ences that any other comparison procedure would not alter the preceding statement. By way of suggesting future lines of attack, it is worth pointing out the similarity between Kozlenkov's relation (14) and a very similar expression underlying the intensity of x-ray scattering by disordered alloys. It can be shown that when short-range order only is present, the intensity

$$I \propto \sum_i \alpha_i \frac{\sin kr_i}{kr_i}, \qquad (15)$$

where α_i is a coefficient dependent on the scattering power and number of atoms in the ith shell about a central atom and $k = (2\pi/\lambda)\,2\sin\theta$. The close relation between absorption and diffraction has already been pointed out above and suggests that a consideration of the ejected electron's diffraction by the atomic arrays may lead to a more convenient formulation of the absorption process. If successful, such an approach also would have the advantage of making absorption-edge studies amenable to the investigation of the structure of solids. A more rigorous theory, however, doubtlessly also will require more exact experimental measurements than are generally available at the present time.

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Thermal Conductivity of Multicomponent Mixtures of Inert Gases

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I. INTRODUCTION

THE proper understanding of the process of thermal conduction in monatomic gases is not only important in itself but is also basic for the more complicated case of polyatomic gases. The investigations during the last five years have thrown considerable light on this problem. In this paper we discuss all the experimental and theoretical work with a view to get an over-all assessment.

Three different groups of workers have reported the experimental thermal conductivity data of binary and ternary mixtures of inert gases. These are: (a) Saxena (1956, 1957) and Srivastava and Saxena (1957a, 1957b), who determined the thermal conductivity of six binary gas systems and of two ternary gas systems at 38°C as a function of composition; (b) von Ubisch (1959), who measured the thermal conductivity of all the ten possible binary systems of the five stable inert gases, and of the ternary system He–Kr–Xe for different proportions of the constituents at 29° and 520°C; and (c) Thornton (1960, 1961) who reported on the thermal conductivity of seven binary gas pairs at 18°C and again as a function of composition.

The *rigorous* treatment of the phenomenon of thermal conduction in gases was given by Enskog (1911) and Chapman (1917) and is adequately described by Chapman and Cowling (1952), and Hirschfelder, Curtiss, and Bird (1954). Recently Muckenfuss and Curtiss (1958) have derived an equation for the complete second approximation to the thermal conductivity of multicomponent gas mixtures. Mason (1958) gave a somewhat simpler expression and Mason and Saxena (1959) have investigated the relative accuracies of both these formulations. Muckenfuss' and Curtiss' (1958) formula for the thermal conductivity of an n-component mixture can be written after the modification suggested by Mason and Saxena (1959) in the following form:

$$\lambda_{\text{mix}} = \begin{vmatrix} L_{11} & \cdots & L_{1n} & x_1 \\ \vdots & & \vdots & \vdots \\ L_{n1} & \cdots & L_{nn} & x_n \\ x_1 & \cdots & x_n & 0 \end{vmatrix} \div \begin{vmatrix} L_{11} & \cdots & L_{1n} \\ \vdots & & \vdots \\ L_{n1} & \cdots & L_{nn} \end{vmatrix}, \qquad (1)$$

where

$$L_{ii} = -\frac{4x_i^2}{[\lambda_i]_1} - \frac{16T}{25p} \sum_{\substack{k=1 \\ k\neq i}}^{n} \frac{x_i x_k[\frac{15}{2}M_i^2 + \frac{5}{2}M_k^2 + 4M_iM_kA^*_{ik}]}{(M_i+M_k)^2 D_{ik}}, \qquad (2)$$

$$L_{ij}\ (i \neq j) = \frac{16Tx_ix_jM_iM_j(10 - 4A^*_{ij})}{(M_i+M_j)^2 D_{ij}}. \qquad (3)$$

Here $[\lambda_i]_1$ is the first approximation to the thermal conductivity of pure component i in units of erg cm^{-1} sec^{-1} deg^{-1}, p is the pressure in dyne cm^{-2}, x_i is the mole fraction of the ith component, D_{ik} is the accurate value of the binary diffusion coefficient for components i and k in units of cm^2 sec^{-1}, the M's are molecular weights, and the A_{ik}^* are dimensionless ratios of collision integrals [Hirschfelder *et al.* (1954)]. The A_{ik}^* depend weakly on the temperature and on the force law between molecules i and k, and are usually nearly equal to unity.

As earlier pointed out by Mason and Saxena (1958) the calculation of λ_{mix} according to Eq. (1) has two disadvantages from practical viewpoint. Firstly the formula is quite complicated and involves laborious computation. Secondly a reliable knowledge of force laws for the various molecular interactions involved is essential, which is very seldom available. To get over these difficulties Mason and Saxena (1958) suggested the following *approximate* formula:

$$\lambda_{\text{mix}} = \sum_{i=1}^{n} \lambda_i \left[1 + \sum_{\substack{k=1\\k\neq i}}^{n} G_{ik}\frac{x_k}{x_i}\right]^{-1}, \tag{4}$$

where

$$G_{ik} = \frac{1.065}{2\sqrt{2}}\left(1 + \frac{M_i}{M_k}\right)^{-\frac{1}{2}}\left[1 + \left(\frac{\lambda_i}{\lambda_k}\right)^{\frac{1}{2}}\left(\frac{M_i}{M_k}\right)^{\frac{1}{4}}\right]^2 \cdot \tag{5}$$

The numerical factor 1.065 in Eq. (5) is introduced to compensate partially for the neglect of higher terms in the expansion of the determinant, Eq. (1), and also to replace a complicated factor in the very first term whose value is close to unity. In assigning this numerical value the data of Srivastava and Saxena (1957b) and Saxena (1957) on the binary gas mixtures were used.

The form of Eq. (4) for λ_{mix} is not very new, it was suggested long back by Wassiljewa (1904). Lindsay and Bromley (1950) have given the following expression for G_{ik}

$$G_{ik} = \frac{1}{4}\left[1 + \left\{\frac{\eta_i}{\eta_k}\left(\frac{M_k}{M_i}\right)^{\frac{3}{4}}\frac{1 + S_i/T}{1 + S_k/T}\right\}^{\frac{1}{2}}\right]^2 \frac{1 + S_{ik}/T}{1 + S_i/T}, \tag{6}$$

where η_i, η_k and S_i, S_k are the viscosities and Sutherland constants of the two components, respectively. S_{ik} is assumed to be the geometric mean of S_i and S_k. G_{ki} is obtained from G_{ik} by interchanging the subscripts. However, as shown by Srivastava and Saxena (1957b) and Saxena (1957), Eq. (4) in conjunction with Eq. (6) does not yield accurate values for λ_{mix} and is therefore not considered in this paper. A modification of the Eq. (4) was therefore also suggested by Srivastava and Saxena (1957b) which involves an additional unknown constant to be determined from the known λ_{mix} value at one composition. Further, G_{ik} may be treated as disposable parameters and determined directly from the known experimental λ_{mix} values at two compositions. These empirically determined G_{ik} and G_{ki} are fairly successful in reproducing the experimental data in the entire composition range as well as in predicting the multicomponent thermal conductivity. We also consider this *empirical* method of calculating λ_{mix} in this paper.

In the empirical method of calculating λ_{mix} a knowledge of its value at two compositions is essential to enable the determination of G_{ik} and G_{ki}. If, however, a relation is established between G_{ik} and G_{ki} the knowledge of λ_{mix} at only one composition will be sufficient to determine these two constants. An approximate relation of this type is suggested by the work of Mason and Saxena (1958), viz.,

$$G_{ik}/G_{ki} = \lambda_i/\lambda_k. \tag{7}$$

Mason and von Ubisch (1960) have exploited this relation and they write these two constants in the form

$$G_{ik} = \lambda_i/\Lambda_{ik},\; G_{ki} = \lambda_k/\Lambda_{ki}, \tag{8}$$

where $\Lambda_{ik} = \Lambda_{ki}$ is an empirical parameter to be determined from the known thermal conductivity of the binary mixture at one composition. A relation of the type of Eq. (8) is implied in Eq. (7). Mason and von Ubisch (1960) suggested Eqs. (4) and (8) for calculating λ_{mix} and designate this method of computation as *semiempirical.*

We thus consider in detail four different procedures of calculating λ_{mix} in this paper. These are, (1) rigorous, Eqs. (1) to (3); (2) approximate, Eqs. (4) and (5); (3) empirical, Eq. (4) along with λ_{mix} values at two compositions; and (4) semiempirical, Eqs. (4), (8), and λ_{mix} value at one composition.

II. COMPARISON OF EXPERIMENT AND THEORY

Calculations described in this section are performed according to the modified exp–six potential [Mason (1954)]

$$\phi(r) = \frac{\epsilon}{1 - \dfrac{6}{\alpha}}\left[\frac{6}{\alpha}\exp\alpha\left(1 - \frac{r}{r_m}\right) - \left(\frac{r_m}{r}\right)^6\right], \tag{9}$$

where $\phi(r)$ is the intermolecular potential energy between two molecules at a molecular separation distance r, ϵ is the depth of the potential energy minimum, r_m is the value of r for which $\phi(r)$ is a minimum, and α is a parameter which is measure of the steepness of repulsive potential energy. α, ϵ, and r_m are called the potential parameters and the values used in the calculations of this paper are those recorded in Table I.

TABLE I. Exp–six potential parameters.[a]

Parameter	Gas	He	Ne	Ar	Kr	Xe
α	He	12.4	13.46	13.21	12.92	12.55
	Ne		14.5	14.17	13.85	13.45
	Ar			14.0	13.74	13.44
	Kr				13.50	13.22
	Xe					13.00
ϵ/k °K	He	9.16	18.71	33.4	45.6	52.3
	Ne		38.0	73.7	115.4	121.8
	Ar			123.2	159.2	178.5
	Kr				200.0	226.3
	Xe					231.2
r_m A	He	3.135	3.143	3.488	3.539	3.65
	Ne		3.147	3.443	3.484	3.574
	Ar			3.866	3.946	4.108
	Kr				4.036	4.221
	Xe					4.45

[a] Mason (1955, 1960). Mason and von Ubisch (1960).

In Table II are recorded the experimental [Thornton (1960), (1961)] and computed values of thermal conductivity according to the four different procedures mentioned in the previous section for seven binary systems as a function of composition at 18°C. Experimental λ_{mix} values of Srivastava and Saxena (1957b) and Saxena (1957) at 38°C as a function of composition are recorded in Table III along with the four sets of calculated values. Similar computed and experimental λ_{mix} values of von Ubisch (1959) at 29°C are listed in Table IV while at 520°C in Table V.

Some of the computed values of these tables have been reported earlier. Thornton (1960, 1961) gave the rigorous computed values of the mixtures of Table II based on the Lennard–Jones (12–6) intermolecular potential. These values do not differ significantly from those of Table II. The average deviation between the two sets of values for a system never exceeds 1.9% and the average deviation for all the seven systems is only 0.13%. Thus, the use of the correct expression for λ_{mix} in conjunction with the exp–six potential does not produce any appreciable change in the values over those obtained from the older less accurate expression [Hirschfelder *et al.* (1954).] in conjunction with the Lennard–Jones (12–6) potential. The rigorous values of λ_{mix} for mixtures of Table III have also been reported earlier [Saxena (1957), Srivastava and Saxena (1957b)]. Approximate calculations have also been performed by Mason and Saxena (1958), who also presented a graphical comparison with the experimental values. Approximate values reported in Table III were, however, calculated afresh. Rigorous, approximate, and semiempirical calculated values of λ_{mix} of Tables IV and V are due to Mason and von Ubisch (1960). Approximate calculations, however, have been repeated and only these values are recorded. Some measurements of λ_{mix} are also available for the ternary mixtures of inert gasses. In Table VI are reported the experimental data of Srivastava and Saxena (1957a) and Saxena (1956) for He–Ar–Xe and Ne–Ar–Kr mixtures at 38°C. Rigorous calculated values of λ_{mix} are those of Muckenfuss and Curtiss (1958) according to the Lennard–Jones (12–6) potential. Approximate λ_{mix} values for these mixtures have been reported earlier by Mason and Saxena (1958). In Tables VII and VIII are given the experimental [von Ubisch (1959)] and various calculated values for the He–Kr–Xe mixtures at 29 and 520°C, respectively. The rigorous, approximate and semi-empirical calculated values of λ_{mix} are those of Mason and von Ubisch (1960). In Tables VI, VII, and VIII, X_1, X_2, and X_3 represent, respectively, the mole fractions of the three molecular species in order of their decreasing molecular weights.

In Table IX are listed the various values of G_{ik} and G_{ki} for the three sets of data and according to approximate, empirical, and semi-empirical procedures of calculations. The empirical values of G_{ik} and G_{ki} do not exhibit any systematic trend for the same mixture as a function of temperature or at the same temperature from one mixture to another. The empirical values also differ considerably from the semi-empirical and approximate values. The reason for the absence of any such correlating formula in the values of G_{ik} and G_{ki} lies in the success of the form of Eq. (4) in reproducing the composition dependence of λ_{mix} with considerable flexibility in the values of these constants. In fact the different choices of λ_{mix} for evaluating these two constants yield, in certain cases, widely different coupled values which are equally good in reproducing the composition variation of λ_{mix}. Recently Gray and Wright (1961) have made a detailed study regarding the nature of these constants. Cowling (1962) interprets G_{ik} as the measure of the ratio of the efficiencies with which molecules k and i separately impede the transport of energy by molecules i. Gray and Wright (1961, 1962), while interpreting experi-

TABLE II. Various calculated and experimental (Thornton) thermal conductivity values at 18°C. The units of λ are cal cm^{-1} sec^{-1} deg^{-1}.

Gas pair	X_1	Exptl.	Rigor.	% Dev.	Approx.	% Dev.	Empir.	% Dev.	Semi-empir.	% Dev.
He–Xe	0.000	3560	3606	+1.3	···	···	···	···	···	···
	0.063	2708	2961	+9.4	2890	+6.7	2869	+5.9	2911	+7.5
	0.139	2180	2378	+9.1	2294	+5.2	2265	+3.9	2324	+6.6
	0.201	1800	2008	+11.6	1922	+6.7	1894	+5.2	1955	+8.6
	0.304	1440	1534	+6.5	1455	+1.0	1429	−0.8	1486	+3.2
	0.401	1110	1196	+7.8	1128	+1.6	···	···	1154	+4.0
	0.494	905	940	+3.9	833	−2.4	865	−4.4	···	···
	0.594	680	710	+4.4	675	−0.7	659	−3.1	689	+1.3
	0.687	518	546	+5.4	512	−1.2	502	−3.2	524	+1.2
	0.792	356	384	+7.9	363	+2.0	···	···	370	+3.9
	0.898	232	247	+6.5	235	+1.3	232	0.0	239	+3.0
	1.000	132	135	+2.3	···	···	···	···	···	···
Ne–Xe	0.000	1160	1141	−1.6	···	···	···	···	···	···
	0.103	925	884	−4.4	908	−1.8	···	···	909	−1.7
	0.199	752	711	−5.5	735	−2.4	754	+0.3	737	−2.0
	0.285	624	591	−5.3	614	−1.6	630	+1.0	616	−1.3
	0.393	500	473	−5.4	495	−1.0	504	+0.8	496	−0.8
	0.504	398	379	−4.8	396	−0.5	400	+0.5	···	···
	0.594	327	317	−3.1	331	+1.2	330	+0.9	333	+1.8
	0.673	277	269	−2.9	282	+2.2	279	+0.7	283	+2.2
	0.794	213	212	−0.5	218	+2.3	···	···	219	+2.8
	0.903	166	168	+1.2	169	+1.8	166	0.0	170	+2.4
Ar–Xe	0.000	416	412	−1.0	···	···	···	···	···	···
	0.109	358	361	+0.8	366	+2.2	358	0.0	360	+0.6
	0.213	311	319	+2.6	325	+4.5	312	−0.3	315	+1.3
	0.300	280	289	+3.2	294	+5.0	···	···	284	+1.4
	0.405	251	257	+2.4	261	+4.0	247	−1.6	251	0.0
	0.498	226	239	+5.8	235	+4.0	223	−1.3	···	···
	0.598	202	208	+3.0	210	+4.0	199	−1.5	202	0.0
	0.701	180	186	+3.3	177	−1.7	179	−0.6	181	+0.6
	0.792	163	169	+3.7	169	+3.7	···	···	164	+0.6
	0.905	145	149	+2.8	148	+2.1	145	0.0	146	+0.7
Kr–Xe	0.000	220	218	−0.9	···	···	···	···	···	···
	0.115	207	205	−1.0	205	−1.0	207	0.0	206	−0.5
	0.201	197	196	−0.5	195	−1.0	···	···	196	−0.5
	0.296	187	186	−0.5	185	−1.1	187	0.0	186	−0.5
	0.397	178	177	−0.6	175	−1.7	177	−0.6	177	−0.6
	0.491	168	169	+0.6	166	−1.2	168	0.0	···	···
	0.595	160	161	+0.6	158	−1.3	159	−0.6	160	0.0
	0.693	152	154	+1.3	151	−0.7	152	0.0	152	0.0
	0.786	145	147	+1.4	145	0.0	···	···	146	+0.7
	0.896	138	141	+2.2	138	0.0	138	0.0	138	0.0
He–Kr	0.069	3050	2971	−2.6	2942	−3.5	2995	−1.5	2952	−3.2
	0.151	2500	2399	−4.0	2414	−3.4	2457	−1.7	2394	−4.2
	0.272	1850	1762	−4.8	1809	−2.2	···	···	1788	−3.4
	0.353	1530	1474	−3.7	1498	−2.1	1532	+0.1	1479	−3.3
	0.439	1210	1204	−0.5	1228	+1.5	1251	+3.4	···	···
	0.600	825	815	−1.2	833	+1.0	840	+1.8	821	−0.5
	0.698	642	631	−1.7	645	+0.5	645	+0.5	636	−0.9
	0.797	480	474	−1.3	484	+0.8	···	···	478	−0.4
	0.891	343	346	+0.9	342	+0.3	348	+1.5	349	+1.7
Ne–Kr	0.065	1030	1011	−1.8	1030	0.0	1034	+0.4	1032	+0.2
	0.111	960	931	−3.0	950	−1.0	955	−0.5	953	−0.7
	0.229	780	758	−2.8	778	−0.3	···	···	782	+0.3
	0.339	650	635	−2.3	651	−0.2	648	−0.3	655	+0.8
	0.438	568	542	−4.6	556	+2.1	559	−1.6	560	−1.4
	0.533	482	467	−3.1	479	+0.6	470	−2.5	···	···
	0.647	400	390	−2.5	400	+0.0	390	−2.5	402	+0.5
	0.797	305	307	+0.7	310	+1.6	···	···	315	+3.3
	0.889	257	264	+2.7	269	+4.7	263	+2.3	269	+4.7
Ar–Kr	0.109	387	381	−1.6	385	−0.5	387	0.0	379	−2.1
	0.228	348	351	+0.9	355	+2.0	···	···	345	−0.9
	0.330	326	328	+0.6	332	+1.8	321	−1.5	320	−1.8
	0.443	302	305	+1.0	308	+2.0	295	−2.3	296	−2.0
	0.546	277	285	+2.9	289	+4.3	276	−0.4	···	···
	0.673	256	264	+3.1	267	+4.3	···	···	257	+0.4
	0.777	242	248	+2.5	251	+3.7	243	+0.4	244	+0.8
	0.865	233	236	+1.3	238	+2.1	233	0.0	233	0.0

TABLE III. Various calculated and experimental (Srivastava and Saxena) thermal conductivity values at 38°C. The units of λ are cal cm^{-1} sec^{-1} deg^{-1}.

Gas pair	X_1	Exptl.	Rigor.	% Dev.	Approx.	% Dev.	Empir.	% Dev.	Semi-empir.	% Dev.
He–Xe	0.0000	3753	3742	−0.30	···	···	···	···	···	···
	0.1139	2582	2665	+3.2	2587	+0.2	2582	0.0	2571	−0.4
	0.2603	1694	1797	+6.1	1704	+0.6	···	···	1686	−0.5
	0.3460	1320	1443	+7.5	1354	+2.6	1345	+1.9	1338	+1.4
	0.4963	898	981	+9.2	910	+1.3	902	+0.4	···	···
	0.6333	616	675	+9.6	622	+1.0	···	···	613	−0.5
	0.8991	248	261	+5.2	241	−2.8	239	−3.6	239	−3.6
	1.0000	135	144	+6.7	···	···	···	···	···	···
Ar–Xe	0.0000	438	435	−0.7	···	···	···	···	···	···
	0.1757	347	338	−2.6	354	+2.0	351	+1.2	346	−0.3
	0.3231	292	293	+0.3	299	+2.4	···	···	289	−1.0
	0.5023	234	240	+2.6	243	+3.8	235	+0.4	···	···
	0.6727	192	200	+4.2	199	+3.6	192	0.0	193	+0.5
	0.7517	175	184	+5.1	182	+4.0	···	···	177	−1.1
	0.8339	163	170	+4.3	165	+1.2	160	−1.8	162	−0.6
Ne–Kr	0.0000	1180	1184	+0.3	···	···	···	···	···	···
	0.0712	1035	1044	+1.0	1042	+0.7	1028	−0.7	1039	+0.4
	0.2076	831	831	0.0	830	−0.1	846	+1.8	825	−0.7
	0.3092	696	707	+1.6	707	+1.6	···	···	701	+0.7
	0.4277	591	588	−0.8	588	−0.8	582	−1.5	583	−1.3
	0.5070	516	520	+0.8	521	+1.0	515	−0.2	···	···
	0.6707	398	403	+1.3	404	+1.5	···	···	401	+0.8
	0.8556	307	299	−2.6	290	−5.5	299	0.0	299	−2.6
	1.0000	234	232	−0.9	···	···	···	···	···	···
Ar–Kr	0.0866	398	404	+1.5	412	+3.5	410	+3.0	412	+3.5
	0.2338	366	376	+2.7	373	+1.9	···	···	373	+1.9
	0.3795	334	343	+2.7	339	+1.5	335	+0.3	339	+1.5
	0.4840	317	322	+1.6	318	+0.3	314	−0.9	···	···
	0.6683	277	287	+3.6	284	+2.5	···	···	283	+2.1
	0.8115	256	262	+2.3	261	+2.0	259	+1.2	260	+1.6
Ar–He	0.1412	2693	2668	−0.9	2812	+4.4	2737	+1.7	2702	+0.3
	0.2302	2247	2190	−2.3	2363	+5.2	···	···	2236	−0.5
	0.4164	1538	1494	−2.9	1653	+7.5	1524	−0.9	···	···
	0.6084	1037	1017	−1.9	1133	+9.3	···	···	1054	+1.6
	0.8398	657	632	−3.8	679	+3.3	640	−2.6	648	−1.4
Ar–Ne	0.1183	1047	1053	+0.6	1031	−1.5	1042	−0.5	1041	−0.6
	0.1370	1025	1031	+0.6	1010	−1.5	···	···	1021	−0.4
	0.3124	839	864	+3.0	839	0.0	857	+2.1	855	+1.1
	0.3472	830	835	+0.6	810	−2.4	828	−0.2	826	−0.5
	0.4215	768	774	+0.8	752	−2.1	770	+0.3	···	···
	0.6683	607	609	+0.3	593	−2.3	···	···	604	−0.5
	0.8286	515	519	+0.8	511	−0.8	519	+0.8	518	+0.6
	0.8381	516	514	−0.4	507	−1.7	514	−0.4	513	−0.6
	0.8660	503	499	−0.8	494	−1.8	500	−0.6	499	−0.8

TABLE IV. Various calculated and experimental (von Ubisch) thermal conductivity data at 29°C. The units of λ are cal cm^{-1} sec^{-1} deg^{-1}.

Gas pair	X_1	Exptl.	Rigor.	% Dev.	Approx.	% Dev.	Empir.	% Dev.	Semi-empir.	% Dev.
He–Xe	0.000	3670	3702	+0.9	···	···	···	···	···	···
	0.213	1882	2011	+6.9	1958	+4.0	1855	−1.4	1910	+1.5
	0.283	1530	1679	+9.7	1622	+6.0	···	···	1580	+3.3
	0.582	717	776	+8.2	741	+3.3	690	−3.8	···	···
	0.798	357	394	+10.3	379	+6.2	···	···	369	+3.3
	1.000	143	140	−2.1	···	···	···	···	···	···
Ne–Xe	0.000	1237	1170	−5.4	···	···	···	···	···	···
	0.330	596	589	−1.2	603	+1.2	···	···	593	−0.5
	0.430	486	486	0.0	494	+1.6	486	0.0	···	···
	0.704	279	283	+1.4	286	+2.5	···	···	281	+0.7

TABLE IV. (*Continued*)

Gas pair	X_1	Exptl.	Rigor.	% Dev.	Approx.	% Dev.	Empir.	% Dev.	Semi-empir.	% Dev.
Ar–Xe	0.271	316	308	−2.5	320	+1.3	···	···	310	−1.9
	0.504	239	237	−0.8	249	+4.2	240	+0.4	···	···
	0.750	181	182	+0.5	190	+5.0	···	···	184	+1.6
Kr–Xe	0.215	206	202	−1.9	205	−0.5	216	+4.9	211	+2.4
	0.490	186	176	−5.4	178	−4.3	···	···	···	···
	0.724	158	158	0.0	160	+1.3	162	+2.5	166	+5.1
	0.842	149	150	+0.7	152	+2.0	···	···	156	+4.7
	0.890	145	147	+1.4	149	+2.8	145	0.0	152	+4.8
He–Kr	0.120	2610	2674	+2.5	2699	+3.4	···	···	2634	+0.9
	0.250	1930	1946	+0.8	1980	+2.6	1897	−1.7	1904	−1.3
	0.423	1280	1302	+1.7	1329	+3.8	1260	−1.6	1265	−1.2
	0.510	1030	1061	+3.0	1084	+5.2	1026	−0.4	···	···
	0.578	888	901	+1.5	920	+3.6	871	−1.9	874	−1.6
	0.760	541	555	+2.6	567	+4.8	···	···	542	+0.2
	1.000	232	226	−2.6	···	···	···	···	···	···
Ne–Kr	0.308	716	687	−4.1	726	+1.4	724	+1.1	725	+1.3
	0.460	568	540	−4.9	570	+0.4	···	···	···	···
	0.750	357	343	−3.9	358	+0.3	···	···	357	0.0
Ar–Kr	0.298	362	347	−4.1	355	−1.9	···	···	358	−1.1
	0.536	308	298	−3.2	306	−0.6	315	+2.3	···	···
	0.764	272	259	−4.8	266	−2.2	···	···	268	−1.5
He–Ar	0.106	2920	2897	−0.8	2957	+1.3	2889	−1.1	2899	−0.7
	0.276	2020	2030	+0.5	2126	+5.2	2031	+0.5	2046	+1.3
	0.541	1220	1205	−1.2	1279	+4.8	···	···	···	···
	0.710	843	855	+1.4	904	+7.2	···	···	867	+2.8
	1.000	434	426	−1.8	···	···	···	···	···	···
Ne–Ar	0.237	951	917	−3.6	938	−1.4	···	···	966	+1.6
	0.423	798	763	−4.4	766	−4.0	792	−0.8	···	···
	0.642	629	615	−2.2	613	−2.5	633	+0.6	637	+1.3
	0.842	519	502	−3.3	505	−2.7	···	···	516	−0.6
He–Ne	0.119	3220	3162	−1.8	3271	+1.6	3171	−1.5	3164	−1.7
	0.130	3120	3117	−0.1	3235	+3.7	3130	+0.3	3122	+0.1
	0.382	2340	2291	−2.1	2514	+7.4	···	···	···	···
	0.755	1570	1510	−3.8	1676	+6.8	···	···	1585	+1.0

TABLE V. Various calculated and experimental (von Ubisch) thermal conductivity data at 520°C. The units of λ are cal cm^{-1} sec^{-1} deg^{-1}.

Gas pair	X_1	Exptl.	Rigor.	% Dev.	Approx.	% Dev.	Empir.	% Dev.	Semi-empir.	% Dev.
He–Xe	0.000	7360	7128	−3.2	···	···	···	···	···	···
	0.213	3960	3982	+0.6	4134	+4.4	···	···	3875	−2.1
	0.283	3270	3348	+2.4	3469	+6.1	3276	+0.2	3218	−1.6
	0.582	1490	1590	+6.7	1635	+9.3	···	···	···	···
	0.798	770	832	+8.0	854	+10.9	804	···	790	+2.5
	1.000	334	322	−3.6	···	···	···	···	···	···
Ne–Xe	0.000	2360	2222	−5.8	···	···	···	···	···	···
	0.330	1240	1186	−4.4	1255	+1.2	···	···	1246	+0.5
	0.430	1040	993	−4.5	1048	+0.8	1034	−0.6	···	···
	0.704	627	604	−3.8	632	+0.8	···	···	628	+0.2
Ar–Xe	0.000	914	871	−4.7	···	···	···	···	···	···
	0.271	681	647	−5.0	696	+2.2	···	···	680	−0.2
	0.504	537	511	−4.8	554	+3.2	528	−1.7	···	···
	0.750	416	404	−2.9	433	+4.1	···	···	423	+1.7
Kr–Xe	0.000	534	503	−5.8	···	···	···	···	···	···
	0.215	479	453	−5.4	474	−1.0	···	···	479	0.0
	0.490	420	400	−4.8	413	−1.7	411	−2.1	···	···
	0.724	358	361	+0.8	372	+3.9	361	+0.8	377	+5.3
	0.842	341	344	+0.9	355	+4.1	343	+0.6	358	+5.0
	0.890	338	337	−0.3	348	+3.0	···	···	350	+3.6

TABLE V. (*Continued*)

Gas pair	X_1	Exptl.	Rigor.	% Dev.	Approx.	% Dev.	Empir.	% Dev.	Semi-empir.	% Dev.
He–Kr	0.120	5510	5216	−5.3	5567	+1.0	5444	−1.2	5455	+1.0
	0.250	3900	3840	−1.5	4171	+7.0	4028	+3.3	4035	+3.5
	0.423	2670	2604	−2.5	2858	+7.0	2738	+2.5	2739	+2.6
	0.510	2250	2138	−5.0	2352	+4.5	...	...	...	...
	0.578	1950	1826	−6.4	2008	+3.0	1922	−1.4	1921	−1.5
	0.760	1210	1150	−5.0	1260	+4.1	...	...	1211	+0.1
Ne–Kr	0.308	1470	1367	−7.0	1490	+1.4	...	...	1479	+0.6
	0.460	1190	1097	−7.8	1200	+0.8	1178	−1.0	...	...
	0.750	780	727	−6.8	790	+1.3	...	...	785	+0.6
Ar–Kr	0.298	774	725	−6.3	768	−0.8	...	...	761	−1.7
	0.536	667	634	−5.0	676	+1.3	673	+0.9	...	...
	0.764	596	563	−5.5	600	+0.7	...	...	595	−0.2
He–Ar	0.106	5900	5616	−4.8	5977	+1.3	...	...	5941	+0.7
	0.276	4220	3969	−5.9	4339	+2.8	4234	+0.3	4288	+1.6
	0.541	2600	2382	−8.4	2639	+1.5	...	...	...	...
	0.710	1790	1704	−4.8	1877	+4.9	1827	−2.1	1852	+3.5
Ne–Ar	0.237	1860	1767	−5.0	1837	−1.2	...	...	1880	+1.1
	0.423	1580	1487	−5.9	1531	−3.1	1539	−2.6	...	...
	0.642	1270	1217	−4.2	1251	−1.5	1231	−3.1	1288	+1.4
	0.842	1030	1012	−1.7	1048	+1.7	...	...	1066	+3.5
He–Ne	0.110	6580	6104	−7.2	6514	−1.0	6658	+1.2	6390	−2.9
	0.130	6580	6019	−8.5	6441	−2.1	...	...	6309	−4.1
	0.382	4740	4432	−6.5	4941	+4.2	4927	+4.0	...	...
	0.755	3170	2903	−8.4	3238	+2.1	...	...	3131	−1.2

TABLE VI. Various calculated and experimental data (Srivastava and Saxena) of ternary mixtures at 38°C. The units of λ are cal cm^{-1} sec^{-1} deg^{-1}.

Gas system	X_1	X_2	X_3	Exptl.	Rigor.	% Dev.	Approx.	% Dev.	Empir.	% Dev.	Semi-empir.	% Dev.
He–Ar–Xe	0.0733	0.6065	0.3202	843	843	0.0	907	+7.1	836	−0.8	848	+0.6
	0.2424	0.3675	0.3901	845	846	+0.1	895	+5.6	836	−1.1	848	+0.4
	0.1319	0.1880	0.6801	1662	1654	−0.5	1694	+1.9	1644	−1.1	1656	−0.4
	0.6233	0.1800	0.1967	400	402	+0.5	414	+3.4	399	−0.3	404	+1.0
	0.7367	0.1495	0.1138	284	285	+0.4	292	+2.7	283	−0.4	285	+0.4
Ne–Ar–Kr	0.2715	0.1301	0.5984	658	653	−0.8	651	−1.1	655	−0.5	656	−0.3
	0.3896	0.1567	0.4537	545	527	−3.3	531	−2.6	530	−2.8	531	−2.6
	0.3133	0.3848	0.3019	480	477	−0.6	470	−2.1	477	−0.6	479	−0.2
	0.1441	0.7172	0.1387	450	453	+0.7	451	+0.2	453	+0.7	455	+1.1
	0.6690	0.1449	0.1861	347	347	0.0	347	0.0	345	−0.6	346	−0.3
	0.7152	0.1569	0.1279	324	314	−3.1	317	−2.2	315	−2.8	317	−2.2

mental data on a few systems, also comment on the lack of uniqueness in the values of these empirical constants and determine the range of lower and upper limits. They (1962) also show on the basis of the rigorous Chapman–Enskog first approximation expression for binary viscosity that the corresponding constants are only weakly dependent on temperature and composition. Empirical constants of Table IX do not follow this trend. The reason for this lies primarily in the large flexibility in the values of G_{ik} and G_{ki} of Eq. (4). However, these empirical constants still retain their importance for the purpose of representing the composition dependence of λ_{mix} and in predicting the multicomponent thermal conductivity values. In fact the incentive to the calculation of these two empirical constants (G_{ik} and G_{ki}) was primarily with the idea of evolving the functional dependence of these constants on temperature, molecular weights, and pure thermal conductivity values, etc. If a relation of this type interconnecting

TABLE VII. Various calculated and von Ubisch experimental thermal conductivity data for the He–Kr–Xe system at 29°C. The units of λ are cal cm^{-1} sec^{-1} deg^{-1}.

X_1	X_2	X_3	Exptl.	Rigor.	% Dev.	Approx.	% Dev.	Empir.	% Dev.	Semi-empir.	% Dev.
0.695	0.086	0.219	405	425	+4.9	412	+1.7	383	−5.4	403	−0.5
0.457	0.057	0.486	916	939	+2.5	904	−1.3	839	−8.4	878	−4.1
0.259	0.032	0.709	1580	1658	+4.9	1606	+1.6	1511	−4.4	1565	−0.9
0.121	0.016	0.864	2470	2488	+0.7	2434	−1.5	2337	−6.1	2394	−3.1
0.633	0.119	0.248	455	474	+4.2	460	+1.1	428	−5.9	450	−1.1
0.438	0.082	0.480	893	930	+4.1	898	+0.6	833	−6.7	871	−2.5
0.217	0.041	0.742	1710	1809	+5.8	1759	+2.9	1662	−2.8	1716	+0.4
0.114	0.021	0.865	2390	2499	+4.6	2449	+2.5	2357	−1.4	2408	+0.7
0.568	0.217	0.215	412	434	+5.3	424	+2.9	400	−2.9	416	+1.0
0.357	0.136	0.507	964	1011	+4.9	983	+1.9	916	−5.0	953	−1.2
0.213	0.081	0.706	1520	1665	+9.5	1626	+7.0	1532	+0.8	1581	+4.0
0.102	0.039	0.859	2380	2471	+3.8	2429	+2.1	2337	−1.8	2384	+0.2
0.379	0.394	0.227	450	475	+5.6	470	+4.4	452	+0.4	461	+2.4
0.255	0.266	0.479	928	968	+4.3	954	+2.8	898	−3.2	923	−0.5
0.133	0.138	0.729	1740	1794	+3.1	1772	+1.8	1682	−3.3	1720	−1.1
0.071	0.073	0.856	2300	2475	+7.6	2451	+6.6	2362	+2.7	2399	+4.3
0.162	0.593	0.245	533	534	+0.2	538	+0.9	519	−2.6	522	−2.1
0.103	0.378	0.519	1060	1107	+4.4	1118	+5.5	1053	−0.7	1066	+0.6
0.055	0.202	0.743	1840	1892	+2.8	1896	+3.0	1811	−1.6	1832	−0.4
0.029	0.106	0.865	2500	2563	+2.5	2561	+2.4	2480	−0.8	2501	0.0

TABLE VIII. Various calculated and von Ubisch experimental thermal conductivity data for the He–Kr–Xe system at 520°C. The units of λ are cal cm^{-1} sec^{-1} deg^{-1}.

X_1	X_2	X_3	Exptl.	Rigor.	% Dev.	Approx.	% Dev.	Empir.	% Dev.	Semi-empir.	% Dev.
0.695	0.086	0.219	860	894	+3.9	927	+7.8	862	+0.2	862	+0.2
0.457	0.057	0.486	1990	1909	−4.1	1984	−0.3	1843	−7.4	1822	−8.4
0.259	0.032	0.709	3450	3305	−4.2	3437	−0.4	3241	−6.1	3202	−7.2
0.121	0.016	0.864	5080	4883	−3.9	5073	−0.1	4884	−3.9	4850	−4.5
0.633	0.119	0.248	976	991	+1.5	1030	+5.5	956	−2.0	957	−1.9
0.438	0.082	0.480	1880	1890	+0.5	1969	+4.7	1827	−2.8	1812	−3.6
0.217	0.041	0.742	3620	3595	−0.7	3745	+3.5	3545	−2.1	3510	−3.0
0.114	0.021	0.865	4880	4904	+0.5	5101	+4.5	4921	+0.8	4884	+0.1
0.568	0.217	0.215	958	911	−4.9	952	−0.6	886	−7.5	893	−6.8
0.357	0.136	0.507	2030	2048	+0.9	2147	+5.8	1997	−1.1	1988	−2.1
0.213	0.081	0.706	3390	3317	−2.2	3474	+2.5	3330	−1.8	3257	−3.9
0.102	0.039	0.859	4830	4848	+0.4	5060	+4.8	4880	+1.0	4853	+0.5
0.379	0.394	0.227	995	993	−0.2	1050	+5.5	990	−0.5	995	0.0
0.255	0.266	0.479	1950	1962	+0.6	2085	+6.9	1953	+0.2	1952	+0.1
0.133	0.138	0.729	3780	3559	−5.8	3765	−0.4	3577	−5.4	3570	−5.6
0.071	0.073	0.856	5340	4852	−9.1	5100	−4.5	4927	−7.7	4918	−7.9
0.162	0.593	0.245	1140	1131	−0.8	1197	+5.0	1145	+0.4	1144	+0.4
0.103	0.378	0.519	2250	2229	−0.9	2411	+7.2	2289	+1.7	2287	+1.6
0.055	0.202	0.743	3840	3743	−2.5	4009	+4.4	3844	+0.1	3845	+0.1
0.029	0.106	0.865	5120	5012	−2.1	5306	+3.6	5158	+0.7	5161	+0.8

the two constants could be predicted calculations would be much simpler. Of course semi-empirical procedure involves the assumption of one such relation, Eq. (7), which the empirical constants do not confirm. The implication, however, is not that Eq. (7) is wrong. The inconsistency in the experimental λ_{mix} values of the three sets of data also may be partially responsible for this anomaly. More confirmatory decision is possible by considering the data on the viscosities of binary mixtures. Saxena and Singh hope to throw light on this point in a separate publication.

III. DISCUSSION OF RESULTS

A few recollections are very essential regarding the relative accuracies of the experimental results of these three groups as the data exhibit inconsistencies. Srivastava and Saxena (1957b) used the "thick-wire" variant of the "hot-wire" method which is capable of yielding accurate absolute values of thermal conductivity. These workers claim an uncertainty of 1% in their results. The accuracy of this method is limited by the accuracy and precision attainable in measuring small increments in the resistance of cell wire. A practical way to improve the accuracy, therefore, would be to increase this increment. The possible choices are to use a thin wire either straight or in spiral form. Either choice gives rise to various other uncertainties of doubtful magnitudes which then impair the accuracy of the final results. Thus, von Ubisch (1959) used a thin straight wire and estimates an uncertainty of 4% in his data, while the precision of his measurements was somewhat better, ±2%. Thornton (1960, 1961) used a spiral form of this wire, the objections against this type of geometry of cell wire have already been pointed out [Srivastava and Saxena (1957b)]. The experimental error of these measurements is approximately ±2.2% for low values of λ_{mix} and this rises to ±4.0% for high values of λ_{mix}. However, recent calculations of Saxena and Agrawal (1962) have shown that these λ_{mix} values possess a great degree of consistency with the binary viscosity data [Thornton (1960, 1961)] which have a better precision of ±1.0%.

TABLE IX. Constants G_{12} and G_{21} according to various formulas for thermal conductivity.

Gas pair	Approximate		Empirical		Semiempirical	
	G_{12}	G_{21}	G_{12}	G_{21}	G_{12}	G_{21}
Experimental data of von Ubisch at 29°C						
He–Xe	0.1410	3.596	0.258	3.913	0.146	3.765
Ne–Xe	0.327	2.831	0.743	2.635	0.336	2.909
A–Xe	0.572	1.735	1.419	1.386	0.613	1.864
Kr–Xe	0.829	1.346	4.150	0.446	0.758	1.232
He–Kr	0.190	3.009	0.264	3.230	0.206	3.258
Ne–Kr	0.434	2.317	0.423	2.350	0.437	2.328
A–Kr	0.756	1.415	0.811	1.241	0.742	1.388
He–A	0.295	2.495	0.449	2.631	0.319	2.698
Ne–A	0.632	1.802	0.680	1.610	0.585	1.667
He–Ne	0.536	1.589	0.924	1.612	0.617	1.832
Experimental data of von Ubisch at 520°C						
He–Xe	0.148	3.25	0.153	3.609	0.169	3.716
Ne–Xe	0.352	2.489	0.414	2.496	0.357	2.521
A–Xe	0.598	1.637	0.189	2.660	0.633	1.732
Kr–Xe	0.835	1.336	2.146	0.769	0.806	1.290
He–Kr	0.200	2.754	0.332	2.872	0.214	2.952
Ne–Kr	0.468	2.067	0.506	2.114	0.474	2.097
A–Kr	0.789	1.350	0.278	2.400	0.806	1.379
He–A	0.301	2.42	0.477	2.421	0.308	2.484
Ne–A	0.659	1.702	1.365	1.275	0.621	1.603
He–Ne	0.523	1.632	0.190	2.198	0.569	1.774
Experimental data of Thornton at 18°C						
He–Xe	0.134	3.727	0.200	3.800	0.134	3.598
Ne–Xe	0.325	2.860	1.362	2.342	0.324	2.848
Ar–Xe	0.562	1.772	0.677	1.902	0.604	1.903
Kr–Xe	0.819	1.365	1.158	1.068	0.801	1.334
He–Kr	0.189	3.054	1.363	2.609	0.193	3.124
Ne–Kr	0.436	2.301	1.115	1.956	0.432	2.276
Ar–Kr	0.752	1.423	0.178	3.267	0.814	1.540
Experimental data of Srivastava and Saxena at 38°C						
He–Xe	0.137	3.798	0.101	3.870	0.139	3.870
Ar–Xe	0.555	1.802	1.116	1.553	0.593	1.924
Ne–Kr	0.444	2.239	0.431	2.303	0.451	2.275
Ar–Kr	0.756	1.415	0.626	1.627	0.760	1.422
He–Ar	0.294	2.515	0.084	3.243	0.332	2.844
Ne–Ar	0.647	1.744	0.597	1.690	0.621	1.674

Tables II to V show that the rigorous calculated values of thermal conductivities of binary mixtures are in reasonable agreement with the experimental values with a few exceptions. The most notable case is of the He–Xe system. In all the four sets, the experimental values of λ_{mix} are always smaller than the computed values by an appreciable amount. The average percentage deviations being +7.3, +6.8, +8.8, and +4.4 for the experimental data of Thornton, Srivastava, and Saxena, von Ubisch at 29°C, and von Ubisch at 520°C, respectively. The maximum percentage deviations in the four cases are +11.6, +9.6, +9.7, and +8.0, respectively. We thus find that the disagreement between theory and experiment for this system is real and cannot be attributed to either any systematic or random errors in the measurements. There are, however, some relative discrepancies among the data of these workers. Mixtures containing up to 50% Xe exhibit good agreement with each other in as much as the three sets of data follow the right type of qualitative trend but for mixtures having higher percentage of Xe there is considerable overlapping and, in fact, for pure Xe, von Ubisch' value is about 6% higher than Saxena's value (1957) in spite of the fact that it corresponds to a temperature which is 9°C lower. Unfortunately only a qualitative comparison is possible, as all the three sets refer to different temperatures. Thornton's (1960, 1961) results are in reasonable agreement with Saxena (1957). The measurements of thermal conductivity [Srivastava and Saxena (1957b), Von Ubisch (1959)] become less accurate for systems which have low λ, and become still worse at low temperatures. He–Xe system is preferable from this viewpoint also and measurements should yield fairly accurate values of λ_{mix}. Furthermore, the Chapman–Enskog theory holds very well for these monatomic, spherically symmetric molecules. In view of all this it becomes puzzling to account for such an amount of disagreement between theory and experiment which is more than the estimated errors of the measurements. Von Ubisch' measurements at 520°C also exhibit the same trend. The agreement between theory and experiment becomes still worse if we account for the fact that von Ubisch' measurements are about 4%

higher than that of other workers, though for most of the other systems it will improve.

We feel that the fault probably lies with the chosen intermolecular potential for Xe and He–Xe. It will be useful if a check on this point is obtained by interpreting data of some other transport property which is more sensitive to the nature of intermolecular force field. Thermal diffusion data [Atkins *et al.* (1939), Grew (1947), Heymann and Kistemaker (1959)] are available for this system and we propose to investigate it in a later publication. It seems also desirable to redetermine accurately the thermal conductivity of this system as a function of temperature.

For the Ne–Xe system the experimental data of Thornton (1960) and von Ubisch (1959) at 29°C are consistent with each other though the agreement with rigorous theory is poor. The experimental values are consistently greater than the computed values according to rigorous theory. We, thus, find that the Ne–Xe system exhibits departure from the rigorous theoretical values of the opposite sign compared to the He–Xe system. We feel the origin of this discrepancy also lies in sources similar to those for the He–Xe system. For most of the other systems of Thornton the agreement between theory and experiment is satisfactory, the percentage deviation being of the order of experimental uncertainty except in the case of He–Kr and to some extent for Ne–Kr. This inference is also substantiated by the results of von Ubisch given in Table IV. From this latter work we find that the agreement is also poor for Ar–Kr and Ne–Ar systems. On the other hand, the Srivastava and Saxena values (1957b) are in good agreement with the rigorous values for both these systems. Except for the He–Xe system, von Ubisch' experimental values at 520°C (Table V) are systematically larger than the calculated values according to the rigorous theory. Most of the discrepancies found in the case of von Ubisch' data (except the He–Xe system) can be explained if allowance is made for the fact that von Ubisch' experimental data are about 4% higher.

The agreement of the experimental ternary thermal conductivity data with the rigorous theory calculated values is good in the case of mixtures of Table VI. In the case of He–Kr–Xe mixtures at 29°C (Table VII) and 520°C (Table VIII) the agreement is satisfactory and discrepancies which appear are of the same nature as encountered and discussed in the corresponding binary mixtures. As the discrepancies in the related three binary mixtures occur in opposite directions, the integrated effect in ternary λ_{mix} values is exhibited in somewhat decreased proportions and so the percentage deviation is less in ternary mixtures than some of the related binary mixtures.

The approximate method of calculation seems to be fairly successful in predicting the thermal conductivities of binary and ternary mixtures. Of all the systems investigated by Srivastava and Saxena (1957a, 1957b) and Saxena (1956, 1957), only for the Ar–He system is good agreement not achieved between calculated and experimental values. This also seems to be the case with von Ubisch' data at 29°C, though satisfactory agreement is achieved at 520°C. On the whole, calculated values obtained according to the approximate formula are in reasonable agreement with the experimental data and more elaborate data of good absolute accuracy are required to properly assess this procedure of calculation.

Empirical and semiempirical methods of calculation are about equally successful in predicting the multicomponent thermal conductivity. We feel the reason for this lies in the great success of the form of Eq. (4) for representing λ_{mix}, so that even an approximate relation connecting G_{ik} and G_{ki} [e.g., Eqs. (7) and (8)] serves to reproduce λ_{mix} values quite precisely. Both of these methods are about equally good, but probably better than the approximate method for calculating multicomponent thermal conductivity of gas mixtures.

IV. CONCLUSIONS

The Chapman–Enskog theory of thermal conduction applies well to monatomic, spherically symmetric gases and quite correct values can be obtained if the force law is correctly known. If the force law is not known with confidence, and also the thermal conductivity at one or two compositions, the approximate method is liable to yield the best reliable values. This approach does require the knowledge of pure thermal conductivities at the same temperature which can be generated from the pure viscosity data also. If both viscosity and thermal conductivity data are not available the theoretical formulas in conjunction with the knowledge of force laws for the pure gases may be used. If, however, the thermal conductivity of the binary mixture is also available at one or two compositions the semiempirical and empirical procedures respectively may be used to predict either the entire range or to extend the scope of calculations for predicting the conductivity values for multicomponent mixtures.

This investigation also brings to light the need for accurate determination of thermal conductivities of pure gases and gaseous mixtures as a function of temperature. The available data are somewhat in disagreement with each other and accurate measurements will clarify the position considerably.

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Erratum: The Measuring Process in Quantum Theory

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[Rev. Mod. Phys. **35**, 145 (1963)]

In my paper several lines of explanation in connection with Eq. (22) on p. 148 were omitted. The following lines should be inserted immediately after this equation, and must replace the 4 lines now following it:

"if we make use of $\sum_m f_{im} f_{lm}^* = \delta_{il}$, which is necessary as the f_{im} determine a unitary transformation from a complete set of orthonormal eigenstates $(\Psi_i)_2$ to another complete set ϑ_m.

That the $(\Psi_i)_2$ indeed form a complete set of orthonormal eigenstates, as is expressed by Eq. (17), is a consequence of assumption (11). This assumption makes that

$$\Phi_2 = \sum_i a_{ki} (\psi_i)_2 (\Psi_i)_2 ,$$

which implies that the eigenstates of the complex system formed out of the original system plus the apparatus are determined by products of the form $(\psi_i)_2(\Psi_i)_2$. These can be decomposed into a factor $(\psi_i)_2$ for the original system, and a second factor $(\Psi_i)_2$ for the apparatus."

Erratum: Relativistic Invariance and Hamiltonian Theories of Interacting Particles

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In Sec. IV of this paper we have used an "angular momentum Helmholtz theorem" due to J. S. Lomont and H. E. Moses [Communs. Pure Appl. Math. **14**, 69 (1961)]. Our footnote 25, which refers only to the second proof of J. B. Keller, should be corrected accordingly. We should also note that our use of this theorem to establish the standard form of classical mechanical angular momentum is similar to the quantum mechanical proof of J. S. Lomont and H. E. Moses [Nuovo Cimento **16**, 96 (1960)]. We regret these omissions.

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