Institute for Physical Science and Technology

University of Maryland
College Park

The Thermal Conductivity of Steam in the Zero Density Limit as a Function of Temperature

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J. V. Sengers and R. S. Basu

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zero density limit as a function of temperature†

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1. Introduction

In formulating an equation for the thermal conductivity λ of steam we consider the thermal conductivity $\lambda(\rho,T)$ as a function of the density ρ and the temperature T. The zero density thermal conductivity $\lambda_o(T)$ is defined as

$$\lambda_o(T) = \lim_{\rho\to o}\lambda(\rho,T) \tag{1}$$

At the meeting of the Special Committee of IAPS at Kyoto, Japan, 1976, we presented a preliminary analysis of $\lambda_o(T)$ for steam.[1] As pointed out in the preceding paper[1] the analysis suffered from defects. First, since the data survey compiled by the German delegation[2] did not include thermal conductivity data for water vapor below 100°C, the equation could not be reliably extrapolated to temperatures below 100°C. Secondly, in our preliminary analysis we identified $\lambda_o(T)$ with the observed thermal conductivity at atmospheric pressures, thus neglecting non-ideality effects between 0 and 1 atmosphere.

In this report we present the results of an analysis in which these two defects have been remedied.

2. Data sources

For the purpose of this analysis we considered experimental thermal conductivity data at pressures of 1 atmosphere and below. The sources of the experimental data used are listed in Table I. The actual data used in the analysis are given in the Appendix. The data are based on the data survey of Scheffler, et al.[2] In addition we included low density data below 100°C obtained by Milverton[17] as was recommended by Alexandrov and Matveev at the Kyoto meeting of the special committee.[18]

Table I

Sources of Experimental Data

Code		References
1120	Timrot	3
1130	Vargaftik	4
1100	Vargaftik	5
1200	Vargaftik	6
1310	Vargaftik	7
1260	Venart	8
1320	Brain	9
1450	Mashirow	10
1360	LeNeindre	11
1380	Brain	12
1440	Bury	13
1410	LeNeindre	14
1430	Tarzimanow	15
1470	Vargaftik	16
	Milverton	17

We considered the initial density dependence of the thermal conductivity and applied a correction for the difference between the thermal conductivity at the density measured and the thermal conductivity in the zero density limit. This correction turned out to be significant at temperatures below 300°C. Data corrected for this density dependence are labeled with an asterisk in the Appendix.

3. Results of Analysis

The data listed in the Appendix were fitted to an equation of the form

$$\lambda = \sqrt{T}\,[\sum_{k=o}^{n} a_k T^{-k}]^{-1} \tag{2}$$

where T represents the temperature in Kelvin. This equation is of the same form as that used for the adopted representation of the viscosity of steam[19] and was recommended at the Kyoto meeting of the Special Committee as the most appropriate one. In fitting the equation to the experimental data we assumed that all data had the same relative error. Specifically, in fitting λ we used as weights $(100/\lambda)^2$ so that the standard deviation σ was returned as a percentage.

In Table II we present the residual standard deviation σ as a function of the number of terms retained in the equation. The minimum standard deviation is obtained for n = 4. However, the reduction in the standard deviation when going from n = 3 to n = 4 is quite small. We give here the values for the coefficients for both n = 3 and n = 4.

Table II

Standard deviation as a function of number of terms in equation (2)

n = 2	σ = 1.70%
n = 3	σ = 1.48%
n = 4	σ = 1.46%
n = 5	σ = 1.46%
n = 6	σ = 1.46%

Sengers 1:

$$\lambda_o(T) = \sqrt{T}\left[a_o + \frac{a_1}{T} + \frac{a_2}{T^2} + \frac{a_3}{T^3}\right]^{-1} \times 10^{-3} \tag{3a}$$

with

$$\begin{aligned} a_o &= +0.1101535 \\ a_1 &= +0.1095266 \times 10^3 \\ a_2 &= +0.1339522 \times 10^6 \\ a_3 &= -0.02874601 \times 10^9 \end{aligned} \tag{3b}$$

Sengers 2:

$$\lambda_o(T) = \sqrt{T}\left[a_o + \frac{a_1}{T} + \frac{a_2}{T^2} + \frac{a_3}{T^3} + \frac{a_4}{T^4}\right]^{-1} \times 10^{-3} \tag{4a}$$

with

$$\begin{aligned} a_o &= -0.0391792 \\ a_1 &= +0.4964565 \times 10^3 \\ a_2 &= -0.2216254 \times 10^6 \\ a_3 &= +0.1091682 \times 10^9 \\ a_4 &= -0.1914082 \times 10^{11} \end{aligned} \tag{4b}$$

where $\lambda_o(T)$ is expressed in W/mK. A plot of the deviations $(\lambda_{exp} - \lambda_{calc})/\lambda_{exp}$ for equation (3) is presented in Fig. 1 and for equation (4) in Fig. 2. Both equations represent the zero density thermal conductivity within the estimated experimental error of 2% to 3%. Equation (3) has the advantage that it is simple and that it preserves the analogy with the equation adopted for the viscosity.[19]

A similar equation was proposed by Alexandrov and Matveev[18]

Alexandrov:

$$\lambda_o(T) = \sqrt{T}[a_o + \frac{a_1}{T} + \frac{a_2}{T^2} + \frac{a_3}{T^3}]^{-1} \times 10^{-3} \tag{5a}$$

with

$a_o = +0.0514485$

$a_1 = +0.2323841 \times 10^3$

$a_2 = +0.5602307 \times 10^5$

$a_3 = -0.1392744 \times 10^8$

A plot of the deviations $(\lambda_{exp} - \lambda_{calc})/\lambda_{exp}$ for this equation is presented in Fig. 3. The deviation plot is very similar to those obtained from equations (3) and (4) except for a few data points at low temperatures. The latter difference is probably due to a different estimate of the nonideality corrections applied to the data.

Yata and Minamiyama have proposed the equation[20]

Yata:

$$\lambda_o(T) = \sqrt{T}[a_o' + a_1' T + a_2' T^2 + a_3' T^3] \times 10^3 \tag{6a}$$

with

$a_o' = +0.404097$

$a_1' = +0.181934 \times 10^{-2}$ (6b)

$a_2' = +0.146476 \times 10^{-5}$

$a_3' = -0.612237 \times 10^{-9}$

A plot of the deviations $(\lambda_{exp} - \lambda_{calc})/\lambda_{exp}$ for this equation is presented in Fig. 4. The plot reveals systematic deviations at temperatures below 300°C. We venture to suggest that these systematic deviations are due to the fact that nonideality corrections were not accounted for in fitting equation (6) to the data.

4. Conclusions

Our first choice is equation (3a) with parameters (3b) to represent $\lambda_o(T)$. Equation (5a) with parameters (5b) proposed by Alexandrov and Matveev would also be acceptable. Equation 6(a) with parameters (6b) proposed by Yata and Minamiyama leads to systematic bias at low temperatures.

Acknowledgments

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Appendix: Comparison between experimental and calculated values of λ_o.

Explanation of computer output.

Column 1: Temperature in degree C

Column 2: Temperature in Kelvin

Column 3: Values of λ_o from experimental data sources in milliwatt/m K.

Column 4: $(\lambda_{exp} - \lambda_{calc})/\lambda_{exp}$ with λ_{calc} from equation (3)

Column 5: $(\lambda_{exp} - \lambda_{calc})/\lambda_{exp}$ with λ_{calc} from equation (4)

Column 6: $(\lambda_{exp} - \lambda_{calc})/\lambda_{exp}$ with λ_{calc} from equation (5)

Column 7: $(\lambda_{exp} - \lambda_{calc})/\lambda_{exp}$ with λ_{calc} from equation (6)

Column 8: Experimental data sources.

ZERO DENSITY THERMAL CONDUCTIVITY
STEAM

DEGREE C	KELVIN	LAMBDA	SENGERS1	SENGERS2	ALEXANDROV	YATA	
1.0450000+02	3.7765000+02	*2.3350000+01	-3.2977762-02	-3.0911658-02	-3.8995927-02	-5.4552856-02	
1.4210000+02	4.1525000+02	*2.6700000+01	-1.8581281-02	-1.4937353-02	-2.9331004-02	-4.4308557-02	
1.4740000+02	4.2055000+02	*2.7500000+01	-5.7007702-03	-2.2787701-03	-1.6615130-02	-3.1140189-02	Timrot 1120
2.0040000+02	4.7355000+02	*3.2350000+01	-6.8822710-03	-6.5798222-03	-1.7902737-02	-2.8596433-02	
2.0590000+02	4.7905000+02	*3.2700000+01	-1.2597804-02	-1.2626327-02	-2.3481736-02	-3.3779596-02	
2.4780000+02	5.2095000+02	*3.7250000+01	-3.4067167-03	-5.3895399-03	-1.2036215-02	-1.8880281-02	
2.5310000+02	5.2624999+02	*3.7800000+01	-3.5659346-03	-5.7138968-03	-1.1869309-02	-1.8315795-02	
1.0450000+02	3.7765000+02	*2.3310000+01	-3.4750352-02	-3.2680702-02	-4.0778844-02	-5.6362469-02	
1.4210000+02	4.1525000+02	*2.6660000+01	-2.0109534-02	-1.6460138-02	-3.0875385-02	-4.5875410-02	
1.4740000+02	4.2055000+02	*2.7460000+01	-7.1657459-03	-3.7387610-03	-1.8096005-02	-3.2642221-02	
2.0040000+02	4.7355000+02	*3.2350000+01	-6.8822710-03	-6.5798222-03	-1.7902737-02	-2.8596433-02	
2.0590000+02	4.7905000+02	*3.2630000+01	-1.4770100-02	-1.4798684-02	-2.5677382-02	-3.5997333-02	
2.4780000+02	5.2095000+02	*3.7200000+01	-4.7553867-03	-6.7408751-03	-1.3396484-02	-2.0249749-02	
2.5310000+02	5.2624999+02	*3.9460000+01	3.8651990-02	3.6594388-02	3.0697921-02	2.4522626-02	
2.8880000+02	5.6195000+02	*4.2120000+01	7.8365786-03	5.1044670-03	1.9430888-03	-2.0141162-03	Vargaftik 1130
2.9470000+02	5.6784999+02	*4.2470000+01	6.4839524-04	-2.1269497-03	-4.8922010-03	-8.5204861-03	
3.1950000+02	5.9264999+02	4.5360000+01	2.8759504-03	2.1819295-04	-1.0047745-03	-3.2726945-03	
3.3150000+02	6.0464999+02	4.6520000+01	-1.7740351-03	-4.2817558-03	-4.8906559-03	-6.5985571-03	
3.3500000+02	6.0814999+02	4.6990000+01	-3.3706370-04	-2.7823078-03	-3.2248865-03	-4.7747240-03	
3.3650000+02	6.0964999+02	4.7100000+01	-1.6788312-03	-4.1005667-03	-4.4747978-03	-5.9614060-03	
3.5900000+02	6.3214999+02	4.9310000+01	-1.0030184-02	-1.1969783-02	-1.1446732-02	-1.2062065-02	
4.0650000+02	6.7964999+02	5.6060000+01	9.9842607-03	9.5333918-03	1.1155293-02	1.1787251-02	
4.0750000+02	6.8064999+02	5.4660000+01	-1.7604102-02	-1.8032435-02	-1.6350952-02	-1.5682918-02	
4.1300000+02	6.8614999+02	5.5820000+01	-8.4990970-03	-8.7310404-03	-6.9922250-03	-6.2350346-03	
4.7670000+02	7.4984999+02	6.6290000+01	3.0934208-02	3.2856518-02	3.4757091-02	3.5945076-02	
3.1990000+02	5.9305000+02	4.4780000+01	-1.1055498-02	-1.3745954-02	-1.4963827-02	-1.7243339-02	
4.2680000+02	6.9995000+02	5.9080000+01	1.8428449-02	1.8680055-02	2.0508009-02	2.1437648-02	
5.4780000+02	8.2094999+02	7.2450000+01	-1.3086741-02	-9.1693844-03	-7.6614206-03	-6.9327581-03	Vargaftik 1100
6.0060000+02	8.7374999+02	8.0360000+01	9.6020145-05	4.5826804-03	5.6182762-03	5.5182093-03	
7.8289999+02	1.0560500+03	1.0458000+02	-3.7715549-03	-3.9776462-03	-2.6784952-03	-6.1397548-03	
1.7690000+02	4.5005000+02	*3.1450000+01	3.5695393-02	3.7421142-02	2.4674193-02	1.2629347-02	
2.8750000+02	5.6064999+02	*4.2550000+01	2.1228981-02	1.8541524-02	1.5329749-02	1.1347043-02	
3.5680000+02	6.2995000+02	4.8700000+01	-1.7365410-02	-1.9375921-02	-1.8926274-02	-1.9624552-02	
4.5490000+02	7.2805000+02	6.0400000+01	-1.8032868-02	-1.6762555-02	-1.4743079-02	-1.3540486-02	Vargaftik 1200
5.0480000+02	7.7795000+02	6.5799999+01	-3.0802565-02	-2.7872205-02	-2.5989625-02	-2.4823114-02	
2.3060000+02	5.0375000+02	*3.6600000+01	2.7487108-02	2.6212494-02	1.8158285-02	1.0222385-02	
3.0810000+02	5.8124999+02	4.5000000+01	2.3561848-02	2.0869933-02	1.9024266-02	1.6223876-02	
3.9400000+02	6.6714999+02	5.6100000+01	3.7742605-02	3.6898280-02	3.8275735-02	3.8645569-02	
4.4220000+02	7.1534999+02	5.9500000+01	-6.7464364-03	-5.9385139-03	-3.9726305-03	-2.8635474-03	
4.8700000+02	7.6014999+02	6.4660000+01	-1.3749164-02	-1.1404889-02	-9.4550186-03	-8.2285161-03	
4.9400000+02	7.6714999+02	6.5009999+01	-2.2037226-02	-1.9454267-02	-1.7523080-02	-1.6310486-02	
6.7500000+02	9.4814999+02	8.8160000+01	-2.4420867-02	-2.0405255-02	-1.9723166-02	-2.1296382-02	
6.8000000+02	9.5314999+02	8.8969999+01	-2.2678112-02	-1.8775057-02	-1.8099692-02	-1.9771747-02	
7.8500000+02	1.0581500+03	1.0362000+02	-1.5840271-02	-1.6170495-02	-1.4825844-02	-1.8358295-02	Vargaftik 1310
9.1700000+02	1.1901500+03	1.2281000+02	-4.3342676-03	-1.5172787-02	-1.0487148-02	-1.4659964-02	
3.3740000+02	6.1055000+02	4.7100000+01	-3.6879743-03	-6.2985430-03	-6.6327238-03	-8.0837565-03	
3.4980000+02	6.2295000+02	4.9310000+01	1.1863063-02	9.7443428-03	9.9267613-03	8.9941680-03	
5.2339999+02	7.9654999+02	6.9200000+01	-1.4817784-02	-1.1433287-02	-9.7152677-03	-8.7121456-03	
5.3230000+02	8.0544999+02	7.1759999+01	5.3044945-03	8.8306707-03	1.0443186-02	1.1338598-02	
6.3139999+02	9.0454999+02	8.4549999+01	1.1111575-03	5.5749060-03	6.3995777-03	5.7260163-03	

ZERO DENSITY THERMAL CONDUCTIVITY
STEAM

DEGREE C	KELVIN	LAMBDA	SENGERS1	SENGERS2	ALEXANDROV	YATA	
6.3850000+02	9.1164999+02	8.7219999+01	2.0794900-02	2.5124835-02	2.5895615-02	2.5100135-02	
7.1820000+02	9.9134999+02	9.6530000+01	3.8338241-03	6.5697026-03	7.2882037-03	4.9228978-03	
7.2420000+02	9.9734999+02	9.8389999+01	1.4383520-02	1.6880103-02	1.7617764-02	1.5167939-02	
7.3839999+02	1.0115500+03	9.7580000+01	-1.3565686-02	-1.1579979-02	-1.0735540-02	-1.3513794-02	Vargaftik 1310
7.4550000+02	1.0186500+03	1.0188000+02	1.9706761-02	2.1349527-02	2.2218524-02	1.9410886-02	
8.2760000+02	1.1007500+03	1.1339000+02	2.0286896-02	1.7273112-02	1.9307418-02	1.5424233-02	
8.3560000+02	1.1087500+03	1.1176000+02	-3.8066760-03	-7.4811979-03	-5.2209658-03	-9.2664871-03	
8.3600000+02	1.1091500+03	1.1246000+02	1.9542013-03	-1.7289524-03	5.2735324-04	-3.4980581-03	
8.4070000+02	1.1138500+03	1.1351000+02	5.5138103-03	1.4919193-03	3.8479259-03	-1.9780067-04	
8.9620000+02	1.1693500+03	1.2235000+02	1.5191280-02	6.5568130-03	1.0435013-02	6.2710770-03	
1.3400000+02	4.0715000+02	*2.5670000+01	-3.5322532-02	-3.1471159-02	-4.5624739-02	-6.1182491-02	
1.4800000+02	4.2115000+02	*2.7800000+01	3.2623123-03	6.6307980-03	-7.5840950-03	-2.1947965-02	Venart 1260
1.5900000+02	4.3215000+02	*2.7900000+01	-2.8170753-02	-2.5228386-02	-3.9766322-02	-5.3912764-02	
2.0100000+02	4.7415000+02	*3.3350000+01	2.1552353-02	2.1810617-02	1.0862837-02	5.1914484-04	
1.4260000+02	4.1555000+02	*2.6900000+01	-1.1971360-02	-8.3594960-03	-2.2670381-02	-3.7536763-02	
1.4390000+02	4.1705000+02	*2.7600000+01	8.9900130-03	1.2482724-02	-1.5772512-03	-1.6065387-02	Brain 1320
1.5860000+02	4.3175000+02	*2.8600000+01	-1.7485585-03	1.1396658-03	-1.3036194-02	-2.6844898-02	
1.0590000+02	3.7905000+02	*2.4300000+01	2.9638078-03	5.1569939-03	-3.1239604-03	-1.8191063-02	
1.0620000+02	3.7934999+02	*2.4300000+01	2.0089071-03	4.2449299-03	-4.1432145-03	-1.9234983-02	
1.0630000+02	3.7945000+02	*2.4200000+01	-2.4348547-03	-1.7546425-04	-8.6339052-03	-2.3796233-02	
1.0630000+02	3.7945000+02	*2.4500000+01	9.8398656-03	1.2071590-02	3.7167218-03	-1.1259945-02	
1.0630000+02	3.7945000+02	*2.4300000+01	1.6903975-03	3.9404900-03	-4.4831425-03	-1.9583074-02	
1.0130000+02	3.7445000+02	*2.3800000+01	-3.1677114-03	-1.6805605-03	-8.3326792-03	-2.3297162-02	Mashirow 1450
1.0130000+02	3.7445000+02	*2.3900000+01	1.0296391-03	2.5105676-03	-4.1137181-03	-1.9015588-02	
1.0130000+02	3.7445000+02	*2.4000000+01	5.1920215-03	6.6667795-03	7.0095062-05	-1.4769683-02	
1.0130000+02	3.7445000+02	*2.4000000+01	5.1920215-03	6.6667795-03	7.0095062-05	-1.4769683-02	
1.0130000+02	3.7445000+02	*2.3900000+01	1.0296391-03	2.5105676-03	-4.1137181-03	-1.9015588-02	
1.1350000+02	3.8665000+02	*2.4400000+01	-1.7355026-02	-1.4270251-02	-2.4945707-02	-4.0496500-02	
2.3490000+02	5.0805000+02	*3.6300000+01	7.2821310-03	5.7972759-03	-2.0054221-03	-9.7674772-03	
3.1090000+02	5.8405000+02	4.4300000+01	1.0117989-03	-1.7258599-03	-3.4443358-03	-6.1590570-03	
3.1100000+02	5.8414999+02	4.4200000+01	-1.5036121-03	-4.2475079-03	-5.9643158-03	-8.6805399-03	
1.1000000+02	3.8315000+02	*2.4250000+01	-1.2258402-02	-9.5268820-03	-1.9212880-02	-3.4626597-02	
1.2000000+02	3.9315000+02	*2.5200000+01	-5.7535512-03	-2.2749390-03	-1.4221962-02	-2.9616280-02	
1.3000000+02	4.0315000+02	*2.6150000+01	-6.9589050-04	3.0274236-03	-1.0283527-02	-2.5440384-02	
1.4000000+02	4.1315000+02	*2.7100000+01	3.1247878-03	6.7438235-03	-7.2576639-03	-2.2008947-02	
1.5000000+02	4.2315000+02	*2.8000000+01	4.1077137-03	7.3921765-03	-6.8211044-03	-2.1064077-02	
1.6000000+02	4.3315000+02	*2.9000000+01	7.7243262-03	1.0510239-02	-3.4896341-03	-1.7077742-02	
1.7000000+02	4.4315000+02	*3.0000000+01	1.0424042-02	1.2623540-02	-8.9093843-04	-1.3758445-02	
1.8000000+02	4.5315000+02	*3.0950000+01	1.0730931-02	1.2305210-02	-5.5079699-04	-1.2672568-02	
1.9000000+02	4.6315000+02	*3.1900000+01	1.0441299-02	1.1381161-02	-6.7917904-04	-1.2024024-02	Le Neindre 1360
2.0000000+02	4.7315000+02	*3.2850000+01	9.6311235-03	9.9527454-03	-1.2217047-03	-1.1772420-02	
2.1000000+02	4.8315000+02	*3.3900000+01	1.1291068-02	1.1029722-02	8.2511115-04	-8.8970078-03	
2.2000000+02	4.9315000+02	*3.4950000+01	1.2386524-02	1.1592860-02	2.3759998-03	-6.5274163-03	
2.3000000+02	5.0315000+02	*3.6000000+01	1.2984448-02	1.1717240-02	3.4845670-03	-4.6169625-03	
2.4000000+02	5.1314999+02	*3.7000000+01	1.1809491-02	1.0130328-02	2.8521048-03	-4.4797433-03	
2.5000000+02	5.2314999+02	*3.8050000+01	1.1616217-02	9.5933495-03	3.2488463-03	-3.3288121-03	
2.6000000+02	5.3314999+02	*3.9100000+01	1.1076903-02	8.7775111-03	3.3255184-03	-2.5280418-03	
2.7000000+02	5.4314999+02	*4.0150000+01	1.0231097-02	7.7216148-03	3.1145839-03	-2.0475376-03	
2.8000000+02	5.5314999+02	*4.1250000+01	1.0314918-02	7.6630910-03	3.8537806-03	-6.4597852-04	
2.9000000+02	5.6314999+02	*4.2300000+01	8.9289956-03	6.1934947-03	3.1217390-03	-7.5792308-04	

ZERO DENSITY THERMAL CONDUCTIVITY
STEAM

DEGREE C	KELVIN	LAMBDA	SENGERS1	SENGERS2	ALEXANDROV	YATA	
3.0000000+02	5.7314999+02	*4.3550000+01	1.1890523-02	9.1425724-03	6.7635108-03	3.4823675-03	Le Neindre 1360
3.1000000+02	5.8314999+02	4.4700000+01	1.2221870-02	9.5092530-03	7.7565938-03	5.0248929-03	
3.2000000+02	5.9314999+02	4.5900000+01	1.3367158-02	1.0742788-02	9.5597124-03	7.3401549-03	
3.3000000+02	6.0314999+02	4.7100000+01	1.4223546-02	1.1732512-02	1.1061417-02	9.3136522-03	
1.4240000+02	4.1555000+02	*2.6900000+01	-1.1971360-02	-8.3594960-03	-2.2670381-02	-3.7536763-02	
1.4380000+02	4.1695000+02	*2.7600000+01	9.3042159-03	1.2798905-02	-1.2538917-03	-1.5742226-02	
1.5860000+02	4.3175000+02	*2.8600000+01	-1.7485585-03	1.1396658-03	-1.3036194-02	-2.6844898-02	
1.7030000+02	4.4345000+02	*2.9000000+01	-2.4652415-02	-2.2393876-02	-3.6369849-02	-4.9671148-02	
1.7060000+02	4.4375000+02	*2.9000000+01	-2.5606155-02	-2.3364503-02	-3.7335716-02	-5.0627034-02	
1.7140000+02	4.4455000+02	*2.9600000+01	-7.3114923-03	-5.1597324-03	-1.8834254-02	-3.1829702-02	
1.7160000+02	4.4475000+02	*2.9300000+01	-1.8255979-02	-1.6093490-02	-2.9904387-02	-4.3026107-02	
1.7280000+02	4.4595000+02	*2.9200000+01	-2.5545832-02	-2.3444679-02	-3.7279072-02	-5.0404121-02	
2.0590000+02	4.7905000+02	*3.2400000+01	-2.1973716-02	-2.2002503-02	-3.2958425-02	-4.3351636-02	
2.0620000+02	4.7934999+02	*3.2300000+01	-2.6052936-02	-2.6099822-02	-3.7069719-02	-4.7479148-02	
2.0720000+02	4.8034999+02	*3.2700000+01	-1.6518485-02	-1.6624118-02	-2.7393478-02	-3.7622729-02	
2.0740000+02	4.8055000+02	*3.2700000+01	-1.7122420-02	-1.7239924-02	-2.7995897-02	-3.8214532-02	
2.4620000+02	5.1934999+02	*3.7150000+01	-1.5949208-03	-3.5206884-03	-1.0305882-02	-1.7259272-02	Brain 1380
2.4660000+02	5.1974999+02	*3.7450000+01	5.3103107-03	3.3843342-03	-3.3165966-03	-1.0191774-02	
2.4690000+02	5.2005000+02	*3.7150000+01	-3.5680640-03	-5.5212994-03	-1.2253752-02	-1.9167403-02	
2.4690000+02	5.2005000+02	*3.6650000+01	-1.7259307-02	-1.9239189-02	-2.6063490-02	-3.3071461-02	
2.4760000+02	5.2074999+02	*3.6750000+01	-1.6487718-02	-1.8489708-02	-2.5242072-02	-3.2190764-02	
2.4770000+02	5.2084999+02	*3.6850000+01	-1.4013836-02	-1.6014314-02	-2.2740759-02	-2.9664848-02	
2.7640000+02	5.4955000+02	*4.0950000+01	1.2641215-02	1.0039442-02	5.9589740-03	1.2361552-03	
2.7670000+02	5.4984999+02	*4.0850000+01	9.4257107-03	6.8114758-03	2.7414226-03	-1.9770707-03	
2.7800000+02	5.5114999+02	*4.0250000+01	-8.8555708-03	-1.1534945-02	-1.5576143-02	-2.0295101-02	
2.7800000+02	5.5114999+02	*4.0650000+01	1.0716578-03	-1.5813515-03	-5.5827837-03	-1.0255307-02	
3.2880000+02	6.0195000+02	4.6300000+01	1.6683121-04	-2.3779962-03	-3.1178765-03	-4.9456870-03	
3.2880000+02	6.0195000+02	4.5900000+01	-8.5463140-03	-1.1113318-02	-1.1859647-02	-1.3703386-02	
3.2890000+02	6.0205000+02	4.5600000+01	-1.5433169-02	-1.8016173-02	-1.8762570-02	-2.0614193-02	
3.2900000+02	6.0214999+02	4.6500000+01	3.9735404-03	1.4414018-03	7.1422002-04	-1.0974330-03	
3.8790000+02	6.6105000+02	5.4400000+01	2.1199821-02	2.0146440-02	2.1428071-02	2.1664719-02	
3.8790000+02	6.6105000+02	5.4500000+01	2.2995791-02	2.1944343-02	2.3223623-02	2.3459837-02	
3.8810000+02	6.6124999+02	5.4500000+01	2.2553986-02	2.1508365-02	2.2792352-02	2.3033439-02	
3.8830000+02	6.6145000+02	5.4900000+01	2.9236980-02	2.8204753-02	2.9484023-02	2.9728191-02	
4.6780000+02	7.4095000+02	6.3800000+01	1.0768964-02	1.2439695-02	1.4399070-02	1.5607015-02	
4.6780000+02	7.4095000+02	6.3800000+01	1.0768964-02	1.2439695-02	1.4399070-02	1.5607015-02	
4.6780000+02	7.4095000+02	6.4000000+01	1.3860315-02	1.5525833-02	1.7479077-02	1.8683255-02	
6.0330000+02	8.7644999+02	8.1599999+01	1.0897494-02	1.5345730-02	1.6349542-02	1.6202798-02	
6.0330000+02	8.7644999+02	8.1500000+01	9.6838780-03	1.4137572-02	1.5142616-02	1.4995692-02	
6.0350000+02	8.7664999+02	8.2099999+01	1.6597697-02	2.1020980-02	2.2017471-02	2.1868031-02	
1.0420000+02	3.7734999+02	*2.3950000+01	-6.1365757-03	-4.1692690-03	-1.1936737-02	-2.7077452-02	
1.0800000+02	3.8115000+02	*2.4500000+01	4.4516349-03	6.9111609-03	-2.0268109-03	-1.7136690-02	
1.2100000+02	3.9415000+02	*2.5300000+01	-4.9878015-03	-1.4657088-03	-1.3582914-02	-2.8959338-02	
1.4490000+02	4.1805000+02	*2.7250000+01	-6.9253204-03	-3.4091319-03	-1.7719934-02	-3.2391461-02	
1.7270000+02	4.4584999+02	*3.0000000+01	2.1108548-03	4.1615963-03	-9.3059221-03	-2.2084395-02	Bury 1440
1.7830000+02	4.5145000+02	*3.0700000+01	7.8712768-03	9.5581930-03	-3.4583275-03	-1.5744837-02	
1.7970000+02	4.5284999+02	*3.1100000+01	1.6408779-02	1.7992944-02	5.1888392-03	-6.8861188-03	
2.0280000+02	4.7595000+02	*3.2550000+01	-7.9064289-03	-7.7497246-03	-1.8854918-02	-2.9361391-02	
2.0550000+02	4.7865000+02	*3.3350000+01	8.3191426-03	8.3144815-03	-2.3550036-03	-1.2472702-02	
2.2890000+02	5.0205000+02	*3.5400000+01	-5.6815013-04	-1.8029967-03	-1.0257373-02	-1.8558179-02	

ZERO DENSITY THERMAL CONDUCTIVITY
STEAM

DEGREE C	KELVIN	LAMBDA	SENGERS1	SENGERS2	ALEXANDROV	YATA	
2.3060000+02	5.0375000+02	*3.5900000+01	8.5244537-03	7.2249862-03	-9.8626927-04	-9.0769075-03	
2.6650000+02	5.3964999+02	*3.9500000+01	3.4833377-03	1.0224717-03	-3.9096301-03	-9.3485072-03	
2.6850000+02	5.4164999+02	*3.8800000+01	-2.0039549-02	-2.2597989-02	-2.7473919-02	-3.2899380-02	
2.8330000+02	5.5645000+02	*4.0350000+01	-2.0704364-02	-2.3473470-02	-2.7143237-02	-3.1566915-02	
2.9140000+02	5.6455000+02	*4.1800000+01	-6.6260174-03	-9.4109403-03	-1.2429878-02	-1.6284388-02	Bury 1440
3.1850000+02	5.9164999+02	4.3900000+01	-2.7695474-02	-3.0445542-02	-3.1762764-02	-3.4151631-02	
3.5680000+02	6.2995000+02	4.9000000+01	-1.1136639-02	-1.3134839-02	-1.2687946-02	-1.3381948-02	
3.7290000+02	6.4605000+02	5.0700000+01	-1.4808117-02	-1.6368390-02	-1.5409788-02	-1.5575063-02	
4.4450000+02	7.1764999+02	5.9100000+01	-1.8411909-02	-1.7511945-02	-1.5514756-02	-1.4374970-02	
4.7510000+02	7.4824999+02	6.3100000+01	-1.4841621-02	-1.2881586-02	-1.0886721-02	-9.6421612-03	
4.7570000+02	7.4884999+02	6.3100000+01	-1.6046923-02	-1.4064603-02	-1.2069028-02	-1.0823093-02	
5.1130000+02	7.8445000+02	6.7900000+01	-1.1236432-02	-8.1798430-03	-6.3770474-03	-5.2764876-03	
5.1130000+02	7.8445000+02	6.7900000+01	-1.1236432-02	-8.1798430-03	-6.3770474-03	-5.2764876-03	
4.7510000+02	7.4824999+02	6.3100000+01	-1.4841621-02	-1.2881586-02	-1.0886721-02	-9.6421612-03	
4.4450000+02	7.1764999+02	5.9100000+01	-1.8411909-02	-1.7511945-02	-1.5514756-02	-1.4374970-02	Le Neindre 1410
4.0620000+02	6.7934999+02	5.4400000+01	-1.9553488-02	-2.0028318-02	-1.8362429-02	-1.7717253-02	
3.7290000+02	6.4605000+02	4.9700000+01	-3.5226791-02	-3.6818458-02	-3.5840568-02	-3.6009169-02	
3.4860000+02	6.2174999+02	4.8400000+01	-3.8186972-03	-5.9983553-03	-5.8598164-03	-6.8533618-03	
4.2600000+02	6.9914999+02	5.7600000+01	-5.0779101-03	-4.8488047-03	-2.9835519-03	-2.0415501-03	Tarzimanow 1430
1.5678000+02	4.2993000+02	*2.8850000+01	1.2588336-02	1.5529371-02	1.5108052-03	-1.2214171-02	
1.6258000+02	4.3573000+02	*2.9600000+01	1.9959292-02	2.2569677-02	8.8330458-03	-4.4195958-03	
1.8232000+02	4.5547000+02	*3.0750000+01	-2.8111683-03	-1.3647855-03	-1.4219881-02	-2.6326916-02	
1.9215000+02	4.6530000+02	*3.2200000+01	1.3251616-02	1.4054079-02	2.2132945-03	-8.9285980-03	
3.0304000+02	5.7618999+02	*4.4450000+01	2.4254330-02	2.1545541-02	1.9390151-02	1.6318773-02	Vargaftik 1470
3.7298000+02	6.4613000+02	5.2700000+01	2.3523761-02	2.2024728-02	2.2949277-02	2.2792536-02	
4.1264000+02	6.8578999+02	5.6000000+01	-4.4705272-03	-4.7141654-03	-2.9866780-03	-2.2384609-03	
5.3750000+02	8.1064999+02	7.2000000+01	-7.6889992-04	2.8932359-03	4.4719246-03	5.3157409-03	
6.0406000+02	8.7720999+02	7.9400000+01	-1.7779804-02	-1.3200102-02	-1.2173076-02	-1.2337987-02	
6.3674000+02	9.0988999+02	8.5000000+01	-2.0068786-03	2.4370530-03	3.2349306-03	2.4553523-03	
7.2452000+02	9.9766999+02	9.6099999+01	-9.5554991-03	-7.0101116-03	-6.2529180-03	-8.7681968-03	
8.3120000+01	3.5627000+02	*2.2650000+01	4.6539517-03	1.1292409-03	4.5006901-03	-8.7619828-03	
8.4230000+01	3.5738000+02	*2.2750000+01	5.5915392-03	2.4995804-03	5.0724993-03	-8.3177692-03	
8.6440000+01	3.5959000+02	*2.2930000+01	6.5533813-03	4.2629096-03	5.3334330-03	-8.3040162-03	
8.8459999+01	3.6161000+02	*2.3220000+01	1.2722270-02	1.1110203-02	1.0902383-02	-2.8660131-03	
9.0679999+01	3.6382999+02	*2.3320000+01	1.0063626-02	9.1161266-03	7.6009111-03	-6.4203506-03	
9.2910000+01	3.6606000+02	*2.3520000+01	1.1549880-02	1.1212617-02	8.4828661-03	-5.7117469-03	
9.5139999+01	3.6829000+02	*2.3690000+01	1.1695644-02	1.1909245-02	8.0519258-03	-6.3139158-03	
7.2330000+01	3.4548000+02	*2.1750000+01	-2.6197762-03	-1.1527072-02	1.3222201-03	-1.0304878-02	Milverton
7.3440000+01	3.4659000+02	*2.1930000+01	2.2389386-03	-5.9697273-03	5.6970951-03	-6.0831419-03	
7.5639999+01	3.4879000+02	*2.2120000+01	4.1243396-03	-2.8503631-03	6.6887190-03	-5.4609064-03	
7.7639999+01	3.5079000+02	*2.2320000+01	6.9561077-03	1.0207562-03	8.7446315-03	-3.7001025-03	
7.9860000+01	3.5300999+02	*2.2480000+01	7.2352827-03	2.3443610-03	8.2087793-03	-4.5712202-03	
8.2080000+01	3.5523000+02	*2.2650000+01	7.8721393-03	3.9395381-03	8.0697058-03	-5.0133164-03	
8.4299999+01	3.5745000+02	*2.2780000+01	6.6840303-03	3.6218796-03	6.1427950-03	-7.2413834-03	

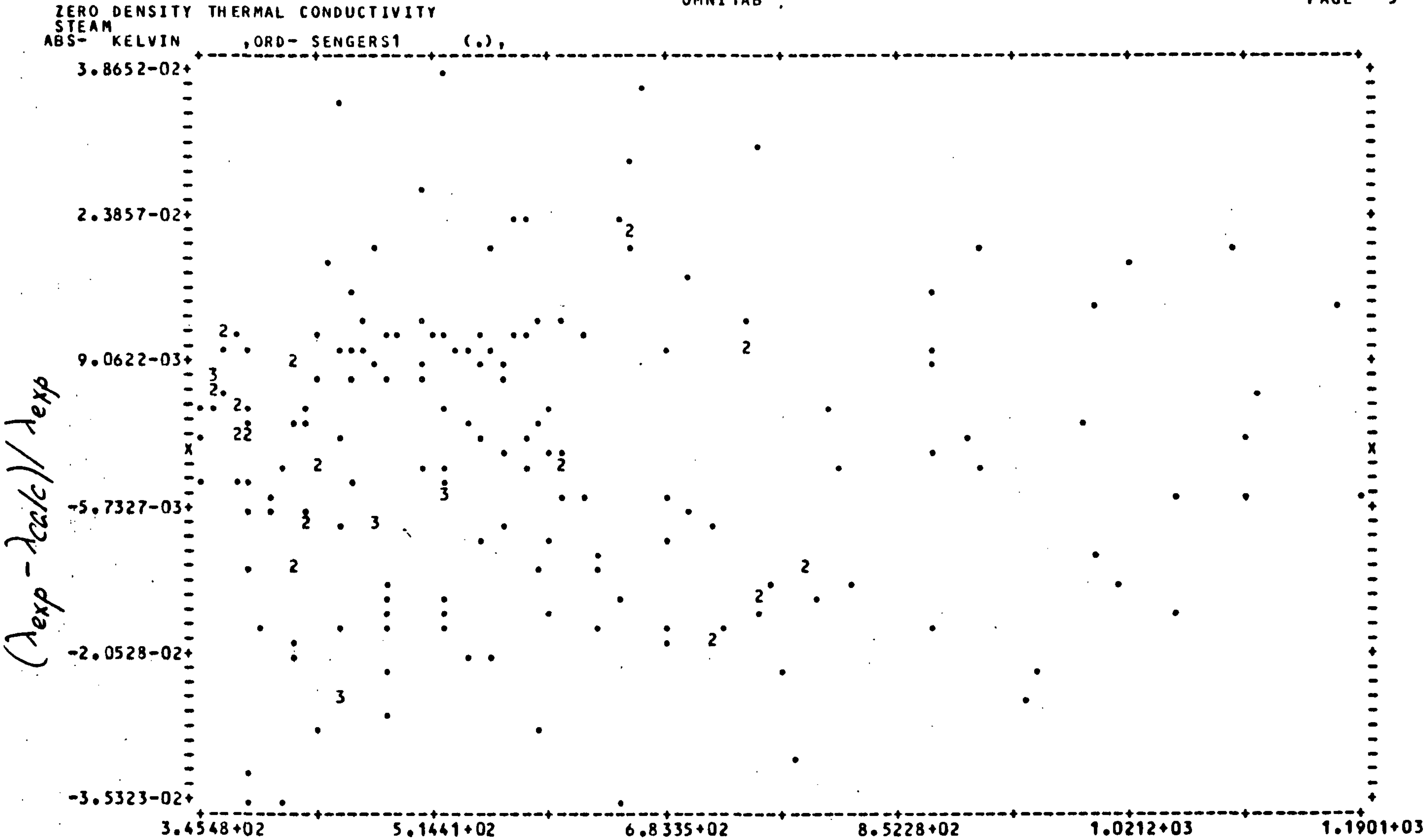

Fig. 1. $\dfrac{\lambda_{exp} - \lambda_{calc}}{\lambda_{exp}}$ versus T with λ_{calc} from equation (3)

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ZERO DENSITY THERMAL CONDUCTIVITY
STEAM
ABS- KELVIN ,ORD- SENGERS2 (.),

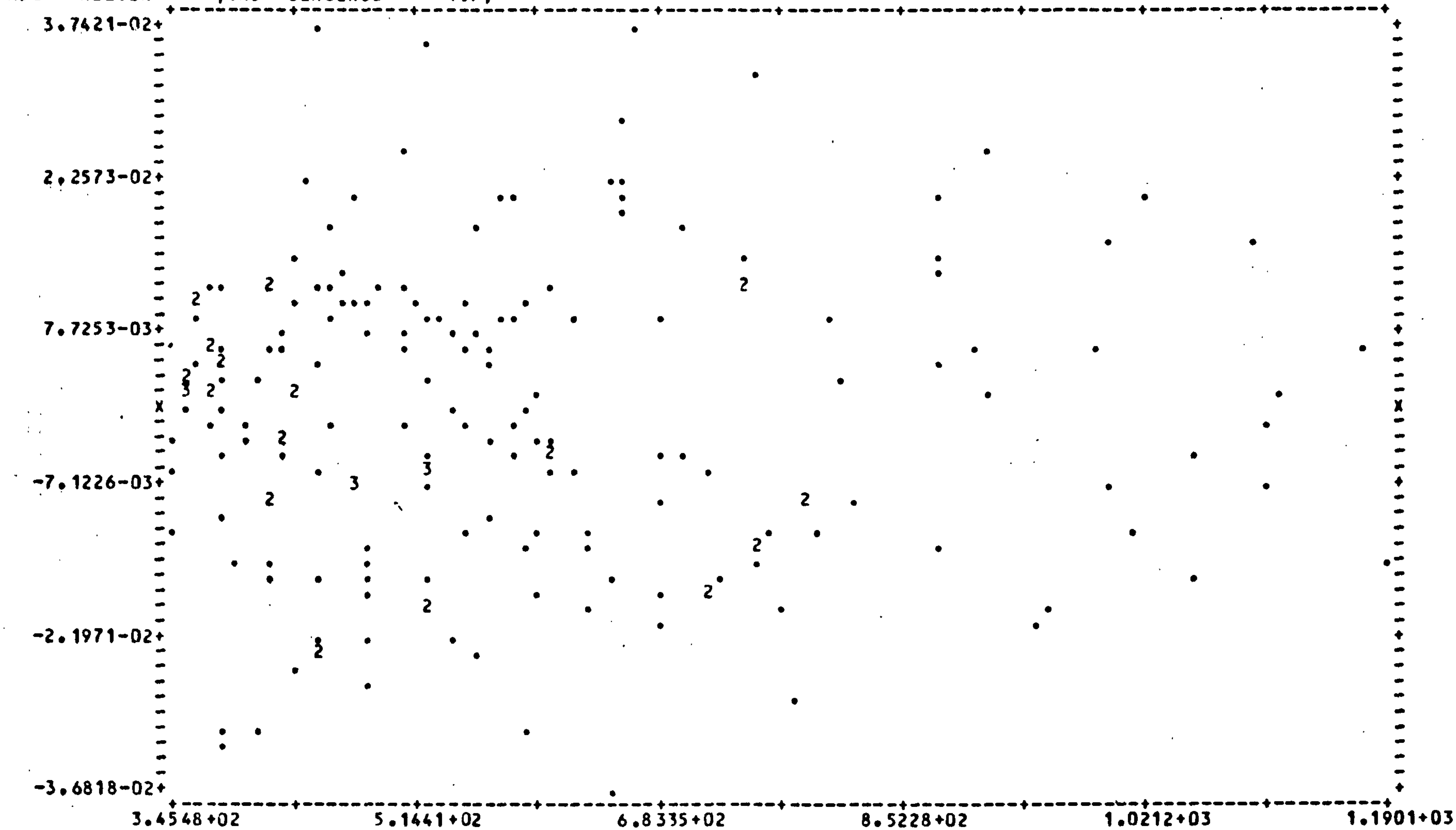

Fig. 2. $\frac{\lambda_{exp} - \lambda_{calc}}{\lambda_{exp}}$ versus T with λ_{calc} from equation (4)

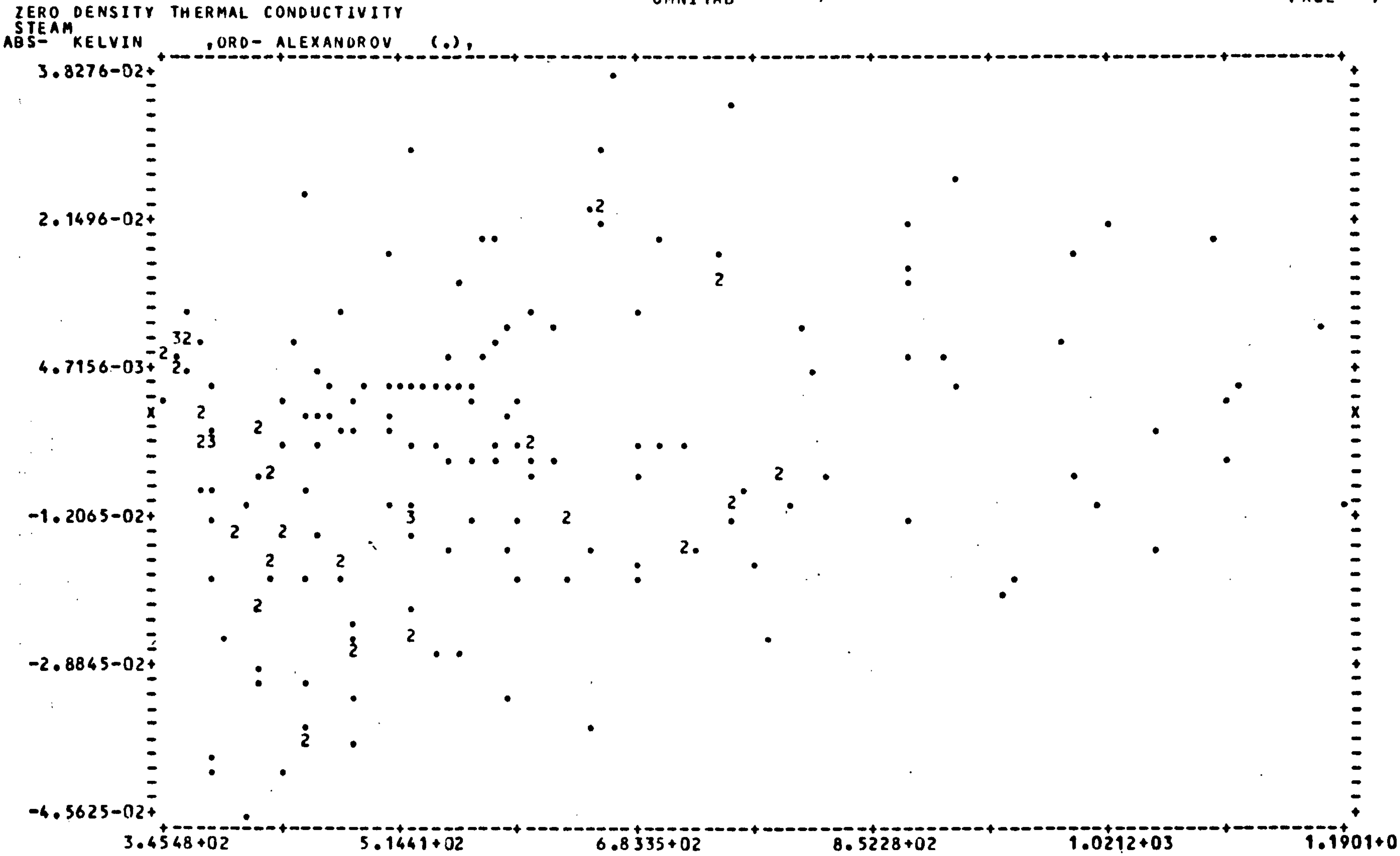

Fig. 3 $\frac{\lambda_{exp} - \lambda_{calc}}{\lambda_{exp}}$ versus T with λ_{calc} from equation (5).

ZERO DENSITY THERMAL CONDUCTIVITY
STEAM
ABS- KELVIN ,ORD- YATA (.),

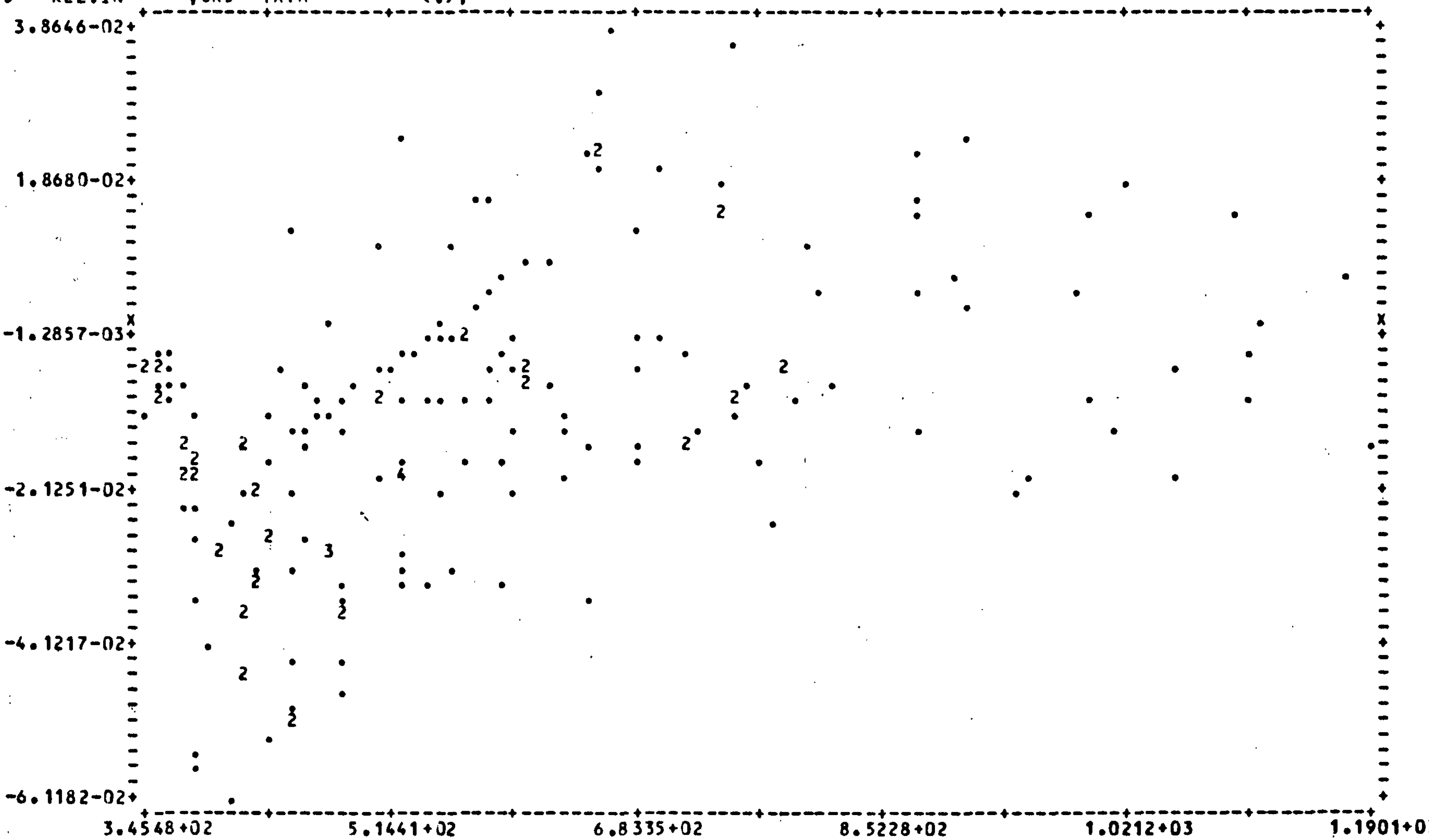

Fig. 4 $\frac{\lambda_{exp} - \lambda_{calc}}{\lambda_{exp}}$ versus T with λ_{calc} from equation (6).