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High-Temperature Properties of Cesium

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ABSTRACT

The experimental program at this Laboratory to measure various thermophysical properties of sodium, potassium, and cesium has been completed. Final reports on two of the alkali metals, sodium and potassium, have been published; and this is the final reporting on cesium. Experimental results are presented for the density and vapor pressure of the liquid and for various saturation and superheat properties of the vapor. A virial equation of state is advanced and is used thermodynamically to derive additional properties of the vapor. For example, enthalpy, entropy, specific volume, and specific heat are tabulated for some 1100 selected vapor states in the temperature range from 1250° to 2550°F and in the pressure range from 0.2 to 34.0 atm.

PROBLEM STATUS

This is the final report on the experimental work with cesium and the final report on this problem. All contracted measurements have been completed except for the surface tension of liquid potassium and cesium. This problem will be considered closed with the issuance of this report.

AUTHORIZATION

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INTRODUCTION

In the development of compact turboelectric systems for space vehicles, the National Aeronautics and Space Administration is sponsoring a property measurement program for the evaluation of several liquid metals as possible working fluids. As an integral part of this program, the U.S. Naval Research Laboratory contracted to measure several thermophysical properties of potassium to 2300°F, sodium to 2500°F, and cesium to 2300°F.

The saturated liquid properties which have been determined experimentally include density, vapor pressure, and specific heat (except for cesium). Saturated and superheated vapor properties, including specific volume, specific heat, enthalpy and entropy, have been derived from experimental pressure-volume-temperature (PVT) studies. All phases of this measurement program have been completed. The final properties of sodium (2) and potassium (1) have been published in companion reports; those of cesium are presented in this report.

EXPERIMENTAL MATERIALS AND METHODS COMMON TO ALL MEASUREMENTS

A number of materials, methods, and techniques were common to many of the experimental measurements. These include the container alloy, the high-pressure furnace system, the temperature measurement, and techniques for purifying and transferring the alkali metals. All are discussed at some length in the companion report on potassium (1), and only a short section to describe the purity of the cesium will be included in this report.

The cesium samples for the density determinations were distilled directly from a small glass still into the pycnometers. However, for the PVT determinations this procedure was impractical, and the metal was distilled and introduced into small columbium alloy capsules for subsequent transfer (1) into the PVT apparatus. Cesium introduced to the distillation retort for the density experiments, the PVT experiments, and one vapor-pressure experiment was a high-purity grade from MSA Research Corporation; and a typical spectrographic analysis of this cesium after one distillation at this Laboratory is presented in Table 1. Although the metal was distilled at low temperature under high vacuum, the still may have introduced some of the metal impurities, particularly silicon and sodium. A high-purity grade of cesium from Dow Chemical Company was used for one vapor-pressure experiment. The distilled sample of this cesium for analysis was lost, and the data reported in Table 1 are for an "as received" sample oxidized on Pyrex glass. It is very probable that silicon, aluminum, and sodium were introduced by reaction with glass under these conditions, and it is recognized that the analysis is unsatisfactory. However, since the volatile and nonvolatile impurities in the MSA metal (and probably the Dow sample, too) are present in concentrations too low to produce a measurable vapor-pressure change, no additional analytical work was performed.

Table 1
Spectrographic Analyses of Cesium at NRL

Metal Impurity	MSAR Sample (ppm)	Dow Chemical Sample (ppm)
Rb	500*	10*
K	<10	1
Na	100*	1000*
Li	Not detected	Not detected
Ca	1 to 10	10 to 100
Ba	Not detected	Not detected
Sr	Not detected	Not detected
Al	Not detected	100 to 1000
B	<1	–
Si	10 to 100	100 to 1000
Mn	Not detected	<1
Fe	Not detected	<1
Mg	<1	<1
Cu	Not detected	10 to 100

*Used standard samples for comparison; figures should be close to quantitative.

EXPERIMENTAL MEASUREMENTS

Pressure-Volume-Temperature Measurements of Cesium

Experimental Superheat Results - The PVT measurements in both the superheat and saturation regions were made with small closed chambers of columbium-1%zirconium using flexible diaphragms as null-detectors. This high-temperature apparatus and the methods employed are described in detail for potassium (1), and only the experimental results for cesium are included in this report.

The twelve PVT experiments for cesium (Table 2) covered a broad range in the superheat region with measured temperatures extending from 1305° to 2570°F and pressures from 1.1 to 33.2 atm. For each experimental point in this table, pressure and temperature were directly observed, and the specific volume was computed from the weight of cesium added to the chamber. The nominal volume of all chambers was 57 cc, and the weights of the cesium samples varied from 0.1173 g in experiment 30 to 2.4205 g in experiment 37.

To obtain the data at each equilibrium point in Table 2, multiple readings of temperature and pressure were made at 5 to 10 min intervals until successive readings showed a temperature drift of 0.07°F/min or less and a temperature difference across the chamber less than 2°F, and generally less than 1°F. In the measurement of pressures with the diaphragm device, the excellent reproducibility obtained during the other alkali metal measurements (1,2) continued for cesium. Measurements for each experiment (except

Table 2
Pressure-Volume-Temperature Measurements of
Cesium Superheat Region

Temp. (°F)	Pressure (abs atm)	Specific Volume (cu ft/lb)
Experiment 27		
1785.3	6.989	1.5321
1953.8	7.697	1.5358
2095.4	8.255	1.5390
2201.6	8.679	1.5415
2319.7	9.122	1.5443
2425.8	9.528	1.5469
2558.6	10.010	1.5502
2520.4	9.873	1.5492
2366.6	9.310	1.5454
2282.5	8.914	1.5429
2163.2	8.542	1.5406
2044.8	8.050	1.5378
1884.5	7.414	1.5342
1826.2	7.167	1.5329
1724.3	6.736	1.5307
1741.1	6.808	1.5311
Experiment 28		
1649.0	4.849	2.0879
1703.2	5.024	2.0894
1822.0	5.378	2.0929
1612.7	4.745	2.0868
1737.2	5.138	2.0904
1854.8	5.480	2.0939
1978.8	5.862	2.0977
2081.0	6.145	2.1009
2178.4	6.419	2.1040
2275.0	6.697	2.1071
2379.1	6.971	2.1105
2485.2	7.258	2.1141
2565.6	7.488	2.1169
2523.2	7.370	2.1154
2441.6	7.143	2.1126
2329.0	6.848	2.1089
2221.4	6.552	2.1054
2116.9	6.252	2.1020
2038.2	6.033	2.0995
1919.5	5.699	2.0959
1766.5	5.223	2.0913
1624.3	4.793	2.0871
1647.5	4.859	2.0878

Temp. (°F)	Pressure (abs atm)	Specific Volume (cu ft/lb)
Experiment 30		
1341.5	1.1489	8.0140
1460.8	1.2438	8.0266
1581.4	1.3384	8.0397
1712.7	1.4337	8.0543
1777.9	1.4772	8.0617
1901.5	1.5616	8.0760
1996.8	1.6275	8.0873
2094.8	1.6958	8.0991
2212.0	1.7752	8.1135
2314.1	1.8425	8.1263
2424.6	1.9155	8.1405
2571.4	2.0137	8.1597
2518.7	1.9786	8.1528
2465.0	1.9420	8.1457
2369.2	1.8827	8.1333
2257.5	1.8069	8.1192
2139.4	1.7288	8.1045
2029.2	1.6527	8.0912
1948.5	1.5970	8.0815
1847.8	1.5262	8.0697
1649.8	1.3853	8.0473
1515.0	1.2853	8.0325
1391.1	1.1901	8.0192
1305.0	1.1227	8.0103
Experiment 31		
1909.1	9.615	1.1606
2037.4	10.327	1.1628
2143.7	10.881	1.1646
2236.7	11.375	1.1663
2363.0	12.033	1.1686
2462.0	12.515	1.1704
2568.2	13.044	1.1724
2518.6	12.800	1.1715
2415.6	12.290	1.1695
2305.0	11.722	1.1675
2186.5	11.115	1.1654
2081.2	10.558	1.1635
1959.5	9.890	1.1614
1827.0	9.158	1.1592

(Table continues)

Table 2 (cont'd)
Pressure-Volume-Temperature Measurements of
Cesium Superheat Region

Temp. (°F)	Pressure (abs atm)	Specific Volume (cu ft/lb)
Experiment 32		
1846.9	9.367	1.1468
1944.1	9.909	1.1484
2058.5	10.549	1.1504
2175.7	11.176	1.1524
2291.4	11.781	1.1545
2396.2	12.331	1.1564
2497.5	12.866	1.1582
2558.8	13.169	1.1594
2452.0	12.613	1.1574
2363.8	12.182	1.1558
2238.3	11.523	1.1535
2140.1	10.993	1.1518
1973.9	10.082	1.1489
1894.9	9.643	1.1476
1830.5	9.283	1.1465
Experiment 34		
2068.0	15.241	.75273
2174.2	16.156	.75394
2184.2	16.245	.75405
2294.0	17.171	.75533
2387.8	17.938	.75644
2483.7	18.723	.75760
2543.1	19.212	.75833
2516.5	18.990	.75800
2437.0	18.360	.75703
2347.6	17.622	.75596
2247.9	16.797	.75479
2119.4	15.700	.75331
2024.9	14.880	.75225
Experiment 35		
2126.4	17.659	.65739
2223.6	18.612	.65836
2329.0	19.636	.65944
2492.6	21.162	.66115
2447.0	20.727	.66067
2401.2	20.307	.66019
2290.3	19.263	.65904
2172.1	18.102	.65784
2061.6	17.013	.65675
Experiment 36		
2300.6	26.112	.45493
2397.6	27.503	.45563

Temp. (°F)	Pressure (abs atm)	Specific Volume (cu ft/lb)
Experiment 37		
2405.0	31.319	.38763
2512.7	33.112	.38830
2519.7	33.223	.38835
2487.5	32.688	.38815
2445.9	31.988	.38789
2355.1	30.470	.38733
2315.1	29.779	.38709
Experiment 38		
1578.9	3.3677	3.0146
1684.9	3.560	3.0190
1801.0	3.805	3.0239
1921.5	4.067	3.0292
2015.7	4.237	3.0334
2136.8	4.462	3.0389
2230.5	4.649	3.0432
2348.2	4.871	3.0488
2437.7	5.041	3.0531
2523.8	5.191	3.0574
2479.4	5.116	3.0552
2314.0	4.816	3.0472
2193.8	4.579	3.0415
2076.7	4.359	3.0361
1970.3	4.162	3.0314
1864.1	3.958	3.0267
1777.8	3.768	3.0230
1640.8	3.488	3.0172
1521.8	3.2316	3.0123
Experiment 39		
2183.7	21.758	.52803
2320.2	23.438	.52915
2423.6	24.691	.53001
2540.7	26.064	.53101
2487.0	25.440	.53055
2379.4	24.173	.52964
2260.0	22.717	.52865
2222.7	22.257	.52835
2149.9	21.356	.52776
Experiment 40		
2355.6	27.309	.44574
2469.1	28.975	.44654
2527.9	29.820	.44696
2414.6	28.214	.44615
2309.9	26.695	.44542
2263.9	25.998	.44510
2228.8	25.491	.44486

experiment 36) were made over a minimum of one full cycle from the normal boiling point to about 2550°F, and equilibrium pressures were generally reproduced in the superheat region to better than ±0.1 psi (0.0068 atm) before, during, and after cycling.

Specific Volumes of Saturated Vapor - Specific volumes of several saturated vapor states (Table 3) were observed over the temperature range from 1251° to 2269°F. The measurements were made in the course of the PVT studies, and each point represents an intersection of the saturated and superheated vapor curves for one of the twelve PVT experiments. In the previous experiments with potassium (1) and sodium (2), observed pressures in the temperature region near the intersection of the saturated and superheat curves were always abnormally low. This phenomenon was also observed for cesium and was particularly noticeable in the low-weight, low-pressure experiments. The several factors which may contribute to this lowering phenomenon include the existence of dual states, elevation of the boiling point by nonvolatile impurities, and the retention of condensed alkali metal on the walls of the chamber by adsorption and capillarity effects. These factors are discussed in detail in the potassium report (1).

Table 3
Specific Volume of Saturated Cesium Vapor

Experiment Number	Temperature (°F)	Specific Volume (cu ft/lb)
30	1250.9	8.005
38	1484.3	3.011
28	1588.2	2.086
27	1687.3	1.530
31	1784.8	1.159
32	1789.9	1.146
34	1955.8	0.7515
35	2014.2	0.6561
39	2114.6	0.5275
36	2187.0	0.4542
40	2197.4	0.4448
37	2269.4	0.3869

The saturated specific volume for each PVT experiment was obtained by a short extrapolation of the superheated vapor curve to the true saturation curve as defined by the vapor-pressure equation (Eq. (1)). Although this extrapolation procedure tended to minimize any error in the saturated specific volume resulting from the depression phenomenon, it is believed that specific volumes obtained from the virial equation (Eq. (13)) and the vapor-pressure equation (Eq. (1)) will be of higher reliability than those observed at the intersection points (Table 3). Even so, corresponding values computed from the virial equation show an average deviation of only ±0.43% from the observed values.

Discussion of Superheat Results - The sources and magnitudes of errors in the PVT measurements are discussed in detail for potassium (1). Many of these were common to the PVT studies of the three alkali metals, and only those which are specific to the cesium work are included here.

Although the procedures developed with potassium and sodium for degassing and closing of null-point apparatuses were very effective, the possibility of inadvertently trapping gas in a chamber still existed. Each cesium apparatus was checked for gas at the conclusion of an experiment by opening the chamber to an evacuated manometer. Gas pressures as low as 0.01 psi were detectable in this manner, and no gas was detected in any of the twelve cesium chambers.

In previous studies with sodium and potassium, two apparatuses (57 cc and 113 cc) with significantly different surface-to-volume ratios were used for each metal. A comparison for each metal of the compressibility factors measured with the two apparatuses provided evidence that adsorption of the alkali metal on the container surfaces was insignificant. Hence, for cesium the standard 57-cc apparatus was used for all experiments.

The possible significance of any thermal ionization in potassium and sodium vapors is discussed in the compa on reports (1,2). It was shown that the degree of ionization to be expected in metal vapor may be obtained from its ionization potential (3). A maximum figure of 10^{-6} was estimated for cesium vapor at 2500°F; this leads to the conclusion that the degree of ionization is several magnitudes too low to produce a measurable increase in pressure.

The results of PVT measurements are generally reported in the form of compressibility factors since these, in one form or another, are employed directly in the thermodynamic reduction of data. It is therefore desirable to express experimental error in terms of these factors. If we take into account all known uncertainties, the percent probable error in the observed compressibility factor ranges from ±0.25 to ±0.28.

Experimental Saturation Pressures - Saturation pressures of cesium from 1.00 atm at 1236°F to 33.53 atm at 2346°F were measured with two separate PVT apparatuses using in each a large excess of the alkali metal. Redistilled cesium metal from two sources (MSA Research Corporation and Dow Chemical Company) was used for these determinations, and the results are presented in the "Vapor-Pressure Experiments" section of Table 4. Pressures up to 24.7 atm were also measured in the course of twelve PVT experiments and are presented in the second section of the same table. It has been shown that the saturation pressures observed for each experiment near the intersection of the saturation and superheat curves were below corresponding values on the true saturation curve. This lowering of the vapor pressure can be satisfactorily explained (1), and observed pressures in these regions are not included in the table.

The vapor-pressure data in Table 4 are presented graphically in Fig. 1. It is evident from a larger scale plot of this figure that $\log p$ versus $1/T$ for cesium is not linear. The data can be effectively fitted for the full temperature range (normal boiling point to 2346°F) with one three-term equation of the Kirchhoff type. Three vapor-pressure equations

$$\log p = 5.87303 - \frac{7040.7}{T} - 0.53290 \log T \qquad (1)$$

$$\log p = 5.87275 - \frac{7039.4}{T} - 0.53290 \log T \qquad (2)$$

$$\log p = 5.79014 - \frac{7020.7}{T} - 0.51090 \log T \qquad (3)$$

for cesium were obtained by least-squares (computer) treatments of the data. Equation (1) was derived from a treatment using all the observed vapor pressures above the normal boiling point, Eq. (2) was derived from the data of the two vapor-pressure experiments in the first section of Table 4, and Eq. (3) was derived from twenty points selected at equal intervals of $1/T$ from a smoothed plot of $\log p$ versus $1/T$ for all the data. The average deviation of all the observed vapor pressures in Table 4 from corresponding values computed with any one of the three equations is ±0.35%. The three equations are, therefore, equivalent; and the thermodynamic quantities in this report are arbitrarily based on Eq. (1). The normal boiling point as obtained from Eqs. (1) and (3) is 1236.0°F (668.9°C) and from Eq. (2) is 1235.8°F (668.8°C).

Table 4
Saturated Vapor Pressures of Cesium

Vapor-Pressure Experiments

Temp. (°F)	Pressure (abs atm)	Temp. (°F)	Pressure (abs atm)
(MSA Research Corporation Sample)			
1238.0	1.0169	2276.1	29.384
1346.6	1.7426	2218.7	26.195
1428.4	2.5054	2169.5	23.632
1535.0	3.829	2140.1	22.178
1618.3	5.179	2067.7	18.833
1699.8	6.825	2027.3	17.108
1785.9	8.918	1943.3	13.885
1885.2	11.857	1857.1	11.013
1977.8	15.108	1759.2	8.263
2100.8	20.264	1677.6	6.354
2183.5	24.276	1588.6	4.672
2243.1	27.471	1491.5	3.2325
2291.0	30.241	1440.0	2.6191
2345.5	33.530	1318.6	1.5122
2316.6	31.738	1214.5	0.8849
(Dow Chemical Company Sample)			
1353.4	1.7991	2247.2	27.730
1505.6	3.438	2177.2	24.015
1654.4	5.905	2130.5	21.720
1806.6	9.543	2034.2	17.392
1948.3	14.068	1888.4	12.039
2091.8	19.909	1761.6	8.396
2201.0	25.215	1601.8	4.925
2322.0	32.067	1431.5	2.5592
2287.9	30.071	1245.5	1.0629

Vapor Pressures from PVT Experiments

Temp. (°F)	Pressure (abs atm)	Temp. (°F)	Pressure (abs atm)
1277.0	1.2421	1284.0	1.2672
1440.6	2.6328	1449.7	2.7180
		1332.1	1.6123
1509.5	3.465	1197.4	0.8110
1377.5	1.9968	1342.0	1.7030
1322.8	1.5498	1480.4	3.1044
1229.6	0.9662	1619.1	5.234
1214.5	0.8794	1546.9	4.026
1361.1	1.8492	1420.4	2.4223
1495.8	3.2740	1312.5	1.4970
1391.6	2.1516	1264.0	1.1811
1510.7	3.503	1404.9	2.2671
1606.9	5.000	1547.7	4.045
1447.6	2.7089	1689.7	6.636
1340.5	1.6879	1262.4	1.1450
1251.9	1.0936	1387.9	2.0987
1403.3	2.2469	1560.5	4.226
1553.9	4.135	1685.6	6.532
1688.5	6.607	1827.6	10.072
1822.1	9.998	1747.5	7.947
1974.5	15.034	1642.6	5.654
1285.4	1.2836	1489.5	3.1996
1436.1	2.5700	1363.5	1.8702
1573.6	4.415	1532.3	3.786
1708.0	7.006	1930.4	13.395
1852.8	10.844	1755.8	8.158
1985.7	15.495	1474.3	3.0178
2131.9	21.796	1281.9	1.2674
2194.4	24.725	1333.3	1.6746
2080.8	19.346	1465.2	2.9205
1923.7	13.164	1480.8	3.1151
1776.1	8.683	1373.5	1.9549
1651.3	5.821	1252.8	1.0887
1514.5	3.533		

The current vapor-pressure results are compared to those of three previous investigators in Fig. 2. Vapor pressures of cesium above the normal boiling point have been observed by Achener (4) over the temperature range from 893° to 1600°F, by Tepper et al. (5) over the temperature range from 852° to 1941°F, and by Bonilla et al. (6) over the temperature range from 754° to 1700°F. In Fig. 2 the NRL results have been arbitrarily taken as standard, and the percent deviation of the vapor pressure of each other investigator is plotted as a function of temperature. It is noteworthy that all data show good agreement, the deviation between any two sets being generally accounted for by the combined experimental errors.

A third-law calculation of the heat of vaporization to the monomer (at a temperature of absolute zero) can be made from saturation pressure data with Eq. (4) if other thermal quantities are known.

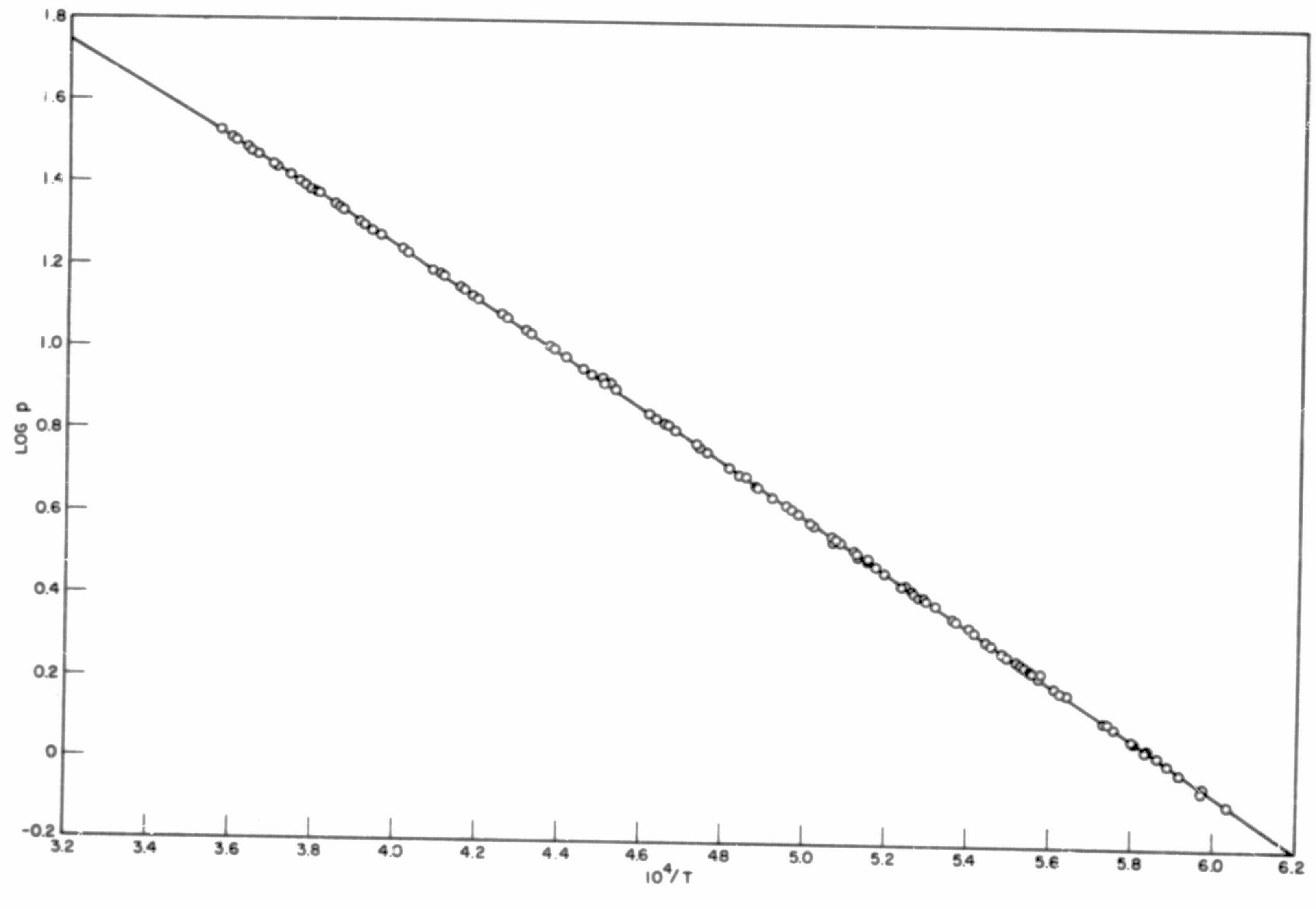


Fig. 1 - Vapor pressure of cesium as a function of the reciprocal absolute temperature

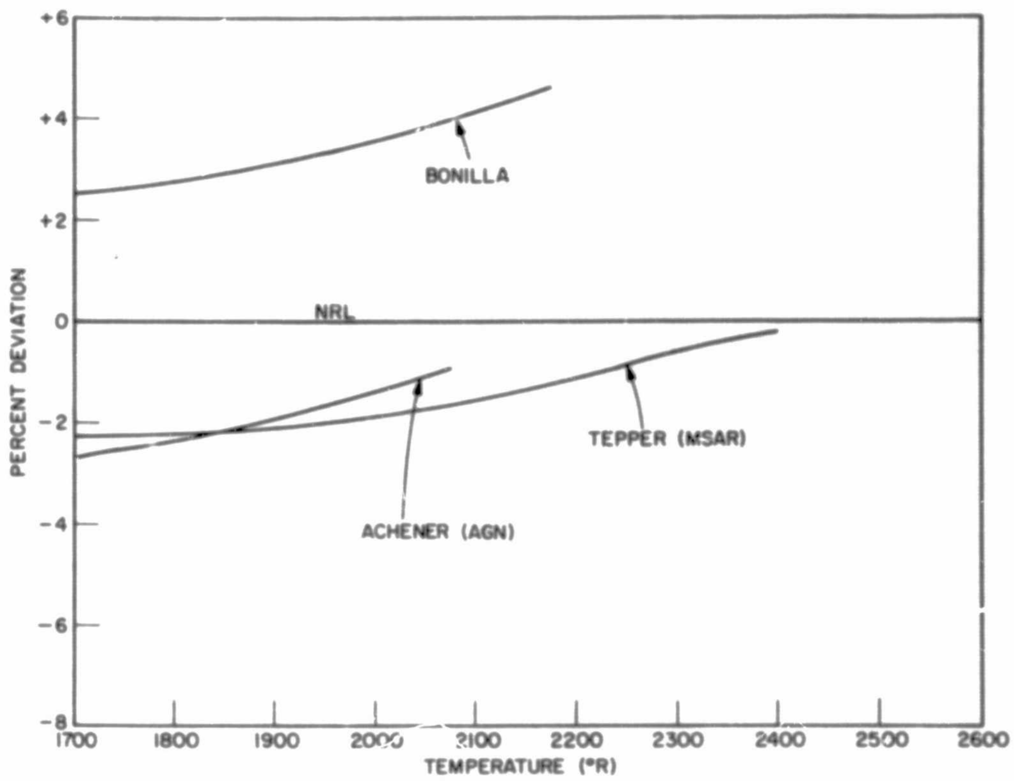


Fig. 2 - Comparison of vapor-pressure data of cesium by several investigators using the NRL data as standard

$$(\Delta h_0^o)_v = -\frac{RT}{M_1}\left(\frac{2B}{\tilde{V}} + \frac{3C}{2\tilde{V}^2} + \frac{4D}{3\tilde{V}^3} + \frac{5E}{4\tilde{V}^4} + \ln p_s - \ln \frac{p_s \tilde{V}}{RT}\right) - T\left[\left(\frac{f^o - h_0^o}{T}\right)\right]_l^g \qquad (4)$$

The virial coefficients for cesium, which appear in the imperfection term, are developed later in this report. The free-energy functions for monomeric cesium gas can be obtained from Evans et al. (7), and corresponding functions for the liquid may be derived from heat-capacity results. Three recent measurements for cesium were found in the literature and pertinent data related to each are summarized in Table 5. It will be noted that there is significant disagreement in the magnitude of the specific heat and the shape of its temperature curve. Since there was no apparent reason to select one set of specific heat data over another, it was decided to base the selection of both c_p^l and $(\Delta h_0^o)_v$ on a third-law analysis of the NRL vapor-pressure results. Normally a third-law analysis is used to check the internal consistency of vapor-pressure measurements. In this case, the analysis was used to obtain the most consistent values for the specific heat of the liquid and the vaporization constant.

Table 5
Summary of Heat Capacity Measurements of Liquid Cesium

Investigator and Reference	Temperature Range (°F)	Heat Capacity Equation
Achener (4)	152 to 1656	$c_p^l = 0.08543 - 9.605 \times 10^{-5} t + 5.985 \times 10^{-8} t^2$
Tepper (5)	620 to 1770	$c_p^l = 0.0545$
Lemmon (8)	570 to 2100	$c_p^l = 0.0600$

In two preliminary analyses, the value of $(\Delta h_0^o)_v$ was computed over the temperature range from 1215° to 2346°F from the vapor-pressure data in Table 4, using in one case a constant liquid heat capacity of 0.0545 and in the other 0.0600 Btu/lb-°F. It will be noted that these are the heat capacities reported by Tepper et al. (5) and Lemmon et al. (8), respectively. (Thermal data at lower temperatures are also required in these analyses, and the data selected are presented in the section entitled "Enthalpy and Entropy of Liquid Cesium.") When the vaporization quantities were plotted against temperature, those computed with a liquid specific-heat value of 0.0600 exhibited a negative slope, and those computed with a value of 0.0545 exhibited a positive slope. It followed that a constant value, intermediate between those chosen, would lead to a nearly constant value of $(\Delta h_0^o)_v$ for all saturation results. By a trial and error procedure this value for the specific heat of the liquid was found to be 0.5683 Btu/lb-°F. The vaporization heats (converted to cgs units) computed from this specific-heat value are plotted as a function of temperature in Fig. 3. The value of $(\Delta h_0^o)_v$ obtained by this procedure is 18.62 mean kcal/mole. Although the agreement is perhaps fortuitous, this is practically the same as the value of 18.66 selected by Hultgren et al. (9), which was obtained by a third-law treatment of several vapor-pressure measurements at lower temperatures.

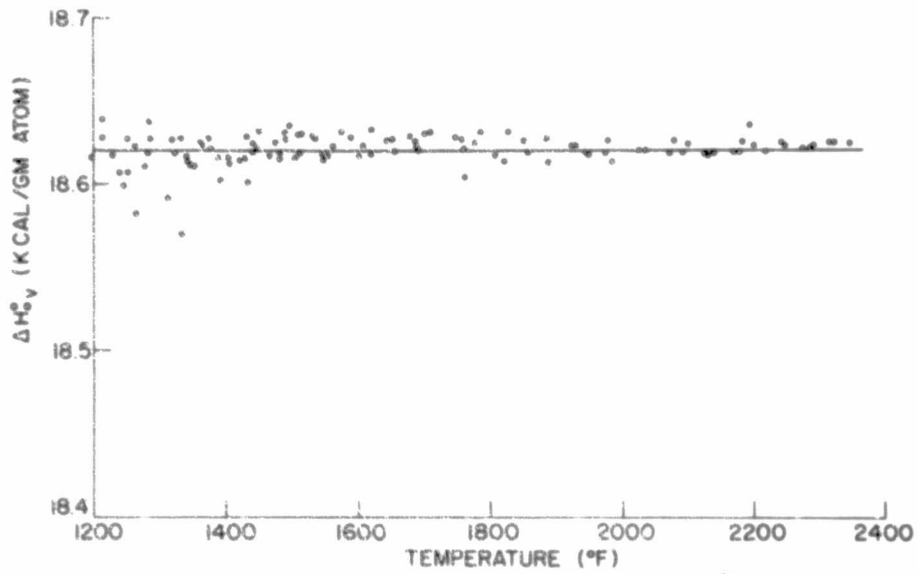


Fig. 3 - Heat of vaporization of monomeric cesium at absolute zero as computed from observed vapor-pressure data

Discussion of Saturation Pressures - Saturation results are presented in Table 4 for cesium samples from two sources, MSA Research Corporation and Dow Chemical Company. Spectrographic analyses of these materials are presented in Table 1. It will be noted that while the impurities differ considerably both as to type and magnitude, the vapor pressures observed are in good agreement. The average deviation of Eq. (1) from the data for the MSAR metal is ±0.25% and for the Dow metal is ±0.32%. This agreement confirms that the two samples are effectively equivalent and that the impurities present do not significantly affect the reported vapor pressures.

The measurement of saturation pressures directly with a diaphragm detector is new to the high-temperature field. The relative merits of the apparatus and the uncertainties to be expected in the various measurement parameters were discussed in the potassium report (1). If all known sources of error in the saturation measurements are considered, the probable error in the reported vapor pressure for cesium at 1 atm is ±0.67% and at 34 atm is ±0.49%.

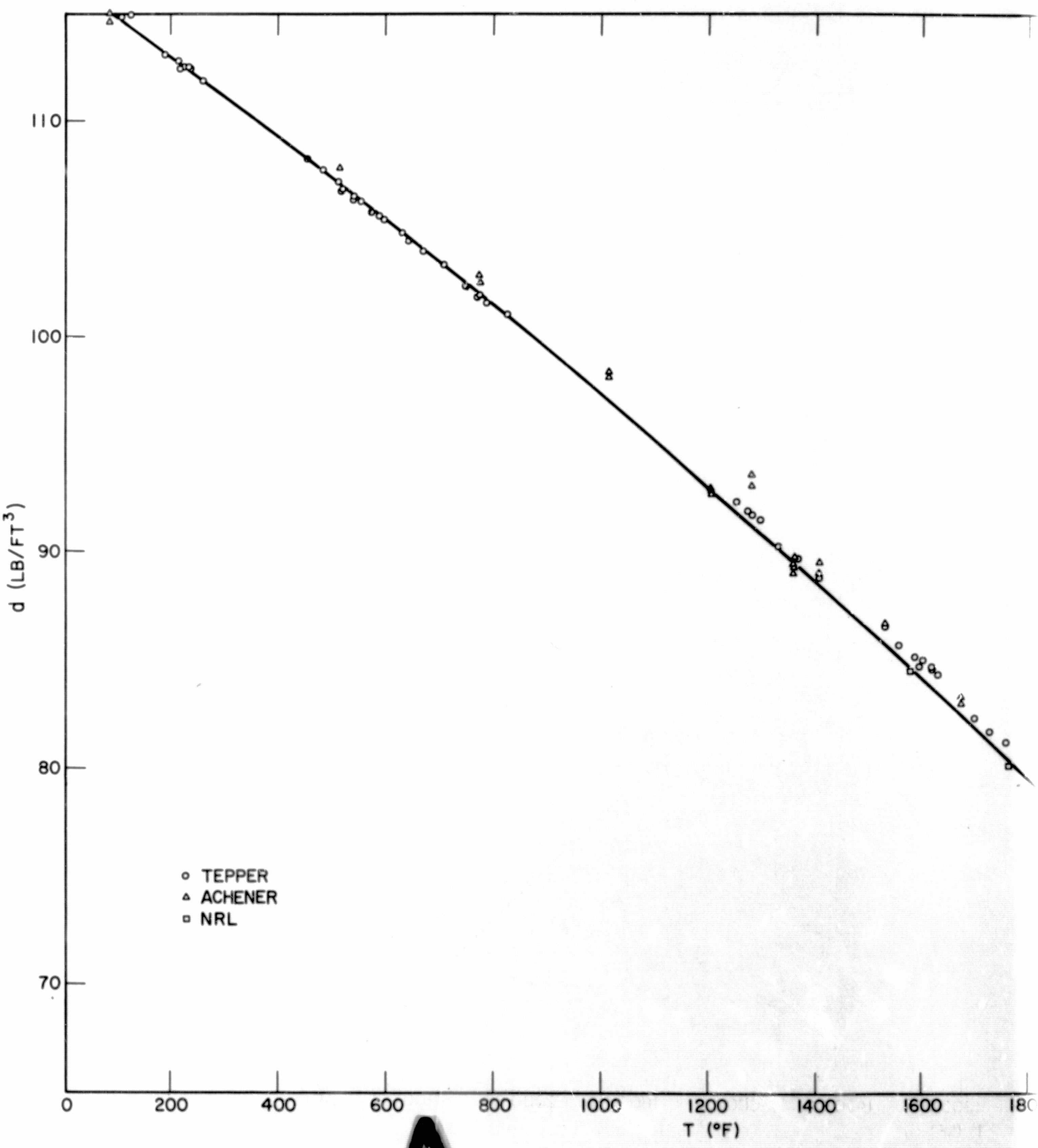


Fig. 4 - Density of liquid cesium

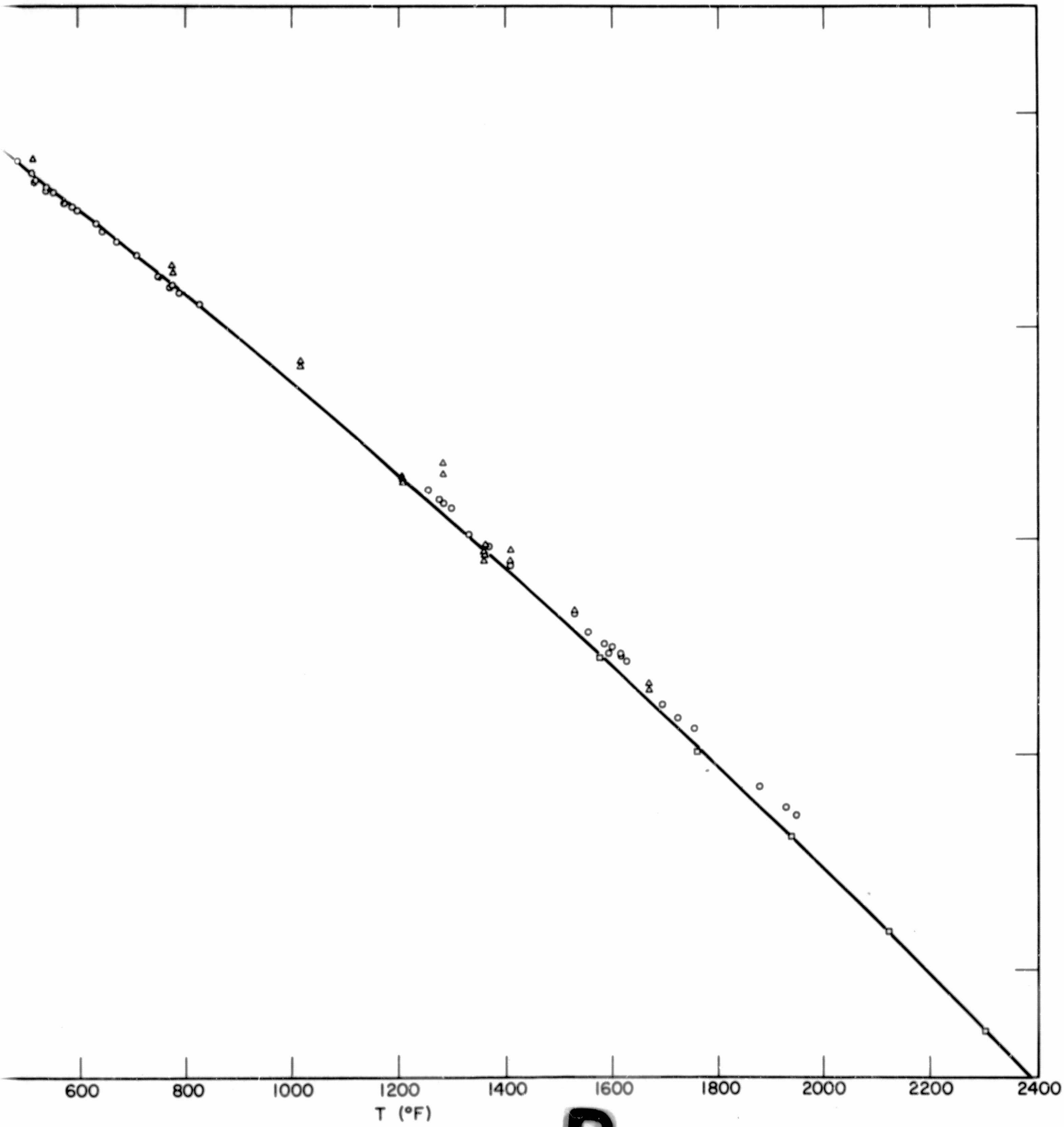


Fig. 4 - Density of liquid cesium

B

Density Measurements of Liquid Cesium

The density of liquid cesium was determined with columbium-1%zirconium pycnometers of 30 cc nominal volume by the method described for potassium (1). Measured densities over the temperature range from 1577.0° to 2303.8°F are reported in Table 6 and presented graphically in Fig. 4 along with those of two other investigators. The uncertainties to be expected in the various parameters of the NRL density measurements are discussed in the potassium report (1). If all known sources are taken into account, the probable error of the reported densities range from ±0.25% at 1577°F to ±0.30% at 2304°F.

Table 6
Density of Liquid Cesium

Temperature (°F)	Density (lb/cu ft)
1577.0	84.563
1762.2	80.209
1939.9	76.267
2122.5	71.845
2303.8	67.189

The recommended density equation for liquid cesium from the melting point to 2300°F is

$$d^l = 124.181 - 1.5970\times 10^{-2}\, T - 1.6855\times 10^{-6}\, T^2. \tag{5}$$

This equation was derived by fitting the best curve to the density determinations of Achener (4), Tepper et al. (5), and NRL (Table 6). These three independent sets of measurements are summarized in Table 7. For each investigation, the temperature range, the general method, and the average deviation of the observed densities from those calculated with Eq. (5) are presented. The three sets of measurements show fair internal consistency over the full temperature range, and it is believed that Eq. (5) will give density values which are accurate to ±0.6% between the melting point and 2300°F.

Table 7
Summary of Density Measurements

Investigator	Method	Temp. Range (°F)	% Average Deviation $\left[\frac{\text{Obs.} - \text{Calc. (Eq. (5))}}{\text{Calc.}}\right]$
Achener	Dilatometric (pycnometers)	(83 to 1671)	±0.70
Tepper	Dilatometric	(105 to 1950)	±0.35
NRL	Dilatometric (pycnometers)	(1577 to 2304)	±0.14

SUMMARY OF FUNDAMENTAL PROPERTIES USED IN THE THERMODYNAMIC TREATMENTS

Density of Liquid Cesium

The density of the condensed phase was required to compute the enthalpy of vaporization from the Clapeyron equation and was obtained from Eq. (5).

Enthalpy and Entropy of Monomeric Cesium Vapor

The monomeric gas properties, together with the values selected for the enthalpy of sublimation, largely determine the absolute accuracy of the superheat properties tabulated in Appendixes A and B. The equations for the enthalpy and entropy of the gas were derived directly from the work of Evans et al. (7) and are based on their standard properties over the temperature range from 0° to 3100°F and on the enthalpy of vaporization to 0°R (18.62 mean kcal/mole) as derived in this report. The equations for the monomeric gas at 1 atm (relative to the solid crystal at 0°R) are

$$(h^g)^o = 252.18 + 0.037361\ T + 2480\ e^{-31,290/T} \tag{6}$$

$$(s^g)^o = 0.037361 \ln T + 0.080604 + 0.371\ e^{-28,598/T}. \tag{7}$$

Specific Heat at Constant Pressure of Monomeric Cesium Vapor

The specific heat of monomeric cesium vapor at constant pressure largely determines the absolute accuracy of the values reported for the specific heat of the equilibrium vapor in Appendix B. The equation for the specific heat of the monomeric gas was derived from the work of Evans et al. (7) and is based on their computed properties over the temperature range from 0° to 2800°F. The relation for the monomeric gas at 1 atm is

$$(c_p^g)^o = 0.037361 + 1.3099\ e^{-25,663/T}. \tag{8}$$

Enthalpy and Entropy of Liquid Cesium

The tabulated thermodynamic properties in this report are based on the properties of the monomeric gas at 1 atm, but comparison calculations were made using the properties of the saturated liquid as a starting point. The absolute properties of the liquid (relative to the solid at 0°R) were computed with

$$h_s^l = -2.6969 + 0.05683\ T \tag{9}$$

$$T > 1030\,°\mathrm{R}$$

$$s_s^l = 0.05683 \ln T - 0.19387. \tag{10}$$

$$T > 1030\,°\mathrm{R}$$

In order to obtain these equations, a knowledge of the specific heat of the liquid was required. In a previous section of this report, a constant value of 0.05683 Btu/lb-°F was shown to give the greatest degree of internal consistency in third-law calculations. A constant value has also been reported in two recent measurements; Tepper et al. (5) reported a value of 0.0546, and Lemmon et al. (8) reported 0.0600. The third-law value of 0.05683 is intermediate between the two published values and was used in deriving Eqs. (9) and (10).

These two equations are based on the absolute properties of solid cesium at 77.0°F by Hultgren et al. (9). Although only a short solidus region remains above this temperature, the change in the properties for this region and the required enthalpy of fusion were taken from the work of Lemmon et al. (8). There is an anomaly (5,8) in the heat-content curve of the liquid in the temperature range to 570°F. The enthalpy change for Eq. (9) in this region was obtained from Lemmon (8). On the other hand, the entropy equation ignores the anomaly in heat content and was derived by assuming the specific heat of the liquid to be constant for the whole liquid range.

Saturation Pressure of Liquid Cesium

Three equivalent vapor-pressure equations (Eqs. (1), (2), and (3)) were derived from least-squares correlations. All thermodynamic quantities in this report are arbitrarily based on Eq. (1).

Enthalpy and Entropy of Vaporization of Cesium

Heats of vaporization were calculated with

$$\Delta h_v = Jp_s \left[\frac{16{,}211.8}{T} - 0.53290\right](v_s^g - v_s^l) \tag{11}$$

which was derived by a differentiation of Eq. (1) and subsequent substitution into the Clapeyron equation. A value of v_s^l at each temperature was obtained from Eq. (5) and a value of v_s^g from the virial equation of state (Eq. (13)).

The heats of vaporization so obtained from the Clapeyron equation are presented graphically in Fig. 5 and are compared with values reported by Achener (4). The four results by Achener were measured directly by noting the heat required to vaporize a given mass of the liquid. The agreement is good; three of Achener's points are within 1% of the corresponding NRL values and the fourth is within 3% of the NRL value.

The entropy of vaporization at each saturation point was obtained by dividing the appropriate enthalpy change by the absolute temperature.

THERMODYNAMIC TREATMENT OF PVT AND ASSOCIATED PROPERTIES

The imperfections which occur in the alkali metal vapors and the various treatments of these imperfections in the reduction of PVT data are discussed at some length in the companion reports (1,2). Quasi-chemical analyses of the PVT data for sodium and potassium have shown that dimeric and, perhaps, tetrameric molecules are present in the metal vapors. From a similar analysis of the cesium system, which is discussed later in this report, it is believed that the major imperfection in cesium also stems from the existence of higher-molecular-weight species.

For a strongly associating gas the important properties (enthalpy, entropy, and specific heat) may be reduced from PVT data by the use of either of two methods, the virial or the quasi-chemical. The two methods were shown for sodium and potassium to be effectively equivalent, so only the virial method was used in the reduction of the cesium data. The virial equation of state for cesium with coefficients through the fifth virial was obtained from raw PVT data and used to compute enthalpies, entropies, specific volumes, and specific heats of the vapor.

The thermodynamic properties of cesium by the virial method were computed along constant temperature lines. The starting point for a particular property could have been

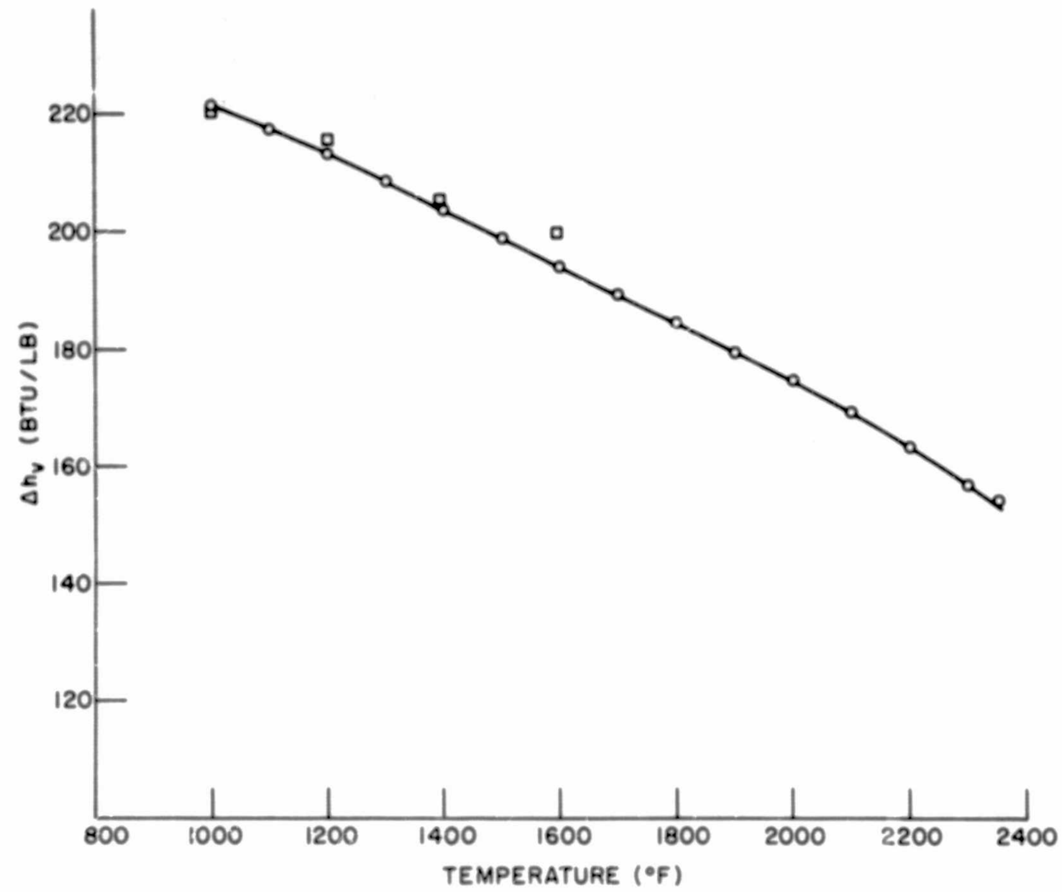


Fig. 5 - Enthalpy of vaporization of cesium
⊡ Achener, ⊙ NRL

the absolute value of that property for either the saturated liquid or the monomeric gas. Therefore, two computational paths exist for obtaining each absolute property in the superheat region. The properties were computed along both paths, and the results are compared in this report.

Virial Coefficients of Cesium

The virial equation of state in its volume expansion form,

$$\frac{p\tilde{V}}{RT} = 1 + \frac{B}{\tilde{V}} + \frac{C}{\tilde{V}^2} + \frac{D}{\tilde{V}^3} + \frac{E}{\tilde{V}^4} + \ldots \quad (12)$$

was chosen for the analyses of all three alkali metal systems.

The PVT data for cesium were more precise than those obtained for either sodium or potassium, and the adjustment procedure (1,2) used to facilitate the graphical reduction of the sodium and potassium data was not required. The coefficients, however, were still derived graphically from the PVT data by plotting functions along constant temperature lines. As a first step, $(z - 1)\tilde{V}$ was plotted as a function of $1/\tilde{V}$ for isotherms at 50-degree intervals between 2050° and 2550°F, and preliminary second virial coefficients were obtained as the $\lim (z - 1)\tilde{V}$ as $1/\tilde{V} \to 0$. The final coefficient at each temperature was obtained by adjusting the preliminary value to give the best internal consistency between the low- and high-pressure results as determined from a plot of $[(z - 1)\tilde{V} - B]\tilde{V}$ versus $1/\tilde{V}$. A final plot of $(z - 1)\tilde{V}$ versus $1/\tilde{V}$ is illustrated in Fig. 6 for the isotherm at 2400°F. In the intermediate temperature range from 1600° to 2050°F, final second virial coefficients were taken as the $\lim (z - 1)\tilde{V}$ as $1/\tilde{V} \to 0$. The coefficients for the full measured range from 1550° to 2550°F may be represented by a simple exponential relationship (Eq. (13)).

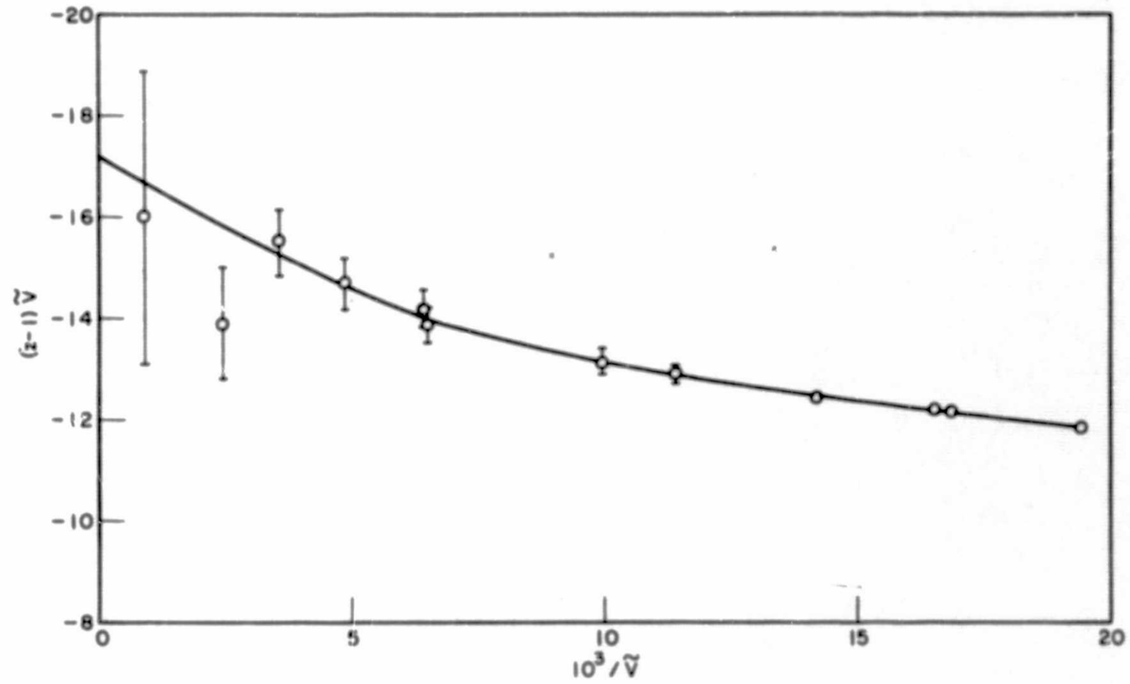


Fig. 6 - Plot of $(z - 1)\tilde{V}$ versus $1/\tilde{V}$ for cesium at 2400°F (vertical line for each point represents probable error)

From a preliminary analysis in which third and fourth virial coefficients were derived in the temperature range from 2050° to 2550°F, it was apparent that a fifth virial would be required to precisely fit all the data along any given isotherm. Only a rough value of this higher virial was required, and this was obtained mathematically. With preliminary values for the third virial, $\{[(z - 1)\tilde{V} - B]\tilde{V}^2 - C\tilde{V}\}$ was plotted versus $1/\tilde{V}$ for several higher temperature isotherms, and the value of 600,000 for E was selected from the average apparent slope of the curves at higher pressures.

Final third and fourth virial coefficients in the same temperature range between 2050° and 2550°F were obtained by plotting the revised quantity $\{[(z - 1)\tilde{V} - B]\tilde{V} - E/\tilde{V}^2\}$ versus $1/\tilde{V}$ for isotherms at 50-degree intervals. This is illustrated in Fig. 7 for the isotherm at 2400°F. From the best linear curve for each isotherm the third virial was obtained as the intercept and the fourth as the slope. The fourth virial coefficient may be represented for the full temperature range as a simple first-degree exponential equation in $1/T$ (Eq. (13)). Additional third virial coefficients were obtained in the intermediate temperature range from 1550° to 2050°F by computing the average value of $\{[(z - 1)\tilde{V} - B]\tilde{V} - D/\tilde{V} - E/\tilde{V}^2\}$ for the higher pressure points on each isotherm. The third virial coefficient for the full range from 1550° to 2550°F may be represented by a second-degree exponential equation (Eq. (13)).

Experimental PVT data were also obtained in a lower temperature range between 1550° and 1275°F, but the number of experimental points along an isotherm was insufficient to permit one to obtain reliable virial coefficients by the graphical method. Consequently, before the virial equation of state for cesium was acceptable for calculations below 1550°F, it was necessary to determine its fit to the observed lower temperature data. At temperatures and pressures corresponding to the observed low-temperature states, compressibility factors were calculated and compared to the observed values. The fit of the virial equation of state to the lower temperature data was found to be equivalent to that obtained at higher temperatures.

Virial Equation of State of Cesium

The virial equation of state of cesium with coefficients through the fifth virial is

$$\frac{p\tilde{V}}{RT} = 1 + \frac{B}{\tilde{V}} + \frac{C}{\tilde{V}^2} + \frac{D}{\tilde{V}^3} + \frac{E}{\tilde{V}^4} + \ldots \quad (13)$$

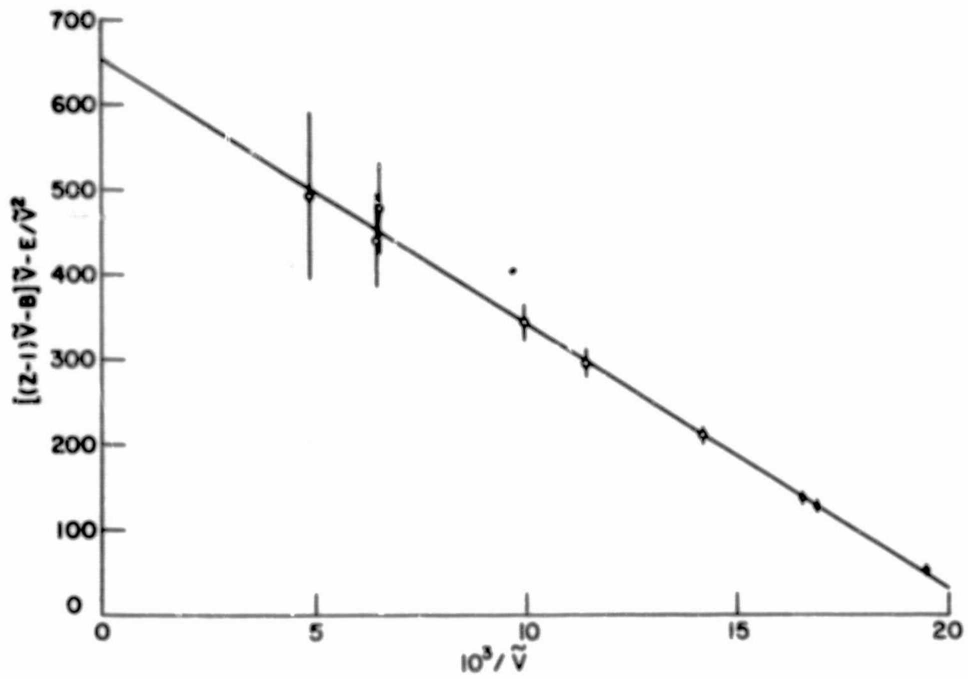


Fig. 7 - Plot of $\left\{\left[(z - 1)\tilde{V} - B\right]\tilde{V} - E/\tilde{V}^2\right\}$ versus $1/\tilde{V}$ for cesium at 2400°F (vertical line for each point represents probable error)

where

$$\log |B| = -3.6200 + 4000.0/T + \log T$$

$$B < 0$$

$$\log C = 3.3551 - 5331.5/T + 10.825\times10^6/T^2$$

$$C > 0$$

$$\log |D| = 4.1856 + 880/T$$

$$D < 0$$

$$E = +600{,}000 .$$

The degree to which the virial equation was fitted to the measured data is shown graphically in Fig. 8, where compressibility isotherms generated with Eq. (13) are compared to experimental compressibilities at 100-degree intervals from 1350° to 2550°F. The degree of fit can also be shown mathematically. For example, all the observed specific-volume data in Table 2 (or compressibility factors derived from that data) may be calculated from the virial equation with an average deviation of only ±0.15%. It is significant that this deviation is of a magnitude predicted by random and systematic errors in the null-point measurements.

Thermodynamic Properties of Cesium by the Virial Method (Monomeric Gas Path)

Expressions for the thermodynamic properties in terms of the second and third virial coefficients were derived by Hirschfelder et al. (10). By the same method, similar equations were derived to include the fourth and fifth virial coefficients. These equations which were used to compute the thermodynamic properties of cesium vapor (Appendixes A and B) are presented below.

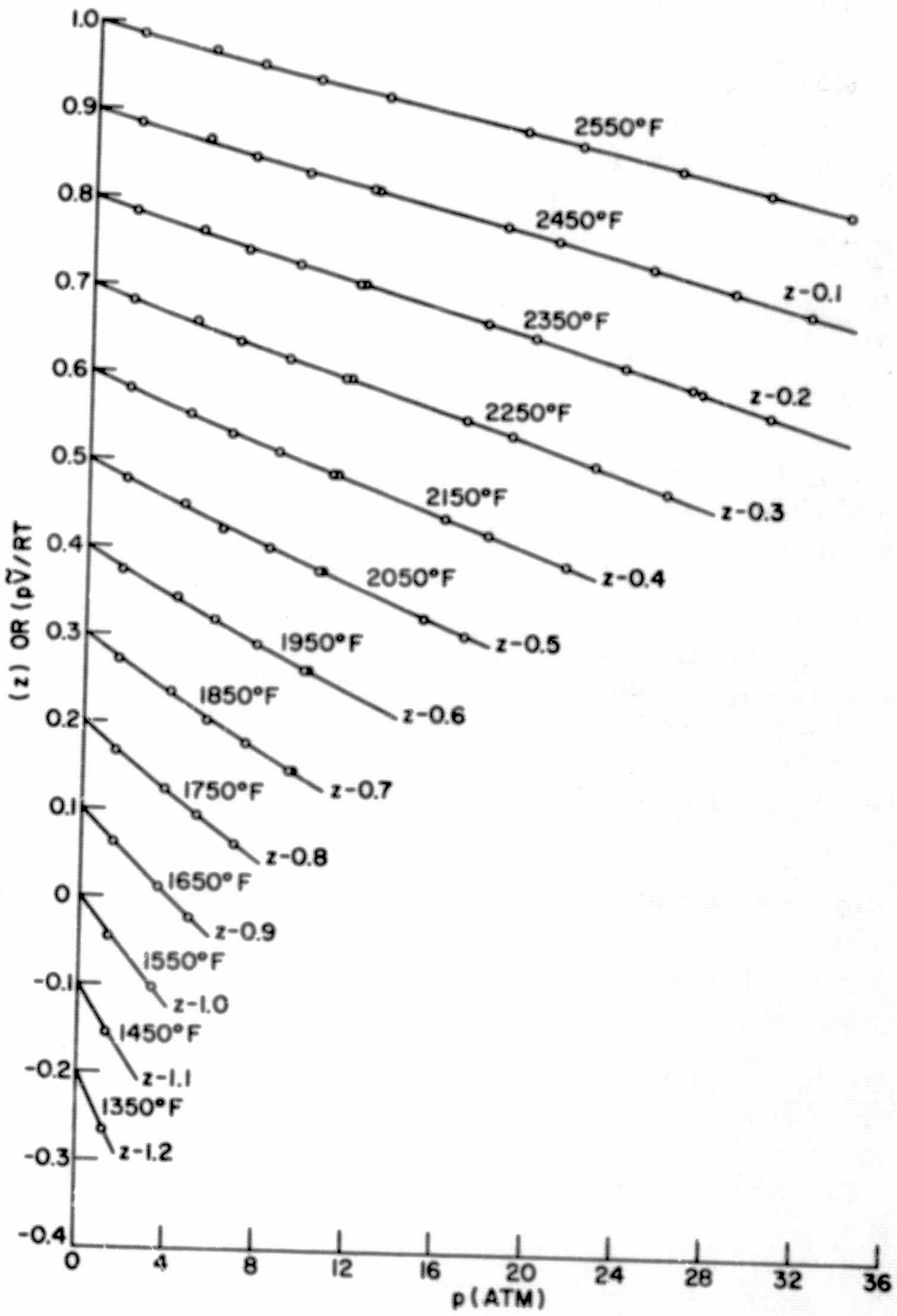


Fig. 8 - Compressibility of cesium vapor at several temperatures

<u>Enthalpy, Entropy, and Specific Heat of Saturated and Superheated Vapor</u> - These properties at all vapor states were computed along isotherms using the following equations:

$$h_i^g = (h^g)^o + \frac{RT}{M_1}\left\{\frac{1}{\tilde{V}}\left[B - T\left(\frac{dB}{dT}\right)\right] + \frac{1}{\tilde{V}^2}\left[C - \frac{T}{2}\left(\frac{dC}{dT}\right)\right] + \frac{1}{\tilde{V}^3}\left[D - \frac{T}{3}\left(\frac{dD}{dT}\right)\right] + \frac{1}{\tilde{V}^4}\left[E - \frac{T}{4}\left(\frac{dE}{dT}\right)\right]\right\} \quad (14)$$

$$s_i^g = (s^g)^o - \frac{R}{M_1}\left\{\ln p - \ln\frac{p\tilde{V}}{RT} + \frac{B}{\tilde{V}} + \frac{T}{\tilde{V}}\left(\frac{dB}{dT}\right) + \frac{C}{2\tilde{V}^2} + \frac{T}{2\tilde{V}^2}\left(\frac{dC}{dT}\right) + \frac{D}{3\tilde{V}^3} + \frac{T}{3\tilde{V}^3}\left(\frac{dD}{dT}\right) + \frac{E}{4\tilde{V}^4} + \frac{T}{4\tilde{V}^4}\left(\frac{dE}{dT}\right)\right\} \quad (15)$$

$$(c_p^g)_i = (c_p^g)^o - \frac{R}{M_1} + \frac{R}{M_1}\left\{\frac{\left[1 + \frac{1}{\tilde{V}}\left(B + T\frac{dB}{dT}\right) + \frac{1}{\tilde{V}^2}\left(C + T\frac{dC}{dT}\right) + \frac{1}{\tilde{V}^3}\left(D + T\frac{dD}{dT}\right) + \frac{1}{\tilde{V}^4}\left(E + T\frac{dE}{dT}\right)\right]^2}{\left[1 + 2\frac{B}{\tilde{V}} + 3\frac{C}{\tilde{V}^2} + 4\frac{D}{\tilde{V}^3} + 5\frac{E}{\tilde{V}^4}\right]}\right\}$$

$$- \frac{RT}{\tilde{V}M_1}\left\{\left(T\frac{d^2B}{dT^2} + 2\frac{dB}{dT}\right) + \frac{1}{2\tilde{V}}\left(T\frac{d^2C}{dT^2} + 2\frac{dC}{dT}\right) + \frac{1}{3\tilde{V}^2}\left(T\frac{d^2D}{dT^2} + 2\frac{dD}{dT}\right) + \frac{1}{4\tilde{V}^3}\left(T\frac{d^2E}{dT^2} + 2\frac{dE}{dT}\right)\right\}. \quad (16)$$

Specific Volume of Saturated and Superheated Vapor - This property at all the vapor states in Appendixes A and B was computed from the virial equation of state (Eq. (13)) by a trial and error solution.

Enthalpy and Entropy of the Condensed Phase - These properties of the saturated liquid (Appendix A) at each temperature were obtained by subtracting the enthalpy or entropy of vaporization from the corresponding properties of the saturated vapor.

Thermodynamic Properties of Cesium by the Virial Method (Liquid Path)

Expressions for the thermodynamic quantities with the properties of the condensed liquid as a base were derived directly from those in the preceding section. These new equations together with a procedural outline of the methods of calculation are presented below.

Enthalpy, Entropy, and Specific Heat of the Saturated Vapor - The enthalpy or entropy of the saturated vapor at a given temperature was obtained by adding the enthalpy or entropy of vaporization to the corresponding property of the saturated liquid. The specific heat at saturation was obtained by numerically evaluating at 50-degree intervals the differential

$$(c_p^g)_s = \left[\left(\frac{\partial h}{\partial T}\right)_p^g\right]_s = \left[\left(\frac{\Delta h}{\Delta T}\right)_p^g\right]_s. \quad (17)$$

Enthalpy, Entropy, and Specific Heat of Superheated Vapor - These properties in the superheat region were computed along constant temperature lines with each saturation state as a starting point. The general equations in virial form are

$$h_i^g = h_s^g - \frac{RT}{M_1}\left[\frac{1}{\tilde{V}}\left(B - \frac{TdB}{dT}\right) + \frac{1}{\tilde{V}^2}\left(C - \frac{TdC}{2dT}\right) + \frac{1}{\tilde{V}^3}\left(D - \frac{TdD}{3dT}\right) + \frac{1}{\tilde{V}^4}\left(E - \frac{TdE}{4dT}\right)\right]_{\tilde{V}_i}^{\tilde{V}_s} \quad (18)$$

$$s_i^g = s_s^g + \frac{R}{M_1}\left[\ln p - \ln\frac{p\tilde{V}}{RT} + \frac{B}{\tilde{V}} + \frac{TdB}{\tilde{V}dT} + \frac{C}{2\tilde{V}^2} + \frac{T}{2\tilde{V}^2}\frac{dC}{dT} + \frac{D}{3\tilde{V}^3} + \frac{T}{3\tilde{V}^3}\frac{dD}{dT} + \frac{E}{4\tilde{V}^4} + \frac{T}{4\tilde{V}^4}\frac{dE}{dT}\right]_{\tilde{V}_i}^{\tilde{V}_s} \quad (19)$$

$$(c_p^g)_i = (c_p^g)_s - \frac{R}{M_1}\left[\frac{\left\{1 + \frac{1}{\tilde{V}}\left(B + T\frac{dB}{dT}\right) + \frac{1}{\tilde{V}^2}\left(C + T\frac{dC}{dT}\right) + \frac{1}{\tilde{V}^3}\left(D + T\frac{dD}{dT}\right) + \frac{1}{\tilde{V}^4}\left(E + T\frac{dE}{dT}\right)\right\}^2}{\left\{1 + \frac{2B}{\tilde{V}} + \frac{3C}{\tilde{V}^2} + \frac{4D}{\tilde{V}^3} + \frac{5E}{\tilde{V}^4}\right\}}\right]_{\tilde{V}_i}^{\tilde{V}_s}$$

$$+ \frac{RT}{\tilde{V}M_1}\left[\left(T\frac{d^2B}{dT^2} + 2\frac{dB}{dT}\right) + \frac{1}{2\tilde{V}}\left(T\frac{d^2C}{dT^2} + 2\frac{dC}{dT}\right) + \frac{1}{3\tilde{V}^2}\left(T\frac{d^2D}{dT^2} + 2\frac{dD}{dT}\right) + \frac{1}{4\tilde{V}^3}\left(T\frac{d^2E}{dT^2} + 2\frac{dE}{dT}\right)\right]_{\tilde{V}_i}^{\tilde{V}_s}. \quad (20)$$

A Comparison of the Monomeric Gas Path and the Liquid Path for Thermodynamic Calculations

The thermodynamic properties of cesium were computed along constant temperature lines. The starting point for a particular property could have been the absolute value of that property for either the saturated liquid or the monomeric gas at 1 atm. The three properties (enthalpy, entropy, and specific heat) of the superheated vapor were computed by both paths, and values at selected states are compared in Table 8. In the temperature range from 1250° to 2350°F, absolute enthalpies in the superheat region, based on enthalpies of the saturated liquid, were 0.2 to 6.9 Btu/lb (approximately 0.1 to 2.0%) lower than corresponding values based on the monomeric gas enthalpies. Likewise, entropies by the liquid path were 0 to 0.0025 Btu/lb-°F (approximately 0 to 0.8%) lower, and specific heats differed by 5.3 to 31%.

The small divergence of the absolute enthalpies (Table 8) as computed along the two paths over the temperature range from 1250° to 2050°F suggests that the selected value of either the specific heat of the liquid or its temperature coefficient is slightly in error. It will also be noted that the enthalpy of the superheated vapor at a given pressure, if computed from the liquid base, exhibits an abnormal change in slope at temperatures above 2100°F. This is reflected in the specific heat values which at 2250°F are 16 to 31% lower and at 2350°F are 7 to 15% higher than those computed by the monomeric gas path. Part of this apparent error at higher temperatures in the enthalpy as computed along the liquid path may have resulted from errors in various quantities along the two computational paths. It is believed that a large part must also be attributed either to errors in the enthalpy of vaporization resulting from small inconsistencies in the virial equation of state or to error generated by the rather arbitrary selection and extrapolation of the liquid specific heat.

Engineering design calculations put prime emphasis on the change in enthalpy or entropy when moving from one state to another rather than on their absolute values; therefore, the choice of path is of minor importance for both these properties. However, the specific heat of the vapor would be expected to be more accurate if computed from the monomeric gas, since this path is independent of vaporization quantities and does not require a knowledge of the specific heat of the liquid. Therefore, the monomeric gas path has been chosen to compute all the tabular properties in this report.

DISCUSSION OF QUASI-CHEMICAL EQUATION OF STATE AND THE COMPOSITION OF CESIUM VAPOR

The PVT results for sodium and potassium were satisfactorily interpreted by a quasi-chemical approach based on the assumption that each metal vapor is an ideal mixture of monomeric, dimeric, and tetrameric species. Although this model of the physical

Table 8
Comparison of Monomeric Gas and Liquid Path Calculations

Temp. (°F)	Pressure (atm)	Monomeric Gas Path			Liquid Path		
		h^g	s^g	c_p^g	h^g	s^g	c_p^g
1250	1.0	306.4	0.3541	0.0653	306.2	0.3540	0.0619
	0.2	314.1	0.3818	0.0435	313.9	0.3817	0.0400
1450	2.0	312.4	0.3479	0.0645	311.4	0.3473	0.0602
	1.0	317.9	0.3605	0.0514	316.9	0.3600	0.0471
	0.2	322.4	0.3864	0.0402	321.4	0.3859	0.0360
1650	5.0	313.5	0.3361	0.0719	311.7	0.3353	0.0685
	1.0	327.4	0.3653	0.0447	325.6	0.3644	0.0413
	0.2	330.3	0.3904	0.0388	328.5	0.3895	0.0354
1850	10.0	315.0	0.3280	0.0748	312.5	0.3268	0.0707
	5.0	326.4	0.3420	0.0582	323.9	0.3409	0.0541
	1.0	336.0	0.3692	0.0416	333.6	0.3681	0.0375
	0.2	338.0	0.3939	0.0382	335.5	0.3928	0.0342
2050	18.0	315.9	0.3212	0.0756	312.2	0.3196	0.0657
	15.0	320.6	0.3252	0.0718	316.8	0.3237	0.0619
	10.0	328.7	0.3336	0.0623	324.9	0.3321	0.0524
	5.0	337.2	0.3465	0.0503	333.4	0.3449	0.0404
	1.0	344.2	0.3726	0.0400	340.4	0.3710	0.0301
	0.2	345.6	0.3970	0.0379	341.8	0.3955	0.0280
2250	25.0	321.2	0.3193	0.0742	314.9	0.3170	0.0625
	20.0	327.6	0.3244	0.0684	321.3	0.3220	0.0567
	15.0	333.9	0.3303	0.0616	327.6	0.3280	0.0500
	10.0	340.2	0.3381	0.0541	333.9	0.3357	0.0424
	5.0	346.8	0.3501	0.0459	340.4	0.3478	0.0343
	1.0	352.1	0.3756	0.0392	345.8	0.3732	0.0275
	0.2	353.2	0.3999	0.0378	346.9	0.3976	0.0261
2350	33.0	318.9	0.3153	0.0768	312.0	0.3129	0.0824
	25.0	328.4	0.3219	0.0697	321.6	0.3196	0.0753
	20.0	334.2	0.3268	0.0638	327.4	0.3243	0.0694
	15.0	339.8	0.3325	0.0577	333.0	0.3300	0.0632
	10.0	345.5	0.3400	0.0512	338.7	0.3375	0.0568
	5.0	351.3	0.3518	0.0445	344.5	0.3493	0.0500
	1.0	356.0	0.3770	0.0389	349.2	0.3746	0.0445
	0.2	357.0	0.4013	0.0378	350.1	0.3988	0.0433

state of the vapor was believed to be the most probable, other models including several imperfect mixtures of two or more molecular species were shown to be equally effective in comparable quasi-chemical treatments. It was concluded from this study of molecular models (2) that all close-approach imperfections may be properly treated from a thermodynamic standpoint as either interactions of the van der Waals type or as molecular associations. It then follows that the molecular species present in a particular metal vapor cannot be positively identified from an analysis of its PVT data. Even so, a quasi-chemical study of the cesium PVT data was made in the hope that this analysis, combined with those previously made for sodium and potassium, would provide some evidence as to the actual molecular state of an alkali metal vapor.

For the quasi-chemical analysis of an alkali metal vapor, the association of the vapor into ideal molecular compounds can be represented by a series of independent equilibria of the type, $n\ X_1 \rightleftharpoons X_n$. For such a system, the apparent equilibrium constant of dimerization k_2' (when all association is taken to be dimerization), can be expressed as a power series (11)

$$k_2' = k_2 + 2k_3 p + 3k_4 p^2 + 2k_3^2 p^3 - 2k_2 k_4 p^3 + \ldots \qquad (21)$$

in terms of the pressure and the true equilibrium constants of the association reactions. The apparent dimerization constants at any given temperature may be readily computed from the raw PVT data, and the relationship of these apparent constants to pressure may be used to predict the compounds present in the vapor.

The apparent dimerization constant k_2' for cesium was computed for each experimental point at a temperature of 2400°F, and these apparent constants are shown plotted against p^2 in Fig. 9. Similar plots for the sodium and potassium systems were effectively linear and predicted the existence of the tetramer as the higher-molecular-weight species. It will be noted that cesium appears to require an even higher degree of imperfection to satisfy the quasi-chemical picture. This additional imperfection may be in the form of associations higher than the tetramer or in gas imperfections of the interaction type. In any event, a vapor model involving a perfect mixture of monomeric, dimeric, and tetrameric species is not satisfactory for cesium.

It has been mentioned that in the companion reports (1,2) several molecular models provided satisfactory quasi-chemical fits to the PVT data for the sodium and potassium systems. The principal model tested, other than the perfect mixture of monomeric, dimeric, and tetrameric species, was an imperfect mixture of monomeric and dimeric species. The cesium results were likewise analyzed with this model. A simplified van der Waals equation was again chosen to treat the gas imperfections (interactions not

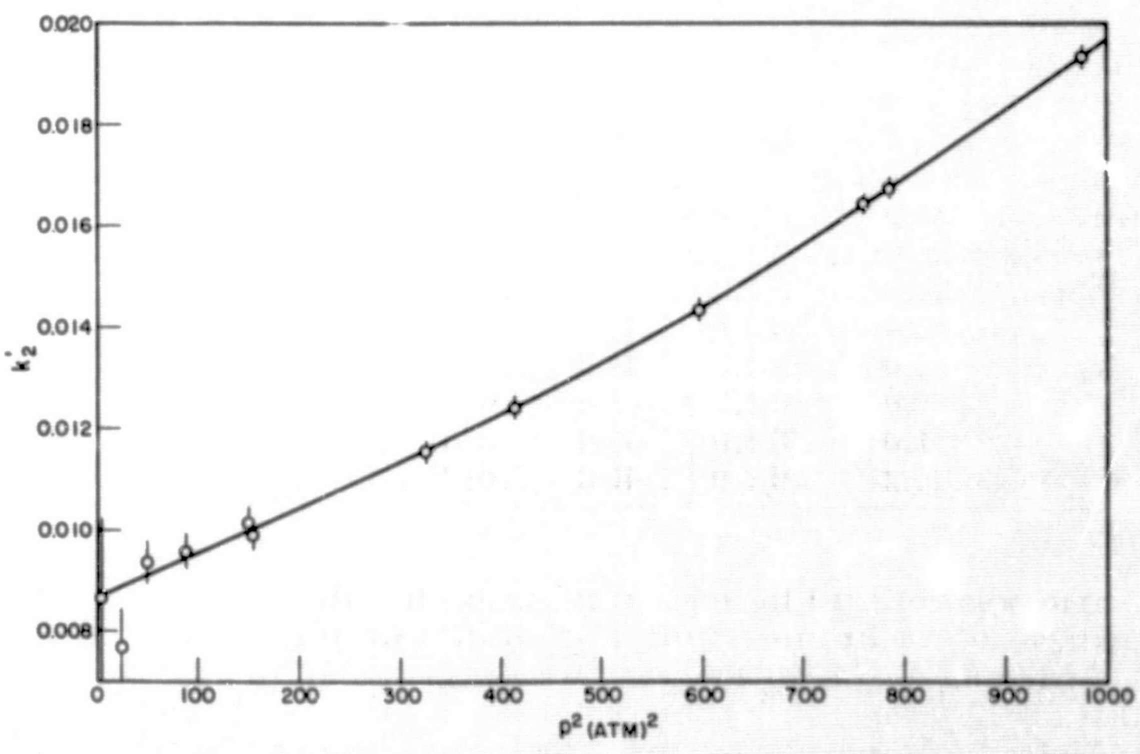


Fig. 9 - Plot of k_2' versus p^2 for cesium at 2400°F (vertical line for each point represents probable error)

leading to stable molecules). This van der Waals relationship

$$\left(p + \frac{\tilde{a}_1}{\tilde{V}^2}\right)\left(\tilde{V} - \tilde{b}_1\right) = \frac{M_1 RT}{M_a} \tag{22}$$

was developed by Vukalovich et al. (12) for an associating gas. For this equation the excluded volume coefficient $\tilde{b}_1$ was reliably estimated (1) from the condensed volume of the vapor, but the pressure coefficient $\tilde{a}_1$ had to be obtained empirically. This latter coefficient was assumed to be constant and was evaluated by selecting a value for which the corresponding dimerization constants were independent of pressure along isotherms for the full temperature range. The object was to see whether or not this physical picture of the vapor would correlate with the PVT results, and no attempt was made to determine exact equational fits. It was shown, however, that an effective equation of state could be obtained in terms of Eq. (22) and the relationship $k_2 = A + B/T$ for the corresponding dimerization reaction.

A direct implication of this analysis is that other physical models of the vapor, including an imperfect mixture of monomeric, dimeric, and tetrameric species, would also satisfy the cesium PVT data. It is believed that any one of these quasi-chemical equations of state, if it had been developed, would have been equivalent to the virial form and could also have been used to derive the thermodynamic properties of the vapor. Quasi-chemical equations are more satisfactory for extrapolation of the thermodynamic quantities beyond the measured range of the PVT data. If an extrapolation of the cesium data becomes important in the future, a second equation of state will be developed.

This study, unfortunately, gives no definitive insight into the composition of cesium vapor. The magnitudes of the pressure coefficients in the van der Waals equation, which are required to correlate the data if one assumes either an imprefect mixture of monomeric and dimeric species, or an imperfect mixture of monomeric, dimeric, and trimeric species, do appear to be high. This suggests that the correct model is either an imperfect mixture of monomeric, dimeric, and tetrameric species or a similar mixture of near perfect gases with a fourth species of molecular weight higher than the tetramer.

Equilibrium Constants of the Dimerization Reaction in Cesium Vapor - Although the higher-molecular-weight reactions in cesium vapor could not be identified, it was still possible to obtain reliable dimerization constants. These were obtained by plotting k_2' versus p^2 for isotherms at 50-degree intervals from 1750° to 2550°F and taking the $\lim k_2'$ for each isotherm as $p^2 \to 0$. This procedure is illustrated in Fig. 10 for isotherms at 100-degree intervals over the temperature range. It will be noted upon close inspection of this figure that the low-pressure experiments for cesium accurately define the intercepts. Thus, the magnitudes of the dimerization constants are not influenced by our lack of knowledge regarding the imperfections present in the vapor.

The observed dimerization constants are shown graphically in Fig. 11. They are well represented by the equation

$$\log k_2 = -3.6561 + \frac{4570}{T}. \tag{23}$$

Enthalpy of the Dimeric Reaction in Cesium Vapor - The enthalpy of dimerization was obtained with the van't Hoff equation

$$\frac{d \ln k_2}{dT} = \frac{\Delta H_2^o}{RT^2} \tag{24}$$

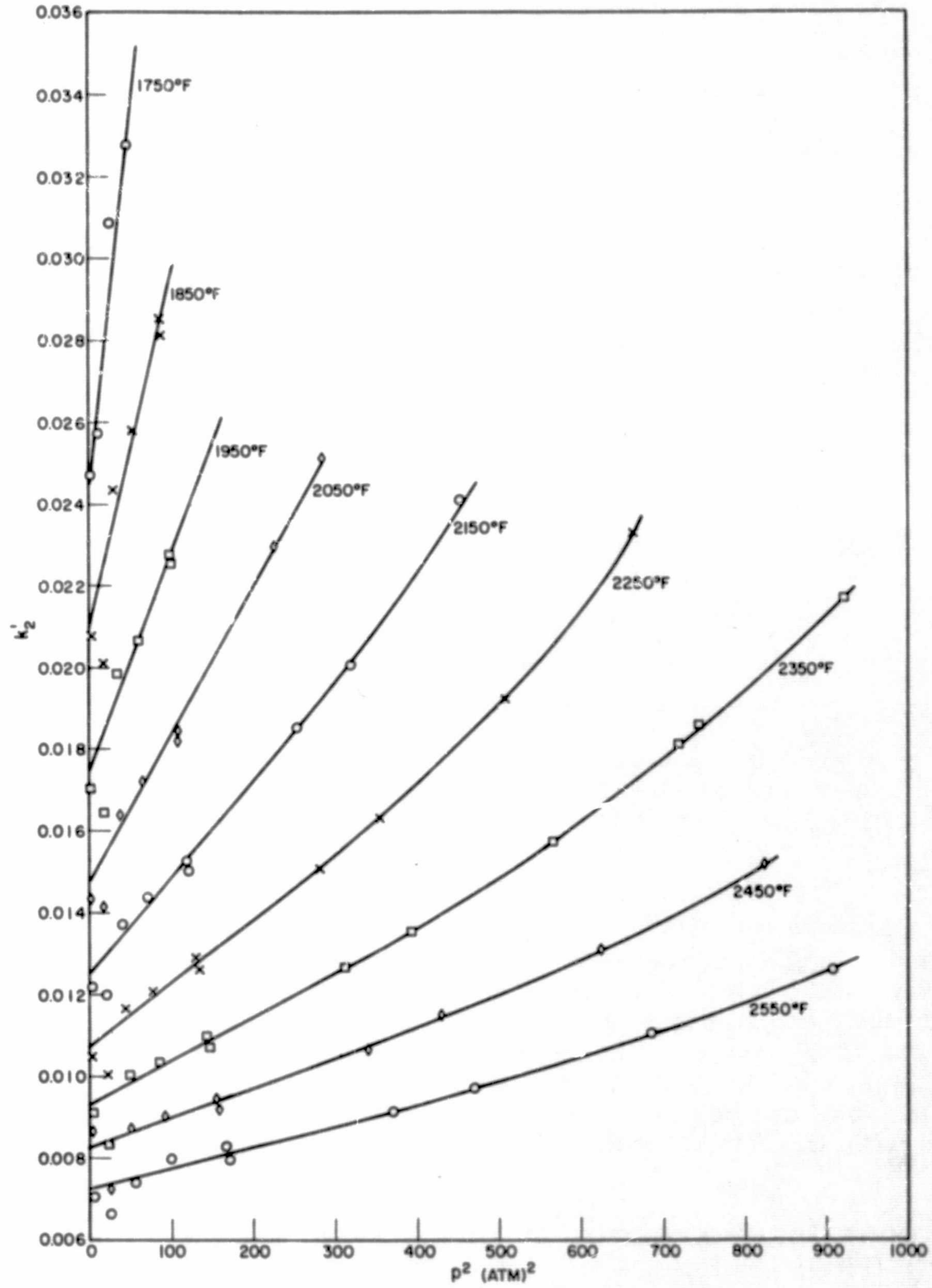


Fig. 10 - Apparent dimerization constants of cesium vapor at several temperatures

by substituting the known differential from Eq. (23). The standard enthalpy so obtained is

$$2Cs \rightleftharpoons Cs_2, \ \Delta H_2 = -20{,}900 \text{ Btu/lb-mole or}$$

$$-11.61 \text{ mean kcal/mole.}$$

The association enthalpy at absolute zero of the dimeric reaction was calculated by two methods. A value of -10.7 kcal/mole was obtained at an average temperature of 2250°F with the equation

$$(\Delta H^\circ_0)_2 = \Delta H^\circ_2 - \Delta(H^\circ - H^\circ_0)^{Cs_2}_{2Cs} \qquad (25)$$

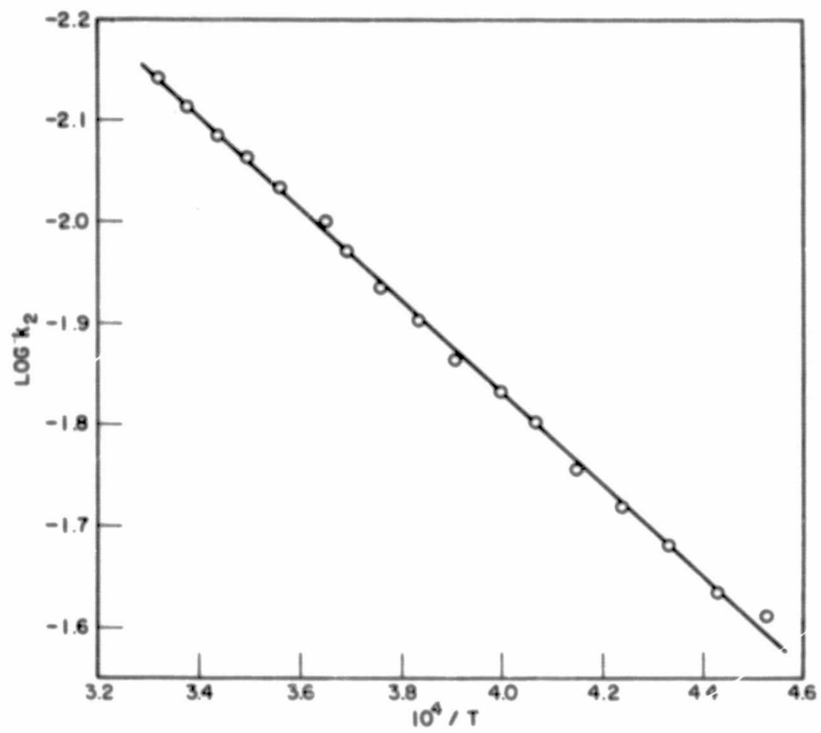


Fig. 11 - Equilibrium constants of dimerization reaction in cesium vapor

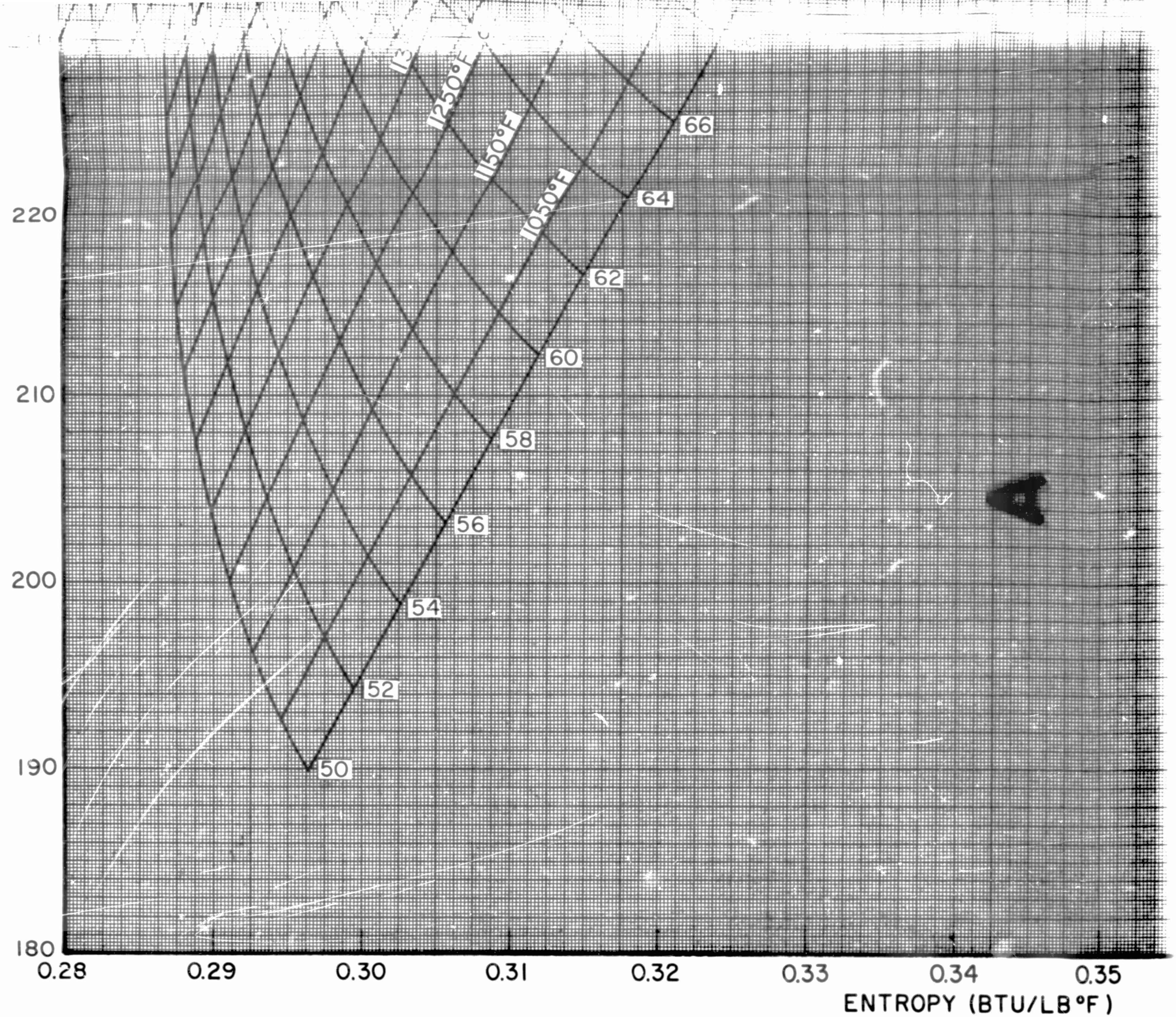
using the observed value of -11.6 for ΔH_2^o and the tabular values of Evans et al. (7) for the enthalpy functions. Another value of -11.0±0.1 kcal/mole (which is an average for the temperature range from 2000° to 2400°F) was obtained with the equation

$$\frac{(\Delta H_0^o)_2}{T} = R \ln k_2 - \Delta\left[\frac{F^o - H_0^o}{T}\right]_{2Cs}^{Cs_2} \tag{26}$$

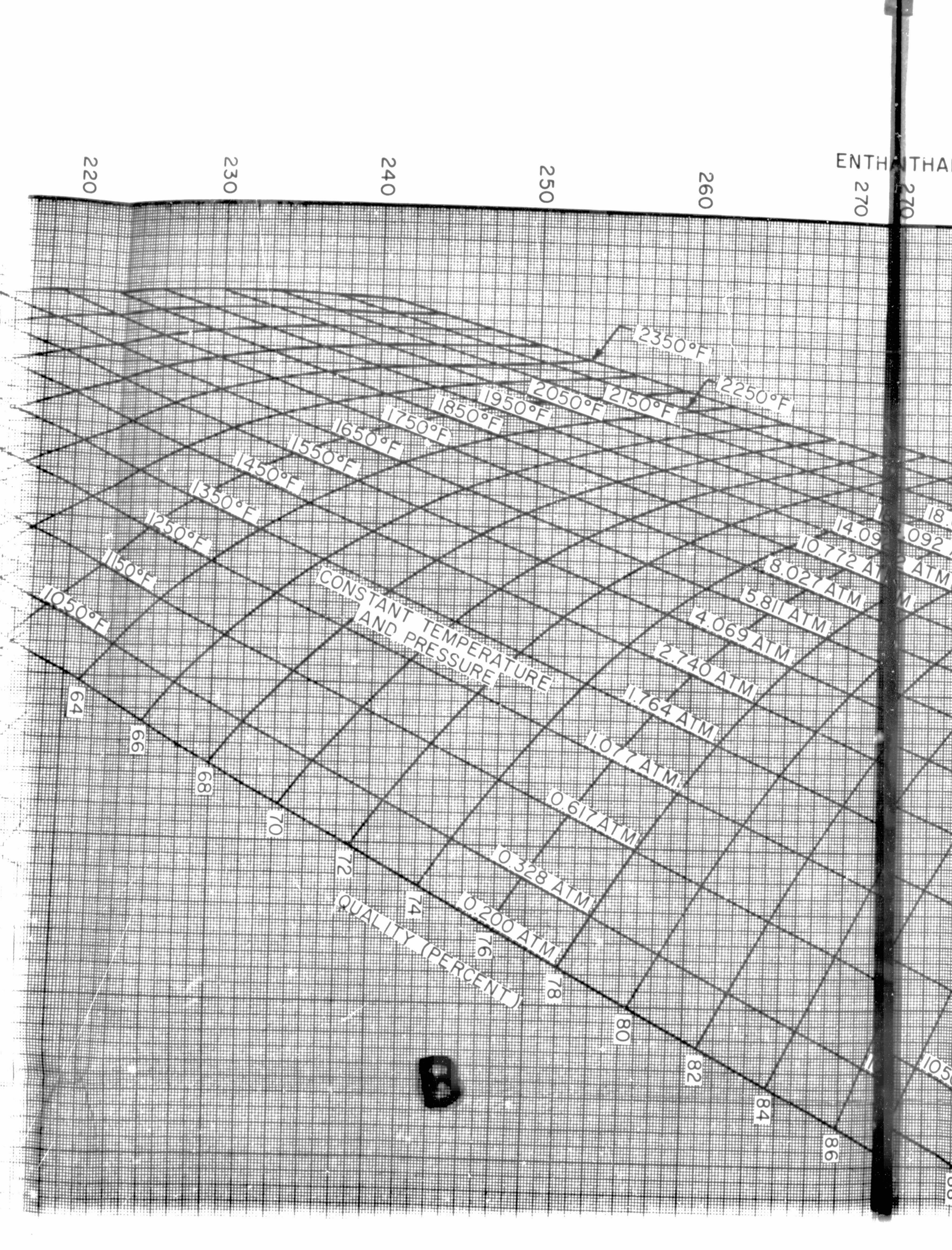
using observed equilibrium constants and the free-energy functions of Evans. The difference between the values as computed by the two methods may be the result of errors in either of the thermal functions or in either of the observed quantities. In any event, since the observed standard enthalpy is probably more reliable than the equilibrium constant and the computed enthalpy function is probably more reliable than the free-energy function, the value of -10.7 is believed to be the more reliable one. This is in reasonable agreement with the spectroscopic value of -10.38 by Herzberg (13).

DISCUSSION OF THERMODYNAMIC AND ENGINEERING PROPERTIES OF CESIUM

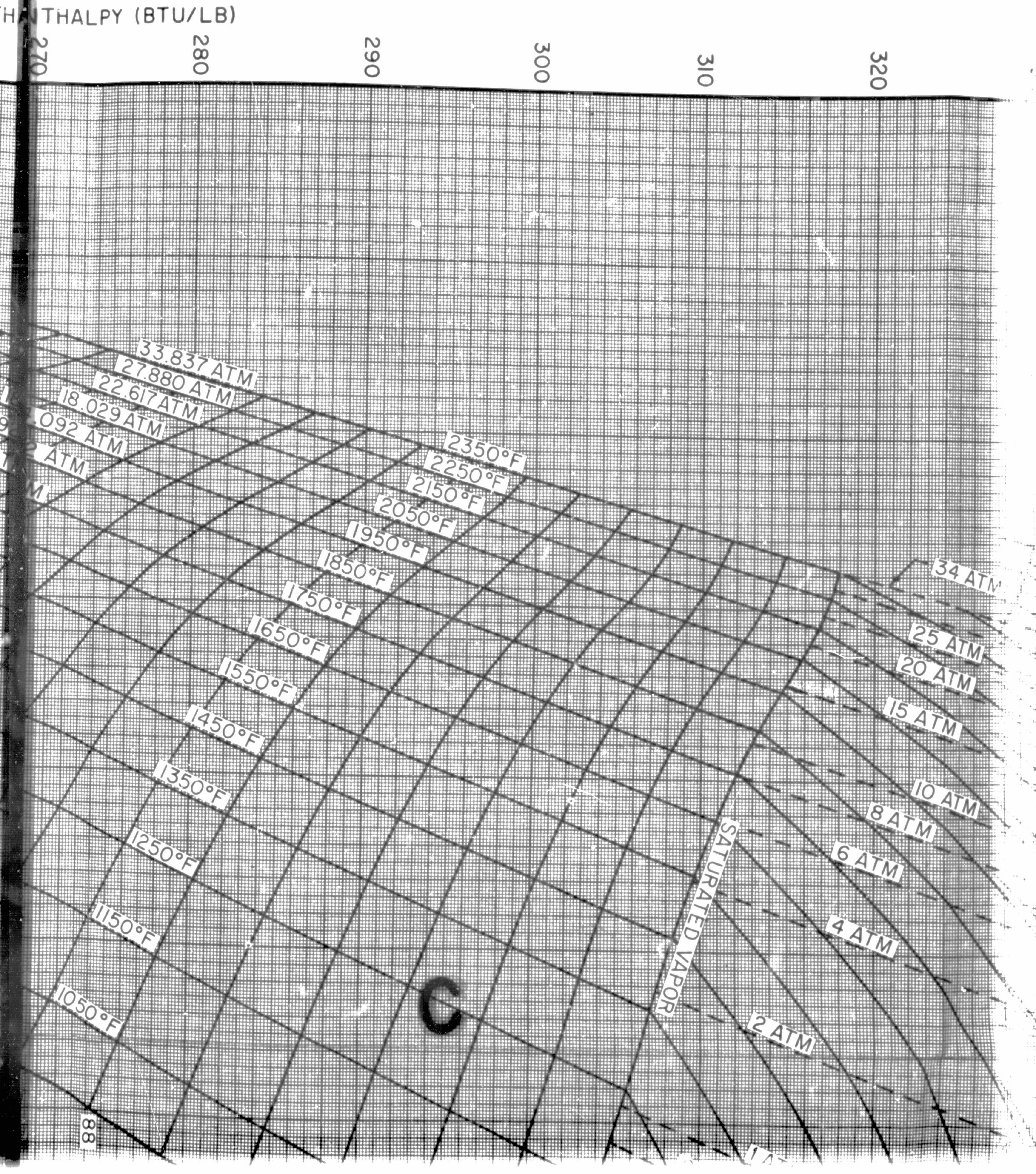
The engineering and thermodynamic properties of cesium, which are presented in Appendixes A and B and in the large Mollier plot (Fig. 12) were computed by the virial method and are based on the properties of the monomeric gas at 1 atm. Two property relationships, the virial equation of state and the vapor-pressure equation, were used with the basic thermodynamic relationships to derive superheat and saturation properties. The virial equation was reduced from PVT data covering a pressure range of 1.12 to 33.2 atm and a temperature range of 1305° to 2571°F. The vapor-pressure equation represents saturation data covering a range of 1.00 to 33.5 atm. Since the reported properties have been limited to a pressure of 34.0 atm and to a temperature of 2550°F, the range of the observed data covers all states in Appendixes A and B except those with pressures below 1.12 atm. For these lower pressure states, short extrapolations with Eqs. (1) and (13) were required. The reported properties have been examined by several methods and evaluated for internal consistency. It is believed that they represent the best values and that they will be satisfactory for any current calculation required in the design of turbines using cesium as working fluid.

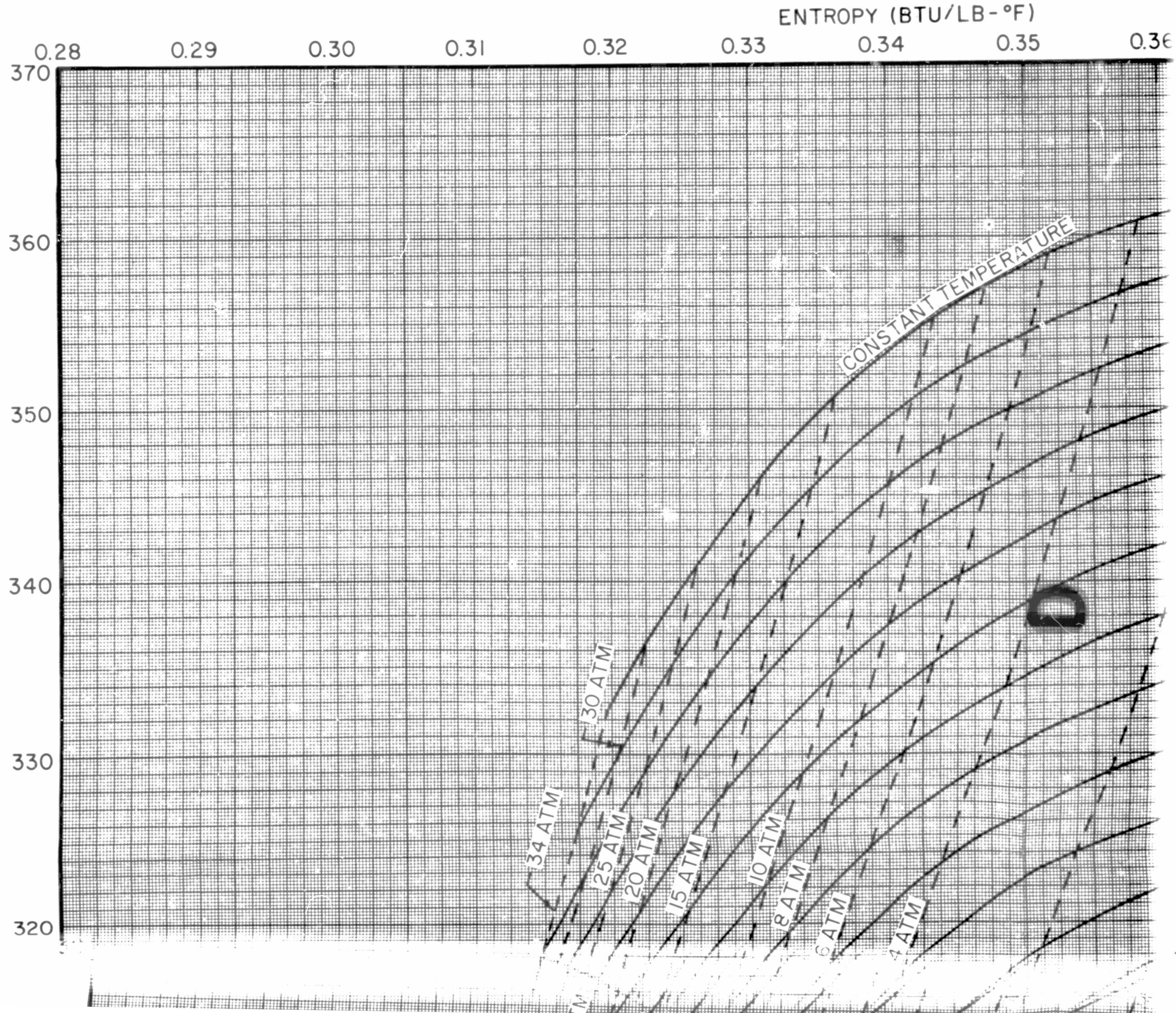


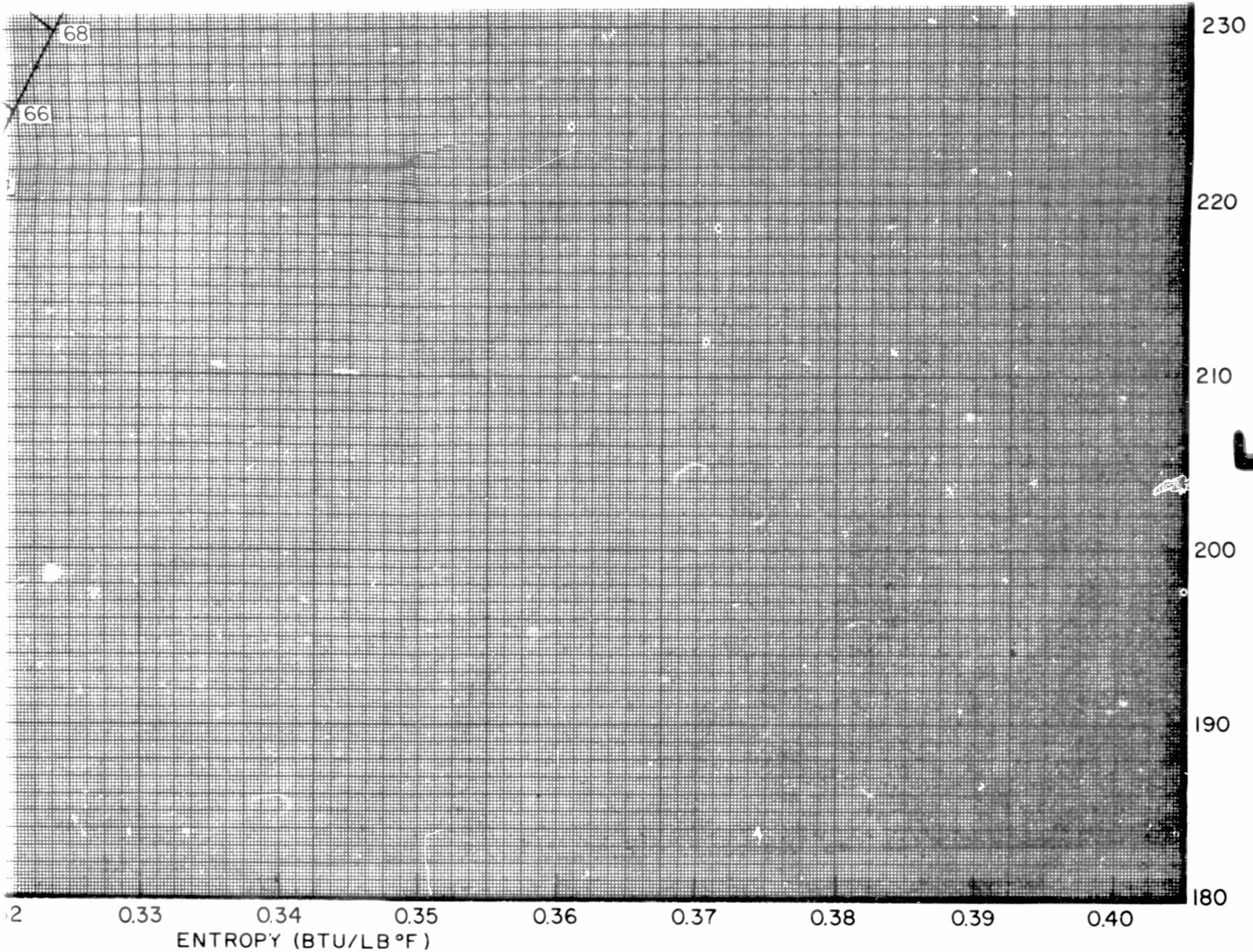
13
1250°F
1150°F
1050°F
66
64
62
60
58
56
54
52
50
220
210
200
190
180
0.28
0.29
0.30
0.31
0.32
0.33
0.34
0.35
ENTROPY (BTU/LB°F)
A



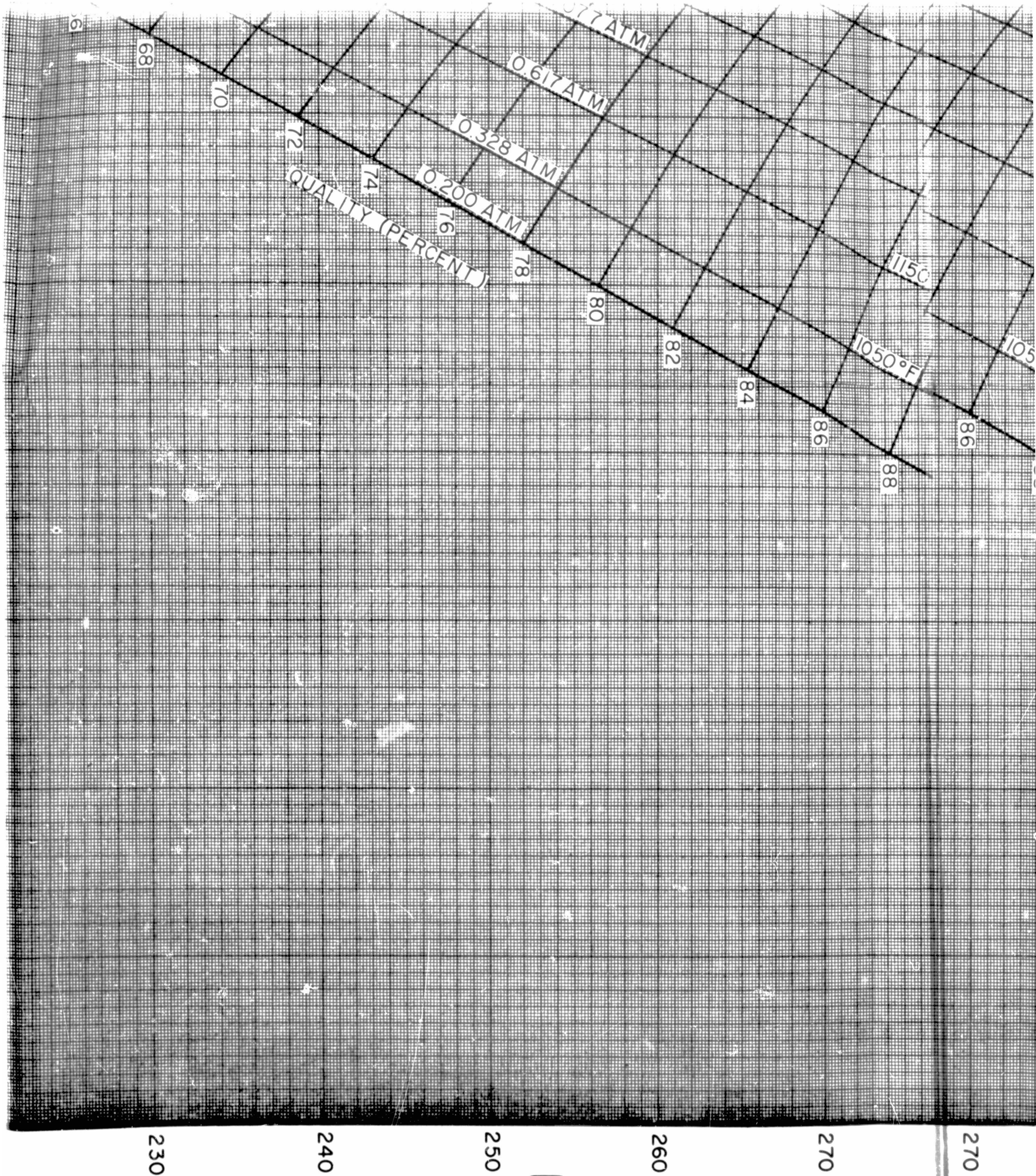
220
230
240
250
260
270
270
ENTH
THAL
2350°F
2250°F
2150°F
2050°F
1950°F
1850°F
1750°F
1650°F
1550°F
1450°F
1350°F
1250°F
1150°F
1050°F
10.772 ATM
8.027 ATM
5.811 ATM
4.069 ATM
2.740 ATM
1.764 ATM
1.077 ATM
0.617 ATM
0.328 ATM
0.200 ATM
CONSTANT TEMPERATURE
AND PRESSURE
QUALITY (PERCENT)
64
66
68
70
72
74
76
78
80
82
84
86
B


ENTHALPY (BTU/LB)
270
280
290
300
310
320
33.837 ATM
27.880 ATM
22.617 ATM
18.029 ATM
2350°F
2250°F
2150°F
2050°F
1950°F
1850°F
1750°F
1650°F
1550°F
1450°F
1350°F
1250°F
1150°F
1050°F
34 ATM
25 ATM
20 ATM
15 ATM
10 ATM
8 ATM
6 ATM
4 ATM
2 ATM
SATURATED VAPOR
C
88


ENTROPY (BTU/LB-°F)
0.28
0.29
0.30
0.31
0.32
0.33
0.34
0.35
0.36
370
360
350
340
330
320
CONSTANT TEMPERATURE
30 ATM
34 ATM
25 ATM
20 ATM
15 ATM
10 ATM
8 ATM
6 ATM
4 ATM



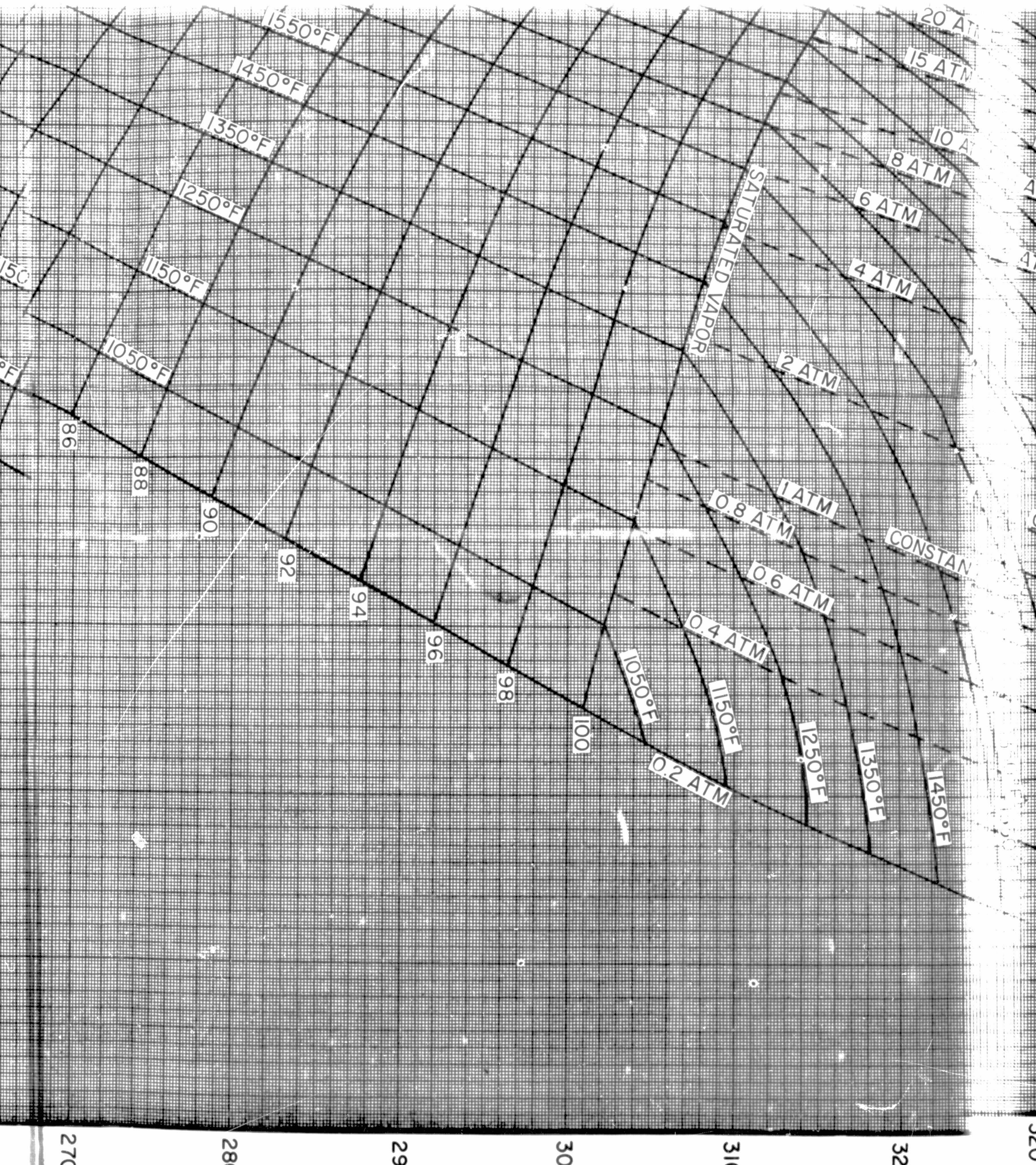
ENTROPY (BTU/LB-°F)



F

ENTHALPY (BENTHALP

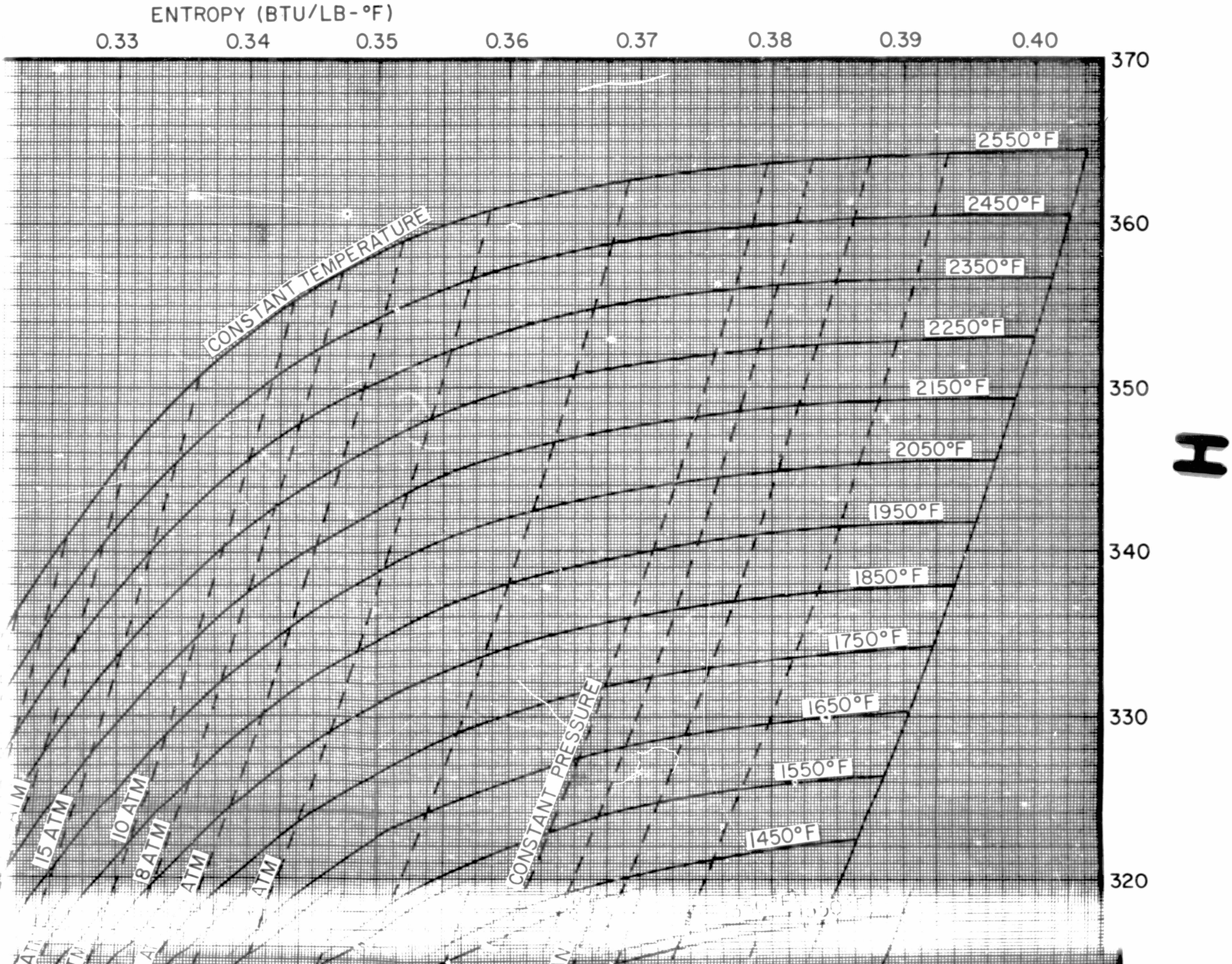
Fig. 12 - Mollier diagra 12 - Mollier



(ENTHALPY (BTU/LB)

...diagram 12 - Mollier diagram of cesium

G



ENTROPY (BTU/LB-°F)
0.33
0.34
0.35
0.36
0.37
0.38
0.39
0.40
370
360
350
340
330
320
H
2550°F
2450°F
2350°F
2250°F
2150°F
2050°F
1950°F
1850°F
1750°F
1650°F
1550°F
1450°F
CONSTANT TEMPERATURE
CONSTANT PRESSURE
15 ATM
10 ATM
8 ATM

The present study represents the only known PVT measurements of cesium which have been published. Measurements in the intermediate temperature range have been in progress at MSAR (5), and the results should be available for comparison in the near future. There are several publications in which thermodynamic properties of the vapor have been computed from saturation pressures, spectroscopic data, and published thermodynamic functions of the monomeric and dimeric vapors. The properties derived in this report from the PVT study were compared with those computed in two recent publications by Agapova et al. (14) and Weatherford et al. (15). If we arbitrarily take the NRL data as a reference and compare at each temperature enthalpy and entropy changes from p_s to 0.2 atm, enthalpy changes reported by Agapova are 23 to 44% lower, and entropy changes are 9% lower. The enthalpy changes reported by Weatherford are 8 to 41% lower and the entropy changes 4 to 8% lower.

Saturation pressures of cesium were measured between 1215° and 2346°F with the null-point apparatus. The precision and internal consistency of the saturation measurements are attested by the small deviation (±0.35%) of all measured data from a simple three-term equation. In the previous studies on sodium (2) and potassium (1), an equation of the Kirchhoff type was effective in fitting the saturation pressures. This study with cesium reaffirms that an equation of this type is required to describe accurately the dependence of vapor pressure on temperature.

Densities of the condensed phase were measured in the temperature range from 1577° to 2304°F with pycnometers. This method was time consuming, since an independent measurement was required at each temperature, but results of unquestionable accuracy were obtained. With these measurements and those generated in other investigations at lower temperatures, overlapping determinations have been made from the melting point to 2304°F, and the density of liquid cesium is well defined for the full temperature range.

The liquid metal program at this Laboratory is a small part of the national effort in this area. The internal consistency and the confidence limits of the properties of sodium, potassium, and cesium can be more fully evaluated as additional properties are measured for the three metals. Particularly important would be reliable determinations of the heat of vaporization, the specific heat of the liquid and vapor, and the electrical conductivity of the vapor. A good example of this type of evaluation is provided by recent measurements at Aerojet-General Nucleonics (4) of the heats of vaporization of cesium. These were measured directly and have been shown to substantiate those computed in this report from the Clapeyron equation. Similarly, a direct determination of the specific heat of the vapor would test the values computed from the virial equation of state, and a determination of the electrical conductivity would provide additional information on the degree of ionization of the vapor.

ACKNOWLEDGMENTS

The authors wish to express their considerable indebtedness to Mrs. Janet P. Mason of the NRL Applied Mathematics Staff for computer programming and to Samuel H. Cress of the NRL Metallurgy Division for spectrochemical analyses of metal samples. The authors are also grateful for the consultation and advice of Thomas B. Douglas, Charles W. Beckett, and Harold W. Woolley of the National Bureau of Standards.

NOMENCLATURE AND UNITS

B second virial coefficient, cu ft/mole

C third virial coefficient, $(\text{cu ft})^2/(\text{mole})^2$

D	fourth virial coefficient, (cu ft)^3/(mole)^3
E	fifth virial coefficient, (cu ft)^4/(mole)^4
c_p	specific heat at constant pressure, Btu/lb-°F
d	density, lb/cu ft
f	free energy, Btu/lb
F	free energy, Btu/lb-mole
h	enthalpy per unit mass, Btu/lb
Δh	enthalpy change per unit mass, Btu/lb
Δh_2	enthalpy change for the formation of a unit mass of dimer from monomer, Btu/lb
Δh_v	enthalpy change upon vaporization of a unit mass at equilibrium, Btu/lb
H	enthalpy per mole, Btu/lb-mole
ΔH	enthalpy change per mole, Btu/lb-mole
ΔH_2	enthalpy change for the formation of one mole of dimer from monomer, Btu/lb-mole
ΔH_v	enthalpy change upon vaporization of a mole at equilibrium, Btu/lb-mole
J	any unit conversion
k	equilibrium constant
k_2'	apparent equilibrium constant assuming only diatomic and monatomic species
M	molecular weight
p	absolute pressure, atm
R	gas constant
s	entropy per unit mass, Btu/lb-°F
Δs_v	entropy change upon vaporization of a unit mass at equilibrium, Btu/lb-°F
T	absolute temperature, °R
t	temperature, °F
$\widetilde{V}$	molal volume (normally per formula weight of monomer), cu ft/lb-mole
v	specific volume, cu ft/lb
z	compressibility factor, $p\widetilde{V}/RT$

Subscripts

a	quantity for equilibrium molecular mixture
i	quantity for the vapor in a state
0	quantity at 0°R
p	constant pressure change
s	quantity at saturation
t	constant temperature change
1	quantity for monatomic species
2	quantity for diatomic species
3	quantity for triatomic species
4	quantity for tetratomic species

Superscripts

g	quantity in gas state
l	quantity in liquid state
o	standard state, 1 atm for gas
$'$	apparent quantity, when assuming only diatomic and monatomic species

REFERENCES

1. Ewing, C.T., Stone, J.P., Spann, J.R., Steinkuller, E.W., Williams, D.D., and Miller, R.R., "High-Temperature Properties of Potassium," NRL Report 6233, Sept. 1965

2. Stone, J.P., Ewing, C.T., Spann, J.R., Steinkuller, E.W., Williams, D.D., and Miller, R.R., "High-Temperature Properties of Sodium," NRL Report 6241, Sept. 1965

3. Lewis, G.N., and Randall, M., "Thermodynamics," New York, N.Y.:McGraw-Hill Book Company Inc., p. 458, 1923

4. Achener, P.Y., "The Determination of the Latent Heat of Vaporization, Vapor Pressure, Enthalpy, Specific Heat, and Density of Liquid Rubidium and Cesium up to 1800°F," Aerojet-General Nucleonics, AGN-8090, Jan. 1964

5. Tepper, F., Murchison, A., Zelenak, J., and Roehlich, F., "Thermophysical Properites of Rubidium and Cesium," MSA Research Corporation, Report No. ML-TDR-64-42, May 1964

6. Bonilla, C.F., Sawhney, D.L., and Makansi, M.M., Trans. ASM 55:877 (1962)

7. Evans, W.H., Jacobson, R., Munson, T.R., and Wagman, D.D., J. Res. Nat. Bur. Std. 55:83 (1955)

8. Lemmon, A.W., Jr., Deem, H.W., Eldridge, E.A., Hall, E.H., Matolich, T., Jr., and Walling, J.F., "The Specific Heat, Thermal Conductivity, and Viscosity of Liquid Cesium," Battelle Memorial Inst., BATT-4673-T7, Feb. 1964

9. Hultgren, R., Orr., R.L., Anderson, P.D., and Kelley, K.K., "Selected Values of Thermodynamic Properties of Metals and Alloys," New York:Wiley, 1963

10. Hirschfelder, J.O., Curtiss, C.F., and Bird, R.B., "Molecular Theory of Gases and Liquids," New York:Wiley, 1954

11. Johnson, E.W., and Nash, L.K., J. Am. Chem. Soc. 72:547 (1950)

12. Vukalovich, M.P., Novikov, I.I., Lebed, D.V., Siletsky, V.S., Dzampov, B.V., Zubarev, V.N., and Rasskasov, D.S., "An Investigation of the Thermodynamic Properties of Imperfect Gases," in the "Proceedings of the Joint Conference on Thermodynamic and Transport Properties of Fluids," London:Institution of Mechanical Engineers, p. 91, 1958

13. Herzberg, G., "Molecular Spectra and Molecular Structure, I. Spectra of Diatomic Molecules," 2nd ed., New York:Van Nostrand, p. 499, 1950

14. Agapova, N.I., Paskar, B.L., and Fokin, L.R., Atomnaya Energiya 15:292 (1963)

15. Weatherford, W.D., Jr., Tyler, J.C., and Ku, P.M., "Properties of Inorganic Energy-Conversion and Heat-Transfer Fluids for Space Application," Southwest Research Institute, WADD Tech. Rept. 61-96, Nov. 1961

APPENDIX A

SATURATION PROPERTIES OF CESIUM

t	p_s	v^l	v_s^g	h^l	Δh_v	h_s^g	s^l	Δs_v	s_s^g
1250.00	1.0768	.01088	8.0598	94.69	210.99	305.69	.2293	.1234	.3527
1275.00	1.2249	.01094	7.1572	96.20	209.85	306.06	.2302	.1210	.3511
1300.00	1.3882	.01101	6.3778	97.72	208.70	306.41	.2310	.1186	.3496
1325.00	1.5676	.01107	5.7022	99.24	207.53	306.76	.2319	.1163	.3482
1350.00	1.7641	.01114	5.1146	100.76	206.34	307.10	.2327	.1140	.3467
1375.00	1.9786	.01121	4.6015	102.28	205.15	307.43	.2336	.1118	.3454
1400.00	2.2122	.01128	4.1522	103.81	203.95	307.76	.2344	.1097	.3441
1425.00	2.4657	.01135	3.7574	105.34	202.74	308.08	.2352	.1076	.3428
1450.00	2.7403	.01142	3.4093	106.86	201.53	308.39	.2360	.1055	.3415
1475.00	3.0369	.01150	3.1017	108.39	200.31	308.70	.2368	.1035	.3403
1500.00	3.3565	.01157	2.8289	109.91	199.10	309.01	.2376	.1016	.3392
1525.00	3.7000	.01165	2.5864	111.43	197.88	309.31	.2383	.0997	.3380
1550.00	4.0685	.01173	2.3703	112.95	196.66	309.62	.2391	.0979	.3369
1575.00	4.4629	.01181	2.1771	114.47	195.45	309.92	.2398	.0961	.3359
1600.00	4.8842	.01189	2.0041	115.98	194.24	310.22	.2406	.0943	.3349
1625.00	5.3333	.01197	1.8487	117.49	193.03	310.53	.2413	.0926	.3339
1650.00	5.8111	.01205	1.7089	119.00	191.83	310.83	.2420	.0909	.3329
1675.00	6.3185	.01213	1.5827	120.51	190.63	311.14	.2427	.0893	.3320
1700.00	6.8565	.01222	1.4687	122.01	189.44	311.45	.2434	.0877	.3311
1725.00	7.4258	.01231	1.3654	123.51	188.26	311.77	.2441	.0862	.3302
1750.00	8.0273	.01240	1.2715	125.01	187.07	312.08	.2447	.0847	.3294
1775.00	8.6619	.01249	1.1862	126.51	185.89	312.40	.2454	.0832	.3286
1800.00	9.3302	.01258	1.1083	128.02	184.71	312.73	.2461	.0817	.3278
1825.00	10.0332	.01268	1.0372	129.53	183.52	313.05	.2467	.0803	.3270
1850.00	10.7715	.01277	.9721	131.05	182.33	313.38	.2474	.0789	.3263
1875.00	11.5459	.01267	.9124	132.57	181.13	313.71	.2480	.0776	.3256
1900.00	12.3570	.01297	.8576	134.11	179.92	314.04	.2487	.0762	.3249
1925.00	13.2054	.01307	.8070	135.66	178.70	314.36	.2493	.0749	.3242
1950.00	14.0919	.01317	.7604	137.23	177.45	314.68	.2499	.0736	.3236
1975.00	15.0170	.01328	.7173	138.82	176.18	315.00	.2506	.0724	.3229
2000.00	15.9812	.01339	.6774	140.43	174.88	315.31	.2512	.0711	.3223
2025.00	16.9852	.01350	.6404	142.06	173.55	315.61	.2519	.0698	.3217
2050.00	18.0294	.01361	.6059	143.72	172.18	315.90	.2525	.0686	.3211
2075.00	19.1142	.01372	.5739	145.40	170.77	316.17	.2532	.0674	.3205
2100.00	20.2402	.01384	.5440	147.10	169.32	316.43	.2538	.0661	.3200
2125.00	21.4077	.01396	.5161	148.83	167.83	316.66	.2545	.0649	.3194
2150.00	22.6171	.01408	.4900	150.58	166.29	316.87	.2551	.0637	.3189
2175.00	23.8687	.01420	.4656	152.35	164.72	317.06	.2558	.0625	.3183
2200.00	25.1630	.01433	.4427	154.12	163.11	317.23	.2564	.0613	.3178
2225.00	26.5001	.01446	.4213	155.88	161.49	317.37	.2571	.0602	.3172
2250.00	27.8803	.01459	.4014	157.61	159.88	317.49	.2577	.0590	.3167
2275.00	29.3039	.01473	.3828	159.30	158.29	317.59	.2583	.0579	.3162
2300.00	30.7711	.01487	.3655	160.91	156.77	317.68	.2589	.0568	.3157
2325.00	32.2820	.01501	.3495	162.42	155.35	317.77	.2594	.0558	.3152
2350.00	33.8367	.01515	.3348	163.79	154.09	317.88	.2599	.0548	.3147

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR

t	p	v^g	z	h^g	s^g	c_p^g
1250.00	1.0768	8.0598	.92387	305.69	.35270	.0671
1250.00	1.0000	8.7283	.92917	306.40	.35414	.0653
1250.00	.8000	11.0740	.94310	308.28	.35836	.0604
1250.00	.6000	14.9858	.95718	310.19	.36357	.0551
1250.00	.4000	22.8122	.97138	312.13	.37055	.0494
1250.00	.2000	46.2952	.98566	314.09	.38183	.0435
1275.00	1.2249	7.1572	.91983	306.06	.35114	.0679
1275.00	1.0000	8.9045	.93426	308.01	.35507	.0631
1275.00	.8000	11.2853	.94724	309.77	.35923	.0584
1275.00	.6000	15.2549	.96033	311.55	.36436	.0535
1275.00	.4000	23.1962	.97350	313.35	.37126	.0483
1275.00	.2000	47.0230	.98673	315.17	.38246	.0429
1300.00	1.3882	6.3778	.91574	306.41	.34963	.0688
1300.00	1.0000	9.0778	.93890	309.56	.35596	.0610
1300.00	.8000	11.4933	.95100	311.20	.36005	.0566
1300.00	.6000	15.5206	.96317	312.87	.36511	.0520
1300.00	.4000	23.5767	.97541	314.54	.37194	.0473
1300.00	.2000	47.7471	.98769	316.23	.38307	.0424
1325.00	1.5676	5.7022	.91160	306.76	.34816	.0696
1325.00	1.0000	9.2482	.94313	311.06	.35681	.0590
1325.00	.8000	11.6985	.95441	312.60	.36084	.0549
1325.00	.6000	15.7833	.96575	314.15	.36583	.0507
1325.00	.4000	23.9540	.97714	315.71	.37260	.0463
1325.00	.2000	48.4680	.98856	317.28	.38367	.0419
1350.00	1.7641	5.1146	.90742	307.10	.34675	.0703
1350.00	1.0000	9.4160	.94698	312.51	.35761	.0572
1350.00	.8000	11.9009	.95751	313.95	.36159	.0534
1350.00	.6000	16.0432	.96809	315.40	.36653	.0495
1350.00	.4000	24.3286	.97870	316.86	.37324	.0455
1350.00	.2000	49.1860	.98934	318.33	.38425	.0415
1375.00	1.9786	4.6015	.90319	307.43	.34538	.0710
1375.00	1.0000	9.5815	.95050	313.92	.35839	.0555
1375.00	.8000	12.1009	.96034	315.27	.36231	.0520
1375.00	.6000	16.3005	.97022	316.63	.36720	.0484
1375.00	.4000	24.7005	.98013	317.99	.37386	.0448
1375.00	.2000	49.9015	.99006	319.36	.38481	.0411
1400.00	2.2122	4.1522	.89895	307.76	.34405	.0717
1400.00	2.0000	4.6407	.90835	309.05	.34611	.0689
1400.00	1.0000	9.7448	.95370	315.29	.35913	.0540
1400.00	.8000	12.2987	.96291	316.55	.36301	.0508
1400.00	.6000	16.5556	.97216	317.83	.36785	.0475
1400.00	.4000	25.0702	.98142	319.10	.37446	.0441
1400.00	.2000	50.6146	.99070	320.38	.38537	.0408
1425.00	2.4657	3.7574	.89468	308.08	.34277	.0724
1425.00	2.0000	4.7325	.91402	310.74	.34701	.0666
1425.00	1.0000	9.9061	.95663	316.62	.35984	.0526
1425.00	.8000	12.4944	.96526	317.81	.36368	.0496
1425.00	.6000	16.8087	.97392	319.00	.36848	.0466
1425.00	.4000	25.4377	.98260	320.20	.37504	.0435
1425.00	.2000	51.3256	.99130	321.40	.38591	.0405
1450.00	2.7403	3.4093	.89040	308.39	.34152	.0730
1450.00	2.0000	4.8227	.91925	312.38	.34787	.0645
1450.00	1.0000	10.0656	.95931	317.92	.36053	.0514
1450.00	.8000	12.6883	.96741	319.04	.36432	.0486
1450.00	.6000	17.0599	.97554	320.16	.36909	.0458
1450.00	.4000	25.8034	.98368	321.28	.37561	.0430
1450.00	.2000	52.0347	.99184	322.40	.38644	.0402
1475.00	3.0369	3.1017	.88612	308.70	.34032	.0735
1475.00	3.0000	3.1445	.88745	308.89	.34058	.0732
1475.00	2.0000	4.9114	.92407	313.97	.34870	.0624

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

t	p	v^g	z	h^g	s^g	c_p^g
1475.00	1.0000	10.2235	.96176	319.19	.36119	.0502
1475.00	.8000	12.8806	.96938	320.24	.36495	.0477
1475.00	.6000	17.3094	.97702	321.29	.36968	.0451
1475.00	.4000	26.1674	.98467	322.35	.37617	.0425
1475.00	.2000	52.7421	.99233	323.41	.38696	.0400
1500.00	3.3565	2.8289	.88185	309.01	.33916	.0740
1500.00	3.0000	3.2082	.89388	310.69	.34150	.0708
1500.00	2.0000	4.9987	.92850	315.50	.34949	.0605
1500.00	1.0000	10.3799	.96401	320.43	.36182	.0492
1500.00	.8000	13.0713	.97118	321.42	.36556	.0468
1500.00	.6000	17.5574	.97837	322.41	.37026	.0445
1500.00	.4000	26.5299	.98557	323.41	.37671	.0421
1500.00	.2000	53.4480	.99278	324.40	.38747	.0397
1525.00	3.7000	2.5864	.87759	309.31	.33803	.0745
1525.00	3.0000	3.2708	.89984	312.43	.34238	.0685
1525.00	2.0000	5.0848	.93259	317.00	.35024	.0588
1525.00	1.0000	10.5348	.96608	321.65	.36244	.0483
1525.00	.8000	13.2607	.97284	322.58	.36615	.0461
1525.00	.6000	17.8040	.97962	323.52	.37082	.0439
1525.00	.4000	26.8910	.98640	324.46	.37725	.0417
1525.00	.2000	54.1525	.99320	325.39	.38797	.0396
1550.00	4.0685	2.3703	.87335	309.62	.33694	.0749
1550.00	4.0000	2.4165	.87536	309.90	.33730	.0744
1550.00	3.0000	3.3324	.90537	314.11	.34323	.0664
1550.00	2.0000	5.1697	.93636	318.45	.35097	.0572
1550.00	1.0000	10.6886	.96799	322.84	.36304	.0474
1550.00	.8000	13.4488	.97437	323.73	.36672	.0454
1550.00	.6000	18.0493	.98076	324.61	.37136	.0434
1550.00	.4000	27.2508	.98716	325.50	.37777	.0414
1550.00	.2000	54.8557	.99358	326.38	.38847	.0394
1575.00	4.4629	2.1771	.86914	309.92	.33588	.0753
1575.00	4.0000	2.4650	.88198	311.73	.33821	.0721
1575.00	3.0000	3.3929	.91050	315.75	.34404	.0644
1575.00	2.0000	5.2534	.93984	319.86	.35167	.0557
1575.00	1.0000	10.8412	.96975	324.02	.36362	.0466
1575.00	.8000	13.6357	.97578	324.85	.36728	.0448
1575.00	.6000	18.2935	.98182	325.69	.37190	.0429
1575.00	.4000	27.6095	.98787	326.53	.37828	.0411
1575.00	.2000	55.5577	.99393	327.36	.38895	.0392
1600.00	4.8842	2.0041	.86496	310.22	.33486	.0756
1600.00	4.0000	2.5127	.88814	313.51	.33907	.0699
1600.00	3.0000	3.4526	.91525	317.33	.34481	.0625
1600.00	2.0000	5.3362	.94306	321.23	.35234	.0544
1600.00	1.0000	10.9928	.97137	325.18	.36419	.0459
1600.00	.8000	13.8216	.97707	325.97	.36782	.0442
1600.00	.6000	18.5367	.98279	326.76	.37242	.0425
1600.00	.4000	27.9671	.98852	327.55	.37878	.0408
1600.00	.2000	56.2587	.99425	328.34	.38943	.0391
1625.00	5.3333	1.8487	.86082	310.53	.33388	.0759
1625.00	5.0000	1.9906	.86892	311.68	.33526	.0741
1625.00	4.0000	2.5597	.89389	315.23	.33991	.0678
1625.00	3.0000	3.5113	.91966	318.87	.34555	.0607
1625.00	2.0000	5.4181	.94604	322.58	.35299	.0532
1625.00	1.0000	11.1434	.97287	326.32	.36474	.0453
1625.00	.8000	14.0066	.97827	327.07	.36835	.0437
1625.00	.6000	18.7789	.98369	327.82	.37293	.0421
1625.00	.4000	28.3237	.98912	328.57	.37927	.0405
1625.00	.2000	56.9588	.99456	329.32	.38990	.0390
1650.00	5.8111	1.7089	.85672	310.83	.33292	.0761
1650.00	5.0000	2.0295	.87542	313.50	.33613	.0719

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

t	p	v^g	z	h^g	s^g	c_p^g
1650.00	4.0000	2.6059	.89924	316.90	.34070	.0658
1650.00	3.0000	3.5692	.92376	320.37	.34627	.0591
1650.00	2.0000	5.4990	.94881	323.89	.35362	.0520
1650.00	1.0000	11.2931	.97426	327.44	.36527	.0447
1650.00	.8000	14.1907	.97939	328.15	.36887	.0433
1650.00	.6000	19.0202	.98453	328.87	.37343	.0418
1650.00	.4000	28.6795	.98967	329.58	.37975	.0403
1650.00	.2000	57.6580	.99483	330.29	.39037	.0388
1675.00	6.3185	1.5827	.85265	311.14	.33200	.0763
1675.00	6.0000	1.6801	.85949	312.12	.33312	.0749
1675.00	5.0000	2.0678	.88150	315.28	.33697	.0698
1675.00	4.0000	2.6514	.90423	318.52	.34147	.0640
1675.00	3.0000	3.6264	.92757	321.83	.34696	.0576
1675.00	2.0000	5.5792	.95137	325.18	.35422	.0510
1675.00	1.0000	11.4420	.97555	328.55	.36580	.0442
1675.00	.8000	14.3740	.98042	329.23	.36938	.0428
1675.00	.6000	19.2607	.98530	329.91	.37392	.0415
1675.00	.4000	29.0345	.99019	330.58	.38022	.0401
1675.00	.2000	58.3563	.99509	331.26	.39082	.0387
1700.00	6.8565	1.4687	.84863	311.45	.33110	.0765
1700.00	6.0000	1.7129	.86611	313.97	.33398	.0728
1700.00	5.0000	2.1055	.88719	316.99	.33777	.0678
1700.00	4.0000	2.6963	.90889	320.10	.34220	.0622
1700.00	3.0000	3.6829	.93111	323.25	.34762	.0563
1700.00	2.0000	5.6587	.95375	326.44	.35481	.0501
1700.00	1.0000	11.5902	.97674	329.65	.36631	.0437
1700.00	.8000	14.5565	.98137	330.30	.36987	.0425
1700.00	.6000	19.5005	.98602	330.94	.37440	.0412
1700.00	.4000	29.3887	.99067	331.58	.38069	.0399
1700.00	.2000	59.0540	.99533	332.23	.39127	.0386
1725.00	7.4258	1.3654	.84465	311.77	.33024	.0766
1725.00	7.0000	1.4623	.85277	312.94	.33152	.0750
1725.00	6.0000	1.7452	.87233	315.76	.33480	.0708
1725.00	5.0000	2.1427	.89251	318.67	.33854	.0659
1725.00	4.0000	2.7405	.91323	321.63	.34291	.0606
1725.00	3.0000	3.7387	.93441	324.64	.34826	.0550
1725.00	2.0000	5.7375	.95597	327.68	.35538	.0492
1725.00	1.0000	11.7377	.97786	330.74	.36681	.0433
1725.00	.8000	14.7384	.98227	331.35	.37036	.0421
1725.00	.6000	19.7396	.98669	331.97	.37487	.0409
1725.00	.4000	29.7423	.99111	332.58	.38115	.0397
1725.00	.2000	59.7509	.99555	333.19	.39172	.0386
1750.00	8.0273	1.2715	.84071	312.08	.32940	.0766
1750.00	8.0000	1.2766	.84120	312.15	.32948	.0765
1750.00	7.0000	1.4905	.85939	314.79	.33236	.0730
1750.00	6.0000	1.7770	.87817	317.51	.33560	.0688
1750.00	5.0000	2.1793	.89749	320.29	.33928	.0641
1750.00	4.0000	2.7842	.91728	323.13	.34359	.0591
1750.00	3.0000	3.7940	.93748	326.00	.34888	.0538
1750.00	2.0000	5.8157	.95804	328.90	.35594	.0484
1750.00	1.0000	11.8846	.97889	331.82	.36730	.0429
1750.00	.8000	14.9196	.98309	332.40	.37084	.0418
1750.00	.6000	19.9780	.98731	332.99	.37534	.0407
1750.00	.4000	30.0952	.99153	333.57	.38160	.0396
1750.00	.2000	60.4472	.99576	334.15	.39216	.0385
1775.00	8.6619	1.1862	.83679	312.40	.32859	.0766
1775.00	8.0000	1.3016	.84810	314.04	.33033	.0746
1775.00	7.0000	1.5183	.86563	316.59	.33318	.0710
1775.00	6.0000	1.8083	.88366	319.20	.33636	.0670
1775.00	5.0000	2.2154	.90216	321.87	.33999	.0625

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

t	p	v^g	z	h^g	s^g	c_p^g
1775.00	4.0000	2.8273	.92107	324.59	.34424	.0577
1775.00	3.0000	3.8486	.94035	327.33	.34948	.0528
1775.00	2.0000	5.8933	.95996	330.10	.35648	.0477
1775.00	1.0000	12.0310	.97986	332.88	.36778	.0425
1775.00	.8000	15.1003	.98387	333.44	.37130	.0415
1775.00	.6000	20.2159	.98789	334.00	.37579	.0405
1775.00	.4000	30.4476	.99192	334.56	.38204	.0394
1775.00	.2000	61.1430	.99595	335.11	.39259	.0384
1800.00	9.3302	1.1083	.83290	312.73	.32781	.0766
1800.00	9.0000	1.1563	.83822	313.50	.32860	.0757
1800.00	8.0000	1.3263	.85463	315.88	.33115	.0727
1800.00	7.0000	1.5458	.87150	318.34	.33395	.0692
1800.00	6.0000	1.8392	.88881	320.85	.33710	.0652
1800.00	5.0000	2.2510	.90653	323.42	.34068	.0609
1800.00	4.0000	2.8699	.92461	326.01	.34488	.0564
1800.00	3.0000	3.9028	.94303	328.64	.35006	.0518
1800.00	2.0000	5.9704	.96176	331.29	.35700	.0470
1800.00	1.0000	12.1768	.98076	333.94	.36825	.0422
1800.00	.8000	15.2804	.98459	334.48	.37176	.0412
1800.00	.6000	20.4533	.98843	335.01	.37624	.0403
1800.00	.4000	30.7994	.99228	335.54	.38248	.0393
1800.00	.2000	61.8382	.99613	336.07	.39302	.0383
1825.00	10.0332	1.0372	.82903	313.05	.32705	.0766
1825.00	10.0000	1.0413	.82953	313.13	.32712	.0765
1825.00	9.0000	1.1785	.84496	315.37	.32942	.0739
1825.00	8.0000	1.3507	.86080	317.68	.33194	.0709
1825.00	7.0000	1.5728	.87704	320.05	.33471	.0674
1825.00	6.0000	1.8697	.89365	322.46	.33780	.0636
1825.00	5.0000	2.2862	.91062	324.92	.34134	.0595
1825.00	4.0000	2.9121	.92793	327.41	.34549	.0552
1825.00	3.0000	3.9565	.94554	329.92	.35062	.0509
1825.00	2.0000	6.0470	.96344	332.45	.35752	.0464
1825.00	1.0000	12.3221	.98160	334.99	.36871	.0419
1825.00	.8000	15.4600	.98526	335.50	.37222	.0410
1825.00	.6000	20.6902	.98893	336.01	.37668	.0401
1825.00	.4000	31.1507	.99261	336.52	.38291	.0392
1825.00	.2000	62.5330	.99630	337.03	.39344	.0383
1850.00	10.7715	.9721	.82515	313.38	.32631	.0765
1850.00	10.0000	1.0615	.83643	315.02	.32795	.0748
1850.00	9.0000	1.2005	.85136	317.19	.33022	.0721
1850.00	8.0000	1.3747	.86664	319.43	.33270	.0691
1850.00	7.0000	1.5994	.88225	321.71	.33543	.0657
1850.00	6.0000	1.8997	.89820	324.03	.33849	.0620
1850.00	5.0000	2.3210	.91446	326.39	.34198	.0582
1850.00	4.0000	2.9538	.93103	328.78	.34609	.0541
1850.00	3.0000	4.0097	.94789	331.18	.35117	.0500
1850.00	2.0000	6.1232	.96501	333.61	.35802	.0458
1850.00	1.0000	12.4669	.98239	336.04	.36917	.0416
1850.00	.8000	15.6392	.98590	336.53	.37266	.0408
1850.00	.6000	20.9266	.98941	337.01	.37712	.0399
1850.00	.4000	31.5016	.99293	337.50	.38334	.0391
1850.00	.2000	63.2272	.99646	337.99	.39385	.0382
1875.00	11.5459	.9124	.82126	313.71	.32560	.0764
1875.00	11.0000	.9666	.82886	314.81	.32667	.0753
1875.00	10.0000	1.0814	.84299	316.86	.32374	.0730
1875.00	9.0000	1.2221	.85742	318.97	.33098	.0704
1875.00	8.0000	1.3985	.87214	321.13	.33343	.0674
1875.00	7.0000	1.6258	.88716	323.33	.33613	.0641
1875.00	6.0000	1.9294	.90247	325.57	.33915	.0606
1875.00	5.0000	2.3553	.91807	327.83	.34260	.0569

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

t	p	v^g	z	h^g	s^g	c_p^g
1875.00	4.0000	2.9951	.93394	330.12	.34667	.0531
1875.00	3.0000	4.0625	.95009	332.42	.35171	.0492
1875.00	2.0000	6.1989	.96649	334.74	.35851	.0453
1875.00	1.0000	12.6113	.98313	337.07	.36962	.0413
1875.00	.8000	15.8180	.98649	337.54	.37310	.0405
1875.00	.6000	21.1626	.98985	338.01	.37755	.0398
1875.00	.4000	31.8521	.99323	338.48	.38376	.0390
1875.00	.2000	63.9211	.99661	338.94	.39427	.0382
1900.00	12.3570	.8576	.81734	314.04	.32491	.0763
1900.00	12.0000	.8882	.82209	314.72	.32556	.0757
1900.00	11.0000	.9848	.83554	316.67	.32746	.0737
1900.00	10.0000	1.1010	.84923	318.67	.32951	.0713
1900.00	9.0000	1.2434	.86316	320.71	.33172	.0687
1900.00	8.0000	1.4219	.87734	322.80	.33414	.0657
1900.00	7.0000	1.6517	.89179	324.91	.33680	.0626
1900.00	6.0000	1.9588	.90649	327.06	.33979	.0592
1900.00	5.0000	2.3893	.92146	329.24	.34320	.0558
1900.00	4.0000	3.0360	.93668	331.43	.34723	.0522
1900.00	3.0000	4.1149	.95215	333.65	.35223	.0485
1900.00	2.0000	6.2743	.96787	335.87	.35899	.0448
1900.00	1.0000	12.7554	.98383	338.11	.37005	.0411
1900.00	.8000	15.9964	.98704	338.55	.37353	.0404
1900.00	.6000	21.3982	.99027	339.00	.37797	.0396
1900.00	.4000	32.2022	.99350	339.45	.38417	.0389
1900.00	.2000	64.6146	.99675	339.90	.39467	.0381
1925.00	13.2054	.8070	.81338	314.36	.32424	.0761
1925.00	13.0000	.8224	.81601	314.74	.32459	.0758
1925.00	12.0000	.9050	.82887	316.59	.32635	.0741
1925.00	11.0000	1.0028	.84191	318.49	.32823	.0720
1925.00	10.0000	1.1205	.85515	320.43	.33025	.0697
1925.00	9.0000	1.2645	.86859	322.41	.33244	.0670
1925.00	8.0000	1.4450	.88225	324.42	.33482	.0642
1925.00	7.0000	1.6774	.89614	326.46	.33745	.0612
1925.00	6.0000	1.9878	.91027	328.53	.34040	.0580
1925.00	5.0000	2.4230	.92464	330.62	.34378	.0547
1925.00	4.0000	3.0766	.93925	332.73	.34777	.0513
1925.00	3.0000	4.1670	.95409	334.85	.35273	.0479
1925.00	2.0000	6.3493	.96917	336.99	.35946	.0444
1925.00	1.0000	12.8991	.98448	339.13	.37049	.0409
1925.00	.8000	16.1744	.98756	339.56	.37395	.0402
1925.00	.6000	21.6335	.99066	339.99	.37839	.0395
1925.00	.4000	32.5519	.99377	340.42	.38458	.0388
1925.00	.2000	65.3077	.99688	340.85	.39507	.0381
1950.00	14.0919	.7604	.80936	314.68	.32358	.0760
1950.00	14.0000	.7665	.81049	314.85	.32373	.0759
1950.00	13.0000	.8380	.82286	316.61	.32537	.0744
1950.00	12.0000	.9217	.83535	318.42	.32711	.0725
1950.00	11.0000	1.0206	.84797	320.27	.32897	.0704
1950.00	10.0000	1.1396	.86076	322.15	.33097	.0681
1950.00	9.0000	1.2853	.87373	324.06	.33313	.0655
1950.00	8.0000	1.4678	.88689	326.01	.33549	.0627
1950.00	7.0000	1.7027	.90025	327.97	.33809	.0598
1950.00	6.0000	2.0165	.91383	329.96	.34100	.0568
1950.00	5.0000	2.4563	.92764	331.97	.34434	.0537
1950.00	4.0000	3.1169	.94166	334.00	.34830	.0505
1950.00	3.0000	4.2187	.95592	336.04	.35323	.0472
1950.00	2.0000	6.4239	.97039	338.09	.35992	.0440
1950.00	1.0000	13.0474	.98509	340.15	.37091	.0407
1950.00	.8000	16.3521	.98806	340.56	.37437	.0400
1950.00	.6000	21.8684	.99103	340.97	.37880	.0394

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

t	p	v^g	z	h^g	s^g	c_p^g
1950.00	.4000	32.9013	.99401	341.39	.38498	.0387
1950.00	.2000	66.0005	.99700	341.80	.39547	.0380
1975.00	15.0170	.7173	.80526	315.00	.32295	.0759
1975.00	15.0000	.7183	.80546	315.03	.32297	.0759
1975.00	14.0000	.7810	.81740	316.73	.32451	.0745
1975.00	13.0000	.8535	.82942	318.46	.32613	.0729
1975.00	12.0000	.9381	.84152	320.22	.32785	.0710
1975.00	11.0000	1.0382	.85373	322.01	.32969	.0688
1975.00	10.0000	1.1586	.86609	323.83	.33167	.0665
1975.00	9.0000	1.3059	.87859	325.68	.33380	.0640
1975.00	8.0000	1.4903	.89127	327.56	.33613	.0614
1975.00	7.0000	1.7278	.90413	329.45	.33870	.0586
1975.00	6.0000	2.0449	.91719	331.37	.34158	.0557
1975.00	5.0000	2.4894	.93046	333.30	.34489	.0528
1975.00	4.0000	3.1568	.94394	335.25	.34882	.0497
1975.00	3.0000	4.2701	.95763	337.21	.35371	.0467
1975.00	2.0000	6.4982	.97154	339.18	.36037	.0436
1975.00	1.0000	13.1854	.98567	341.16	.37133	.0405
1975.00	.8000	16.5294	.98852	341.56	.37479	.0399
1975.00	.6000	22.1030	.99138	341.96	.37920	.0393
1975.00	.4000	33.2503	.99424	342.35	.38538	.0386
1975.00	.2000	66.6929	.99712	342.75	.39586	.0380
2000.00	15.9812	.6774	.80105	315.31	.32233	.0758
2000.00	15.0000	.7320	.81242	316.91	.32374	.0746
2000.00	14.0000	.7955	.82403	318.57	.32526	.0731
2000.00	13.0000	.8688	.83568	320.26	.32687	.0714
2000.00	12.0000	.9543	.84740	321.97	.32857	.0694
2000.00	11.0000	1.0556	.85921	323.71	.33039	.0673
2000.00	10.0000	1.1773	.87113	325.48	.33234	.0650
2000.00	9.0000	1.3262	.88319	327.27	.33445	.0626
2000.00	8.0000	1.5126	.89541	329.07	.33675	.0601
2000.00	7.0000	1.7526	.90779	330.90	.33929	.0574
2000.00	6.0000	2.0730	.92036	332.75	.34215	.0547
2000.00	5.0000	2.5221	.93312	334.61	.34543	.0519
2000.00	4.0000	3.1965	.94608	336.49	.34932	.0490
2000.00	3.0000	4.3213	.95925	338.37	.35419	.0461
2000.00	2.0000	6.5723	.97263	340.27	.36082	.0432
2000.00	1.0000	13.3282	.98621	342.17	.37174	.0403
2000.00	.8000	16.7065	.98895	342.56	.37519	.0397
2000.00	.6000	22.3373	.99170	342.94	.37960	.0391
2000.00	.4000	33.5991	.99446	343.32	.38578	.0386
2000.00	.2000	67.3851	.99723	343.70	.39625	.0380
2025.00	16.9852	.6404	.79673	315.61	.32172	.0757
2025.00	16.0000	.6893	.80785	317.16	.32306	.0746
2025.00	15.0000	.7455	.81911	318.76	.32449	.0732
2025.00	1[illegible].0000	.8097	.83037	320.38	.32599	.0716
2025.00	13.0000	.8839	.84165	322.02	.32758	.0699
2025.00	12.0000	.9704	.85299	323.69	.32926	.0679
2025.00	11.0000	1.0728	.86440	325.38	.33106	.0659
2025.00	10.0000	1.1958	.87591	327.09	.33299	.0636
2025.00	9.0000	1.3463	.88755	328.82	.33507	.0613
2025.00	8.0000	1.5347	.89932	330.56	.33735	.0589
2025.00	7.0000	1.7772	.91129	332.32	.33986	.0563
2025.00	6.0000	2.1009	.92335	334.10	.34269	.0537
2025.00	5.0000	2.5546	.93563	335.90	.34595	.0511
2025.00	4.0000	3.2358	.94810	337.70	.34982	.0484
2025.00	3.0000	4.3721	.96077	339.52	.35465	.0457
2025.00	2.0000	6.6461	.97365	341.35	.36125	.0429
2025.00	1.0000	13.4706	.98672	343.18	.37215	.0402
2025.00	.8000	16.8833	.98936	343.55	.37559	.0396

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

t	p	v^g	z	h^g	s^g	c_p^g
2025.00	.6000	22.5713	.99201	343.91	.38000	.0391
2025.00	.4000	33.9476	.99466	344.28	.38617	.0385
2025.00	.2000	68.0770	.99733	344.65	.39664	.0380
2050.00	18.0294	.6059	.79227	315.90	.32113	.0756
2050.00	18.0000	.6072	.79260	315.94	.32117	.0756
2050.00	17.0000	.6518	.80362	317.47	.32245	.0745
2050.00	16.0000	.7020	.81458	319.01	.32380	.0733
2050.00	15.0000	.7589	.82551	320.57	.32522	.0718
2050.00	14.0000	.8238	.83642	322.15	.32670	.0702
2050.00	13.0000	.8988	.84734	323.75	.32827	.0684
2050.00	12.0000	.9863	.85831	325.37	.32994	.0665
2050.00	11.0000	1.0898	.86934	327.01	.33171	.0645
2050.00	10.0000	1.2141	.88045	328.66	.33362	.0623
2050.00	9.0000	1.3662	.89167	330.33	.33568	.0601
2050.00	8.0000	1.5565	.90302	332.02	.33793	.0577
2050.00	7.0000	1.8015	.91452	333.72	.34042	.0553
2050.00	6.0000	2.1285	.92617	335.44	.34323	.0529
2050.00	5.0000	2.5869	.93800	337.16	.34646	.0503
2050.00	4.0000	3.2750	.95001	338.91	.35030	.0478
2050.00	3.0000	4.4227	.96221	340.66	.35511	.0452
2050.00	2.0000	6.7196	.97461	342.42	.36168	.0426
2050.00	1.0000	13.6128	.98721	344.18	.37255	.0400
2050.00	.8000	17.0599	.98975	344.54	.37599	.0395
2050.00	.6000	22.8051	.99230	344.89	.38039	.0390
2050.00	.4000	34.2958	.99486	345.24	.38655	.0384
2050.00	.2000	68.7687	.99743	345.60	.39701	.0379
2075.00	19.1142	.5739	.78767	316.17	.32055	.0756
2075.00	19.0000	.5783	.78891	316.34	.32068	.0755
2075.00	18.0000	.6187	.79970	317.82	.32191	.0745
2075.00	17.0000	.6639	.81041	319.31	.32319	.0733
2075.00	16.0000	.7146	.82105	320.82	.32452	.0719
2075.00	15.0000	.7721	.83163	322.35	.32592	.0704
2075.00	14.0000	.8378	.84220	323.89	.32739	.0688
2075.00	13.0000	.9136	.85277	325.45	.32894	.0670
2075.00	12.0000	1.0020	.86337	327.02	.33059	.0651
2075.00	11.0000	1.1066	.87402	328.60	.33235	.0631
2075.00	10.0000	1.2322	.88475	330.20	.33423	.0611
2075.00	9.0000	1.3858	.89558	331.82	.33627	.0589
2075.00	8.0000	1.5781	.90652	333.45	.33850	.0567
2075.00	7.0000	1.8256	.91761	335.09	.34097	.0544
2075.00	6.0000	2.1559	.92884	336.75	.34375	.0520
2075.00	5.0000	2.6189	.94024	338.41	.34695	.0496
2075.00	4.0000	3.3139	.95181	340.09	.35077	.0472
2075.00	3.0000	4.4731	.96357	341.78	.35555	.0448
2075.00	2.0000	6.7928	.97552	343.48	.36210	.0423
2075.00	1.0000	13.7548	.98766	345.18	.37295	.0399
2075.00	.8000	17.2362	.99011	345.52	.37638	.0394
2075.00	.6000	23.0386	.99257	345.86	.38078	.0389
2075.00	.4000	34.6439	.99504	346.20	.38693	.0384
2075.00	.2000	69.4601	.99752	346.55	.39739	.0379
2100.00	20.2402	.5440	.78290	316.43	.31998	.0756
2100.00	20.0000	.5523	.78546	316.77	.32025	.0754
2100.00	19.0000	.5893	.79606	318.21	.32142	.0744
2100.00	18.0000	.6302	.80654	319.67	.32263	.0733
2100.00	17.0000	.6758	.81693	321.13	.32390	.0720
2100.00	16.0000	.7271	.82723	322.61	.32522	.0706
2100.00	15.0000	.7852	.83749	324.09	.32661	.0691
2100.00	14.0000	.8516	.84771	325.59	.32806	.0674
2100.00	13.0000	.9281	.85793	327.10	.32960	.0657
2100.00	12.0000	1.0175	.86818	328.63	.33122	.0638

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

t	p	v^g	z	h^g	s^g	c_p^g
2100.00	11.0000	1.1232	.87847	330.17	.33296	.0619
2100.00	10.0000	1.2500	.88883	331.72	.33482	.0599
2100.00	9.0000	1.4053	.89928	333.28	.33684	.0578
2100.00	8.0000	1.5995	.90984	334.85	.33905	.0557
2100.00	7.0000	1.8495	.92053	336.44	.34150	.0535
2100.00	6.0000	2.1831	.93137	338.04	.34425	.0513
2100.00	5.0000	2.6507	.94236	339.65	.34744	.0490
2100.00	4.0000	3.3526	.95352	341.27	.35123	.0467
2100.00	3.0000	4.5232	.96486	342.90	.35599	.0444
2100.00	2.0000	6.8659	.97538	344.53	.36251	.0421
2100.00	1.0000	13.8965	.98810	346.18	.37334	.0397
2100.00	.8000	17.4122	.99046	346.50	.37677	.0393
2100.00	.6000	23.2720	.99283	346.83	.38116	.0388
2100.00	.4000	34.9916	.99521	347.16	.38731	.0383
2100.00	.2000	70.1513	.99760	347.49	.39776	.0379
2125.00	21.4077	.5161	.77797	316.66	.31941	.0757
2125.00	21.0000	.5290	.78225	317.23	.31986	.0753
2125.00	20.0000	.5628	.79267	318.64	.32098	.0744
2125.00	19.0000	.6002	.80295	320.06	.32214	.0733
2125.00	18.0000	.6415	.81311	321.48	.32334	.0720
2125.00	17.0000	.6877	.82317	322.91	.32459	.0707
2125.00	16.0000	.7395	.83315	324.35	.32590	.0693
2125.00	15.0000	.7982	.84307	325.80	.32727	.0677
2125.00	14.0000	.8652	.85296	327.26	.32871	.0661
2125.00	13.0000	.9426	.86285	328.73	.33023	.0643
2125.00	12.0000	1.0328	.87275	330.21	.33184	.0626
2125.00	11.0000	1.1396	.88269	331.70	.33355	.0607
2125.00	10.0000	1.2677	.89270	333.20	.33540	.0588
2125.00	9.0000	1.4245	.90279	334.71	.33740	.0568
2125.00	8.0000	1.6207	.91299	336.23	.33959	.0547
2125.00	7.0000	1.8732	.92330	337.77	.34201	.0527
2125.00	6.0000	2.2101	.93376	339.31	.34475	.0505
2125.00	5.0000	2.6822	.94436	340.86	.34791	.0484
2125.00	4.0000	3.3910	.95513	342.43	.35168	.0462
2125.00	3.0000	4.5732	.96608	344.00	.35642	.0440
2125.00	2.0000	6.9387	.97720	345.58	.36292	.0418
2125.00	1.0000	14.0381	.98850	347.17	.37372	.0396
2125.00	.8000	17.5881	.99079	347.49	.37715	.0392
2125.00	.6000	23.5051	.99308	347.80	.38153	.0387
2125.00	.4000	35.3392	.99538	348.12	.38766	.0383
2125.00	.2000	70.8422	.99769	348.44	.39813	.0379
2150.00	22.6171	.4900	.77288	316.87	.31866	.0758
2150.00	22.0000	.5079	.77927	317.72	.31950	.0753
2150.00	21.0000	.5391	.78952	319.10	.32058	.0743
2150.00	20.0000	.5733	.79961	320.49	.32169	.0732
2150.00	19.0000	.6110	.80957	321.88	.32284	.0721
2150.00	18.0000	.6527	.81941	323.27	.32403	.0708
2150.00	17.0000	.6993	.82915	324.67	.32527	.0694
2150.00	16.0000	.7517	.83881	326.07	.32656	.0679
2150.00	15.0000	.8110	.84841	327.48	.32792	.0664
2150.00	14.0000	.8787	.85797	328.90	.32934	.0648
2150.00	13.0000	.9569	.86753	330.32	.33084	.0631
2150.00	12.0000	1.0480	.87710	331.76	.33243	.0614
2150.00	11.0000	1.1558	.88671	333.20	.33413	.0596
2150.00	10.0000	1.2853	.89637	334.65	.33596	.0577
2150.00	9.0000	1.4436	.90612	336.12	.33794	.0558
2150.00	8.0000	1.6417	.91597	337.59	.34011	.0539
2150.00	7.0000	1.8967	.92593	339.07	.34251	.0519
2150.00	6.0000	2.2369	.93603	340.57	.34523	.0499
2150.00	5.0000	2.7136	.94627	342.07	.34837	.0478

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

t	p	v^g	z	h^g	s^g	c_p^g
2150.00	4.0000	3.4293	.95666	343.58	.35212	.0458
2150.00	3.0000	4.6229	.96723	345.10	.35684	.0437
2150.00	2.0000	7.0114	.97797	346.62	.36332	.0416
2150.00	1.0000	14.1794	.98889	348.16	.37410	.0395
2150.00	.8000	17.7638	.99110	348.46	.37752	.0391
2150.00	.6000	23.7380	.99331	348.77	.38191	.0387
2150.00	.4000	35.6866	.99553	349.08	.38805	.0383
2150.00	.2000	71.5330	.99776	349.39	.39850	.0378
2175.00	23.8687	.4656	.76765	317.06	.31831	.0759
2175.00	23.0000	.4887	.77652	318.24	.31918	.0752
2175.00	22.0000	.5176	.78659	319.59	.32022	.0743
2175.00	21.0000	.5491	.79651	320.95	.32128	.0732
2175.00	20.0000	.5836	.80629	322.30	.32238	.0721
2175.00	19.0000	.6217	.81593	323.66	.32352	.0708
2175.00	18.0000	.6638	.82545	325.02	.32470	.0695
2175.00	17.0000	.7109	.83487	326.38	.32592	.0681
2175.00	16.0000	.7638	.84421	327.75	.32720	.0666
2175.00	15.0000	.8237	.85349	329.12	.32854	.0651
2175.00	14.0000	.8921	.86274	330.50	.32995	.0635
2175.00	13.0000	.9710	.87198	331.88	.33144	.0619
2175.00	12.0000	1.0631	.88124	333.28	.33301	.0602
2175.00	11.0000	1.1719	.89052	334.68	.33470	.0585
2175.00	10.0000	1.3026	.89987	336.08	.33651	.0567
2175.00	9.0000	1.4625	.90928	337.50	.33847	.0549
2175.00	8.0000	1.6626	.91880	338.93	.34062	.0530
2175.00	7.0000	1.9200	.92842	340.36	.34301	.0512
2175.00	6.0000	2.2635	.93817	341.80	.34570	.0492
2175.00	5.0000	2.7449	.94807	343.26	.34883	.0473
2175.00	4.0000	3.4674	.95811	344.72	.35256	.0453
2175.00	3.0000	4.6725	.96832	346.19	.35726	.0434
2175.00	2.0000	7.0839	.97870	347.66	.36372	.0414
2175.00	1.0000	14.3206	.98926	349.14	.37448	.0394
2175.00	.8000	17.9393	.99139	349.44	.37790	.0390
2175.00	.6000	23.9707	.99353	349.74	.38228	.0386
2175.00	.4000	36.0338	.99568	350.04	.38842	.0382
2175.00	.2000	72.2236	.99784	350.33	.39886	.0378
2200.00	25.1630	.4427	.76233	317.23	.31777	.0761
2200.00	25.0000	.4466	.76397	317.44	.31792	.0760
2200.00	24.0000	.4713	.77399	318.78	.31889	.0752
2200.00	23.0000	.4981	.78389	320.11	.31989	.0742
2200.00	22.0000	.5272	.79364	321.44	.32091	.0732
2200.00	21.0000	.5590	.80324	322.76	.32197	.0721
2200.00	20.0000	.5938	.81269	324.09	.32306	.0708
2200.00	19.0000	.6322	.82202	325.42	.32418	.0696
2200.00	18.0000	.6748	.83123	326.74	.32535	.0682
2200.00	17.0000	.7224	.84034	328.07	.32656	.0668
2200.00	16.0000	.7758	.84937	329.40	.32783	.0654
2200.00	15.0000	.8362	.85635	330.74	.32915	.0639
2200.00	14.0000	.9053	.86729	332.07	.33054	.0624
2200.00	13.0000	.9850	.87623	333.42	.33202	.0608
2200.00	12.0000	1.0779	.88517	334.77	.33358	.0592
2200.00	11.0000	1.1879	.89415	336.13	.33524	.0575
2200.00	10.0000	1.3199	.90318	337.49	.33704	.0558
2200.00	9.0000	1.4813	.91229	338.86	.33898	.0540
2200.00	8.0000	1.6833	.92149	340.24	.34112	.0523
2200.00	7.0000	1.9431	.93079	341.63	.34349	.0505
2200.00	6.0000	2.2900	.94021	343.03	.34617	.0487
2200.00	5.0000	2.7759	.94978	344.43	.34927	.0468
2200.00	4.0000	3.5053	.95949	345.85	.35298	.0450
2200.00	3.0000	4.7219	.96936	347.27	.35767	.0431

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

t	p	v^g	z	h^g	s^g	c_p^g
2200.00	2.0000	7.1562	.97940	348.69	.36411	.0412
2200.00	1.0000	14.4615	.98961	350.13	.37485	.0393
2200.00	.8000	18.1146	.99167	350.42	.37826	.0389
2200.00	.6000	24.2033	.99374	350.70	.38264	.0386
2200.00	.4000	36.3808	.99582	350.99	.38878	.0382
2200.00	.2000	72.9140	.99791	351.28	.39921	.0378
2225.00	26.5001	.4213	.75696	317.37	.31723	.0763
2225.00	26.0000	.4323	.76189	318.02	.31769	.0760
2225.00	25.0000	.4553	.77170	319.33	.31863	.0752
2225.00	24.0000	.4803	.78141	320.64	.31959	.0742
2225.00	23.0000	.5073	.79098	321.95	.32058	.0732
2225.00	22.0000	.5367	.80041	323.25	.32159	.0720
2225.00	21.0000	.5687	.80969	324.55	.32264	.0709
2225.00	20.0000	.6039	.81884	325.85	.32371	.0696
2225.00	19.0000	.6427	.82785	327.14	.32483	.0683
2225.00	18.0000	.6857	.83675	328.43	.32598	.0670
2225.00	17.0000	.7337	.84556	329.73	.32718	.0656
2225.00	16.0000	.7876	.85429	331.02	.32843	.0642
2225.00	15.0000	.8486	.86298	332.32	.32974	.0627
2225.00	14.0000	.9184	.87163	333.62	.33112	.0612
2225.00	13.0000	.9988	.88027	334.92	.33258	.0597
2225.00	12.0000	1.0927	.88892	336.23	.33413	.0581
2225.00	11.0000	1.2037	.89760	337.55	.33578	.0565
2225.00	10.0000	1.3369	.90634	338.87	.33755	.0549
2225.00	9.0000	1.4999	.91515	340.20	.33948	.0532
2225.00	8.0000	1.7038	.92404	341.54	.34160	.0516
2225.00	7.0000	1.9661	.93304	342.88	.34395	.0498
2225.00	6.0000	2.3162	.94215	344.24	.34682	.0481
2225.00	5.0000	2.8068	.95140	345.60	.34971	.0464
2225.00	4.0000	3.5431	.96079	346.96	.35340	.0446
2225.00	3.0000	4.7711	.97034	348.34	.35807	.0428
2225.00	2.0000	7.2283	.98006	349.72	.36449	.0410
2225.00	1.0000	14.6024	.98994	351.11	.37522	.0392
2225.00	.8000	18.2898	.99194	351.39	.37863	.0389
2225.00	.6000	24.4357	.99394	351.67	.38300	.0385
2225.00	.4000	36.7277	.99595	351.95	.38913	.0382
2225.00	.2000	73.6043	.99797	352.22	.39957	.0378
2250.00	27.8803	.4014	.75165	317.49	.31670	.0766
2250.00	27.0000	.4191	.76009	318.62	.31749	.0760
2250.00	26.0000	.4407	.76967	319.91	.31839	.0751
2250.00	25.0000	.4640	.77917	321.20	.31932	.0742
2250.00	24.0000	.4892	.78856	322.49	.32028	.0731
2250.00	23.0000	.5164	.79781	323.76	.32125	.0720
2250.00	22.0000	.5461	.80692	325.04	.32225	.0709
2250.00	21.0000	.5784	.81589	326.31	.32329	.0697
2250.00	20.0000	.6139	.82472	327.57	.32435	.0684
2250.00	19.0000	.6531	.83343	328.83	.32545	.0671
2250.00	18.0000	.6965	.84203	330.09	.32660	.0658
2250.00	17.0000	.7449	.85055	331.35	.32778	.0644
2250.00	16.0000	.7993	.85900	332.61	.32902	.0630
2250.00	15.0000	.8609	.86739	333.87	.33032	.0616
2250.00	14.0000	.9313	.87576	335.14	.33169	.0602
2250.00	13.0000	1.0125	.88412	336.40	.33313	.0587
2250.00	12.0000	1.1073	.89249	337.68	.33466	.0572
2250.00	11.0000	1.2193	.90089	338.95	.33630	.0556
2250.00	10.0000	1.3538	.90934	340.24	.33806	.0541
2250.00	9.0000	1.5184	.91786	341.52	.33997	.0525
2250.00	8.0000	1.7242	.92647	342.82	.34208	.0509
2250.00	7.0000	1.9890	.93517	344.12	.34441	.0492
2250.00	6.0000	2.3424	.94399	345.43	.34706	.0476

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

t	p	v^g	z	h^g	s^g	c_p^g
2250.00	5.0000	2.8375	.95294	346.75	.35013	.0459
2250.00	4.0000	3.5807	.96204	348.07	.35382	.0442
2250.00	3.0000	4.8202	.97128	349.41	.35846	.0426
2250.00	2.0000	7.3003	.98068	350.75	.36487	.0409
2250.00	1.0000	14.7430	.99025	352.09	.37558	.0392
2250.00	.8000	18.4648	.99219	352.36	.37899	.0388
2250.00	.6000	24.6679	.99413	352.63	.38336	.0385
2250.00	.4000	37.0744	.99608	352.90	.38949	.0381
2250.00	.2000	74.2944	.99804	353.17	.39992	.0378
2275.00	29.3039	.3828	.74650	317.59	.31618	.0768
2275.00	29.0000	.3882	.74930	317.97	.31644	.0767
2275.00	28.0000	.4071	.75858	319.24	.31730	.0760
2275.00	27.0000	.4273	.76790	320.51	.31818	.0751
2275.00	26.0000	.4491	.77717	321.78	.31908	.0742
2275.00	25.0000	.4726	.78636	323.04	.32000	.0731
2275.00	24.0000	.4980	.79543	324.30	.32094	.0720
2275.00	23.0000	.5255	.80436	325.55	.32191	.0709
2275.00	22.0000	.5554	.81316	326.79	.32290	.0697
2275.00	21.0000	.5880	.82182	328.03	.32392	.0685
2275.00	20.0000	.6238	.83035	329.27	.32497	.0672
2275.00	19.0000	.6633	.83877	330.50	.32606	.0659
2275.00	18.0000	.7071	.84708	331.72	.32719	.0646
2275.00	17.0000	.7560	.85532	332.95	.32837	.0633
2275.00	16.0000	.8109	.86349	334.17	.32960	.0619
2275.00	15.0000	.8731	.87161	335.40	.33088	.0606
2275.00	14.0000	.9441	.87970	336.63	.33223	.0592
2275.00	13.0000	1.0261	.88779	337.86	.33366	.0577
2275.00	12.0000	1.1218	.89589	339.09	.33518	.0563
2275.00	11.0000	1.2348	.90402	340.33	.33680	.0548
2275.00	10.0000	1.3706	.91220	341.58	.33855	.0533
2275.00	9.0000	1.5367	.92045	342.83	.34045	.0518
2275.00	8.0000	1.7444	.92878	344.08	.34254	.0502
2275.00	7.0000	2.0117	.93721	345.35	.34486	.0487
2275.00	6.0000	2.3684	.94575	346.62	.34750	.0471
2275.00	5.0000	2.8681	.95441	347.89	.35055	.0455
2275.00	4.0000	3.6182	.96322	349.18	.35422	.0439
2275.00	3.0000	4.8691	.97217	350.47	.35885	.0423
2275.00	2.0000	7.3721	.98128	351.76	.36525	.0407
2275.00	1.0000	14.8835	.99055	353.07	.37594	.0391
2275.00	.8000	18.6397	.99243	353.33	.37934	.0388
2275.00	.6000	24.9000	.99431	353.59	.38371	.0384
2275.00	.4000	37.4210	.99620	353.85	.38984	.0381
2275.00	.2000	74.9844	.99810	354.11	.40026	.0378
2300.00	30.7711	.3655	.74169	317.68	.31567	.0770
2300.00	30.0000	.3783	.74846	318.64	.31630	.0766
2300.00	29.0000	.3960	.75739	319.88	.31714	.0759
2300.00	28.0000	.4150	.76640	321.13	.31799	.0751
2300.00	27.0000	.4355	.77542	322.38	.31886	.0742
2300.00	26.0000	.4574	.78439	323.62	.31975	.0731
2300.00	25.0000	.4811	.79326	324.86	.32066	.0720
2300.00	24.0000	.5067	.80202	326.09	.32159	.0709
2300.00	23.0000	.5344	.81064	327.31	.32255	.0697
2300.00	22.0000	.5646	.81914	328.52	.32353	.0685
2300.00	21.0000	.5975	.82750	329.73	.32454	.0673
2300.00	20.0000	.6336	.83574	330.93	.32558	.0660
2300.00	19.0000	.6734	.84387	332.13	.32666	.0648
2300.00	18.0000	.7176	.85191	333.33	.32778	.0635
2300.00	17.0000	.7669	.85987	334.52	.32894	.0622
2300.00	16.0000	.8224	.86777	335.71	.33016	.0609
2300.00	15.0000	.8851	.87563	336.90	.33143	.0596

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

t	p	v^g	z	h^g	s^g	c_p^g
2300.00	14.0000	.9568	.88346	338.10	.33277	.0582
2300.00	13.0000	1.0396	.89129	339.29	.33418	.0568
2300.00	12.0000	1.1361	.89913	340.49	.33569	.0554
2300.00	11.0000	1.2503	.90700	341.69	.33730	.0540
2300.00	10.0000	1.3873	.91493	342.90	.33903	.0526
2300.00	9.0000	1.5549	.92291	344.11	.34092	.0511
2300.00	8.0000	1.7645	.93098	345.33	.34299	.0496
2300.00	7.0000	2.0343	.93914	346.56	.34530	.0482
2300.00	6.0000	2.3942	.94741	347.79	.34792	.0467
2300.00	5.0000	2.8986	.95581	349.03	.35097	.0451
2300.00	4.0000	3.6555	.96434	350.27	.35462	.0436
2300.00	3.0000	4.9179	.97302	351.52	.35924	.0421
2300.00	2.0000	7.4438	.98185	352.78	.36562	.0406
2300.00	1.0000	15.0239	.99084	354.04	.37630	.0390
2300.00	.8000	18.8144	.99266	354.30	.37970	.0387
2300.00	.6000	25.1320	.99448	354.55	.38406	.0384
2300.00	.4000	37.7674	.99632	354.81	.39019	.0381
2300.00	.2000	75.6742	.99815	355.06	.40061	.0378
2325.00	32.2820	.3495	.73741	317.77	.31518	.0771
2325.00	32.0000	.3537	.73968	318.11	.31540	.0770
2325.00	31.0000	.3692	.74797	319.32	.31618	.0765
2325.00	30.0000	.3858	.75652	320.54	.31699	.0759
2325.00	29.0000	.4037	.76520	321.77	.31782	.0751
2325.00	28.0000	.4229	.77395	323.00	.31866	.0741
2325.00	27.0000	.4435	.78267	324.22	.31952	.0731
2325.00	26.0000	.4657	.79133	325.44	.32040	.0720
2325.00	25.0000	.4895	.79990	326.64	.32130	.0709
2325.00	24.0000	.5153	.80834	327.84	.32223	.0697
2325.00	23.0000	.5433	.81667	329.04	.32317	.0685
2325.00	22.0000	.5737	.82486	330.22	.32414	.0673
2325.00	21.0000	.6069	.83294	331.40	.32514	.0661
2325.00	20.0000	.6433	.84090	332.57	.32617	.0649
2325.00	19.0000	.6835	.84876	333.74	.32724	.0637
2325.00	18.0000	.7281	.85653	334.90	.32835	.0624
2325.00	17.0000	.7778	.86422	336.06	.32950	.0612
2325.00	16.0000	.8337	.87187	337.22	.33070	.0599
2325.00	15.0000	.8971	.87947	338.38	.33196	.0586
2325.00	14.0000	.9694	.88705	339.54	.33329	.0573
2325.00	13.0000	1.0529	.89463	340.70	.33469	.0560
2325.00	12.0000	1.1503	.90222	341.87	.33619	.0546
2325.00	11.0000	1.2655	.90985	343.03	.33778	.0533
2325.00	10.0000	1.4038	.91752	344.21	.33951	.0519
2325.00	9.0000	1.5730	.92526	345.38	.34138	.0505
2325.00	8.0000	1.7845	.93307	346.57	.34344	.0491
2325.00	7.0000	2.0567	.94098	347.76	.34574	.0477
2325.00	6.0000	2.4200	.94900	348.95	.34834	.0462
2325.00	5.0000	2.9289	.95714	350.15	.35137	.0448
2325.00	4.0000	3.6927	.96541	351.36	.35501	.0433
2325.00	3.0000	4.9666	.97382	352.57	.35962	.0419
2325.00	2.0000	7.5154	.98239	353.79	.36598	.0404
2325.00	1.0000	15.1642	.99111	355.02	.37665	.0390
2325.00	.8000	18.9890	.99288	355.27	.38005	.0387
2325.00	.6000	25.3638	.99465	355.51	.38441	.0384
2325.00	.4000	38.1137	.99642	355.76	.39053	.0381
2325.00	.2000	76.3639	.99821	356.00	.40095	.0378
2350.00	33.8367	.3348	.73386	317.88	.31470	.0769
2350.00	33.0000	.3462	.74005	318.85	.31532	.0768
2350.00	32.0000	.3608	.74786	320.03	.31608	.0764
2350.00	31.0000	.3765	.75598	321.22	.31686	.0758
2350.00	30.0000	.3933	.76431	322.43	.31767	.0750

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

t	p	v^g	z	h^g	s^g	c_p^g
2350.00	29.0000	.4114	.77275	323.63	.31848	.0741
2350.00	28.0000	.4307	.78121	324.84	.31932	.0731
2350.00	27.0000	.4515	.78964	326.03	.32017	.0720
2350.00	26.0000	.4738	.79800	327.22	.32104	.0709
2350.00	25.0000	.4979	.80626	328.40	.32193	.0697
2350.00	24.0000	.5239	.81441	329.57	.32284	.0686
2350.00	23.0000	.5520	.82244	330.73	.32378	.0674
2350.00	22.0000	.5827	.83035	331.89	.32474	.0662
2350.00	21.0000	.6161	.83814	333.04	.32573	.0650
2350.00	20.0000	.6529	.84583	334.18	.32675	.0638
2350.00	19.0000	.6934	.85343	335.31	.32780	.0626
2350.00	18.0000	.7384	.86094	336.45	.32890	.0614
2350.00	17.0000	.7886	.86838	337.58	.33004	.0602
2350.00	16.0000	.8450	.87578	338.70	.33123	.0589
2350.00	15.0000	.9089	.88314	339.83	.33248	.0577
2350.00	14.0000	.9819	.89048	340.96	.33380	.0564
2350.00	13.0000	1.0662	.89782	342.09	.33519	.0552
2350.00	12.0000	1.1645	.90517	343.22	.33667	.0539
2350.00	11.0000	1.2807	.91256	344.36	.33826	.0526
2350.00	10.0000	1.4202	.92000	345.50	.33997	.0512
2350.00	9.0000	1.5909	.92750	346.64	.34183	.0499
2350.00	8.0000	1.8044	.93507	347.79	.34388	.0486
2350.00	7.0000	2.0791	.94274	348.94	.34616	.0472
2350.00	6.0000	2.4456	.95052	350.10	.34875	.0458
2350.00	5.0000	2.9591	.95841	351.27	.35177	.0445
2350.00	4.0000	3.7298	.96643	352.44	.35540	.0431
2350.00	3.0000	5.0151	.97459	353.62	.35999	.0417
2350.00	2.0000	7.5868	.98290	354.80	.36634	.0403
2350.00	1.0000	15.3043	.99137	355.99	.37700	.0389
2350.00	.8000	19.1635	.99308	356.23	.38039	.0386
2350.00	.6000	25.5955	.99480	356.47	.38475	.0383
2350.00	.4000	38.4599	.99653	356.71	.39087	.0381
2350.00	.2000	77.0535	.99826	356.95	.40129	.0378
2375.00	34.0000	.3394	.74083	319.61	.31526	.0766
2375.00	33.0000	.3531	.74813	320.76	.31600	.0762
2375.00	32.0000	.3679	.75580	321.93	.31676	.0757
2375.00	31.0000	.3837	.76374	323.11	.31753	.0749
2375.00	30.0000	.4007	.77184	324.29	.31833	.0740
2375.00	29.0000	.4189	.78001	325.47	.31914	.0730
2375.00	28.0000	.4384	.78819	326.65	.31996	.0720
2375.00	27.0000	.4594	.79632	327.82	.32080	.0709
2375.00	26.0000	.4819	.80439	328.98	.32167	.0697
2375.00	25.0000	.5061	.81236	330.13	.32255	.0686
2375.00	24.0000	.5323	.82022	331.27	.32345	.0674
2375.00	23.0000	.5607	.82796	332.41	.32437	.0663
2375.00	22.0000	.5916	.83560	333.53	.32532	.0651
2375.00	21.0000	.6253	.84312	334.65	.32630	.0639
2375.00	20.0000	.6624	.85055	335.76	.32731	.0628
2375.00	19.0000	.7032	.85789	336.87	.32835	.0616
2375.00	18.0000	.7486	.86516	337.97	.32944	.0604
2375.00	17.0000	.7992	.87236	339.07	.33057	.0592
2375.00	16.0000	.8561	.87952	340.17	.33175	.0580
2375.00	15.0000	.9206	.88664	341.26	.33299	.0568
2375.00	14.0000	.9943	.89375	342.36	.33429	.0556
2375.00	13.0000	1.0793	.90086	343.46	.33567	.0544
2375.00	12.0000	1.1785	.90799	344.56	.33714	.0531
2375.00	11.0000	1.2958	.91515	345.66	.33872	.0519
2375.00	10.0000	1.4366	.92236	346.77	.34042	.0506
2375.00	9.0000	1.6088	.92963	347.88	.34227	.0494

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

t	p	v^g	z	h^g	s^g	c_p^g
2375.00	8.0000	1.8242	.93698	349.00	.34430	.0481
2375.00	7.0000	2.1013	.94442	350.12	.34658	.0468
2375.00	6.0000	2.4711	.95196	351.24	.34916	.0455
2375.00	5.0000	2.9892	.95962	352.38	.35216	.0442
2375.00	4.0000	3.7668	.96740	353.51	.35578	.0428
2375.00	3.0000	5.0635	.97533	354.66	.36036	.0415
2375.00	2.0000	7.6581	.98340	355.81	.36670	.0402
2375.00	1.0000	15.4443	.99162	356.96	.37734	.0388
2375.00	.8000	19.3378	.99328	357.20	.38073	.0386
2375.00	.6000	25.8271	.99495	357.43	.38509	.0383
2375.00	.4000	38.8059	.99663	357.66	.39121	.0380
2375.00	.2000	77.7430	.99831	357.89	.40162	.0378
2400.00	34.0000	.3460	.74878	321.52	.31593	.0760
2400.00	33.0000	.3599	.75598	322.66	.31666	.0755
2400.00	32.0000	.3749	.76350	323.81	.31742	.0746
2400.00	31.0000	.3909	.77123	324.97	.31819	.0739
2400.00	30.0000	.4080	.77908	326.13	.31897	.0730
2400.00	29.0000	.4264	.78699	327.28	.31977	.0719
2400.00	28.0000	.4461	.79489	328.43	.32059	.0708
2400.00	27.0000	.4671	.80274	329.58	.32142	.0697
2400.00	26.0000	.4898	.81051	330.71	.32227	.0686
2400.00	25.0000	.5142	.81820	331.83	.32314	.0675
2400.00	24.0000	.5406	.82578	332.94	.32403	.0663
2400.00	23.0000	.5692	.83325	334.05	.32495	.0652
2400.00	22.0000	.6004	.84062	335.15	.32589	.0640
2400.00	21.0000	.6344	.84789	336.23	.32685	.0629
2400.00	20.0000	.6718	.85507	337.32	.32785	.0618
2400.00	19.0000	.7130	.86216	338.39	.32889	.0606
2400.00	18.0000	.7587	.86919	339.47	.32996	.0595
2400.00	17.0000	.8098	.87616	340.54	.33108	.0583
2400.00	16.0000	.8672	.88309	341.61	.33225	.0572
2400.00	15.0000	.9323	.88999	342.67	.33348	.0560
2400.00	14.0000	1.0066	.89688	343.74	.33478	.0548
2400.00	13.0000	1.0923	.90377	344.81	.33615	.0537
2400.00	12.0000	1.1924	.91068	345.88	.33761	.0525
2400.00	11.0000	1.3107	.91762	346.95	.33917	.0513
2400.00	10.0000	1.4528	.92462	348.03	.34086	.0501
2400.00	9.0000	1.6265	.93167	349.11	.34270	.0488
2400.00	8.0000	1.8438	.93880	350.19	.34472	.0476
2400.00	7.0000	2.1234	.94602	351.28	.34699	.0464
2400.00	6.0000	2.4965	.95334	352.38	.34956	.0451
2400.00	5.0000	3.0192	.96077	353.48	.35255	.0439
2400.00	4.0000	3.8037	.96833	354.58	.35615	.0426
2400.00	3.0000	5.1119	.97603	355.69	.36072	.0413
2400.00	2.0000	7.7294	.98386	356.81	.36705	.0401
2400.00	1.0000	15.5843	.99185	357.93	.37768	.0388
2400.00	.8000	19.5121	.99347	358.16	.38107	.0385
2400.00	.6000	26.0586	.99509	358.39	.38543	.0383
2400.00	.4000	39.1519	.99672	358.61	.39154	.0380
2400.00	.2000	78.4323	.99836	358.84	.40195	.0378
2425.00	34.0000	.3527	.75652	323.41	.31659	.0753
2425.00	33.0000	.3667	.76360	324.54	.31732	.0746
2425.00	32.0000	.3818	.77094	325.67	.31806	.0738
2425.00	31.0000	.3980	.77845	326.80	.31882	.0729
2425.00	30.0000	.4153	.78605	327.94	.31960	.0719
2425.00	29.0000	.4338	.79369	329.07	.32039	.0708
2425.00	28.0000	.4536	.80131	330.19	.32120	.0697
2425.00	27.0000	.4748	.80889	331.30	.32202	.0686
2425.00	26.0000	.4977	.81638	332.41	.32287	.0675

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

t	p	v^g	z	h^g	s^g	c_p^g
2425.00	25.0000	.5223	.82379	333.50	.32373	.0664
2425.00	24.0000	.5489	.83111	334.59	.32461	.0652
2425.00	23.0000	.5777	.83832	335.67	.32551	.0641
2425.00	22.0000	.6091	.84543	336.73	.32644	.0630
2425.00	21.0000	.6434	.85246	337.79	.32740	.0619
2425.00	20.0000	.6811	.85939	338.85	.32839	.0608
2425.00	19.0000	.7226	.86625	339.90	.32941	.0597
2425.00	18.0000	.7688	.87305	340.94	.33048	.0586
2425.00	17.0000	.8203	.87980	341.99	.33159	.0575
2425.00	16.0000	.8782	.88651	343.03	.33275	.0564
2425.00	15.0000	.9438	.89319	344.06	.33397	.0552
2425.00	14.0000	1.0188	.89987	345.10	.33525	.0541
2425.00	13.0000	1.1053	.90655	346.14	.33661	.0530
2425.00	12.0000	1.2062	.91325	347.18	.33806	.0518
2425.00	11.0000	1.3256	.91999	348.23	.33962	.0507
2425.00	10.0000	1.4689	.92677	349.27	.34129	.0495
2425.00	9.0000	1.6442	.93362	350.32	.34312	.0484
2425.00	8.0000	1.8634	.94054	351.38	.34514	.0472
2425.00	7.0000	2.1455	.94755	352.44	.34739	.0460
2425.00	6.0000	2.5218	.95465	353.50	.34995	.0448
2425.00	5.0000	3.0491	.96188	354.57	.35293	.0436
2425.00	4.0000	3.8404	.96922	355.64	.35652	.0424
2425.00	3.0000	5.1601	.97670	356.73	.36108	.0412
2425.00	2.0000	7.8005	.98431	357.81	.36740	.0400
2425.00	1.0000	15.7241	.99208	358.90	.37802	.0388
2425.00	.8000	19.6862	.99365	359.12	.38141	.0385
2425.00	.6000	26.2900	.99523	35[illegible].34	.38576	.0383
2425.00	.4000	39.4978	.99681	35[illegible].56	.39187	.0380
2425.00	.2000	79.1216	.99840	359.78	.40228	.0378
2450.00	34.0000	.3593	.76403	325.28	.31724	.0744
2450.00	33.0000	.3735	.77096	326.39	.31796	.0736
2450.00	32.0000	.3887	.77811	327.50	.31870	.0728
2450.00	31.0000	.4050	.78539	328.61	.31945	.0718
2450.00	30.0000	.4225	.79275	329.72	.32022	.0708
2450.00	29.0000	.4411	.80012	330.82	.32100	.0697
2450.00	28.0000	.4610	.80748	331.92	.32180	.0686
2450.00	27.0000	.4824	.81478	333.01	.32261	.0675
2450.00	26.0000	.5054	.82201	334.08	.32344	.0664
2450.00	25.0000	.5302	.82916	335.15	.32429	.0653
2450.00	24.0000	.5570	.83621	336.21	.32516	.0642
2450.00	23.0000	.5861	.84317	337.26	.32606	.0631
2450.00	22.0000	.6177	.85004	338.30	.32698	.0620
2450.00	21.0000	.6523	.85682	339.33	.32793	.0609
2450.00	20.0000	.6903	.86353	340.36	.32891	.0599
2450.00	19.0000	.7322	.87017	341.38	.32992	.0588
2450.00	18.0000	.7787	.87675	342.40	.33098	.0577
2450.00	17.0000	.8306	.88328	343.41	.33208	.0567
2450.00	16.0000	.8891	.88978	344.42	.33323	.0556
2450.00	15.0000	.9552	.89626	345.44	.33444	.0545
2450.00	14.0000	1.0309	.90273	346.45	.33572	.0534
2450.00	13.0000	1.1181	.90921	347.46	.33707	.0523
2450.00	12.0000	1.2200	.91571	348.47	.33851	.0512
2450.00	11.0000	1.3404	.92225	349.49	.34005	.0501
2450.00	10.0000	1.4849	.92883	350.50	.34172	.0490
2450.00	9.0000	1.6617	.93548	351.53	.34354	.0479
2450.00	8.0000	1.8829	.94220	352.55	.34554	.0468
2450.00	7.0000	2.1674	.94901	353.58	.34778	.0456
2450.00	6.0000	2.5470	.95591	354.62	.35033	.0445
2450.00	5.0000	3.0789	.96293	355.66	.35331	.0434
2450.00	4.0000	3.8771	.97007	356.70	.35689	.0422

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

t	p	v^g	z	h^g	s^g	c_p^g
2450.00	3.0000	5.2082	.97733	357.75	.36144	.0410
2450.00	2.0000	7.8715	.98474	358.81	.36775	.0399
2450.00	1.0000	15.8638	.99229	359.87	.37835	.0387
2450.00	.8000	19.8603	.99382	360.09	.38174	.0385
2450.00	.6000	26.5213	.99536	360.30	.38609	.0383
2450.00	.4000	39.8435	.99690	360.51	.39220	.0380
2450.00	.2000	79.8107	.99845	360.73	.40261	.0378
2475.00	34.0000	.3658	.77130	327.13	.31787	.0734
2475.00	33.0000	.3802	.77806	328.22	.31858	.0726
2475.00	32.0000	.3956	.78501	329.31	.31931	.0717
2475.00	31.0000	.4120	.79206	330.39	.32006	.0707
2475.00	30.0000	.4295	.79917	331.48	.32082	.0696
2475.00	29.0000	.4483	.80629	332.55	.32159	.0686
2475.00	28.0000	.4684	.81339	333.62	.32238	.0675
2475.00	27.0000	.4900	.82043	334.68	.32318	.0664
2475.00	26.0000	.5131	.82740	335.73	.32401	.0653
2475.00	25.0000	.5381	.83429	336.77	.32485	.0643
2475.00	24.0000	.5651	.84110	337.80	.32571	.0632
2475.00	23.0000	.5944	.84782	338.82	.32660	.0621
2475.00	22.0000	.6262	.85445	339.83	.32751	.0611
2475.00	21.0000	.6611	.86101	340.84	.32845	.0600
2475.00	20.0000	.6994	.86749	341.84	.32942	.0590
2475.00	19.0000	.7416	.87391	342.84	.33042	.0579
2475.00	18.0000	.7886	.88028	343.83	.33147	.0569
2475.00	17.0000	.8409	.88661	344.82	.33256	.0559
2475.00	16.0000	.8998	.89291	345.80	.33370	.0548
2475.00	15.0000	.9666	.89919	346.79	.33490	.0538
2475.00	14.0000	1.0429	.90547	347.77	.33617	.0528
2475.00	13.0000	1.1309	.91175	348.76	.33751	.0517
2475.00	12.0000	1.2336	.91806	349.75	.33894	.0507
2475.00	11.0000	1.3550	.92441	350.73	.34048	.0496
2475.00	10.0000	1.5009	.93080	351.72	.34214	.0485
2475.00	9.0000	1.6792	.93726	352.72	.34395	.0475
2475.00	8.0000	1.9022	.94379	353.72	.34594	.0464
2475.00	7.0000	2.1892	.95040	354.72	.34817	.0453
2475.00	6.0000	2.5721	.95712	355.73	.35071	.0442
2475.00	5.0000	3.1086	.96394	356.74	.35368	.0431
2475.00	4.0000	3.9137	.97088	357.75	.35725	.0420
2475.00	3.0000	5.2562	.97795	358.78	.36179	.0409
2475.00	2.0000	7.9425	.98515	359.81	.36809	.0398
2475.00	1.0000	16.0034	.99250	360.84	.37869	.0387
2475.00	.8000	20.0342	.99399	361.05	.38207	.0385
2475.00	.6000	26.7525	.99548	361.26	.38642	.0382
2475.00	.4000	40.1892	.99698	361.46	.39252	.0380
2475.00	.2000	80.4998	.99849	361.67	.40293	.0378
2500.00	34.0000	.3723	.77832	328.95	.31849	.0724
2500.00	33.0000	.3868	.78491	330.02	.31919	.0715
2500.00	32.0000	.4023	.79164	331.08	.31992	.0706
2500.00	31.0000	.4189	.79847	332.15	.32065	.0696
2500.00	30.0000	.4365	.80534	333.20	.32140	.0685
2500.00	29.0000	.4554	.81221	334.25	.32217	.0675
2500.00	28.0000	.4757	.81905	335.29	.32295	.0664
2500.00	27.0000	.4974	.82584	336.33	.32374	.0654
2500.00	26.0000	.5207	.83256	337.35	.32456	.0643
2500.00	25.0000	.5459	.83921	338.36	.32539	.0633
2500.00	24.0000	.5731	.84578	339.37	.32624	.0622
2500.00	23.0000	.6026	.85227	340.36	.32712	.0612
2500.00	22.0000	.6347	.85868	341.35	.32802	.0602
2500.00	21.0000	.6698	.86502	342.33	.32895	.0592
2500.00	20.0000	.7084	.87129	343.31	.32991	.0581

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

t	p	v^g	z	h^g	s^g	c_p^g
2500.00	19.0000	.7510	.87750	344.28	.33091	.0571
2500.00	18.0000	.7983	.88367	345.24	.33195	.0561
2500.00	17.0000	.8512	.88980	346.21	.33303	.0551
2500.00	16.0000	.9106	.89590	347.17	.33417	.0541
2500.00	15.0000	.9779	.90200	348.13	.33536	.0531
2500.00	14.0000	1.0548	.90809	349.09	.33661	.0521
2500.00	13.0000	1.1436	.91419	350.04	.33795	.0511
2500.00	12.0000	1.2472	.92031	351.01	.33937	.0501
2500.00	11.0000	1.3696	.92648	351.97	.34090	.0491
2500.00	10.0000	1.5167	.93269	352.93	.34255	.0481
2500.00	9.0000	1.6966	.93895	353.90	.34435	.0471
2500.00	8.0000	1.9215	.94531	354.87	.34633	.0460
2500.00	7.0000	2.2110	.95174	355.85	.34856	.0450
2500.00	6.0000	2.5972	.95827	356.83	.35109	.0439
2500.00	5.0000	3.1382	.96490	357.81	.35404	.0429
2500.00	4.0000	3.9502	.97165	358.80	.35760	.0418
2500.00	3.0000	5.3042	.97853	359.80	.36213	.0408
2500.00	2.0000	8.0133	.98554	360.80	.36842	.0397
2500.00	1.0000	16.1429	.99270	361.81	.37901	.0387
2500.00	.8000	20.2081	.99415	362.01	.38240	.0384
2500.00	.6000	26.9836	.99560	362.21	.38674	.0382
2500.00	.4000	40.5348	.99706	362.41	.39285	.0380
2500.00	.2000	81.1888	.99853	362.62	.40325	.0378
2525.00	34.0000	.3787	.78509	330.75	.31909	.0714
2525.00	33.0000	.3933	.79149	331.79	.31979	.0705
2525.00	32.0000	.4090	.79802	332.83	.32051	.0695
2525.00	31.0000	.4256	.80462	333.87	.32123	.0685
2525.00	30.0000	.4435	.81125	334.90	.32198	.0675
2525.00	29.0000	.4625	.81788	335.93	.32273	.0664
2525.00	28.0000	.4829	.82448	336.94	.32350	.0654
2525.00	27.0000	.5047	.83102	337.95	.32429	.0643
2525.00	26.0000	.5282	.83751	338.94	.32509	.0633
2525.00	25.0000	.5536	.84393	339.93	.32592	.0623
2525.00	24.0000	.5810	.85027	340.91	.32676	.0613
2525.00	23.0000	.6107	.85653	341.88	.32763	.0603
2525.00	22.0000	.6431	.86273	342.84	.32852	.0593
2525.00	21.0000	.6785	.86886	343.80	.32945	.0583
2525.00	20.0000	.7174	.87492	344.75	.33040	.0573
2525.00	19.0000	.7603	.88094	345.70	.33139	.0564
2525.00	18.0000	.8080	.88691	346.64	.33242	.0554
2525.00	17.0000	.8613	.89286	347.58	.33349	.0545
2525.00	16.0000	.9212	.89878	348.51	.33462	.0535
2525.00	15.0000	.9891	.90468	349.45	.33580	.0525
2525.00	14.0000	1.0666	.91060	350.38	.33705	.0516
2525.00	13.0000	1.1562	.91652	351.32	.33838	.0506
2525.00	12.0000	1.2606	.92247	352.25	.33979	.0496
2525.00	11.0000	1.3842	.92846	353.19	.34131	.0486
2525.00	10.0000	1.5325	.93449	354.13	.34295	.0477
2525.00	9.0000	1.7139	.94059	355.07	.34474	.0467
2525.00	8.0000	1.9408	.94676	356.02	.34672	.0457
2525.00	7.0000	2.2327	.95302	356.97	.34893	.0447
2525.00	6.0000	2.6221	.95937	357.92	.35146	.0437
2525.00	5.0000	3.1677	.96582	358.88	.35440	.0427
2525.00	4.0000	3.9866	.97240	359.85	.35796	.0417
2525.00	3.0000	5.3521	.97909	360.82	.36248	.0407
2525.00	2.0000	8.0841	.98592	361.79	.36876	.0396
2525.00	1.0000	16.2824	.99289	362.77	.37934	.0386
2525.00	.8000	20.3819	.99430	362.97	.38272	.0384
2525.00	.6000	27.2146	.99571	363.17	.38706	.0382
2525.00	.4000	40.8803	.99714	363.36	.39317	.0380

APPENDIX B

THERMODYNAMIC PROPERTIES OF CESIUM VAPOR (cont'd)

t	p	v^g	z	h^g	s^g	c_p^g
2525.00	.2000	81.8777	.99857	363.56	.40357	.0378
2550.00	34.0000	.3850	.79161	332.52	.31968	.0703
2550.00	33.0000	.3998	.79782	333.54	.32037	.0694
2550.00	32.0000	.4156	.80414	334.56	.32108	.0684
2550.00	31.0000	.4324	.81052	335.57	.32180	.0674
2550.00	30.0000	.4503	.81692	336.58	.32253	.0664
2550.00	29.0000	.4695	.82331	337.57	.32328	.0654
2550.00	28.0000	.4900	.82968	338.56	.32404	.0644
2550.00	27.0000	.5120	.83599	339.54	.32482	.0634
2550.00	26.0000	.5357	.84225	340.52	.32562	.0624
2550.00	25.0000	.5612	.84844	341.48	.32643	.0614
2550.00	24.0000	.5888	.85457	342.43	.32727	.0604
2550.00	23.0000	.6188	.86062	343.38	.32813	.0594
2550.00	22.0000	.6514	.86661	344.32	.32901	.0585
2550.00	21.0000	.6871	.87254	345.25	.32993	.0575
2550.00	20.0000	.7263	.87841	346.17	.33087	.0566
2550.00	19.0000	.7696	.88424	347.10	.33186	.0556
2550.00	18.0000	.8177	.89003	348.01	.33288	.0547
2550.00	17.0000	.8714	.89579	348.93	.33394	.0538
2550.00	16.0000	.9318	.90153	349.84	.33506	.0529
2550.00	15.0000	1.0002	.90726	350.75	.33624	.0519
2550.00	14.0000	1.0784	.91300	351.66	.33748	.0510
2550.00	13.0000	1.1687	.91875	352.57	.33880	.0501
2550.00	12.0000	1.2740	.92453	353.49	.34020	.0491
2550.00	11.0000	1.3986	.93035	354.40	.34171	.0482
2550.00	10.0000	1.5482	.93622	355.32	.34334	.0473
2550.00	9.0000	1.7311	.94215	356.23	.34513	.0463
2550.00	8.0000	1.9599	.94816	357.16	.34710	.0454
2550.00	7.0000	2.2543	.95424	358.08	.34930	.0444
2550.00	6.0000	2.6470	.96042	359.01	.35182	.0435
2550.00	5.0000	3.1972	.96671	359.95	.35476	.0425
2550.00	4.0000	4.0229	.97311	360.89	.35830	.0415
2550.00	3.0000	5.3998	.97963	361.83	.36281	.0406
2550.00	2.0000	8.1548	.98628	362.78	.36909	.0396
2550.00	1.0000	16.4218	.99307	363.74	.37966	.0386
2550.00	.8000	20.5556	.99444	363.93	.38304	.0384
2550.00	.6000	27.4456	.99582	364.12	.38738	.0382
2550.00	.4000	41.2257	.99721	364.32	.39348	.0380
2550.00	.2000	82.5665	.99860	364.51	.40389	.0378

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13. ABSTRACT

The experimental program at this Laboratory to measure various thermophysical properties of sodium, potassium, and cesium has been completed. Final reports on two of the alkali metals, sodium and potassium, have been published; and this is the final reporting on cesium. Experimental results are presented for the density and vapor pressure of the liquid and for various saturation and superheat properties of the vapor. A virial equation of state is advanced and is used thermodynamically to derive additional properties of the vapor. For example, enthalpy, entropy, specific volume, and specific heat are tabulated for some 1100 selected vapor states in the temperature range from 1250° to 2550°F and in the pressure range from 0.2 to 34.0 atm.

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Security Classification

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Cesium						
High-temperature properties						
Compressibility data						
Saturated vapor						
Superheated vapor						
Monomeric gas path						
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