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SPECIFIC HEAT OF LIQUID AMMONIA.

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CONTENTS.—I. Introduction. II. Previous Work. III. General Description of Apparatus and Method. IV. Material. V. First Method. Measurements under Saturation Conditions. VI. Second Method. Measurements at Constant Pressure. VII. Form of Empirical Equation for Specific Heat of the Saturated Liquid. VIII. Conclusions. IX. Summary. Appendix. Tables of Specific Heat and Heat Content.

I. Introduction.

In reviewing the existing data on the thermodynamic properties of ammonia, the dearth of calorimetric measurements is at once apparent. Only when it is remembered that calorimetric data are of primary importance in the computation of tables adapted to the needs of the engineer can the difficulties of the computer be appreciated. With regard to the specific heat of liquid ammonia it appears that the experimental difficulty of measurement and the absence of urgent need for accurate values have deterred all but a few from the attempt. More recently the progress in the production of artificial refrigeration has led to a need for more accurate tables than those existing, and the measurement of the specific heat of liquid ammonia, together with other thermodynamic properties, has been undertaken in response to the expressed wish of the refrigeration industries.

II. Previous Work.

The previous determinations of specific heat of liquid ammonia are represented graphically in Fig. 1, together with the results of the present measurements. None of the previous measurements extend to temperatures below $0°$.
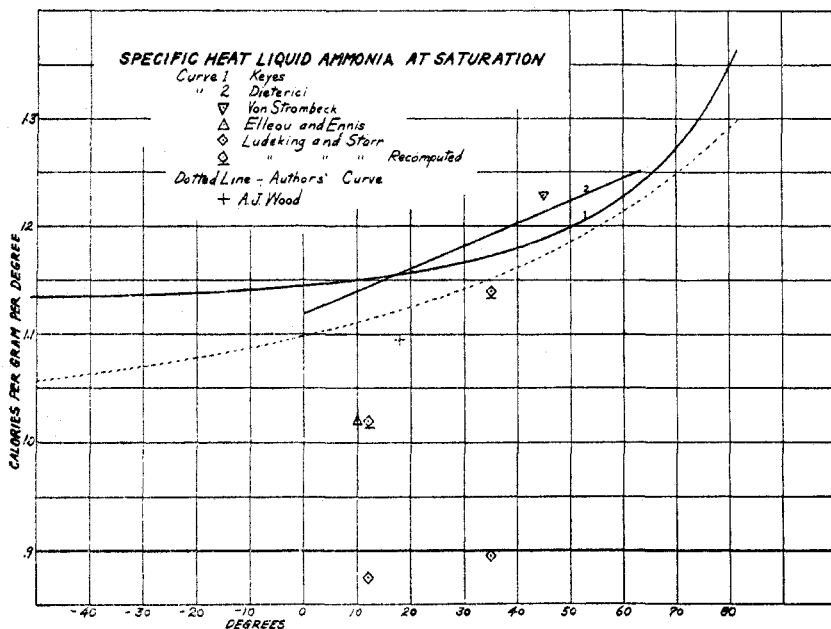

Fig. 1.

Von Strombeck[1] (1890) used the method of mixtures. About 128 g. of ammonia contained in a steel bomb were used in a calorimeter having a water equivalent of about 1 kg. The heat capacity from $+ 30°$ to $+ 60°$ was observed. Eight experiments were made.

Ludeking and Starr[2] (1893) employed a method similar to that of Von Strombeck but smaller apparatus. The total heat capacity of a steel shell of 16.12 cc. capacity containing 10.01 g. of ammonia was measured between $+46°$ and $+26°$. It appears from present knowledge of the specific volume of liquid ammonia that at temperatures above $13°$ the liquid would have completely filled the container, and from the compressibility it may be estimated that at $46°$, if the steel did not stretch considerably, the pressure within would have been in the neighborhood of 300 atmospheres. From the heat of compression of liquid ammonia it can be estimated that the heat capacity between $0°$ and $24°$ was approximately 15 % lower than it would have been under saturation condi-

[1] *J. Franklin Inst.*, **130**, 467 (1890).

[2] *Phil. Mag.*, **35**, 393 (1893); *Am. J. Sci.*, [3] **45**, 200 (1893).

tions and that between 26° and 46° it was about 21% lower. Both the published values and the values recomputed as indicated are shown in Fig. 1.

Elleau and Ennis[1] (1898) also used the method of mixtures between 0° and +25°. Nine grams of ammonia in a capsule of 20 cc. capacity were used.

Dieterici and Drewes[2] (1904) used the Bunsen ice calorimeter. The specimen of ammonia was inclosed in a sealed glass capsule of 1.2 cc. capacity.

A. J. Wood[3] (1912) used the method of mixtures with a sample of about 60 g. of ammonia. Six experiments were made between 16° and 20°.

Keyes and Brownlee[4] (1916) have given an equation based upon experimental work of Babcock.[5]

About 29 g. of ammonia were contained in a steel bomb of 52.65 cc. capacity. The heat capacity was determined with reference to water by a method of substitution in which a second identical bomb was adjusted to contain such an amount of water that the heat capacities of the two bombs were the same. The calorimetric method of mixtures was employed to measure the relative heat capacities. The calorimeter consisted of a Dewar vessel. An ingenious automatic device was used to transfer the bomb to the calorimeter from the preheater in a definite manner. The results of two determinations are given, being the mean specific heat capacities between 0° and 20°, and between 20° and 50°, respectively.

III. General Description of Apparatus and Method.

In carrying out the measurements of specific heat of the liquid two independent methods were used. In one method the heat added to a fixed amount confined in the calorimeter and the resulting change in temperature were measured under saturation conditions. By using independent data for the specific volumes of the two phases and for the latent heat of vaporization the correction for the heat used to change the temperature and amount of vapor present may be determined and the specific heat of the saturated liquid obtained.

In the other method the calorimeter is kept full of liquid at a constant pressure above saturation, the heat added to the variable quantity, and the resulting change in temperature measured, due consideration being paid to the amount and temperature of the expelled portion. The result of this method of measurement is to give the specific heat of the liquid at a constant pressure.

[1] J. Franklin Inst., 145, 189, 280 (1898).
[2] Z. ges. Kalte Ind., 11, 21, 47 (1904).
[3] Ice Refrig., April, 1912.
[4] "Thermodynamic Properties of Ammonia," John Wiley & Sons, 1916.
[5] Keyes and Babcock, THIS JOURNAL, 39, 1524 (1917).

By using the independent data for the latent heat of pressure variation of the liquid, obtained from supplementary experiments with the same apparatus, the specific heat of the saturated liquid may be computed by general thermodynamic formulas, thus giving an independent check on the two methods of measurement.

The calorimeter used in making the experimental determinations having been previously described in detail elsewhere,[1] only a brief description is here given. The instrument is of the aneroid type and was specially designed to meet the requirements of this investigation. A metal shell of sufficient strength is made in the form of a cylinder having a re-entrant central tube. The interior annular space contains the material to be investigated. An electric heating coil and a resistance thermometer are located in the central tube. Heat developed in the coil is transmitted to the surrounding liquid, the distribution being favored by radial metal vanes. The interior of the shell is tinned and the outside nickeled. For preventing the transfer of unmeasured heat between this calorimeter and its environment it is suspended within a shield consisting of a thermally controlled jacket, with an air space between for thermal insulation. For evaluating the thermal leakage—that is, the heat exchanged with the surroundings by reason of temperature differences—multiple thermocouples with junctions distributed on the surfaces indicate temperature differences between calorimeter and jacket. Leakage is usually annulled by keeping the average jacket and calorimeter surface temperatures equal. The heat supplied to the calorimeter electrically is developed at a nearly constant rate in the heating coil by current from a storage battery. Temperature changes are measured either by the resistance thermometer in the calorimeter or by an auxiliary resistance thermometer in the envelope, using thermocouples for the transfer. The energy supplied is determined by potentiometer measurements of current and potential drop and by the duration of the heating current.

The material which is the subject of the measurement is introduced into the previously evacuated calorimeter through the tube provided for this purpose. The sample is confined in a special steel reservoir, which is closed by means of a valve. After being weighed the reservoir is suspended in an auxiliary thermoregulated bath and connected to the calorimeter. When the valves in this connection are open, the flow into the calorimeter is induced by vapor-pressure difference caused by heating the reservoir above the temperature of the calorimeter. If the connecting tube is made to extend down to the bottom of the reservoir the transfer occurs by liquid flow, while if this tube terminates at the top of the reservoir the transfer occurs by distillation. The removal of the material from the calorimeter, except in the case of actual overflow by expansion when al-

[1] Bur. of Standards, *Bull.* 14, 133 (1917); *Scientific Paper* No. 301.

ready full of liquid, is necessarily by distillation, since the orifices are at the top. The large amount of heat transferred when distilling to or from the calorimeter can be readily extracted or added by use of the cooling device or the heating coil as needed.

IV. Material.

The material used in these determinations was prepared by McKelvy and Taylor of the chemical division of this Bureau by methods described in detail in an independent paper.[1] Abrief description of the process of preparation is here given.

A sample of commercial ammonia was transferred by distillation into a steel container which would hold about a kg. From this it was again transferred by distillation into a similar vessel containing metallic sodium, to remove any remaining traces of water. Following this dehydration, the purification was continued by from six to eight consecutive fractional distillations, the first and last tenths of each distillation being rejected. Removal of the rejected first fractions was performed in such a way as to extract the noncondensing gas present.

Two samples purified in the above manner, designated A and C, were used in the determination.

Sample A, used in the determinations by the first method, was made from commercial anhydrous ammonia manufactured from ammonium sulfate.

Tests showed the following impurities in this sample: Noncondensing gases in the vapor phase at 25°, 1 part in 10,000 by volume; water, 1 part in 10,000 by weight.

Sample C, used in the determinations by the second method, was made from commercial anhydrous ammonia manufactured by the synthetic method. The sample showed about the same proportion of noncondensing gases as Sample A.

V. First Method. Measurements under Saturation Conditions.

In the determinations by this method the ammonia contained in the calorimeter is part liquid and part vapor, and, therefore, the pressure is that of saturated vapor, and the state and relative amount of each phase when in equilibrium are completely defined by the temperature. The observations yield, as a direct result, the heat added to the contained ammonia per degree temperature rise. For the obvious purpose of minimizing the variation with temperature of the heat content of the vapor present, only enough vapor space is allowed when filling to insure a safe margin at all temperatures to be experienced.

The experimental data obtained from the observations made by the first method, together with the computations for obtaining the specific heat σ of the saturated liquid, are given in Table I. The computations

[1] To be published in the Bulletin of Bureau of Standards.

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TABLE I.

First Method.—Measurements of Specific Heat of Liquid Ammonia under Saturation Conditions.

Part 1.—Mass in Calorimeter, 274.33 G.

Experiment No.	$\Delta\theta$ Mean. Degrees.	Heat cap., calorimeter and contents. Joules/deg.	N. Heat capacity calorimeter. Joules/deg.	Heat cap. contents. $\frac{1}{M}\frac{\Delta Q}{\Delta\theta}$ J./g. deg.	$\frac{\theta_1 + \theta_2}{2} = \theta_m$. Mean temperature. °C.	Correction term for vapor. J./g. deg.	Specific heat of liquid. σ. J./g. deg.	Deviations from Equation A. J./g. deg.
1......	10.007	2151.1	929.0	4.455	−38.68	−0.014	4.441	±0.000
2......	9.8735	2175.2	941.8	4.496	−28.74	−0.016	4.480	+0.006
3......	9.755	2197.4	953.8	4.534	−18.93	−0.019	4.515	+0.004
4......	9.8225	2219.7	964.5	4.576	−9.13	−0.019	4.557	+0.004
5......	9.7075	2242.4	974.8	4.620	+0.63	−0.019	4.601	+0.002
6......	9.786	2221.0	965.0	4.578	−8.56	−0.019	4.559	+0.005
7......	10.1605	2244.0	975.5	4.624	+1.42	−0.019	4.605	+0.002
8......	10.047	2267.7	985.7	4.673	+11.52	−0.016	4.657	±0.000
9......	10.428	2293.1	995.8	4.729	+21.76	−0.004	4.725	+0.002
10......	10.306	2319.0	1005.8	4.787	+32.12	+0.015	4.802	+0.004
11......	5.252	2129.7	918.5	4.415	−46.32	−0.010	4.405	−0.012
12......	10.392	2150.4	929.3	4.451	−38.49	−0.014	4.437	−0.004
13......	10.2685	2175.1	942.5	4.493	−28.16	−0.017	4.476	±0.000
14......	10.151	2198.1	954.6	4.533	−17.95	−0.018	4.515	+0.001
15......	10.040	2221.3	965.8	4.577	−7.86	−0.020	4.557	−0.001
16......	10.099	2236.5	972.7	4.607	−1.33	−0.019	4.588	−0.002
17......	9.989	2259.8	983.0	4.654	+8.72	−0.016	4.638	−0.004
18......	9.876	2283.6	992.8	4.705	+18.65	−0.009	4.696	−0.007
19......	9.760	2308.0	1002.3	4.760	+28.47	+0.008	4.768	−0.001
20......	9.6465	2333.6	1011.3	4.820	+38.17	+0.028	4.848	±0.000

Part 2.—Mass Ammonia in Calorimeter, 274.72 G.

21......	9.4715	2153.1	929.0	4.456	−38.65	−0.014	4.442	+0.001
22......	9.3655	2175.0	941.2	4.491	−29.23	−0.015	4.476	+0.003
23......	9.267	2196.1	952.4	4.527	−19.92	−0.018	4.509	+0.002
24......	9.168	2218.1	962.6	4.570	−10.70	−0.019	4.551	+0.005
25......	9.7475	2220.3	964.2	4.572	−9.37	−0.019	4.553	+0.001
26......	4.816	2236.3	972.0	4.602	−2.08	−0.019	4.583	−0.002
27......	4.776	2247.9	976.8	4.627	+2.71	−0.019	4.608	−0.002
28......	9.729	2258.0	981.7	4.646	+7.46	−0.016	4.630	−0.005
29......	9.549	2147.1	926.2	4.444	−40.89	−0.013	4.431	−0.002
30......	9.448	2169.2	938.5	4.480	−31.39	−0.015	4.465	±0.000
31......	9.3425	2191.2	949.8	4.519	−21.96	−0.018	4.501	−0.002
32......	9.237	2212.6	960.5	4.558	−12.70	−0.019	4.539	+0.002
33......	9.140	2233.9	970.5	4.599	−3.51	−0.019	4.580	+0.001
34......	9.105	2233.5	970.0	4.599	−4.00	−0.019	4.580	+0.003
35......	8.983	2253.0	979.3	4.636	+5.05	−0.018	4.618	−0.004
36......	8.8895	2274.1	988.3	4.680	+13.98	−0.014	4.666	−0.007
37......	8.7915	2296.2	996.8	4.730	+22.82	−0.002	4.728	−0.001
38......	8.707	2317.1	1005.4	4.775	+31.57	−0.015	4.790	−0.003
39......	8.697	2315.8	1004.6	4.773	+30.85	+0.013	4.786	−0.001
40......	8.5995	2337.7	1012.4	4.824	+39.49	+0.034	4.858	+0.002
41......	4.250	2356.5	1018.2	4.872	+45.92	+0.054	4.926	+0.005

are made by means of the following equation, derivation of which can be found in the original paper:[1]

$$\sigma = \frac{\Delta Q}{\Delta \theta} \frac{1}{M} - \frac{1}{\Delta \theta} \int_{\theta_1}^{\theta_2} \theta \frac{d}{d\theta} \left(\frac{Lx}{\theta} \right) d\theta.$$

ΔQ = heat added to ammonia.
$\Delta \theta$ = temperature change θ_1 to θ_2.
M = total mass in calorimeter.
L = latent heat of vaporization.
x = mass vapor in calorimeter per gram total.

The second term in this equation represents the correction for change in amount and temperature of the vapor.

The values of x, the dryness factor, or the mass of vapor per gram of ammonia in the calorimeter for each of the two fillings are shown graphically as functions of θ in Fig. 2.

MASS VAPOR IN CALORIMETER PER GRAM TOTAL

$X = \frac{\frac{V}{M} - u}{u' - u}$

$V = 502 \ cm^3$
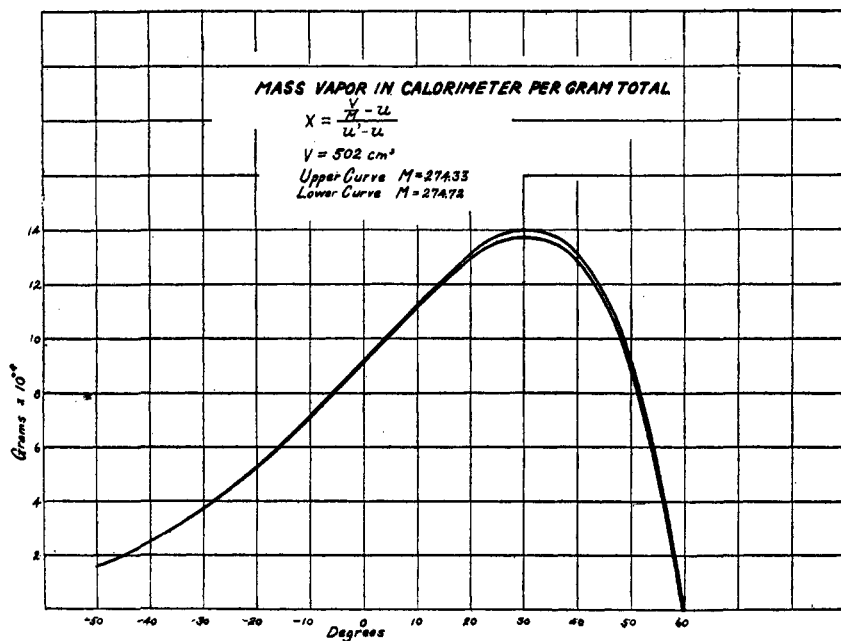
Upper Curve $M = 274.33$
Lower Curve $M = 274.72$

Fig. 2.

The value of the correction term for vapor used in the calculations of Table I was obtained graphically.

The volume V of the calorimeter was determined before the calorimeter was assembled by weighing empty and again filled with water at a known temperature. The variation in volume with temperature need not be known accurately. It was obtained from independent determinations of

[1] Bur. of Standards, *Bull.* 14, 397 (1917); *Scientific Paper* No. 313.

the change in amount of liquid ammonia contained at various temperatures and pressures.

The values for the specific volumes of ammonia liquid and vapor are preliminary values from the measurements made at this Bureau by Harper, Cragoe, and O'Connor, the final results of which will be published in a separate paper.

The values of the latent heat of vaporization are from data published under a separate title.[1]

The results of the foregoing direct measurements of the specific heat of liquid ammonia under saturation conditions may be represented by the empirical equation

$$\sigma = 3.0931 - 0.00064\theta + \frac{17.329}{\sqrt{133 - \theta}} \qquad (A)$$

in which $133°$ is taken as the temperature at the critical point. The form of this equation is discussed in Section VII.

VI. Second Method. Measurements at Constant Pressure.

The primary object of this series of measurements was to afford a check upon the accuracy of the previous series of measurements under saturation conditions. In the first method distillation in the connecting tubes might occur, thus introducing an error[2] which could not be readily evaluated. The method of measurement at constant pressure, however, in which the tubes are kept filled with liquid, eliminates this possibility. The two methods are fundamentally independent. In the first method a fixed mass of material consisting of both liquid and vapor phases is confined in the calorimeter. The relative amounts of these two phases depend upon the temperature, and corrections involving a knowledge of the specific volumes and the latent heat of vaporization are therefore necessary. In the second method the liquid phase alone entirely fills the calorimeter space, and since the thermal expansion of the material differs from that of the calorimeter itself, the amount contained varies with the temperature. It was scarcely anticipated when the second method was undertaken that it would yield results comparable in precision with the first method, on account of greater experimental difficulty, although it was expected to disclose any serious error in the first method, due to distillation in the connecting tubes. As eventually carried out, however, this method gave a precision equal to that of the first, and the possible sources of systematic error, while different from those in the first method, appeared no greater.

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[1] Osborne and Van Dusen, "Latent Heat of Vaporization of Ammonia," THIS JOURNAL, 40, 14 (1918).

[2] It is estimated that the maximum error due to this cause could not have exceeded 1 part in 1000, and that the average error was much less than this, but the comparison between the results of the two methods furnishes the most convincing evidence as to its limit.

The computations for obtaining $[C_p]_{\text{Sat.}}$ the value of the constant pressure specific heat at the saturation limit, together with the specific heat σ of the saturated liquid, are given in Table II. The computations were made by means of the following equations, derivation of which can be found in the original paper:

$$[C_p]_{\text{Sat.}} = \frac{1}{M_m}\frac{\Delta Q}{\Delta \theta} - \frac{1}{M_m}\frac{\Delta M}{\Delta \theta}C_p\lambda - \theta\frac{d}{d\theta}\left(\frac{l}{\theta}\right)_p (p - \pi)$$

$$\sigma = [C_p]_{\text{Sat.}} + [l]_{\text{Sat.}}\, d\pi/d\theta$$

C_p = specific heat of liquid at constant pressure.
M_m = mass liquid in calorimeter at mean temperature.
λ = lag of outgoing liquid.
l = latent heat of pressure variation of liquid.
p = pressure in calorimeter.
π = saturation vapor pressure.

The pressure p corresponding to saturated vapor pressures at temeratures, θ_r, in the reservoir were obtained from data for pressure of saturated ammonia vapor given by Keyes and Brownlee.[1]

The values of the latent heat of pressure variation, l, used both in the calculation of $[C_p]_{\text{Sat.}}$ and of the specific heat of the saturated liquid σ were obtained from a series of measurements described elsewhere.[2]

TABLE II.

Second Method.—Measurements of Specific Heat of Liquid Ammonia at Constant Pressure.

Calculation of Specific Heat of Saturated Liquid Ammonia.

Experiment No.	Mean temperature θ_m. °C.	Mass in calorimeter at mean temperature M_m. Grams.	Net heat added $\dfrac{1}{M_m}\dfrac{\Delta Q}{\Delta\theta}$ Joules/deg.	Corr. for heat to expelled liquid.	$-\theta\dfrac{d}{d\theta}\left(\dfrac{l}{\theta}\right)(p-\pi)$. J./g. deg.	Specific heat at const. press. $[C_p]$Sat. J./g. deg.	Heat of pressure variation $[l]_{\theta\pi}\dfrac{d\pi}{d\theta}$ J./g. deg.	Specific heat at saturation, σ. J./g. deg.	Derivations from Equation B. J./g. deg.
42	−38.95	345.64	4.440	+0.005	+0.002	4.447	−0.002	4.445	−0.002
43	−26.32	337.85	4.488	+0.005	0.003	4.496	0.005	4.491	+0.002
44	−15.90	331.36	4.530	+0.005	0.003	4.538	0.008	4.530	+0.001
45	−5.94	325.14	4.571	+0.005	0.007	4.583	0.012	4.571	±0.000
46	+5.00	317.78	4.628	+0.005	0.007	4.640	0.018	4.622	−0.001
47	+14.86	310.89	4.689	+0.005	0.008	4.702	0.026	4.676	−0.002
48	+18.05	308.43	4.717	+0.005	0.004	4.726	0.029	4.697	±0.000
49	+25.29	303.21	4.769	+0.005	0.006	4.780	0.038	4.742	−0.001
50	+35.72	295.28	4.868	+0.006	0.005	4.879	0.055	4.824	+0.003

[1] "Thermodynamic Properties of Ammonia," p. 13, John Wiley & Sons, 1916.
[2] "Latent Heat of Pressure Variation of Liquid Ammonia," Bur. of Standards, Bull. 14, 433 (1917); Scientific Paper No. 314.

The values of the specific heat σ of the saturated liquid computed from the measurements made at constant pressure may be represented by the empirical equation

$$\sigma = 3.1800 - 0.00050\,\theta + \frac{16.356}{\sqrt{133 - \theta}}. \tag{B}$$

A comparison between the values of σ computed by this equation and those actually determined is given in the same table.

VII. Form of Empirical Equation for Specific Heat of the Saturated Liquid.

A form of empirical equation was sought which would closely fit the experimental data and which would also be consistent with other known physical facts. Keyes and Brownlee[1] have given an empirical equation for the specific heat of saturated liquid ammonia, the form of which they chose because "it seems probable that the heat capacity becomes infinite at the critical temperature." This conclusion appears as certain as any physical fact well can be which is not susceptible of direct experimental proof. It is, however, not of more importance than the manner of variation by which the infinite value is reached, and if used alone may easily lead to a form of empirical equation which gives the absurd result of an infinite value for the heat content of the liquid at the critical point. Therefore the limitation should also be imposed that the heat added for any finite temperature increment must be finite.

An empirical equation for σ over an extended range should, therefore, conform to two criteria in addition to adaptability to the experimental data, namely,

$$\sigma_c = \infty$$

$$\int_0^{\theta_2} \sigma d\theta =\!\!|= \infty$$

where θ_c is the temperature of the critical point.

An equation of the form $\sigma = A + B\theta + C/(\theta_c - \theta)^{\frac{1}{2}}$ has been found to meet these requirements, and has been used to represent the results of the present investigation. The equation has the further advantage of giving no real values above the critical temperature.

The form of equation used by Keyes and Brownlee[1] was found to be unsuited to represent these results; indeed, when applied to the data here given the constants found were such as to give a maximum for σ at about 100° and $-\infty$ at the critical temperature 133°.

VIII. Conclusions.

The results of the determinations by the two independent methods have been expressed by the following two empirical equations:

[1] "Thermodynamic Properties of Ammonia," John Wiley & Sons, 1916.

First method: $\sigma = 3.0931 - 0.00064\,\theta + \dfrac{17.329}{\sqrt{133-\theta}}$ (A)

Second method: $\sigma = 3.1800 - 0.00050\theta + \dfrac{16.356}{\sqrt{133-\theta}}$ (B)

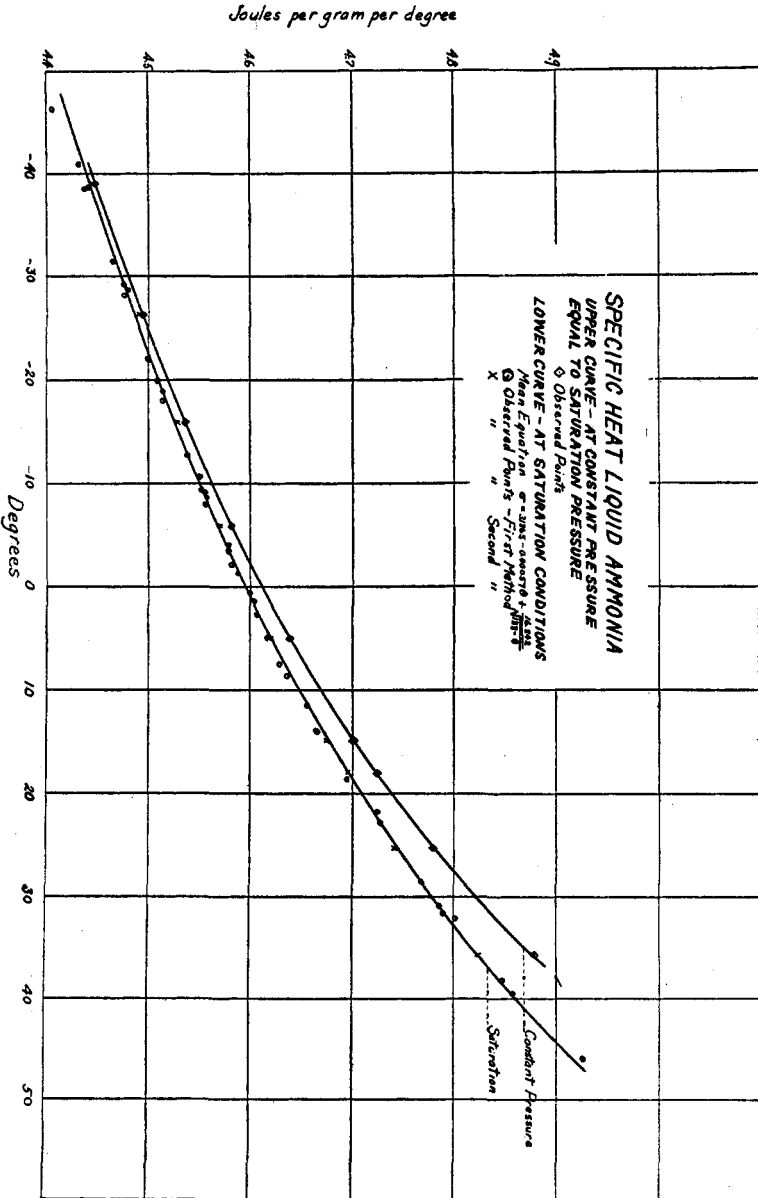where the positive value of the square root is to be used.

Fig. 3.

The agreement of the results by two methods is shown by the following values computed from the equations:

Temperature.	−40°.	−20°.	0°.	20°.	40°.
Equation A.......	4.438	4.508	4.599	4.711	4.864
Equation B.......	4.444	4.513	4.599	4.710	4.856
Mean...........	4.441	4.510	4.599	4.710	4.860

The greatest difference between the mean results by both methods and the results of either method as represented by empirical equations is seen to be less than 1 part in 1000.

In Fig. 3 the results of all the determinations by both methods are shown graphically.

The order of accuracy of the two methods seems to be about the same, with a slight advantage in favor of the second. Giving each method equal weight, the final mean value of σ in joules per gram per degree is expressed in the range −45° to +45° by the equation

$$\sigma = 3.1365 - 0.00057\,\theta + \frac{16.842}{\sqrt{133 - \theta}}. \qquad (C)$$

If the relation between the joule and the 20° calorie[1] be taken as 1 calorie$_{20}$ = 4.183 joules, the specific heat σ in Ca_{20}/g. deg., of liquid ammonia under saturation conditions is given by the equation

$$\sigma = 0.7498 - 0.000136\,\theta + \frac{4.0263}{\sqrt{133 - \theta}}. \qquad (D)$$

IX. Summary.

Using a calorimeter of the aneroid type specially designed for the peculiar conditions, the specific heat of saturated liquid ammonia has been determined throughout the temperature interval −45° to +45°.

A brief description of the instrument is given in this paper. A detailed description of the design and construction are given in a separate paper.

Two distinct and independent methods were used, each of which avoids sources of error present in the other. In the first method the heat added to a fixed amount confined in the calorimeter under saturation conditions and the resulting change in temperature are measured. By using data for the specific volumes of the two phases and the latent heat of vaporization, the corrections for the vapor are applied, giving the specific heat of the liquid kept saturated.

In the second method the calorimeter is kept full of liquid at a constant pressure. The heat added to the variable amount in the calorimeter and the resulting change in temperature are measured. A correction for the heat withdrawn in the expelled liquid is determined by special experiments.

[1] The 20° calorie is taken as the quantity of heat per gram (mass) per degree centigrade required to raise the temperature of water at 20° at normal atmospheric pressure.

By use of the data for the latent heat of pressure variation of the liquid, obtained from separate measurements, made with the same apparatus and material, the corrections for pressure variation are applied, the result being to give a second determination of the specific heat of the saturated liquid.

The greatest difference between the mean results of both methods and the results of either method as represented by empirical equations is less than 1 part in 1000.

As a final result, the specific heat σ in joules per gram per degree centigrade, of liquid ammonia, kept saturated, at the temperature θ, is given in the range $-45°$ to $+45°$ by the equation

$$\sigma = 3.1365 - 0.00057\,\theta + \frac{16.842}{\sqrt{133 - \theta}}.$$

Appendix.

TABLE III.
Specific Heat of Liquid Ammonia under Saturation Conditions.
Expressed in Calories$_{20}$ per G. per Degree.

Temp. °.	0.	1	2.	3.	4.	5.	6.	7.	8.	9.
—40	1.062	1.061	1.060	1.059	0.058	1.058	1.057	1.056	1.055	1.055
—30	1.070	1.069	1.068	1.067	1.066	1.065	1.064	1.064	1.063	1.062
—20	1.078	1.077	1.076	1.075	1.074	1.074	1.073	1.072	1.071	1.070
—10	1.088	1.087	1.086	1.085	1.084	1.083	1.082	1.081	1.080	1.079
—0	1.099	1.098	1.097	1.096	1.094	1.093	1.092	1.091	1.090	1.089
+0	1.099	1.100	1.101	1.103	1.104	1.105	1.106	1.108	1.109	1.110
+10	1.112	1.113	1.114	1.116	1.117	1.118	1.120	1.122	1.123	1.125
+20	1.126	1.128	1.129	1.131	1.132	1.134	1.136	1.137	1.139	1.141
+30	1.142	1.144	1.146	1.148	1.150	1.152	1.154	1.156	1.158	1.160
+40	1.162	1.164	1.166	1.169	1.171	1.173	1.176	1.178	1.181	1.183

TABLE IV.
Heat Content of Saturated Liquid Ammonia.[1]
Calories per G.

Temp.°.	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
—40	—43.3	—44.3	—45.4	—46.4	—47.5	—48.6	—49.6	—50.7	—51.7	—52.8
—30	32.6	33.6	34.7	35.8	36.8	37.9	39.0	40.0	41.1	42.2
—20	21.8	22.9	24.0	25.1	26.2	27.2	28.3	29.3	30.4	31.5
—10	11.0	12.1	13.1	14.2	15.3	16.4	17.5	18.6	19.7	20.8
—0	0.0	1.0	2.2	3.3	4.4	5.5	6.6	7.7	8.8	9.9
+0	+0.0	+1.1	+2.2	+3.3	+4.4	+5.5	+6.7	+7.8	+8.9	+10.0
+10	11.1	12.2	13.4	14.5	15.6	16.7	17.9	19.0	20.1	21.3
+20	22.4	23.5	24.7	25.8	27.0	28.1	29.3	30.4	31.6	32.7
+30	33.9	35.0	36.2	37.4	38.5	39.7	40.8	42.0	43.2	44.4
+40	45.5	46.7	47.9	49.1	50.3	51.5	52.7	53.8	55.0	56.2

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[1] Heat content as used here is defined by the relation
$$H = \epsilon + pv$$
where H = heat content, taken as zero at the temperature of melting ice, ϵ = internal or "intrinsic" energy, and H, ϵ, and pv are all expressed in the same units.
[Reckoned from the temperature of melting ice.]