THE PROPERTIES OF SATURATED AND SUPERHEATED AMMONIA VAPOR

BY

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THE PROPERTIES OF SATURATED AND SUPERHEATED AMMONIA VAPOR

I. Introduction

1. *Historical Review.*—The vapor of anhydrous ammonia first became of interest in the field of Mechanical Engineering with the advent of Carré's absorption and Linde's compression refrigerating machines. With the development and increased application of the refrigeration industry this vapor has become more important and an accurate knowledge of its properties is highly desirable.

As in the case of steam and many other technically important vapors, the first reliable experimental knowledge of the properties of ammonia was derived from the work of Regnault.[1]* He determined experimentally the relation between the pressure and the temperature of the saturated vapor and expressed it by means of empirical formulas. He also determined the relative volumes of the superheated vapor at different pressures along an isotherm for the temperature 8.1° C.,[2] the specific heat,[3] the theoretical density[3] and the experimental density[4] of the gas. The determinations made by Regnault of the specific heat of the liquid and the latent heat of vaporization were lost in the reign of the Commune in 1870; twelve of the determinations of the latter magnitude, however, have been found.[5]

The first attempt to establish the fundamental equations for the vapor of ammonia and to compute tables of its properties was made by Ledoux.[6] These equations and resulting tables, resting as they do upon unsound hypotheses and meager experimental data, are, in the light of later investigations, quite inaccurate. The next theoretical investigation of the subject was undertaken by Zeuner,[7] who computed new constants for ammonia, in the equation of state of the form already applied by him to steam, and used by Ledoux for ammonia. He also constructed empirical formulas for the inner and outer latent heat, and the specific heat of the liquid, and by use of these formulas computed tables which appeared in the earlier editions of his thermodynamics.[8] In the later editions[9] the values thus calculated have still been used for temperatures below 32° F., but results of later experimental determinations have been used above that temperature. These tables for ammonia vapor are given in both English and French units.

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* Numerals refer to the bibliography given in Section V.

The tables now used most extensively in refrigeration work and included in most handbooks on refrigeration are those of Wood.[10] These tables are computed from formulas derived by the author and based upon Regnault's experiments. About the same date (1889) that Wood's tables appeared, another set of tables was published by Peabody.[11] These tables were based upon the work of Ledoux and upon the same form of equation of state, namely, that derived by Zeuner and applied to ammonia by Ledoux, but with the constants recomputed.

Since the above mentioned tables were published the properties of ammonia have been made the subject of considerable experimental work, although comparatively little is known even now when its importance in technical work is considered. Beside the experimental work enumerated above we have the following determinations: Pressure-temperature relation by Blümcke,[12] Pictet,[13] Faraday,[14] Davies,[15] and Brill;[16] critical temperature and pressure by Dewar,[17] Vincent and Chappuis,[18] Jaquerod,[70] and Scheffer;[71] latent heat of vaporization by von Strombeck,[19] Franklin and Kraus,[20] Estreicher and Schnerr,[21] and Denton and Jacobus;[22] specific heat of the liquid by von Strombeck,[19] Ludeking and Starr,[23] Elleau and Ennis,[24] and Dieterici;[25] volume (or density) of the liquid by D'Andréeff,[26] Lange,[27] and Dieterici;[25] volume of saturated vapor by Dieterici;[25] volume of superheated vapor by Leduc,[28] Guye,[29] and Perman and Davies;[30] specific heat of the superheated vapor by Keutel, Voller, Wiedemann and Nernst, the existing data on the latter property being summed up by Nernst.[31] In addition to the above direct experimental determinations of the various properties of ammonia there is available a set of throttling experiments performed by Wobsa.[59]

It will be seen that a great deal of the recent experimental work has been done by Dieterici. He has computed a table of the properties of ammonia,[25] but this table is available in metric units only, and for reasons which will appear later it may be improved upon. In 1907 Wobsa published tables for ammonia vapor based upon his own experimental work and that of Dieterici. These tables appear in the 1908 edition of Hütte and have been converted into English units and extended for every degree Fahrenheit by Macintire.[60] In 1908 Wobsa published a revised table[61] based upon a new form of equation of state. Among other tables of the properties of ammonia which have appeared in metric units are those of Mollier[62] and of Hýbl.[63]

Very recently Dr. Chas. E. Lucke has published a new table of the properties of ammonia in his treatise on thermodynamics. Lack of time has precluded a critical examination of the experimental basis of the table.

2. *Purpose of this Investigation.*—The present investigation has been undertaken with the object of collecting and correlating the various scattered experimental data on the subject of the properties of ammonia. An attempt has been made to reconcile these data by means of well-known thermodynamic laws and principles so that the results may be consistent with each other; and to express the various properties by means of formulas from which tables and charts in English units may be prepared for use in solving the many problems connected with refrigeration work.

It is fully realized that the experimental evidence is not as complete as could be desired and that more accurate experimental work may render necessary a slight revision of the value of the constants in the equations here presented. Hence the tabular values resulting from the equations are not to be considered as final, but as best representing our present knowledge of the properties of ammonia.

3. *Acknowledgment.*—The assistance of Mr. G. W. Philleo in establishing the constants in the characteristic equation of the superheated vapor is hereby gratefully acknowledged. To Mr. Ray B. Ponder credit is due for work on the specific heat of liquid ammonia.

4. *Notation*

J = Joule's equivalent.
A = Reciprocal of same.
t = Temperature on the F. or the C. scale.
T = Absolute temperature.
p = Pressure.
v = Specific volume.
γ = Specific weight.
u = Intrinsic energy.
i = Heat content at constant pressure.
s = Entropy.
r = Latent heat of vaporization.
ρ = Internal latent heat.
Ψ = External latent heat $= Ap(v''-v')$.
c = Specific heat.
c_p = Specific heat at constant pressure.
x = Quality of vapor mixture.
Subscript $_k$ indicates critical data.
($'$) indicates properties of liquid.
($''$) indicates properties of saturated vapor.

II. Tables

5. *Description of Tables.*—Of the four tables given, the first and second are for the liquid and the saturated vapor of ammonia and give explicitly all of the properties that are ordinarily needed for use. Table 3 is primarily for superheated ammonia vapor, but includes the saturated vapor as the special case of zero superheat. Table 4 gives the thermal properties of liquid ammonia.

In Tables 1 and 4 the argument is the temperature. Since it is often convenient to be able to work roughly at very high and very low temperatures, these tables have been extended on the one hand to the critical point itself and on the other hand to −110° F. However, since the data upon which the tables are based are not well known at these extreme temperatures, the values above about 160° and below about −40° should not be used with too much confidence.

In Tables 2 and 3 the argument is the pressure. The values above 500 lb. per sq. in. and those below 10 lb. per sq. in. are less certain than those lying between these pressures.

TABLE 1.

Saturated Ammonia Vapor: Temperature Table

Temp. Fahr. t	Pressure, lb. per sq. in. p	Sp. Vol cu. ft. per lb. v''	Density lb. per cu. ft. $1/v''$	Heat Content of Liquid i'	Latent Heat of Evap. r	Heat Content of Vapor i''	Internal Energy B. t. u.		Entropy			Temp. Fahr.
							Evap. ρ	Vapor u''	Liquid s'	Evap. r/T	Vapor s''	
−110°	0.758	291.	0.00344	....	648.5	....	607.7	....	....	1.8548	....	**−110°**
−105°	0.947	236.	0.00424	....	645.4	....	604.0	....	....	1.8198	....	**−105°**
−100°	1.176	192.	0.00520	....	642.2	....	600.3	....	....	1.7857	....	**−100°**
− 95°	1.450	158.	0.00633	....	639.0	....	596.6	....	....	1.7524	....	**− 95°**
− 90°	1.778	130.	0.00767	....	635.8	....	592.9	....	....	1.7200	....	**− 90°**
− 85°	2.167	108.	0.00924	....	632.5	....	589.1	....	....	1.6884	....	**− 85°**
− 80°	2.626	90.3	0.01107	....	629.3	....	585.3	....	....	1.6575	....	**− 80°**
− 75°	3.164	75.8	0.01320	....	625.9	....	581.5	....	....	1.6273	....	**− 75°**
− 70°	3.791	64.0	0.01564	....	622.6	....	577.7	....	....	1.5979	....	**− 70°**
− 65°	4.518	54.2	0.01845	....	619.2	....	573.9	....	....	1.5691	....	**− 65°**
− 60°	5.358	46.2	0.02165	....	615.8	....	570.0	....	....	1.5410	....	**− 60°**
− 55°	6.324	39.6	0.02530	....	612.4	....	566.1	....	....	1.5134	....	**− 55°**
− 50°	7.43	34.01	0.02940	−85.7	608.9	523.3	562.2	476.5	−0.1901	1.4865	1.2964	**− 50°**
− 49°	7.67	32.98	0.03032	−84.7	608.2	523.6	561.4	476.7	−0.1875	1.4811	1.2936	**− 49°**
− 48°	7.92	32.00	0.03125	−83.6	607.5	523.9	560.6	476.9	−0.1850	1.4758	1.2908	**− 48°**
− 47°	8.17	31.07	0.03218	−82.6	606.8	524.3	559.8	477.2	−0.1825	1.4705	1.2880	**− 47°**
− 46°	8.43	30.19	0.03312	−81.5	606.1	524.6	559.0	477.4	−0.1801	1.4653	1.2853	**− 46°**
− 45°	8.69	29.34	0.03408	−80.5	605.4	524.9	558.2	477.6	−0.1776	1.4601	1.2825	**− 45°**
− 44°	8.96	28.52	0.03506	−79.5	604.7	525.3	557.4	477.9	−0.1751	1.4549	1.2797	**− 44°**
− 43°	9.24	27.72	0.03607	−78.4	604.0	525.6	556.6	478.2	−0.1727	1.4497	1.2770	**− 43°**
− 42°	9.53	26.94	0.03712	−77.4	603.3	525.9	555.8	478.4	−0.1702	1.4445	1.2743	**− 42°**
− 41°	9.82	26.18	0.03820	−76.4	602.6	526.2	555.0	478.6	−0.1678	1.4394	1.2716	**− 41°**
− 40°	10.12	25.45	0.03930	−75.3	601.9	526.6	554.2	478.9	−0.1653	1.4343	1.2690	**− 40°**
− 39°	10.43	24.74	0.04042	−74.3	601.2	526.9	553.4	479.1	−0.1628	1.4292	1.2663	**− 39°**
− 38°	10.75	24.06	0.04156	−73.3	600.5	527.2	552.6	479.3	−0.1604	1.4241	1.2637	**− 38°**
− 37°	11.07	23.40	0.04273	−72.2	599.7	527.5	551.8	479.6	−0.1580	1.4190	1.2611	**− 37°**
− 36°	11.40	22.76	0.04393	−71.2	599.0	527.9	551.0	479.8	−0.1555	1.4140	1.2585	**− 36°**
− 35°	11.74	22.14	0.04516	−70.2	598.3	528.2	550.2	480.0	−0.1531	1.4090	1.2559	**− 35°**
− 34°	12.09	21.55	0.04641	−69.1	597.6	528.5	549.4	480.3	−0.1507	1.4040	1.2533	**− 34°**
− 33°	12.45	20.97	0.04769	−68.1	596.9	528.8	548.6	480.5	−0.1483	1.3990	1.2507	**− 33°**
− 32°	12.81	20.41	0.04900	−67.1	596.1	529.1	547.8	480.7	−0.1458	1.3940	1.2482	**− 32°**
− 31°	13.18	19.87	0.05033	−66.0	595.4	529.4	547.0	481.0	−0.1434	1.3891	1.2457	**− 31°**
− 30°	13.56	19.35	0.05168	−65.0	594.7	529.8	546.2	481.2	−0.1410	1.3842	1.2432	**− 30°**
− 29°	13.95	18.84	0.05306	−63.9	594.0	530.1	545.4	481.4	−0.1386	1.3793	1.2407	**− 29°**
− 28°	14.35	18.35	0.05449	−62.9	593.2	530.4	544.6	481.6	−0.1362	1.3744	1.2382	**− 28°**
− 27°	14.76	17.87	0.05596	−61.8	592.5	530.7	543.7	481.9	−0.1338	1.3696	1.2358	**− 27°**
− 26°	15.18	17.40	0.05747	−60.8	591.8	531.0	542.9	482.1	−0.1314	1.3647	1.2333	**− 26°**
− 25°	15.61	16.95	0.0590	−59.8	591.1	531.3	542.1	482.3	−0.1290	1.3598	1.2309	**− 25°**
− 24°	16.05	16.51	0.0606	−58.7	590.3	531.6	541.3	482.5	−0.1266	1.3550	1.2285	**− 24°**
− 23°	16.50	16.09	0.0622	−57.7	589.6	531.9	540.5	482.8	−0.1242	1.3502	1.2260	**− 23°**
− 22°	16.96	15.68	0.0638	−56.6	588.8	532.2	539.7	483.0	−0.1218	1.3454	1.2236	**− 22°**
− 21°	17.43	15.28	0.0654	−55.6	588.1	532.5	538.9	483.2	−0.1195	1.3407	1.2213	**− 21°**
− 20°	17.91	14.89	0.0671	−54.6	587.4	532.8	538.0	483.4	−0.1171	1.3360	1.2189	**− 20°**
− 19°	18.40	14.52	0.0689	−53.5	586.6	533.1	537.2	483.6	−0.1147	1.3313	1.2165	**− 19°**
− 18°	18.90	14.16	0.0706	−52.5	585.9	533.4	536.4	483.8	−0.1124	1.3266	1.2142	**− 18°**
− 17°	19.41	13.81	0.0724	−51.4	585.1	533.7	535.6	484.0	−0.1100	1.3219	1.2118	**− 17°**
− 16°	19.93	13.48	0.0742	−50.4	584.4	534.0	524.8	484.3	−0.1077	1.3172	1.2095	**− 16°**

TABLE 1—TEMPERATURE

Temp. Fahr.	Pressure, lb. per sq. in.	Sp. Vol. cu. ft. per lb.	Density lb. per cu. ft.	Heat Content of Liquid	Latent Heat of Evap.	Heat Content of Vapor	Internal Energy B. t. u.		Entropy			Temp. Fahr.
							Evap.	Vapor	Liquid	Evap.	Vapor	
t	p	v''	$1/v''$	i'	r	i''	ρ	u''	s'	r/T	s''	
−15°	20.46	13.15	0.0760	−49.4	583.6	534.3	533.9	484.5	−0.1054	1.3126	1.2072	−15°
−14°	21.00	12.83	0.0779	−48.3	582.9	534.6	533.1	484.7	−0.1031	1.3080	1.2049	−14°
−13°	21.56	12.51	0.0799	−47.3	582.1	534.8	532.3	484.9	−0.1007	1.3033	1.2026	−13°
−12°	22.13	12.21	0.0819	−46.2	581.4	535.1	531.4	485.1	−0.0984	1.2987	1.2003	−12°
−11°	22.71	11.92	0.0839	−45.2	580.6	535.4	530.6	485.3	−0.0961	1.2941	1.1980	−11°
−10°	23.30	11.63	0.0860	−44.2	579.9	535.7	529.8	485.5	−0.0938	1.2896	1.1958	−10°
− 9°	23.90	11.35	0.0881	−43.1	579.1	536.0	528.9	485.7	−0.0915	1.2851	1.1935	− 9°
− 8°	24.52	11.08	0.0903	−42.1	578.4	536.3	528.1	485.9	−0.0893	1.2806	1.1913	− 8°
− 7°	25.15	10.82	0.0924	−41.0	577.6	536.6	527.3	486.1	−0.0870	1.2761	1.1891	− 7°
− 6°	25.80	10.57	0.0946	−40.0	576.8	536.9	526.4	486.3	−0.0847	1.2716	1.1869	− 6°
− 5°	26.46	10.32	0.0969	−38.9	576.1	537.1	525.6	486.6	−0.0824	1.2671	1.1847	− 5°
− 4°	27.13	10.08	0.0992	−37.9	575.3	537.4	524.7	486.8	−0.0801	1.2626	1.1825	− 4°
− 3°	27.82	9.85	0.1015	−36.8	574.6	537.7	523.9	487.0	−0.0778	1.2582	1.1804	− 3°
− 2°	28.52	9.62	0.1039	−35.8	573.8	538.0	523.1	487.2	−0.0755	1.2537	1.1782	− 2°
− 1°	29.23	9.40	0.1064	−34.7	573.0	538.2	522.2	487.4	−0.0732	1.2493	1.1761	− 1°
0°	29.95	9.19	0.1089	−33.7	572.2	538.5	521.4	487.6	−0.0709	1.2449	1.1740	0°
1°	30.69	8.98	0.1114	−32.6	571.4	538.8	520.5	487.8	−0.0686	1.2405	1.1719	1°
2°	31.44	8.78	0.1139	−31.6	570.7	539.1	519.7	488.0	−0.0663	1.2362	1.1699	2°
3°	32.21	8.58	0.1165	−30.5	569.9	539.3	518.8	488.2	−0.0640	1.2318	1.1678	3°
4°	32.99	8.39	0.1192	−29.5	569.1	539.6	518.0	488.4	−0.0618	1.2275	1.1657	4°
5°	33.79	8.20	0.1219	−28.4	568.3	539.9	517.1	488.6	−0.0595	1.2231	1.1636	5°
6°	34.60	8.02	0.1247	−27.4	567.5	540.1	516.3	488.7	−0.0572	1.2188	1.1615	6°
7°	35.43	7.84	0.1275	−26.3	566.7	540.4	515.4	488.9	−0.0550	1.2145	1.1595	7°
8°	36.28	7.67	0.1304	−25.3	565.9	540.7	514.6	489.1	−0.0527	1.2102	1.1575	8°
9°	37.14	7.50	0.1333	−24.2	565.2	540.9	513.7	489.3	−0.0505	1.2059	1.1554	9°
10°	38.02	7.34	0.1363	−23.2	564.4	541.2	512.9	489.5	−0.0483	1.2017	1.1534	10°
11°	38.93	7.18	0.1393	−22.1	563.6	541.4	512.0	489.7	−0.0461	1.1975	1.1514	11°
12°	39.84	7.02	0.1424	−21.1	562.8	541.7	511.2	489.9	−0.0438	1.1932	1.1494	12°
13°	40.77	6.87	0.1455	−20.0	562.0	542.0	510.3	490.1	−0.0416	1.1890	1.1474	13°
14°	41.71	6.72	0.1487	−19.0	561.2	542.2	509.4	490.3	−0.0394	1.1848	1.1454	14°
15°	42.67	6.583	0.1519	−17.9	560.4	542.5	508.6	490.5	−0.0372	1.1806	1.1434	15°
16°	43.65	6.444	0.1552	−16.8	559.6	542.7	507.7	490.6	−0.0350	1.1765	1.1415	16°
17°	44.65	6.308	0.1585	−15.8	558.8	543.0	506.8	490.8	−0.0328	1.1723	1.1395	17°
18°	45.67	6.176	0.1619	−14.7	558.0	543.2	506.0	491.0	−0.0306	1.1682	1.1376	18°
19°	46.70	6.047	0.1654	−13.6	557.1	543.5	505.1	491.2	−0.0284	1.1640	1.1356	19°
20°	47.75	5.920	0.1689	−12.6	556.3	543.7	504.2	491.4	−0.0262	1.1599	1.1337	20°
21°	48.82	5.796	0.1725	−11.5	555.5	544.0	503.3	491.6	−0.0240	1.1558	1.1318	21°
22°	49.91	5.676	0.1762	−10.4	554.7	544.2	502.4	491.8	−0.0218	1.1516	1.1298	22°
23°	51.02	5.560	0.1799	− 9.4	553.9	544.5	501.6	491.9	−0.0196	1.1475	1.1279	23°
24°	52.15	5.447	0.1836	− 8.3	553.1	544.7	500.7	492.1	−0.0174	1.1435	1.1260	24°
25°	53.30	5.336	0.1874	− 7.3	552.2	545.0	499.8	492.3	−0.0153	1.1395	1.1242	25°
26°	54.47	5.228	0.1913	− 6.2	551.4	545.2	498.9	492.5	−0.0131	1.1354	1.1223	26°
27°	55.66	5.122	0.1953	− 5.1	550.6	545.5	498.1	492.7	−0.0109	1.1314	1.1205	27°
28°	56.87	5.019	0.1993	− 4.1	549.8	545.7	497.2	492.9	−0.0087	1.1274	1.1187	28°
29°	58.10	4.918	0.2034	− 3.0	549.0	546.0	496.3	493.0	−0.0066	1.1234	1.1168	29°
30°	59.35	4.820	0.2075	− 1.9	548.1	546.2	495.4	493.2	−0.0044	1.1194	1.1150	30°
31°	60.62	4.724	0.2117	− 0.8	547.3	546.4	494.5	493.4	−0.0022	1.1154	1.1132	31°
32°	61.91	4.631	0.2159	+ 0.3	546.5	546.7	493.6	493.6	0.0000	1.1114	1.1114	32°
33°	63.22	4.540	0.2203	+ 1.3	545.6	546.9	492.8	493.8	+0.0021	1.1075	1.1097	33°
34°	64.55	4.451	0.2247	+ 2.4	544.8	547.1	491.9	493.9	+0.0043	1.1036	1.1079	34°

TABLE 1—TEMPERATURE

Temp. Fahr.	Pressure, lb. per sq. in.	Sp. Vol. cu. ft. per lb.	Density lb. per cu. ft.	Heat Content of Liquid	Latent Heat of Evap.	Heat Content of Vapor	Internal Energy B. t. u.		Entropy			Temp. Fahr.
							Evap.	Vapor	Liquid	Evap.	Vapor	
t	p	v''	$1/v''$	i'	r	i''	ρ	u''	s'	r/T	s''	
35°	65.91	4.364	0.2292	3.5	543.9	547.4	491.0	494.1	0.0065	1.0996	1.1061	**35°**
36°	67.29	4.279	0.2337	4.6	543.1	547.6	490.1	494.3	0.0087	1.0957	1.1043	**36°**
37°	68.69	4.196	0.2384	5.6	542.2	547.8	489.2	494.5	0.0108	1.0918	1.1026	**37°**
38°	70.11	4.115	0.2431	6.7	541.4	548.1	488.3	494.6	0.0130	1.0879	1.1009	**38°**
39°	71.56	4.036	0.2478	7.8	540.5	548.3	487.4	494.8	0.0151	1.0840	1.0991	**39°**
40°	73.03	3.959	0.2526	8.9	539.7	548.5	486.5	495.0	0.0173	1.0801	1.0974	**40°**
41°	74.53	3.884	0.2575	10.0	538.8	548.8	485.5	495.2	0.0194	1.0763	1.0957	**41°**
42°	76.05	3.810	0.2625	11.1	537.9	549.0	484.6	495.3	0.0216	1.0724	1.0940	**42°**
43°	77.59	3.738	0.2675	12.2	537.1	549.2	483.7	495.5	0.0237	1.0686	1.0923	**43°**
44°	79.16	3.668	0.2727	13.3	536.2	549.4	482.8	495.7	0.0259	1.0647	1.0906	**44°**
45°	80.75	3.599	0.2779	14.3	535.3	549.7	481.9	495.9	0.0280	1.0609	1.0889	**45°**
46°	82.37	3.532	0.2832	15.4	534.5	549.9	481.0	496.0	0.0301	1.0571	1.0872	**46°**
47°	84.01	3.466	0.2885	16.5	533.6	550.1	480.1	496.2	0.0323	1.0533	1.0856	**47°**
48°	85.68	3.402	0.2940	17.6	532.7	550.3	479.2	496.4	0.0344	1.0495	1.0839	**48°**
49°	87.37	3.339	0.2995	18.7	531.8	550.6	478.3	496.5	0.0366	1.0457	1.0822	**49°**
50°	89.09	3.278	0.3051	19.8	531.0	550.8	477.3	496.7	0.0387	1.0419	1.0806	**50°**
51°	90.83	3.219	0.3107	20.9	530.1	551.0	476.4	496.9	0.0408	1.0382	1.0790	**51°**
52°	92.59	3.161	0.3164	22.0	529.2	551.2	475.5	497.0	0.0430	1.0344	1.0774	**52°**
53°	94.38	3.104	0.3222	23.1	528.3	551.4	474.6	497.2	0.0451	1.0306	1.0757	**53°**
54°	96.19	3.048	0.3281	24.2	527.4	551.6	473.6	497.4	0.0473	1.0268	1.0741	**54°**
55°	98.03	2.992	0.3342	25.3	526.5	551.9	472.7	497.5	0.0494	1.0231	1.0725	**55°**
56°	99.90	2.938	0.3404	26.4	525.6	552.1	471.8	497.7	0.0516	1.0194	1.0710	**56°**
57°	101.8	2.885	0.3467	27.5	524.7	552.3	470.8	497.9	0.0537	1.0157	1.0694	**57°**
58°	103.7	2.833	0.3530	28.7	523.8	552.5	469 9	498.0	0.0559	1.0119	1.0678	**58°**
59°	105.7	2.783	0.3594	29.8	522.9	552.7	469.0	498.2	0.0580	1.0083	1.0663	**59°**
60°	107.7	2.734	0.3658	30.9	522.0	522.9	468.0	498.4	0.0601	1.0046	1.0647	**60°**
61°	109.7	2.686	0.3723	32.0	521.1	553.1	467.1	498.5	0.0623	1.0009	1.0632	**61°**
62°	111.7	2.639	0 3790	33.1	520.2	553.3	466.1	498.7	0.0644	0.9973	1.0617	**62°**
63°	113.8	2.592	0.3858	34.2	519.3	553.5	465.2	498.9	0.0665	0.9937	1.0602	**63°**
64°	115.9	2.547	0.3927	35.3	518.4	553.7	464.2	499.0	0.0687	0.9900	1.0587	**64°**
65°	118.1	2.503	0.3996	36.5	517.5	554.0	463.3	499.2	0.0708	0.9863	1.0571	**65°**
66°	120.3	2.460	0.4066	37.6	516.5	554.2	462.3	499.4	0.0729	0.9827	1.0556	**65°**
67°	122.5	2.418	0.4136	38.7	515.6	554.4	461.4	499.5	0.0750	0.9791	1.0541	**67°**
68°	124.7	2.377	0.4207	39.9	514.7	554.6	460.4	499.7	0.0771	0.9755	1.0526	**68°**
69°	126.9	2.336	0.4280	41.0	513.7	554.8	459.5	499.9	0.0792	0.9719	1.0511	**69°**
70°	129.2	2.296	0.4354	42.1	512.8	555.0	458.5	500.0	0.0813	0.9683	1.0496	**70°**
71°	131.5	2.257	0.4430	43.3	511.9	555.2	457.6	500.2	0.0834	0.9647	1.0481	**71°**
72°	133.9	2.219	0.4506	44.4	511.0	555.4	456.6	500.4	0.0855	0.9612	1.0467	**72°**
73°	136.3	2.182	0.4583	45.5	510.0	555.6	455.7	500.5	0.0876	0.9576	1.0452	**73°**
74°	138.7	2.145	0.4662	46.7	509.1	555.8	454.7	500.7	0.0898	0.9540	1.0438	**74°**
75°	141.1	2.109	0.4742	47.8	508.1	556.0	453.7	500.9	0.0919	0.9504	1.0423	**75°**
76°	143.6	2.074	0.4823	49 0	507.2	556.2	452.7	501.0	0.0940	0.9469	1.0409	**76°**
77°	146.1	2.039	0.4905	50.1	506.2	556.4	451.7	501.2	0.0961	0.9434	1.0395	**77°**
78°	148.7	2.005	0.4988	51.3	505.3	556.6	450.8	501.3	0.0983	0.9398	1.0381	**78°**
79°	151.3	1.972	0.5071	52.4	504.3	556.8	449.8	501.5	0.1004	0.9363	1.0367	**79°**
80°	153.9	1.940	0.5155	53.6	503.4	557.0	448.8	501.7	0.1025	0.9328	1.0353	**80°**
81°	156.5	1.908	0.5241	54.8	502.4	557.1	447.8	501.8	0.1047	0.9293	1.0339	**81°**
82°	159.2	1.877	0.5328	55.9	501.4	557.3	446.9	502.0	0.1068	0.9258	1.0326	**82°**
83°	161.9	1.847	0.5416	57.1	500.5	557.5	445.9	502.2	0.1090	0.9222	1.0312	**83°**
84°	164.6	1.817	0.5504	58.3	499.5	557.7	444.9	502.3	0.1111	0.9187	1.0298	**84°**

TABLE 1—TEMPERATURE

Temp. Fahr.	Pressure, lb. per sq. in.	Sp. Vol. cu. ft. per lb.	Density lb. per cu. ft.	Heat Content of Liquid	Latent Heat of Evap.	Heat Content of Vapor	Internal Energy B. t. u.		Entropy			Temp. Fahr.
							Evap.	Vapor	Liquid	Evap.	Vapor	
t	p	v''	$1/v''$	i'	r	i''	ρ	u''	s'	r/T	s''	
85°	167.4	1.788	0.5594	59.4	498.5	557.9	443.9	502.5	0.1132	0.9153	1.0285	**85°**
86°	170.2	1.759	0.5685	60.6	497.5	558.1	442.9	502.7	0.1153	0.9118	1.0271	**86°**
87°	173.0	1.731	0.5777	61.8	496.5	558.3	441.9	502.8	0.1175	0.9083	1.0258	**87°**
88°	175.9	1.704	0.5869	63.0	495.5	558.5	440.9	503.0	0.1196	0.9049	1.0245	**88°**
89°	178.8	1.677	0.5964	64.2	494.5	558.7	439.9	503.1	0.1217	0.9014	1.0231	**89°**
90°	181.8	1.650	0.6060	65.3	493.5	558.9	438.9	503.3	0.1238	0.8980	1.0218	**90°**
91°	184.8	1.624	0.6158	66.5	492.5	559.1	437.9	503.5	0.1259	0.8945	1.0205	**91°**
92°	187.8	1.598	0.6258	67.7	491.5	559.2	436.9	503.6	0.1281	0.8910	1.0191	**92°**
93°	190.9	1.573	0.6358	68.9	490.5	559.4	435.9	503.8	0.1302	0.8876	1.0178	**93°**
94°	194.1	1.548	0.6460	70.1	489.5	559.6	434.9	504.0	0.1323	0.8842	1.0165	**94°**
95°	197.3	1.524	0.656	71.3	488.5	559.8	433.9	504.1	0.1344	0.8808	1.0152	**95°**
96°	200.5	1.500	0.667	72.5	487.5	560.0	432.8	504.3	0.1365	0.8774	1.0139	**96°**
97°	203.8	1.477	0.677	73.7	486.5	560.2	431.8	504.5	0.1387	0.8740	1.0127	**97°**
98°	207.1	1.454	0.688	74.9	485.4	560.3	430.8	504.6	0.1408	0.8706	1.0114	**98°**
99°	210.4	1.431	0.699	76.1	484.4	560.5	429.8	504.8	0.1429	0.8672	1.0101	**99°**
100°	213.8	1.408	0.710	77.3	483.4	560.7	428.7	504.9	0.1450	0.8638	1.0088	**100°**
101°	217.2	1.386	0.721	78.5	482.3	560.9	427.7	505.1	0.1471	0.8604	1.0076	**101°**
102°	220.7	1.365	0.732	79.7	481.3	561.1	426.7	505.2	0.1493	0.8570	1.0063	**102°**
103°	224.2	1.345	0.743	80.9	480.3	561.2	425.6	505.4	0.1514	0.8537	1.0051	**103°**
104°	227.7	1.325	0.755	82.2	479.2	561.4	424.6	505.6	0.1535	0.8503	1.0039	**104°**
105°	231.2	1.305	0.766	83.4	478.2	561.6	423.5	505.7	0.1557	0.8469	1.0026	**105°**
106°	234.8	1.285	0.778	84.6	477.1	561.8	422.5	505.9	0.1578	0.8436	1.0014	**106°**
107°	238.4	1.266	0.790	85.8	476.1	561.9	421.4	506.1	0.1599	0.8403	1.0002	**107°**
108°	242.1	1.247	0.802	87.1	475.0	562.1	420.4	506.2	0.1621	0.8369	0.9990	**108°**
109°	245.8	1.228	0.814	88.3	474.0	562.3	419.3	506.4	0.1642	0.8336	0.9978	**109°**
110°	249.6	1.210	0.826	89.6	472.9	562.5	418.3	506.6	0.1664	0.8302	0.9966	**110°**
111°	253.4	1.192	0.839	90.8	471.8	562.6	417.2	506.7	0.1686	0.8268	0.9954	**111°**
112°	257.3	1.174	0.852	92.1	470.7	562.8	416.1	506.9	0.1707	0.8235	0.9942	**112°**
113°	261.2	1.156	0.865	93.3	469.6	563.0	415.1	507.1	0.1729	0.8202	0.9930	**113°**
114°	265.2	1.139	0.878	94.6	468.5	563.1	414.0	507.2	0.1750	0.8169	0.9919	**114°**
115°	269.2	1.122	0.891	95.9	467.4	563.3	412.9	507.4	0.1772	0.8135	0.9907	**115°**
116°	273.3	1.105	0.905	97.1	466.3	563.5	411.9	507.6	0.1794	0.8102	0.9896	**116°**
117°	277.4	1.088	0.919	98.4	465.2	563.7	410.8	507.7	0.1816	0.8068	0.9884	**117°**
118°	281.5	1.072	0.933	99.7	464.1	563.8	409.7	507.9	0.1838	0.8035	0.9873	**118°**
119°	285.7	1.057	0.946	101.0	463.0	564.0	408.6	508.1	0.1859	0.8002	0.9861	**119°**
120°	289.9	1.042	0.960	102.2	461.9	564.2	407.5	508.2	0.1881	0.7969	0.9850	**120°**
121°	294.2	1.027	0.974	103.5	460.8	464.4	406.4	508.4	0.1903	0.7936	0.9839	**121°**
122°	298.5	1.012	0.988	104.8	459.7	564.5	405.3	508.6	0.1925	0.7903	0.9828	**122°**
123°	302.8	0.998	1.002	106.1	458.6	564.7	404.2	508.8	0.1947	0.7870	0.9817	**123°**
124°	307.2	0.984	1.016	107.4	457.4	564.9	403.1	508.9	0.1968	0.7838	0.9806	**124°**
125°	311.6	0.970	1.031	108.7	456.3	565.0	402.0	509.1	0.1990	0.7805	0.9795	**125°**
126°	316.1	0.956	1.046	110.0	455.2	565.2	400.9	509.3	0.2012	0.7772	0.9784	**126°**
127°	320.6	0.942	1.061	111.3	454.0	565.4	399.8	509.4	0.2034	0.7739	0.9773	**127°**
128°	325.2	0.929	1.076	112.6	452.8	565.5	398.7	509.6	0.2056	0.7707	0.9763	**128°**
129°	329.9	0.916	1.092	114.0	451.7	565.7	397.6	509.8	0.2078	0.7674	0.9752	**129°**
130°	334.6	0.903	1.108	115.3	450.6	565.9	396.4	510.0	0.2100	0.7641	0.9741	**130°**
131°	339.4	0.890	1.124	116.6	449.4	566.0	395.3	510.2	0.2122	0.7609	0.9731	**131°**
132°	344.2	0.877	1.140	118.0	448.2	566.2	394.2	510.3	0.2145	0.7576	0.9720	**132°**
133°	349.0	0.865	1.156	119.3	447.0	566.4	393.0	510.5	0.2167	0.7543	0.9710	**133°**
134°	353.9	0.853	1.172	120.7	445.8	566.5	391.9	510.7	0.2189	0.7511	0.9700	**134°**

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Temp. Fahr.	Pressure, lb. per sq. in.	Sp. Vol. cu. ft. per lb.	Density lb. per cu. ft.	Heat Content of Liquid	Latent Heat of Evap.	Heat Content of Vapor	Internal Energy B. t. u.		Entropy			Temp. Fahr.
							Evap.	Vapor	Liquid	Evap.	Vapor	
t	p	v''	$1/v''$	i'	r	i''	ρ	u''	s'	r/T	s''	
135°	358.8	0.841	1.189	122.0	444.7	566.7	390.7	510.8	0.2211	0.7478	0.9689	**135°**
136°	363.8	0.829	1.206	123.4	443.5	566.8	389.6	511.0	0.2234	0.7445	0.9679	**136°**
137°	368.9	0.817	1.224	124.7	442.3	567.0	388.4	511.2	0.2256	0.7413	0.9669	**137°**
138°	374.0	0.806	1.241	126.1	441.1	567.2	387.3	511.3	0.2278	0.7380	0.9658	**138°**
139°	379.2	0.795	1.258	127.4	439.9	567.3	386.1	511.5	0.2301	0.7347	0.9648	**139°**
140°	384.4	0.784	1.275	128.8	438.6	567.5	384.9	511.7	0.2323	0.7315	0.9638	**140°**
141°	389.7	0.773	1.293	130.2	437.4	567.6	383.8	511.8	0.2346	0.7282	0.9628	**141°**
142°	395.0	0.762	1.312	131.6	436.2	567.8	382.6	512.0	0.2368	0.7250	0.9618	**142°**
143°	400.4	0.751	1.331	133.0	435.0	567.9	381.4	512.2	0.2391	0.7217	0.9608	**143°**
144°	405.8	0.741	1.349	134.4	433.7	568.1	380.2	512.4	0.2413	0.7185	0.9598	**144°**
145°	411.3	0.731	1.368	135.8	432.5	568.3	379.0	512.6	0.2436	0.7153	0.9588	**145°**
146°	416.8	0.721	1.387	137.2	431.2	568.4	377.8	512.7	0.2459	0.7120	0.9578	**146°**
147°	422.4	0.711	1.406	138.6	430.0	568.6	376.6	512.9	0.2481	0.7088	0.9569	**147°**
148°	428.0	0.701	1.425	140.0	428.7	568.7	375.4	513.1	0.2504	0.7055	0.9559	**148°**
149°	433.7	0.692	1.445	141.5	427.4	568.9	374.2	513.3	0.2527	0.7023	0.9550	**149°**
150°	439.5	0.683	1.464	142.9	426.2	569.0	373.0	513.4	0.2550	0.6990	0.9540	**150°**
155°	469.1	0.638	1.567	150.1	419.7	569.8	366.9	514.4	0.2666	0.6828	0.9494	**155°**
160°	500.1	0.597	1.676	157.5	413.0	570.5	360.6	515.3	0.2784	0.6665	0.9449	**160°**
165°	532.6	0.558	1.792	165.1	406.2	571.3	354.2	516.2	0.2903	0.6502	0.9405	**165°**
170°	566.6	0.522	1.915	172.9	399.1	572.0	347.6	517.2	0.3023	0.6339	0.9362	**170°**
175°	602.2	0.489	2.045	180.9	391.8	572.7	340.8	518.2	0.3146	0.6174	0.9320	**175°**
180°	639.5	0.458	2.183	189.0	384.3	573.4	333.9	519.2	0.3271	0.6009	0.9280	**180°**
185°	678.4	0.429	2.330	197.5	376.6	574.0	326.8	520.2	0.3399	0.5842	0.9241	**185°**
190°	719.0	0.402	2.488	206.2	368.5	574.7	319.4	521.2	0.3530	0.5673	0.9203	**190°**
195°	761.4	0.376	2.660	215.2	360.2	575.4	311.8	522.3	0.3664	0.5502	0.9166	**195°**
200°	805.6	0.352	2.84	....	351.5	....	303.9	....	....	0.5328	....	**200°**
205°	851.7	0.330	3.03	....	342.4	....	295.7	....	....	0.5152	....	**205°**
210°	899.7	0.309	3.24	....	332.9	....	287.2	....	....	0.4971	....	**210°**
215°	949.6	0.289	3.46	....	322.9	....	278.2	....	....	0.4786	....	**215°**
220°	1001.4	0.270	3.70	....	312.3	....	268.8	....	....	0.4595	....	**220°**
225°	1055.3	0.252	3.97	....	301.1	....	258.9	....	....	0.4398	....	**225°**
230°	1111.3	0.235	4.26	....	289.2	....	248.3	....	....	0.4193	....	**230°**
235°	1169.5	0.219	4.57	....	276.3	....	237.0	....	....	0.3977	....	**235°**
240°	1229.9	0.203	4.93	....	262.3	....	224.8	....	....	0.3749	....	**240°**
245°	1292.5	0.188	5.32	....	246.9	....	211.4	....	....	0.3504	....	**245°**
250°	1357.4	0.173	5.8	....	229.7	....	196.4	....	....	0.3237	....	**250°**
255°	1424.7	0.158	6.3	....	210.0	....	179.4	....	....	0.2938	....	**255°**
260°	1494.4	0.142	7.0	....	186.4	....	149.1	....	....	0.2590	....	**260°**
265°	1566.6	0.125	8.0	....	156.2	....	133.2	....	....	0.2156	....	**265°**
270°	1641.3	0.104	9.6	....	110.1	....	93.9	....	....	0.1510	....	**270°**
273.2°	1690.0	0.068	14.75	....	000.0	....	00.0	....	....	0.0000	....	**273.2°**

TABLE 2

SATURATED AMMONIA VAPOR: PRESSURE TABLE

Pressure, lb. p	Temp. Fahr. t	Sp. Vol. cu. ft. per lb. v''	Density lb. per cu. ft. $1/v''$	Heat Content of Liquid i'	Latent Heat of Evap. r	Heat Content of Vapor i''	Internal Energy B. t. u.		Entropy			Pressure, lb. p
							Evap. ρ	Vapor u''	Liquid s'	Evap. r/T	Vapor s''	
1	−103.7	225.	0.0044	....	644.6	....	603.0	....	....	1.8106	....	1
2	−87.1	117.	0.0085	....	633.9	....	590.7	....	....	1.7016	....	2
3	−76.5	80.	0.0125	....	626.9	....	582.7	....	....	1.6362	....	3
4	−68.5	61.	0.0164	....	621.6	....	576.5	....	....	1.5890	....	4
5	−62.0	49.3	0.0203	−98.1	617.2	519.1	571.5	473.4	−0.2207	1.5522	1.3315	5
6	−56.6	41.6	0.0241	−92.5	613.5	521.1	567.3	474.9	−0.2070	1.5222	1.3152	6
7	−51.9	35.9	0.0279	−87.6	610.2	522.7	563.7	476.2	−0.1947	1.4964	1.3017	7
8	−47.6	31.6	0.0316	−83.2	607.3	524.1	560.4	477.1	−0.1840	1.4739	1.2899	8
9	−43.9	28.3	0.0353	−79.3	604.7	525.3	557.4	478.0	−0.1747	1.4540	1.2793	9
10	−40.4	25.75	0.0388	−75.7	602.2	526.4	554.6	478.8	−0.1661	1.4362	1.2701	10
11	−37.2	23.60	0.0424	−72.4	599.9	527.5	552.0	479.5	−0.1584	1.4201	1.2617	11
12	−34.3	21.75	0.0460	−69.4	597.8	528.4	549.6	480.2	−0.1513	1.4053	1.2540	12
13	−31.5	20.16	0.0496	−66.5	595.8	529.3	547.4	480.9	−0.1446	1.3916	1.2470	13
14	−28.9	18.79	0.0532	−63.8	593.9	530.1	545.4	481.5	−0.1384	1.3788	1.2404	14
15	−26.4	17.60	0.0568	−61.2	592.1	530.9	543.3	482.0	−0.1324	1.3668	1.2344	15
16	−24.1	16.56	0.0604	−58.8	590.4	531.6	541.4	482.5	−0.1268	1.3556	1.2288	16
17	−21.9	15.64	0.0639	−56.5	588.8	532.2	539.6	483.0	−0.1215	1.3450	1.2235	17
18	−19.8	14.82	0.0675	−54.4	587.2	532.8	537.9	483.4	−0.1165	1.3350	1.2185	18
19	−17.8	14.09	0.0710	−52.3	585.7	533.4	536.3	483.9	−0.1119	1.3256	1.2137	19
20	−15.9	13.45	0.0744	−50.3	584.3	534.0	534.7	484.3	−0.1075	1.3167	1.2092	20
21	−14.0	12.82	0.0780	−48.4	582.9	534.6	533.1	484.7	−0.1032	1.3081	1.2049	21
22	−12.2	12.27	0.0815	−46.5	581.5	535.1	531.6	485.1	−0.0990	1.2998	1.2008	22
23	−10.5	11.77	0.0850	−44.7	580.2	535.6	530.2	485.4	−0.0950	1.2919	1.1969	23
24	−8.8	11.30	0.0885	−42.9	579.0	536.1	528.8	485.8	−0.0912	1.2843	1.1931	24
25	−7.2	10.88	0.0919	−41.3	577.8	536.5	527.4	486.1	−0.0874	1.2770	1.1896	25
26	−5.7	10.50	0.0953	−39.7	576.6	536.9	526.1	486.4	−0.0840	1.2700	1.1861	26
27	−4.2	10.13	0.0987	−38.1	575.4	537.4	524.9	486.7	−0.0805	1.2633	1.1828	27
28	−2.7	9.78	0.1022	−36.5	574.3	537.8	523.7	487.0	−0.0771	1.2568	1.1797	28
29	−1.3	9.47	0.1056	−35.0	573.2	538.2	522.5	487.3	−0.0739	1.2506	1.1767	29
30	+0.1	9.17	0.1090	−33.6	572.1	538.5	521.3	487.6	−0.0708	1.2446	1.1738	30
31	1.4	8.90	0.1124	−32.2	571.1	538.9	520.2	487.8	−0.0677	1.2388	1.1711	31
32	2.7	8.64	0.1158	−30.8	570.1	539.3	519.1	488.1	−0.0648	1.2331	1.1683	32
33	4.0	8.39	0.1192	−29.5	569.1	539.6	518.0	488.4	−0.0617	1.2274	1.1657	33
34	5.3	8.15	0.1226	−28.2	568.1	540.0	516.9	488.6	−0.0589	1.2219	1.1630	34
35	6.5	7.93	0.1260	−26.9	567.1	540.3	515.8	488.8	−0.0561	1.2167	1.1606	35
36	7.7	7.73	0.1294	−25.6	566.2	540.6	514.8	489.1	−0.0534	1.2115	1.1580	36
37	8.9	7.52	0.1328	−24.4	565.3	540.9	513.8	489.3	−0.0508	1.2065	1.1557	37
38	10.0	7.84	0.1362	−23.2	564.4	541.2	512.8	489.5	−0.0483	1.2017	1.1534	38
39	11.1	7.16	0.1397	−22.0	563.5	541.5	511.9	489.7	−0.0458	1.1970	1.1512	39
40	12.2	6.989	0.1431	−20.8	562.6	541.8	511.0	489.9	−0.0433	1.1923	1.1490	40
41	13.3	6.824	0.1465	−19.7	561.7	542.0	510.0	490.1	−0.0409	1.1877	1.1468	41
42	14.4	6.668	0.1500	−18.6	560.9	542.3	509.1	490.3	−0.0386	1.1832	1.1447	42
43	15.4	6.520	0.1534	−17.5	560.0	542.6	508.2	490.5	−0.0363	1.1789	1.1426	43
44	16.4	6.380	0.1567	−16.4	559.2	542.8	507.3	490.7	−0.0341	1.1747	1.1406	44

TABLE 2—PRESSURE

Pressure, lb.	Temp. Fahr.	Sp. Vol. cu. ft. per lb.	Density lb. per cu. ft.	Heat Content of Liquid	Latent Heat of Evap.	Heat Content of Vapor	Internal Energy B. t. u.		Entropy			Pressure, lb.
p	t	v''	$1/v''$	i'	r	i''	Evap. ρ	Vapor u''	Liquid s'	Evap. r/T	Vapor s''	p
45	17.4	6.247	0.1601	−15.3	558.4	543.1	506.4	490.9	−0.0319	1.1706	1.1387	**45**
46	18.4	6.120	0.1634	−14.3	557.6	543.3	505.6	491.1	−0.0296	1.1665	1.1369	**46**
47	19.4	5.999	0.1667	−13.3	556.8	543.6	504.7	491.3	−0.0276	1.1625	1.1349	**47**
48	20.3	5.883	0.1700	−12.3	556.1	543.8	503.9	491.4	−0.0255	1.1586	1.1331	**48**
49	21.2	5.772	0.1733	−11.3	555.3	544.0	503.1	491.6	−0.0235	1.1558	1.1313	**49**
50	22.1	5.665	0.1765	−10.3	554.6	544.3	502.3	491.8	−0.0216	1.1511	1.1296	**50**
51	23.0	5.562	0.1798	− 9.3	553.9	544.5	501.5	491.9	−0.0196	1.1475	1.1279	**51**
52	23.9	5.463	0.1831	− 8.4	553.1	544.7	500.8	492.1	−0.0177	1.1440	1.1263	**52**
53	24.8	5.367	0.1863	− 7.5	552.4	544.9	500.0	492.3	−0.0158	1.1405	1.1246	**53**
54	25.6	5.274	0.1896	− 6.6	551.7	545.1	499.3	492.4	−0.0140	1.1371	1.1230	**54**
55	26.4	5.184	0.1929	− 5.7	551.1	545.3	498.6	492.6	−0.0122	1.1337	1.1215	**55**
56	27.3	5.097	0.1962	− 4.8	550.4	545.5	497.8	492.7	−0.0103	1.1303	1.1200	**56**
57	28.1	5.012	0.1996	− 3.9	549.7	545.7	497.1	492.9	−0.0085	1.1270	1.1185	**57**
58	28.9	4.929	0.2029	− 3.0	549.0	545.9	496.4	493.0	−0.0068	1.1238	1.1170	**58**
59	29.7	4.848	0.2063	− 2.2	548.4	546.1	495.7	493.2	−0.0050	1.1206	1.1156	**59**
60	30.5	4.770	0.2097	− 1.3	547.7	546.3	495.0	493.3	−0.0033	1.1174	1.1141	**60**
61	31.3	4.695	0.2130	− 0.5	547.0	546.5	494.3	493.5	−0.0016	1.1143	1.1127	**61**
62	32.1	4.623	0.2163	+ 0.3	546.4	546.7	493.6	493.6	+0.0001	1.1112	1.1113	**62**
63	32.8	4.554	0.2196	1.1	545.8	546.9	492.9	493.7	0.0018	1.1082	1.1100	**63**
64	33.6	4.487	0.2229	1.9	545.1	547.1	492.2	493.9	0.0035	1.1052	1.1086	**64**
65	34.3	4.422	0.2262	2.7	544.5	547.2	491.6	494.0	0.0051	1.1022	1.1073	**65**
66	35.1	4.359	0.2294	3.5	543.8	547.4	490.9	494.1	0.0067	1.0993	1.1060	**66**
67	35.8	4.298	0.2327	4.3	543.2	547.6	490.3	494.3	0.0082	1.0965	1.1047	**67**
68	36.5	4.238	0.2360	5.1	542.6	547.7	489.6	494.4	0.0097	1.0938	1.1035	**68**
69	37.2	4.179	0.2394	5.8	542.0	547.9	489.0	494.5	0.0113	1.0910	1.1023	**69**
70	37.9	4.121	0.2427	6.6	541.4	548.1	488.4	494.6	0.0128	1.0882	1.1010	**70**
71	38.6	4.065	0.2461	7.4	540.8	548.2	487.7	494.8	0.0143	1.0855	1.0998	**71**
72	39.3	4.011	0.2494	8.1	540.2	548.4	487.1	494.9	0.0158	1.0828	1.0986	**72**
73	40.0	3.958	0.2527	8.9	539.6	548.5	486.5	495.0	0.0173	1.0801	1.0974	**73**
74	40.7	3.907	0.2560	9.6	539.0	548.7	485.9	495.1	0.0187	1.0775	1.0962	**74**
75	41.3	3.858	0.2592	10.3	538.5	548.8	485.3	495.2	0.0201	1.0750	1.0951	**75**
76	42.0	3.811	0.2624	11.0	537.9	549.0	484.7	495.3	0.0215	1.0725	1.0940	**76**
77	42.6	3.765	0.2656	11.7	537.4	549.1	484.1	495.4	0.0229	1.0700	1.0929	**77**
78	43.3	3.720	0.2688	12.4	536.8	549.3	483.5	495.6	0.0243	1.0675	1.0918	**78**
79	43.9	3.676	0.2721	13.1	536.3	549.4	482.9	495.7	0.0257	1.0650	1.0907	**79**
80	44.5	3.633	0.2753	13.8	535.8	549.5	482.3	495.8	0.0271	1.0626	1.0897	**80**
81	45.1	3.591	0.2785	14.5	535.2	549.7	481.8	495.9	0.0284	1.0602	1.0887	**81**
82	45.8	3.549	0.2818	15.2	534.6	549.8	481.2	496.0	0.0297	1.0579	1.0876	**82**
83	46.4	3.508	0.2851	15.8	534.1	550.0	480.6	496.1	0.0310	1.0556	1.0866	**83**
84	47.0	3.468	0.2884	16.5	533.6	550.1	480.1	496.2	0.0323	1.0533	1.0856	**84**
85	47.6	3.429	0.2917	17.2	533.1	550.2	479.5	496.3	0.0336	1.0510	1.0846	**85**
86	48.2	3.390	0.2950	17.8	532.5	550.4	479.0	496.4	0.0349	1.0487	1.0836	**86**
87	48.8	3.352	0.2983	18.5	532.0	550.5	478.4	496.5	0.0362	1.0464	1.0826	**87**
88	49.4	3.315	0.3017	19.1	531.5	550.6	477.9	496.6	0.0374	1.0442	1.0816	**88**
89	50.0	3.278	0.3051	19.8	531.0	550.8	477.3	496.7	0.0386	1.0420	1.0806	**89**
90	50.5	3.252	0.3075	20.4	530.5	550.9	476.8	496.8	0.0398	1.0399	1.0797	**90**
91	51.1	3.216	0.3110	21.0	530.0	551.0	476.3	496.9	0.0410	1.0378	1.0788	**91**
92	51.7	3.181	0.3144	21.7	529.5	551.1	475.8	497.0	0.0422	1.0357	1.0779	**92**
93	52.2	3.147	0.3178	22.3	529.0	551.2	475.3	497.1	0.0434	1.0336	1.0770	**93**
94	52.8	3.114	0.3212	22.9	528.5	551.4	474.8	497.2	0.0446	1.0315	1.0761	**94**

TABLE 2—PRESSURE

Pressure, lb. p	Temp. Fahr t	Sp. Vol. cu. ft. per lb. v''	Density lb. per cu. ft. $1/v''$	Heat Content of Liquid i'	Latent Heat of Evap. r	Heat Content of Vapor i''	Internal Energy B. t. u.		Entropy			Pressure, lb. p
							Evap. ρ	Vapor u''	Liquid s'	Evap. r/T	Vapor s''	
95	53.3	3.082	0.3245	23.5	528.0	551.5	474.3	497.3	0.0458	1.0294	1.0752	**95**
96	53.9	3.051	0.3278	24.1	527.5	551.6	473.8	497.4	0.0470	1.0273	1.0743	**96**
97	54.4	3.021	0.3310	24.7	527.0	551.7	473.3	497.4	0.0482	1.0253	1.0735	**97**
98	55.0	2.992	0.3342	25.3	526.5	551.9	472.8	497.5	0.0494	1.0233	1.0726	**98**
99	55.5	2.964	0.3374	25.9	526.1	552.0	472.3	497.6	0.0505	1.0213	1.0718	**99**
100	56.0	2.936	0.3406	26.5	525.6	552.1	471.8	497.7	0.0516	1.0194	1.0709	**100**
101	56.6	2.909	0.3438	27.1	525.1	552.2	471.3	497.8	0.0527	1.0174	1.0701	**101**
102	57.1	2.882	0.3470	27.7	524.6	552.3	470.8	497.9	0.0539	1.0154	1.0693	**102**
103	57.6	2.855	0.3503	28.2	524.2	552.4	470.3	498.0	0.0550	1.0135	1.0685	**103**
104	58.1	2.829	0.3535	28.8	523.7	552.5	469.8	498.1	0.0561	1.0116	1.0677	**104**
105	58.6	2.803	0.3568	29.3	523.3	552.6	469.3	498.1	0.0572	1.0097	1.0669	**105**
106	59.1	2.777	0.3601	29.9	522.8	552.7	468.9	498.2	0.0583	1.0078	1.0661	**106**
107	59.6	2.752	0.3634	30.4	522.4	552.8	468.4	498.3	0.0594	1.0060	1.0653	**107**
108	60.1	2.727	0.3667	31.0	521.9	552.9	467.9	498.4	0.0604	1.0042	1.0646	**108**
109	60.6	2.703	0.3700	31.5	521.5	553.0	467.5	498.5	0.0614	1.0024	1.0638	**109**
110	61.1	2.679	0.3733	32.1	521.0	553.1	467.0	498.6	0.0625	1.0005	1.0630	**110**
111	61.6	2.656	0.3765	32.6	520.6	553.2	466.5	498.6	0.0636	0.9987	1.0623	**111**
112	62.1	2.633	0.3798	33.2	520.1	553.3	466.1	498.7	0.0646	0.9969	1.0615	**112**
113	62.6	2.611	0.3831	33.7	519.7	553.4	465.6	498.8	0.0657	0.9950	1.0607	**113**
114	63.1	2.589	0.3863	34.3	519.2	553.5	465.1	498.9	0.0668	0.9932	1.0600	**114**
115	63.6	2.568	0.3895	34.8	518.8	553.6	464.6	499.0	0.0678	0.9915	1.0593	**115**
116	64.0	2.547	0.3927	35.4	518.4	553.7	464.2	499.0	0.0688	0.9898	1.0586	**116**
117	64.5	2.526	0.3959	35.9	517.9	553.8	463.8	499.1	0.0697	0.9882	1.0579	**117**
118	64.9	2.506	0.3991	36.4	517.5	553.9	463.4	499.2	0.0706	0.9866	1.0572	**118**
119	65.4	2.486	0.4023	36.9	517.1	554.0	462.9	499.3	0.0716	0.9849	1.0565	**119**
120	65.8	2.466	0.4056	37.4	516.7	554.1	462.5	499.4	0.0725	0.9833	1.0557	**120**
121	66.3	2.446	0.4089	37.9	516.3	554.2	462.1	499.4	0.0735	0.9816	1.0551	**121**
122	66.8	2.426	0.4121	38.5	515.8	554.3	461.6	499.5	0.0745	0.9799	1.0544	**122**
123	67.2	2.409	0.4153	39.0	515.4	554.4	461.2	499.6	0.0754	0.9783	1.0538	**123**
124	67.7	2.390	0.4185	39.5	515.0	554.5	460.8	499.7	0.0764	0.9767	1.0531	**124**
125	68.1	2.371	0.4218	40.0	514.6	554.6	460.4	499.7	0.0773	0.9751	1.0524	**125**
126	68.6	2.353	0.4250	40.5	514.1	554.7	459.9	499.8	0.0783	0.9735	1.0518	**126**
127	69.0	2.335	0.4283	41.0	513.7	554.8	459.5	499.9	0.0792	0.9719	1.0511	**127**
128	69.5	2.317	0.4316	41.5	513.3	554.9	459.0	500.0	0.0802	0.9703	1.0504	**128**
129	69.9	2.300	0.4348	42.0	512.9	555.0	458.6	500.0	0.0811	0.9687	1.0498	**129**
130	70.4	2.283	0.4381	42.5	512.5	555.0	458.2	500.1	0.0820	0.9671	1.0492	**130**
131	70.8	2.266	0.4414	43.0	512.1	555.1	457.8	500.2	0.0829	0.9655	1.0484	**131**
132	71.2	2.249	0.4447	43.5	511.7	555.2	457.4	500.2	0.0838	0.9640	1.0478	**132**
133	71.6	2.233	0.4479	44.0	511.3	555.3	457.0	500.3	0.0847	0.9625	1.0472	**133**
134	72.0	2.217	0.4511	44.5	510.9	555.4	456.6	500.4	0.0856	0.9610	1.0466	**134**
135	72.5	2.201	0.4544	45.0	510.5	555.5	456.2	500.5	0.0865	0.9595	1.0460	**135**
136	72.9	2.185	0.4577	45.5	510.1	555.6	455.8	500.5	0.0874	0.9580	1.0454	**136**
137	73.3	2.169	0.4610	46.0	509.7	555.6	455.4	500.6	0.0883	0.9565	1.0448	**137**
138	73.7	2.154	0.4643	46.4	509.4	555.7	455.0	500.7	0.0892	0.9550	1.0442	**138**
139	74.1	2.139	0.4675	46.9	509.0	555.8	454.6	500.7	0.0901	0.9535	1.0436	**139**
140	74.5	2.124	0.4708	47.3	508.6	555.9	454.2	500.8	0.0910	0.9520	1.0430	**140**
141	75.0	2.109	0.4741	47.8	508.2	556.0	453.8	500.9	0.0919	0.9505	1.0424	**141**
142	75.4	2.095	0.4773	48.3	507.8	556.1	453.4	500.9	0.0928	0.9490	1.0418	**142**
143	75.8	2.082	0.4804	48.8	507.4	556.1	453.0	501.0	0.0936	0.9476	1.0412	**143**
144	76.2	2.070	0.4835	49.2	507.0	556.2	452.6	501.1	0.0944	0.9462	1.0406	**144**

TABLE 2—PRESSURE

Pressure, lb.	Temp. Fahr.	Sp. Vol. cu. ft. per lb.	Density lb. per cu. ft.	Heat Content of Liquid	Latent Heat of Evap.	Heat Content of Vapor	Internal Energy B. t. u.		Entropy			Pressure, lb.
							Evap.	Vapor	Liquid	Evap.	Vapor	
p	t	v''	$1/v''$	i'	r	i''	ρ	u''	s'	r/T	s''	p
145	76.5	2.057	0.4867	49.6	506.7	556.3	452.2	501.1	0.0952	0.9449	1.0401	**145**
146	76.9	2.043	0.4899	50.0	506.3	556.4	451.8	501.2	0.0960	0.9435	1.0395	**146**
147	77.3	2.029	0.4931	50.5	506.0	556.4	451.4	501.2	0.0968	0.9422	1.0390	**147**
148	77.7	2.015	0.4963	50.9	505.6	556.5	451.0	501.3	0.0976	0.9409	1.0385	**148**
149	78.1	2.002	0.4995	51.4	505.2	556.6	450.7	501.4	0.0985	0.9395	1.0379	**149**
150	78.5	1.989	0.5028	51.8	504.8	556.7	450.3	501.4	0.0993	0.9381	1.0374	**150**
151	78.9	1.976	0.5060	52.3	504.4	556.7	449.9	501.5	0.1002	0.9367	1.0368	**151**
152	79.3	1.964	0.5092	52.7	504.0	556.8	449.5	501.6	0.1010	0.9353	1.0363	**152**
153	79.6	1.952	0.5123	53.1	503.7	556.9	449.2	501.6	0.1018	0.9340	1.0358	**153**
154	80.0	1.940	0.5155	53.6	503.3	557.0	448.8	501.7	0.1026	0.9327	1.0353	**154**
155	80.4	1.928	0.5187	54.0	503.0	557.0	448.4	501.7	0.1034	0.9313	1.0347	**155**
156	80.8	1.916	0.5220	54.5	502.6	557.1	448.0	501.8	0.1042	0.9300	1.0342	**156**
157	81.2	1.904	0.5253	54.9	502.2	447.2	447.6	501.8	0.1050	0.9287	1.0337	**157**
158	81.5	1.892	0.5286	55.3	501.9	557.2	447.3	501.9	0.1058	0.9274	1.0332	**158**
159	81.9	1.880	0.5320	55.8	501.5	557.3	446.9	502.0	0.1066	0.9261	1.0327	**159**
160	82.3	1.868	0.5353	56.2	501.1	557.4	446.6	502.1	0.1074	0.9248	1.0322	**160**
161	82.7	1.857	0.5386	56.7	500.7	557.5	446.2	502.1	0.1082	0.9235	1.0317	**161**
162	83.0	1.846	0.5418	57.1	500.4	557.5	445.9	502.2	0.1090	0.9222	1.0312	**162**
163	83.4	1.835	0.5450	57.5	500.0	557.6	445.5	502.2	0.1098	0.9209	1.0307	**163**
164	83.8	1.824	0.5483	58.0	499.7	557.7	445.1	502.3	0.1106	0.9196	1.0302	**164**
165	84.1	1.814	0.5515	58.4	499.4	557.7	444.8	502.3	0.1114	0.9183	1.0297	**165**
166	84.5	1.803	0.5547	58.8	499.0	557.8	444.4	502.4	0.1122	0.9170	1.0292	**166**
167	84.9	1.793	0.5578	59.3	498.6	557.9	444.0	502.5	0.1130	0.9157	1.0287	**167**
168	85.2	1.783	0.5609	59.7	498.3	558.0	443.7	502.5	0.1137	0.9145	1.0282	**168**
169	85.6	1.773	0.5641	60.1	497.9	558.0	443.3	502.6	0.1145	0.9132	1.0277	**169**
170	85.9	1.763	0.5673	60.5	497.6	558.1	443.0	502.7	0.1152	0.9120	1.0272	**170**
171	86.3	1.753	0.5705	61.0	497.2	558.2	442.6	502.7	0.1160	0.9107	1.0267	**171**
172	86.6	1.743	0.5738	61.4	496.9	558.2	442.3	502.8	0.1167	0.9095	1.0263	**172**
173	87.0	1.733	0.5771	61.8	496.5	558.3	441.9	502.8	0.1175	0.9083	1.0258	**173**
174	87.3	1.723	0.5804	62.2	496.2	558.4	411.6	502.9	0.1182	0.9071	1.0253	**174**
175	87.7	1.713	0.5836	62.6	495.8	558.4	441.2	502.9	0.1190	0.9059	1.0249	**175**
176	88.0	1.704	0.5869	63.0	495.5	558.5	440.9	503.0	0.1197	0.9047	1.0244	**176**
177	88.4	1.694	0.5902	63.4	495.1	558.6	440.5	503.0	0.1204	0.9036	1.0240	**177**
178	88.7	1.685	0.5935	63.8	494.8	558.6	440.2	503.1	0.1211	0.9024	1.0235	**178**
179	89.0	1.676	0.5967	64.2	494.5	558.7	439.9	503.1	0.1218	0.9012	1.0231	**179**
180	89.4	1.666	0.6000	64.6	494.1	558.8	439.5	503.2	0.1226	0.9000	1.0226	**180**
181	89.7	1.656	0.6034	65.0	493.8	558.8	439.2	503.3	0.1233	0.8988	1.0222	**181**
182	90.1	1.647	0.6068	65.4	493.4	558.9	438.8	503.3	0.1241	0.8976	1.0217	**182**
183	90.4	1.639	0.6102	65.8	493.1	558.9	438.5	503.4	0.1248	0.8965	1.0213	**183**
184	90.7	1.630	0.6135	66.2	492.8	559.0	438.2	503.4	0.1254	0.8954	1.0209	**184**
185	91.1	1.621	0.6168	66.6	492.4	559.1	437.8	503.5	0.1261	0.8943	1.0204	**185**
186	91.4	1.613	0.6200	67.0	492.1	559.1	437.5	503.5	0.1268	0.8932	1.0200	**186**
187	91.7	1.605	0.6233	67.4	491.8	559.2	437.2	503.6	0.1274	0.8920	1.0195	**187**
188	92.1	1.596	0.6266	67.8	491.5	559.3	436.8	503.6	0.1283	0.8908	1.0191	**188**
189	92.4	1.588	0.6298	68.2	491.2	559.3	436.5	503.7	0.1289	0.8897	1.0186	**189**
190	92.7	1.580	0.6330	68.6	490.9	559.4	436.2	503.7	0.1296	0.8886	1.0182	**190**
191	93.0	1.572	0.6362	68.9	490.5	559.4	435.9	503.8	0.1303	0.8875	1.0178	**191**
192	93.4	1.563	0.6395	69.3	490.1	559.5	435.5	503.9	0.1310	0.8864	1.0173	**192**
193	93.7	1.555	0.6428	69.7	489.8	559.6	435.2	503.9	0.1317	0.8853	1.0169	**193**
194	94.0	1.548	0.6460	70.1	489.5	559.6	434.9	504.0	0.1323	0.8842	1.0165	**194**

TABLE 2 — PRESSURE

Pressure, lb.	Temp. Fahr.	Sp. Vol. cu. ft. per lb.	Density lb. per cu. ft.	Heat Content of Liquid	Latent Heat of Evap.	Heat Content of Vapor	Internal Energy B. t. u.		Entropy			Pressure, lb.
							Evap.	Vapor	Liquid	Evap.	Vapor	
p	t	v''	$1/v''$	i'	r	i''	ρ	u''	s'	r/T	s''	p
195	94.3	1.541	0.6492	70.5	489.2	559.7	434.5	504.0	0.1329	0.8832	1.0161	**195**
196	94.6	1.533	0.6524	70.8	488.9	559.7	434.2	504.1	0.1336	0.8821	1.0157	**196**
197	94.9	1.526	0.6554	71.2	488.6	559.8	433.9	504.1	0.1342	0.8811	1.0153	**197**
198	95.2	1.519	0.6584	71.6	488.3	559.8	433.6	504.2	0.1349	0.8800	1.0149	**198**
199	95.5	1.512	0.6614	71.9	488.0	559.9	433.3	504.2	0.1356	0.8789	1.0145	**199**
200	95.9	1.504	0.665	72.3	487.6	560.0	433.0	504.3	0.1363	0.8778	1.0141	**200**
202	96.5	1.489	0.672	73.1	487.0	560.1	432.3	504.4	0.1376	0.8757	1.0133	**202**
204	97.1	1.474	0.679	73.8	486.4	560.2	431.7	504.5	0.1389	0.8736	1.0125	**204**
206	97.7	1.460	0.685	74.6	485.8	560.3	431.1	504.6	0.1402	0.8715	1.0117	**206**
208	98.3	1.447	0.691	75.3	485.1	560.4	430.5	504.7	0.1414	0.8696	1.0110	**208**
210	98.9	1.433	0.698	76.0	484.5	560.5	429.8	504.8	0.1427	0.8675	1.0102	**210**
212	99.5	1.419	0.705	76.7	483.9	560.6	429.2	504.9	0.1440	0.8655	1.0094	**212**
214	100.1	1.406	0.711	77.4	483.3	560.7	428.6	505.0	0.1452	0.8635	1.0087	**214**
216	100.7	1.394	0.717	78.1	482.7	560.8	428.0	505.0	0.1464	0.8615	1.0079	**216**
218	101.2	1.382	0.724	78.8	482.1	560.9	427.4	505.1	0.1476	0.8596	1.0072	**218**
220	101.8	1.370	0.730	79.5	481.5	561.0	426.8	505.2	0.1488	0.8577	1.0065	**220**
222	102.4	1.358	0.736	80.2	480.9	561.1	426.2	505.3	0.1500	0.8558	1.0058	**222**
224	103.0	1.346	0.743	80.9	480.3	561.2	425.6	505.4	0.1512	0.8539	1.0051	**224**
226	103.5	1.335	0.749	81.6	479.7	561.3	425.1	505.5	0.1524	0.8520	1.0044	**226**
228	104.1	1.323	0.756	82.3	479.1	561.4	424.5	505.6	0.1537	0.8500	1.0037	**228**
230	104.7	1.312	0.762	83.0	478.5	561.5	423.9	505.7	0.1549	0.8481	1.0030	**230**
232	105.2	1.301	0.769	83.7	477.9	561.6	423.3	505.8	0.1561	0.8462	1.0023	**232**
234	105.8	1.290	0.775	84.4	477.3	561.7	422.7	505.9	0.1573	0.8443	1.0016	**234**
236	106.3	1.279	0.782	85.0	476.8	561.8	422.2	505.9	0.1585	0.8425	1.0010	**236**
238	106.9	1.268	0.789	85.7	476.2	561.9	421.6	506.0	0.1597	0.8406	1.0003	**238**
240	107.4	1.258	0.795	86.4	475.6	562.0	421.0	506.1	0.1609	0.8388	0.9997	**240**
242	108.0	1.248	0.801	87.1	475.0	562.1	420.4	506.2	0.1621	0.8370	0.9990	**242**
244	108.5	1.238	0.808	87.7	474.5	562.2	419.8	506.3	0.1632	0.8352	0.9984	**244**
246	109.0	1.228	0.814	88.4	473.9	562.3	419.3	506.4	0.1643	0.8334	0.9978	**246**
248	109.6	1.218	0.821	89.1	473.3	562.4	418.7	506.5	0.1655	0.8316	0.9971	**248**
250	110.1	1.208	0.828	89.7	472.8	562.5	418.1	506.6	0.1666	0.8299	0.9965	**250**
252	110.6	1.199	0.834	90.4	472.2	562.6	417.6	506.6	0.1677	0.8282	0.9959	**252**
254	111.1	1.189	0.841	91.0	471.6	562.6	417.1	506.7	0.1688	0.8265	0.9953	**254**
256	111.7	1.179	0.848	91.7	471.0	562.7	416.5	506.8	0.1700	0.8247	0.9946	**256**
258	112.2	1.170	0.855	92.3	470.5	562.8	415.9	506.9	0.1711	0.8229	0.9940	**258**
260	112.7	1.161	0.861	93.0	470.0	562.9	415.4	507.0	0.1722	0.8212	0.9934	**260**
262	113.2	1.153	0.867	93.6	469.4	563.0	414.8	507.1	0.1733	0.8195	0.9928	**262**
264	113.7	1.144	0.874	94.2	468.9	563.1	414.3	507.2	0.1744	0.8178	0.9922	**264**
266	114.2	1.136	0.880	94.8	468.3	563.2	413.8	507.2	0.1755	0.8161	0.9916	**266**
268	114.7	1.127	0.887	95.5	467.8	563.3	413.2	507.3	0.1766	0.8144	0.9910	**268**
270	115.2	1.119	0.894	96.1	467.2	563.4	412.7	507.4	0.1777	0.8128	0.9905	**270**
272	115.7	1.110	0.901	96.7	466.7	563.4	412.2	507.5	0.1787	0.8112	0.9899	**272**
274	116.2	1.102	0.908	97.4	466.1	563.5	411.7	507.6	0.1798	0.8095	0.9893	**274**
276	116.7	1.094	0.914	98.0	465.6	563.6	411.2	507.7	0.1809	0.8079	0.9887	**276**
278	117.1	1.087	0.920	98.6	465.1	563.7	410.7	507.7	0.1819	0.8063	0.9882	**278**
280	117.6	1.079	0.927	99.2	464.6	563.8	410.2	507.8	0.1829	0.8047	0.9877	**280**
282	118.1	1.071	0.934	99.8	464.0	563.9	409.6	507.9	0.1840	0.8031	0.9871	**282**
284	118.6	1.063	0.941	100.4	463.5	563.9	409.1	508.0	0.1850	0.8015	0.9866	**284**
286	119.1	1.056	0.947	101.1	462.9	564.0	408.5	508.1	0.1861	0.7999	0.9860	**286**
288	119.6	1.049	0.953	101.7	462.4	564.1	408.0	508.2	0.1872	0.7983	0.9855	**288**

TABLE 2—PRESSURE

Pressure, lb.	Temp. Fahr.	Sp. Vol. cu. ft. per lb.	Density lb. per cu. ft.	Heat Content of Liquid	Latent Heat of Evap.	Heat Content of Vapor	Internal Energy B. t. u.		Entropy			Pressure, lb.
							Evap.	Vapor	Liquid	Evap.	Vapor	
p	t	v''	$1/v''$	i'	r	i''	ρ	u''	s'	r/T	s''	p
290	120.0	1.042	0.960	102.3	461.9	564.2	407.5	508.2	0.1882	0.7968	0.9850	**290**
292	120.5	1.035	0.966	102.9	461.4	564.3	407.0	508.3	0.1892	0.7953	0.9845	**292**
294	120.9	1.028	0.973	103.5	460.9	564.3	406.5	508.4	0.1902	0.7938	0.9840	**294**
296	121.4	1.021	0.980	104.1	460.4	564.4	406.0	508.5	0.1912	0.7923	0.9835	**296**
298	121.9	1.014	0.986	104.7	459.8	564.5	405.5	508.6	0.1922	0.7907	0.9829	**298**
300	122.4	1.007	0.993	105.3	459.3	564.6	405.0	508.7	0.1932	0.7892	0.9824	**300**
310	124.6	0.975	1.026	108.2	456.8	565.0	402.5	509.0	0.1981	0.7819	0.9800	**310**
320	126.8	0.945	1.059	111.1	454.3	565.3	400.0	509.4	0.2030	0.7746	0.9775	**320**
330	129.0	0.916	1.092	114.0	451.8	565.7	397.6	509.8	0.2078	0.7675	0.9753	**330**
340	131.1	0.889	1.125	116.8	449.3	566.1	395.2	510.1	0.2125	0.7605	0.9730	**340**
350	133.2	0.863	1.159	119.6	446.8	566.4	392.8	510.5	0.2171	0.7537	0.9708	**350**
360	135.2	0.838	1.193	122.3	444.4	566.7	390.5	510.8	0.2216	0.7471	0.9687	**360**
370	137.2	0.815	1.227	125.0	442.0	567.0	388.2	511.2	0.2261	0.7406	0.9667	**370**
380	139.2	0.793	1.261	127.7	439.6	567.3	385.9	511.5	0.2305	0.7342	0.9647	**380**
390	141.1	0.772	1.295	130.3	437.3	567.6	383.7	511.9	0.2348	0.7280	0.9628	**390**
400	142.9	0.752	1.330	132.9	435.0	567.9	381.5	512.2	0.2390	0.7219	0.9608	**400**
410	144.8	0.733	1.364	135.5	432.7	568.2	379.3	512.5	0.2431	0.7160	0.9591	**410**
420	146.6	0.715	1.399	138.1	430.4	568.5	377.2	512.8	0.2472	0.7101	0.9573	**420**
430	148.4	0.698	1.434	140.6	428.2	568.8	375.0	513.2	0.2513	0.7043	0.9556	**430**
440	150.1	0.681	1.469	143.1	426.0	569.0	372.9	513.5	0.2553	0.6986	0.9539	**440**
450	151.9	0.665	1.504	145.6	423.8	569.3	370.8	513.8	0.2593	0.6930	0.9523	**450**
460	153.5	0.650	1.539	148.0	421.6	569.6	368.7	514.1	0.2632	0.6875	0.9507	**460**
470	155.2	0.636	1.574	150.4	419.4	569.8	366.6	514.4	0.2671	0.6821	0.9492	**470**
480	156.9	0.622	1.608	152.8	417.2	570.1	364.5	514.7	0.2710	0.6767	0.9477	**480**
490	158.5	0.609	1.642	155.2	415.0	570.3	362.5	515.0	0.2749	0.6714	0.9463	**490**
500	160.0	0.597	1.675	157.5	413.0	570.5	360.5	515.3	0.2786	0.6663	0.9449	**500**
525	163.9	0.566	1.765	163.4	407.7	571.1	355.6	516.0	0.2876	0.6539	0.9415	**525**
550	167.6	0.539	1.855	169.2	402.5	571.7	350.8	516.7	0.2965	0.6418	0.9383	**550**
575	171.2	0.514	1.946	174.8	397.4	572.2	346.0	517.4	0.3052	0.6300	0.9352	**575**
600	174.7	0.491	2.038	180.4	392.3	572.7	341.3	518.1	0.3138	0.6185	0.9323	**600**
625	178.1	0.469	2.132	185.9	387.2	573.1	336.6	518.8	0.3223	0.6072	0.9295	**625**
650	181.4	0.449	2.227	191.4	382.2	573.6	332.0	519.5	0.3307	0.5962	0.9269	**650**
675	184.6	0.431	2.321	196.8	377.2	574.0	327.4	520.1	0.3389	0.5855	0.9244	**675**
700	187.7	0.414	2.416	202.1	372.2	574.4	322.8	520.7	0.3469	0.5751	0.9220	**700**

TABLE 3—SATURATED AND

Pressure lb.	Liquid	Sat. Vapor	Degrees of Superheat								
			10	20	30	40	50	60	70	80	90
5 t	−62.0		−52.0	−42.0	−32.0	−22.0	−12.0	−2.0	+8.0	18.0	28.0
v	0.023	49.3	50.7	52.1	53.4	54.7	56.1	57.4	58.7	60.0	61.3
i	−98.1	519.1	524.1	529.1	534.1	539.0	543.9	548.8	553.6	558.4	563.3
s	−0.2207	1.3315	1.3440	1.3560	1.3677	1.3791	1.3901	1.4008	1.4113	1.4216	1.4317
6 t	−56.6		−46.6	−36.6	−26.6	−16.6	−6.6	+3.4	13.4	23.4	33.4
v	0.023	41.6	42.8	43.9	45.0	46.1	47.2	48.3	49.4	50.5	51.6
i	−92.5	521.0	526.1	531.1	536.1	541.0	546.0	550.9	555.8	560.7	565.6
s	−0.2070	1.3152	1.3277	1.3398	1.3515	1.3628	1.3738	1.3845	1.3949	1.4051	1.4151
7 t	−51.9		−41.9	−31.9	−21.9	−11.9	−1.9	+8.1	18.1	28.1	38.1
v	0.023	35.9	37.0	38.9	38.9	39.9	40.8	41.8	42.7	43.7	44.6
i	−87.6	522.7	527.8	532.9	537.9	542.9	547.9	552.8	557.7	562.6	567.5
s	−0.1947	1.3017	1.3141	1.3261	1.3378	1.3491	1.3600	1.3706	1.3810	1.3912	1.4012
8 t	−47.6		−37.6	−27.6	−17.6	−7.6	+2.4	12.4	22.4	32.4	42.4
v	0.023	31.6	32.6	33.5	34.4	35.2	36.0	36.9	37.7	38.5	39.3
i	−83.2	524.1	529.3	534.4	539.5	544.6	549.6	554.5	559.5	564.4	569.3
s	−0.1840	1.2899	1.3023	1.3144	1.3261	1.3374	1.3483	1.3589	1.3693	1.3794	1.3894
9 t	−43.9		−33.9	−23.9	−13.9	−3.9	+6.1	16.1	26.1	36.1	46.1
v	0.023	28.3	29.2	30.0	30.8	31.5	32.3	33.0	33.7	34.5	35.2
i	−79.3	525.3	530.5	535.7	540.9	546.0	551.0	556.0	561.0	566.0	570.9
s	−0.1747	1.2793	1.2918	1.3039	1.3155	1.3268	1.3377	1.3483	1.3587	1.3688	1.3788
10 t	−40.4		−30.4	−20.4	−10.4	−0.4	+9.6	19.6	29.6	39.6	49.6
v	0.023	25.8	26.5	27.2	27.9	28.5	29.2	29.9	30.5	31.2	31.9
i	−75.7	526.4	531.7	537.0	542.2	547.3	552.4	557.4	562.4	567.4	572.3
s	−0.1661	1.2701	1.2826	1.2947	1.3063	1.3176	1.3285	1.3391	1.3494	1.3595	1.3694
11 t	−37.2		−27.2	−17.2	−7.2	+2.8	12.8	22.8	32.8	42.8	52.8
v	0.023	23.6	24.2	24.9	25.5	26.1	26.7	27.3	27.9	28.5	29.1
i	−72.4	527.5	532.8	538.1	543.3	548.4	553.5	558.6	563.6	568.6	573.6
s	−0.1584	1.2617	1.2742	1.2863	1.2979	1.3092	1.3201	1.3307	1.3410	1.3511	1.3609
12 t	−34.3		−24.3	−14.3	−4.3	+5.7	15.7	25.7	35.7	45.7	55.7
v	0.024	21.7	22.3	22.9	23.5	24.1	24.6	25.2	25.7	26.3	26.8
i	−69.4	528.4	533.8	539.1	544.3	549.5	554.6	559.7	564.8	569.8	574.8
s	−0.1513	1.2540	1.2665	1.2786	1.2902	1.3015	1.3124	1.3229	1.3332	1.3433	1.3531
13 t	−31.5		−21.5	−11.5	−1.5	+8.5	18.5	28.5	38.5	48.5	58.5
v	0.024	20.2	20.7	21.3	21.8	22.3	22.8	23.4	23.9	24.4	24.9
i	−66.5	529.3	534.7	540.1	545.4	550.6	555.7	560.8	565.9	570.9	576.0
s	−0.1446	1.2470	1.2595	1.2716	1.2832	1.2945	1.3054	1.3160	1.3263	1.3364	1.3462
14 t	−28.9		−18.9	−8.9	+1.1	11.1	21.1	31.1	41.1	51.1	61.1
v	0.024	18.8	19.3	19.8	20.3	20.8	21.3	21.8	22.2	22.7	23.2
i	−63.8	530.1	535.6	541.0	546.3	551.5	556.7	561.8	566.9	571.0	577.0
s	−0.1384	1.2404	1.2530	1.2651	1.2767	1.2880	1.2989	1.3095	1.3198	1.3298	1.3396
15 t	−26.4		−16.4	−6.4	+3.6	13.6	23.6	33.6	43.6	53.6	63.6
v	0.024	17.6	18.1	18.6	19.1	19.5	20.0	20.4	20.9	21.3	21.7
i	−61.2	530.9	536.4	541.8	547.1	552.4	557.6	562.7	567.8	572.9	578.0
s	−0.1324	1.2344	1.2470	1.2591	1.2707	1.2820	1.2929	1.3035	1.3138	1.3238	1.3335
16 t	−24.1		−14.1	−4.1	+5.9	15.9	25.9	35.9	45.9	55.9	65.9
v	0.024	16.6	17.1	17.5	17.9	18.4	18.8	19.2	19.6	20.0	20.4
i	−58.8	531.6	537.1	542.5	547.9	553.2	558.5	563.7	568.8	573.9	579.0
s	0.1268	1.2288	1.2414	1.2535	1.2651	1.2763	1.2872	1.2978	1.3081	1.3181	1.3278

SUPERHEATED AMMONIA VAPOR

Degrees of Superheat											Pressure lb.
100	110	120	130	140	150	160	180	200	250	300	
38.0	48.0	58.0	68.0	78.0	88.0	98.0	118.0	138.0	188.0	238.0	t 5
62.6	63.8	65.1	66.4	67.7	69.0	70.3	72.8	75.3	81.7	88.1	v
568.1	572.9	577.7	582.6	587.5	592.3	597.2	606.9	616.7	641.4	666.5	i
1.4415	1.4511	1.4605	1.4697	1.4788	1.4878	1.4966	1.5138	1.5304	1.5701	1.6074	s
43.4	53.4	63.4	73.4	83.4	93.4	103.4	123.4	143.4	193.4	243.4	t 6
52.7	53.7	54.8	55.9	56.9	58.0	59.1	61.2	63.3	68.6	73.9	v
570.4	575.3	580.1	585.0	589.9	594.7	599.6	609.4	619.2	644.0	669.1	i
1.4249	1.4344	1.4438	1.4530	1.4621	1.4710	1.4797	1.4968	1.5133	1.5528	1.5899	s
48.1	58.1	68.1	78.1	88.1	93.1	108.1	128.1	148.1	198.1	248.1	t 7
45.5	46.4	47.4	48.3	49.2	50.1	51.0	52.9	54.7	59.2	63.7	v
572.4	577.3	582.2	587.1	592.0	596.8	601.7	611.6	621.4	646.3	671.4	i
1.4109	1.4204	1.4297	1.4389	1.4479	1.4568	1.4655	1.4826	1.4990	1.5383	1.5752	s
52.4	62.4	72.4	82.4	92.4	102.4	112.4	132.4	152.4	202.4	252.4	t 8
40.1	40.9	41.8	42.6	42.4	44.2	45.0	46.6	48.2	52.2	56.1	v
574.2	579.1	584.1	589.0	593.9	598.8	603.7	613.6	623.4	648.3	673.5	i
1.3990	1.4085	1.4178	1.4269	1.4359	1.4447	1.4533	1.4703	1.4867	1.5259	1.5626	s
56.1	66.1	76.1	86.1	96.1	106.1	116.1	136.1	156.1	206.1	256.1	t 9
35.9	36.6	37.3	38.1	38.8	39.5	40.2	41.6	43.1	46.6	50.1	v
575.8	580.7	585.7	590.6	595.5	600.4	605.4	615.3	625.1	650.1	675.3	i
1.3884	1.3978	1.4071	1.4162	1.4251	1.4339	1.4425	1.4594	1.4758	1.5148	1.5514	s
59.6	69.6	79.6	89.6	99.6	109.6	119.6	139.6	159.6	209.6	259.6	t 10
32.5	33.2	33.8	34.5	35.1	35.8	36.4	37.7	39.0	42.1	45.3	v
577.2	582.2	587.2	592.1	597.1	602.0	606.9	616.8	626.7	651.8	677.1	i
1.3790	1.3884	1.3977	1.4067	1.4156	1.4243	1.4330	1.4498	1.4661	1.5049	1.5414	s
62.8	72.8	82.8	92.8	102.8	112.8	122.8	142.8	162.8	212.8	262.8	t 11
29.7	30.3	30.9	31.5	32.1	32.7	33.3	34.4	35.6	38.5	41.4	v
578.6	583.6	588.5	593.4	598.4	603.4	608.4	618.3	628.2	653.3	678.6	i
1.3705	1.3799	1.3892	1.3982	1.4071	1.4158	1.4244	1.4411	1.4574	1.4961	1.5325	s
65.7	75.7	85.7	95.7	105.7	115.7	125.7	145.7	165.7	215.7	265.7	t 12
27.4	27.9	28.5	29.0	29.5	30.1	30.6	31.7	32.8	35.4	38.1	v
579.8	584.8	589.8	594.8	599.7	604.7	609.7	619.6	629.5	654.7	680.1	i
1.3627	1.3721	1.3813	1.3903	1.3992	1.4079	1.4165	1.4332	1.4494	1.4880	1.5243	s
68.5	78.5	88.5	98.5	108.5	118.5	128.5	148.5	168.5	218.5	268.5	t 13
25.4	25.9	26.4	26.9	27.4	27.9	28.4	29.4	30.4	32.8	35.3	v
581.0	586.0	591.0	596.0	600.9	605.9	610.9	620.8	630.8	656.0	681.5	i
1.3557	1.3651	1.3743	1.3833	1.3921	1.4008	1.4093	1.4260	1.4422	1.4807	1.5169	s
71.1	81.1	91.1	101.1	111.1	121.1	131.1	151.1	171.1	221.1	271.1	t 14
23.7	24.1	24.6	25.1	25.5	26.0	26.4	27.4	28.3	30.5	32.8	v
582.1	587.1	592.1	597.1	602.1	607.1	612.1	622.0	632.0	657.3	682.8	i
1.3491	1.3585	1.3677	1.3767	1.3855	1.3942	1.4027	1.4194	1.4355	1.4739	1.5100	s
73.6	83.6	93.6	103.6	113.6	123.6	133.6	153.6	173.6	223.6	273.6	t 15
22.2	22.6	23.1	23.5	23.9	24.4	24.8	25.7	26.5	28.6	30.8	v
583.1	588.1	593.2	598.2	603.2	608.2	613.2	623.2	633.2	658.5	684.0	i
1.3430	1.3524	1.3616	1.3706	1.3794	1.3880	1.3965	1.4131	1.4292	1.4676	1.5036	s
75.9	85.9	95.9	105.9	115.9	125.9	135.9	155.9	175.9	225.9	275.9	t 16
20.8	21.3	21.7	22.1	22.5	22.9	23.3	24.1	24.9	26.9	28.9	v
584.0	589.1	594.1	599.1	604.2	609.2	614.2	624.2	634.2	659.5	685.1	i
1.3373	1.3467	1.3558	1.3648	1.3736	1.3822	1.3907	1.4073	1.4233	1.4617	1.4976	s

TABLE 3—SUPERHEATED VAPOR

Pressure lb.	Liquid	Sat. Vapor	Degrees of Superheat								
			10	20	30	40	50	60	70	80	90
17 t	−21.9		−11.9	−1.9	+8.1	18.1	28.1	38.1	48.1	58.1	68.1
v	0.024	15.6	16.1	16.5	16.9	17.3	17.7	18.1	18.5	18.9	19.3
i	−56.5	532.2	537.8	543.3	548.7	554.0	559.3	564.5	569.6	574.7	579.8
s	−0.1215	1.2235	1.2361	1.2482	1.2598	1.2710	1.2819	1.2925	1.3028	1.3128	1.3225
18 t	−19.8		−9.8	+0.2	10.2	20.2	30.2	40.2	50.2	60.2	70.2
v	0.024	14.8	15.3	15.7	16.1	16.4	16.8	17.2	17.6	17.9	18.3
i	−54.4	532.8	538.5	544.0	549.4	554.8	560.1	565.3	570.4	575.6	580.7
s	−0.1165	1.2185	1.2311	1.2432	1.2548	1.2661	1.2770	1.2876	1.2978	1.3078	1.3175
19 t	−17.8		−7.8	+2.2	12.2	22.2	32.2	42.2	52.2	62.2	72.2
v	0.024	14.1	14.5	14.9	15.3	15.6	16.0	16.4	16.7	17.1	17.4
i	−52.3	533.4	539.1	544.6	550.0	555.4	560.7	566.0	571.2	576.4	581.5
s	−0.1119	1.2137	1.2263	1.2384	1.2501	1.2614	1.2723	1.2829	1.2931	1.3031	1.3128
20 t	−15.9		−5.9	+4.1	14.1	24.1	34.1	44.1	54.1	64.1	74.1
v	0.024	13.4	13.8	14.2	14.5	14.9	15.2	15.6	15.9	16.3	16.6
i	−50.3	534.0	539.7	545.2	550.7	556.1	561.4	566.7	571.9	577.1	582.3
s	−0.1075	1.2092	1.2218	1.2339	1.2456	1.2569	1.2678	1.2784	1.2886	1.2986	1.3083
21 t	−14.0		−4.0	+6.0	16.0	26.0	36.0	46.0	56.0	66.0	76.0
v	0.024	12.8	13.2	13.6	13.9	14.2	14.6	14.9	15.2	15.5	15.8
i	−48.3	534.6	540.3	545.9	551.4	556.8	562.1	567.4	572.6	577.8	583.0
s	−0.1032	1.2049	1.2176	1.2298	1.2415	1.2527	1.2636	1.2742	1.2844	1.2944	1.3041
22 t	−12.2		−2.2	+7.8	17.8	27.8	37.8	47.8	57.8	67.8	77.8
v	0.024	12.3	13.7	13.0	13.3	13.6	13.9	14.2	14.5	14.9	15.2
i	−46.5	535.1	540.9	546.5	552.0	557.4	562.8	568.1	573.3	578.5	583.7
s	−0.0990	1.2008	1.2135	1.2257	1.2375	1.2487	1.2596	1.2702	1.2804	1.2904	1.3001
23 t	−10.5		−0.5	+9.5	19.5	29.5	39.5	49.5	59.5	69.5	79.5
v	0.024	11.8	12.1	12.4	12.8	13.1	13.4	13.7	14.0	14.3	14.5
i	−44.7	535.6	541.4	547.0	552.5	558.0	563.4	568.7	574.0	579.2	584.4
s	−0.0950	1.1969	1.2096	1.2218	1.2336	1.2449	1.2558	1.2664	1.2766	1.2865	1.2962
24 t	−8.8		+1.2	11.2	21.2	31.2	41.2	51.2	61.2	71.2	81.2
v	0.024	11.3	11.7	12.0	12.3	12.6	12.8	13.1	13.4	13.7	14.0
i	−42.9	536.1	541.9	547.6	553.1	558.6	564.0	569.3	574.6	579.8	585.0
s	−0.0912	1.1931	1.2159	1.2182	1.2300	1.2412	1.2521	1.2627	1.2729	1.2828	1.2925
25 t	−7.2		+2.8	12.8	22.8	32.8	42.8	52.8	62.8	72.8	82.8
v	0.024	10.9	11.2	11.5	11.8	12.1	12.4	12.7	12.9	13.2	13.5
i	−41.3	536.5	542.4	548.1	553.6	559.1	564.5	569.9	575.2	580.4	585.6
s	−0.0874	1.1896	1.2024	1.2147	1.2264	1.2377	1.2486	1.2591	1.2693	1.2793	1.2890
26 t	−5.7		+4.3	14.3	24.3	34.3	44.3	54.3	64.3	74.3	84.3
v	0.024	10.5	10.8	11.1	11.4	11.6	11.9	12.2	12.4	12.7	13.0
i	−39.7	536.9	542.8	548.5	554.1	559.6	565.0	570.4	575.7	581.0	586.2
s	−0.0840	1.1861	1.1990	1.2113	1.2230	1.2342	1.2451	1.2557	1.2659	1.2759	1.2856
27 t	−4.2		+5.8	15.8	25.8	35.8	45.8	55.8	65.8	75.8	85.8
v	0.024	10.1	10.4	10.7	11.0	11.2	11.5	11.7	12.0	12.3	12.5
i	−38.1	537.4	543.2	549.0	554.6	560.1	565.6	571.0	576.3	581.6	586.8
s	−0.0805	1.1828	1.1957	1.2080	1.2197	1.2310	1.2418	1.2524	1.2626	1.2726	1.2823
28 t	−2.7		+7.3	17.3	27.3	37.3	47.3	57.3	67.3	77.3	87.3
v	0.024	9.78	10.08	10.35	10.60	10.85	11.10	11.35	11.60	11.85	12.09
i	−36.5	537.8	543.7	549.5	555.1	560.6	566.1	571.5	576.8	582.1	587.4
s	−[illegible].0771	1.1797	1.1926	1.2050	1.2167	1.2279	1.2388	1.2494	1.2596	1.2695	1.2792

TABLE 3 — SUPERHEATED VAPOR

Degrees of Superheat											Pressure lb.
100	110	120	130	140	150	160	180	200	250	300	
78.1	88.1	98.1	108.1	118.1	128.1	138.1	158.1	178.1	228.1	278.1	t 17
19.7	20.1	20.5	20.9	21.3	21.6	22.0	22.8	23.5	25.4	27.3	v
584.9	590.0	595.1	600.1	605.1	610.1	615.1	625.2	635.3	660.6	686.2	i
1.3321	1.3414	1.3505	1.3595	1.3683	1.3769	1.3853	1.4019	1.4179	1.4562	1.4921	s
80.2	90.2	100.2	110.2	120.2	130.2	140.2	160.2	180.2	230.2	280.2	t 18
18.7	19.1	19.4	19.8	20.1	20.5	20.9	21.6	22.3	24.1	25.8	v
585.8	590.9	595.9	601.0	606.0	611.0	616.1	626.1	636.2	661.6	687.2	i
1.3271	1.3364	1.3455	1.3543	1.3632	1.3718	1.3802	1.3968	1.4128	1.4510	1.4868	s
82.2	92.2	102.2	112.2	122.2	132.2	142.2	162.2	182.2	232.2	282.2	t 19
17.8	18.1	18.5	18.8	19.1	19.5	19.8	20.5	21.2	22.9	24.5	v
586.6	591.7	596.8	601.8	606.9	611.9	616.9	627.0	637.1	662.5	688.1	i
1.3224	1.3316	1.3407	1.3496	1.3584	1.3670	1.3754	1.3920	1.4079	1.4460	1.4818	s
84.1	94.1	104.1	114.1	124.1	134.1	144.1	164.1	184.1	234.1	284.1	t 20
16.9	17.3	17.6	17.9	18.2	18.6	18.9	19.5	20.2	21.8	23.4	v
587.4	592.5	597.5	602.6	607.7	612.7	617.8	627.9	638.0	663.4	689.1	i
1.3178	1.3271	1.3362	1.3451	1.3539	1.3625	1.3709	1.3874	1.4033	1.4413	1.4771	s
86.0	96.0	106.0	116.0	126.0	136.0	146.0	166.0	186.0	236.0	286.0	t 21
16.2	16.5	16.8	17.1	17.4	17.7	18.0	18.7	19.3	20.8	22.3	v
588.1	593.3	598.4	603.4	608.5	613.5	618.6	628.7	638.9	664.3	690.0	i
1.3136	1.3229	1.3319	1.3408	1.3496	1.3582	1.3666	1.3831	1.3990	1.4370	1.4727	s
87.8	97.8	107.8	117.8	127.8	137.8	147.8	167.8	187.8	237.8	287.8	t 22
15.5	15.8	16.1	16.4	16.7	17.0	17.3	17.8	18.4	19.9	21.3	v
588.8	594.0	599.1	604.2	609.3	614.3	619.4	629.5	639.7	665.2	690.9	i
1.3096	1.3189	1.3279	1.3368	1.3455	1.3541	1.3625	1.3789	1.3948	1.4327	1.4684	s
89.5	99.5	109.5	119.5	129.5	139.5	149.5	169.5	189.5	239.5	289.5	t 23
14.8	15.1	15.4	15.7	16.0	16.3	16.5	17.1	17.7	19.1	20.5	v
589.5	594.7	599.8	604.9	610.0	615.0	620.1	630.3	640.5	666.0	691.7	i
1.3057	1.3150	1.3240	1.3329	1.3416	1.3502	1.3586	1.3750	1.3909	1.4287	1.4643	s
91.2	101.2	111.2	121.2	131.2	141.2	151.2	171.2	191.2	241.2	291.2	t 24
14.3	14.5	14.8	15.1	15.4	15.6	15.9	16.4	17.0	18.3	19.6	v
590.2	595.3	600.5	605.6	610.7	615.8	620.9	631.0	641.2	666.7	692.5	i
1.3020	1.3113	1.3203	1.3292	1.3379	1.3465	1.3549	1.3713	1.3872	1.4249	1.4605	s
92.8	102.8	112.8	122.8	132.8	142.8	152.8	172.8	192.8	242.8	292.8	t 25
13.7	14.0	14.2	14.5	14.8	15.0	15.3	15.8	16.3	17.6	18.9	v
590.8	596.0	601.2	606.3	611.4	616.5	621.6	631.7	641.9	667.5	693.3	i
1.2985	1.3078	1.3168	1.3257	1.3344	1.3429	1.3513	1.3677	1.3835	1.4212	1.4567	s
94.3	104.3	114.3	124.3	134.3	144.3	154.3	174.3	194.3	244.3	294.3	t 26
13.2	13.5	13.7	14.0	14.2	14.5	14.7	15.2	15.7	17.0	18.2	v
591.4	596.6	601.8	606.9	612.0	617.1	622.2	632.4	642.6	668.2	694.0	i
1.2950	1.3043	1.3133	1.3222	1.3309	1.3394	1.3479	1.3642	1.3800	1.4176	1.4531	s
95.8	105.8	115.8	125.8	135.8	145.8	155.8	175.8	195.8	245.8	295.8	t 27
12.8	13.0	13.3	13.5	13.7	14.0	14.2	14.7	15.2	16.4	17.6	v
592.0	597.2	602.4	607.5	612.6	617.7	622.8	633.0	643.3	668.9	694.7	i
1.2917	1.3010	1.3100	1.3189	1.3276	1.3361	1.3445	1.3608	1.3766	1.4142	1.4497	s
97.3	107.3	117.3	127.3	137.3	147.3	157.3	177.3	197.3	247.3	297.3	t 28
12.33	12.56	12.80	13.04	13.27	13.50	13.74	14.20	14.67	15.81	16.96	v
592.6	597.8	603.0	608.1	613.2	618.4	623.5	633.7	644.0	669.6	695.5	i
1.2887	1.2979	1.3069	1.3157	1.3244	1.3330	1.3414	1.3577	1.3735	1.4110	1.4464	s

TABLE 3 — SUPERHEATED VAPOR

Pressure lb.		Liquid	Sat. Vapor	Degrees of Superheat								
				10	20	30	40	50	60	70	80	90
30	t	+0.1		10.1	20.1	30.1	40.1	50.1	60.1	70.1	80.1	90.1
	v	0.024	9.17	9.45	9.70	9.94	10.18	10.41	10.64	10.87	11.10	11.32
	i	−33.6	538.5	544.5	550.3	556.0	561.6	567.1	572.5	577.9	583.2	558.5
	s	−0.0708	1.1738	1.1867	1.1990	1.2107	1.2220	1.2329	1.2435	1.2537	1.2636	1.2733
32	t	2.7		12.7	22.7	32.7	42.7	52.7	62.7	72.7	82.7	92.7
	v	0.024	8.64	8.89	9.12	9.35	95.8	9.80	10.01	10.23	10.44	10.66
	i	−30.8	539.3	545.2	551.1	556.8	567.9	567.9	573.4	578.8	584.1	589.4
	s	−0.0648	1.1683	1.1811	1.1933	1.2050	1.2164	1.2273	1.2378	1.2480	1.2580	1.2677
34	t	5.3		15.3	25.3	35.3	45.3	55.3	65.3	75.3	85.3	95.3
	v	0.025	8.15	8.40	8.62	8.83	9.04	9.25	9.46	9.66	9.86	10.06
	i	−28.2	540.0	546.0	551.9	557.7	563.3	568.8	574.3	579.7	585.1	590.4
	s	−0.0589	1.1630	1.1759	1.1881	1.1999	1.2113	1.2222	1.2327	1.2429	1.2528	1.2625
36	t	7.7		17.7	27.7	37.7	47.7	57.7	67.7	77.7	87.7	97.7
	v	0.025	7.73	7.96	8.17	8.37	8.57	8.77	8.96	9.16	9.35	9.54
	i	−25.6	540.6	546.7	552.6	558.4	564.1	569.7	575.2	580.6	586.0	591.4
	s	−0.0534	1.1580	1.1709	1.1831	1.1948	1.2062	1.2171	1.2276	1.2378	1.2478	1.2576
38	t	10.0		20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0
	v	0.025	7.34	7.56	7.76	7.96	8.15	8.33	8.52	8.70	8.88	9.06
	i	−23.2	541.2	547.3	553.3	559.1	564.8	570.5	576.0	581.4	586.8	592.2
	s	−0.0483	1.1534	1.1764	1.1786	1.1904	1.2018	1.2127	1.2232	1.2334	1.2433	1.2530
40	t	12.2		22.2	32.2	42.2	52.2	52.2	72.2	82.2	92.2	102.2
	v	0.025	6.99	7.21	7.40	7.58	7.76	7.94	8.12	8.29	8.46	8.63
	i	−20.8	541.8	547.9	553.9	559.8	565.5	571.2	576.8	582.3	587.7	593.0
	s	−0.0433	1.1490	1.1619	1.1742	1.1861	1.1974	1.2082	1.2188	1.2291	1.2390	1.2487
42	t	14.4		24.4	34.4	44.4	54.4	64.4	74.4	84.4	94.4	104.4
	v	0.025	6.67	6.88	7.07	7.24	7.41	7.58	7.75	7.92	8.09	8.25
	i	−18.6	542.3	548.5	554.6	560.5	566.2	571.9	577.5	583.0	588.5	593.8
	s	−0.0386	1.1447	1.1578	1.1701	1.1820	1.1933	1.2042	1.2147	1.2250	1.2349	1.2446
44	t	16.4		26.4	36.4	46.4	56.4	66.4	76.4	86.4	96.4	106.4
	v	0.025	6.38	6.58	6.76	6.93	7.10	7.26	7.42	7.58	7.74	7.89
	i	−16.4	542.8	549.1	555.2	561.1	566.9	572.6	578.2	583.7	589.2	594.6
	s	−0.0341	1.1406	1.1537	1.1661	1.1779	1.1892	1.2001	1.2107	1.2210	1.2309	1.2406
46	t	18.4		28.4	38.4	48.4	58.4	68.4	78.4	88.4	98.4	108.4
	v	0.025	6.12	6.30	6.48	6.65	6.81	6.96	7.12	7.27	7.42	7.57
	i	−14.3	543.3	549.7	555.8	561.7	567.5	573.2	578.9	584.4	589.9	595.4
	s	−0.0296	1.1369	1.1500	1.1624	1.1742	1.1855	1.1964	1.2070	1.2172	1.2271	1.2368
48	t	20.3		30.3	40.3	50.3	60.3	70.3	80.3	90.3	100.3	110.3
	v	0.025	5.88	6.06	6.23	6.39	6.54	6.69	6.84	6.98	7.13	7.27
	i	−12.3	543.8	550.2	556.3	562.2	568.1	573.8	579.5	585.1	590.6	596.1
	s	−0.0255	1.1331	1.1463	1.1587	1.1706	1.1819	1.1929	1.2035	1.2137	1.2236	1.2333
50	t	22.1		32.1	42.1	52.1	62.1	72.1	82.1	92.1	102.1	112.1
	v	0.025	5.67	5.83	5.99	6.14	6.29	6.44	6.58	6.72	6.86	7.00
	i	−10.3	544.3	550.7	556.8	562.7	568.6	574.4	580.1	585.7	591.2	596.7
	s	−0.0216	1.1296	1.1427	1.1552	1.1671	1.1784	1.1894	1.2000	1.2102	1.2201	1.2298
55	t	26.4		36.4	46.4	56.4	66.4	76.4	86.4	96.4	106.4	116.4
	v	0.025	5.18	5.33	5.47	5.61	5.75	5.88	6.01	6.14	6.27	6.40
	i	−5.7	545.3	551.8	558.0	564.0	569.9	575.8	581.5	587.1	592.7	598.2
	s	−0.0122	1.1215	1.1346	1.1470	1.1589	1.1702	1.1813	1.1919	1.2021	1.2120	1.2217

TABLE 3—SUPERHEATED VAPOR

Degrees of Superheat											Pressure lb.
100	110	120	130	140	150	160	180	200	250	300	
100.1	110.1	120.1	130.1	140.1	150.1	160.1	180.1	200.1	250.1	300.1	t **30**
11.55	11.77	11.99	12.21	12.43	12.65	12.87	13.30	13.74	14.81	15.88	v
593.7	598.9	604.1	609.3	614.4	619.5	624.7	635.0	645.2	670.9	696.9	i
1.2827	1.2919	1.3010	1.3098	1.3185	1.3270	1.3384	1.3516	1.3674	1.4049	1.4402	s
102.7	112.7	122.7	132.7	142.7	152.7	162.7	182.7	202.7	252.7	302.7	t **32**
10.87	11.08	11.28	11.49	11.70	11.90	12.11	12.52	12.92	13.93	14.93	v
594.7	599.9	605.2	610.4	615.5	620.6	625.8	636.1	646.4	672.1	698.1	i
1.2771	1.2863	1.2954	1.3042	1.3129	1.3214	1.3297	1.3459	1.3617	1.3992	1.4344	s
105.3	115.3	125.3	135.3	145.3	155.3	165.3	185.3	205.3	255.3	305.3	t **34**
10.26	10.46	10.66	10.85	11.05	11.24	11.43	11.82	12.20	13.15	14.09	v
595.7	601.0	606.2	611.4	616.6	621.7	626.9	637.2	647.5	673.3	699.3	i
1.2720	1.2812	1.2902	1.2990	1.3077	1.3162	1.3245	1.3407	1.3565	1.3939	1.4290	s
107.7	117.7	127.7	137.7	147.7	157.7	167.7	187.7	207.7	257.7	307.7	t **36**
9.73	9.91	10.10	10.28	10.47	10.65	10.83	11.20	11.56	12.45	13.34	v
596.7	602.0	607.2	612.4	617.6	622.7	627.9	638.3	648.6	674.4	700.5	i
1.2671	1.2763	1.2853	1.2941	1.3027	1.3112	1.3195	1.3357	1.3514	1.3888	1.4239	s
110.0	120.0	130.0	140.0	150.0	160.0	170.0	190.0	210.0	260.0	310.0	t **38**
9.24	9.42	9.60	9.77	9.95	10.12	10.29	10.64	10.98	11.83	12.67	v
597.5	602.8	608.1	613.3	618.5	623.7	628.9	639.3	649.6	675.5	701.6	i
1.2624	1.2716	1.2806	1.2895	1.2981	1.3065	1.3148	1.3310	1.3467	1.3840	1.4190	s
112.2	122.2	132.2	142.2	152.2	162.2	172.2	192.2	212.2	262.2	312.2	t **40**
8.80	8.97	9.14	9.31	9.47	9.64	9.80	10.13	10.46	11.26	12.07	v
598.3	603.6	608.9	614.2	619.4	624.6	629.8	640.2	650.6	676.6	702.7	i
1.2581	1.2673	1.2763	1.2851	1.2937	1.3021	1.3104	1.3265	1.3422	1.3795	1.4145	s
114.4	124.4	134.4	144.4	154.4	164.4	174.4	194.4	214.4	264.4	314.4	t **42**
8.41	8.57	8.73	8.89	9.05	9.21	9.37	9.68	9.99	10.76	11.52	v
599.2	604.5	609.8	615.1	620.3	625.5	630.7	641.1	651.5	677.6	703.7	i
1.2540	1.2632	1.2721	1.2809	1.2896	1.2980	1.3063	1.3224	1.3380	1.3752	1.4102	s
116.4	126.4	136.4	146.4	156.4	166.4	176.4	196.4	216.4	266.4	316.4	t **44**
8.05	8.20	8.36	8.51	8.66	8.81	8.96	9.26	9.56	10.29	11.02	v
600.0	605.3	610.6	615.9	621.1	626.4	631.6	642.0	652.4	678.5	704.7	i
1.2500	1.2592	1.2681	1.2769	1.2856	1.2940	1.3023	1.3184	1.3340	1.3711	1.4060	s
118.4	128.4	138.4	148.4	158.4	168.4	178.4	198.4	218.4	268.4	318.4	t **46**
7.72	7.87	8.01	8.16	8.30	8.45	8.59	8.88	9.16	9.86	10.56	v
600.8	606.1	611.4	616.7	621.9	627.2	632.5	642.9	653.3	679.4	705.6	i
1.2463	1.2555	1.2644	1.2732	1.2819	1.2903	1.2985	1.3146	1.3302	1.3673	1.4021	s
120.3	130.3	140.3	150.3	160.3	170.3	180.3	200.3	220.3	270.3	320.3	t **48**
7.42	7.56	7.70	7.84	7.98	8.12	8.25	8.53	8.80	9.47	10.14	v
601.5	606.8	612.1	617.4	622.7	628.0	633.3	643.7	654.2	680.3	706.5	i
1.2427	1.2519	1.2608	1.2696	1.2782	1.2866	1.2948	1.3109	1.3265	1.3635	1.3983	s
122.1	132.1	142.1	152.1	162.1	172.1	182.1	202.1	222.1	272.1	322.1	t **50**
7.14	7.27	7.41	7.54	7.68	7.81	7.94	8.20	8.46	9.11	9.76	v
602.1	607.5	612.8	618.1	623.4	628.7	634.0	644.4	655.0	681.1	707.4	i
1.2392	1.2484	1.2573	1.2661	1.2747	1.2831	1.2913	1.3074	1.3230	1.3600	1.3947	s
126.4	136.4	146.4	156.4	166.4	176.4	186.4	206.4	226.4	276.4	326.4	t **55**
6.52	6.64	6.77	6.89	7.01	7.13	7.25	7.49	7.73	8.32	8.91	v
603.7	609.1	614.5	619.8	625.1	630.4	635.8	646.3	656.8	683.0	709.4	i
1.2311	1.2403	1.2492	1.2580	1.2666	1.2750	1.2832	1.2993	1.3148	1.3517	1.3863	s

TABLE 3—SUPERHEATED VAPOR

Pressure lb.	Liquid	Sat. Vapor	Degrees of Superheat								
			10	20	30	40	50	60	70	80	90
60 t	30.5		40.5	50.5	60.5	70.5	80.5	90.5	100.5	110.5	120.5
v	0.025	4.77	4.91	5.04	5.17	5.30	5.42	5.54	5.66	5.77	5.89
i	−1.3	546.3	552.8	559.1	565.2	571.2	577.1	582.9	588.6	594.2	599.7
s	−0.0033	1.1141	1.1272	1.1396	1.1515	1.1629	1.1740	1.1846	1.1948	1.2047	1.2144
65 t	34.3		44.3	54.3	64.3	74.3	84.3	94.3	104.3	114.3	124.3
v	0.025	4.42	4.55	4.68	4.80	4.91	5.02	5.13	5.24	5.35	5.46
i	2.7	547.2	553.7	560.1	566.3	572.4	578.3	584.1	589.8	595.5	601.1
s	0.0051	1.1073	1.1205	1.1329	1.1448	1.1562	1.1673	1.1779	1.1881	1.1980	1.2077
70 t	37.9		47.9	57.9	67.9	77.9	87.9	97.9	107.9	117.9	127.9
v	0.025	4.12	4.24	4.36	4.47	4.58	4.68	4.79	4.89	4.99	5.09
i	6.6	548.1	554.6	561.1	567.3	573.4	579.4	585.3	591.0	596.7	602.4
s	0.0128	1.1010	1.1141	1.1266	1.1385	1.1500	1.1611	1.1717	1.1814	1.1918	1.2015
75 t	41.3		51.3	61.3	71.3	81.3	91.3	101.3	111.3	121.3	131.3
v	0.025	3.86	3.97	4.08	4.19	4.29	4.39	4.49	4.58	4.68	4.77
i	10.3	548.8	555.5	562.0	568.3	574.4	580.4	586.4	592.2	597.9	603.6
s	0.0201	1.0951	1.1083	1.1208	1.1328	1.1443	1.1554	1.1660	1.1763	1.1862	1.1959
80 t	44.5		54.5	64.5	74.5	84.5	94.5	104.5	114.5	124.5	134.5
v	0.026	3.63	3.74	3.84	3.94	4.04	4.13	4.22	4.31	4.40	4.49
i	13.8	549.5	556.3	562.8	569.1	574.3	581.4	587.4	593.2	599.0	604.7
s	0.0271	1.0897	1.1028	1.1154	1.1274	1.1389	1.1500	1.1606	1.1709	1.1808	1.1905
85 t	47.6		57.6	67.6	77.6	97.6	97.6	107.6	117.6	127.6	137.6
v	0.026	3.43	3.53	3.63	3.72	3.81	3.90	3.98	4.07	4.15	4.24
i	17.2	550.2	557.0	563.6	570.0	576.3	582.4	588.3	594.2	600.0	605.7
s	0.0336	1.0846	1.0978	1.1104	1.1224	1.1339	1.1450	1.1556	1.1659	1.1758	1.1855
90 t	50.5		60.5	70.5	80.5	90.5	100.5	110.5	120.5	130.5	140.5
v	0.026	3.25	3.34	3.43	3.52	3.61	3.69	3.77	3.85	3.93	4.01
i	20.4	550.9	557.7	564.3	570.8	577.1	583.2	589.2	595.2	601.0	606.7
s	0.0398	1.0797	1.0929	1.1056	1.1177	1.1292	1.1402	1.1509	1.1612	1.1711	1.1808
95 t	53.3		63.3	73.3	83.3	93.3	103.3	113.3	123.3	133.3	143.3
v	0.026	3.08	3.17	3.26	3.34	3.43	3.51	3.58	3.66	3.74	3.81
i	23.5	551.5	558.4	565.0	571.5	577.9	584.0	590.1	596.1	601.9	607.7
s	0.0458	1.0752	1.0884	1.1011	1.1132	1.1247	1.1358	1.1465	1.1568	1.1667	1.1764
100 t	56.0		66.0	76.0	86.0	96.0	106.0	116.0	126.0	136.0	146.0
v	0.026	2.94	3.02	3.10	3.18	3.26	3.34	3.41	3.49	3.56	3.63
i	26.5	552.1	559.0	565.7	572.2	578.6	584.8	590.9	596.9	602.8	608.6
s	0.0516	1.0709	1.0841	1.0968	1.1089	1.1204	1.1315	1.1422	1.1525	1.1625	1.1721
105 t	58.6		68.6	78.6	88.6	98.6	108.6	118.6	128.6	138.6	148.6
v	0.026	2.80	2.88	2.96	3.04	3.12	3.19	3.26	3.33	3.40	3.47
i	29.3	552.6	559.6	566.3	572.9	579.3	585.6	591.7	597.7	603.6	609.5
s	0.0572	1.0669	1.0801	1.0928	1.1049	1.1165	1.1276	1.1383	1.1486	1.1586	1.1682
110 t	61.1		71.1	81.1	91.1	101.1	111.1	121.1	131.1	141.1	151.1
v	0.026	2.68	2.76	2.84	2.91	2.98	3.05	3.12	3.18	3.25	3.32
i	32.1	553.1	560.2	573.0	573.6	580.0	586.3	592.5	598.5	604.4	610.3
s	0.0625	1.0630	1.0762	1.0890	1.1011	1.1126	1.1237	1.1345	1.1448	1.1548	1.1644
115 t	63.6		73.6	83.6	93.6	103.6	113.6	123.6	133.6	143.6	153.6
v	0.026	2.57	2.65	2.72	2.79	2.86	2.92	2.99	3.05	3.12	3.18
i	34.8	553.6	560.8	567.6	574.3	580.7	587.0	593.2	599.3	605.2	611.1
s	0.0678	1.0593	1.0726	1.0854	1.0975	1.1091	1.1203	1.1310	1.1413	1.1513	1.1609

TABLE 3—SUPERHEATED VAPOR

Degrees of Superheat											Pressure lb.
100	110	120	130	140	150	160	180	200	250	300	
130.5	140.5	150.5	160.5	170.5	180.5	190.5	210.5	230.5	280.5	330.5	t 60
6.01	6.12	6.23	6.35	6.46	6.57	6.68	6.90	7.12	7.66	8.20	v
605.2	610.7	616.1	621.5	626.8	632.1	637.5	648.0	658.6	684.9	711.3	i
1.2238	1.2330	1.2419	1.2506	1.2592	1.2676	1.2758	1.2919	1.3074	1.3442	1.3787	s
134.3	144.3	154.3	164.3	174.3	184.3	194.3	214.3	234.3	284.3	334.3	t 65
5.57	5.67	5.78	5.88	5.99	6.09	6.19	6.40	6.60	7.10	7.60	v
606.6	612.1	617.5	622.9	628.3	633.7	639.0	649.6	660.2	686.6	713.1	i
1.2171	1.2263	1.2352	1.2439	1.2524	1.2608	1.2690	1.2851	1.3006	1.3374	1.3718	s
137.9	147.9	157.9	167.9	177.9	187.9	197.9	217.9	237.9	287.9	337.9	t 70
5.19	5.29	5.39	5.49	5.58	5.68	5.77	5.96	6.15	6.62	7.08	v
607.9	613.4	618.9	624.3	629.7	635.1	640.5	651.1	661.7	688.2	714.8	i
1.2109	1.2201	1.2291	1.2378	1.2463	1.2547	1.2629	1.2789	1.2943	1.3310	1.3653	s
141.3	151.3	161.3	171.3	181.3	191.3	201.3	221.3	241.3	291.3	341.3	t 75
4.86	4.96	5.05	5.14	5.23	5.32	5.41	5.59	5.76	6.20	6.63	v
609.2	614.7	620.2	625.6	631.1	636.5	641.9	652.6	663.2	689.8	716.4	i
1.2053	1.2145	1.2234	1.2320	1.2405	1.2489	1.2571	1.2731	1.2885	1.3251	1.3594	s
144.5	154.5	164.5	174.5	184.5	194.5	204.5	224.5	244.5	294.5	344.5	t 80
4.57	4.66	4.75	4.83	4.92	5.00	5.08	5.25	5.42	5.83	6.23	v
610.3	615.8	621.3	626.8	632.3	637.7	643.1	653.9	664.6	691.2	717.9	i
1.1999	1.2091	1.2180	1.2267	1.2352	1.2436	1.2518	1.2676	1.2830	1.3196	1.3538	s
147.6	157.6	167.6	177.6	187.6	197.6	207.6	227.6	247.6	297.6	347.6	t 85
4.32	4.40	4.48	4.56	4.64	4.72	4.80	4.96	5.11	5.50	5.88	v
611.4	617.0	622.5	628.0	633.5	639.0	644.4	655.2	665.8	692.5	719.3	i
1.1949	1.2041	1.2130	1.2217	1.2302	1.2385	1.2467	1.2626	1.2780	1.3145	1.3487	s
150.5	160.5	170.5	180.5	190.5	200.5	210.5	230.5	250.5	300.5	350.5	t 90
4.09	4.17	4.24	4.32	4.40	4.47	4.55	4.70	4.84	5.21	5.57	v
612.4	618.0	623.6	629.1	634.6	640.1	645.6	656.4	667.0	693.8	720.6	i
1.1902	1.1994	1.2083	1.2170	1.2255	1.2338	1.2420	1.2579	1.2732	1.3096	1.3437	s
153.3	163.3	173.3	183.3	193.3	203.3	213.3	233.3	253.3	303.3	353.3	t 95
3.89	3.96	4.03	4.10	4.18	4.25	4.32	4.46	4.60	4.95	5.29	v
613.4	619.0	624.6	630.2	635.7	641.2	646.7	657.5	668.2	695.1	721.9	i
1.1858	1.1949	1.2038	1.2125	1.2210	1.2293	1.2375	1.2534	1.2687	1.3051	1.3391	s
156.0	166.0	176.0	186.0	196.0	206.0	216.0	236.0	256.0	306.0	356.0	t 100
3.70	3.77	3.84	3.91	3.98	4.05	4.12	4.25	4.38	4.71	5.03	v
614.3	619.9	625.6	631.2	636.7	642.2	647.7	658.6	669.4	696.3	723.2	i
1.1815	1.1907	1.1996	1.2083	1.2168	1.2251	1.2333	1.2492	1.2645	1.3008	1.3348	s
158.6	168.6	178.6	188.6	198.6	208.6	218.6	238.6	258.6	308.6	358.6	t 105
3.53	3.60	3.67	3.73	3.80	3.86	3.93	4.06	4.18	4.49	4.80	v
615.2	620.8	626.5	632.1	637.6	643.2	648.7	659.6	670.5	697.4	724.3	i
1.1776	1.1867	1.1956	1.2043	1.2138	1.2211	1.2293	1.2451	1.2604	1.2967	1.3307	s
161.1	171.1	181.1	191.1	201.1	211.1	221.1	241.1	261.1	311.1	361.1	t 110
3.38	3.44	3.51	3.57	3.63	3.70	3.76	3.88	4.00	4.30	4.60	v
616.1	621.8	627.5	633.1	638.6	644.2	649.7	660.6	671.5	698.5	725.5	i
1.1738	1.1829	1.1918	1.2005	1.2090	1.2173	1.2255	1.2413	1.2566	1.2928	1.3268	s
163.6	173.6	183.6	193.6	203.6	213.6	223.6	243.6	263.6	313.6	363.6	t 115
3.24	3.30	3.36	3.42	3.48	3.54	3.60	3.72	3.84	4.12	4.40	v
616.9	622.7	628.4	634.0	639.6	645.2	650.7	661.6	672.5	699.6	726.6	i
1.1703	1.1794	1.1883	1.1970	1.2055	1.2138	1.2220	1.2378	1.2530	1.2892	1.3231	s

TABLE 3—SUPERHEATED VAPOR

Pressure lb.		Liquid	Sat. Vapor	Degrees of Superheat								
				10	20	30	40	50	60	70	80	90
120	**t**	65.8		75.8	85.8	95.8	105.8	115.8	125.8	135.8	145.8	155.8
	v	0.026	2.47	2.54	2.61	2.68	2.74	2.80	2.87	2.93	2.99	3.05
	i	37.4	554.1	561.3	568.2	574.9	581.4	587.7	593.9	600.0	605.9	611.8
	s	0.0725	1.0557	1.0690	1.0818	1.0939	1.1055	1.1167	1.1274	1.1377	1.1477	1.1573
125	**t**	68.1		78.1	88.1	98.1	108.1	118.1	128.1	138.1	148.1	158.1
	v	0.026	2.37	2.44	2.51	2.57	2.64	2.70	2.76	2.82	2.88	2.94
	i	40.0	554.6	561.8	568.7	575.4	582.0	588.3	594.6	600.7	606.7	612.6
	s	0.0773	1.0524	1.0657	1.0785	1.0906	1.1022	1.1134	1.1241	1.1344	1.1444	1.1540
130	**t**	70.4		80.4	90.4	100.4	110.4	120.4	130.4	140.4	150.4	160.4
	v	0.026	2.28	2.35	2.42	2.48	2.54	2.60	2.66	2.72	2.77	2.83
	i	42.5	555.0	562.3	569.2	576.0	582.6	589.0	595.2	601.3	607.4	613.3
	s	0.0820	1.0492	1.0626	1.0754	1.0875	1.0992	1.1104	1.1211	1.1314	1.1414	1.1510
135	**t**	72.5		82.5	92.5	102.5	112.5	122.5	132.5	142.5	152.5	162.5
	v	0.027	2.20	2.27	2.33	2.39	2.45	2.51	2.56	2.62	2.67	2.73
	i	45.0	555.5	562.7	569.7	576.5	583.1	589.6	595.8	602.0	608.1	614.0
	s	0.0865	1.0460	1.0595	1.0723	1.0844	1.0961	1.1073	1.1180	1.1283	1.1383	1.1480
140	**t**	74.5		84.5	94.5	104.5	114.5	124.5	134.5	144.5	154.5	164.5
	v	0.027	2.12	2.19	2.25	2.31	2.37	2.42	2.48	2.53	2.58	2.63
	i	47.3	555.9	563.1	570.2	577.0	583.6	590.1	596.4	602.6	608.7	614.7
	s	0.0910	1.0430	1.0565	1.0693	1.0814	1.0931	1.1043	1.1150	1.1254	1.1354	1.1450
145	**t**	76.5		86.5	96.5	106.5	116.5	126.5	136.5	146.5	156.5	166.5
	v	0.027	2.06	2.12	2.18	2.23	2.28	2.34	2.39	2.44	2.50	2.55
	i	49.6	556.3	563.6	570.7	577.5	584.2	590.7	597.0	603.2	609.3	615.3
	s	0.0952	1.0401	1.0536	1.0664	1.0786	1.0903	1.1015	1.1122	1.1225	1.1325	1.1422
150	**t**	78.5		88.5	98.5	108.5	118.5	128.5	138.5	148.5	158.5	168.5
	v	0.027	1.99	2.05	2.11	2.16	2.21	2.26	2.32	2.37	2.42	2.47
	i	51.8	556.7	564.0	571.1	578.0	584.7	591.2	597.5	603.8	609.9	615.9
	s	0.0993	1.0374	1.0509	1.0637	1.0759	1.0876	1.0988	1.1095	1.1198	1.1298	1.1395
155	**t**	80.4		90.4	100.4	110.4	120.4	130.4	140.4	150.4	160.4	170.4
	v	0.027	1.93	1.99	2.04	2.09	2.14	2.19	2.24	2.29	2.34	2.39
	i	54.0	557.0	564.4	571.6	578.5	585.2	591.7	598.0	604.3	610.5	616.5
	s	0.1034	1.0347	1.0482	1.0610	1.0732	1.0849	1.0961	1.1068	1.1172	1.1272	1.1369
160	**t**	82.3		92.3	102.3	112.3	122.3	132.3	142.3	152.3	162.3	172.3
	v	0.027	1.87	1.93	1.98	2.03	2.08	2.13	2.18	2.22	2.27	2.32
	i	56.2	557.4	564.8	572.0	578.9	585.7	592.2	598.6	604.9	611.1	617.1
	s	0.1074	1.0322	1.0457	1.0585	1.0707	1.0824	1.0936	1.1043	1.1147	1.1247	1.1344
165	**t**	84.1		94.1	104.1	114.1	124.1	134.1	144.1	154.1	164.1	174.1
	v	0.027	1.81	1.87	1.92	1.97	2.02	2.07	2.11	2.16	2.20	2.25
	i	58.4	557.7	565.2	572.4	579.3	586.1	592.7	599.1	605.4	611.6	617.7
	s	0.1114	1.0297	1.0432	1.0560	1.0682	1.0799	1.0911	1.1018	1.1123	1.1223	1.1320
170	**t**	85.9		95.9	105.9	115.9	125.9	135.9	145.9	155.9	165.9	175.9
	v	0.027	1.76	1.81	1.86	1.91	1.96	2.01	2.06	2.11	2.15	2.19
	i	60.5	558.1	565.5	572.8	579.8	586.6	593.2	599.6	606.0	612.2	618.3
	s	0.1152	1.0272	1.0407	1.0536	1.0658	1.0775	1.0878	1.0995	1.1099	1.1199	1.1296
180	**t**	89.4		99.4	109.4	119.4	129.4	139.4	149.4	159.4	169.4	179.4
	v	0.027	1.67	1.72	1.77	1.81	1.86	1.90	1.94	1.99	2.03	2.07
	i	64.6	558.8	566.3	573.6	580.6	587.5	594.1	600.6	607.0	613.2	619.4
	s	0.1226	1.0226	1.0362	1.0491	1.0614	1.0731	1.0843	1.0950	1.1054	1.1154	1.1251

TABLE 3 — SUPERHEATED VAPOR

Degrees of Superheat											Pressure lb.
100	110	120	130	140	150	160	180	200	250	300	
165.8	175.8	185.8	195.8	205.8	215.8	225.8	245.8	265.8	315.8	365.8	**t 120**
3.11	3.17	3.23	3.29	3.34	3.40	3.46	3.57	3.68	3.96	4.23	**v**
617.6	623.4	629.2	634.8	640.4	646.0	651.5	662.5	673.4	700.6	727.6	**i**
1.1667	1.1759	1.1848	1.1935	1.2020	1.2103	1.2184	1.2342	1.2494	1.2856	1.3195	**s**
168.1	178.1	188.1	198.1	208.1	218.1	228.1	248.1	268.1	318.1	368.1	**t 125**
3.00	3.05	3.10	3.16	3.21	3.27	3.33	3.44	3.54	3.81	4.07	**v**
618.4	624.2	630.0	635.6	641.3	646.9	652.4	663.4	674.4	701.6	728.7	**i**
1.1634	1.1726	1.1815	1.1902	1.1987	1.2070	1.2151	1.2309	1.2461	1.2823	1.3161	**s**
170.4	180.4	190.4	200.4	210.4	220.4	230.4	250.4	270.4	320.4	370.4	**t 130**
2.88	2.94	2.99	3.05	3.10	3.15	3.20	3.31	3.41	3.67	3.92	**v**
619.2	625.0	630.8	636.4	642.1	647.7	653.3	664.3	675.3	702.6	729.7	**i**
1.1604	1.1696	1.1785	1.1872	1.1957	1.2040	1.2121	1.2278	1.2430	1.2791	1.3129	**s**
172.5	182.5	192.5	202.5	212.5	222.5	232.5	252.5	272.5	322.5	372.5	**t 135**
2.78	2.83	2.89	2.94	2.99	3.04	3.09	3.19	3.29	3.54	3.78	**v**
619.9	625.7	631.5	637.2	642.9	648.5	654.1	665.1	676.1	703.5	730.6	**i**
1.1574	1.1665	1.1754	1.1841	1.1926	1.2009	1.2090	1.2248	1.2400	1.2760	1.3098	**s**
174.5	184.5	194.5	204.5	214.5	224.5	234.5	254.5	274.5	324.5	374.5	**t 140**
2.69	2.74	2.79	2.84	2.89	2.94	2.99	3.08	3.17	3.41	3.65	**v**
620.6	626.4	632.2	637.9	643.6	649.3	654.9	665.9	676.9	704.3	731.5	**i**
1.1544	1.1635	1.1724	1.1811	1.1896	1.1979	1.2060	1.2218	1.2370	1.2730	1.3067	**s**
176.5	186.5	196.5	206.5	216.5	226.5	236.5	256.5	296.5	326.5	376.5	**t 145**
2.60	2.65	2.70	2.74	2.79	2.84	2.89	2.98	3.07	3.30	3.53	**v**
621.2	627.1	632.9	638.7	644.4	650.0	655.6	666.7	677.8	705.2	732.4	**i**
1.1516	1.1607	1.1696	1.1783	1.1868	1.1951	1.2032	1.2190	1.2342	1.2701	1.3038	**s**
178.5	188.5	198.5	208.5	218.5	228.5	238.5	258.5	278.5	328.5	378.5	**t 150**
2.51	2.56	2.61	2.66	2.70	2.75	2.80	2.89	2.97	3.19	3.41	**v**
621.9	627.8	633.6	639.4	645.1	650.7	656.3	667.5	678.6	706.0	733.3	**i**
1.1489	1.1580	1.1669	1.1757	1.1841	1.1924	1.2005	1.2163	1.2315	1.2674	1.3010	**s**
180.4	190.4	200.4	210.4	220.4	230.4	240.4	260.4	280.4	330.4	380.4	**t 155**
2.44	2.48	2.53	2.57	2.62	2.66	2.71	2.80	2.88	3.10	3.31	**v**
622.5	628.4	634.2	640.0	645.7	651.4	657.0	668.2	679.3	706.8	734.2	**i**
1.1463	1.1554	1.1643	1.1730	1.1814	1.1897	1.1978	1.2136	1.2288	1.2647	1.2983	**s**
182.3	192.3	202.3	212.3	222.3	232.3	242.3	262.3	282.3	332.3	382.3	**t 160**
2.36	2.41	2.45	2.50	2.54	2.58	2.63	2.71	2.79	3.00	3.21	**v**
623.2	629.1	634.9	641.7	646.4	652.1	657.7	669.0	680.1	707.6	735.0	**i**
1.1438	1.1529	1.1618	1.1705	1.1789	1.1872	1.1954	1.2112	1.2263	1.2622	1.2957	**s**
184.1	194.1	204.1	214.1	224.1	234.1	244.1	264.1	284.1	334.1	384.1	**t 165**
2.29	2.34	2.38	2.42	2.47	2.51	2.55	2.63	2.71	2.91	3.10	**v**
623.7	629.7	635.5	641.3	647.1	652.8	658.4	669.7	680.8	708.4	735.8	**i**
1.1414	1.1505	1.1594	1.1681	1.1765	1.1848	1.1929	1.2086	1.2237	1.2596	1.2931	**s**
185.9	195.9	205.9	215.9	225.9	235.9	245.9	265.9	285.9	335.9	385.9	**t 170**
2.23	2.27	2.31	2.36	2.40	2.44	2.48	2.56	2.64	2.83	3.02	**v**
624.3	630.3	636.1	641.9	647.7	653.4	659.0	670.3	681.5	709.1	736.6	**i**
1.1390	1.1481	1.1570	1.1657	1.1741	1.1824	1.1905	1.2062	1.2213	1.2572	1.2907	**s**
189.4	199.4	209.4	219.4	229.4	239.4	249.4	269.4	289.4	339.4	389.4	**t 180**
2.11	2.15	2.19	2.23	2.27	2.31	2.35	2.42	2.49	2.68	2.86	**v**
625.4	631.4	637.3	643.1	648.9	654.7	660.3	671.6	682.8	710.5	738.1	**i**
1.1346	1.1436	1.1525	1.1612	1.1696	1.1779	1.1860	1.2017	1.2168	1.2527	1.2861	**s**

TABLE 3—SUPERHEATED VAPOR

Pressure lb.	Liquid	Sat. Vapor	Degrees of Superheat								
			10	20	30	40	50	60	70	80	90
190 t	92.7		102.7	112.7	122.7	132.7	142.7	152.7	162.7	172.7	182.7
v	0.027	1.58	1.63	1.68	1.72	1.76	1.80	1.84	1.88	1.92	1.96
i	68.6	559.4	567.0	574.3	581.4	588.3	595.0	601.5	607.9	614.2	620.4
s	0.1296	1.0182	1.0319	1.0448	1.0571	1.0688	1.0800	1.0908	1.1012	1.1112	1.1209
200 t	95.9		105.9	115.9	125.9	135.9	145.9	155.9	165.9	175.9	185.9
v	0.027	1.50	1.55	1.59	1.63	1.67	1.71	1.75	1.79	1.83	1.87
i	72.3	560.0	567.6	575.0	582.2	589.1	595.8	602.4	608.8	615.2	621.4
s	0.1363	1.0141	1.0278	1.0407	1.0530	1.0648	1.0760	1.0868	1.0972	1.1072	1.1169
210 t	98.9		108.9	118.9	128.9	138.9	148.9	158.9	168.9	178.9	188.9
v	0.027	1.43	1.48	1.52	1.56	1.60	1.64	1.67	1.71	1.75	1.78
i	76.0	560.5	568.2	575.7	582.9	589.8	596.6	603.2	609.7	616.1	622.3
s	0.1427	1.0102	1.0239	1.0368	1.0491	1.0609	1.0721	1.0829	1.0933	1.1033	1.1130
220 t	101.8		111.8	121.8	131.8	141.8	151.8	161.8	171.8	181.8	191.8
v	0.028	1.37	1.41	1.45	1.49	1.53	1.56	1.60	1.64	1.67	1.70
i	79.5	561.0	568.8	576.3	583.5	590.5	507.3	603.9	610.5	616.9	623.2
s	0.1488	1.0065	1.0202	1.0332	1.0455	1.0573	1.0685	1.0793	1.0897	1.0997	1.1094
230 t	104.7		114.7	124.7	134.7	144.7	154.7	164.7	174.7	184.7	194.7
v	0.028	1.31	1.35	1.39	1.43	1.46	1.50	1.53	1.57	1.60	1.63
i	83.0	561.5	569.4	576.9	584.1	591.2	598.0	604.7	611.3	617.7	624.0
s	0.1549	1.0030	1.0167	1.0297	1.0421	1.0539	1.0651	1.0759	1.0863	1.0963	1.1060
240 t	107.4		117.4	127.4	137.4	147.4	157.4	167.4	177.4	187.4	197.4
v	0.028	1.26	1.30	1.33	1.37	1.40	1.44	1.47	1.50	1.53	1.57
i	86.4	562.0	569.9	577.4	584.7	591.8	598.7	605.4	612.0	618.5	624.8
s	0.1609	0.9997	1.0134	1.0264	1.0387	1.0505	1.0617	1.0725	1.0829	1.0930	1.1027
250 t	110.1		120.1	130.1	140.1	150.1	160.1	170.1	180.1	190.1	200.1
v	0.028	1.21	1.25	1.28	1.31	1.35	1.38	1.41	1.44	1.47	1.50
i	89.7	562.5	570.4	578.0	585.3	592.4	599.4	606.1	612.8	619.3	625.6
s	0.1666	0.9965	1.0102	1.0232	1.0356	1.0474	1.0587	1.0695	1.0799	1.0899	1.0996
260 t	112.7		122.7	132.7	142.7	152.7	162.7	172.7	182.7	192.7	202.7
v	0.028	1.16	1.20	1.23	1.26	1.30	1.33	1.36	1.39	1.42	1.45
i	93.0	562.9	570.9	578.5	585.9	593.0	600.0	606.8	613.5	620.0	626.4
s	0.1722	0.9934	1.0072	1.0202	1.0326	1.0444	1.0556	1.0664	1.0768	1.0869	1.0966
270 t	115.2		125.2	135.2	145.2	155.2	165.2	175.2	185.2	195.2	205.2
v	0.028	1.12	1.15	1.18	1.22	1.25	1.28	1.31	1.34	1.37	1.40
i	96.1	563.4	571.4	579.0	586.4	593.6	600.6	607.4	614.1	620.7	627.1
s	0.1777	0.9905	1.0043	1.0173	1.0297	1.0415	1.0527	1.0635	1.0739	1.0840	1.0937
280 t	117.6		127.6	137.6	147.6	157.6	167.6	177.6	187.6	197.6	207.6
v	0.028	1.08	1.11	1.14	1.17	1.20	1.23	1.26	1.29	1.32	1.35
i	99.2	563.8	571.8	579.4	586.9	594.2	601.2	608.0	614.7	621.3	627.8
s	0.1829	0.9877	1.0015	1.0144	1.0268	1.0386	1.0498	1.0606	1.0711	1.0812	1.0909
290 t	120.0		130.0	140.0	150.0	160.0	170.0	180.0	190.0	200.0	210.0
v	0.028	1.04	1.07	1.10	1.13	1.16	1.19	1.22	1.25	1.27	1.30
i	102.3	564.2	572.2	579.9	587.4	594.7	601.8	608.7	615.4	622.0	628.5
s	0.1882	0.9850	0.9987	1.0117	1.0241	1.0359	1.0472	1.0580	1.0685	1.0786	1.0882
300 t	122.4		132.4	142.4	152.4	162.4	172.4	182.4	192.4	202.4	212.4
v	0.029	1.01	1.04	1.07	1.10	1.13	1.15	1.18	1.21	1.23	1.26
i	105.3	564.6	572.7	580.5	588.0	595.3	602.4	609.3	616.1	622.7	629.2
s	0.1932	0.9824	0.9962	1.0093	1.0217	1.0335	1.0448	1.0556	1.0660	1.0761	1.0858

TABLE 3—SUPERHEATED VAPOR

Degrees of Superheat											Pressure lb.
100	110	120	130	140	150	160	180	200	250	300	
192.7	202.7	212.7	222.7	232.7	242.7	252.7	272.7	292.7	342.7	392.7	**t 190**
2.00	2.04	2.08	2.12	2.15	2.19	2.23	2.30	2.37	2.55	2.72	**v**
626.5	632.5	638.4	644.3	650.1	655.9	661.6	672.9	684.1	711.9	739.6	**i**
1.1303	1.1394	1.1483	1.1570	1.1654	1.1737	1.1818	1.1975	1.2126	1.2483	1.2817	**s**
195.9	205.9	215.9	225.9	235.9	245.9	255.9	275.9	295.9	345.9	395.9	**t 200**
1.90	1.94	1.97	2.01	2.04	2.08	2.11	2.18	2.25	2.41	2.57	**v**
627.5	633.5	639.5	645.4	651.2	657.0	662.7	674.1	685.4	713.3	741.0	**i**
1.1263	1.1354	1.1443	1.1530	1.1614	1.1697	1.1778	1.1935	1.2085	1.2442	1.2776	**s**
198.9	208.9	218.9	228.9	238.9	248.9	258.9	278.9	298.9	348.9	398.9	**t 210**
1.82	1.85	1.89	1.92	1.96	1.99	2.02	2.09	2.15	2.31	2.47	**v**
628.4	634.5	640.5	646.4	652.3	658.1	663.8	675.2	686.6	714.5	742.2	**i**
1.1224	1.1316	1.1405	1.1492	1.1576	1.1659	1.1740	1.1897	1.2047	1.2403	1.2736	**s**
201.8	211.8	221.8	231.8	241.8	251.8	261.8	281.8	301.8	351.8	401.8	**t 220**
1.74	1.77	1.80	1.84	1.87	1.90	1.93	2.00	2.06	2.21	2.36	**v**
629.3	635.4	641.4	647.4	653.3	659.1	664.9	676.3	687.7	715.7	743.4	**v**
1.1188	1.1280	1.1369	1.1455	1.1539	1.1622	1.1703	1.1860	1.2010	1.2366	1.2699	**s**
204.7	214.7	224.7	234.7	244.7	254.7	264.7	284.7	304.7	354.7	404.7	**t 230**
1.67	1.70	1.73	1.76	1.79	1.82	1.85	1.91	1.97	2.12	2.26	**v**
630.2	636.3	642.3	648.3	654.2	660.1	665.9	677.4	688.8	716.8	744.6	**i**
1.1154	1.1245	1.1334	1.1421	1.1505	1.1588	1.1669	1.1826	1.1976	1.2331	1.2664	**s**
207.4	217.4	227.4	237.4	247.4	257.4	267.4	287.4	307.4	357.4	407.4	**t 240**
1.60	1.63	1.66	1.69	1.72	1.75	1.78	1.84	1.89	2.03	2.17	**v**
631.1	637.2	643.2	649.2	655.1	661.0	666 9	678.4	689.8	717.9	745.8	**i**
1.1121	1.1212	1.1301	1.1388	1.1472	1.1555	1.1635	1.1792	1.1943	1.2298	1.2630	**s**
210.1	220.1	230.1	240.1	250.1	260.1	270.1	290.1	310.1	360.1	410.1	**t 250**
1.53	1.56	1.59	1.62	1.65	1.68	1.71	1.76	1.81	1.95	2.08	**v**
631.9	638.0	644.1	650.1	656.0	661.9	667.8	679.4	690.8	719.0	747.0	**i**
1.1090	1.1182	1.1271	1.1358	1.1442	1.1524	1.1604	1.1761	1.1911	1.2266	1.2598	**s**
212.7	222.7	232.7	242.7	252.7	262.7	272.7	292.7	312.7	362.7	412.7	**t 260**
1.48	1.51	1.53	1.56	1.59	1.62	1.65	1.70	1.75	1.88	2.01	**v**
632.7	638.8	644.9	651.0	656.9	662.8	668.7	680.3	691.8	720.1	748.1	**i**
1.1060	1.1151	1.1240	1.1327	1.1411	1.1493	1.1574	1.1731	1.1881	1.2236	1.2567	**s**
215.2	225.2	235.2	245.2	255.2	265.2	275.2	295.2	315.2	365.2	415.2	**t 270**
1.42	1.45	1.48	1.50	1.53	1.56	1.58	1.64	1.69	1.81	1.93	**v**
633.4	639.6	645.7	651.8	657.7	663.7	669.6	681.2	692.7	721.1	749.1	**i**
1.1032	1.1123	1.1211	1.1298	1.1382	1.1464	1.1545	1.1702	1.1852	1.2207	1.2537	**s**
217.6	227.6	237.6	247.6	257.6	267.6	277.6	297.6	317.6	367.6	417.6	**t 280**
1.37	1.40	1.43	1.45	1.48	1.50	1.53	1.58	1.63	1.75	1.87	**v**
634.1	640.3	646.5	652.5	658.5	664.5	670.4	682.1	693.6	722.0	750.1	**i**
1.1004	1.1095	1.1184	1.1271	1.1355	1.1437	1.1518	1.1674	1.1824	1.2178	1.2508	**s**
220.0	230.0	240.0	250.0	260.0	270.0	280.0	300.0	320.0	370.0	420.0	**t 290**
1.33	1.35	1.38	1.40	1.43	1.45	1.48	1.53	1.57	1.69	1.80	**v**
634.8	641.1	647.2	653.3	659.3	665.3	671.2	682.9	694.5	722.9	751.1	**i**
1.0977	1.1068	1.1157	1.1244	1.1328	1.1411	1.1492	1.1647	1.1797	1.2151	1.2481	**s**
222.4	232.4	242.2	252.4	262.4	272.4	282.4	302.4	322.4	372.4	422.4	**t 300**
1.28	1.31	1.33	1.36	1.38	1.41	1.43	1.48	1.52	1.63	1.74	**v**
635.5	641.8	648.0	654.1	660.1	666.1	672.0	683.8	695.4	723.9	752.1	**i**
1.0953	1.1044	1.1132	1.1219	1.1303	1.1386	1.1467	1.1622	1.1772	1.2125	1.2455	**s**

TABLE 3 — SUPERHEATED VAPOR

Pressure lb.	Liquid	Sat. Vapor	Degrees of Superheat								
			10	20	30	40	50	60	70	80	90
320 t	126.8		136.8	146.8	156.8	166.8	176.8	186.8	196.8	206.8	216.8
v	0.029	0.94	0.97	1.00	1.03	1.06	1.08	1.11	1.13	1.16	1.18
i	111.1	565 3	573.4	581.3	588.9	596.2	603.4	610.4	617.2	623.8	630.4
s	0.2030	0.9775	0.9912	1.0043	1.0167	1.0285	1.0398	1.0506	1.0611	1.0712	1.0809
340 t	131.1		141.1	151.1	161.1	171.1	181.1	191.1	201.1	211.1	221.1
v	0.029	0.89	0.92	0.94	0.97	0.99	1.02	1.40	1.06	1.09	1.11
i	116.8	566.1	574.2	582.1	589.8	597.2	604.4	611.4	618.3	625.0	631.5
s	0.2125	0.9730	0.9867	0.9998	1.0121	1.0239	1.0352	1.0461	1.0566	1.0667	1.0764
360 t	135.2		145.2	155.2	165.2	175.2	185.2	195.2	205.2	215.2	225.2
v	0.029	0.84	0.86	0.89	0.91	0.94	0.96	0.98	1.01	1.03	1.05
i	122.3	566.7	574.9	582.9	590.6	598.1	605.4	612.4	619.3	626.1	632.7
s	0.2216	0.9687	0.9824	0.9955	1.0079	1.0197	1.0311	1.0419	1.0524	1.0625	1.0722
380 t	139.2		149.2	159.2	169.2	179.2	189.2	199.2	209.2	219.2	229.2
v	0.029	0.79	0.82	0.84	0.87	0.89	0.91	0.93	0.95	0.97	0.99
i	127.7	567.3	575.6	583.7	591.4	599.0	606.3	613.3	620.3	627.1	633.8
s	0.2305	0.9647	0.9785	0.9916	1.0040	1.0158	1.0271	1.0380	1.0485	1.0586	1.0683
400 t	142.9		152.9	162.9	172.9	182.9	102.9	202.9	212.9	222.9	232.9
v	0.029	0.75	0.78	0.80	0.82	0.84	0.86	0.88	0.90	0.92	0.94
i	132.9	567.9	576.3	584.4	592.2	599.8	607.1	614.2	621.2	628.0	634.8
s	0.2390	0.9608	0.9746	0.9877	1.0001	1.0119	1.0232	1.0341	1.0446	1.0547	1.0644
425 t	147.5		157.5	167.5	177.5	187.5	197.5	207.5	217.5	227.5	237.5
v	0.030	0.71	0.73	0.75	0.77	0.79	0.81	0.83	0.85	0.87	0.89
i	139.8	568.6	577.1	585.2	593.1	600.7	608.1	615.3	622.3	629.2	636.0
s	0.2492	0.9565	0.9703	0.9834	0.9958	1.0076	1.0190	1.0299	1.0404	1.0505	1.0602
450 t	151.9		161.9	171.9	181.9	191.9	201.9	211.9	221.9	231.9	241.9
v	0.030	0.67	0.69	0.71	0.73	0.75	0.77	0.79	0.80	0.82	0.84
i	145.6	569.3	577.8	586.0	594.0	601.6	609.1	616.3	623.3	630.3	637.1
s	0.2593	0.9523	0.9662	0.9793	0.9917	1.0035	1.0149	1.0258	1.0363	1.0464	1.0561
475 t	156.1		166.1	176.1	136.1	196.1	206.1	216.1	226.1	236.1	246.1
v	0.030	0.63	0.65	0.67	0.69	0.71	0.72	0.74	0.76	0.78	0.79
i	151.6	569.9	578.5	586.8	594.8	602.5	610.0	617.3	624.3	631.3	638.1
s	0.2690	0.9485	0.9624	0.9755	0.9880	0.9998	1.0112	1.0220	1.0325	1.0426	1.0523
500 t	160.0		170.0	180.0	190.0	200.0	210.0	220.0	230.0	240.0	250.0
v	0.031	0.60	0.62	0.64	0.65	0.67	0.69	0.70	0.72	0.74	0.75
i	157.5	570.5	579.2	587.5	595.5	603.3	610.8	618.2	625.3	632.2	639.1
s	0.2786	0.9449	0.9587	0.9718	0.9842	0.9960	1.0074	1.0183	1.0287	1.0388	1.0485
550 t	167.6		177.6	187.6	197.6	207.6	217.6	227.6	237.6	247.6	257.6
v	0.031	0.54	0.56	0.57	0.59	0.61	0.62	0.64	0.65	0.67	0.68
i	169.2	571.7	580.4	588.8	596.9	604.8	612.4	619.8	627.0	634.0	641.0
s	0.2965	0.9383	0.9521	0.9651	0.9775	0.9893	1.0007	1.0116	1.0221	1.0322	1.0419
600 t	174.7		184.7	194.7	204.7	214.7	224.7	234.7	244.7	254.7	264.7
v	0.032	0.49	0.51	0.52	0.54	0.55	0.57	0.58	0.60	0.61	0.62
i	180.4	572.7	581.5	590.0	598.2	606.1	613.8	621.2	628.5	635.7	642.7
s	0.3138	0.9323	0.9460	0.9591	0.9715	0.9833	0.9947	1.0056	1.0161	1.0263	1.0358

TABLE 3 — SUPERHEATED VAPOR

Degrees of Superheat											Pressure lb
100	110	120	130	140	150	160	180	200	250	300	
226.8	236.8	246.8	256.8	266.8	276.8	286.8	306.8	326.8	376.8	426.8	t **320**
1.20	1.23	1.25	1.27	1.30	1.32	1.34	1.39	1.43	1.54	1.64	v
636.8	643.1	649.3	655.4	661.5	667.5	673.5	685.3	696.9	725.6	753.9	i
1.0903	1.0994	1.1083	1.1170	1.1254	1.1337	1.1417	1.1572	1.1722	1.2075	1.2404	s
231.1	241.1	251.1	261.1	271.1	281.1	291.1	311.1	331.1	381.1	431.1	t **340**
1.13	1.16	1.18	1.20	1.22	1.24	1.26	1.30	1.34	1.44	1.54	v
638.0	644.3	650.6	656.8	662.9	668.9	674.9	686.8	698.4	727.2	755.6	i
1.0859	1.0950	1.1039	1.1125	1.1209	1.1292	1.1372	1.1527	1.1677	1.2030	1.2358	s
235.2	245.2	255.2	265.2	275.2	285.2	295.2	315.2	335.2	385.2	435.2	t **360**
1.07	1.09	1.11	1.13	1.15	1.17	1.19	1.23	1.27	1.37	1.46	v
639.2	645.5	651.8	658.1	664.2	670.3	676.3	688.2	699.9	728.8	757.3	i
1.0816	1.0907	1.0996	1.1082	1.1166	1.1249	1.1329	1.1484	1.1634	1.1987	1.2314	s
239.2	249.2	259.2	269.2	279.2	289.2	299.2	319.2	339.2	389.2	439.2	t **380**
1.01	1.03	1.05	1.07	1.09	1.11	1.13	1.17	1.21	1.30	1.38	v
640.3	646.7	653.0	659.3	665.4	671.5	677.6	689.5	701.3	730.3	758.9	i
1.0777	1.0868	1.0957	1.1043	1.1127	1.1210	1.1290	1.1445	1.1595	1.1947	1.2274	s
242.9	252.9	262.9	272.9	282.9	292.9	302.9	322.9	342.9	392.9	442.9	t **400**
0.96	0.98	1.00	1.02	1.04	1.06	1.07	1.11	1.14	1.23	1.31	v
641.3	647.7	654.1	660.4	666.6	672.7	678.8	690.7	702.6	731.7	760.4	i
1.0739	1.0830	1.0919	1.1005	1.1089	1.1171	1.1251	1.1406	1.1556	1.1907	1.2234	s
247.5	257.5	267.5	277.5	287.5	297.5	307.5	327.5	347.5	397.5	447.5	t **425**
0.91	0.93	0.94	0.96	0.98	0.99	1.01	1.05	1.08	1.16	1.24	v
642.5	649.0	655.4	661.8	668.0	674.2	680.3	692.3	704.2	733.4	762.2	i
1.0696	1.0787	1.0875	1.0961	1.1045	1.1128	1.1208	1.1363	1.1511	1.1862	1.2189	s
251.9	261.9	271.9	281.9	291.9	301.9	311.9	331.9	351.9	401.9	451.9	t **450**
0.85	0.87	0.89	0.91	0.92	0.94	0.95	0.99	1.02	1.10	1.17	v
643.7	650.2	656.7	663.1	669.3	675.5	681.7	693.8	705.7	735.0	763.8	i
1.0656	1.0747	1.0835	1.0921	1.1005	1.1087	1.1167	1.1322	1.1470	1.1821	1.2147	s
256.1	266.1	276.1	286.1	296.1	306.1	316.1	336.1	356.1	406.1	456.1	t **475**
0.81	0.83	0.84	0.86	0.87	0.89	0.90	0.93	0.96	1.04	1.11	v
644.8	651.4	657.8	664.2	670.5	676.8	682.9	695.1	707.1	736.5	765.4	i
1.0617	1.0708	1.0796	1.0883	1.0967	1.1048	1.1127	1.1282	1.1430	1.1780	1.2106	s
260.0	270.0	280.0	290.0	300.0	310.0	320.0	340.0	360.0	410.0	460.0	t **500**
0.77	0.78	0.80	0.81	0.83	0.84	0.86	0.89	0.92	0.99	1.05	v
645.8	652.5	658.9	665.3	671.7	678.0	684.1	696.3	708.4	737.9	766.9	i
1.0579	1.0671	1.0759	1.0845	1.0929	1.1011	1.1090	1.1245	1.1393	1.1743	1.2068	s
267.6	277.6	287.6	297.6	307.6	317.6	327.6	347.6	367.6	417.6	467.6	t **550**
0.70	0.71	0.73	0.74	0.75	0.77	0.78	0.81	0.83	0.89	0.95	v
647.8	654.5	661.0	667.5	673.9	680.2	686.4	698.7	710.9	740.6	769.8	i
1.0513	1.0604	1.0692	1.0778	1.0862	1.0944	1.1023	1.1178	1.1326	1.1675	1.1999	s
274.7	284.7	294.7	304.7	314.7	324.7	334.7	354.7	374.7	424.7	474.7	t **600**
0.64	0.65	0.66	0.68	0.69	0.70	0.71	0.74	0.76	0.82	0.87	v
649.5	656.3	662.9	669.4	675.9	682.2	688.5	700.9	713.1	743.0	772.3	i
1.0452	1.0543	1.0631	1.0717	1.0801	1.0883	1.0962	1.1116	1.1264	1.1612	1.1936	s

TABLE 4

THERMAL PROPERTIES OF LIQUID AMMONIA AT SATURATION PRESSURE

Temp. Fahr.	Pressure lb.	Sp. Vol. cu. ft. per lb.	Density lb. per cu. ft.	144 Apv′	Heat Content	Temp. Fahr.
−110°	0.758	0.02202	45.42	0.003	......	−110°
−105°	0.947	0.02211	45.23	0.004	......	−105°
−100°	1.176	0.02220	45.04	0.005	......	−100°
− 95°	1.450	0.02229	44.85	0.006	......	− 95°
− 90°	1.778	0.02239	44.66	0.007	......	− 90°
− 85°	2.167	0.02248	44.47	0.009	......	− 85°
− 80°	2.626	0.02258	44.28	0.011	......	− 80°
− 75°	3.164	0.02268	44.09	0.013	......	− 75°
− 70°	3.791	0.02278	43.89	0.016	......	− 70°
− 65°	4.518	0.02288	43.70	0.019	......	− 65°
− 60°	5.358	0.02299	43.51	0.023	......	− 60°
− 55°	6.324	0.02309	43.31	0.027	......	− 55°
− 50°	7.43	0.02320	43.11	0.032	−85.67	− 50°
− 45°	8.69	0.02331	42.91	0.038	−80.49	− 45°
− 40°	10.12	0.02342	42.71	0.044	−75.31	− 40°
− 35°	11.74	0.02353	42.50	0.051	−70.13	− 35°
− 30°	13.56	0.02364	42.30	0.059	−64.94	− 30°
− 25°	15.61	0.02376	42.09	0.069	−59.75	− 25°
− 20°	17.91	0.02388	41.88	0.079	−54.56	− 20°
− 15°	20.46	0.02400	41.67	0.091	−49.36	− 15°
− 10°	23.30	0.02412	41.46	0.104	−44.15	− 10°
− 5°	26.46	0.02424	41.25	0.119	−38.92	− 5°
0°	29.95	0.02437	41.04	0.135	−33.68	0°
5°	33.79	0.02450	40.83	0.153	−28.43	5°
10°	38.02	0.02463	40.61	0.173	−23.17	10°
15°	42.67	0.02476	40.39	0.196	−17.89	15°
20°	47.75	0.02490	40.17	0.220	−12.59	20°
25°	53.30	0.02503	39.95	0.247	− 7.26	25°
30°	59.35	0.02518	39.72	0.277	− 1.90	30°
35°	65.91	0.02531	39.50	0.309	+ 3.48	35°
40°	73.03	0.02547	39.27	0.344	+ 8.88	40°
45°	80.75	0.02562	39.04	0.383	+14.32	45°
50°	89.1	0.02577	38.81	0.425	19.80	50°
55°	98.0	0.02593	38.57	0.471	25.31	55°
60°	107.7	0.02609	38.33	0.520	30.87	60°
65°	118.1	0.02626	38.09	0.574	36.48	65°
70°	129.2	0.02642	37.85	0.632	42.14	70°
75°	141.1	0.02660	37.60	0.70	47.84	75°
80°	153.9	0.02678	37.35	0.76	53.60	80°
85°	167.4	0.02696	37.10	0.84	59.43	85°
90°	181.8	0.02714	36.84	0.92	65.32	90°
95°	197.3	0.02734	36.58	1.00	71.28	95°
100°	213.8	0.02753	36.32	1.09	77.30	100°
105°	231.2	0.02774	36.06	1.19	83.39	105°
110°	249.6	0.02795	35.79	1.29	89.57	110°
115°	269.2	0.02816	35.51	1.40	95.85	115°
120°	289.9	0.02839	35.23	1.52	102.24	120°

TABLE 4—LIQUID

Temp. Fahr.	Pressure lb.	Sp. Vol. cu. ft. per lb.	Density lb. per cu. ft.	144 Apv′	Heat Content	Temp. Fahr.
125°	311.6	0.02862	34.95	1.65	108.73	**125°**
130°	334.6	0.02886	34.66	1.79	115.32	**130°**
135°	358.8	0.02910	34.36	1.93	122.02	**135°**
140°	384.4	0.02936	34.06	2.09	128.83	**140°**
145°	411.3	0.02963	33.76	2.26	135.78	**145°**
150°	439.5	0.0299	33.45	2.43	142.87	**150°**
155°	469.1	0.0302	33.13	2.62	150.11	**155°**
160°	500.1	0.0305	32.80	2.82	157.52	**160°**
165°	532.6	0.0308	32.47	3.04	165.11	**165°**
170°	566.6	0.0312	32.03	3.27	172.88	**170°**
175°	602.2	0.0315	31.8	3.51	180.85	**175°**
180°	639.5	0.0318	31.5	3.77	189.03	**180°**
185°	678.4	0.0322	31.1	4.05	197.45	**185°**
190°	719.0	0.0326	30.7	4.34	206.16	**190°**
195°	761.4	0.0330	30.3	4.65	215.18	**195°**
200°	805.6	0.0335	29.9	4.99	......	**200°**
205°	851.7	0.0340	29.4	5.36	......	**205°**
210°	899.7	0.0345	29.0	5.75	......	**210°**
215°	949.6	0.0350	28.6	6.16	......	**215°**
220°	1001.4	0.0355	28.2	6.59	......	**220°**
225°	1055.3	0.0361	27.7	7.1	......	**225°**
230°	1111.3	0.0368	27.2	7.6	......	**230°**
235°	1169.5	0.0376	26.6	8.1	......	**235°**
240°	1229.9	0.0384	26.0	8.7	......	**240°**
245°	1292.5	0.0393	25.4	9.4	......	**245°**
250°	1357.4	0.0404	24.8	10.2	......	**250°**
255°	1424.7	0.0417	24.0	11.0	......	**255°**
260°	1494.4	0.0435	23.0	12.0	......	**260°**
265°	1566.6	0.0457	21.8	13.3	......	**265°**
270°	1641.3	0.0500	20.0	15.2	......	**270°**
273.2°	1690.0	0.0678	14.75	21.2	......	**273.2°**

III. Mollier Diagram for Ammonia

7. *Description of Diagram.*—In order to facilitate the solution of refrigeration problems, a *Heat Content-Entropy Diagram* has been prepared to accompany this bulletin, and is inserted in an envelope attached to the back cover. This diagram has two families of curves: (a) curves of constant pressure, and (b) curves of constant quality in the saturated region and constant temperature in the region of superheat. The ordinates are heat contents; the abscissas are entropies.

In order to use as large scales as possible and at the same time to bring the diagram into reasonable compass oblique coördinates have been used. The axis of ordinates instead of being vertical is inclined to the left at an angle of 30 degrees with the axis of abscissas. Taking the values of entropy along the horizontal axis, values of heat content may be taken either along the inclined axis or along a vertical axis. Since vertical distances are equal to distances along the oblique axis multiplied by the sine of 30 degrees, the scale for measuring heat contents along the oblique lines is such that a distance measured along the 30 degree lines represents sine 30° (or ½) times as many units of heat content as are represented by the same distance measured vertically.

The 30° lines are lines of constant entropy and show the change of condition of the ammonia during adiabatic compression or expansion. Measurements along these lines give the change in heat content during adiabatic compression or expansion. Horizontal lines are lines of constant heat content; they show the change in condition of the ammonia which results from a throttling process, such as the passage through the expansion valve of a refrigerating machine.

The lines of constant pressure after meeting the liquid line should be extended beyond this line to the left to represent the cooling of the liquid at constant pressure below the temperature of saturation for that pressure. The constant pressure lines are so nearly tangent to the liquid line that the several lines could not be distinguished with the scale employed. The process of cooling the liquid below saturation temperature is therefore represented for all pressures by the liquid line itself.

9. *Examples of the Use of the Diagram.*—The following examples will illustrate the method of solution of some of the more commonly occurring problems.

WORK DONE IN THE COMPRESSOR ASSUMING THE RANKINE IDEAL CYCLE

In the Rankine cycle, the ammonia is admitted at a constant pressure, is compressed adiabatically to the discharge pressure and is discharged against this constant pressure. The compressor is supposed to have no clearance. The cycle is ideal with no internal friction, no heat losses and no free or imperfectly resisted expansion. In such a cycle the work done per pound of ammonia is the difference in heat content at the beginning and end of compression, that is i_1-i_2. As the only compression that takes place is adiabatic, the ammonia leaving has the same entropy as that entering.

To find the work done upon one pound of ammonia, in a Rankine cycle admitting ammonia at a known quality and pressure, and compressing it to a known discharge pressure, locate the point representing the quality and pressure of the suction ammonia, and measure the distance upward to the left along a 30° line to the discharge pressure line. If the quality and pressure at discharge and the suction pressure only are known, locate the point representing the quality and pressure of the discharge ammonia, and measure the distance downward to the right along a 30° line to the suction pressure line. In either case the distance represents the work done in B.t.u.

Example 1. In a dry compression system, ammonia, initially dry and saturated at a pressure of 25 lb. per sq. in. absolute, goes through a Rankine cycle in which it is compressed to a pressure of 200 lb. per sq. in. absolute. How much work is done on each pound of ammonia?

The heat content of dry and saturated ammonia at a pressure of 25 lb. is seen from the diagram to be 536 B.t.u. Ammonia of the same entropy at 200 lb. pressure has a temperature of 271° F. and has a heat content of 671 B.t.u. The work of the Rankine cycle is

$$536-671=-135 \text{ B.t.u.},$$

the minus sign signifying work done on the ammonia.

The same value is obtained with twice as great accuracy by measuring the distance along the 30° line between the points representing the initial and final states of the ammonia.

Example 2. In a wet compression system, ammonia, after having gone through a Rankine cycle with a suction pressure of 25 lb., is discharged dry and saturated at a pressure of 200 lb. How much work is done on each pound of ammonia?

The heat content of dry and saturated ammonia at a pressure of 200 lb. is seen to be 560 B.t.u. Ammonia of the same entropy at 25 lb. pressure has a quality of 0.86 and has a heat content of 457 B.t.u. The work of the Rankine cycle is

$$457-560=-103 \text{ B.t.u.}$$

HEAT REJECTED BY AMMONIA IN CONDENSER AND COOLER

In any constant pressure process the change of i measures the heat taken in or given out. To show this take the general equation:

$$dQ = du + Apdv$$

Then

$$\begin{aligned} dQ &= (du + Apdv + Avdp) - Avdp \\ &= [du + Ad(pv)] - Avdp \\ &= di - Avdp \end{aligned}$$

Hence, when p is constant during the change,

$$dQ = di$$

and $Q = i_2 - i_1$ for any two states.

Therefore the heat rejected to the cooling water in the condenser and cooler is directly measured by the decrease in i which the ammonia undergoes after adiabatic compression up to the expansion valve.

To find the heat rejected per pound of ammonia in the condenser and cooler, locate the point representing the state of the ammonia after compression, and pass down a constant pressure curve to the point representing the state of the ammonia before the expansion valve. The vertical distance passed through, that is the difference between the heat contents at the initial and final states, gives the heat rejected to the cooling water per pound of ammonia. Part of this heat is taken out as the superheat, if any, is removed; the greater part is taken out as the ammonia is condensed; and the remainder is taken out as the liquid is cooled from the temperature of saturation at the given pressure to the temperature before the expansion valve; this latter part usually takes place in a cooler separate from the condenser.

Example 3. Ammonia, after being compressed as in example 1 to a pressure of 200 lb. and a temperature of 271° F., is passed through the cooler and condenser and when it reaches the expansion valve has a temperature of 80° F. How much heat is rejected to the cooling water?

The heat content after compression was found in example 1 to be 671 B.t.u. Passing down the constant pressure line the superheat is removed, the ammonia condensed, and the liquid cooled from saturation temperature of 96° F. to 80° F. At the latter point the heat content is seen from the diagram to be 54 B.t.u. The heat rejected to the cooling water is

$$671 - 54 = 617 \text{ B.t.u.}$$

Example 4. Find the heat rejected to the cooling water if the ammonia compressed as in example 2 to a dry and saturated state at 200 lb. pressure is cooled to a temperature of 80° F. before the expansion valve.

By a process similar to that given in example 3, the heat rejected to the cooling water is

$$560-54=506 \text{ B.t.u.}$$

THROTTLING THROUGH THE EXPANSION VALVE

If vapor is allowed to expand through a small orifice, such as the expansion valve, without the addition or abstraction of heat, and is finally brought to its initial velocity, its heat content will be unchanged. The proof of this statement is based on the thermodynamic theory of flow of fluids and may be found in any standard text. Horizontal lines on the diagram are lines of constant heat content and consequently show the changes in the condition of the ammonia which result from throttling in the expansion valve.

Example 5. Liquid ammonia in front of the expansion valve has a temperature of 80° F., and after passing through the valve the pressure of the mixture of vapor and liquid is 25 lb. What is the quality of the mixture?

The horizontal line which intersects the liquid line at a temperature of 80° F., intersects the 25 lb. pressure line at a point which is found by interpolation to correspond to a quality of 0.16. This horizontal line represents a constant heat content of 54 B.t.u.

REFRIGERATING EFFECT

The refrigerating effect is measured directly by the change in i which the ammonia undergoes during evaporation, this being a constant pressure process in which, as shown above, the increase in i is equal to the heat absorbed.

To find the refrigerating effect per pound of ammonia, locate the point representing the state of the ammonia after its passage through the expansion valve, and pass up along a constant pressure line to the point representing the state of the ammonia at the beginning of compression. The vertical distance passed through, that is the difference between the heat contents at the initial and final states, gives the refrigerating effect per pound of ammonia.

Example 6. After being throttled through the expansion valve to a pressure of 25 lb. and a quality of 0.16, the ammonia evaporates in the refrigerating coils until it is just dry and saturated at this pressure. What is the refrigerating effect per pound of ammonia circulated?

From the diagram the change in i, or the heat absorbed by the ammonia is

$$536-54=482 \text{ B.t.u.}$$

Example 7. Find the refrigerating effect per pound of ammonia, when the condition after the expansion valve is the same as in example 6, but evaporation takes place as in the wet compression system of example 2 only until a quality of 0.86 is reached.

From the chart the refrigerating effect is

$$457-54=403 \text{ B.t.u.}$$

THEORETICAL COEFFICIENT OF PERFORMANCE AND REFRIGERATING EFFECT PER HORSE-POWER HOUR

By definition the coefficient of performance is equal to the ratio of the heat absorbed by the refrigerating medium to the work done upon it. It has been shown that both of these quantities can be read from the diagram, and therefore the coefficient of performance can be calculated for any assumed conditions of operation.

Example 8. What is the coefficient of performance of the dry compression process of examples 1, 3, 5, and 6?

From example 6 the heat absorbed is 482 B.t.u., and from example 1 the work done on the ammonia is 135 B.t.u. The coefficient of performance is therefore =

$$482 \div 135 = 3.57.$$

Since one horse-power hour is equal to 2546 B.t.u., the refrigerating effect per horse-power hour is

$$2546 \times 3.57 = 9090 \text{ B.t.u.}$$

Example 9. What is the coefficient of performance of the wet compression system of examples 2, 4, 5, and 7?

From example 7 the heat absorbed is 403 B.t.u., and from example 2 the work done on the ammonia is 103 B.t.u. The coefficient of performance is therefore =

$$403 \div 103 = 3.91.$$

The refrigerating effect per horse-power hour is

$$2546 \times 3.91 = 9960 \text{ B.t.u.}$$

From the above examples it is seen that the theoretical loss with dry compression as compared with wet compression under these conditions is

$$\frac{9960-9090}{9960} = 8.7\%$$

SAVING POSSIBLE BY USE OF EXPANSION CYLINDER

If instead of the expansion valve an expansion cylinder were used the irreversible throttling process would be replaced by a reversible adiabatic expansion. In that case the reduction of pressure instead of being represented on the diagram by a horizontal line extending from the point representing the state before the expansion valve to the refrigerator pressure line, would be represented by an adiabatic. The length of this adiabatic would measure in heat units the work recovered by the use of the expansion cylinder and the gain in refrigerating effect would be measured by the change in i along the adiabatic.

Example 10. Find the per cent. gain due to substituting an expansion cylinder for the expansion valve in the wet compression system described in examples 2, 4, 5, and 7.

The work of compression would be the same as in example 2, or 103 B.t.u. The heat rejected to cooling water would be the same as in example 4, or 506 B.t.u. The expansion in the expansion cylinder would be represented by a 30° adiabatic extending from the point representing liquid at a temperature of 80° F. downward to the 25 lb. pressure line. The length of this line gives the work obtained in the expansion cylinder, assuming a Rankine cycle, or 9 B.t.u. The refrigerating effect would be increased by the same amount, or

$$54-45=9 \text{ B.t.u.}$$

The coefficient of performance would therefore be

$$\frac{403+9}{103-9}=4.38$$

The per cent gain due to using the expansion cylinder is therefore

$$\frac{4.38-3.91}{3.91}=12\%$$

IV. Basis of the Tables

The tables given in the preceding pages are based upon the most reliable experimental data available at the present time. The purpose of the following pages is to present this body of data together with the derivation therefrom of the formulas from which the tables were calculated.

10. *Absolute Temperature.*—In the computation of tables of the properties of a vapor, absolute temperatures must be used; hence an evaluation of the absolute thermodynamic scale is necessary. In this evaluation two problems must be solved. The first is the determination of the absolute temperature of melting ice; and the second is the determination, degree by degree, of the difference between the absolute scale and that of the nitrogen-in-glass thermometer which is the usual standard in scientific work. For the present purpose the second of these problems need not be considered, for the variation of the nitrogen thermometer from the absolute scale is nowhere greater than one twentieth of a degree Fahrenheit between 0° and 400°. Even con-

siderably larger errors than this would be within the limit of error of the other experimental data.

The determination of the absolute zero has been satisfactorily accomplished and the results are summed up by Marks and Davis[33]. The following table is taken from their "Steam Tables" and gives the determinations of Berthelot[34], Buckingham[35], and Rose-Innes[36].

Table 5. Determinations of Ice-Point on Absolute Scale

Author	Year	Method	Gases	Final Value for Ice-point
Berthelot	1903	Extrapolation to p=o	H_2 and N_2	491.54°F
Berthelot	1903	Joule-Thomson effect	H_2, N_2, CO_2, air	491.63
Buckingham	1907	Joule-Thomson effect	H_2, N_2, CO_2, air	491.71
Rose-Innes	1908	Joule-Thomson effect and other data	H_2 and N_2	491.64

The determination of Rose-Innes is probably the best and incidentally it agrees almost exactly with the mean of the other three. Since the temperature of melting ice on the ordinary Fahrenheit scale is 32°, the number that must be added to temperatures on the ordinary scale to reduce them to absolute temperatures is

$$491.64 - 32 = 459.64$$

11. *Mechanical Equivalent of Heat.*—In several of the equations used in the computation of vapor tables the mechanical equivalent of heat, J, or its reciprocal, A, appears. This equivalent has been experimentally determined by two methods: by transforming mechanical work into heat directly, and by transforming electrical energy into heat. The first method has been used by Rowland,[37] and Reynolds and Moorby;[38] the latter by Griffiths,[39] Schuster and Gannon,[40] and Barnes.[41] These various investigations have been discussed by Smith,[42] who accepts as most trustworthy the mean of the values of Barnes and of Reynolds and Moorby. Smith gives as this mean,

1 mean calorie $= 4.1834 \times 10^7$ ergs. and this is the value used in the Marks and Davis Steam Tables.

Barnes[43] later points out that his work must be considered as leading to the value 4.1849. Since the work done by Reynolds and Moorby leads, according to Smith, to the value 4.1836, the mean of these determinations is 4.1842.

Griffiths in his discussion of the most trustworthy experiments then available (1893) decided that the most probable value of J is 4.184. That is, taking the 17½° gram-calorie, or the mean calorie which is practically equal to it,

1 mean calorie $= 4.184 \times 10^7$ ergs. To change this into English units, one needs the conversion factor[44]

$$1 \text{ kg.} = 2.204622 \text{ lb.}$$

and a value of the gravitation constant, for which

$$g = 980.655 \text{ cm. per sec.}^2$$

has been adopted by international agreement.[45] The result is

$$1 \text{ mean B.t.u.} = 777.64 \text{ standard ft. lb.}$$

This value has been used in the present investigation.

It may be mentioned here that all factors for conversion from metric into English units have been taken from the tables given in the Marks and Davis Steam Tables.

12. *Relation between Pressure and Temperature of Saturated Vapor.*—To express the relation between the pressure and temperature of saturated vapors scores of formulas have been proposed. Some are of more or less rational form involving empirical constants, but the greater number are purely empirical. A few of the formulas that have been applied to ammonia, together with the constants giving p in lb. per sq. in. when temperatures are given in degrees Fahrenheit, are here given.

(a) Biot's equation as used by Regnault has the form

$$\log p = a - b\alpha^n + c\beta^n, \text{ where } n = t - k$$

The constants used by Regnault are;[1]

$$\begin{aligned} a &= 9.790830 \\ b &= 7.450352 \\ c &= 0.949967 \\ \log \alpha &= \bar{1}.999779 \\ \log \beta &= \bar{1}.996652 \\ n &= t + 7.6 \end{aligned}$$

Limits, −8° F. to 180° F.

The same formula was used in the computation of Peabody's[11] tables.

(b) Zeuner[8] used the Biot formula, but omitted the third term and expressed the second term as a function of t:

$$\log p = a - b\alpha^\tau$$

where

$$a = 3.844672$$

$$\log b\alpha^\tau = 0.312482 - 0.0019457\ (t - 32)$$

This form was used also by Dieterici,[25] who applied it at temperatures above the limit of the range for which Zeuner's empirical equation for $\log b\alpha^\tau$ holds. He thus obtained pressures far too low at high temperatures, also low values of $\frac{dp}{dt}$ and consequently low values of r when the Clapeyron-Clausius equation is used.

(c) Wood[10] used Rankine's formula in the form

$$\log p = a - \frac{b}{T}$$

with

$$a = 6.2495$$
$$b = 2196$$

Limits, −20° F. to 100° F.

(d) Goodenough[32] used the Bertrand formula in the form

$$\log\ p = \log k - n \log \frac{T}{T-b}$$

with

$$\log\ k = 5.87395$$
$$n = 50$$
$$b = 84.3$$

It does not seem to be possible to find constants which will make equations of the above forms apply over more than a limited range of temperature, either with steam or with other vapors. However, an equation for steam has recently been proposed by Marks,[46] which is remarkable in that it gives pressures agreeing closely with experimental values throughout the range from 32° F. to 706.1° F., the latter point being the critical temperature. This equation is based on the equation used by van der Waals:

$$\log \frac{p_k}{p} = a\left(\frac{T_k}{T} - 1\right)$$

where p_k and T_k denote respectively the critical pressure and critical temperature. Instead of being a constant as used by van der Waals, a varies for different substances and for different temperatures with the same substance. Prof. Marks found values of a at different temperatures for steam and then found an expression for its value in terms of the temperature and the critical temperature. By substituting this expression for a and the proper values for p_k and T_k in the equation $\log \frac{p_k}{p} = a\left(\frac{T_k}{T} - 1\right)$, he arrived at the following relation between the pressure and temperature of saturated steam:

$$\log\ p = a - \frac{b}{T} - cT + eT^2 \qquad (1)$$

where

$$a = 10.515354$$
$$b = 4873.71$$
$$c = 0.00405096$$
$$e = 0.000001392964$$

In the present investigation an attempt was made to use the above method to determine the pressure-temperature relation of ammonia. Several factors rendered the use of this method undesirable. They are: the sensitiveness of the method to changes in the critical data and the uncertainty of these data for ammonia; the lack of experimental data at temperatures near the critical point; and the large discrepancies existing in the data throughout the entire range. As will be seen later, however, this equation plays an important part in the present investigation.

Physicists have repeatedly attempted to find a relation between the pressures of different vapors at the same temperature such that a determination of the function $p=f(t)$ for one vapor would serve to determine this function for all other vapors. Ramsey and Young[47] proposed the law

$$R=R'+k(T-T')$$

Where R and R' are the ratios of the temperatures of two saturated vapors at two different pressures, and T and T' are the temperatures of one of the vapors corresponding to these pressures. They show that the law holds very closely for some 22 different substances arranged in 23 different pairs. In their paper they use the T and T' in the term $k(T-T')$ as being indiscriminately the numerators or the denominators of the ratios R and R'; i. e. they use the two equations

$$\frac{T_b}{T_a}=\frac{T_b'}{T_a'}+k'(T_a-T_a') \qquad \text{(a)}$$

$$\frac{T_a}{T_b}=\frac{T_a'}{T_b'}+k(T_a-T_a') \qquad \text{(b)}$$

without making any mention of the change from one form to the other and without recognizing that the two forms lead to different results.

This law has been corroborated by the work of Richardson[48] and by the work of Ramsey and Travers[49] on crypton, argon and xenon.

Ayrton and Perry,[50] and Everett[51] have each remarked upon the lack of symmetry of equation (a) and have shown that equation (b) is symmetrical. This is most clearly demonstrated by Moss,[52] who shows that (a) may be thrown into the form

$$\frac{T_b}{T_a}=\left[\frac{T_b'}{T_a'}-k'T_a'\right]+k'T_a$$

and (b) may be thrown into the form

$$\frac{T_a}{T_b}=\left[\frac{T_a'}{T_b'}-kT_a'\right]+kT_a$$

Since T_a' and T_b' are the temperatures corresponding to some particular vapor pressure, these equations may be written respectively

$$\frac{T_b}{T_a}=k'T_a+c' \qquad \text{(c)}$$

and

$$\frac{T_a}{T_b}=kT_a+c \qquad \text{(d)}$$

Now to test the symmetry of these equations they may be written

$$\frac{T_a}{T_b}=\left[-\frac{k'}{c'}\right]\frac{T_a^2}{T_b}+\frac{1}{c'} \tag{e}$$

and

$$\frac{T_b}{T_a}=\left[-\frac{k}{c}\right]T_b+\frac{1}{c} \tag{f}$$

It is seen that if the left hand member of (c) is a linear function of the denominator, its reciprocal will not be a linear function of the new denominator. On the other hand, if the left hand member of (d) is a linear function of the numerator, its reciprocal will also be a linear function of the new numerator.

Moss replotted the data used by Ramsey and Young in their original paper but used in all cases the symmetrical form (d). He found that in all cases where they had used the unsymmetrical form the symmetrical form fitted just as well and in most cases much better, in addition to its superiority in being reversible.

Equation (d) may be written in the simple form

$$\frac{1}{T_b}=c\frac{1}{T_a}+k \tag{g}$$

$\frac{1}{T_b}$ and $\frac{1}{T_a}$ thus being linear functions of each other. Suppose there are available two values of saturation temperatures corresponding to known vapor pressures for some substance. If water vapor or some other substance whose vapor pressures are known is taken as the other substance, then from the two temperatures the constants c and k may be determined. The temperatures for all vapor pressures for the substance in question may then be readily computed.

Since equation (g) may be written

$A-\frac{B}{T_b}=A'-\frac{B'}{T_a}$, it follows that any equation to be applicable to all vapors in the same form with only its constants changed, and at the same time to be consistent with the temperature ratio law as stated above, must satisfy the condition that $p=f(A-\frac{B}{T})$, all other constants remaining the same for all vapors. Now it happens that the equations which may be thrown into this form, such as the Rankine short form, the Roche equation, etc., do not satisfy the experimental data for steam throughout its range with the necessary degree of accuracy. On the other hand the Marks equation, which does satisfy these data with remarkable accuracy throughout its complete range, cannot be thrown into the required form. In view of the various considerations mentioned it has been decided in the present investigation to accept the temperature ratio law as expressed in equation (g), to use water as the standard substance, to use the Marks equation, equation (1), as representing the pressure-temperature relation for water, and to make a step by step solution of the pressure-temperature relation for ammonia by means of these equations.

The method used in applying the temperature ratio law and in determining the value of the constants c and k in equation (g), is that used by Moss[52], who has applied it to 17 different vapors. A description of this method will now be given.

Using formula (g) to obtain the saturation temperatures of ammonia from those of water,

$$\frac{1}{T_a}=c\frac{1}{T_w}+k$$

Put

$$-\frac{1}{T_w}=y \text{ and } -\frac{1}{T_a}=x;$$

then

$$-x=-cy+k$$

Since y is a function of the water vapor temperature corresponding to pressure p, y is also a function of p. The value of y for a given value of p may be found by making use of the tables of water vapor pressure. The quantity x is a function of the temperature of the ammonia corresponding to this same vapor pressure p. The curve giving x as a function of y is evidently a straight line.

Since y is a function of the pressure p and x a function of the corresponding temperature, we may label the values of x and y with the respective values of the pressure and temperature which they represent. Then we may read off directly from the diagram the corresponding values of saturation temperature and vapor pressure.

Fig. 1 was constructed in this manner. Integral values of temperature were assumed and the corresponding values of x were computed according to the relation $x=-\frac{1}{T}$. These values of x were then laid off to a convenient scale and each labeled with the temperature to which the value of x corresponds. Integral values of pressure were assumed, the corresponding values of temperature found from steam tables, and the corresponding values of y computed according to the relation $y=-\frac{1}{T}$. These values of y were laid off to a convenient scale and each labeled with the pressure to which the value of y corresponds.

The value of vapor pressure at a given temperature as taken from the Marks and Davis Steam Tables was found to agree with the value given by the new Marks formula with sufficient accuracy up to a temperature of 400° F.; above this temperature the values differed materially. In the construction of the chart, therefore, the Steam Tables were used to find the pressures corresponding to temperatures below 400° F. and the newer formula was used to find the pressures corresponding to temperatures above that point.

The following tables show the calculations for a few of the values of Fig. 1.

TABLE 6. CALCULATIONS FOR VALUES OF FIG. 1

ABSCISSAS

Fahrenheit Temperature	Absolute Temperature	Reciprocal of Absolute Temp.	Corresponding value of x in inches referred to the point −10 as origin $= -(8000 \times \frac{1}{T} - 10)$
−100	359.64	0.0027806	12.244
−50	409.64	0.0024412	9.529
0	459.64	0.0021756	7.405
+50	509.64	0.0019622	5.697
100	559.64	0.0017869	4.295
150	609.64	0.0016403	3.122
200	659.64	0.0015160	2.128
250	709.64	0.0014092	1.273

ORDINATES

Pressure lb. per sq. in.	Corresponding Saturation Temperature of Water Vapor in degrees F.	Absolute Temperature	Reciprocal of Absolute Temperature	Corresponding value of y in inches referred to the point −18 as or gin $= -(20000 \times \frac{1}{T} - 18)$
1	101.83	561.47	0.0017810	17.621
5	162.28	621.92	0.0016079	14.158
10	193.22	652.86	0.0015317	12.634
50	281.0	740.64	0.0013502	9.004
100	327.8	787.44	0.0012699	7.399
500	467.2	926.84	0.0010789	3.579
1000	544.9	1004.54	0.0009955	1.910
1700	613.4	1073.04	0.0009319	0.639

In order to settle upon the most probable location of the straight line representing the pressure-temperature relation of saturated ammonia upon this chart the experimental data must be plotted. The data obtained by Regnault[1] are given in Table 7 and are shown in Fig. 1. by the open circles. The data obtained by Blümcke[12] are given in Table 8, and are plotted in Fig. 1 as crosses. The data obtained by Brill[16] are given in Table 9 and are indicated in Fig. 1 by the solid circles. The data obtained by Davies[15] are given in Table 10 and are represented in Fig. 1 by means of solid squares. The pressures observed by Pictet[13] over a temperature range of −22° F. to 122° F. agree almost exactly with those observed by Regnault; they are neither tabulated nor plotted. Faraday's[14] results, which are given in Table 11, are, on the other hand, quite inconsistent with those of Regnault. They are neither plotted in Fig. 1 nor given weight in the determination of the constants of the equation.

The two points in the upper right hand corner of Fig. 1 represent the experiments at the critical point. The open square shows the

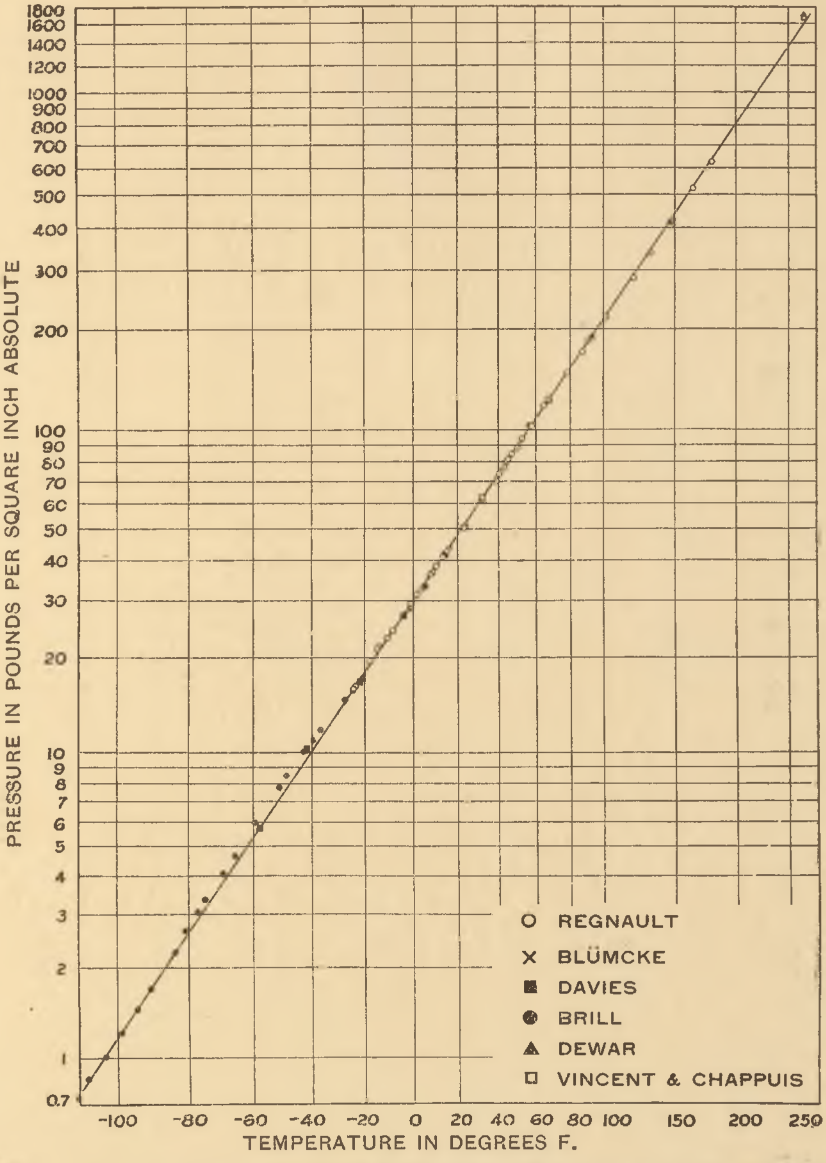

FIG. 1. SHOWING THE AGREEMENT OF PRESSURES FOUND BY THE TEMPERATURE RATIO LAW WITH THOSE FOUND BY EXPERIMENT.

values given by Vincent and Chappuis[13] and the solid triangle the values given by Dewar.[17] The values from which these points were plotted are given in Table 12.

After plotting the points representing the experimental data the straight line shown in Fig. 1 was drawn in such a manner as to represent all the points in the best possible manner.

TABLE 7. SUMMARY OF PRESSURE-TEMPERATURE DETERMINATIONS OF REGNAULT

Series	Temperature °C.	Pressure in mm. of Mercury	Temperature °F.	Pressure in lb. per sq. in.
2	−31.48	815.09	−24.66	15.77
2	−31.37	823.59	−24.47	15.93
2	−30.96	838.41	−23.73	16.22
2	−27.47	1002.91	−17.45	19.40
2	−27.36	1006.71	−17.25	19.47
3	−25.84	1097.21	−14.51	21.22
3	−25.70	1117.74	−14.26	21.62
3	−23.92	1187.30	−11.06	22.97
2	−22.71	1244.47	− 8.88	24.07
2	−22.60	1251.71	− 8.68	24.21
2	−18.37	1518.19	− 1.07	29.37
2	−18.35	1513.53	− 1.03	29.28
3	−18.31	1518.70	− 0.96	29.38
3	−18.10	1529.90	− 0.58	29.59
1	−18.03	1524.92	− 0.45	29.50
1	−16.79	1614.86	+ 1.78	31.24
1	−16.58	1630.47	+ 2.16	31.54
3	−16.17	1669.95	+ 2.89	32.20
3	−13.55	1859.93	+ 7.61	35.98
3	−13.51	1867.93	+ 7.68	36.13
1	−13.09	1900.37	+ 8.44	36.76
1	−12.15	1980.87	+10.13	38.32
2	−10.52	2133.78	+13.06	41.27
2	−10.42	2119.44	+13.24	41.00
3	− 9.21	2222 35	+15.42	42.99
3	− 5.03	2599.55	+22.95	50.28
3	− 0.10	3159.07	+31.82	61.11
2	0	3203.66	+32.00	62.04
2	0	3206.68		
1	0	3207.70		
1	0	3212.66		
1	0	3207.48		
1	0	3214.73		
1	0	3198.44		
1	+ 3.97	3615.65	+39.15	69.94
1	+ 4.72	3812.09	+40.50	73.74
3	+ 6.24	3963.67	+43.23	76.67
2	+ 6.93	4139.96	+44.47	80.08
2	+ 7.32	4199.74	+45.18	81.24
2	+ 7.34	4198.12	+45.21	81.21
2	+ 8.45	4368.87	+47.21	84.51
3	+ 9.98	4550.44	+49.96	88.02
2	+11.42	4835.82	+52.57	93.54
2	+13.52	5335.26	+56.34	103.20
3	+14.38	5302.37	+57.88	102.57
2	+18.15	6134.92	+64.67	118.67
2	+19.29	6399.12	+66.72	123.62
2	+19.29	6382.70		
3	+19.70	6317.97	+67.46	122.21
2	+25.35	7676.26	+77.63	148.48
3	+30.49	8802.88	+86.88	170.28
2	+32.70	9569.56	+90.86	185.11
3	+38.90	11236.07	+102.02	217.34
3	+48.93	14669.97	+120.07	283.77
3	+55.47	17333.92	+131.85	335.30
3	+64.35	21619.67	+147.83	418.20
3	+73.32	26766.40	+163.98	517.75
3	+81.72	32171.03	+179.10	622.30

NOTE — In this table all pressures, besides being multiplied by the proper factor to convert mm of mercury into lb. per sq. in., were multiplied by the number 1.00033, this being the constant given by Landolt and Börnstein to reduce pressures at Paris where Regnault worked to pressures at 45° latitude and at sea-level.

Table 8. Summary of Pressure–Temperature Determinations of Blümcke

Temperature °F.	Pressure in lb. per sq. in.
+ 1.30	28.08
+ 32.00	62.05
+ 93.20	188.2
+146.30	412.2

Table 9. Summary of Pressure–Temperature Determinations of Brill

Temperature °C.	Pressure in mm. of Mercury	Temperature °F.	Pressure in lb. per sq. in.
−79.0	38.0	−110.20	0.735
−77.6	44.1	−107.68	0.853
−75.1	51.8	−103.18	1.002
−72.7	62.5	− 98.86	1.209
−70.4	74.9	− 94.72	1.448
−68.3	87.5	− 90.94	1.692
−64.4	116.0	− 83.92	2.243
−62.8	136.0	− 81.04	2.630
−60.8	157.6	− 77.44	3.048
−59.5	172.4	− 75.10	3.334
−56.5	210.0	− 69.70	4.061
−54.4	239.5	− 65.92	4.631
−50.7	309.3	− 59.26	5.981
−46.2	403.5	− 51.16	7.802
−45.0	437.1	− 49.00	8.452
−41.5	521.9	− 42.70	10.09
−39.8	568.2	− 39.64	10.99
−38.2	610.4	− 36.76	11.80
−33.0	761.0	− 27.40	14.72

Table 10 Summary of Pressure–Temperature Determinations of Davies

Temperature °C.	Pressure in mm. of Mercury	Temperature °F.	Pressure in lb. per sq. in.
−49.8	297.95	−57.64	5.761
−41.0	530.95	−41.80	10.27
−30.0	866.95	−22.00	16.76
−20.0	1392.9	− 4.00	26.93
−15.0	1726.2	+ 5.00	33.38
−10.0	2145.9	+14.00	41.50
− 5.0	2616.9	+23.00	50.60

Table 11. Summary of Pressure–Temperature Determinations of Faraday

Temp. °F.	Pressure in Atmos. of 30″ of Mercury	Pressure in lb. per sq. in.	Temp. °F.	Pressure in Atmos. of 30″ of Mercury	Pressure in lb. per sq. in.
0	2.48	36.54	49.0	5.83	85.90
9.3	3.00	44.20	51.4	6.00	88.41
18.0	3.50	51.57	52.0	6.10	89.88
21.0	3.72	54.81	55.0	6.38	94.01
26.0	4.04	59.53	56.5	6.50	95.78
32.0	4.44	65.42	60.0	6.90	101.67
33.0	4.50	66.31	61.3	7.00	103.14
41.0	5.10	75.15	65.6	7.50	110.51
44.0	5.36	78.98	67.0	7.63	112.43
45.0	5.45	80.30	83.0	10.00	147.35

TABLE 12. SUMMARY OF DETERMINATIONS OF CRITICAL DATA FOR AMMONIA

Investigator	Date	Temperature° Centigrade	Pressure in Atmospheres	Temperature° Fahrenheit	Pressure in lb. per sq. in.
Dewar..................	1884	130.0	115	266.0	1690.0
Vincent and Chappuis....	1886	131.0	113	267.8	1660.8
Jaquerod................	1908	132.3	109.6	270.1	1610.7
Sheffer..................	1910	132.1	111.3	269.8	1635.7

The effectiveness of any method that enables one to throw given data into such a form that they may be represented by straight lines lies in the fact that straight lines immediately and strikingly disclose any departure from the general trend and unerringly reveal points that depart from this trend. It enables one to give various observations their proper weight and it affords a much safer basis of extrapolation than can be obtained from curves. The case in hand illustrates this principle. If the points are plotted on the regular *pt* plane it is easily seen that no smooth curve such as represents a law of nature, could, if passed through Regnault's lower temperature points and Brill's lower points, at the same time pass through Brill's points in the region −80° F. to −30° F. Furthermore the chart discloses nothing, as an infinite number of curves could be drawn, giving different weights to the different points, or all points could be given equal weight and the equation could then be determined by least squares An inspection of Fig. 1 shows, however, that the straight line which best represents the whole range represents very accurately Regnault's lower points, Brill's highest point and all of his points from −80° F. to −110° F. In the range −80° F. to −30° F. all of Brill's points lie above the line, as does Davies' −41.8° F. point. It is significant, however, that Davies' −57.64° F. point lies exactly on the line at precisely the point where Brill's points lie farthest from it.

Through the range −30° F. to +100° F. the line represents the experimental points very accurately; above 100° F. Regnault's points lie slightly below the line. Now by referring to Table 7 it is seen that all of Regnault's points above 100° F. belong to his third series of experiments. In all of the higher pressure points of this series Regnault used a closed manometer and extensive corrections had to be applied to the height of mercury observed. We may now compare the experiments in the range 40° F. to 90° F. where the second and third series overlap; it is seen that invariably the points determined in the third series by the use of the closed manometer lie below those determined in the second series by the use of the open manometer. The conclusion is evident that there was probably an error in the correction applied by Regnault to his readings with the closed manometer; the fact that these points lie below the line should therefore not be taken as evidence of the incorrectness of the line.

Now as to the critical data. It is seen that the points of both Dewar, and Vincent and Chappuis lie above the line. If the line be taken as correct this indicates either higher temperature, lower pressure, or both at the critical point. It will be instructive in this connection to examine the history of the determinations of the critical data for water. Table 13, which is for the most part taken from Marks' paper[46] referred to above, gives several of these determinations.

TABLE 13. SUMMARY OF DETERMINATIONS OF CRITICAL DATA FOR WATER

Investigator	Date	Critical Temperature,° Fahrenheit	Critical Pressure, lb. per sq. in.
Nadejdine	1885	676.6	
Battelli	1890	687.7	2859
Cailletet and Colardeau	1891	689.0	2994
Strauss	1892	698.0	2873
Traube and Teichner	1904	705.2	
Holborn and Bauman	1910	706.3	3200

This table shows that as methods have been improved and greater precautions taken in the experimental work, the value found for the critical temperature has risen steadily until the latest determination, that of Holborn and Bauman, is 30° higher than that found by Nadejdine, 25 years earlier. The only available determinations of the critical data of ammonia were made at about the same time and with about the same methods as the earliest determination for water as shown in the table. It is reasonable to assume that the same errors may have been made in the ammonia determinations that were made in the earlier water determinations and that the true critical temperature of ammonia is higher than that found by either Dewar, or Vincent and Chappuis. The table shows also that a higher value for the critical pressure of water has been found in the later determinations. In the present investigation the critical data of ammonia are not of prime importance and the purely arbitrary assumption has been made, on the basis of the above reasoning and for want of better data, that the higher of the critical pressure determinations, that of Dewar, is correct. The corresponding temperature as determined by the temperature ratio law has been taken as the critical temperature. The resulting values are:

$$p_k = 1690 \text{ lb. per sq. in.}$$
$$t_k = 273.2° \text{ F.}$$

Since the above conclusions were drawn the articles giving the determinations of Jaquerod[70] and Scheffer[71] have been found. If plotted in Fig. 1 the point representing Jaquerod's determination falls below the straight line and that representing Scheffer's value falls almost exactly upon it. If Scheffer's value for the critical temperature is substituted in the temperature ratio law the resulting pressure is 1638.6 lb. per sq. in. while his experimental value is 1635.7 lb. per sq. in., the difference being about $^1/_6$ of one per cent. These results offer corroboration of the correctness of the location of the straight line in Fig. 1, although the arbitrary values chosen for the critical temperature and pressure may be too high.

The equation of the straight line in Fig. 1 is

$$\frac{1}{T_a}=1.70356\,\frac{1}{T_w}-0.0002242 \tag{2}$$

In constructing tables with pressure as the argument the temperature of saturated steam at any pressure is found from steam tables. The corresponding saturation temperature of ammonia is then found by using equation (2) in the form

$$T_a=\frac{1}{\dfrac{1.70356}{T_w}-0.0002242}$$

If temperature is taken as the argument the temperature at which steam will be saturated under the same pressure may be found by using equation (2) in the form

$$T_w=\frac{1}{\dfrac{0.587006}{T_a}+0.0001316}$$

and the corresponding pressure is found from steam tables.

13. *Specific Volume of the Liquid.*—There are available three sets of experimental data from which the specific volume of the liquid may be determined. Lange[27] determined the density of liquid ammonia over the temperature range of −56° F. to +208° F.; his results are given in Table 14. Dieterici,[25] working by Young's method, obtained simultaneously the specific volumes of the liquid and of the saturated vapor over a temperature range of 32° F. to 222° F.; his results for the former are given in Table 15. In addition to these we have the specific gravity determinations of D'Andréeff,[26] from which the specific volume may be calculated; these experiments cover the range of 14° F. to 68° F. and are given in Table 16.

In Fig. 2 the experimental values are plotted with specific volumes as ordinates and temperatures as abscissas. The form of equation used to express volumes of the liquid in terms of the temperature is that used by Avenarius,[53] or

$$v'=a-b\log(t_k-t) \tag{3}$$

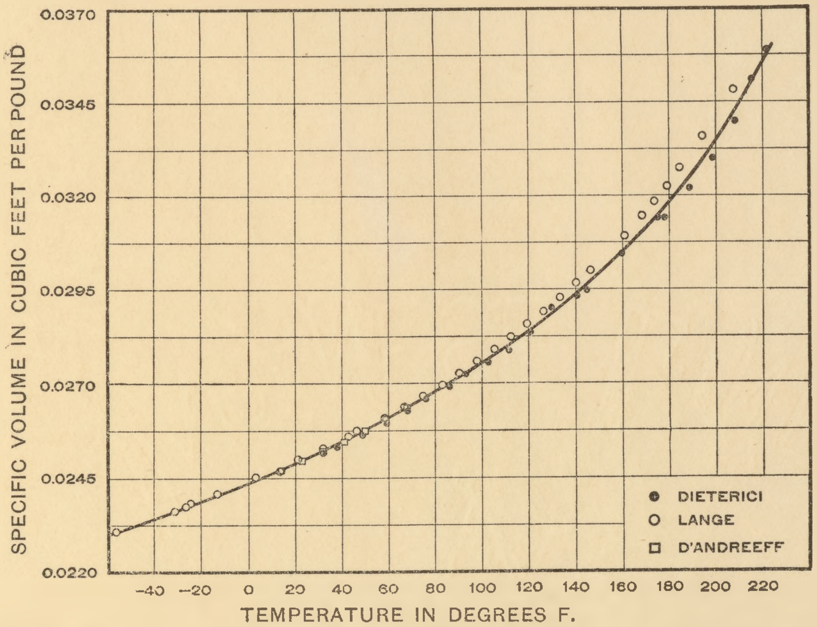

Fig. 2. Showing the Agreement of Volumes of the Liquid as Calculated with Those Found by Experiment.

Table 14. Summary of Determinations of Volume of the Liquid by Lange.

Temp. °C.	Sp. Density of Liquid in gr. per c.c.	Temp. °F.	Sp. Density of Liquid in lb. per cu. ft.	Sp. Vol. of Liquid in cu. ft. per lb.
−49.0	0.6943	− 56.20	43.344	0.023071
−35.0	0.6781	− 31.00	42.333	0.023622
−32.5	0.6742	− 26.50	42.089	0.023759
−31.2	0.6720	− 24.16	41.952	0.023837
−25.0	0.6650	− 13.00	41.515	0.024088
−16.2	0.6534	+ 2.84	40.791	0.024515
−10.2	0.6488	13.64	40.503	0.024690
− 6.0	0.6408	21.20	40.004	0.024998
0.0	0.6341	32.00	39.586	0.025261
+ 6.0	0.6256	42.80	39.055	0.025605
7.9	0.6215	46.22	38.799	0.025774
14.7	0.6141	58.46	38.337	0.026084
19.4	0.6072	66.92	37.906	0.026381
23.9	0.6007	75.02	37.501	0.026666
28.4	0.5939	83.12	37.076	0.026972
32.6	0.5875	90.68	36.677	0.027265
36.7	0.5807	98.06	36.252	0.027585
40.8	0.5739	105.44	35.828	0.027911
44.7	0.5672	112.46	35.409	0.028241
48.6	0.5606	119.48	34.997	0.028574
52.5	0.5540	126.50	34.585	0.028914
56.4	0.5472	133.52	34.161	0.029273
60.2	0.5404	140.36	33.736	0.029642
63.6	0.5340	146.48	33.337	0.029997
71.6	0.5181	160.88	32.344	0.030918
75.8	0.5096	168.44	31.813	0.031434
78.8	0.5033	173.84	31.420	0.031827
81.8	0.4966	179.24	31.002	0.032256
84.7	0.4899	184.46	30.584	0.032697
90.2	0.4771	194.36	29.785	0.033574
97.8	0.4576	208.04	28.567	0.034805

The curve shown in Fig. 2, up to 160° F. represents this equation with the constants as follows

$a = 0.06335$

$b = 0.016$

$t_k = 273.2$

In determining these constants the work of Dieterici was given the most weight, both because the methods he employed are superior to the others, and because the volumes of the vapor to be used with these values are those determined by Dieterici by the same method in the same series of experiments.

The part of the curve above 160° F. represents the values found by the method discussed in Article (16).

TABLE 15. SUMMARY OF DETERMINATIONS OF VOLUME OF THE LIQUID BY DIETERICI.

Temp. °C.	Sp. Vol. of Liquid in c. c. per gm.	Temp. °F.	Sp. Vol. of Liquid in cu. ft. per lb.	Sp. Density of Liquid in lb. per cu. ft.
0.0	1.5656	32.00	0.025078	39.876
3.4	1.5769	38.12	0.025259	39.590
9.5	1.5977	49.10	0.025593	39.073
15.0	1.6161	59.00	0.025887	38.629
20.1	1.6358	68.18	0.026203	38.164
24.65	1.6565	76.37	0.026534	37.688
30.3	1.6778	86.54	0.026876	37.208
34.3	1.6983	93.74	0.027204	36.759
39.3	1.7221	102.74	0.027585	36.252
44.4	1.7448	111.92	0.027949	35.779
49.6	1.7695	121.28	0.028345	35.280
55.4	1.8090	129.92	0.028977	34.510
60.4	1.8289	140.72	0.029296	34.134
60.9	1.8309	141.62	0.029328	34.097
62.8	1.8403	145.04	0.029479	33.922
71.1	1.8957	159.98	0.030366	32.932
79.8	1.9619	175.64	0.031426	31.821
81.2	1.9618	178.16	0.031425	31.822
87.2	2.0119	188.96	0.032227	31.030
92.6	2.0624	198.68	0.033026	30.279
98.1	2.1211	208.58	0.033977	29.432
102.1	2.1878	215.78	0.035045	28.535
105.6	2.2425	222.08	0.035921	27.839

TABLE 16. SUMMARY OF DETERMINATIONS OF VOLUME OF THE LIQUID BY D'ANDRÉEFF.

Temp. °F.	Sp. gravity, referred to Water as Unity	Density in lb. per cu. ft.	Sp. Vol. in cu. ft. per lb.
14	0.6492	40.481	0.02470
23	0.6429	40.088	0.02495
32	0.6364	39.683	0.02520
41	0.6298	39.271	0.02546
50	0.6230	38.847	0.02574
59	0.6160	38.411	0.02603
68	0.6089	37.968	0.02634

14. *Latent Heat of Vaporization.*—The experimental information regarding the latent heat of vaporization of ammonia is too meager to be used as a basis for the determination of the relation existing

between it and the temperature of vaporization. The latent heat may, however, be determined indirectly by thermodynamic relations, and the available data will serve as a check on the method.

Let equation (g) be differentiated with respect to the pressure Then

$$\frac{-\frac{dT_a}{dp}}{T_a^2}=\frac{-c\frac{dT_w}{dp}}{T_w^2},$$

which may be written

$$\frac{T_a\frac{dp}{dT_a}}{T_w\frac{dp}{dT_w}}=\frac{1}{c}\,\frac{T_w}{T_a},$$

or since

$$\frac{T_w}{T_a}=c+kT_w$$

there results

$$\frac{T_a\frac{dp}{dT_a}}{T_w\frac{dp}{dT_w}}=1+\left(\frac{k}{c}\right)T_w \tag{h}$$

Now by the well-known Clapeyron relation connecting the latent heat and the absolute temperature of vaporization with the change of volume during vaporization we have

$$\frac{(v''-v')}{r}=\frac{1}{144\,AT\left(\frac{dp}{dT}\right)_{sat.}}$$

Substituting in equation (h)

$$\frac{(v''-v')_w/r_w}{(v''-v')_a/r_a}=1+\left(\frac{k}{c}\right)T_w \tag{i}$$

or with the proper values of the constants introduced

$$\frac{(v''-v')_w/r_w}{(v''-v')_a/r_a}=1-0.0001316\;T_w \tag{4}$$

The quantity $\frac{(v''-v')_w}{r_w}$ may be found from steam tables or as follows:

From the Clapeyron relation

$$\frac{(v''-v')_w}{r_w}=\frac{1}{144\;AT\left[\frac{dp}{dT_w}\right]_{sat.}}$$

By differentiating equation (1)

$$\left[\frac{dp}{dT_w}\right]_{sat.}=p\left[\frac{11222.13}{T_w^2}+0.00000641484\;T_w-0.00932768\;T_w^2\right]$$

Substituting this value in the Clapeyron relation we have

$$\frac{(v''-v')_w}{r_w}=\frac{1}{p\left[\frac{2078.07}{T_w}-0.00172726\,T_w+0.00000118787\,T_w^2\right]} \qquad (5)$$

By the use of equation (4) and equation (5), $\frac{(v''-v')_a}{r_a}$ may be calculated and if either one is known the other may be found. Fortunately we have the experimental determinations of Dieterici of the specific volumes of the liquid and saturated vapor; the former were given in the last section and the latter will be discussed in the next section. From these determinations various values of $(v''-v')$ were found and values of r calculated as described above.

According to the generally accepted ideas concerning the critical point, at that point $r=0$ and $\frac{dr}{dt}=-\infty$. These facts led Thiesen[54] to suggest as an empirical formula

$$r=C(t_k-t)^n$$

This form of equation has been used for water by Thiesen, Henning, and Marks and Davis, and for ammonia by Dieterici.[25] When plotted on logarithmic cross-section paper this form of equation is represented by a straight line, the slope of the line being equal to n.

The values of r found by the above method were plotted to the corresponding values of (t_k-t) on logarithmic cross-section paper and were found to lie almost exactly on a straight line, indicating that the Thiesen formula might be used to express the desired relation. The formula may be written in the form

$$\log r=\log C+n\log(t_k-t)$$

and it was found that the values of the constants giving the best agreement with the plotted points were

$$\log C=1.856064$$

and

$$n=0.37$$

Therefore the final equation is

$$\log r=1.856064+0.37\log(273.2-t) \qquad (6)$$

The available data concerning the latent heat of vaporization are given in Table 17 and the various points are plotted in Fig. 3, the full line in this figure representing equation (6). Of the determinations of r made by Regnault, the greater number were lost in the reign of the Commune, but twelve were saved and later published.[5] The results of these experiments do not give r directly and have been variously interpreted by different writers. The table contains the interpretation of Jacobus[55] and the three values of r as quoted from Regnault by

TABLE 17. SUMMARY OF VARIOUS DETERMINATIONS OF THE LATENT HEAT OF VAPORIZATION.

Temp. °C.	Cal. per Kg.	Temp. °F.	B. t. u. per lb.	Authority
10.90	287.0	51.62	516.6	Regnault (Jacobus)
15.53	285.2	59.95	513.3	
16.00	290.5	60.80	522.8	
12.94	283.8	55.29	510.8	
11.90	285.8	53.42	514.4	
10.73	288.1	51.31	518.5	
11.04	292.5	51.87	526.4	
10.15	292.4	50.27	526.2	
9.52	295.0	49.14	531.0	
10.99	293.3	51.78	527.9	
12.60	291.6	54.68	524.8	
7.80	291.8	46.04	525.2	
7.80	294.2	46.04	529.5	Regnault (Dieterici)
11.00	291.3	51.80	524.3	
16.00	297.4	60.80	535.3	
19.53	296.5	67.15	533.7	von Strombeck
17.00	296.8	62.60	534.2	
−33.64	337.0	−28.55	606.6	Franklin and Kraus
−33.40	321.3	−28.12	578.3	Estreicher and Schnerr
		84.6	524.8	Denton and Jacobus
		82.7	525.7	
		87.7	512.4	
		−10.7	569.2	
		− 3.2	603.5	
		+14.5	570.4	

Dieterici.[25] Two values for r are given by von Strombeck,[19] one being an average of twelve experiments, the other of eight. The value given by Franklin and Kraus[20] is an average of three determinations at the normal boiling point, and the value obtained is exactly the value deduced by the same writers from the absolute boiling point and the molecular elevation. A different value was found at the normal boiling point by Estreicher and Schnerr.[21] The values given by Denton and Jacobus,[22] represented in Fig. 3 by crosses, were calculated from readings taken during a test of an ammonia compressor and hence cannot be considered of much weight; because of the scarcity of scientific data, however, these points are included in the table and chart.

In Fig. 3 are also plotted the curves that represent various equations used in calculating the latent heat of vaporization, as given in the various existing tables. These are plotted exactly as given and it should be remembered that there is some variation in the value of the heat unit used by different writers; consequently the various curves are not exactly comparable and are given simply to show the variation in the values of latent heat as given in the tables now in use.

The equations of the curves shown in Fig. 3 are

Ledoux[6]: $r=583.33-0.5499t-0.0001173t^2$
Wood[10]: $r=555.5-0.613t-0.000219t^2$
Peabody[11]: $r=540-0.8\,(t-32)$
Dieterici[25]: $\log r=1.56141+0.5\log(266.9-t)$
Goodenough[32]: $\log r=1.7920+0.4\log(266-t)$

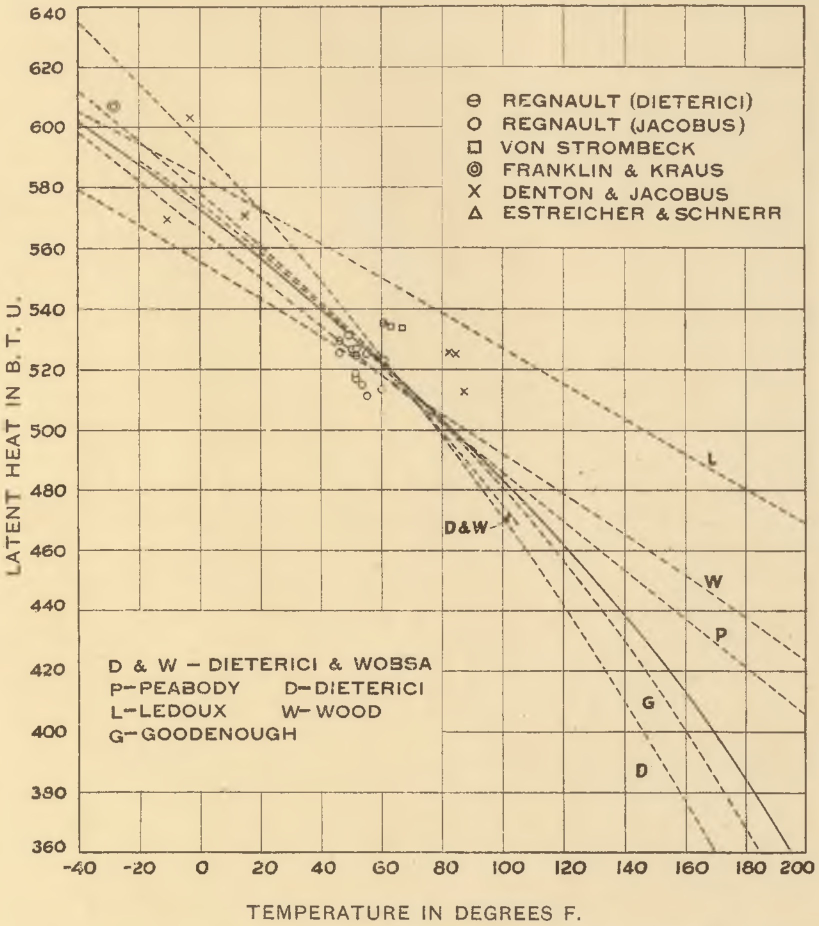

FIG. 3. SHOWING COMPARISON BETWEEN EXPERIMENTAL VALUES FOR LATENT HEAT OF VAPORIZATION AND VALUES AS CALCULATED BY VARIOUS WRITERS.

No comment is necessary regarding the curves for *r* according to Ledoux, Wood, and Peabody, since their equations are not of such form as to give correct results at high temperatures. Moreover they were derived before we had experimental determinations of the volume of the saturated vapor, from which latent heats could be calculated.

Dieterici, as mentioned in Section 12, used Zeuner's empirical expression for the second term of Regnault's pressure-temperature equation, and omitted the third term entirely. This approximation is quite accurate for low temperatures but as the temperature increases the pressures thus calculated become too small and this error increases rapidly at high temperatures. For instance, Regnault extrapolates his curve and gives for 212° F. a pressure of 901.6 lb. per sq. in., while the value calculated by Dieterici for this temperature is 847.1 lb. per sq. in. or 6% lower. As the error is increasing, the values of $\left[\frac{dp}{dt}\right]_{sat.}$ are too small and values of r calculated by means of the Clapeyron equation are too small at high temperatures. Since the relation employed between r and (t_k-t) is a straight line on logarithmic paper and the values of $\frac{dp}{dt}$, consequently of r, agree at some medium temperature, the values given by the equation at low temperatures will be too high. This is shown in Fig. 3, where it is seen that Dieterici's curve passes above even the highest of the actual experimental determinations of r at $-28°$ F.

The equation used by Goodenough fits the actual determinations and is consistent with the Clausius relation, using Dieterici's values for volumes and Goodenough's constants in Bertrand's pressure-temperature equation. This latter equation, however, only applies over a small temperature range. The variation between Goodenough's curve for r and the present one is due to the different pressure-temperature relation used and the higher value assumed for the critical temperature.

It is believed that, due to the form of equation (6) and the accuracy with which it represents the derived values of r where known, the equation may be safely extrapolated as far as required in this investigation.

The comparison between the values of r given by equation (6), the corresponding values of v'' from the Clausius relation, and the experimental values for v'' properly belongs in the next section and is there shown.

15. *Specific Volume of Saturated Vapor.*—The only available experimental determinations of the specific volume of the saturated vapor are those of Dieterici.[25] These experiments extend up to a temperature of 222° F., but unfortunately were not carried below a temperature of 32° F. Owing to the form of the curve representing the volume-temperature relation, any extended extrapolation of the curve or of any empirical equation to represent this relation would be very unsafe below 32° F.; it is seen that below this point the volume is increasing very rapidly.

As shown in the preceding section, however, equation (6) is believed to be of such form that extrapolation can be carried to very low temperatures. Therefore in the present investigation the volumes of the saturated vapor have been calculated as follows:

By the use of equation (4) and equation (5) values of $\frac{(v''-v')_a}{r_a}$ were calculated. These values multiplied by the corresponding values of r found from equation (6) gave the values of $(v''-v')$. The addition of the proper values of v' found from equation (3) gave the values of v'', the quantity desired.

The values of v'' as found by Dieterici are given in Table 18, and the agreement of the values calculated by the above method is shown in Fig. 4, the curve in this figure representing the calculated values and the points the observed values.

TABLE 18. SUMMARY OF DETERMINATIONS OF VOLUME OF THE SATURATED VAPOR BY DIETERICI.

Temp.° C.	Sp. Vol. of Sat. Vapor in c. c. per gm.	Temp.° F.	Sp. Vol. of Sat. Vapor in cu. ft. per lb.	Sp. Density of Sat. Vapor in lb. per cu. ft.
3.4	257.2	38.12	4.120	0.2427
9.5	208.2	49.10	3.335	0.2999
15.0	173.9	59.00	2.786	0.3589
20.1	147.5	68.18	2.363	0.4232
24.65	125.2	76.37	2.006	0.4985
30.3	106.6	86.54	1.708	0.5855
34.3	93.8	93.74	1.503	0.6653
39.3	82.5	102.74	1.322	0.7564
44.4	74.3	111.92	1.190	0.8403
49.6	63.2	121.28	1.012	0.9881
55.4	52.8	129.92	0.8458	1.1823
60.4	48.1	140.72	0.7705	1.2979
60.9	47.2	141.62	0.7561	1.3226
62.8	45.4	145.04	0.7272	1.3751
71.1	37.22	159.98	0.5962	1.6773
79.8	30.00	175.64	0.4806	2.0807
81.2	29.92	178.16	0.4793	2.0864
87.2	26.23	188.96	0.4202	2.3798
92.6	23.10	198.68	0.3700	2.7027
98.1	20.11	208.58	0.3221	3.1046
102.1	17.88	215.78	0.2864	3.4916
105.6	16.11	222.08	0.2581	3.8745

16. *Specific Volume of Liquid and Saturated Vapor at High Temperatures.*—The "Law of the Straight Diameter" was first proposed by Cailletet and Mathias[56] in 1886. This law, as originally given, stated that if the densities of a liquid and its saturated vapor are plotted as abscissas, against the corresponding temperature as ordinates to form a dome, the mid-points of the horizontal chords of this dome will lie in a straight line nearly parallel to the axis of temperatures.

This law has been frequently tested and applied to many different substances. References to the law may be found in an article by Davis,[57] who applies the law to water as a basis for the calculation of volumes of saturated steam at high temperatures.

It was found by Young[58] that the diameter is actually straight in the case of but few substances, normal pentane being an example of this class. In the case of most substances, however, the diameter can be represented accurately by a second degree equation; some substances, such as alcohols, require a third degree equation.

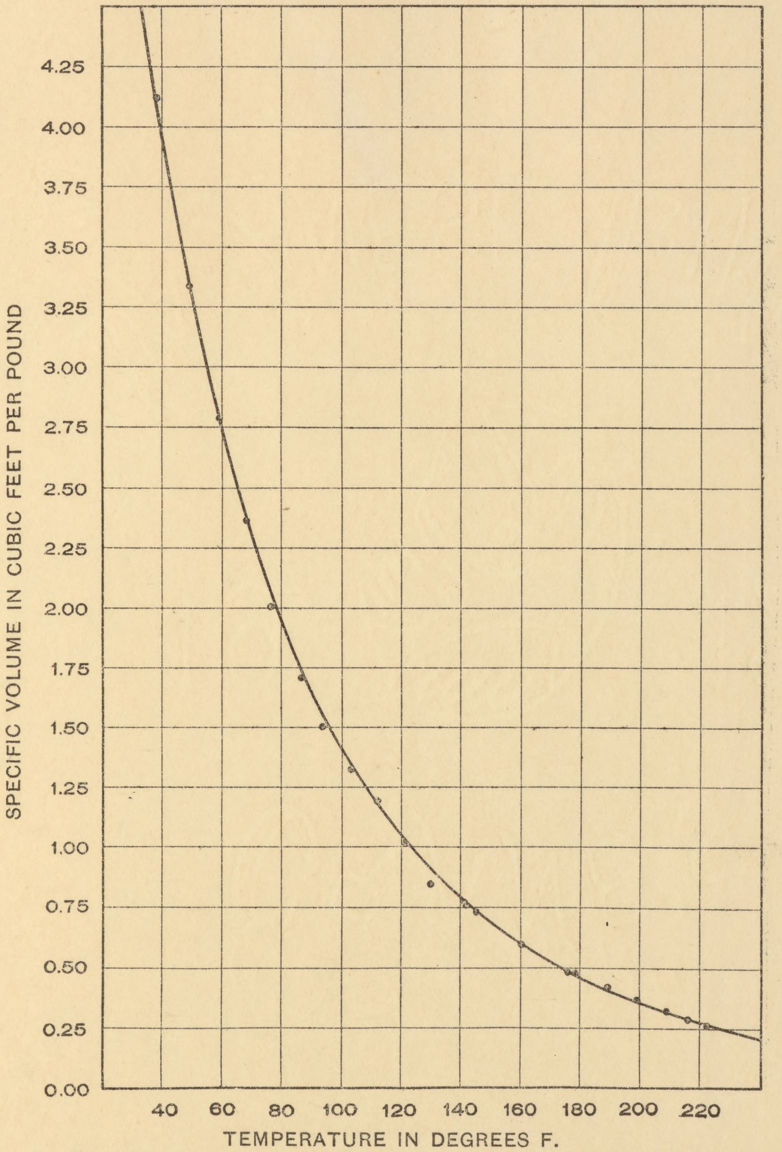

FIG. 4. SHOWING AGREEMENT OF VOLUMES OF THE SATURATED VAPOR AS CALCULATED WITH THOSE FOUND EXPERIMENTALLY BY DIETERICI.

TABLE 19. THE LAW OF THE STRAIGHT DIAMETER FOR AMMONIA.

Temp.° F.	Density of Vapor	Density of Liquid	Mean Density	Mean Density Formula	Difference
− 40	0.0393	42.704	21.372	21.372	±0.000
− 30	0.0517	42.296	21.174	21.174	±0.000
− 20	0.0671	41.883	20.975	20.974	−0.001
− 10	0.0860	41.461	20.774	20.774	±0.000
0	0.1088	41.039	20.574	20.572	−0.002
+ 10	0.1362	40.608	20.372	20.370	−0.002
20	0.1689	40.169	20.169	20.167	−0.002
30	0.2075	39.722	19.965	19.964	−0.001
40	0.2525	39.267	19.760	19.759	−0.001
50	0.3051	38.803	19.554	19.554	±0.000
60	0.3657	38.329	19.347	19.347	±0.000
70	0.4355	37.844	19.140	19.140	±0.000
80	0.5152	37.348	18.932	18.932	±0.000
90	0.6061	36.841	18.724	18.724	±0.000
100	0.7099	36.319	18.514	18.514	±0.000
110	0.8265	35.782	18.304	18.303	−0.001
120	0.9590	35.228	18.093	18.092	−0.001
130	1.1062	34.655	17.881	17.880	−0.001
140	1.2756	34.061	17.668	17.667	−0.001
150	1.4643	33.444	17.454	17.453	−0.001
160	1.6763	32.798	17.237	17.238	+0.001

In order to find the equation of the "straight diameter" for ammonia the values of the densities of the liquid and of the saturated vapor were found at 10° intervals. The values for the liquid were calculated by the use of equation (3), and those for the vapor by the method described in Section 15. At each of the temperatures the mean density was calculated. The results are given in Table 19 and plotted in Fig. 5. In this figure the points for the liquid and vapor are shown as large

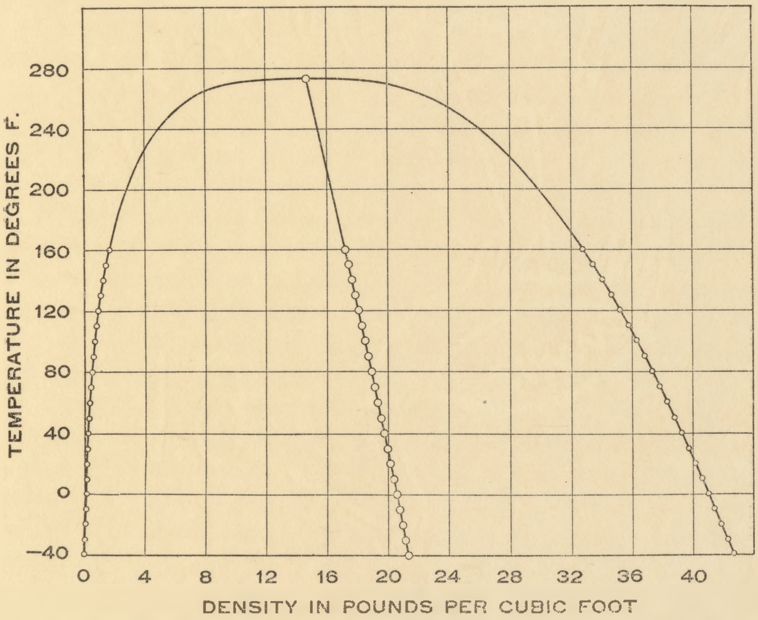

FIG. 5. SHOWING THE DOME ON THE TEMPERATURE-DENSITY PLANE AND THE "STRAIGHT DIAMETER" OF CAILLETET AND MATHIAS.

circles and the mean points as small circles. The diameter is seen to be slightly curved but it may be accurately represented by the second degree equation:

$$\gamma = 19.3473 - 0.02067\ (t-60) - 0.0000042\ (t-60)^2 \qquad (7)$$

The table shows that this equation represents the mean densities as calculated by the other method with a maximum error of about 0.01 of 1% over a temperature range of $-40°$ F. to $+160°$ F.

The method used at ordinary temperatures for finding the change of volume on vaporization or $(v''-v')$, may be employed at temperatures up to the critical point if we assume that the values for r found by equation (6) are correct up to that point. Equation (7) gives values for

$$\gamma = \frac{\gamma''+\gamma'}{2} = \frac{1}{2}\left[\frac{1}{v''}+\frac{1}{v'}\right]$$

A simple algebraic manipulation gives

$$v'' = \frac{\gamma(v''-v')+1+\sqrt{\gamma^2(v''-v')^2+1}}{2\gamma}$$

Having values for v'' and $(v''-v')$, the values for v' may be easily found. This method enables the values of the volumes of the liquid and the saturated vapor to be found at least qualitatively up to the critical point itself.

It was found that above 160° F. the values found for v' by this method were materially lower than those found by equation (3) and that the difference increased as the temperature increased above this point. An inspection of equation (3) shows that this equation would give a value of $+\infty$ for the volume of the liquid at the critical point, whereas we know that at this point the liquid has a finite volume. In the case of other vapors it has been shown that the form of equation used, that of Avenarius, gives accurate values at temperatures somewhat removed from the critical point, but that it does not hold near this point. Therefore, in the present case equation (3) has been used only up to 160° F., and the values above this temperature have been calculated by the law of the straight diameter.

Since the diameter is nearly parallel to the axis of temperatures a considerable error in the value of the critical temperature will cause but a small error in the resulting value of the critical density. The substitution in equation (7) of the value of t_k assumed in Section 12, or 273.2° F., gives for the critical density and volume respectively

$\gamma_k = 14.75$ lb. per cu. ft.

$v_k = 0.0678$ cu. ft. per lb.

17. *Specific Volume of the Superheated Vapor.*—The attempt has often been made to deduce rationally an equation of state which with suitable change of constants will represent the relation $f(p, v, T)=0$ for various fluids in all states from the gaseous condition above the critical temperature to the liquid condition. Such equations are constructed with special reference to the behavior of fluids in the neighborhood of the critical state and apply more particularly to fluids the critical temperature of which is within the range encountered in practice. In the case of a fluid such as ammonia, however, the critical temperature of which is far above the working range, purely empirical equations of simpler form give better results throughout the smaller range covered in practice and in addition lend themselves much more readily to the formation of the various heat equations. A few of these empirical equations which have been applied to ammonia are here given.

(a) Zeuner[9] and Ledoux[6] both used the form

$$pv=BT-Cp^n$$

The constants used by Zeuner with the variables expressed in metric units are $B=52.642$ $C=29.783$ $n=0.3655$

This form was also used by Peabody.[11] In English units with p in lb. per sq. ft., his values for the constants are

$B=99$ $C=710$ $n=0.25$

(b) Wood[10] used the form proposed by Rankine

$$pv=BT-\frac{C}{v^n}$$

In English units with p in lb. per sq. ft., his values of the constants are

$B=91$ $C=16920$ $n=0.97$

(c) Wobsa[59] in his first paper used the form of equation proposed by Linde

$$v=\frac{BT}{p}-(1+ap)\left[\frac{C(273)^n}{T}-D\right]$$

In metric units his values for the constants are

$B=49.8$ $a=0.0000014$

$C\times 273^n=2250$ $n=2$ $D=0.01$

(d) In his second paper Wobsa[61] used a new form of equation

$$v-a=\frac{BT}{p}-\frac{C}{T^n}+\frac{b}{p}$$

with $B=49.736$ $C=2450$ $b=80$

$a=0.0075$ $n=2$

The equations of Ledoux, Zeuner, Peabody, and Wood were derived before experimental determinations of the volume of either the saturated or the superheated vapor were available, and they were based upon various doubtful assumptions. Wobsa's first equation gives values that do not agree closely with experimental results, but his second equation is quite satisfactory in this respect.

In choosing a characteristic equation several points must be considered.

(1) The equation must represent with fair accuracy the available reliable experimental data on the relations of p, v, and T.

(2) The equation should be of such form as to give as simple forms as possible to the various thermodynamic relations that are derived from it.

(3) These derived equations must represent accurately the experimental data.

Wobsa's second equation fulfils the first of these conditions admirably. It is, however, somewhat defective with respect to the other requirements. The good results obtained from Goodenough's equation[64] for superheated steam, namely,

$$v+c=\frac{BT}{p}-(1+ap)\frac{m}{T^n} \tag{j}$$

suggested the adoption of the same form of equation for supherheated ammonia in the preliminary investigation. This equation satisfies the second condition, in that it gives derived relations of comparatively simple form. A trial with various sets of constants showed that it could be made to represent the volume measurements with substantially the same accuracy as Wobsa's second equation, and thereby satisfy the first condition. Having established the fact that the proposed equation is permissible, the next step was the determination of the constants. In connection with this process emphasis must be placed on the third consideration heretofore mentioned. From the characteristic equation are derived expressions for (a) the specific heat at constant pressure; (b) the heat content of the superheated and also of the saturated vapor; (c) the Joule-Thomson coefficient. Hence the constants must not be chosen with reference to volume alone. While the volume measurements must be satisfied, three other derived relations must equally well conform to the experimental data in the respective fields.

With due consideration of all the conditions the following values were finally assumed for the constants:

$B=0.6321$, p in lb. per sq. in.
$\log m=12.900000$
$c=0.100$
$n=5$
$a=0$

The final equation with constants inserted is therefore

$$v+0.100=0.6321\frac{T}{p}-\frac{79433\times10^8}{T^5} \tag{8}$$

It will be seen that the constant a is taken as zero. In view of the fact that the available data consist only of values along the saturation curve and in most cases but one point on each isotherm in the superheated region, no information is available regarding the shape or curvature of these isotherms on the $pv-p$ plane; moreover the derived equations demand an exceedingly small value of a. The use of straight lines for these isotherms therefore seems to be as well justified as the use of parabolas; hence a was made equal to zero.

TABLE 20. SUMMARY OF VARIOUS DETERMINATIONS OF VOLUME OF THE SUPERHEATED VAPOR.

Authority	Pressure in Atmos.	Temp. °C.	Volume in Liters per gm.	Temp. °F.	Volume in Çu. ft. per lb.
Perman	½	0	2.6096	32	41.8006
	1	— 20	1.19575	— 4	19.1535
		0	1.2973	32	20.7802
		50	1.5473	122	24.7847
		100	1.7964	212	28.7747
Leduc		0	1.2955	32	20.7513
Guye		0	1.2974	32	20.7818

TABLE 21. COMPARISON OF VALUES OBTAINED FROM VARIOUS EQUATIONS FOR VOLUME OF THE SUPERHEATED VAPOR WITH EXPERIMENTAL VALUES.

Pressure in Atmos.	Temp. °F.	Experimental Values		Computed from (8)		Computed by Wobsa I		Computed by Wobsa II	
		Authority	Value	Value	% Diff. from Exp.	Value	% Diff. from Exp.	Value	% Diff. from Exp.
1	−4	Perman	19.154	19.093	−0.32	19.121	−0.17	19.140	−0.07
	32	Perman	20.780	20.769	−0.05	20.745	−0.17	20.767	−0.06
		Guye	20.782	20.769	−0.06	20.745	−0.18	20.767	−0.07
		Leduc	20.751	20.769	+0.09	20.745	−0.03	20.767	+0.08
	122	Perman	24.785	24.798	+0.05	24.746	−0.16	24.775	−0.04
	212	Perman	28.775	28.730	−0.16	28.695	−0.28	28.725	−0.17
½	32	Perman	41.801	41.916	+0.28	41.821	+0.05	41.939	+0.33

A summary of the various direct determinations of the specific volume of the superheated vapor according to Perman and Davies,[30] Leduc[28] and Guye[29] is given in Table 20. In Table 21 the values given by equation (8) and by Wobsa's first and second equations are compared with these experimental determinations. It is seen that both equation (8) and Wobsa's second equation give results agreeing better with experiment at the one atmosphere points that those obtained from Wobsa's first equation. At the 32°, 122°, and 212° points at one atmosphere pressure equation (8) and Wobsa's second equation give practically the same percentage deviation from the experimental values. At −4° Wobsa's second equation gives a better agreement with the experimental value than does equation (8); this point, however, is considerably below the range found for superheated ammonia in practice, and it is believed that the considerations appearing in the discussion of the heat equations derived from the characteristic equation justify the use of equation (8) in preference to Wobsa's equations.

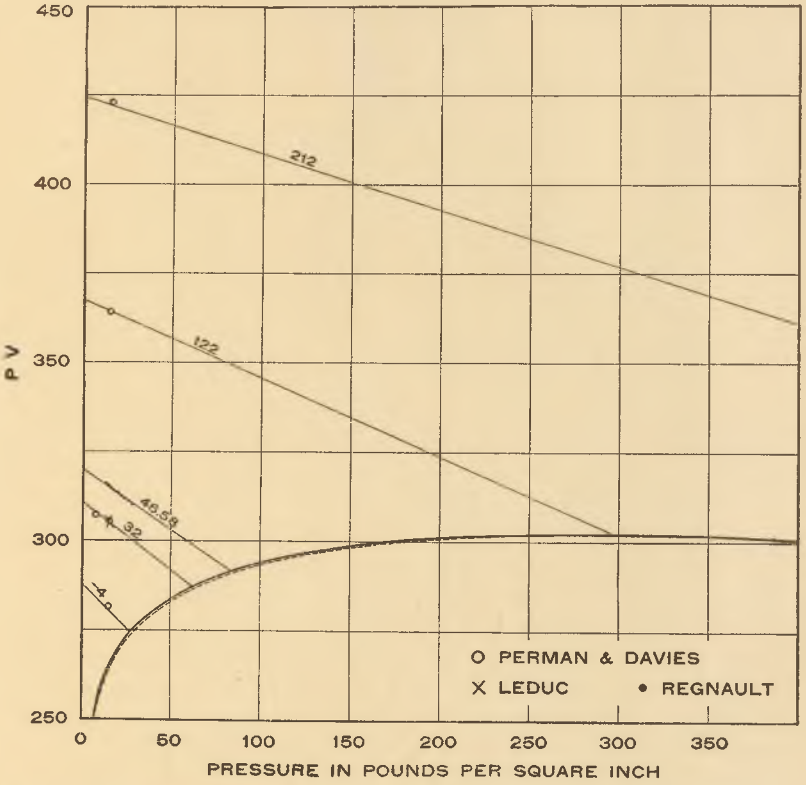

FIG. 6. COMPARISON OF ISOTHERMS DEDUCED FROM EQUATION (8) WITH THE POINTS REPRESENTING EXPERIMENTAL DETERMINATION ON THE PV-P PLANE.

In Fig. 6 the isotherms deduced from equation (8) are drawn on the $pv-p$ plane and the various experimental points are plotted in order to show the agreement. From this chart it is seen that if both of the determinations of Perman and Davies at 32° are correct, the one at one atmosphere and the other at one-half atmosphere, then either the saturation curve should lie considerably higher or the 32° isotherm should be sharply curved. Since the one atmosphere determination agrees closely with the determinations of Leduc and Guye, since there is good authority for the location of the saturation curve, and since the flatness of the isotherms is fairly well established, it would seem that the half atmosphere point of Perman and Davies is probably in error.

TABLE 22. COMPARISON OF VALUES OBTAINED FROM EQUATION (8) WITH VALUES OBTAINED FROM EQUATION (6) AND THE CLAPEYRON–CLAUSIUS FORMULA.

Temp. °F	Calculated from (6) and the Clapeyron-Clausius formula	Calculated from (8)	Per cent. difference
− 40	25.452	25.501	+0.19
− 20	14.895	14.933	0.25
0	9.187	9.214	0.29
20	5.920	5.936	0.27
40	3.9595	3.9695	0.25
60	2.7344	2.7402	0.21
80	1.9400	1.9428	0.14
100	1.4087	1.4099	0.09
120	1.0424	1.0425	0.01
140	0.7840	0.7835	−0.06
160	0.5966	0.5962	−0.07
180	0.4577	0.4580	+0.07
200	0.3525	0.3539	0.40

In Table 22 the values of the specific volume along the saturation curve as calculated by equation (8) are compared with those found by the use of equation (6) and the Clapeyron-Clausius formula. In Fig. 6 the full line curve represents values resulting from equation (8) and the dotted line curve represents the values resulting from equation (6). A comparison of Wobsa's equation is not given because the constants in those equations were determined on the assumption of a different pressure-temperature relation along the saturation curve; the substitution in Wobsa's equations of the values of pressure corresponding to given temperatures as used in this investigation therefore would not give values of volume comparable with those deduced from equation (8). It may be stated, however, that Wobsa's equations give very fair agreement with the values found experimentally by Dieterici. The maximum deviation of the second equation from the values given in Dieterici's table being a little over 2%.

In addition to the preceeding there are available the results of a series of experiments performed by Regnault, which may be used for the purpose of checking the characteristic equation. In these experiments measurements were made of the relative volumes occupied by a quantity of ammonia gas at different pressures along the isotherm corresponding to a temperature of 8.1° C. or 46.58° F. As the weight of ammonia used was not recorded, the experiments can be used only to obtain the relative values of the specific volume or of the product pv along this isotherm. In making use of these values the products pv were plotted against the corresponding values of p, both quantities being measured in the units employed by Regnault. A straight line was next passed through these points by the method of least squares. It was found that the pressure equivalent to 20 lb. per sq. in. came at about the center of the group of points, and the value of the specific volume was calculated by equation (8) for this pressure and a temperature of 46.58° F.; this value multiplied by the pressure gave a value of the product *pv* in English units. The value of this product in the units used by Regnault was then found at the point where the straight line determined by least squares crossed the pressure co-ordinate equivalent to a pressure of 20 lb. per sq. in. From these two values for *pv* the conversion factor 0.00561 was found, this being the number by which Regnault's values of *pv* must be multiplied in order that the isotherm calculated from equation (8) shall pass through the center of Regnault's group of points. All of his values of *pv* were multiplied by this factor and the resulting values appear in Table 23. The points representing these values of *pv* are plotted in Fig. 6 as small black dots. The only information they afford is a check on the slope of the isotherm for 46.58° F. on the $pv-p$ plane. The points seem to indicate that the isotherms, near this temperature at least, are very flat curves or even straight lines.

TABLE 23. SUMMARY OF REGNAULT'S *PV* MEASUREMENTS ALONG THE ISOTHERM FOR 46.58 DEGREES F.

Mark	Volume (Relative)	Pressure in. mm. Hg.	$pv/10$	New pv	Pressure in lb. per sq. in.
72	841.95	668.93	56325	315.98	12.94
68	800.00	703.53	56282	315.74	13.61
64	758.56	741.23	56227	315.43	14.34
60	717.26	783.18	56174	315.14	15.15
56	675.84	829.98	56094	314.69	16.06
52	634.46	882.98	56022	314.28	17.08
48	592.83	943.18	55915	313.68	18.25
44	551.40	1013.63	55892	313.55	19.61
40	509.98	1092.53	55715	312.56	21.13
36	468.37	1186.38	55568	311.74	22.95
32	426.85	1299.11	55452	311.09	25.13
28	384.89	1435.33	55243	309.91	27.77

The data on coefficients of dilatation, of compressibility, and similar coefficients afford a further check on the characteristic equation. In the experiments just discussed Regnault found for 46.58° F. and for the range from 1 to 2 atmospheres, $\frac{p_1v_1}{p_2v_2}=1.01881$. Calculating this same ratio for the same pressure limits from the characteristic equation, there results $\frac{p_1v_1}{p_2v_2}=1.01606$.

At 9.7° C., or 49.46° F., Lord Rayleigh[72] found

$$\frac{pv \text{ at } \frac{1}{2} \text{ atmosphere}}{pv \text{ at 1 atmosphere}}=1.00632.$$

From the characteristic equation there results

$$\frac{pv \text{ at } \frac{1}{2} \text{ atmosphere}}{pv \text{ at } 1 \text{ atmosphere}} = 1.00770$$

It is seen that the deviations of the values resulting from the equation from the experimental values are in opposite directions at these two temperatures which are but 3° F. apart and it seems probable that one or the other of the experimental values is in error.

For the coefficient of dilatation, $\frac{1}{v_o} \cdot \frac{\Delta v}{\Delta t}$, from 32° F. to 212° F. at atmospheric pressure Perman and Davies[30] found 0.003847 and Leduc[73] found 0.003797. The value found from the characteristic equation is 0.003833, which agrees well with the mean of the experimental values.

The values of $\frac{1}{v} \cdot \frac{dv}{dt}$ at 32° F. and one atmosphere as found experimentally by Leduc[73] and from the characteristic equation are respectively 0.003857 and 0.003932. The corresponding values of $\frac{1}{p} \cdot \frac{dp}{dt}$ at the same point are respectively 0.003801 and 0.003710.

It will be seen that the characteristic equation gives results which do not always agree closely with the experimental values of the various coefficients. The other proposed characteristic equations, however, give results which do not agree any better with the whole body of experimental data, and considering the inconsistencies in the experimental data it is probable that equation (8) is as good an equation as can be devised on the basis of the existing information.

18. *Specific Heat of the Superheated Vapor.*—The first determination of the specific heat of superheated ammonia was made by Regnault,[3] who found a value of 0.50836 at atmospheric pressure and over a temperature range of 75° F. to 420° F. Later Wiedemann[65] performed two series of experiments at a pressure of about 16 lb. per sq. in.; he found a value of 0.5202 between 77° F. and 212° F., and a value of 0.5356 between 77° F. and 392° F. He proposed the equation

$$c_p = 0.4949 + 0.000172t$$

Thus far the history is much the same as in the case of superheated steam, the specific heat of which was long supposed to be independent of both temperature and pressure and equal to 0.48 as determined by Regnault; later the investigations of Mallard and LeChatelier and of Lange agreed in making it a linear function of the temperature. In the case of steam, however, the experiments of Knoblauch and Jakob, Thomas, and Knoblauch and Mollier have shown that the specific heat of superheated steam depends upon the pressure. While no experiments have been made to investigate the variation of the specific heat of superheated ammonia with pressure, it is very probable that there is such a variation and its rate may be determined by means of Clausius' thermodynamic relation, providing a sufficiently accurate characteristic equation has been determined. The process of obtaining an explicit expression for c_p in terms of the variables p and T has inherent difficulties and is rendered more difficult in this case by the meagerness of the data available. The success with which the method has been applied to superheated steam by Goodenough, however, seems to warrant its use in the present investigation.

The Clausius relation is expressed by the equation

$$\left[\frac{\partial c_p}{\partial p}\right]_T = -AT\left[\frac{\partial^2 v}{\partial T^2}\right]_p$$

The derivative in the right hand member is determined from the characteristic equation. Thus from equation (8)

$$\frac{\partial v}{\partial T} = \frac{B}{p} + \frac{mn}{T^{n+1}}$$

and

$$\frac{\partial^2 v}{\partial T^2} = \frac{-mn(n+1)}{T^{n+2}}$$

Substituting the second derivative in the Clausius relation the result is

$$\left[\frac{\partial c_p}{\partial p}\right]_T = \frac{Amn(n+1)}{T^{n+1}}$$

Taking T as a constant and integrating with respect to p as the independent variable, the result is

$$c_p = \frac{Amn(n+1)}{T^{n+1}}\, p + \text{const. of integration.}$$

The constant of integration may be a function of T since T was held constant during the integration; hence

$$c_p = \phi(T) + \frac{Amn(n+1)}{T^{n+1}}\, p$$

If the arbitrary function $\phi(T)$ can be determined, there will result an explicit expression for c_p in terms of the variables p and T. Wobsa has used the same method of analysis starting with his own characteristic equations and has obtained equations for c_p similar to the present one.

The determination of the proper function $\phi\,(T)$ is the critical point of the investigation. In evaluating this function Wobsa equated his expression for c_p at atmospheric pressure to Wiedemann's linear equation for c_p at atmospheric pressure and thus found the $\phi(T)$ to be of the form

$$\phi(T) = a + bT - \frac{c}{T^3}$$

He shows that the term in the third power of T, which is the "correction term" for atmospheric pressure, is vanishingly small above 212° F.

and that above this temperature c_p at infinitely small pressures will not differ from c_p at atmospheric pressure, or $\phi(T)=0.4949+0.000172t$. Below 212° F. where the correction term becomes appreciable, Wobsa substitutes the linear function $\phi(T)=0.4712+0.000278t$.

For the determination of $\phi(T)$ in the present investigation there are available the recent determinations of c_p at high temperatures by Nernst. In addition to the results of his own work, Nernst[31] gives a summary of the results of previous investigations; See Table 24. In this table the values are given as molecular specific heats and these have been converted into specific heats per unit of weight by dividing by the molecular weight of ammonia or 17.064. It is seen that the values given for Wiedemann are lower than those quoted earlier in this section from the original; while the value given for Regnault is higher than the original. As the original papers of Keutel and Voller are not at hand the values given in this table for their results are assumed to be correct, but the values used for Weidemann and Regnault are those taken from the original.

TABLE 24. SUMMARY OF DETERMINATIONS OF SPECIFIC HEAT AT CONSTANT PRESSURE AS GIVEN BY NERNST.

Authority	Temp. °C	Molecular c_p	Temp. °F	c_p
Keutel	20	8.64	68	0.506
Voller	20	8.62	68	0.505
E. Wiedemann	25–100	8.84	77–212	0.518
E. Wiedemann	25–200	9.11	77–392	0.534
Regnault	24–216	8.71	75–421	0.510
Nernst	365–567	10.4	689–1053	0.609
Nernst	480–680	11.2	896–1256	0.656

If in the equation for c_p, $p=0$, the equation reduces to $c_p=\phi(T)$. Therefore if we have values for c_p at zero pressure the $\phi(T)$ may be determined. To obtain these values the proper correction terms were calculated and subtracted from the values of c_p. The resulting values of $(c_p)_o$ seemed to justify the assumption that $(c_p)_o$ is a linear function of the temperature. This linear relation may not, and probably does not, hold for the entire range of superheat, but it may be assumed as a close approximation, and the only assumption justified by the experimental data available. The function therefore takes the simple form

$$\phi(T)=\alpha+\beta T$$

and the equation for c_p becomes

$$c_p=\alpha+\beta T+\frac{Amn(n+1)}{T^{n+1}}\,p \tag{k}$$

The constants m and n are those heretofore given in connection with the characteristic equation, and the values finally chosen for α and β

are: $\alpha = 0.382$, $\beta = 0.000174$. Replacing $Amn(n+1)$ by a single constant C, and substituting the proper value for the various constants the formula for the specific heat becomes:

$$c_p = 0.382 + 0.000174T + p\frac{C}{T^6} \tag{9}$$

where $\log C = 13.644705$.

Values of c_p have been calculated for various pressures up to 400 lb. per sq. in. and for temperatures up to 1100° F.; these values are plotted against temperatures in Fig. 7. The experimental determinations are also plotted to show the agreement. The determinations of Regnault, Nernst, Keutel, and Voller were made at atmospheric pressure, while those of Wiedemann were at a pressure of about 16 lb. per sq. in. absolute. The agreement between the curve derived from equation (9) for a pressure of 15 lb. per sq. in. and the points representing the determinations of Regnault, Nernst, Keutel, and Voller is seen

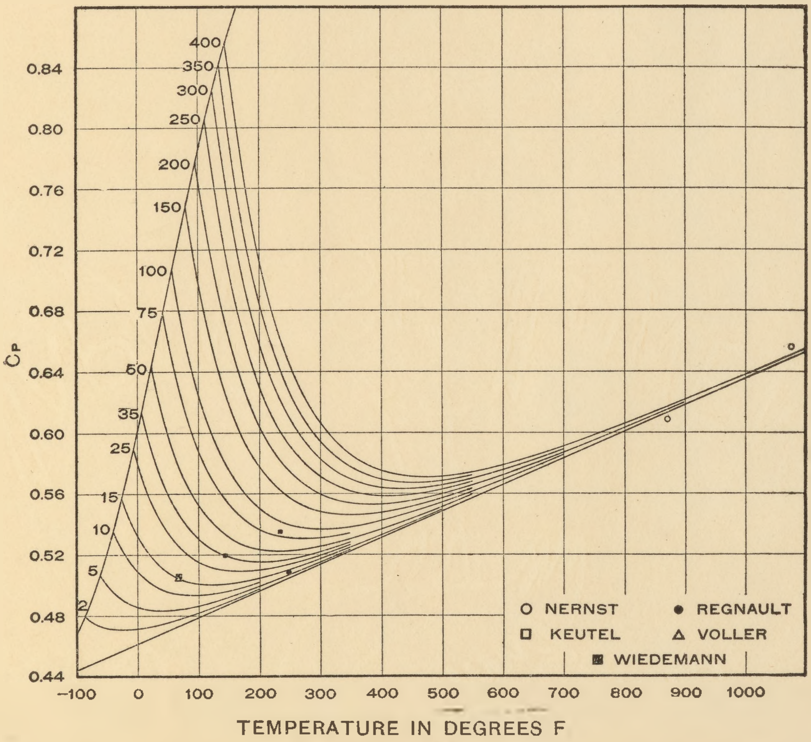

Fig. 7. Curves Showing Values of c_p at Different Pressures and Temperatures.

to be very good, while the points representing Wiedemann's determinations lie considerably above the curve.

19. *Heat Content of Saturated and Superheated Vapor.*—Having an explicit formula for the specific heat at constant pressure in terms of the variables p and T, an expression for the heat content in terms of these variables may be easily derived. For this purpose the general equation

$$dq=c_pdT-AT\left[\frac{\partial v}{\partial T}\right]_p dp \qquad \text{(l)}$$

is most convenient. Since the heat content is defined by the relation

$$i=A(u+pv)$$

then

$$di=A(du+d(pv))$$

or $$di=dq+Avdp$$

Hence by substitution in equation (l) there results

$$di=c_pdT-A\left[T\frac{\partial v}{\partial T}-v\right]dp \qquad \text{(m)}$$

From the characteristic equation

$$\frac{\partial v}{\partial T}=\frac{B}{p}+\frac{nm}{T^{n+1}}$$

whence

$$T\frac{\partial v}{\partial T}-v=(n+1)\frac{m}{T^n}$$

Substituting this and the general expression for c_p in equation (m) the result is

$$di=(\alpha+\beta T)dT+Amn(n+1)p\frac{dT}{T^{n+1}}-\frac{Am(n+1)}{T^n}dp-Acdp \qquad \text{(n)}$$

Since i depends upon the state of the substance only, the second member of equation (n) must be an exact differential. The integral is readily found to be

$$i=\alpha T+\frac{\beta}{2}T^2-A(n+1)p\frac{m}{T^n}-Acp+i_o \qquad \text{(o)}$$

The constant of integration i_o is determined by passing to the saturation limit. Since the constants α, β, m, n, and c are known, the value of the right hand member of equation (o), exclusive of i_o may be found for any given pressure and temperature. If the value of i is known at this point i_o may be determined by subtraction. Now for the saturated vapor

$$i''=i'+r=u+Apv'+r$$

If the energy u be taken equal to zero at 32° F., then at this temperature

$$i''_{32}=0+Ap_{32}v'_{32}+r_{32}$$

Substituting the proper values as determined by the formulas for the saturated vapor there results

$$i''_{32}=0.3+546.4=546.7$$

By the substitution of the proper values of p and T in equation (o) there results

$$i-i_o=188.7$$

By subtraction

$$i_o=358.0$$

Introducing known constants equation (o) becomes, with pressure in lb. per sq. in.

$$i=0.382\mathrm{T}+0.000087T^2-p\frac{C}{T^5}-0.0185p+358.0, \qquad (10)$$

where log $C=12.945735$.

There are no direct measurements of the total heat or heat content of the superheated or saturated vapor by which equation (10) may be checked. A check on the accuracy of the equation at the saturation limit is afforded by a comparison of the values of the heat content of the liquid, obtained by subtracting values of r calculated by equation (6) from values of i'' calculated by equation (10), with the experimental determinations of Dieterici. This comparison is shown in the following section. A check on the accuracy of the formula in the superheated region may be obtained by a comparison, by means of the law of corresponding states, of the values for the Joule-Thomson coefficient resulting from equation (10) with the values of this coefficient for other vapors. There is also available a set of throttling experiments performed by Wobsa.[59]

Since i is constant in a throttling process, the Joule-Thomson coefficient μ may be defined as the derivative

$$\left[\frac{\partial T}{\partial p}\right]_i$$

From calculus

$$\left[\frac{\partial T}{\partial p}\right]_i=-\frac{\dfrac{\partial i}{\partial p}}{\dfrac{\partial i}{\partial T}}$$

and from the definition of heat content i,

$$\frac{\partial i}{\partial T}=c_p$$

Hence

$$\mu=\left[\frac{\partial T}{\partial p}\right]_i=-\frac{1}{c_p}\frac{\partial i}{\partial p}$$

or

$$\mu=\frac{A}{c_p}\left[\frac{m(n+1)}{T^n}+c\right] \qquad (p)$$

From equation (p) it is seen that μ varies with the pressure; as the temperature rises, however, the influence of pressure decreases. Joule and Kelvin, working with gases far removed from the saturation limit, found that μ varies inversely as the square of the absolute temperature. In reviewing the available data on the Joule-Thomson coefficient for hydrogen, nitrogen, oxygen, air, and carbon dioxide, and applying the law of corresponding states, Buckingham[66] discusses the variation of the "reduced" values of μ with the "reduced" temperature, but does not take into account the effect of pressure. Davis,[67] by making use of the throttling experiments of Grindley, Griessmann, Peake, and Dodge on superheated steam, has shown that carbon dioxide and water obey the law of corresponding states. The experimental values of μ for steam expressed in pounds per square inch and degrees Fahrenheit were reduced by multiplying by 2.56, a factor which is the ratio of the critical pressure of water (2947 lb. per sq. in.) to the critical temperature (1149° F.), these critical values being the ones determined by Cailletet and Colardeau. Davis gives a curve which he says represents the experimental values for water in the best possible manner; the values in this curve are those translated back to ordinary units. Later determination of the critical constants for water by Holborn and Bauman give 3200 lb. per sq. in. for the critical pressure and 1166° F. for the critical temperature. If then the values of μ on the Davis curve are multiplied by $\frac{3200}{1166}$, or 2.745, and the temperatures are divided by 1166, there results a curve expressing the variation of μ with temperature, both expressed in reduced units, according to the best available experimental data. This curve is shown in Fig. 8 as the heavy full line curve. The values resulting from equation (p) and those resulting from Wobsa's equation for ammonia may now be compared with the values for water. Wobsa's throttling experiments were performed at pressures of from 2 to 10 atmospheres and at temperatures of 42.8°, 60.8°, 86°, and 104° F. In his paper he gives a table comparing the values of μ resulting from his equation with his experimental values. The values of μ at the same pressures and temperatures have been calculated from equation (p). In Table 20 the first line at each temperature gives the averages of Wobsa's experimental determinations, the second line the values resulting from Wobsa's equation, and the third line the values given by equation (p). The values in the second and third lines have been converted into reduced units and are plotted in Fig. 8, the dotted curves representing the values from Wobsa's equation and the full line curves representing values

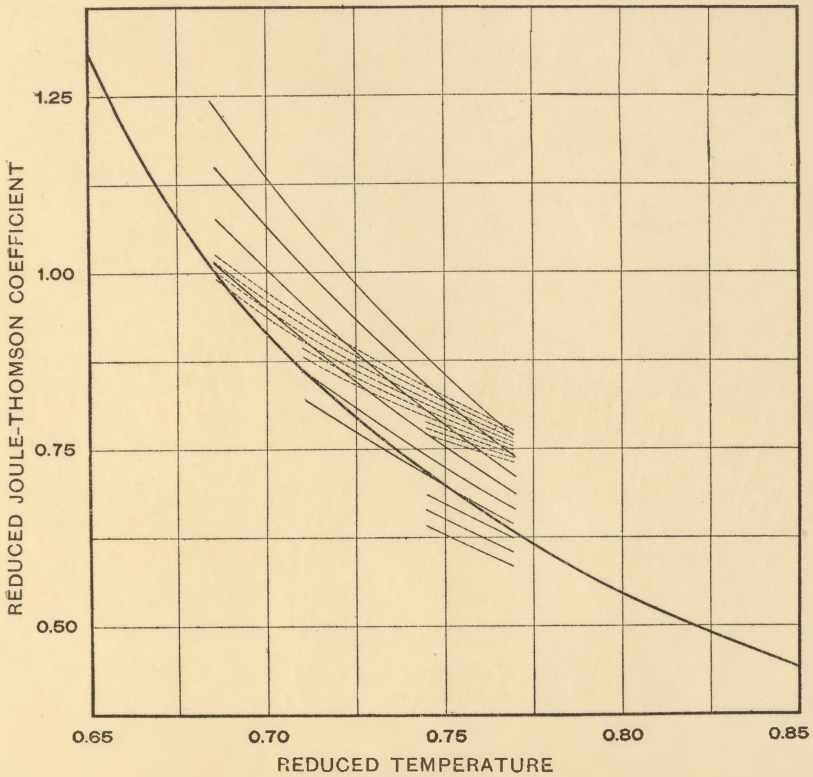

Fig. 8. Comparison of Values of Reduced Joule-Thomson Coefficient for Ammonia According to Wobsa and Those Resulting from Equation (p) With Values for Water as Given by Davis.

from equation (p). It is seen that while the full line curves form a rather strongly diverging brush yet the Davis line passes through the center of the brush and it appears that the brush would converge into the Davis curve at high temperatures. On the other hand the brush of dotted curves has an entirely different trend and would not merge into the Davis curve.

In his discussion Davis states that he has investigated the data for steam in search of a systematic variation of the value of μ with the pressure, but that none could be found. He therefore concludes that if there is such a variation it is within the error of the experimental observations. It will be interesting, however, to compare the pair of lines for each pressure as shown in Fig. 8 with the points according to Grindley, Griessmann, Peake, and Dodge for the same reduced pressure.

TABLE 25. COMPARISON OF VALUES OF JOULE–THOMSON COEFFICIENT RESULTING FROM PRESENT EQUATIONS AND THOSE RESULTING FROM WOBSA'S EQUATIONS WITH WOBSA'S EXPERIMENTAL VALUES.

Pres. in lb. sq. in.	29.39	44.09	58.78	73.48	88.18	102.87	117.57	132.26	146.96
42.8°F.	0.434	0.439	0.435	0.436					
	0.445	0.440	0.435	0.430					
	0.535	0.498	0.466	0.438					
60.8°F.	0.393	0.393	0.392	0.390	0.387	0.382			
	0.407	0.402	0.397	0.392	0.387	0.377			
	0.464	0.438	0.414	0.393	0.374	0.356			
86.0°F.	0.361	0.356	0.348	0.343	0.343	0.347	0.342	0.339	
	0.364	0.360	0.356	0.353	0.349	0.345	0.342	0.338	
	0.382	0.365	0.349	0.335	0.322	0.310	0.298	0.288	
104.0°F.		0.332	0.331	0.327		0.322	0.317		0.314
	0.337	0.334	0.332	0.329	0.327	0.325	0.322	0.320	0.317
	0.334	0.321	0.310	0.299	0.289	0.279	0.271	0.262	0.255

To do this the reduced values as given by Davis have been multiplied by the proper factor to express the quantities in terms of the latest determination of the critical data for water; the reduced temperatures were multiplied by $\frac{1149}{1166} = 0.9854$, the reduced pressures by $\frac{2947}{3200} = 0.921$, and the reduced coefficients by $\frac{2.745}{2.56} = 1.072$. The values were then

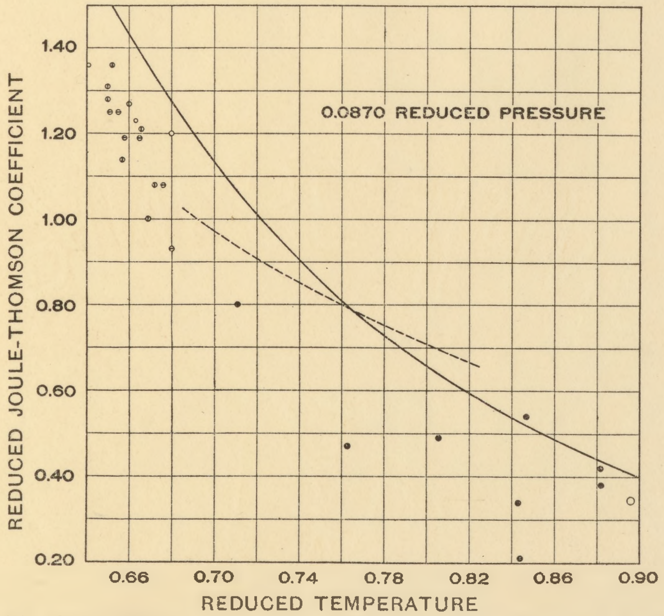

FIG. 9 (a) COMPARISON OF VALUES OF REDUCED JOULE-THOMSON COEFFICIENT FOR AMMONIA ACCORDING TO WOBSA AND THOSE RESULTING FROM EQUATION (p) WITH THE DETERMINATIONS FOR WATER BY GRINDLEY, GRIESSMANN, PEAKE, AND DODGE.

divided into nine groups so that each group included the determinations at reduced pressures nearest to the reduced pressures for ammonia corresponding to 2 to 10 atmospheres. The data divided into such groups are given in Table 26. In Fig. 9 the points in each of the groups are plotted together with the proper curve calculated from equation (p) again shown as full line and the dotted line curve representing Wobsa's

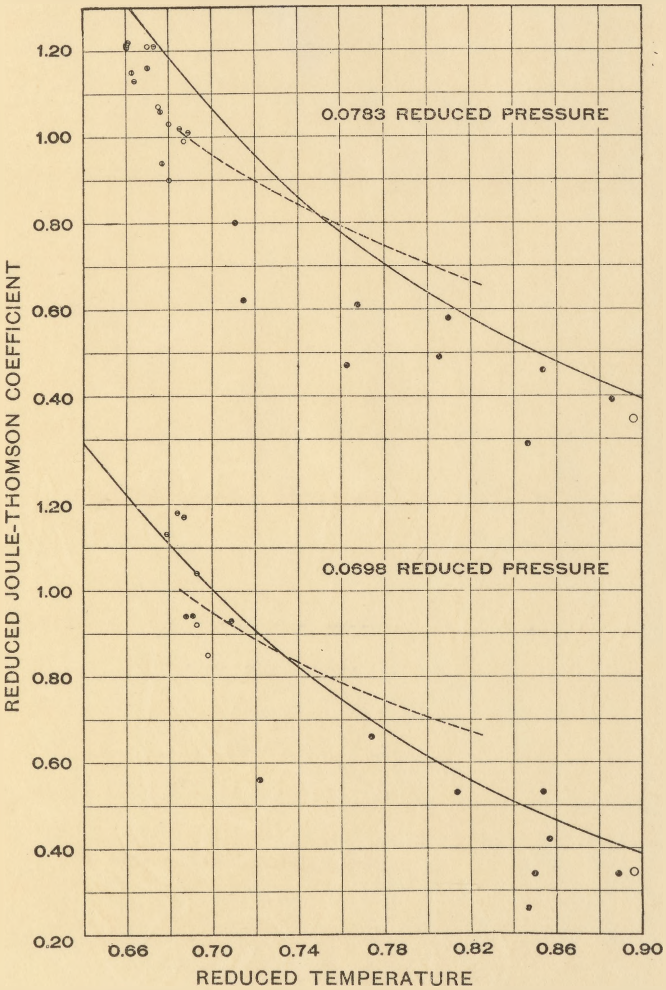

FIG. 9 (b) COMPARISON OF VALUES OF REDUCED JOULE-THOMSON COEFFICIENT FOR AMMONIA ACCORDING TO WOBSA AND THOSE RESULTING FROM EQUATION (p) WITH THE DETERMINATIONS FOR WATER BY GRINDLEY, GRIESSMANN, PEAKE, AND DODGE.

equation. Grindley's values are plotted as open circles, Griessmann's as circles with vertical crossbars, and Peake's as circles with horizontal crossbars; Dodge's values given in Table IV of Davis' paper are plotted as large black dots and his other values as corrected by Davis and given in Table V of his paper appear as small black dots. The large open circle in the lower right hand corner of each curve represents the value found for carbon dioxide by Kester at the lowest temperature investigated. It will be seen that the full line curves give excellent agreement with the experimental values for pressures of 4, 5, 7, and 9 atmospheres although Fig. 8 shows that the 4 and 5 atmosphere curves lie above the Davis curve, the 9 atmosphere curve lies below it and the 7 atmosphere curve cuts across it. The 2 and 3 atmosphere curves lie above the experimental values and the 10 atmosphere curve lies below

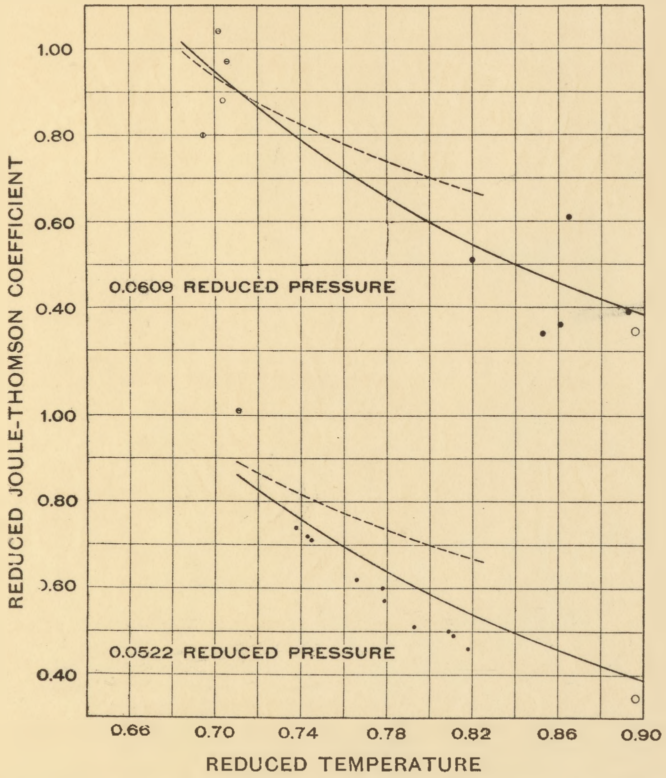

Fig. 9 (c) Comparison of Values of Reduced Joule-Thomson Coefficient for Ammonia According to Wobsa and Those Resulting from Equation (p) With the Determinations for Water by Grindley, Griessmann, Peake, and Dodge.

them but in all cases the curves follow the trend of the points. The agreement is not good in the case of the 6 atmosphere curve and a sufficient number of points do not lie in the region of the 8 atmosphere curve to show the trend. The Wobsa curves in all cases show a trend distinctly different from that of the points and in most cases the curves lie considerably above the points. The values in the first line at each temperature in Table 25 show that the values obtained experimentally by Wobsa are quite erratic and in several cases show no regular variation whatever in the value of μ for different pressures at the same temperature. This fact in connection with the evidence offered by the use of the law of corresponding states tends to discredit the accuracy of the experimental work of Wobsa and his resulting equation.

It should also be mentioned that in calculating values of i and s Wobsa makes the assumption that the specific heat at zero pressure is constant and equal to 0.49 although he has previously assumed it to be equal to $0.4949+0.000172\ t$ up to 212° F. and equal to $0.4712+0.000278\ t$ above that temperature.

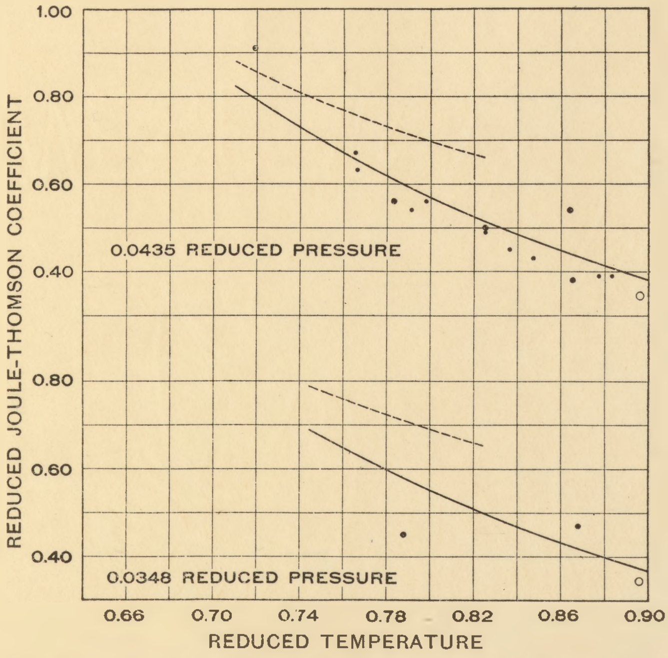

FIG. 9 (d) COMPARISON OF VALUES OF REDUCED JOULE-THOMSON COEFFICIENT FOR AMMONIA ACCORDING TO WOBSA AND THOSE RESULTING FROM EQUATION (p) WITH THE DETERMINATIONS FOR WATER BY GRINDLEY, GRIESSMANN, PEAKE, AND DODGE.

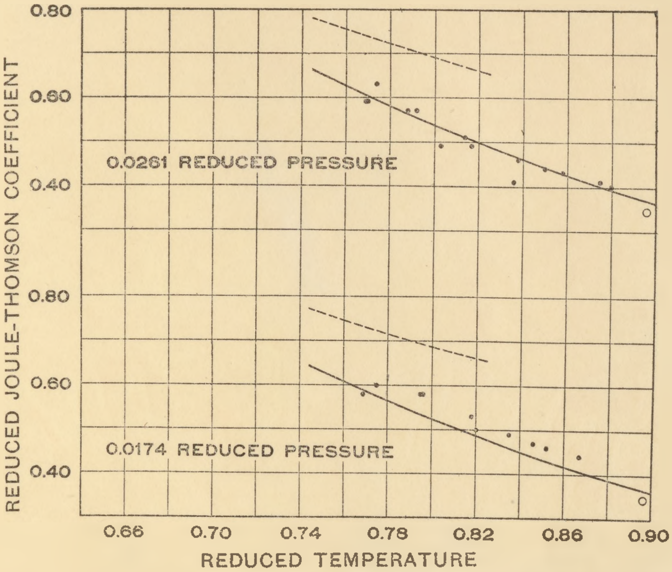

Fig. 9 (c) Comparison of Values of Reduced Joule-Thomson Coefficient for Ammonia According to Wobsa and Those Resulting from Equation (p) With the Determinations for Water by Grindley, Griessmann, Peake, and Dodge.

Table 26. Reduced Joule–Thomson Coefficients for Water Recalculated from Data Given by Davis.

FOR NH_3 CURVE AT REDUCED PRESSURE OF 0.01739

Authority	Reduced quantities based on critical data of Cailletet and Colardeau			Reduced quantities based on critical data of Holborn and Bauman		
	Reduc. Press.	Reduc. Temp.	Reduc. μ	Reduc. Press.	Reduc. Temp.	Reduc. μ
Grindley.....	0.0207	0.690	1.12	0.0191	0.680	1.20
	0.0197	0.673	1.15	0.0181	0.663	1.23
	0.0172	0.651	1.27	0.0158	0.641	1.36
Griessmann...	0.0188	0.682	1.01	0.0173	0.672	1.08
	0.0219	0.679	0.93	0.0202	0.669	1.00
	0.0180	0.676	1.13	0.0166	0.666	1.21
	0.0176	0.670	1.18	0.0162	0.660	1.27
	0.0202	0.667	1.06	0.0186	0.657	1.14
	0.0199	0.662	1.27	0.0183	0.652	1.36
	0.0144	0.660	1.22	0.0133	0.650	1.31
	0.0210	0.660	1.99	0.0193	0.650	1.28
	0.0144	0.646	1.26	0.0133	0.637	1.35
Peake........	0.0213	0.690	0.87	0.0196	0.680	0.93
	0.0221	0.686	1.01	0.0204	0.676	1.08
	0.0199	0.675	1.11	0.0183	0.665	1.19
	0.0233	0.668	1.11	0.0215	0.658	1.19
	0.0200	0.665	1.17	0.0184	0.655	1.25
	0.0165	0.661	1.17	0.0152	0.651	1.25
Dodge I......	0.0196	0.895	0.39	0.0181	0.882	0.42
	0.0195	0.895	0.35	0.0180	0.882	0.38
	0.0196	0.860	0.50	0.0181	0.847	0.54
	0.0195	0.857	0.20	0.0180	0.844	0.21
	0.0183	0.856	0.32	0.0169	0.843	0.34
	0.0184	0.818	0.46	0.0169	0.806	0.49
	0.0178	0.774	0.44	0.0164	0.763	0.47
	0.0195	0.722	0.75	0.0180	0.711	0.80

FOR NH_3 CURVE AT REDUCED PRESSURE OF 0.02609

Authority	Reduced quantities based on critical data of Cailletet and Colardeau			Reduced quantities based on critical data of Holborn and Bauman		
	Reduc. Press.	Reduc. Temp.	Reduc. μ	Reduc. Press.	Reduc. Temp.	Reduc. μ
Grindley.....	0.0277	0.697	0.92	0.0255	0.687	0.99
	0.0296	0.685	1.00	0.0273	0.675	1.07
	0.0253	0.680	1.13	0.0233	0.670	1.21
Griessmann...	0.0313	0.690	0.84	0.0288	0.680	0.90
	0.0268	0.690	0.96	0.0247	0.680	1.03
	0.0308	0.687	0.88	0.0284	0.677	0.94
	0.0243	0.686	0.99	0.0224	0.676	1.06
	0.0237	0.680	1.08	0.0218	0.670	1.16
	0.0260	0.673	1.07	0.0239	0.663	1.15
Peake........	0.0304	0.699	0.94	0.0280	0.689	1.01
	0.0312	0.695	0.95	0.0287	0.685	1.02
	0.0274	0.683	1.13	0.0252	0.673	1.21
	0.0277	0.674	1.05	0.0255	0.664	1.13
	0.0260	0.671	1.14	0.0239	0.661	1.22
Dodge I......	0.0289	0.899	0.36	0.0266	0.886	0.39
	0.0308	0.867	0.43	0.0284	0.854	0.46
	0.0246	0.860	0.27	0.0227	0.847	0.29
	0.0306	0.822	0.54	0.0282	0.810	0.58
	0.0248	0.818	0.46	0.0228	0.806	0.49
	0.0306	0.779	0.57	0.0282	0.768	0.61
	0.0288	0.774	0.44	0.0265	0.763	0.47
	0.0288	0.726	0.58	0.0265	0.715	0.62
	0.0286	0.722	0.75	0.0263	0.711	0.80

FOR NH_3 CURVE AT REDUCED PRESSURE OF 0.03478

Grindley.....	0.0412	0.708	0.79	0.0379	0.698	0.85
	0.0344	0.703	0.86	0.0317	0.693	0.92
Griessmann ...	0.0398	0.701	0.88	0.0367	0.691	0.94
	0.0347	0.698	0.88	0.0320	0.688	0.94
Peake........	0.0413	0.709	0.87	0.0380	0.699	0.93
	0.0403	0.703	0.97	0.0371	0.693	1.04
	0.0405	0.697	1.09	0.0373	0.687	1.17
	0.0379	0.694	1.10	0.0349	0.684	1.18
	0.0337	0.689	1.05	0.0310	0.679	1.13
Dodge I......	0.0356	0.902	0.32	0.0328	0.889	0.34
	0.0409	0.870	0.39	0.0377	0.857	0.42
	0.0356	0.867	0.49	0.0328	0.854	0.53
	0.0347	0.863	0.32	0.0320	0.850	0.34
	0.0343	0.860	0.24	0.0316	0.847	0.26
	0.0409	0.826	0.49	0.0377	0.814	0.53
	0.0409	0.785	0.62	0.0377	0.774	0.66
	0.0389	0.733	0.52	0.0358	0.722	0.56

FOR NH_3 CURVE AT REDUCED PRESSURE OF 0.04348

Grindley....	0.0480	0.714	0.82	0.0442	0.704	0.88
Griessmann..	0.0438	0.705	0.75	0.0403	0.695	0.80
Peake.......	0.0502	0.716	0.90	0.0460	0.706	0.97
	0.0499	0.712	0.97	0.0462	0.702	1.04
Dodge I......	0.0482	0.906	0.36	0.0444	0.893	0.39
	0.0482	0.878	0.57	0.0444	0.865	0.61
	0.0516	0.874	0.34	0.0475	0.861	0.36
	0.0432	0.866	0.32	0.0398	0.853	0.34
	0.0516	0.832	0.48	0.0475	0.820	0.51
	0.0516	0.790	0.54	0.0475	0.778	0.58

FOR NH_3 CURVE AT REDUCED PRESSURE OF 0.05218

Authority	Reduced quantities based on critical data of Cailletet and Colardeau			Reduced quantities based on critical data of Holborn and Bauman		
	Reduc. Press.	Reduc. Temp.	Reduc. μ	Reduc. Press.	Reduc. Temp.	Reduc. μ
Peake........	0.0569	0.722	0.94	0.0524	0.711	1.01
Dodge II.....	0.057	0.830	0.43	0.0525	0.818	0.46
	0.057	0.805	0.48	0.0525	0.793	0.51
	0.057	0.777	0.58	0.0525	0.766	0.62
	0.057	0.749	0.69	0.0525	0.738	0.74
	0.056	0.823	0.46	0.0516	0.811	0.49
	0.056	0.791	0.53	0.0516	0.779	0.57
	0.056	0.756	0.66	0.0516	0.745	0.71
	0.055	0.821	0.47	0.0507	0.809	0.50
	0.055	0.790	0.56	0.0507	0.778	0.60
	0.055	0.754	0.67	0.0507	0.743	0.72
FOR NH_3 CURVE AT REDUCED PRESSURE OF 0.06087						
Peake........	0.0639	0.730	0.85	0.0588	0.719	0.91
Dodge I......	0.0681	0.877	0.50	0.0627	0.864	0.54
	0.0626	0.878	0.35	0.0577	0.865	0.38
	0.0625	0.837	0.47	0.0576	0.825	0.50
	0.0625	0.795	0.52	0.0576	0.783	0.56
Dodge II	0.070	0.890	0.36	0.0645	0.877	0.39
	0.070	0.860	0.40	0.0645	0.847	0.43
	0.070	0.803	0.50	0.0645	0.791	0.54
	0.070	0.777	0.59	0.0645	0.766	0.63
	0.069	0.837	0.46	0.0635	0.825	0.49
	0.069	0.810	0.52	0.0635	0.798	0.56
	0.069	0.776	0.62	0.0635	0.765	0.67
	0.068	0.896	0.36	0.0626	0.883	0.39
	0.068	0.848	0.42	0.0626	0.836	0.45
FOR NH_3 CURVE AT REDUCED PRESSURE OF 0.06975						
Dodge I......	0.0765	0.881	0.44	0.0705	0.868	0.47
	0.0724	0.800	0.42	0.0667	0.788	0.45
FOR NH_3 CURVE AT REDUCED PRESSURE OF 0.07826						
Dodge II.....	0.087	0.893	0.37	0.0801	0.880	0.40
	0.087	0.871	0.40	0.0801	0.858	0.43
	0.087	0.850	0.43	0.0801	0.838	0.46
	0.087	0.829	0.46	0.0801	0.817	0.49
	0.087	0.800	0.53	0.0801	0.788	0.57
	0.087	0.781	0.55	0.0801	0.770	0.59
	0.087	0.848	0.38	0.0801	0.836	0.41
	0.087	0.815	0.46	0.0801	0.803	0.49
	0.087	0.780	0.55	0.0801	0.769	0.59
	0.086	0.888	0.38	0.0792	0.875	0.41
	0.086	0.863	0.41	0.0792	0.850	0.44
	0.086	0.826	0.48	0.0792	0.814	0.51
	0.086	0.785	0.59	0.0792	0.774	0.63
	0.086	0.804	0.53	0.0792	0.792	0.57
FOR NH_3 CURVE AT REDUCED PRESSURE OF 0.08696						
Dodge II.....	0.103	0.880	0.41	0.0949	0.867	0.44
	0.103	0.865	0.43	0.0949	0.852	0.46
	0.103	0.847	0.46	0.0949	0.835	0.49
	0.103	0.832	0.47	0.0949	0.820	0.50
	0.103	0.808	0.54	0.0949	0.796	0.58
	0.103	0.786	0.56	0.0949	0.775	0.60
	0.103	0.880	0.41	0.0949	0.867	0.44
	0.103	0.859	0.44	0.0949	0.846	0.47
	0.103	0.830	0.49	0.0949	0.818	0.53
	0.103	0.807	0.54	0.0949	0.795	0.58
	0.103	0.780	0.54	0.0949	0.769	0.58

20. *Heat Content of the Liquid.*—The values of heat content of the liquid may be found by subtracting the values of r found by equation (6) from the values of i'' found by equation (10). The most important

check on these values is derived from a series of experiments performed by Dieterici[25] and by Drewes[68] working in Dieterici's laboratory. In these experiments the quantity measured was the amount of heat given up by a certain weight of a mixture of saturated and liquid ammonia cooling at constant volume in a sealed tube. This quantity was corrected for the heat due to the latent heat of the portion of vapor condensed and the remaining amount of heat was divided by the change in temperature to obtain the mean "inner" specific heat of the liquid over that temperature range. In his paper Dieterici gives only the formula which he chose as best representing the results of his experiments, which states that the mean "inner" specific heat between t and 32° F. $=1.118+0.000578(t-32)$. Since this is a linear function of the temperature it follows that the instantaneous "inner" specific heat $=1.118+0.001176(t-32)$. The original data of the experiments are not given, but Professor Dieterici has kindly furnished the values which he actually obtained for the mean "inner" specific heat and also a copy of Mr. Drewes' dissertation containing the values obtained by him. If each of these values of the mean "inner" specific heat is multiplied by the temperature range covered the result will be approximately equal to the internal energy u above 32° F. at the temperature t. Since $i'=u'+Apv'$, in order to obtain values of i' the product Apv' corresponding to the temperature t must be added to the value of u'

TABLE 27. THE HEAT CONTENT OF THE LIQUID AS DEDUCED FROM THE EXPERIMENTS OF DIETERICI AND DREWES.

Authority	$(C_i')_m$ (t-0°C)	u' above 0°C. Cal. of 4.222 Joules	u' above 0°C. Cal. of 4.184 Joules	Temp. °C.	Temp. °F.	u' above 32° F. B. t. u.	$i'=u'+Apv'$
Dieterici	1.148	10.65	10.75	9.28	48.70	19.35	19.77
	1.162	10.93	11.03	9.41	48.94	19.85	20.27
	1.141	24.25	24.47	21.25	70.25	44.04	44.67
	1.140	24.57	24.79	21.55	70.79	44.62	45.26
	1.139	38.67	39.02	33.95	93.11	70.23	71.21
	1.147	39.27	39.62	34.24	93.63	71.31	72.30
	1.200	42.03	42.41	35.02	95.03	76.34	77.35
Drewes,—reliable according to Dieterici	1.172	48.17	48.60	41.1	105.96	87.46	88.68
	1.158	48.35	48.78	41.75	107.15	87.78	89.02
	1.186	61.44	62.00	51.8	125.22	111.60	113.25
	1.163	60.42	60.97	51.95	125.46	109.75	111.41
	1.187	70.74	71.38	59.6	139.3	128.50	130.57
	1.164	72.75	73.41	62.5	144.5	132.15	134.40
	1.179	82.76	83.50	70.2	158.4	150.30	153.07
	1.205	87.48	88.27	72.6	162.7	158.90	161.84
Drewes,—questioned by Dieterici	0.974	11.50	11.60	11.8	53.24	20.89	21.35
	1.098	21.62	21.81	19.7	67.46	39.26	39.86
	1.069	22.82	23.02	21.35	70.43	41.44	42.08
	1.140	34.61	34.92	30.36	86.64	62.85	63.72
	1.148	35.83	36.16	31.21	88.17	65.08	65.97
	0.7065	−10.49	−10.59	−14.85	5.27	−19.06	−18.91

obtained as described. The results of these calculations appear in Table 27. Since Dieterici reported his results in terms of a mean calorie equal to 4.222 joules while in the present investigation a mean calorie of 4.184 joules is used, all of Dieterici's heat quantities must be multiplied by 1.009. The table includes the determinations made by Dieterici himself and all of the determinations made by Drewes: part of the latter are called reliable by Dieterici, while the rest are marked "falsch" in the copy of Drewes' dissertation loaned by Dieterici. The ground for this statement is not given. In Fig. 10

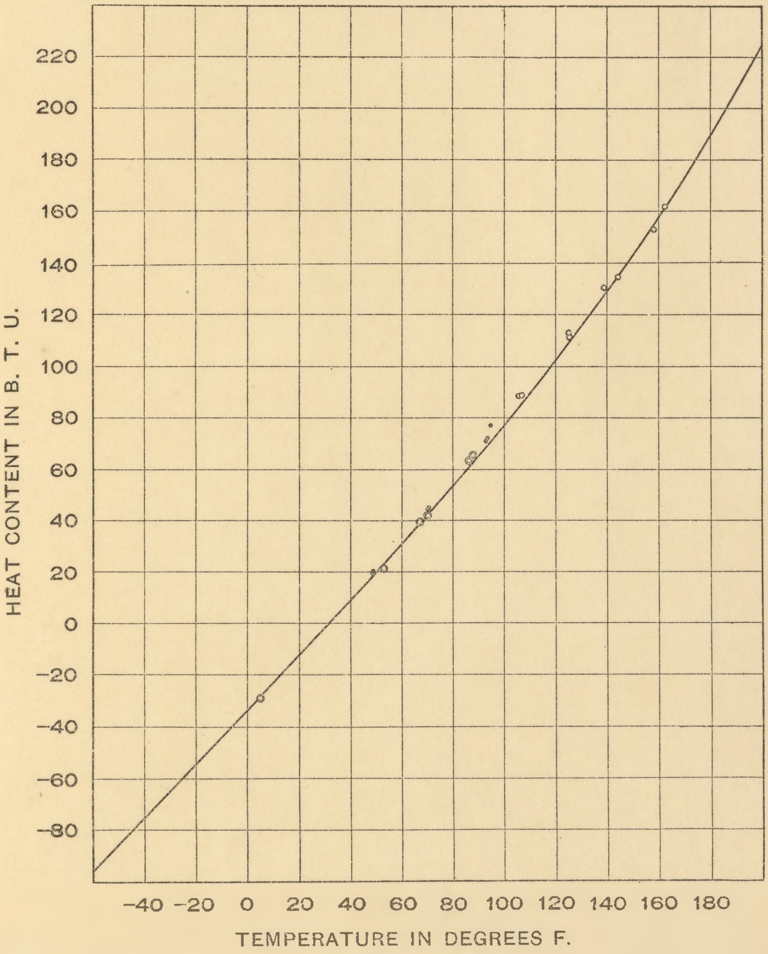

Fig. 10. Comparison of Calculated Values of Heat Content of the Liquid with Values Deduced from the Experimental Work of Dieterici and Drewes.

Dieterici's values are plotted as black dots, and those of Drewes as circles; the values questioned by Dieterici are indicated by means of a double circle. The curve represents the values found by the use of equations (6) and (10). It is seen that in several cases the curve passes between the Dieterici points and the doubtful Drewes points.

Since the quotient obtained by dividing the change in i between two temperatures by the difference in temperature is very nearly equal to the specific heat, the other determinations which have been made of the specific heat may be used to check the calculated values of i'.

TABLE 28. SUMMARY OF DETERMINATIONS OF THE SPECIFIC HEAT OF LIQUID AMMONIA.

Authority	Temp.°C.	Temp.°F.	Specific Heat of Liquid
von Strombeck	62–30	144–86	1.22876
Elleau and Ennis	20–0	68–32	1.02
Ludeking and Starr	77.7	139.9	0.886
A. J. Wood	20–16	68–61	1.094

Table 28 contains a summary of the determinations of the specific heat of the liquid in addition to the work of Dieterici and Drewes already given; this includes the work of Elleau and Ennis,[24] von Strombeck,[19] Ludeking and Starr,[23] and A. J. Wood.[69] In Fig. 11 these values

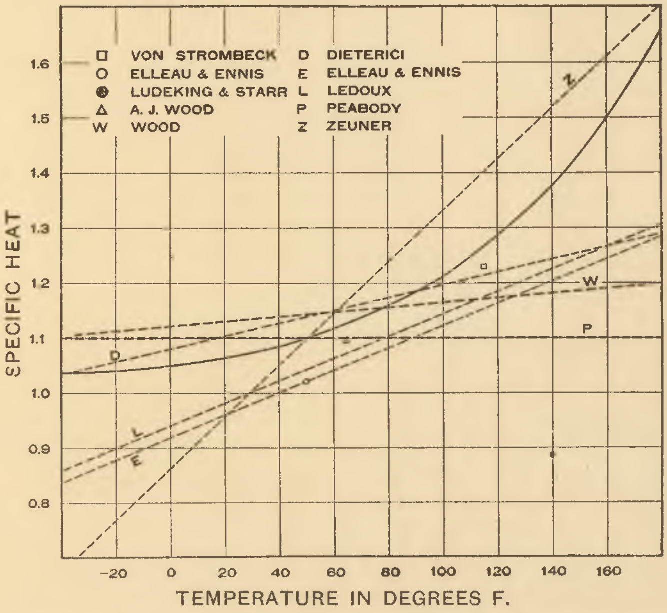

FIG. 11. COMPARISON OF VARIOUS DETERMINATIONS OF SPECIFIC HEAT OF THE LIQUID AND VARIOUS EQUATIONS FOR THE SAME.

are plotted, together with the curves representing the following equations used in the computation of various tables:

Dieterici:[25] $c'=1.118+0.001156\ (t-32)$
Zeuner:[9] $c'=1.01235+0.00468\ (t-32)$
Wood:[10] $c'=1.12136+0.000438\ t$
Ledoux:[6] $c'=1.0058+0.0020322\ (t-32)$
Elleau and Ennis:[24] $c'=0.9834+0.0020322\ (t-32)$
Peabody:[11] $c'=1.1$ constant.

The full line curve represents the values of the tangents to the heat content curve of the present investigation. Since according to modern ideas of the critical point the specific heat of the liquid there becomes equal to plus infinity, the full line curve is of a more rational form than any linear relation.

21. *Entropy of the Saturated and Superheated Vapor.*—An expression for entropy is readily found from equation (l) which is

$$dq=c_p dT-AT\left[\frac{\partial v}{\partial T}\right]_p dp \qquad \text{(l)}$$

Thus

$$ds=\frac{dq}{T}=c_p\frac{dT}{T}-A\left[\frac{\partial v}{\partial T}\right]_p dp \qquad \text{(q)}$$

Introducing in equation (q) the expressions previously derived for c_p and $\left[\frac{\partial v}{\partial T}\right]_p$, the result is

$$ds=\left[\frac{a}{T}+\beta\right]dT+Amn(n+1)p\frac{dT}{T^{n+2}}-AB\frac{dp}{p}-\frac{Amn}{T^{n+1}}dp \qquad \text{(r)}$$

The integral of equation (r) is

$$s=\alpha\ \log_e T+\beta T-AB\ \log_e p-Anp\frac{m}{T^{n+1}}+s_o \qquad \text{(s)}$$

The constant s_o is determined by passing to the saturation limit at 32° F., where $s'=0$ and therefore $s''=\frac{r}{T}$. Substituting this value for s in the left hand member of equation (s) and the proper values of p and T in the right hand member, s_o is found to be equal to -0.82656. Substituting this value and the known values of the other constants, and passing to common logarithms, equation (s) becomes

$$s=0.8796\ \log T+0.000174T-0.2695\ \log p-\frac{p}{T^6}C-0.82656 \qquad (11)$$

where $\log C=12.866554$

22. *Computation of Tables.*—The methods by which the various tabular values were obtained from the experimental data are in many cases obvious. In Tables 1 and 2, the first seven columns either depend directly on the data selected or their derivation has been explained in

the previous paragraphs. The eighth column, giving the internal energy of evaporation, comes from the formula

$$\rho = r - 144\,Ap\,(v'' - v');$$

and the ninth column, giving the internal energy of the saturated vapor, from the corresponding formula

$$u'' = i'' - 144\,Apv''$$

The entropy of the saturated vapor in column twelve was calculated by means of equation (11). The entropy of evaporation in column eleven is r/T. Column ten is the difference between columns twelve and eleven.

In all these cases the required quantities were computed, usually to one extra significant figure, for each of a series of standard temperatures. These values were then plotted to a large scale and smooth curves drawn through the points. Intermediate values were read from these curves and checked by the method of differences.

In the computation of Table 3 the process was as follows: The expression for heat content is

$$i = 0.382T + 0.000087T^2 - p\frac{C}{T^5} - 0.0185p + 358.0$$

where $\log C = 12.945735$.

This expression was separated into two parts, a temperature function $(0.382T + 0.000087T^2 + 358.0)$, and a function of both pressure and temperature $p\left(0.0185 + \frac{C}{T^5}\right)$. The value of the temperature function was calculated at integral values throughout the necessary range of temperature and plotted to a large scale; a smooth curve was then drawn through the points. Similarly a curve was drawn to represent the part of the second function which appears in the parenthesis, or $\left(0.0185 + \frac{C}{T^5}\right)$. To find the value of i at any desired pressure and temperature the value of this parenthesis was read from the curve and multiplied by p; this value subtracted from the proper value of the temperature function as read from its curve gave the required value of i.

A similar method was used in the calculation of values of entropy and specific volume. All final values were checked by the method of differences.

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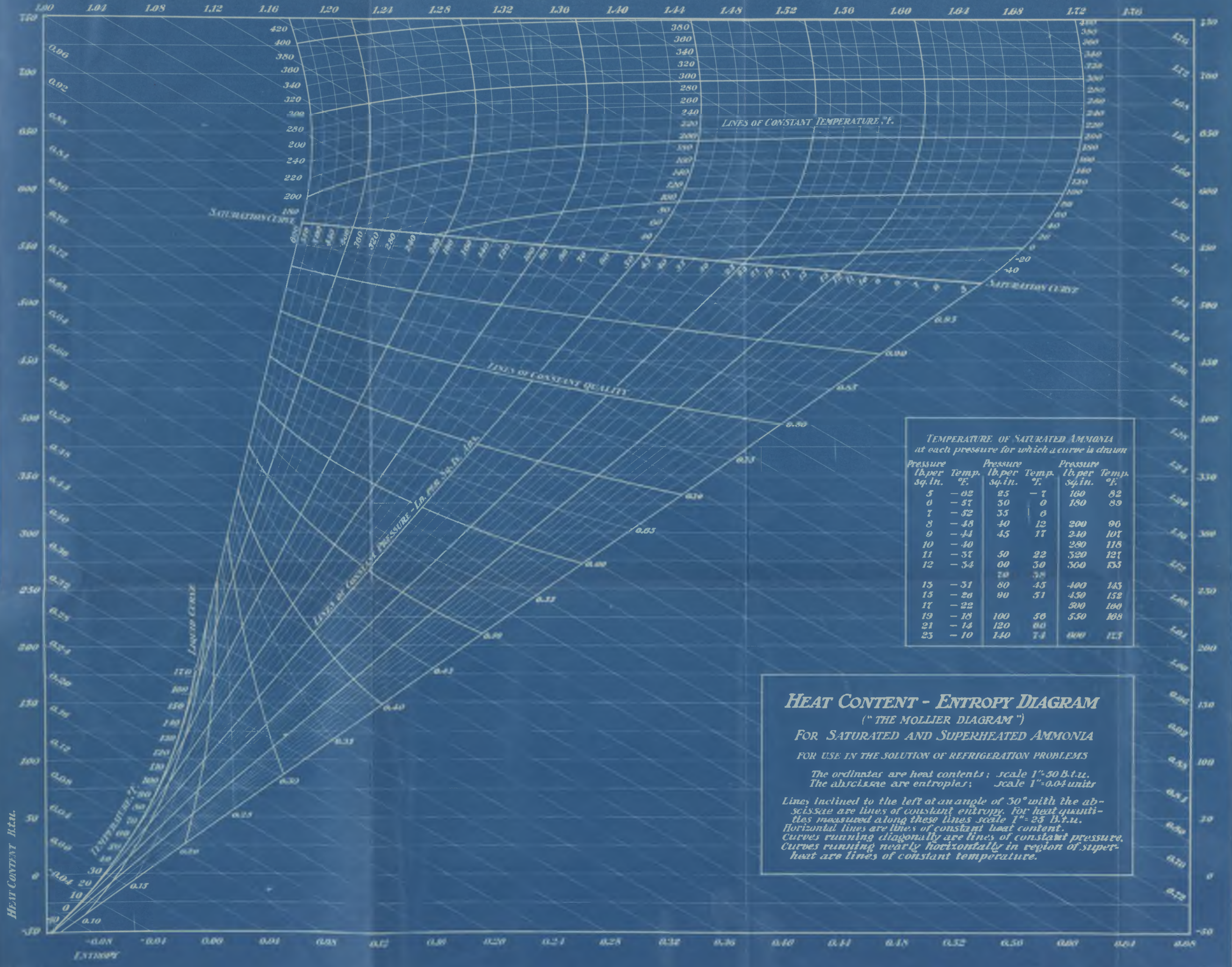


TEMPERATURE OF SATURATED AMMONIA
at each pressure for which a curve is drawn

Pressure lb. per sq. in.	Temp. °F.	Pressure lb. per sq. in.	Temp. °F.	Pressure lb. per sq. in.	Temp. °F.
5	− 62	25	− 7	160	82
6	− 57	30	0	180	89
7	− 52	35	6		
8	− 48	40	12	200	96
9	− 44	45	17	240	107
10	− 40			280	118
11	− 37	50	22	320	127
12	− 34	60	30	360	135
		70	38		
13	− 31	80	45	400	143
15	− 26	90	51	450	152
17	− 22			500	160
19	− 18	100	56	550	168
21	− 14	120	66		
23	− 10	140	74	600	175

HEAT CONTENT - ENTROPY DIAGRAM

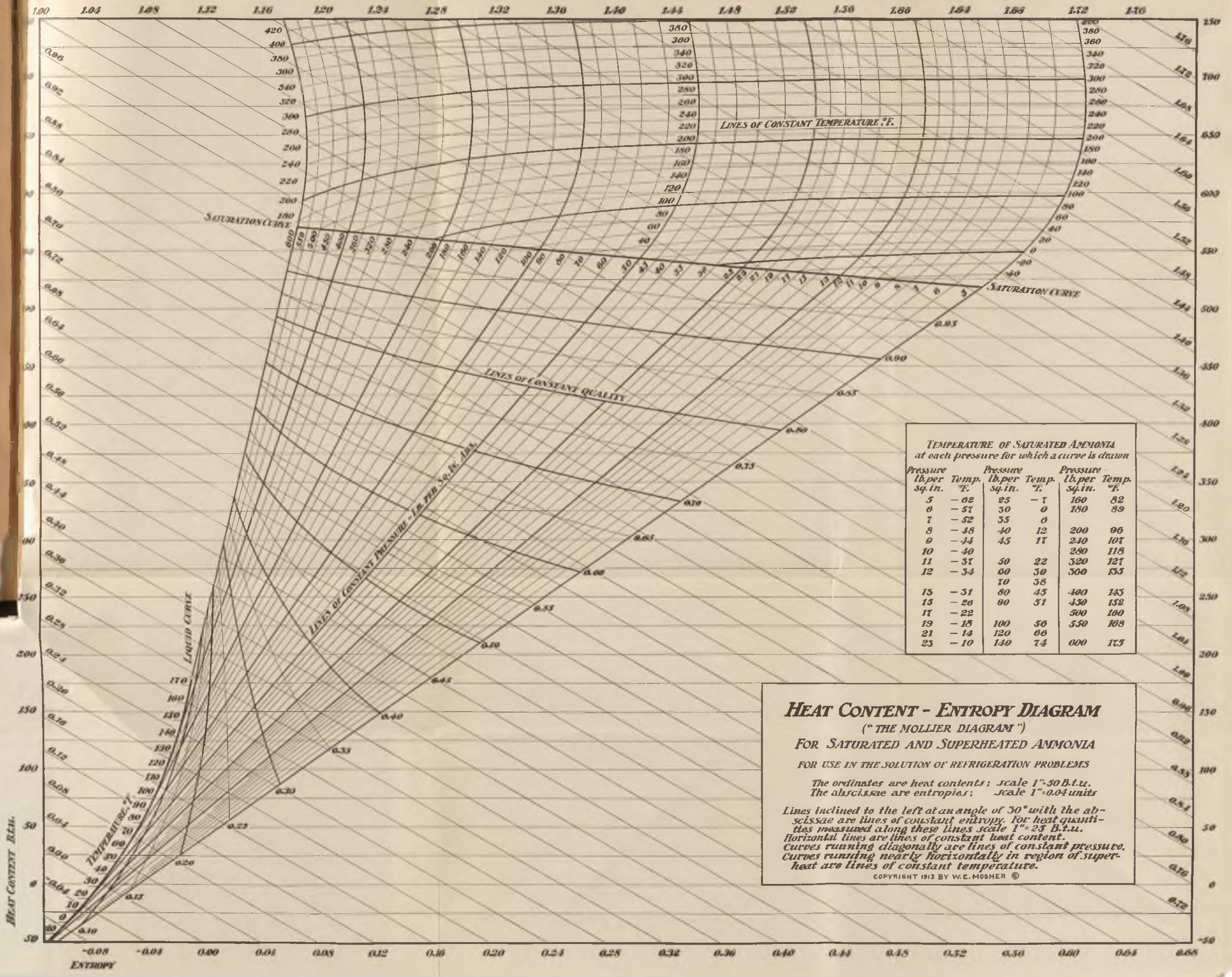
("THE MOLLIER DIAGRAM")

FOR SATURATED AND SUPERHEATED AMMONIA

FOR USE IN THE SOLUTION OF REFRIGERATION PROBLEMS

The ordinates are heat contents; scale 1" = 50 B.t.u.
The abscissae are entropies; scale 1" = 0.04 units

Lines inclined to the left at an angle of 30° with the abscissae are lines of constant entropy. For heat quantities measured along these lines scale 1" = 25 B.t.u.
Horizontal lines are lines of constant heat content.
Curves running diagonally are lines of constant pressure.
Curves running nearly horizontally in region of superheat are lines of constant temperature.



Temperature of Saturated Ammonia
at each pressure for which a curve is drawn

Pressure lb. per sq. in.	Temp. °F.	Pressure lb. per sq. in.	Temp. °F.	Pressure lb. per sq. in.	Temp. °F.
5	– 62	25	– 7	160	82
6	– 57	30	0	180	89
7	– 52	35	6		
8	– 48	40	12	200	96
9	– 44	45	17	240	107
10	– 40			280	118
11	– 37	50	22	320	127
12	– 34	60	30	360	135
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