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A Method for Calculating Viscosity and Thermal Conductivity of a Helium-Xenon Gas Mixture

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Abstract

A method for calculating viscosity and thermal conductivity of a helium-xenon (He-Xe) gas mixture was employed, and results were compared to AiResearch analytical data. The method of choice was that presented by Hirschfelder with Singh's third-order correction factor applied to thermal conductivity. Values for viscosity and thermal conductivity were calculated over a temperature range of 400 to 1200 K for He-Xe gas mixture molecular weights of 20.183, 39.94 and 83.8 kg/kmol. First-order values for both transport properties were in good agreement with AiResearch analytical data. Third-order-corrected thermal conductivity values were all greater than AiResearch data, but were considered to be a better approximation of thermal conductivity because higher-order effects of mass and temperature were taken into consideration. Viscosity, conductivity, and Prandtl number were then compared to experimental data presented by Taylor.

Introduction

In an effort to generate transport properties, namely viscosity and thermal conductivity, of a helium-xenon (He-Xe) gas mixture a method described by Hirschfelder was employed and compared to analytical data generated by AiResearch[a] (Coombs, 1970, pp. 274–373). The goal was to produce data similar to that of AiResearch's with the added value of knowing the method with which the data was generated. This document will describe in detail the implementation of Hirschfelder's method and compare the calculated properties to AiResearch data and a sampling of experimental data (Taylor, 1988). All tables and figures are located at the end of the document due to their size.

The text *Molecular Theory of Gases and Liquids* by Hirschfelder, Curtiss, and Bird (1964) presents equations for the first-order viscosity and first-order thermal conductivity of dilute, monatomic, binary gas mixtures. A dilute gas assumes the effect of collisions involving more than two molecules is negligible. The equations are based on the Chapman-Enskog theory that models the molecules as spheres, and therefore the molecules have no internal degrees of freedom (Hirschfelder, 1964, p. 20). Calculations for the pure-gas properties and gas-mixture properties require temperature, molecular weights, mole fractions, and force constants of the species.

Method

To begin, one must obtain the two force constants for each gas: collision diameter, σ, and potential parameter, ε/k. For helium $\sigma = 2.576$ Å and $\varepsilon/k = 10.22$ K; for xenon $\sigma = 4.055$ Å and $\varepsilon/k = 229$ K (Hirschfelder, 1964, app. table I–A). These values are based on the Lennard-Jones (6-12) potential. Because no measurements of σ and ε/k exist for gas mixtures, an empirical "combining law" for force constants between unlike molecules is recommended (Hirschfelder, 1964, p. 567).

$$\sigma_{12} = \frac{1}{2}(\sigma_1 + \sigma_2)$$

[a]AiResearch subsequently became part of AlliedSignal, and has since become part of Honeywell.

$$\varepsilon/k_{12} = \sqrt{\varepsilon/k_1 \cdot \varepsilon/k_2}$$

For the remainder of the report, subscript 1 will represent values for helium, subscript 2 will represent values for xenon, and subscript 12 will represent values for combined helium and xenon.

Using the potential parameters, one can calculate the reduced temperatures, T^*, at any given temperature.

$$T_1^* = \frac{T}{\varepsilon/k_1} \qquad T_2^* = \frac{T}{\varepsilon/k_2} \qquad T_{12}^* = \frac{T}{\varepsilon/k_{12}}$$

The reduced temperature allows one to look up table values for the integral $\Omega^{(2,2)*}$, and quantities A^*, and B^*. Since all three values are functions of T^*, table lookups will have to be performed at each desired temperature. The method requires values for $\Omega_1^{(2,2)*}$, $\Omega_2^{(2,2)*}$, $\Omega_{12}^{(2,2)*}$, A^*_{12}, and B^*_{12}, listed in tables 1 and 2. It should be noted that tables for $\Omega^{(2,2)*}$, A^*, and B^* exist for both the Lennard-Jones potential and the modified Buckingham (6-EXP) potential. This report uses values from the Lennard-Jones table because the force constants are of the Lennard-Jones potential.

Next, one calculates the first-order transport properties of the pure gases and of the hypothetical pure substance (Hirschfelder, 1964, pp. 528–529, 534–535).

$$[\mu_1]_1 \times 10^7 = 266.93 \frac{\sqrt{M_1 T}}{\sigma_1^2 \Omega_1^{(2,2)*}} \quad [\lambda_1]_1 \times 10^7 = 1989.1 \frac{\sqrt{T/M_1}}{\sigma_1^2 \Omega_1^{(2,2)*}}$$

$$[\mu_2]_1 \times 10^7 = 266.93 \frac{\sqrt{M_2 T}}{\sigma_2^2 \Omega_2^{(2,2)*}} \quad [\lambda_2]_1 \times 10^7 = 1989.1 \frac{\sqrt{T/M_2}}{\sigma_2^2 \Omega_2^{(2,2)*}}$$

$$[\mu_{12}]_1 \times 10^7 = 266.93 \frac{\sqrt{2M_1 M_2 T/(M_1 + M_2)}}{\sigma_{12}^2 \Omega_{12}^{(2,2)*}}$$

$$[\lambda_{12}]_1 \times 10^7 = 1989.1 \frac{\sqrt{T(M_1 + M_2)/(2M_1 M_2)}}{\sigma_{12}^2 \Omega_{12}^{(2,2)*}}$$

where
$[\mu]_1$ = first-order viscosity (g/cm-s)
$[\lambda]_1$ = first-order thermal conductivity (cal/cm-s-K)
T = temperature (K)
M = molecular weight (g/mol)
σ = collision diameter (Å)
$\Omega^{(2,2)*}$ = integral value that is a function of reduced temperature, T^*
Note: 1 g/cm-s = 0.1 kg/m-s
1 cal/cm-s-K = 418.4 W/m-K

Using the values calculated above, the first-order viscosity and first-order thermal conductivity can be calculated (Hirschfelder, 1964, pp. 530 and 535).

$$[\mu_{mix}]_1 = \frac{1+Z_\mu}{X_\mu + Y_\mu}$$

$$X_\mu = \frac{x_1^2}{[\mu_1]_1} + \frac{2x_1x_2}{[\mu_{12}]_1} + \frac{x_2^2}{[\mu_2]_1}$$

$$Y_\mu = \frac{3}{5}A_{12}^*\left\{\frac{x_1^2}{[\mu_1]_1}\left(\frac{M_1}{M_2}\right) + \frac{2x_1x_2}{[\mu_{12}]_1}\left(\frac{(M_1+M_2)^2}{4M_1M_2}\right)\left(\frac{[\mu_{12}]_1^2}{[\mu_1]_1[\mu_2]_1}\right) + \frac{x_2^2}{[\mu_2]_1}\left(\frac{M_2}{M_1}\right)\right\}$$

$$Z_\mu = \frac{3}{5}A_{12}^*\left\{x_1^2\left(\frac{M_1}{M_2}\right) + 2x_1x_2\left[\left(\frac{(M_1+M_2)^2}{4M_1M_2}\right)\left(\frac{[\mu_{12}]_1}{[\mu_1]_1} + \frac{[\mu_{12}]_1}{[\mu_2]_1}\right) - 1\right] + x_2^2\left(\frac{M_2}{M_1}\right)\right\}$$

$$[\lambda_{mix}]_1 = \frac{1+Z_\lambda}{X_\lambda + Y_\lambda}$$

$$X_\lambda = \frac{x_1^2}{[\lambda_1]_1} + \frac{2x_1x_2}{[\lambda_{12}]_1} + \frac{x_2^2}{[\lambda_2]_1}$$

$$Y_\lambda = \frac{x_1^2}{[\lambda_1]_1}U^{(1)} + \frac{2x_1x_2}{[\lambda_{12}]_1}U^{(Y)} + \frac{x_2^2}{[\lambda_2]_1}U^{(2)}$$

$$Z_\lambda = x_1^2U^{(1)} + 2x_1x_2U^{(Y)} + x_2^2U^{(2)}$$

$$U^{(1)} = \frac{4}{15}A_{12}^* - \frac{1}{12}\left(\frac{12}{5}B_{12}^* + 1\right)\frac{M_1}{M_2} + \frac{1}{2}\frac{(M_1-M_2)^2}{M_1M_2}$$

$$U^{(2)} = \frac{4}{15}A_{12}^* - \frac{1}{12}\left(\frac{12}{5}B_{12}^* + 1\right)\frac{M_2}{M_1} + \frac{1}{2}\frac{(M_2-M_1)^2}{M_1M_2}$$

$$U^{(Y)} = \frac{4}{15}A_{12}^*\left(\frac{(M_1+M_2)^2}{4M_1M_2}\right)\frac{[\lambda_{12}]_1^2}{[\lambda_1]_1[\lambda_2]_1} - \frac{1}{12}\left(\frac{12}{5}B_{12}^* + 1\right) - \frac{5}{32A_{12}^*}\left(\frac{12}{5}B_{12}^* - 5\right)\frac{(M_1-M_2)^2}{M_1M_2}$$

$$U^{(Z)} = \frac{4}{15}A_{12}^*\left[\left(\frac{(M_1+M_2)^2}{4M_1M_2}\right)\left(\frac{[\lambda_{12}]_1}{[\lambda_1]_1} + \frac{[\lambda_{12}]_1}{[\lambda_2]_1}\right) - 1\right] - \frac{1}{12}\left(\frac{12}{5}B_{12}^* + 1\right)$$

where $[\mu]_1$ = first-order viscosity (g/cm-s)
$[\lambda]_1$ = first-order thermal conductivity (cal/cm-s-K)
M = molecular weight (g/mol)
x = mole fraction
A^*_{12}, B^*_{12} = quantities for Lennard-Jones potential, functions of T^*

First-order mixture properties calculated using the Hirschfelder equations above closely match the AiResearch data. The calculated Hirschfelder values compare well to Glenn Research Center (GRC) in-

house curve fits[b] that are representative of the AiResearch data. Over a temperature range of 400 to 1200 K, calculated viscosity values differ from the GRC curve fits by no more than 0.19, 0.43 and 0.51 percent for He-Xe mixture molecular weights of 20.183, 39.94, and 83.8 kg/kmol, respectively; calculated thermal conductivity values differ by no more than 0.12, 0.20, and 0.37 percent. Tables 4 to 6 give calculated values and their comparison to the GRC curve fits.

The Hirschfelder equations thus far have only produced first-order properties. Even though there are tables for the Lennard-Jones third-order correction factors for both viscosity and conductivity, they are only for pure substances (Hirschfelder, 1964, app. table I–P). Work has been done by Singh to calculate third-order correction factors for thermal conductivity. The correction factor, $f_{\lambda\mathrm{mix}}^{(3)}$, accounts for mass and concentration dependence and temperature dependence of higher-order contributions (Singh, 1992, p. 679). Singh presents a table of Lennard-Jones potential $f_{\lambda\mathrm{mix}}^{(3)}$ values, given in table 3, for He-Xe mixtures as a function of helium mole fraction for temperatures ranging from 400 to 2000 K. Corrections for the third-order viscosity of binary mixtures are unnecessary because viscosity is not as sensitive to unlike molecular interactions as is thermal conductivity (Mason, 1957, p. 80). Therefore, Hirschfelder's first-order approximation of viscosity is considered adequate, but Hirschfelder's first-order approximation of thermal conductivity is multiplied by Singh's third-order correction factor to obtain the third-order approximation of thermal conductivity (Singh, 1992, p. 680).

$$\lambda_{mix}^{(3)} = f_{\lambda mix}^{(3)} \lambda_{mix}^{(1)}$$

As shown in tables 4 to 6, the calculated third-order thermal conductivity values are greater than the GRC curve fits by 2.13 to 2.31, 2.79 to 3.12, and 3.77 to 4.40 percent for He-Xe mixture molecular weights of 20.183, 39.94, and 83.8 kg/kmol, respectively, over a temperature range of 400 to 1200 K. This report has already shown good agreement between first-order calculations and the AiResearch data, which indicates that the AiResearch data reported in 1970 was most likely generated using first-order approximations. However, the third-order calculations are believed to be a better estimate of thermal conductivity because they account for mass and temperature effects. Given the large difference in molecular weights between helium and xenon, higher-order contributions apply especially to a He-Xe gas mixture (Singh, 1992, p. 681).

Values calculated according to the method described in this report for first-order viscosity and third-order thermal conductivity are considered to be in good agreement with the AiResearch analytical data, noting Singh's third-order correction factor. More importantly, this report documents the method used to calculate such values and ties together the supporting references. Using the equations given and tables 1 to 3, one has all the information needed to calculate viscosity and thermal conductivity of a He-Xe gas mixture. Data values from the method described in this report were incorporated into NASA Glenn Research Center in-house design and analysis codes.

Comparison to Experimental Data

In an article entitled "Empirical Relationship for Higher Order Contributions to Thermal Conductivity of Gas Mixtures," Taylor assembles experimental data for He-Xe transport properties from a host of references. Mixture molecular weights range from pure He to pure Xe, and temperatures range from 291 to 793 K. Figures 1 and 2 compare Hirschfelder first-order viscosity and third-order thermal conductivity to the experimental data. However, the values shown have a high uncertainty because they were extracted from a graph in Taylor's article. In general, the Hirschfelder viscosities match up well with the data and tend to over predict the data by no more than 3 percent; Hirschfelder conductivities match up well at the lower temperatures, but under predict the test data by as much as 8 percent at the higher temperature case.

[b]The source of the GRC in-house curve fits is undocumented. The only published source of data referenced by this report is from AiResearch (Coombs, 1970). GRC curve fits are representative of the AiResearch data and are used for their ease of comparison to the calculated values.

Taylor also presents his own Prandtl number experimental data for four mixture molecular weights. As shown in table 7, Hirschfelder over predicts Taylor's Prandtl numbers by 2 to 4 percent. The data supports Singh's application of a third-order thermal conductivity correction factor, because without it Hirschfelder would under predict thermal conductivity and over predict Prandtl number by even more.

Conclusions

The method employed for calculating transport properties of a He-Xe mixture was that presented by Hirschfelder with Singh's third-order correction factor applied to thermal conductivity. For a temperature range of 400 to 1200 K, first-order viscosity values differed from the GRC curve fits by no more than 0.51 percent for any of the He-Xe mixtures considered; third-order thermal conductivity values were greater than the GRC curve fits by as little as 2.13 percent and as much as 4.40 percent. First-order viscosity calculations were considered to be adequate because viscosity is not strongly affected by unlike molecular interactions, and third-order thermal conductivity calculations were considered to be an improvement upon first-order calculations because they account for higher-order effects of mass and temperature.

Although the primary focus of this paper was not to compare calculated He-Xe properties to experimental data, the small amount of locatable data helped to substantiate Hirscfelder's method as well as Singh's third-order thermal conductivity correction factor. An extensive empirical database of He-Xe properties does not exist, so for the time being Hirschfelder's method provides an acceptable alternative.

References

Coombs, M.G., Morse, C.J., and Richard, C.E. "Conceptual Design Study of Nuclear Brayton Cycle Heat Exchanger And Duct Assembly (HXDA)." NASA CR–72783, NASA Lewis Research Center, Cleveland, OH, 1970.

Hirschfelder, J.O., Curtiss, C.F., and Bird, R.B. *Molecular Theory of Gases and Liquids*. New York: John Wiley and Sons, Inc., 1964.

Mason, E.A. "Higher Approximations for the Transport Properties of Binary Gas Mixtures. I. General Formulas." *Journal of Chemical Physics* 27 (1957): 75–84.

Singh, K., Dham, A.K., and Gupta, S.C. "Empirical Relationship for Higher Order Contributions to Thermal Conductivity of Gas Mixtures." *Journal of Physics B, Atomic, Molecular, and Optical Physics* 25 (1992): 679–685.

Taylor, M.F., Bauer, K.E., McEligot, D.M. "Internal Forced Convection to Low-Prandtl-Number Gas Mixtures." *International Journal of. Heat and Mass Transfer* 31 (1988): 13–25.

TABLE 1.—THE INTEGRAL $\Omega^{(2,2)*}$ FOR CALCULATING THE TRANSPORT COEFFICIENTS FOR THE LENNARD-JONES POTENTIAL[c]

T*	$\Omega^{(2,2)}$	T*	$\Omega^{(2,2)}$
0.30	2.785	2.7	1.069
0.35	2.628	2.8	1.058
0.40	2.492	2.9	1.048
0.45	2.368	3.0	1.039
0.50	2.257	3.1	1.030
0.55	2.156	3.2	1.022
0.60	2.065	3.3	1.014
0.65	1.982	3.4	1.007
0.70	1.908	3.5	0.9999
0.75	1.841	3.6	0.9932
0.80	1.780	3.7	0.9870
0.85	1.725	3.8	0.9811
0.90	1.675	3.9	0.9755
0.95	1.629	4.0	0.9700
1.00	1.587	4.1	0.9649
1.05	1.549	4.2	0.9600
1.10	1.514	4.3	0.9553
1.15	1.482	4.4	0.9507
1.20	1.452	4.5	0.9464
1.25	1.424	4.6	0.9422
1.30	1.399	4.7	0.9382
1.35	1.375	4.8	0.9343
1.40	1.353	4.9	0.9305
1.45	1.333	5	0.9269
1.50	1.314	6	0.8963
1.55	1.296	7	0.8727
1.60	1.279	8	0.8538
1.65	1.264	9	0.8379
1.70	1.248	10	0.8242
1.75	1.234	20	0.7432
1.80	1.221	30	0.7005
1.85	1.209	40	0.6718
1.90	1.197	50	0.6504
1.95	1.186	60	0.6335
2.00	1.175	70	0.6194
2.10	1.156	80	0.6076
2.20	1.138	90	0.5973
2.30	1.122	100	0.5882
2.40	1.107	200	0.532
2.50	1.093	300	0.5016
2.6	1.081	400	0.4811

[c]Table values taken from Hirschfelder, 1964, app. table I–M.

TABLE 2.—THE QUANTITIES A^* AND B^* FOR CALCULATING THE TRANSPORT COEFFICIENTS OF MIXTURES FOR THE LENNARD-JONES POTENTIAL[d]

T*	A*	B*	T*	A*	B*
0.30	1.046	1.289	2.7	1.094	1.103
0.35	1.062	1.296	2.8	1.094	1.104
0.40	1.075	1.296	2.9	1.095	1.102
0.45	1.084	1.289	3.0	1.095	1.101
0.50	1.093	1.284	3.1	1.095	1.100
0.55	1.097	1.275	3.2	1.096	1.096
0.60	1.101	1.263	3.3	1.096	1.099
0.65	1.102	1.254	3.4	1.096	1.096
0.70	1.104	1.242	3.5	1.097	1.096
0.75	1.105	1.233	3.6	1.097	1.095
0.80	1.105	1.223	3.7	1.097	1.097
0.85	1.105	1.216	3.8	1.097	1.093
0.90	1.104	1.206	3.9	1.097	1.093
0.95	1.103	1.200	4.0	1.098	1.095
1.00	1.103	1.192	4.1	1.098	1.093
1.05	1.102	1.183	4.2	1.098	1.093
1.10	1.102	1.179	4.3	1.099	1.094
1.15	1.101	1.172	4.4	1.099	1.094
1.20	1.100	1.169	4.5	1.099	1.092
1.25	1.099	1.165	4.6	1.100	1.091
1.30	1.099	1.159	4.7	1.100	1.093
1.35	1.098	1.156	4.8	1.100	1.095
1.40	1.097	1.154	4.9	1.101	1.091
1.45	1.097	1.148	5	1.101	1.092
1.50	1.097	1.143	6	1.103	1.090
1.55	1.096	1.140	7	1.105	1.092
1.60	1.096	1.137	8	1.107	1.090
1.65	1.096	1.137	9	1.109	1.091
1.70	1.095	1.133	10	1.110	1.094
1.75	1.094	1.129	20	1.119	1.095
1.80	1.094	1.127	30	1.124	1.095
1.85	1.094	1.126	40	1.127	1.095
1.90	1.094	1.124	50	1.130	1.095
1.95	1.094	1.122	60	1.132	1.096
2.00	1.094	1.119	70	1.134	1.095
2.10	1.094	1.116	80	1.135	1.095
2.20	1.094	1.113	90	1.137	1.096
2.30	1.094	1.110	100	1.138	1.095
2.40	1.094	1.108	200	1.146	1.095
2.50	1.094	1.106	300	1.151	1.095
2.60	1.094	1.104	400	1.154	1.095

[d] Table values taken from Hirschfelder, 1964, app. table I–N.

TABLE 3.—VALUES OF $f_{\lambda mix}^{(3)}$ FOR VARIOUS TEMPERATURES AND COMPOSITIONS OF He-Xe MIXTURE FOR THE LENNARD-JONES POTENTIAL (x_1 IS THE CONCENTRATION OF THE LIGHTER COMPONENT[e] OF THE MIXTURE)[f]

T (K)	x_1	$f_{\lambda mix}^{(3)}$
400	0.01	1.0056
	0.10	1.0272
	0.30	1.0388
	0.50	1.0374
	0.70	1.0304
	0.90	1.0192
	0.99	1.0130
800	0.01	1.0101
	0.10	1.0289
	0.30	1.0394
	0.50	1.0377
	0.70	1.0306
	0.90	1.0191
	0.99	1.0127
1500	0.01	1.0137
	0.10	1.0304
	0.30	1.0396
	0.50	1.0375
	0.70	1.0302
	0.90	1.0187
	0.99	1.0125
2000	0.01	1.0146
	0.10	1.0310
	0.30	1.0399
	0.50	1.0377
	0.70	1.0303
	0.90	1.0188
	0.99	1.0124

[e]In this case concentration of the lighter component is defined as mole fraction of helium.
[f]Table values taken from Singh, 1992 table 1.

TABLE 4.—VISCOSITY AND CONDUCTIVITY CALCULATED VALUES AND COMPARISON TO NASA GRC IN-HOUSE CURVE FITS FOR He-Xe MOLECULAR WEIGHT OF 20.183 kg/kmol

	Viscosity (10^{-6} kg/m-s)			Thermal conductivity (W/m-K)			
T (K)	Hirschfelder	GRC curve fit	% diff Hirschfelder from GRC	Hirschfelder (third-order)[g]	GRC curve fit	% diff Hirschfelder from GRC	Conductivity third-order correction factor
400	31.6340	31.5844	0.16	0.124434	0.121842	2.13	1.0220
420	32.7501	32.6887	0.19	0.128500	0.125798	2.15	1.0220
440	33.8311	33.7740	0.17	0.132511	0.129688	2.18	1.0220
460	34.8957	34.8412	0.16	0.136472	0.133516	2.21	1.0219
480	35.9283	35.8911	0.10	0.140381	0.137285	2.25	1.0219
500	36.9556	36.9246	0.08	0.144259	0.141000	2.31	1.0219
520	37.9641	37.9424	0.06	0.148001	0.144662	2.31	1.0219
540	38.9587	38.9451	0.04	0.151694	0.148275	2.31	1.0219
560	39.9383	39.9333	0.01	0.155329	0.151840	2.30	1.0219
580	40.9011	40.9078	–0.02	0.158893	0.155361	2.27	1.0219
600	41.8444	41.8689	–0.06	0.162369	0.158838	2.22	1.0219
620	42.7750	42.8173	–0.10	0.165798	0.162274	2.17	1.0219
640	43.7057	43.7534	–0.11	0.169264	0.165671	2.17	1.0218
660	44.6249	44.6778	–0.12	0.172692	0.169029	2.17	1.0218
680	45.5328	45.5908	–0.13	0.176083	0.172352	2.16	1.0218
700	46.4371	46.4929	–0.12	0.179441	0.175640	2.16	1.0218
720	47.3225	47.3845	–0.13	0.182764	0.178893	2.16	1.0218
740	48.1999	48.2660	–0.14	0.186056	0.182115	2.16	1.0218
760	49.0694	49.1377	–0.14	0.189318	0.185305	2.17	1.0218
780	49.9314	50.0001	–0.14	0.192551	0.188465	2.17	1.0218
800	50.7860	50.8534	–0.13	0.195756	0.191596	2.17	1.0218
820	51.6334	51.6980	–0.13	0.198934	0.194698	2.18	1.0217
840	52.4737	52.5343	–0.12	0.202087	0.197773	2.18	1.0217
860	53.3072	53.3625	–0.10	0.205214	0.200821	2.19	1.0217
880	54.1339	54.1829	–0.09	0.208318	0.203844	2.19	1.0217
900	54.9539	54.9959	–0.08	0.211399	0.206842	2.20	1.0217
920	55.7675	55.8017	–0.06	0.214457	0.209815	2.21	1.0217
940	56.5745	56.6006	–0.05	0.217491	0.212765	2.22	1.0217
960	57.3751	57.3929	–0.03	0.220504	0.215691	2.23	1.0216
980	58.1693	58.1788	–0.02	0.223493	0.218596	2.24	1.0216
1000	58.9570	58.9586	0.00	0.226460	0.221478	2.25	1.0216
1020	59.7383	59.7326	0.01	0.229403	0.224340	2.26	1.0216
1040	60.5056	60.5009	0.01	0.232274	0.227180	2.24	1.0216
1060	61.2675	61.2639	0.01	0.235128	0.230001	2.23	1.0216
1080	62.0242	62.0217	0.00	0.237965	0.232802	2.22	1.0216
1100	62.7757	62.7746	0.00	0.240787	0.235583	2.21	1.0215
1120	63.5222	63.5228	0.00	0.243592	0.238346	2.20	1.0215
1140	64.2637	64.2665	0.00	0.246382	0.241091	2.19	1.0215
1160	65.0004	65.0060	–0.01	0.249156	0.243817	2.19	1.0215
1180	65.7323	65.7415	–0.01	0.251915	0.246526	2.19	1.0215
1200	66.4595	66.4731	–0.02	0.254660	0.249218	2.18	1.0215

[g] First-order thermal conductivity can be calculated by dividing the third-order conductivity by the third-order correction factor.

TABLE 5.—VISCOSITY AND CONDUCTIVITY CALCULATED VALUES AND COMPARISON TO NASA GRC IN-HOUSE CURVE FITS FOR He-Xe MOLECULAR WEIGHT OF 39.94 kg/kmol

	Viscosity (10^{-6} kg/m–s)			Thermal conductivity (W/m-K)			
T (K)	Hirschfelder	GRC curve fit	% diff Hirschfelder from GRC	Hirschfelder (third-order)[h]	GRC curve fit	% diff Hirschfelder from GRC	Conductivity third-order correction factor
400	33.1088	32.9759	0.40	0.080589	0.078295	2.93	1.0291
420	34.3748	34.2279	0.43	0.083284	0.080888	2.96	1.0291
440	35.5839	35.4583	0.35	0.085936	0.083439	2.99	1.0291
460	36.7834	36.6677	0.32	0.088554	0.085950	3.03	1.0292
480	37.9473	37.8569	0.24	0.091132	0.088423	3.06	1.0292
500	39.1022	39.0267	0.19	0.093695	0.090861	3.12	1.0292
520	40.2355	40.1776	0.14	0.096132	0.093265	3.08	1.0292
540	41.3528	41.3104	0.10	0.098541	0.095636	3.04	1.0292
560	42.4536	42.4256	0.07	0.100917	0.097977	3.00	1.0292
580	43.5374	43.5239	0.03	0.103256	0.100288	2.96	1.0292
600	44.6032	44.6059	–0.01	0.105553	0.102572	2.91	1.0292
620	45.6541	45.6720	–0.04	0.107822	0.104828	2.86	1.0293
640	46.6959	46.7229	–0.06	0.110098	0.107059	2.84	1.0293
660	47.7231	47.7591	–0.08	0.112350	0.109265	2.82	1.0293
680	48.7356	48.7811	–0.09	0.114580	0.111446	2.81	1.0293
700	49.7509	49.7894	–0.08	0.116791	0.113605	2.80	1.0293
720	50.7328	50.7845	–0.10	0.118978	0.115742	2.80	1.0293
740	51.7063	51.7669	–0.12	0.121146	0.117857	2.79	1.0293
760	52.6712	52.7371	–0.12	0.123295	0.119952	2.79	1.0293
780	53.6279	53.6956	–0.13	0.125427	0.122027	2.79	1.0293
800	54.5763	54.6427	–0.12	0.127540	0.124082	2.79	1.0294
820	55.5165	55.5790	–0.11	0.129634	0.126118	2.79	1.0293
840	56.4487	56.5049	–0.10	0.131712	0.128137	2.79	1.0293
860	57.3728	57.4208	–0.08	0.133773	0.130137	2.79	1.0293
880	58.2891	58.3272	–0.07	0.135818	0.132120	2.80	1.0293
900	59.1975	59.2244	–0.05	0.137848	0.134087	2.81	1.0293
920	60.0981	60.1130	–0.02	0.139863	0.136037	2.81	1.0293
940	60.9910	60.9933	0.00	0.141863	0.137972	2.82	1.0293
960	61.8763	61.8656	0.02	0.143847	0.139891	2.83	1.0293
980	62.7541	62.7305	0.04	0.145817	0.141795	2.84	1.0293
1000	63.6242	63.5883	0.06	0.147771	0.143684	2.84	1.0292
1020	64.4869	64.4394	0.07	0.149711	0.145560	2.85	1.0292
1040	65.3388	65.2841	0.08	0.151616	0.147421	2.85	1.0292
1060	66.1838	66.1229	0.09	0.153509	0.149268	2.84	1.0292
1080	67.0221	66.9561	0.10	0.155390	0.151103	2.84	1.0292
1100	67.8538	67.7842	0.10	0.157259	0.152924	2.83	1.0292
1120	68.6790	68.6073	0.10	0.159116	0.154732	2.83	1.0292
1140	69.4979	69.4261	0.10	0.160962	0.156528	2.83	1.0292
1160	70.3106	70.2406	0.10	0.162796	0.158312	2.83	1.0292
1180	71.1172	71.0515	0.09	0.164619	0.160084	2.83	1.0291
1200	71.9178	71.8589	0.08	0.166432	0.161844	2.83	1.0291

[h]First-order thermal conductivity can be calculated by dividing the third-order conductivity by the third-order correction factor.

TABLE 6.—VISCOSITY AND CONDUCTIVITY CALCULATED VALUES AND COMPARISON TO NASA GRC IN-HOUSE CURVE FITS FOR He-Xe MOLECULAR WEIGHT OF 83.8 kg/kmol

	Viscosity (10^{-6} kg/m–s)			Thermal Conductivity (W/m-K)			
T (K)	Hirschfelder	GRC curve fit	% diff Hirschfelder from GRC	Hirschfelder (third-order)[i]	GRC curve fit	% diff Hirschfelder from GRC	Conductivity third-order correction factor
400	31.8624	31.7122	0.47	0.032369	0.031045	4.26	1.0401
420	33.1977	33.0301	0.51	0.033514	0.032130	4.31	1.0401
440	34.4551	34.3261	0.38	0.034630	0.033197	4.32	1.0401
460	35.7171	35.6008	0.33	0.035735	0.034248	4.34	1.0401
480	36.9497	36.8545	0.26	0.036822	0.035284	4.36	1.0401
500	38.1669	38.0876	0.21	0.037901	0.036305	4.40	1.0402
520	39.3633	39.3007	0.16	0.038921	0.037312	4.31	1.0402
540	40.5416	40.4942	0.12	0.039928	0.038305	4.24	1.0402
560	41.7021	41.6686	0.08	0.040924	0.039286	4.17	1.0402
580	42.8448	42.8244	0.05	0.041908	0.040254	4.11	1.0402
600	43.9699	43.9621	0.02	0.042879	0.041211	4.05	1.0402
620	45.0779	45.0822	–0.01	0.043840	0.042155	4.00	1.0402
640	46.1693	46.1852	–0.03	0.044794	0.043089	3.96	1.0403
660	47.2430	47.2715	–0.06	0.045737	0.044012	3.92	1.0403
680	48.2983	48.3418	–0.09	0.046671	0.044925	3.89	1.0403
700	49.3648	49.3965	–0.06	0.047601	0.045827	3.87	1.0403
720	50.3808	50.4362	–0.11	0.048515	0.046720	3.84	1.0403
740	51.3882	51.4614	–0.14	0.049421	0.047603	3.82	1.0403
760	52.3870	52.4725	–0.16	0.050319	0.048477	3.80	1.0403
780	53.3771	53.4702	–0.17	0.051211	0.049342	3.79	1.0404
800	54.3585	54.4548	–0.18	0.052095	0.050199	3.78	1.0404
820	55.3312	55.4271	–0.17	0.052971	0.051047	3.77	1.0404
840	56.2952	56.3873	–0.16	0.053841	0.051886	3.77	1.0404
860	57.2505	57.3362	–0.15	0.054703	0.052718	3.77	1.0404
880	58.1972	58.2741	–0.13	0.055559	0.053542	3.77	1.0404
900	59.1351	59.2017	–0.11	0.056408	0.054358	3.77	1.0404
920	60.0645	60.1194	–0.09	0.057250	0.055166	3.78	1.0404
940	60.9853	61.0277	–0.07	0.058085	0.055968	3.78	1.0404
960	61.8976	61.9271	–0.05	0.058914	0.056762	3.79	1.0404
980	62.8015	62.8181	–0.03	0.059737	0.057549	3.80	1.0404
1000	63.6970	63.7013	–0.01	0.060553	0.058329	3.81	1.0404
1020	64.5844	64.5772	0.01	0.061363	0.059102	3.83	1.0404
1040	65.4631	65.4461	0.03	0.062164	0.059869	3.83	1.0404
1060	66.3339	66.3087	0.04	0.062960	0.060629	3.84	1.0403
1080	67.1969	67.1654	0.05	0.063749	0.061383	3.86	1.0403
1100	68.0522	68.0167	0.05	0.064533	0.062130	3.87	1.0403
1120	68.9001	68.8631	0.05	0.065311	0.062872	3.88	1.0403
1140	69.7406	69.7051	0.05	0.066084	0.063607	3.89	1.0403
1160	70.5739	70.5431	0.04	0.066851	0.064336	3.91	1.0403
1180	71.4003	71.3777	0.03	0.067613	0.065060	3.92	1.0403
1200	72.2199	72.2092	0.01	0.068370	0.065778	3.94	1.0403

[i]First-order thermal conductivity can be calculated by dividing the third-order conductivity by the third-order correction factor.

TABLE 7.—He-Xe CALCULATED AND EXPERIMENTAL[j] PRANDTL NUMBER AT FOUR MIXTURE MOLECULAR WEIGHTS

He-Xe mol. wt. (kg/kmol)	Temperature (K)	Prandtl number		% Diff Hirsch. from Taylor
		Taylor	Hirsch.	
14.5	972	0.301	0.308	2.33
28.3	982	0.231	0.240	3.90
40.0	941	0.214	0.224	4.67
83.8	962	0.251	0.261	3.98

[j]Table values taken from (Taylor, 1988, table 2).

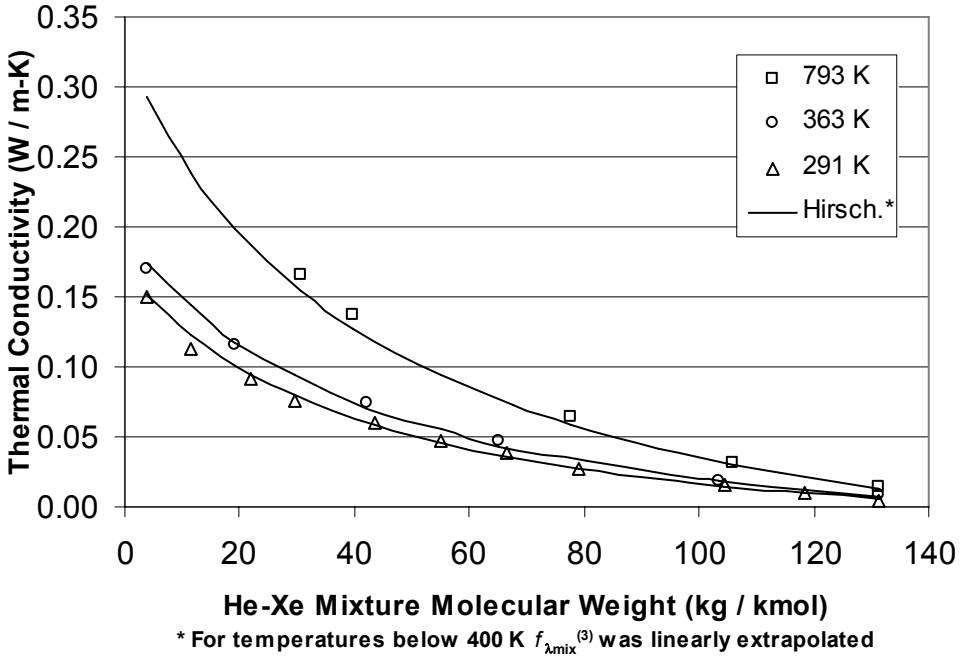

Figure 1.—He-Xe calculated and experimental[k] thermal conductivity as a function of molecular weight.

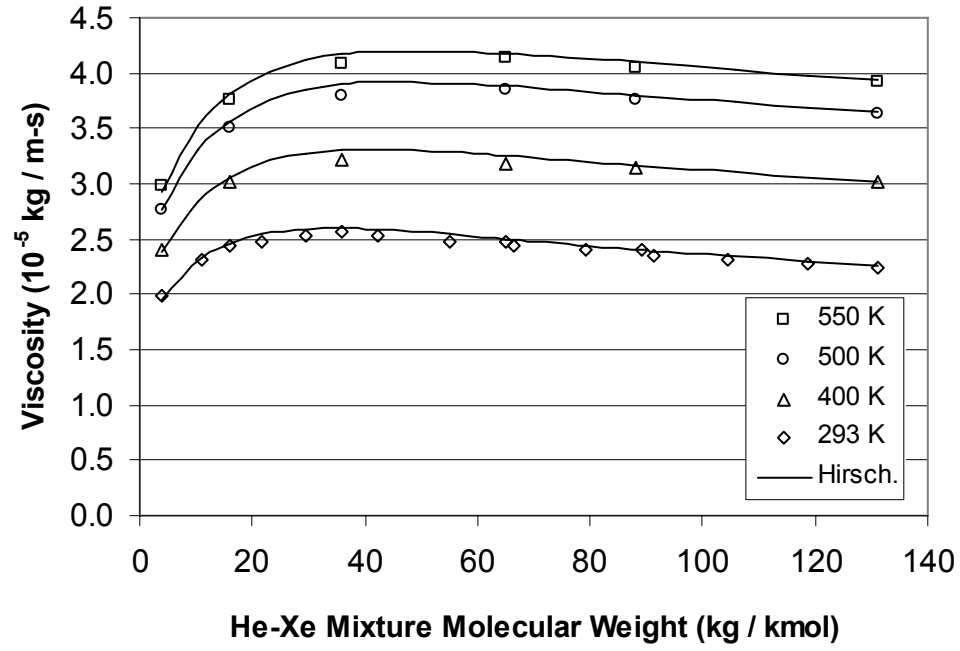

Figure 2.—He-Xe calculated and experimental[j] viscosity as a function of molecular weight.

[k]Experimental values from Taylor's article were extracted from a graph.

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13. ABSTRACT ***(Maximum 200 words)***

A method for calculating viscosity and thermal conductivity of a helium-xenon (He-Xe) gas mixture was employed, and results were compared to AiResearch (part of Honeywell) analytical data. The method of choice was that presented by Hirschfelder with Singh's third-order correction factor applied to thermal conductivity. Values for viscosity and thermal conductivity were calculated over a temperature range of 400 to 1200 K for He-Xe gas mixture molecular weights of 20.183, 39.94, and 83.8 kg/kmol. First-order values for both transport properties were in good agreement with AiResearch analytical data. Third-order-corrected thermal conductivity values were all greater than AiResearch data, but were considered to be a better approximation of thermal conductivity because higher-order effects of mass and temperature were taken into consideration. Viscosity, conductivity, and Prandtl number were then compared to experimental data presented by Taylor.

14. SUBJECT TERMS

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