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THE THERMODYNAMIC AND TRANSPORT PROPERTIES
OF SODIUM AND SODIUM VAPOR

by

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by

E. L. Dunning

ABSTRACT

The thermodynamic properties for the saturated and superheated phases of sodium are presented in tabular form and as a Mollier diagram. The density, thermal conductivity, viscosity, specific heat, and surface tension of the metal are given by tables and charts. The methods used in determining the properties are discussed.

I. INTRODUCTION

Sodium has become an important heat transfer medium and more knowledge of the thermodynamic and transport properties of the metal is needed. Heretofore, reliable data on sodium properties were scattered and covered a narrow range of temperature. It is the purpose of this report to present, in convenient form, the thermodynamic and transport properties of sodium and sodium vapor, to increase the range of coverage, and to discuss the methods used in determining the values for the given properties.

Current literature on the subject of the properties of sodium is meager, and the values which are reported are not always in agreement. To the extent that they are available, experimental data which seemed the most reliable were used. For areas not covered by reported data, theoretical calculations were combined with known or estimated values. The results obtained are believed to be of sufficient accuracy for most uses.

The properties presented here are not complete but are of sufficient scope to be used in making design calculations for heat transfer equipment. The values given cover the portion of the saturation curve from the melting point, 97.81°C , to 1300°C , the mixture region from 50 to 100% of saturation, and the superheat values range from 428°C to 1300°C .

II. VAPOR PRESSURE RELATIONSHIPS

Several empirical equations have been expressed for determining the vapor pressure data of sodium. Likewise, this is the area where most inconsistencies of published data occur. Some of the equations follow and are discussed.

A. Vapor Pressure Equations

Ditchburn and Gilmour⁽¹⁾ developed an equation by correlating the experimental results of a number of investigators:

$$\log P = - \frac{5567}{T} - 0.5 \log T + 6.354 \quad . \quad (1)$$

This equation gives a normal boiling point of 1154°K.

An equation in two parameters was obtained from their own experimental work by Makansi, Muendel, and Selke:⁽²⁾

$$\log P = - \frac{5220}{T} + 4.521 \quad . \quad (2)$$

This equation gives a normal boiling point of 1154.5°K.

Inatomi and Parrish⁽³⁾ used the equation

$$\log P = - \frac{5775}{T} - 1.274 \log T + 8.863 \quad (3)$$

and obtained a normal boiling point of 1165°K.

In more recent work, Kirillov and Grachev⁽⁴⁾ developed an equation as follows:

$$\log P = - \frac{5589}{T} - 0.5 \log T + 6.270 \quad (4)$$

which gives 1180°K as the boiling point.

B. Temperature Pressure Data

The temperature pressure data presented in this report were obtained by the use of Equation (1) above, which gives a normal boiling point temperature of 1154°K. Equation (2) gives almost the same value as well as coincidental values at other pressures. The Liquid-Metals Handbook⁽⁵⁾ and a report of the Wright Air Development Center⁽⁶⁾ list 1154°K as the boiling point for sodium at one atmosphere. Equation (1) was selected instead of Equation (2) because Equation (2), being of the form

$$\log P = - (A/T) + C \quad ,$$

assumes that the latent heat of vaporization is independent of temperature. This is not the case, as can be seen later in this report.

III. DENSITY

Two equations were considered in determining the density of liquid sodium. The following equation was given in the Liquid-Metals Handbook⁽⁵⁾ and was used by Sittig:⁽⁷⁾

$$d = 0.9490 - 22.3 \times 10^{-5}t - 1.75 \times 10^{-8}t^2 \quad . \quad (5)$$

Another equation given in the Liquid-Metals Handbook⁽⁵⁾ is

$$d = 0.9514 - 2.392 \times 10^{-4}t \quad . \quad (6)$$

Both of these equations give the same results over the temperature range between 97.81°C and 900°C. Their results differ slightly between 900°C and 1300°C. Equation (5) was used to determine the data in this report, as it was thought to be more reliable at the higher temperatures. The WADC report⁽⁶⁾ also shows a nonlinear relationship for the liquid density.

A. Specific Volume

Values of the specific volume of the liquid sodium are presented in Table 1 (Appendix) as the reciprocals of the density, $1/d$, where d is obtained from Equation (5).

The specific volumes of the saturated and superheated vapors were obtained by using the perfect gas equation and applying the compressibility factor, z , giving

$$Pv = zRT \quad . \quad (7)$$

The compressibility factor was obtained from the generalized compressibility charts.⁽⁸⁾

B. Critical Temperature and Pressure

The values of the critical constants are needed in order to make use of the compressibility charts. Two methods of determining the critical values were used.

1. Meisner and Redding⁽⁹⁾ suggest that the following empirical equations be used.

$$T_c = 1.70 T_b - 2.0 \quad (8)$$

$$V_c = (0.377 \bar{P} + 11.0)^{1.25} \quad (9)$$

$$P_c = \frac{20.8 T_c}{V_c - 8.0} \quad . \quad (10)$$

where $T_b = 1154^\circ\text{K}$ and T_c becomes 1960°K . $\bar{P}$, the parachor, was estimated from data in Sittig,⁽⁷⁾ to be 104.2. Then $V_c = 130$ cc/gram and $P_c = 363$ atm.

2. Watson⁽¹⁰⁾ suggests the following empirical equations:

$$\ln T_e = \frac{9.8 T_e}{T_b} - 4.2 \quad (11)$$

$$\frac{T_e}{T_c} = 0.283 \left(\frac{M}{d_b} \right)^{0.18} \quad (12)$$

Using the known values $T_b = 1154^\circ\text{K}$ and $M = 23$, there is found $d_b = 0.739$ gm/cc (density at the boiling point). Substitution in Equations (1) and (12) gives $T_c = 2560^\circ\text{K}$.

All the literature sources^(3,6,11,12) give 2273°K for the critical temperature and 343 atm for the critical pressure. An average of the values obtained by the above two methods is approximately that reported in the literature cited. The literature sources do not refer to the primary source of their data.

In light of the foregoing discussion the values selected for use in this report are as follows:

$$T_c = 2273^\circ\text{K}$$

$$P_c = 343 \text{ atm.}$$

IV. DIMERIZATION

Sodium vapor is monatomic at normal temperature and dimerizes to Na_2 as the temperature is increased at constant pressure. The reaction can be expressed as

In the calculations carried out for this report, the dimer formed was accounted for by first evaluating the properties on a molar basis and then dividing by the molecular weights of the mixture.

A. Molecular Weights

The molecular weight is proportional to the amount of dimer in the mixture. To obtain the mole fractions, X_1 and X_2 , of the Na and Na_2 components, respectively, the following equation was used:

$$K_p = P_{\text{Na}_2} / (P_{\text{Na}})^2 \quad (13)$$

where K_p is the equilibrium constant, and P_{Na} and P_{Na_2} represent the partial pressures of the Na and Na_2 vapor, respectively. The values of the partial pressures were taken from data by Sittig⁽⁷⁾ for the temperature range from 97.81°C to 1125°C. From 1125°C to 1300°C the values used were extrapolated from the given data. Now K_p remains constant with temperature, and by the following equation⁽¹³⁾ X_1 and X_2 can be determined:

$$n_1 = \frac{1}{1 + 4 P_t K_p} \quad , \quad (14)$$

where n_1 is moles of Na vapor at equilibrium and P_t is the total pressure in atmospheres,

$$X_1 = \frac{2n_1}{1 + n_1} \quad ,$$

and $X_1 + X_2 = 1$.

For saturated vapor the values of X_2 have been tabulated by Sittig⁽⁷⁾ for temperatures up to 1125°C.

V. ENTHALPY

The melting point of sodium, 97.81°C, was used as the datum plane for evaluating all enthalpy values.

A. Enthalpy of Saturated Liquid

The enthalpy of the liquid was determined by using the average specific heat over small temperature differences. The specific heat data were available in Sittig⁽⁷⁾ for the temperature range from 97.81°C to 1125°C. For the range from 1125°C to 1300°C extrapolated values were used.

A check on the enthalpy values obtained as outlined above was made by using an equation given by Inatomi and Parrish⁽³⁾ as follows:

$$c_p = 0.389 - 1.99 \times 10^{-4} T + 1.10 \times 10^{-7} T^2 \text{ cal/gm-}^\circ\text{K} \quad . \quad (16)$$

From the relation $dh = c_p dT$, there is obtained

$$h_1 - h_2 = \int_{T_1}^{T_2} (0.389 - 1.99 \times 10^{-4}T + 1.10 T^2) dT \quad (17)$$

Evaluation of Equation (17) gave results consistent with those obtained by the direct method.

B. Enthalpy of Vaporization

The Clapeyron equation was used to obtain the enthalpy of vaporization. A check on the values was made by using the heat of formation. Values for the heats of formation are reported in the Journal of Research of the National Bureau of Standards.⁽¹³⁾ The Clapeyron equation is

$$\frac{dP}{dT} = \frac{h_{fg}}{T (V_g - V_f)} \quad (18)$$

By neglecting V_f and substituting the perfect gas law, $V_g = RT/P$, this equation can be written

$$h_{fg} = \frac{dP}{dT} \frac{RT^2}{P} \quad (19)$$

Solving for dP/dT from Equation (1) gives

$$\frac{dP}{dT} = P \left(\frac{12821}{T^2} - \frac{0.5}{T} \right) \quad (20)$$

Substituting Equation (20) in Equation (19) gives

$$h_{fg} = (12821 - 0.5T)R \text{ cal/gm-mole} \quad (21)$$

By using the heats of formation of Na and Na₂, the equation for the enthalpy of vaporization is given as

$$h_{fg} = \frac{X_1(\Delta H_{f1}) + X_2(\Delta H_{f2})}{X_1(M_1) + X_2(M_2)} \text{ cal/gm} \quad (22)$$

C. Enthalpy of Saturated Vapor

The enthalpy of saturated vapor was obtained by using the equation

$$h_g = h_f + h_{fg} \quad .$$

D. Enthalpy of Superheated Vapor

The enthalpy of the superheated vapor was obtained by selecting constant pressures and determining points at various temperatures. The following Equation⁽¹⁴⁾ gives the enthalpy at any temperature:

$$h = h_{fg} + \frac{X_1(\Delta H_{f_1} + X_2(\Delta H_{f_2}))}{X_1(M_1) + X_2(M_2)} \quad (23)$$

VI. ENTROPY

The melting point of sodium, 97.81°C, was used as the datum plane for evaluating all entropy values.

A. Entropy of Saturated Liquid

The entropy of saturated liquid was obtained by means of the equation

$$\Delta s = \Delta h / T \quad ,$$

using the average temperature over small increments of Δh . This method was checked by evaluating

$$s_1 - s_2 = \int_{T_1}^{T_2} c_p \frac{dT}{T} \quad (24)$$

and using $c_p = 0.389 - 1.99 \times 10^{-4} + 1.10 \times 10^{-7} T^2$.

B. Entropy of Vaporization

The entropy of vaporization was obtained from the equation

$$s_{fg} = h_{fg} / T \quad .$$

C. Entropy of Saturated Vapor

The entropy of saturated vapor was determined by means of the equation

$$s_g = s_f + s_{fg} \quad .$$

D. Entropy of Superheated Vapor

The entropy of superheated vapor was determined from the equation

$$\Delta s = \Delta h/T \quad ,$$

again using the average temperature over small increments of Δh .

VII. OTHER PROPERTIES

Tables and charts for the liquid density, saturated vapor density, liquid thermal conductivity, vapor thermal conductivity, liquid viscosity, vapor viscosity, liquid specific heat, vapor specific heat, and surface tension have been prepared and are given in the Appendix.

A. Density

The values of liquid density were obtained as described in Section III. The saturated vapor density was taken from the values of the specific volumes as given in the saturated tables.

B. Thermal Conductivity

The liquid thermal conductivity values were taken from Sittig⁽⁷⁾ up to a temperature of 550°C. Above 550°C the values were estimated by an equation given in Sittig⁽⁷⁾ as follows:

$$k = 0.2166 - 0.000116t \quad . \quad (25)$$

The values used above were checked against experimental values as given in the Liquid-Metals Handbook⁽⁵⁾ and from a chart given in the WADC report.⁽⁶⁾

The thermal conductivity of the vapor was determined by a method recommended by Lindsay and Bromley⁽¹⁵⁾ for the thermal conductivity of gas mixtures. They recommended the following equation:

$$k_m = \frac{k_1}{1 + \left(A_{12} \frac{X_2}{X_1} \right)} + \frac{k_2}{1 + \left(A_{21} \frac{X_1}{X_2} \right)} \quad , \quad (26)$$

where A can be evaluated by

$$A_{12, 21} = 0.25 (1 + a^{0.5}) b \quad ; \quad (27)$$

Here a is defined as

$$\frac{\mu_1}{\mu_2} \left(\frac{M_2}{M_1} \right)^{0.75} \left(\frac{1 + \frac{S_1}{T}}{1 + \frac{S_2}{T}} \right)$$

and b represents

$$\left[1 + \frac{S_{12}}{T} \right] / \left[1 + \frac{S_1}{T} \right] ,$$

where $S = 1.47 T_b$.⁽¹⁶⁾⁽¹⁷⁾ For the case of Na and Na₂, as occurs here, $S_1 = S_2 = S_{12}$, so that b becomes unity and a becomes equal to

$$\frac{\mu_1}{\mu_2} \left(\frac{M_2}{M_1} \right)^{0.75} .$$

The values for μ_1 and μ_2 can be determined as outlined in the next subsection of this report.

The values obtained by this method check approximately those given on a plot in the WADC report.⁽⁶⁾

C. Viscosity

The viscosity of the liquid sodium was determined by a method given by Andrade⁽¹⁸⁾ according to the relation

$$\log \mu = A + \frac{B}{T} . \quad (28)$$

When two values are known, Equation (28) can be used to get other values. The known values for liquid viscosity were listed in the Liquid Metals Handbook.⁽⁵⁾

The viscosity of sodium vapor was determined by using an equation given by Johnson, Huang, and Kemp⁽¹⁹⁾ for a pure vapor and by an equation expressed by Wilke⁽²⁰⁾ for a gas mixture. The Johnson, Huang, and Kemp equation is given as

$$\mu_g = \frac{4.53 (M)^{0.5} P_c^{0.667} T^{0.782}}{T_c} \times 10^{-4} , \quad (29)$$

and the equation given by Wilke is

$$\mu_m = \frac{\mu_1}{1 + \left(\frac{X_2}{X_1}\right) \phi_{12}} + \frac{\mu_2}{1 + \left(\frac{X_1}{X_2}\right) \phi_{21}} \quad (30)$$

To facilitate the use of Equation (30), Bromley and Wilke⁽²¹⁾ presented plots of ϕ as a function of μ_1/μ_2 and M_1/M_2 . The plots are also given in Gambill⁽²²⁾ and were used for the determinations presented in this report.

In the WADC report⁽⁶⁾ is given a plot of temperature against the viscosity of saturated sodium vapor. Agreement with the values obtained by use of the above equations was favorable enough to indicate the same equations may have been used.

D. Specific Heat

The specific heat of the liquid was taken from Sittig⁽⁷⁾ and checked against those plotted in the WADC report⁽⁶⁾ for the range of temperature given. Beyond the given range extrapolated values were used.

Values for the specific heat of saturated vapor were taken from those shown on a WADC chart⁽⁶⁾ and were checked by assuming that the perfect gas law was applicable.

E. Surface Tension

The surface tension values were obtained by use of the relationship

$$\sigma = 202 - 0.10 t \quad , \quad (31)$$

which is given by Sittig.⁽⁷⁾ The Liquid Metals Handbook⁽⁵⁾ also gives a linear equation for surface tension as follows:

$$\sigma = 200.12 - 9.833 \times 10^{-2} t \quad . \quad (32)$$

Both of the above empirical equations give approximately the same values. These equations cover the range from the melting point to 450°C. Extrapolated values were used from 500°C to 1300°C.

It is noted here that, if the critical temperature (2273°K) is substituted in either of the above equations, the surface tension becomes approximately zero. This is as it should be and gives a further clue as to the accuracy of the critical temperature.

VIII. MOLLIER DIAGRAM

A Mollier diagram for sodium is given in the Appendix. Constant pressure lines ranging from 0.001 atm to 15 atm are given. The superheat range is covered to a temperature of 1300°C.

A. Superheat Region

Values for plotting constant temperature and constant pressure lines in the superheat region were those which are given in Table 2 of the thermodynamic properties.

To make the superheat region easier to read, some of the constant pressure lines were not extended beyond the saturation line.

B. Mixture Region

The quality lines show the percent of sodium vapor contained in the liquid-vapor mixture. Quality in the range from 50 to 100% is designated on the chart. The data for plotting were obtained by the equations

$$\text{Quality, \%} = \frac{h - h_f}{h_{fg}} \times 100 \quad (32)$$

and

$$\text{Quality, \%} = \frac{s - s_f}{s_{fg}} \times 100 \quad (33)$$

APPENDIX A
TABLES OF PROPERTIES

Table I

THERMODYNAMIC PROPERTIES OF SODIUM
SATURATED PHASES

Temp (°C)	Pressure (atm)	Volume (cc/gram)		Enthalpy (cal/gram)			Entropy (cal/gm - °K)		
		v _f	v _g	h _f	h _{fg}	h _g	s _f	s _{fg}	s _g
97.81	1.14×10 ⁻¹⁰	1.078	116.0 ×10 ¹¹	0	1091	1091	0	2.9407	2.9407
100	1.41×10 ⁻¹⁰	1.079	93.8 ×10 ¹¹	0.66	1091	1092	0.0018	2.9249	2.9267
125	1.19×10 ⁻⁹	1.086	119.0 ×10 ¹⁰	8.89	1090	1099	0.0227	2.7386	2.7613
150	7.55×10 ⁻⁹	1.092	200.0 ×10 ⁹	17.05	1089	1106	0.0426	2.5740	2.6166
175	3.98×10 ⁻⁸	1.099	404.0 ×10 ⁸	25.14	1084	1109	0.0612	2.4285	2.4879
200	1.77×10 ⁻⁷	1.106	95.5 ×10 ⁸	33.17	1080	1113	0.0787	2.2833	2.3620
225	6.71×10 ⁻⁷	1.114	262.0 ×10 ⁷	41.14	1076	1117	0.0952	2.1606	2.2558
250	2.30×10 ⁻⁶	1.122	75.4 ×10 ⁷	49.06	1071	1120	0.1107	2.0478	2.1585
275	5.32×10 ⁻⁶	1.129	36.3 ×10 ⁷	56.93	1065	1122	0.1212	1.9434	2.0646
300	1.80×10 ⁻⁵	1.136	11.16 ×10 ⁷	64.75	1060	1125	0.1393	1.8498	1.9891
325	4.52×10 ⁻⁵	1.144	4.62 ×10 ⁷	72.52	1054	1127	0.1526	1.7625	1.9151
350	1.05×10 ⁻⁴	1.152	2.06 ×10 ⁷	80.25	1049	1129	0.1653	1.6830	1.8483
375	2.26×10 ⁻⁴	1.161	0.990×10 ⁷	87.93	1043	1131	0.1772	1.6096	1.7868
400	4.66×10 ⁻⁴	1.168	0.496×10 ⁷	95.60	1035	1131	0.1890	1.5393	1.7283
425	9.11×10 ⁻⁴	1.176	0.261×10 ⁷	103.21	1028	1131	0.1999	1.4728	1.6727
450	1.68×10 ⁻³	1.185	1468.0 ×10 ³	110.82	1021	1132	0.2108	1.4122	1.6230
475	3.04×10 ⁻³	1.193	826.5 ×10 ³	118.36	1014	1132	0.2209	1.3556	1.5765
500	5.15×10 ⁻³	1.202	503.0 ×10 ³	125.90	1007	1133	0.2310	1.3014	1.5324
525	8.28×10 ⁻³	1.211	320.0 ×10 ³	133.48	999	1133	0.2404	1.2519	1.4923
550	1.38×10 ⁻²	1.220	197.0 ×10 ³	140.95	992	1133	0.2498	1.2053	1.4551
575	2.14×10 ⁻²	1.229	130.0 ×10 ³	148.45	985	1133	0.2587	1.1615	1.4202
600	3.21×10 ⁻²	1.238	88.0 ×10 ³	155.96	978	1134	0.2675	1.2260	1.3935
625	4.72×10 ⁻²	1.246	61.9 ×10 ³	163.45	971	1134	0.2761	1.0824	1.3585
650	6.97×10 ⁻²	1.256	43.5 ×10 ³	170.95	964	1135	0.2848	1.0455	1.3303
675	9.83×10 ⁻²	1.266	30.7 ×10 ³	178.45	956	1135	0.2947	1.0084	1.3011
700	0.136	1.276	22.7 ×10 ³	185.95	950	1136	0.3006	0.9763	1.2769
725	0.190	1.285	16.6 ×10 ³	193.47	943	1136	0.3081	0.9438	1.2519
750	0.259	1.295	12.3 ×10 ³	200.99	935	1136	0.3156	0.9140	1.2296
775	0.341	1.305	9800	208.54	929	1137	0.3227	0.8865	1.2092
800	0.453	1.315	7500	216.10	921	1137	0.3298	0.8583	1.1881
825	0.581	1.326	5820	223.70	916	1140	0.3367	0.8352	1.1719
850	0.736	1.337	4670	231.30	910	1141	0.3436	0.8094	1.1530
875	0.946	1.348	3700	238.96	904	1143	0.3503	0.7883	1.1386
*881	1.000	1.351	3540	240.81	903	1144	0.3519	0.7826	1.1345
900	1.173	1.362	3000	246.63	897	1144	0.3570	0.7647	1.1217
925	1.468	1.374	2445	254.37	893	1147	0.3634	0.7454	1.1088
950	1.832	1.386	1960	262.11	887	1149	0.3699	0.7252	1.0951
975	2.200	1.399	1630	269.94	881	1151	0.3762	0.7059	1.0821
1000	2.710	1.412	1340	277.77	877	1155	0.3824	0.6889	1.0713
1025	3.200	1.426	1140	285.75	873	1159	0.3885	0.6726	1.0611
1050	3.855	1.438	958	293.63	868	1162	0.3946	0.6545	1.0491
1075	4.620	1.451	813	301.68	862	1164	0.4004	0.6394	1.0398
1100	5.360	1.465	707	309.73	858	1168	0.4063	0.6249	1.0312
1125	6.350	1.479	605	317.91	854	1172	0.4126	0.6109	1.0235
1150	7.280	1.494	535	326.09	850	1176	0.4180	0.5973	1.0153
1175	8.500	1.509	467	334.40	848	1182	0.4238	0.5856	1.0094
1200	9.800	1.523	405	342.71	844	1187	0.4295	0.5730	1.0025
1225	11.17	1.538	361	351.15	842	1193	0.4355	0.5621	0.9976
1250	12.88	1.555	321	359.59	838	1198	0.4415	0.5502	0.9917
1275	14.72	1.572	312	368.16	835	1203	0.4471	0.5394	0.9865
1300	16.42	1.589	258	376.72	833	1210	0.4526	0.5296	0.9822

*Normal boiling point

Table II

THERMODYNAMIC PROPERTIES OF SODIUM
SUPERHEATED VAPOR

Temp, °C	v, cc/gram	h, cal/gram	s, cal/gm -°K	Temp, °C	v, cc/gram	h, cal/gram	s, cal/gm -°K
Pressure = 0.001 atm				Pressure = 0.02 atm			
*428	2.47×10^6	1131	1.6668	*571	142,000	1133	1.4265
500	2.73×10^6	1166	1.7143	600	146,200	1150	1.4463
550	2.97×10^6	1181	1.7325	650	157,900	1176	1.4744
600	3.11×10^6	1196	1.7507	700	169,700	1202	1.5026
650	3.23×10^6	1208	1.7637	750	179,500	1218	1.5182
700	3.36×10^6	1220	1.7767	800	189,600	1234	1.5338
750	3.60×10^6	1231	1.7874	850	198,900	1247	1.5453
800	3.83×10^6	1242	1.7982	900	208,300	1260	1.5568
850	4.01×10^6	1253	1.8079	950	217,500	1273	1.5678
900	4.19×10^6	1264	1.8177	1000	226,700	1287	1.5789
950	4.36×10^6	1276	1.8275	1050	235,800	1298	1.5875
1000	4.53×10^6	1288	1.8373	1100	244,900	1310	1.5962
1050	4.72×10^6	1299	1.8458	1150	253,800	1322	1.6049
1100	4.90×10^6	1310	1.8543	1200	262,800	1335	1.6137
1150	5.08×10^6	1322	1.8632	1250	271,700	1348	1.6222
1200	5.25×10^6	1335	1.8718	1300	280,600	1361	1.6308
1250	5.43×10^6	1348	1.8803	Pressure = 0.05 atm			
1300	5.61×10^6	1361	1.8888	*628	59,700	1135	1.3515
Pressure = 0.005 atm				650	61,990	1149	1.3674
*497	542,400	1133	1.5377	700	67,200	1184	1.4037
500	544,500	1134	1.5396	750	71,100	1204	1.4237
550	578,300	1159	1.5696	800	75,000	1225	1.4437
600	612,000	1184	1.5997	850	78,850	1240	1.4548
650	652,000	1200	1.6164	900	82,700	1255	1.4659
700	692,000	1215	1.6332	950	86,600	1269	1.4774
750	728,000	1229	1.6468	1000	90,500	1283	1.4889
800	764,000	1243	1.6605	1050	94,000	1296	1.4989
850	801,000	1253	1.6695	1100	97,600	1309	1.5089
900	838,000	1264	1.6785	1150	101,300	1322	1.5180
950	874,000	1276	1.6880	1200	105,000	1335	1.5271
1000	910,000	1288	1.6975	1250	110,000	1348	1.5356
1050	946,000	1299	1.7060	1300	115,000	1361	1.5441
1100	981,000	1310	1.7145	Pressure = 0.10 atm			
1150	1.02×10^6	1322	1.7232	*676	31,000	1135	1.2914
1200	1.05×10^6	1335	1.7320	700	31,800	1146	1.3028
1250	1.09×10^6	1348	1.7405	750	34,100	1179	1.3355
1300	1.13×10^6	1361	1.7490	800	35,400	1213	1.3682
Pressure = 0.01 atm				850	37,400	1231	1.3837
*533	280,640	1133	1.4803	900	41,200	1248	1.3993
600	310,100	1176	1.5315	950	43,000	1262	1.4112
650	326,300	1193	1.5504	1000	44,800	1277	1.4230
700	342,600	1211	1.5694	1050	46,800	1292	1.4347
750	364,200	1223	1.5816	1100	48,700	1308	1.4464
800	385,800	1236	1.5938	1150	50,400	1321	1.4558
850	401,500	1249	1.6058	1200	52,400	1335	1.4653
900	417,200	1263	1.6179	1250	54,200	1348	1.4738
950	435,200	1275	1.6281	1300	56,200	1361	1.4824
1000	453,300	1288	1.6383				
1050	471,300	1299	1.6468				
1100	489,400	1310	1.6553				
1150	507,400	1322	1.6640				
1200	525,500	1335	1.6728				
1250	543,800	1348	1.6818				
1300	562,200	1361	1.6899				

*Temperature at saturation

Table II (Cont'd.)

Temp, °C	v, cc/gram	h, cal/gram	s, cal/gm - °K	Temp, °C	v, cc/gram	h, cal/gram	s, cal/gm - °K
Pressure = 0.25 atm				Pressure = 2.5 atm			
*747	12,800	1136	1.2323	*991	1445	1154	1.0793
800	13,900	1178	1.2724	1000	1580	1159	1.0832
850	14,900	1201	1.2933	1050	1640	1189	1.1058
900	15,900	1225	1.3142	1100	1700	1219	1.1285
950	16,800	1246	1.3313	1150	1810	1249	1.1495
1000	17,700	1267	1.3485	1200	1925	1279	1.1706
1050	18,500	1282	1.3598	1250	2019	1304	1.1870
1100	19,300	1297	1.3711	1300	2158	1329	1.2034
1150	20,000	1313	1.3823	Pressure = 5.0 atm			
1200	20,810	1329	1.3935	*1088	740	1166	1.0347
1250	21,700	1343	1.4027	1100	756	1170	1.0376
1300	22,400	1357	1.4118	1150	835	1206	1.0625
Pressure = 0.5 atm				1200	904	1241	1.0874
*812	6,694	1141	1.1794	1250	964	1274	1.1087
850	7,060	1165	1.2004	1300	1022	1306	1.1300
900	7,700	1196	1.2281	Pressure = 7.5 atm			
950	8,190	1222	1.2493	*1154	524	1177	1.0136
1000	8,660	1248	1.2706	1200	577	1214	1.0391
1050	9,100	1267	1.2846	1250	614	1248	1.0614
1100	9,490	1285	1.2985	1300	654	1282	1.0837
1150	9,950	1303	1.3111	Pressure = 10 atm			
1200	10,340	1321	1.3238	*1202	402	1187	1.0015
1250	10,720	1337	1.3343	1250	442	1227	1.0275
1300	11,090	1353	1.3448	1300	475	1266	1.0533
Pressure = 1.0 atm				Pressure = 15 atm			
*881	3,540	1144	1.1338	*1279	280	1204	.9858
900	3,630	1155	1.1433	1300	297	1237	1.0069
950	3,860	1187	1.1694				
1000	4,140	1219	1.1956				
1050	4,420	1242	1.2129				
1100	4,610	1265	1.2303				
1150	4,825	1288	1.2464				
1200	5,050	1311	1.2626				
1250	5,300	1329	1.2741				
1300	5,495	1346	1.2855				

*Temperature at saturation

Table III

THERMODYNAMIC PROPERTIES OF SODIUM
SATURATED PHASES

Temp, °F	Pressure, psia	Volume, ft ³ /lb		Enthalpy, Btu/lb			Entropy, Btu/(lb)(°R)		
		v_f	v_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
208	16.80 x 10 ⁻¹⁰	0.01726	18.53 x 10 ¹⁰	0	1964	1964	0	2.9407	2.9407
250	15.02 x 10 ⁻⁹	0.01736	21.98 x 10 ⁹	13.85	1962	1976	0.0201	2.7633	2.7834
300	1.071 x 10 ⁻⁷	0.01749	32.96 x 10 ⁸	30.20	1961	1991	0.0423	2.5802	2.6225
350	7.44 x 10 ⁻⁷	0.01762	50.45 x 10 ⁷	46.40	1952	1998	0.0629	2.4099	2.4728
400	37.52 x 10 ⁻⁷	0.01775	10.59 x 10 ⁷	62.45	1943	2005	0.0821	2.2593	2.3414
450	16.59 x 10 ⁻⁶	0.01788	25.36 x 10 ⁶	78.35	1933	2011	0.1000	2.1241	2.2241
500	51.5 x 10 ⁻⁶	0.01801	8.576 x 10 ⁶	94.10	1924	2018	0.1168	2.0041	2.1209
550	17.45 x 10 ⁻⁵	0.01818	26.52 x 10 ⁵	109.80	1913	2023	0.1327	1.8940	2.0267
600	52.00 x 10 ⁻⁵	0.01829	9.298 x 10 ⁵	125.40	1902	2027	0.1478	1.7943	1.9421
650	13.00 x 10 ⁻⁴	0.01843	38.78 x 10 ⁴	140.90	1890	2031	0.1621	1.7027	1.8648
700	3.050 x 10 ⁻³	0.01858	17.18 x 10 ⁴	156.30	1880	2036	0.1757	1.6207	1.7964
750	6.721 x 10 ⁻³	0.01871	8.072 x 10 ⁴	171.60	1864	2036	0.1886	1.5404	1.7290
800	14.30 x 10 ⁻³	0.01886	3.921 x 10 ⁴	186.85	1849	2036	0.2009	1.4674	1.6683
850	27.82 x 10 ⁻³	0.01901	2.081 x 10 ⁴	202.05	1835	2037	0.2127	1.4008	1.6135
900	53.40 x 10 ⁻³	0.01916	1.118 x 10 ⁴	217.20	1821	2038	0.2240	1.3389	1.5629
950	94.10 x 10 ⁻³	0.01931	6529	232.30	1806	2038	0.2349	1.2809	1.5158
1000	0.1662	0.01947	3801	247.35	1792	2039	0.2454	1.2274	1.4728
1050	0.2740	0.01963	2367	262.35	1778	2040	0.2555	1.1774	1.4329
1100	0.4280	0.01978	1555	277.35	1764	2041	0.2653	1.1308	1.3961
1150	0.6575	0.01995	1037	292.35	1750	2042	0.2748	1.0869	1.3617
1200	1.012	0.02011	689.5	307.35	1736	2043	0.2840	1.0458	1.3298
1250	1.489	0.02029	479.0	322.35	1722	2044	0.2929	1.0070	1.2999
1300	2.120	0.02045	344.0	337.35	1707	2045	0.3015	0.9699	1.2714
1350	3.060	0.02064	243.0	352.40	1693	2045	0.3099	0.9354	1.2453
1400	4.275	0.02081	178.0	367.45	1678	2045	0.3181	0.9022	1.2203
1450	5.855	0.02100	132.0	382.55	1665	2048	0.3261	0.8717	1.1978
1500	7.880	0.02118	100.3	397.70	1654	2052	0.3339	0.8438	1.1777
1550	10.180	0.02137	79.12	412.90	1642	2055	0.3416	0.8169	1.1585
1600	13.28	0.02156	61.81	428.20	1631	2059	0.3491	0.7917	1.1408
1618	14.70	0.02170	56.12	433.70	1626	2060	0.3519	0.7826	1.1345
1650	17.12	0.02175	48.84	443.55	1618	2062	0.3565	0.7668	1.1233
1700	22.00	0.02195	38.60	459.00	1606	2065	0.3637	0.7435	1.1072
1750	27.82	0.02225	31.14	474.55	1594	2069	0.3708	0.7212	1.0920
1800	34.42	0.02247	25.60	490.20	1584	2074	0.3778	0.7009	1.0787
1850	42.72	0.02271	20.99	505.95	1576	2082	0.3847	0.6823	1.0670
1900	52.05	0.02294	17.52	521.85	1567	2090	0.3915	0.6639	1.0554
1950	63.87	0.02317	14.52	537.80	1557	2095	0.3982	0.6461	1.0443
2000	75.75	0.02341	12.49	553.90	1546	2100	0.4048	0.6285	1.0333
2050	91.02	0.02372	10.31	570.15	1538	2108	0.4113	0.6128	1.0241
2100	107.2	0.02393	8.796	586.50	1530	2117	0.4177	0.5977	1.0154
2150	127.2	0.02419	7.457	603.00	1524	2127	0.4241	0.5839	1.0080
2200	147.3	0.02446	6.537	619.60	1518	2138	0.4304	0.5706	1.0010
2250	171.0	0.02474	5.719	636.30	1513	2149	0.4366	0.5583	0.9949
2300	198.5	0.02503	4.947	653.15	1507	2160	0.4428	0.5460	0.9888

Table IV

THERMODYNAMIC PROPERTIES OF SODIUM
SUPERHEATED VAPOR

Temp, °F	v, ft ³ /lb	h, Btu/lb	s, Btu/(lb)(°R)	Temp, °F	v, ft ³ /lb	h, Btu/lb	s, Btu/(lb)(°R)
Pressure = 0.02 psia				Pressure = 1.0 psia			
*821	28,530	2036	1.6453	*1198	702	2043	1.3309
900	30,830	2073	1.6733	1200	703	2044	1.3315
1000	33,630	2117	1.7045	1300	769	2148	1.3906
1100	36,060	2144	1.7223	1400	825	2173	1.4032
1200	38,530	2172	1.7397	1500	882	2198	1.4158
1300	40,950	2192	1.7536	1600	938	2233	1.4335
1400	43,340	2221	1.7675	1700	995	2268	1.4512
1500	45,680	2242	1.7784	1800	1043	2296	1.4635
1600	48,000	2264	1.7891	1900	1092	2324	1.4759
1700	50,330	2286	1.7998	2000	1140	2350	1.4864
1800	52,670	2312	1.8106	2100	1188	2376	1.4970
1900	55,000	2335	1.8214	2200	1236	2403	1.5072
2000	57,320	2358	1.8310	2300	1285	2430	1.5173
2100	59,660	2382	1.8405	Pressure = 5.0 psia			
2200	61,990	2406	1.8495	*1423	157.0	2049	1.2097
2300	64,320	2430	1.8585	1500	163.8	2092	1.2320
Pressure = 0.05 psia				1600	177.3	2151	1.2606
*893	10,560	2038	1.5697	1700	190.9	2210	1.2892
900	11,910	2044	1.5728	1800	202.3	2251	1.3075
1000	13,100	2089	1.6042	1900	213.8	2293	1.3259
1100	14,300	2134	1.6356	2000	224.1	2323	1.3382
1200	15,300	2163	1.6533	2100	234.4	2354	1.3506
1300	16,300	2193	1.6711	2200	244.7	2386	1.3626
1400	17,250	2216	1.6834	2300	255.1	2419	1.3745
1500	18,200	2239	1.6958	Pressure = 14.7 psia			
1600	19,150	2262	1.7072	*1618	56.12	2060	1.1345
1700	20,100	2286	1.7186	1700	60.23	2111	1.1585
1800	21,030	2312	1.7294	1800	64.82	2169	1.1843
1900	21,960	2335	1.7402	1900	69.41	2228	1.2102
2000	22,890	2358	1.7497	2000	72.96	2269	1.2269
2100	23,820	2382	1.7593	2100	76.52	2310	1.2436
2200	24,750	2406	1.7683	2200	80.95	2352	1.2596
2300	25,680	2430	1.7773	2300	85.39	2395	1.2756
Pressure = 0.10 psia				Pressure = 30 psia			
*954	4,019	2038	1.5124	*1767	29.30	2071	1.0876
1000	4,985	2063	1.5293	1800	30.01	2092	1.0967
1100	7,085	2118	1.5661	1900	32.17	2155	1.1242
1200	7,611	2152	1.5868	2000	34.20	2210	1.1465
1300	8,138	2187	1.6076	2100	36.23	2265	1.1689
1400	8,622	2212	1.6213	2200	38.36	2315	1.1877
1500	9,106	2238	1.6350	2300	40.50	2365	1.2064
1600	9,575	2260	1.6457	Pressure = 75 psia			
1700	10,040	2282	1.6564	*1998	12.54	2099	1.0337
1800	10,520	2308	1.6672	2000	12.55	2100	1.0342
1900	11,000	2335	1.6780	2100	13.01	2167	1.0604
2000	11,470	2358	1.6885	2200	14.12	2230	1.0841
2100	11,930	2382	1.6971	2300	15.23	2293	1.1078
2200	12,400	2406	1.7061	Pressure = 150 psia			
2300	12,860	2430	1.7151	*2206	6.444	2139	1.0003
*Temperature at saturation				2300	6.958	2215	1.0282

Table V

DENSITY OF LIQUID SODIUM

Temp, °C	Density, gram/cc	Temp, °C	Density, gram/cc
97.81	0.9270	700	0.7843
100	0.9265	750	0.7719
150	0.9152	800	0.7594
200	0.9037	850	0.7468
250	0.8922	900	0.7343
300	0.8805	950	0.7212
350	0.8688	1000	0.7080
400	0.8570	1050	0.6958
450	0.8451	1100	0.6827
500	0.8331	1150	0.6695
550	0.8211	1200	0.6564
600	0.8089	1250	0.6432
650	0.7967	1300	0.6291

Table VI

DENSITY OF SATURATED SODIUM VAPOR

Temp, °C	Density, gram/cc	Temp, °C	Density, gram/cc
97.81	8.62×10^{-14}	700	4.41×10^{-5}
100	1.066×10^{-13}	750	8.13×10^{-5}
150	5.00×10^{-12}	800	1.28×10^{-4}
200	1.047×10^{-10}	850	2.14×10^{-4}
250	1.326×10^{-9}	900	3.33×10^{-4}
300	8.96×10^{-9}	950	5.10×10^{-4}
350	4.85×10^{-8}	1000	7.46×10^{-4}
400	2.016×10^{-7}	1050	1.043×10^{-3}
450	6.81×10^{-7}	1100	1.414×10^{-3}
500	1.989×10^{-6}	1150	1.869×10^{-3}
550	5.076×10^{-6}	1200	2.469×10^{-3}
600	1.136×10^{-5}	1250	3.115×10^{-3}
650	2.23×10^{-5}	1300	3.875×10^{-3}

Table VII

THERMAL CONDUCTIVITY OF
LIQUID SODIUM

Temp, °C	Thermal Conductivity, cal/(cm ²)(sec)(°C/cm)
97.81	0.205
100	0.205
150	0.199
200	0.193
250	0.188
300	0.182
350	0.176
400	0.170
450	0.164
500	0.159
550	0.153
600	0.147
650	0.141
700	0.135
750	0.130
800	0.124
850	0.118
900	0.112
950	0.106
1000	0.100
1050	0.095
1100	0.089
1150	0.083
1200	0.077
1250	0.072
1300	0.067

Table VIII

THERMAL CONDUCTIVITY OF
SATURATED SODIUM VAPOR

Temp, °C	Thermal Conductivity, cal/(cm ²)(sec)(°C/cm)
97.81	16.4×10^{-6}
100	16.4×10^{-6}
150	18.4×10^{-6}
200	20.5×10^{-6}
250	21.6×10^{-6}
300	22.7×10^{-6}
350	23.8×10^{-6}
400	25.0×10^{-6}
450	26.2×10^{-6}
500	27.5×10^{-6}
550	28.6×10^{-6}
600	29.7×10^{-6}
650	30.8×10^{-6}
700	32.0×10^{-6}
750	33.1×10^{-6}
800	34.2×10^{-6}
850	35.3×10^{-6}
900	36.5×10^{-6}
950	37.7×10^{-6}
1000	38.8×10^{-6}
1050	39.9×10^{-6}
1100	41.0×10^{-6}
1150	42.1×10^{-6}
1200	43.2×10^{-6}
1250	44.3×10^{-6}
1300	45.5×10^{-6}

Table IX

VISCOSITY OF LIQUID SODIUM

Temp, °C	Viscosity, centipoise	Temp, °C	Viscosity, centipoise
97.81	0.690	700	0.193
100	0.682	750	0.185
150	0.542	800	0.179
200	0.450	850	0.173
250	0.387	900	0.167
300	0.340	950	0.163
350	0.305	1000	0.159
400	0.278	1050	0.157
450	0.257	1100	0.154
500	0.239	1150	0.152
550	0.225	1200	0.150
600	0.212	1250	0.149
650	0.202	1300	0.148

Table X

VISCOSITY OF SODIUM VAPOR

Temp, °C	Viscosity, centipoise	Temp, °C	Viscosity, centipoise
97.81	0.0058	700	0.0108
100	0.0058	750	0.0113
150	0.0062	800	0.0117
200	0.0065	850	0.0120
250	0.0070	900	0.0122
300	0.0075	950	0.0129
350	0.0078	1000	0.0136
400	0.0082	1050	0.0139
450	0.0087	1100	0.0142
500	0.0091	1150	0.0149
550	0.0095	1200	0.0157
600	0.0100	1250	0.0161
650	0.0104	1300	0.0165

Table XI

SPECIFIC HEAT, C_p ,
OF LIQUID SODIUM

Temp, °C	C_p , cal/(gm)(°C)
97.81	0.331
100	0.331
150	0.325
200	0.320
250	0.316
300	0.312
350	0.308
400	0.306
450	0.303
500	0.302
550	0.301
600	0.300
650	0.300
700	0.300
750	0.301
800	0.303
850	0.305
900	0.308
950	0.311
1000	0.315
1050	0.320
1100	0.324
1150	0.330
1200	0.334
1250	0.340
1300	0.345

Table XII

SPECIFIC HEAT OF
SODIUM VAPOR

Temp, °C	Specific Heat, cal/(gm)(°C)
97.81	0.216
100	0.216
150	0.216
200	0.216
250	0.216
300	0.216
350	0.216
400	0.216
450	0.215
500	0.215
550	0.215
600	0.215
650	0.215
700	0.215
750	0.215
800	0.215
850	0.214
900	0.214
950	0.214
1000	0.214
1050	0.214
1100	0.214
1150	0.214
1200	0.215
1250	0.215
1300	0.215

Table XIII

SURFACE TENSION OF
SODIUM

Temp, °C	Surface Tension, dynes/cm
97.81	192.2
100	192.0
150	187.0
200	182.0
250	177.0
300	172.0
350	167.0
400	162.0
450	157.0
500	152.0
550	147.0
600	142.0
650	137.0
700	132.0
750	127.0
800	122.0
850	117.0
900	112.0
950	107.0
1000	102.0
1050	97.0
1100	92.0
1150	87.0
1200	82.0
1250	77.0
1300	72.0

APPENDIX B
PROPERTY CHARTS

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REFERENCES

1. Ditchburn, R. W., and Gilmour, J. C., Vapor Pressure of Monatomic Vapors, Revs. of Mod. Phys. 13, 310-27 (1941).
2. Makansi, M. M., Muendel, C. H., and Selke, W. A., Determination of the Vapor Pressure of Sodium, J. Phys. Chem., 59, 40 (1955).
3. Inatomi, T. H., and Parrish, W. C., Thermodynamic Diagrams for Sodium, North American Aviation, NAA-SR-62 (1950).
4. Kirillov, P. L., and Grachev, N. S., Determination of Sodium Vapor Pressure at Temperatures from 880 to 1300°C, Journal of Engineering Physics, 11, 3 (1959).
5. Atomic Energy Commission, Liquid-Metals Handbook, Sodium-NaK Supplement, U. S. Government Printing Office (July 1955).
6. Wright Air Development Center, Properties of Inorganic Coolants for Space Applications, WADC TR 59-598.
7. Sittig, Marshall, Sodium, Its Manufacture, Properties, and Uses, Reinhold Publishing Co., New York (1956).
8. Nelson, L. C., and Obert, E. F., Generalized Compressibility Charts, Chemical Engineering, 61, 203-8 (July 1954).
9. Meisner, H. P., and Redding, E. M., Prediction of Critical Constants, Ind. Eng. Chem. 34, 521-525 (1942).
10. Watson, K. M., Prediction of Critical Temperatures and Heats of Vaporization, Ind. Eng. Chem. 23, 360 (1931).
11. Grant, J., Hackh's Chemical Dictionary, 3rd Ed. Blakinston Co., Philadelphia, (1946) p. 778.
12. Kirk, R. E., and Othmer, D. F., Editors, Encyclopedia of Chemical Technology Vol. 1, The Interscience Encyclopedia, Inc., New York (1947).
13. Evans, W. H., Jacobson, Rosemary, Munson, T. R., and Wagman, D. D., Thermodynamic Properties of the Alkali Metals, J. Research Natl. Bur. Standards, 55, 83 (1955).
14. Oak Ridge National Laboratory, Thermodynamic Diagrams for Lithium, Sodium, and Potassium, ORNL Central Files No. 59-11-67.
15. Lindsay, A. L., and Bromley, L. A., Thermal Conductivity of Gas Mixtures, Ind. Eng. Chem. 42, 1508-1511 (1950).

16. Gambill, Wallace R., How to Estimate Engineering Properties, Gas Conductivity, Chemical Engineering, 64, 272-82 (April 1957).
17. Perry, J. H., Chemical Engineer's Handbook, 3rd Ed. McGraw-Hill Book Company, Inc., New York (1950) p. 370.
18. Andrade, E. N. da C., The Viscosity of Liquids, Nature, 125, 309, 582 (1930).
19. Johnson, A. I., Huang, C., and Kemp, J. D., Chart for Getting Vapor Viscosities, Chemical Engineering, 61, 195-196 (Dec. 1954).
20. Wilke, C. R., A Viscosity Equation For Gas Mixtures, J. Chem. Phys. 18, 517-519 (1950).
21. Bromley, L. A., and Wilke, C. R., Viscosity Behavior of Gases, Ind. Eng. Chem. 43, 1642-1648 (1951).
22. Gambill, Wallace R., How to Estimate Engineering Properties, Viscosity for a Gas Mixture, Chemical Engineering 65, 157-160 (November 1958).

NOMENCLATURE

T	Temperature, °K
P	Pressure, atmospheres
d	Density, gm/cc
t	Temperature, °C
v	Specific volume, cc/gm
z	Compressibility factor
R	Universal gas constant, (cc)(atm/gm°K)
T _c	Critical temperature, °K
T ₁	Normal boiling point temperature, °K
V _c	Critical volume, cc/gm-mole
P _c	Critical pressure, atm
M	Molecular weight
d _b	Density at the boiling point, gm/cc
K _p	Equilibrium constant
X ₁	Mole fraction of component 1
X ₂	Mole fraction of component 2
P _t	Total pressure, atm
c _p	Specific heat, cal/gm-°K
h	Enthalpy, cal/gm
h _{fg}	Enthalpy of vaporization cal/gm
v _g	Specific volume of saturated vapor, cc/gm
v _f	Specific volume of saturated liquid, cc/gm
ΔH _{f1}	Heat of formation, component 1, cal/mole
ΔH _{f2}	Heat of formation, component 2, cal/mole
M ₁	Molecular weight of component 1
M ₂	Molecular weight of component 2
h _g	Enthalpy of saturated vapor, cal/gm
h _f	Enthalpy of saturated liquid, cal/gm

s	Entropy, cal/gm-°K
s_{fg}	Entropy of vaporization, cal/gm-°K
s_g	Entropy of saturated vapor, cal/gm-°K
s_f	Entropy of saturated liquid, cal/gm-°K
k	Thermal conductivity, cal/(cm ²)(sec)(°C/cm)
k_m	Thermal conductivity of a mixture, cal/(cm ²)(sec)(°C/cm)
μ	Viscosity, centipoises
μ_1	Viscosity of component 1, centipoise
μ_2	Viscosity of component 2, centipoises
μ_m	Viscosity of the gaseous mixture, centipoises
μ_g	Viscosity of the gas, centipoises