

Thermal conductivity of liquids: Aliphatic amines

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THERMAL CONDUCTIVITY OF LIQUIDS: ALIPHATIC AMINES

CONTENTS

	Page
1. INTRODUCTION	1
2. NOTATION AND UNITS	1
3. CONVERSION FACTORS	2
4. THERMAL CONDUCTIVITY	2
4.1 Thermal Conductivity at Saturation Pressure	2
4.2 Effect of Pressure	3
5. EXPLANATION OF TABLES	3
6. REFERENCES	4
7. TABLES	5
TABLE 7.1 Constants for Equation (4.2)	5

Data sheets for each of the liquids are given in the following order:-

Formula	Name	Alternative Name(s)
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PRIMARY ALKYLAMINES

1. CH_3NH_2	Methanamine	Methanamine Aminomethane	7
2. $\text{CH}_3\text{CH}_2\text{NH}_2$	Ethanamine	Ethanamine Aminoethane	8
3. $\text{CH}_3[\text{CH}_2]_2\text{NH}_2$	1-Propanamine	1-Propanamine Propylamine 1-Aminopropane	9
4. $(\text{CH}_3)_2\text{CHNH}_2$	2-Propanamine	2-Propanamine Isopropylamine 2-Aminopropane	10
5. $\text{CH}_3[\text{CH}_2]_3\text{NH}_2$	1-Butanamine	1-Butanamine Butylamine 1-Aminobutane	11
6. $\text{CH}_3[\text{CH}_2]_4\text{NH}_2$	1-Pentanamine	1-Pentanamine Pentylamine Amylamine 1-Aminopentane	12
7. $\text{CH}_3[\text{CH}_2]_5\text{NH}_2$	1-Hexanamine	1-Hexanamine Hexylamine 1-Aminohexane	13
8. $\text{CH}_3[\text{CH}_2]_6\text{NH}_2$	1-Heptanamine	1-Heptanamine Heptylamine 1-Aminoheptane	14
9. $\text{CH}_3[\text{CH}_2]_7\text{NH}_2$	1-Octanamine	1-Octanamine Octylamine 1-Aminooctane	15
10. $\text{CH}_3[\text{CH}_2]_8\text{NH}_2$	1-Nonanamine	1-Nonanamine Nonylamine 1-Aminononane	16

Formula	Name	Alternative Name(s)	
11. $\text{CH}_3[\text{CH}_2]_9\text{NH}_2$	1-Decanamine	Decylamine	17
		1-Aminodecane	
12. $\text{CH}_3[\text{CH}_2]_{10}\text{NH}_2$	1-Undecanamine	Undecylamine	18
		1-Aminoundecane	
13. $\text{CH}_3[\text{CH}_2]_{11}\text{NH}_2$	1-Dodecanamine	Dodecylamine	19
		Laurylamine	
		1-Aminododecane	
14. $\text{CH}_3[\text{CH}_2]_{12}\text{NH}_2$	1-Tridecanamine	Tridecylamine	20
		1-Aminotridecane	
15. $\text{CH}_3[\text{CH}_2]_{13}\text{NH}_2$	1-Tetradecanamine	Tetradecylamine	21
		1-Aminotetradecane	
16. $\text{CH}_3[\text{CH}_2]_{14}\text{NH}_2$	1-Pentadecanamine	Pentadecylamine	22
		1-Aminopentadecane	
17. $\text{CH}_3[\text{CH}_2]_{15}\text{NH}_2$	1-Hexadecanamine	Hexadecylamine	23
		1-Aminohexadecane	
18. $\text{CH}_3[\text{CH}_2]_{16}\text{NH}_2$	1-Heptadecanamine	Heptadecylamine	24
		1-Aminoheptadecane	
19. $\text{CH}_3[\text{CH}_2]_{17}\text{NH}_2$	1-Octadecanamine	Octadecylamine	25
		1-Aminooctadecane	

SECONDARY ALKYLAMINES

20. $(\text{CH}_3)_2\text{NH}$	<i>N</i> -Methylmethanamine	Dimethylamine	26
		(Methylamino)methane	
21. $(\text{CH}_3\text{CH}_2)_2\text{NH}$	<i>N</i> -Ethylethanamine	Diethylamine	27
		(Ethylamino)ethane	
22. $(\text{CH}_3[\text{CH}_2]_2)_2\text{NH}$	<i>N</i> -Propyl-1-propanamine	Dipropylamine	28
		1-(Propylamino)propane	
23. $((\text{CH}_3)_2\text{CH})_2\text{NH}$	<i>N</i> -(1-Methylethyl)-2-propanamine	Diisopropylamine	29
		2-((1-Methylethyl)amino)propane	
24. $(\text{CH}_3[\text{CH}_2]_3)_2\text{NH}$	<i>N</i> -Butyl-1-butanamine	Dibutylamine	30
		1-(Butylamino)butane	

TERTIARY ALKYLAMINES

25. $(\text{CH}_3)_3\text{N}$	<i>N,N</i> -Dimethylmethanamine	Trimethylamine	31
		(Dimethylamino)methane	
26. $(\text{CH}_3\text{CH}_2)_3\text{N}$	<i>N,N</i> -Diethylethanamine	Triethylamine	32
		(Diethylamino)ethane	
27. $(\text{CH}_3[\text{CH}_2]_2)_3\text{N}$	<i>N,N</i> -Dipropyl-1-propanamine	Tripropylamine	33
		1-(Dipropylamino)propane	
28. $((\text{CH}_3)_2\text{CH})_3\text{N}$	<i>N,N</i> -Bis(1-methylethyl)-2-propanamine	Triisopropylamine	34
		2-(Bis(1-methylethyl)amino)propane	
29. $(\text{CH}_3[\text{CH}_2]_3)_3\text{N}$	<i>N,N</i> -Dibutyl-1-butanamine	Tributylamine	35
		1-(Dibutylamino)butane	

ALKENYLAMINES

30. $\text{H}_2\text{C}=\text{CHCH}_2\text{NH}_2$	1-Prop-2-enamine	3-Aminoprop-1-ene	36
		1-Aminoprop-2-ene	
		Allylamine	

THERMAL CONDUCTIVITY OF LIQUIDS: ALIPHATIC AMINES

1. INTRODUCTION

This Item presents values of thermal conductivity at saturation pressure, in tabular form, for liquid aliphatic amines.

The data on which these recommended values of thermal conductivity are based are the most reliable available and the temperature range covered is from the melting temperature to approximately 0.9 of the critical temperature. Quantities are expressed in SI units and conversion factors to other units are provided in Section 3.

Section 4 describes the procedure used to obtain the values of thermal conductivity presented and indicates the effect of pressure. Section 5 gives an explanation of the Tables and indicates the uncertainties in the values presented in them.

References to sources of supplementary information are given in Section 6. The data sources for each particular compound are listed on the appropriate data sheet.

2. NOTATION AND UNITS

The SI unit of thermal conductivity is the watt per metre kelvin (W/m K). A convenient submultiple SI unit for the range of thermal conductivity in this Item is the milliwatt per metre kelvin (mW/m K); hence that is the unit adopted here.

A	constant for each liquid in Equation (4.2)	mW/m K
A'	constant for each liquid in Equation (4.1)	mW/m K
B, C, D	non-dimensional constants for each liquid in Equation (4.2)	–
p	pressure	N/m ² (Pa)
T	kelvin temperature	K
t	Celsius temperature, $T - 273.15$	°C
λ	thermal conductivity	mW/m K

Subscripts

c	denotes value at the critical point
p	denotes value at pressure p
r	denotes reduced quantity, <i>e.g.</i> $T_r = T/T_c$.

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3. CONVERSION FACTORS

$$\begin{aligned}
 1 \text{ mW/m K} &= 0.8598 \times 10^{-3} \text{ kcal/m h } ^\circ\text{C}^* \\
 &= 2.3885 \times 10^{-6} \text{ cal/cm s } ^\circ\text{C}^* \\
 &= 0.5778 \times 10^{-3} \text{ Chu/ft h } ^\circ\text{C}^* \\
 &= 0.5778 \times 10^{-3} \text{ Btu/ft h } ^\circ\text{F}^* \\
 &= 6.9335 \times 10^{-3} \text{ Btu in/ft}^2 \text{ h } ^\circ\text{F}^*
 \end{aligned}$$

$$\begin{aligned}
 10^5 \text{ N/m}^2 &= 1 \text{ bar} \\
 &= 14.5038 \text{ lbf/in}^2 \\
 &= 1.0197 \text{ kgf/cm}^2 \\
 &= 0.9869 \text{ atm} \\
 &= 750.062 \text{ mmHg.}
 \end{aligned}$$

* The values used for the calorie and British Thermal Unit are International Table values.

4. THERMAL CONDUCTIVITY

4.1 Thermal Conductivity at Saturation Pressure

In Reference 2 Riedel showed that the experimental data for the thermal conductivity of normal (that is unassociated) liquids along the saturation line could be represented by the equation:

$$\lambda = A'[1 + (20/3)(1 - T_r)^{2/3}]. \quad (4.1)$$

The range of applicability of Equation (4.1) is limited for most compounds. For the liquids considered in this Item a good representation of the data* between the melting temperature and $T_r = 0.9$ is obtained from the equation:

$$\lambda = A[1 + B(1 - T_r)^{1/3} + C(1 - T_r)^{2/3} + D(1 - T_r)]. \quad (4.2)$$

Measurements of thermal conductivity have been made for relatively few liquids at $T_r > 0.9$ and so, because of the uncertain variation of thermal conductivity in the critical region, data are presented only for temperatures up to $T_r = 0.9$. The equation extrapolates in a physically realistic manner to within a few kelvin of the critical point.

The critical temperatures for these compounds have either been taken from ESDU 97012, 97014 (References 9 and 10) or estimated from correlations of ESDU values with chemical structure. In this Item, the critical temperatures should be regarded as correlating parameters only and should not be taken as a source of accurate values.

The derived values of A , B , C and D given in Table 7.1 are a correlated set of values giving the best fit to the experimental data, not only as individual compounds but also as members of their chemical series. This method of correlating data for a series of compounds has been described in References 5 and 6. For

* Experimental data at temperatures below the normal boiling temperature, t_b are often at 1 atm pressure. As indicated in Section 4.2 the difference between values of λ at 1 atm pressure and at saturation pressure below t_b is not significant.

the primary and secondary amines in this Item, it was found that B , C and D could be held constant,* as was observed for other liquids exhibiting hydrogen bonding such as the alcohols. For the tertiary amines in this Item, it was found that C and D are directly related to $B^\dagger$, as was observed for other non-hydrogen-bonded compounds such as the alkanes. Correlated values of the constants A , B , C and D were used to estimate constants for the majority of the liquids, for which no experimental data exist. Using these values with the values of T_c given in Table 7.1, values of λ in mW/m K have been calculated for each compound from Equation (4.2) and are presented in the data sheets.

4.2 Effect of Pressure

At temperatures up to the normal boiling point, the effect of pressure from the saturation pressure to $50 \times 10^5 \text{ N/m}^2$ (up to 50 atm) is to increase the thermal conductivity by approximately 1 per cent and, for most practical purposes, values at saturation pressure may be taken as equal to those at atmospheric pressure.

Reference 1 gives measurements of thermal conductivity for a number of liquids up to $12\,000 \times 10^5 \text{ N/m}^2$ ($\approx 12\,000$ atm) at 30 °C and 75 °C. A generalised correlation of these results is given in Reference 3, but a knowledge of the critical pressure of the substance is required for its use.

For pressures up to $500 \times 10^5 \text{ N/m}^2$ (≈ 500 atm) between the melting temperature and the normal boiling point a very approximate relationship:

$$\lambda_p/\lambda \approx 1 + 0.2p \times 10^{-8}, \quad (4.3)$$

may be used where λ_p is the thermal conductivity at pressure p and λ is the thermal conductivity at a pressure of 10^5 N/m^2 (≈ 1 atm), both at the same temperature.

5. EXPLANATION OF TABLES

The constants of Equation (4.2) are given in Table 7.1 and on the data sheets. Values of the thermal conductivity are given in the data sheets at 10 kelvin intervals in K and °C, from within 10 kelvin of the melting temperature, or an appropriate starting temperature where the melting temperature is unknown, to a temperature corresponding with $T_r \approx 0.9$.

The sources are given in the data sheets and extrapolated values are indicated in parentheses.

For uniformity and ease of interpolation the data are presented and can be read to more significant digits than is warranted by their estimated accuracy.

The experimental data from the most reliable individual sources have a repeatability of about ± 1 per cent although differences in technique used by different workers (and possibly also in the purity of samples) can increase the uncertainty in the absolute values to about ± 2 per cent. However, such reliable data are not available for all the compounds considered, nor over the whole temperature range covered. Although it is considered that the correlation procedures adopted keep the errors in the values presented to a minimum, the user should in general allow for an uncertainty of ± 5 per cent unless the value in the data sheet is truncated to a whole number. Where whole numbers are given the uncertainty increases to ± 10 per cent.

Some fluids have poor thermal stability coupled with a high critical temperature. Values have been tabulated for all fluids up to $T_r \approx 0.9$ but many of these fluids will decompose at elevated temperatures. As most

* $B = 3.0$, $C = -6.5$ and $D = 5.4$ (primary amines) or 7.5 (secondary amines).

† $C = 1 - 3B$ and $D = 3B$.

compounds will decompose rapidly at temperatures above about 300 °C, uncertainties of greater than ± 10 per cent may occur for temperatures ≥ 573 K.

6. REFERENCES

The references given are recommended sources of information supplementary to that in this Item.

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7. BSI *Recommendations for names for chemicals used in industry*. British Standards Institution, BS 2474, 1983.
8. HMSO *A guide to the tariff classification of chemicals in the combined nomenclature*. HMSO, London, UK, 1991.
9. ESDU Vapour pressures and critical points of liquids: Aliphatic and alicyclic amines Part I. Primary amines. Data Item 97012, ESDU International plc, London, UK, 1997.
10. ESDU Vapour pressures and critical points of liquids: Aliphatic and alicyclic amines Part II. Secondary and tertiary amines. Data Item 97014, ESDU International plc, London, UK, 1997.

7. TABLES

TABLE 7.1 Constants for Equation (4.2)

Compound	T_c K	A mW/m K	B	C	D	Range of Applicability °C
1. Methanamine	430.7	116.7	3.0	-6.5	5.4	-90 to 120
2. Ethanamine	456.2	104.8	3.0	-6.5	5.4	-80 to 150
3. 1-Propanamine	497.	93.9	3.0	-6.5	5.4	-80 to 180
4. 2-Propanamine	471.9	78.2	3.0	-6.5	5.4	-100 to 160
5. 1-Butanamine	531.9	84.7	3.0	-6.5	5.4	-50 to 210
6. 1-Pentanamine	561.	80.4	3.0	-6.5	5.4	-60 to 240
7. 1-Hexanamine	588.	77.1	3.0	-6.5	5.4	-20 to 260
8. 1-Heptanamine	613.	74.9	3.0	-6.5	5.4	-20 to 290
9. 1-Octanamine	635.	73.8	3.0	-6.5	5.4	0 to 310
10. 1-Nonanamine	655.	73.8	3.0	-6.5	5.4	0 to 320
11. 1-Decanamine	674.	74.1	3.0	-6.5	5.4	20 to 340
12. 1-Undecanamine	691.	74.9	3.0	-6.5	5.4	10 to 360
13. 1-Dodecanamine	707.	75.7	3.0	-6.5	5.4	30 to 370
14. 1-Tridecanamine	722.	76.8	3.0	-6.5	5.4	30 to 380
15. 1-Tetradecanamine	736.	77.9	3.0	-6.5	5.4	40 to 400
16. 1-Pentadecanamine	749.	79.0	3.0	-6.5	5.4	40 to 410
17. 1-Hexadecanamine	761.	79.8	3.0	-6.5	5.4	40 to 420
18. 1-Heptadecanamine	772.	80.4	3.0	-6.5	5.4	40 to 430
19. 1-Octadecanamine	782.	80.9	3.0	-6.5	5.4	50 to 440
20. <i>N</i> -Methylmethanamine	437.22	60.0	3.0	-6.5	7.5	-90 to 130
21. <i>N</i> -Ethylethanamine	496.65	50.3	3.0	-6.5	7.5	-50 to 180
22. <i>N</i> -Propyl-1-propanamine	550.	44.7	3.0	-6.5	7.5	-60 to 230
23. <i>N</i> -(1-Methylethyl)-2-propanamine	526.	39.9	3.0	-6.5	7.5	-100 to 210
24. <i>N</i> -Butyl-1-butanamine	602.	42.9	3.0	-6.5	7.5	-60 to 280
25. <i>N,N</i> -Dimethylmethanamine	432.79	57.7	2.3	-5.9	6.9	-120 to 120
26. <i>N,N</i> -Diethylethanamine	535.6	54.2	1.7	-4.1	5.1	-120 to 220
27. <i>N,N</i> -Dipropyl-1-propanamine	597.	55.4	1.2	-2.6	3.6	-90 to 270
28. <i>N,N</i> -Bis(1-methylethyl)-2-propanamine	670.	53.3	1.2	-2.6	3.6	-100 to 340
29. <i>N,N</i> -Dibutyl-1-butanamine	650.	57.7	0.9	-1.7	2.7	-50 to 320
30. 1-Prop-2-enamine	507.	100.0	3.0	-6.5	5.4	-90 to 190

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CH₃NH₂ METHANAMINE (METHYLAMINE, AMINOMETHANE)

$$\lambda = A[1 + B(1 - T_r)^{1/3} + C(1 - T_r)^{2/3} + D(1 - T_r)]$$

where

λ = thermal conductivity at saturation pressure (mW/m K)

$T_r = T/T_c$, T = temperature (K)

$T_c = 430.7$ K

$A = 116.7$, $B = 3.0$, $C = -6.5$, $D = 5.4$

T K	λ mW/m K	T K	λ mW/m K	t °C	λ mW/m K	t °C	λ mW/m K
180	(247.)	290	(204.)	-90	(246.)	20	203.
190	(243.)	300	201.	-80	(241.)	30	200.
200	(238.)	310	198.	-70	(237.)	40	197.
210	(234.)	320	195.	-60	(233.)	50	194.
220	(230.)	330	192.	-50	(229.)	60	191.
230	(226.)	340	189.	-40	(225.)	70	188.
240	(222.)	350	187.	-30	(221.)	80	186.
250	(218.)	360	184.	-20	(217.)	90	184.
260	(214.)	370	182.	-10	(213.)	100	182.
270	(211.)	380	180.	0	(210.)	110	180.
280	(207.)	390	178.	10	(206.)	120	178.

*FEDOSOV, V.

Teplofiz. Vys. Temp., Vol. 18, No. 6, pp. 1324-1326, 1980.

* The recommended data agree with the trends for other members of the series and with data for other liquids that exhibit hydrogen bonding, such as the alcohols. They do not however agree with Fedosov's published values.

CH₃CH₂NH₂ ETHANAMINE (ETHYLAMINE, AMINOETHANE)

$$\lambda = A[1 + B(1 - T_r)^{1/3} + C(1 - T_r)^{2/3} + D(1 - T_r)]$$

where

λ = thermal conductivity at saturation pressure (mW/m K)

$T_r = T/T_c$, T = temperature (K)

$T_c = 456.2$ K

$A = 104.8$, $B = 3.0$, $C = -6.5$, $D = 5.4$

T K	λ mW/m K	T K	λ mW/m K	t °C	λ mW/m K	t °C	λ mW/m K
190	(222.)	310	(182.)	-80	(221.)	40	(181.)
200	(218.)	320	(180.)	-70	(217.)	50	(179.)
210	(215.)	330	(177.)	-60	(214.)	60	(176.)
220	(211.)	340	(175.)	-50	(210.)	70	(174.)
230	(208.)	350	(172.)	-40	(206.)	80	(171.)
240	(204.)	360	(170.)	-30	(203.)	90	(169.)
250	(201.)	370	(168.)	-20	(200.)	100	(167.)
260	(197.)	380	(166.)	-10	(196.)	110	(165.)
270	(194.)	390	(164.)	0	(193.)	120	(163.)
280	(191.)	400	(162.)	10	(190.)	130	(162.)
290	(188.)	410	(161.)	20	(187.)	140	(160.)
300	(185.)	420	(159.)	30	(184.)	150	(158.)

CH₃[CH₂]₂NH₂ 1-PROPANAMINE (PROPYLAMINE, 1-AMINOPROPANE)

$$\lambda = A[1 + B(1 - T_r)^{1/3} + C(1 - T_r)^{2/3} + D(1 - T_r)]$$

where

λ = thermal conductivity at saturation pressure (mW/m K)

$T_r = T/T_c$, T = temperature (K)

$T_c = 497. \text{ K}$

$A = 93.9$, $B = 3.0$, $C = -6.5$, $D = 5.4$

T K	λ mW/m K	T K	λ mW/m K	t °C	λ mW/m K	t °C	λ mW/m K
190	(204.)	330	(165.1)	-80	(203.)	60	(164.4)
200	(201.)	340	(162.8)	-70	(200.)	70	(162.1)
210	(198.)	350	(160.6)	-60	(197.)	80	(159.9)
220	(195.)	360	(158.5)	-50	194.0	90	(157.8)
230	192.0	370	(156.5)	-40	191.0	100	(155.8)
240	189.0	380	(155.)	-30	188.1	110	(154.)
250	186.1	390	(153.)	-20	185.2	120	(152.)
260	183.2	400	(151.)	-10	182.4	130	(150.)
270	180.5	410	(149.)	0	179.6	140	(149.)
280	177.7	420	(148.)	10	176.9	150	(147.)
290	175.1	430	(146.)	20	174.2	160	(146.)
300	(172.5)	440	(145.)	30	(171.7)	170	(144.)
310	(169.9)	450	(144.)	40	(169.2)	180	(143.)
320	(167.5)			50	(166.7)		

SCHUHMANN, H.
MARKEFSKI, M.
LAABS, R.

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