32$$

[10 marks/markah]

4. [a] [i] The higher heating value (HHV) of a fuel is its standard heat of combustion at 298.15 K with liquid water as a product. Whereas, the lower heating value (LHV) is for water vapor as product. Explain the origin of these terms.

Nilai pemanasan tinggi (HHV) bahan api adalah haba pembakaran piawai pada 298.15 K dengan air cecair sebagai hasil. Manakala, nilai pemanasan rendah (LHV) adalah dengan wap air sebagai hasil. Jelaskan asal usul syarat-syarat ini.

[ii] Saturated water vapor (steam) is commonly used as a heat source in heat-exchanger applications. Why saturated vapor is used?

Wap air tepu biasanya digunakan sebagai sumber haba untuk aplikasi penukar haba. Mengapa wap air tepu digunakan?

[iii] Can a binary benzene/toluene liquid vapor system be approximately modeled by Raoult's law? Explain your answer.

Bolehkah sistem wap cecair campuran benzena/toluena diandaikan dengan hukum Raoult? Jelaskan jawapan anda.

[iv] Why instead of CO_2 but not air is the gas of choice for making soda water even thought air is inexpensive and nontoxic? Henry's constants for CO_2 and air dissolved in water at 25°C are 1670 and 72950, respectively.

Mengapa CO_2 dipilih berbanding untuk pembuatan air soda walaupun udara adalah lebih murah dan tanpa toksik? Pemalar Henry untuk CO_2 dalam air pada suhu 25°C adalah 1670 dan 72950.

[10 marks/markah]

[b] Ethylene gas and steam at 320°C and atmospheric pressure are fed to a reaction process as an equimolar mixture. The process produces ethanol by reaction:

Campuran gas etilena dan stim pada suhu 320°C dan tekanan atmosfera disalurkan ke dalam satu proses tindakbalas dengan mol sekadar. Proses ini menghasilkan etanol dengan tindakbalas berikut:

$$C_2H_4\,(g) + H_2O\,(g) \rightarrow C_2H_5OH\,(l)$$

The liquid ethanol exits the process at 25°C. What is the heat transfer associated with this overall process per mole of ethanol produced?

Cecair etanol keluar dari proses pada 25°C. Apakah pemindahan haba untuk proses ini dengan penghasilan satu mol etanol?

Given: $\dfrac{\langle C_p \rangle_H}{R} = A + \dfrac{B}{2}T_0(\tau + 1) + \dfrac{C}{3}T_0^2(\tau^2 + \tau + 1) + \dfrac{D}{\tau T_0^2}$, where $\tau = \dfrac{T}{T_0}$

Diberi: $\dfrac{\langle C_p \rangle_H}{R} = A + \dfrac{B}{2} T_0(\tau + 1) + \dfrac{C}{3} T_0^2(\tau^2 + \tau + 1) + \dfrac{D}{\tau T_0^2}$ *, dimana* $\tau = \dfrac{T}{T_0}$

[15 marks/markah]

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Appendix

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

The unit for H [=] kJ/kg, V [=] cm^3/g (applied for all tables)

…2/-

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

P/kPa (t^{sat}/°C)		sat. liq.	sat. vap.	TEMPERATURE: t °C (TEMPERATURE: T kelvins) 300 (573.15)	350 (623.15)	400 (673.15)	450 (723.15)	500 (773.15)	550 (823.15)	600 (873.15)	650 (923.15)
1 (6.98)	V	1.000	129200.	264500.	287580.	310660.	333730.	356810.	379880.	402960.	426040.
	U	29.334	2385.2	2812.3	2889.9	2969.1	3049.9	3132.4	3216.7	3302.6	3390.3
	H	29.335	2514.4	3076.8	3177.5	3279.7	3383.6	3489.2	3596.5	3705.6	3816.4
	S	0.1060	8.9767	10.3450	10.5133	10.6711	10.8200	10.9612	11.0957	11.2243	11.3476
10 (45.83)	V	1.010	14670.	26440.	28750.	31060.	33370.	35670.	37980.	40290.	42600.
	U	191.822	2438.0	2812.2	2889.8	2969.0	3049.8	3132.3	3216.6	3302.6	3390.3
	H	191.832	2584.8	3076.6	3177.3	3279.6	3383.5	3489.1	3596.5	3705.5	3816.3
	S	0.6493	8.1511	9.2820	9.4504	9.6083	9.7572	9.8984	10.0329	10.1616	10.2849
20 (60.09)	V	1.017	7649.8	13210.	14370.	15520.	16680.	17830.	18990.	20140.	21300.
	U	251.432	2456.9	2812.0	2889.6	2968.9	3049.7	3132.3	3216.5	3302.5	3390.2
	H	251.453	2609.9	3076.4	3177.1	3279.4	3383.4	3489.0	3596.4	3705.4	3816.2
	S	0.8321	7.9094	8.9618	9.1303	9.2882	9.4372	9.5784	9.7130	9.8416	9.9650
30 (69.12)	V	1.022	5229.3	8810.8	9581.2	10350.	11120.	11890.	12660.	13430.	14190.
	U	289.271	2468.6	2811.8	2889.5	2968.7	3049.6	3132.2	3216.5	3302.5	3390.2
	H	289.302	2625.4	3076.1	3176.9	3279.3	3383.3	3488.9	3596.3	3705.4	3816.2
	S	0.9441	7.7695	8.7744	8.9430	9.1010	9.2499	9.3912	9.5257	9.6544	9.7778
40 (75.89)	V	1.027	3993.4	6606.5	7184.6	7762.5	8340.1	8917.6	9494.9	10070.	10640.
	U	317.609	2477.1	2811.6	2889.4	2968.6	3049.5	3132.1	3216.4	3302.4	3390.1
	H	317.650	2636.9	3075.9	3176.8	3279.1	3383.1	3488.8	3596.2	3705.3	3816.1
	S	1.0261	7.6709	8.6413	8.8100	8.9680	9.1170	9.2583	9.3929	9.5216	9.6450
50 (81.35)	V	1.030	3240.2	5283.9	5746.7	6209.1	6671.4	7133.5	7595.5	8057.4	8519.2
	U	340.513	2484.0	2811.5	2889.2	2968.5	3049.4	3132.0	3216.3	3302.3	3390.1
	H	340.564	2646.0	3075.7	3176.6	3279.0	3383.0	3488.7	3596.1	3705.2	3816.0
	S	1.0912	7.5947	8.5380	8.7068	8.8649	9.0139	9.1552	9.2898	9.4185	9.5419
75 (91.79)	V	1.037	2216.9	3520.5	3829.4	4138.0	4446.4	4754.7	5062.8	5370.9	5678.9
	U	384.374	2496.7	2811.0	2888.9	2968.2	3049.2	3131.8	3216.1	3302.2	3389.9
	H	384.451	2663.0	3075.1	3176.1	3278.6	3382.7	3488.4	3595.8	3705.0	3815.9
	S	1.2131	7.4570	8.3502	8.5191	8.6773	8.8265	8.9678	9.1025	9.2312	9.3546
100 (99.63)	V	1.043	1693.7	2638.7	2870.8	3102.5	3334.0	3565.3	3796.5	4027.7	4258.8
	U	417.406	2506.1	2810.6	2888.6	2968.0	3049.0	3131.6	3216.0	3302.0	3389.8
	H	417.511	2675.4	3074.5	3175.6	3278.2	3382.4	3488.1	3595.6	3704.8	3815.7
	S	1.3027	7.3598	8.2166	8.3858	8.5442	8.6934	8.8348	8.9695	9.0982	9.2217

...3/-

	V	1.044	1673.0	2604.2	2833.2	3061.9	3290.3	3518.7	3746.9	3975.0	4203.1
101.325	*U*	418.959	2506.5	2810.6	2888.5	2968.0	3048.9	3131.6	3215.9	3302.0	3389.8
(100.00)	*H*	419.064	2676.0	3074.4	3175.6	3278.2	3382.3	3488.1	3595.6	3704.8	3815.7
	S	1.3069	7.3554	8.2105	8.3797	8.5381	8.6873	8.8287	8.9634	9.0922	9.2156
	V	1.049	1374.6	2109.7	2295.6	2481.2	2666.5	2851.7	3036.8	3221.8	3406.7
125	*U*	444.224	2513.4	2810.2	2888.2	2967.7	3048.7	3131.4	3215.8	3301.9	3389.7
(105.99)	*H*	444.356	2685.2	3073.9	3175.2	3277.8	3382.0	3487.9	3595.4	3704.6	3815.5
	S	1.3740	7.2847	8.1129	8.2823	8.4408	8.5901	8.7316	8.8663	8.9951	9.1186
	V	1.053	1159.0	1757.0	1912.2	2066.9	2221.5	2375.9	2530.2	2684.5	2838.6
150	*U*	466.968	2519.5	2809.7	2887.9	2967.4	3048.5	3131.2	3215.6	3301.7	3389.5
(111.37)	*H*	467.126	2693.4	3073.3	3174.7	3277.5	3381.7	3487.6	3595.1	3704.4	3815.3
	S	1.4336	7.2234	8.0280	8.1976	8.3562	8.5056	8.6472	8.7819	8.9108	9.0343
	V	1.057	1003.34	1505.1	1638.3	1771.1	1903.7	2036.1	2168.4	2300.7	2432.9
175	*U*	486.815	2524.7	2809.3	2887.5	2967.1	3048.3	3131.0	3215.4	3301.6	3389.4
(116.06)	*H*	487.000	2700.3	3072.7	3174.2	3277.1	3381.4	3487.3	3594.9	3704.2	3815.1
	S	1.4849	7.1716	7.9561	8.1259	8.2847	8.4341	8.5758	8.7106	8.8394	8.9630
	V	1.061	885.44	1316.2	1432.8	1549.2	1665.3	1781.2	1897.1	2012.9	2128.6
200	*U*	504.489	2529.2	2808.8	2887.2	2966.9	3048.0	3130.8	3215.3	3301.4	3389.2
(120.23)	*H*	504.701	2706.3	3072.1	3173.8	3276.7	3381.1	3487.0	3594.7	3704.0	3815.0
	S	1.5301	7.1268	7.8937	8.0638	8.2226	8.3722	8.5139	8.6487	8.7776	8.9012
	V	1.064	792.97	1169.2	1273.1	1376.6	1479.9	1583.0	1686.0	1789.0	1891.9
225	*U*	520.465	2533.2	2808.4	2886.9	2966.6	3047.8	3130.6	3215.1	3301.2	3389.1
(123.99)	*H*	520.705	2711.6	3071.5	3173.3	3276.3	3380.8	3486.8	3594.4	3703.8	3814.8
	S	1.5705	7.0873	7.8385	8.0088	8.1679	8.3175	8.4593	8.5942	8.7231	8.8467
	V	1.068	718.44	1051.6	1145.2	1238.5	1331.5	1424.4	1517.2	1609.9	1702.5
250	*U*	535.077	2536.8	2808.0	2886.5	2966.3	3047.6	3130.4	3214.9	3301.1	3389.0
(127.43)	*H*	535.343	2716.4	3070.9	3172.8	3275.9	3380.4	3486.5	3594.2	3703.6	3814.6
	S	1.6071	7.0520	7.7891	7.9597	8.1188	8.2686	8.4104	8.5453	8.6743	8.7980
	V	1.071	657.04	955.45	1040.7	1125.5	1210.2	1294.7	1379.0	1463.3	1547.6
275	*U*	548.564	2540.0	2807.5	2886.2	2966.0	3047.3	3130.2	3214.7	3300.9	3388.8
(130.60)	*H*	548.858	2720.7	3070.3	3172.4	3275.5	3380.1	3486.2	3594.0	3703.4	3814.4
	S	1.6407	7.0201	7.7444	7.9151	8.0744	8.2243	8.3661	8.5011	8.6301	8.7538
	V	1.073	605.56	875.29	953.52	1031.4	1109.0	1186.5	1263.9	1341.2	1418.5
300	*U*	561.107	2543.0	2807.1	2885.8	2965.8	3047.1	3130.0	3214.5	3300.8	3388.7
(133.54)	*H*	561.429	2724.7	3069.7	3171.9	3275.2	3379.8	3486.0	3593.7	3703.2	3814.2
	S	1.6716	6.9909	7.7034	7.8744	8.0338	8.1838	8.3257	8.4608	8.5898	8.7135

…4/-

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

P/kPa (t^{sat}/°C)		sat. liq.	sat. vap.	TEMPERATURE: t °C (TEMPERATURE: T kelvins) 425 (698.15)	450 (723.15)	475 (748.15)	500 (773.15)	525 (798.15)	550 (823.15)	600 (873.15)	650 (923.15)
2400 (221.78)	V	1.193	83.199	130.44	135.61	140.73	145.82	150.88	155.91	165.92	175.86
	U	949.066	2600.7	2984.5	3027.1	3069.9	3112.9	3156.1	3199.6	3287.7	3377.2
	H	951.929	2800.4	3297.5	3352.6	3407.7	3462.9	3518.2	3573.8	3685.9	3799.3
	S	2.5343	6.2690	7.1189	7.1964	7.2713	7.3439	7.4144	7.4830	7.6152	7.7414
2500 (223.94)	V	1.197	79.905	125.07	130.04	134.97	139.87	144.74	149.58	159.21	168.76
	U	958.969	2601.2	2983.4	3026.2	3069.0	3112.1	3155.4	3198.9	3287.1	3376.7
	H	961.962	2800.9	3296.1	3351.3	3406.5	3461.7	3517.2	3572.9	3685.1	3798.6
	S	2.5543	6.2536	7.0986	7.1763	7.2513	7.3240	7.3946	7.4633	7.5956	7.7220
2600 (226.04)	V	1.201	76.856	120.11	124.91	129.66	134.38	139.07	143.74	153.01	162.21
	U	968.597	2601.5	2982.3	3025.2	3068.1	3111.2	3154.6	3198.2	3286.5	3376.1
	H	971.720	2801.4	3294.6	3349.9	3405.3	3460.6	3516.2	3571.9	3684.3	3797.9
	S	2.5736	6.2387	7.0789	7.1568	7.2320	7.3048	7.3755	7.4443	7.5768	7.7033
2700 (228.07)	V	1.205	74.025	115.52	120.15	124.74	129.30	133.82	138.33	147.27	156.14
	U	977.968	2601.8	2981.2	3024.2	3067.2	3110.4	3153.8	3197.5	3285.8	3375.6
	H	981.222	2801.7	3293.1	3348.6	3404.0	3459.5	3515.2	3571.0	3683.5	3797.1
	S	2.5924	6.2244	7.0600	7.1381	7.2134	7.2863	7.3571	7.4260	7.5587	7.6853
2800 (230.05)	V	1.209	71.389	111.25	115.74	120.17	124.58	128.95	133.30	141.94	150.50
	U	987.100	2602.1	2980.2	3023.2	3066.3	3109.6	3153.1	3196.8	3285.2	3375.0
	H	990.485	2802.0	3291.7	3347.3	3402.8	3458.4	3514.1	3570.0	3682.6	3796.4
	S	2.6106	6.2104	7.0416	7.1199	7.1954	7.2685	7.3394	7.4084	7.5412	7.6679
2900 (231.97)	V	1.213	68.928	107.28	111.62	115.92	120.18	124.42	128.62	136.97	145.26
	U	996.008	2602.3	2979.1	3022.3	3065.5	3108.8	3152.3	3196.1	3284.6	3374.5
	H	999.524	2802.2	3290.2	3346.0	3401.6	3457.3	3513.1	3569.1	3681.8	3795.7
	S	2.6283	6.1969	7.0239	7.1024	7.1780	7.2512	7.3222	7.3913	7.5243	7.6511
3000 (233.84)	V	1.216	66.626	103.58	107.79	111.95	116.08	120.18	124.26	132.34	140.36
	U	1004.7	2602.4	2978.0	3021.3	3064.6	3107.9	3151.5	3195.4	3284.0	3373.9
	H	1008.4	2802.3	3288.7	3344.6	3400.4	3456.2	3512.1	3568.1	3681.0	3795.0
	S	2.6455	6.1837	7.0067	7.0854	7.1612	7.2345	7.3056	7.3748	7.5079	7.6349
3100 (235.67)	V	1.220	64.467	100.11	104.20	108.24	112.24	116.22	120.17	128.01	135.78
	U	1013.2	2602.5	2976.9	3020.3	3063.7	3107.1	3150.8	3194.7	3283.3	3373.4
	H	1017.0	2802.3	3287.3	3343.3	3399.2	3455.1	3511.0	3567.2	3680.2	3794.3
	S	2.6623	6.1709	6.9900	7.0689	7.1448	7.2183	7.2895	7.3588	7.4920	7.6191

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	V	1.224	62.439	96.859	100.83	104.76	108.65	112.51	116.34	123.95	131.48
3200	U	1021.5	2602.5	2975.9	3019.3	3062.8	3106.3	3150.0	3193.9	3282.7	3372.8
(237.45)	H	1025.4	2802.3	3285.8	3342.0	3398.0	3454.0	3510.0	3566.2	3679.3	3793.6
	S	2.6786	6.1585	6.9738	7.0528	7.1290	7.2026	7.2739	7.3433	7.4767	7.6039
	V	1.227	60.529	93.805	97.668	101.49	105.27	109.02	112.74	120.13	127.45
3300	U	1029.7	2602.5	2974.8	3018.3	3061.9	3105.5	3149.2	3193.2	3282.1	3372.3
(239.18)	H	1033.7	2802.3	3284.3	3340.6	3396.8	3452.8	3509.0	3565.3	3678.5	3792.9
	S	2.6945	6.1463	6.9580	7.0373	7.1136	7.1873	7.2588	7.3282	7.4618	7.5891
	V	1.231	58.728	90.930	94.692	98.408	102.09	105.74	109.36	116.54	123.65
3400	U	1037.6	2602.5	2973.7	3017.4	3061.0	3104.6	3148.4	3192.5	3281.5	3371.7
(240.88)	H	1041.8	2802.1	3282.8	3339.3	3395.5	3451.7	3507.9	3564.3	3677.7	3792.1
	S	2.7101	6.1344	6.9426	7.0221	7.0986	7.1724	7.2440	7.3136	7.4473	7.5747
	V	1.235	57.025	88.220	91.886	95.505	99.088	102.64	106.17	113.15	120.07
3500	U	1045.4	2602.4	2972.6	3016.4	3060.1	3103.8	3147.7	3191.8	3280.8	3371.2
(242.54)	H	1049.8	2802.0	3281.3	3338.0	3394.3	3450.6	3506.9	3563.4	3676.9	3791.4
	S	2.7253	6.1228	6.9277	7.0074	7.0840	7.1580	7.2297	7.2993	7.4332	7.5607
	V	1.238	55.415	85.660	89.236	92.764	96.255	99.716	103.15	109.96	116.69
3600	U	1053.1	2602.2	2971.5	3015.4	3059.2	3103.0	3146.9	3191.1	3280.2	3370.6
(244.16)	H	1057.6	2801.7	3279.8	3336.6	3393.1	3449.5	3505.9	3562.4	3676.1	3790.7
	S	2.7401	6.1115	6.9131	6.9930	7.0698	7.1439	7.2157	7.2854	7.4195	7.5471
	V	1.242	53.888	83.238	86.728	90.171	93.576	96.950	100.30	106.93	113.49
3700	U	1060.6	2602.1	2970.4	3014.4	3058.2	3102.1	3146.1	3190.4	3279.6	3370.1
(245.75)	H	1065.2	2801.4	3278.4	3335.3	3391.9	3448.4	3504.9	3561.5	3675.2	3790.0
	S	2.7547	6.1004	6.8989	6.9790	7.0559	7.1302	7.2021	7.2719	7.4061	7.5339
	V	1.245	52.438	80.944	84.353	87.714	91.038	94.330	97.596	104.06	110.46
3800	U	1068.0	2601.9	2969.3	3013.4	3057.3	3101.3	3145.4	3189.6	3279.0	3369.5
(247.31)	H	1072.7	2801.1	3276.8	3333.9	3390.7	3447.2	3503.8	3560.5	3674.4	3789.3
	S	2.7689	6.0896	6.8849	6.9653	7.0424	7.1168	7.1888	7.2587	7.3931	7.5210
	V	1.249	51.061	78.767	82.099	85.383	88.629	91.844	95.033	101.35	107.59
3900	U	1075.3	2601.6	2968.2	3012.4	3056.4	3100.5	3144.6	3188.9	3278.3	3369.0
(248.84)	H	1080.1	2800.8	3275.3	3332.6	3389.4	3446.1	3502.8	3559.5	3673.6	3788.6
	S	2.7828	6.0789	6.8713	6.9519	7.0292	7.1037	7.1759	7.2459	7.3804	7.5084
	V	1.252	49.749	76.698	79.958	83.169	86.341	89.483	92.598	98.763	104.86
4000	U	1082.4	2601.3	2967.0	3011.4	3055.5	3099.6	3143.8	3188.2	3277.7	3368.4
(250.33)	H	1087.4	2800.3	3273.8	3331.2	3388.2	3445.0	3501.7	3558.6	3672.8	3787.9
	S	2.7965	6.0685	6.8581	6.9388	7.0163	7.0909	7.1632	7.2333	7.3680	7.4961

...6/-

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

P/kPa (t^{sat}/°C)		sat. liq.	sat. vap.	TEMPERATURE: t °C (TEMPERATURE: T kelvins) 475 (748.15)	500 (773.15)	525 (798.15)	550 (823.15)	575 (848.15)	600 (873.15)	625 (898.15)	650 (923.15)
	V	1.391	22.863	38.893	40.614	42.295	43.943	45.566	47.166	48.747	50.313
8200	U	1315.2	2569.5	3015.6	3063.3	3110.5	3157.4	3204.3	3251.1	3298.1	3345.2
(296.70)	H	1326.6	2757.0	3334.5	3396.4	3457.3	3517.8	3577.9	3637.9	3697.8	3757.7
	S	3.2239	5.7338	6.6311	6.7124	6.7900	6.8646	6.9365	7.0062	7.0739	7.1397
	V	1.398	22.231	37.887	39.576	41.224	42.839	44.429	45.996	47.544	49.076
8400	U	1324.3	2567.2	3013.6	3061.6	3108.9	3155.9	3202.9	3249.8	3296.9	3344.1
(298.39)	H	1336.1	2754.0	3331.9	3394.0	3455.2	3515.8	3576.1	3636.2	3696.2	3756.3
	S	3.2399	5.7207	6.6173	6.6990	6.7769	6.8516	6.9238	6.9936	7.0614	7.1274
	V	1.404	21.627	36.928	38.586	40.202	41.787	43.345	44.880	46.397	47.897
8600	U	1333.3	2564.9	3011.6	3059.8	3107.3	3154.4	3201.5	3248.5	3295.7	3342.9
(300.06)	H	1345.4	2750.9	3329.2	3391.6	3453.0	3513.8	3574.3	3634.5	3694.7	3754.9
	S	3.2557	5.7076	6.6037	6.6858	6.7639	6.8390	6.9113	6.9813	7.0492	7.1153
	V	1.411	21.049	36.011	37.640	39.228	40.782	42.310	43.815	45.301	46.771
8800	U	1342.2	2562.6	3009.6	3058.0	3105.6	3152.9	3200.1	3247.2	3294.5	3341.8
(301.70)	H	1354.6	2747.8	3326.5	3389.2	3450.8	3511.8	3572.4	3632.8	3693.1	3753.4
	S	3.2713	5.6948	6.5904	6.6728	6.7513	6.8265	6.8990	6.9692	7.0373	7.1035
	V	1.418	20.495	35.136	36.737	38.296	39.822	41.321	42.798	44.255	45.695
9000	U	1351.0	2560.1	3007.6	3056.1	3104.0	3151.4	3198.7	3246.0	3293.3	3340.7
(303.31)	H	1363.7	2744.6	3323.8	3386.8	3448.7	3509.8	3570.6	3631.1	3691.6	3752.0
	S	3.2867	5.6820	6.5773	6.6600	6.7388	6.8143	6.8870	6.9574	7.0256	7.0919
	V	1.425	19.964	34.298	35.872	37.405	38.904	40.375	41.824	43.254	44.667
9200	U	1359.7	2557.7	3005.6	3054.3	3102.3	3149.9	3197.3	3244.7	3292.1	3339.6
(304.89)	H	1372.8	2741.3	3321.1	3384.4	3446.5	3507.8	3568.8	3629.5	3690.0	3750.5
	S	3.3018	5.6694	6.5644	6.6475	6.7266	6.8023	6.8752	6.9457	7.0141	7.0806
	V	1.432	19.455	33.495	35.045	36.552	38.024	39.470	40.892	42.295	43.682
9400	U	1368.2	2555.2	3003.5	3052.5	3100.7	3148.4	3195.9	3243.4	3290.9	3338.5
(306.44)	H	1381.7	2738.0	3318.4	3381.9	3444.3	3505.9	3566.9	3627.8	3688.4	3749.1
	S	3.3168	5.6568	6.5517	6.6352	6.7146	6.7906	6.8637	6.9343	7.0029	7.0695
	V	1.439	18.965	32.726	34.252	35.734	37.182	38.602	39.999	41.377	42.738
9600	U	1376.7	2552.6	3001.5	3050.7	3099.0	3146.9	3194.5	3242.1	3289.7	3337.4
(307.97)	H	1390.6	2734.7	3315.6	3379.5	3442.1	3503.9	3565.1	3626.1	3686.9	3747.6
	S	3.3315	5.6444	6.5392	6.6231	6.7028	6.7790	6.8523	6.9231	6.9918	7.0585

…7/-

	V	1.446	18.494	31.988	33.491	34.949	36.373	37.769	39.142	40.496	41.832
9800	U	1385.2	2550.0	2999.4	3048.8	3097.4	3145.4	3193.1	3240.8	3288.5	3336.2
(309.48)	H	1399.3	2731.2	3312.9	3377.0	3439.9	3501.9	3563.3	3624.4	3685.3	3746.2
	S	3.3461	5.6321	6.5268	6.6112	6.6912	6.7676	6.8411	6.9121	6.9810	7.0478
	V	1.453	18.041	31.280	32.760	34.196	35.597	36.970	38.320	39.650	40.963
10000	U	1393.5	2547.3	2997.4	3047.0	3095.7	3143.9	3191.7	3239.5	3287.3	3335.1
(310.96)	H	1408.0	2727.7	3310.1	3374.6	3437.7	3499.8	3561.4	3622.7	3683.8	3744.7
	S	3.3605	5.6198	6.5147	6.5994	6.6797	6.7564	6.8302	6.9013	6.9703	7.0373
	V	1.460	17.605	30.599	32.058	33.472	34.851	36.202	37.530	38.837	40.128
10200	U	1401.8	2544.6	2995.3	3045.2	3094.0	3142.3	3190.3	3238.2	3286.1	3334.0
(312.42)	H	1416.7	2724.2	3307.4	3372.1	3435.5	3497.8	3559.6	3621.0	3682.2	3743.3
	S	3.3748	5.6076	6.5027	6.5879	6.6685	6.7454	6.8194	6.8907	6.9598	7.0269
	V	1.467	17.184	29.943	31.382	32.776	34.134	35.464	36.770	38.056	39.325
10400	U	1410.0	2541.8	2993.2	3043.3	3092.4	3140.8	3188.9	3236.9	3284.8	3332.9
(313.86)	H	1425.2	2720.6	3304.6	3369.7	3433.2	3495.8	3557.8	3619.3	3680.6	3741.8
	S	3.3889	5.5955	6.4909	6.5765	6.6574	6.7346	6.8087	6.8803	6.9495	7.0167
	V	1.474	16.778	29.313	30.732	32.106	33.444	34.753	36.039	37.304	38.552
10600	U	1418.1	2539.0	2991.1	3041.4	3090.7	3139.3	3187.5	3235.6	3283.6	3331.7
(315.27)	H	1433.7	2716.9	3301.8	3367.2	3431.0	3493.8	3555.9	3617.6	3679.1	3740.4
	S	3.4029	5.5835	6.4793	6.5652	6.6465	6.7239	6.7983	6.8700	6.9394	7.0067
	V	1.481	16.385	28.706	30.106	31.461	32.779	34.069	35.335	36.580	37.808
10800	U	1426.2	2536.2	2989.0	3039.6	3089.0	3137.8	3186.1	3234.3	3282.4	3330.6
(316.67)	H	1442.2	2713.1	3299.0	3364.7	3428.8	3491.8	3554.1	3615.9	3677.5	3738.9
	S	3.4167	5.5715	6.4678	6.5542	6.6357	6.7134	6.7880	6.8599	6.9294	6.9969
	V	1.489	16.006	28.120	29.503	30.839	32.139	33.410	34.656	35.882	37.091
11000	U	1434.2	2533.2	2986.9	3037.7	3087.3	3136.2	3184.7	3233.0	3281.2	3329.5
(318.05)	H	1450.6	2709.3	3296.2	3362.2	3426.5	3489.7	3552.2	3614.2	3675.9	3737.5
	S	3.4304	5.5595	6.4564	6.5432	6.6251	6.7031	6.7779	6.8499	6.9196	6.9872
	V	1.496	15.639	27.555	28.921	30.240	31.521	32.774	34.002	35.210	36.400
11200	U	1442.1	2530.3	2984.8	3035.8	3085.6	3134.7	3183.3	3231.7	3280.0	3328.4
(319.40)	H	1458.9	2705.4	3293.4	3359.7	3424.3	3487.7	3550.4	3612.5	3674.4	3736.0
	S	3.4440	5.5476	6.4452	6.5324	6.6147	6.6929	6.7679	6.8401	6.9099	6.9777
	V	1.504	15.284	27.010	28.359	29.661	30.925	32.160	33.370	34.560	35.733
11400	U	1450.0	2527.2	2982.6	3033.9	3083.9	3133.1	3181.9	3230.4	3278.8	3327.2
(320.74)	H	1467.2	2701.5	3290.5	3357.2	3422.1	3485.7	3548.5	3610.8	3672.8	3734.6
	S	3.4575	5.5357	6.4341	6.5218	6.6043	6.6828	6.7580	6.8304	6.9004	6.9683

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Table C.1: Heat Capacities of Gases in the Ideal-Gas State†

Constants in equation $C_P^{ig}/R = A + BT + CT^2 + DT^{-2}$ T (kelvins) from 298 to T_{max}

Chemical species		T_{max}	$C_{P_{298}}^{ig}/R$	A	$10^3\ B$	$10^6\ C$	$10^{-5}\ D$
Paraffins:							
Methane	CH_4	1500	4.217	1.702	9.081	−2.164	
Ethane	C_2H_6	1500	6.369	1.131	19.225	−5.561	
Propane	C_3H_8	1500	9.011	1.213	28.785	−8.824	
n-Butane	C_4H_{10}	1500	11.928	1.935	36.915	−11.402	
iso-Butane	C_4H_{10}	1500	11.901	1.677	37.853	−11.945	
n-Pentane	C_5H_{12}	1500	14.731	2.464	45.351	−14.111	
n-Hexane	C_6H_{14}	1500	17.550	3.025	53.722	−16.791	
n-Heptane	C_7H_{16}	1500	20.361	3.570	62.127	−19.486	
n-Octane	C_8H_{18}	1500	23.174	4.108	70.567	−22.208	
1-Alkenes:							
Ethylene	C_2H_4	1500	5.325	1.424	14.394	−4.392	
Propylene	C_3H_6	1500	7.792	1.637	22.706	−6.915	
1-Butene	C_4H_8	1500	10.520	1.967	31.630	−9.873	
1-Pentene	C_5H_{10}	1500	13.437	2.691	39.753	−12.447	
1-Hexene	C_6H_{12}	1500	16.240	3.220	48.189	−15.157	
1-Heptene	C_7H_{14}	1500	19.053	3.768	56.588	−17.847	
1-Octene	C_8H_{16}	1500	21.868	4.324	64.960	−20.521	
Miscellaneous organics:							
Acetaldehyde	C_2H_4O	1000	6.506	1.693	17.978	−6.158	
Acetylene	C_2H_2	1500	5.253	6.132	1.952	......	−1.299
Benzene	C_6H_6	1500	10.259	−0.206	39.064	−13.301	
1,3-Butadiene	C_4H_6	1500	10.720	2.734	26.786	−8.882	
Cyclohexane	C_6H_{12}	1500	13.121	−3.876	63.249	−20.928	
Ethanol	C_2H_6O	1500	8.948	3.518	20.001	−6.002	
Ethylbenzene	C_8H_{10}	1500	15.993	1.124	55.380	−18.476	
Ethylene oxide	C_2H_4O	1000	5.784	−0.385	23.463	−9.296	
Formaldehyde	CH_2O	1500	4.191	2.264	7.022	−1.877	
Methanol	CH_4O	1500	5.547	2.211	12.216	−3.450	
Styrene	C_8H_8	1500	15.534	2.050	50.192	−16.662	
Toluene	C_7H_8	1500	12.922	0.290	47.052	−15.716	
Miscellaneous inorganics:							
Air		2000	3.509	3.355	0.575	......	−0.016
Ammonia	NH_3	1800	4.269	3.578	3.020	......	−0.186
Bromine	Br_2	3000	4.337	4.493	0.056	......	−0.154
Carbon monoxide	CO	2500	3.507	3.376	0.557	......	−0.031
Carbon dioxide	CO_2	2000	4.467	5.457	1.045	......	−1.157
Carbon disulfide	CS_2	1800	5.532	6.311	0.805	......	−0.906
Chlorine	Cl_2	3000	4.082	4.442	0.089	......	−0.344
Hydrogen	H_2	3000	3.468	3.249	0.422	......	0.083
Hydrogen sulfide	H_2S	2300	4.114	3.931	1.490	......	−0.232
Hydrogen chloride	HCl	2000	3.512	3.156	0.623	......	0.151
Hydrogen cyanide	HCN	2500	4.326	4.736	1.359	......	−0.725
Nitrogen	N_2	2000	3.502	3.280	0.593	......	0.040
Nitrous oxide	N_2O	2000	4.646	5.328	1.214	......	−0.928
Nitric oxide	NO	2000	3.590	3.387	0.629	......	0.014
Nitrogen dioxide	NO_2	2000	4.447	4.982	1.195	......	−0.792
Dinitrogen tetroxide	N_2O_4	2000	9.198	11.660	2.257	......	−2.787
Oxygen	O_2	2000	3.535	3.639	0.506	......	−0.227
Sulfur dioxide	SO_2	2000	4.796	5.699	0.801	......	−1.015
Sulfur trioxide	SO_3	2000	6.094	8.060	1.056	......	−2.028
Water	H_2O	2000	4.038	3.470	1.450	......	0.121

†Selected from H. M. Spencer, *Ind. Eng. Chem.*, vol. 40, pp. 2152–2154, 1948; K. K. Kelley, *U.S. Bur. Mines Bull. 584*, 1960; L. B. Pankratz, *U.S. Bur. Mines Bull. 672*, 1982.

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Table C.4: Standard Enthalpies and Gibbs Energies of Formation at 298.15 K†

Joules per mole of the substance formed

Chemical species		State (Note 2)	$\Delta H^\circ_{f_{298}}$ (Note 1)	$\Delta G^\circ_{f_{298}}$ (Note 1)
Paraffins:				
Methane	CH_4	(*g*)	−74,520	−50,460
Ethane	C_2H_6	(*g*)	−83,820	−31,855
Propane	C_3H_8	(*g*)	−104,680	−24,290
n-Butane	C_4H_{10}	(*g*)	−125,790	−16,570
n-Pentane	C_5H_{12}	(*g*)	−146,760	−8,650
n-Hexane	C_6H_{14}	(*g*)	−166,920	150
n-Heptane	C_7H_{16}	(*g*)	−187,780	8,260
n-Octane	C_8H_{18}	(*g*)	−208,750	16,260
1-Alkenes:				
Ethylene	C_2H_4	(*g*)	52,510	68,460
Propylene	C_3H_6	(*g*)	19,710	62,205
1-Butene	C_4H_8	(*g*)	−540	70,340
1-Pentene	C_5H_{10}	(*g*)	−21,280	78,410
1-Hexene	C_6H_{12}	(*g*)	−41,950	86,830
1-Heptene	C_7H_{14}	(*g*)	−62,760	
Miscellaneous organics:				
Acetaldehyde	C_2H_4O	(*g*)	−166,190	−128,860
Acetic acid	$C_2H_4O_2$	(*l*)	−484,500	−389,900
Acetylene	C_2H_2	(*g*)	227,480	209,970
Benzene	C_6H_6	(*g*)	82,930	129,665
Benzene	C_6H_6	(*l*)	49,080	124,520
1,3-Butadiene	C_4H_6	(*g*)	109,240	149,795
Cyclohexane	C_6H_{12}	(*g*)	−123,140	31,920
Cyclohexane	C_6H_{12}	(*l*)	−156,230	26,850
1,2-Ethanediol	$C_2H_6O_2$	(*l*)	−454,800	−323,080
Ethanol	C_2H_6O	(*g*)	−235,100	−168,490
Ethanol	C_2H_6O	(*l*)	−277,690	−174,780
Ethylbenzene	C_8H_{10}	(*g*)	29,920	130,890
Ethylene oxide	C_2H_4O	(*g*)	−52,630	−13,010
Formaldehyde	CH_2O	(*g*)	−108,570	−102,530
Methanol	CH_4O	(*g*)	−200,660	−161,960
Methanol	CH_4O	(*l*)	−238,660	−166,270
Methylcyclohexane	C_7H_{14}	(*g*)	−154,770	27,480
Methylcyclohexane	C_7H_{14}	(*l*)	−190,160	20,560
Styrene	C_8H_8	(*g*)	147,360	213,900
Toluene	C_7H_8	(*g*)	50,170	122,050
Toluene	C_7H_8	(*l*)	12,180	113,630

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Table C.4 (Continued)

Chemical species		State (Note 2)	$\Delta H^\circ_{f_{298}}$ (Note 1)	$\Delta G^\circ_{f_{298}}$ (Note 1)
Miscellaneous inorganics:				
Ammonia	NH_3	(*g*)	−46,110	−16,450
Ammonia	NH_3	(*aq*)		−26,500
Calcium carbide	CaC_2	(*s*)	−59,800	−64,900
Calcium carbonate	$CaCO_3$	(*s*)	−1,206,920	−1,128,790
Calcium chloride	$CaCl_2$	(*s*)	−795,800	−748,100
Calcium chloride	$CaCl_2$	(*aq*)		−8,101,900
Calcium chloride	$CaCl_2 \cdot 6H_2O$	(*s*)	−2,607,900	
Calcium hydroxide	$Ca(OH)_2$	(*s*)	−986,090	−898,490
Calcium hydroxide	$Ca(OH)_2$	(*aq*)		−868,070
Calcium oxide	CaO	(*s*)	−635,090	−604,030
Carbon dioxide	CO_2	(*g*)	−393,509	−394,359
Carbon monoxide	CO	(*g*)	−110,525	−137,169
Hydrochloric acid	HCl	(*g*)	−92,307	−95,299
Hydrogen cyanide	HCN	(*g*)	135,100	124,700
Hydrogen sulfide	H_2S	(*g*)	−20,630	−33,560
Iron oxide	FeO	(*s*)	−272,000	
Iron oxide (hematite)	Fe_2O_3	(*s*)	−824,200	−742,200
Iron oxide (magnetite)	Fe_3O_4	(*s*)	−1,118,400	−1,015,400
Iron sulfide (pyrite)	FeS_2	(*s*)	−178,200	−166,900
Lithium chloride	$LiCl$	(*s*)	−408,610	
Lithium chloride	$LiCl \cdot H_2O$	(*s*)	−712,580	
Lithium chloride	$LiCl \cdot 2H_2O$	(*s*)	−1,012,650	
Lithium chloride	$LiCl \cdot 3H_2O$	(*s*)	−1,311,300	
Nitric acid	HNO_3	(*l*)	−174,100	−80,710
Nitric acid	HNO_3	(*aq*)		−111,250
Nitrogen oxides	NO	(*g*)	90,250	86,550
	NO_2	(*g*)	33,180	51,310
	N_2O	(*g*)	82,050	104,200
	N_2O_4	(*g*)	9,160	97,540
Sodium carbonate	Na_2CO_3	(*s*)	−1,130,680	−1,044,440
Sodium carbonate	$Na_2CO_3 \cdot 10H_2O$	(*s*)	−4,081,320	
Sodium chloride	$NaCl$	(*s*)	−411,153	−384,138
Sodium chloride	$NaCl$	(*aq*)		−393,133
Sodium hydroxide	$NaOH$	(*s*)	−425,609	−379,494
Sodium hydroxide	$NaOH$	(*aq*)		−419,150
Sulfur dioxide	SO_2	(*g*)	−296,830	−300,194
Sulfur trioxide	SO_3	(*g*)	−395,720	−371,060
Sulfur trioxide	SO_3	(*l*)	−441,040	
Sulfuric acid	H_2SO_4	(*l*)	−813,989	−690,003
Sulfuric acid	H_2SO_4	(*aq*)		−744,530
Water	H_2O	(*g*)	−241,818	−228,572
Water	H_2O	(*l*)	−285,830	−237,129

†From *TRC Thermodynamic Tables—Hydrocarbons*, Thermodynamics Research Center, Texas A & M Univ. System, College Station, TX; "The NBS Tables of Chemical Thermodynamic Properties," *J. Phys. and Chem. Reference Data*, vol. 11, supp. 2, 1982.

Notes

1. The standard property changes of formation $\Delta H^\circ_{f_{298}}$ and $\Delta G^\circ_{f_{298}}$ are the changes occurring when 1 mol of the listed compound is formed from its elements with each substance in its standard state at 298.15 K (25°C).
2. Standard states: (*a*) Gases (*g*): pure ideal gas at 1 bar and 25°C. (*b*) Liquids (*l*) and solids (*s*): pure substance at 1 bar and 25°C. (*c*) Solutes in aqueous solution (*aq*): Hypothetical ideal 1-molal solution of solute in water at 1 bar and 25°C.