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THERMODYNAMIC PROPERTIES OF CARBON DISULPHIDE

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ABSTRACT

Thermodynamic properties of carbon disulphide have been evaluated up to a temperature of 750°K and a pressure of 300 atmospheres using Martin and Hou equation of state. Tables of thermodynamic properties and a temperature entropy diagram are presented.

SURVEY OF EXISTING DATA

1. Molecular Weight and Critical Data:

The available critical constants of carbon disulphide are presented in Table I.

The data earlier than 1880 is not considered for this work. The sample used by Hannay[7] was digested over sodium and distilled from quick lime into a small flask and stored over sulphuric acid under a bell jar. Calibration of the thermometer was made daily and the mean probable error was fixed at 0.16°C. For the measurement of pressure, hydrogen was used as a reference gas. The probable error in the measurement of pressure is stated to be about 0.07 atmospheres.

TABLE I

Molecular weight and critical constants of carbon disulphide
Molecular weight of carbon disulphide=76.142

Year	Investigator	T_c, °K	P_c, atm.	d_c gm./c.c.	Method	Reference
1821	de la Tour	548.16	77.8	......	a	12
1874	Avenarius	549.16	......	......	a	1
1878	Sajotschewsky	544.96	74.7	......	?*	22
1880	Hannay and Hogarth	546.12	77.9	......	a	8
1882	Hannay	550.84	78.14	......	a	7
1890	Battelli	546.16	72.87	0.377	?*	2
1890	Galitzine	552.76	......	......	?*	5
1898	Mathias	......	......	0.441	c	17
1943	Fischer and Reichel	552.16	......	......	b	4
Values selected		552.16	78.0	0.44		

a = disappearance of the meniscus.
b = disappearance of the droplets after the meniscus has broadened.
c = law of rectilinear diameter.
?* = Methods unknown.

Fischer and Reichel[4] determined the critical temperatere by the micro-melting apparatus. The refractive index of the sample of carbon disulphide used is stated to be 1.6278.

The data of Fischer and Reichel[4] for the critical temperature agrees well with those of Hannay[7] and Galitzine[5]. The data of Hannay[7] for the critical pressure was selected as the most probable. Critical density was determined by Mathias by the law of rectilinear diameters. Hence, this value is selected.

Thus, the critical constants used for this work are:

$T_c = 552.16°K$;

$P_c = 78.0$ atmospheres ;

and $d_c = 0.44$ gm/cc.

2. *Vapour Pressure*

Vapour pressure of carbon disulphide has been determined by various investigators, including Henning and Stock[9], Siemens[25], Rex[20], Waddington *et al.*[28] and Hannay[7]. The available data along with the range of availability are presented in Table II. Excepting Waddington *et al.*[28] no investigator has reported the extent of purity of sample used.

Waddington *et al.*[28] determined the purity of the sample to be 99.98 mole % by the time-temperature freezing point method. Vapour pressures were determined by ebulliometric method. Their data extend up to a pressure of about 2.7 atmospheres. The data of Siemens[25] extend up to 1 atmosphere pressure. The author claims an accuracy of 0.1 mm Hg. Vapour pressure data up to the critical point are presented in the International Critical Tables[11].

TABLE II

Vapour pressure of carbon disulphide

Year	Investigator	Range of temperature, °K	Range of pressure, atm.	Reference
1880	Wullner and Grotrian	293 – 358	0.4 – 3.0	30
1882	Hannay	313 – 550	0.8 – 78.1	7
1906	Rex	273 – 303	0.17 – 0.57	20
1913	Siemens	194 – 319	0.0 – 1.0	25
1921	Henning and Stock	248 – 284	0.04 – 0.28	9
1928	International Critical Tables	203 – 546	0 – 75	11
1962	Waddington *et al.*	277 – 353	0 – 2.7	28

In general all the available data are concordant. However, at higher temperatures the data of Hannay[7] are lower than those presented in the International Critical Tables. This may be possibly because of some error in the measurements. Hannay[7] reported a value of 78.0 atmospheres, at 550°K and 550.84°K. For this work the vapour pressure data of Hannay were not considered.

All the data were combined and smoothened taking into account the selected critical point. More weightage was given to the data of Waddington *et al.*, and the data presented in the International Critical Tables. The data were fitted to the equation :

$$\log P = A + B/T + C \log T + DT \qquad [1]$$

where, $A = 4.299296$

$B = -1385.15367$

$C = -2.087939 \times 10^{-2}$

$D = 2.929449 \times 10^{-4}$.

Over a pressure range of 1 – 78 atmospheres, the equation predicts vapour pressures with average absolute and maximum deviations of 0.48 % and 0.9 % respectively. Below 1 atmosphere, the smoothened data were used.

3. *Density of Saturated Liquid and Vapour* :

Density of saturated liquid has been determined by Schewers[23], Thorpe[26], Lowry[13], Seitz *et al* [24] and Tyrer[27]. Table III gives these data along with the range of availability. Accuracy of the data is not reported.

All the data agree very closely, the differences not exceeding 0.2%. Hence all the data were combined and smoothened.

Saturated vapour densities are presented in the International Critical Tables[11]. The data were smoothened and were used for this investigation.

TABLE III

Saturated liquid densities of carbon disulphide

Year	Investigator	Range of temperature, °K	Reference
1880	Thorpe	273.2 – 319.2	26
1912	Schwers	286.6 – 307.1	23
1914	Tyrer	273.2 – 312.2	27
1914	Lowry	293.16	13
1916	Seitz *et al.*	163.2 – 283.2	24

The saturated vapour densities wherever not available were evaluated using Martin and Hou equation of state (Equation 5).

The saturated vapour densities – available and calculated – and the saturated liquid densities were plotted and a smooth curve was drawn. The saturated liquid densities accepted for this work were taken from the smooth curve taking into consideration the observance of the law of rectilinear diameters.

4. *Heat Capacity of Ideal Gas* :

Heat capacity of carbon disulphide in the ideal gaseous state have been determined by Cross[3], Waddington *et al.*[28], and by Gordon[6].

Gordon's data are for a rigid rotator harmonic oscillator approximation, but includes the anharmonicity correction.

Waddington *et al.*[28], have taken account of centrifugal stretching, rotation-vibration interaction, vibrational anharmonicity and effect of isotopic composition. Fundamental constants recommended by Rossini *et al.*[21] were used. Also, their data agree with their experimental heat capacity data. The data of Cross[3], Waddington *et al.*[28] and Gordon[6] all agree within about 0.1%.

The data of Waddington *et al.*, was fitted over a temperature range of 273 – 1500°K to the equation :

$$C_p^* = a + bT + cT^2 + dT^3 \qquad [2]$$

where, $a = 7.130$

$b = 1.596 \times 10^{-2}$

$c = -1.234 \times 10^{-5}$

and $d = 3.363 \times 10^{-9}$.

Equation [2] predicts heat capacities with average absolute and maximum deviations of 0.21% and 0.61% respectively.

5. *Heat of Vaporization* :

Heat of vaporization of carbon disulphide has been experimentally determined at the normal boiling point by Mills[18], Mathews[16] and Wirtz[29]. Waddington *et al.*[28] determined the heat of vaporization over a temperature range of 282 – 320°K. Mills[18], Mathews[16] and Wirtz[29] did not give the extent of purity of the sample used. The sample used by Waddington *et al.*[28] is stated to be 99 98 mole% pure. All these data agree within 1%. Heat of vaporization has been tabulated in the International Critical Tables[11] and the Hand Book of Physics and Chemistry[10].

All the data were combined and smoothened. However more weightage was given to the experimental data. The smoothened data were found to agree with the actual values with a maximum deviation of 1%.

The smoothened data over a temperature range of 250 – 420°K were fitted to the equation:

$$\lambda = \lambda_0 \, (T_c - T)^n \qquad [3]$$

where, $\lambda_0 = 27.509$

$n = 0\ 40$.

Equation [3] predicts the smoothened data with average absolute and maximum deviations of 0.69% and 1.74% respectively. Over this range the Clausius-Clapeyron equation, namely,

$$\Delta H_v = (dP/dT) \cdot T (V_g - V_l) \qquad [4]$$

predicts the data with average absolute deviation of about 2.5%. Above a temperature of 420°K heats of vaporization were evaluated using Equation [3].

CALCULATION OF THERMODYNAMIC PROPERTIES

For the calculation of thermodynamic properties Martin and Hou equation of state, namely,

$$P = \frac{RT}{(V-b_0)} + \frac{A_2 + B_2 T + C_2 \exp.(-KT/T_c)}{(V-b_0)^2} + \frac{A_3 + B_3 T + C_3 \exp(-KT/T_c)}{(V-b_0)^3} + \frac{A_4}{(V-b_0)^4} + \frac{B_5 T + C_5 \exp.(-KT/T_c)}{(V-b_0)^5} \quad [5]$$

with $K = 5.475$ has been used.

The constants evaluated by the method outlined by the authors[15] are:

$$\begin{aligned}
b_0 &= 4.57371 \times 10^{-2} \\
A_2 &= -12.362892 \\
B_2 &= 6.5174345 \times 10^{-3} \\
C_2 &= -424.13465 \\
A_3 &= 1.3361083 \\
B_3 &= -6.3478989 \times 10^{-4} \\
C_3 &= 58.190466 \\
A_4 &= -7.198832 \times 10^{-2} \\
B_5 &= 3.5879031 \times 10^{-6} \\
C_5 &= -6.801570 \times 10^{-2}
\end{aligned}$$

In the region of available data Martin and Hou Equation was found to predict pressures with average absolute and maximum deviations of 1.95% and 6% respectively. These are shown in Table IV.

Entropy and Enthalpy of the Superheated Vapour:

Considering the entropy and enthalpy to be functions of volume and temperature, we have,

$$dS = (\partial S/\partial T)_V \, dT + (\partial S/\partial V)_T \, dV \quad [6]$$

Using Maxwell's relations, we obtain,

$$dS = (C_v^* / T) \, dT + (\partial P/\partial T)_V \, dV \quad [7]$$

Using $dH = TdS + VdP$ in Equation [7] we obtain,

$$\begin{aligned}
dH &= C_v^* \, dT + T(\partial P/\partial T)_V \, dV + VdP \\
&= C_v^* \, dT + d(PV) - PdV + T(\partial P/\partial T)_V \, dV \quad [8]
\end{aligned}$$

TABLE IV

Comparison of calculated pressures

Temp. °K	P. Atm. *	$P_{calc.}$ (This work)	% Deviation	$P_{calc.}$ (O'Brien) & Alford[19])	% Deviation
330.0	1.40	1.379	1.49	1.407	−0.521
340.0	1.88	1.847	1.76	1.889	−0.50
350.0	2.48	2.422	2.35	2.484	−0.16
360.0	3.20	3.120	2.48	3.208	−0.26
370.0	4.09	3.985	2.58	4.106	−0.39
380.0	5.19	5.057	2.57	5.223	−0.63
390.0	6.45	6.263	2.90	6.477	−0.43
400.0	7.92	7.797	1.56	8.078	−1.99
410.0	9.70	9.438	2.70	9.746	−0.47
420.0	11.70	11.406	2.52	11.82	−1.04
430.0	14.00	13.871	0.93	14.379	−2.71
440.0	16.70	16.607	0.56	17.197	−2.98
450.0	19.75	19.767	−0.09	20.430	−3.44
460.0	23.15	23.246	−0.41	23.943	−3.43
470.0	27.00	27.598	−2.21	27.922	−3.42
480.0	31.25	33.026	−5.68	33.617	−7.58
490.0	36.10	38.255	−5.97	38.466	−6.55
500.0	41.60	43.530	−4.64	43.016	−3.40
510.0	47.60	49.313	−3.60	47.481	0.25
520.0	54.20	55.443	−2.29	51.290	5.37
530.0	61.50	61.908	−0.66	53.595	12.85
535.0	65.00	65.264	−0.41	53.698	17.39
540.0	68.80	68.760	0.06	52.260	24.04
545.0	72.55	72.409	0.19	47.145	35.02
550.0	76.25	76.227	0.03	30.396	60.14
552.16	78.00	78.000	0.00	15.488	80.14
Average absolute deviation%			1.947		10.58

Deviation = $(P - P_{calc.})/P$

*Smoothened experimental data

From Equation [5] we have,

$$(dP/dT)_V = \frac{R}{(V-b_0)} + \frac{B_2 - (K/T_c)\, C_2 \exp.(-KT/T_c)}{(V-b_0)^2}$$

$$+ \frac{B_3 - (K/T_c)\, C_3 \exp.(-KT/T_c)}{(V-b_0)^3} + \frac{B_5 + C_5\,(K/T_c) \exp.(-KT/T_c)}{(V-b_0)^5} \qquad [9]$$

Using Equations [7] and [8],

$$S = \int (C_v^* / T)\, dT + \int (\partial P/\partial T)_V\, dV \qquad [10]$$

and

$$H = \int (C_v^*)\, dT + \int T\,(\partial P/\partial T)_V\, dV - \int P dV + PV \qquad [11]$$

Using Equations [2] and [9] in the above equations and carrying out the integration, we obtain expressions for entropy and enthalpy as :

$$S = (a-R)\, ln\, T + bT + (c/2)T^2 + (d/3)T^3 + R\, ln\,(V-b_0)$$

$$- \frac{B_2}{(V-b_0)} - \frac{B_3}{2\,(V-b_0)^2} - \frac{B_5}{4\,(V-b_0)^4}$$

$$+ \left[\frac{C_2}{(V-b_0)} + \frac{C_3}{2\,(V-b_0)^2} + \frac{C_5}{4\,(V-b_0)^4}\right](K/T_c)\exp.(-KT/T_c) + C_S \qquad [12]$$

and

$$H = (a-R)\,T + (b/2)\,T^2 + (c/3)\,T^3 + (d/4)\,T^4$$

$$+ \frac{A_2 + (1 + KT/T_c)\, C_2 \exp.(-KT/T_c)}{(V-b_0)} + \frac{A_3 + (1 + KT/T_c)\, C_3 \exp.(-KT/T_c)}{(V-b_0)^2}$$

$$+ \frac{A_5}{3\,(V-b_0)^3} + \frac{(1 + KT/T_c)\, C_5 \exp.(-KT/T_c)}{4\,(V-b_0)^4} + PV - RT + C_H \qquad [13]$$

where C_S and C_H are the constants of integration.

In the present work the reference state chosen is $H = 0$ and $S + R\, ln\, P = 0$ for elements.

Entropy value at the normal boiling point was evaluated using the ideal gas thermodynamic properties and the Berthelot correction. Enthalpy at the normal boiling point was evaluated by making use of the heat of formation at 0°K, the ideal gas thermodynamic properties and the Berthelot correction for enthalpy. The integration constants C_S and C_H were evaluated using the values of entropy and enthalpy at the normal boiling point.

Entropy and enthalpy of the superheated vapour were evaluated by making use of the calculated specific volume in Equations [12] and [13].

Entropy and enthalpy of saturated vapour were evaluated by using the experimental specific volumes in Equations [12] and [13]. Wherever the experimental data were not available these were calculated using Equation [5] and were used.

Entropy and Enthalpy of the Saturated Liquid:

The entropy of vaporization is related to the heat of vaporization by the relation

$$\Delta H_v = T \Delta S_v \qquad [14]$$

The entropy and enthalpy of the saturated liquid were calculated using the equations

$$S_l = S_g - \Delta S_v \qquad [15]$$

$$H_l = H_g - \Delta H_v \qquad [16]$$

INTERNAL CONSISTENCY OF THE TABULATED RESULTS

The relation $dH = TdS + VdP$ may be used to check the internal consistency of the entropy and enthalpy values.

At constant pressure,

$$dH = TdS \qquad [17]$$

Hence, $dH = d(TS) - SdT$ from which,

$$H_1^2 = T_2 S_2 - T_1 S_1 - \int_1^2 SdT \qquad [18]$$

Internal consistency checks were made for superheated region by using Equation [18]. The definite integral in Equation [18] was evaluated by Simpson's rule. Table V gives the comparison of calculated and tabulated values of changes of enthalpy ΔH for 5 isobars.

TABLE V

Comparison of the values of Δ H

Isobar atm.	Range of temp. °K	$\Delta H_{calc.}$	ΔH_{Tables}	% Deviation
1.0	350 – 750	5131.0	5129	0.04
10 0	450 – 750	4178.5	4180	0.04
100.0	570 – 750	5438.7	5444	0.10
200.0	670 – 750	2348.5	2350	0.06
250.0	690 – 750	1606.1	1608	0.12

RESULTS AND DISCUSSION

The properties of saturated liquid and vapour are presented in Table VI and of the superheated vapour in Table VII.

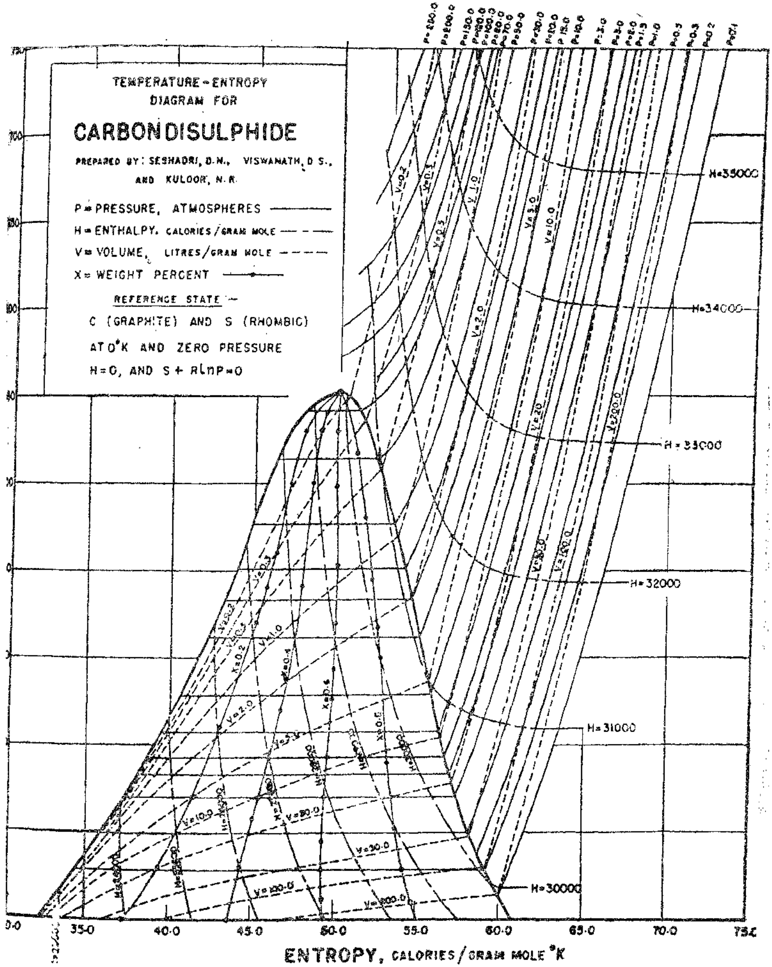
Thermodynamic properties of carbon disulphide were evaluated earlier by O'Brien and Alford[19]. These workers used Beattie-Bridgeman equation of state for the evalution of thermodynamic properties. The Beattie-Bridgeman equation of state constants were evaluated by using the generalised constants given by Maron and Turnbull[14].

The critical temperature and pressure used by O'brien and Alford[19], namely $T_c = 546.16^\circ K$ and $P_c = 75.0$ atmospheres correspond to the data prior to 1900. An authoritative review of Kobe and Lynn[12] gives the constants as $T_c = 552.16^\circ K$ and $P_c = 78.0$ atmospheres. Hence, it can be seen that O'Brien and Alford did not use the correct set of critical constants.

Using the correct set of critical constants, the constants of the Beattie-Bridgeman equation were calculated. The constants were found to agree well with those calculated by O'Brien and Alford[19].

A comparison of Martin and Hou equation and the Beattie-Bridgeman equations with the experimental data are made in Table IV for the saturated region. Around the critical region Beattie-Bridgeman equation fails to predict pressures satisfactorily However in the low pressure regions a good comparison could be seen. A comparison of the two equations in the superheated region is highly desirable, but could not be made owing to lack of data. In general it is believed that the data calculated in this work is superior to the data of O'Brien and Alford[19] as it can predict properties around the critical region and also at high pressures.

Calculation of thermodynamic properties of carbon disulphide were made up to a temperature of $750^\circ K$ and a pressure of 300 atmospheres. The calculated properties are represented graphically as an entropy temperature diagram and is shown as Fig. 1.


TEMPERATURE – ENTROPY
DIAGRAM FOR
CARBON DISULPHIDE
PREPARED BY: SESHADRI, D.N., VISWANATH, D.S., AND KULOOR, N.R.
P = PRESSURE, ATMOSPHERES
H = ENTHALPY, CALORIES / GRAM MOLE
V = VOLUME, LITRES / GRAM MOLE
X = WEIGHT PERCENT
REFERENCE STATE –
C (GRAPHITE) AND S (RHOMBIC)
AT 0°K AND ZERO PRESSURE
H = 0, AND S + R ln P = 0
H=35000
H=34000
H=33000
H=32000
H=31000
H=30000
35·0
40·0
45·0
50·0
55·0
60·0
65·0
70·0
ENTROPY, CALORIES / GRAM MOLE °K

CARBON DISULPHIDE

TABLE VI

Properties of Saturated Liquid and Vapour

T°K	P Atm.	V_l	V_g	S_l	ΔS_v	S_g	H_l	ΔH_v	H_g
250.0	0.0526	0.05742	390.0	32.35	28.43	60.78	22701	7107	29808
260.0	0.0882	0.05803	241.9	33.20	26.97	60.17	22904	7011	29915
270.0	0.1447	0.05866	151.6	33.98	25.61	59.59	23085	6915	30000
280.0	0.2270	0.05930	98.82	34.70	24.33	59.03	23279	6812	30091
290.0	0.3464	0.06000	66.24	35.39	23.14	58.53	23470	6710	30180
300.0	0.5092	0.06067	45.17	36.03	22.03	58.06	23657	6601	30258
310.0	0.7300	0.06143	30.66	36.70	20.98	57.68	23809	6505	30314
320.0	1.0200	0.06228	24.70	37.39	19.99	57.38	24077	6396	30473
330.0	1.4000	0.06298	18.66	37.99	19.04	57.03	24281	6284	30565
340.0	1.88	0.06502	14.22	38.57	18.15	56.72	24478	6170	30648
350.0	2.48	0.06524	11.04	39.15	17.29	56.44	24678	6052	30730
360.0	3.20	0.06569	8.712	39.72	16.47	56.19	24877	5930	30807
370.0	4.09	0.06627	6.921	40.25	15.69	55.94	25074	5804	30878
380.0	5.19	0.06780	5.517	40.73	14.95	55.68	25263	5680	30943
390.0	6.45	0.06897	4.505	41.26	14.21	55.47	25470	5541	31011
400.0	7.92	0.07005	3.643	41.72	13.51	55.23	25653	5402	31055
410.0	9.70	0.07129	3.033	42.23	12.82	55.05	25865	5257	31122
420.0	11.70	0.07272	2.521	42.68	12.17	54.85	26058	5113	31171
430.0	14.00	0.07443	2.069	43.10	11.51	54.61	26244	4948	31192
440.0	16.70	0.07614	1.722	43.52	10.87	54.39	26440	4781	31221

TABLE VI—(*contd.*)

T°K	P atm.	V_l	V_g	S_l	ΔS_v	S_g	H_l	ΔH_v	H_g
450.0	19.75	0.07809	1.436	43.93	10.24	54.17	26631	4606	31237
460.0	23.15	0.08023	1.210	44.35	9.61	53.96	26831	4421	31252
470.0	27.00	0.08294	0.9965	44.69	8.98	53.67	26999	4221	31220
480 0	31.25	0.08574	0.7964	44.92	8.35	53.27	27115	4009	31124
490.0	36.10	0.08916	0.6621	45.25	7.71	52 96	27293	3777	31070
500.0	41.60	0 09285	0.5619	45.68	7.04	52.72	27514	3520	31034
510.0	47.60	0.09749	0.4729	46.09	6.34	52.43	27733	3233	30966
520.0	54.20	0.10345	0.3966	46.53	5.58	52.11	27973	2901	30874
530.0	61.50	0.11230	0.3297	47.03	4.72	51.75	28246	2499	30745
535.0	65 00	0.11786	0.2992	47.31	4.22	51.53	28405	2257	30662
540.0	68.80	0.12441	0.2681	47.63	3.64	51.27	28582	1966	30548
545.0	72.55	0.13311	0.2339	48.00	2.92	50.92	28782	1591	30373
550.0	76.25	0.14929	0.1923	48.51	1.81	50.32	29087	984.4	30071
552.16	78.00	0.17305	0.17305	50.01	0.0	50.01	29909	0.0	29909

TABLE VII

Properties of Superheated Carbon disulphide

Pressure range: 0.10 to 5.00 atms.

T°K	P Atms.	0.10	0.20	0.30	0.50	0.80	1.00	1.50	2.00	3.00	5.00
280.0	V	228.2	113.3								
	H	30130	30115								
	S	60.72	59.30								
300.0	V	244.9	121.8	80.78	47.94						
	H	30349	30337	30324	30297						
	S	61.47	60.06	59.23	58.14						
320.0	V	261.6	130.3	86.49	51.47	31.77	25.19				
	H	30572	30561	30550	30529	30496	30473				
	S	62.19	60.79	59.96	58.89	57.88	57.38				
340.0	V	278.1	138.6	92.15	54.95	34.01	27.03	17.72			
	H	30796	30788	30779	30762	30735	30717	30670			
	S	62.87	61.48	60.65	59.60	58.60	58.12	57.21			
360.0	V	294.7	147.0	97.77	58.38	36.21	28.82	18.97	14.04	9.094	
	H	31025	31018	31011	30996	30974	30959	30921	30882	30800	
	S	63.53	62.13	61.31	60.27	59.29	58.81	57.92	57.27	56.29	
380.0	V	311.2	155.3	103.3	61.77	38.38	30.59	20.19	14.98	9.774	5.587
	H	31257	31251	31245	31232	31214	31202	31170	31138	31072	30929
	S	64.15	62.76	61.95	60.91	59.94	59.47	58.60	57.96	57.02	55.71

TABLE VII – (*contd.*)

Pressure Range: 0.10 to 5.00 atms.

T°K	P Atms.	0.10	0.20	0.30	0.50	0.80	1.00	1.50	2.00	3.00	5.00
400.0	V	327.7	163.6	108.9	65.15	40 53	32.32	21.37	15.90	10.42	6.027
	H	31491	31486	31481	31471	31455	31444	31419	31392	31337	31222
	S	64.75	63.37	62.55	61.52	60.55	60.09	59.24	58.61	57.70	56.46
420.0	V	344.2	171.9	114.5	68 50	42.65	34.03	22.54	16.80	11.05	6.441
	H	31729	31724	31720	31711	31698	31689	31667	31645	31599	31504
	S	65.33	63.95	63.13	62.10	61.15	60.69	59.84	59.23	58.34	57.15
440.0	V	360.7	180.2	120.0	71.84	44.76	35.73	23.70	17.68	11.66	6.836
	H	31969	31965	31961	31954	31943	31935	31917	31898	31859	31780
	S	65.89	64.51	63.70	62.67	61.72	61.26	60.42	59.82	58.95	57.79
460.0	V	377.1	188.4	125.5	75 17	46 86	37.42	24.84	18.55	12.25	7.217
	H	32212	32208	32205	32200	32189	32183	32167	32151	32118	32051
	S	66.43	65.05	64.24	63.21	62.26	61.81	60.98	60.38	59.52	58.40
480.0	V	393 6	196.7	131.0	78.49	48.95	39.10	25.97	19.41	12.84	7.587
	H	32457	32454	32452	32446	32438	32432	32418	32404	32376	32319
	S	66.95	65.57	64.76	63.74	62.79	62.34	61.51	60.92	60.07	58.96
500.0	V	410.0	204.9	136.5	81.81	51.03	40.78	27.10	20.26	13.42	7.950
	H	32705	32703	32700	32695	32688	32683	32671	32659	32635	32585
	S	67.46	66.08	65.27	64.25	63.30	62.85	62.03	61.44	60.60	59.51

TABLE VII—(*contd.*)

Pressure Range : 0.10 to 5.00 atms.

T°K	P atms.	0.10	0.20	0.30	0.50	0.80	1.00	1.50	2.00	3.00	5.00
520.0	V	426.5	213.1	142.0	85.12	53.11	42.45	28.22	21.11	14.00	8.307
	H	32955	32953	32951	32947	32941	32936	32926	32915	32894	32850
	S	67.95	66.57	65.76	64.74	63.80	63.35	62.53	61.94	61.11	60.03
540.0	V	442.2	221 4	147.5	88.42	55.19	44.11	29.34	21.95	14.57	8.659
	H	33208	33206	33204	33201	33195	33191	33182	33172	33154	33115
	S	68.43	67.05	66.24	65.22	64.28	63.83	63.01	62.43	61.60	60.53
560.0	V	459.3	229.6	153.0	91.72	57.25	45.77	30 45	22.80	15.14	9 008
	H	33463	33461	33459	33456	33451	33448	334 9	33431	33414	33380
	S	68.89	67.51	66.70	65.68	64.74	64.30	63.48	62.90	62.07	61.01
580.0	V	475.8	237 8	158 5	95.02	59.33	47.43	31.56	23.63	15.70	9.354
	H	33720	33718	33717	33714	33709	33706	33699	33691	33676	33646
	S	69.34	67.96	67.15	66.14	65.20	64.75	63 93	63.35	62.53	61.48
600.0	V	492.2	246.0	164.0	98.32	61.39	49 09	32.67	24 47	16 26	9.697
	H	33979	33977	33976	33973	33969	33963	33957	33950	33936	33909
	S	69.78	68.40	67.59	66.58	65.64	65.19	64.38	63 80	62 98	61.93
620.0	V	508.6	254.2	169.4	101.6	63 46	50.73	33.78	25.30	16.82	10 04
	H	34239	34238	34237	34234	34231	34128	34222	34216	34204	34179
	S	70.21	68.83	68 02	67.00	66.07	65.62	64.81	64.23	63.41	62.36

TABLE VII—(*contd.*)

Pressure Range : 0.10 to 5.00 atms.

T°K	P atms.	0.10	0.20	0.30	0.50	0.80	1.00	1.50	2.00	3 00	5.00
	V	525.0	262.5	174 9	104.9	65.52	52.39	34 89	26.13	17.38	10.38
640.0	H	34502	34501	34500	34498	34494	34492	34486	34481	34468	34445
	S	70.62	69.25	68.44	67.42	66.48	66.04	65.23	64.65	63.83	62.79
	V	541.5	270.7	180.4	108.2	67.58	54.04	36 00	28.96	17.94	10.72
660.0	H	34766	34765	34764	34762	34759	34757	34752	34748	34737	34716
	S	71.03	69.65	68.85	67.83	66.89	66.45	65.64	65.06	64.24	63.20
	V	557.9	278.9	185.9	111.5	69.64	55.69	37.09	27.79	18 49	11.05
680.0	H	35023	35022	35021	35019	35016	35015	35010	35005	34995	34976
	S	71.43	70.05	69.24	68.23	67.29	66.84	66.03	65.46	64 64	63.61
	V	574.3	287.1	191.4	114.8	71.70	57.34	38.20	28 62	19 05	11.39
700.0	H	35300	35299	35298	35296	35293	35292	35287	35283	35274	35256
	S	71.81	70.44	69.63	68.61	67.68	67.23	66.42	65.85	65.03	64.00
	V	590.7	295.3	196.8	118.1	73.76	58.99	39.30	29.45	19.60	11.73
720.0	H	35569	35568	35567	35565	35563	35861	35557	35552	35544	35527
	S	72.19	70.82	70.01	69 00	68.06	67.61	66.80	66.23	65.41	64.38
	V	615.3	307.6	205 1	123.0	76.85	61.46	40.95	30.69	20.43	12.23
750.0	H	35974	35974	35973	35971	35969	35967	35964	35960	35952	35937
	S	72.75	71.37	70.56	69.55	68.61	68.17	67.36	66 78	65.97	64.94

TABLE VII—(*contd.*)

Pressure Range: 8.0 to 60.0 atms.

T°K	P Atms.	8.0	10.0	15.0	20.0	25.0	30.0	40.0	50.0	60.0
	V	3.836	2.958							
420.0	H	31350	31228							
	S	55.93	55.27							
	V	4.115	3.202	1.968						
440.0	H	31653	31563	31309						
	S	56.64	56.03	54.77						
	V	4.377	3.427	2.149	1.495					
460.0	H	31945	31870	31668	31434					
	S	57.28	56.71	51.56	54.58					
	V	4.627	3.638	2.313	1.641	1.228	0.9390			
480.0	H	32229	32166	32000	31815	31604	31349			
	S	57.89	57.34	56.27	55.39	54.60	53.79			
	V	4.869	3.840	2.464	1.770	1.348	1.060	0.6739		
500.0	H	32508	32455	32315	32163	31997	31809	31319		
	S	58.46	57.93	56.91	56.11	55.40	54.73	53.34		
	V	5.104	4.035	2.606	1.889	1.454	1.161	0.7824	0.5295	
520.0	H	32783	32737	32618	32491	32354	32205	31856	31364	
	S	59.00	58.49	57.51	56.75	56.10	55.51	54.39	53.15	

TABLE VII—(*contd.*)

Pressure Range: 8.0 to 60.0 atms.

T°K	P Atms.	8.0	10.0	15.0	20.0	25.0	30.0	40.0	50.0	60.0
	V	5.334	4.224	2.743	2.000	1.552	1.250	0 8672	0.6265	0.4480
540.0	H	33056	33016	32913	32804	32689	32566	32291	31957	31499
	S	59.51	59.01	58.06	57.34	56.73	56.19	55.22	54,27	53.18
	V	5.560	4.410	2.875	2.106	1.643	1.332	0.9403	0.6993	0.5315
560.0	H	33328	33293	33202	33108	33009	32905	32678	32419	32110
	S	60.01	59.52	58.59	57.89	57.31	56.81	55.92	55.11	54.29
	V	5.783	4.592	3.003	2.208	1.729	1.409	1.006	0.7613	0.5941
580.0	H	33599	33568	33487	33404	33318	33228	33036	32824	32585
	S	60.48	60 00	59.09	58.41	57.86	57.37	56.55	55.82	55.12
	V	6.003	4.772	3.129	2.307	1.812	1.482	1.068	0.8167	0.6472
600 0	H	33870	33842	33770	33696	33619	33540	33374	33195	32998
	S	60.94	60.46	59.57	58.91	58.37	57 90	57.12	56.45	55.83
	V	6.222	4.949	3.252	2.403	1.893	1.552	1.125	0.8678	0.6947
620.0	H	34141	34115	34050	33984	33915	33845	33699	33543	33377
	S	61.39	60.91	60.03	59.38	58.85	58.40	57.65	57.02	56.45
	V	6.439	5.125	3.374	2.498	1.972	1.620	1.181	0.9158	0.7384
640.0	H	34412	34389	34330	34269	34208	34145	34014	33877	33732
	S	61.82	61.35	60.47	59.83	59.32	58.88	58.15	57.55	57.01

TABLE VII—(*contd.*)

Pressure Range: 8.0 to 60.0 atm.

T°K	P Atms.	8.0	10.0	15.0	20.0	25.0	30.0	40.0	50.0	60.0
	V	6.654	5.300	3.494	2.591	2.048	1.687	1.234	0.9616	0.7795
660.0	H	34683	34662	34608	34553	34497	34440	34322	34199	34072
	S	62.23	61.77	60.90	60.27	59.76	59.33	58.63	58.04	57.53
	V	6.869	5.474	3.613	2.683	2.124	1.752	1.286	1.006	0.8186
680.0	H	34955	34936	34886	34835	34784	34732	34625	34514	34399
	S	62.64	62.18	61.32	60.69	60.19	59.77	59.08	58 51	58.02
	V	7.082	5.646	3.731	2.773	2.199	3.815	1.336	1.048	0.8561
700.0	H	35228	35210	35164	35117	35070	35002	34923	34822	34719
	S	63.04	62.57	61.72	61.10	60.60	60.19	59 51	58.96	58.48
	V	7.295	5.818	3.848	2.863	2.272	1.878	1.385	1.090	0.8924
720.0	H	35502	35485	35442	35398	35354	35310	35219	35126	35032
	S	63.42	62.96	62.11	61.49	61.00	60.60	59.93	59.39	58.92
	V	7.613	6.074	4.023	2.997	2.381	1 971	1.458	1.150	0.9451
750.0	H	35914	35898	35859	35820	35780	35740	35659	35576	35492
	S	63.98	63.52	62.68	62 07	61.58	61.18	60.53	60.00	59.55

TABLE VII – (*contd.*)

Pressure Range: 80.0 to 300.0 atms.

T°K	P. Atms.	80.0	100.0	150.0	200.0	250.0	300 0
	V	0.2775					
560.0	H	31057					
	S	52.06					
	V	0.3713	0.1942				
580.0	H	31970	30763				
	S	53.67	51.35				
	V	0.4286	0 2861				
600.0	H	32537	31918				
	S	54.63	53.31				
	V	0.4745	0.3373	0.1289			
620.0	H	33003	32553	30746			
	S	55.39	54.36	51.01			
	V	0.5144	0.3773	0.1806			
640.0	H	33417	33057	31822			
	S	56.05	55.16	52.72			
	V	0.5505	0.4117	0.2211			
660 0	H	33798	33496	32580			
	S	56.64	55.83	53.88			

TABLE VII—(*concld.*)

Pressure Range: 80.0 to 300.0 atms.

T°K	P Atms.	80.0	100.0	150.0	200.0	250.0	300.0
680.0	V	0.5840	0.4424	0.2514			
	H	34157	33897	33150			
	S	57.17	56.43	54.74			
700.0	V	0.6155	0.4708	0.2771	0.1778	0.1325	
	H	34502	34272	33637	32882	32275	
	S	57.67	56.97	55.44	53.98	52.85	
720.0	V	0.6456	0.4974	0.2999	0.2006	0.1447	0.1273
	H	34835	34629	34074	33453	32810	32566
	S	58.14	57.48	56.06	54.78	53.60	53.04
750.0	V	0.6887	0.5349	0.3306	0.2292	0.1687	0.1384
	H	35320	33141	34673	34174	33637	33244
	S	58.59	58.17	56.87	55.76	54.73	53.96

Nomenclature

$A, B, C, D,$	– Constants in Equation [1].
$a, b, c, d,$	– Constants in Equation [2].
$b_0, A_2, B_2, C_2, A_3, B_3, C_3, A_4, B_5, C_5, K$	– Constants in Equation [5]
C_p	– Heat capacity at constant pressure, cal./gm. mole °K.
C_v	– Heat capacity at constant volume, cal./gm. mole °K.
C_S, C_H	– Constants of integration in Equations [12] and [13] respectively.
H	– Enthalpy, cal./gm. mole.
P	– Pressure, atmospheres.
R	– Gas constant, liter atm/gm. mole °K.
S	– Entropy, cal./gm. mole °K.
T	– Temperature, °K.
V	– Specific volume, litres/gm. mole.
ΔH_v	– Enthalpy of vaporization, cals./gm mole.
ΔS_v	– Entropy of vaporization, cals./gm. mole °K.

Superscript :

*	– Properties at zero pressure or ideal gaseous state.

Subscripts :

c	– Critical point.
g	– Gas or vapour.
l	– Liquid
p	– Pressure
T	– Temperature
v	– Volume.

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