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

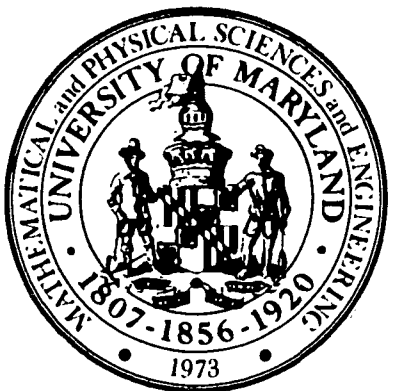
University of  
Maryland  
College Park

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J. V. Sengers and R. S. Basu

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The thermal conductivity of steam in the  
zero density limit as a function of temperature<sup>†</sup>

J. V. Sengers and R. S. Basu

Institute for Physical Science and Technology  
University of Maryland, College Park, Maryland 20742 U. S. A.

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<sup>†</sup>Interim report prepared for the meeting of the special thermal conductivity task group of the International Association for the Properties of Steam, Providence, R. I., May, 1977.

## 1. Introduction

In formulating an equation for the thermal conductivity  $\lambda$  of steam we consider the thermal conductivity  $\lambda(\rho, T)$  as a function of the density  $\rho$  and the temperature  $T$ . The zero density thermal conductivity  $\lambda_0(T)$  is defined as

$$\lambda_0(T) = \lim_{\rho \rightarrow 0} \lambda(\rho, T) \quad (1)$$

At the meeting of the Special Committee of IAPS at Kyoto, Japan, 1976, we presented a preliminary analysis of  $\lambda_0(T)$  for steam.<sup>1</sup> As pointed out in the preceding paper<sup>1</sup> the analysis suffered from defects. First, since the data survey compiled by the German delegation<sup>2</sup> 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  $\lambda_0(T)$  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.<sup>2</sup> In addition we included low density data below 100°C obtained by Milverton<sup>17</sup> as was recommended by Alexandrov and Matveev at the Kyoto meeting of the special committee.<sup>18</sup>

Table I

## Sources of Experimental Data

<u>Code</u>	<u>References</u>
1120 Timrot	3
1130 Vargaftik	4
1100 Vargaftik	5
1200 Vargaftik	6
1310 Vargaftik	7
1260 Venart	8
1320 Brain	9
1450 Mashirov	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

$$\lambda = \sqrt{T} \left[ \sum_{k=0}^n a_k T^{-k} \right]^{-1} \quad (2)$$

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<sup>19</sup> 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  $\lambda$  we used as weights  $(100/\lambda)^2$  so that the standard deviation  $\sigma$  was returned as a percentage.

In Table II we present the residual standard deviation  $\sigma$  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	$\sigma = 1.70\%$
n = 3	$\sigma = 1.48\%$
n = 4	$\sigma = 1.46\%$
n = 5	$\sigma = 1.46\%$
n = 6	$\sigma = 1.46\%$

Sengers 1:

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

with

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

Sengers 2:

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

with

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

where  $\lambda_o(T)$  is expressed in W/mK. A plot of the deviations  $(\lambda_{\text{exp}} - \lambda_{\text{calc}})/\lambda_{\text{exp}}$  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.<sup>19</sup>

A similar equation was proposed by Alexandrov and Matveev<sup>18</sup>

Alexandrov:

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

with

$$\begin{aligned} a_o &= +0.0514485 \\ a_1 &= +0.2323841 \times 10^3 \\ a_2 &= +0.5602307 \times 10^5 \\ a_3 &= -0.1392744 \times 10^8 \end{aligned}$$

A plot of the deviations  $(\lambda_{\text{exp}} - \lambda_{\text{calc}})/\lambda_{\text{exp}}$  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<sup>20</sup>

Yata:

$$\lambda_o(T) = \sqrt{T} [a'_o + a'_1 T + a'_2 T^2 + a'_3 T^3] \times 10^3 \quad (6a)$$

with

$$\begin{aligned} a'_o &= +0.404097 \\ a'_1 &= +0.181934 \times 10^{-2} \\ a'_2 &= +0.146476 \times 10^{-5} \\ a'_3 &= -0.612237 \times 10^{-9} \end{aligned} \quad (6b)$$

A plot of the deviations  $(\lambda_{\text{exp}} - \lambda_{\text{calc}})/\lambda_{\text{exp}}$  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  $\lambda_0(T)$ . 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  $\lambda_o$ .

Explanation of computer output.

Column 1: Temperature in degree C

Column 2: Temperature in Kelvin

Column 3: Values of  $\lambda_o$  from experimental data sources in milliwatt/m K.

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

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

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

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

Column 8: Experimental data sources.

ZERO DENSITY THERMAL CONDUCTIVITY  
STEAM  
DEGREE C

OMNITAB

PAGE 1

	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
1.0040000+02	4.7355000+02	*3.2350000+01	-6.8822710-03	-6.5798222-03	-1.7902737-02	-2.8596433-02
1.0590000+02	4.7905000+02	*3.2630000+01	-1.2597804-02	-1.2626327-02	-2.3481736-02	-3.3779596-02
1.4780000+02	5.2095000+02	*3.7250000+01	-3.4067167-03	-5.3895399-03	-1.2036215-02	-1.8880281-02
1.5262000+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	-1.4777010-02	-1.4798684-02	-2.5677382-02	-3.5997335-02
2.4780000+02	5.2095000+02	*3.7250000+01	-4.7553867-03	-6.7408751-03	-3.3964884-02	-5.0249749-02
2.5262000+02	5.2624999+02	*3.7460000+01	-3.8665199-02	-3.6594388-02	-3.0697921-02	-2.4522626-02
2.0880000+02	5.6195000+02	*4.2120000+01	7.8365786-03	5.1044670-03	-1.9430888-03	-2.0141162-03
2.1390000+02	5.6784999+02	*4.2670000+01	6.4839524-04	5.1269497-03	-4.8922019-03	-8.5204861-03
2.1950000+02	5.9264999+02	*4.5360000+01	-2.8759554-03	-2.1819295-04	-1.0047745-03	-6.2726945-03
2.2450000+02	6.1500000+02	4.6520000+01	-1.7740351-03	-2.2817558-03	-4.8906559-03	-6.3985571-03
2.3000000+02	6.0814999+02	4.6990000+01	-3.3706370-04	-2.7823078-03	-3.2248865-03	-4.7747240-03
2.3500000+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
3.6450000+02	6.79064999+02	5.6060000+01	-9.9842607-03	-9.5333918-03	-1.1155295-02	-1.1787251-02
3.7000000+02	6.80064999+02	5.4660000+01	-1.7604102-03	-1.8032435-02	-1.6350952-02	-1.5682918-02
3.7500000+02	6.8664999+02	5.5820000+01	-8.4990970-03	-8.7310404-03	-6.9922250-03	-6.2350346-03
3.8000000+02	7.4784999+02	6.6290000+01	3.0934208-02	3.2856518-02	3.4757019-02	3.5945076-02
3.8500000+02	5.9305000+02	4.4780000+01	-1.1055498-02	-1.3745954-02	-1.4963827-02	-1.7243339-02
3.9000000+02	6.9995000+02	5.9080000+01	-1.8428449-02	-1.8680055-02	-2.0508009-02	-2.1437648-02
3.9500000+02	8.2094999+02	7.2450000+01	-1.30886741-02	-9.1693844-03	-7.6614206-03	-6.9327581-03
4.0000000+02	8.7374999+02	8.0036000+01	-9.6020145-03	-4.5826804-03	5.6182762-03	5.5182093-03
4.0500000+02	1.0560500+02	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
1.81875000+02	5.6064999+02	*4.2550000+01	-2.1228981-02	-1.8541524-02	-1.5329749-02	-1.1347043-02
1.8680000+02	6.2995000+02	4.8700000+01	-1.7365410-02	-1.9375921-02	-1.8926274-02	-1.9624552-02
1.91749000+02	7.2803000+02	6.0400000+01	-1.8032868-02	-1.6762555-02	-1.4743079-02	-1.3540486-02
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2.0163000+02	5.0375000+02	*3.6600000+01	-2.7487108-03	3.6212494-03	1.8158285-02	1.0232385-02
2.0658000+02	5.8124999+02	4.5000000+01	2.3561848-02	3.0869933-02	1.9024266-02	1.6223876-02
2.1153000+02	6.67114999+02	5.6100000+01	3.7742675-02	3.6898280-02	3.8275735-02	3.8645569-02
2.1648000+02	7.1534999+02	5.9500000+01	-6.7464364-03	-5.9385139-03	-3.9726305-03	-2.8635474-03
2.2143000+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
4.9900000+02	9.4814999+02	8.8160000+01	-2.4420867-02	-2.0405255-02	-1.9723166-02	-2.1296382-02
5.0400000+02	9.5334999+02	8.8969999+01	-2.2678112-02	-1.8775757-02	-1.8099692-02	-1.9771747-02
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5.1400000+02	1.1901500+03	1.2228100+02	-4.3342676-03	-1.5172787-02	-1.0487148-02	-1.4659964-02
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5.2900000+02	7.96634999+02	6.9920000+01	-1.4817784-02	-1.1433287-02	-9.7152677-03	-8.7121456-03
5.3400000+02	8.05344999+02	7.1759999+01	5.3044945-03	8.8306707-03	1.0443186-02	1.1338598-02
5.3900000+02	9.0454999+02	8.4549999+01	1.1111575-03	5.5749060-03	6.3995777-03	5.7260163-03

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Timrot 1120

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Vargattik 1130

--- X ---

Vargattik 1100

--- X ---

Vargattik 1200

--- X ---

Vargattik 1310

ZERO DENSITY THERMAL CONDUCTIVITY  
STEAM

OMNITAB

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	9.6533000+01	3.6538241-03	6.5697726-03	7.0282037-03	4.9228978-03
7.2420000+02	9.9734999+02	9.8389999+01	4.4383570-02	1.6880103-02	1.7647764-02	1.3513793-02
7.3839999+02	1.0115500+03	9.7580000+01	5.565686-02	1.779979-02	1.7555470-02	1.3513793-02
7.4550000+03	1.0186500+03	1.0188000+02	9.9706761-02	2.1349527-02	2.2385524-02	1.459410886-02
8.2760000+02	1.1007500+03	1.1339000+02	0.286896-02	1.7273112-02	1.9507418-02	1.542424333-02
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1.4800000+02	4.2115000+02	2.7800000+01	6.2623123-03	6.63717980-03	6.56249250-03	5.519912965-02
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1.4590000+02	4.1705000+02	2.7600000+01	2.9200130-03	1.4882724-02	1.3023381-02	4.42986784-02
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1.0130000+02	3.7445000+02	2.3800000+01	1.677114-03	2.680565-03	4.3326181-03	2.3297362-02
1.0130000+02	3.7445000+02	2.3800000+01	2.9296391-03	2.5505676-03	4.11170518-03	1.55862-02
1.0130000+02	3.7445000+02	2.3800000+01	5.920215-03	6.6807795-03	7.000955062-03	1.470966883-02
1.0130000+02	3.7445000+02	2.3800000+01	1.9220215-03	6.6807795-03	7.000955062-03	1.470966883-02
1.0130000+02	3.7445000+02	2.3800000+01	2.9296391-03	2.5505676-03	4.11170518-03	1.55862-02
1.3500000+02	3.8665000+02	2.4400000+01	3.7355026-02	1.4270251-02	2.4945707-02	4.04965000-02
2.3490000+02	5.3805000+02	3.6300000+01	1.2821310-03	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	4.4290000+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	4.09315000+02	2.5200000+01	5.753512-03	2.274390-03	1.4221962-02	2.9616280-02
1.3000000+02	4.40315000+02	2.6150000+01	6.9589050-04	3.0274236-03	1.02283357-02	2.5640388-02
1.4000000+02	4.1315000+02	2.7100000+01	1.247878-03	6.7438233-03	7.2458639-03	2.20089471-02
1.5000000+02	4.2315000+02	2.8000000+01	1.077137-03	7.3921765-03	6.8211044-03	2.1064077-02
1.6000000+02	4.3315000+02	2.9000000+01	7.243262-03	1.06510239-02	4.8996341-03	1.7077747-02
1.7000000+02	4.4315000+02	3.0000000+01	1.2624043-02	1.26333540-02	9.0093843-04	1.3758445-02
1.8000000+02	4.5315000+02	3.0950000+01	1.0730931-02	1.2305210-02	5.5079699-04	1.2027258-02
1.9000000+02	4.6315000+02	3.1900000+01	1.0441299-02	1.1381161-02	6.7917904-04	1.2027258-02
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	3.5511115-04	8.8970078-03
2.2000000+02	4.9315000+02	3.4950000+01	1.2386524-02	1.1592860-02	4.79098-03	6.5274163-03
2.3000000+02	5.0315000+02	3.6000000+01	1.4986468-02	1.1717260-02	6.470670-03	4.6169623-03
2.4000000+02	5.1314999+02	3.7000000+01	1.809491-02	1.10328-02	8.84048-03	3.2704213-03
2.5000000+02	5.2314999+02	3.8000000+01	1.1616217-02	9.5993495-03	3.250863-03	3.3288721-03
2.6000000+02	5.3314999+02	3.9100000+01	1.10776903-02	8.7779111-03	3.250863-03	3.3288721-03
2.7000000+02	5.4314999+02	4.0150000+01	1.0231097-02	7.7221618-03	1.136509-03	3.067531-03
2.8000000+02	5.5314999+02	4.1200000+01	1.1414918-02	7.6630918-03	1.853509-03	2.4575857-03
2.9000000+02	5.6314999+02	4.2300000+01	8.989956-03	6.1934947-03	3.1217390-03	1.75792308-04

Vargafik 1310

Venart 1260

Brain 1320

Mashirow 1450

Le Neindre 1360

ZERO DENSITY THERMAL CONDUCTIVITY

OMNITAB

STEAM DEGREE C	KELVIN	LAMBDA	SENGERS1	SENGERS2	ALEXANDROV	YATA
3.000000+02	5.7314999+02	#4.355000+01	1.1890523-02	9.1425724-03	6.7635108-03	3.6823675-03
3.100000+02	5.8314999+02	4.470000+01	1.2221870-02	9.5092530-03	6.7265938-03	3.6248929-03
3.200000+02	5.9314999+02	4.590000+01	1.3367158-02	1.0742788-02	6.5597124-03	3.5401549-03
3.300000+02	6.0314999+02	4.710000+01	1.4223546-02	1.1732512-02	6.4061417-02	3.4336522-03
1.424000+02	4.1555000+02	#2.690000+01	-1.19771360-02	-8.3594960-03	-1.2670381-02	-3.75336763-02
1.438000+02	4.1695000+02	#2.760000+01	-9.3042159-03	-1.2798905-02	-1.2538917-03	-3.5742226-02
1.586000+02	4.3175000+02	#2.860000+01	-1.7465585-03	-1.1396658-03	-1.1036194-02	-3.6846898-02
1.703000+02	4.4345000+02	#2.900000+01	-2.9000000+01	-2.9000000+01	-2.9000000+01	-2.9000000+01
1.706000+02	4.4375000+02	#2.900000+01	-2.5606155-02	-3.364503-02	-3.364503-02	-3.364503-02
1.714000+02	4.4455000+02	#2.960000+01	-7.3114923-03	-5.1597324-03	-4.8834254-02	-3.1829702-02
1.716000+02	4.4475000+02	#2.930000+01	-1.8255979-02	-1.6093490-02	-2.9934387-02	-4.3026107-02
1.728000+02	4.4595000+02	#2.920000+01	-2.5545832-02	-2.3444679-02	-4.7279072-02	-3.9504102-02
2.059000+02	4.7905000+02	#3.240000+01	-2.1973716-02	-2.6002503-02	-3.2958425-02	-4.3351636-02
2.062000+02	4.7934999+02	#3.230000+01	-2.6052936-02	-2.20099822-02	-3.7069719-02	-4.7479148-02
2.072000+02	4.8034999+02	#3.270000+01	-1.6518485-02	-1.6624118-02	-2.7393478-02	-3.7622729-02
2.074000+02	4.8055000+02	#3.270000+01	-1.7122420-02	-1.7122420-02	-1.7122420-02	-1.7122420-02
2.462000+02	5.1934999+02	#3.715000+01	-1.5949208-03	-1.5206884-03	-1.50305882-02	-1.1319172-02
2.466000+02	5.1974999+02	#3.745000+01	-3.3103107-03	-3.8433342-03	-3.3659666-03	-1.0179174-02
2.469000+02	5.2005000+02	#3.715000+01	-1.5680640-03	-1.5212994-03	-1.53335752-02	-1.19167403-02
2.469000+02	5.2005000+02	#3.665000+01	-1.7259307-02	-1.9239189-02	-2.6063490-02	-3.3071461-02
2.477000+02	5.2074999+02	#3.675000+01	-1.6487718-02	-1.8489708-02	-2.5242072-02	-3.2190764-02
2.477000+02	5.2084999+02	#3.685000+01	-1.4013836-02	-1.6014314-02	-2.2740759-02	-2.9664848-02
2.764000+02	5.4955000+02	#4.095000+01	-1.2641215-02	-1.0039442-02	-1.927589740-03	-1.23361358-02
2.767000+02	5.4984999+02	#4.085000+01	-4.2557107-03	-6.8114758-03	-5.7414226-03	-1.9770370-02
2.780000+02	5.5114999+02	#4.150000+01	-8.8555778-03	-1.5349445-02	-2.5576143-02	-2.0295101-02
2.780000+02	5.5114999+02	#4.065000+01	-1.0716578-03	-1.5813515-03	-1.5827837-03	-1.0255307-02
3.288000+02	6.0195000+02	4.630000+01	-1.6683121-04	-1.3779962-03	-1.3178765-03	-1.492553870-02
3.288000+02	6.0195000+02	4.590000+01	-1.3463140-03	-1.1113318-02	-1.1859647-02	-1.3703386-02
3.289000+02	6.0205000+02	4.560000+01	-1.5433169-02	-1.8016173-02	-1.872570-02	-2.0674193-02
3.290000+02	6.0214999+02	4.650000+01	-3.9735404-03	-1.6414018-03	-7.1422002-04	-1.0974330-02
3.879000+02	6.6105000+02	5.440000+01	-2.1199821-02	-2.0166440-02	-2.1428071-02	-2.1664719-02
3.879000+02	6.6105000+02	5.450000+01	-2.2995791-02	-2.1944343-02	-2.223623-02	-2.3459837-02
3.881000+02	6.6124999+02	5.450000+01	-2.553986-02	-2.1508365-02	-2.292352-02	-2.3033439-02
3.883000+02	6.6145000+02	5.490000+01	-2.9236980-02	-2.8204753-02	-2.92484023-02	-2.9728491-02
4.678000+02	7.4095000+02	6.380000+01	-1.0768964-02	-1.2439695-02	-1.4399070-02	-1.5607015-02
4.678000+02	7.4095000+02	6.380000+01	-1.0768964-02	-1.2439695-02	-1.4399070-02	-1.5607015-02
4.678000+02	7.4095000+02	6.400000+01	-1.3860315-02	-1.2439695-02	-1.4399070-02	-1.5607015-02
6.033000+02	8.7644999+02	8.159999+01	-1.0897494-02	-1.5345730-02	-1.6349542-02	-1.6202923-02
6.033000+02	8.7644999+02	8.150000+01	-9.6838780-03	-1.4137572-02	-1.5142616-02	-1.4992692-02
6.035000+02	8.7664999+02	8.209999+01	-1.6597697-02	-2.1020980-02	-2.2017471-02	-2.1868031-02
1.042000+02	3.7734999+02	#2.395000+01	-6.1365757-03	-4.1692690-03	-1.1936737-02	-2.7077452-02
1.080000+02	3.8115000+02	#2.450000+01	-4.4516349-03	-6.9111609-03	-2.0268109-03	-1.7136690-02
1.210000+02	3.9415000+02	#2.530000+01	-4.9878015-03	-1.4657088-03	-1.3582914-02	-2.8959338-02
1.449000+02	4.1805000+02	#2.725000+01	-6.9253274-03	-3.4091319-03	-1.7719934-02	-3.2391461-02
1.727000+02	4.4584999+02	#3.000000+01	-2.1108548-03	-4.1615963-03	-4.3059221-03	-3.084395-02
1.783000+02	4.5145000+02	#3.070000+01	-7.8712768-03	-9.581930-03	-1.08883275-03	-1.4481837-02
1.797000+02	4.5284999+02	#3.110000+01	-1.6408779-02	-1.7992944-02	-1.8888392-03	-1.6861188-02
2.028000+02	4.7595000+02	#3.255000+01	-7.9064289-03	-7.7497246-03	-1.188854918-02	-2.9361391-02
2.055000+02	4.7865000+02	#3.335000+01	-8.3191426-03	-8.3144815-03	-2.3580036-03	-1.2467102-02
2.289000+02	5.0205000+02	#3.540000+01	-5.6815013-04	-1.8029967-03	-1.0257373-02	-1.8558179-02

LeNeindre 1360

----- X -----

Brain 1380

----- X -----

Bury 1440

ZERO DENSITY THERMAL CONDUCTIVITY

OMNITAB

STEAM DEGREE C	KELVIN	LAMBDA	SENGERS1	SENGERS2	ALEXANDROV	YATA
2.3060000+02	5.0375000+02	#3.5970000+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
2.8850000+02	5.4164999+02	#3.8800000+01	-2.0039549-02	-2.2597969-02	-2.7473919-02	-3.2899380-02
2.9833000+02	5.5644500+02	#4.0350000+01	-2.0704364-03	-2.3473470-02	-2.7143237-02	-3.4343691-02
3.0914000+02	5.6443500+02	#4.1800000+01	-6.6260174-03	-9.4109403-03	-1.2429878-02	-1.36284388-02
3.1850000+02	5.9164999+02	4.3900000+01	-2.7695474-02	-3.0445542-02	-3.1762764-02	-1.34151631-02
3.2790000+02	6.2995000+02	4.9000000+01	-1.1136639-02	-1.3134839-02	-1.2687946-02	-1.33381948-02
3.3729000+02	6.4605000+02	5.3700000+01	-1.4808117-02	-1.6368390-02	-1.5409788-02	-1.35575063-02
3.4445000+02	7.1764999+02	5.9100000+01	-1.8411909-02	-1.7511945-02	-1.5514756-02	-1.34374970-02
3.5100000+02	7.4824999+02	6.3100000+01	-1.4841621-02	-1.2881586-02	-1.0886721-02	-9.6421612-03
4.7370000+02	7.4884999+02	6.3100000+01	-1.6046923-02	-1.4064603-02	-1.2069028-02	-1.0823093-02
4.8113000+02	7.8444500+02	6.7900000+01	-1.1236432-02	-8.1798430-03	-6.3770474-03	-5.2764876-03
4.8511000+02	7.8444500+02	6.7900000+01	-1.1236432-02	-8.1798430-03	-6.3770474-03	-5.2764876-03
4.9113000+02	7.4884999+02	6.3100000+01	-1.4841621-02	-1.2881586-02	-1.0886721-02	-9.6421612-03
4.9445000+02	7.1764999+02	5.9100000+01	-1.8411909-02	-1.7511945-02	-1.5514756-02	-1.34374970-02
4.9702000+02	6.4605000+02	5.4400000+01	-1.9554488-02	-2.0028318-02	-1.8362429-02	-1.47717253-02
5.0729000+02	6.4605000+02	4.9700000+01	-3.5226791-02	-3.6818458-02	-3.5840568-02	-3.6009169-02
5.1486000+02	6.2174999+02	4.8400000+01	-3.8186972-03	-5.9983553-03	-5.8598164-03	-6.85333618-03
5.2600000+02	6.9914999+02	5.7600000+01	-5.0779101-03	-4.8488047-03	-4.9835519-03	-4.90215501-03
5.3678000+02	4.2993000+02	#2.8850000+01	1.2588336-02	1.5529371-02	1.5108052-03	-4.2214171-02
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	-8.9326916-02
1.9215000+02	4.6530000+02	#3.2200000+01	1.3251616-02	1.4054079-02	2.2132945-03	-8.9326916-02
1.9304000+02	5.7618999+02	#4.4450000+01	2.4254330-03	2.1545541-02	1.9390151-02	-3.16318773-03
1.9729000+02	6.646413000+02	5.2700000+01	2.3523761-03	2.2024728-02	2.2949277-02	-2.2792536-03
1.9826000+02	6.646413000+02	5.2700000+01	2.3523761-03	2.2024728-02	2.2949277-02	-2.2792536-03
2.0750000+02	8.81064999+02	7.2000000+01	-7.6889992-04	-2.8932359-03	4.4719246-03	-2.9866780-03
2.1406000+02	8.87720999+02	7.9400000+01	-1.7779804-02	-1.3200102-02	-1.2173076-02	-1.2173076-02
2.1674000+02	9.0988999+02	8.5000000+01	-2.0068786-03	-2.4370530-03	-3.2349306-03	-1.2173076-02
2.2452000+02	9.9766999+02	9.6099999+01	-9.5554991-03	-7.0101116-03	-6.2529180-03	-8.7681968-03
8.3120000+01	3.55627000+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
8.8440000+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	#2.3200000+01	1.2722270-02	1.1110203-02	1.0902383-02	-2.8660131-03
8.9067999+01	3.6382999+02	#2.3320000+01	1.0063626-02	9.1161266-03	7.6009111-03	-6.4203506-03
8.9291000+01	3.6806000+02	#2.3350000+01	1.1549880-02	1.1212617-02	8.4828661-03	-5.7117469-03
8.9513999+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
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	-3.4609064-03
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
8.2380000+01	3.5523000+02	#2.2650000+01	7.8721393-03	3.9395381-03	8.0697058-03	-4.0133164-03
8.4299999+01	3.5745000+02	#2.2780000+01	6.6840303-03	3.6218796-03	6.1427950-03	-7.2413834-03

Bury 1440

----- X -----  
 Le Neindre 1410  
 ----- V -----  
 Tarzimanow 1430  
 ----- A -----

Vargaftik 1470

----- X -----

Milverton

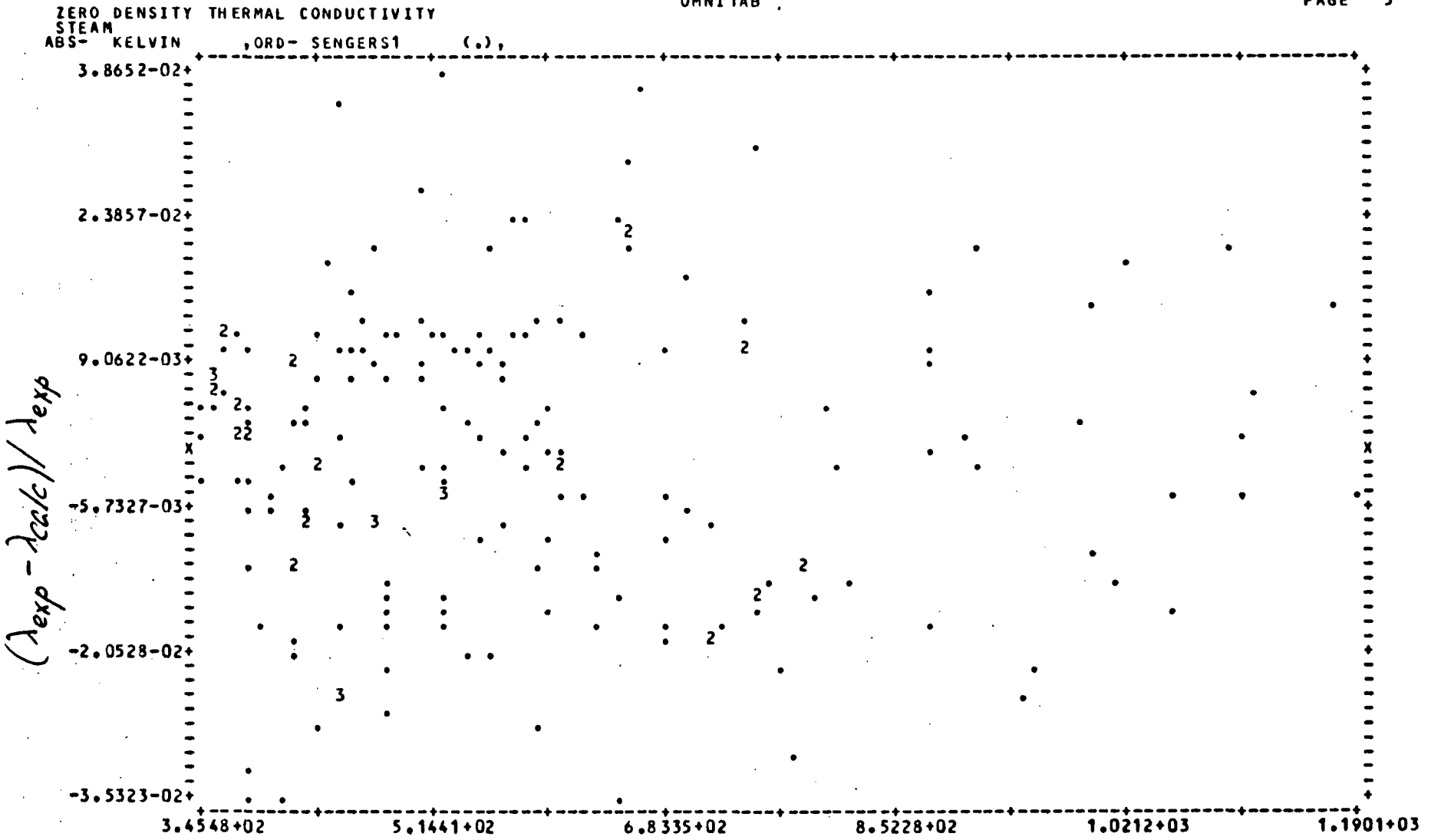


Fig. 1.  $\frac{\lambda_{exp} - \lambda_{calc}}{\lambda_{exp}}$  versus  $T$  with  $\lambda_{calc}$  from equation (3)

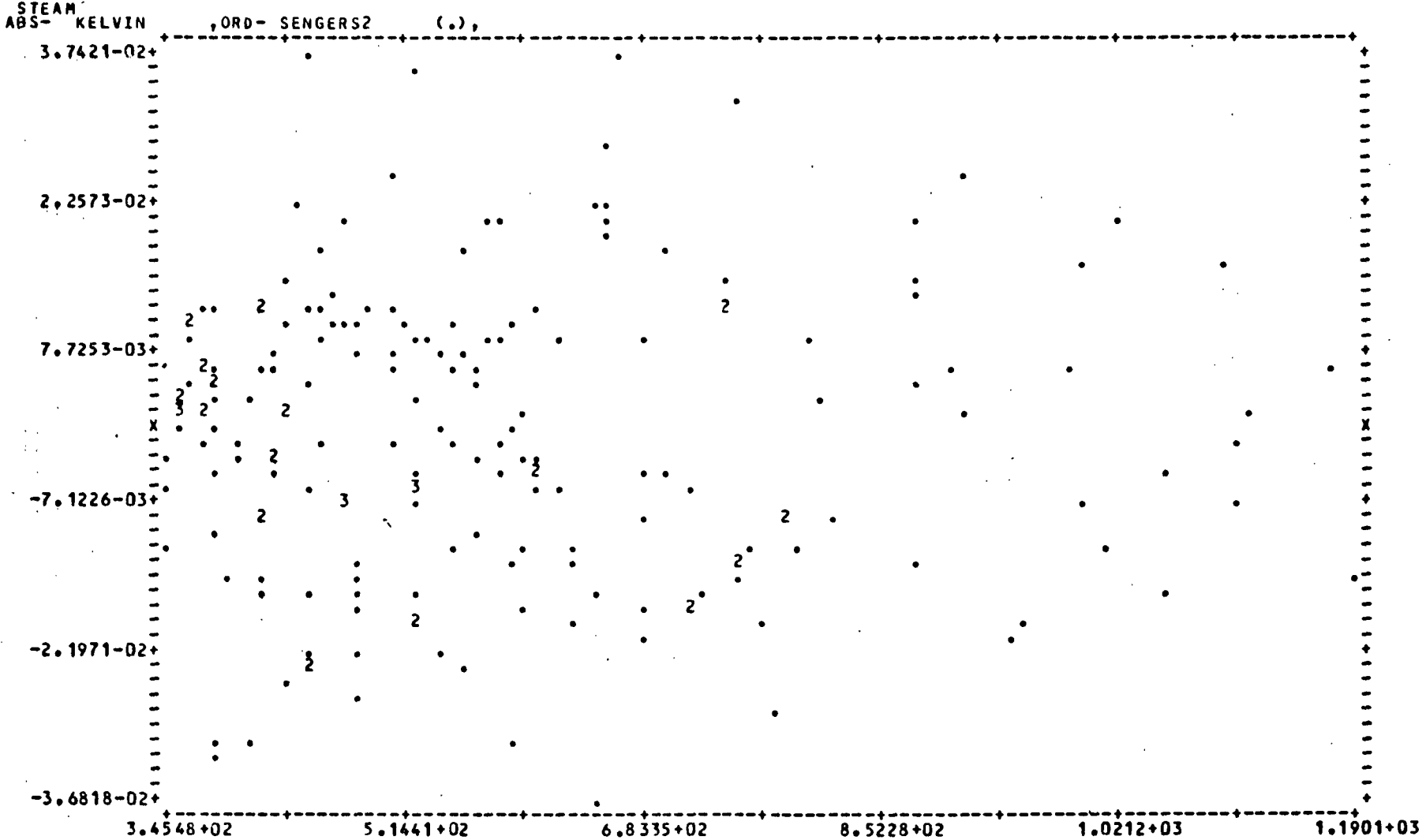


Fig. 2.  $\frac{\lambda_{exp} - \lambda_{calc}}{\lambda_{exp}}$  versus  $T$  with  $\lambda_{calc}$  from equation (4)



, ORD- ALEXANDROV (.),

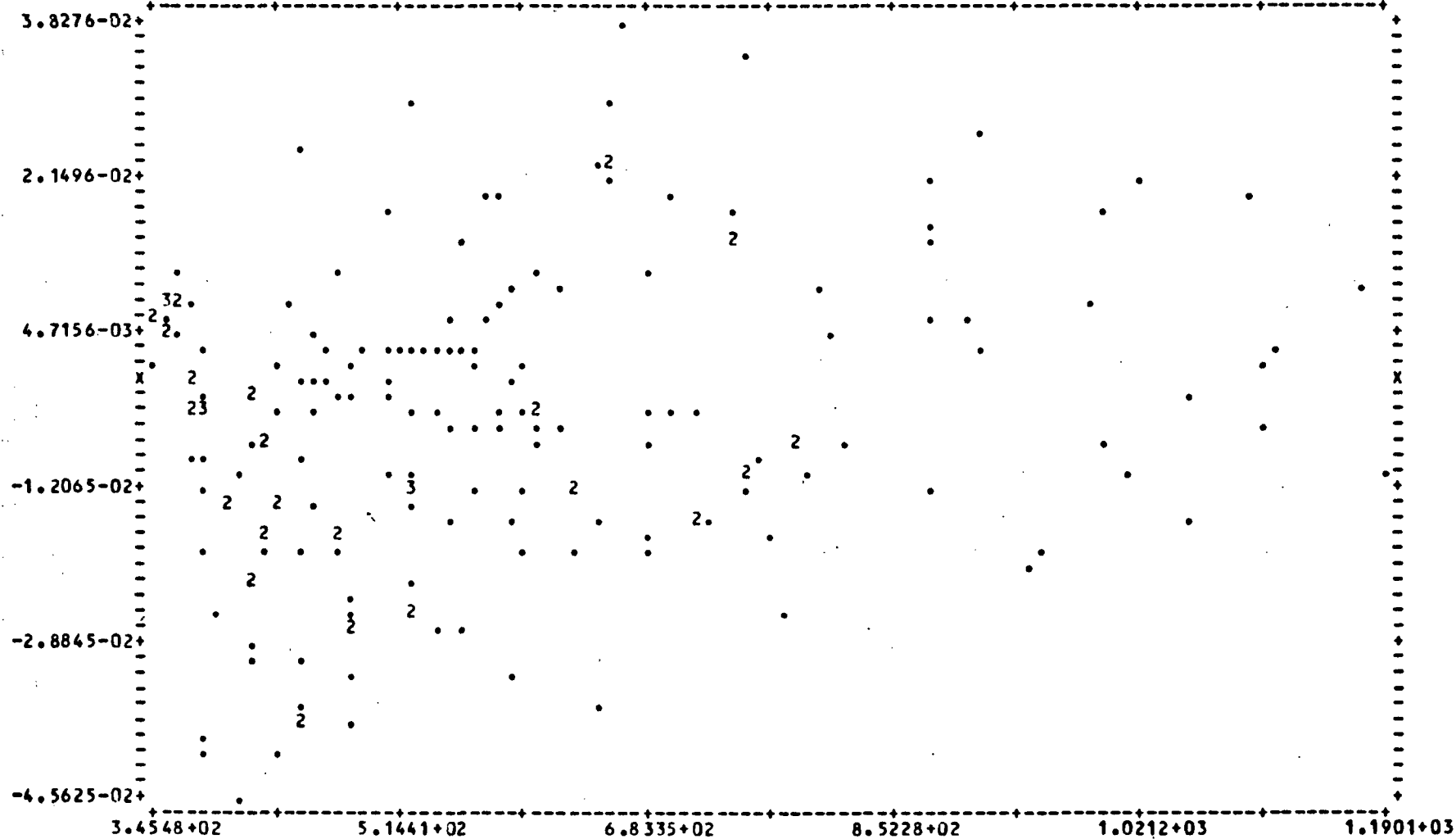


Fig. 3  $\frac{\lambda_{exp} - \lambda_{calc}}{\lambda_{exp}}$  versus  $T$  with  $\lambda_{calc}$  from equation (5).

ZERO DENSITY THERMAL CONDUCTIVITY

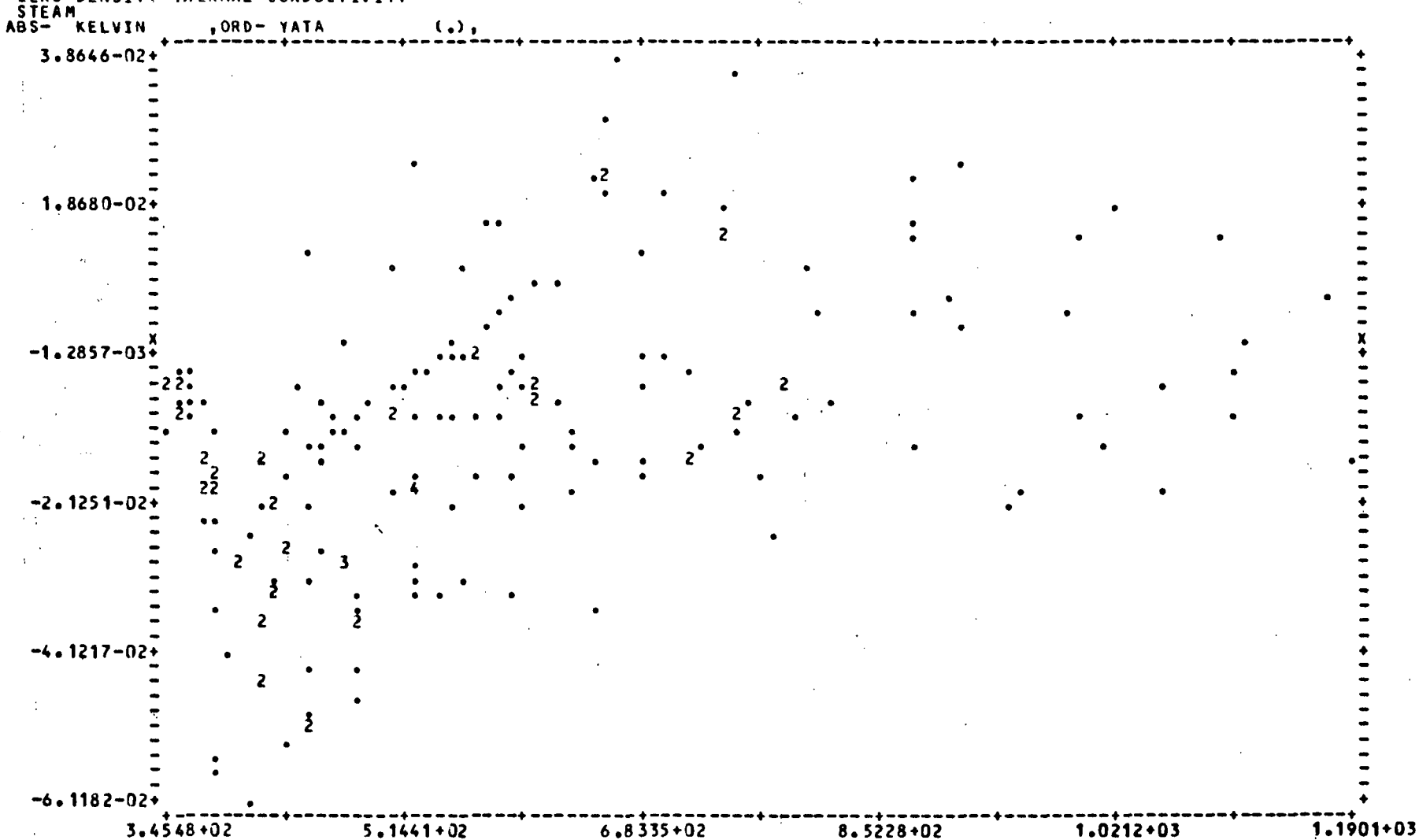


Fig. 4  $\frac{\lambda_{exp} - \lambda_{calc}}{\lambda_{exp}}$  versus  $T$  with  $\lambda_{calc}$  from equation (6).