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NAVAL POSTGRADUATE SCHOOL

Monterey, California

GAS PROPERTIES COMPUTATIONAL PROCEDURE SUITABLE FOR ELECTRONIC CALCULATORS

J. R. Andrews and O. Biblarz

1 July 1974

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NAVAL POSTGRADUATE SCHOOL
Monterey, California

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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

A calculating procedure is presented, based on a least squares polynomial approximation, for duplicating existing tabular values of selected thermodynamic and transport properties of various important gases. Most of the data refer to ideal gases; however, for functions of both temperature and pressure the pressure has been specified such that the polynomial approximations have only temperature as the independent variable. Suggested algorithms for polynomial evaluations up to the sixth degree are presented and optimized for

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SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*) hand-held or desk top calculators. Using the suggested polynomial fits and a suitable calculator, it is possible to duplicate existing table values for the various functions of the selected gases without interpolation or reference to the tables per se. The error of the included fits is generally less than 0.5%. With the lowest order approximation the error can be as high as 1%.

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1. OBJECTIVES

The main objective of this work is to provide a straightforward, accurate method of calculating values for temperature dependent functions for selected gases. It is intended to collect, under a single cover, enough information such that thermodynamic properties of certain gases may be calculated, within the provided temperature band, without interpolation or reference to actual gas tables. By specifying the pressures for functions normally of both temperature and pressure, a least squares polynomial curve fit is directly applicable to discrete data pairs from reference sources. The single independent variable is temperature and the function at any desired temperature can be directly calculated. Within the constraints of the temperature bands provided and at the specified pressure for pressure dependent functions, this calculating procedure essentially obviates the necessity to carry and use standard gas reference tables. For the first approximation for functions of gases, being considered as ideal gases, the pressure dependence is generally eliminated. For real gases, the pressure dependence for most functions, except entropy, is rather small and the singular dependence on temperature is a reasonable approximation. The presented calculating procedure will duplicate the table values to within approximately 0.5% of the reference cited for each selected function.

2. DATA SOURCES

The discrete data pairs of temperature and a temperature function were obtained from the selected references included in the Bibliography. There was an attempt to select generally accepted, authoritative sources and data published at the latest dates to take advantage of the more recent and hopefully the most accurate methods of measurements. There are significant discrepancies between some of the older references (i.e., Ref. 6) and more recent data on thermal conductivity and viscosity measurements. Additionally, since a reference level for energy functions is arbitrary, the important thing is not the association with the arbitrary energy level but the difference in energy levels between any two specified temperatures. This difference was generally found to be in rather close but not exact agreement among the sources.

3. FORMULATING THE POLYNOMIAL FITS

Data were taken from the selected sources with temperature as the independent parameter. These data pairs were reduced by subroutine LSQPL2 in the IBM SSP-3 library using an IBM-S360/67 in double precision with the results being the coefficients of a polynomial for a least-squares approximation to the data. The functions of temperature for gases, both real and ideal, tend to be smooth plots with few abrupt changes and no discontinuities in the range limit considered here. Many of the functions were also monotonic, further lending themselves to be approximated by polynomials of varying degrees. The polynomials are grouped together for each of the selected gases and may be found in Appendix B. The units throughout this publication are completely consistent and are as follows:

C_p, ϕ, C_v, k, s - BTU/lb_m-°R; h, u - BTU/lb_m; γ, Pr, h/u - no units

μ - lb_f - SEC/FT^2; k - BTU/FT^2 - SEC -°R/FT (or BTU/FT - SEC -°R)

In a few instances, the specific function was not available in the literature but could be calculated using other available data. Such is the case for Prandtl number for ammonia, bromine, neon, water vapor, and Freon-12 as well as the ratio of specific heats for ammonia. For each of these, sufficient data exists to permit direct calculation using the definition of Prandtl number $P_r \equiv \mu C_p/k$ and for gamma $\gamma \equiv C_p/C_v$. Tables II through XII represent summary data for the properties using only the third order approximation. Appendix B contains the complete set of results of our curve fits.

4. CROSS CORRELATION OF FUNCTIONS

The included polynomial fits provide the capability to calculate a wide variety of thermodynamic properties for the selected gases. Several of these properties may be defined in terms of other selected properties. For example:

$$\gamma = C_p/C_v; \quad Pr = \mu C_p/k, \quad \int d\phi = \int C_p dT/T; \quad du = C_v dT;$$

$$dh = C_p dT, \quad \text{and } h/u = h(T)/u(T).$$

Ideally, these functions should cross correlate; using the included polynomials to calculate a specific function (for example γ), it should exactly agree with the ratio of the polynomials, for each C_p and C_v, at the same temperature. Generally, this cross correlation will not be in exact agreement for at least two major reasons. First, a single literature reference seldom contains all of the functions for any given gas of interest. One might find C_p and γ, but C_v values being omitted and left to the researcher to calculate. In trying to provide fits for as many functions as possible, it was necessary to use a variety of reference sources. Data from various observers may differ, particularily with the more difficult viscosity and thermal conductivity measurements. The second source of trouble is the potential for error propagation associated with approximations multiplying other approximations. The errors could be compensating or complementing. This is further discussed under the remarks below.

5. ERROR SOURCES AND POLYNOMIAL APPROXIMATIONS

At the very best, the results of a polynomial evaluation for a temperature dependent function will be only as valid as the reference source of the input data. The stated objective is simply to be able to reproduce the table values with the minimum effort. There are several sources for potential error, both in the published table values and in the subsequent operations which result in polynomial curve fit approximations. The published table values have the included uncertainties of experimental (procedural and instrument) error. Many of the tables values were converted into a consistent set of units thus further contributing to error due to roundoff. Double precision calculation, however, made this contribution extremely small. The most significant single source of error is a polynomial approximation to a non-polynomial function. A least squares fit attempts to do just that.

The quality or excellence of fit for a least squares fit is dependent on the nature of the data pairs available. The spacing, total number, range, equidistant or unequal spacing, monotonic or not, degree of polynomial being fitted, and location of points of inflections are a few of the variables which influence the quality of the fit. The only perfect fit for a polynomial would be the polynomial itself and for a non-polynomial curve the best one can hope for is a close bracketing of the function. The results from subroutine LSQPL2 show the approximating polynomial to overestimate then underestimate the real function over the entire range. This variation about the true function value at the known discrete points represents the "noise" generated by the approximation. As the curve fit gets closer to the true value, the noise amplitude diminishes and becomes more random. The noise directly relates to the error estimate.

The errors of the included polynomials are generally less than 0.5%, where the error is defined as; $\varepsilon = [1 - \xi_1/\eta_1] \times 100\%$ (ξ_1 is the value estimated at a known data point using the polynomial approximation and η_1 is the table value for the same data point.) If the polynomial approximation happened to cross the real function in the immediate neighborhood of a data point, the error naturally approaches zero for the point. For polynomial fits which are significantly in error by more than about 0.5% over the range, appropriate comments are included. The degree of the fit is a major contribution on quality such that in general the second and third degree polynomials might have average errors greater than 0.5% and the fifth and sixth degrees are frequently much less than 0.5%.

Curve fits from the second through ninth degree were evaluated but only the second through the sixth are presented. For a generally smooth function, particularly those which are also monotonic, the polynomial approximations are closer as the degree of the polynomial increases. This is true only to about the sixth degree then the accuracy tends to level off for the seventh through ninth degrees. The five choices of polynomial for each function provides the user with a degree of flexibility and permits one to choose a trade-off between accuracy and time required to calculate a value.

It is likely that there will exist an error propagation when multiplying and dividing one or more approximate values, such as when evaluating Prandtl number (see Paragraph 3). The manner in which the error may propagate could only be analyzed on an individual basis for each polynomial. This results from the random nature of the "noise" which is different for every polynomial approximation. For the best case, the errors could be cancelling with the resulting error propagation approaching zero. The worst case is, of course, that which results when, for a given point of interest, the individual polynomials are all in error on the same side of the true value for a multiplication or on opposite sides for division. The resulting error would be the sum of the individual errors. Consider the following examples assuming $/\mathcal{E}/ = 0.5\%$ for all functions:

a) $C_p = \gamma C_v$

1) let $\varepsilon_\gamma = +.5\%$ and $\varepsilon_{c_v} = -.5\%$

$C_p = (\gamma + .5\%)\ (C_v - .5\ \%)$ $\qquad \varepsilon_{c_p} \approx 0.$

2) let $\varepsilon_\gamma = +.5\%$ and $\varepsilon_{c_v} = +.5\%$

$C_p = (\gamma + .5\%)\ (C_v + .5\%)$ $\qquad \varepsilon_{c_p} \approx 1.0\%$

b) $Pr = \mu C_p/k$

1) let $\varepsilon_\mu = 0.5\%$; $\varepsilon_{c_p} = 0.5\%$; $\varepsilon_k = 0.5\%$

$$Pr = \frac{(\mu + 0.5\%)(C_p + 0.5\%)}{(k + 0.5\%)} \qquad \varepsilon_{pr} \doteq 0.5\%$$

2) let $\varepsilon_\mu = 0.5\%$; $\varepsilon_{c_p} = 0.5\%$; $\varepsilon_k = -0.5\%$

$$Pr = \frac{(\mu + 0.5\%)(C_p + 0.5\%)}{(k - 0.5\%)} \qquad \varepsilon_{pr} \doteq 1.5\%$$

3) let $\varepsilon_\mu = -0.5\%$; $\varepsilon_{c_p} = 0.5\%$; $\varepsilon_k = 0.5\%$

$$Pr = \frac{(\mu - 0.5\%)(C_p + 0.5\%)}{(k + 0.5\%)} \qquad \varepsilon_{pr} \doteq -0.5\%$$

4) let $\varepsilon_\mu = -0.5\%$; $\varepsilon_{c_p} = 0.5\%$; $\varepsilon_k = -0.5\%$

$$Pr = \frac{(\mu - 0.5\%)(C_p + 0.5\%)}{(k - 0.5\%)} \qquad \varepsilon_{pr} \doteq 0.5\%$$

The rule of thumb is : like errors are additive when multiplying and canceling when dividing.

6. KINETIC THEORY FOR MONATOMIC AND DIATOMIC GASES

(Reference: 4, Chapter 12)

a) Monatomic Gases: Argon, Helium, Neon and Xenon

The classic theory of equipartition of energy sets the total energy of a molecule with f degrees of freedom to be $(f/2)kT$ where k is Boltzmann's constant, $k = \bar{R}/N_a$. Monatomic molecules have only the three translational degrees of freedom of three dimensional space such that the internal energy can be written as:

$$u(T) = (3/2)k\,\frac{N_a}{MW}\,T$$

N_a is Avogadro's number.

$N_a = \dfrac{\text{number of molecules}}{\text{mole}}$

MW is the molecular weight.

(1) $u(T) = 3/2T\,(\bar{R}/MW) = (3/2)(R/J)T$

(2) $C_v = (3/2)(R/J) = \text{CONST}$

(3) $(C_p - C_v) = R/J = \text{CONST}$

(4) $C_p = (5/2)(R/J) = \text{CONST}$

(5) $\gamma = C_p/C_v = 1.667 = \text{CONST}$

$$N_a k = \bar{R} = 1545.43\ \frac{\text{ft-lb}_f}{\text{lb}_m\text{- mole °R}}$$

$$R = \bar{R}/MW = \frac{\text{ft-lb}_f}{\text{lb}_m\text{- °R}}$$

$$R/J = \text{BTU}/\text{lb}_m\text{- °R} ;$$

$$J = 778.26\ \frac{\text{ft-lb}_f}{\text{BTU}}$$

(i) ARGON: $R/J = 0.04971\ \text{BTU}/\text{lb}_m\text{- °R}$

THEORY	TABLES
$C_v = 0.07457$	C_v (432°R) = .97474
$C_p = 0.12428$	C_p (720°R) = 0.1245
$\gamma = 1.6666$	γ (576°R) = 1.669

(ii) HELIUM: $R/J - 0.496068\ \text{BTU}/\text{lb}_m\text{-°R}$

THEORY	TABLES
$C_v = 0.7441$	not directly available
$C_p = 1.2402$	C_p = 1.2404
$\gamma = 1.6667$	not directly available

b) Diatomic Molecules: Bromine, Carbon Monoxide, Chlorine, Flourine, Hydrogen, Nitrogen and Oxygen

Diatomic molecules have additional degrees of rotational and vibrational freedom. The monatomic theory of energy equipartition must be modified to account for the observed differences. Diatomic molecules have the 3 translational degrees of freedom plus two rotational and two vibrations modes along the bonding axis for a total of 7 degrees of freedom. The value of $C_v = (7/2)(R/J)$ from classical equipartition theory is approximated only at elevated temperatures with diatomic molecules. The theory fails to predict the temperatures at which the rotational and vibrational modes become fully excited. From quantum mechanics, the diatomic molecular energy can be quantized. Using this approach, it is possible to account for the contributions from the rotational and vibrational degrees of freedom. The rotational degrees of freedom are fully excited at extremely low temperatures and make their full, constant contribution above their discrete temperature quantum levels. This fact simplifies the prediction for C_v and C_p very nicely. The vibrational modes become excited at much higher temperatures. With θ_{vib} being the quantum temperature level for full excitation of the vibrational modes, the equations become: defining $\beta(T)$ as

$$(1)\quad \beta(T) = (R/J)(\theta_{vib}/T)^2\ [e^{\theta_{vib}/T}/(e^{\theta_{vib}/T} - 1)^2] = C_{v_{vib}}$$

$$(2)\quad C_v = (5/2)(R/J) + C_{v_{vib}} = (5/2)(R/J) + \beta(T)$$

$$(3)\quad C_p = (7/2)(R/J) + \beta(T)$$

$$(4)\quad (C_p - C_v) = R/J$$

$$(5)\quad \gamma = C_p/C_v = \frac{(7/2)(R/J) + \beta(T)}{(5/2)(R/J) + \beta(T)} = 1.4 \text{ in the limit as } \beta \to 0$$

other relationships for calorically imperfect diatomic gases are:

$$(6)\quad V^2/2g_c = R\ [7/2(T_t - T) + \theta_{vib}\left\{\frac{1}{e^{\Theta vib/T_t}-1} - \frac{1}{e^{\Theta vib/T}-1}\right\}]$$

$$(7)\quad M^2 = 2/\gamma\ [7/2\left(\frac{T_t}{T} - 1\right) + \theta_{vib}/T\left\{\frac{1}{e^{\Theta vib/T_t}-1} - \frac{1}{e^{\Theta vib/T}-1}\right\}]$$

and for isentropic, thermally perfect, calorically imperfect diatomic gases:

$$(8)\quad P_t/P = (T_t/T)^{7/2}\,(e^{\theta_{vib}/T_t}-1)/(e^{\theta_{vib}/T}-1)$$

$$\mathrm{Exp}\left\{[(\theta_{vib}/T_t)(e^{\theta_{vib}/T_t})/(e^{\theta_{vib}/T_t}-1)] - [(\theta_{vib}/T)(e^{\theta_{vib}/T})/(e^{\theta_{vib}/T}-1)]\right\}$$

$$(9)\quad M^2 = V^2/a^2 \qquad (10)\quad a^2 = \gamma RT$$

TABLE I

Summary of Θ_{vib} for several gases

GAS	θ_{vib} (°R)	$R\left(\frac{ft\text{-}lb_f}{lb_m\text{-}°R}\right)$	$R/J\left(\frac{BTU}{lb_m\text{-}°R}\right)$
Bromine	837*	9.67	0.012425
Carbon Monoxide	5616	55.17	0.070888
Chlorine	1463	21.79	0.0279984
Fluorine	2391*	40.67	0.0522576
Hydrogen	11052	766.58	0.98499
Nitrogen	6012	55.16	0.070876
Oxygen	4068	48.29	0.06205

---

*Calculated from Ref. 5, Equation 19-73.

examples: (C_p and C_v in BTU/lbm-R)

(i) Carbon Monoxide:

THEORY	TABLES
C_v (1600) = 0.20496	C_v (1600) = 0.20637
C_p (864) = 0.25262	C_p (864) = 0.2533
γ (1440) = 1.35452	γ (1440) = 1.353

(ii) Chlorine

THEORY	TABLES
C_v (1200) = 0.0947697	C_v(1200) = 0.09474623
C_p (1200) = 0.122768	C_p (1200) = 0.123869
γ (1200) = 1.29544	γ (1200) = 1.295545

(iii) Hydrogen

THEORY	TABLES
C_v (1500) = 2.4963	C_v (1500) = 2.534
C_p (1368) = 3.4667	C_p (1368) = 3.5026
γ (540) = 1.3999	γ (540) = 1.405

(iv) Nitrogen

THEORY	TABLES
C_v (1500) = 0.19865	C_v (1500) = 0.198877
C_p (1440) = 0.26766	C_p (1440) = 0.26856
γ (1152) = 1.37749	γ (1152) = 1.3777

(v) Oxygen

THEORY	TABLES
C_v (1160) = 0.17945	C_v (1160) = 0.17922
C_p (1160) = 0.241497	C_p (1160) = 0.24248
γ (1160) = 1.34576	γ (1160) = 1.346

For polyatomic molecules, the number of degrees of freedom is higher and the rotational and vibrational contributions appropriately more complex. The C_v should be slightly higher for triatomic molecules and the γ slightly lower than the diatomics.

7. ALGORITHMS FOR POLYNOMIAL EVALUATIONS

All of the polynomials included here have temperature as the single independent variable. Such equations are extremely easy to evaluate with a pocket or desk-top calculator. All of the polynomials are of the form:

$$FCTN(T_i) = B1 + B2T + B3T^2 + \ldots B(N+1)T^N$$

with N ranging from 0 to 7.

One method of evaluating a given function at a specified temperature is the "brute force" method. This involves raising T_i to the Nth power, multiplying by the B(N+1) coefficient; raising the T_i to the (N-1)th power and multiplying by its coefficient and adding to the previous product, etc. until just the B1 coefficient is added. At this point the last sum equals the function evaluated at the desired temperature, T_i. This method involves multiplication of very large numbers, T^N, by very small coefficient numbers and requires a machine with the capabilities of raising x to the y power. This is an inefficient way to evaluate a polynomial.

The recommended method is called nested multiplication (Ref. 26). This eliminates the requirement to raise x to the y power such that any machine that can handle numbers $\times 10^{-29}$ can perform any polynomial evaluation included.

a) Generalized nested multiplication:

Given the (N+1) coefficients B(1), B(2), . . . B(N+1) for the polynomial $P(T_i) = B(1) + B(2)T + . . . B(N+1)T^N$ and any arbitrary independent variable temperature, T_i:

```
SET  $A(N+1) = B(N+1)$

FOR  $K = N, N-1, N-2 . . . 1$, DO
    SET  $A(K) = B(K) + T_i A(K+1)$

     $A(1) = P(T_i)$
```

The above algorithm can be stated in words as follows: multiply the highest degree coefficient by T_i and add the next lower coefficient; multiply the sum by T_i and add the next lower coefficient; multiply the new sum by T_i. Continue this until $B(3)\ T_i + B(2)$ sum is calculated. Multiply this by T_i. The only coefficient left is B(1) which is the coefficient of T_i°. By just adding B(1) to the previous sum, the polynomial is evaluated at T_i.

b) Specific example (using Hewlett Packard model HP-35)

Desire to calculate thermal conductivity of ammonia at $T_i = 1620\,^{\circ}R$: arbitrary choice of a sixth degree fit:

$$P(T_i) = -4.4701E-06 + 4.47694E-08T_i - 1.293E-10T_i^2 + 2.19149E-13$$
$$- 1.86776E-16T_i^4 + 7.95013E-20T_i^5 - 1.34258E-23T_i^6$$

(see Appendix B for source of this polynomial)

STEP-BY-STEP PROCEDURE		CALCULATOR VALUES SHOULD BE:
(1) - 1.34258E-23 X 1620	$[B(7) \times T_i]$	- 2.1749796E-20
(2) + 7.95013E-20	+ B(6)	5.7751504E-20
(3) x 1620	x T_i	9.355743648E-17

STEP BY STEP PROCEDURE		CALCULATOR VALUES SHOULD BE:
(4) - 1.86776E-16	+ B(5)	-9.321856352E-17
(5) x 1620	x T_i	-1.510140729E-13
(6) + 2.19149E-13	+ B(4)	6.81349271E-14
(7) x 1620	x T_i	1.103785819E-10
(8) -1.293E-10	+ B(3)	-1.89214181E-11
(9) x 1620	x T_i	-3.065269732E-08
(10) + 4.47694E-08	+ B(2)	1.411670268E-08
(11) x 1620	x T_i	2.286905834E-05
(12) - 4.4701E-06	+ B(1) $\parallel$ $P(T_i)$	1.839895834E-05 = $P(T_i)$ $\left\{ \begin{array}{l} \text{1.8405269E-05 TABLE VALUE} \\ \varepsilon = 0.034\% \end{array} \right.$

For programmable calculators, nested multiplication is extremely efficient and highly recommended. It is further suggested to store negative coefficients as negatives such that the add-multiply-add-multiply simplicity can be preserved.

8. COMMENTS ON APPENDICES

In the following two major sections (Appendix A and B) can be found extensive conversion tables and the groupings of the polynomial approximations for the various selected gases in the respective order. Appendix B is immediately preceeded by two tables of significance. The first is a summary of constants of each of the included gases and the second is a quick cross reference for the included functions of the gases, the temperature range and the units of each function.

The format for the polynomials included in Appendix B needs a word of explanation to be used effectively. Included in each section is a separate function for a specific gas, valid over a specified temperature range and, perhaps, restricted to a given pressure. The results using the polynomial approximations are valid only within these stated limits.

Also included is the reference from which came the data, if available, or stated that the function was calculated from other existing polynomial approximations. (Note: the error for the calculated values may greatly exceed that of a single polynomial evaluation. See section 4 for the discussion.)

The format for Appendix B polynomials is as follows:

FCTN(T) AIR
UNITS
PRESSURE
TEMP. RANGE

REF: # / CALC.

$$B1 + B2T + B3T^2$$

$$B1 + B2T + B3T^2 + B4T^3$$

$$B1 + B2T + B3T^2 + B4T^3 + B5T^4$$

$$\vdots$$

$$B1 + B2T + B3T^2 + B4T^3 + B5T^4 + B6T^5 + B7T^6$$

FCTN(1) = XXXX

FCTN(T_i) = YYYYY

FCTN(2) = YXYX

The limiting parameters, function, gas,units and reference (or calculated) information is located in a standard format at the top. The five polynomials, second through sixth degree, follow. The majority of the coefficients are very small numbers thus requiring the scientific notation of B(I) = X.XXXXXE ± YY. The E ± YY means to multiply the preceeding number by 10 to the YY power. (Example: 1.42031E-09 means 1.42031 x 10^{-09}). Beneath the polynomials are three other numbers representing the function at the enclosed temperature. FCTN(385) means the value of FCTN at 385°R. FCTN(1) is the known table value at the lower end of the valid temperature range. FCTN(T_i) is the function evaluated at approximately a mid-point temperature using the highest degree polynomial presented. If the true function were monotonic, FCTN(1) and FCTN(2) are the respective lower and upper bounds for the function values and may be used as a check for calculating procedure. If the function is somewhat parabolic, FCTN(T_i) will not necessarily be between FCTN(1) and FCTN(2). Fortunately, most of the functions are monotonic in the temperature range considered. Although the data could seldom support more than six significant digits and often less, FCTN(1), FCTN(2) and FCTN(T_i) are generally carried to at least six places. This is intended, in the case of FCTN(T_i), to provide a calculation procedure check for at least one temperature for each function.

9. COMPRESSIBILITY FACTOR AND THE EQUATION OF STATE

Up to the point, nothing has been said about the equation of state for compressible fluids. For ideal gases, the compressibility factor, Z, is unity and the equation of state is the familiar $p = \rho RT$. For real gases, the compressibility factor may widely deviate from unity under conditions of extreme temperatures and pressures. The compressibility factor is, at least in part, a function of the inter-molecular forces which change under the influence of temperatures and pressure extremes. The ideal gas theory assumes no inter-molecular forces and thus cannot account for the density variation caused by a non-unity factor. From the practical point of view for general problem solutions there are two important items of note. First, at very low pressures, ideal gas behavior may be assumed with good accuracy regardless of temperature. For temperatures that are at least double the critical temperature, ideal behavior may be assumed up to approximately half the critical pressure. From Fig. B.8, page 796 of Reference 5, for $T = 2T_c$ and $p = 0.5\ p_c$, $Z = 0.99$. As the pressure is reduced or the temperature raised, Z approaches unity in the limit. For purposes of calculations, the compressibility factor should be assumed unity throughout.

10. GAS MIXTURES: (REF: 5, Ch. 11, and REF: 12, Ch. 10)

The thermodynamic properties of a mixture of pure gases is a function of the individual properties of the constituent gases. The following is applicable solely to inert gases and does not account for chemical reactions. The principles are:

a) the total mass of the mixture equals the sums of the individual gas masses:

$$m = m_z + m_b + m_c + \ldots = \sum_i m_i$$

b) the number of moles of the mixture is equal to the sum of the moles of the individual gases.

$$n = n_a + n_b + n_c + \ldots = \sum_i n_i$$

c) the static pressure of the mixture is the sum of the partial static pressures. The partial pressure of a gas in a mixture is the pressure the individual gas would exert if it alone occupied the entire volume of the mixture at the same temperature (Dalton's Law).

$$p = p_a + p_b + p_c + \ldots = \sum_i p_i \Big)_{v,T}$$

d) from Amagat's Law, the total volume equals the sum of the partial volumes.

$$V = V_a + V_b + V_c + \ldots = \sum_i V_i \Big)_{p,T} \; ; \; (V_i = m_i v_i)$$

Both Dalton's and Amagat's Law assume no inter-molecular forces present (ideal gas assumption) and that each constituent acts as if alone. Using Dalton's Law, the ideal gas law can be applied to the individual gases and summed for the mixture.

$$p_a V = n_a \bar{R} T$$

$p_a, p_b \ldots$ static partial pressures

$$p_b V = n_b \bar{R} T$$

where $\bar{R} = 1545.43$ ft. lb_f/lb_m-mole R

$$p_c V = n_c \bar{R} T$$

.

.

.

or

$R_g = (\overline{R}/MW)$ ft-lb_f/lb_m - R

$R_m = \overline{R}/MW_{mix}$; MW - molecular wt

$(P_a + P_b + P_c \ldots) V = (n_a + n_b + n_c + \ldots) \overline{R} T$ for the mixture

$PV = n\overline{R}T$ P - static pressure of the mixture

$P v = R_{mix} T$; $v=1/\rho$

$PV = m R_{mix} T$

e) By dividing the equation of state for each component by that for the mixture:

$$P_a = (n_a/n)P = X_a P$$

$$P_b = (n_b/n)P = X_b P$$

.

.

.

etc.

or for the ith component

$P_i = X_i P$ where X_i is the mole fraction

$$X_i = n_i / \sum_j n_j$$

The sum of the mole fractions must total to unity $\sum_i X_i = 1.0$

From the relationship $P_i = (n_i/n)P = X_i P$ and the fact that each constituent has the same static temperature and occupies the same volume:

$P_a/n_a = P_b/n_b = \ldots P_i/n_i = P/n$ (consequence of Dalton's Law)

From Amagat's analysis the corresponding results all:

$V_a/n_a = V_b/n_b = \ldots V_i/n_i = V/n$ with the major point being:

$$X_i = n_i/n = V_i/V = P_i/P$$

f) Determining the gas constant R_{mix} and molecular weight, MW_{mix}:

From $V\sum_i P_i = T\sum_i M_i R_i$ the ideal gas equation of state for the mixture is simply:

$$(P_a + P_b + P_c + \ldots) V = (m_a R_a + m_b R_b + \ldots) T$$

$$R_{mix} = (m_a/m) R_a + (m_b/m) R_b + \ldots = \sum_i (m_i R_i/m)$$

$$R_{mix} = \overline{R}/MW_{mix}$$

$$MW_{mix} = \sum_i m_i / \sum_i n_i = \sum_i m_i / \sum_i (m_i/MW_i) = \sum_i (nMW)_i /n$$

$$m = n\ MW_{mix}$$

$$MW_{mix} = X_a MW_a + X_a MW_a + \ldots = \sum_i X_i MW_i$$

g) Specific heats, entropy, internal energy and enthalpy for the mixture:

$$\text{(i)} \quad C_v(T) = \frac{m_a C_{v_a}(T)}{m} + \frac{m_b C_{v_b}(T)}{m} + \frac{m_c C_{v_c}(T)}{m} + \ldots \frac{BTU}{lb_m - {}^\circ R}$$

$$= \frac{\sum_i m_i C_{v_i}(T)}{\sum_i m_i} = \frac{\sum_i m_i C_{v_i}(T)}{m}$$

(ii) $C_p(T) = \sum_i m_i C_{p_i}(T)/m$ BTU/lbm-R

(iii) $C_p(T)-C_v(T) = R/J = (\overline{R}/MW)/J$ where $J=778.76$ ft-lb_f/BTU

R in ft-lb_f/lbm-R

(iv) $\gamma(T) = C_p(T)/C_v(T)$

(v) $*s_2-s_1 = \sum_i (m_i/m)(s_2-s_1)_i = \sum_i (m_i/m) \int_{T_1}^{T2} C_{p_i}(T)(dT/T)$

$- \sum_i (m_i/m) R_i/J(\ln(P_i/P))$

or

$= \int_{T_1}^{T_2} C_p(T)(dT/T) - R/J\ln(P_2/P_1) = \int_{T_1}^{T_2} C_v(T)(dT/T) + R/J\ln(v_2/v_1)$

(entropy units in BTU/lbm-R are consistent)

$s = \sum_i (m_i s_i)/m$ at a given temperature and pressure

(vi) $u_2-u_1 = \Sigma(m_i/m)(u_2-u_1)_i = \int_{T_1}^{T_2} C_v(T)\,dT$ BTU/lbm

$u = \sum_i (m_i/m)u_i$ at a given temperature

(vii) $h_2-h_1 = \Sigma(m_i/m)(h_2-h_1)_i = \int_{T_1}^{T_2} C_p(T)\,dT$ BTU/lbm

$h = \Sigma(m_i/m)h_i$ at a given temperature

---

* This is the entropy change of a mixture resulting from changes in temperature and/or pressure. There is an additional change resulting from the initial mixing process as well.

h) Entropy change due to initial mixing process

When individual perfect gases are initially mixed, each gas may be considered to undergo a free expansion from its initial partial pressure to its partial pressure in the mixture, with no work interaction. Mixing is an irreversible process. From the second law of Thermodynamics, if the process is adiabatic, $ds = \sum_i (m_i dS_i/m) \geq 0$. At the very best, the process could be isentropic. On a unit mass basis:

$$\Delta S = -\sum_i (m_i/m)(R_i/J)\ln(Pi_2/Pi_1)$$

where the subscripts indicate the initial and final equilibrium states

$$\Delta S \geq 0$$

i) Mixtures of pure gases at different initial pressures and temperatures:

$$T = \sum_i X_i T_i \qquad P = (1/V)(\sum_i) P_i V_i$$

$$u = \sum (m_i/m)(C_{v_i})T_i \qquad h = \sum (m_i/m)(C_{p_i})T_i$$

11. PROBLEM SOLUTIONS - REMARKS AND SUGGESTIONS

Appendix B provides sufficient information to calculate a wide variety of functions for both pure gases and any combination thereof. It is essential to any accuracy whatever that the polynomials be used only within the temperature and pressure limits stated for each function. Of the included functions, C_p, C_v, γ, μ, k, and Pr should be directly translatable to any reference and, except for small experimental measurements discrepancies, should differ only by a conversion factor. The remaining functions of ϕ, h, u, h/u, and s have an arbitrary reference datum. The difference between any two end points should translate directly with other references.

The best way to use Appendix B is direct calculation for functions provided. In some instances, the functions were not available in literature with sufficient data points to provide a satisfactory curve fit. A familarity with basic thermodynamic relationship show several alternate calculations possible when the desired function is not directly provided. The remainer is devoted to some suggestions for alternate calculations.

a) Calculations involving entropy S(P,T)

$$S_2 - S_1 = \int_{T_1}^{T_2} \frac{C_p(T)dT}{T} - (R/J)\ln(P_2/P_1) \equiv \phi_2^p - \phi_1^p - (R/J)\ln(P_2/P_1)$$

$$= \int_{T_1}^{T_2} \frac{C_v(T)dT}{T} + (R/J)\ln(v_2/v_1) \equiv \phi_2^v - \phi_1^v + (R/J)\ln(v_2/v_1)$$

(1) If $\phi(T)$ is available, $S_2 - S_1$ can be directly calculated for any desired pressure ratio P_2/P_1.

(2) If $\phi(T)$ is not available but either $C_v(T)$ or $C_p(T)$ is provided:

(a) $$\left.\begin{aligned} S_2 - S_1 &= \bar{C}_p\ln(T_2/T_1) - (R/J)\ln(P_2/P_1) \\ &= \bar{C}_v\ln(T_2/T_1) + (R/J)\ln(v_2/v_1) \end{aligned}\right\} \text{use an average specific heat if } \Delta T \text{ is not too great}$$

(b) $$\phi_2 - \phi_1 = \int_{T_1}^{T_2} [C_p(T)/T]dT = \int_{T_1}^{T_2} [B1 + B2T + B3T^2 + \ldots B(7)T^6]dT\ /T$$

$$= (B1)\ln(T_2/T_1) + B2(T_2 - T_1) + (B3/2)(T_2^2 - T_1^2)$$

$$+ \ . \ . \ . \ (B7/6)(T_2^6 - T_1^6)$$

knowing $\Delta\phi$, calculate ΔS for desired P_2/P_1

(3) If S(T) at 1 atmosphere is available:

Calculate ΔS @ 1 atmosphere for the 1 atmosphere isobar between the desired ΔT. Then calculate the remaining ΔS based on constant-temperature pressure change. Since entropy is a property, it has a unique value at the end points and is not path dependent. On the T-S diagram it looks like:

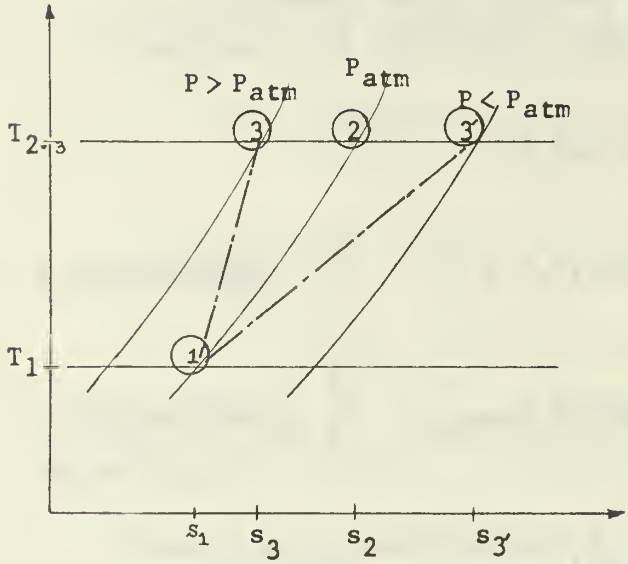

Fig. 1 Temperature-entropy diagram

with S(T) function polynomial directly available

a) $S_2 - S_1 = S(T_2) - S(T_1)$: P= const.

$S_3 - S_1 = (S_2 - S_1) + (S_3 - S_2)$

$S_{3'} - S_1 = (S_2 - S_1) + (S_{3'} - S_2)$

b) $S_3 - S_2 = \cancelto{0}{\int_{T_2}^{T_3} \frac{C_p\,dT}{T}} - (R/J)\ln(P_3/P_2)$

$= (R/J)\ln(v_3/v_2)$

in other words, treat the problem as isobaric at one atmosphere between the desired temperatures, then isothermal between the desired pressures.

b) Calculations involving internal energies and enthalpies:

Note: the reference datum lines are purely arbitrary for u(T) and h(T); differences are significant.

(1) If h(T) or u (T) are not provided but $C_p(T)$ and $C_v(T)$ are:

$$\int_1^2 dh(T) = \int_{T_1}^{T_2} C_p(T)dt \doteq \bar{C}_p(T_2 - T_1) \text{ for } \Delta T \text{ small}$$

$$= B1(T_2 - T_1) + (B2/2)(T_2^{\,2} - T_1^{\,2}) + (B3/3)(T_2^{\,3} - T_1^{\,3})$$

$$+ \;.\;.\;.\; (B6/6)(T_2^{\,6} - T_1^{\,6}) + (B7/7)(T_2^{\,7} - T_1^{\,7})$$

similarily for u(T). $\int du(T) = \int C_v(T)dT$. Knowing the enthalpy or the internal energy may not necessarily lead back to find correct values of C_p or C_v due to the arbitrariness of the reference datum.

2) If neither h(T) nor $C_p(T)$ or u(T) nor $C_v(T)$ are presented and the gas of interest is either monatomic or diatomic, kinetic theory presented in Section 5 can provide approximations to C_v and C_p. Knowing these values enables one to calculate changes in internal energy or enthalpy .

TABLE II

$C_p(T)$ BTU/lbm-R Specific Heat @ Constant Pressure.

$\mathrm{FCTN}=B1+B2T+B3T^2+B4T^3$

GAS	B1	B2	B3	B4	Range - deg. R
AIR	0.242333	-2.15256E-05	3.65E-08	-8.43996E-12	180-2340
AMMONIA	0.358467	2.64143E-04	4.06609E-09	-9.4211E-12	400-2460
ARGON	0.129518	-1.36274E-05	1.05456E-08	-2.46576E-12	180-2340
BROMINE	4.8013E-02	1.45148E-05	-8.54282E-09	1.67065E-12	360-2460
CARBON DIOXIDE	0.122652	1.82976E-04	-6.35135E-08	8.39019E-12	360-2460
CARBON MONOXIDE	0.261766	-5.5907E-05	6.79431E-08	-1.66981E-11	360-1440
CHLORINE	9.1047E-02	5.83198E-05	-3.3183E-08	6.40593E-12	360-2360
FLUORINE	0.15346	1.05287E-04	-4.78364E-08	7.735E-12	360-2460
FREON-12	3.98143E-02	2.53247E-04	-1.33539E-07	2.3993E-11	180-2460
HELIUM	1.240164	-	-	-	*
HYDROGEN	2.50963	2.18533E-03	-1.50994E-06	3.41529E-10	180-2460
NEON	0.2459682	-	-	-	*
NITROGEN	0.252428	-2.52138E-05	3.59637E-08	-7.69919E-12	270-2610
OXYGEN	0.198806	3.58425E-05	4.80518E-09	-3.14427E-12	460-2460
WATER VAPOR	0.872541	-1.10895E-03	9.75232E-07	-2.62136E-10	684-1530
XENON	0.0378094	-	-	-	*

* calculated constants from kinetic theory.

TABLE III

$C_v(T)$ BTU/lbm-R Specific Heat @ Constant Volume.

$\mathrm{FCTN}=B1+B2T+B3T^2+B4T^3$

GAS	B1	B2	B3	B4	Range - deg. R
AIR	0.164435	7.69284E-06	1.21419E-08	-2.61289E-12	300-3600
AMMONIA	0.400144	-2.77713E-04	6.03509E-07	-2.29279E-10	576-1044
ARGON	8.02449E-02	-2.69774E-05	4.07132E-08	-1.92432E-11	162-1080
BROMINE	3.66763E-02	1.12846E-05	-6.32263E-09	1.15725E-12	400-2570
CARBON DIOXIDE	7.06064E-02	1.93292E-04	-6.75883E-08	8.74976E-12	300-3000
CARBON MONOXIDE	0.176238	-9.67381E-06	2.63333E-08	-5.6751E-12	300 3000
CHLORINE	5.85948E-02	6.97138E-05	-4.34525E-08	9.0423E-12	250-2178
FLUORINE	0.150486	-1.72961E-04	4.70883E-07	-3.13487E-10	162-540
FREON-12	not available				
HELIUM	0.7440983	-	-	-	*
HYDROGEN	1.75698	1.39838E-03	-8.0439E-07	1.6083E-10	200-2900
NEON	0.1475809	-	-	-	*
NITROGEN	0.177257	-1.05204E-05	2.28181E-08	-4.41429E-12	200-3400
OXYGEN	0.143786	3.03129E-05	2.0739E-09	-1.41517E-12	200-3400
WATER VAPOR	0.326063	-9.63657E-06	5.93762E-08	-1.10588E-11	300-3000
XENON	0.0226856	-	-	-	*

* calculated constants from kinetic theory.

TABLE IV

$\gamma(T)=C_p/C_v$ Specific Heat Ratio no units

FCTN=B1+B2T+B3T^2+B4T^3

GAS	B1	B2	B3	B4	Range - deg. R
AIR	1.42616	-4.21505E-05	-7.93962E-09	2.40318E-12	198-3420
AMMONIA	1.39459	-2.78203E-04	1.13379E-07	1.46383E-11	576-1044
ARGON	1.75022	-3.67538E-04	5.33183E-07	-2.50109E-10	180-1008
*BROMINE	1.3372	-9.0523E-05	5.38983E-08	-1.05E-11	400-2400
CARBON DIOXIDE	1.56184	-7.39734E-04	5.32245E-07	-1.35797E-10	396-1620
CARBON MONOXIDE	1.41418	-5.43095E-06	-3.94182E-08	1.00754E-11	360-2790
*CHLORINE	1.43937	-2.87793E-04	1.83999E-07	-3.85425E-11	250-2250
FLUORINE	1.51089	-7.13918E-04	1.58057E-06	-1.4369E-09	162-540
FREON-12	not available				
*HELIUM	1.66667	-	-	-	-
HYDROGEN	1.80808	-1.68434E-03	2.23199E-06	-9.56775E-10	180-1080
*NEON	1.66667	-	-	-	-
NITROGEN	1.4059	1.52556E-05	-4.72063E-08	1.0644E-11	270-2880
OXYGEN	1.4406	-9.78523E-05	1.37403E-08	8.0034E-13	216-3060
WATER VAPOR	1.3463	-2.24709E-05	-2.8864E-08	7.00874E-12	300-3000
*XENON	1.66667	-	-	-	-

* calculated fron kinetic theory.

TABLE V

$\mu(T)$ lbf-sec/ft.^{2} molecular viscosity

FCTN=B1+B2T+B3T^2+B4T^3

GAS	B1	B2	B3	B4	Range - deg. R
AIR	2.74877E-08	7.85557E-10	-2.51179E-13	4.0851E-17	260-2560
AMMONIA	4.59333E-09	3.61045E-10	4.43819E-14	-1.82028E-18	460-1460
ARGON	2.42105E-08	9.4593E-10	-2.5037E-13	3.34968E-17	260-2860
BROMINE	6.99652E-08	5.02169E-10	-1.47247E-13	1.69649E-16	460-920
CARBON DIOXIDE	-1.97493E-08	7.05895E-10	-1.76601E-13	2.48862E-17	360-2860
CARBON MONOXIDE	3.39232E-08	7.11432E-10	-1.8641E-13	2.77278E-17	270-2700
CHLORINE	-3.39665E-09	5.4603E-10	-2.49582E-14	-1.41739E-17	460-1660
FLUORINE	-1.86865E-08	1.14685E-09	-3.06333E-13	-7.89963E-17	160-1100
FREON-12	-1.34814E-08	6.45425E-10	-2.6929E-13	4.83045E-17	440-960
HELIUM	not available				
HYDROGEN	-5.03306E-08	5.53477E-10	-2.7895E-13	6.39674E-17	560-2560
NEON	9.34812E-08	1.29751E-09	-5.30558E-13	1.26959E-16	260-2260
NITROGEN	4.4789E-08	6.93784E-10	-1.90658E-13	2.715E-17	260-2860
OXYGEN	9.54299E-08	6.81319E-10	-1.24826E-13	1.50221E-17	360-3060
WATER VAPOR	2.01511E-08	3.40295E-10	5.94828E-14	-1.49343E-17	740-2660
XENON	-4.21081E-08	1.08327E-09	-2.09688E-13	5.49662E-19	420-1260

TABLE VI

k(T) BTU/ft-sec-R thermal conductivity

$FCTN=B1+B2T+B3T^2+B4T^3$

GAS	B1	B2	B3	B4	Range - Deg. R
AIR	1.48844E-07	8.12546E-09	-1.49776E-12	1.4482E-16	180-2520
AMMONIA	4.29762E-07	2.7288E-09	7.99878E-12	-1.75037E-15	450-1620
ARGON	4.26251E-07	4.73128E-09	-7.67798E-13	7.5791E-17	180-4860
BROMINE	-3.10747E-06	1.82455E-08	-3.06197E-11	1.87227E-14	450-630
CARBON DIOXIDE	-7.85007E-06	5.72261E-09	1.69217E-12	-6.90018E-16	360-2250
CARBON MONOXIDE	-1.27634E-07	9.01106E-09	-2.63386E-12	4.76956E-16	180-2250
CHLORINE	-6.20427E-08	2.20449E-09	1.43919E-12	-7.70715E-16	432-1260
FLUORINE	3.92382E-08	7.42551E-09	2.56397E-12	-2.04974E-15	180-1440
FREON-12	-5.19247E-07	3.12354E-09	1.3724E-12	-6.35186E-17	450-900
HELIUM	6.22626E-06	3.40444E-08	-3.41609E-12	3.19323E-16	180-4320
HYDROGEN	2.82639E-06	5.37253E-08	-1.46949E-11	2.85135E-15	180-2610
NEON	2.12319E-06	1.11828E-08	-1.96329E-12	1.95363E-16	180-4320
NITROGEN	1.23844E-07	8.57171E-09	-2.37072E-12	3.82796E-16	260-2860
OXYGEN	-2.4701E-08	8.77107E-09	-1.72883E-12	2.30711E-16	180-2700
WATER VAPOR	1.13512E-06	-6.23951E-10	8.51026E-12	-2.33593E-15	504-1620
XENON	9.13157E-10	1.81758E-09	-2.72407E-13	-2.94542E-19	360-1332

TABLE VII

$\Delta\Phi(T)=\int C_p(T)dT/T$ BTU/lbm-R "temperature function"

$FCTN=B1+B2T+B3T^2+B4T^3$

GAS	B1	B2	B3	B4	Range - Deg. R
AIR	0.232404	8.56494E-04	-4.08016E-07	7.64068E-11	200-2400
*AMMONIA	-0.388219	1.15678E-03	-3.33501E-07	4.86868E-11	400-2460
*ARGON	-4.03556E-02	4.17858E-04	-1.96373E-07	3.61134E-11	180-2340
*BROMINE	-4.11293E-02	1.42893E-04	-5.54945E-08	8.8608E-12	360-2460
CARBON DIOXIDE	0.923566	5.0671E-04	-1.51025E-07	1.99587E-11	300-3000
CARBON MONOXIDE	1.38796	6.54878E-04	-2.34238E-07	3.39601E-11	300-3000
*CHLORINE	-9.1076E-02	3.11039E-04	-1.21582E-07	1.98783E-11	360-2360
*FLUORINE	-1.50548E-01	5.13262E-04	-1.85779E-07	2.86895E-11	360-2460
*FREON-12	-5.80762E-02	3.89855E-04	-1.3072E-07	1.95411E-11	180-2460
*HELIUM	-0.717177	3.91478E-03	-1.79516E-06	3.29118E-10	250-2250
HYDROGEN	11.5873	8.31522E-03	-2.80508E-06	3.8395E-10	300-3000
*NEON	-0.142241	7.76439E-04	-3.56043E-07	6.52756E-11	250-2250
NITROGEN	1.3331	6.55749E-04	-2.36418E-07	3.44189E-11	300-3000
OXYGEN	1.26596	5.76141E-04	-2.00312E-07	2.85177E-11	300-3000
WATER VAPOR	1.96748	1.16367E-03	-4.07186E-07	5.96368E-11	300-3000
*XENON	-2.18649E-02	1.19352E-04	-5.47297E-08	1.0034E-11	250-2250

* calculated

TABLE VIII

$Pr(T)=\mu(T)C_p(T)/k(T)$ no units Prandtl number

$FCTN=B1+B2T+B3T^2+B4T^3$

GAS	B1	B2	B3	B4	Range - Deg. R
AIR	0.776769	-1.31645E-04	2.80229E-08	2.59569E-12	260-2260
AMMONIA	1.0796	-7.30896E-04	7.06829E-07	-1.93878E-10	460-1460
ARGON	0.700487	-5.8009E-05	2.34596E-08	-1.97692E-12	180-1440
BROMINE	4.27221	-1.83804E-02	3.22558E-05	-1.91866E-08	460-630
CARBON DIOXIDE	1.00224	-6.86227E-04	6.22539E-07	-2.54631E-10	396-1080
CARBON MONOXIDE	0.863382	-3.60646E-04	2.5387E-07	-3.58356E-11	360-1080
CHLORINE	0.804124	-1.96901E-04	1.05186E-07	-5.8586E-12	460-1260
FLUORINE	0.682529	1.60336E-04	-2.36512E-07	4.90444E-11	360-1100
FREON-12	1.28342	-1.69373E-03	1.91824E-06	-9.08582E-10	450-900
HELIUM	not available				
HYDROGEN	0.704128	1.12073E-04	-2.63566E-07	1.15759E-10	180-1440
NEON	0.647415	5.77577E-05	-6.10706E-08	2.2094E-11	260-2260
NITROGEN	0.849496	-3.82263E-04	2.69565E-07	-5.30766E-11	180-2160
OXYGEN	0.913618	-6.91632E-04	7.00018E-07	-2.2162E-10	180-1080
WATER VAPOR	2.09544	-2.42043E-03	1.61261E-06	-3.54911E-10	740-1530
XENON	0.562866	2.79847E-04	-2.66293E-07	7.82523E-11	420-1260

TABLE IX

h(T) BTU/lbm static enthalpy

*$FCTN=B1T+B2T^2+B3T^3+B4T^4$ $FCTN=B1+B2T+B3T^2+B4T^3$

GAS	B1	B2	B3	B4	Range - Deg. R
*AIR	0.239788	-6.71311E-06	9.69339E-09	-1.60794E-12	200-2400
AMMONIA	740.517	0.427092	6.17597E-05	2.08788E-08	540-1044
ARGON	80.9133	0.135952	-2.56082E-05	1.94633E-08	162-540
BROMINE	-19.3333	5.25417E-02	1.86025E-06	-2.94235E-10	360-2460
*CARBON DIOXIDE	0.137468	6.89219E-05	-9.27995E-09	8.46312E-14	300-3000
*CARBON MONOXIDE	0.238726	-3.67254E-06	1.34861E-08	-2.8716E-12	300-3000
CHLORINE	-40.4627	0.107167	9.72128E-06	-1.59492E-09	360-2460
FLUORINE	-23.8687	2.00613	-5.3029E-04	6.40045E-07	162-540
FREON-12	-21.6583	8.80787E-02	6.15282E-05	-1.06053E-08	180-2460
HELIUM	5.72024	1.24746	-2.28079E-05	2.23289E-08	20-540
*HYDROGEN	3.37356	-1.08333E-06	3.01892E-08	-2.85439E-12	300-3000
NEON	-61.4919	0.245968	-3.58635E-10	9.56427E-14	250-2250
*NITROGEN	0.250102	-9.69119E-06	1.0385E-08	-1.62097E-12	300-3000
*OXYGEN	0.215027	-1.50639E-06	1.0399E-08	-2.09808E-12	300-3000
*WATER VAPOR	0.439412	-1.04775E-05	2.30972E-08	-3.36771E-12	300-3000
XENON	-9.45233	3.78094E-02	-5.4887E-11	1.46371E-14	250-2250

* use the polynomial on the left above.

TABLE X

u(T) BTU/lbm internal energy

*$FCTN=B1T+B2T^2+B3T^3+B4T^4$ $FCTN=B1+B2T+B3T^2+B4T^3$

GAS	B1	B2	B3	B4	Range - Deg. R
*AIR	0.171225	-6.68651E-06	9.67706E-09	-1.60477E-12	200-2400
AMMONIA	-191.39	0.274263	9.43435E-05	1.13717E-08	576-1044
ARGON	81.6692	8.14908E-02	-1.50656E-05	1.13713E-08	162-540
BROMINE	-16.6153	4.05935E-02	1.37311E-06	-2.26001E-10	400-2650
*CARBON DIOXIDE	9.23449E-02	6.89232E-05	-9.28104E-09	8.4872E-14	300-3000
*CARBON MONOXIDE	0.179066	-9.92801E-06	1.17292E-08	-1.94727E-12	300-3000
CHLORINE	-19.9704	7.34877E-02	1.3884E-05	-2.7592E-09	250-2178
FLUORINE	-16.668	1.43717	-4.25909E-04	5.59062E-07	162-540
FREON-12	not available				
HELIUM	5.92049	0.747731	-1.1543E-05	1.1296E-08	20-540
*HYDROGEN	2.38843	-9.27131E-07	3.00986E-08	-2.83829E-12	300-3000
NEON	-36.8951	0.147581	-2.15709E-10	5.75145E-14	250-2250
*NITROGEN	0.179212	-9.67386E-06	1.03733E-08	-1.6186E-12	300-3000
*OXYGEN	0.152975	-1.52136E-06	1.0408E-08	-2.09968E-12	300-3000
*WATER VAPOR	0.329174	-1.04572E-05	2.30857E-08	-3.36573E-12	300-3000
XENON	-5.6714	2.26857E-02	-3.32254E-11	8.85899E-15	250-2250

* use the polynomial on the left above

TABLE XI

h(T)/u(T) no units ratio of enthalpy to internal energy.

$FCTN=B1+B2T+B3T^2+B4T^3$

GAS	B1	B2	B3	B4	Range - Deg. R
AIR	1.40057	1.51205E-05	-2.27076E-08	4.13655E-12	200-2400
ARGON	0.99394	6.28267E-04	-5.33195E-07	2.57353E-10	162-540
CARBON DIOXIDE	1.45987	-2.29764E-04	7.73689E-08	-9.67236E-12	300-3000
CARBON MONOXIDE	1.3332	5.53634E-05	-1.49804E-08	-8.4451E-13	300-3000
FLUORINE	1.38966	8.01579E-05	-1.73983E-07	5.20784E-11	162-540
HELIUM	1.47951	1.68018E-03	-5.14387E-06	4.97088E-09	20-540
HYDROGEN	1.41248	1.77489E-07	-5.33006E-09	6.23351E-13	300-3000
NITROGEN	1.39602	2.02843E-05	-2.25596E-08	3.74142E-12	300-3000
OXYGEN	1.40727	-2.30938E-06	-2.1207E-08	4.65935E-12	300-3000
WATER VAPOR	1.33606	6.79299E-06	-2.08846E-08	3.6175E-12	300-3000

Ammonia, bromine, chlorine, freon-12, neon and xenon not calculated due to probable excessive error.

TABLE XII

s(T) BTU/lbm-R entropy @ 1 atmosphere

$FCTN=B1+B2T+B3T^2+B4T^3$

GAS	B1	B2	B3	B4	Range - Deg. R
AIR	1.25715	9.10432E-04	-4.58246E-07	8.97664E-11	180-2340
AMMONIA	2.61008	6.05613E-04	4.03951E-07	-2.7286E-10	420-1060
ARGON	0.73114	4.5156E-04	-2.15042E-07	3.88E-11	180-2520
CARBON DIOXIDE	0.927345	5.05824E-04	-1.55077E-07	2.1604E-11	396-2700
CARBON MONOXIDE	1.39638	6.41379E-04	-2.32837E-07	3.50049E-11	360-2790
FLUORINE	0.81659	1.87441E-03	-2.98684E-06	2.02761E-09	162-540
HELIUM	3.24188	2.60655E-02	-6.41867E-05	5.73241E-08	20-540
HYDROGEN	8.98152	1.98668E-02	-1.79158E-05	6.66945E-09	108-1080
NEON	1.05393	3.174E-03	-5.93218E-06	4.43268E-09	90-540
NITROGEN	1.3027	6.80574E-04	-2.26751E-07	2.86714E-11	180-3780
OXYGEN	1.19726	7.55907E-04	-3.33615E-07	5.79808E-11	180-2610
WATER VAPOR	1.92593	1.3842E-03	-6.70928E-07	1.4644E-10	684-1530

Bromine, chlorine, freon-12 and xenon values not available.

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APPENDIX A

CONVERSION SUMMARY

TABLE 12
Systems of units(RE: 11)

Name of unit	Dimension	British	Metric	Metric Absolute
		ft-lbf-sec	kg· m-sec	cg-sec
Force	F	lbf	Kg	dyne
Length	L	ft	m	cm
Time	T	sec	sec	sec
Velocity	L/T	ft/sec	m/sec	cm/sec
Acceleration	L/T^2	ft/sec^2	m/sec^2	cm/sec^2
Pressure	F/L^2	lbf/ft^2	Kg/m^2	$dynes/cm^2$
Momentum	FT	lbf-sec	Kg-sec	dyne-sec
Work - Energy	FL	ft-lbf	Kg-m	dyne-cm (=erg)
Power	FL/T	ft-lbf/sec	Kg-m/sec	ergs/sec
Mass	FT^2/L	$lbf-sec^2/ft$ (=slug)	$Kg-sec^2/m$ (metric slug)	$dyne-sec^2/cm$ (=gram mass)

A) Temperature conversions:

°R= °F+459.67 °K= °C+273.15
°R= 9/5 °K °K= 5/9 °R

B) Molecular viscosity

Centipoise = 2.0886E-05 $lbf-sec/ft^2$ (=slugs/ft-sec)
= 6.71986164E-04 lbm/ft-sec
= 2.41915 lbm/ft-hr

C) Thermal conductivity:

mw/cm-K = 5.78176E-02 BTU/ft-hr-R
= 1.60604444E-05 BTU/ft-sec-R
= 2.39006E-04 Cal/cm-sec-R

D) Specific energy:

Cal/mole-K =(1/MW)BTU/lbm-R
Cal/mole =(1.8/MW)BTU/lbm
Joule/mole-K = 4.184^{-1}(1/MW)BTU/lbm-R
Joule/mole = 1.8/4.184(1/MW)BTU/lbm

The following conversion summary is alphabetically organized. Within each group, the summary is designed to be read from left-to-right. To convert from the units on the left to the units on the right, simply multiply by the appropriate conversion factor. Any of the units on the right may be converted to those of the left by either dividing by the conversion factor or multiplying by its reciprocal. A third possible way to use the summary is to equate any two units on the right within a single group. As an example, consider the viscosity conversions provided in B) above.

a) direct conversion: (X)centipoise =(X)2.0886E-05 slugs/ft-sec
b) inverse conversion:(X)slugs/ft-sec =(X)/2.0886E-05 centipoise
c) alternate conversions: 5.78176E-02 BTU/ft-hr-R = 1.60604444E-05 BTU/ft-sec-R

APPENDIX A

Angstrom units	1E-08	cm
	1E-10	m
	3.9370079E-09	in
	1E-04	microns
Atmospheres (pressure)	1.01325	bars
	76.00	cm Hg @0° C
	1033.25676	cm H_2O @4° C
	1.01325E+06	dynes/cm^2
	33.8995	ft H_2O @39.2°F
	29.9213	in Hg @32° F
	1.03323	Kg/cm^2
	14.696	lbf/in^2
	2116.224	lbf/ft^2
Bars (pressure)	0.98692327	atmospheres
	1E+06	dynes/cm^2
	33.4883	ft H_2O @60°F
	29.530	in Hg @32° F
	1.019716	Kg/cm^2
BTU * (work) * mean value	3.933172E-04	HP-hr
	1055.867	joules
	778.76809	ft-lbf
	107.6687	Kg-m
	2.932965E-04	Kw-hr
	252.3584	cal. gm
	1.0558673E+10	ergs
	1.0766872E+07	gram-cm
	3.4749435E-06	tons of refrig.(US)
	1055.867	watt-sec (=joules)
	0.2932965	watt-hrs
BTU/hr (power)	0.2523584	Kg-cal/hr
	2.9329657E+06	ergs/sec
	778.76809	ft-lbf/hr
	3.93317197E-04	HP
	2.93296467E-04	Kilowatts
BTU/min (power)	0.2523584	Kg-cal/min
	1.7597794E+08	ergs/sec
	778.76809	ft-lbf/min
	0.023599	HP
	17.59779	joules/sec
	107.6687	Kg-m /min
	0.01759779	kilowatts
	17.59779	watts
BTU/lbm	0.5563545	gm cal/gram
	778.76809	ft-lbf/lbm
	2.32778503	joules/gram
	see section D also.	

BTU/sec	3600	BTU/hr
	60	BTU/min
	908.4905	kg-cal/hr
	15.1414583	kg-cal/min
	1.0558673	ergs/sec
	778.76809	ft-lbf/sec
	1.4159447	HP
	107.6687	Kg m /sec
	1.0558673	kilowatts
Calories-gm	4.184	joules
	3.96262E-03	BTU
	4.184E+07	ergs
	3.08596	ft-lbf
	1.55857E-06	HP-hrs
	0.426649	Kg-m
	1.162222E-06	Kw-hrs
	4.184	watt-sec
	0.001	Kg-cal
	4.26649E+04	gram-cm
Calories/hr	11622.222	ergs/sec
	1.1622222E-03	watts
Calories/sec	4.184E+07	ergs/sec
	3.08596	ft-lbf/sec
	5.61084E-03	HP
	4.184	watts
Centimeter	1E+08	Angstrom units
	3.2808399E-02	ft
	1E+05	microns
	0.39370079	in
	5.399568E-06	nautical miles
	6.2137119E-06	statute miles
	1.9883878E-03	rods
	1.0936133E-02	yards
	0.0100	m
	10	mm
cm Hg @0° C (pressure)	1.3157895E-02	atmospheres
	0.0133322	bars
	13332.2	dynes/cm^2
	0.44605	ft H_2O @4° C
	0.446474	ft H_2O @60° F
	0.39370079	in Hg @ 0° C
	135.951	Kg/m^2
	27.845	lbf/ft^2
	0.193368	lbf/in^2
	10	torrs
cm H_2O @4° C (pressure)	9.67814E-04	atmospheres
	980.638	dynes/cm^2
	0.0142229	lbf/in^2

APPENDIX A

cm/sec	1.9685039	ft/min
	0.032808399	ft/sec
	0.036	Km/hr
	0.0006	Km/min
	2.2369363E-02	miles/hr
centipoise (viscosity)	2.41915	lbm/ft-hr
	6.7196898E-04	lbm/ft-sec
	2.0886E-05	lbf-sec/ft^2
cm^3	3.5314667E-05	ft^3
	0.061023744	in^3
	1E-06	m^3
	1.3079506E-06	yards^3
ft^3 H_2O @39.2° F	62.4262	lbf of H_2O
@60° F	62.3663	lbf of H_2O
ft^3	2.8316847E+04	cm^3
	0.028316847	m^3
in^3	16.387064	cm^3
	5.787037E-04	ft^3
	1.6387064E-05	m^3
	2.143347E-05	yards^3
m^3	35.314667	ft^3
	1E+06	cm^3
	61023.7446	in^3
	1.3079506	yards^3
dynes (force)	1.019716E-03	grams
	1E-05	Newtons
	2.248089E-06	lbf
	1	ergs/cm^2
dynes/cm^2 (pressure)	9.86923E-07	atmosphere
	1E-06	bars
	7.50062E-05	cm Hg @0° C
	1.019745E-03	cm H_2O @4° C
	1.019716E-03	grams/cm^2
	2.953E-05	in Hg @0° C
	4.01474E-03	in H_2O @4° C
	0.01019716	Kg/m^2
	1.450377E-05	lbf/in^2
dyne-cm	1	erg
	7.37562E-08	ft-lbf
	1.019716E-03	gram-cm
	8.850744E-07	in-lbf
	1E-07	Newton-m

ergs	9.470887109E-11	BTU
	2.39006E-08	cal-gm
	1	dyne-cm
	7.37562E-08	ft-lbf
	1E-07	joules
	2.777777E-14	kw-hrs
	1.019716E-08	Kg-m
	1E-07	watt-sec
ergs/sec (power)	1.34102E-10	HP
	1	dyne-cm/sec
	4.42537E-06	ft-lbf/min
	1E-10	kilowatts
ft	12	in
	30.48	cm
	0.3048	m
	3.048E+05	microns
	1.89393E-04	stat. miles
	1.6457883E-04	naut. miles
	0.060606	rods
ft Hg @0° C (pressure)	5.89385	lbf/in^2
	848.7144	lbf/ft^2
	13.6085	ft H_2O @60° F
ft H_2O @4° C	0.029499	atmosphere
	2.24192	cm Hg @0° C
	29889.8	dynes/cm^2
	0.882646	in Hg @0° C
	304.791	Kg/m^2
	0.433515	lbf/in^2
	62.42616	lbf/ft^2
ft/min	0.508	cm/sec
	0.0166666	ft/sec
	0.018288	Km/hr
	0.01136363	miles/hr
ft-lbf	1.28408E-03	BTU
	0.324048	cal(gm.)
	1.35582E+07	dyne-cm(=ergs)
	13825.5	gram-cm
	5.0505E-07	HP-hrs
	1.35582	joules
	0.138255	Kg-m
	3.76616E-07	Kwatt-hrs
	1.355818	Newton-m
	3.76616E-04	watt-hrs

ft-lbf/hr	2.14013E-05	BTU/min
(power)	5.4008E-03	cal(gm)/min
	2.2597E+05	ergs/min
	5.050505E-07	HP
	3.76616E-07	kilowatt
ft-lbf/min	3.030303E-05	HP
	2.2597E-02	joules/sec
grams	980.665	dynes
(mass)	6.852177E-05	slugs
grams/cm^2	9.67841E-04	atmospheres
(pressure)	9.80665E-04	bars
	0.0735559	cm Hg @0° C
	0.028959	in H$_2$O @32° F
	10	Kg/m^2
	0.014223343	lbf/in^2
gram-cm	9.28776E-06	BTU
	2.34385E-05	cal,(gm)
	980.665	ergs(=dyne-cm)
	7.2330138E-05	ft-lbf
	3.65303E-11	HP-hr
	9.80665E-05	joules(=Newton-m)
	2.72407E-11	kilowatt-hrs
gram-cm/sec	1.31509E-07	HP
(power)	9.80665E-08	kilowatt
gram/cm^2	3.41717E-04	lbf/in^2
horsepower	550.0	ft-lbf/sec
(mechanical)	2542.48	BTU/hr
	6.41616E+05	cal,(gm)/hr
	7.457E+09	ergs/sec
	1.98E+06	ft-lbf/hr
	33000.0	ft-lbf/min
	0.0760181	HP(boiler)
	0.999598	HP(electrical)
	1.01387	HP(metric)
	745.7	joules/sec(=watts)
	0.7457	kilowatts
	0.21204	tons refrig(US)
in	2.54E+08	Angstrom units
	2.54	cm
	0.083333	ft
	0.0254	m
in Hg @0° C	0.0334211	atmospheres
(pressure)	0.0338639	bars
	33863.9	dynes/cm^2
	1.132957	ft H$_2$O @39.2° F
	34.5316	grams/cm^2
	70.7262	lbf/ft^2
	0.49115417	lbf/in^2
in H$_2$O @4° C	0.0024582	atmospheres
	2490.82	dynes/cm^2
	0.0735539	in Hg @0° C
	25.3993	Kg/m^2
	5.20218	lbf/ft^2
	0.03612628	lbf/in^2
joules	9.47088E-04	BTU
	0.239006	cal,(gm)
	1E+07	ergs
	0.737562	ft-lbf
	10197.16	gram-cm
	3.72506E-07	HP-hr
	0.1019716	Kg-m
	2.7777E-07	Kw-hr
	1	watt-sec
joules/sec	0.0568253	BTU/min
(power)	14.3403	cal,(gm)/min
	1E+07	dyne-cm/sec
	0.737562	ft-lbf/sec
	1.34102E-03	HP
	1	watt
kilowatts	3409.52	BTU/hr
	1E+10	ergs/sec
	2.65522E+06	ft-lbf/hr
	737.562	ft-lbf/sec
	1.019716E+07	gram-cm/sec
	1.34102	HP
	3.6E+06	joules/hr
	1E+03	joules/sec
	3.67098E+05	Kg-m/hr
kilowatt-hr	3409.52	BTU
	2.65522E+06	ft-lbf
	1.34102	HP-hr
	3.67098E+05	Kg-m
knots	6076.1155	ft/hr
	30.8666	m/min
	1.15077945	stat. mi/hr
	1	naut. mi/hr
m	1E+10	Angstrom units
	3.2808399	ft
	39.370079	in
	6.2137119E-04	stat. mile
m/sec	196.85039	ft/min
	2.2369363	mile/hr
microns	1E-04	cm
	3.2808399E-04	ft
	1E-06	m

lbf/ft^2	4.72541E-04	atmosphere	radian	57.29577951	degree
(pressure)	4.78803E-04	bars		0.15915494	revolutions
	0.0359131	cm Hg @0°C			
	478.803	dynes/cm^2			
	0.014139	in Hg @0°C	slugs	1	lbf-sec^2/ft
	0.192227	in H_2O @39.2° F	(mass)	14.5939	Kg
	4.8824276	Kg/m^2		32.174	lbm

APPENDIX B TABLE XIII

PHYSICAL CONSTANTS FOR THE SELECTED GASES

SELECTED GAS	MOLECULAR FORMULA	MOLECULAR WEIGHT	R_g GAS CONST. ft-lbf/lbm-R	CRITICAL TEMP. R	CRITICAL PRESS. ATM	CRITICAL VOL. ft^3/lbm-mol	TRIPLE PT. TEMP. R	TRIPLE PT. PRESS. ATM	NORMAL MELT R	NORMAL BOIL R
AIR	- - -	28.968	53.349	239.37	37.21	- - -	- - -	- - -	102.47	141.87
AMMONIA	NH_3	17.032	90.737	729.9	111.3	1.16	351.72	0.05996	351.77	431.67
ARGON	A	39.944	38.690	271.17	47.986	- - -	- - -	- - -	150.97	157.07
BROMINE	Br_2	159.818	9.67	1051.49	102.0	- - -	- - -	- - -	442.52	596.97
CARBON DIOXIDE	CO_2	44.010	35.12	547.56	72.85	1.51	389.81	5.112	350.48†	- - -
CARBON MONOXIDE	CO	28.010	55.17	239.27	34.529	1.49	122.67	1.15	119.07	146.97
CHLORINE	Cl_2	70.914	21.79	750.6	76.1	1.99	- - -	- - -	309.91	430.38
FLUORINE	F_2	38.00	40.67	259.27	55.0	- - -	- - -	- - -	96.47	153.07
FREON-12	CCl_2F_2	120.930	12.78	693.27	40.605	- - -	96.47	2.2E-03	207.67	438.05
HELIUM	He	4.003	386.07	9.37	2.26	0.929	24.912	0.0695	- - -	7.57
HYDROGEN	H_2	2.016	766.58	59.9	12.8	1.04	25.11	0.0708	25.07	36.67
NEON	Ne	20.183	76.57	79.92	26.85	- - -	44.19	0.4275	44.07	48.77
NITROGEN	N_2	28.016	55.16	227.2	33.5	1.44	113.64	0.124	113.97	139.31
OXYGEN	O_2	32.00	48.29	277.9	49.7	1.19	97.78	0.0158	98.57	162.27
WATER VAPOR	H_2O	18.016	85.78	1165.1	218.2	0.897	491.688	0.00603	491.67	671.67
XENON	Xe	131.30	11.77	521.57	58.185	- - -	290.43	0.805	239.67	297.07

† normal sublimation temperature

APPENDIX B TABLE XIV

TEMPERATURE RANGE OF INCLUDED FUNCTIONS (deg. R)

SELECTED GAS	$C_p(T)$ BTU/lbm-R	$C_v(T)$ BTU/lbm-R	$\gamma=C_p/C_v$ no units	$\mu(T)$ lbf-sec/ft^2	k(T) BTU/ft-sec-R	$\phi(T)$ BTU/lbm-R	Pr(T) no units	h(T) BTU/lbm	u(T) BTU/lbm	h(T)/u(T) no units	s(T) @ 1 atm. BTU/lbm-R
AIR	180-4680	300-3000	200-3420	260-2560	180-2520	200-5000	260-2260	200-5000	200-5000	200-5000	180-2340
AMMONIA	400-2460	576-1044	576-1044	460-1460	450-1620	400-2460	460-1460	540-1044	576-1044	- - -	420-1060
ARGON	180-2340	162-1080	180-1008	260-2860	180-4860	180-2340	180-1440	162-540	162-540	162-540	180-2520
BROMINE	360-2460	400-2570	400-2400	460-920	450-630	360-2460	460-630	360-2460	400-2650	- - -	- - -
CARBON DIOXIDE	360-2460	300-3000	396-1620	360-2860	360-2250	300-3000	396-1080	300-3000	300-3000	300-3000	396-2700
CARBON MONOXIDE	360-1440	300-3000	360-2790	270-2700	180-2250	300-3000	360-1080	300-3000	300-3000	300-3000	360-2790
CHLORINE	360-2360	250-2178	250-2250	460-1660	432-1260	360-2360	460-1260	360-2460	250-2178	- - -	- - -
FLUORINE	360-2460	162-540	162-540	160-1100	180-1440	360-2460	360-1100	162-540	162-540	162-540	162-540
FREON-12	180-2460	not av.	not av.	440-960	450-900	180-2460	450-900	180-2460	not av.	- - -	- - -
HELIUM	C*	C*	C*	not av.	180-4320	250-2250	not av.	20-540	20-540	20-540	20-540
HYDROGEN	180-2460	200-2900	180-1080	560-2560	180-2610	300-3000	180-1440	300-3000	300-3000	300-3000	108-1080
NEON	C*	C*	C*	260-2260	180-4320	250-2250	260-2260	250-2250	250-2250	- - -	90-540
NITROGEN	270-2610	200-3400	270-2880	260-2860	260-2860	300-3000	180-2160	300-3000	300-3000	300-3000	180-3780
OXYGEN	460-2460	200-3400	216-3060	360-3060	180-2700	300-3000	180-1080	300-3000	300-3000	300-3000	180-2610
WATER VAPOR	684-1530	300-3000	300-3000	740-2660	504-1620	300-3000	740-1530	300-3000	300-3000	300-3000	684-1530
XENON	C*	C*	C*	420-1260	360-1332	250-2250	420-1260	250-2250	250-2250	- - -	- - -

C* - constants calculated from kinetic theory for monatomic gases.

TABLE XV

GAS FUNCTION - PAGE CROSS REFERENCE

GAS	C_p	C_v	γ	μ	k	Φ	Pr	h	u	h/u	s
AIR	40	40	41	41	41	41	42	42	42	43	43
AMMONIA	44	44	44	44	45	45	45	45	46	- -	46
ARGON	46	46	47	47	47	47	48	48	48	48	49
BROMINE	49	49	49	50	50	50	50	51	51	- -	- -
CARBON DIOXIDE	51	51	52	52	52	52	53	53	53	53	54
CARBON MONOXIDE	54	54	54	55	55	55	55	56	56	56	56
CHLORINE	57	57	57	57	58	58	58	58	59	- -	- -
FLUORINE	59	59	59	60	60	60	60	61	61	61	61
FREON-12	62	N.A.	N.A.	62	63	63	63	63	N.A.	- -	- -
HELIUM	64	64	64	N.A.	64	65	N.A.	65	65	66	66
HYDROGEN	66	66	67	67	67	67	68	68	68	68	69
NEON	69	69	69	69	69	70	70	70	70	- -	71
NITROGEN	71	71	71	72	72	72	72	73	73	73	73
OXYGEN	74	74	74	74	75	75	75	75	76	76	76
WATER VAPOR	76	77	77	77	77	78	78	78	78	79	79
XENON	79	79	79	79	80	80	80	80	81	- -	- -

N.A. indicates that the values were not available. The dashed entries indicate an intentional omission due to excessive error propagation.

APPENDIX B

$C_p(T)$ AIR
BTU/1bm-R RE:9 table 2-11
180-2430 R

$0.232829 \quad +1.43429E-05T +3.56638E-09T^{2}$
$0.242333 \quad -2.15256E-05T +3.65E-08T^{2} -8.43996E-12T^{3}$
$0.244384 -3.28793E-05T+5.41829E-08T^{2}-1.86657E-11T^{3}+1.96205E-15T^{4}$
$0.240826-7.11378E-06T-3.95639E-09T^{2}+3.65913E-11T^{3}-2.12492E-14T^{4}+3.5552E-18T^{5}$
$0.23724+2.46993E-05T-9.90133E-08T^{2}+1.65884E-10T^{3}-1.0898E-13T^{4}+3.24768E-17T^{5}-3.68828E-21T^{6}$

$C_p(180)=0.23936$ $\quad C_p(1260)=0.2566978$
$C_p(2430)=0.2853083$

$C_p(T)$ AIR
BTU/1bm-R RE:9 table 2-11
2430-4680 R

$0.23985+2.40523E-05T-2.1408E-09T^{2}$
$0.215137+4.58711E-05T-8.41419E-09T^{2}+5.88266E-13T^{3}$
$0.196846+6.74746E-05T-1.78236E-08T^{2}+2.38036E-12T^{3}-1.26026E-16T^{4}$
$0.189883+7.77709E-05T-2.38347E-08T^{2}+4.11279E-12T^{3}-3.72593E-16T^{4}+1.38699E-20T^{5}$
$1.4927E-02+3.88539E-04T-2.51418E-07T^{2}+9.20765E-11T^{3}-1.93016E-14T^{4}+2.16465E-18T^{5}-1.00837E-22T^{6}$

$C_p(2430)=0.2853083$ $\quad C_p(3510)=0.297912$
$C_p(4680)=0.305787$

$C_v(T)$ AIR
BTU/1bm-R RE:6 table 2
300-3600 R

$0.154597+3.18817E-05T-2.88038E-09T^{2}$
$0.164435+7.69284E-06T+1.21419E-08T^{2}-2.61289E-12T^{3}$
$0.176395-3.44335E-05T+5.58155E-08T^{2}-1.97034E-11T^{3}+2.22766E-15T^{4}$
$0.181376-5.72472E-05T+8.96817E-08T^{2}-4.12298E-11T^{3}+8.31674E-15T^{4}-6.29696E-19T^{5}$
$0.177941-3.78582E-05T+5.15798E-08T^{2}-6.58662E-12T^{3}-7.52271E-15T^{4}+2.9011E-18T^{5}-3.04847E-22T^{6}$

$C_v(300)=0.1707$ $\quad C_v(1600)=0.1984383$
$C_v(3600)=0.2300$

$\gamma= C_p(T)/C_v(T)$ AIR
no units RE:9 table 2-6
198-3420 R
@ 1 atmosphere

$1.43231-6.02053E-05T+4.69735E-09T^{2}$
$1.42616-4.21505E-05T-7.93962E-09T^{2}+2.40318E-12T^{3}$
$1.41663-1.33492E-06T-5.57684E-08T^{2}+2.28633E-11T^{3}-2.87017E-15T^{4}$
$1.41937-1.69334E-05T-2.88906E-08T^{2}+3.69628E-12T^{3}+3.08782E-15T^{4}-6.68384E-19T^{5}$
$1.43632-1.36059E-04T+2.44058E-07T^{2}-2.75289E-10T^{3}+1.43445E-13T^{4}-3.46478E-17T^{5}+3.15976E-21T^{6}$

$\gamma(198)=1.4202$ $\quad \gamma(1260)=1.365829$
$\gamma(3420)=1.2820$

$\mu(T)$ AIR
molecular viscosity
lbf-sec/ft.^{2} (=slugs/ft-sec) RE:1 Vol. 2
260-2560 R

$$\begin{array}{l}
9.50322E-08+5.74977E-10T-7.79938E-14T^2 \\
2.74877E-08+7.85557E-10T-2.51179E-13T^2+4.0851E-17T^3 \\
-5.097E-09+9.30986E-10T-4.25481E-13T^2+1.47777E-16T^3-1.91059E-20T^4 \\
-1.294E-08+9.77633E-10T-5.45944E-13T^2+2.29055E-16T^3-5.0777E-20T^4+4.53271E-24T^5 \\
5.87538E-09+8.40557E-10T-1.89321E-13T^2-2.06504E-16T^3+2.19267E-19T^4-7.76696E-23T^5 \\
\qquad +9.74558E-27T^6
\end{array}$$

$\mu(260)=2.0969544E-07$ $\mu(1160)=6.6146476E-07$
$\mu(2560)=1.0722872E-06$

$k(T)$ AIR
thermal conductivity RE:1 Vol. 2
BTU/ft-sec-R
180-2520 R

$$\begin{array}{l}
3.32542E-07+7.46152E-09T-9.11245E-13T^2 \\
1.48844E-07+8.12546E-09T-1.49776E-12T^2+1.4482E-16T^3 \\
-8.39925E-08+9.36228E-09T-3.35474E-12T^2+1.1804E-15T^3-1.91892E-19T^4 \\
-3.37101E-07+1.1139E-08T-7.2443E-12T^2+4.7633E-15T^3-1.64849E-18T^4+2.15793E-22T^5 \\
-2.06529E-07+1.00039E-08T-3.93252E-12T^2+3.8016E-16T^3+1.23855E-18T^4-7.06587E-22T^5 \\
\qquad +1.13874E-25T^6
\end{array}$$

$k(180)=1.4807725E-06$ $k(1350)=8.70187634E-06$
$k(2520)=1.3410467E-05$

$\Phi(T)$ AIR
"temperature function"* RE:6
BTU/lbm-R
200-2400 R

$$\begin{array}{l}
0.3218+5.29473E-04T-1.1003E-07T^2 \\
0.232404+8.56494E-04T-4.08016E-07T^2+7.64068E-11T^3 \\
0.165535+1.212E-03T-9.5452E-07T^2+3.91614E-10T^3-6.06168E-14T^4 \\
0.113728+1.57281E-03T-1.75722E-06T^2+1.15176E-09T^3-3.80418E-13T^4+4.92002E-17T^5 \\
0.072739+1.92396E-03T-2.79107E-06T^2+2.55088E-09T^3-1.33001E-12T^4+3.6329E-16T^5-4.02679E-20T^6
\end{array}$$

$\Phi(200)=0.36303$ $\Phi(1327)=0.8225509$
$\Phi(2400)=0.98331$
* this is the integral function $\Phi=\int C_p dT/T$

$\Phi(T)$ AIR
"temperature function"* RE:6
BTU/lbm-R
2400-5000 R

$$\begin{array}{l}
0.661725+1.5954E-04T-1.03741E-08T^2 \\
0.58026+2.29402E-04T-2.97705E-08T^2+1.74742E-12T^3 \\
0.524848+2.93032E-04T-5.66004E-08T^2+6.6748E-12T^3-3.32931E-16T^4 \\
0.483087+3.53104E-04T-9.06054E-08T^2+1.6147E-11T^3-1.63199E-15T^4+7.02192E-20T^5 \\
0.468867+3.7768E-04T-1.08069E-07T^2+2.26791E-11T^3-2.98882E-15T^4+2.18675E-19T^5-6.68722E-24T^6
\end{array}$$

$\Phi(2400)=0.98331$ $\Phi(3756)=1.1144112$
$\Phi(5000)=1.20129$

APPENDIX B

Pr(T) AIR
Prandtl number RE: calculated $Pr=\mu(T)C_p(T)/k(T)$
no units
260-2260 R

$0.733616-4.69569E-05T$
$0.779809-1.423E-04T+3.78346E-08T^2$
$0.776769-1.31645E-04T+2.80229E-08T^2+2.59569E-12T^3$
$0.787346-1.84159E-04T+1.07953E-07T^2-4.43022E-11T^3+9.30514E-15T^4$
$0.817922-3.7973E-04T+5.31057E-07T^2-4.46142E-10T^3+1.81869E-13T^4-2.73911E-17T^5$
$0.846748-6.04271E-04T+1.1645E-06T^2-1.29451E-09T^3+7.6325E-13T^4-2.24083E-16T^5+2.60174E-20T^6$

Pr(260)=0.74927 Pr(1287)=0.65935
Pr(2260)=0.652431

---

h(T) AIR
enthalpy RE:6
BTU/lbm
200-2400 R

$0.237906T+1.68873E-07T^2+3.42243E-09T^3$
$0.239788T-6.71311E-06T^2+9.69339E-09T^3-1.60794E-12T^4$
$0.238709T-9.76692E-07T^2+8.7513E-10T^3+3.47818E-12T^4-9.78099E-16T^5$
$0.237213T+9.43746E-06T^2-2.22938E-08T^3+2.54187E-11T^4-1.02087E-14T^5+1.4201E-18T^6$
$0.236481T+1.57119E-05T^2-4.0767E-08T^3+5.04189E-11T^4-2.71764E-14T^5+7.03238E-18T^6-7.19523E-22T^7$

h(200)=47.670 h(1338)=326.766
h(2400)=617.220

---

h(T) AIR
enthalpy RE:6
BTU/lbm
2400-5000 R

$0.224305T+1.64159E-05T^2-1.11633E-09T^3$
$0.218268T+2.15926E-05T^2-2.5536E-09T^3+1.29484E-13T^4$
$0.218076T+2.18135E-05T^2-2.64671E-09T^3+1.46583E-13T^4-1.15536E-18T^5$
$0.223957T+1.3353E-05T^2+2.14253E-09T^3-1.18747E-12T^4+1.81803E-16T^5-9.88964E-21T^6$
$0.236055T-7.55439E-06T^2+1.69991E-08T^3-6.74446E-12T^4+1.33609E-15T^5-1.36185E-19T^6$
$+5.68897E-24T^7$

h(2400)=617.220 h(3653)=984.050
h(5000)=1392.870

---

u(T) AIR
internal energy RE:6
BTU/lbm
200-2400 R

$0.169348T+1.81908E-07T^2+3.14846E-09T^3$
$0.171225T-6.68651E-06T^2+9.67706E-09T^3-1.60477E-12T^4$
$0.170148T-9.5631E-07T^2+8.68353E-10T^3+3.47584E-12T^4-9.77039E-16T^5$
$0.168672T+9.32277E-06T^2-2.20E-08T^3+2.51318E-11T^4-1.0088E-14T^5+1.40168E-18T^6$
$0.167971T+1.53278E-05T^2-3.96799E-08T^3+4.90583E-11T^4-2.63269E-14T^5+6.77293E-18T^6$
$-6.88622E-22T^7$

u(200)=33.960 u(1237)=215.956
u(2400)=452.70

---

u(T) AIR
internal energy RE:6
BTU/lbm
2400-5000 R

$0.155745T+1.6422E-05T^2-1.11714E-09T^3$
$0.149646T+2.1652E-05T^2-2.56918E-09T^3+1.30815E-13T^4$
$0.149264T+2.20911E-05T^2-2.75437E-09T^3+1.64824E-13T^4-2.29795E-18T^5$
$0.156615T+1.15159E-05T^2+3.23197E-09T^3-1.50269E-12T^4+2.26392E-16T^5-1.23616E-20T^6$
$0.172389T-1.57449E-05T^2+2.26032E-08T^3-8.74837E-12T^4+1.73146E-15T^5-1.77036E-19T^6$
$+7.41778E-24T^7$

u(2400)=452.70 u(3643)=731.34
u(5000)=1050.12

---

h(T)/u(T) AIR
ratio of enthalpy and internal energy
no units RE:6
200-2400 R

$1.40541-2.58397E-06T-6.57504E-09T^2$
$1.40057+1.51205E-05T-2.27076E-08T^2+4.13655E-12T^3$
$1.40274+3.61186E-06T-5.01604E-09T^2-6.06742E-12T^3+1.9623E-15T^4$
$1.40626-2.08948E-05T+4.95051E-08T^2-5.76979E-11T^3+2.36839E-14T^4-3.34178E-18T^5$
$1.40789-3.49005E-05T+9.07406E-08T^2-1.13503E-10T^3+6.15587E-14T^4-1.58694E-17T^5+1.6061E-21T^6$

h/u(200)=1.4037102 h/u(1227)=1.3928832
h/u(2400)=1.3634195

---

h(T)/u(T) AIR
ratio of enthalpy and internal energy
no units RE:6
2400-5000 R

$1.42666-3.24782E-05T+2.49656E-09T^2$
$1.44584-4.89293E-05T+7.06402E-09T^2-4.11483E-13T^3$
$1.45394-5.82281E-05T+1.09849E-08T^2-1.13156E-13T^3+4.86539E-17T^4$
$1.43722-3.41774E-05T-2.62957E-09T^2+2.66079E-12T^3-4.71445E-16T^4+2.81135E-20T^5$
$1.388+5.0885E-05T-6.30738E-08T^2+2.52696E-11T^3-5.16772E-15T^4+5.41949E-19T^5-2.31458E-23T^6$

h/u(2400)=1.3634195 h/u(3673)=1.34105152
h/u(5000)=1.3263913

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s(T) AIR
entropy @ 1 atmosphere RE:9 table 2-5
BTU/lbm-R
180-2340 R

$1.34921+5.56529E-04T-1.21309E-07T^2$
$1.25715+9.10432E-04T-4.58246E-07T^2+8.97664E-11T^3$
$1.18896+1.28846E-03T-1.06862E-06T^2+4.57613E-10T^3-7.35759E-14T^4$
$1.1347+1.68313E-03T-1.98959E-06T^2+1.36832E-09T^3-4.71999E-13T^4+6.35458E-17T^5$
$1.08977+2.08536E-03T-3.2289E-06T^2+3.11943E-09T^3-1.70914E-12T^4+4.88375E-16T^5-5.64267E-20T^6$

s(180)=1.3745394 s(1080)=1.80812816
s(2340)=2.015566

APPENDIX F

$C_p(T)$ AMMONIA
BTU/lbm-R RE:2
400-2460 R

$3.4093+3.14431E-04T-3.60471E-08T^2$
$0.358467+2.64143E-04T+4.06609E-09T^2-9.4211E-12T^3$
$0.481225-2.14589E-04T+6.17498E-07T^2-3.22911E-10T^3+5.51751E-14T^4$
$0.67797-1.19371E-03T+2.37173E-06T^2-1.75244E-09T^3+5.93061E-13T^4-7.57935E-17T^5$ *
$0.410177+4.20634E-04T-1.34029E-06T^2+2.4419E-09T^3-1.88787E-12T^4+6.59903E-16T^5-8.62136E-20T^6$ *

$C_p(400)=0.4764$ $C_p(1160)=0.663889669$
$C_p(2460)=0.8969$
* poor fits between 1050-1550 R approximatelt 1.5% error.

$C_v(T)$ AMMONIA
BTU/lbm-R RE:16 Vol. 1
@ 1 atmosphere
576-1044 R

$0.285288+1.64944E-04T+4.63612E-08T^2$
$0.400144-2.77713E-04T+6.03509E-07T^2-2.29279E-10T^3$
$0.583368-1.22168E-03T+2.40087E-06T^2-1.72887E-09T^3+4.62835E-13T^4$
$1.09343-4.50983E-03T+1.07854E-05T^2-1.23018E-08T^3+7.05771E-12T^4-1.62836E-15T^5$
$5.3823-3.76953E-02T+1.16817E-04T^2-1.91386E-07T^3+1.75712E-10T^4-8.56144E-14T^5+1.72811E-17T^6$

$C_v(576)=0.39689995$ $C_v(792)=0.444983254$
$C_v(1044)=0.5072804$

$\gamma=C_p(T)/C_v(T)$ AMMONIA
no units PE: calculated
576-1044 R

$1.40196-3.06499E-04T+1.4895E-07T^2$
$1.39459-2.78203E-04T+1.13379E-07T^2+1.46383E-11T^3$
$0.829723+2.62469E-03T-5.40489E-06T^2+4.61508E-09T^3-1.41989E-12T^4$
$-1.18031+1.5548E-02T-3.83242E-05T^2+4.60841E-08T^3-2.72736E-11T^4+6.38362E-15T^5$
$-14.1832+0.116007T-3.58889E-04T^2+5.87022E-07T^3-5.36407E-10T^4+2.59848E-13T^5-5.21532E-17T^6$

$\gamma(576)=1.273264$ $\gamma(801)=1.2516778$
$\gamma(1044)=1.2436879$

$\mu(T)$ AMMONIA
molecular viscosity RE:1
lbf-sec/ft.^{2}
460-1460 R

$3.31575E-09+3.65684E-10T+3.91824E-14T^2$
$4.59333E-09+3.61045E-10T+4.43819E-14T^2-1.82028E-18T^3$
$4.25521E-09+3.62695E-10T+4.15214E-14T^2+2.75613E-19T^3-5.50667E-22T^4$
$-6.31989E-10+3.92429E-10T-2.78852E-14T^2+7.81132E-17T^3-4.26145E-20T^4+8.79306E-24T^5$
$-6.02329E-08+8.28766E-10T-1.31524E-12T^2+2.03893E-15T^3-1.67114E-18T^4+7.09393E-22T^5$
$-1.2223E-25T^6$

$\mu(460)=1.7982846E-07$ $\mu(800)=3.208715471E-07$
$\mu(1460)=6.2052306E-07$

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k(T) AMMONIA
thermal conductivity RE:1
BTU/ft-sec-R
450-1620 R

$-1.08718E-06+7.95707E-09T+2.55465E-12T^2$
$4.29762E-07+2.7288E-09T+7.99878E-12T^2-1.75037E-15T^3$
$2.10079E-06-4.98751E-09T+2.04628E-11T^2-1.01777E-14T^3+2.03079E-18T^4$
$5.22243E-06-2.30996E-08T+6.03141E-11T^2-5.19048E-14T^3+2.29281E-17T^4-4.02528E-21T^5$
$-4.4701E-06+4.47694E-08T-1.293E-10T^2+2.19149E-13T^3-1.86776E-16T^4+7.95013E-20T^5-1.34258E-23T^6$

k(450)=3.1639075E-06 k(1080)=1.0531706E-05
k(1620)=1.8405269E-05

Φ(T) AMMONIA
"temperature function"* RE: calculated, ref 400 R
BTU/lbm-R
400-2460 R

$-0.279899+8.73431E-04T-1.19262E-07T^2$
$-0.388219+1.15678E-03T-3.33501E-07T^2+4.86868E-11T^3$
$-0.461903+1.42118E-03T-6.51859E-07T^2+2.04283E-10T^3-2.652E-14T^4$
$-0.56523+1.89118E-03T-1.43439E-06T^2+8.06998E-10T^3-2.43771E-13T^4+2.96228E-17T^5$
$-0.697755+2.62001E-03T-2.98704E-06T^2+2.45728E-09T^3-1.17368E-12T^4+2.94951E-16T^5$
$-3.01485E-20T^6$

Φ(473.6)=8.15186E-02 Φ(1430)=0.72429979
Φ(2460)=1.1608313
* this is the integral function $\Phi=\int C_p dT/T$

Pr(T) AMMONIA
Prandtl number RE: calculated $Pr=\mu(T)C_p(T)/k(T)$
no units
460-1460 R

$0.938004-2.26044E-04T+1.4846E-07T^2$
$1.0796-7.30896E-04T+7.06829E-07T^2-1.93878E-10T^3$
$0.780509+7.07761E-04T-1.75386E-06T^2+1.58882E-09T^3-4.64244E-13T^4$
$0.33421+3.40696E-03T-8.01773E-06T^2+8.57762E-09T^3-4.22506E-12T^4+7.83503E-16T^5$
$0.413107+2.83246E-03T-6.333E-06T^2+6.02736F-09T^3-2.1195E-12T^4-1.17391E-16T^5+1.56405E-19T^6$

Pr(460)=0.86699 Pr(941)=0.85305
Pr(1460)=0.91266

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h(T) AMMONIA
enthalpy RE:16 Vol.1
@ 1 atmosphere
BTU/lbm
540-1044 R

$7.50173E+02+0.388706T+1.11368E-04T^2$
$740.517+0.427092T+6.17597E-05T^2+2.08788E-08T^3$
$846.46-1.36253E-01T+1.16523E-03T^2-9.23343E-07T^3+2.9805E-10T^4$
$1.704E+03-5.84385T+1.61535E-02T^2-2.034E-05T^3+1.27113E-08T^4-3.13467E-12T^5$
$2.4435E+03-11.7525T+3.56087E-02T^2-5.41337E-05T^3+4.53782E-08T^4-1.98011E-11T^5+3.50724E-15T^6$

h(540)=992.78973 h(792)=1128.01145
h(1044)=1277.501

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u(T) AMMONIA
internal energy RE: calculated , ref.576 R
BTU/lbm
576-1044 R

$-185.462+0.251789T+1.22262E-04T^2$
$-191.39+0.274263T+9.43435E-05T^2+1.13717E-08T^3$
$-210.856+0.372914T-9.08293E-05T^2+1.63994E-07T^3-4.66247E-11T^4$
$-213.167+0.387575T-1.27671E-04T^2+2.09846E-07T^3-7.48942E-11T^4+6.90888E-15T^5$
$-230.011+0.515874T-5.31676E-04T^2+8.83099E-07T^3-7.01167E-10T^4+3.15284E-13T^5-6.28038E-17T^6$

u(592.7)=6.65645 u(793.3)=91.219216
u(1044)=210.6891

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s(T) AMMONIA
entropy @ 1 atmosphere RE:20 table 14-2
BTU/lbm-R
420-1060 R

$2.51416+1.03161E-03T-1.98353E-07T^2$
$2.61008+6.05613E-04T+4.03951E-07T^2-2.7286E-10T^3$
$1.78685+5.50612E-03T-1.01771E-05T^2+9.56658E-09T^3-3.33308E-12T^4$
$0.800326+1.28833E-02T-3.16735E-05T^2+4.00994E-08T^3-2.44993E-11T^4+5.73751E-15T^5$
$1.38235+7.65085E-03T-1.24826E-05T^2+3.32828E-09T^3+1.43486E-11T^4-1.57369E-14T^5+4.85702E-18T^6$

s(420)=2.9080 s(720)=3.149968809
s(1060)=3.376

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$C_p(T)$ ARGON
@ 1 atmosphere RE:9 table 3-3
BTU/lbm-R
180-2340 R

$0.127313-4.78028E-06T+1.6229E-09T^2$
$0.129518-1.36274E-05T+1.05456E-08T^2-2.46576E-12T^3$
$0.132327-2.97271E-05T+3.75659E-08T^2-1.92942E-11T^3+3.44762E-15T^4$
$0.136206-5.84558E-05T+1.06075E-07T^2-8.85851E-11T^3+3.43482E-14T^4-5.00166E-18T^5$
$0.140741-9.97927E-05T+2.36658E-07T^2-2.7837E-10T^3+1.72099E-13T^4-5.34348E-17T^5+6.56031E-21T^6$

$C_p(180)=0.12964598$ $C_p(720)=0.1244971039$
$C_p(2340)=0.12430144$

$C_p^o(T)=0.1242915$ a constant for the ideal gas (kinetic theory)

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$C_v(T)$ ARGON
@ 1 atmosphere RE:16 Vol. 2
BTU/lbm-R
162-1080 R

$7.75918E-02-8.93725E-06T+6.1255E-09T^2$
$8.02449E-02-2.69774E-05T+4.07132E-08T^2-1.92432E-11T^3$
$8.3578E-02-5.81328E-05T+1.35861E-07T^2-1.34428E-10T^3+4.76211E-14T^4$
$8.74206E-02-1.03485E-04T+3.26999E-07T^2-4.99661E-10T^3+3.68667E-13T^4-1.05234E-16T^5$
$9.09271E-02-1.54125E-04T+6.04428E-07T^2-1.24405E-09T^3+1.41019E-12T^4-8.32511E-16T^5$
$+1.99746E-19T^6$

$C_v(162)=7.7426753E-02$ $C_v(432)=7.47358593E-02$
$C_v(1080)=7.4614499E-02$

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APPENDIX E

$\gamma = C_p(T)/C_v(T)$ ARGON
no units RE:9 table 3-6
180-1008 R
@ 1 atmosphere

$$1.71437-1.30688E-04T+8.74888E-08T^2$$
$$1.75022-3.67538E-04T+5.33183E-07T^2-2.50109E-10T^3$$
$$1.79612-7.8515E-04T+1.79184E-06T^2-1.77727E-09T^3+6.42746E-13T^4$$
$$1.86777-1.61288E-03T+5.25476E-06T^2-8.42677E-09T^3+6.58494E-12T^4-2.00074E-15T^5$$
$$1.93095-2.49571E-03T+9.99156E-06T^2-2.10178E-08T^3+2.42319E-11T^4-1.44732E-14T^5+3.49956E-18T^6$$

$\gamma(180)=1.706$ $\gamma(576)=1.669306053$
$\gamma(1008)=1.667$

$\mu(T)$ ARGON
molecular viscosity RE: 1
lbf-sec/ft.^{2}
260-2860 R

$$9.44203E-08+7.37888E-10T-9.36047E-14T^2$$
$$2.42105E-08+9.4593E-10T-2.5037E-13T^2+3.34968E-17T^3$$
$$1.39941E-08+9.89509E-10T-3.05362E-13T^2+5.97944E-17T^3-4.21435E-21T^4$$
$$-1.20041E-08+1.134E-09T-5.67635E-13T^2+2.6473E-16T^3-7.5798E-20T^4+9.1774E-24T^5$$
$$-6.16608E-08+1.47275E-09T-1.37785E-12T^2+1.16579E-15T^3-5.8181E-19T^4+1.48259E-22T^5 -1.48591E-26T^6$$

$\mu(260)=2.4603708E-07$ $\mu(1460)=9.75653978E-07$
$\mu(2860)=1.4641086E-06$

$k(T)$ ARGON
thermal conductivity RE: 1
BTU/ft-sec-R
180-4860 R

$$9.64623E-07+3.55503E-09T-1.94818E-13T^2$$
$$4.26251E-07+4.73128E-09T-7.67798E-13T^2+7.5791E-17T^3$$
$$8.53917E-08+5.89472E-09T-1.76319E-12T^2+3.79184E-16T^3-3.00985E-20T^4$$
$$-6.92271E-08+6.62832E-09T-2.70956E-12T^2+8.65627E-16T^3-1.37617E-19T^4+8.53319E-24T^5$$
$$-3.569E-08+6.42369E-09T-2.34644E-12T^2+5.91373E-16T^3-3.78551E-20T^4-8.74155E-24T^5 +1.14251E-27T^6$$

$k(180)=1.047141E-06$ $k(2340)=8.164077964E-06$
$k(4860)=1.3876224E-05$

$\Phi(T)$ ARGON
"temperature function"* RE: calculated, ref 180 R
BTU/lbm-R
180-2340 R

$$6.0024E-03+2.60364E-04T-5.56856E-08T^2$$
$$-4.03556E-02+4.17858E-04T-1.96373E-07T^2+3.61134E-11T^3$$
$$-7.43033E-02+5.8141E-04T-4.37945E-07T^2+1.73648E-10T^3-2.64781E-14T^4$$
$$-0.101024+7.47588E-04T-7.87225E-07T^2+4.95732E-10T^3-1.60718E-13T^4+2.0675E-17T^5$$
$$-0.123694+9.1975E-04T-1.25999E-06T^2+1.1113E-09T^3-5.70461E-13T^4+1.55239E-16T^5-1.72708E-20T^6$$

$\Phi(257)=4.55875E-02$ $\Phi(1260)=0.243915$
$\Phi(2340)=0.320817$
* this is the integral function $\Phi = \int C_p dT/T$

Pr(T) ARGON
Prandtl number RE:9 table 3-10
@ 1 atmosphere
180-1440 R

$0.699882-5.47321E-05T+1.87237E-08T^2$

$0.700487-5.8009E-05T+2.34596E-08T^2-1.97692E-12T^3$

$0.709863-1.29349E-04T+1.94253E-07T^2-1.61099E-10T^3+5.0079E-14T^4$

$0.739664-4.18291E-04T+1.16612E-06T^2-1.61593E-09T^3+1.04167E-12T^4-2.50259E-16T^5$

$0.81218-1.27116E-03T+4.87781E-06T^2-9.38694E-09T^3+9.4317E-12T^4-4.74111E-15T^5+9.41472E-19T^6$

Pr(180)=0.700 Pr(648)=0.673514647
Pr(1440)=0.660

---

h(T) ARGON
enthalpy @ 1 atmosphere RF: 21
BTU/1bm
162-540 R

$81.5786+0.129335T-5.28791E-06T^2$

$80.9133+0.135952T-2.56082E-05T^2+1.94633E-08T^3$

$80.2605+0.14477T-6.77939E-05T^2+1.04464E-07T^3-6.12454E-11T^4$

$79.6456+0.155132T-1.3452E-04T^2+3.10207E-07T^3-3.6608E-10T^4+1.74318E-13T^5$

$79.0955+0.166232T-2.24472E-04T^2+6.8543E-07T^3-1.21747E-09T^4+1.17298E-12T^5-4.74279E-16T^6$

h(162)=102.3322 h(306)=120.6664193
h(540)=149.91232

---

u(T) ARGON
internal energy RE: 21
@ 1 atmosphere
BTU/1bm
162-540 R

$82.0579+7.76247E-02T-3.19368E-06T^2$

$81.6692+8.14908E-02T-1.50656E-05T^2+1.13713E-08T^3$

$81.3222+8.6179E-02T-3.74935E-05T^2+5.65617E-08T^3-3.25609E-11T^4$

$81.0848+9.01784E-02T-6.32492E-05T^2+1.35977E-07T^3-1.50225E-10T^4+6.72856E-14T^5$

$81.1656+8.85489E-02T-5.00438E-05T^2+8.08929E-08T^3-2.52384E-11T^4-7.93208E-14T^5+6.96258E-17T^6$

u(162)=94.516166 u(306)=105.5165224
u(540)=123.0651

---

h(T)/u(T) ARGON
ratio of enthalpy and internal energy
@ 1 atmosphere RE:21
no units
162-540 R

$1.00274+5.4077E-04T-2.6451E-07T^2$

$0.99394+6.28267E-04T-5.33195E-07T^2+2.57353E-10T^3$

$0.989175+6.92631E-04T-8.41105E-07T^2+8.77768E-10T^3-4.47025E-13T^4$

$0.984342+7.74072E-04T-1.36557E-06T^2+2.49492E-09T^3-2.84304E-12T^4+1.37015E-15T^5$

$0.976958+9.23071E-04T-2.57301E-06T^2+7.53153E-09T^3-1.42712E-11T^4+1.47751E-14T^5-6.36624E-18T^6$

h/u(162)=1.0826952 h/u(306)=1.14357764
h/u(540)=1.2181546

---

s(T) ARGON
entropy @ 1 atmosphere RE:9
BTU/lbm-R
180-2520 R

$0.77765+2.77329E-04T-5.89988E-08T^{2}$
$0.73114+4.5156E-04T-2.15042E-07T^{2}+3.88E-11T^{3}$
$0.696079+6.39797E-04T-4.99001E-07T^{2}+1.9766E-10T^{3}-2.94653E-14T^{4}$
$0.667317+8.40147E-04T-9.37036E-07T^{2}+6.01176E-10T^{3}-1.93632E-13T^{4}+2.43355E-17T^{5}$
$0.643374+1.04589E-03T-1.53718E-06T^{2}+1.3972E-09T^{3}-7.19255E-13T^{4}+1.92645E-16T^{5}-2.08193E-20T^{6}$

s(180)=0.78763524 s(1260)=1.0313233
s(2520)=1.1175297

$C_p(T)$ BROMINE
BTU/lbm-R RE: 1
360-2460 R

$5.08065E-02+6.08059E-06T-1.5858E-09T^{2}$
$4.8013E-02+1.45148E-05T-8.54282E-09T^{2}+1.67065E-12T^{3}$
$4.48162E-02+2.77141E-05T-2.61973E-08T^{2}+1.09708E-11T^{3}-1.67296E-15T^{4}$
$4.41834E-02+4.519E-05T-5.87703E-08T^{2}+3.8297E-11T^{3}-1.21796E-14T^{4}+1.50507E-18T^{5}$
$3.88714E-02+6.17306E-05T-9.83453E-08T^{2}+8.4461E-11T^{3}-4.01906E-14T^{4}+9.98403E-18T^{5}$
$-1.0104E-21T^{6}$

$C_p(360)=5.169E-02$ $C_p(1060)=5.55873656E-02$
$C_p(2460)=5.663E-02$

$C_v(T)$ BROMINE
BTU/lbm-R RE: calculated from kinetic theory
400-2570 R $\Theta_{vib}=837$ R

$3.91637E-02+4.50662E-06T-1.16768E-09T^{2}$
$3.66763E-02+1.12846E-05T-6.32263E-09T^{2}+1.15725E-12T^{3}$
$3.38996E-02+2.17758E-05T-1.92097E-08T^{2}+7.45717E-12T^{3}-1.06072E-15T^{4}$
$3.09541E-02+3.59605E-05T-4.35502E-08T^{2}+2.64077E-11T^{3}-7.87275E-15T^{4}+9.17556E-19T^{5}$
$2.79622E-02+5.34325E-05T-8.2185E-08T^{2}+6.82696E-11T^{3}-3.15936E-14T^{4}+7.65474E-18T^{5}$
$-7.56229E-22T^{6}$

$C_v(400)=3.9797E-02$ $C_v(1525)=4.3188E-02$
$C_v(2570)=4.33785E-02$

$\gamma=C_p(T)/C_v(T)$ BROMINE
no units RE: calculated from kinetic theory
400-2400 R $\Theta_{vib}=837$ R

$1.31784-3.55382E-05T+9.79826E-09T^{2}$
$1.3372-9.0523E-05T+5.38983E-08T^{2}-1.05E-11T^{3}$
$1.35962-1.78512E-04T+1.67356E-07T^{2}-6.90949E-11T^{3}+1.04634E-14T^{4}$
$1.38443-3.02418E-04T+3.89792E-07T^{2}-2.51429E-10T^{3}+7.97705E-14T^{4}-9.90101E-18T^{5}$
$1.41092-4.62592E-04T+7.59447E-07T^{2}-6.71967E-10T^{3}+3.3108E-13T^{4}-8.54213E-17T^{5}+8.99051E-21T^{6}$

$\gamma(400)=1.312212$ $\gamma(1437)=1.287942$
$\gamma(2400)=1.28654$

μ(T) BROMINE
molecular viscosity RE: 1
lbf-sec/ft.^{2}
460-920 R

$1.21667E-07+2.65699E-10T+2.03927E-13T^{2}$
$6.99652E-08+5.02169E-10T-1.47247E-13T^{2}+1.69649E-16T^{3}$
$-2.60088E-07+2.5225E-09T-4.69813E-12T^{2}+4.64337E-15T^{3}-1.62091E-18T^{4}$
$-1.63527E-06+1.30645E-08T-3.65538E-11T^{2}+5.2088E-14T^{3}-3.64638E-17T^{4}+1.00994E-20T^{5}$
$-9.36429E-06+8.42354E-08T-3.06387E-10T^{2}+5.91326E-13T^{3}-6.35678E-16T^{4}+3.61263E-19T^{5}$
$-8.48221E-23T^{6}$

$\mu(460)=2.840496E-07$ $\mu(660)=3.8579595E-07$
$\mu(920)=5.388588E-07$

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k(T) BROMINE
thermal conductivity RE: 1
BTU/ft-sec-R
450-630 R

$-2.17621E-07+1.9748E-09T-2.88865E-13T^{2}$
$-3.10747E-06+1.82455E-08T-3.06197E-11T^{2}+1.87227E-14T^{3}$
$7.94913E-06-6.48177E-08T+2.02278E-10T^{2}-2.70142E-13T^{3}+1.33734E-16T^{4}$
$2.49378E-04-2.33244E-06T+8.69102E-09T^{2}-1.61018E-11T^{3}+1.48445E-14T^{4}-5.44842E-18T^{5}$

k(450)=6.1029689E-07 k(540)=7.71755E-07
k(630)=9.1544533E-07

Φ(T) BROMINE
"temperature function"* RE: calculated, ref. 360 R
BTU/lbm-R
360-2460 R

$-2.27147E-02+9.30398E-05T-1.70164E-08T^{2}$
$-4.11293E-02+1.42893E-04T-5.54945E-08T^{2}+8.8608E-12T^{3}$
$-5.41213E-02+1.91336E-04T-1.1537E-07T^{2}+3.86655E-11T^{3}-5.14761E-15T^{4}$
$-6.3759E-02+2.36982E-04T-1.93692E-07T^{2}+1.00364E-10T^{3}-2.77705E-14T^{4}+3.12579E-18T^{5}$
$-7.09827E-02+2.78391E-04T-2.84852E-07T^{2}+1.99793E-10T^{3}-8.49542E-14T^{4}+1.97107E-17T^{5}$
$-1.90961E-21T^{6}$

$\Phi(435)=9.885097E-03$ $\Phi(1485)=7.726905E-02$
$\Phi(2460)=1.057099E-01$
* this is the integral function $\Phi=\int C_{p}dT/T$

Pr(T) BROMINE
Prandtl number RE: calculated $Pr=\mu(T)C_{p}(T)/k(T)$
no units
460-630 R

$1.2149-1.37277E-03T+8.8564E-07T^{2}$
$4.27221-1.83804E-02T+3.22558E-05T^{2}-1.91866E-08T^{3}$
$1.42754+2.73471E-03T-2.62957E-05T^{2}+5.27028E-08T^{3}-3.29767E-11T^{4}$
$-2.50964E+02+2.34541T-8.69856E-03T^{2}+1.60575E-05T^{3}-1.47587E-08T^{4}+5.40391E-12T^{5}$
$-6.19029E+02+6.4459T-2.76873E-02T^{2}+6.28438E-05T^{3}-7.94476E-08T^{4}+5.29935E-11T^{5}-1.45533E-14T^{6}$

Pr(460)=0.77242 Pr(542)=0.7303975
Pr(630)=0.69891

$h(T)$ BROMINE
enthalpy RE: calculated, ref 360 R
BTU/lbm
360-2460 R

$-19.9448+5.41972E-02T+5.82535E-07T^2$
$-19.3333+5.25417E-02T+1.86025E-06T^2-2.94235E-10T^3$
$-18.7936+5.05292E-02T+4.34775E-06T^2-1.53245E-09T^3+2.13854E-13T^4$
$-18.2085+4.77583E-02T+9.10219E-06T^2-5.27776E-09T^3+1.58715E-12T^4-1.89747E-16T^5$
$-17.4465+4.33899E-02T+1.87189E-05T^2-1.57668F-08T^3+7.61965E-12T^4-1.93935F-15T^5+2.01451F-19T^6$

$h(435)=3.918947$ $h(1485)=61.844103$
$h(2460)=116.82572$

$u(T)$ BROMINE
internal energy RE: calculated from kinetic theory
BTU/lbm $\Theta_{vib}=837$ R ref. 400 R
400-2650 R

$-17.214+4.20834E-02T+3.11917E-07T^2$
$-16.6153+4.05935E-02T+1.37311E-06T^2-2.26001E-10T^3$
$-16.0645+3.87081E-02T+3.5201E-06T^2-1.21292E-09T^3+1.57636E-13T^4$
$-15.5445+3.64488E-02T+7.08774E-06T^2-3.80502E-09T^3+1.03564E-12T^4-1.12192E-16T^5$
$-14.9759+3.34594E-02T+1.3139E-05T^2-9.88656E-09T^3+4.26352E-12T^4-9.77206E-16T^5+9.21101E-20T^6$

$u(480.4)=3.238665$ $u(1525)=47.70057244$
$u(2650)=96.42215$

$C_p(T)$ CARBON DIOXIDE CO_2
BTU/lbm-R RE: 1
360-2460 R

$0.137625+1.38997E-04T-2.8023E-08T^2$
$0.122652+1.82976E-04T-6.35135E-08T^2+8.39019E-12T^3$
$0.121766+1.86604E-04T-6.82691E-08T^2+1.08507E-11T^3-4.36263E-16T^4$
$0.134141+1.21953E-04T+5.06023E-08T^2-8.75009E-11T^3+3.69306E-14T^4-5.30026E-18T^5$
$0.156622-2.04527E-05T+3.88747E-07T^2-4.78E-10T^3+2.715E-13T^4-7.56542E-17T^5+8.31607E-21T^6$

$C_p(360)=0.18140$ $C_p(1360)=0.2748840956$
$C_p(2460)=0.3130$

$C_v(T)$ CARBON DIOXIDE CO_2
BTU/lbm-R RE:6 table 18
300-3000 R

$9.29839E-02+1.32088E-04T-2.42769E-08T^2$
$7.06064E-02+1.93292E-04T-6.75883E-08T^2+8.74976E-12T^3$
$6.38403E-02+2.19722E-04T-9.87056E-08T^2+2.27548E-11T^3-2.12198E-15T^4$
$6.4385E-02+2.16963E-04T-9.40596E-08T^2+1.93534E-11T^3-1.00248E-15T^4-1.35697E-19T^5$
$6.96152E-02+1.84539E-04T-2.24187E-08T^2-5.49986E-11T^3+3.82085E-14T^4-1.02977E-17T^5$
$+1.02646E-21T^6$

$C_v(300)=0.122267666$ $C_v(1600)=0.24185662$
$C_v(3000)=0.277209725$

$\gamma=C_p(T)/C_v(T)$ CARBON DIOXIDE CO_2
no units RE:9 table 4-6
@ 1 atmosphere
396-1620 R

$1.45898-3.67007E-04T+1.26417E-07T^2$
$1.56184-7.39734E-04T+5.32245E-07T^2-1.35797E-10T^3$
$1.6654-1.24676E-03T+1.39223E-06T^2-7.40917E-10T^3+1.50659E-13T^4$
$1.76282-1.85064E-03T+2.79818E-06T^2-2.28514E-09T^3+9.55817E-13T^4-1.60437E-16T^5$
$1.79894-2.12045E-03T+3.59579E-06T^2-3.48297E-09T^3+1.92333E-12T^4-5.60628E-16T^5+6.64928E-20T^6$

$\gamma(396)=1.3490$ $\gamma(864)=1.23421682$
$\gamma(1620)=1.1860$

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$\mu(T)$ CARBON DIOXIDE CO_2
molecular viscosity RE:1
$lbf\text{-}sec/ft.^2$
360-2860 R

$4.36204E-08+5.3752E-10T-5.64005E-14T^2$
$-1.97493E-08+7.05895E-10T-1.76601E-13T^2+2.48862E-17T^3$
$-2.66007E-08+7.31478E-10T-2.06544E-13T^2+3.85492E-17T^3-2.12159E-21T^4$
$-3.7168E-08+7.82134E-10T-2.90312E-13T^2+1.00084E-16T^3-2.27075E-20T^4+2.55726E-24T^5$
$-5.13521E-08+8.64878E-10T-4.68079E-13T^2+2.83455E-16T^3-1.20217E-19T^4+2.82847E-23T^5$
$-2.66329E-27T^6$

$\mu(360)=2.1073974E-07$ $\mu(1660)=7.790659435F-07$
$\mu(2860)=1.1361984E-06$

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$k(T)$ CARBON DIOXIDE CO_2
thermal conductivity RE:2
BTU/ft-sec-R
360-2250 R

$-1.79156E-06+8.84415E-09T-1.00926E-12T^2$
$-7.85007E-07+5.72261E-09T+1.69217E-12T^2-6.90018E-16T^3$
$2.19969E-07+1.404E-09T+7.72668E-12T^2-4.04625E-15T^3+6.42956E-19T^4$
$-2.10115E-07+3.7572E-09T+3.13658E-12T^2+1.77524E-17T^3-1.01886E-18T^4+2.54684E-22T^5$
$-1.88832E-06+1.48759E-08T-2.47804E-11T^2+3.43895E-14T^3-2.31627E-17T^4+7.40836E-21T^5$
$-9.13624E-25T^6$

$k(360)=1.5305604E-06$ $k(1350)=8.3966408E-06$
$k(2250)=1.2880476E-05$

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$\Phi(T)$ CARBON DIOXIDE CO_2
"temperature function"* RE:6 table 17
BTU/lbm-R
300-3000 R

$0.974611+3.67098E-04T-5.22294E-08T^2$
$0.923566+5.0671E-04T-1.51025E-07T^2+1.99587E-11T^3$
$0.892653+6.27464E-04T-2.93197E-07T^2+8.39466E-11T^3-9.69513E-15T^4$
$0.870304+7.40647E-04T-4.8382E-07T^2+2.23509E-10T^3-5.56282E-14T^4+5.56764E-18T^5$
$0.85229+8.52323E-04T-7.30568E-07T^2+4.79594E-10T^3-1.9068E-13T^4+4.05679E-17T^5-3.53538E-21T^6$

$\Phi(300)=1.0532379$ $\Phi(1600)=1.426600712$
$\Phi(3000)=1.6190638$
* this is the integral function $\Phi=\int C_p dT/T$

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APPENDIX B

Pr(T) CARBON DIOXIDE CO_2
Prandtl number RE:9 table 4-10
no units
@ 1 atmosphere
396-1080 R

$0.912036-2.82494E-04T+5.38475E-08T^2$
$1.00224-6.86227E-04T+6.22539E-07T^2-2.54631E-10T^3$
$1.32638-2.63597E-03T+4.84168E-06T^2-4.1608E-09T^3+1.3112E-12T^4$
$1.98594-7.63528E-03T+1.95269E-05T^2-2.50859E-08T^3+1.58036E-11T^4-3.91183E-15T^5$
$3.03249-1.71883E-02T+5.49312E-05T^2-9.33241E-08T^3+8.80263E-11T^4-4.37666E-14T^5+8.97216E-18T^6$

Pr(396)=0.818 Pr(810)=0.7200435
Pr(1080)=0.6680

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h(T) CARBON DIOXIDE CO_2
enthalpy RE:6 table 17
BTU/lbm
300-3000 R

$0.137685T+6.83299E-05T^2-8.86103E-09T^3$
$0.137468T+6.89219E-05T^2-9.27995E-09T^3+8.46312E-14T^4$
$0.143284T+4.62042E-05T^2+1.74671E-08T^3-1.19535E-11T^4+1.82396E-15T^5$
$0.150706T+8.61816E-06T^2+8.07695E-08T^3-5.82998E-11T^4+1.70775E-14T^5-1.84892E-18T^6$
$0.158339T-3.87039E-05T^2+1.85327E-07T^3-1.66814E-10T^4+7.43046E-14T^5-1.668E-17T^6+1.49809E-21T^7$

h(300)=47.903 h(1600)=359.638
h(3000)=790.880

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u(T) CARBON DIOXIDE CO_2
internal energy RE:6 table 17
BTU/lbm
300-3000 R

$9.2562E-02T+6.83295E-05T^2-8.86092E-09T^3$
$9.23449E-02T+6.89232E-05T^2-9.28104E-09T^3+8.4872E-14T^4$
$9.81588E-02T+4.62131E-05T^2+1.74571E-08T^3-1.19492E-11T^4+1.82335E-15T^5$
$0.105574T+8.65859E-06T^2+8.07063E-08T^3-5.82566E-11T^4+1.70641E-14T^5-1.84737E-18T^6$
$0.11319T-3.85546E-05T^2+1.85023E-07T^3-1.66521E-10T^4+7.41595E-14T^5-1.66443E-17T^6$
$+1.49464E-21T^7$

u(300)=34.3650 u(1600)=287.4420
u(3000)=655.510

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h(T)/u(T) CARBON DIOXIDE CO_2
ratio of enthalpy and internal energy
no units RE:6 table 17
300-3000 R

$1.43513-1.62106E-04T+2.94907E-08T^2$
$1.45987-2.29764E-04T+7.73689E-08T^2-9.67236E-12T^3$
$1.45962-2.28803E-04T+7.62378E-08T^2-9.16326E-12T^3-7.71361E-17T^4$
$1.44335-1.46404E-04T-6.25398E-08T^2+9.24415E-11T^3-3.35175E-14T^4+4.05338E-18T^5$
$1.41771+1.25463E-05T-4.13738E-07T^2+4.5693E-10T^3-2.25737E-13T^4+5.38695E-17T^5-5.03193E-21T^6$

h/u(300)=1.3939434 h/u(1600)=1.251250939
h/u(3000)=1.2065098

$s(T)$ CARBON DIOXIDE CO_2
entropy @ 1 atmosphere RE:9 table 4-5
BTU/lbm-R
396-2700 R

$0.977457+3.71343E-04T-5.54868E-08T^2$
$0.927345+5.05824E-04T-1.55077E-07T^2+2.1604E-11T^3$
$0.897093+6.19373E-04T-2.9187E-07T^2+8.65719E-11T^3-1.05624E-14T^4$
$0.873323+7.32214E-04T-4.80511E-07T^2+2.28622E-10T^3-5.97223E-14T^4+6.35566E-18T^5$
$0.852809+8.49459E-04T-7.32333E-07T^2+4.92435E-10T^3-2.03782E-13T^4+4.56887E-17T^5$
$-4.23621E-21T^6$

s(396)=1.1001085 s(1440)=1.3967639
s(2700)=1.58514

$C_p(T)$ CARBON MONOXIDE CO
BTU/lbm-R RE:9 table 5-3
@ 1 atmosphere
360-1440 R

$0.252636-1.90827E-05T+2.32498E-08T^2$
$0.261766-5.5907E-05T+6.79431E-08T^2-1.66981E-11T^3$
$0.254941-1.87983E-05T-2.13166E-09T^2+3.83263E-11T^3-1.53213E-14T^4$
$0.246685+3.79707E-05T-1.49004E-07T^2+2.17863E-10T^3-1.19653E-13T^4+2.32026E-17T^5$
$0.249061+1.83577E-05T-8.48321E-08T^2+1.11031E-10T^3-2.38445E-14T^4-2.08615E-17T^5+8.15189E-21T^6$

$C_p(360)=0.24935143$ $C_p(864)=0.2532666$
$C_p(1440)=0.27210998$

$C_v(T)$ CARBON MONOXIDE CO
BTU/lbm-R RE:6 table 22
300-3000 R

$0.161724+3.00235E-05T-1.75843E-09T^2$
$0.176238-9.67381E-06T+2.63333E-08T^2-5.6751E-12T^3$
$0.188012-5.56623E-05T+8.04787E-08T^2-3.00445E-11T^3+3.69233E-15T^4$
$0.188293-5.70875E-05T+8.2879E-08T^2-3.18018E-11T^3+4.27072E-15T^4-7.01075E-20T^5$
$0.179783-4.33056E-06T-3.36869E-08T^2+8.9175E-11T^3-5.95288E-14T^4+1.64643E-17T^5$
$-1.67014E-21T^6$

$C_v(300)=0.17718672$ $C_v(1600)=0.2063688952$
$C_v(3000)=0.23295252$

$\gamma=C_p(T)/C_v(T)$ CARBON MONOXIDE CO
no units RE:9 table 5-6
@ 1 atmosphere
360-2790 R

$1.43847-7.0842E-05T+8.18809E-09T^2$
$1.41418-5.43095E-06T-3.94182E-08T^2+1.00754E-11T^3$
$1.38619+1.00264E-04T-1.65251E-07T^2+6.86653E-11T^3-9.29998E-15T^4$
$1.38641+9.92105E-05T-1.63481E-07T^2+6.73407E-11T^3-8.84759E-15T^4-5.74459E-20T^5$
$1.41627-7.67671E-05T+2.2007E-07T^2-3.35268E-10T^3+2.09467E-13T^4-5.88797E-17T^5+6.22457E-21T^6$

$\gamma(360)=1.4050$ $\gamma(1440)=1.3525587$
$\gamma(2790)=1.3080$

μ(T) CARBON MONOXIDE CO
molecular viscosity RE:9 table 5-8
@ 1 atmosphere
$lbf\text{-}sec/ft.^2$
270-2700 R

$8.5619E-08+5.54328E-10T-6.28832E-14T^2$
$3.39232E-08+7.11432E-10T-1.8641E-13T^2+2.77278E-17T^3$
$9.02129E-10+8.5475E-10T-3.73897E-13T^2+1.21487E-16T^3-1.57843E-20T^4$
$-1.48125E-08+9.43178E-10T-5.39375E-13T^2+2.56101E-16T^3-6.50115E-20T^4+6.62993E-24T^5$
$-2.59727E-08+1.02005E-09T-7.28099E-13T^2+4.7373E-16T^3-1.92535E-19T^4+4.33513E-23T^5$
$-4.12137E-27T^6$

μ(270)=2.0453702E-07 μ(1530)=7.825361152E-07
μ(2700)=1.1367013E-06

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k(T) CARBON MONOXIDE CO
thermal conductivity RE: 1
BTU/ft-sec-R
180-2250 R

$3.23925E-07+7.23122E-09T-8.95353E-13T^2$
$-1.27634E-07+9.01106E-09T-2.63386E-12T^2+4.76956E-16T^3$
$-1.89778E-07+9.36811E-09T-3.22341E-12T^2+8.41253E-16T^3-7.49582E-20T^4$
$-1.13616E-07+8.79358E-09T-1.8477E-12T^2-5.56476E-16T^3+5.54859E-19T^4-1.03674E-22T^5$
$-1.32015E-07+8.96461E-09T-2.3907E-12T^2+2.33762E-16T^3-1.9776E-20T^4+9.98644E-23T^5$
$-2.79202E-26T^6$

k(180)=1.4052889E-06 k(1170)=7.568615E-06
k(2250)=1.2221998E-05

Φ(T) CARBON MONOXIDE CO
"temperature function"* RE:6 table 21
BTU/lbm-R
300-3000 R

$1.47482+4.17327E-04T-6.61354E-08T^2$
$1.38796+6.54878E-04T-2.34238E-07T^2+3.39601E-11T^3$
$1.32053+9.18265E-04T-5.44342E-07T^2+1.7353E-10T^3-2.11469E-14T^4$
$1.26536+1.19768E-03T-1.01494E-06T^2+5.18071E-10T^3-1.34543E-13T^4+1.3745E-17T^5$
$1.22042+1.47632E-03T-1.63058E-06T^2+1.15701E-09T^3-4.71502E-13T^4+1.01072E-16T^5$
$-8.82091E-21T^6$

Φ(300)=1.5431275 Φ(1600)=1.969151045
Φ(3000)=2.1524456
* this is the integral function $\Phi=\int C_p dT/T$

Pr(T) CARBON MONOXIDE CO
@ 1 atmosphere RE:9
no units
360-1080 R

$0.852207-3.0797E-04T+1.76465E-07T^2$
$0.863382-3.60646E-04T+2.5387E-07T^2-3.58356E-11T^3$
$0.817254-6.76897E-05T-4.10349E-07T^2+6.04134E-10T^3-2.22212E-13T^4$
$0.790691+1.44239E-04T-1.06124E-06T^2+1.56806E-09T^3-9.12408E-13T^4+1.91721E-16T^5$
$0.414096+3.75837E-03T-1.507E-05T^2+2.96702E-08T^3-3.17316E-11T^4+1.7743E-14T^5-4.06279E-18T^6$

Pr(360)=0.7640 Pr(684)=0.723811494
Pr(1080)=0.7240

APPENDIX B

h(T) CARBON MONOXIDE CO
enthalpy RE:6 table 21
BTU/lbm
300-3000 R

$$0.231382T+1.64143E-05T^{2}-7.28358E-10T^{3}$$
$$0.238726T-3.67254E-06T^{2}+1.34861E-08T^{3}-2.8716E-12T^{4}$$
$$0.264017T-1.02465E-04T^{2}+1.29801E-07T^{3}-5.52217E-11T^{4}+7.93183E-15T^{5}$$
$$0.322358T-3.97922E-04T^{2}+6.2741E-07T^{3}-4.19541E-10T^{4}+1.27838E-13T^{5}-1.4534E-17T^{6}$$
$$0.407508T-9.25803E-04T^{2}+1.79376E-06T^{3}-1.63002E-09T^{4}+7.66209E-13T^{5}-1.79976E-16T^{6}$$
$$+1.67113E-20T^{7}$$

h(300)=74.327 h(1600)=410.077
h(3000)=820.1860

---

u(T) CARBON MONOXIDE CO
internal energy RE:6 table 21
BTU/lbm
300-3000 R

$$0.174086T+3.69314E-06T^{2}+2.09025E-09T^{3}$$
$$0.179066T-9.92801E-06T^{2}+1.17292E-08T^{3}-1.94727E-12T^{4}$$
$$0.17958T-1.19356E-05T^{2}+1.40929E-08T^{3}-3.01107E-12T^{4}+1.61182E-16T^{5}$$
$$0.177309T-4.35643E-07T^{2}-5.27528E-09T^{3}+1.11691E-11T^{4}-4.50584E-15T^{5}+5.65699E-19T^{6}$$
$$0.174952T+1.41768E-05T^{2}-3.75614E-08T^{3}+4.4677E-11T^{4}-2.21768E-14T^{5}+5.14536E-18T^{6}$$
$$-4.62592E-22T^{7}$$

u(300)=53.056 u(1600)=296.5260
u(3000)=607.490

---

h(T)/u(T) CARBON MONOXIDE CO
no units RE:6 table 21
300-3000 R

$$1.33104+6.12707E-05T-1.91607E-08T^{2}$$
$$1.3332+5.53634E-05T-1.49804E-08T^{2}-8.4451E-13T^{3}$$
$$1.47091-4.82545E-04T+6.18335E-07T^{2}-2.85883E-10T^{3}+4.31876E-14T^{4}$$
$$1.81802-2.2405E-03T+3.57904E-06T^{2}-2.45353E-09T^{3}+7.5661E-13T^{4}-8.64754E-17T^{5} \quad *$$
$$2.31788-5.33931E-03T+1.04259E-05T^{2}-9.55948E-09T^{3}+4.50407E-12T^{4}-1.05768E-15T^{5}+9.8101E-20T^{6}$$

h/u(300)=1.4009151 h/u(1600)=1.3828143
h/u(3000)=1.3501217
* generally poor fit, particularily between 400-1700 R

---

s(T) CARBON MONOXIDE CO
entropy @ 1 atmosphere RE:9 table 5-5
BTU/lbm-R
360-2790 R

$$1.48078+4.14122E-04T-6.74386E-08T^{2}$$
$$1.39638+6.41379E-04T-2.32837E-07T^{2}+3.50049E-11T^{3}$$
$$1.32974+8.93035E-04T-5.3244E-07T^{2}+1.74505E-10T^{3}-2.21429E-14T^{4}$$
$$1.27429+1.16154E-03T-9.83369E-07T^{2}+5.11984E-10T^{3}-1.37402E-13T^{4}+1.46361E-17T^{5}$$
$$1.22801+1.43423E-03T-1.5777E-06T^{2}+1.13584E-09T^{3}-4.75688E-13T^{4}+1.05783E-16T^{5}-9.6452E-21T^{6}$$

s(360)=1.584945 s(1530)=1.9537322
s(2790)=2.1273215

$C_p(T)$ CHLORINE
BTU/lbm-R RE:2 Vol.6
360-2360 R

$0.101559+2.73156E-05T-7.23931E-09T^2$
$9.1047E-02+5.83198E-05T-3.3183E-08T^2+6.40593E-12T^3$
$8.15054E-02+9.76205E-05T-8.60992E-08T^2+3.48329E-11T^3-5.25848E-15T^4$
$7.56481E-02+1.2865E-04T-1.44632E-07T^2+8.49218E-11T^3-2.50294E-14T^4+2.92026E-18T^5$
$7.56035E-02+1.28938E-04T-1.45333E-07T^2+8.57597E-11T^3-2.55523E-14T^4+3.0837E-18T^5$
$-2.01688E-23T^6$

$C_p(360)=0.10680$ $C_p(1200)=0.12386889$
$C_p(2360)=0.12730$

$C_v(T)$ CHLORINE
BTU/lbm-R RE: calculated from kinetic theory
250-2178 R

$6.82163E-02+3.51247E-05T-1.05127E-08T^2$
$5.85948E-02+6.97138E-05T-4.34525E-08T^2+9.0423E-12T^3$
$5.2922E-02+9.85438E-05T-8.87189E-08T^2+3.65443E-11T^3-5.66218E-15T^4$
$5.18611E-02+1.05491E-04T-1.04204E-07T^2+5.17514E-11T^3-1.24293E-14T^4+1.11459E-18T^5$
$5.52583E-02+7.83557E-05T-2.53281E-08T^2-5.74249E-11T^3+6.50407E-14T^4-2.60582E-17T^5$
$+3.7296E-21T^6$

$C_v(250)=7.2777687E-02$ $C_v(1250)=9.4964512E-02$
$C_v(2178.6)=9.697878E-02$

$\gamma=C_p(T)/C_v(T)$ CHLORINE
no units RE: calculated from kinetic theory
250-2250 R

$1.39509-1.31921E-04T+3.94646E-08T^2$
$1.43937-2.87793E-04T+1.83999E-07T^2-3.85425E-11T^3$
$1.47353-4.58142E-04T+4.44991E-07T^2-1.92824E-10T^3+3.08563E-14T^4$
$1.49246-5.79943E-04T+7.10378E-07T^2-4.46788E-10T^3+1.40773E-13T^4-1.75867E-17T^5$
$1.49312-5.85168E-04T+7.25243E-07T^2-4.66866E-10T^3+1.54645E-13T^4-2.23179E-17T^5+6.30832E-22T^6$

$\gamma(250)=1.384764$ $\gamma(1213)=1.29535963$
$\gamma(2250)=1.2885586$

$\mu(T)$ CHLORINE
molecular viscosity RE: 1
lbf-sec/ft.^{2}
460-1660 R

$-1.70062E-08+5.91081E-10T-7.03485E-14T^2$
$-3.39665E-09+5.4603E-10T-2.49582E-14T^2-1.41739E-17T^3$
$-4.07752E-09+5.49089E-10T-2.9773E-14T^2-1.09994E-17T^3-7.46022E-22T^4$
$-7.97069E-09+5.71127E-10T-7.71279E-14T^2+3.74829E-17T^3-2.45097E-20T^4+4.48239E-24T^5$
$-2.51778E-08+6.8842E-10T-3.96233E-13T^2+4.81967E-16T^3-3.59815E-19T^4+1.34788E-22T^5$
$-2.04462E-26T^6$

$\mu(460)=2.4102444E-07$ $\mu(1060)=5.30485686E-07$
$\mu(1660)=7.6944024E-07$

APPENDIX L

k(T) CHLORINE
thermal conductivity RE: 1
BTU/ft-sec-R
432-1260 R

$-4.6521E-07+3.79585E-09T-5.29511E-13T^2$

$-6.20427E-08+2.20449E-09T+1.43919E-12T^2-7.70715E-16T^3$

$-8.66777E-07+6.49938E-09T-6.76681E-12T^2+5.91189E-15T^3-1.96642E-18T^4$

$7.07859E-07-4.12575E-09T+2.08802E-11T^2-2.88355E-14T^3+1.9182E-17T^4-5.00041E-21T^5$

$9.64102E-06-7.66438E-08T+2.58833E-10T^2-4.33296E-13T^3+3.95398E-16T^4-1.86907E-19T^5$
$+3.57863E-23T^6$

k(432)=1.0921102E-06 k(864)=2.4092926E-06
k(1260)=3.4529955E-06

* * *

Φ(T) CHLORINE
"temperature function"* RE: calculated, ref 360 R
BTU/lbm-R
360-2360 R

$-5.36167E-02+2.06732E-04T-3.83368E-08T^2$

$-9.1076E-02+3.11039E-04T-1.21582E-07T^2+1.98783E-11T^3$

$-0.117696+4.12922E-04T-2.51488E-07T^2+8.67993E-11T^3-1.19858E-14T^4$

$-0.137324+5.0833E-04T-4.20219E-07T^2+2.24206E-10T^3-6.41778E-14T^4+7.48105E-18T^5$

$-0.145957+5.59106E-04T-5.35299E-07T^2+3.53772E-10T^3-1.41253E-13T^4+3.06387E-17T^5$
$-2.76546E-21T^6$

Φ(431.4)=1.9639335E-02 Φ(1360)=0.1560574
Φ(2360)=2.256562E-01
* this is the integral function $\Phi = \int C_p dT/T$

* * *

Pr(T) CHLORINE
Prandtl number RE: Calculated $Pr=\mu(T)C_p(T)/k(T)$
no units
460-1260 R

$0.800916-1.84505E-04T+9.00709E-08T^2$

$0.804124-1.96901E-04T+1.05186E-07T^2-5.8586E-12T^3$

$1.23517-2.43694E-03T+4.29893E-06T^2-3.36795E-09T^3+9.77352E-13T^4$

$1.21899-2.33137E-03T+4.03192E-06T^2-3.04024E-09T^3+7.81813E-13T^4+4.54742E-17T^5$

$-2.04828+2.33081E-02T-7.76921E-05T^2+1.32486E-07T^3-1.22673E-10T^4+5.86903E-14T^5-1.13653E-17T^6$

Pr(460)=0.737413 Pr(845.2)=0.712850157
Pr(1260)=0.71443

* * *

h(T) CHLORINE
enthalpy RE: calculated, ref 360 R
BTU/lbm
360-2460 R

$-43.7772+0.11614T+2.79532E-06T^2$

$-40.4627+0.107167T+9.72128E-06T^2-1.59492E-09T^3$

$-37.8904+9.75755E-02T+2.15759E-05T^2-7.49585E-09T^3+1.01916E-12T^4$

$-35.4897+8.62054E-02T+4.10855E-05T^2-2.28646E-08T^3+6.65441E-12T^4-7.78618E-16T^5$

$-33.656+7.56937E-02T+6.42265E-05T^2-4.81047E-08T^3+2.11705E-11T^4-4.98872E-15T^5+4.84756E-19T^6$

h(435)=8.1480843 h(1335)=116.241509
h(2460)=258.39595

* * *

u(T) CHLORINE
internal energy RE: calculated, ref 250 R
BTU/lbm
250-2178 R

$$-23.4242+8.48551E-02T+3.55001E-06T^2$$
$$-19.9704+7.34877E-02T+1.3884E-05T^2-2.7592E-09T^3$$
$$-17.4546+6.19666E-02T+3.08709E-05T^2-1.26698E-08T^3+1.98461E-12T^4$$
$$-15.7743+5.21395E-02T+5.11747E-05T^2-3.15928E-08T^3+1.00959E-11T^4-1.29944E-15T^5$$
$$-15.3592+4.91929E-02T+5.90373E-05T^2-4.18168E-08T^3+1.70207E-11T^4-3.64354E-15T^5+3.1294E-19T^6$$

u(318.9)=5.132236 u(1214)=84.91615
u(2178)=177.6437

C_p(T) FLUORINE
BTU/lbm-R RE:2 Vol.6
360-2460 R

$$0.167293+6.53909E-05T-1.54295E-08T^2$$
$$0.15346+1.05287E-04T-4.78364E-08T^2+7.735E-12T^3$$
$$0.152654+1.08544E-04T-5.21389E-08T^2+9.98416E-12T^3-4.02536E-16T^4$$
$$0.160238+6.93741E-05T+1.99052E-08T^2-4.99258E-11T^3+2.25052E-14T^4-3.27008E-18T^5$$
$$0.163759+4.7153E-05T+7.28798E-08T^2-1.11602E-10T^3+5.9903E-14T^4-1.45905E-17T^5+1.34947E-21T^6$$

C_p(360)=0.18580 C_p(1160)=0.2234299619
C_p(2460)=0.23780

C_v(T) FLUORINE
BTU/lbm-R RF:22 table 16
@ 1 atmosphere
162-540 R

$$0.139964-6.70824E-05T+1.44289E-07T^2$$
$$0.150486-1.72961E-04T+4.70883E-07T^2-3.13487E-10T^3$$
$$0.152244-1.96598E-04T+5.83427E-07T^2-5.3932E-10T^3+1.62131E-13T^4$$
$$0.161098-3.46119E-04T+1.54969E-06T^2-3.52996E-09T^3+4.60893E-12T^4-2.55074E-15T^5$$
$$0.191888-9.70956E-04T+6.64465E-06T^2-2.49124E-08T^3+5.3405E-11T^4-6.00926E-14T^5+2.74613E-17T^6$$

C_v(162)=0.13366578 C_v(306)=0.1327090758
C_v(540)=0.14505096

γ(T) FLUORINE
no units RE:22 table 16
162-540 R
@ 1 atm.

$$1.46266-2.2861E-04T+8.35905E-08T^2$$
$$1.51089-7.13918E-04T+1.58057E-06T^2-1.4369E-09T^3$$
$$1.64523-2.51993E-03T+1.01797E-05T^2-1.86921E-08T^3+1.23879E-11T^4$$
$$1.82007-5.47269E-03T+2.92617E-05T^2-7.77517E-08T^3+1.00204E-10T^4-5.03725E-14T^5$$
$$1.99644-9.05181E-03T+5.84461E-05T^2-2.00232E-07T^3+3.79713E-10T^4-3.79977E-13T^5+1.57301E-16T^6$$

γ(162)=1.4348235 γ(288)=1.40336105
γ(540)=1.3620989

APPENDIX B

μ(T) FLUORINE
molecular viscosity RE: 1
lbf-sec/ft.^{2}
160-1100 R

$-3.22002E-08+1.23334E-09T-4.58614E-13T^2$
$-1.86865E-08+1.14685E-09T-3.06333E-13T^2-7.89963E-17T^3$
$-1.63313E-08+1.12546E-09T-2.44078E-13T^2-1.50582E-16T^3+2.82228E-20T^4$
$-2.04308E-08+1.17336E-09T-4.40921E-13T^2+2.1361E-16T^3-2.8152E-19T^4+9.84221E-23T^5$
$-7.44709E-09+9.89692E-10T+5.31365E-13T^2-2.28924E-15T^3+3.07205E-18T^4-2.14747E-21T^5$
$+5.93355E-25T^6$

μ(160)=1.5685386E-07 μ(660)=5.82086729E-07
μ(1100)=7.6818708E-07

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k(T) FLUORINE
thermal conductivity RE: 1
BTU/ft-sec-R
180-1440 R

$-6.40261E-07+1.10029E-08T-2.471E-12T^2$
$3.92382E-08+7.42551E-09T+2.56397E-12T^2-2.04974E-15T^3$
$4.2303E-08+7.40273E-09T+2.61683E-12T^2-2.09747E-15T^3+1.46388E-20T^4$
$5.62132E-08+7.26964E-09T+3.05482E-12T^2-2.7366E-15T^3+4.38863E-19T^4-1.04462E-22T^5$
$1.01705E-07+6.73937E-09T+5.3267E-12T^2-7.40344E-15T^3+5.37591E-18T^4-2.69409E-21T^5$
$+5.32649E-25T^6$

k(180)1.44544E-06 k(774)=6.37173468E-06
k(1440)=9.9253546E-06

Φ(T) FLUORINE
"temperature function"* RE: calculated, ref 360 R
BTU/lbm-R
360-2460 R

$-9.09251E-02+3.51847E-04T-6.11946E-08T^2$
$-1.50548E-01+5.13262E-04T-1.85779E-07T^2+2.86895E-11T^3$
$-1.90003E-01+6.60378E-04T-3.67613E-07T^2+1.19202E-10T^3-1.56325E-14T^4$
$-2.20691E-01+8.05721E-04T-6.17003E-07T^2+3.15659E-10T^3-8.76674E-14T^4+9.953E-18T^5$
$-0.247589+9.59909E-04T-9.56441E-07T^2+6.85888E-10T^3-3.00594E-13T^4+7.17079E-17T^5-7.11052E-21T^6$

Φ(435)=3.563074E-02 Φ(1410)=0.282727
Φ(2460)=0.41262379
* this is the integral function $\Phi=\int C_p dT/T$

Pr(T) FLUORINE
Prandtl number RE:Calculated $Pr=\mu(T)C_p(T)/k(T)$
no units
360-1100 R

$0.698455+8.6248E-05T-1.29105E-07T^2$
$0.682529+1.60336E-04T-2.36512E-07T^2+4.90444E-11T^3$
$0.693635+9.06972E-05T-8.06869E-08T^2-9.90752E-11T^3+5.07259E-14T^4$
$0.613779+7.20007E-04T-1.989E-06T^2+2.69009E-09T^3-1.91961E-12T^4+5.39818E-16T^5$
$0.608475+7.70311E-04T-2.18162E-06T^2+3.07163E-09T^3-2.33259E-12T^4+7.71858E-16T^5-5.29772E-20T^6$

Pr(360)=0.7117252 Pr(716.3)=0.69411
Pr(1100)=0.63849

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h(T) FLUORINE
enthalpy @ 1 atmosphere RE:22 table 16
BTU/lbm
162-540 R

$-2.38713+1.78996T+1.36515E-04T^{2}$
$-23.8687+2.00613T-5.3029E-04T^{2}+6.40045E-07T^{3}$
$-39.2667+2.21313T-1.51588E-03T^{2}+2.61775E-06T^{3}-1.41984E-09T^{4}$
$-49.3479+2.38338T-2.61613E-03T^{2}+6.02308E-06T^{3}-6.48324E-09T^{4}+2.90443E-12T^{5}$
$-64.8434+2.69784T-5.18023E-03T^{2}+1.67841E-05T^{3}-3.10405E-08T^{4}+3.18631E-11T^{5}-1.38202E-14T^{6}$

h(162)=289.52197 h(306)=558.5342179
h(540)=1005.3050

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u(T) FLUORINE
internal energy @ 1 atmosphere
BTU/lbm RE:22 table 16
162-540 R

$2.09559+1.24835T+1.56528E-04T^{2}$
$-16.668+1.43717T-4.25909E-04T^{2}+5.59062E-07T^{3}$
$-28.4153+1.59509T-1.17783E-03T^{2}+2.06787E-06T^{3}-1.08321E-09T^{4}$
$-33.7076+1.68446T-1.75543E-03T^{2}+3.85557E-06T^{3}-3.74134E-09T^{4}+1.52474E-12T^{5}$
$-43.7502+1.88826T-3.4172E-03T^{2}+1.08297E-05T^{3}-1.96568E-08T^{4}+2.02927E-11T^{5}-8.9568E-15T^{6}$

u(162)=207.06182 u(306)=399.1290523
u(540)=723.00669

---

h(T)/u(T) FLUORINE
ratio of enthalpy and internal energy
@ 1 atmosphere RE:22 table 16
no units
162-540 R

$1.39141+6.25686E-05T-1.19727E-07T^{2}$
$1.38966+8.01579E-05T-1.73983E-07T^{2}+5.20784E-11T^{3}$
$1.39035+7.08104E-05T-1.29476E-07T^{2}-3.72305E-11T^{3}+6.4117E-14T^{4}$
$1.38397+1.78692E-04T-8.26649E-07T^{2}+2.12056E-09T^{3}-3.14431E-12T^{4}+1.8404E-15T^{5}$
$1.37219+4.17724E-04T-2.77574E-06T^{2}+1.03005E-08T^{3}-2.18114E-11T^{4}+2.38531E-14T^{5}-1.05054E-17T^{6}$

h/u(162)=1.398239 h/u(306)=1.39937603
h/u(540)=1.3904505

---

s(T) FLUORINE
entropy @ 1 atmosphere RE:22 table 16
BTU/lbm-R
162-540 R

$0.884642+1.1896E-03T-8.74462E-07T^{2}$
$0.81659+1.87441E-03T-2.98684E-06T^{2}+2.02761E-09T^{3}$
$0.759781+2.6381E-03T-6.62307E-06T^{2}+9.3241E-09T^{3}-5.23832E-12T^{4}$
$0.71025+3.4746E-03T-1.20289E-05T^{2}+2.60553E-08T^{3}-3.01161E-11T^{4}+1.42702E-14T^{5}$
$0.658418+4.52644E-03T-2.06057E-05T^{2}+6.20504E-08T^{3}-1.12259E-10T^{4}+1.11136E-13T^{5}-4.62282E-17T^{6}$

s(162)=1.048946 s(306)=1.167083245
s(540)=1.2760836

$C_p(T)$ FREON-12 CCl_2F_2
BTU/lbm-R RE: 2
180-2460 R

$6.74937E-02+1.49132E-04T-3.8839E-08T^2$
$3.98143E-02+2.53247E-04T-1.33539E-07T^2+2.3993E-11T^3$
$2.76723E-02+3.20058E-04T-2.3667E-07T^2+8.30036E-11T^3-1.11924E-14T^4$
$2.47123E-02+3.41409E-04T-2.84558E-07T^2+1.28145E-10T^3-2.99719E-14T^4+2.84588E-18T^5$
$2.7201E-02+3.19347E-04T-2.18854E-07T^2+3.93244E-11T^3+2.98112E-14T^4-1.66774E-17T^5$
$+2.46415E-21T^6$

$C_p(180)=0.07790$ $C_p(1260)=0.1928238135$
$C_p(2460)=0.20910$

$C_v(T)$ FREON-12 CCl_2F_2
BTU/lbm-R RE:

not available

$\gamma=C_p(T)/C_v(T)$ FREON-12 CCl_2F_2
no units RE:

not available

$\mu(T)$ FREON-12 CCl_2F_2
molecular viscosity RE: 1
$lbf\text{-}sec/ft.^2$
440-960 R

$1.61277E-09+5.76524E-10T-1.6785E-13T^2$
$-1.34814E-08+6.45425E-10T-2.6929E-13T^2+4.83045E-17T^3$
$-3.40305E-08+7.71103E-10T-5.50748E-13T^2+3.22145E-16T^3-9.78002E-20T^4$
$-5.55078E-07+4.76427E-09T-1.25674E-11T^2+1.808E-14T^3-1.29931E-17T^4+3.68437E-21T^5$
$-3.45761E-06+3.14938E-08T-1.13597E-10T^2+2.18742E-13T^3-2.3396E-16T^4+1.31658E-19T^5$
$-3.04698E-23T^6$

$\mu(440)=2.213916E-07$ $\mu(700)3.2324907E-07$
$\mu(960)=4.010112E-07$

$k(T)$ FREON-12 CCl_2F_2
thermal conductivity RE: 1
BTU/ft-sec-R
450-900 R

$-5.37378E-07+3.20829E-09T+1.24377E-12T^2$

$-5.19247E-07+3.12354E-09T+1.3724E-12T^2-6.35186E-17T^3$

$-8.79247E-07+5.37544E-09T-3.81175E-12T^2+5.14549E-15T^3-1.92926E-18T^4$

$-4.14753E-06+3.09791E-08T-8.28833E-11T^2+1.25512E-13T^3-9.22839E-17T^4+2.67717E-20T^5$

$-3.20964E-06+2.21529E-08T-4.86831E-11T^2+5.56573E-14T^3-1.29415E-17T^4-2.07573E-20T^5$
$+1.17356E-23T^6$

$k(450)=1.156352E-06$ $k(666)=2.15029085E-06$
$k(900)=3.3566329E-06$

$\Phi(T)$ FREON-12 CCl_2F_2
"temperature function"* RE: calculated, ref. 180 R
BTU/lbm-R
180-2460 R

$-2.95159E-02+2.96503E-04T-5.09507E-08T^2$

$-5.80762E-02+3.89855E-04T-1.3072E-07T^2+1.95411E-11T^3$

$-7.01402E-02+4.45911E-04T-2.10099E-07T^2+6.27392E-11T^3-7.93667E-15T^4$

$-7.5886E-02+4.80427E-04T-2.79779E-07T^2+1.24254E-10T^3-3.24339E-14T^4+3.60064E-18T^5$

$-7.98584E-02+5.0959E-04T-3.56809E-07T^2+2.20408E-10T^3-9.3661E-14T^4+2.28087E-17T^5$
$-2.35269E-21T^6$

$\Phi(261.4)=3.24036E-02$ $\Phi(1320)=0.272636572$
$\Phi(2460)=0.399095$
* this is the integral function $\Phi= \int C_p dT/T$

$Pr(T)$ FREON-12 CCl_2F_2
Prandtl number RE: calculated $Pr=\mu(T)C_p(T)/k(T)$
no units
450-900 R

$1.02396-4.81404E-04T+7.8355E-08T^2$

$1.28342-1.69373E-03T+1.91824E-06T^2-9.08582E-10T^3$

$1.95871-5.9167E-03T+1.16383E-05T^2-1.06744E-08T^3+3.61697E-12T^4$

$-2.33195+2.76877E-02T-9.21223E-05T^2+1.47256E-07T^3-1.14928E-10T^4+3.51245E-14T^5$

$-6.33022+6.53056E-02T-2.37862E-04T^2+4.44896E-07T^3-4.52965E-10T^4+2.37612E-13T^5-4.99969E-17T^6$

$Pr(450)=0.82697$ $Pr(683)=0.73275$
$Pr(900)=0.65280$

$h(T)$ FREON-12 CCl_2F_2
enthalpy RE: calculated, ref 180 R
BTU/lbm
180-2460 R

$-37.1585+0.138742T+1.82356E-05T^2$ **

$-21.6583+8.80787E-02T+6.15282E-05T^2-1.06053E-08T^3$

$-13.690+5.10534E-02T+1.13958E-04T^2-3.91378E-08T^3+5.24219E-12T^4$

$-9.99165+2.8837E-02T+1.58808E-04T^2-7.87318E-08T^3+2.10098E-11T^4-2.31755E-15T^5$

$-9.02658+2.17519E-02T+1.77522E-04T^2-1.02092E-07T^3+3.58847E-11T^4-6.98406E-15T^5+5.71576E-19T^6$

$h(261.4)=7.117384$ $h(1320)=178.171543$
$h(2460)=410.5950$
** errors up to 2.6% between 505 and 1075 R.

APPENDIX B

u(T) FREON-12 CCl_2F_2
internal energy RE:
BTU/lbm

not available

- - - - - - - - - - - - - - - - - -

The following values are for Helium calculated from kinetic theory:

C_p =1.24016379 BTU/lbm-R constant

C_v =0.744098275BTU/lbm-R constant

$\gamma=C_p/C_v$ =1.666667 constant

- - - - - - - - - - - - - - - - - -

$\mu(T)$ HELIUM
molecular viscosity PE:
lbf-sec/ft.^{2}

not available

- - - - - - - - - - - - - - - - - - -

k(T) HELIUM
thermal conductivity PE: 1
BTU/ft-sec-R
180-4320 R

$$7.86042E{-}06+3.00849E{-}08T-1.26065E{-}12T^2$$
$$6.22626E{-}06+3.40444E{-}08T-3.41609E{-}12T^2+3.19323E{-}16T^3$$
$$5.64863E{-}06+3.62157E{-}08T-5.48586E{-}12T^2+1.02477E{-}15T^3-7.83829E{-}20T^4$$
$$5.71194E{-}06+3.58874E{-}08T-5.01582E{-}12T^2+7.55182E{-}16T^3-1.17325E{-}20T^4-5.92449E{-}24T^5$$
$$5.45425E{-}06+3.75928E{-}08T-8.35897E{-}12T^2+3.56472E{-}15T^3-1.15286E{-}18T^4+2.15131E{-}22T^5-1.63745E{-}26T^6$$

k(180)=1.1724124E-05 k(1980)=6.26294754E-05
k(4320)=1.1499278E-04

- -

$\Phi(T)$ HELIUM
"temperature function"* RE: calculated from kinetic theory, ref. 250 R
BTU/lbm-R
250-2250 R

$-0.270816+2.47951E-03T-5.25702E-07T^{2}$
$-0.717177+3.91478E-03T-1.79516E-06T^{2}+3.29118E-10T^{3}$
$-1.04409+5.3796E-03T-3.89989E-06T^{2}+1.52307E-09T^{3}-2.32158E-13T^{4}$
$-1.30113+6.85148E-03T-6.86724E-06T^{2}+4.21529E-09T^{3}-1.35385E-12T^{4}+1.74486E-16T^{5}$
$-1.51223+8.31944E-03T-1.06929E-05T^{2}+9.06299E-09T^{3}-4.54829E-12T^{4}+1.22534E-15T^{5}-1.36222E-19T^{6}$

$\Phi(321.4)=3.11671E-01$ $\Phi(1250)=1.996137688$
$\Phi(2250)=2.724918$
* this is the integral function $\Phi = \int C_p dT/T$

Pr(T) HELIUM
Prandtl number RE:
no units

not available

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h(T) HELIUM
enthalpy @ 1 atmosphere RE:19
BTU/lbm
20-540 R

$5.91183+1.24336T-4.30687E-06T^{2}$
$5.72024+1.24746T-2.28079E-05T^{2}+2.23289E-08T^{3}$
$5.5472+1.25316T-6.76428E-05T^{2}+1.4668E-07T^{3}-1.11736E-10T^{4}$
$5.37372+1.26081T-1.57574E-04T^{2}+5.64919E-07T^{3}-9.46206E-10T^{4}+5.97167E-13T^{5}$
$5.19672+1.27052T-3.1251E-04T^{2}+1.61786E-06T^{3}-4.39295E-09T^{4}+5.96837E-12T^{5}-3.19701E-15T^{6}$

h(20)=30.430 h(240)=304.0496
h(540)=676.160

---

u(T) HELIUM
internal energy @ 1 atmosphere
BTU/lbm RE:19
20-540 R

$6.01742+0.745656T-2.18348E-06T^{2}$
$5.92049+0.747731T-1.1543E-05T^{2}+1.1296E-08T^{3}$
$5.83058+0.750689T-3.48404E-05T^{2}+7.59121E-08T^{3}-5.8061E-11T^{4}$
$5.73556+0.754883T-8.40959E-05T^{2}+3.04983E-07T^{3}-5.15104E-10T^{4}+3.27071E-13T^{5}$
$5.64525+0.759836T-1.63152E-04T^{2}+8.42243E-07T^{3}-2.2738E-09T^{4}+3.06772E-12T^{5}-1.63127E-15T^{6}$

u(20)=20.750 u(260)=199.727026
u(540)=408.080

h(T)/u(T) HELIUM
@ 1 atmosphere RE:19
no units
20-540 R

$1.52216+7.66757E-04T-1.02514E-06T^2$
$1.47951+1.68018E-03T-5.14387E-06T^2+4.97088E-09T^3$
$1.44211+2.9102E-03T-1.48344E-05T^2+3.18478E-08T^3-2.41504E-11T^4$
$1.40741+4.44207E-03T-3.28216E-05T^2+1.155E-07T^3-1.91054E-10T^4+1.1944E-13T^5$
$1.37396+6.27647E-03T-6.21047E-05T^2+3.14507E-07T^3-8.42494E-10T^4+1.13461E-12T^5-6.04242E-16T^6$

h/u(20)=1.466506 h/u(280)=1.649508
h/u(540)=1.65693

---

s(T) HELIUM
entropy @ 1 atmosphere RE:19
BTU/lbm-R
20-540 R

$3.73375+1.55319E-02T-1.66896E-05T^2$ *
$3.24188+2.60655E-02T-6.41867E-05T^2+5.73241E-08T^3$ *
$2.89802+3.73753E-02T-1.53286E-04T^2+3.04444E-07T^3-2.22051E-10T^4$
$2.62714+4.93339E-02T-2.93707E-04T^2+9.57498E-07T^3-1.52502E-09T^4+9.32439E-13T^5$
$2.3974+6.19313E-02T-4.94804E-04T^2+2.32414E-06T^3-5.99867E-09T^4+7.90391E-12T^5-4.14952E-15T^6$

s(20)=3.3940 s(280)=6.69717313
s(540)=7.5030
* errors of approximately 1.2%

$C_p(T)$ HYDROGEN
BTU/lbm-R RE: 2
180-2460 R

$2.90363+7.03301E-04T-1.61919E-07T^2$
$2.50963+2.18533E-03T-1.50994E-06T^2+3.41529E-10T^3$
$2.07374+4.58383E-03T-5.2123E-06T^2+2.45999E-09T^3-4.01804E-13T^4$
$1.68808+7.36567E-03T-1.14515E-05T^2+8.34148E-09T^3-2.84857E-12T^4+3.70787E-16T^5$
$1.41455+9.79051E-03T-1.86729E-05T^2+1.81036E-08T^3-9.41918E-12T^4+2.51655E-15T^5-2.70829E-19T^6$

$C_p(180)=2.6640$ $C_p(1360)=3.50264559$
$C_p(2460)=3.7550$ $C_p(\text{atomic hydrogen})=2.46265$ constant

---

$C_v(T)$ HYDROGEN
BTU/lbm-R RE:6 table 19
200-2900 R

$2.0636+4.27767E-04T-5.65301E-08T^2$
$1.75698+1.39838E-03T-8.0439E-07T^2+1.6083E-10T^3$
$1.33437+3.36948E-03T-3.38977E-06T^2+1.4186E-09T^3-2.02866E-13T^4$
$0.927366+5.88316E-03T-8.20492E-06T^2+5.28924E-09T^3-1.5747E-12T^4+1.77011E-16T^5$
$0.602708+8.37017E-03T-1.45643E-05T^2+1.26441E-08T^3-5.801E-12T^4+1.35379E-15T^5-1.26536E-19T^6$

$C_v(200)=1.7748016$ $C_v(1500)=2.53358178$
$C_v(2900)=2.8953373$

$\gamma(T)$ HYDROGEN
@ 1 atmosphere RE:9 table 6-6
no units
180-1080 R

$1.64901-6.797E-04T+4.32044E-07T^2$
$1.80808-1.68434E-03T+2.23199E-06T^2-9.56775E-10T^3$
$1.95103-2.93759E-03T+5.8358E-06T^2-5.09643E-09T^3+1.64164E-12T^4$
$2.0519-4.05641E-03T+1.02975E-05T^2-1.3228E-08T^3+8.51698E-12T^4-2.18499E-15T^5$
$2.10225-4.73584E-03T+1.37948E-05T^2-2.20974E-08T^3+2.03215E-11T^4-1.00783E-14T^5+2.08942E-18T^6$

$\gamma(180)=1.587$ $\gamma(540)=1.40491031$
$\gamma(1080)=1.396$

$\mu(T)$ HYDROGEN
molecular viscosity RE: 1
lbf-sec/ft.^{2}
560-2560 R

$1.17463E-07+1.4365E-10T+1.55953E-14T^2$
$-5.03306E-08+5.53477E-10T-2.7895E-13T^2+6.39674E-17T^3$
$2.16838E-07-3.22534E-10T+7.01616E-13T^2-3.86481E-16T^3+7.26344E-20T^4$
$3.3477E-09+5.58732E-10T-6.51559E-13T^2+5.86043E-16T^3-2.57035E-19T^4+4.24914E-23T^5$
$1.06653E-08+5.22339E-10T-5.80482E-13T^2+5.16022E-16T^3-2.20162E-19T^4+3.25992E-23T^5$
$+1.06153F-27T^6$

$\mu(560)=1.9194234E-07$ $\mu(1360)=3.506263066E-07$
$\mu(2560)=6.2825088E-07$

$k(T)$ HYDROGEN
thermal conductivity RE: 1
BTU/ft-sec-R
180-2610 R

$6.7893E-06+3.97869E-08T-2.76201E-12T^2$
$2.82639E-06+5.37253E-08T-1.46949E-11T^2+2.85135E-15T^3$
$-7.3202E-07+7.21662E-08T-4.15703E-11T^2+1.73788E-14T^3-2.60348E-18T^4$
$-3.18232E-06+8.89808E-08T-7.7359E-11T^2+4.93439E-14T^3-1.51914E-17T^4+1.80472E-21T^5$
$-2.7223E-06+8.50653E-08T-6.62343E-11T^2+3.50484E-14T^3-6.06408E-18T^4-1.0191E-21T^5$
$+3.37373E-25T^6$

$k(180)=1.085686E-05$ $k(1260)=5.224557178E-05$
$k(2610)=9.2989973E-05$

$\Phi(T)$ HYDROGEN
"temperature function"* RE:6 table 19
BTU/lbm-R
300-3000 R

$12.5693+5.62949E-03T-9.04531E-07T^2$
$11.5873+8.31522E-03T-2.80508E-06T^2+3.8395E-10T^3$
$11.0072+1.05813E-02T-5.47315E-06T^2+1.58477E-09T^3-1.81943E-13T^4$
$10.0303+1.55286E-02T-1.38053E-05T^2+7.68507E-09T^3-2.18969E-12T^4+2.43363E-16T^5$
$8.0079+2.80663E-02T-4.15073E-05T^2+3.64353E-08T^3-1.73517E-11T^4+4.17278E-15T^5-3.96911E-19T^6$

$\Phi(300)=13.56002$ $\Phi(1600)=19.27388689$
$\Phi(3000)=21.584325$
* this is the integral function $\Phi=$ C_pdT/T

Pr(T) HYDROGEN
Prandtl number RE:9 table 6-10
@ 1 atmosphere
180-1440 R

$0.739633-8.19845E-05T+1.55766E-08T^2$
$0.704128+1.12073E-04T-2.63566E-07T^2+1.15759E-10T^3$
$0.674482+3.32604E-04T-7.77455E-07T^2+5.83299E-10T^3-1.44938E-13T^4$
$0.668676+3.88074E-04T-9.60744E-07T^2+8.51462E-10T^3-3.23139E-13T^4+4.39094E-17T^5$
$0.648422+6.24924E-04T-1.98282E-06T^2+2.96393E-09T^3-2.56832E-12T^4+1.22547E-15T^5-2.4358E-19T^6$

Pr(180)=0.7120 Pr(720)=0.6897319553
Pr(1440)=0.660

---

h(T) HYDROGEN
enthalpy RE:6 table 19
BTU/lbm
300-3000 R

$3.36626T+1.88831E-05T^2+1.606E-08T^3$
$3.37356T-1.08333E-06T^2+3.01892E-08T^3-2.85439E-12T^4$
$3.41843T-1.76331E-04T^2+2.3652E-07T^3-9.57182E-11T^4+1.40703E-14T^5$
$3.53147T-7.48817E-04T^2+1.2007E-06T^3-8.01634E-10T^4+2.46403E-13T^5-2.81615E-17T^6$
$3.70994T-1.85524E-03T^2+3.64532E-06T^3-3.33876E-09T^4+1.58441E-12T^5-3.74921E-16T^6$
$+3.50263E-20T^7$

h(300)=1023.562 h(1600)=5500.6650
h(3000)=10702.8270

---

u(T) HYDROGEN
internal energy RE:6 table 19
BTU/lbm
300-3000 R

$2.38117T+1.89267E-05T^2+1.60491E-08T^3$
$2.38843T-9.27131E-07T^2+3.00986E-08T^3-2.83829E-12T^4$
$2.43323T-1.75922E-04T^2+2.36131E-07T^3-9.55681E-11T^4+1.405E-14T^5$
$2.54613T-7.47713E-04T^2+1.19914E-06T^3-8.00628E-10T^4+2.46101E-13T^5-2.81274E-17T^6$
$2.72438T-1.85274E-03T^2+3.64068E-06T^3-3.33456E-09T^4+1.58242E-12T^5-3.74451E-16T^6$
$+3.49822E-20T^7$

u(300)=728.026 u(1600)=3924.5240
u(3000)=7747.6690

---

h(T)/u(T) HYDROGEN
no units RE:6 table 19
300-3000 R

$1.41407-4.18285E-06T-2.24447E-09T^2$
$1.41248+1.77489E-07T-5.33006E-09T^2+6.23351E-13T^3$
$1.40493+2.96427E-05T-4.00215E-08T^2+1.6237E-11T^3-2.36571E-15T^4$
$1.38578+1.26655E-04T-2.0341E-07T^2+1.3586E-10T^3-4.17364E-14T^4+4.7722E-18T^5$
$1.35525+3.15885E-04T-6.21511E-07T^2+5.69783E-10T^3-2.70574E-13T^4+6.40783E-17T^5-5.99052E-21T^6$

h/u(300)=1.4059413 h/u(1600)=1.401600656
h/u(3000)=1.3814255

APPENDIX B

s(T) HYDROGEN
entropy @ 1 atmosphere RE:9 table 6-5
BTU/lbm-R
108-1080 R

$9.78691+1.37459E-02T-5.94556E-06T^2$
$8.98152+1.98668E-02T-1.79158E-05T^2+6.66945E-09T^3$
$8.50386+2.50712E-02T-3.48772E-05T^2+2.77618E-08T^3-8.82471E-12T^4$
$8.12452+3.04004E-02T-5.96732E-05T^2+7.79111E-08T^3-5.44421F-11T^4+1.52889E-14T^5$
$7.76167+3.66376F-02T-9.78617E-05T^2+1.87787E-07T^3-2.15151E-10T^4+1.30837E-13T^5-3.23856E-17T^6$

s(108)=10.774586 s(594)=15.8203916
s(1080)=17.886719

---

the following values are for Neon calculated from kinetic theory:

C_p =0.245968174 BTU/lbm-R constant

C_v =0.1475809045 BTU/lbm-R constant

γ C_p/C_v=1.666667 constant

μ(T) NEON
molecular viscosity RE: 1
lbf-sec/ft.^{2}
260-2260 R

$2.42187E-07+7.76368E-10T-5.06542E-14T^2$
$9.34812E-08+1.29751E-09T-5.30558E-13T^2+1.26959E-16T^3$
$6.10042E-08+1.45874E-09T-7.75969E-13T^2+2.7095E-16T^3-2.85697E-20T^4$
$6.06465E-08+1.46103E-09T-7.80919E-13T^2+2.75651E-16T^3-3.05884E-20T^4+3.20429E-25T^5$
$6.09549E-08+1.45863E-09T-7.74141E-13T^2+2.66574E-16T^3-2.43681E-20T^4-1.78401E-24T^5$
$+2.78365E-28T^6$

μ(260)=3.9244794E-07 μ(1160)=1.080185375E-06
μ(2260)=1.776772E-06

---

k(T) NEON
thermal conductivity RE: 1
BTU/ft-sec-R
180-4320 R

$3.12298E-06+8.76038E-09T-6.44589E-13T^2$
$2.12319E-06+1.11828E-08T-1.96329E-12T^2+1.95363E-16T^3$
$1.50969E-06+1.3489E-08T-4.16161E-12T^2+9.44621E-16T^3-8.3251E-20T^4$
$9.26782E-07+1.6512E-08T-8.4897E-12T^2+3.42693E-15T^3-6.96956E-19T^4+5.45515E-23T^5$
$6.32091E-07+1.84622E-08T-1.2313E-11T^2+6.63997E-15T^3-2.00197F-18T^4+3.07355E-22T^5$
$-1.87262E-26T^6$

k(180)=3.5654187E-06 k(2160)=1.894951868E-05
k(4320)=2.9390613E-05

$\Phi(T)$ NEON
"temperature function"* RE: calculated from kinetic theory
BTU/lbm-R ref. 250 R
250-2250 R

$-5.37123E-02+4.91774E-04T-1.04265E-07T^{2}$
$-0.142241+7.76439E-04T-3.56043E-07T^{2}+6.52756E-11T^{3}$
$-0.207081+1.06696E-03T-7.73486E-07T^{2}+3.02079E-10T^{3}-4.6045E-14T^{4}$
$-0.258059+1.35889E-03T-1.36202E-06T^{2}+8.36041E-10T^{3}-2.68517E-13T^{4}+3.46067E-17T^{5}$
$-0.299928+1.65004E-03T-2.12079E-06T^{2}+1.79751E-09T^{3}-9.02087E-13T^{4}+2.43028E-16T^{5}-2.70176E-20T^{6}$

$\Phi(321.4)=6.18154E-02$ $\Phi(1250)=0.39588714$
$\Phi(2250)=0.540447$
* this is the integral function $\Phi= \int C_p dT/T$

Pr(T) NEON
Prandtl number RE: calculated $Pr=\mu(T)C_p(T)/k(T)$
no units
260-2260 R

$0.673702-3.32576E-05T+2.24447E-08T^{2}$
$0.647415+5.77577E-05T-6.10706E-08T^{2}+2.2094E-11T^{3}$
$0.647743+5.61562E-05T-5.86481E-08T^{2}+2.06757E-11T^{3}+2.81396E-16T^{4}$
$0.656487+1.02533E-06T+5.97197E-08T^{2}-9.13227E-11T^{3}+4.83077E-14T^{4}-7.62321E-18T^{5}$
$0.662265-4.341E-05T+1.84122E-07T^{2}-2.57209E-10T^{3}+1.61726E-13T^{4}-4.59588E-17T^{5}+5.07085E-21T^{6}$

Pr(260)=0.6596765 Pr(1223)=0.667099
Pr(2260)=0.7206085

---

h(T) NEON
enthalpy RE: calculated from kinetic theory
BTU/lbm ref. 250 R
250-2250 R

$-61.4918+2.45968E-01T+2.51269E-14T^{2}$
$-61.4919+0.245968T-3.58635E-10T^{2}+9.56427E-14T^{3}$
$-61.4919+0.245968T-3.59448E-10T^{2}+9.61233E-14T^{3}-9.61163E-20T^{4}$
$-61.4896+0.245953T+3.2213E-08T^{2}-3.10744E-11T^{3}+1.34906E-14T^{4}-2.15851E-18T^{5}$
$-61.4896+0.245953T+3.21806E-08T^{2}-3.10306E-11T^{3}+1.34604E-14T^{4}-2.14819E-18T^{5}-1.37619E-24T^{6}$

h(250)=0.00 h(1287)=255.07824
h(2250)=491.93503

---

u(T) NEON
internal energy RE: calculated from kinetic theory
BTU/lbm ref. 250 R
250-2250 R

$-36.8951+0.147581T-2.97362E-14T^{2}$
$-36.8951+0.147581T-2.15709E-10T^{2}+5.75145E-14T^{3}$
$-36.8951+0.147581T-2.17293E-10T^{2}+5.84508E-14T^{3}-1.87245E-19T^{4}$
$-36.8937+0.147572T+1.93257E-08T^{2}-1.86434E-11T^{3}+8.09405E-15T^{4}-1.29508E-18T^{5}$
$-36.8937+0.147572T+1.93536E-08T^{2}-1.8681E-11T^{3}+8.12004E-15T^{4}-1.30394E-18T^{5}+1.182E-24T^{6}$

u(250)=0.00 u(1287)=153.04728
u(2250)=295.16181

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s(T) NEON
entropy @ 1 atmosphere RE:23 table XXXIV
BTU/lbm-R
90-540 R

$1.14215+2.01428E-03T-1.74329E-06T^2$
$1.05393+3.174E-03T-5.93218E-06T^2+4.43268E-09T^3$
$0.989522+4.34615E-03T-1.27882E-05T^2+2.02912E-08T^3-1.25862E-11T^4$
$0.93929+5.50238E-03T-2.22097E-05T^2+5.49963E-08T^3-7.14797E-11T^4+3.73927E-14T^5$
$0.898904+6.61645E-03T-3.38207E-05T^2+1.14266E-07T^3-2.29723E-10T^4+2.49209E-13T^5-1.12072E-16T^6$

s(90)=1.2900461 s(315)=1.600351095
s(540)=1.7330427

$C_p(T)$ NITROGEN
BTU/lbm-R RE:9 table 7-12
270-2610 R

$0.239227+1.58837E-05T+2.70324E-09T^2$
$0.252428-2.52138E-05T+3.59637E-08T^2-7.69919E-12T^3$
$0.257707-4.86323E-05T+6.74375E-08T^2-2.39092E-11T^3+2.81423E-15T^4$
$0.253927-2.69217E-05T+2.5769E-08T^2+1.09541E-11T^3-1.032E-14T^4+1.8242E-18T^5$
$0.242235+5.51799E-05T-1.80654E-07T^2+2.5546E-10T^3-1.57763E-13T^4+4.55719E-17T^5-5.06339E-21T^6$

$C_p(270)=0.24815158$ $C_p(1440)=0.2685608726$
$C_p(2610)=0.29574599$

$C_v(T)$ NITROGEN
BTU/lbm-R RE:6 table 12
200-3400 R

$0.165195+2.39076E-05T-6.71453E-10T^2$
$0.177257-1.05204E-05T+2.28181E-08T^2-4.41429E-12T^3$
$0.1843-4.03609E-05T+5.77024E-08T^2-1.93991E-11T^3+2.11527E-15T^4$
$0.182575-3.06706E-05T+4.12025E-08T^2-7.7369E-12T^3-1.49522E-15T^4+4.0489E-19T^5$
$0.17657+1.14808E-05T-5.53382E-08T^2+9.10174E-11T^3-5.12853E-14T^4+1.24977E-17T^5-1.12899E-21T^6$

$C_v(200)=0.17711308$ $C_v(1500)=0.1988766515$
$C_v(3400)=0.23425899$

$\gamma(T)=C_p(T)/C_v(T)$ NITROGEN
@ 1 atmosphere RE:9 table 7-6
no units
270-2880 R

$1.42476-4.46581E-05T+8.38108E-10T^2$
$1.4059+1.52556E-05T-4.72063E-08T^2+1.0644E-11T^3$
$1.39574+5.94336E-05T-1.03879E-07T^2+3.80823E-11T^3-4.42884E-15T^4$
$1.40797-8.0401E-06T+1.92386E-08T^2-5.91684E-11T^3+2.98711E-14T^4-4.42577E-18T^5$
$1.44151-2.30489E-04T+5.45059E-07T^2-6.41983E-10T^3+3.57142E-13T^4-9.44253E-17T^5+9.61398E-21T^6$

$\gamma(270)=1.4090$ $\gamma(1152)=1.3777486$
$\gamma(2880)=1.310$

μ(T) NITROGEN
molecular viscosity RE: 1
lbf-sec/ft.^{2}
260-2860 R

1.01696E-07+5.2516E-10T-6.35956E-14T^2
4.4789E-08+6.93784E-10T-1.90658E-13T^2+2.715E-17T^3
1.0497E-08+8.40062E-10T-3.75243E-13T^2+1.1542E-16T^3-1.41458E-20T^4
1.07413E-08+8.38705E-10T-3.72779E-13T^2+1.13494E-16T^3-1.34732E-20T^4-8.62423E-26T^5
1.03904E-08+8.41098E-10T-3.78503E-13T^2+1.19861E-16T^3-1.70483E-20T^4+8.96424E-25T^5
-1.04986E-28T^6

μ(260)=2.055182E-07 μ(1360)=7.008934143E-07
μ(2860)=1.0973504E-06

k(T) NITROGEN
thermal conductivity RE: 1
BTU/ft-sec-R
260-2860 R

9.26191E-07+6.19424E-09T-5.79231E-13T^2
1.23844E-07+8.57171E-09T-2.37072E-12T^2+3.82796E-16T^3
3.84912E-08+8.9358E-09T-2.83015E-12T^2+6.025E-16T^3-3.52089E-20T^4
-2.21871E-07+1.03828E-08T-5.45671E-12T^2+2.65485E-15T^3-7.52092E-19T^4+9.19081E-23T^5
-4.33891E-07+1.18292E-08T-8.91611E-12T^2+6.50213E-15T^3-2.91262E-18T^4+6.85746E-22T^5
-6.34442E-26T^6

k(260)=2.14444E-06 k(1460)=8.7671883E-06
k(2860)=1.419444E-05

Φ(T) NITROGEN
"temperature function"* RE:6 table 11
BTU/lbm-R
300-3000 R

1.42113+4.14989E-04T-6.60441E-08T^2
1.3331+6.55749E-04T-2.36418E-07T^2+3.44189E-11T^3
1.2648+9.22547E-04T-5.50536E-07T^2+1.75795E-10T^3-2.14207E-14T^4
1.20979+1.20117E-03T-1.01979E-06T^2+5.19351E-10T^3-1.34493E-13T^4+1.37057E-17T^5
1.16563+1.47489E-03T-1.62459E-06T^2+1.14704E-09T^3-4.65516E-13T^4+9.94944E-17T^5-8.66552E-21T^6

Φ(300)=1.4882567 Φ(1600)=1.911864852
Φ(3000)=2.092804
* this is the integral function $\Phi = \int C_p dT/T$

Pr(T) NITROGEN
Prandtl number RE:9 table 7-10
no units
@ 1 atmosphere
180-2160 R

0.811377-2.15777E-04T+9.0258E-08T^2
0.849496-3.82263E-04T+2.69565E-07T^2-5.30766E-11T^3
0.850917-3.9092E-04T+2.84998E-07T^2-6.33615E-11T^3+2.2647E-15T^4
0.834121-2.60244E-04T-4.55389E-08T^2+2.93216E-10T^3-1.6808E-13T^4+2.9625E-17T^5
0.81136-4.54502E-05T-7.56812E-07T^2+1.38473E-09T^3-1.00965E-12T^4+3.45407E-16T^5-4.5805E-20T^6

Pr(180)=0.7860 Pr(756)=0.689711288
Pr(2160)=0.7480

h(T) NITROGEN
enthalpy RE:6 table 11
BTU/lbm
300-3000 R

$0.245957T+1.64751E-06T^{2}+2.36118E-09T^{3}$
$0.250102T-9.69119E-06T^{2}+1.0385E-08T^{3}-1.62097E-12T^{4}$
$0.249684T-8.05577E-06T^{2}+8.4595E-09T^{3}-7.5436E-13T^{4}-1.31305E-16T^{5}$
$0.247289T+4.07277E-06T^{2}-1.19674E-08T^{3}+1.4201E-11T^{4}-5.05344E-15T^{5}+5.96623E-19T^{6}$
$0.245643T+1.42773E-05T^{2}-3.45141E-08T^{3}+3.76009E-11T^{4}-1.73938E-14T^{5}+3.79479E-18T^{6}$
$-3.23047E-22T^{7}$

h(300)=74.3150 h(1600)=407.237
h(3000)=812.429

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u(T) NITROGEN
internal energy RE:6 table 11
BTU/lbm
300-3000 R

$0.175072T+1.64827E-06T^{2}+2.3612E-09T^{3}$
$0.179212T-9.67386E-06T^{2}+1.03733E-08T^{3}-1.6186E-12T^{4}$
$0.178792T-8.03628E-06T^{2}+8.44525E-09T^{3}-7.50844E-13T^{4}-1.31479E-16T^{5}$
$0.17638T+4.17952E-06T^{2}-1.21286E-08T^{3}+1.43121E-11T^{4}-5.08903E-15T^{5}+6.00915E-19T^{6}$
$0.174738T+1.43612E-05T^{2}-3.46249E-08T^{3}+3.76597E-11T^{4}-1.74018E-14T^{5}+3.79193E-18T^{6}$
$-3.22325E-22T^{7}$

u(300)=53.048 u(1600)=293.823
u(3000)=599.7960

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h(T)/u(T) NITROGEN
no units RE:6 table 11
300-3000 R

$1.40559-5.88692E-06T-4.03957E-09T^{2}$
$1.39602+2.02843E-05T-2.25596E-08T^{2}+3.74142E-12T^{3}$
$1.39612+1.99079E-05T-2.21164E-08T^{2}+3.54196E-12T^{3}+3.02214E-17T^{4}$
$1.40167-8.17865E-06T+2.51869E-08T^{2}-3.10907E-11T^{3}+1.14286E-14T^{4}-1.38162E-18T^{5}$
$1.40583-3.39798E-05T+8.21943E-08T^{2}-9.02554E-11T^{3}+4.26302E-14T^{4}-9.46791E-18T^{5}+8.16796E-22T^{6}$

h/u(300)=1.4008882 h/u(1600)=1.386
h/u(3000)=1.354507

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s(T) NITROGEN
entropy @ 1 atmosphere RE:9 table 7-5
BTU/lbm-R
180-3780 R

$1.3977+4.20629E-04T-6.08049E-08T^{2}$
$1.3027+6.80574E-04T-2.26751E-07T^{2}+2.86714E-11T^{3}$
$1.2318+9.73115E-04T-5.49792E-07T^{2}+1.56307E-10T^{3}-1.63811E-14T^{4}$
$1.17265+1.29743E-03T-1.07183E-06T^{2}+4.98532E-10T^{3}-1.13484E-13T^{4}+9.91102E-18T^{5}$
$1.1266+1.61546E-03T-1.76646E-06T^{2}+1.16421E-09T^{3}-4.23891E-13T^{4}+7.90431E-17T^{5}-5.88578E-21T^{6}$

s(180)=1.358964 s(1350)=1.8633369
s(3780)=2.1630076

APPENDIX B

$C_p(T)$ OXYGEN
BTU/lbm-R RE: 2
460-2460 R

$1.92368E-01+5.3464E-05T-8.84478E-09T^2$
$0.198806+3.58425E-05T+4.80518E-09T^2-3.14427E-12T^3$
$0.219637-4.05339E-05T+9.82925E-08T^2-4.93672E-11T^3+7.94021E-15T^4$
$0.236469-1.18643E-04T+2.3093E-07T^2-1.53216E-10T^3+4.58578E-14T^4-5.22125E-18T^5$
$0.229854-8.13461E-05T+1.49538E-07T^2-6.48996E-11T^3-4.757E-15T^4+9.41833E-18T^5-1.68156E-21T^6$

$C_p(460)=0.21764$ $C_p(1160)=0.242480884$
$C_p(2460)=0.27021$

- - - - - - - - - - - - - - - - - - -

Cv(T) OXYGEN
BTU/lbm-R RE:6 table 14
200-3400 R

$0.139919+4.13501E-05T-5.45661E-09T^2$
$0.143786+3.03129E-05T+2.0739E-09T^2-1.41517E-12T^3$
$0.15521-1.80831E-05T+5.86498E-08T^2-2.57179E-11T^3+3.43058E-15T^4$
$0.16456-7.0584E-05T+1.48044E-07T^2-8.89022E-11T^3+2.29917E-14T^4-2.19364E-18T^5$
$0.166725-8.57805E-05T+1.82849E-07T^2-1.24505E-10T^3+4.09421E-14T^4-6.55334E-18T^5+4.07024E-22T^6$

$C_v(200)=0.15525$ $C_v(1500)=0.1914013373$
$C_v(3400)=0.2178125$

- - - - - - - - - - - - - - - - - - -

$\gamma(T)$ OXYGEN
@ 1 atmosphere RF:9 table 8-6
no units
216-3060 R

$1.44218-1.0274E-04T+1.75184E-08T^2$
$1.4406-9.78523E-05T+1.37403E-08T^2+8.0034E-13T^3$
$1.42218-1.57991E-05T-9.11422E-08T^2+5.02769E-11T^3-7.68485E-15T^4$
$1.41836-4.58405E-06T-7.71997E-08T^2-7.65048E-12T^3+4.51461E-14T^4-1.89799E-17T^5+2.38893E-21T^6$
fifth degree fit not available

$\gamma(216)=1.4170$ $\gamma(1008)=1.356826657$
$\gamma(3060)=1.2890$

- - - - - - - - - - - - - - - - - - -

$\mu(T)$ OXYGEN
molecular viscosity RE: 1
lbf-sec/ft.^{2}
360-3060 R

$1.40425E-07+5.67154E-10T-4.77625E-14T^2$
$9.54299E-08+6.81319E-10T-1.24826E-13T^2+1.50221E-17T^3$
$-1.99924E-08+1.0946E-09T-5.84012E-13T^2+2.12884E-16T^3-2.89271E-20T^4$
$-1.96287E-08+1.09292E-09T-5.81372E-13T^2+2.11047E-16T^3-2.83473E-20T^4-6.78154E-26T^5$
$-2.02631E-08+1.09649E-09T-5.88685E-13T^2+2.1821E-16T^3-3.195E-20T^4+8.28848E-25T^5$
$-8.73941E-29T^6$

$\mu(360)=3.0785964E-07$ $\mu(1560)=9.0322036E-07$
$\mu(3060)=1.4244252E-06$

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k(T) OXYGEN
thermal conductivity RE: 1
BTU/ft-sec-R
180-2700 R

$3.14442E-07+7.59939E-09T-7.44966E-13T^2$
$-2.4701E-08+8.77107E-09T-1.72883E-12T^2+2.30711E-16T^3$
$-1.22464E-07+9.26654E-09T-2.43214E-12T^2+6.00533E-16T^3-6.4457E-20T^4$
$-2.37869E-07+1.00412E-08T-4.0363E-12T^2+1.99108E-15T^3-5.95192E-19T^4+7.36865E-23T^5$
$-2.45876E-07+1.0108E-08T-4.22168E-12T^2+2.22291E-15T^3-7.38981E-19T^4+1.16845E-22T^5-4.99731E-27T^6$

k(180)=1.4534702E-06 k(1260)=8.72301766E-05
k(2700)=1.557863E-05

Φ(T) OXYGEN
"temperature function"* RE:6 table 13
BTU/lbm-R
300-3000 R

$1.3389+3.7666E-04T-5.91498E-08T^2$
$1.26596+5.76141E-04T-2.00312E-07T^2+2.85177E-11T^3$
$1.21152+7.88803E-04T-4.50693E-07T^2+1.41207E-10T^3-1.70742E-14T^4$
$1.16535+1.02265E-03T-8.44535E-07T^2+4.29555E-10T^3-1.11976E-13T^4+1.15032E-17T^5$
$1.12471+1.2746E-03T-1.40122E-06T^2+1.00731E-09T^3-4.16665E-13T^4+9.04671E-17T^5-7.97615E-21T^6$

Φ(300)=1.4039688 Φ(1600)=1.787031497
Φ(3000)=1.954375
* this is the integral function $\Phi = \int C_p dT/T$

Pr(T) OXYGEN
Prandtl number @ 1 atmosphere
no units RE:9 table 8-10
180-1080 R

$0.876487-4.56772E-04T+2.81155E-07T^2$
$0.913618-6.91632E-04T+7.00018E-07T^2-2.2162E-10T^3$
$0.920503-7.51805E-04T+8.72625E-07T^2-4.19796E-10T^3+7.86413E-14T^4$
$0.963641-1.23142E-03T+2.78836E-06T^2-3.91182E-09T^3+3.02912E-12T^4-9.36661E-16T^5$
$1.05359-2.44253E-03T+9.00728E-06T^2-1.96461E-08T^3+2.39331E-11T^4-1.48988E-14T^5+3.69368E-18T^6$

Pr(180)=0.8150 Pr(612)=0.701461794
Pr(1080)=0.704

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h(T) OXYGEN
enthalpy RE:6 table 13
BTU/lbm
300-3000 R

$0.209661T+1.31696E-05T^2+1.35377E-11T^3$
$0.215027T-1.50639E-06T^2+1.0399E-08T^3-2.09808E-12T^4$
$0.218931T-1.67567E-05T^2+2.83542E-08T^3-1.01792E-11T^4+1.22442E-15T^5$
$0.219134T-1.77839E-05T^2+3.00842E-08T^3-1.14458E-11T^4+1.64128E-15T^5-5.05291E-20T^6$
$0.216509T-1.51441E-06T^2-5.86299E-09T^3+2.58617E-11T^4-1.80335E-14T^5+5.04844E-18T^6-5.15048E-22T^7$

h(300)=64.7970 h(1600)=369.7880
h(3000)=744.303

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u(T) OXYGEN
internal energy RE:6 table 13
BTU/lbm
300-3000 R

$0.147605T+1.31659E-05T^{2}+1.45254E-11T^{3}$
$0.152975T-1.52136E-06T^{2}+1.0408E-08T^{3}-2.09968E-12T^{4}$
$0.156887T-1.67999E-05T^{2}+2.83964E-08T^{3}-1.01958E-11T^{4}+1.22668E-15T^{5}$
$0.157097T-1.78645E-05T^{2}+3.01895E-08T^{3}-1.15086E-11T^{4}+1.65875E-15T^{5}-5.23724E-20T^{6}$
$0.154488T-1.69099E-06T^{2}-5.54576E-09T^{3}+2.55789E-11T^{4}-1.79001E-14T^{5}+5.01653E-18T^{6}$
$-5.12011E-22T^{7}$

u(300)=46.180 u(1600)=270.490
u(3000)=558.1280

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h(T)/u(T) OXYGEN
no units RE:6 table 13
300-3000 R

$1.41919-3.49015E-05T+1.85682E-09T^{2}$
$1.40727-2.30938E-06T-2.1207E-08T^{2}+4.65935E-12T^{3}$
$1.3964+4.01498E-05T-7.1197E-08T^{2}+2.71585E-11T^{3}-3.40897E-15T^{4}$
$1.39431+5.07595E-05T-8.90659E-08T^{2}+4.0241E-11T^{3}-7.71471E-15T^{4}+5.21908E-19T^{5}$
$1.40037+1.31763E-05T-6.02615E-09T^{2}-4.5941E-11T^{3}+3.77351E-14T^{4}-1.1257E-17T^{5}+1.18978E-21T^{6}$

h/u(300)=1.4030992 h/u(1600)=1.367074547
h/u(3000)=1.3335704

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s(T) OXYGEN
entropy @ 1 atmosphere RE:9 table 8-5
BTU/lbm-R
180-2610 R

$1.27784+4.72477E-04T-9.09656E-08T^{2}$
$1.19726+7.55907E-04T-3.33615E-07T^{2}+5.79808E-11T^{3}$
$1.1359+1.07392E-03T-7.97084E-07T^{2}+3.08508E-10T^{3}-4.48973E-14T^{4}$
$1.08557+1.41926E-03T-1.53211E-06T^{2}+9.65003E-10T^{3}-3.03426E-13T^{4}+3.7065E-17T^{5}$
$1.0439+1.77396E-03T-2.53987E-06T^{2}+2.26002E-09T^{3}-1.13026E-12T^{4}+2.92871E-16T^{5}-3.05623E-20T^{6}$

s(180)=1.2904507 s(1440)=1.7610839
s(2610)=1.9164874

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$C_p(T)$ WATER VAPOR H_2O
@ 1 atmosphere RE:9 table 9-3
BTU/lbm-R
684-1530 R

$0.55703-1.87291E-04T+1.09692E-07T^{2}$
$0.872541-1.10895E-03T+9.75232E-07T^{2}-2.62136E-10T^{3}$
$1.59757-3.94404E-03T+5.02805E-06T^{2}-2.77429E-09T^{3}+5.70519E-13T^{4}$
$3.06929-1.11451E-02T+1.88444E-05T^{2}-1.57721E-08T^{3}+6.57019E-12T^{4}-1.08807E-15T^{5}$
$5.66428-2.63498E-02T+5.53724E-05T^{2}-6.18393E-08T^{3}+3.87487E-11T^{4}-1.2898E-14T^{5}+1.7803E-18T^{6}$

$C_p(684)$=0.4918418 $C_p(1062)$=0.482763319
$C_p(1530)$=0.52237523

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$C_v(T)$ WATER VAPOR H_2O
BTU/lbm-R RE:6 table 16
300-3000 R

$0.297781+6.77198E-05T+4.6351E-09T^2$
$0.326063-9.63657E-06T+5.93762E-08T^2-1.10588E-11T^3$
$0.338317-5.75013E-05T+1.15731E-07T^2-3.64224E-11T^3+3.84297E-15T^4$
$0.345914-9.59731E-05T+1.80525E-07T^2-8.38608E-11T^3+1.9456E-14T^4-1.89249E-18T^5$
$0.352403-1.36203E-04T+2.69413E-07T^2-1.76112E-10T^3+6.81067E-14T^4-1.45009E-17T^5+1.27358E-21T^6$

$C_v(300)=0.3312611$ $C_v(1600)=0.4184789667$
$C_v(3000)=0.5348024$

$\gamma(T)$ WATER VAPOR H_2O
no units RE:6 table 16
300-3000 R

$1.36422-7.1497E-05T+5.82923E-09T^2$
$1.3463-2.24709E-05T-2.8864E-08T^2+7.00874E-12T^3$
$1.33029+4.00832E-05T-1.02513E-07T^2+4.01562E-11T^3-5.02235E-15T^4$
$1.31761+1.04283E-04T-2.10638E-07T^2+1.19319E-10T^3-3.10765E-14T^4+3.15808E-18T^5$
$1.30918+1.56539E-04T-3.26096E-07T^2+2.39146E-10T^3-9.42699E-14T^4+1.95354E-17T^5-1.65428E-21T^6$

$\gamma(300)=1.333$ $\gamma(1600)=1.26366074$
$\gamma(3000)=1.206$

$\mu(T)$ WATER VAPOR H_2O
molecular viscosity RE: 1
$lbf-sec/ft.^2$
740-2660 R

$-3.57088E-08+4.57525E-10T-1.57129E-14T^2$
$2.01511E-08+3.40295E-10T+5.94828E-14T^2-1.49343E-17T^3$
$2.20693E-08+3.34887E-10T+6.48499E-14T^2-1.71686E-17T^3+3.31522E-22T^4$
$2.09711E-08+3.38782E-10T+5.95937E-14T^2-1.3787E-17T^3-7.09738E-22T^4+1.23295E-25T^5$
$5.98705E-09+4.02699E-10T-4.94589E-14T^2+8.16057E-17T^3-4.5933E-20T^4+1.11699E-23T^5$
$-1.08927E-27T^6$

$\mu(740)=2.9846094E-07$ $\mu(1520)=6.224105282E-07$
$\mu(2660)=1.065186E-06$

$k(T)$ WATER VAPOR H_2O
thermal conductivity RE: 2 table 24
BTU/ft-sec-R
504-1620 R

$-1.06777E-06+6.61102E-09T+1.15939E-12T^2$
$1.13512E-06-6.23951E-10T+8.51026E-12T^2-2.33593E-15T^3$
$2.1359E-07+3.41078E-09T+2.23718E-12T^2+1.78984E-15T^3-9.74207E-19T^4$
$-4.52883E-06+2.94473E-08T-5.26121E-11T^2+5.73285E-14T^3-2.80822E-17T^4+5.1188E-21T^5$
$-1.7502E-05+1.15411E-07T-2.82023E-10T^2+3.7323E-13T^3-2.6519E-16T^4+9.72768E-20T^5$
$-1.45225E-23T^6$

$k(504)=2.6339129E-06$ $k(954)=6.24488026E-06$
$k(1620)=1.2527147E-05$

APPENDIX B

$\Phi(T)$ WATER VAPOR H_2O
"temperature function"* RE:6 table 15
BTU/lbm-R
300-3000 R

$$2.12+7.46511E-04T-1.11983E-07T^2$$
$$1.96748+1.16367E-03T-4.07186E-07T^2+5.96368E-11T^3$$
$$1.84959+1.62417E-03T-9.49367E-07T^2+3.03658E-10T^3-3.69729E-14T^4$$
$$1.75499+2.10327E-03T-1.75627E-06T^2+8.94423E-10T^3-2.31407E-13T^4+2.35677E-17T^5$$
$$1.67628+2.59122E-03T-2.83437E-06T^2+2.01332E-09T^3-8.21481E-13T^4+1.76493E-16T^5-1.5447E-20T^6$$

$\Phi(300)=2.2446159$ $\Phi(1600)=3.020651222$
$\Phi(3000)=3.388266$
* this is the integral function $\Phi=\int C_p dT/T$

$Pr(T)$ WATER VAPOR H_2O
no units RE: calculated $Pr=\mu(T)C_p(T)/k(T)$
740-1530 R

$$1.61695-1.08444E-03T+4.04135E-07T^2$$
$$2.09544-2.42043E-03T+1.61261E-06T^2-3.54911E-10T^3$$
$$2.64564-4.47723E-03T+4.43736E-06T^2-2.04537E-09T^3+3.72349E-13T^4$$
$$4.25073-1.19935F-02T+1.82935E-05T^2-1.46193E-08T^3+5.99215E-12T^4-9.90273E-16T^5$$
$$12.5762-5.88331E-02T+1.26676E-04T^2-1.4667E-07T^3+9.53638F-11T^4-3.28593E-14T^5+4.67974E-18T^6$$

$Pr(740)=1.04678$ $Pr(1091)=0.91385138$
$Pr(1530)=0.89745$

$h(T)$ WATER VAPOR H_2O
enthalpy RE:6 table 15
BTU/lbm
300-3000 R

$$0.430799T+1.30796E-05T^2+6.42701E-09T^3$$
$$0.439412T-1.04775E-05T^2+2.30972E-08T^3-3.36771E-12T^4$$
$$0.440586T-1.50638E-05T^2+2.48969E-08T^3-5.79798E-12T^4+3.68222E-16T^5$$
$$0.439124T-7.66062E-06T^2+1.60285E-08T^3+3.33063E-12T^4-2.63621E-15T^5+3.64173E-19T^6$$
$$0.435898T+1.23435E-05T^2-2.81703E-08T^3+4.9202F-11T^4-2.68274E-14T^5+6.63361E-18T^6$$
$$-6.33276E-22T^7$$

$h(300)=131.417$ $h(1600)=749.089$
$h(3000)=1575.616$

$u(T)$ WATER VAPOR H_2O
BTU/lbm RE:6 table 15
300-3000 R

$$0.320566T+1.30861E-05T^2+6.42531E-09T^3$$
$$0.329174T-1.04572E-05T^2+2.30857E-08T^3-3.36573E-12T^4$$
$$0.330344T-1.50269E-05T^2+2.84659E-08T^3-5.78722E-12T^4+3.66893E-16T^5$$
$$0.328869T-7.55761E-06T^2+1.58861E-08T^3+3.42298E-12T^4-2.66439E-15T^5+3.67428E-19T^6$$
$$0.325608T+1.26609E-05T^2-2.87865E-08T^3+4.9786E-11T^4-2.71148E-14T^5+6.70406E-18T^6$$
$$-6.40064E-22T^7$$

$u(300)=98.346$ $u(1600)=572.727$
$u(3000)=1244.93$

APPENDIX B

h(T)/u(T) WATER VAPOR H_2O
no units RE:6 table 15
300-3000 R

$1.34532-1.85114E-05T-2.97801E-09T^2$
$1.33606+6.79299E-06T-2.08846E-08T^2+3.6175E-12T^3$
$1.33346+1.69526E-05T-3.28463E-08T^2+9.00111E-12T^3-8.15698E-16T^4$
$1.33487+9.81369E-06T-2.08229E-08T^2+1.98303E-13T^3+2.0815E-15T^4-3.51176E-19T^5$
$1.33852-1.2802E-05T+2.91461E-08T^2-5.16616E-11T^3+2.94308E-14T^4-7.43909E-18T^5+7.15951E-22T^6$

h/u(300)=1.3362682 h/u(1600)=1.307929746
h/u(3000)=1.265624

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s(T) WATER VAPOR H_2O
entropy @ 1 atmosphere RE:9 table 9-5
BTU/1bm-R
684-1530 R

$2.10193+8.69448E-04T-1.87363E-07T^2$
$1.92593+1.3842E-03T-6.70928E-07T^2+1.4644E-10T^3$
$1.72474+2.16905E-03T-1.79029E-06T^2+8.38781E-10T^3-1.56926E-13T^4$
$1.44486+3.53813E-03T-4.41689E-06T^2+3.30993E-09T^3-1.29778E-12T^4+2.06946E-16T^5$
$0.914388+6.65398E-03T-1.19204E-05T^2+1.27943E-08T^3-7.93663E-12T^4+2.64821E-15T^5-3.6866E-19T^6$

s(684)=2.6044908 s(1026)=2.7974969
s(1530)=2.9969061

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the following values are for Xenon calculated from kinetic theory:

C_p=0.0378094109 BTU/1bm-R constant

C_v=0.0226856465 BTU/1bm-R constant

$\gamma=C_p/C_v$=1.666667 no units constant

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μ(T) XENON
molecular viscosity RE:$_1$
lbf-sec/ft.^{2}
420-1260 R

$-4.18445E-08+1.08219E-09T-2.08318E-13T^2$
$-4.21081E-08+1.08327E-09T-2.09688E-13T^2+5.49662E-19T^3$
$-4.2E-08+1.08267E-09T-2.08528E-13T^2-4.15906E-19T^3+2.89759E-22T^4$
$-5.24189E-08+1.15374E-09T-3.95123E-13T^2+2.35873E-16T^3-1.4442E-19T^4+3.43938E-23T^5$
$-3.36433E-08+1.0001E-09T+1.12883E-13T^2-6.33919E-16T^3+6.70089E-19T^4-3.61823E-22T^5$
$+7.8365E-26T^6$

μ(420)=3.75948E-07 μ(800)=6.9056447E-07
μ(1260)=9.910407E-07

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APPENDIX L

k(T) XENON
thermal conductivity RE: 1
BTU/ft-sec-R
360-1332 R

$7.72678E-10+1.81817E-09T-2.73154E-13T^2$
$9.13157E-10+1.81758E-09T-2.72407E-13T^2-2.94542E-19T^3$
$5.6794E-10+1.81953E-09T-2.76288E-13T^2+2.92599E-18T^3-9.51693E-22T^4$
$1.43146E-08+1.72139E-09T-1.0778E-14T^2-3.38705E-16T^3+2.0917E-19T^4-4.96741E-23T^5$
$-7.36834E-08+2.47852E-09T-2.6077E-12T^2+4.21654E-15T^3-4.11348E-18T^4+2.06135E-21T^5$
$-4.15883E-25T^6$

k(360)=6.1993315E-07 k(828)=1.319093075E-06
k(1332)=1.9368896E-06

Φ(T) XENON
"temperature function"* RE: calculated from kinetic theory
BTU/lbm-R ref. 250 R
250-2250 R

$-8.25648E-03+7.55938E-05T-1.60273E-08T^2$
$-2.18649E-02+1.19352E-04T-5.47297E-08T^2+1.0034E-11T^3$
$-3.18317E-02+1.6401E-04T-1.18898E-07T^2+4.64346E-11T^3-7.07789E-15T^4$
$-3.9668E-02+2.08884E-04T-2.09365E-07T^2+1.28513E-10T^3-4.12755E-14T^4+5.31962E-18T^5$
$-4.6104E-02+2.53638E-04T-3.26E-07T^2+2.76307E-10T^3-1.38666E-13T^4+3.73575E-17T^5-4.15306E-21T^6$

Φ(321.4)=9.502051E-03 Φ(1250)=6.0853946E-02
Φ(2250)=8.307577E-02
* this is the integral function $\Phi = \int C_p dT/T$

Pr(T) XENON
Prandtl number RE: Calculated $Pr=\mu(T)C_p(T)/k(T)$
no units
420-1260 R

$0.601787+1.23083E-04T-6.90974E-08T^2$
$0.562866+2.79847E-04T-2.66293E-07T^2+7.82523E-11T^3$
$0.51556+5.36568E-04T-7.64277E-07T^2+4.89174E-10T^3-1.22298E-13T^4$
$0.458004+9.29034E-04T-1.79541E-06T^2+1.79649E-09T^3-9.24203E-13T^4+1.9093E-16T^5$
$0.47278+8.07778E-04T-1.39328E-06T^2+1.10589E-09T^3-2.75535E-13T^4-1.25594E-16T^5+6.28024E-20T^6$

Pr(420)=0.63834 Pr(855.6)=0.656021
Pr(1260)=0.64877

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h(T) XENON
enthalpy RE: calculated from kinetic theory
BTU/lbm ref 250 R
250-2250 R

$-9.45231+3.78094E-02T+2.1482E-15T^2$
$-9.45233+3.78094E-02T-5.4887E-11T^2+1.46371E-14T^3$
$-9.45233+3.78094E-02T-5.49402E-11T^2+1.46685E-14T^3-6.28427E-21T^4$
$-9.45197+3.78071E-02T+4.94738E-09T^2-4.77235E-12T^3+2.07183E-15T^4-3.31494E-19T^5$
$-9.45197+3.78071E-02T+4.94639E-09T^2-4.77101E-12T^3+2.07091E-15T^4-3.31179E-19T^5-4.19956E-26T^6$

h(250)=0.00 h(1287)=39.2098146
h(2250)=75.618822

$u(T)$ XENON
internal energy
BTU/lbm
250-2250 R

RE: calculated from kinetic theory
ref 250 R

$$-5.67139+2.26856E-02T-4.22076E-15T^{2}$$

$$-5.6714+2.26857E-02T-3.32254E-11T^{2}+8.85899E-15T^{3}$$

$$-5.6714+2.26857E-02T-3.34403E-11T^{2}+8.98599E-15T^{3}-2.54009E-20T^{4}$$

$$-5.67118+2.26843E-02T+2.97121E-09T^{2}-2.86634E-12T^{3}+1.24443E-15T^{4}-1.99112E-19T^{5}$$

$$-5.67118+2.26843E-02T+2.97188E-09T^{2}-2.86724E-12T^{3}+1.24505E-15T^{4}-1.99324E-19T^{5}+2.82383E-26T^{6}$$

$u(250)=0.00$ $u(1287)=23.525944$
$u(2250)=45.37129$

* * *

LIST OF SYMBOLS/UNITS

a	Thermal Diffusivity	ft^2/SEC
$C_p(T)$	Specific Heat @ Const Pressure	BTU/lb_m-°R
$C_v(T)$	Specific Heat @ Const Volume	BTU/lb_m-°R
$\gamma(T)$	Gamma, $C_p(T)/C_v(T)$	No Units
H	Total Enthalpy	BTU/lb_m
h	Static Enthalpy	BTU/lb_m
k(T)	Thermal Conductivity	BTU/ft-sec °R
$\phi(T)$	"Temperature Function"	BTU/lb_m-°R
$\mu(T)$	Molecular Viscosity	lb_f-sec/ft^2
Pr	Prandtl Number	No Units
P_t	Total Pressure	lb_f/ in^2
p	Static Pressure	lb_f/ in^2
T_t	Total Temp	Deg. R
T	(Static) Temperature	Deg. R
U	Internal Energy	BTU/lb_m
ρ	Density	Mass/ in^3
ν	Kinematic Viscosity	ft^2/sec

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