Thermodynamic Properties of Carbon Dioxide to 24,000° K.

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INTEREST in the thermodynamic properties of carbon dioxide at high temperatures over a wide range of pressures is important because carbon dioxide may be found in appreciable quantities in the Venusian atmosphere (*1*). To make possible early studies of some of the problems of entry into the Venusian atmosphere, selected thermodynamic properties were calculated for pure carbon dioxide gas (*3*).

A Mollier chart is presented for 100% CO_2 in the temperature range of 1000° to 24,000° K. and pressure range of 10^{-4} to 10^{2} atm. The temperatures and pressures estimated for the anticipated Venusian approach speed of 34,000 feet per second lie well within these ranges. The free energy, internal energy, and reaction energy were taken from Gilmore's tables (*2*). Other properties besides enthalpy and entropy, such as molecular weight, density, internal energy, and resulting number of moles, some of which are presented below, were also calculated over the same temperature and pressure ranges. Both tabulated and graphical data are presented.

ASSUMPTIONS

For the calculations, the various constituents are treated as ideal gases, and thermodynamic equilibrium is assumed. The first assumption amounts to the fact that the intermolecular forces, and hence compressibility, are neglected. This does not appear too severe a limitation, however, since the ranges of pressure and temperatures considered are far enough removed from critical pressures and temperatures of the molecular constituents to have negligible effect on the molar composition of the gas. As a check, the compressibility was calculated by using the second and third virial coefficients of state at a pressure of 10^2 atm. (the worst case considered). The compressibility was 1.026, which therefore suggested that extensive calculations using the second and third virial coefficients (based on the Lennard-Jones Potential) not be made. It should be recalled that the virial coefficients in a volumetric expansion are

$$\frac{pV}{RT} = 1 + \frac{B(T)}{V} + \frac{C(T)}{V^2} + \dots$$

All of the molecular constituents vanish above T = 10,000° K., with appreciable amounts of atomic constituents frequently appearing above T = 4000° K. Hence, the high temperature results (above T = 10,000° K.) are expected to be substantially correct in this respect and may be used satisfactorily for the present.

The data are presented per cold mole of CO_2. The molecular weight of cold CO_2 was taken as 44.011 grams (*2*).

CALCULATION AND RESULTS

The molar constituents of the various species derived from CO_2 were calculated by the method of White, Johnson, and Dantzig (*4*). This method of calculating the equilibrium composition of a gas at a given temperature and pressure is based on the fact that equilibrium is established at that composition where the Gibbs free energy is minimized.

Initial results were obtained by calculating the amount of dissociation or ionization and thereby determining the total number of moles of mixture (Figure 1 and Table I). Since the mole fraction per mole of mixture resulted directly from

Table I. Total Number of Moles, *n*

T, ° K.	10^2	3×10	10	3	1.0	3×10^{-1}	10^{-1}	3×10^{-2}	10^{-2}	3×10^{-3}	10^{-3}	3×10^{-4}	10^{-4}
							p, Atm.						
1,000	1.0000		1.0000		1.0000		1.0000		1.0000		1.0000		1.0000
1,500	1.0000		1.0001		1.0002		1.0004		1.0008		1.0018		1.0038
2,000	1.0016		1.0035		1.0075		1.0161		1.0346		1.0736		1.1538
3,000	1.0624		1.1288		1.2543		1.4651		1.7553		1.9532		1.9948
4,000	1.3113		1.5428		1.8259		1.9725		1.9976		2.0002		2.0030
5,000	1.6452		1.9007		1.9881		2.0008		2.0201		2.1620		2.6356
6,000	1.8830		1.9860		2.0150		2.1447		2.6028		2.9673		3.0993
7,000	1.9682		2.0381		2.2864		2.7968		3.0338		3.1843		3.5006
8,000	2.0338	2.1327	2.3091	2.5889	2.8195	2.9711	3.0496	3.1253	3.2201	3.3779	3.5822	3.8572	4.1447
9,000	2.2288	2.4890	2.7445	2.9352	3.0305	3.1105	3.2014	3.3517	3.5534	3.8424	4.1623	4.6094	5.1017
10,000	2.5641	2.8256	2.9719	3.0674	3.1486	3.2727	3.4448	3.7146	4.0325	4.4722	4.9646	5.4808	5.7818
11,000	2.8364	2.9919	3.0799	3.1779	3.3060	3.5206	3.7992	4.2003	4.6619	5.2238	5.6331	5.8697	5.9540
12,000	2.9800	3.0852	3.1791	3.3266	3.5327	3.8596	4.2577	4.8005	5.3144	5.7164	5.8939	5.9676	5.9906
13,000	3.0673	3.1738	3.3063	3.5302	3.8326	4.2850	4.7971	5.3620	5.7193	5.9051	5.9687	5.9952	6.0117
14,000	3.1449	3.2824	3.4738	3.7931	4.2022	4.7677	5.2978	5.7105	5.8917	5.9684	5.9970	6.0248	6.0778
15,000	3.2313	3.4196	3.6858	4.1116	4.6202	5.2195	5.6380	5.8744	5.9597	5.9993	6.0338	6.1152	6.2781
16,000	3.3355	3.5901	3.9417	4.4718	5.0326	5.5527	5.8220	5.9474	5.9940	6.0430	6.1303	6.3316	6.5976
17,000	3.4616	3.7940	4.2345	4.8412	5.3740	5.7553	5.9145	5.9887	6.0389	6.1425	6.3334	6.6312	6.8802
18,000	3.6110	4.0281	4.5487	5.1747	5.6160	5.8689	5.9674	6.0330	6.1272	6.3325	6.6029	6.9015	7.1580
19,000	3.7834	4.2858	4.8588	5.4395	5.7702	5.9362	6.0131	6.1118	6.2860	6.5855	6.8750	7.1937	7.5999
20,000	3.9762	4.5536	5.1384	5.6309	5.8665	5.9871	6.0763	6.2462	6.5080	6.8457	7.1629	7.6276	8.1634
21,000	4.1845	4.8152	5.3696	5.7614	5.9325	6.0438	6.1778	6.4381	6.7557	7.1248	7.5569	8.1472	8.5982
22,000	4.4014	5.0547	5.5481	5.8517	5.9887	6.1237	6.3282	6.6663	7.0213	7.4899	8.0308	8.5574	8.8253
23,000	4.6174	5.2613	5.6814	5.9202	6.0518	6.2400	6.5215	6.9167	7.3384	7.9228	8.4418	8.7899	8.9244
24,000	4.8242	5.4314	5.7812	5.9822	6.1354	6.3969	6.7443	7.2019	7.7186	8.3228	8.7072	8.9019	8.9660

the calculations, and since the data are presented per cold mole of CO_2,

then

$$X_i = X_{i_m} \frac{M_{CO_2}}{M_m} \tag{1}$$

where

$$X_i = \frac{n_i}{n_{CO_2}} \tag{2}$$

and

$$X_{i_m} = \frac{n_i}{n_m} \tag{3}$$

The number of moles of each constituent of the mixture n_i is plotted in Figure 2 with tabulated values in Table II for $p = 10^2$ and 10^{-4} atm., respectively.

The enthalpy per cold mole of CO_2 in dimensionless form is

$$\frac{H}{RT_0} = \frac{T}{T_0} \sum_i X_i \left[\left(\frac{E^0 - E_0^0}{RT} \right)_i + \left(\frac{E_0^0}{RT} \right)_i + 1 \right] \tag{4}$$

The entropy per cold mole of CO_2 in dimensionless form is

$$\frac{S}{R} = \sum_i X_i \left(\frac{S_i^0}{R} - \ln p_i \right) \tag{5}$$

where

$$\frac{S_i^0}{R} = \left(\frac{E^0 - E_0^0}{RT} \right)_i - \left(\frac{F^0 - E_0^0}{RT} \right)_i + 1 \tag{6}$$

Since

$$p_i = (n_i / \sum_i n_i) p \tag{7}$$

then

$$\frac{S}{R} = \sum_i X_i \left[\left(\frac{E^0 - E_0^0}{RT} \right)_i - \left(\frac{F^0 - E_0^0}{RT} \right)_i + 1 - \ln \left(\frac{n_i}{n} p \right) \right] \tag{8}$$

The Mollier chart is plotted in Figure III with values for enthalpy and entropy tabulated in Tables III and IV.

The reaction energy, E_0^0, is measured from some reference state: in the above equations at 0° K. temperature and zero

Table II. Molar Composition, n_i

T, ° K.	CO_2	O_2	CO	O	C	C^+	C^{+2}	O^+	O^{-2}	e^-
					$p = 10^2$ Atm.					
1,000	1.0		0							
1,500	0.9999	0	0.0001							
2,000	0.9968	0.0016	0.0032	0						
3,000	0.8781	0.0596	0.1219	0.0028						
4,000	0.4584	0.2303	0.5416	0.0810						
5,000	0.1310	0.2238	0.8690	0.4213	0					
6,000	0.0299	0.0872	0.9699	0.7958	0.0002			0		0
7,000	0.0101	0.0262	0.9853	0.9419	0.0045	0		0.0001		0.0001
8,000	0.0040	0.0098	0.9490	1.0233	0.0467	0.0003		0.0002		0.0005
9,000	0.0017	0.0052	0.7660	1.2200	0.2299	0.0025		0.0005		0.0030
10,000	0.0006	0.0036	0.4423	1.5478	0.5471	0.0099		0.0014		0.0114
11,000	0.0002	0.0025	0.1899	1.8010	0.7846	0.0253		0.0038		0.0291
12,000	0.0001	0.0017	0.0761	1.9114	0.8748	0.0490		0.0089		0.0580
13,000	0	0.0012	0.0319	1.9472	0.8860	0.0820		0.0185		0.1005
14,000		0.0008	0.0141	1.9495	0.8609	0.1250		0.0348		0.1598
15,000		0.0006	0.0069	1.9310	0.8154	0.1777		0.0610		0.2387
16,000		0.0004	0.0035	1.8951	0.7576	0.2389		0.1006		0.3395
17,000		0.0003	0.0019	1.8402	0.6916	0.3065		0.1573		0.4638
18,000		0.0002	0.0010	1.7639	0.6214	0.3776		0.2346		0.6123
19,000		0.0002	0.0006	1.6645	0.5500	0.4493	0	0.3347		0.7841
20,000		0.0001	0.0003	1.5421	0.4805	0.5191	0.0001	0.4573		0.9766
21,000		0	0.0002	1.3999	0.4149	0.5847	0.0002	0.5997		1.1849
22,000			0.0001	1.2439	0.3548	0.6446	0.0005	0.7559		1.4015
23,000			0	1.0822	0.3010	0.6980	0.0009	0.9177	0	1.6176
24,000				0.9237	0.2539	0.7444	0.0017	1.0762	0.0001	1.8242
					$p = 10^{-4}$ Atm.					
1,000	1.0	0	0							
1,500	0.9923	0.0039	0.0077	0						
2,000	0.7178	0.1284	0.2822	0.0254						
3,000	0.0013	0.0039	0.9987	0.9909	0					
4,000	0	0	0.9970	1.0030	0.0030	0		0		0
5,000			0.3717	1.6283	0.6211	0.0072		0.0001		0.0073
6,000			0.0064	1.9918	0.8896	0.1040		0.0018		0.1057
7,000			0.0001	1.9738	0.5252	0.4747		0.0260		0.5007
8,000			0	1.7240	1.1312	0.8688		0.2760		1.1447
9,000				0.8711	0.0271	0.9729		1.1288		2.1018
10,000				0.2121	0.0060	0.9939		1.7879		2.7818
11,000				0.0445	0.0015	0.9985	0	1.9555		2.9540
12,000				0.0109	0.0004	0.9975	0.0020	1.9891		2.9906
13,000				0.0031	0.0001	0.9850	0.0149	1.9969	0	3.0117
14,000				0.0011	0.0001	0.9212	0.0787	1.9987	0.0002	3.0778
15,000				0.0004	0	0.7235	0.2765	1.9975	0.0021	3.2781
16,000				0.0002		0.4145	0.5855	1.9873	0.0125	3.5978
17,000				0.0001		0.1800	0.8200	1.9395	0.0604	3.8802
18,000				0		0.0711	0.9289	1.7708	0.2291	4.1580
19,000						0.0290	0.9710	1.3711	0.6289	4.5999
20,000						0.0127	0.9873	0.8240	1.1760	5.1633
21,000						0.0058	0.9942	0.3960	1.6040	5.5982
22,000						0.0028	0.9972	0.1719	1.8281	5.8253
23,000						0.0014	0.9986	0.0742	1.9258	5.9244
24,000						0.0007	0.9992	0.0332	1.9668	5.9660

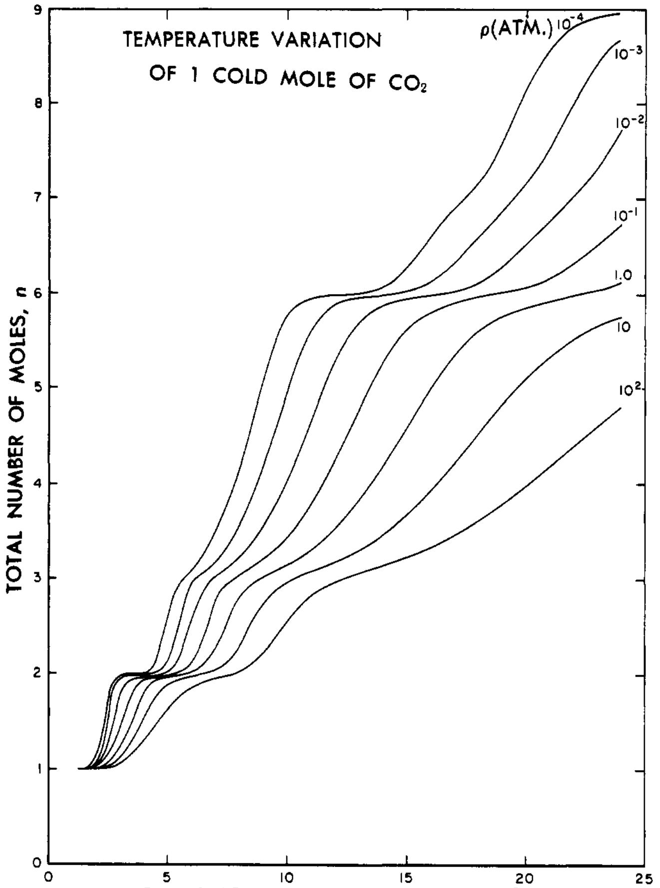

Figure 1. Total number of moles as a function of temperature

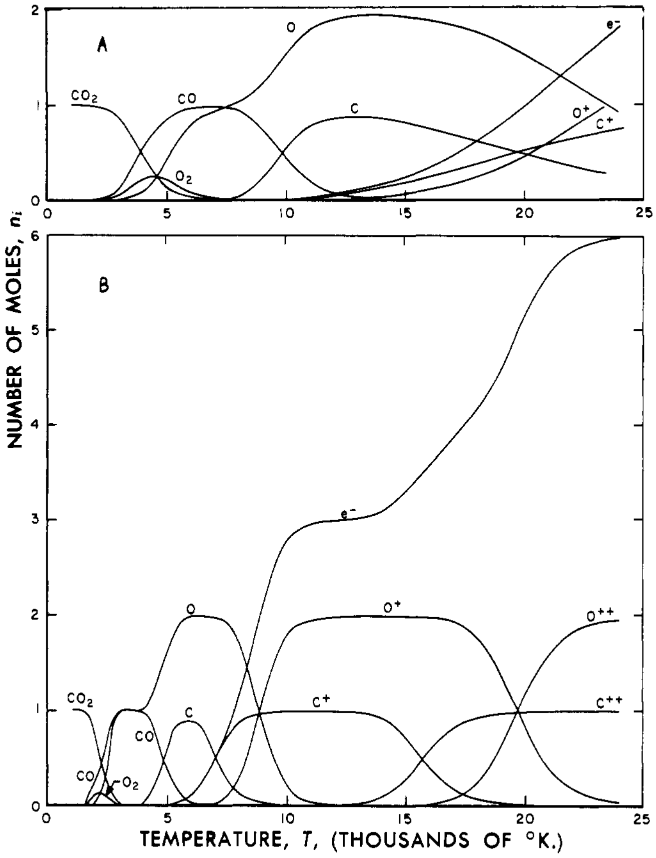

Figure 2. Molar composition

A. Temperature variation of 1 cold mole of CO_2, $p = 10^2$ atm.

B. Temperature variation of 1 cold mole of CO_2, $p = 10^{-4}$ atm.

Table III. Enthalpy, H/RT_0

T, ° K.	10^2	3×10	10	3	1.0	3×10^{-1}	10^{-1}	3×10^{-2}	10^{-2}	3×10^{-3}	10^{-3}	3×10^{-4}	10^{-4}
							p, Atm.						
1,000	-154.3		-154.3		-154.3		-154.3		-154.3		-154.3		-154.3
1,500	-141.8		-141.8		-141.8		-141.7		-141.6		-141.4		-140.9
2,000	-128.3		-127.9		-126.9		-124.8		-120.3		-110.8		-91.3
3,000	-86.7		-70.8		-41.0		-8.5		75.5		120.8		130.3
4,000	1.0		52,6		117.5		151.0		056.7		157.4		158.7
5,000	102.5		160.8		180.8		184.2		193.2		262.5		493.8
6,000	183.4		207.2		218.2		281.1		506.2		686.2		754.0
7,000	233.3		259.2		380.4		631.9		750.6		831.2		1003.5
8,000	284.5	331.3	418.4	557.5	672.7	749.2	789.9	831.0	883.2	970.8	1085.4	1243.4	1416.6
9,000	408.6	537.8	665.7	762.0	811.4	854.9	905.8	990.9	1106.4	1275.9	1471.8	1757.8	2079.8
10,000	606.5	737.7	812.4	863.4	908.8	980.1	1080.2	1239.9	1434.7	1716.3	2040.7	2384.9	2586.3
11,000	775.3	855.1	902.9	959.1	1034.4	1162.3	1332.3	1586.1	1889.9	2268.0	2545.2	2706.0	2763.4
12,000	881.9	939.0	993.8	1082.2	1208.0	1412.3	1670.0	2034.0	2385.3	2662.1	2784.9	2835.6	2852.6
13,000	963.3	1025.4	1106.2	1244.5	1437.9	1735.4	2083.8	2475.4	2725.6	2856.0	2901.2	2921.3	2937.4
14,000	1043.8	1128.3	1249.2	1455.3	1727.6	2116.3	2488.7	2781.1	2910.6	2966.3	2989.2	3017.7	3078.9
15,000	1134.3	1254.6	1428.3	1713.9	2066.0	2491.2	2791.7	2962.3	3025.5	3058.5	3094.8	3189.3	3382.3
16,000	1241.0	1408.5	1645.7	2014.1	2414.5	2791.7	2988.9	3082.4	3122.3	3172.7	3275.4	3516.3	3837.2
17,000	1367.2	1592.3	1898.9	2332.9	2722.7	3004.0	3123.5	3184.1	3235.8	3358.8	3589.9	3954.0	4271.1
18,000	1515.1	1805.3	2177.3	2635.6	2964.0	3154.8	3233.2	3297.6	3409.0	3659.6	3002.7	4384.5	4756.4
19,000	1685.2	2043.1	2461.9	2894.9	3144.7	3274.8	3345.5	3459.5	3674.4	4051.0	4432.6	4898.4	5543.1
20,000	1876.5	2296.0	2731.0	3103.3	3285.7	3388.8	3486.2	3695.8	4028.8	4476.3	4938.1	5674.1	6546.6
21,000	2085.4	2551.0	2968.8	3269.6	3408.0	3517.9	3680.7	4014.1	4435.4	4971.7	5647.4	6608.5	7349.8
22,000	2306.1	2794.4	3170.6	3408.6	3530.2	3683.3	3944.7	4394.3	4898.0	5627.1	6506.6	7373.3	7815.9
23,000	2531.0	3017.0	3340.6	3535.9	3669.1	3903.1	4275.6	4828.2	5472.4	6416.7	7273.1	7849.8	8072.7
24,000	2752.6	3213.5	3488.2	3665.5	3841.2	4183.2	4662.8	5343.5	6171.2	7167.2	7804.0	8127.9	8235.2

pressure. For example, the zero of internal energy for C (graphite) + O_2 (gas) is at 0° K. For CO_2 at 0° K., the reaction energy is −93.9639 kcal. per mole or $E_0^0/RT_0 = -173.105 = H_0^0/RT_0$, $T_0 = 273.16°$ K.

The density of the gas mixture is

$$\rho = pM_m/82.0561T \qquad (9)$$

where

$$M_m = M_{CO_2}/(n_m/n_{CO_2}) = \frac{44.011}{n_m} \qquad (10)$$

since $n_{CO_2} = 1$, and $M_{CO_2} = 44.011$. The density in grams per cubic centimeter and the molecular weight of the mixture are tabulated in Tables V and VI, respectively.

Enthalpy and entropy at T = 1000° K., and p = 1 atm.

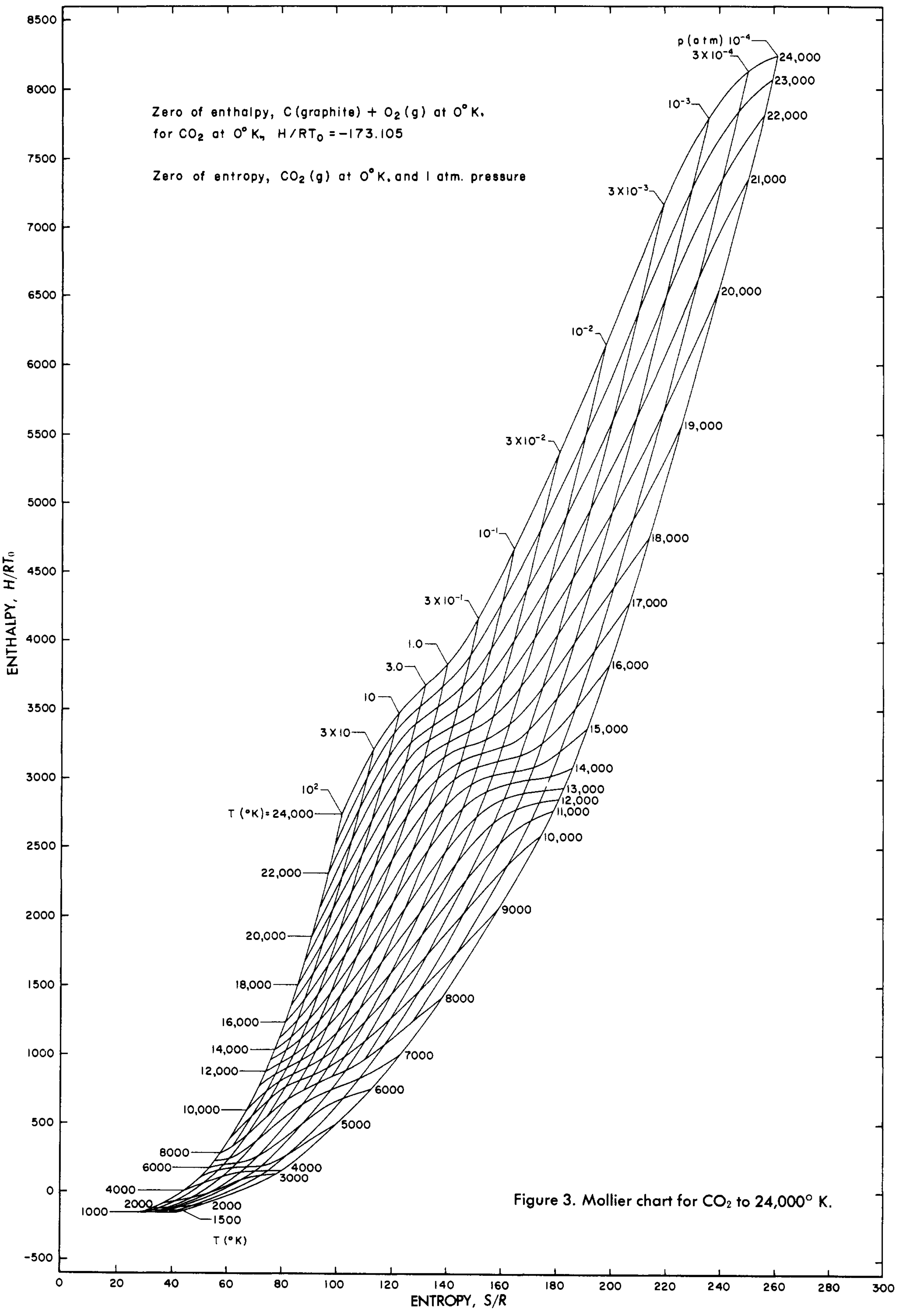

Figure 3. Mollier chart for CO_2 to 24,000° K.

Table V. Density, ρ, Gram per Cubic Centimeter

	p, Atm.												
T, °K.	10^2	3×10	10	3	1.0	3×10^{-1}	10^{-1}	3×10^{-2}	10^{-2}	3×10^{-3}	10^{-3}	3×10^{-4}	10^{-4}
1,000	5.3635^{-2}		5.3635^{-3}		5.3635^{-4}		5.3635^{-5}		5.3635^{-6}		5.3635^{-7}		5.3635^{-8}
1,500	3.5756^{-2}		3.5754^{-3}		3.5750^{-4}		3.5743^{-5}		3.5727^{-6}		3.5693^{-7}		3.5620^{-8}
2,000	2.6774^{-2}		2.6724^{-3}		2.6617^{-4}		2.6392^{-5}		2.5920^{-6}		2.4980^{-7}		2.3243^{-8}
3,000	1.6829^{-2}		1.5838^{-3}		1.4254^{-4}		1.2203^{-5}		1.0185^{-6}		9.1533^{-8}		8.9625^{-9}
4,000	1.0226^{-2}		8.6915^{-4}		7.3438^{-5}		6.7978^{-6}		6.7125^{-7}		6.7037^{-8}		6.6944^{-9}
5,000	6.5203^{-3}		5.6436^{-4}		5.3957^{-5}		5.3612^{-6}		5.3101^{-7}		4.9617^{-8}		4.0701^{-9}
6,000	4.7471^{-3}		4.5010^{-4}		4.4343^{-5}		4.1680^{-6}		3.4344^{-7}		3.0125^{-8}		2.8843^{-9}
7,000	3.8929^{-3}		3.7593^{-4}		3.3512^{-5}		2.7396^{-6}		2.5256^{-7}		2.4062^{-8}		2.1888^{-9}
8,000	3.2965^{-3}	9.4301^{-4}	2.9035^{-4}	7.7688^{-5}	2.3779^{-5}	6.7694^{-6}	2.1985^{-6}	6.4351^{-7}	2.0821^{-7}	5.9541^{-8}	1.8716^{-8}	5.2142^{-9}	1.6176^{-9}
9,000	2.6741^{-3}	7.1825^{-4}	2.1713^{-4}	6.0906^{-5}	1.9665^{-5}	5.7475^{-6}	1.8615^{-6}	5.3339^{-7}	1.6772^{-7}	4.5627^{-8}	1.4318^{-8}	3.8787^{-9}	1.1681^{-9}
10,000	2.0917^{-3}	5.6945^{-4}	1.8048^{-4}	5.2454^{-5}	1.7035^{-5}	4.9165^{-6}	1.5370^{-6}	4.3317^{-7}	1.3301^{-7}	3.5976^{-8}	1.0804^{-8}	2.9356^{-9}	9.2765^{-10}
11,000	1.7190^{-3}	4.8888^{-4}	1.5831^{-4}	4.6027^{-5}	1.4728^{-5}	4.1548^{-6}	1.2834^{-6}	3.4825^{-7}	1.0459^{-7}	2.7999^{-8}	8.6559^{-9}	2.4920^{-9}	8.1893^{-10}
12,000	1.4998^{-3}	4.3462^{-4}	1.4059^{-4}	4.0306^{-5}	1.2652^{-5}	3.4739^{-6}	1.0498^{-6}	2.7931^{-7}	8.4104^{-8}	2.3456^{-8}	7.5834^{-9}	2.2470^{-9}	7.4610^{-10}
13,000	1.3450^{-3}	3.8996^{-4}	1.2479^{-4}	3.5059^{-5}	1.0764^{-5}	2.8884^{-6}	8.6006^{-7}	2.3084^{-7}	7.2137^{-8}	2.0960^{-8}	6.9123^{-8}	2.0645^{-9}	6.8630^{-10}
14,000	1.2182^{-3}	3.5014^{-4}	1.1029^{-4}	3.0299^{-5}	9.1168^{-6}	2.4105^{-6}	7.2314^{-7}	2.0127^{-7}	6.5026^{-8}	1.9256^{-8}	6.3884^{-9}	1.9076^{-4}	6.3034^{-10}
15,000	1.1066^{-3}	3.1367^{-4}	9.7013^{-5}	2.6088^{-5}	7.7393^{-6}	2.0550^{-6}	6.3420^{-7}	1.8261^{-7}	5.9998^{-8}	1.7879^{-8}	5.9261^{-9}	1.7541^{-9}	5.6955^{-10}
16,000	1.0050^{-3}	2.8012^{-4}	8.5045^{-5}	2.2488^{-5}	6.6609^{-6}	1.8111^{-6}	5.7578^{-7}	1.6908^{-7}	5.5912^{-8}	1.6641^{-8}	5.4682^{-9}	1.5882^{-9}	5.0802^{-10}
17,000	9.1142^{-4}	2.4947^{-4}	7.4505^{-5}	1.9551^{-5}	5.8702^{-6}	1.6445^{-6}	5.3343^{-7}	1.5804^{-7}	5.2244^{-8}	1.5408^{-8}	4.9814^{-9}	1.4274^{-9}	4.5856^{-10}
18,000	8.2518^{-4}	2.2190^{-4}	6.5507^{-5}	1.7274^{-5}	5.3057^{-6}	1.5230^{-6}	4.9934^{-7}	1.4816^{-7}	4.8631^{-8}	1.4117^{-8}	4.5093^{-9}	1.2951^{-9}	4.1628^{-10}
19,000	7.4614^{-4}	1.9759^{-4}	5.8098^{-5}	1.5567^{-5}	4.8923^{-6}	1.4265^{-6}	4.6946^{-7}	1.3855^{-7}	4.4907^{-8}	1.2860^{-8}	4.1060^{-9}	1.1772^{-9}	3.7144^{-10}
20,000	6.7445^{-4}	1.7667^{-4}	5.2191^{-5}	1.4288^{-5}	4.5713^{-6}	1.3437^{-6}	4.4135^{-7}	1.2880^{-7}	4.1208^{-8}	1.1752^{-8}	3.7440^{-9}	1.0547^{-9}	3.2852^{-10}
21,000	6.1034^{-4}	1.5912^{-4}	4.7566^{-5}	1.3299^{-5}	4.3052^{-6}	1.2678^{-6}	4.1343^{-7}	1.1900^{-7}	3.7806^{-8}	1.0749^{-8}	3.3798^{-9}	9.4045^{-10}	2.9704^{-10}
22,000	5.5391^{-4}	1.4469^{-4}	4.3943^{-5}	1.2498^{-5}	4.0709^{-6}	1.1944^{-6}	3.8525^{-7}	1.0970^{-7}	3.4723^{-8}	9.7642^{-8}	3.0358^{-9}	8.5465^{-10}	2.7625^{-10}
23,000	5.0503^{-4}	1.3296^{-4}	4.1046^{-5}	1.1817^{-5}	3.8533^{-6}	1.1210^{-6}	3.5758^{-7}	1.0115^{-7}	3.1777^{-8}	8.8303^{-9}	2.7624^{-9}	7.9586^{-10}	2.6130^{-10}
24,000	4.6325^{-4}	1.2344^{-4}	3.8656^{-5}	1.1207^{-5}	3.6424^{-6}	1.0480^{-6}	3.3136^{-7}	9.3095^{-8}	2.8954^{-8}	8.0545^{-9}	2.5666^{-9}	7.5313^{-10}	2.4925^{-10}

Table IV. Entropy, S/R

	10^2	3×10	10	3	1.0	3×10^{-1}	10^{-1}	3×10^{-2}	10^{-2}	3×10^{-3}	10^{-3}	$3 - 10^{-4}$	10^{-4}
T, ° K.							p, Atm.						
1,000	27.77		30.07		32.38		34.68		36.98		39.28		41.59
1,500	30.53		32.83		35.14		37.45		39.78		42.13		44.53
2,000	32.64		35.01		37.46		40.08		43.05		46.77		51.98
3,000	37.13		40.75		47.65		54.15		63.96		72.38		77.81
4,000	43.78		50.71		59.03		65.72		70.69		75.34		80.04
5,000	50.10		57.16		62.98		67.76		72.88		81.43		99.54
6,000	54.16		59.72		64.83		72.44		88.10		102.77		112.86
7,000	56.15		61.80		71.44		87.16		98.64		108.87		123.25
8,000	58.10	62.20	67.60	75.30	82.21	88.32	93.02	98.02	103.40	110.36	118.09	127.96	138.26
9,000	62.06	68.81	75.57	81.93	86.71	91.72	96.73	103.25	110.54	120.14	130.47	144.42	159.52
10,000	67.75	74.59	79.82	84.85	89.51	95.32	101.73	110.40	119.96	132.77	146.81	162.51	174.22
11,000	72.16	77.66	82.18	87.34	92.77	100.05	108.28	119.39	131.79	147.13	159.99	170.94	178.86
12,000	74.70	79.65	84.34	90.26	96.88	105.97	116.29	130.02	143.57	156.54	165.73	174.03	180.99
13,000	76.48	81.54	86.79	93.82	101.90	113.03	125.33	139.68	151.05	160.80	168.28	175.91	182.84
14,000	78.11	83.62	89.68	98.07	107.76	120.74	133.54	145.89	154.80	163.04	170.06	177.85	185.69
15,000	79.81	85.99	93.05	102.94	114.13	127.81	139.26	149.32	156.98	164.78	172.05	181.08	191.38
16,000	81.69	88.71	96.88	108.22	120.28	133.11	142.74	151.44	158.68	166.79	175.22	186.82	199.40
17,000	83.78	91.75	101.07	113.50	125.39	136.63	144.98	153.12	160.56	169.86	180.42	194.07	206.59
18,000	86.09	95.07	105.42	118.23	129.16	138.99	146.69	154.89	163.26	174.55	186.86	200.79	214.15
19,000	88.60	98.58	109.62	122.06	131.83	140.77	148.35	157.28	167.17	180.33	193.21	208.37	225.75
20,000	91.28	102.13	113.39	124.99	133.81	142.36	150.32	160.58	172.13	186.28	200.28	219.22	239.81
21,000	94.06	105.53	116.57	127.21	135.44	144.08	152.91	164.82	177.55	192.87	209.72	231.67	250.53
22,000	96.86	108.62	119.13	128.97	136.99	146.18	156.26	169.65	183.42	201.20	220.64	241.40	256.47
23,000	99.60	111.32	121.20	130.58	138.68	148.85	160.27	174.92	190.39	210.78	229.95	247.20	259.59
24,000	102.17	113.61	122.91	132.02	146.68	152.10	164.77	180.91	198.51	219.51	236.14	250.44	261.48

Table VI. Molecular Weight, M_m, Grams

	10^2	3×10	10	3	1.0	3×10^{-1}	10^{-1}	3×10^{-2}	10^{-2}	3×10^{-3}	10^{-3}	3×10^{-4}	10^{-4}
T, ° K.							p, Atm.						
1,000	44.011		44.011		44.011		44.011		44.011		44.011		44.011
1,500	44.010		44.007		44.003		43.994		43.974		43.932		43.842
2,000	43.939		43.858		43.682		43.313		42.538		40.995		38.144
3,000	41.427		38.987		35.089		30.040		25.073		22.533		22.063
4,000	33.563		28.527		24.104		22.312		22.032		22.003		21.972
5,000	26.752		23.154		22.137		21.996		21.786		20.356		16.699
6,000	23.371		22.160		21.832		20.521		16.909		14.832		14.200
7,000	22.360		21.593		19.249		15.736		14.507		13.821		12.572
8,000	21.640	20.636	19.060	17.000	15.610	14.813	14.432	14.082	13.668	13.029	12.286	11.410	10.618
9,000	19.748	17.682	16.035	14.994	14.523	14.149	13.747	13.131	12.386	11.454	10.574	9.548	8.627
10,000	17.164	15.576	14.809	14.348	13.978	13.448	12.776	11.848	10.914	9.841	8.865	8.030	7.612
11,000	15.516	14.710	14.289	13.849	13.312	12.501	11.584	10.478	9.441	8.425	7.813	7.498	7.392
12,000	14.769	14.265	13.844	13.230	12.458	11.403	10.337	9.168	8.282	7.699	7.467	7.375	7.347
13,000	14.348	13.867	13.311	12.467	11.483	10.271	9.175	8.208	7.695	7.453	7.374	7.341	7.321
14,000	13.994	13.408	12.669	11.603	10.473	9.231	8.307	7.707	7.470	7.374	7.339	7.305	7.241
15,000	13.621	12.870	11.941	10.704	9.526	8.432	7.806	7.492	7.385	7.336	7.294	7.197	7.010
16,000	13.194	12.259	11.166	9.842	8.745	7.926	7.559	7.400	7.341	7.283	7.179	6.951	6.670
17,000	12.714	11.600	10.393	9.091	8.189	7.647	7.441	7.349	7.288	7.165	6.949	6.637	6.397
18,000	12.188	10.926	9.675	8.505	7.837	7.499	7.375	7.295	7.183	6.950	6.660	6.377	6.148
19,000	11.633	10.269	9.058	8.091	7.627	7.414	7.319	7.201	7.001	6.683	6.402	6.118	5.791
20,000	11.068	9.665	8.565	7.816	7.502	7.351	7.243	7.046	6.762	6.429	6.144	5.770	5.391
21,000	10.517	9.140	8.196	7.639	7.419	7.282	7.124	6.836	6.515	6.174	5.824	5.402	5.119
22,000	9.999	8.707	7.933	7.521	7.349	7.187	6.955	6.602	6.268	5.876	5.480	5.143	4.987
23,000	9.531	8.365	7.746	7.434	7.272	7.053	6.748	6.363	5.997	5.555	5.213	5.007	4.932
24,000	9.123	8.103	7.618	7.357	7.173	6.880	6.526	6.111	5.702	5.288	5.054	4.944	4.909

agree with those of Woolley (*5*) for CO_2, as they should. At higher temperatures significant amounts of dissociation products occur, so that meaningful comparisons could no longer be made with pure CO_2.

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