

1. Report No. NASA TN D-7808	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle <b>GASP - A COMPUTER CODE FOR CALCULATING THE THERMODYNAMIC AND TRANSPORT PROPERTIES FOR TEN FLUIDS: PARAHYDROGEN, HELIUM, NEON, METHANE, NITROGEN, CARBON MONOXIDE, OXYGEN, FLUORINE, ARGON, AND CARBON DIOXIDE</b>		5. Report Date February 1975	
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9. Performing Organization Name and Address Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135		8. Performing Organization Report No. E-6501	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		10. Work Unit No. 502-24	
15. Supplementary Notes		11. Contract or Grant No.	
		13. Type of Report and Period Covered Technical Note	
		14. Sponsoring Agency Code	
16. Abstract <p>A FORTRAN IV subprogram called GASP calculates the thermodynamic and transport properties for 10 pure fluids: parahydrogen, helium, neon, methane, nitrogen, carbon monoxide, oxygen, fluorine, argon, and carbon dioxide. The pressure range is generally from 0.1 to 400 atmospheres (to 100 atm for helium and to 1000 atm for hydrogen). The temperature ranges are from the triple point to 300 K for neon; to 500 K for carbon monoxide, oxygen, and fluorine; to 600 K for methane and nitrogen; to 1000 K for argon and carbon dioxide; to 2000 K for hydrogen; and from 6 to 500 K for helium. GASP accepts any two of pressure, temperature, and density as input conditions. In addition, pressure and either entropy or enthalpy are also accepted as input variables, a desirable flexibility for cycle analysis. The properties available in any combination as output include temperature, density, pressure, entropy, enthalpy, specific heats (<math>C_p</math>, <math>C_v</math>), sonic velocity, <math>(\partial P/\partial \rho)_T</math>, <math>(\partial P/\partial T)_\rho</math>, viscosity, thermal conductivity, and surface tension. The subprogram design is modular so that the user can choose only those subroutines necessary to the calculations. GASP was written for the engineer user who requires both accuracy and speed in calculating thermodynamic and transport properties.</p>			
17. Key Words (Suggested by Author(s)) Fluids; Thermodynamic; Transport properties; Computer; Hydrogen; Helium; Neon; Methane; Nitrogen; Carbon monoxide; Oxygen; Fluorine; Argon; Carbon dioxide		18. Distribution Statement Unclassified - unlimited STAR category 34 (rev.)	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 210	22. Price* \$7.25



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SUMMARY

A FORTRAN IV subprogram, GASP, has been developed to calculate the thermodynamic and transport properties for 10 pure fluids: parahydrogen, helium, neon, methane, nitrogen, carbon monoxide, oxygen, fluorine, argon, and carbon dioxide. The pressure range is generally from 0.1 to 400 atmospheres (to 100 atm for helium and to 1000 atm for hydrogen). The temperature ranges are from the triple point to 300 K for neon; to 500 K for carbon monoxide, oxygen, and fluorine; to 600 K for methane and nitrogen; to 1000 K for argon and carbon dioxide; to 2000 K for hydrogen; and from 6 to 500 K for helium. Two-phase liquid-vapor properties are available; however, fluid mixtures are not at this time part of GASP.

GASP accepts any two of pressure, temperature, and density as input conditions. In addition, pressure and either entropy or enthalpy are also accepted as input variables, a desirable flexibility for cycle analysis. The properties available in any combination as output include temperature, density, pressure, entropy, enthalpy, specific heats ( $C_p$ ,  $C_v$ ), sonic velocity,  $(\partial P/\partial \rho)_T$ ,  $(\partial P/\partial T)_\rho$ , viscosity, thermal conductivity, and surface tension.

The subprogram design is modular so that the user can choose only those subroutines necessary to his calculations. Existing equations are used for all fluids except fluorine and hydrogen. The equations for these fluids were developed by the authors from National Bureau of Standards data and the PVT surface curve-fitting technique of Bender. GASP was written for the engineer user who requires both accuracy and speed in calculating thermodynamic and transport properties.

## INTRODUCTION

Cryogens are important fluids in many areas of modern technology. Among these are food preparation, power transmission, antipollution power-conditioning systems, neurosurgery, the H<sub>2</sub>-O<sub>2</sub> propulsion systems for land-based and space vehicles, and proposed high-energy fuels for aeronautics. Because their properties are known and gradients are readily established, cryogens are often the primary test fluids in heat-transfer and fluid dynamics research.

A Lewis Research Center literature and computer library search revealed no single computer code that could provide a flexible medium for calculating internally consistent thermodynamic and transport properties of the desired cryogenic fluids. A subprogram (subroutine) exists for nitrogen, called NTWO (ref. 1), which has the desired input-output flexibility. However, its results for nitrogen are not the best currently available. We decided to construct a multifluid, multiproperty computer subprogram based on the NTWO input-output structure using, for eight fluids, the best available equations that were also compatible with the desired program logic structure. The program is called GASP, an acronym for gas properties (ref. 2).

We then decided that the only feasible way to maintain a viable properties program is by modifying and updating a basic properties program at periodic intervals. For this report, the 10 fluids chosen are based on the current and projected requirements of cryogenics research and development for aerospace and environmental applications at the Lewis Research Center and other NASA facilities and in industry. The equation-of-state coefficients are programmed so that fluids may easily be added, replaced, or updated when new equations or additional data become available. As such, we suggest that this report represent an ongoing program of maintaining GASP, where future revisions can be made by issuing looseleaf inserts to replace pages of this document.

The main report consists of two sections which are directed to the research-oriented GASP user who must know both what is included in GASP and how to use it. The first section, ANALYSIS OF GASP, explains the contents of the program. It includes the Bender method for pressure-volume-temperature (PVT) surface curve-fitting (refs. 3 to 5); the equations of state selected for eight of the fluids; the equations of state developed by the authors for parahydrogen and fluorine; a discussion of the transport property calculations, including the prediction of the thermal conductivity anomaly in the critical region; comparisons to measured PVT data for each fluid; the question of extrapolation to higher pressures for parahydrogen in particular and other fluids in general; and comparison of PVT data to other equations of state.

The second section, USER'S GUIDE TO GASP, presents detailed instructions for input and output summarized in table form for handy reference. Three accuracy ranges for thermodynamic calculations using PVT measured data are discussed in relation to GASP. The use of a modular design in the programming of GASP simplifies dividing it

into smaller subprograms for users with limited interest or limited core storage. Certain options are also provided for users wishing to make calculations in troublesome areas of the PVT surface.

The mathematical and FORTRAN symbols used are defined in appendix A. The exact equations used are presented in appendixes B to E. Detailed information about the computer program is given in appendixes F to J. And the properties of parahydrogen are discussed in appendix K.

## ANALYSIS OF GASP

### THEORY (EMPIRICAL EQUATIONS)

#### Selection of Equation of State

We relied heavily on the published and private work of the German researcher Dr. Eberhard Bender (refs. 3 to 5). The equations of state for all but carbon monoxide, neon, and helium are those published by Bender or developed by us using Bender's computer program.

The history of equation-of-state development is well delineated in the literature and only the important aspects of the authors' work will be mentioned. The modified Benedict-Webb-Rubin (BWR) virial equation (ref. 6) developed by Strobridge (ref. 7) was an important advance. The form of this equation is

$$P = P(T, \rho) = \sum_{i=1}^4 A_i(T) \rho^i + \sum_{j=1}^2 B_j(T) \rho^{2j+1} e^{-c\rho^2} \quad (1)$$

where  $P$  is the pressure and  $A_i(T)$  and  $B_j(T)$  are polynomials in  $T$  and  $T^{-1}$ . (All symbols are defined in appendix A and details are found in appendix B.)

This equation enabled PVT calculations to be made in the liquid and vapor phases with a single set of coefficients. The derived properties of enthalpy, entropy,  $(\partial P / \partial T)_\rho$ , and  $(\partial P / \partial \rho)_T$  could also be obtained. The equation, however, had several serious shortcomings: PVT predictions at the higher densities were greatly in error, calculations could not be made at the liquid-vapor boundary without an additional saturation equation, calculations could not be made in the two-phase or metastable region, and the  $\partial^2 P / \partial T^2$  did not give good values so that specific heats could not be calculated directly.

Bender (ref. 4), whose major interest was fluid mixtures, used a modified Strobridge-BWR equation with additional terms in the "i" summation to improve PVT predictions at the higher densities. This equation is

$$P = P(T, \rho) = \sum_{i=1}^6 A_i(T) \rho^i + \sum_{j=1}^2 B_j(T) \rho^{2j+1} e^{-c\rho^2} \quad (2)$$

where the explicit temperature-dependent forms of  $A_i(T)$  and  $B_j(T)$  and other functional forms are given in appendix B. Similar forms have been used by others (refs. 8 to 11) for better high-density predictions.

Several constraints have been found useful in the least-squares analysis of measured PVT data to obtain coefficients for equation (2). For example, Hust and Stewart (ref. 9) applied the principle of corresponding states to the Strobridge-BWR equations to fit carbon monoxide data. McCarty and Stewart (ref. 10) used the Joule-Thomson inversion locus as a constraint on their fit of neon data. However, Bender felt that the introduction of caloric data of lesser accuracy tends to compromise the accuracy of the fit to the PVT surface.

Bender (ref. 4) used the common constraints, see appendix C, with one important additional constraint. Bender was particularly interested in assuring thermodynamic consistency throughout the PVT surface and especially along the liquid-vapor boundaries so as to make possible the direct calculation of saturation properties from the equation of state. In order to accomplish this, he used a relation commonly referred to as the Maxwell phase rule (ref. 12) as an additional constraint in the least-squares fit. This relation

$$-\int_{V'}^{V''} P(V, T) dV + P_{\text{sat}} (V'' - V') = 0 \quad (3)$$

where

$$V \equiv \frac{1}{\rho}$$

is a formulation of the equilibrium condition which exists at the liquid-vapor boundary. It states that the sum of the surface areas between the theoretical isotherm of the state equation (metastable isotherm) and the stable straight-line isotherm of the wet-vapor region must be zero for a pure substance. The reader is referred to reference 3 for the complete analysis (also see ref. 5).

When an equation of state is obtained with the Maxwell-phase-rule constraint along with the other usual constraints (eq. (C6) to (C11)), saturation properties and metastable properties are directly calculable from equation (2). It should be noted that the GASP values for the critical parameters are the results of the least-squares fit but also agree well with reported values.

Bender's equations for methane, nitrogen, oxygen, argon, and carbon dioxide. - The ability of the coefficients in the Bender equation to represent the PVT surface for any particular fluid depends, of course, on the existence of consistent and accurate PVT data over the surface range of interest. These measurements are expensive, time consuming, and especially difficult in the near-critical region and along the liquid-vapor boundary, where accurate measurements are most necessary. Bender (refs. 4 and 5) carefully evaluated the existing data for the fluids methane, nitrogen, argon, oxygen, and carbon dioxide. We chose his equations of state for these fluids for GASP. The PVT ranges and critical parameters are given in table I. Bender carefully reported comparisons to the measured PVT data used in his curve-fits. Additional data sets and PVT predictions of other equations when available are herein compared to PVT predictions by GASP. As additional data become available (as is now the case for methane, refs. 13 and 14), the Bender coefficients could be reevaluated with the improved or extended-range PVT data sets. However, we are confident of the equations for these five fluids for all but the most critical user. Extrapolation of the equations used in GASP has been satisfactorily compared to more recent data, as discussed in the section Pressure-Temperature Extrapolations of the Bender Fluids.

Equations for carbon monoxide, neon, and helium. - The equations chosen for GASP for the fluids carbon monoxide, helium, and neon were the best available that were also compatible with the GASP program structure. They are, however, Strobridge-BWR-type equations fit on quite limited data sets without some of the constraints employed by Bender and recent researchers and investigators.

The equation for carbon monoxide (eqs. (B1) and (B2)) has been reported by Hust and Stewart (ref. 9). It is converted directly from the Strobridge nitrogen equation by using the Su principle of corresponding states. Since carbon monoxide has been of limited interest, the results are satisfactory at present.

The neon equation (eqs. (B1) and (B2)) is a slightly modified Strobridge-BWR equation reported by McCarty and Stewart (ref. 10). The helium equation developed by Mann (ref. 11) and Mann and Stewart (ref. 15) differs from the Strobridge-BWR equation in that the exponential term is a function of temperature (eqs. (B1) and (B2)). More recently, McCarty (refs. 16 and 17) presented an improved helium equation in a form not compatible to GASP. We attempted, unsuccessfully, to fit McCarty's recent helium data compilation to the Bender equation using Bender's program. The reasons for the failure have not been investigated. Any user wishing the best currently available subcritical temperature or near-critical temperature and pressure calculations for helium should use reference 17 or a program by the authors, HELP,<sup>1</sup> based on references 16 and 17. The helium equation (ref. 11) in GASP should be considered valid above 6 K.

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<sup>1</sup>Internal NASA program for IBM 7094-7044, IBM 360-67, and Univac 1106.

Equations for fluorine and parahydrogen. - Prydz and Straty (ref. 18) have recently measured PVT data for fluorine. Their report on the properties of fluorine and on the entire  $F_2$  PVT data set used by Prydz (including his own and other researchers) was chosen as the best and most up-to-date source for fluorine. The coefficients which we obtained for fluorine,<sup>2</sup> table II, by using Bender's curve-fitting technique compare well with the data as reported in the next section.

We found no single coefficient set for the fluid parahydrogen, although its properties are and have been of much interest. Many limited-range equations, especially the early work of Roder and Goodwin (refs. 8 and 19) have been available in computerized forms. Tables of smoothed hydrogen data and their extrapolations have been compiled and computerized, the most popular being the NBS TABCODE computer program.<sup>3</sup> A most recent publication by McCarty and Weber (ref. 20) uses several equations of state, depending on the region of interest, and includes many useful parahydrogen properties over a wide PVT range.

We wanted a coefficient set for a Bender parahydrogen equation to use in GASP that could also compare favorably to reference 19. Goodwin's parahydrogen data set and Bender's curve-fit program were used to develop a set of coefficients (table II) that predict parahydrogen PVT data quite well and can also reproduce the NBS high-pressure PVT extrapolations of reference 20. The simplicity of this Bender-type equation (eq. (2)) compared to the computerization of reference 19 should be preferable for all but the most critical user.

### Calculation of Transport Properties

Transport properties are related to the dynamics of the system (e.g., viscosity to fluid flow, and thermal conductivity to heat transfer). Precise measurements in such systems are extremely difficult, and errors of over 5 percent in the gaseous phase and 15 to 20 percent in the dense-gas or liquid phase are not uncommon. Consequently, at this point in the development of GASP, we chose to abandon "precision" in favor of consistency. In order to do this, we chose generalized forms for fitting the transport properties which, for the most part, are (1) functions of only temperature for the dilute gases and (2) functions of only density (excess data, i.e.,  $\mu - \mu^*$  and  $k - k^*$ ) for dense fluid regions. Such representations can obviously lead to erroneous results. For example, thermal conductivity data near the critical density but at 1.5 times the critical temperature are not representative of all data along the critical isochore, as would be implied; and viscosity coefficients are temperature sensitive at reduced densities greater than 2.

<sup>2</sup>The derived properties of fluorine need further work. The authors recommend that the user check the results above 1 MPa (10 atm). The extensive PVT data were made available from NBS.

<sup>3</sup>Available from H. M. Roder, National Bureau of Standards, Boulder, Colorado.

Viscosity. - The dilute-gas viscosity for all fluids in GASP, with the exception of hydrogen, is based on the simplified Chapman-Enskog model (ref. 21)

$$\mu^* = 0.2669 \times 10^{-4} \frac{\sqrt{MT}}{\sigma^2 \Omega^*(2, 2)} \quad (4)$$

The dilute-gas viscosity for hydrogen is based on the work of Diller, Hanley, and Roder (ref. 22). Extensions of this work to higher temperatures (1000 K) proved satisfactory. However, above 1000 K, the Chapman-Enskog model was again used.

The Enskog dense-gas theory suggests that an excess in viscosity can be treated as a function of density alone. From the work of Jossi, Stiel, and Thodos (ref. 23), this seems justified for the fluids in GASP and was modified and adopted for use herein.

$$[\xi(\mu - \mu^*) + 10^{-4}]^{1/4} = \sum_{i=0}^4 a_i \rho_R^i \quad (5)$$

where

$$\xi = \frac{T_c^{1/6}}{M^{1/2} P_c^{2/3}}$$

The formulation appears valid except for dissociation and some regions beyond  $\rho_R = 2$  where some temperature dependence can be noted. For fluorine, a small correction factor was added, based on the work of Hanley<sup>4</sup>.

The regions covered and the specific formulation and coefficients used are given in table X and appendix B.

Thermal conductivity. - Eucken proposed that the dilute-gas thermal conductivity be the sum of translational and internal molecular energies times some factor

$$\frac{kM}{\mu} = \sum f_i C_i \quad (6)$$

The Mason and Monchick model (ref. 24) gives the sum as

$$\sum f_i C_i = 1.32 C_v + 1.77 R - 0.917 \sum \frac{C_v}{Z} \quad (7)$$

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<sup>4</sup>Private communication with H. J. M. Hanley of National Bureau of Standards, Boulder, Colorado.

where  $Z$  represents the collision number. Brokaw (ref. 25) determined a simple empirical form for the sum

$$\sum f_i C_i = 1.24 C_v + 2.54 \quad (8)$$

While the preceding equations are the basis of dilute-gas theory and used to determine the thermal conductivity of fluorine, empirical formulations given by Stiel and Thodos (ref. 26) and by Roder and Diller (ref. 27) for hydrogen are used in GASP. Reference 26 gives a reduced form

$$\log_{10} \left( \frac{k^*}{k_c^*} \right) = \sum a_i T_R^i \quad (9)$$

while reference 27 gives a slightly more elaborate form for the sum. See appendix B and table X for specific forms and coefficients and table III for the sources of the constants and coefficients.

For the dense-gas region, excluding near critical, the excess thermal conductivity (like viscosity) is a function of density alone. The exceptions here are the thermal conductivities of helium and hydrogen near the saturation boundaries, which are also functions of temperature. These fluids are handled separately and use the fits determined by McCarty and Roder (refs. 16 and 28) and by Roder and Diller (ref. 27) for helium and hydrogen, respectively. For other fluids covered by GASP, the formulation of Stiel and Thodos (ref. 26) is used:

$$\log_{10} [(k - k^*) Z_c^5 \lambda] = \sum_{i=0}^4 a_i (\log \rho_R)^i \quad (10)$$

where

$$Z_c = \frac{P_c}{R \rho_c T_c}$$

and

$$\lambda = \frac{\sqrt{M} T_c^{1/6}}{P_c^{2/3}}$$

It is expected that none of the results from these equations can be any better than  $\pm 5$  percent in the gas phase and  $\pm 15$  percent in the liquid or dense-fluid phase. Diller, Hanley, and Roder (ref. 22) report that even higher errors may be likely because of our inherent lack of understanding of the problem. However, current work by Sengers, LeNeindre, Tufeu, and Bury (refs. 29 and 30), Hanley, and others should bring these problems sharply into focus in the near future.

### Calculation of Anomalous Properties

Thermal conductivity. - The anomalous behavior of the thermal conductivity in the region near the thermodynamic critical point is directly related to the specific heat at a constant pressure; see, for example, Roder and Diller (ref. 27) and Brokaw (ref. 25). In reference 31 the authors compare the techniques of Brokaw and of Sengers and Keyes (ref. 32) and conclude that both techniques are capable of reproducing the carbon dioxide data. However, the technique of Sengers and Keyes (ref. 32), as extended to other fluids in reference 31, was adopted because of its simplicity, accuracy, and relation to the scaling laws. GASP returns the anomalous thermal conductivity values for the region  $0.4 \leq \rho_R \leq 1.6$ . However, to obtain the total thermal conductivity, the anomalous value must be added by the user to the thermal conductivity

$$k_{\text{total}} = k + \lambda_r \quad (11)$$

More recent work of Sengers, LeNeindre, Tufeu, and Bury (refs. 29 and 30) indicates that an acceptable theoretical approach based on scaling laws and molecular potentials may be developed.

Viscosity. - Quite close to the thermodynamic critical point, viscosity also exhibits anomalous behavior. Unlike thermal conductivity, where the anomalous behavior is very strong, the anomalous behavior of viscosity appears quite weak and more closely parallels the behavior of  $C_V$ . In simplified terms, the near-critical behavior (along the critical isochore) can be thought of in terms of the function

$$|1 - T_R|^{-p} \quad (12)$$

where

$$p = 1.2 \text{ to } 1.3 \quad \text{for thermal conductivity}$$

and

$$p = 0.04 \text{ to } 0.06 \quad \text{for viscosity}$$

The effect, for viscosity, appears quite weak and is not calculated herein.

Surface tension. - In 1894, van der Waals suggested that the behavior of the surface-tension group with temperature follows a power law,

$$\frac{\sigma}{T_c^{1/3} P_c^{2/3}} = C_\sigma (1 - T_R)^p \quad (13)$$

where  $C_\sigma$  and  $p$  are constants. Brock and Bird (ref. 33) determined that  $C_\sigma$  varied with the Riedel factor  $\alpha_c$ :

$$C_\sigma = 0.133 \alpha_c - 0.281 \quad (14)$$

where

$$\alpha_c = \left[ \frac{d \ln P_R}{d \ln T_R} \right]_c$$

and

$$p = 11/9$$

The Brock and Bird equation is used in GASP to determine surface tension. However, the equation is not applicable to hydrogen or helium because of quantum effects, and consequently we used pseudocritical values for these fluids. Details of the equations and coefficients are found in appendix B.

## EVALUATION (RESULTS)

### Pressure-Volume-Temperature Comparison

We have evaluated Bender's equation of state for methane, nitrogen, oxygen, argon, carbon dioxide, fluorine, and parahydrogen by comparing GASP-calculated PVT values to the measured PVT data of several investigators. The comparisons presented for most fluids are in the near-critical range or near the two-phase boundary. Although we made

other comparisons, those in the near-critical range are the most revealing since this portion of the PVT surface is the most difficult to represent by an equation of state valid for the whole surface.

The comparisons for the fluids fit by the authors, fluorine and parahydrogen, and for a fluid of interest to the Lewis Research Center's Aerospace Safety Research and Data Institute, oxygen, are made with most of the available data for the fluid as furnished to the authors by the NBS Cryogenic Data Center. Comparisons of data to values calculated from a state equation for carbon monoxide and neon can be found in references 9 and 10, respectively.

The results of these comparisons are presented as figures 1 to 18 and summarized in table IV. The measured PVT data are the standard for comparison, and three plots are shown for each set with the percent deviations plotted as the ordinate and the reduced compared parameter, T, P, or  $\rho$  in that order, as the abscissa for each fluid.

Methane. - Figure 1 compares GASP-calculated PVT data for methane to the data of Jansoone, Gielen, DeBoelpaep, and Verbeeke (ref. 34). The temperatures are within  $\pm 0.1$  percent, and the pressures generally agree within -0.5 to 1.0 percent. The densities show some irregularities near  $P_R = 0.98$ ; but since the temperature range is within  $\pm 2$  K of the critical value (190.77 K), this is expected. In general, the GASP program will show significant deviations slightly below the critical point, but it is good above the critical point. This may be caused by the mismatch, near the critical point, between Bender's saturation data and the vapor pressure equation used in GASP (eq. (B18)). While reference 34 presents an equation that predicts these data very well, the equation is valid only for the near-critical range.

The PVT data of Vennix (ref. 35) for methane are compared in figure 2. The GASP-calculated temperatures are within  $\pm 0.25$  percent of the Vennix data, except for a few points which are within  $\pm 1.0$  percent; the pressures are generally within  $\pm 1.0$  percent, with more than one-half of the pressure values agreeing within  $\pm 0.5$  percent.

A few pressures near the maximum density range ( $\sim 2.5 \rho_c$ ) show deviations greater than 2 percent. The GASP densities are within  $\pm 2.5$  percent, with most of the values within  $\pm 1.0$  percent. One density value at 190.80 K showed a 6.5 percent deviation from the Vennix data. Vennix (ref. 35) presented an equation of state for methane with 24 coefficients which predicts his PVT data with about the same deviation in pressure as the Bender equation in GASP (fig. 3). The claimed density predictions of reference 35 are better than the GASP values. We tested the Vennix equation and found it unacceptable for PVT and derived property calculations at temperatures less than  $\sim 155$  K and for some higher ranges in derived properties.

The PVT data of Goodwin (ref. 13) for methane are compared in figure 4. The GASP-calculated temperatures are within -0.8 to 0.3 percent, with most data within  $\pm 0.2$  percent and major departures confined to  $0.7 < T_R < 1$ . The calculated pressures are most satisfactory for  $P_R > 1$ , with deviations of -0.5 to 3.0 percent, and least

satisfactory at very low pressures, where there are five points with deviations above 20 percent. The calculated densities are within  $\pm 0.5$  percent, except in the critical region ( $\rho_R \sim 1$ ), where departures of -3 to 2 percent are noted.

Nitrogen. - The Strobridge PVT values for nitrogen were calculated by using equation (1) and necessary constants from reference 7. The equation was extrapolated to 1000 K and 50 megapascals (or MN/m<sup>2</sup>). As might be expected, these extrapolated PVT data show the largest deviations from Bender's results. The results in figures 6 to 8 show temperatures within  $\pm 2$  percent for densities less than  $2.5 \rho_c$ . The temperature deviation in the dense liquid ranges to -4 percent, with the largest errors at the highest densities. The pressures are within  $\pm 5$  percent, except for the dense-liquid low-temperature region, where deviations to -10 percent and greater are found. The Strobridge fit is inadequate in this portion of the PVT surface, and we consider Bender's values more accurate than the Strobridge-BWR fit of the standard PVT surface. The densities, figure 6(c), are within  $\pm 2.0$  percent, except for deviations near the critical isochore.

Figure 9 compares calculated PVT values with the liquid-saturation and near-critical data of Weber (ref. 36). The density comparison is most crucial in the near-critical area of the PVT surface. The values calculated by GASP are within  $\pm 0.5$  percent, except for data on two isochores at 0.265 and 0.467 g/cm<sup>3</sup>, where deviations are from -3.0 to 1.0 percent. The liquid values (high density) predicted by Bender are lower than those of Weber by approximately 0.003 g/cm<sup>3</sup>, while the Bender density along the 0.265-g/cm<sup>3</sup> isochore is slightly higher. Figure 10 is discussed later.

Coleman and Stewart (ref. 37), after an exhaustive compilation of the literature, derived an equation of state similar to that of Strobridge (ref. 7). A comparison of this wide-range PVT equation presented in reference 38 with the Bender fit indicated little difference in PVT results. However, the equation was judged unacceptable because of anomalous calculated derived properties and also because it was the more complicated form.

Oxygen. - From the PVT data of Weber (ref. 39), 1352 data points were used by Bender (ref. 4) in his oxygen fit. We compare 1478 PVT data points from reference 39 with those computed from GASP in figure 11. Most temperatures are within  $\pm 0.15$  percent, including the PVT saturation data. The majority of the pressures are within 1 percent, except in the high-density region ( $\rho > 2.5 \rho_c$ ), where 1 to 2 percent deviations are common and a few deviations to 20 percent are found at very low temperatures (<70 K). Most densities are within  $\pm 0.2$  percent, except in the critical region, where the maximum deviation is  $\pm 2$  percent. Figure 12 is discussed later.

Argon. - Subcritical PVT data for argon reported by Van Itterbeek, Verbeeke, and Staes (ref. 40) are compared with GASP-computed values in figure 13. The temperatures agree within  $\pm 0.3$  percent, with most being within  $\pm 0.1$  percent. The pressures are within  $\pm 5$  percent, with a few errors to 10 percent for the 90 to 110 K range. The

densities are in excellent agreement, with more than one-half the Bender values being within  $\pm 0.1$  percent of the data. We noted two discrepancies in the plotted and tabulated data of reference 40, so the temperature value selected for two of the isotherms may be in error by 0.05 K.

Carbon dioxide. - The PVT data of Michels, Blaisse, and Michels (ref. 41) are compared to the GASP-calculated carbon dioxide values in figure 14. A few values listed in reference 41 were in the GASP two-phase region and are not considered. The temperatures are within  $\pm 0.1$  percent. The pressures are within  $\pm 0.5$  percent, except for three deviations to 5 percent at the highest measured density. The density deviations are well scattered within  $\pm 4$  percent.

Helium. - Helium values for five isobars and a temperature range of 2.5 to 1500 K were calculated by using McCarty's three-region fit (ref. 17) as the best available source for comparison. The comparison to the Mann equation used in GASP is shown in figure 15 (eqs. (B1) and (B2)). The temperatures are within  $\pm 1$  percent, except for near-critical deviations to 3 percent and dense-liquid ( $\rho > 2.8 \rho_c$ ) deviations to  $\pm 10$  percent. The pressures are within  $\pm 0.1$  percent for  $T > T_c$  and within  $\pm 10$  percent at subcritical temperatures. Large density deviations occur in the near-critical region (3 to 6 K), and elsewhere density agrees within 1 percent. The PVT range for helium based on Mann's equation from reference 11 (table I) is quite limited compared to reference 17. Therefore, part of the comparison is really an extrapolation and hence subject to uncertainty. We do not recommend the use of Mann's equations in GASP for  $T < 6$  K.

Fluorine. - An extensive compilation of the thermodynamic properties of fluorine has been made by Prydz and Straty (ref. 18), including 850 points of measured PVT data. These data and saturation data from reference 42 were used by the authors to obtain the fluorine coefficients in table II. The comparisons are shown in figure 16. The temperatures are within  $\pm 0.15$  percent, except for very low temperatures, where a few deviations are near 1 percent. The pressure errors are within 1 percent, except for the region where densities are greater than  $2.5 \rho_c$  (melting locus) and temperature is less than 90 K, where larger errors occur. The densities are within  $\pm 0.5$  percent, except near the critical isochore or isotherm, where deviations to 3 percent occur.

Parahydrogen. - The parahydrogen data compiled by Roder, Weber, and Goodwin (ref. 19) and by McCarty and Weber (ref. 20) are compared to GASP-calculated values in figures 17 and 18.

The temperatures agree within  $\pm 0.25$  percent, except for a few points which deviate to  $\pm 0.5$  percent. The pressures are within  $\pm 1$  percent, except for several points in the near-critical area or near the melting locus. The densities are within  $\pm 0.5$  percent, except near the critical isochore, where deviations to  $\pm 3$  percent occur. Densities greater than  $0.06 \text{ g/cm}^3$  are all within  $\pm 0.1$  percent. The critical density  $\rho_c$  of reference 19 is  $0.03142 \text{ g/cm}^3$ , whereas the  $\rho_c$  we determined in the Bender fit is  $0.0311 \text{ g/cm}^3$ .

Additional comparisons. - The derived properties for all the fluids were compared to the existing standard data source for the fluid published by the National Bureau of Standards (e.g., refs. 9 to 11, 17, 39, and 43). The results are in excellent agreement for most fluids, except for small differences in the critical and dense-liquid regions in the specific heats and the velocity of sound. Slight differences in calculated pressure in the dense-liquid region result in larger differences in the  $(\partial P/\partial T)_\rho$  and  $(\partial P/\partial \rho)_T$  and much larger differences in  $(\partial^2 P/\partial T^2)_\rho$  (e.g.,  $C_v$  for neon and carbon monoxide along the saturation locus can be negative). Also slight differences in the calculated densities near the critical region can cause problems when comparing derivatives. The critical parameters used in GASP are the least-squares-determined values, whereas the NBS standard reports correct the equation of state along the two-phase boundary and in the near-critical region to agree with known measured parameters, including  $C_v$ , in this region.

For all but the most critical user, the GASP-derived values are compatible with standard references for each fluid. The exceptions are carbon monoxide, neon, and helium, where nothing better than GASP is available for the first two fluids. McCarty's helium references are to be used in preference to GASP for all subcritical or high-density helium derived-property calculations.

### Pressure-Temperature Extrapolations of the Bender Fluids

Recent interest in both very low- and very high-pressure results for hydrogen and oxygen prompted us to attempt calculations in this range using GASP.

Low pressure. - Results in the low-pressure region for both hydrogen and oxygen show that the equation approaches ideality at  $10^{-4}$  megapascal, as verified by the calculated isotherm and isochore derivatives.

High pressure and high temperature. - High-pressure-hydrogen extrapolations were compared with the data of McCarty and Weber (ref. 20). We were amazed at the excellent agreement, as shown in figure 19 for density,  $(\partial P/\partial T)_\rho$ , and  $(\partial P/\partial \rho)_T$ . The density deviations are systematic with pressure, yet within +0.5 to -1.5 percent, except at 68.948 megapascals ( $10^4$  psia), where deviations near  $\rho = 1.5 \rho_c$  are closer to +0.6 to -1.8 percent. Deviations in  $(\partial P/\partial T)_\rho$  and  $(\partial P/\partial \rho)_T$  are most significant near 300 K, yet are less than  $2\frac{1}{2}$  percent for the extended temperature range 600 to 2779 K. Since the range of reference 8 is to 300 K, the disagreement may be due to matching of regions. The agreement is remarkable over the extended range to 2779 K and 68.948 megapascals ( $10^4$  psia) as Bender's equation uses no dissociation corrections. Reference 20 is a multiregion approximation, while the Bender extrapolation is only one equation.

Streett<sup>5</sup> measured PVT data for oxygen along six isotherms (96, 100, 110, 170, 190, and 250 K) with pressure varying to 680 atmospheres. High-pressure-oxygen extrapolations were made to these data, as illustrated in figures 20 and 21. As with the hydrogen, the extrapolation seems remarkably good, except for low pressures and high temperatures. Such results are inconsistent with the remarks of reference 39. At the higher densities (high pressure and low temperature), which is the region of major interest, the deviations in pressure are less than 3 percent for  $P > 0.8 P_c$ , the deviations in density are less than  $\pm 0.05$  percent, and the deviations in temperature are less than  $\pm 0.2$  percent ( $T < 170$  K) and less than 0.2 to -1.6 percent for all the data.

The extrapolations necessary for Joule-Thomson calculations were consistent with other published values and are presented in reference 38. In general, the temperature range can be increased with greater confidence (up to dissociation) than the pressure range. The best extrapolated results come from extending the temperature range for oxygen and parahydrogen. Also, the helium temperature (but definitely not pressure) extrapolations give good results. The maximum range for each fluid (table I) includes extrapolated limits, where we found the errors to be within the same range as the errors in the original fitted surface.

The melting locus is not programmed in GASP and would be useful for calculations in the very dense liquid region.

#### Pressure-Volume-Temperature Comparisons to Other Equations of State

The comparison, given in reference 38, of the Coleman-Stewart equation (ref. 37) to the Bender fit can also be considered part of this section (see the discussion of nitrogen in the section Pressure-Volume-Temperature Comparison and fig. 7). The basic equation for comparison here was developed by Stewart, Jacobsen, and Meyers (ref. 44). It is a 33-term modified BWR equation and is readily adapted to equation (B1), where  $N = 9$  and  $M = 6$ . Other differences are found in the specific form of the coefficient arrays and the appearance of a  $\sqrt{T}$  term. The specific forms are found in appendix D.

In order to put the Stewart formulation into GASP, a number of changes had to be made. A few problems in operation were encountered. This formulation involves rather large powers of density, which gave exponents greater than  $10^{\pm 35}$ . Convergence to a meaningful density on an IBM 7094-7044 type machine was not found, except for the gaseous region, where the exponentials are not important. The equations as such are not easily run on machines such as the 7094-7044. Double precision does not alleviate the problem. In order to make the following comparisons, the equation had to be reprogrammed in double precision on the IBM 360-67, which carries exponents to  $10^{\pm 88}$ . Even there, underflows were quite often encountered, but most times convergence on

<sup>5</sup>Unpublished data taken by William B. Streett, U. S. Military Academy, West Point, N. Y.

density and calculation of pressure gave meaningful results.

Nitrogen - generated "data." - While a consistent set of nitrogen data is not available, several comparisons can be made in figure 7. The PVT values were compared by inputting either  $(P, T)$ ,  $(P, \rho)$ , or  $(\rho, T)$  as generated by GASP into the equation of Coleman and Stewart (ref. 37). The deviations are quite small, but a change in form of equation (B1) does not appear warranted.

In figure 8 a similar comparison was made to the 33-term modified BWR equation of Stewart, Jacobsen, and Meyers (ref. 44). Generated  $P, T$  data gave a comparison of deviations in density, as shown in figure 8(b). The deviations are well within 1 percent, with increased deviations at higher densities. However, the generated density, when inputted into the 33-term equation, did not always properly converge, and significant deviations for  $T < T_c$  were noted.

We then generated  $\rho, T$  and compared the deviations in calculated pressure. Again the deviations for  $T < T_c$  or  $T \leq T_{sat}$  in the liquid region were large, and the convergence not always assured. The technique of solution and the cause of these irregularities require further investigation.

Nitrogen - measured data. - Figure 10 compares the calculated values of reference 44 with the near-critical nitrogen data of Weber (ref. 36). The deviations in pressure (-1 to 3 percent, fig. 10(a)) appear slightly better than those of figure 9(a). The deviations in density range from 1.5 percent at low densities to  $\pm 0.1$  percent at higher densities (fig. 10(b)) and also appear slightly better than those of figure 9(b).

Methane. - The recent methane data of Goodwin (ref. 13) represent an accurate consistent set of PVT measurements for fluid methane. Using these data and the techniques of Hust and McCarty (ref. 45), McCarty (ref. 46) developed a Stewart-type equation, and the relative errors in pressure are given as figure 5(a). For the most part, the relative error falls between  $\pm 1$  percent, with the exception of a few points at lower pressure (with rather large deviations,  $\sim 10$  percent) and some near the critical pressure. The density deviations of figure 5(b) are for the most part within -0.25 to 0.5 percent, except for a few points near the critical density.

Comparing figure 4(b) with 5(a) and figure 4(c) with 5(b) gives

Parameter	Region	Equation of state (eq. (B1))	
		$N = 6, M = 2$ (Bender-type equation, ref. 4)	$N = 9, M = 6$ (Stewart-type equation, ref. 44)
Pressure	Low	A few points (5) to 40 percent	A few points (4) to 10 percent
	Near critical	A few points to 10 percent; for the most part, 1 to 5 percent -1 to 3 Percent	$\pm 2$ Percent $\pm 1$ Percent -0.7 to 1 Percent
	High		
Density	Near critical	-2 to 1.5 Percent	$\pm 0.2$ Percent
	Other	-0.3 to 0.1 Percent	-0.25 to 0.6 Percent
	High only	-0.4 to 0.05 Percent	-0.2 to 0.05 Percent

The McCarty fit (ref. 46) of the Goodwin data does represent the data more accurately than the Bender-type fit. However, a refit of methane using the Goodwin data may also prove fruitful.

Oxygen. - The data of Weber (ref. 39) represent an accurate and consistent set of PVT data for fluid oxygen. These data and the Bender-type equation are compared in figure 11. When the 33-term equation and coefficients as determined by Stewart, Jacobsen, and Meyers (ref. 44) are used, the relative error in pressure appears as in figure 12(a). The relative error at low pressure appears systematically scattered about  $\pm 2$  percent, with a few points outside this range. At higher pressure the scatter appears about  $\pm 1$  percent, again a few points outside this range. The relative error in density is illustrated in figure 12(b). For the most part the scatter is within  $\pm 0.1$  percent, except near the critical density and some points at rather low densities.

Comparing figure 11(b) with 12(a) and figure 11(c) with 12(b) reveals

Parameter	Region	Equation of state (eq. (B1))	
		$N = 6, M = 2$ (Bender-type equation, ref. 4)	$N = 9, M = 6$ (Stewart-type equation, ref. 44)
Pressure	Low	$\pm 2.5$ Percent	$\pm 2$ Percent
	High	$\pm 1.5$ Percent	$\pm 1$ Percent
Density	Near critical	$\pm 2$ Percent	$\pm 0.8$ Percent
	Other	$\pm 0.3$ Percent	$\pm 0.1$ Percent

From these comparisons, either equation can be used with good results, except in predicting density near the critical point, where the Stewart-type equation is better.

Parahydrogen. - The parahydrogen data of Goodwin (refs. 8 and 19) represent probably one of the most exhaustive PVT studies in the literature. We used these data to determine a Bender-type equation (eq. (B1)) for parahydrogen. The PVT comparisons are made in figure 17. When the 33-term equation and coefficients as determined by Stewart (ref. 44) are used, the relative error in pressure is given as in figure 18(a). The relative errors lie for the most part between  $\pm 1$  percent at low pressures and  $\pm 0.5$  percent at high pressures. The relative errors in density (fig. 18(b)) are for the most part within  $\pm 0.2$  percent, except near the critical density, where errors to  $\pm 0.7$  percent are noted. Cross-comparing the relative errors of figure 17(b) with 18(a) and figure 17(c) with 18(b) reveals

Parameter	Region	Equation of state (eq. (B1))	
		N = 6, M = 2 (Bender-type equation, ref. 4)	N = 9, M = 6 (Stewart-type equation, ref. 44)
Pressure	Low	-0.5 to 1.5 Percent	-1.0 to 0.8 Percent
	Moderate	$\pm 0.2$ Percent	$\pm 0.4$ Percent
	High	$\pm 0.3$ Percent	$\pm 0.5$ Percent
Density	Near critical	$\pm 2$ Percent	$\pm 0.6$ Percent
	Other	-0.3 to 0.2 Percent	$\pm 0.2$ Percent

It would appear that the Bender-type equation is superior except in predicting density in the near-critical region, where clearly the number of constraints of reference 44 (13 additional terms) does appear helpful.

The greatest advantage of having a single accurate and consistent set of data to derive a curve fit is the accuracy with which it reproduces the data. This is readily obvious from the parahydrogen results, where both McCarty (ref. 46) and the authors used Goodwin's data to develop a PVT surface. The results are self-evident. There is virtually no improvement in predicting the PVT surface, except for density near the critical point. Here the extra terms do seem to merit use.

While similar remarks can be made for oxygen, methane serves as an example of not having a self-consistent set of data available (e.g., the comparison of the Bender-fit to the McCarty fit in the section Methane). Clearly, the McCarty fit is better. The question as to whether it would be better if all the methane data were used in the fit still remains to be investigated.

Some current drawbacks in changing to a 33-term equation (Stewart type) are as follows:

- (1) The coefficients are available for only four fluids. Thus, several refits would be required.
- (2) Such an equation is limited to specific computing machines
  - (a) Because it requires double precision,  $10^{+88}$  capability, additional storage, and data set modifications
  - (b) Because exponentials can become sufficiently large as to cause overflow and underflow
- (3) Thirteen additional constants (i.e., 33 as opposed to 20 for the Bender-type equation) are required.
- (4) The first virial coefficient is not a polynomial.

Some current advantages in changing to a 33-term equation are

- (1) Better PVT representation of the near-critical region and along the freezing locus
- (2) Better behavior of  $\partial^2 P / \partial T^2$  at low temperatures (One may not have to use numerical determination of  $C_v$  in this range, as is now done in GASP.)

At this time, we feel that the Bender-type equation will provide adequate physical properties for all but the most critical user. However, the revision of the Bender-type equation is under consideration. And as delineated in the INTRODUCTION, we suggest that this report represent an ongoing program where revision can be made as more information becomes available.

#### USER'S GUIDE TO GASP

Researchers interested in thermodynamic property calculations generally require highly accurate results; another class of user requires high-speed access; while still another class requires moderate accuracy and access time. Calculations for such projects as a final analysis or calibration, scientific calculations, or tabulated data require the best accuracy attainable. Speed and core storage are of lesser concern. For this purpose, isochores and isotherms of the best data available are used to obtain PVT data and derived properties. The user is usually working with a limited portion of the PVT surface and is not too concerned about the consistency of the whole surface.

Cycle or system analysis, simulation for Skylab, or flight simulation are examples of calculations requiring speed and having limited core storage. Tabular look-ups or interpolation with limited-range equations using few coefficients provide the greatest speed and the least core storage. The parahydrogen computer program TABCODE<sup>6</sup> is an example. Depending on the grid of the table or the spacing of the polynomial ranges, accuracy can be obtained, but thermodynamic consistency is not guaranteed.

Most calculations with test data from thermodynamic-related experiments require both accurate, thermodynamically consistent properties and efficient calculation methods. Usually, a wide range of the PVT surface is needed. For this type of calculation the equation-of-state method is best. The equation can be almost as accurate as the data from which it is obtained, and it is flexible and consistent over a wide range of the PVT surface. The core storage required is less than for the isochore-isotherm system, and the computing speed is much greater.

It is for the user requiring both accuracy and speed that GASP is written. Some users requiring only accuracy can use GASP until their calculations need a final accurate value. The user requiring speed can use GASP to generate tables for portions of the PVT surface to use for interpolation.

This section gives operating instructions for GASP designed for the user with limited programming experience. Table V, the operations sheet, and table VI, the units specification instructions, are provided for handy reference for the experienced GASP user, while table VII provides the user with time estimates for the various calls to GASP.

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<sup>6</sup>Available from H. M. Roder, National Bureau of Standards, Boulder, Colorado.

## HOW GASP HANDLES INPUT AND OUTPUT

GASP is a group of subroutines designed to be used as a subprogram with the user's program. Standard communication between the user's program and GASP is achieved by the following three FORTRAN statements, which contain the symbols representing the input and output parameters and options:

COMMON/PROPTY/KU, DL, DV, HL, HV, etc.

CALL SETUP (NAMGAS)

CALL GASP (KS, KP, T, P, D, H, KR)

See appendix A for definition of symbols and table V for operation modes.

Four requirements must be fulfilled for a successful call to GASP:

(1) The cards for COMMON/PROPTY/KU, DL, DV, etc., must be included in the user's main program or subroutine that calls GASP. The GASP subprogram deck must be correctly loaded with the user's program as shown in table VIII. The variables MU, MUL, K, KL, and KV must be declared REAL. You cannot use K as an index for a subscripted variable; however, the user can change the names of these variables in COMMON/PROPTY/. . . .

(2) The units system for input and output must be correctly specified. The input control KU is specified in the COMMON/PROPTY/KU, DL, DV, etc., and must be set such that  $1 \leq KU \leq 5$ . KU identifies the units system for input and output, and KU is never altered by GASP. Therefore, unless the user switches from one system to another, he need set his value for KU only once, before any calls to subroutine GASP.

There are three specific units options described in table VI. The option KU=1 is the units system internal to the program. The other two options are commonly used in engineering calculations. If the user does not wish to use one of these options, he can specify any desired units system for KU=4 and KU=5, provided the conversion factors for this system are stored as directed in table VI.

(3) The call to SETUP must be made before any calls to GASP and is reissued for each change in fluid. (All subroutines are described in appendix F.) The variable NAMGAS in the call statement is a Hollerith code for the fluids:

Fluid	Hollerith code	Fluid	Hollerith code
Parahydrogen	H2	Nitrogen	N2
Helium	HE	Oxygen	O2
Methane	CH4	Fluorine	F2
Neon	NE	Argon	AR
Carbon monoxide	CO	Carbon dioxide	CO2

Since many coefficients are put into the program COMMONS by SETUP, it is recommended that all calculations for one fluid be made before changing fluids.

(4) The controls KR, KS, and KP which tell GASP what variables are to be used as input and what properties are requested for output must be correctly initialized in the call statement for subroutine GASP. The corresponding input variables in the call statement and COMMON/PROPTY/... must also be correctly initialized.

The controls KS and KR determine which of the variables T, P, D, H, or S or combinations thereof are needed as thermodynamic input. The input control KP specifies which properties are sought as output. KR is also an output variable since it gives the correct region number for the variables in a specific call to GASP, as shown by the sketch in table V. Depending on the input for KS and KP, the other possible output variables are T, P, D, H, and all of COMMON/PROPTY/ except the control KU.

As mentioned above, KR is both input and output and must be reset before each call to GASP. The input options are

- (1) KR=0 when the user wishes GASP to determine a value for KR
- (2) KR=1 when the user wishes saturation conditions<sup>7</sup>

The output for KR will be

- (1) KR=1 for saturation
- (2) KR=2 for liquid
- (3) KR=3 for vapor

The control KS specifies which variables are to be used as input for a call to subroutine GASP. (In the remaining discussion on GASP input and output, the input variables are assumed to be in user's units specified by KU. Output is always returned in the KU system of units.)

The following table shows the input and output for all KS, KR combinations:

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<sup>7</sup>Saturation or coexistence conditions exist on the PVT surface when pressure is a function of only temperature and the liquid and vapor states both exist at that pressure. Thus, when KR=1, two outputs for each property are available in COMMON/PROPTY/ and only one independent variable is required for some input options, as shown in the KS-KR input/output chart (table V).

To find saturation properties given temperature T1: prior to the call to GASP, set P=0, T=T1, and KR=1. Select the proper KP and CALL GASP(KS, KP, T, P, D, H, KR). The saturation pressure is returned as P. All other properties are in COMMON/PROPTY/etc.

To find saturation properties given pressure P1: follow the above procedure except set T=0 and P=P1. The saturation temperature is returned as T.

If you give GASP both T and P, it uses T and does not alter P.

KR	KS				
	1	2	3	4	5
Input					
0	T and P	T and D	P and D	P and H	P and S
1	T or P <sup>a</sup>	T	P	P	P
Output					
1	T or P <sup>a</sup> , DL and DV	P	T	T, DL, and DV	T, DL, and DV
2	D	P	T	D and T	D and T
3	D	P	T	D and T	D and T

<sup>a</sup>See footnote 7, p. 21.

The input control KP specifies which derived and transport properties are requested by the user. It is the sum of the individual KP options and is described in table V. This binary sum allows GASP to uniquely identify any combination of requests. The following table shows the output locations for the specific KR, KP combinations:

Value added to KP input	Output for KR=2 or KR=3	Output for KR=1		Name of calculated property
		Liquid	Vapor	
0	-----	-----	-----	None requested
1	H	HL	HV	Enthalpy
2	S	SL	SV	Entropy
4	CP	CPL	CPV	Specific heat at constant pressure
	CV	CVL	CVV	Specific heat at constant volume
	GAMMA	GAMMAL	GAMMAV	Specific-heat ratio
	C	CL	CVP	Sonic velocity
8	MU	MUL	MUV	Viscosity
16	K	KL	KV	Thermal conductivity
	EXCESK	EXCL	EXCV	Anomalous thermal conductivity
32	SIGMA	SIGMA	-----	Surface tension of fluid as function of temperature

## TROUBLESHOOTING FOR USER ERRORS

After experience with GASP, we have found that several common errors are easily detected and corrected:

- (1) Failure to set  $1 \leq KU \leq 5$  will cause a "division by 0.0" and/or no valid answers. Set KU to its proper value.
- (2) Failure to set  $1 \leq KS \leq 5$  will most likely cause a halt to the program because

of an execution error. The branching on KS in subroutine GASP is a computed "GO TO." Simply set KS to its proper value.

(3) Failure to set KP will return enthalpy if KP is odd and no derived properties if KP is even.

(4) If a wrong value is entered for KR, it is treated as KR=0. If a user enters KR=1 when he does not want saturation properties, he will get them anyway for  $T < T_c$  and otherwise will get a wrong answer.

(5) If any T, P, D, H, or S is entered incorrectly, that value will be used and the answer will be wrong.

(6) If the COMMON/PROPTY/ is duplicated incorrectly, there are a variety of possible errors, almost all serious.

(7) If the call to SETUP has an illegal fluid request (not one of 10 fluids, keypunch error, etc.), the execution stops after an error message.

Other small problems may be encountered if GASP is modified for different compilers or computers. The FORTRAN IV coding in GASP is machine independent except for a few Hollerith format statements which can be easily changed. The reader who needs more detailed information should read the appendixes.

#### ADDITIONAL INFORMATION

The approximate core storage for the complete GASP program is  $(23306)_8 = (9926)_{10}$  locations.

The following problems have previously been encountered when converting to non-IBM machines or to different FORTRAN IV - FORTRAN V compilers:

(1) Users of the IBM 360-67 should run in double precision by inserting IMPLICIT REAL\*8 (A-H, O-Z) and REAL\*8 MU, MUL, MUV, K, KL, KV in subprogram GASP and IMPLICIT REAL\*8 (A-H, O-Z) in all other subroutines. COMMON/PROPTY/KU, KZ, DL, DV, etc., should be changed for proper alinement.

(2) Data statements are found in subroutines BLOCK DATA, THERM, VISC, and SURF. Many compilers differ in formatting data statements.

(3) The multiple-entry routine CHECK (TCHECK, PCHECK, DCHECK) has an entry point, DCHECK, whose input vector (KU, D) does not correspond in kind and number with the other entry points (KU, KR, T) or (KU, KR, P). To our knowledge, this has caused a problem on only one compiler, a FORTRAN IV for a CDC 3800. It was easily remedied by an equivalence statement.

We adapted the code to fit all the compilers and machines<sup>8</sup> tried so far with the preceding exceptions.

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<sup>8</sup>The machines tried so far are the UNIVAC 1108, CDC 3600, CDC 3800, IBM 360/67, and IBM 7094-7044 DC.

## CONCLUDING REMARKS

A FORTRAN IV subprogram called GASP has been developed to calculate the thermodynamic and transport properties of 10 fluids: parahydrogen, helium, neon, methane, nitrogen, carbon monoxide, oxygen, fluorine, argon, and carbon dioxide.

The basic concept of both GASP and this report is to provide the user with reliable fluid properties and to permit periodic updating of the program. As new data and new techniques for evaluating data become available, reevaluation of existing computational techniques (addition, modification, and/or deletion of subroutines) is an essential part of a viable properties program.

No computer code for fluid properties can remain viable without incorporating improved data as they become available. It is strongly recommended that NASA continue its support of the NASA-NBS thermophysical properties program, continue the effort initiated by GASP to provide the engineer with a means to calculate thermodynamic and transport properties with accuracy and speed, combine these programs in a continuing effort to update the fluids and the computational techniques, and provide distribution of the programs and their results.

Lewis Research Center,  
National Aeronautics and Space Administration,  
Cleveland, Ohio, June 27, 1974,  
502-24.

## APPENDIX A

### SYMBOLS

Mathematical symbol	FORTRAN symbol <sup>9</sup>	Description
$A_i$		coefficients of terms in eqs. (B1) and (B2)
$B_j$		coefficients of terms in eqs. (B1) and (B2)
$C_i, D_j$		coefficients of terms in eq. (B10)
c	C	sonic velocity, cm/sec
	CL	sonic velocity of saturated liquid, cm/sec
	CVP	sonic velocity of saturated gas, cm/sec
$C_p$	CP	specific heat at constant pressure, J/(g)(K)
$C_{p,0}$		specific heat at "zero" pressure, J/(g)(K)
	CPOCOR	specific-heat units correction factor
	CPL	specific heat of saturated liquid at constant pressure, J/(g)(K)
	CPV	specific heat of saturated vapor at constant pressure, J/(g)(K)
$C_v$	CV	specific heat at constant volume, J/(g)(K)
	CVL	specific heat of saturated liquid at constant volume, J/(g)(K)
	CVV	specific heat of saturated vapor at constant volume, J/(g)(K)
	EXCL	reacting conductivity of saturated liquid, W/(cm)(K)
	EXCV	reacting conductivity of saturated vapor, W/(cm)(K)
H	H	enthalpy, J/g
$H_0$		reference enthalpy, J/g
	HL	enthalpy of saturated liquid, J/g
	HV	enthalpy of saturated vapor, J/g
j <sub>1-7</sub>		set of constants for equation of vapor pressure curve

<sup>9</sup>Symbols used in the individual subroutines are identified in the work statement of that subroutine (see appendix F).

Mathematical symbol	FORTRAN symbol	Description
k	K	thermal conductivity, W/(cm)(K)
$k^*$		thermal conductivity of dilute gas, W/(cm)(K)
	KCP	region delimiter used in numerical calculation of $C_v$
	KL	thermal conductivity of saturated liquid, W/(cm)(K)
	KP	thermodynamic and transport properties specification
	KR	thermodynamic region specification
	KS	state relation specification
	KU	units specification
	KV	thermal conductivity of saturated vapor, W/(cm)(K)
M		molecular weight, g/g-mole
$m_{1-5}$		set of constants for equation of specific heat at "zero" pressure
	NAMGAS	Hollerith code used to specify fluid
$n_{1-24}$		set of constants for equation of state
P	P	pressure, MPa
$P_c$	PC	pressure at thermodynamic critical point
$P_{\max}$		upper pressure limit, MPa
$P_{\min}$		lower pressure limit, MPa
$P_{\text{sat}}$	PS	pressure used internal to program, MPa
$(\partial P / \partial T)_\rho$	PSS	saturation pressure used internal to program, MPa
		saturation pressure (eq. (3)), MPa
	PTV	partial derivative of pressure at constant volume, MPa/K
	PTVL	partial derivative of pressure at constant volume of saturated liquid, MPa/K
	PTVV	partial derivative of pressure at constant volume of saturated vapor, MPa/K
$(\partial P / \partial \rho)_T$	PDT	partial derivative of pressure at constant temperature, J/g

Mathematical symbol	FORTRAN symbol	Description
PDTL		partial derivative of pressure at constant temperature of saturated liquid, J/g
PDTV		partial derivative of pressure at constant temperature of saturated vapor, J/g
R		gas constant, J/(g)(K)
S	S	entropy, J/(g)(K)
$S_0$		reference entropy, J/(g)(K)
	SL	entropy of saturated liquid, J/(g)(K)
	SV	entropy of saturated vapor, J/(g)(K)
T	T	temperature, K
$T_c$	TC	temperature at thermodynamic critical point, K
$T_{\max}$		upper temperature limit, K
$T_{\min}$		lower temperature limit, K
	TS	temperature used internal to program, K
	TSS	saturation temperature computed by function TSS, K
$T_t$		triple-point temperature, K
$T_0$		reference temperature, K
U		internal energy, $H - (P/\rho)$ , J/g
V		specific volume, $\text{cm}^3/\text{g}$
$V'$		volume of saturated liquid, eq. (3)
$V''$		volume of saturated vapor, eq. (3)
Z		compressibility factor, $P/\rho RT$
$Z_c$		compressibility factor at critical point, eq. (10)
$\gamma$	GAMMA	ratio of specific heats, $C_p/C_v$
	GAMMAL	ratio of specific heats of saturated liquid
	GAMMAV	ratio of specific heats of saturated vapor
$\epsilon/k$	EPSK	potential parameter, used to reduce temperature, K
$\lambda$		thermal conductivity parameter, $\sqrt{M} T_c^{1/6} / P_c^{2/3} = \xi M$ , cal/(cm)(sec)(K)

Mathematical symbol	FORTRAN symbol	Description
$\lambda_r$	EXCESK	reacting conductivity, W/(cm)(K)
$\mu$	MU	dynamic viscosity, g/(cm)(sec)
$\mu^*$		dynamic viscosity of dilute gas, g/(cm)(sec)
	MUL	dynamic viscosity of saturated liquid, g/(cm)(sec)
	MUV	dynamic viscosity of saturated vapor, g/(cm)(sec)
$\xi$		viscosity parameter, $T_c^{1/6} / \sqrt{M} P_c^{2/3}$ , where the units are $T_c$ in K, $P_c$ in atm, and viscosity in cP
$\rho$	D	density, g/cm <sup>3</sup>
	DL	density of saturated liquid, g/cm <sup>3</sup>
	DS	density used internal to program, g/cm <sup>3</sup>
	DSL	density of saturated liquid, used internal to program, g/cm <sup>3</sup>
$\rho_c$	RHOC	density at thermodynamic critical point, g/cm <sup>3</sup>
$\rho_{\text{switch}}$		density where calculation of $C_v$ changes from numeric to analytic
$\rho_t$		triple-point density, g/cm <sup>3</sup>
	DV	density of saturated vapor, g/cm <sup>3</sup>
$\sigma$	SIGMA	surface tension, dyne/cm
$\sigma_d$		hard-sphere collision diameter, Å (or $10^{-10}$ m)
$\Omega^{(1, 1)*}$		Lennard-Jones collision integral for diffusion
$\Omega^{(2, 2)*}$		Lennard-Jones collision integral for viscosity
Subscripts:		
c		critical point
exp		experimental
R		reduced
t		triple point
total		total

## APPENDIX B

### EQUATIONS USED IN GASP

#### EQUATION OF STATE

The modified virial equation of state

$$P = P(\rho, T) = \sum_{i=1}^N A_i(T)\rho^i + \sum_{j=1}^M B_j(T)\rho^{2j+1} e^{-c\rho^2/T_2} \quad (B1)$$

is used to calculate all PVT and derived properties returned by GASP. The terms  $A_i(T)$  and  $B_j(T)$  are polynomials in  $T$  and  $T^{-1}$ . If the fluid is helium,  $T_2 = T$  and  $\alpha = 1$ ; otherwise,  $T_2 = 1$  and  $\alpha = 0$ <sup>10</sup> (Mann's equation, ref. 11). The values of  $N$  and  $M$  depend on the nature of the data and the curve-fitting technique. Herein, we use  $N = 6$  and  $M = 2$ . The coefficients  $A_i$  and  $B_j$  become

$$\left. \begin{aligned} A_1(T) &= RT \\ A_2(T) &= n_1 T + n_2 + \frac{n_3}{T} + \frac{n_4}{T^2} + \frac{n_5}{T^3} + \frac{n_{21}}{T^4} \\ A_3(T) &= n_{22} T^2 + n_6 T + n_7 + \frac{n_8}{T} + \frac{n_{23}}{T^2} \\ A_4(T) &= n_9 T + n_{10} \\ A_5(T) &= n_{11} T + n_{12} + \frac{n_{24}}{T} \\ A_6(T) &= n_{13} \\ B_1(T) &= \frac{n_{14} + \frac{n_{15}}{T} + \frac{n_{16}}{T^2}}{T^2} \\ B_2(T) &= \frac{n_{17} + \frac{n_{18}}{T} + \frac{n_{19}}{T^2}}{T^2} \end{aligned} \right\} \quad (B2)$$

---

<sup>10</sup> For use of  $T_2$  and  $\alpha$ , see eq. (B12) and subsequent equations.

and

$$c = n_{20}$$

The coefficients  $n_1$  to  $n_{20}$  represent Bender's original equation, while  $n_{21}$  to  $n_{24}$  have been added to accommodate carbon monoxide, neon, and helium.

While the fluids fit using Bender's routine (appendix C) do not require a vapor pressure curve, carbon monoxide, neon, and helium do. We decided to use a vapor pressure curve for each fluid. As an immediate consequence, the critical points and slope of the vapor pressure loci and those of the PVT surface fit did not match. As a result the saturation properties are forced to match, and returned derived properties are not smooth for temperatures less than but within 0.1 to 0.2 K of the critical point.

#### DERIVATIVES AND INTEGRALS OF GASP

In order to obtain thermodynamic functions, with the exception of a direct pressure calculation, several derivatives and integrals must be evaluated. The required derivatives of equation (B1) are

$$\left(\frac{\partial P}{\partial \rho}\right)_T \quad (B3)$$

$$\left(\frac{\partial P}{\partial T}\right)_\rho \quad (B4)$$

$$\left(\frac{\partial^2 P}{\partial T^2}\right)_\rho \quad (B5)$$

The required integrals are

$$\int \left[ \frac{T}{\rho^2} \left( \frac{\partial^2 P}{\partial T^2} \right)_\rho \right]_T d\rho \quad (B6)$$

$$\int \left[ \frac{P}{\rho^2} - \frac{T}{\rho^2} \left( \frac{\partial P}{\partial T} \right)_\rho \right]_T d\rho \quad (B7)$$

$$\int \left[ \frac{R}{\rho} - \frac{1}{\rho^2} \left( \frac{\partial P}{\partial T} \right)_\rho \right]_T d\rho \quad (B8)$$

The derivative  $(\partial P/\partial \rho)_T$  (eq. (B3)) is straightforward. From equation (B1),

$$\left(\frac{\partial P}{\partial \rho}\right)_T = \sum_{i=1}^6 i A_i(T) \rho^{i-1} + \sum_{j=1}^2 B_j(T) \left(2j+1 - \frac{2c\rho^2}{T_2}\right) \rho^{2j} e^{-c\rho^2/T_2} \quad (B9)$$

To calculate the derivatives  $(\partial P/\partial T)_\rho$  and  $(\partial^2 P/\partial T^2)_\rho$ , it is more convenient to rearrange the virial equation:

$$P = \sum_{i=1}^7 C_i(\rho) T^{3-i} + \sum_{j=1}^3 D_j(\rho) e^{-c\rho^2/T_2} T^{-(j+1)} \quad (B10)$$

where

$$\left. \begin{aligned} C_1 &= n_{22} \rho^3 \\ C_2 &= R\rho + n_1 \rho^2 + n_6 \rho^3 + n_9 \rho^4 + n_{11} \rho^5 \\ C_3 &= n_2 \rho^2 + n_7 \rho^3 + n_{10} \rho^4 + n_{12} \rho^5 + n_{13} \rho^6 \\ C_4 &= n_3 \rho^2 + n_8 \rho^3 + n_{24} \rho^5 \\ C_5 &= n_4 \rho^2 + n_{23} \rho^3 \\ C_6 &= n_5 \rho^2 \\ C_7 &= n_{21} \rho^2 \\ D_1 &= \rho^3 (n_{14} + n_{17} \rho^2) \\ D_2 &= \rho^3 (n_{15} + n_{18} \rho^2) \\ D_3 &= \rho^3 (n_{16} + n_{19} \rho^2) \end{aligned} \right\} \quad (B11)$$

$$\left(\frac{\partial P}{\partial T}\right)_\rho = \sum_{i=1}^7 (3-i)C_i(\rho)T^{2-i} + \sum_{j=1}^3 D_j(\rho) \left[ \frac{c\rho^2}{T_2^2} \alpha - \frac{(j+1)}{T} \right] e^{-c\rho^2/T_2} T^{-(j+1)} \quad (B12)$$

For fluids other than helium,  $\alpha = 0$  and  $T_2 = 1$ .

In order to determine the specific heats, the  $\left(\frac{\partial^2 P}{\partial T^2}\right)_\rho$  is required, although it is never used in that form. After differentiating equation (B12) to give (B5), the integral (eq. (B6)) becomes

$$\begin{aligned} \int \frac{T}{\rho^2} \left( \frac{\partial^2 P}{\partial T^2} \right)_\rho d\rho &= \int \sum_{i=1}^7 (3-i)(2-i)C_i(\rho) \frac{T^{2-i}}{\rho^2} \\ &\quad + \int \sum_{j=1}^3 \frac{D_j(\rho)}{\rho^2} \left\{ \frac{(j+1)(j+2)}{T^2} - \frac{2c\alpha}{T_2^2} \left[ \frac{1}{T_2} + \frac{(j+1)}{T} \right] \rho^2 + \alpha \frac{c^2}{T_2^4} \rho^4 \right\} e^{-c\rho^2/T_2} T^{-j} \\ &= \int \sum_{i=1}^4 \left[ E_i(T) \rho^{i-1} + F_i(T) \rho^{2i-1} e^{-c\rho^2/T_2} \right] d\rho \\ &= \sum_{i=1}^4 \left[ E_i(T) \frac{\rho^i}{i} - \frac{1}{2} e^{-c\rho^2/T_2} \left( \frac{T_2}{c} \right)^i F_i(T) \sum_{j=1}^i \frac{(i-1)!}{(j-1)!} \left( \frac{c\rho^2}{T_2} \right)^{j-1} \right] \quad (B13) \end{aligned}$$

$$E_1(T) = \frac{2n_3 + \frac{6n_4}{T} + \frac{12n_5}{T^2} + \frac{20n_{21}}{T^3}}{T^2}$$

$$E_2(T) = 2n_{22}T + \frac{2n_8}{T^2} + \frac{6n_{23}}{T^3}$$

$$E_3(T) = 0$$

$$E_4(T) = \frac{2n_{24}}{T^2}$$

$$F_1(T) = \frac{6n_{14} + \frac{12n_{15}}{T} + \frac{20n_{16}}{T^2}}{T^3}$$

$$F_2(T) = \frac{-2n_{20}\alpha \left[ n_{14} \left( \frac{1}{T_2} + \frac{2}{T} \right) + \frac{n_{15}}{T} \left( \frac{1}{T_2} + \frac{3}{T} \right) + \frac{n_{16}}{T^2} \left( \frac{1}{T_2} + \frac{4}{T} \right) \right] + \left( 6n_{17} + \frac{12n_{18}}{T} + \frac{20n_{19}}{T^2} \right)}{T^3}$$

$$F_3(T) = \frac{-2n_{20}\alpha}{TT_2^2} \left[ n_{17} \left( \frac{1}{T_2} + \frac{2}{T} \right) + \frac{n_{18}}{T} \left( \frac{1}{T_2} + \frac{3}{T} \right) + \frac{n_{14}}{T^2} \left( \frac{1}{T_2} + \frac{4}{T} \right) \right] + \frac{(n_{20})^2\alpha}{TT_2^4} \left( n_{14} + \frac{n_{15}}{T} + \frac{n_{16}}{T^2} \right)$$

$$F_4(T) = \frac{(n_{20})^2\alpha}{TT_2^4} \left( n_{17} + \frac{n_{18}}{T} + \frac{n_{19}}{T^2} \right)$$

(B14)

In order to facilitate evaluating equation (B7), rearrange the virial equation to the form

$$P = \rho T \left[ R + \sum_{i=2}^6 A_i(T) \frac{\rho^{i-1}}{T} + \sum_{j=1}^2 B_j(T) \frac{\rho^{2j}}{T} e^{-c\rho^2/T_2^2} \right] = \rho T[\Omega] \quad (B15)$$

After differentiation of equation (B15) with respect to  $T$  and substitution into equation (B7), the integral becomes

$$\begin{aligned}
\int \left[ \frac{P}{\rho^2} - \frac{T}{\rho^2} \left( \frac{\partial P}{\partial T} \right)_\rho \right]_T d\rho &= - \int \left[ \frac{T^2}{\rho} \left( \frac{\partial [\Omega]}{\partial T} \right)_\rho \right]_T d\rho \\
&= - \int \left\{ \sum_{i=2}^6 \left( T \frac{dA_i}{dT} - A_i \right) \rho^{i-2} + \sum_{j=1}^2 \left[ T \frac{dB_j}{dT} + B_j \left( \alpha \frac{T}{T_2^2} c\rho^2 - 1 \right) \rho^{2j-1} e^{-c\rho^2/T_2} \right] \right\} d\rho \\
&= - \sum_{i=2}^6 \left( T \frac{dA_i}{dT} - A_i \right) \frac{\rho^{i-1}}{i-1} + \frac{1}{2} \sum_{j=1}^2 \left\{ \left( T \frac{dB_j}{dT} - B_j \right) \left[ \left( \frac{T_2}{c} \right)^j e^{-c\rho^2/T_2} \sum_{k=1}^j \frac{(j-1)!}{(k-1)!} \left( \frac{c\rho^2}{T_2} \right)^{k-1} \right. \right. \\
&\quad \left. \left. + \alpha \frac{TB_j}{T_2^2} c \left( \frac{T_2}{c} \right)^{j+1} e^{-c\rho^2/T_2} \sum_{k=1}^{j+1} \frac{j!}{(k-1)!} \left( \frac{c\rho^2}{T_2} \right)^{k-1} \right] \right\} \quad (B16)
\end{aligned}$$

Equation (B15) is used to evaluate equation (B8) and the integral becomes

$$\begin{aligned}
\int \left[ \frac{R}{\rho} - \frac{1}{\rho^2} \left( \frac{\partial P}{\partial T} \right)_\rho \right]_T d\rho &= - \int \frac{1}{\rho^2} \left\{ \sum_{i=2}^6 \frac{dA_i}{dT} \rho^i + \sum_{j=1}^2 \left[ \frac{dB_j}{dT} + \alpha B_j \frac{c\rho^2}{T_2^2} \right] \rho^{2j+1} e^{-c\rho^2/T_2} \right\} d\rho \\
&= - \sum_{i=2}^6 \frac{dA_i}{dT} \left( \frac{\rho^{i-1}}{i-1} \right) + \frac{1}{2} \sum_{j=1}^2 \left\{ \frac{dB_j}{dT} \left( \frac{T_2}{c} \right)^j e^{-c\rho^2/T_2} \sum_{k=1}^j \frac{(j-1)!}{(k-1)!} \left( \frac{c\rho^2}{T_2} \right)^{k-1} \right. \\
&\quad \left. + \alpha \frac{B_j c}{T_2^2} \left( \frac{T_2}{c} \right)^{j+1} e^{-c\rho^2/T_2} \sum_{k=1}^{j+1} \frac{j!}{(k-1)!} \left( \frac{c\rho^2}{T_2} \right)^{k-1} \right\} \quad (B17)
\end{aligned}$$

Equations (B1) to (B17) constitute the basic relations in GASP; however, one also needs the constants of integration (i.e.,  $H_0$ ,  $S_0$  as well as  $C_{p,0}$  (or  $C_{v,0}$ ) to determine the derived properties and the saturation pressures needed to isolate the two-phase region. The sources for these constants are found in table III.

## CONSTANTS OF INTEGRATION

The equation for the saturation pressure is

$$\log_{10} P_{\text{sat}} = j_1 + \frac{j_2}{T} + j_3 T + j_4 T^2 + j_5 T^3 + j_6 T^4 + j_7 T^5 \quad (\text{B18})$$

The values  $j_1$  to  $j_7$  are listed for each fluid in table IX.

The specific heat for the dilute gas  $C_{p,0}$  is a function of temperature only (except for hydrogen, see appendix K):

$$C_{p,0} = \sum_{i=1}^{5} m_i T^{i-1} \quad (\text{B19})$$

with  $m_i$  listed in table IX for each fluid. The values of  $H_0$  and  $S_0$  are also listed in table IX.

With these constants and equations (B1) to (B19), the following general forms for derived properties can be evaluated:

Enthalpy:

$$H = H_0 + \int_{T_0}^T C_{p,0} dT + (Z - 1)RT + \int_0^\rho \left[ \frac{P}{\rho^2} - \frac{T}{\rho^2} \left( \frac{\partial P}{\partial T} \right)_\rho \right]_T d\rho \quad (\text{B20})$$

Entropy:

$$S = S_0 + \int_{T_0}^T C_{p,0} d \ln T - R \ln (RT\rho) + \int_0^\rho \left[ \frac{R}{\rho} - \frac{1}{\rho^2} \left( \frac{\partial P}{\partial T} \right)_\rho \right]_T d\rho \quad (\text{B21})$$

Specific heat at constant volume:

$$C_v = C_{p,0} - R - \int_0^\rho \frac{T}{\rho^2} \left( \frac{\partial^2 P}{\partial T^2} \right)_\rho d\rho \quad (\text{B22})$$

Specific heat at constant pressure:

$$C_p = C_v + \frac{T}{\rho} \frac{\left(\frac{\partial P}{\partial T}\right)_P^2}{2 \left(\frac{\partial P}{\partial \rho}\right)_T} \quad (B23)$$

An alternate method for  $C_v$  used at high density is

$$C_v = \frac{\Delta U}{\Delta T} = \frac{\Delta \left(H - \frac{P}{\rho}\right)}{\Delta T} \quad (B24)$$

$$C_p = \frac{\Delta H}{\Delta T} \quad (B25)$$

Sonic velocity:

$$c = \sqrt{\frac{C_p}{C_v} \left(\frac{\partial P}{\partial \rho}\right)_T} \quad (B26)$$

With  $(\partial P / \partial T)_{\rho}$ ,  $(\partial P / \partial \rho)_T$ ,  $P$ ,  $\rho$ ,  $T$ , and the Bridgeman Tables (appendix E), the user can calculate any other thermodynamic relation of his choice.

## TRANSPORT PROPERTIES

In general, the thermal conductivity, viscosity, and surface tension are calculated by the techniques outlined in the main text under Calculation of Transport Properties. Here we specify these calculations in greater detail.

### Viscosity

For fluids other than hydrogen, the dilute-gas viscosity is given by

$$\mu^* = 0.26693 \times 10^{-4} \frac{\sqrt{MT}}{\sigma^2 \Omega^{*(2,2)}} \quad (B27)$$

and the excess viscosity function is specified by

$$\mu - \mu^* = \frac{\left[ 0.0093324 \rho_R^4 - 0.040758 \rho_R^3 + 0.058533 \rho_R^2 + 0.023364 \rho_R + 0.10230 \right]^4 - 1 \times 10^{-4}}{100 \xi} \quad (B28)$$

If the fluid is fluorine, a small correction factor is used

$$(\mu - \mu^*)_{F_2} = (\mu - \mu^*) \left[ 1 - \frac{1}{4} \sin(2.3808 \ln \rho_R) \right] \quad (B29)$$

The viscosity then becomes

$$\mu = (\mu - \mu^*) + \mu^* \quad (B30)$$

If the fluid is hydrogen, a two-part fit is used which for the most part is from H. M. Roder of NBS, Boulder, Colorado:

$$\mu_{H_2}^* = 8.5558 \left( \frac{T^{3/2}}{T + 19.55} \right) \left( \frac{T + 650.39}{T + 1175.9} \right) \quad T \leq 100 \text{ K} \quad (B31)$$

$$\mu_{H_2}^* = 1.799 T^{0.6835} \quad T > 100 \text{ K} \quad (B32)$$

Let

$$R = -58.75 \left( \frac{\rho}{0.07} \right)^3 \quad \text{where } R \geq -80 \quad (B33)$$

and

$$A = \exp \left[ 5.7694 + \ln \rho + 65\rho^{3/2} - 6 \times 10^{-4} e^{127.2\rho} \right] \quad (B34)$$

$$B = 10 + 7.2 \left[ \left( \frac{\rho}{0.07} \right)^6 - \left( \frac{\rho}{0.07} \right)^{3/2} - 17.63e^R \right] \quad (B35)$$

The viscosity for hydrogen becomes

$$\mu_{H_2} = \left[ \mu_{H_2}^* + A e^{(B/T)} \right] \times 10^{-6} \quad (B36)$$

At elevated temperatures, the value of  $\mu_{H_2}^*$  predicted from equation (B32) dominates, and it becomes unnecessary to correct for density effects (i. e., one can assume that  $A \approx 0$ ).

While it is known that the excess viscosity of cryogens is temperature dependent (refs. 47 to 55), it is not yet known how to represent this effect for several fluids by using corresponding-states principles. Gibbon and Kuebler (ref. 56) present a pseudo-corresponding-states analogy to predict the viscosities of argon, nitrogen (limited), neon, and helium. Haynes (ref. 55) presents a "virial" equation for argon viscosity. However, attempts to extend these equations to other fluids were met with limited success. Further, as will be shown later, the data of various investigators differ substantially for the same fluid region. These data appear to be dependent on the apparatus, the measurement technique, and the fluid region where the measurements are made (refs. 57 to 59). (Recall that thermal conductivity measurements suffer the same problems; so perhaps do all transport properties.)

It is difficult to make generalizations, however, the authors have found some trends. In figure 22 we plot the viscosity data of Diller (ref. 50) as a function of reduced density. Similar plots were made for nitrogen and argon by using the data of Zhdanova (refs. 60 and 61). See also reference 47.

(1) The isotherms are nearly linear and intersect the saturation locus for  $T_R < 1$ ; the extended isotherms appear to "focus" at  $\rho_R = 2$ . For  $T_R > 1$  the isotherms tend to "focus" near  $\rho_R = 1$ .

(2) The saturation locus appears to be continuous; however, at  $T_R \approx 1$ , some discontinuities in the surface are noticeable.

(3) Viscosity in the region  $\rho_R \geq 2$  can be described by

$$\rho = 0.63(\rho_R - 2)\tan[m(T_R)]$$

$$m = \begin{cases} 1.3 - \frac{T_R}{2} & T_R \leq 1 \\ 0.08(9 + T_R^{-3}) & T_R > 1 \end{cases}$$

$$\Delta\mu = \frac{(1.616 \times 10^{P-5})}{\xi} \quad (B37)$$

However, the formulation is limited to this region; subsequent comparisons found equation (B37) better, but not significantly better, than assuming that the temperature de-

pendence for  $1.5 \leq \rho_R < 2.8$  may be expressed as an additional density-dependent term for each fluid:

$$\mu = \frac{\mu |_{\text{Eq. (B30)}}}{1 - [A + B(\rho_R - 1.5)]} \quad (\text{B38})$$

where  $A = B = 0$  for  $\rho_R < 1.5$  and  $(\rho_R - 1.5) \rightarrow 1.3$  for  $\rho_R > 2.8$ . The following table lists the values of  $A$  and  $B$  used in GASP:

Fluid	A	B	Fluid	A	B
Methane	-0.06	0.07	Neon	0.1	0.2
Nitrogen	0	.2	Carbon monoxide	.1	0
Oxygen	.04	0	Helium <sup>a</sup>	0	0
Argon	0	.2	Fluorine	0	0
Carbon dioxide	0	0	Hydrogen <sup>a</sup>	0	0

<sup>a</sup>Special equation.

Several sets of viscosity data are compared with calculated values in figures 23 to 28. The ordinate is  $[(\mu_{\text{exp}} - \mu_{\text{calc}})/\mu_{\text{exp}}] \times 100$ , and the abscissa is reduced density.

Nitrogen. - The data of references 49, 53, and 54 are compared in figure 23. Note the deviations in the data of these references near  $1.5 < \rho_R < 2$ . Generally, the deviations are  $\pm 20$  percent; most are less than  $\pm 10$  percent.

Oxygen. - The data of references 52 to 54 are compared in figure 24. Again note the deviations in the data sets of references 52 and 54 near  $1.5 < \rho_R < 2$ . If one ignores these latter data, the deviations are -20 to +10 percent.

Argon. - The data of references 51, 53, and 55 are compared in figure 25. The data of reference 55 are extensive and, in general, the deviations are  $\pm 15$  percent, with most deviations within  $\pm 5$  percent.

Neon, carbon monoxide, and methane. - These data sets are limited to saturation data. The neon data (refs. 62 and 63) deviate by  $\pm 5$  percent over the domain indicated in figure 26. The carbon monoxide data (ref. 64) deviate by  $\pm 10$  percent over a limited domain (fig. 27). The methane data (ref. 59) deviate by -8 to +4 percent (fig. 28).

While these results do not necessarily apply to the dense fluid regions, in the absence of data we assume that they are applicable. The extensive data of Diller (ref. 50) were not compared because GASP uses the equations developed by Diller. Also, helium

data were not compared because GASP uses the equations of McCarty.<sup>11</sup> Recall that the helium equation in GASP is valid for  $T > 6$  K and the calculations of reference 17; otherwise, the computer program HELP<sup>1</sup> should be used.

### Thermal Conductivity

The quantum fluids hydrogen and helium are treated separately, as is fluid fluorine. The excess functions  $k - k^*$  for parahydrogen and fluorine are nearly functions of density alone; however, for helium the excess thermal conductivity is a function of temperature and density. The dilute-gas thermal conductivity  $k^*$  for parahydrogen does not reduce as do other fluids to form a universal curve. Fluorine has been addressed by Hanley<sup>12</sup> and his fit is used herein. Thus, for fluids other than hydrogen, helium, and fluorine, the dilute-gas thermal conductivity becomes

$$k^* = k_{T_c}^* \frac{10}{\left( \sum_{i=1}^5 b_i T_R^i \right)} \quad (B39)$$

where the coefficients  $b_i$  and  $k_{T_c}^*$  are given in table X. Table X also lists a lower bound LB on the excess function  $k - k^*$ . If the density is less than  $10^{LB}$ ,

$$k - k^* = \rho_R \times 10^{-7} \quad \text{for } \log_{10} \rho_R \leq LB \quad (B40)$$

$$k - k^* = \frac{\left( \sum_{i=1}^5 a_i \rho_R^i \right)}{Z_c^{5\lambda}} \quad \text{for } \log_{10} \rho_R > LB \quad (B41)$$

where the coefficients  $a_i$ ,  $Z_c$ , and  $\lambda$  are given in table X(b). For these coefficients,

$$k = [(k - k^*) + k^*] \times 4.184 \quad (B42)$$

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<sup>11</sup>Private communication with R. D. McCarty of National Bureau of Standards, Boulder, Colorado.

<sup>12</sup>Private communication with H. J. M. Hanley of National Bureau of Standards, Boulder, Colorado.

Fluorine. - First, compute the dilute-gas thermal conductivity

$$k_{F_2}^* = \frac{1.77R + 6 \frac{\Omega^{(2,2)}^*}{\Omega^{(1,1)}^*} C_{v,0} - \frac{2}{\pi} \left[ \frac{5}{2} - \frac{\Omega^{(2,2)}^*}{\Omega^{(1,1)}^*} \right]^2 \left( C_{v,0} - \frac{3R}{2} \right)}{2 + 0.02 T^{0.83333}} \quad (B43)$$

Then add the excess function

$$(k - k^*) + k_{F_2}^* \quad (B44)$$

Parahydrogen. - From an interpolation routine provided by Roder,

$$\ln k_{H_2}^* = [(\text{Interpolation of tabulated values}) - (\text{Dependent on } T \text{ alone})] \quad (B45)$$

Let

$$B = 39.6 - 2 \left[ 265 - \left( \frac{T}{10} \right)^2 \right]^{1/2} \quad (B46)$$

Then

$$k_{H_2} = 0.1 k_{H_2}^* \exp \left\{ C_1 B \rho + \left[ C_2 + \left( \frac{C_3}{T - 9} \right) \right] \rho^2 \right\} \quad T < 250 \text{ K} \quad (B47)$$

where

$$C_1 = 0.9885311$$

$$C_2 = 32.0887$$

$$C_3 = -910.141$$

For temperatures between 150 and 250 K, the thermal conductivity is given by

$$k = (k - k^*)_{\text{Eq. (B41)}} \times 4.184 + 3.383 \times 10^{-5} \times T^{0.72872} \quad \text{for } T > 250 \text{ K} \quad (B48)$$

and

$$k = x(k)_{\text{Eq. (B48)}} + (1 - x)k_{\text{Eq. (B47)}} \quad \text{for } 150 \leq T \leq 250 \text{ K} \quad (\text{B49})$$

where

$$x = 0.01(T - 150 \text{ K}) \quad (\text{B50})$$

Above 2000 K, departures due to dissociation begin to become noticeable.

Helium. - From an interpolation routine provided by Roder, compute  $k^*$  as a function of  $\text{CONZ}(T)$ :

$$k_{\text{He}}^* = \frac{\text{CONZ}(T)}{1000} \quad (\text{B51})$$

Let

$$\log_{10} S = -621.369 \rho^3 + 224.256 \rho^2 - 29.485 \rho + 2.094196 \quad (\text{B52})$$

Then the excess function becomes

$$(k - k^*)_{\text{He}} = \frac{\log_{10} (T)}{10S} \times 10^{-3} \quad (\text{B53})$$

and finally, the thermal conductivity is given by

$$k = (k - k^*)_{\text{He}} + k_{\text{He}}^* \quad (\text{B54})$$

### Thermal Conductivity Anomaly

The prediction of the anomalous thermal conductivity of simple substances has been investigated by Sengers (refs. 29, 30, and 32), Brokaw (ref. 25), and Hendricks and Baron (ref. 31). While each technique reproduces the  $\text{CO}_2$  data of references 29, 30, and 32 with good agreement, the simplified technique of reference 32 is used herein.

Define the parametric groupings:

$$x^\beta = \frac{|1 - T_R|^{0.35}}{|1 - \rho_R|} \quad (B55)$$

$$y = \frac{(k - \lambda_F) \sqrt{\rho_R}}{3.05 \times 10^{-5} |1 - T_R|^{-0.6}} \quad (B56)$$

where

$$\lambda_F = f(\rho) + k^* \quad (B57)$$

and  $\lambda_F$  is the frozen or nonanomalous part.

Within the region  $0.4 \leq \rho_R \leq 1.6$ , the anomalous thermal conductivity can be computed by using the following formulas:

For  $x^2 < 0.4$ :

$$\lambda_r = k - \lambda_F = \frac{3.05 \times 10^{-5} \sqrt{\rho_R}}{(1 - \rho_R)^{1.71}} \quad (B58)$$

For  $0.4 \leq x^\beta \leq 3$ :

$$y = \left[ 1 + \frac{0.9}{(x^\beta)^{1/0.35}} \right]^{-0.6} \quad (B59)$$

For  $x^\beta > 3$ :

$$\lambda_r = k - \lambda_F = \frac{3.05 \times 10^{-5} \sqrt{\rho_R}}{|1 - T_R|^{0.6}} \quad (B60)$$

## Surface Tension

The surface tension of fluids other than hydrogen and helium are given as

$$\sigma = C_{\sigma} |1 - T_R|^{11/9} \left( \frac{0.432}{Z_c} - 0.951 \right) T_c^{1/3} P_c^{2/3} \quad (B61)$$

where  $Z_c$  is the compressibility at the initial point and  $P_c$  is in (atmospheres) $^{2/3}$  and  $C_{\sigma}$ =FIXIT is given by the following table:

Fluid	$C_{\sigma}$	Fluid	$C_{\sigma}$
Hydrogen	1	Carbon monoxide	1
Helium	2.27	Oxygen	1
Neon	1.1	Fluorine	1
Methane	1.015	Argon	1
Nitrogen	1	Carbon dioxide	1.02

For hydrogen and helium, a slightly different slope is noted and

$$\sigma = C_1 (1 - T_R)^{1.065} \quad (B62)$$

where

$$C_1 = 5.369 \quad \text{for hydrogen}$$

$$C_1 = 5.308 \quad \text{for helium}$$

## APPENDIX C

### BENDER CURVE FIT - SUMMARY

It is customary today to find the coefficients for an equation of state from the measured PVT values with the well-known method of least squares by using a digital computer. The method as applied to the Bender equation for methane is explained in reference 3 (see also refs. 4 and 5). The formulation is summarized here for the interested user.

The least-squares sum  $S$  which must be made a minimum is defined as the summation over the square of the residuals. In which case the residual  $r$  is the difference between the calculated pressure  $P$  of the state equation and the measured pressure  $P_{exp}$ .

$$S = \sum_{n=1}^N \omega_{P,n} r_{P,n}^2 = \sum_{n=1}^N \omega_{P,n} [P(v_n, T_n) - P_{exp,n}]^2 \quad (C1)$$

Individual values can be distinctly weighted with the factor  $\omega_{P,n}$ .

The equation can then be expanded to include any number of constraints. For Bender's equation the following constraints are used for the two-phase boundary equilibrium:

$$P' = P'' = P_{sat} \quad (C2)$$

$$g'(T, P_{sat}) = g''(T, P_{sat}) \quad (C3)$$

The specific free enthalpy  $g'$  is of the liquid and  $g''$  is of the vapor. The expanded sum  $S$  is now

$$S = \sum_{n=1}^N \omega_{P,n} [P(v_n, T_n) - P_{exp,n}]^2 + \sum_{j=1}^N \omega_{D,j} [P(v'_j, T_j) - P(v''_j, T_j)]^2 + \sum_{j=1}^J \omega_{g,j} (g''_j - g'_j)^2 \quad (C4)$$

Then

$$g''_j - g'_j = - \int_{v'_j}^{v''_j} P(v_j, T_j) dv + P_{sat,j} (v''_j - v'_j) \quad (C5)$$

In addition, the critical constraints used are

$$P_c = P_c(\rho_c, T_c) \quad (C6)$$

$$\left[ \left( \frac{\partial P}{\partial \rho} \right)_T \right]_c = 0 \quad (C7)$$

$$\left[ \left( \frac{\partial^2 P}{\partial \rho^2} \right)_T \right]_c = 0 \quad (C8)$$

$$\left[ \frac{T}{P} \left( \frac{\partial P}{\partial T} \right)_\rho \right]_c = \alpha_c \text{ as determined by the saturation data} \quad (C9)$$

Two additional constraints

$$\left[ \left( \frac{\partial^3 P}{\partial \rho^3} \right)_T \right]_c = 0 \quad (C10)$$

$$\left[ \left( \frac{\partial^4 P}{\partial \rho^4} \right)_T \right]_c = 0 \quad (C11)$$

are sometimes needed to obtain a good fit in the critical region. These constraints are referred to as the fifth-order attachment, while equations (C7) and (C8) give the usual third-order attachment.

The coefficient  $n_{20}$  in equation (B2) is not determined in the fit but must be varied systematically until an acceptable set of coefficients is determined. The data needed for this method then are

- (1) PVT data over the pressure and temperature range of interest
- (2) Smoothed PVT data along the saturation boundary
- (3) Estimates of the critical parameters and  $\alpha_c$  (Initial estimates can be found from the saturation loci.)
- (4) Value of  $n_{20}$  in equation (B2) (Initial estimate satisfies  $n_{20} \rho_c^2 \approx 1$ .)

The items (3) and (4) along with the weight factors can be varied to obtain the best set of coefficients for equation (B2).

Techniques to actually solve the system of equations are in the literature; see, for example, Hust and McCarty (ref. 45) and Morsy (ref. 65).

## APPENDIX D

### STATE EQUATION OF STEWART, JACOBSEN, AND MEYERS

Stewart, along with Jacobsen and Meyers (ref. 44), extended the work of Coleman and Stewart (ref. 37) to nitrogen and oxygen. As Bender's analysis and program was made available to Stewart and his coworkers, they utilized Bender's technique to develop another state equation. The state equation is essentially equation (B1) where  $N = 9$  and  $M = 6$ , with a  $\sqrt{T}$  term. The explicit forms for  $A_i(T)$  and  $B_i(T)$  become

$$\left. \begin{aligned}
 A_1(T) &= RT \\
 A_2(T) &= n_1 T + n_3 + \frac{n_4}{T} + \frac{n_5}{T^2} + E_1(T) \\
 A_3(T) &= n_6 T + n_7 + \frac{n_8}{T} + \frac{n_9}{T^2} \\
 A_4(T) &= n_{10} T + n_{11} + \frac{n_{12}}{T} \\
 A_5(T) &= n_{13} \\
 A_6(T) &= \frac{n_{14}}{T} + \frac{n_{15}}{T^2} \\
 A_7(T) &= \frac{n_{16}}{T} \\
 A_8(T) &= \frac{n_{17}}{T} + \frac{n_{18}}{T^2} \\
 A_9(T) &= \frac{n_{19}}{T^2}
 \end{aligned} \right\} \quad (D1)$$

$$\left. \begin{aligned}
 B_1(T) &= \frac{n_{20}}{T^2} + \frac{n_{21}}{T^3} \\
 B_2(T) &= \frac{n_{22}}{T^2} + \frac{n_{23}}{T^4} \\
 B_3(T) &= \frac{n_{24}}{T^2} + \frac{n_{25}}{T^3} \\
 B_4(T) &= \frac{n_{26}}{T^2} + \frac{n_{27}}{T^4} \\
 B_5(T) &= \frac{n_{28}}{T^2} + \frac{n_{29}}{T^3} \\
 B_6(T) &= \frac{n_{30}}{T^2} + \frac{n_{31}}{T^3} + \frac{n_{32}}{T^4}
 \end{aligned} \right\} \quad (D2)$$

where

$$E_1(T) = n_2 \sqrt{T} \quad (D3)$$

The exponential term of equation (B1) becomes

$$e^{-n_{33}\rho^2} \quad (D4)$$

The explicit forms for  $C_i(\rho)$  and  $D_j(\rho)$  become

$$\left. \begin{aligned}
C_1(\rho) &= 0 = C_6(\rho) = C_7(\rho) \\
C_2(\rho) &= R\rho + n_1\rho^2 + n_6\rho^3 + n_{10}\rho^4 \\
C_3(\rho) &= n_3\rho^2 + n_7\rho^3 + n_{11}\rho^4 + n_{13}\rho^5 \\
C_4(\rho) &= n_4\rho^2 + n_8\rho^3 + n_{12}\rho^4 + n_{14}\rho^6 + n_{16}\rho^7 + n_{17}\rho^8 \\
C_5(\rho) &= n_5\rho^2 + n_9\rho^3 + n_{15}\rho^6 + n_{18}\rho^8 + n_{19}\rho^9
\end{aligned} \right\} \quad (D5)$$

$$F_1(\rho) = n_2\rho^2 \quad (D6)$$

$$\left. \begin{aligned}
D_1(\rho) &= (n_{20} + n_{22}\rho^2 + n_{24}\rho^4 + n_{26}\rho^6 + n_{28}\rho^8 + n_{30}\rho^{10})\rho^3 \\
D_2(\rho) &= (n_{21} + n_{25}\rho^4 + n_{29}\rho^8 + n_{31}\rho^{10})\rho^3 \\
D_3(\rho) &= (n_{23}\rho^2 + n_{27}\rho^6 + n_{32}\rho^{10})\rho^3
\end{aligned} \right\} \quad (D7)$$

With these coefficients now defined, equations (B9), (B10), (B12), (B13), (B16), and (B17) may be written, where  $N = 9$  and  $M = 6$  as follows:<sup>13</sup>

$$P = P_{\text{Eq. (B10)}} + F_1 \sqrt{T} \quad (D8)$$

$$\left( \frac{\partial P}{\partial T} \right)_\rho = \left( \frac{\partial P}{\partial T} \right)_{\text{Eq. (B12)}} + \frac{F_1}{2\sqrt{T}} \quad (D9)$$

$$\int \left[ \frac{T}{\rho^2} \left( \frac{\partial^2 P}{\partial T^2} \right)_\rho \right] d\rho = \left\{ \int \left[ \frac{T}{\rho^2} \left( \frac{\partial^2 P}{\partial T^2} \right)_\rho \right] d\rho \right\}_{\text{Eq. (B13)}} - \frac{F_1}{4\rho^2 \sqrt{T}} \quad (D10)$$

---

<sup>13</sup>When referring to these equations, we assume the reader will alter the summation indices appropriately for  $N = 9$ ,  $M = 6$  rather than  $N = 6$ ,  $M = 2$ , and substitute the proper coefficients as defined by eqs. (D1) to (D7). Under these conditions, eq. (B9) is unchanged.

$$\int \left[ \frac{P}{\rho^2} - \frac{T}{\rho^2} \left( \frac{\partial P}{\partial T} \right)_{\rho} \right] d\rho = \left\{ \int \left[ \frac{P}{\rho^2} - \frac{T}{\rho^2} \left( \frac{\partial P}{\partial T} \right)_{\rho} \right] d\rho \right\}_{\text{Eq. (B16)}} - \frac{F_1 T}{2\rho^2 \sqrt{T}} \quad (\text{D11})$$

$$\int \left[ \frac{P}{\rho} - \frac{1}{\rho^2} \left( \frac{\partial P}{\partial T} \right)_{\rho} \right] d\rho = \left\{ \int \left[ \frac{P}{\rho} - \frac{1}{\rho^2} \left( \frac{\partial P}{\partial \rho} \right)_{\rho} \right] d\rho \right\}_{\text{Eq. (B17)}} - \frac{F_1}{2\rho^2 \sqrt{T}} \quad (\text{D12})$$

With these alterations, and subsequent alteration of SETUP and BLOCK, GASP will return results as outlined in the report if GASP is operating in double precision on a machine with  $10^{+88}$  capability.

## APPENDIX E

### THERMODYNAMIC RELATIONS AND DERIVATIVES

The symbols  $C_p$ ,  $C_v$ ,  $H$ ,  $P$ ,  $R$ ,  $S$ ,  $T$ , and  $\rho$  have the same meaning as defined elsewhere in this report. The other symbols used exclusively in this appendix are defined as follows:

$A = E - TS$  Helmholtz free energy or work content

$E$  internal energy

$F = H - TS$  Gibbs free energy or free energy

$K$  equilibrium constant

$V$  specific volume

To illustrate the facility of the partial derivatives, Roder and Weber (ref. 66) give five which are useful to engineers:

Specific heat input:

$$V \left( \frac{\partial H}{\partial V} \right)_P = \rho C_p \left[ \frac{\left( \frac{\partial P}{\partial \rho} \right)_T}{\left( \frac{\partial P}{\partial T} \right)_\rho} \right]$$

Energy derivative:

$$V \left( \frac{\partial P}{\partial E} \right)_V = \frac{1}{\rho C_v} \left( \frac{\partial P}{\partial T} \right)_\rho$$

Isothermal bulk modulus:

$$V \left( \frac{\partial P}{\partial V} \right)_T = - \rho \left( \frac{\partial P}{\partial \rho} \right)_T$$

Volume expansivity:

$$\frac{1}{V} \left( \frac{\partial V}{\partial T} \right)_P = \frac{1}{\rho} \left[ \frac{\left( \frac{\partial P}{\partial T} \right)_\rho}{\left( \frac{\partial P}{\partial \rho} \right)_T} \right]$$

The background material necessary to derive these and other parameters as the Joule-Thomson coefficient

$$\mu = \left( \frac{\partial T}{\partial \rho} \right)_H = \frac{1}{\rho C_p} \left[ T \frac{\left( \frac{\partial P}{\partial T} \right)_\rho}{\rho \left( \frac{\partial P}{\partial \rho} \right)_T} - 1 \right]$$

can be found in most thermodynamic texts.

GASP provides the partial derivatives  $(\partial P / \partial \rho)_T$  and  $(\partial P / \partial T)_\rho$ . With the aid of the following thermodynamic derivatives and the Bridgeman Tables, any thermodynamic parameter can be found. The following thermodynamic tables were taken from reference 67.

Differential energy formulas:

$$dE = T dS - P dV$$

$$dH = T dS + V dP$$

$$dA = -S dT - P dV$$

$$dF = -S dT + V dP$$

Maxwell relations:

$$\left( \frac{\partial T}{\partial V} \right)_S = - \left( \frac{\partial P}{\partial S} \right)_V$$

$$\left( \frac{\partial T}{\partial P} \right)_S = \left( \frac{\partial V}{\partial S} \right)_P$$

$$\left(\frac{\partial S}{\partial V}\right)_T = \left(\frac{\partial P}{\partial T}\right)_V$$

$$\left(\frac{\partial S}{\partial P}\right)_T = - \left(\frac{\partial V}{\partial T}\right)_P$$

**Energy-function derivatives:**

$$\left(\frac{\partial E}{\partial S}\right)_V = \left(\frac{\partial H}{\partial S}\right)_P = T$$

$$\left(\frac{\partial E}{\partial V}\right)_S = \left(\frac{\partial A}{\partial V}\right)_T = -P$$

$$\left(\frac{\partial H}{\partial P}\right)_S = \left(\frac{\partial F}{\partial P}\right)_T = V$$

$$\left(\frac{\partial F}{\partial T}\right)_P = \left(\frac{\partial A}{\partial T}\right)_V = -S$$

**Heat-capacity relations:**

$$C_V = \left(\frac{\partial E}{\partial T}\right)_V = T \left(\frac{\partial S}{\partial T}\right)_V$$

$$C_P = \left(\frac{\partial H}{\partial T}\right)_P = T \left(\frac{\partial S}{\partial T}\right)_P$$

$$C_P - C_V = -T \left(\frac{\partial V}{\partial T}\right)_P^2 \left(\frac{\partial P}{\partial V}\right)_T$$

$$C_P - C_{\text{sat}} = T \left(\frac{\partial V}{\partial T}\right)_P \left(\frac{\partial P}{\partial T}\right)_{\text{sat}}$$

$$\left(\frac{\partial C_V}{\partial V}\right)_T = T \left(\frac{\partial^2 P}{\partial T^2}\right)_V$$

$$\left(\frac{\partial C_P}{\partial P}\right)_T = -T \left(\frac{\partial^2 V}{\partial T^2}\right)_P$$

Effect of P or V on H or E:

$$\left(\frac{\partial H}{\partial P}\right)_T = V - T \left(\frac{\partial V}{\partial T}\right)_P$$

$$\left(\frac{\partial E}{\partial V}\right)_T = T \left(\frac{\partial P}{\partial T}\right)_V - P$$

Temperature effect on  $\Delta F/T = -R \ln K$ :

$$\left[ \frac{\partial \left( \frac{\Delta F}{T} \right)}{\partial T} \right]_P = -R \frac{\partial \ln K}{\partial T} = -\frac{\Delta H}{T^2}$$

Partial molal quantities, where Y is any extensive quantity:

$$\bar{y}_1 = \left( \frac{\partial Y}{\partial n_1} \right)_{P, T, n_2, n_3, \dots}$$

$$Y = n_1 \bar{y}_1 + n_2 \bar{y}_2 + \dots$$

$$x_1 \left( \frac{\partial \bar{y}_1}{\partial x_1} \right) + x_2 \left( \frac{\partial \bar{y}_2}{\partial x_1} \right) + \dots = 0$$

$$\left( \frac{\partial \bar{y}_i}{\partial n_j} \right) = \frac{\partial^2 Y}{\partial n_i \partial n_j} = \left( \frac{\partial \bar{y}_j}{\partial n_i} \right)$$

The so-called Bridgeman Tables are summarized as follows:

$$(\partial T)_P = - (\partial P)_T = 1$$

$$(\partial V)_P = - (\partial P)_V = \left( \frac{\partial V}{\partial T} \right)_P$$

$$(\partial S)_P = - (\partial P)_S = \frac{C_P}{T}$$

$$(\partial E)_P = - (\partial P)_E = C_P - P \left( \frac{\partial V}{\partial T} \right)_P$$

$$(\partial H)_P = - (\partial P)_H = C_P$$

$$(\partial F)_P = - (\partial P)_F = - S$$

$$(\partial A)_P = - (\partial P)_A = - \left[ S + P \left( \frac{\partial V}{\partial T} \right)_P \right]$$

$$(\partial V)_T = - (\partial T)_V = - \left( \frac{\partial V}{\partial P} \right)_T$$

$$(\partial S)_T = - (\partial T)_S = \left( \frac{\partial V}{\partial T} \right)_P$$

$$(\partial E)_T = - (\partial T)_E = T \left( \frac{\partial V}{\partial T} \right)_P + P \left( \frac{\partial V}{\partial P} \right)_T$$

$$(\partial H)_T = - (\partial T)_H = - V + T \left( \frac{\partial V}{\partial T} \right)_P$$

$$(\partial F)_T = - (\partial T)_F = - V$$

$$(\partial A)_T = - (\partial T)_A = P \left( \frac{\partial V}{\partial P} \right)_T$$

$$(\partial S)_V = -(\partial V)_S = \frac{1}{T} \left[ C_P \left( \frac{\partial V}{\partial P} \right)_T + T \left( \frac{\partial V}{\partial T} \right)_P^2 \right]$$

$$(\partial E)_V = -(\partial V)_E = C_P \left( \frac{\partial V}{\partial P} \right)_T + T \left( \frac{\partial V}{\partial T} \right)_P^2$$

$$(\partial H)_V = -(\partial V)_H = C_P \left( \frac{\partial V}{\partial P} \right)_T + T \left( \frac{\partial V}{\partial T} \right)_P^2 - V \left( \frac{\partial V}{\partial T} \right)_P$$

$$(\partial F)_V = -(\partial V)_F = - \left[ V \left( \frac{\partial V}{\partial T} \right)_P + S \left( \frac{\partial V}{\partial P} \right)_T \right]$$

$$(\partial A)_V = -(\partial V)_A = - S \left( \frac{\partial V}{\partial P} \right)_T$$

$$(\partial E)_S = -(\partial S)_E = \frac{P}{T} \left[ C_P \left( \frac{\partial V}{\partial P} \right)_T + T \left( \frac{\partial V}{\partial T} \right)_P^2 \right]$$

$$(\partial H)_S = -(\partial S)_H = - \frac{VC_P}{T}$$

$$(\partial F)_S = -(\partial S)_F = - \frac{1}{T} \left[ VC_P - ST \left( \frac{\partial V}{\partial T} \right)_P \right]$$

$$(\partial A)_S = -(\partial S)_A = \frac{1}{T} \left\{ P \left[ C_P \left( \frac{\partial V}{\partial P} \right)_T + T \left( \frac{\partial V}{\partial T} \right)_P^2 \right] + ST \left( \frac{\partial V}{\partial T} \right)_P \right\}$$

$$(\partial H)_E = -(\partial E)_H = -V \left[ C_P - P \left( \frac{\partial V}{\partial T} \right)_P \right] - P \left[ C_P \left( \frac{\partial V}{\partial P} \right)_T + T \left( \frac{\partial V}{\partial T} \right)_P^2 \right]$$

$$(\partial F)_E = -(\partial E)_F = -V \left[ C_P - P \left( \frac{\partial V}{\partial T} \right)_P \right] + S \left[ T \left( \frac{\partial V}{\partial T} \right)_P + P \left( \frac{\partial V}{\partial P} \right)_T \right]$$

$$(\partial A)_E = -(\partial E)_A = P \left[ (C_P + S) \left( \frac{\partial V}{\partial P} \right)_T + T \left( \frac{\partial V}{\partial T} \right)_P^2 \right] + ST \left( \frac{\partial V}{\partial T} \right)_P$$

$$(\partial F)_H = -(\partial H)_F = -V(C_P + S) + TS\left(\frac{\partial V}{\partial T}\right)_P$$

$$(\partial A)_H = -(\partial H)_A = -\left[S + P\left(\frac{\partial V}{\partial T}\right)_P\right]\left[V - T\left(\frac{\partial V}{\partial T}\right)_P\right] + PC_P\left(\frac{\partial V}{\partial P}\right)_T$$

$$(\partial A)_F = -(\partial F)_A = -S\left[V + P\left(\frac{\partial V}{\partial P}\right)_T\right] - PV\left(\frac{\partial V}{\partial T}\right)_P$$

## APPENDIX F

### DESCRIPTION OF SUBROUTINES IN GASP

This appendix includes a discussion of the input and output and important features of the major subroutines in GASP. The equations are presented in appendix B. The FORTRAN IV variables mentioned correspond to the program listing in appendix H (see also symbol list, appendix A).

#### GENERAL MATHEMATICAL ROUTINES

##### Function SOLVE(X1, F, DF)

Function SOLVE performs a Newton-Raphson iteration given the initial estimate X1, the function F, and the derivative function DF. The convergence is determined when

$$\left| \frac{X_N - X_{N-1}}{X_N} \right| < TOL$$

The value of TOL is 1.E-5 for iterations 1 to 40, 1.E-4 for 41 to 60, 1.E-3 for 61 to 80, and 1.E-2 for 81 to 100. In all cases studied, the convergence was usually obtained in fewer than 40 iterations. For the exceptions, usually in the near-critical region of the PVT surface, the values returned with the increased tolerance are the best obtainable using equation (B3). The maximum number of iterations is 100, and an appropriate message is written if this number is reached.

Subroutines ROOT(X0, X2, F0FX, FUNC, X1)

and ROOTX(X0, X2, F0FX, FUNC, X1)

Subroutines ROOT and ROOTX are identical except for name. The duplication is necessary for the double iterations in the solutions for temperature and density given pressure and enthalpy (KS=4) or pressure and entropy (KS=5) as input (see also table V).

The solution method is a modified, half-interval, search technique for a monotonic function, FUNC, with a root between X0 and X2 such that FUNC(X1) = F0FX, where X1 is the answer returned. The number of iterations does not exceed 100, and the tolerance is varied in the same manner as in function SOLVE. In addition, both the root and the

function value FUNC(X1) must meet a tolerance. While the tolerance on X1 is TOL, the tolerance on FUNC(X1) is 10.\*TOL. Error messages are written when the iterations reach 100 or when there is no solution in the interval X0 to X2.

#### Subroutine SPLINA(X, Y, NX, T, NT, YINT, KFD, KERROR)

Subroutine SPLINA performs a spline curve fit for interpolation in the numerical calculation for  $C_p$  (eq. (B25)) and  $C_v$  (eq. (B24)) in the dense liquid region.

#### Subroutine POLY(X, COEF)

Subroutine POLY evaluates the polynomial at X for the transport equations given in appendix B, where F(X) is described by the coefficient array COEF.

#### Subroutine SETUP(NAMGAS)

Subroutine SETUP uses NAMGAS, a two- or three-letter Hollerith code tabulated in this section, to select the coefficients for a particular fluid and overlay them into the COMMON blocks needed by GASP. The coefficients include

- |  |          |
|--|----------|
| (1) Equation-of-state coefficients               | Table II |
| (2) Saturated-vapor-law coefficients             | Table IX |
| (3) Specific-heat-at-zero-pressure coefficients  | Table IX |
| (4) Transport coefficients                       | Table X  |
| (a) Viscosity, $\mu - \mu^*$ and $\mu^*$         |          |
| (b) Thermal conductivity, $k - k^*$ and $k^*$    |          |
| (c) Force constants                              |          |
| (d) Surface tension, $\sigma$                    |          |
| (5) Region delimiters on P, T, $\rho$ , H, and S | Table IX |

Fluid	Hollerith code	Fluid	Hollerith code
Helium	HE	Nitrogen	N2
Methane	CH4	Oxygen	O2
Neon	NE	Argon	AR
Carbon monoxide	CO	Carbon dioxide	CO2
Fluorine	F2	Hydrogen	H2

More specifically, subroutine SETUP(NAMGAS) transfers the proper coefficients from BLOCK as follows:

COF(55, element number)<sup>14</sup> is stored as

(1, element number)	R	gas constant, (MPa)(cm <sup>3</sup> /g-K); J/(g-K)
(2, element number)	CP1 to CP25	equation-of-state coefficients
(26, element number)	CPS1 to CPS7	saturation-curve coefficients
(33, element number)	T0	reference temperature, T <sub>0</sub>
(34, element number)	CCPO1 to CCPO5	specific-heat-at-zero-pressure coefficients
(39, element number)	SOTO	reference entropy at T <sub>0</sub> , S <sub>0</sub>
(40, element number)	HOTO	reference enthalpy at T <sub>0</sub> , H <sub>0</sub>
(41, element number)	CPOCOR	units correction for C <sub>p,0</sub>
(42, element number)	DCH1	minimum density, g/cm <sup>3</sup>
(43, element number)	DCH2	maximum density, g/cm <sup>3</sup>
(44, element number)	PCH1	triple-point pressure, P <sub>t</sub> , MPa
(45, element number)	PCH2	pressure at thermodynamic critical point, P <sub>c</sub> , MPa
(46, element number)	PCH3	upper pressure limit, P <sub>max</sub> , MPa
(47, element number)	TCH1	triple-point temperature, T <sub>t</sub> , K
(48, element number)	TCH2	temperature at thermodynamic criti- cal point, T <sub>c</sub> , K
(49, element number)	TCH3	upper temperature limit, T <sub>max</sub> , K
(50, element number)	DST	estimate of liquid density for SOLVE, g/cm <sup>3</sup>
(51, element number)	TST	estimate of gas temperature for SOLVE, K

---

<sup>14</sup>Element number refers to the fluid, e.g., (1, 3) is R for oxygen.

(52, element number)	HSCH1	minimum enthalpy, J/g
(53, element number)	HSCH2	maximum enthalpy, J/g
DIST(element number)		intermolecular distance
EPSOK(element number)		potential parameter used to reduce temperature, $k/\epsilon$
OM2OM1(element number)		correction factor for $\lambda_r$
WTMOL		molecular weight
TCCOF(15, element number) is stored as		
(1, element number)	XLAMB	used in $k - k^*$ reduced correlation for thermal conductivity; $Z_c$ also used in surface tension
(2, element number)	ZC5	
(3, element number)	TCR	temperature at thermodynamic critical point, $T_c$ , K
(4, element number)	RHOCR	density at thermodynamic critical point, $\rho_c$ , g/cm <sup>3</sup>
(5, element number)	CKMKST	$(k - k^*)\lambda Z_c^5$ coefficients for POLY
(14, element number)	KODE	index for $k^*/k_{T_c}^*$ curve
(15, element number)	TCSTAR	$k_{T_c}^*$ , cal/sec-cm-K
AKSTCO(18, KODE)		$k^*/k_{T_c}^*$ curve coefficients for POLY KODE=1 for inert gas =2 for diatomic =3 for carbon dioxide =4 for methane ( $CH_4$ )
ZETA		viscosity normalizing parameter, $\xi$
FF		surface tension multiplier, $C_\sigma$
DTRIPL		density at the triple point
SWT		lower temperature switch to numerical specific heats
KSWT		use numerical techniques on neon, carbon monoxide, and helium where temperature or density switch is set

DIFTT	temperature increment for evaluating numerical specific heats
RHOSWT	density delimiter for switching to numerical specific heat calculation
AMUC, BMUC	viscosity correction parameters at high density (eq. (B38))

### Function CHECK

Entry: DCHECK(KU, D). - At this entry point the density D is converted to g/cm<sup>3</sup> and checked to see if D is out of range.

Entry: PCHECK(KU, KR, P). - This entry converts the pressure P to MPa and checks for out of range. If KR=1, P is checked to see if it is out of saturation range. If P is out of range, the program writes an out-of-range note and continues.

Entry: TCHECK(KU, KR, T). - This entry converts the temperature T to Kelvin and checks for out of range. If KR=1, T is checked to see if it is out of saturation range. If T is out of range, the program writes an out-of-range note and continue.

These entry points convert the variables from the user's units to those represented by KU=1 and check for out-of-range variables. Appropriate messages are written for any out-of-range input, but the calculation is allowed to continue.

### SUBROUTINES TO OBTAIN STATE VARIABLES(KS OPTIONS)

The following subroutines use the mathematical routines, function CHECK, and subroutines listed with each (see the modular structure of GASP, appendix G and table XI). Their use is determined by the KS and KP options (table V), and they are called by subroutine GASP. If a user wants to use only a few of these subroutines, he can disassemble the GASP program by following the instructions in appendix G and the discussion for the routine of interest. These subroutines are called twice by GASP for saturation properties, once with DL and once with DV as input for D.

#### Subroutine DENS(KU, T, P, D, DL, DV, KR)

Subroutine DENS solves equation (B1) for the density, given T and P in units indicated by KU. The region number KR is returned, and the density is returned in D for KR=2 or KR=3. For KR=1, the saturation values are returned in DL and DV. If KR=1

for input and either  $T=0$ . or  $P=0$ . for input, the saturated value is calculated and returned for the variable which was input as 0.

The solution is obtained by ROOT for subcritical pressures and by SOLVE for saturation or supercritical pressures. Special initial estimates were found necessary for convergence with SOLVE in the near-subcritical temperature region when

$$0.9 T_c < T < 0.9999 T_c.$$

#### Subroutine PRESS(KU, T, D, P, KR)

Subroutine PRESS solves equation (B1) for the pressure as a function of  $T$  and  $D$  in regions  $KR=2$  and  $KR=3$  and as a function of only  $T$  in region  $KR=1$  (using subroutine PSSS). The result,  $P$ , is returned in user's units indicated by  $KU$ . The correct value of  $KR$  is also returned, and the calculation is direct. Equation (B1) is repeated in its expanded form for  $N = 6$ ,  $M = 2$ :

$$P = R_p T + A(T)\rho^2 + B(T)\rho^3 + C(T)\rho^4 + D(T)\rho^5 + n_{13}\rho^6 + \rho^3 [E(T) + \rho^2 F(T)] e^{-n_{20}\rho^2/T_2}$$

where if the fluid is helium,  $T_2 = T$ , otherwise  $T_2 = 1$ ; and where

$$A(T) = n_1 T + n_2 + \frac{n_3}{T} + \frac{n_4}{T^2} + \frac{n_5}{T^3} + \frac{n_{21}}{T^4}$$

$$B(T) = n_{22} T^2 + n_6 T + n_7 + \frac{n_8}{T} + \frac{n_{23}}{T^2}$$

$$C(T) = n_9 T + n_{10}$$

$$D(T) = n_{11} T + n_{12} + \frac{n_{24}}{T}$$

$$E(T) = \left( n_{14} + \frac{n_{15}}{T} + \frac{n_{16}}{T^2} \right) \frac{1}{T^2}$$

$$F(T) = \left( n_{17} + \frac{n_{18}}{T} + \frac{n_{19}}{T^2} \right) \frac{1}{T^2}$$

The coefficients  $n_1$  to  $n_{20}$  are from Bender's original equation, while  $n_{21}$  to  $n_{24}$  have been added for carbon monoxide, neon, and helium.

#### Subroutine TEMP(KU, P, D, T, KR)

Subroutine TEMP solves equation (B10) for the temperature parameter T, given P and D in user's units specified by KU. In regions KR=2 and KR=3, SOLVE is used to obtain the solution. In region KR=1, which is either input or determined, T is a function of P only and is obtained from subroutine TSS by solving equation (B18) for T. Subroutine TSS also uses SOLVE. The correct KR is returned.

#### Function DSF(DS)

Function DSF is a multiple-entry routine used with DENS to solve for density DS, given temperature TS and pressure PS:

$$DSF = P_{\text{Equation of state}} - P_{\text{Given}}$$

#### Entry DDSF(DS)

Entry DDSF calculates the derivative of function DSF(DS) and is used with DENS to solve for density DS, given temperature TS and pressure PS:

$$DDSF = \frac{\partial(DSF)}{\partial\rho}$$

#### Subroutine PSSS(PSS)

Subroutine PSSS computes the saturation pressure PSS, given temperature TS, where

$$\log_{10} P = j_1 + \frac{j_2}{T} + j_3 T + j_4 T^2 + j_5 T^3 + j_6 T^4 + j_7 T^5$$

and the values  $j_1$  to  $j_7$  are stored by subroutine SETUP.

#### Function TSS(PS)

Function TSS(PS) is used to compute saturation temperature, given the pressure PS.

#### Function TSSF(TSS)

Function TSSF is a multiple-entry routine used with function TSS to solve for saturation temperature TSS, given pressure PSS:

$$TSSF = (\text{Vapor-pressure equation}) - \log_{10} (PS)$$

#### Entry DTSSF(TSS)

Entry DTSSF provides the derivative of function TSSF(TSS) and is used with function TSS to solve for saturation temperature TSS, given the pressure PSS:

$$DTSSF = \frac{\partial(TSSF)}{\partial T}$$

#### Function TSF(TS)

Function TSF is a multiple-entry routine used with TEMP to solve for the temperature TS, given pressure PS and density DS:

$$TSF = (\text{Equation of state}) - PS$$

#### Entry DTSF(TS)

Entry DTSF calculates the derivative of function TSF(TS) and is used with TEMP to

solve for temperature TS, given pressure PS, and density DS:

$$DTSF = \frac{\partial(TSF)}{\partial T}$$

#### Subroutine TEMPPH(KU, P, H, T, D, DL, DV, KR)

Subroutine TEMPPH solves equation (B20) by using equation (B10) for the temperature parameter T and density D, given P and H as input in user's units indicated by KU. The double iteration is performed by using ROOT and ROOTX with function TSHF for regions KR=2 and KR=3. In region KR=1 the saturation values are determined for DL and DV by DENS, and T is found by function TSS (using SOLVE). KR is also returned.

#### Subroutine TEMPS(KU, P, S, T, D, DL, DV, KR)

Subroutine TEMPS solves equations (B21) and (B16) for T and D in the same manner as TEMPPH, by using P and S as input and function TPSF for the double iteration with ROOT and ROOTX.

#### Function TSHF(TS)

Function TSHF is a multiple-entry routine used in conjunction with TEMPPH. It obtains a trial value of DS by using the given PS and a trial TS. Then it obtains a trial H, which is compared with the input enthalpy within an iteration in TEMPPH.

#### Entry TPSF(TS)

Entry TPSF is a function used in conjunction with TEMPPS. It obtains a trial value of DS from the given PS and a trial TS. Then it finds a trial S, which is compared to the input entropy within an iteration in TEMPPS.

### SUBROUTINES TO OBTAIN DERIVED THERMODYNAMIC PROPERTIES

The following routines assume that the variables T and D have been input or previously calculated in the user's units. This condition is satisfied in subroutine GASP.

When KR=1 is input or has been so determined, the corresponding saturated variable (HL, SL, etc., or HV, SV, etc.) is output.

Subroutine ENTH(KU, KR, T, P, D, H, HL, HV)

Subroutine ENTH calculates enthalpy H in user's units (KU) by using equation (B20). SL and SV are returned for saturation conditions, KR=1.

Subroutine ENT(KU, KR, T, P, D, S, SL, SV)

Subroutine ENT calculates entropy S in user's units (KU) by using equation (B21). SL and SV are returned for saturation conditions, KR=1.

Function HDINT(DS, DSL)

Function HDINT is a multiple-entry routine which computes the integral used in the enthalpy computation from density DSL to density DS.

$$\Delta H = \int_{DSL}^{DS} \left[ \frac{P}{\rho^2} - \frac{T}{\rho^2} \left( \frac{\partial P}{\partial T} \right)_\rho \right]_T d\rho$$

Entry SDINT(DS, DSL)

Entry SDINT computes the entropy integral from the density DSL to the density DS.

$$\Delta S = \int_{DSL}^{DS} \left[ - \frac{1}{\rho^2} \left( \frac{\partial P}{\partial T} \right)_\rho \right]_T d\rho$$

### Function HDINTF(DS)

Function HDINTF is a multiple-entry routine which evaluates the integrand of function HDINT, where DS is the variable of integration.

$$\frac{P}{\rho^2} - \frac{T}{\rho^2} \left( \frac{\partial P}{\partial T} \right)_{\rho}$$

### Entry SDINTF(DS)

Entry SDINTF evaluates the integrand of function SDINT, where DS is the variable of integration.

$$- \frac{1}{\rho^2} \left( \frac{\partial P}{\partial T} \right)_{\rho}$$

### Function HSS(PS, DS)

Function HSS is a multiple-entry routine which computes the enthalpy in the region KR=3 (table V) or saturated vapor enthalpy (KR=1), given pressure PS, density DS, and temperature TS.

$$H = H_0 + \int_{T_0}^T C_{p,0} dT + (Z - 1)RT + \int_0^{\rho} \left[ \frac{P}{\rho^2} - \frac{T}{\rho^2} \left( \frac{\partial P}{\partial T} \right)_{\rho} \right]_T d\rho$$

where

$$C_{p,0} = \sum_{j=1}^5 m_j T^{j-1}$$

and the values  $m_1$  to  $m_5$  are stored by subroutine SETUP, except those for hydrogen.

### Entry SSS(PS, DS)

Entry SSS computes the entropy in the region KR=3 or the saturated vapor entropy (KR=1), given pressure PS, density DS, and temperature TS.

$$S = S_0 + \int_{T_0}^T C_{p,0} d(\ln T) - R \ln(RT\rho) + \int_0^\rho \left[ \frac{R}{\rho} - \frac{1}{\rho^2} \left( \frac{\partial P}{\partial T} \right)_T \right] d\rho$$

### Subroutine HSLV(PS)

Subroutine HSLV is a multiple-entry routine used in conjunction with HSS to compute the saturated liquid and vapor enthalpies, given pressure PS and temperature TS. HV comes from HSS, and HL = HV - T\*HSSLVF.

### Entry SSLV(PS)

Entry SSLV is used with SSS to compute the saturated liquid and vapor entropies, given pressure PS and temperature TS. SV comes from SSS, and SL = SV - HSSLVF.

### Function HSSLVF(PS)

Function HSSLVF is used with HSLV to compute saturated liquid enthalpy from saturated vapor enthalpy or saturated liquid entropy from saturated vapor entropy, given pressure PS and temperature TS.

$$HSSLVF = \frac{\partial P}{\partial T} \Delta V$$

where  $V = 1/\rho$ .

Subroutine CPPRL(PS, DS, T, CPPART, CVPART, KU, KR, KCP)

This routine calculates the following in user's units KU:

- (1) Specific heat at constant volume CV
- (2) Specific heat at constant pressure CP

These specific heats are computed by

$$CV = C_{p,0} - R - \int_0^{\rho} \frac{T}{\rho^2} \left( \frac{\partial^2 P}{\partial T^2} \right)_P d\rho \quad (B22)$$

and

$$CP = C_V + \frac{T}{\rho^2} \frac{\left( \frac{\partial P}{\partial T} \right)_P}{\left( \frac{\partial P}{\partial \rho} \right)_T} \quad (B23)$$

provided the input density is less than  $\rho_{switch}/\rho_c$  (the ratio of the density where the calculation of CV changes from numeric to analytic to the critical density). These ratios for the fluids of interest are given in the following table:

Fluid	$\rho_{switch}/\rho_c$	Fluid	$\rho_{switch}/\rho_c$
Helium	2.4	Oxygen	2.4
Methane	2.5	Argon	2.4
Neon	2.4	Carbon dioxide	2.4
Nitrogen	2.2	Fluorine	2.2
Carbon monoxide	2.4	Hydrogen	2.2

At a certain density ratio for each fluid, the calculation of the specific heat CV changes from the direct calculation of equation (B22) to a numeric method where

$$CV = \left( \frac{\Delta U}{\Delta T} \right)_P = \frac{\Delta \left( H - \frac{P}{\rho} \right)}{\Delta T}$$

is solved by using a spline interpolation of five enthalpy values calculated on the isochore. This numeric calculation is performed by subroutines SPCHV, CVPS, and SPLINA.

While direct calculation of CV may be valid at densities greater than the switching densities for some fluids in GASP, the numeric method is preferred because of the sometimes erratic behavior of  $\partial P^2 / \partial T^2$ . In addition, if  $T < T_c$ , the specific heats for neon, carbon monoxide, and helium are computed by SPCHV. The P-T diagram given in figure 29 will give the user a better feel for the physical regions involved.

The first partial derivatives from subroutine PTRHO (eqs. (B9) and (B12)) are made available through COMMON/DERIV/PDT, PDTL, PDTV, PTVL, and PTVV. These are

$$PDT = \left( \frac{\partial P}{\partial \rho} \right)_T$$

with PDTV for saturated vapor and PDTL for saturated liquid and

$$PTV = \left( \frac{\partial P}{\partial T} \right)_\rho$$

with PTVL for saturated liquid and PTVV for saturated vapor.

#### Function CPPRLF(DS)

Function CPPRLF evaluates the integral used in computing specific heats:

$$CPPRLF = \int \frac{T}{\rho^2} \left( \frac{\partial^2 P}{\partial T^2} \right)_\rho d\rho$$

#### Subroutine PTRHO(D, T)

Subroutine PTRHO evaluates two partial derivatives. The answers are returned in COMMON/PARTLS/PTV, PDT.

$$PTV = \left( \frac{\partial P}{\partial T} \right)_\rho$$

$$PDT = \left( \frac{\partial P}{\partial \rho} \right)_T$$

#### Subroutine SPCHV(KU, KR, T, P, D, CV, CVL, CVV)

Subroutine SPCHV computes the specific heat at constant volume CV given temperature T, pressure P, and density D. If KR=1, the saturated liquid or vapor specific heat, CVL or CVV, respectively, is computed as requested by GASP.

$$CV = \frac{\Delta U}{\Delta T} = \frac{\Delta \left( H - \frac{P}{\rho} \right)}{\Delta T}$$

See subroutine CPPRL.

#### Subroutine CVPS(KVP, KR, CVS)

Given temperature, pressure, and density, this routine is used to determine five values of internal energy U for a spline fit used in SPCHV to compute the specific heat at constant volume.

#### Subroutine SONIC(KU, KR, T, D, GAMMA, C)

This routine calculates the sonic velocity C, in user's units KU, by using equation (B26) and the ratio GAMMA=CP/CV, where GAMMA is calculated in subroutine GASP.

#### Subroutine VISC(KU, KR, T, D, MU)

Subroutine VISC uses T and D as input in user's units KU. Dynamic viscosity is calculated by using one or more of equations (B27) to (B36) depending on the fluid, as explained in appendix B. Calculations of dynamic viscosity are direct evaluations of curve fits but may be altered as by equation (B38). A special form is used for hydrogen and helium.

### Function VISCD(DS, TS)

Function VISCD, developed by McCarty of NBS, computes the dynamic viscosity of helium.

### Subroutine THERM(KU, KR, T, P, D, EXCESK, FK)

Subroutine THERM uses T, P, and D in user's units KU to calculate the thermal conductivity FK in user's units KU. An optional coding section calculates the critical excess thermal conductivity EXCESK associated with the critical anomaly in the PVT region,  $0.4 < \rho/\rho_c < 1.6$ . See also references 25 and 29 to 32, the subroutine listing in appendix H, and equations (B55) to (B60). EXCESK will be computed for the density regime  $0.4 < \rho/\rho_c < 1.6$ . To obtain the thermal conductivity of a near-critical fluid, the user must add FK and EXCESK.

The equations used for the thermal conductivity of the different fluids are (B39) to (B54). Subroutines CONZ and CONC are used for the special forms for parahydrogen and helium (eqs. (B45) to (B47) and (B51)).

### Subroutine SURF(KU, KR, T, SIGMA)

Subroutine SURF uses T in user's units KU to calculate the surface tension SIGMA of the liquid by using equations (B61) and (B62).

### Subroutine DGUESS(TS, TCR, DST)

Subroutine DGUESS provides an estimate of near-critical density that is used by subroutine DENS.

### Function CONZ(TEMP)

Function CONZ computes the thermal conductivity of dilute gaseous helium as a function of temperature by the technique of H. M. Roder of NBS, Boulder, Colorado (private communication).

**Function CONC(T, D)**

Function CONC computes the thermal conductivity of hydrogen in both the dense-and dilute-gas regions.

**Subroutine SETCPO(T)**

Subroutine SETCPO computes  $C_{p,0}$  for hydrogen according to the regions established in appendix K.

## APPENDIX G

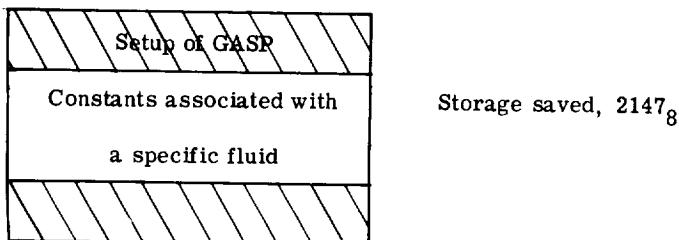
### MODULAR DESIGN OF GASP

A user with limited core storage or with specific property needs may wish to use only parts of GASP. The subroutines have been coded so that most of the subroutines corresponding to the "KP" option requests may be removed without causing errors in logic or calculation. Table XI indicates which routines are absolutely necessary and which are optional. The conditions for removal must be strictly followed. For simplicity, the KP options are discussed as though only one option was being requested. In reality, the input variable KP is always the sum of the KP options desired.

Prior to modifying GASP, the user should note that the internal structure of GASP is best seen from the flow chart of appendix H and table V, noting the various KP options. (The separate calls which use enthalpy and entropy are assumed to have been deleted whenever the enthalpy or entropy subroutine is removed.)

Other storage savings may be constructed by using table XII. Some changes that can be made to GASP and the corresponding reduction in storage requirements are as follows:

- (1) Setup can be narrowed to one fluid, that is, eliminate 9 of 10 fluids



A more prudent trimming of BLOCK and SETUP results in a savings of more storage spaces. Similarly, by editing each subroutine and function in GASP, further savings can be realized. Also, parahydrogen requires several special subroutines that are not required for other fluids such as methane, for example, FUNCTION VISCD, FUNCTION CONC, FUNCTION CONZ, SUBROUTINE SETCPO, special calculations in VISC and THERM, special branching and subsequent calculations throughout the program. Thus, if results for only a single fluid other than hydrogen are desired, a maximum savings in storage can be attained by deleting these special subroutines.

- (2) Calculations with P,  $\rho$ , and T only (eliminate all others)

P, $\rho$ , T calculations (KS=1, 5)	
KP=1	Enthalpy
KP=2	Entropy
KP=4	Specific heats, sonic velocity, and derivatives
KP=8	Viscosity
KP=16	Thermal conductivity
KP=32	Surface tension

Storage saved, 6631<sub>8</sub>

### (3) Enthalpy-entropy calculations

P, $\rho$ , T calculations (KS=1, 3)	
KP=1	Enthalpy
KP=2	Entropy
KP=4	Specific heats, sonic velocity, and derivatives
KP=8	Viscosity
KP=16	Thermal conductivity
KP=32	Surface tension

Storage saved, 13137<sub>8</sub>

### (4) Specific user requirement - specific heats, sonic velocity, and derivatives

(a) If  $\rho \leq \rho_{\text{switch}}$  (see table on p. 70 of appendix F),

P, $\rho$ , T calculations (KS=1, 3)	
KR=1	Enthalpy
KP=2	Entropy
KP=4	Specific heats, sonic velocity, and derivatives
KP=8	Viscosity
KP=16	Thermal conductivity
KP=32	Surface tension

Storage saved, 11175<sub>8</sub>

(b) If  $\rho > \rho_{\text{switch}}$ ,

P, $\rho$ , T calculations (KS=1, 3)	
KP=1	Enthalpy
KP=2	Entropy
KP=4	Specific heats, sonic velocity, and derivatives
KP=8	Viscosity
KP=16	Thermal conductivity
KP=32	Surface tension

Storage saved, 4650<sub>8</sub>

## (5) Transport property calculations

P, $\rho$ , T calculations (KS=1, 3)	
KP=1	Enthalpy
KP=2	Entropy
KP=4	Specific heats, sonic velocity, and derivatives
KP=8	Viscosity
KP=16	Thermal conductivity
KP=32	Surface tension

Storage saved, 7612<sub>8</sub>

The specific illustration of removing all but one fluid from subroutine SETUP and BLOCK DATA is given as follows:

```

C TEST PROGRAM PREPARES TABLES FOR EACH FLUID OVER A RANGE OF PVT
C
COMMON/PROPTY/KU,DV,HL,HV,S,SL,SV,CV,CVL,CVV,CP,CPL,GAMMA,
1GAMMAL,GAMMAV,C,CL,CVP,MU,MUL,MUV,K,KL,KV,SIGMA,EXCESK,EXCL,EXCV
COMMON/DERIV/PDT,PTV,PDTL,PDTV,PTVL,PTVV
REAL MU,MUL,MUV,K,KL,KV
COMMON/CHECKS/DCH1,DCH2,PCH1,PCH2,PCH3,TCH1,TCH2,TCH3,DST,TST,H
1SCH1,HSCH2
DATA NAM/3HCH4,2HN2,2HO2,2HAR,3HCO2,2HNE,2HCO,2HHE,2HF2,2HH2/
DIMENSION NAM(10),P(3),T(250),YPL(250,10),TSTART(3,10),DTA(3,10)
DATA P/1.,1.,100./
DATA TSTART/95.,295.,400.,65.,200.,400.,60.,225.,400.,85.,225.,400
*,220.,420.,500.,25.,80.,400.,70.,200.,400.,3.,10.,100.,70.,200.,
*400.,16.,40.,200./
DATA CTA/10.,20.,100.,10.,20.,100.,10.,20.,100.,10.,20.,100.,
* 10.,20.,100.,10.,20.,100.,10.,20.,100.,5.,10.,100.,5.,20.,100.,
* 2.,10.,100./
KS=1
KP=31
KU=1
WRITE(6,1)
1 FORMAT(1H1)
DO 1000 L=10,10
CALL SETUP (NAM(L))
P(2)=PCH2/.101325
T(1)=TSTART(1,L)
DT=DTA(1,L)
TS=TSTART(2,L)
N=2
KPT=0
DO 20 J=1,50
KPT=J
T(J+1)=T(J)+DT
TJ=T(J+1)
IF(TJ.GE.TCH3) GOTO 25
IF(L.EQ.10 .AND. TJ.GE.1999.5) GOTO 25
IF(TJ-TS+.051 20,210,210
210 T(J+1)=TS
DT=DTA(N,L)
N=N+1
TS=TCH3
IF(N.LT.4) TS=TSTART(N,L)
20 CONTINUE
25 KPT=KPT+1
T(KPT)=TCH3
DO 100 I=1,3
Z= P(I)*.101325
DO 50 J=1,KPT
KR=0
CALL GASP (KS,KP,T(J),Z,D,H,KR)
YPL(J,1)=D
YPL(J,2)=H
YPL(J,3)=S
YPL(J,4)=CP
YPL(J,5)=CV
YPL(J,6)=C
YPL(J,7)=K
YPL(J,8)=MU
YPL(J,9)=PDT
YPL(J,10)=PTV
46 FORMAT(1H ,I6,6E14.6)
50 CONTINUE
C          TABLE      OF
C          DENSITY, ENTROPY, ENTHALPY, CP, CV,           SONIC VELOCITY
C          THERMAL CONDUCTIVITY, VISCOSITY AND PARTIAL DERIVATIVES
C          FOR EACH T P
WRITE(6,800) NAM(L),KU
800 FORMAT(1H1,45X,3H THERMODYNAMIC PROPERTY TABLE -- ,A4 ,3X,3HKU=
1 I3)
WRITE(6,801) P(I)
801 FORMAT(1HO ,5X, F10.2 ,1H ATM 1 SOBAR)
WRITE(6,701)
WRITE(6,702)
701 FORMAT(3HO ,4HTEMP,5X,7HDENSITY,4X,8HENHALPY,4X,7HENENTROPY,7X,2HC
*p,10X,2HCV,9X,7HSDN VEL,4X,10HTHERM COND,5X,4HVISC,7X,5HDP/DD,7X,5
*HDP/DT,/)
702 FORMAT(4X,1HK,8X,4HG/CC,8X,3HJ/G,8X,5HJ/G-K,7X,5HJ/G-K,7X,5HJ/G-K,
*8X,4HCM/S,7X,8HJ/CM-S-K,5X,6HG/CM-S,4X,1HMMN-CC/G-M2,3X,7HMMN/K-M2,
*/)
DO 150 J=1,KPT
WRITE(6,803) T(J),(YPL(J, N),N=1,10)
IF (40C(J,50).NE.0) GO TO 150
IF ( J.EQ. KPT) GO TO 150
WRITE(6,800) NAM(L)
WRITE(6,801) P(I)

```

```

803 FORMAT (1H ,F6.1,2X,1O(1X,G11.4))
150 CONTINUE
100 CONTINUE
51 FORMAT(12H ISOBARS = 5F10.3 )
1000 CONTINUE
RETURN
END

C      -----THIS ROUTINE OVEFLAYS COEFFICIENTS FOR SPECIFIED FLUID=NAMGAS
C      ----- IN PROGRAM COMMON BLOCKS
C      -----COEFFICIENTS FOR ALL FLUIDS ARE PRESTORED IN BLOCK DATA
C
C      SUBROUTINE SETUP (NAMGAS)
COMMON/ALLCOF/COF(53),TCCOF(15),AKSTCO(18),DIST,
1WTMOL,EPSOK,ZETA,FF,SWT,KSWT,DIFFT,
2RHOSWT,CTRIPL,AMUC,BMUC
C      COMMON TO DETERMINE FLUID AND INFORM USER OF HIS CHOICE
COMMON/GASES/MESSAG(15)
COMMON/WHAT/KGAS
C      SPECIAL SWITCHES FOR HELIUM,FLUORINE,HYDROGEN
COMMON/HFLFLU/IHE,IFL,IHY
C      COMMON FOR EQUATION OF STATE COEFFICIENTS
COMMON/BEND/ R(1),CP1,CP2,CP3,CP4,CP5,CP6,CP7,CP8,CP9,CP10,
ICP11,CP12,CP13,CP14,CP15,CP16,CP17,CP18,CP19,CP20
Z,CP21,CP22,CP23,CP24
C      SATURATION CURVE COEFFICIENTS
COMMON/COSAT/ CPS1(1),CPS2,CPS3,CPS4,CPS5,CPS6,CPS7
C      CPO CURVE COEFFICIENTS
COMMON/CCOP0/T0(1),CCOP1,CCOP2,CCOP3,CCOP4,CCOP5
C      REFERENCE ENTROPY, ENTHALPY , CP CORRECTION FACTOR
COMMON/REFNO/SOTO,HOTO,CPOCOR,HTERM,STERM
C      PARAMETERS FOR CHECKING REGION AND RANGE LIMITS ON DENSITY
C      PRESSURE, TEMPERATURE, ENTHALPY. DENSITY AND TEMPERATURE ESTIMATES FOR
C      NEWTON-RAPHSON ITERATIONS
COMMON/CHECKS/DCH1(1),DCH2,PCH1,PCH2,PCH3,TCH1,TCH2,TCH3,DST,TST,H
1SCH1,HSC+2
C      CONSTANTS FOR THERMAL CONDUCTIVITY CALCULATION.
COMMON/TCOND/CKMKST(9),XLAMB,ZCS,RHOCR,TCR,TCSTAR,CKSTAR(18)
C      CONSTANTS FOR VISCOSITY CALCULATION.
COMMON/COFMU/EPSK,WM,DIS,RHOCRT,ZETAA,AMUX,BMUX
C      CONSTANTS FOR SURFACE TENSION CALCULATION.
COMMON/SURCON/PCTC,TCRIT,FIXIT,ZET
C      SWITCH FOR CP-CV CALCULATION. VALUES IN CERTAIN REGIONS ARE
C      CALCULATED BY NUMERICAL DIFFERENTIATION ...WHENEVER THE ANALYTICAL
C      DERIVATIVES ARE GOOD, THEY ARE USED.....
COMMON/SWITS/KSWIT,TSWIT,DIFFT,RSWIT
COMMON/SOLID/DTRIP
IHE=0
IFL=C
C      NAMGAS IS ALWAYS H2 FOR PARA-HYDROGEN
C
KGAS=10
IHY=1
WRITE(6,101) (MESSAG(I),I=1,15)
101 FORMAT (1H0,15A6)
C      STORE CONSTANTS FOR BENDER-S EQ. OF STATE
DO 20 I=1,25
20 R(I)= COF(I)
C      STORE SATURATION CURVE FOR GAS
DO 25 I=26,32
25 CPS1(I-25) = COF(I)
C      STORE CPO COEFFICIENTS AND REFERENCE TO
DO 30 I=33,38
30 T0(I-32) = COF(I)
C      STORE REFERENCE ENTROPY, ENTHALPY, CPO CORRECTION FACTOR
TX=T0(1)
C      COMPUTE LOWER BOUND FOR THE ENTHALPY AND ENTROPY CALCULATIONS IN HSS
C
10.312 = 4.968*4.184/2.01572
STERM=10.312* ALOG(TX)
HTERM=10.312*TX
SOTO= COF(39)
HOTO= COF(40)
CPOCUR=COF(41)
C      STORE CRITICAL VALUES AND REGION BOUNDARY CONSTANTS
DO 35 I=42,53
35 DCH1(I-41) = COF(I)
XLAMB= TCCOF(1)
ZCS= TCCOF(2)
TCR= TCCOF(3)
RHOCR = TCCOF(4)

```

```

C      LOAD K-K*  CURVE COEFFICIENTS
      DO 45  I=5,13
45  CKMKST(I-4)= TCCOF(I)
      TCSTAR= TCCOF(15)
      I= TCCOF(14)+1
C                           LOAD KSTAR/KSTARTC  CURVE COEFFICIENTS
      DO 50  J=1,18
50  CKSTAR(J)= AKSTCO(J)
      STORE CONSTANTS FOR U-U* AND VISCOSITY CALCULATION
      WM=WTMOL
      ZETAA=ZETA
      RHOCRT=TCCOF(4)
      EPSK =EPSOK
      DIS=DIST
C      STORE CONSTANTS FOR SURFACE TENSION ( RF IS RIEDEL FACTOR)
      TCRIT=TCH2
      PCTC=(PCF2/.101325)**.6666667*TCH2**.333333
      FIXIT=FF
      ZET=ZC5**.2
C      ENTER SWITCHING PARAMETER FOR CP,CV CALCULATION
      KSWIT=KSWT
      TSWIT=SWT
      IF (KSWIT.EQ.2) TSWIT=TCH2
      DIFT=DIFTT
      RSWIT=RHSWT*RHOCRT
      DTRIP=CTRIP
      AMUX=AMUC
      BMUX=BMUC
      RETURN
      END

C      STORES THE COEFFICIENTS FOR ALL FLUIDS FOR THE EQUATION OF STATE
C      AND THE TRANSPORT EQUATIONS.
C      STORES CONVERSION CONSTANTS NEEDED BY ALL FLUIDS
C
BLOCK DATA
COMMON/GASES/MESSAG(15)
COMMON/ CON123/ DCONV(5),TCONV(5),PCONV(5)
COMMON/CONV4/SCONV(5)
COMMON/CONV5/CCONV(5)
COMMON/CONV6/HCONV(5)
COMMON/ALLCOF(COF(53),TCCOF(15),AKSTCO(18),DIST,
1WTMOL,EPSSK,ZETA,FF,SWT,KSWT,DIFTT,
2RHOSWT,CTRIP,AMUC,BMUC
DIMENSION MH2(15)
EQUIVALENCE (MESSAG(1),MH2(1))
DATA MF2(1)/ 90HTHERMODYNAMIC AND TRANSPORT PROPERTIES FOR HYDRO
1GENPC=12.759ATM,TC=32.976K,RHOC=.03143G/CC /
DATA TCONV /1.,1.,1.8,2*1./
DATA PCONV/1.,9.8692327,145.03774 ,2*1./
DATA ECONV/21.,62.42796,2*1./
DATA SCONV/2*1.,0.23900574,2*1./
DATA FCONV/2*1.,0.4302103,2*1./
DATA CCONV/2*1.,0.0328084,2*1./
DATA (COF(1 ),I=1,53)/4.1260486, .44446150E+2,
1-.38655634E+4,-.10966555E+6, .12080022E+7, -.54747655E+7,
2-.33278647E+3, .81345734E+5, .26294257E+6, .30063983E+5,
3-.33024955E+7,-.24686707E+6, .47555234E+8, -.12064332E+9,
4-.49285827E+8, .15925894E+10, -.87182365E+10, .66330266E+11,
5.16366622E+11, -.12954419E+14, .1050E+4, 4*0.,
6-.10593817E+1, -.35249570E+2, .37870039E+0, -.23601614E-1,
7.85529568E-3, -.16180625E-4, .12500233E-6, 20.268,
V14.7595360,-.21977388,.32100769E-2,-.12061502E-4,.57121808E-8,
X21.17E42,209.9406,1.0,
8.1E-4, .11, .101325E-3, 1.2928, 100., 13.8, 32.976,
A3000., .09, 60.,-309.89197 , 49289.7 /
C
C      TRANSPORT PROPERTIES ARE LIMITED BY THE STATE OF THE ART
C      READ REPORT ON GASP FOR COMPLETE DETAILS
C
C
      DATA (AKSTCO(I ),I=1,18)/3.,3.,-4.,0., 1.0, 0.,
10.0,-1.12398985,.79352374,.83465682,-.21370471E-2,.39794,          N2
20..0., .729, .081707270, 1.0 /                                02
      DATA (TCCOF(I),I=1,15)/1.4978,.252512E-2,32.976,.03143,1.,4.,
1-1.,2.70581484,4.30610645,1.88960889,1.26994786,-6.82428539,.4,
22.,.61974E-4/
      DATA DIST,EPSSK,WTMOL,ZETA,FF,CTRIP,SWT,KSWT,DIFTT,RHOSWT,AMUC,BM
1UC/2.528,.027,2.0159,.40786245E-1,1.,.11,68.,1,1.,2.2,2*0./
      END

```

THERMODYNAMIC AND TRANSPORT PROPERTIES FOR HYDROGENPC=12.759ATM, TC=32.976K, RHOC=0.03143G/CC  
 J. 818.5E-051 OUT OF RANGE FOR D IN SUB-E-NT  
 0. 818.5E-051 OUT OF RANGE FOR D IN SUB-E-NT  
 0. 818.5E-051 OUT OF RANGE FOR D IN SUB-E-NT  
 0. 818.5E-051 OUT OF RANGE FOR D IN SUB-E-NT  
 0. 818.5E-051 OUT OF RANGE FOR D IN SUB-E-NT  
 0. 818.5E-051 OUT OF RANGE FOR D IN SUB-E-NT

THERMODYNAMIC PROPERTY TABLE -- H2 KU# 1

1.00 ATM ISOBAR

TEMP K	1.00 ATM ISOBAR		CP J/G-K	CV J/G-K	ENTROPY J/G-K	ENTROPY J/G-K	SOL VEL CM/S	THERM COND J/CM-S-K	VISC G/C/M-S	DP/DD MN-C/C-G-M2	DP/DT MN/K-G-M2
	DENSITY G/CC	ENTHALPY J/G									
16.0	0.7519E-01	-291.95	6.0160	8.2828	5.8330	0.1205E+06	0.8950E-03	0.1995E-03	1022.8	0.9410	
18.0	0.7326E-01	-274.86	7.0220	8.8288	5.7932	0.1150E+06	0.9555E-03	0.1627E-03	867.85	0.8863	
20.0	0.7108E-01	-256.62	7.9819	9.4205	5.5421	0.1109E+06	0.9838E-03	0.1364E-03	722.97	0.8416	
22.0	0.6909E-02	210.80	31.4116	6.2346	3.7513	0.3753E+05	0.1726E-03	0.1124E-04	5.148E-02	0.4623E-02	
24.0	0.1090E-02	233.41	31.987	11.200	6.2363	0.3952E+05	0.1919E-03	0.1124E-04	86.96	0.4230E-02	
26.0	0.5546E-03	255.64	32.877	11.044	6.2360	0.4138E+05	0.2015E-03	0.1455E-04	96.66	0.4205E-02	
28.0	0.5145E-03	277.61	33.691	10.926	6.2342	0.4313E+05	0.2125E-03	0.1622E-04	106.12	0.3856E-02	
30.0	0.8415E-03	299.36	34.491	10.834	6.2315	0.4479E+05	0.2307E-03	0.1622E-04	115.38	0.3566E-02	
32.0	0.7901E-03	320.96	35.138	10.761	6.2285	0.4638E+05	0.2544E-03	0.1717E-04	126.49	0.3318E-02	
34.0	0.7403E-03	342.42	35.789	10.702	6.2254	0.4790E+05	0.2632E-03	0.1811E-04	133.47	0.3104E-02	
36.0	0.6967E-03	363.77	36.399	10.654	6.2223	0.4937E+05	0.2802E-03	0.1902E-04	143.7	0.2917E-02	
38.0	0.6581E-03	385.04	36.974	10.614	6.2193	0.5079E+05	0.2924E-03	0.1992E-04	151.18	0.2752E-02	
40.0	0.6236E-03	406.23	37.518	10.616	6.2523	0.5211E+05	0.3081E-03	0.2080E-04	159.93	0.2605E-02	
50.0	0.4951E-03	511.39	39.865	10.484	6.2183	0.5850E+05	0.3776E-03	0.2498E-04	204.98	0.2061E-02	
60.0	0.4111E-03	617.08	41.791	10.703	6.4858	0.6363E+05	0.44479E-03	0.2885E-04	245.36	0.1707E-02	
70.0	0.2511E-03	726.30	43.474	11.178	6.9884	0.7680E+05	0.5251E-03	0.3245E-04	287.37	0.1459E-02	
80.0	0.2014E-03	841.24	45.008	11.834	7.6616	0.7131E+05	0.6071E-03	0.3518E-04	322.17	0.1274E-02	
90.0	0.1730E-03	963.37	46.445	12.604	8.4428	0.7441E+05	0.7017E-03	0.3908E-04	370.84	0.1131E-02	
100.0	0.1446E-03	1093.5	47.815	13.425	9.2708	0.7728E+05	0.8007E-03	0.4449E-04	412.42	0.1017E-02	
110.0	0.2222E-03	1023.1	49.133	14.235	10.086	0.8004E+05	0.9033E-03	0.4933E-04	453.93	0.9237E-03	
120.0	0.2046E-03	1378.0	50.404	14.975	10.831	0.8276E+05	0.1006E-02	0.46497E-04	495.39	0.8463E-03	
130.0	0.1888E-03	1530.9	51.628	15.589	11.448	0.8550E+05	0.1092E-02	0.4761E-04	536.82	0.7809E-03	
140.0	0.1753E-03	1689.1	52.801	16.021	11.882	0.8830E+05	0.1172E-02	0.5218E-04	575.22	0.7249E-03	
150.0	0.1636E-03	1850.6	53.914	16.217	12.080	0.9120E+05	0.1252E-02	0.5469E-04	619.60	0.6764E-03	
160.0	0.1534E-03	2011.3	54.952	16.237	12.101	0.9417E+05	0.1335E-02	0.5715E-04	660.97	0.6340E-03	
170.0	0.1444E-03	2173.6	55.936	16.220	12.085	0.9709E+05	0.1415E-02	0.6078E-04	702.32	0.5960E-03	
180.0	0.1333E-03	2335.6	56.862	16.173	12.039	0.9995E+05	0.1491E-02	0.6394E-04	743.66	0.5634E-03	
190.0	0.1292E-03	2497.0	57.734	16.101	11.969	0.1028E+06	0.1522E-02	0.6424E-04	784.99	0.5337E-03	
200.0	0.1227E-03	2657.6	58.558	16.050	11.878	0.1052E+06	0.1630E-02	0.6555E-04	826.32	0.5070E-03	
300.0	0.8181E-04	4198.9	64.824	14.846	10.717	0.1310E+06	0.2160E-02	0.8778E-04	1239.3	0.3379E-03	
400.0	0.6136E-04	5660.9	69.031	14.591	10.464	0.1518E+06	0.2664E-02	0.1068E-03	1621.1	0.2534E-03	
500.0	0.4909E-04	7126.9	72.303	14.516	10.389	0.1679E+06	0.3134E-02	0.12444E-03	2064.8	0.2027E-03	
600.0	0.4031E-04	8698.8	74.944	14.544	10.417	0.1860E+06	0.4194E-02	0.1410E-03	2477.5	0.1689E-03	
700.0	0.3537E-04	10166.05	77.193	14.652	10.526	0.2006E+06	0.5005E-02	0.1566E-03	2890.0	0.1448E-03	
800.0	0.31569E-04	11631E-05	79.158	14.778	10.652	0.2141E+06	0.4414E-02	0.1716E-03	3302.8	0.1267E-03	
900.0	0.2728E-04	1311E-05	80.907	14.919	10.793	0.2197E+06	0.4810E-02	0.1886E-03	3715.4	0.1126E-03	
1000.0	0.2455E-04	1461E-05	82.486	15.074	10.948	0.2384E+06	0.5194E-02	0.1998E-03	4128.0	0.1013E-03	
1100.0	0.2232E-04	1613E-05	83.931	15.239	11.113	0.2495E+06	0.5567E-02	0.2133E-03	4549.7	0.9212E-04	
1200.0	0.2046E-04	1766E-05	95.264	15.414	11.288	0.2601E+06	0.5931E-02	0.2264E-03	4953.3	0.8444E-04	
1300.0	0.1889E-04	1921E-05	86.505	15.596	11.470	0.2701E+06	0.6455E-02	0.2391E-03	5365.9	0.7798E-04	
1400.0	0.1754E-04	2078E+05	87.668	15.783	11.657	0.2797E+06	0.6637E-02	0.2519E-03	5778.5	0.7238E-04	
1500.0	0.1637E-04	2237E+05	88.763	15.974	11.848	0.2889E+06	0.6859E-02	0.2637E-03	6191.1	0.6755E-04	
1600.0	0.1535E-04	2398E+05	89.800	16.167	12.041	0.2978E+06	0.7315E-02	0.2755E-03	6603.7	0.6333E-04	
1700.0	0.1444E-04	2560E+05	90.786	16.361	12.234	0.3063E+06	0.7645E-02	0.2872E-03	7016.4	0.5960E-04	
1800.0	0.1364E-04	2725E+05	91.727	16.554	12.427	0.3146E+06	0.7970E-02	0.2986E-03	7429.0	0.5629E-04	
1900.0	0.1292E-04	2891E-05	92.627	16.745	12.619	0.3226E+06	0.8291E-02	0.3099E-03	7841.6	0.5332E-04	
3000.0	0.8185E-05	0.4836E+05	100.67	18.484	14.358	0.3992E+06	0.4234E-03	0.4234E-03	0.1238E-05	0.3378E-05	

THERMODYNAMIC PROPERTY TABLE -- H2 KU= 1

12.76 ATM ISOBAR						12.76 ATM ISOBAR					
TEMP K	DENSITY G/CC	ENTHALPY J/G	ENTROPY J/G-K	CP J/G-K	CV J/G-K	SON VEL CM/S	THERM COND J/CM-S-K	VI SC G/CM-S	DP/DD MN-CC/G-M2	DP/DT MN/K-M2	
16.0	0.7630E-01	279.14	5.8338	8.0870	5.9072	0.1244E+06	0.9077E-03	0.2261E-03	1130.6	0.9469	
18.0	0.7455E-01	262.44	6.8070	8.5080	5.5373	0.1200E+06	0.9815E-03	0.1765E-03	983.18	0.9049	
20.0	0.7260E-01	245.09	7.7296	8.5401	5.5377	0.1162E+06	0.1018E-02	0.1885E-03	845.92	0.8710	
22.0	0.7041E-01	226.44	8.6176	9.7592	5.4777	0.1127E+06	0.1050E-02	0.1727E-03	713.34	0.8296	
24.0	0.6792E-01	205.64	9.5219	10.7758	5.3858	0.1092E+06	0.1055E-02	0.1622E-03	583.38	0.7775	
26.0	0.6504E-01	181.68	10.487	9.6610	2.7785	0.1258E+06	0.1031E-02	0.9595E-04	455.13	0.7139	
28.0	0.6156E-01	152.80	11.549	12.6449	3.4954	0.1489E+06	0.9977E-03	0.8328E-04	327.92	0.6374	
30.0	0.5702E-01	117.56	12.67	13.794	4.2584	0.9161E+05	0.9313E-03	0.7108E-04	200.83	0.5428	
32.0	0.4954E-01	64.770	14.461	35.366	5.0282	0.7076E+05	0.8044E-03	0.5681E-04	71.195	0.070	
34.0	0.1684E-01	169.34	21.557	41.541	6.0303	0.4233E+05	0.3879E-03	0.2439E-04	28.484	0.9111E-01	
36.0	0.1311E-01	228.83	23.261	23.443	6.6478	0.4489E+05	0.3717E-03	0.2313E-04	57.153	0.6768E-01	
38.0	0.1128E-01	270.42	24.386	18.824	6.6325	0.4720E+05	0.3723E-03	0.2324E-04	78.594	0.5658E-01	
40.0	0.1006E-01	305.63	25.20	16.640	6.6394	0.4918E+05	0.3779E-03	0.2366E-04	96.516	0.4944E-01	
50.0	0.6935E-02	448.17	28.485	12.888	6.4699	0.5745E+05	0.4227E-03	0.2687E-04	166.19	0.225E-01	
60.0	0.5521E-02	571.95	30.744	12.172	6.6508	0.6351E+05	0.4884E-03	0.3034E-04	222.19	0.274E-01	
70.0	0.4613E-02	692.24	32.599	12.074	7.1013	0.6810E+05	0.5602E-03	0.3371E-04	272.75	0.2030E-01	
80.0	0.3979E-02	814.71	34.234	12.4668	7.7420	0.7120E+05	0.6333E-03	0.3694E-04	320.48	0.1731E-01	
90.0	0.3507E-02	942.31	35.736	13.077	8.5019	0.7508E+05	0.7204E-03	0.4000E-04	366.51	0.1514E-01	
100.0	0.3139E-02	1076.6	37.150	13.190	9.3155	0.7804E+05	0.8274E-03	0.4236E-04	411.45	0.1347E-01	
110.0	0.2844E-02	1218.2	38.499	14.526	10.121	0.8087E+05	0.9283E-03	0.4505E-04	455.64	0.1215E-01	
120.0	0.2601E-02	1366.9	39.764	15.22	10.858	0.8364E+05	0.1029E-02	0.4770E-04	499.29	0.1107E-01	
130.0	0.2357E-02	1522.1	41.034	15.786	11.470	0.8641E+05	0.1114E-02	0.5028E-04	542.53	0.1017E-01	
140.0	0.2223E-02	1682.1	42.220	16.187	11.903	0.8924E+05	0.1193E-02	0.5281E-04	587.46	0.9144E-02	
150.0	0.2074E-02	1845.0	43.344	16.359	12.095	0.9274E+05	0.1270E-02	0.5528E-04	628.16	0.8163E-02	
160.0	0.1943E-02	2007.1	44.390	16.359	12.113	0.9517E+05	0.1353E-02	0.5770E-04	670.66	0.8197E-02	
170.0	0.1828E-02	2170.6	45.381	16.327	12.096	0.9810E+05	0.1431E-02	0.6009E-04	713.00	0.7701E-02	
180.0	0.1726E-02	2333.6	46.313	16.267	12.048	0.1010E+06	0.1504E-02	0.6423E-04	755.00	0.7262E-02	
190.0	0.1635E-02	2495.8	47.190	16.185	11.976	0.1038E+06	0.1574E-02	0.6473E-04	797.33	0.6872E-02	
200.0	0.1553E-02	2657.2	48.018	16.084	11.884	0.1066E+06	0.1640E-02	0.6700E-04	839.35	0.6321E-02	
210.0	0.1437E-02	4203.2	54.303	14.816	10.719	0.1322E+06	0.1720E-02	0.7204E-04	878.4	0.4325E-02	
220.0	0.1312E-03	5667.5	58.518	14.664	10.464	0.1528E+06	0.2664E-02	0.1071E-03	1671.6	0.3229E-02	
230.0	0.1223E-03	7134.8	61.792	14.526	10.390	0.1708E+06	0.3134E-02	0.1246E-03	2085.6	0.2589E-02	
240.0	0.1197E-03	8707.6	64.434	14.551	10.418	0.1868E+06	0.3579E-02	0.1411E-03	2476.9	0.2157E-02	
250.0	0.1077E-03	10376.0	66.685	14.657	10.526	0.2014E+06	0.4005E-02	0.1567E-03	2912.3	0.1848E-02	
260.0	0.9571E-03	12047.6	68.084	14.782	10.652	0.2148E+06	0.4414E-02	0.1717E-03	3325.4	0.1617E-02	
270.0	0.8370E-03	13720.5	70.399	14.922	10.793	0.2273E+06	0.4810E-02	0.1860E-03	3738.4	0.1431E-02	
280.0	0.7173E-03	15404.0	71.979	14.975	11.848	0.2495E+06	0.6979E-02	0.2237E-03	4151.3	0.1233E-02	
290.0	0.6000E-03	17087.5	73.424	15.241	11.113	0.2502E+06	0.5576E-02	0.2134E-03	4564.1	0.1117E-02	
300.0	0.4923E-03	18771.0	74.757	15.416	11.288	0.2607E+06	0.5931E-02	0.2264E-03	4976.9	0.1078E-02	
310.0	0.3942E-03	20454.5	75.999	15.597	10.470	0.2707E+06	0.6288E-02	0.2392E-03	5389.7	0.9966E-03	
320.0	0.2962E-03	22138.0	77.161	15.657	10.652	0.2803E+06	0.6637E-02	0.2516E-03	5802.4	0.9236E-03	
330.0	0.2079E-03	23821.5	78.257	15.727	10.816	0.2995E+06	0.6979E-02	0.2637E-03	6215.2	0.8620E-03	
340.0	0.1284E-03	25495.0	79.294	16.041	11.048	0.2983E+06	0.7315E-02	0.2756E-03	6627.9	0.8081E-03	
350.0	0.1954E-03	27168.5	80.280	16.361	12.234	0.3068E+06	0.7645E-02	0.2873E-03	7040.6	0.7603E-03	
360.0	0.1840E-03	28842.0	81.221	16.554	12.427	0.3151E+06	0.7970E-02	0.2987E-03	7453.3	0.7183E-03	
370.0	0.1738E-03	30515.5	82.121	16.745	12.619	0.3231E+06	0.8291E-02	0.3099E-03	7866.0	0.6805E-03	
380.0	0.1646E-03	32189.0	82.121	16.944	14.358	0.3396E+06	0.8639E-02	0.4235E-03	8245.0	0.4309E-03	

0.41836E+CO IS OUT OF RANGE OF CURVE FIT VALUE IS EXTRAPOLATED.

0.41239E+CO IS OUT OF RANGE OF CURVE FIT VALUE IS EXTRAPOLATED.

0.4050E+CO IS OUT OF RANGE OF CURVE FIT VALUE IS EXTRAPOLATED.

THERMODYNAMIC PROPERTY TABLE -- H2 KU= 1

100.00 ATM ISOBAR		TEMP K		ENTHALPY J/G		ENTROPY J/G-K		CP J/G-K		CV J/G-K		SON VEL CM/S		THERM COND J/CM-S-K		VI SC G/CM-S		DP/DD MN-CC/G-M2		DP/DD MN/K-M2	
16.0	0.8236E-01	-182.83	4.9059	7.2316	5.9901	0.1479E+06	0.1007E-02	0.3566E-03	1812.9	0.9768	0.9925										
18.0	0.8123E-01	-168.28	5.7627	7.2710	5.6823	0.1471E+06	0.1124E-02	0.2834E-03	1691.2	0.9925	1.0022										
20.0	0.8001E-01	-153.62	6.5349	7.3588	5.3682	0.1470E+06	0.1158E-02	0.2367E-03	1576.4	0.9981	1.0022										
22.0	0.7869E-01	-138.54	7.2533	7.4574	5.3315	0.1459E+06	0.1269E-02	0.2032E-03	1465.9	0.9981	0.9981										
24.0	0.7729E-01	-122.35	7.9572	8.5174	5.6692	0.1429E+06	0.1313E-02	0.1781E-03	1359.2	0.9816	0.9816										
26.0	0.7581E-01	-104.41	8.6744	9.4875	6.1985	0.1387E+06	0.1336E-02	0.1585E-03	1256.4	0.9557	0.9557										
28.0	0.7425E-01	-84.640	9.4067	10.295	6.5572	0.1348E+06	0.1345E-02	0.1429E-03	1157.9	0.9231	0.9231										
30.0	0.7262E-01	-63.496	10.136	10.426	6.2288	0.1335E+06	0.1342E-02	0.1300E-03	1064.0	0.8860	0.8860										
32.0	0.7052E-01	-40.724	10.870	9.0235	4.3556	0.1421E+06	0.1322E-02	0.1192E-03	975.00	0.8458	0.8458										
34.0	0.6915E-01	-20.892	11.471	10.630	5.4749	0.1315E+06	0.1279E-02	0.1100E-03	891.19	0.8038	0.8038										
36.0	0.6731E-01	1.3541	12.107	11.589	5.9360	0.1260E+06	0.1269E-02	0.1021E-03	812.90	0.7605	0.7605										
38.0	0.6541E-01	25.406	12.757	12.449	6.2559	0.1211E+06	0.1239E-02	0.9517E-04	740.48	0.7168	0.7168										
40.0	0.6334E-01	51.095	13.416	13.263	6.5875	0.1165E+06	0.1208E-02	0.8906E-04	674.27	0.6710	0.6710										
50.0	0.5300E-01	198.67	16.697	15.947	7.1179	0.9986E+05	0.1052E-02	0.5124E-04	445.08	0.4638	0.4638										
60.0	0.4318E-01	362.66	19.686	16.519	7.3829	0.9094E+05	0.9461E-03	0.5650E-04	369.60	0.3239	0.3239										
70.0	0.2566E-01	525.45	22.196	15.994	7.7334	0.8789E+05	0.9144E-03	0.5204E-04	373.51	0.2367	0.2367										
80.0	0.3027E-01	683.01	24.301	15.574	8.2433	0.8753E+05	0.9220E-03	0.5083E-04	405.55	0.1845	0.1845										
90.0	0.2635E-01	838.11	26.128	15.501	8.8907	0.8833E+05	0.9819E-03	0.5113E-04	447.55	0.1511	0.1511										
100.0	0.2339E-01	993.95	27.769	15.704	9.6176	0.8974E+05	0.1052E-02	0.5152E-04	493.26	0.1282	0.1282										
110.0	0.2107E-01	1152.07	29.282	16.064	10.358	0.9153E+05	0.1052E-02	0.5124E-04	501.11	0.1116	0.1116										
120.0	0.1921E-01	1315.4	30.698	16.474	11.047	0.9357E+05	0.1218E-02	0.5444E-04	587.10	0.9898E-01	0.9898E-01										
130.0	0.1776E-01	1482.0	32.031	16.839	11.622	0.9583E+05	0.1289E-02	0.5626E-04	633.83	0.8911E-01	0.8911E-01										
140.0	0.1638E-01	1651.8	33.289	17.079	12.025	0.9829E+05	0.1256E-02	0.5817E-04	680.18	0.8115E-01	0.8115E-01										
150.0	0.1527E-01	1823.0	34.470	17.126	12.198	0.1010E+06	0.1427E-02	0.6016E-04	726.12	0.7457E-01	0.7457E-01										
160.0	0.1431E-01	1992.2	35.562	17.036	12.200	0.1038E+06	0.1495E-02	0.6219E-04	771.69	0.6944E-01	0.6944E-01										
170.0	0.1347E-01	2161.9	36.591	16.912	12.169	0.1066E+06	0.1642E-02	0.6431E-04	816.91	0.6431E-01	0.6431E-01										
180.0	0.1273E-01	2330.4	37.554	16.786	12.111	0.1093E+06	0.1712E-02	0.6630E-04	861.81	0.6023E-01	0.6023E-01										
190.0	0.1207E-01	2497.6	38.458	16.648	12.030	0.1120E+06	0.1689E-02	0.6836E-04	906.44	0.5666E-01	0.5666E-01										
200.0	0.1148E-01	3663.4	39.308	16.501	11.931	0.1174E+06	0.1746E-02	0.7042E-04	950.83	0.5349E-01	0.5349E-01										
300.0	0.7736E-02	4237.2	45.710	15.063	10.734	0.1394E+06	0.2195E-02	0.9029E-04	1385.7	0.3459E-01	0.3459E-01										
400.0	0.5856E-02	5715.6	49.966	14.715	10.471	0.1596E+06	0.2688E-02	0.1087E-03	1811.7	0.2568E-01	0.2568E-01										
500.0	0.4717E-02	7191.7	10.393	16.912	10.177	0.1715E+06	0.3154E-02	0.1259E-03	2233.3	0.2044E-01	0.2044E-01										
600.0	0.3952E-02	8770.4	55.913	14.601	10.420	0.1928E+06	0.3597E-02	0.1422E-03	2652.4	0.1699E-01	0.1699E-01										
700.0	0.3401E-02	10123E+05	58.170	14.615	10.527	0.2070E+06	0.4022E-02	0.1577E-03	3070.0	0.1554E-01	0.1554E-01										
800.0	0.2985E-02	0.1171E+05	60.140	14.811	10.653	0.2202E+06	0.4414E-02	0.1725E-03	3486.5	0.1211E-01	0.1211E-01										
900.0	0.2661E-02	0.1320E+05	61.892	14.946	10.794	0.2324E+06	0.4810E-02	0.1868E-03	3902.2	0.1129E-01	0.1129E-01										
1000.0	0.2400E-02	0.1470E+05	63.474	15.095	10.948	0.2440E+06	0.5194E-02	0.2005E-03	4317.4	0.1015E-01	0.1015E-01										
1100.0	0.2186E-02	0.1622E+05	64.920	15.257	11.114	0.2549E+06	0.5567E-02	0.2140E-03	4732.2	0.9228E-02	0.9228E-02										
1200.0	0.2007E-02	0.1775E+05	66.255	15.429	11.288	0.2652E+06	0.5932E-02	0.2270E-03	5146.2	0.8447E-02	0.8447E-02										
1300.0	0.1855E-02	0.1930E+05	67.497	15.509	11.470	0.2751E+06	0.6288E-02	0.2397E-03	5560.8	0.7804E-02	0.7804E-02										
1400.0	0.1724E-02	0.2087E+05	68.661	15.794	11.657	0.2845E+06	0.6637E-02	0.2521E-03	5974.8	0.7246E-02	0.7246E-02										
1500.0	0.1611E-02	0.2246E+05	69.757	15.984	11.848	0.2936E+06	0.6979E-02	0.2642E-03	6388.6	0.6762E-02	0.6762E-02										
1600.0	0.1512E-02	0.2407E+05	70.795	16.176	12.041	0.3023E+06	0.7315E-02	0.2776E-03	6802.3	0.6338E-02	0.6338E-02										
1700.0	0.1424E-02	0.2570E+05	71.781	16.368	12.235	0.3107E+06	0.7645E-02	0.2877E-03	7215.9	0.5956E-02	0.5956E-02										
1800.0	0.1346E-02	0.2734E+05	72.722	16.560	12.428	0.3189E+06	0.7970E-02	0.2991E-03	7629.3	0.5633E-02	0.5633E-02										
1900.0	0.1276E-02	0.2901E+05	73.623	16.751	12.619	0.3267E+06	0.8291E-02	0.3103E-03	8042.7	0.5336E-02	0.5336E-02										
3000.0	0.8117E-03	0.4846E+05	81.671	18.487	14.358	0.4026E+06	0.4423E-03	0.4257E-03	0.9378E-02	0.1259E-03	0.1259E-03										

## APPENDIX H

### PROGRAM LISTING AND FLOW CHART FOR GASP

This appendix contains a complete listing of GASP and a set of flow charts to aid the user in interpreting the program operation and logic.

#### LISTING OF GASP

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C BENDER-S EQUATION OF STATE FOR THE FIVE GASES--N2,CH4,AR,C2,CC2
C ALSO EQUATIONS OF STATE FOR CO, NE, HE, AND FLUORINE
C ALSO PARA-HYDROGEN
C
C COMPUTE THE STATE RELATIONS AND THERMODYNAMIC AND
C TRANSPORT PROPERTIES OF SPECIFIED FLUID GIVEN TEMPERATURE T,
C PRESSURE P, DENSITY D, OR ENTHALPY H. STATE RELATIONS ARE
C SPECIFIED BY KS. THERMODYNAMIC AND TRANSPORT PROPERTIES
C ARE SPECIFIED BY KP. IF KR IS RETURNED OR SPECIFIED AS 1,
C PROPERTIES ARE COMPUTED AT SATURATION.
C
C SUBROUTINE GASPI(KS,KP,T,P,D,H,KR)
COMMON/PROPTY/KU,DL,DV,HL,HV,S,SL,SV,CV,CVL,CVV,CP,CPL,CPV,GAMMA,
1GAMMAL,GAMMAV,C,CL,CVP,MU,MUL,MUV,K,KL,KV,SIGMA,EXCESK,EXCL,EXCV
REAL MU,MUL,MUV,K,KL,KV
COMMON/DERIV/PDT,PTV,PDTL,PDTV,PTVL,PTVV
COMMON/PARTLS/PTV1,PDT1
COMMON/CHECKS/DCH1 ,DCH2,PCH1,PCH2,PCH3,TC11,TCH2,TCH3,DST,TST,H
ISCH1,HSCH2
COMMON/CON123/DCONV(5),TCONV(5),PCONV(5)
COMMON/HEFLU/ IHE,IFY,IHY
KTR=0
GO TO (10,20,30,40,45),KS
C
C COMPUTE DENSITY
10 CALL DENS(KU,T,P,D,DL,DV,KR)
GO TO 50
C
C COMPUTE PRESSURE
20 CALL PRESS(KU,T,D,P,KR)
GO TO 50
C
C COMPUTE TEMPERATURE
30 CALL TEMP(KU,P,D,T,KR)
GO TO 50
C
C COMPUTE TEMPERATURE AND DENSITY GIVEN PRESSURE AND ENTHALPY
40 CALL TEMPPH(KU,P,H,T,D,DL,DV,KR)
GO TO 50
C
C COMPUTE TEMPERATURE AND DENSITY GIVEN PRESSURE AND ENTROPY
45 CALL TEMPSS ( KU,P,S,T,D,DL,DV,KR )
C
C
50 CONTINUE
KTRA=KP/2**KTR
IF(KTRA.EQ.0) RETURN
KTR=KTR+1
IF(MOD(KTRA,2).EQ.0) GOTO 50
GOTO( 60,100,130,160,180,240 ), KTR
```

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C
C
C      COMPUTE ENTHALPY
60 CALL ENTH(KU,KR,T,P,D,H,HL,HV)
GOTO 50
C
C      COMPUTE ENTROPY
100 CALL ENT(KU,KR,T,P,D,S,SL,SVI)
GOTO 50
C
C      COMPUTE SPECIFIC HEATS AND SONIC VELOCITY
130 KCP=0
IF (KR.NE.1) GO TO 200
CALL DENS(KU,T,P,D,DL,DV,1)
CALL CPPRL(P,DL,T,CPL,CVL,KU,KR,KCP,GAMMAL,CL)
PTVL=PTV1*PCJNV(KU)/TCNV(KU)
PDTL=PCT1*PCJNV(KU)/DCNV(KU)
CALL CPPRL(P,DV,T,CPV,CVV,KU,KR,KCP,GAMMAV,CVP)
PTVV=PTV1*PCJNV(KU)/TCNV(KU)
PDTV=PCT1*PCJNV(KU)/DCNV(KU)
GO TO 140
200 CALL CPPRL(P,D,T,CP,CV,KU,KR,KCP,GAMMA,C)
PTV =PTV1*PCJNV(KU)/TCNV(KU)
PDT =PCT1*PCJNV(KU)/DCNV(KU)
140 GOTO 50
C
C      COMPUTE VISCOSITY
160 IF (KR.NE.1) GO TO 165
CALL DENS(KU,T,P,D,DL,DV,1)
CALL VISC(KU,KR,T,DL,MUL)
CALL VISC(KU,KR,T,DV,MUV)
GO TO 170
165 CALL VISC(KU,KR,T,D,MU)
170 GOTO 50
C
C      COMPUTE THERMAL CONDUCTIVITY
C      NOTE-- FROZEN VALUE AVAILABLE IN K,KL,KY
C      -- REACTING CONDUCTIVITY RETURNED IN EXCESK, EXCL,EXCV
180 IF (KR.NE.1) GO TO 220
CALL DENS(KU,T,P,D,DL,DV,1)
CALL TTERM (KU,KR,P,T,DL,EXCL,KL)
CALL TTERM (KU,KR,P,T,DV,EXCV,KV)
GO TO 190
220 CALL TTERM (KU,KR,P,T,D,EXCESK,K)
190 GOTO 50
C
C      COMPUTE SURFACE TENSION
240 CALL SURF (KU,KR,T,SIGMA)
RETURN
END

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C      -----THIS ROUTINE OVERLAYS COEFFICIENTS FOR SPECIFIED FLUID-NAMGAS
C      -----IN PROGRAM COMMON BLOCKS
C      -----COEFFICIENTS FOR ALL FLUIDS ARE PRESTORED IN BLOCK DATA
C
SUBROUTINE SETUP (NAMGAS)
COMMON/ALLCOF/COF(53,10),TCCOF(15,10),AKSTCD(18,4),DIST(10),
1WTMOL(10),EPSNK(10),ZETA(10),FF(10),SWT(10),KSWT(10),DIFTT(10),
2RHOSWT(10),DTRIPL(10),AMUC(10),BMUC(10)
C      COMMON TO DETERMINE FLUID AND INFORM USER OF HIS CHOICE
COMMON/GASES/MATCH(10),MESSAG(15,10)
COMMON/WHAT/KGAS
C      SPECIAL SWITCHES FOR HELIUM,FLUORINE,HYDROGEN
COMMON/HFLFLU/ IHE, IFL, IHY
C      COMMON FOR EQUATION OF STATE COEFFICIENTS
COMMON/BEND/ R(1),CP1,CP2,CP3,CP4,CP5,CP6,CP7,CP8,CP9,CP10,
1CP11,CP12,CP13,CP14,CP15,CP16,CP17,CP18,CP19,CP20
2 ,CP21,CP22,CP23,CP24

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C      SATURATION CURVE COEFFICIENTS
COMMON/COSAT/ CPS1(1),CPS2,CPS3,CPS4,CPS5,CPS6,CPS7
C      CPO CURVE COEFFICIENTS
COMMON/CCOP0/T0(1),CCOP1,CCOP2,CCOP3,CCOP4,CCOP5
C      REFERENCE ENTROPY, ENTHALPY , CP CORRECTION FACTOR
COMMON/REFNO/SOTO,HOTO,CPOCOR,HTERM,STERM
C      PARAMETERS FOR CHECKING REGION AND RANGE LIMITS ON DENSITY
C      PRESSURE, TEMPERATURE, ENTHALPY. DENSITY AND TEMPERATURE ESTIMATES FOR
C      NEWTON-RAPHSON ITERATIONS
COMMON/CHECKS/DCH1(1),DCH2,PCH1,PCH2,PCH3,TCH1,TCH2,TCH3,DST,TST,H
ISCH1,HSCH2
C      CONSTANTS FOR THERMAL CONDUCTIVITY CALCULATION.
COMMON/TCOND/CKMKST(9),XLAMB,ZC5,RHOCR,TCR,TCSTAR,CKSTAR(18)
C      CONSTANTS FOR VISCOSITY CALCULATION.
COMMON/COFMU/EPSK,WM,DIS,RHOCRT,ZETAA,AMUX,BMUX
C      CONSTANTS FOR SURFACE TENSION CALCULATION.
COMMON/SURCON/PCTC,TCRIT,FIXIT,ZET
C      SWITCH FOR CP-CV CALCULATION. VALUES IN CERTAIN REGIONS ARE
C      CALCULATED BY NUMERICAL DIFFERENTIATION ... WHENEVER THE ANALYTICAL
C      DERIVATIVES ARE GOOD, THEY ARE USED.....
COMMON/SWITS/KSWIT,TSWIT,DIIFT,RSWIT
COMMON/SOL ID/DTRIP
<KGAS=0
DO 10 I=1,10
IF(NAMGAS.EQ.MATCH(I)) KGAS=I
10 CONTINUE
IF(KGAS.EQ.0) GO TO 70
IHE=0
IF (KGAS.EQ.8) IHE=1
IRL=0
IF (KGAS.EQ.9) IFL=1
IF (IFL.EQ.1) WRITE(6,72)
IHY=0
IF(KGAS.EQ.10) IHY=1
WRITE(6,101) (MESSAG(I,KGAS),I=1,15)
101 FORMAT (1H0,15A6)
C      STORE CONSTANTS FOR BENDER-S EQ. OF STATE
DO 20 I=1,25
20 R(I)= COF(I,KGAS)
C      STORE SATURATION CURVE FOR GAS
DO 25 I=26,32
25 CPS1(I-25) = COF(I,KGAS)
C      STORE CPO COEFFICIENTS AND REFERENCE TO
DO 30 I=33,38
30 T0(I-32) = COF(I,KGAS)
C      STORE REFERENCE ENTROPY, ENTHALPY, CPO CORRECTION FACTOR
TX=T0(1)
C      COMPUTE LOWER BOUND FOR THE ENTHALPY AND ENTROPY CALCULATIONS IN HSS
C
A1=CCOP5*.25
A2=CCOP4*.3333333
A3=CCOP3*.5
STERM    =(((A1*TX+A2)*TX+A3)*TX+CCOP2)*TX+CCOP1* ALOG(TX)
A1=CCOP5*.2
A2=CCOP4*.25
A3=CCOP3*.3333333
A4=CCOP2*.5
HTERM    =(((A1*TX+A2)*TX+A3)*TX+A4)*TX+CCOP1*TX
10.312 = 4.968*4.184/2.01572
IF (HY.EQ.1) STERM=10.312*ALOG(TX)
IF (HY.EQ.1) HTERM=10.312*TX
SOTO= COF(39,KGAS)
HOTO= COF(40,KGAS)
CPOCOR=COF(41,KGAS)
C      STORE CRITICAL VALUES AND REGION BOUNDARY CONSTANTS
DO 35 I=42,53
35 DCH1(I-41) = COF(I,KGAS)
XLAMB= TCCOF(1,KGAS)
ZC5= TCCOF(2,KGAS)
TCR= TCCOF(3,KGAS)
RHOCR = TCCOF(4,KGAS)
C      LOAD K-K* CURVE COEFFICIENTS
DO 45 I=5,13

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45 CKMKST(I-4)= TCCDF(I,KGAS)
TCSTAR= TCCDF(15,KGAS)
I= TCCDF(14,KGAS)+.1
C          LOAD KSTAR/KSTARTC    CURVE COEFFICIENTS
DO 50 J=1,18
50 CKSTAR(J)= AKSTCD(J,I)
C          STORE CONSTANTS FOR U-U* AND VISCOSITY CALCULATION
WM=WTMOL(KGAS)
ZETAA=ZETA(KGAS)
RHOCRT=TCCDF(4,KGAS)
EPSK =EPSOK(KGAS)
DIS=DIST(KGAS)
C          STORE CONSTANTS FOR SURFACE TENSION ( RF IS RIEDEL FACTOR)
TCRIT=TCH2
PCTC=(PCF2-.101325)**.6666667*TCH2**.333333
FIXIT=FF(KGAS)
ZET=ZC5**.2
C          ENTER SWITCHING PARAMETER FOR CP,CV CALCULATION
KSWIT=KSWT(KGAS)
TSWIT=SWT(KGAS)
IF (KSWIT.EQ.2) TSWIT=TCH2
DIFT=DIFTT(KGAS)
RSWIT=RHO SWT(KGAS) *RHOCRT
DTRIP=CTR IPL(KGAS)
AMUX=AMUC(KGAS)
BMUX=BMUC(KGAS)
RETURN
70 WRITE(6,71)
71 FORMAT(1H0, 69H ERROR IN CODE FOR NAMGAS - NO CONSTANTS STORED-
2 PROGRAM STOP.      )
72 FORMAT(1H0,115H THE REGION 125-145K FOR T AND P GREATER THAN 10
1ATM YIELDS POOR RESULTS FOR THE DERIVED PROEPRTIES--BEWARE.      )
STOP
END

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C          STORES THE COEFFICIENTS FOR ALL FLUIDS FOR THE EQUATION OF STATE
C          AND THE TRANSPORT EQUATIONS.
C          STORES CONVERSION CONSTANTS NEEDED BY ALL FLUIDS
C
BLOCK DATA
COMMON/GASES/MATCH(10),MESSAG(15,10)
COMMON/ CON123/ DCONV(5),TCONV(5),PCUNV(5)
COMMON/CONV4/SCONV(5)
COMMON/CONV5/CCONV(5)
COMMON/CONV6/HCONV(5)
COMMON/ALLCOF/COF(53,10),TCCDF(15,10),AKSTCD(18,4),DIST(10),
1WTMOL(10),EPSOK(10),ZETA(10),FF(10),SWT(10),KSWT(10),DIFT(10),
2RHOSWT(10),DTRIPL(10),AMUC(10),BMUC(10)
DIMENSION MCH4(15),MN2(15),MD2(15),MAR(15),MC02(15),MNE(15),MCO(15
1),MHE(15),MF2(15),MH2(15)
EQUIVALENCE(MESSAG(1,1),MCH4(1)),(MESSAG(1,2),MN2(1)),(MESSAG(1,3)
1,MJ2(1)),(MESSAG(1,4),MAR(1)),(MESSAG(1,5),MC02(1)),(MESSAG(1,6),
2MNE(1)),(MESSAG(1,7),MCO(1)),(MESSAG(1,8),MHE(1)),(MESSAG(1,9),MF2
3(1)),(MESSAG(1,10),MH2(1))
DATA (MATCH(I), I=1,8)/3HC4,2HN2,2H02 ,2HAR,3HCO2,2HNE,2HCO,2HHE/
DATA MATCH(9)/2HF2/
DATA MATCH(10)/2HH2/
DATA MCH4(1)    /90H THERMODYNAMIC AND TRANSP CRT PROPERTIES FOR ME
ITHANE PC=45.66 ATM,TC=190.77 K,RDC=.162 G/CC /
DATA MN2(1)     /90H THERMODYNAMIC AND TRANSPORT PROPERTIES FOR N
1ITROGEN PC=33.72ATM,TC=126.3 K,RDC=.3105G/CC /
DATA MD2(1)     /90H THERMODYNAMIC AND TRANSP CRT PROPERTIES FOR OX
1YGEN PC=50.16ATM,TC=154.78 K,RDC=.4325G/CC /
DATA MAR(1)     /90H THERMODYNAMIC AND TRANSPORT PROPERTIES FOR AR
1GN PC= 48.014ATM, TC=150.7 K,RDC=.531 G/CC /
DATA MC02(1)    /90H THERMODYNAMIC AND TRANSP CRT PROPERTIES FOR CO
2 PC=72.869ATM, TC=304.21 K, RDC=.464 G/CC /
DATA MNE(1)     /90H THERMODYNAMIC AND TRANSP CRT PROPERTIES FOR NE

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ION PC= 26.19ATM ,TC=44.4 K, RHOC=.483 G/CC /
DATA MCO(1) /9OH THERMODYNAMIC AND TRANSPORT PROPERTIES FOR CO
I PC=34.529ATM, TC=132.91 K, RHOC=.2997 G/CC /
DATA MHE(1) /9OH THERMODYNAMIC AND TRANSPORT PROPERTIES FOR HE
I PC = 2.245ATM, TC = 5.2K, RHOC = .0693G/CC /
DATA MF2(1) /90HTHERMODYNAMIC AND TRANSPORT PROPERTIES FOR FLU
ORINE PC=51.47ATM, TC=144.31K,RHOC=.5738G/CC /
DATA MH2(1)/ 90HTHERMODYNAMIC AND TRANSPORT PROPERTIES FCR HYDRO
IGEVP=12.759ATM,TC=32.976K,RHOC=.03143G/CC /
DATA TCONV /1.,1.,1.8,2*1./
DATA PCONV/1.,9.8692327,145.03774 ,2*1./
DATA DCONV/2*1.,62.42796,2*1./
DATA SCONV/2*1.,0.23900574,2*1./
DATA HCONV/2*1.,0.4302103,2*1./
DATA CCONV/2*1.,0.0328084,2*1./

C METTANE-----BENDER 1971
DATA (COF(I,1),I=1,53)/ .518251 , .17191020E1
1-.86366402E3 , .25005236E5 ,-.12533848E8 , .34169547E9
2 .75523689 ,-.12111233E3 ,.20547188E6 , .32337540E2
3-.61948317E4 ,-.25603803E2 ,.11556713E4 , .27425297E5
4 .49495630E8 ,-.11956135E11 ,.88302981E12 ,-.31713486E10
5 .12302028E13 ,-.64499295E14 ,.37E2 ,4*0. , -.32097996E2
6 .29976933E3 ,.70773219 ,-.72349122E-2 , .40851153E-4
7-.12130439E-6 ,.148489295E-9 ,.11167E3 ,.796986252
8 .39225023E-2 ,-.56781803E-4 ,.23442607E-5 ,-.22395007E-9
98 .35517346 ,.803207E 3 ,.260815 , .1E-4
1 .57 ,.01167 ,.4627 , .5067E2
2 .9066E2 ,.19077E 3 ,.6E3 , .45
3 .25E3 ,.220.28242 ,.2007. /

C NITROGEN-----BENDER 1971
DATA (COF(I,2),I=1,53)/ .296797 , .48058175
1-.15047010E3 , .26071365E 4 ,-.12792742E7 , .29436228E8
2 .37500265 ,-.50738465E 2 ,.14499236E5 , .1440998E1
3-.24136776E3 ,.28954771 ,-.27613799E2 ,.36048264E3
4-.20083357E7 ,.43265184E9 ,-.16513521E11 ,.10141439E8
5 .47216396E10 ,-.12016418E12 ,.1E2 ,4*0. , -.66869126E1
6-.20086668E3 ,.37077481 ,-.62602129E-2 ,.56187159E-4
7-.25984366E-6 ,.49025967E-9 ,.77364 E2 ,.29090035E+2
8 .89930170E-3 ,-.92394038E-5 ,.26008592E-7 ,-.14102926E-10,
9 .23351167 E1 ,.231188578E3 ,.35693888E-1 ,.1449 E-3
11.1208 ,.010132 ,.3417 ,.5067 E2
2 .64 E2 ,.1263 E3 ,.100 E4 ,.92
3 .18 E3 ,.2.1159267 ,.1262. /

C OXYGEN-----BENDER 1970
DATA (COF(I,3),I=1,53)/ .259832 , .34811077
1-.14070678E3 ,.25061744E 4 ,-.10081345E7 ,.19074164E8
2-.40134966E-2 ,.65172112E2 ,.10962206E5 ,.6972158
3-.26242449E3 ,.191378 ,.29416771 E2 ,.78932076E2
4-.1923158E7 ,.4610824E9 ,-.39936263E11 ,.5668995E7
5 .13644286E10 ,.91977198E11 ,.5.4 ,4*0. , -.51504418E1
6-.25626822E3 ,.26280757 ,-.36222681E-2 ,.26516635E-4
7-.10004384E-6 ,.15423155E-9 ,.90E2 ,.29145189E2
8-.5691586E-3 ,.68032634E-5 ,-.48456604E-7 ,.13822647E-9
94.72426938 ,.35642E3 ,.03125117 ,.15E-3
1 .1.50 ,.0101325 ,.5.083 ,.1.0000E2
2 .5435C7E2 ,.15478E3 ,.5.E+3 ,.1.3
3 .23E3 ,.88.464226 ,.739.86 /

C ARGON-----BENDER 1970
DATA (COF(I,4),I=1,53)/ .208128 , .19825921
1-.81733119E2 ,.1777747E4 ,-.82406544E6 ,.31666098E8
2-.44202671E-1 ,.6216142E2 ,.11443248E4 ,.4779752
3-.19645227E3 ,-.21572754 ,.16544141E3 ,.28142112E2
4 .82532059E5 ,-.91538377E 7 ,-.18340752E10 ,.33858136E7
5 .15532886E10 ,-.67479568E11 ,.3.5 ,4*0. ,.13814448E+2
6-.5739E331E+3 ,-.18072036E+0 ,.18350292E-2 ,-.10957549E-4
7 .36123787E-7 ,-.50097228E-10 ,.8728E2 ,.2.5
8 .0 ,.0 ,.0 ,.0
9 2.757177 ,.237932E 3 ,.208152 ,.1E-3
11.48 ,.0101325 ,.4.865 ,.5066E2
2 .8378E2 ,.1507E3 ,.1 E4 ,.1.3
3 .25E3 ,.70.051092 ,.725.24043 /
```

C CARBON DIOXIDE-----BENDER 1970

DATA (COF (I,5), I=1, 53)/ .18818 , .22488558 ,  
 1-.13717965E3 , -.14430214E5 , -.29630491E7 , -.20606039E9 ,  
 2 .45554393E-1 , .77042840E2 , .40602371E5 , .40029509 ,  
 3-.39436077E3 , .12115286 , .10783386E3 , .43962336E2 ,  
 4-.36505545E8 , .19490511E11 , .29186718E13 , .24358627E8 ,  
 5-.37546530E11 , .11898141E14 , .5. , 4\*0. , -.95913112E+2 ,  
 6 .26738653E+4 , .11405373E+1 , .67026553E-2 , .21745017E-4 ,  
 7-.37153665E-7 , .26225608E-10 , .19471 E3 , .5.152 ,  
 8 .015224 , .9681E-5 , .2313E-8 , .0. ,  
 94 .0851019 , .72665417E3 , .095067 , .83E-5 ,  
 11.25 , .010132 , .7.3835 , .50669E2 ,  
 2 .21656E3 , .30421E3 , .100E4 , .1.1 ,  
 3 .37 E3 , .381.34364 , .1567.66 , /

C NEON-----MCCARTY AND STEWART 1965

DATA (COF(I,6),I=1,53)/ .41185435 , .42879277 ,  
 1-.41617333E2 , .15368388E4 , .21705583E5 , .0 ,  
 2.5237778E-1 , .31832376E2 , .15304725E4 , .86991276 ,  
 3-.86565802E2 , .0 , .0 , .41994281E2 ,  
 4 .23856729E6 , .10444366E8 , .0 , .19828098E7 ,  
 5 .70965701E8 , .0 , .13590153E2 , .0.0 ,  
 6-.12553439E-2 , .76888021E3 , .84938358E3 , .67422985E1 ,  
 7-.11786837E3 , .19946844 , .69680979E-2 , .14623832E-3 ,  
 8 .17229114E-5 , .83773053E-8 , .27.09 , .1.02986 ,  
 9 .0 , .0 , .0 , .3 ,  
 12.454C781 , .9234824E2 , .1. , .00015 ,  
 2 1.350 , .0101325 , .2.6537 , .2029E2 ,  
 3 24.54 , .44.4 , .600. , .1.2 ,  
 4 100. , .06205 , .694.635 , /

C CARBON MONOXIDE-----HUST AND STEWART 1963

DATA (COF(I,7),I=1,53)/ .29692807 , .36547544 ,  
 1-.80241533E2 , .16713841E5 , .13129095E6 , .0 ,  
 2 .65308710 , .80131497E2 , .0 , .73365157 ,  
 3 .0 , .0 , .0 , .41363247E3 ,  
 4 .18061147E7 , .63943277E9 , .66472139E11 , .24767075E8 ,  
 5 .96546154E10 , .47286423E12 , .74632444E1 , .58725319E9 ,  
 6 .0 , .0 , .0 , .13172848E2 ,  
 7-.52482838E3 , .18207888 , .20385068E-2 , .13699320E-4 ,  
 8 .51448459E-7 , .81676932E-10 , .68.14 , .1.0392602 ,  
 9-.5033322E-5 , .26032523E-7 , .0 , .0 ,  
 14.7928763 , .35387E3 , .1. , .5E-4 ,  
 2.86 , .0101325 , .3.4986 , .2027E2 ,  
 3 68.14 , .132.91 , .600. , .81 ,  
 4 180. , .120.13179 , .908.8334 , /

C HELIUM-----MANN 1962

DATA (COF(I,8),I=1,53)/ 2.07722241 , .8.44702446 ,  
 1-.234056435E3 , .478576622E2 , .119375479E3 , .0 ,  
 2 .202301846E2 , .146535214E4 , .0 , .0 ,  
 3-.11186866E5 , .0 , .763244863E5 , .70728125E5 ,  
 4-.790460718E4 , .545307676E5 , .159411473E6 , .182597797E7 ,  
 5.414625688E7 , .168878287E8 , .405704262E3 , .303082504E3 ,  
 6 .0 , .0 , .0 , .21700826E1 ,  
 7-.32255748E1 , .23561801E1 , .95999492 , .22307327 ,  
 8-.26190460E-1 , .12190675E-2 , .42144E1 , .519306235E1 ,  
 9 .0 , .0 , .0 , .0 ,  
 A4.5053 , .36.5582 , .1E1 , .4E-4 ,  
 B .2100 , .010132 , .2274644 , .101325E2 ,  
 C .3E1 , .52E1 , .600E3 , .18 ,  
 D .35E2 , .5.329044 , .3167.6647 , /

C FLUORINE BARON (BENDER) 1/72 NBS DATA USED

DATA (COF(I,9),I=1,53)/ .2188159E+0 , .21051539 ,  
 1-.81175243E+02 , .23064630E+04 , .63183150E+06 , .96908966E+07 ,  
 2 .25933660E+00 , .63689419E+02 , .68240310E+04 , .13779899E+00 ,  
 3 .74842154E+02 , .30516478E+00 , .13304083E+03 , .50315749E+02 ,  
 4 .40392186E+06 , .27617459E+08 , .42709623E+10 , .33659737E+07 ,  
 5 .65832302E+09 , .619C7880E+09 , .3.06E+00 , .4\*0. ,  
 6 .51121868E+00 , .35538649E+03 , .16184765E+00 , .28441699E-02 ,  
 7 .25041457E-04 , .11104809E-06 , .1987869E-09 , .84.953 ,  
 87 .1981845E+00 , .37629101E-J2 , .26888016E-04 , .38658913E-07 ,  
 9 .17515391E-10 , .3.8416E+00 , .63.23E+00 , .1101145E+00 ,  
 A1.3E-06 , .2.25 , .011 E+00 , .5.215E+00 ,  
 B 20.3E+00 , .53.48 E+00 , .144.31L+00 , .500.E+00 ,  
 C 1.9E+00 , .170.2E+00 , .-158.155 , .405.686

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C      PAFAHYDROGEN -----BARON (BENDER) 1971
C      DATA (COF(I,10),I=1,53)/4.1260486,.44446150E+2,
1-.38659604E+4,-.10966550E+6,.12080022E+7,-.54747655E+7,
2-.33278647E+3,.81345734E+5,.26294257E+6,.30063983E+5,
3-.33024955E+7,-.24686707E+6,.47555234E+8,-.12064332E+9,
4-.49289827E+8,.15925894E+10,-.87182365E+10,.66330266E+11,
5.16366622E+11,-.12954419E+14,.1050E+4,4*0.,
6-.10593817E+1,-.35249570E+2,.37870039E+0,-.23601614E-1,
7.85529568E-3,-.16180625E-4,.12500233E-6,20.268,
V14.7599360,-.21977388,.32100769E-2,-.12061502E-4,.57121808E-8,
X21.17E42,209.9406,1.0,
8.1E-4,.11,.101325E-3,1.2928,100.,13.8,32.976,
A3000.,.09,60.,-309.89197,49289.7/
C
C      TRANSPORT PROPERTIES ARE LIMITED BY THE STATE OF THE ART
C      READ REPORT ON GASP FOR COMPLETE DETAILS
C
C      DATA (AKSTC(I,1),I=1,18)/3.,3.,-4.,0.,0.,.983,.3891166E-2,   INERT
1-.96910013E-1,-.16491245E-1,-.84178805E-1,.85181928,.17517383E-1   GAS
2,.903089987,0.0.,.631,.136720567,1.778 /
DATA (AKSTC(I,2),I=1,18)/3.,3.,-4.,0.,0.,1.0,0.,   CO
10.0,-.1.12398985,.79352374,.8465682,-.21370471E-2,.39794,   N2
20.,0.,.729,.081707270,1.0 /   O2
DATA (AKSTC(I,3),I=1,8)/1.,3.,-22,-.10587949,-.21522105,   CO
11.31584644,.16196636E-2,1.0/
DATA (AKSTC(I,4),I=1,15)/2.,4.,-.280,0.0,.36187029,.26550054,
11.0243779,-.3075470,.238,1.6717516,-.6259505,2.7281748,
2.48625031,-.26386826,.71948992/
C      CH4
DATA (TCCOF(I,1),I=1,15)/.75226444,.20119504E-2,190.77,
1.1620,1.,4.,-.9586073,.92583319,1.55004971,.87042136,
21.29907897,-.7.01464957,.617,4.,1.E-4/
C      N2
DATA (TCCOF(I,2),I=1,15)/.11425981E1,.20865873E-2,126.3,
1.3105,1.,4.,-1.39794,.51372790E-1,.17155947,.39312360,
21.56022809,-.6.85395932,.39967,2.,2.77E-5/
C      O2
DATA (TCCOF(I,3),I=1,15)/.96364877,.21320779E-2,154.78,
1.4325,1.,4.,-2.6383,0.,.58701320E-1,.23887321,1.39461538,
2-6.86562723,.5132176,2.,3.40E-5/
C      AR
DATA (TCCOF(I,4),I=1,15)/.11037087E1,.21277034E-2,150.70,
1.5310,1.,4.,-1.744727,.47325357E-1,.29305409,.72199889,
21.56855570,-.6.94782507,.45108,1.,2.24E-5/
C      CO2
C      K-K* FROM KEYES-SENGERS
DATA (TCCOF(I,5),I=1,15)/.98614941,.16279794E-2,304.2,
1.4640,1.,4.,-4.699,.25170328E-1,.29823104,.59310573,
21.5385050,-.6.98446882,.4226,3..4.03E-5/
C      NE      USING K-K* FOR ARGON WITH NE XLAM AND ZCS
DATA (TCCOF(I,6),I=1,15)/.95859,.244676E-2,44.4,.483,
11.,4.,-1.744727,.47325357E-1,.29305409,.72199889,1.56855570,
2-6.94782507,.45108,1.,2.6E-5/
C      CJ      USE N2 WITH CO CONSTANTS
DATA (TCCOF(I,7),I=1,15)/1.127527,.226934E-2,132.91,
1.2997,1.,4.,-1.39794,.51372790E-1,.17155947,.39312360,1.56022809,
2-6.85395932,.39967,2.,2.79E-5/
C      HE
DATA (TCCOF(I,8),I=1,15)/1.536,.2579E-2,5.2,.0693,1.,4.,-1.744727,
1.47325357E-1,.29305409,.72199889,1.56855570,-.6.94782507,.45108,1.,
25.E-5/
C      F2      SETUP TO LOAD DIATOMIC CURVE FOR K* EVEN THOUGH IS NOT USED
DATA (TCCOF(I,9),I=1,15)/1.02031,.19754E-2,144.31,.57375,
1.1.,4.,-1.301,.9474771,1.3197988,.47309461,1.3532272,
2-6.3527256,.4625,2.,1./
C      LOAD CRITICAL RHO AND T FOR THERM AND H2
DATA (TCCOF(I,10),I=1,15)/1.4978,.252512E-2,32.976,.03143,1.,4.,
1-1.,2.70581484,4.30610645,1.88960889,1.26994786,-.82428539,.4,
22.,.61974E-4/
DATA DIST/3.822,3.681,3.499,3.421,3.952,2.82,3.59,2.551,3.357,
12.928/
DATA EPSOK/.73E-2,1.093E-2,1.E-2,.837E-2,.5E-2,3.0488E-2,.9066E-2,
19.7847E-2,.8881E-2,.027/
DATA WTMOL/16.04,28.016,31.9988,39.94,44.01,20.183,28.01,4.003,

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139.98,2.0159/
DATA ZETA           /.46890513E-1,.40786245E-1,.30115154E-1,
1.27628636E-1,.22407394E-1,.47495F-1,.402544E-1,.3843, .268525E-1,
2 .40786245E-1/
DATA FF/ 1.015, 3*1.0, 1.02, 1.1, 1., 2.27, 1.0, 1.0/
DATA DTRIPL/.57,1.121,1.400,1.415,1.17,1.247,.836,.21,1.71,.11/
DATA SWT/113.,2*68.,86.,216.,25.,70.,6.3,60.,68. /
DATA KSWT /5*1,3*2,2*1/
DATA DIFTT/7*1.,.1,2*1./
DATA RHOSWT/2.5,2.2,6*2.4,2.2,2.2/
DATA AMUC/- .06,0.,.04,2*0.,2*.1,3*0./
DATA BMUC/.07,.2,0.,.2,0.,.2,4*0. /
END

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```

C      COMPUTE PRESSURE P GIVEN TEMPERATURE T AND DENSITY D.
C      UNITS ARE SPECIFIED BY KU. IF KR IS RETURNED OR
C      SPECIFIED AS 1, P IS COMPUTED AT SATURATION AS A
C      FUNCTION OF T ONLY.
C
C      SUBROUTINE PRESS(KU,T,D,P,KR)
COMMON/ CON123/ DCNV(5),TCNV(5),PCNV(5)
COMMON/BEND/ R ,CP1,CP2,CP3,CP4,CP5,CP6,CP7,CP8,CP9,CP10,
1CP11,CP12,CP13,CP14,CP15,CP16,CP17,CP18,CP19,CP20
2 ,CP21,CP22,CP23,CP24
COMMON/CHECKS/DCH1,DCH2,PCH1,PCH2,PCH3,TCH1,TCH2,TCH3,DST,TST,
1HSCH1,HSCH2
COMMON/BEND17/TS
COMMON/HEFLU/ IHE, IFL, IHY
COMMON /IERROr/IROUT
IROUT=2
C
C      DETERMINE REGION
C
TS=TCHECK(KU,KR,T)
T2=1.0
IF (IHE.EQ.1) T2=TS
IF (KR-1) 10,70,10
10 DS=DCH-ECK(KU,D)
IF (TS-TCH2) 20,20,50
20 CALL DENS(1,TS,ZE,ZE,DSL,DSV,1)
IF (DS-DSL) 30,60,40
30 IF (DS-DSV) 50,60,60
40 KR=2
GO TO 80
50 KR=3
GO TO 80
C
C      REGION 1
C
60 KR=1
70 CALL PSSS(PS)
GO TO 90
C
C      REGIONS 2 AND 3
C
80 A1= R*TS
A2 = 1./TS
A3 = A2*A2
A4=((CP21*A2+CP5)*A2+CP4)*A2+CP3)*A2+CP2+CP1*TS
A5=(CP23*A2+CP8)*A2+CP7+(CP22*TS+CP6)*TS
A6 = CP9*TS+CP10
A7= CP11*TS+CP12 +CP24*A2
A8 = ((CP16*A2+CP15)*A2+CP14)*A3
A9 = ((CP19*A2+CP18)*A2+CP17)*A3
B1=EXP(-CP20*DS*DS/T2)
PS=((((CP13*DS+A7+A9*B1)*DS+A6)*DS+A5+A8*B1)*DS+A4)*DS+A1)*DS
90 P=PS*PCNV(KU)
RETJRN
END

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C      COMPUTE TEMPERATURE T GIVEN PRESSURE P AND DENSITY D.
CC     UNITS ARE SPECIFIED BY KU. IF KR IS RETURNED OR
C
C      SUBROUTINE TEMP(KU,P,D,T,KR)
COMMON/ CON123/ DCONV(5),TCONV(5),PCONV(5)
COMMON/BEND/ R ,CP1,CP2,CP3,CP4,CP5,CP6,CP7,CP8,CP9,CP10,
1CP11,CP12,CP13,CP14,CP15,CP16,CP17,CP18,CP19,CP20
2 ,CP21,CP22,CP23,CP24
COMMON/HEFLU/ IHE, IFL, IHY
COMMON/CHECKS/DCH1,DCH2,PCH1,PCH2,PCH3,TCH1,TCH2,TCH3,DST,TST,
1HSCH1,HSCH2
COMMON/BEND3/DS,A1,A3,A4,A5,A6B,A7B,A8B,A12
COMMON /IERRDR/IROUT
IROUT=3
EXTERNAL TSF,DTSF
PS=PCHECK(KU,KR,P)

C      DETERMINE REGION
C
IF (KR-1) 10,70,10
10 DS=DCHECK(KU,D)
IF (PS-PCH2) 20,20,50
20 TS=TSS(PS)
CALL DENS(1,TS,ZE,ZE,DSL,DSV,1)
IF (DS-DSL) 30,60,40
30 IF (DS-DSV) 50,60,60
40 KR=2
TS=TS-10.
IF (IHE.EQ.1) TS=3.0
GO TO 80
50 KR=3
TS=TST
GO TO 80

C      REGION 1
C
60 KR=1
GO TO 110
70 TS=TSS(PS)
GO TO 110

C      REGIONS 2 AND 3
C
80 A1= DS*DS
A3 =(((CP13*DS+CP12)*DS+CP10)*DS+CP7)*DS+CP2)*A1 -PS
A4 = (((CP11*DS+CP9)*DS+CP6)*DS+CP1)*DS+R)*DS
A5=((CP24*A1+CP8)*DS+CP3)*A1
A6B= (CP23*DS+CP4)*A1
A7B=CP5*A1
A8B=CP21*A1
A12 =2.*CP22*A1*DS
TS=SOLVE(TS,TSF,DTSF)

C      VERIFY REGION
C
IF (PS-PCH2)110,110,90
90 IF (TS-TCH2) 100,100,110
100 KR=2
110 T=TS*TCONV(KU)
RETURN
END

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C      COMPUTE DENSITY D GIVEN TEMPERATURE T AND PRESSURE P.
C      UNITS ARE SPECIFIED BY KU. IF KR IS RETURNED OR
C      SPECIFIED AS 1, THE SATURATED LIQUID AND VAPOR DENSITIES,
C      DL AND DV RESPECTIVELY, ARE COMPUTED AS A FUNCTION
C      OF T OR P. THE OTHER VALUE MUST BE INPUT AS 0.0 .
C
C      SUBROUTINE DENS(KU,T,P,D,DL,DV,KR)
COMMON/ CON123/ DCONV(5),TCONV(5),PCONV(5)
COMMON /CHECK 1/NI
COMMON/BEND/ R    ,CP1,CP2,CP3,CP4,CP5,CP6,CP7,CP8,CP9,CP10,
ICP11,CP12,CP13,CP14,CP15,CP16,CP17,CP18,CP19,CP20
2 ,CP21,CP22,CP23,CP24
COMMON/BEND13/A1,A4,A5,A6,A7,A8,A9,PS
COMMON/BEND15/A10,A11,A12,A13,A14
COMMON/BEND17/TS
COMMON/CHECKS/DCH1,DCH2,PCH1,PCH2,PCH3,TCH1,TCH2,TCH3,DST,TST,
1HSCH1,HSCH2
COMMON/COFMU/ EPSSK,WM,DIS,RHOCRT,ZETAA
COMMON/FELFLU/ IHE, IFL, IHY
COMMON/SOLID/DTrip
COMMON /IERROR/IROUT
EXTERNAL DSF,DDSF
IROUT=1
IF (KR.EQ.1) GO TO 70
TS=TCHECK(KU,KR,T)
GO TO 5
70 IF (T.GT.0.0) GO TO 75
PS=PCHECK(KU,KR,P)
TS=TSS(PS)
IF (T.LE.0.) T=TS*TCONV(KU)
GO TO 5
75 TS=TCHECK(KU,KR,T)
CALL PSSS(PS)
IF (P.LE.0.) P=PS*PCONV(KU)
5 T2=1.0
IF (IHE.EQ.1) T2=TS
C
C      COMPUTATIONS COMMON TO ALL REGIONS
C
A1= R*TS
A2= 1./TS
A3= A2*A2
A4=((CP21*A2+CP5)*A2+CP4)*A2+CP3)*A2+CP2+CP1*TS
A5=(CP23*A2+CP8)*A2+CP7+(CP22*TS+CP6)*TS
A6= CP9*TS+CP10
A7= CP11*TS+CP12 +CP24*A2
A8=(CP16*A2+CP15)*A2+CP14)*A3
A9=(CP19*A2+CP18)*A2+CP17)*A3
A10=-2.*CP20/T2
A11=6.*CP13
A12=5.*A7
A13= 4.*A6
A14= 2.*A4
C
C      DETERMINE REGION
C
IF (<R-1) 10,80,10
10 PS=PCHECK(KU,KR,P)
IF (PS-PCH2)110,110,100
100 IF (TS-TCH2)120,120,130
120 KR=2
EST=RHOCRT*.90
CALL ROOT(DCH2,EST,0.,DSF,DS)
GO TO 150
130 KR=3
EST=RHOCRT*3.
CALL ROOT(EST,DCH1,0.,DSF,DS)
GO TO 150
110 IF (TS-TCH2) 20,20,50
20 CALL PSSS(PSS)
IF (ABS((PSS-PS)/PSS)-1.E-4) 60,30,30
30 IF (PS-PSS) 50,60,40

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40 KR=2
  DS=DST
  IF (TS/TCH2.LT..90.DR.PS/PSS.LT..95*PSS) GO TO 90
  CALL DGUESS(TS,TCH2,DS)
  GO TO 90
50 KR=3
  DS=.5*PS/(R*TS)
  GO TO 90
C
C      REGION 1
C
60 KR=1
80 CONTINUE
  DS=DST
  T11=TCH2-TS
  IF(T11.LT.1.E-4) GOTO 84
  IF(T11.LT..1) GOTO 81
  CALL DGUESS(TS,TCH2,DS)
  DSL=SOLVE(DS, DSF, DDSF)
  DS=.5*PS/(R*TS)
  T11=TS/TCH2
  IF(T11.GT..985) DS=.65*RHOCRT
  IF(T11.GT..995) DS=.75*RHOCRT
  IF(T11.GT..9991 DS=.85*RHOCRT
  IF(T11.GT..9995) DS=.90*RHOCRT
  DSV=SOLVE(DS, DSF, DDSF)
  DL=DSL*DCONV(KU)
  DV=DSV*CConv(KU)
  RETURN
81 DL=RHOCRT*DConv(KU)*1.001
  DV=RHOCRT*DConv(KU)*.999
C
C      THIS FIX IS APPLIED IN THE NEAR SUBCRITICAL AREA TO COMPENSATE FOR
C      THE FAILURE OF NEWTON-RAPHSON TO CONVERGE ON A DENSITY WITHOUT AN
C      ACCURATE ESTIMATE. PERHAPS ROOTX SHOULD BE USED IN THE REGION
C      T/TCRT .GT..99 TO PREVENT THIS PROBLEM
C      IF YOU WANT AN ERROR MESSAGE WHEN THIS HAPPENS REMOVE THE C-S FROM
C      FOLLOWING THREE CARDS.
C      WRITE(6,82) TS
C      82 FORMAT(1H ,25H SATURATION CALL FOR TS= ,F10.3,65H IS TOO NEAR CRIT
C      1ICAL. DL=1.001*RHOCRT DV=.999*RHOCRT
C      ) )
  RETURN
84 DL=RHOCRT*DConv(KU)
  DV=DL
  RETURN
C
C      REGIONS 2 AND 3
C
90 DS=SOLVE(DS, DSF, DDSF)
150 D=DS*DConv(KU)
  IF (DS.GT.DTRIP) WRITE(6,152) T,P
152 FORMAT(1H , 98H DENSITY SOLUTION IS BEYOND THE GRASP OF GASP. AND
  1WER IS ON SOLID SIDE OF MELTING LOCUS FOR T = F9.0,6H P = ,F10.3
  23,4H MN. )
  RETURN
END

C
FUNCTION CHECK(KU,KR,T)
COMMON/ CON123/ DCONV(5),TCONV(5),PCONV(5)
COMMON/ IERROR/ IROUT
COMMON/ CHECKS/ DCH1,DCH2,PCH1,PCH2,PCH3,TCH1,TCH2,TCH3,DST,TST,
1HSCH1,FSCH2
DIMENSION FM1(9), FM2(9), FM3(9), FMT(9), ROUT(13)
DATA FM1 /51H(1H ,G12.4 ,31HIS OUT OF RANGE FOR T IN SJB.-,A6 ) 1/
DATA FM2 /51H(1H ,G12.4 ,31HIS OUT OF RANGE FOR P IN SUB.-,A6 ) 1/

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1 /
DATA FM3 /51H(1H ,G12.4 ,31HIS OUT OF RANGE FOR D IN SUB.-,A6 )
1 /
DATA ROUT /4HDENS,5HPRESS,4HTEMP ,4HENTH,3HE NT ,6HTEMPH,6HTEMPPS
1,5HSonic,5HSPCHP,5HSPCHV,5HTHERM,4HVISC,4HSURF /
C
C      CONVERT TEMPERATURE T TO DEGREES KELVIN AND CHECK
C      FOR OUT OF RANGE. UNITS ARE SPECIFIED BY KU. IF KR
C      IS SPECIFIED AS 1, T IS CHECKED FOR OUT OF SATURATION
C      RANGE.
C
ENTRY TCHECK (KU,KR,T)
CHECK=T/TCONV(KU)
CH1=TCH1
CH2=TCH2
CH3=TCH3
DO 1 J=1,9
1 FMT(J)=FM1(J)
GO TO 10
C
C      CONVERT PRESSURE P TO ATMOSPHERES AND CHECK
C      FOR OUT OF RANGE. UNITS ARE SPECIFIED BY KU. IF KR IS
C      SPECIFIED AS 1, P IS CHECKED FOR OUT OF SATURATION
ENTRY PCHECK(KU,KR,P)
CHECK=P/PCONV(KU)
CH1= PCH1
CH2= PCH2
CH3= PCH3
DO 2 J=1,9
2 FMT(J)=FM2(J)
GO TO 10
C
C      CONVERT DENSITY D TO GRAM-MOLES/LITER AND CHECK
C      FOR OUT OF RANGE. UNITS ARE SPECIFIED BY KU.
C
ENTRY DCHECK(KU,D)
CHECK =D/DCONV(KU)
CH1=DCH1
CH3=DCH2
DO 3 J=1,9
3 FMT(J)=FM3(J)
GO TO 20
10 IF(KR.EQ.1) GO TO 30
20 IF(CHECK.LT.CH1) GO TO 40
IF(CHECK.GT.CH3) GO TO 40
25 RETURN
30 IF(CHECK.LT.CH1) GO TO 40
IF(CHECK.LE.CH2) GO TO 25
40 WRITE(6,FMT) CHECK,ROUT(IROUT)
RETURN
END

C
C      SAME AS ROOTX - NEEDED TO PREVENT RECURSION
C      SOLVE FOR X1 SUCH THAT FUNC(X1) = FOFX, WHERE X1 LIES
C      BETWEEN X0 AND X2
C
SUBROUTINE ROOT (X0,X2,FOFX,FUNC,X1)
COMMON /CHECK/ KOUNT
TOL=1.E-5
XX0 = X0
XX2 = X2
F0 = FUNC(XX0)
F2 = FUNC(XX2)
A=(F2-F0)/(F2-F0)
IF (A) 1007,120,120
120 IF (A-.1) 130,130,1008
130 IF (FOFX-0.) 80,70,80

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70 ASSIGN 100 TO JUMP
GO TO 90
80 ASSIGN 110 TO JUMP
90 X=(XX0+XX2)*.5
KOUNT = 0
150 X1 = X
KOUNT = KOUNT + 1
A = FOFX - F2
FX = FUNC(X)
FXL=FO+(X-XX0)*(F2-FO)/(XX2-XX0)
B=ABS((FX-FXL)/(F2-FO))
IF (A*(FX-FOFX) .LT. 0.) GO TO 1001
XX0 = X
FO=FX
IF (B-.3) 10,20,20
20 X=(X+XX2)*.5
GO TO 40
1001 XX2 = X
F2 = FX
IF (B-.3) 10,30,30
30 X=(XX0+X)*.5
GO TO 40
10 X=XX0+(FOFX-FO)*(XX2-XX0)/(F2-FO)
40 IF (ABS((X-X1)/X)-TOL ) 50,1000,1000
50 GO TO JUMP,(100,110)
100 IF (ABS(FUNC(X))-TOL*10. ) 60,1000,1000
110 IF (ABS((FOFX-FUNC(X))/FOFX)-TOL ) 60,1000,1000
1000 IF (KOUNT.GT.40) TOL=TOL*10.
IF (KOUNT.GT.60) TOL=TOL*10.
IF (KOUNT.GT.80) TOL=TOL*10.
IF (KOUNT.LT.100) GO TO 150
160 WRITE (6,170) X1,X
170 FORMAT (1HL,79HAN ITERATION HAS BEEN TERMINATED AT 100 ITERATIONS.
1 THE LAST TWO VALUES WERE ,3G15.5)
60 X1=x
RETURN
1007 X1 = X0
GO TO 140
1008 X1 = X2
140 WRITE(6,141)
141 FORMAT(1HO,24H SOLUTION OUT OF RANGE           )
RETURN
END

```

```

C      SOLVE FOR X1 SUCH THAT FUNC(X1) = FOFX, WHERE X1 LIES
C      BETWEEN X0 AND X2
C
SUBROUTINE ROOTX(X0,X2,FOFX,FUNC,X1)
COMMON /CHECK2/KOUNT
TOL=1.E-5
XX0 = X0
XX2 = X2
FO = FUNC(XX0)
F2 = FUNC(XX2)
A=(FOFX-FO)/(F2-FO)
IF (A) 1007,120,120
120 IF (A-.1.) 130,130,1008
130 IF (FOFX-0.) 80,70,80
70 ASSIGN 100 TO JUMP
GO TO 90
80 ASSIGN 110 TO JUMP
90 X=(XX0+XX2)*.5
KOUNT = 0
150 X1 = X
KOUNT = KOUNT + 1
A = FOFX - F2
FX = FUNC(X)

```

```

FXL=F0+(X-XX0)*(F2-F0)/(XX2-XX0)
B=ABS((FX-FXL)/(F2-F0))
IF (A*(FX-FOFX) .LT. 0.) GO TO 1001
XX0 = X
FO=FX
IF (B-.3) 10,20,20
20 X=(X+XX2)*.5
GO TO 40
1001 XX2 = X
F2 = FX
IF (B-.3) 10,30,30
30 X=(XX0+X)*.5
GO TO 40
10 X=XX0+(FOFX-FO)*(XX2-XX0)/(F2-F0)
40 IF (ABS((X-X1)/X)-TOL ) 50,1000,1000
50 GO TO JUMP,(100,110)
100 IF (ABS(FUNC(X))-TOL*10. ) 60,1000,1000
110 IF (ABS((FOFX-FUNC(X))/FOFX)-TOL ) 60,1000,1000
1000 IF (KOUNT.GT.40) TOL=TOL*10.
IF (KOUNT.GT.60) TOL=TOL*10.
IF (KOUNT.GT.80) TOL=TOL*10.
IF (KOUNT.LT.100) GO TO 150
160 WRITE (6,170) X1,X
170 FORMAT (1HL,79HAN ITERATION HAS BEEN TERMINATED AT 100 ITERATIONS.
1 THE LAST TWO VALUES WERE ,3G15.5)
60 X1=X
RETURN
1007 X1 = X0
GO TO 140
1008 X1 = X2
140 WRITE(6,141)
141 FORMAT(1HO,24H SOLUTION OUT OF RANGE           )
RETURN
END

```

```

C      NEWTON-RAPHSON ITERATION GIVEN AN INITIAL ESTIMATE XI
C      AND THE FUNCTIONS F AND DF
C
FUNCTION SOLVE(XI,F,DF)
COMMON /CHECK/NI
TOL=1.E-5
NI=0
X0=XI
XN=XI
10 XOO=X0
XO=XN
XN=X0-F(X0)/DF(X0)
12 NI=NI+1
IF (ABS((XN-X0)/XN)-TOL ) 70,20,20
20 IF (NI.GT.40) TOL=TOL*10.
IF (NI.GT.60) TOL=TOL*10.
IF (NI.GT.80) TOL=TOL*10.
IF (NI>100) 30,50,50
30 IF (ABS((XN-XOO)/XN)-TOL ) 40,10,10
40 XN=(X0+XN)/2.
GO TO 10
50 WRITE (6,60) XOO,X0,XN
60 FORMAT (1HL,81HAN ITERATION HAS BEEN TERMINATED AT 100 ITERATIONS.
1 THE LAST THREE VALUES WERE ,3G15.5)
70 SOLVE=XN
IF (XN.GE.0.) RETURN
SOLVE=XI
WRITE(6,75) XI
75 FORMAT(1F ,82H N-R ITERATION DID NOT FIND A VALID ANSWER. INITIAL
1 ESTIMATE RETURNED AS ANSWER.          E12.6)
RETURN
END

```

```

C
      SUBROUTINE SPLINA(X,Y,NX,T,NT,YINT,KFD,KERROR)
      DIMENSION X(1), Y(1), T(1), YINT(1), U(50), XM(1)
      EQUIVALENCE (XM(1), U(1))
      NXM1= NX-1
      NXP1 = NX+1
      H= X(2)-X(1)
      KERROR=0
      H2 = H*H
      YINT( 1)= .5
      U(1)= 0.
      DO 10 I=2,NX41
      P= .5*YINT( I-1)+2.
      YINT( I)= -.5/P
      D = 3.*((Y(I+1)-Y(I))-(Y(I)-Y(I-1)))/H2
      10 U(I)= (D-.5*U(I-1))/P
      P =-.5*YINT(NXM1)+1.
      YINT(NX)= 0.
      U(NX)= .5*U(NXM1)/P
      XM(NX) = U(NX)
      DO 20 I=2,NX
      K= NX+1-I
      20 XM(K)= YINT(K)*XM(K+1)+U(K)
      DO 90 I=1,NT
      K=2
      IF(T( I)-X(1))60,85,70
      60 WRITE(6,600) T(1), X(1), X(NX)
      600 FORMAT(1HL,40H AN ERROR OCCURRED DURING INTERPOLATION /
      1         96H THE X WHERE INTERPOLATION DESIRED (XINT) IS OUT OF
      2 RANGE. THE ROUTINE WILL TRY TO EXTRAPOLATE./ 6H XINT=G15.7,     6H
      3 X(1)=G15.7, 6H X(N)=G15.7  )
      KERROR = KERROR+1
      GO TO 85
      70 IF(T( I)-X(K)) 85,85,80
      80 K= K+1
      IF(K-NX) 70,70,81
      81 KERROR = KERROR+1
      WRITE(6,600) T(I), X(1), X(NX)
      K=NX
      85 IF (KFD) 40,40,50
      40 YINT( I)=(XM(<-1)*(X(K)-T(I))**3+XM(K)*(T(I)-X(K-1))**3+(6.*Y(K-1)-
      1XM(K-1)*H2)*(X(K)-T(I))+(6.*Y(K)-XM(K)*H2)*(T(I)-X(K-1)))/(6.*H)
      GO TO 90
      50 YINT( I)=(-XM(K-1)*(X(K)-T(I))**2/2.+XM(K)*(T(I)-X(K-1))**2/2.+
      1Y(K)-Y(K-1)-(XM(K)-XM(K-1))*H2/6.)/H
      90 CONTINUE
      RETURN
      END

```

```

C
      EVALUATE THE POLYNOMIAL IN X DESCRIBED BY COEF
C
      FUNCTION POLY(X,COEF)
      DIMENSION COEF(1)
      XS=X
      NRANGE=COEF( 1)+.1
      NDEG=COEF( 2)+.1
      ISTEP=NDEG+2
      ITEST=3*NRANGE*ISTEP
      IF (XS-COEF( 3)) 10,20,20
      20 IF (XS-COEF( ITEST)) 30,30,40
      30 IBEG=3+ISTEP
      IEND=ISTEST-ISTEP
      DO 50 I=IBEG, IEND, ISTEP
      IF (XS-COEF( I)) 60,60,50
      50 CONTINUE
      I=ISTEST
      GO TO 60
      10 I=3+ISTEP
      GO TO 70

```

```

40 I=ITEST
70 WRITE(6,71) XS
71 FORMAT(1HO,E14.5,6H IS OUT OF RANGE OF CURVE FIT VALUE IS EXTRAP
    OLATED.)
60 IBEG=I-ISTEP+2
    IEND=IBEG+NDEG-1
    POLY=COEF(IBEG-1)
    DO 80 I=IBEG, IEND
80 POLY=POLY*XS+COEF(I)
    RETURN
    END

```

```

C
SUBROUTINE DGUSS(TS,TCR,DST)
COMMON/COFMU/EP SK,WM,DIS,RHOCRT,ZETAA
TEST=TS/TCR
IF (TEST .GT..9) DST=RHOCRT*1.75
IF (TEST .GT..96) DST=RHOCRT*1.60
IF (TEST .GT..98) DST=RHOCRT*1.50
IF (TEST .GT..993) DST = RHOCRT*1.4
IF (TEST .GT..998) DST = RHOCRT*1.30
IF (TEST .GT..999) DST=RHOCRT*1.20
IF (TEST .GT..9995) DST=RHOCRT*1.10
IF (TEST .GT..9999) DST=RHOCRT*1.05
RETURN
END

```

```

C      FUNCTION USED TO SOLVE FOR SATURATION TEMPERATURE TSS
C      GIVEN PRESSURE
C
FUNCTION TSSF(TSS)
COMMON/COSAT/ CPS1 ,CPS2,CPS3,CPS4,CPS5,CPS6,CPS7
COMMON/BEND9/A1,A2,A3,A4,A5
TSSF=(((CPS7*TSS+CPS6)*TSS+CPS5)*TSS+CPS4)*TSS+CPS3)*TSS+CPS2/
1TSS+A1
RETURN
C
C      DERIVATIVE OF FUNCTION USED TO SOLVE FOR SATURATION
C      TEMPERATURE TSS GIVEN PRESSURE
C
ENTRY CTSSF(TSS)
DTSSF=(((A2*TSS+A3)*TSS+A4)*TSS+A5)*TSS+CPS3-CPS2/(TSS*TSS)
TSSF=DTSSF
RETURN
END

```

```

C      FUNCTION USED TO SOLVE FOR TEMPERATURE TS GIVEN PRESSURE
C      AND DENSITY
C
FUNCTION TSF(TS)
COMMON/BEND/ R ,CP1,CP2,CP3,CP4,CP5,CP6,CP7,CP8,CP9,CP10,
1CP11,CP12,CP13,CP14,CP15,CP16,CP17,CP18,CP19,CP20
2 ,CP21,CP22,CP23,CP24
COMMON/FELFLU/ IHE, IFL, IHY
COMMON/BEND3/DS,A1,A3,A4,A5,A6B,A7B,A8B,A12
T2=1.0
IF (IHE.EQ.1) T2=TS

```

```

A2=DS*EXP(-CP 20*DS*DS/T2)
A6A=( CP17*A1+CP 14)*A1*A2
A7A=( CP18*A1+CP 15)*A1*A2
A8A=( CP19*A1+CP16)*A1*A2
A6=A6A+A6B
A7=A7A+A7B
A8=A8A+A8B
A9 = 2.*A6
A10= 3.*A7
A11= 4.*A8
B1=1./TS
B2=B1*B1
A13=0.0
IF (IHE.EQ.1) A13=(A6A+A7A+B1+A8A*B2)*CP20*AL*B2*B2
TSF=((A8*B1+A7)*B1+A6)*B1+A5)*B1+(CP22*TS*AL*DS+A4)*TS+A3
RETURN
C
C      DERIVATIVE OF FUNCTION USED TO SOLVE FOR TEMPERATURE TS
C      GIVEN PRESSURE AND DENSITY
C
ENTRY CTSF(TS)
DTSF=A4+A12*TS-((A11*B1+A10)*B1+A9)*B1+A5)*B1*B1+A13
TSF=DTSF
RETURN
END

C
C      FUNCTION USED TO SOLVE FOR DENSITY DS GIVEN TEMPERATURE
C      AND PRESSURE
C
FUNCTION DSF(DS)
COMMON/BEND/ R ,CP1,CP2,CP3,CP4,CP5,CP6,CP7 ,CP8 ,CP9 ,CP10 ,
1CP11,CP12,CP13,CP 14,CP15,CP16,CP17,CP18,CP19,CP20
2 ,CP21,CP22,CP23,CP24
COMMON/BEND13/A1,A4,A5,A6,A7,A8,A9,PS
COMMON/BEND15/A10,A11,A12,A13,A14
COMMON/HEFLU/ IHE, IFL, IHY
COMMON/BEND17/TS
T2=1.0
IF (IHE.EQ.1) T2=TS
B1=EXP(-CP20*DS*DS/T2)
B2= A8*B1
B3= A9*B1
DSF=((((CP13*DS+A7+B3)*DS+A6)*DS+A5+B2)*DS+A4)*DS+A1)*DS-PS
RETURN
C
C      DERIVATIVE OF FUNCTION USED TO SOLVE FOR DENSITY DS GIVEN
C      TEMPERATURE AND PRESSURE
C
ENTRY DCSF(DS)
DCSF=((((A10*B3*DS+A11)*DS+A12+(5.*A9+A10*A8)*B1)*DS+A13)*DS
* +3.*(A5+A8*B1))*DS+A14)*DS+A1
DSF=DCSF
RETURN
END

C
C      COMPUTE SATURATION PRESSURE PSS GIVEN TEMPERATURE
C
SUBROUTINE PSS(PSS)
COMMON/BEND17/TS
COMMON/COSAT/ CPS1 ,CPS2,CPS3,CPS4,CPS5,CPS6,CPS7
PSS=10.***1(((CPS7*TS+CPS6)*TS+CPS5)*TS+CPS4)*TS+CPS3)*TS+CPS2/TS+
1CPS1)

```

```

PSS=PSS*.101325
RETURN
END

```

```

C      COMPUTE SATURATION TEMPERATURE GIVEN PRESSURE PS
C
FUNCTION TSS(PS)
COMMON/CHECKS/DCH1(1),DCH2,PCH1,PCH2,PCH3,TCH1,TCH2,TCH3,DST,TST,H
ISCH1,HSCH2
COMMON/COSAT/ CPS1 ,CPS2,CPS3,CPS4,CPS5,CPS6,CPS7
COMMON/BEND9/A1,A2,A3,A4,A5
EXTERNAL TSSF,DTSSF
PS1=PS/.101325
A1=CPS1-ALOG10(PS1)
A2=5.*CPS7
A3=4.*CPS6
A4=3.*CPS5
A5=2.*CPS4
TESTM=PS/(PCH1-PCH2)*(TCH2-TCH1)+TCH1 -10.
IF (TESTM.LT.TCH1) TESTM=TCH1
TSS=SOLVE(TESTM,TSSF,DTSSF)
RETURN
END

C
SUBROUTINE TEMPPH(KU,P,H,T,D,DL,DV,KR)
COMMON/CON123/DCONV(5),TCONV(5),PCONV(5)
COMMON/CONV6/HCONV(5)
COMMON/BEND31/PS
COMMON/BEND33/HS
COMMON/CHECKS/DCH1,DCH2,PCH1,PCH2,PCH3,TCH1,TCH2,TCH3,DST,TST,
1HSCH1,HSCH2
COMMON /IERROR/IROUT
IROUT=6
EXTERNAL TSHF
PS=PCHECK(KU,KR,P)
HS=H/HCONV(KU)
IF (HS-HSCH1) 20,10,10
10 IF (HS-HSCH2) 40,40,20
20 WRITE(6,21) HS
21 FORMAT(1HO,E14.6,40H INPUT H IS OUT OF RANGE--CALC.CONT.
40 IF (PS-PCH2) 140,140,130
130 TS1=TCH1
TS2=TCH3
GO TO 110
140 CALL TEMP(1,PS,ZE,TS,1)
IF (KR-1) 50,70,50
50 CALL ENTH(1,1,TS,PS,ZE,ZE,HSL,HSV)
IF (HS-HSL) 90,70,60
60 IF (HS-HSV) 70,70,100
C
C      REGION 1
C
70 KR=1
80 CALL DENS(1,TS,ZE,ZE,DSL,DSV,1)
DL=DSL*DCONV(KU)
DV=DSV*DCONV(KU)
GO TO 120
C
C      REGION 2
C
90 KR=2
TS1=TCH1

```

```

      PS=PS*1.00011
      TS2= TS-1.E-5
      GO TO 110
C
C      REGION 3
C
100 KR=3
      TS1= TS+1.E-5
      PS= PS*.99988
      TS2=TCH3
C
C      REGIONS 2 AND 3
C
110 CALL ROOTX(TS1,TS2,HS,TSHF,TS)
      CALL DENS(1,TS,PS,DS,ZE,ZE,KR)
      D=DS*DCONV(KU)
C
C      VERIFY REGION
C
      IF (PS-PCH2) 120,120,150
150 IF (TS-TCH2) 160,160,170
160 KR=2
      GO TO 120
170 KR=3
120 T=TS*TCONV(KU)
      RETURN
      END

C
C      SUBROUTINE TEMPPS (KU,P,S,T,D,DL,DV,KR )
COMMON/ CON123/ DCONV(5),TCONV(5),PCONV(5)
COMMON/CONV4/ SCONV(5)
COMMON/BEND31/PS
COMMON /BEND55/SS
COMMON/CHECKS/DCH1,DCH2,PCH1,PCH2,PCH3,TCH1,TCH2,TCH3,DST,TST,
1HSCH1,1SCH2
COMMON /IERROR/IROUT
IROUT=7
EXTERNAL TPSF
PS=PCHECK(KU,KR,P)
SS = S/SCONV(KU)
40 IF (PS-PCH2) 140,140,130
130 TS1=TCH1
      TS2=TCH3
      GO TO 110
140 CALL TEMP(1,PS,ZE,TS,1)
      IF (KR-1) 50,70,50
      50 CALL ENT ( 1,1,TS,PS,ZE ,ZE ,SSL,SSV )
      IF ( SS-SSL ) 90,70,60
      60 IF ( SS-SSV) 70,70,100
C
C      REGION 1
C
      70 KR=1
      80 CALL DENS(1,TS,ZE,ZE,DSL,DSV,1)
      DL=DSL*DCONV(KU)
      DV=DSV*C CONV(KU)
      GO TO 120
C
C      REGION 2
C
      90 KR=2
      TSL=TCH1
      PS=PS*1.00011
      TS2= TS-1.E-5
      GO TO 110
C
C      REGION 3

```

```

C
100 KR=3
    TS1= TS+1.E-5
    PS= PS*.99988
    TS2=TCH3
C
C      REGIONS 2 AND 3
C
110 CALL ROOTX ( TS1,TS2,SS,TPSF,TS )
    CALL DENS(1,TS,PS,DS,ZE,ZE,KR)
    D=DS*DCONV(KU)
C
C      VERIFY REGION
C
    IF (PS-PCH2) 120,120,150
150 IF (TS-TCH2) 160,160,170
160 KR=2
    GO TO 120
170 KR=3
120 T=TS*TCONV(KU)
    RETURN
    END

```

```

FUNCTION TSHF(TS)
COMMON/BEND31/PS
COMMON/BEND33/HS
KR=0
CALL DENS(1,TS,PS,DS,ZE,ZE,KR)
CALL ENTH(1,KR,TS,PS,DS,HSC,ZE,ZE)
TSHF=HSC
RETURN
ENTRY TPSF(TS)
COMMON /BEND55/ SS
KR = 0
CALL DENS ( 1,TS,PS,DS,ZE,ZE,KR)
CALL ENT ( 1,KR,TS,PS,DS,SSC,ZE,ZE)
TSHF = SSC
RETURN
END

```

```

C      COMPUTE ENTHALPY H GIVEN TEMPERATURE T, PRESSURE P, AND
C      DENSITY D. UNITS ARE SPECIFIED BY KU. REGION IS
C      SPECIFIED BY KR. IF KR IS SPECIFIED AS 1, THE SATURATED
C      LIQUID AND VAPOR ENTHALPIES, HL AND HV RESPECTIVELY,
C      ARE COMPUTED AS A FUNCTION OF T ONLY.
C
SUBROUTINE ENTH(KU,KR,T,P,D,H,HL,HV)
COMMON/CONV6/HCONV(5)
COMMON /BEND17/TS
COMMON /BEND23/DSL,DSV
COMMON /BEND29/HSL,HSV
COMMON /IERROR/IROUT
IROUT=4
TS=TCH4CK(KU,KR,T)
PS=PCHECK(KU,KR,P)
IF (KR.NE.1) DS=DCHECK(KU,D)
GO TO (10,20,30),KR
C
C      REGION 1
C
10 CALL HSLV(PS)
    HL=HSL*HCONV(KU)
    HV=HSV*HCONV(KU)

```

```

      RETURN
C
      REGION 2
C
20 CALL PSSS(PSS)
CALL HSLV(PSS)
HS = HSL+ PS/DS-P SS/DSL+HDINT(DS,DSL)
GO TO 40
C
      REGION 3
C
30 HS=HSS(PS,DS)
40 H=HS*HCONV(KU)
RETURN
END

C      FUNCTION USED TO COMPUTE SATURATED LIQUID ENTHALPY
C      FROM SATURATED VAPOR ENTHALPY OR SATURATED LIQUID ENTROPY
C      FROM SATURATED VAPOR ENTROPY GIVEN PRESSURE PS AND
C      TEMPERATURE
C
FUNCTION HSSLVF(PS)
COMMON/COSAT/ CPS1 ,CPS2,CPS3,CPS4,CPS5,CPS6,CPS7
COMMON/BEND17/TS
COMMON/BEND23/DSL,DSV
DPDT=2.30258509*PS*(((5.*CPS7*TS+4.*CPS6)*TS+3.*CPS5)*TS+
12.*CPS4)*TS+CPS3-CPS2/(TS*TS))
HSSLVF=DPDT*(1./DSV-1./DSL)
RETURN
END

C      COMPUTE SATURATED LIQUID AND VAPOR ENTHALPIES GIVEN
C      PRESSURE PS AND TEMPERATURE
C
SUBROUTINE HSLV(PS)
COMMON/BEND17/TS
COMMON/BEND23/DSL,DSV
COMMON/BEND29/HSL,HSV
CALL DENS(1,TS,ZE,ZE,DSL,DSV,1)
HSV=HSS(PS,DSV)
HSL=HSV-TS*HSSLVF(PS)
RETURN
C
ENTRY SSLV(PS)
C
      COMPUTE SATURATED LIQUID AND VAPOR ENTROPIES GIVEN
      PRESSURE PS AND TEMPERATURE
COMMON/BEND21/SSL,SSV
CALL DENS(1,TS,ZE,ZE,DSL,DSV,1)
SSV=SSS(PS,DSV)
SSL=SSV-HSSLVF(PS)
RETURN
END

C      COMPUTE ENTROPY S GIVEN TEMPERATURE T, PRESSURE P, AND
C      DENSITY D. UNITS ARE SPECIFIED BY KU. REGION IS
C      SPECIFIED BY KR. IF KR IS SPECIFIED AS 1, THE SATURATED
C      LIQUID AND VAPOR ENTROPIES, SL AND SV RESPECTIVELY,

```

```

C      ARE COMPUTED AS A FUNCTION OF T ONLY.
C
C      SUBROUTINE ENT(KU,KR,T,P,D,S,SL,SV)
COMMON/BEND/ R ,CP1,CP2,CP3,CP4,CP5,CP6,CP7 ,CP8,CP9,CP10,
1CP11,CP12,CP13,CP14,CP15,CP16,CP17,CP18,CP19,CP20
2 ,CP21,CP22,CP23,CP24
COMMON/BEND21/SSL,SSV
COMMON/BEND23/DSL,DSV
COMMON/BEND17/TS
COMMON/CONV4/SCONV(5)
COMMON /IERROR/IROUT
IROUT=5
TS=TCHECK(KU,KR,T)
PS=PCHECK(KU,KR,P)
IF (KR.NE.1) DS=DCHECK(KU,D)
GO TO (10,20,30),KR
C
C      REGION 1
C
10 CALL SSLV(PS)
SL=SSL*SCONV(KU)
SV=SSV*SCONV(KU)
RETURN
C
C      REGION 2
C
20 CALL PSSS(PSS)
CALL SSLV(PSS)
SS = SSL + R*(ALOG(DSL)-ALOG(DS)) + SDINT(DS,DSL)
GO TO 40
C
C      REGION 3
C
30 SS=SSS(PSS,DS)
40 S=SS*SCONV(KU)
RETURN
END

C      COMPUTE THE INTEGRAL IN THE ENTHALPY COMPUTATION FROM
C      DENSITY DSL TO DENSITY DS
FUNCTION HDINT(DS,DSL)
C
COMMON/BEND/ R ,CP1,CP2,CP3,CP4,CP5,CP6,CP7 ,CP8,CP9,CP10,
1CP11,CP12,CP13,CP14,CP15,CP16,CP17,CP18,CP19,CP20
2 ,CP21,CP22,CP23,CP24
COMMON/BEND17/TS
COMMON/BEND27/A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13
COMMON/HEFLU/ IHE, IFL, IHY
T2=1.0
IF (IHE.EQ.1) T2=TS
A1= 1./TS
A2= A1*A1
A3=-.5*A2*T2/CP20
A4=((5.*CP21*A1+4.*CP5)*A1+3.*CP4)*A1+2.*CP3)*A1+CP2
A5=(-CP22*A2+CP7+2.*CP8*A1+3.*CP23*A2)*.5
A6=(5.*CP16*A1+4.*CP15)*A1+3.*CP14
A7=(5.*CP19*A1+4.*CP18)*A1+3.*CP17
A8=CP10*.3333333
A9= (CP12+2.*CP24*A1)*.25
A10 = CP13*.2
A11=T2/CP20
A12= ((CP16*A1+CP15)*A1+CP14)*A2
A13= ((CP19*A1+CP18)*A1+CP17)*A2
HDINT=HCINTF(DS)-HDINTF(DSL)
RETURN
C
ENTRY      SDINT(DS,DSL)
C

```

```

C      COMPUTE THE INTEGRAL IN THE ENTROPY COMPUTATION FROM
C      DENSITY DSL TO DENSITY DS
T2=1.0
IF (IHE.EQ.1) T2=TS
A1=1./TS
A2=A1*A1
A3=((4.*CP21*A1+3.*CP5)*A1+2.*CP4)*A1+CP3)*A2-CP1
A4=(-2.*CP22*TS-CP6+(2.*CP23*A1+CP8)*A2)*.5
A5=(4.*CP16*A1+3.*CP15)*A1+2.*CP14
A6=(4.*CP19*A1+3.*CP18)*A1+2.*CP17
A7=-.5*A2/CP20*A1*T2
A8=-CP9*.333333
A9=(-CP11+CP24*A2)*.25
A10=T2/CP20
A12=((CP16*A1+CP15)*A1+CP14)*A2
A13=((CP19*A1+CP18)*A1+CP17)*A2
SCINT=SCINTF(DS)-SDINTF(DSL)
HDINT=SDINT
RETURN
END

C      FUNCTION USED TO COMPUTE THE INTEGRAL IN THE ENTHALPY
C      COMPUTATION BASED ON DENSITY DS
C
FUNCTION HDINTF(DS)
COMMON/BEND/ R ,CP1,CP2,CP3,CP4,CP5,CP6,CP7,CP8,CP9,CP10,
1CP11,CP12,CP13,CP14,CP15,CP16,CP17,CP18,CP19,CP20
2 ,CP21,CP22,CP23,CP24
COMMON/HELFLU/ IHE, IFL, IHY
COMMON/BEND1/T5
COMMON/BEND2/A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13
T2=1.0
IF (IHE.EQ.1) T2=TS
B1=DS*CS
B2 = EXP(-CP20*B1/T2)
A15=0.0
IF (IHE.EQ.1) A15=(A12*(B1+A11)+A13*((B1+2.*A11)*B1+2.*A11*A11))
1*B2*.5
HDINTF=(((A10*DS+A9)*DS+A8)*DS+A5)*DS+A4)*DS
* +A3*B2*(A6+A7*(B1+A11))+A15
RETURN

C      FUNCTION USED TO COMPUTE THE INTEGRAL IN THE ENTROPY
C      COMPUTATION BASED ON DENSITY DS
C
ENTRY SDINTF(DS)
T2=1.0
IF (IHE.EQ.1) T2=TS
B1=DS*CS
B2= EXP(-CP20*B1/T2)
A15=0.0
IF(IHE.EQ.1) A15=A12*B2*.5*(B1/T2+1./CP20)+A13*B2*(.5*B1*B1/T2
* +(B1+A10)/CP20)
SDINTF=((A9*DS+A8)*DS+A4)*DS+A3)*DS+B2*A7*(A5+A6*(B1+A10))+A15
HDINTF=SDINTF
RETURN
END

C      COMPUTE ENTHALPY IN REGION 3 OR SATURATED VAPOR ENTHALPY
C      GIVEN PRESSURE PS, DENSITY DS, AND TEMPERATURE
C
FUNCTION HSS(PS,DS)
COMMON/BEND/ R ,CP1,CP2,CP3,CP4,CP5,CP6,CP7,CP8,CP9,CP10,

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```

ICP11,CP12,CP13,CP14,CP15,CP16,CP17,CP18,CP19,CP20
2 ,CP21,CP22,CP23,CP24
COMMON/FELFLU/ IHE, IFL, IHY
COMMON/CCOP0/TO ,CCOP1,CCOP2,CCOP3,CCOP4,CCOP5
COMMON/BEND17/TS
COMMON/BEND25/ A1,A2,A3,A4
COMMON/HYDRJ/DELH,DELS
COMMON/REFND/SOTO,HOTO,CPOCOR,HTERM,STERM
HTINTF(TX)=(((A1*TX+A2)*TX+A3)*TX+A4)*TX+CCOP1)*TX
STINTF(TX)=(((A1*TX+A2)*TX+A3)*TX+CCOP2)*TX+CCOP1*ALOG(TX)
DELH=0.0
IF (IHY.EQ.1) CALL SETCPO(TS)
A1=CCOP5*.2
A3=CCOP3*.3333333
A4=CCOP2*.5
A2=CCOP4*.25
HTERM1=HTINTF(TS)
HSS=HOTO+(HTERM1+DELH-HTERM)*CPOCOR+PS/DS-R*TS+HINT(DS,0)
RETURN

C
C      GIVEN PRESSURE PS, DENSITY DS, AND TEMPERATURE
C      COMPUTE ENTROPY IN REGION 3 OR SATURATED VAPOR ENTROPY
C
ENTRY SSS(PS,DS)
C THE TERM R*LN(RTD) IS NOT DIMENSIONLESS CONSEQUENTLY THE TERM
C SHOULD BE          R*LN(RTD*CONV) = R*LN(CONV) + R*LN(RTD)
C THEREFORE ADD THE TERM R*LN(CONV)
C      FOR R ATM-LITER/(GM-MOLE K) DINNS VALUE IMPLIES CONV=1
C      FOR R PSIA-CC/(GM K)           CONV= 14.696
C      FOR R J/(GM K)                CONV= .101325
C FOR NITROGEN THE CORRECTION BECOMES
C BENDER SCORR=R*ALOG(.101325) =-.6794936
DELS=0.0
IF (IHY.EQ.1) CALL SETCPO(TS)
A1=CCOP5*.25
A2=CCOP4*.3333333
A3=CCOP3*.5
STERM1=STINTF(TS)
SSS= SOTO + (STERM1 + DELS-STERM )*CPOCOR-R*ALOG(R*TS*DS)
1 + SDINT(DS,0.)
HSS=SSS
RETURN
END

C
C      NEEDED FOR STEPWISE INTEGRATION
C
SUBROUTINE SETCPO(TIN)
DIMENSION ADDH(4),ADDI(4),HCPO(5,3)
DATA ADDH/0.,-62.9775,-147.6,61.7/
DATA ADDI/0.,-9.9313,5.361,-16.707/
COMMON/CCOP0/TO(1),CCOP1,CCOP2,CCOP3,CCOP4,CCOP5
COMMON/HYDRJ/DELH,DELS
DATA HCPO/
A14.7599260,-.21977388,.32100769E-2,-.12061502E-4,.57121808E-8,
16.6557899,.15621077,-.86913643E-03,.18972274E-05,-.14418461E-08,
214.41148E1,-.71767870E-03,.18638538E-05,-.53065470E-09,.46649305E-
313/
TEST=TIN
C
C      MULTIPLE FIT REQUIRES STEPWISE INTEGRATION FOR H2
C
IF (TEST.LT.40.) GO TO 40
K=3
IF(TEST.LE.500.) K=2
IF(TEST.LE.150.) K=1
5 DO 10 I=2,6
10 TO(I)=HCPO(I-1,K)
GO TO 50

```

```

        40 DO 41 I=3,6
41 T0(I)=0.0
C      10.312 = 4.968*4.184/2.01572
      T0(2)=10.312
      RETURN
50 DELH=ADDH(K+1)
      DELS=ACCS(K+1)
      RETURN
      END

C
      SUBROUTINE PTRHO(DS,TS)
COMMON/BEND/ R ,CP1,CP2,CP3,CP4,CP5,CP6,CP7 ,CP8,CP9,CP10,
1CP11,CP12,CP13,CP14,CP15,CP16,CP17,CP18,CP19,CP20
2 ,CP21,CP22,CP23,CP24
COMMON/BEND35/A2,A3,A4,A5,A6A,A6B,A7A,A7B,A8A,A8B,A11,A12,A13,A14,
A15,A16
COMMON/HEFLU/ IHE, IFL, IHY
COMMON/PARTLS/PTV,PDT
T2=1.
IF (IHE.EQ.1) T2=TS
PDT = ((((( 6.*CP13-2.*CP20*A16*A2/T2)*DS+5.*A14)*DS+(5.*A1
16-2.*CP20/T2*A15)*A2+4.*A13)*DS+3.*A12)*DS+(2.*A11+3.*A15*A2))*DS+
2R*TS
A9=1./TS
A10=A9*A9
A6=A6A+A6B
A7=A7A+A7B
A8=A8A+A8B
A17=0.0
IF (IHE.EQ.1) A17=(A6A+A7A*A9+A8A*A10)*CP20*DS*DS*(A10*A10)
PTV=A4-A10*((4.*A8*A9+3.*A7)*A9+2.*A6)*A9+A5)+A17
RETURN
END

C
      SUBROUTINE CPPRL(P,D,T,CPPART,CVPART,KU,KR,KCP,GAMMA,CSQN)
COMMON/BEND/ R ,CP1,CP2,CP3,CP4,CP5,CP6,CP7 ,CP8,CP9,CP10,
1CP11,CP12,CP13,CP14,CP15,CP16,CP17,CP18,CP19,CP20
2 ,CP21,CP22,CP23,CP24
COMMON/CCOP0/TO ,CCOP1,CCOP2,CCOP3,CCOP4,CCOP5
COMMON/BEND17/TT
COMMON/BEND35/A2,A3,A4,A5,A6A,A6B,A7A,A7B,A8A,A8B,A11,A12,A13,A14,
A15,A16
COMMON/HEFLU/ IHE, IFL, IHY
COMMON/BEND36/CP0
COMMON/PARTLS/PTV,PDT
COMMON/REFN0/SOTO,HOTO,CPUCOR,HTERM,STERM
COMMON/SWITS/KSWIT,TSWIT,DIIFT,RSWIT
COMMON/CONV4/SCONV(5)
COMMON/CONV5/CCONV(5)
COMMON /IERRO/IROUT
TS=TCHECK(KU,KR,T)
PS=PCHECK(KU,KR,P)
DS=DCHECK(KU,D)
IF (IHY.EQ.1) CALL SETCP0(TS)
      TT=TS
IF (KR.EQ.1) KCP=KCP+1
ASSIGN 500 TO JUMP
IF (DS.GT.RSWIT) ASSIGN 600 TO JUMP
IF ((SWIT.EQ.2.AND.(TS.LE.TSWIT.OR. DS.GT.RSWIT))ASSIGN 600TOJMP
GO TO JUMP,(500,600)
500 A9 = 1./TS

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```

A10 = A9*A9
A15 = ((CP16*A9 + CP15) * A9 + CP14) * A10
A16 = ((CP19*A9 + CP18)*A9 + CP17)*A10
C
C           TEST CP COMPUTED BY THE INTEGRAL OF THE SECOND
C           PARTIAL OF P BY T
C
CPO = (((CCOP5*TS+CCOP4) *TS+CCOP3)*TS+CCOP2)*TS+CCOP1
CVO= CPO*CPDCOR-R
CVPART= -(CPPRLF(DS) - CPPRLF(0.)) + CVO
GO TO 1000
600 CALL SPCHV(KU,KP,KCP,TS,PS,DS,CVPART)
1000 A1= DS*DS
T2=1.0
IF (IHE.EQ.1) T2=TS
A2= DS*EXP(-CP20*DS*DS/T2)
A3=(((CP13*DS+CP12)*DS+CP11)*DS+CP7)*DS+CP2)*A1
A4=((((CP11*DS+CP9)*DS+CP6)*DS+CP1)*DS+R)*DS
A4=A4+2.*CP22*A1*DS*TS
A5=(CP24*A1+CP8)*DS+CP3)*A1
A6A=(CP17*A1+CP14)*A1*A2
A6B= (CP23*DS+CP4)*A1
A7A=(CP18*A1+CP15)*A1*A2
A7B=CP5*A1
A8A=(CP19*A1+CP16)*A1*A2
A8B=CP21*A1
A9 = 1./TS
A10 = A9*A9
A11= ((CP21 *A9+CP5)*A9+CP4)*A9+CP3 )*A9+CP2+CP1*TS
A12=(CP23*A9+CP8)*A9+CP7+(CP22*TS+CP6)*TS
A13 = CP10 + CP9 * TS
A14= CP11*TS+CP12 +CP24*A9
A15 = ((CP16*A9 + CP15) * A9 + CP14) * A10
A16 = ((CP19*A9 + CP18)*A9 +CP17)*A10
CALL PTRHO(DS,TS)
CPPART = CVPART+ TS*PTV*PTV/(PDT*DS*DS)
IF (KCP.EQ.2) KCP=0
CPPART=CPPART*SConv(KU)
CVPART=CVPART*SConv(KU)

C
C           SONIC VELOCITY CSQN FOR REGIONS 1, 2, AND 3
IROUT=8
GAMMA=CPPART/CVPART
GAMPR=GAMMA*10.*PDT
CS=0.
IF (GAMPR.GT.0.) CS=1000.*SQRT(GAMPR)
CSQN=CS*CConv(KU)
RETURN
END

C
FUNCTION CPPRLF(DS)
COMMON/BEND/ R ,CP1,CP2,CP3,CP4,CP5,CP6,CP7,CP8,CP9,CP10,
1CP11,CP12,CP13,CP14,CP15,CP16,CP17,CP18,CP19,CP20
2 ,CP21,CP22,CP23,CP24
COMMON/BEND17/TS
COMMON/HEFLU/ IHE, IFL, IHY
C
           INTEGRAL OF ((T /RHO**2)(D2P/DT2) AT CONSTANT RHO)
COMMON/BEND35/A2,A3,A4,A5,A6A,A6B,A7A,A7B,A8A,A8B,A11,A12,A13,A14,
1A15,A16
T2=1.0
IF (IHE.EQ.1) T2=TS
V1=1./CP20
R2 = DS*DS
V2=R2/T2
B3=EXP(-CP20*V2)

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```

B1=-B3*.5*V1*T2/TS
A1 = 1./TS
D2=B2+T2*V1
D3=B2*B2+2.*V1*(B2*V1)
D4 = A1*A1
A17=( 10.*CP16*A1+6.*CP15)*A1+3.*CP14
A18=( 10.*CP19*A1+6.*CP18)*A1+3.*CP17
A19=T2/CP20
A20=A19*A19
A21=( 10.*CP16*A1+8.*CP15)*A1+6.*CP14
A22=( 10.*CP19*A1+8.*CP18)*A1+6.*CP17
D5=V1+V2*( 1.+ .5*V2*CP20)
D52=D5/CP20
D7=( (B2/A19+3.) *B2+6.*A19)*B2+6.*A20
B3= EXP(-CP20*B2/T2)
TERM=0
IF (IHE.NE.1) GO TO 10
TERM=B3*(D2*A21*.5/(T2*T2*T2)-A15*D5+A22*D52/ T2-A16*D7*.5/ T2)
10 CONTINUE
CPPRL F=2.*D4*(((( 10.*CP21*A1+6.*CP5)*A1+3.*CP4)*A1+CP3)*DS
* +( 2.*CP22*TS +CP8+3.*CP23*A1+.5*CP24*B2)*.5*B2+(A17+D2*A18)*B1)
* +TERM
RETURN
END

```

```

C      COMPUTE SPECIFIC HEAT CV GIVEN TEMPERATURE T, PRESSURE P,
C      AN DENSITY D. UNITS ARE SPECIFIED BY KU. REGION IS
C      SPECIFIED BY KR. IF KR IS SPECIFIED AS 1, THE SATURATED
C      LIQUID AND VAPOR SPECIFIC HEATS, CVL AND CVV RESPECTIVELY,
C      ARE COMPUTED.
C
C      SUBROUTINE SPCHV(KU,KR,KCP,T ,P ,D ,CV)
DIMENSION CVS(5)
COMMON /CONV4/ SCONV(5)
COMMON/BEND38/ TSH(6),TS
COMMON/BEND39/DS
COMMON/CHECKS/DCH1(1),DCH2,PCH1,PCH2,PCH3,TC41,TCH2,TCH3,DST,TST,H
ISCH1,HSCH2
COMMON/SWITS/KSWIT,TSWIT,DIFFT,RSWIT
COMMON /IERRDP/IROUT
IROUT=10
TS=T
PS=P
DS=D
IF (KR-1) 100,10,100
C
C      REGIONS 2 AND 3
C
100 IF(PS-PCH2) 40,40,150
150 TSS = TCH2
GO TO 160
40 CALL TEMP(1,PS,ZE,TSS,1)
160 GO TO (10,20,30),KR
C
C      REGION 1
10 GO TO (12,14),KCP
12 TSH(1)=TS
CALL CVPS(1,2,CVS)
CV=CVS(1)
RETURN
14 TSH(1)=TS
C
CALL CVPS(1,3,CVS)
CV=CVS(1 )
P ETURN
C
C      REGION 2
C

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```

20 TSH(1)=TS
    IF (TSS.LE.TS-DIFT) TSH(1)=TS-DIFT
    IF (TSS.GE.TS-2.*DIFT) TSH(1)=TS-2.*DIFT
    GO TO 90
C
C      REGION 3
C
30 TSH(1)=TS-2.*DIFT
    IF (TSS.GE.TS-2.*DIFT) TSH(1)=TS-DIFT
    IF (TSS.GE.TS-DIFT) TSH(1)=TS
90 CONTINUE
    CALL CVPS(1,KR,CVS)
    CV=CVS(1)
    RETURN
    END

C
C      ROUTINE USED TO COMPUTE SPECIFIC HEAT CVS GIVEN
C      TEMPERATURE, PRESSURE, AND DENSITY. WHETHER DENSITY OR
C      PRESSURE IS CONSTANT IS SPECIFIED BY KVP. REGION IS
C      SPECIFIED BY KR.
C
SUBROUTINE CVPS(KVP,KR,CVS)
DIMENSION HS(5),CVS(5)
COMMON/SWITS/KSWIT,TSWIT,DIFT,RSWIT
COMMON/BEND37/PS
COMMON/BEND38/ TSH(6),TS
COMMON/BEND39/DS
IF (KVP-1) 60,70,60
70 ASSIGN 80 TO JUMP
    GO TO 90
60 ASSIGN 100 TO JUMP
90 DO 50 I=1,5
    GO TO JUMP,(80,100)
80 CALL PRESS(1,TSH(I),DS,PSH,KRH)
    CALL ENTH(1,KRH,TSH(I),PSH,DS,HS(I),HSL,HSV)
    IF (KRH.EQ.1) GO TO 95
    HS(I)=HS(I)-PSH/DS
    UHS = HS(I)
    GO TO 50
95 IF (KR.EQ.2) HS(I)=HSL-PSH/DS
    IF (KR.EQ.3) HS(I)=HSV-PSH/DS
    KFH=0
    GO TO 50
100 CALL DENS(1,TSH(I),PS,DSH,DLS,DVS,KRH)
    CALL ENTH(1,KRH,TSH(I),PS,DSH,HS(I),HSL,HSV)
110 IF (KRH-1) 50,10,50
10 IF (KR-2) 30,20,30
20 HS(I)=HSL
    GO TO 40
30 HS(I)=HSV
40 KRH=0
50 TSH(I+1)=TSH(I)+DIFT
    CALL SPLINA(TSH,HS,5,TS,1,CVS,1,KERROR)
    RETURN
    END

C
C      COMPUTE VISCOSITY MU GIVEN TEMPERATURE T AND DENSITY D.
C      UNITS ARE SPECIFIED BY KU. REGION IS SPECIFIED BY KR.
C
C      (U-U*)/Z PARAMETER IS CALCULATED FROM JOSSI,STIEL,AND THOOLS
C      VOL.8 NO.1 A.I.C.H.E.JOURNAL PAGE 60
C
SUBROUTINE VISC(KU,KR,T,D,MU)

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      DIMENSION COMEGA(15),MCONV(5)
      REAL MUS,MCONV,MU,MUMZ
      DATA (COMEGA(I),I=1,15)/2.,4.,-.52288,-1.33115022,.56160244,
     11.49894829,-1.84681526,1.58946684,.60206,.32481334E-1,
     2-.23524079,.65223929,-1.03095995,1.40383078,2.60206/
      COMMON/COFMU/EPSK,WM,DIS,RHOCRT,ZETA ,AMUX,BMUX
      DATA MCONV/2*1.,.67196899E-1,2*1./
      COMMON/HEFLU/IHE,IFL,IHY
      COMMON /IERROR/IROUT
      IROUT=12
      TS=TCHECK(KU,KR,T)
      DS=DHECK(KU,D)
      IF (IHY.EQ.1) GO TO 20
      IF (IHE.EQ.1) GO TO 40
C      REGIONS 1, 2, AND 3
C
      XMS=.26693E-4*SQRT(WM*TS)/(DIS*DIS*POLY ALOG10(TS*EPSK),COMEGA))
      RHOR=DS/RHOCRT
      MUMZ=(RHOR*(RHOR*(RHOR*(RHOR*.0093324-.040758)+.058533)+.023364)
     *+.10230)**4-1.E-4)/ZETA*.01
C      CORRECTION APPLIED TO FLUORINE DERIVED BY RCH FROM HANLEYS DATA
C
      IF (IFL.EQ.1) MUMZ=MUMZ*(1.-.25*SIN(2.3808*ALOG(RHOR)))
      SCA1=1.
      IF(RHOR.GT.1.5) SCA1=(1.-(AMUX+BMUX*(RHOR -1.5)))
      IF(RHOR.GT.2.8) SCA1=(1.-(AMUX+BMUX*1.3))
      MUS=(MUMZ+XMS)/SCA1
      GO TO 30
      40 MUS=VISCD(DS,TS)
      GO TO 30
      20 XMS=8.5558*(TS**1.5/(TS+19.55)*(TS+650.39)/(TS+1175.9))*1.E-6
      IF(TS.GE.100.) XMS=1.779E-6*TS**.6835
      AFUNC=EXP(5.7694+ALOG(DS)+65.*DS**1.5-6.E-6*EXP(127.2*DS))
      DSTERM=DS/.07
      C      -171282.8 = -58.75/.07**3
      RANGE=-171282.8*DS**3
      IF (RANGE.LT.-80.) RANGE=-80.
      BFUNC=10.0+7.2*(DSTERM**6-DSTERM**1.5)-17.63*EXP(RANGE)
      MUS= XMS+AFUNC*EXP(BFUNC/TS)*1.E-6
      30 MU=MUS*MCONV(KU)
      RETURN
      END

```

```

      FUNCTION VISCD (DGC,T)
C      FROM MC CARTY NBS AND W.G. STEWARD,S DATA
      R=DGC
      TL= ALOG(T)
      A = -0.135311743/TL + 1.00347841 + 1.20654649*TL
      1 -0.149564551*TL*TL+0.0125208416*TL**3
      B = R*(-47.5295259/TL + 87.6799309 -42.0741589*TL
      1+8.33128289*TL*TL -0.589252385*TL**3)
      C = R*R*(547.309267/TL - 904.870586 + 431.404928*TL
      1-81.45C4854*TL*TL + 5.37008433*TL**3)
      D = R**3*(-1684.39324/TL + 3331.08630 - 1632.19172*TL
      1+308.804413*TL*TL - 20.2936367*TL**3)
      VISCD = EXP (A+ B+ C+ D)*1.E-6
      RETURN
      END

```

```

C      COMPUTE THERMAL CONDUCTIVITY K GIVEN TEMPERATURE T AND
C      DENSITY D. UNITS ARE SPECIFIED BY KU. REGION IS SPECIFIED
C      BY KR.

```

```

C
      SUBROUTINE THERM (KU,KR,P,T,D,EXCESK, K)
      COMMON/FELFLU/ IHE, IFL, IHY
      COMMON/TCOND/CKMKST(9), XLAMB,ZC5, RHOCR, TCR, TCSTAR, CKSTAR(18)
      COMMON/BEND/R,DUMY(28)
      COMMON/COFMU/EPSK,WM,DIS,RHOCR,ZETA ,AMUX,BMUX
      COMMON/REFNO/SOTO,HOTO,CPOCOR,HTERM,STERM
      COMMON/COCPO/TO,CCOP1,CCOP2,CCOP3,CCOP4,CCOP5
      DIMENSION OMEGA1(9),OMEGA2(15)
      REAL KMKS, KSRAT, K, KCONV ,KZERO
      DIMENSION KCONV(5)
      DATA (OMEGA1(I),I=1,9),1.,4.,-.5228,.82359030E-1,-.53982316,
11.28552593,-1.53509952,1.44223760,2.602 /
      DATA (OMEGA2(I),I=1,15),2.,4.,-.52288,-1.33115022,.56160244,
11.49894829,-1.84681526,1.58946684,.60206,.32481334E-1,
2-.23524079,.65223929,-1.03095995,1.40383078,2.60206/
      DATA KCONV/2*1.,.01606044,2*1./
      COMMON /IERROR/IROUT
      IRROUT=11
      TS=TCHECK(KU,KR,T)
      DS=DCHECK(KU,D)

C      REGIONS 1, 2, AND 3
C
      IF (IHE.EQ.1) GO TO 30
      RHO = DS/RHOCR
      ARHO ALOG10(RHO)
      IF (ARHO.GT.CKMKST(3)) GO TO 10
      KMKS=10.**(ARHO-7.0)
      GO TO 20
 10 KMKS = 10.**(POLY(ALOG10(RHO),CKMKST)) / (ZC5*XLAMB)
 20 IF (IFL.EQ.1) GO TO 35
      IF (IHY.EQ.1) GO TO 38
      TR = TS/TCR
      KSRAT = 10.** (POLY (ALOG10(TR),CKSTAR))*TCSTAR
      K= (KMKS + KSRAT) * KCONV(KU) * 4.184
      GO TO 40
 30 SLOPE=10.**((DS*(DS*IDS*(-621.369011)+224.2564)-29.48514)+2.0941961
1)
      KMKS= ALOG10(TS)/SLOPE*1.E-3
C      USE HANS RODERS KO
      KZERO=CONZ(TS)*.001
      K=(KMKS*KZERO)*KCONV(KU)
      GO TO 40
C      FLUORINE KZERO CURVE BASED ON MASON-MONCHICK ANALYSIS
C      FROM REID AND SHERWOOD PAGE 461 EQ 10-12
C
 35 OM1=POLY(ALOG10(TS*EPSK),OMEGA1)
      OM2=POLY(ALOG10(TS*EPSK),OMEGA2)
      OM21=1.2*OM2/OM1
      XMO=.26653E-4*SQR(T(WM*TS)/(DIS*DIS*OM2))
      CVO=CPOCOR*((CCOP5*TS+CCOP4)*TS+CCOP3)*TS+CCOP2)*TS+CCOP1)
      .6366203 = 2./3.14159
      KZERO=(1.77*R+OM21*CVO-.6366203*(2.5-OM21)**2*(CVO-1.5*R)/
1(2.+.02*TS**.83333)*XMO
      K=(KMKS*KZERO)*KCONV(KU)
      GO TO 40
C      USES RODERS HYDROGEN CALCULATION BUT NOT HIS CRITICAL SCALING FOR
C      REACTING CONDUCTIVITY NEAR THE CRITICAL REGION.
C
 38 K=0.
      IF(TS.GT.2000.) GO TO 40
      IF(TS.LE.250.) K=CONC(TS,DS)*1.E-3*KCONV(KU)
      SK=K
      IF(TS.GT.150.) K=(KMKS*4.184+3.383E-5*TS**.72872)*KCONV(KU)
      X=.01*(TS-150.)
      IF((TS.GT.150.).AND.(TS.LT.250.)) K=X*K+(1.-X)*SK
C      REACTING CONDUCTIVITY CALCULATED BY THE SENGERS-KEYES METHOD
C      GENERAL FLUID
C

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```

40 DRHOC=ABS(DS-RHOCR)/RHOCR
  DELAMB=0.0
  IF (DRHOC.GT..6) GO TO 50
  DELTC=ABS((TS-TCR)/TCR)
  RAT=DS/RHOCR
  IF (DRHOC.LT..00001) GO TO 102
  IF (DELTG.LT.1.E-7) GO TO 101
  XBETA=DELTG**.35/DRHOC
  IF (XBETA.GT..4) GO TO 104
101 DELAMB= 3.05E-5/(SQRT(RAT)*DRHOC**1.71)
  GO TO 50
104 IF (XBETA.GT.3.) GO TO 102
C   2.857143 = 1./.35
  DELAMB=3.05E-5/(SQRT(RAT)*DELTG**.6)/(1.+.9/XBETA**2.857143)**.6
  GO TO 50
102 IF (DELTG.LT.1.E-7) GO TO 105
  DELAMB=3.05E-5/(SQRT(RAT)*DELTG**.6)
50 EXCESK=DELAMB*KCONV(KU)
  RETURN
105 EXCESK=1.E30
  RETURN
END

```

```

C   KZERO TABLE IN MW/CM-K, T IN KELVIN, DECK OF 18 SEPT 70
C   COURTESY OF HANS RODER      NBS LAB BOULDER COLORADO
C
FUNCTION CONZ(TEMP)
DIMENSION A(55),T(55)
DATA A/0.0376,0.0496,0.0608,0.0720,0.0829,0.0932,0.1028,0.1200,
1 0.1350,0.1486,0.1610,0.1725,0.1933,0.2121,0.2292,0.2448,0.2594,
2 0.2983,0.3357,0.3709,0.4042,0.4360,0.4666,0.5259,0.5821,0.6359,
3 0.6877,0.7381,0.7862,0.8333,0.8791,0.9241,0.9680,1.0113,1.054,
4 1.096,1.136,1.176,1.216,1.255,1.293,1.331,1.369,1.406,1.443,
5 1.479,1.516,1.551,           1.912,2.208,2.4836,2.743,2.99,
63.226,3.453/
DATA T/1.9,2.5,3.0,3.5,4.0,4.5,5.0,6.,7.,8.,9.,10.,12.,14.,16.,
1 18.,20.,25.,30.,35.,40.,45.,50.,60.,70.,80.,90.,100.,110.,120.,
2 130.,140.,150.,160.,170.,180.,190.,200.,210.,220.,230.,240.,250.,
3 260.,270.,280.,290.,300.,400.,500.,600.,700.,800.,900.,1000./
TT= TEMP
9 DO 11 J=1,58
10 IF(TT-T(J))12,12,11
11 CONTINUE
12 CONTINUE
13 CONZ=A(J-1)+(TT-T(J-1))*(A(J)-A(J-1))/(T(J)-T(J-1))
  RETURN
END

```

```

C   THIS ROUTINE BY HANS RODER HAS BEEN CHANGED TO COMMENT OUT THE
C   REACTING CONDUCTIVITY CALCULATIONS WHICH ARE NOT USED AT PRESENT
C   T KELVIN, DEN MUST BE IN GR/CC, CP IN CAL/MOLE
C
FUNCTION CONC(TMEAN,DEN)
DIMENSION AAA(12),TTT(12),D(3)
DATA TTT           /13.000,17.020,19.587,25.100,30.310,33.063,
1 40.145,59.187,79.845,99.852,122.909,153.0/
DATA AAA           /0.1765,0.3203,0.4121,0.5679,0.8491,0.9363,
1 1.1153,1.4781,1.7895,2.0757,2.3357,2.5450/
DATA D             /9.88531118E-01,3.2086940E+01,-9.10140989E+02/
CONC=0.
C   THIS CALCULATION BLOWS UP IF EXTRAPOLATED TOO FAR
IF (TMEAN.GT. 300.) GO TO 20
DO 9 J=1,12

```

```

      IF(TMEAN -TTT(J))10,10,9
9  CONTINUE
10  CONZ1=C.1*EXP (AAA(J-1))
    CONZJ=0.1*EXP (AAA(J))
    AAVE =CONZ1 +(TMEAN-TTT(J-1))*(CONZJ-CONZ1)/(TTT(J)-TTT(J-1))
    AAVE=ALOG(10.0*AAVE)
    BB=39.6-2.*SQRT(248.0-(.1*TMEAN-17.)*2)
    DENSQ=CEN*DEN
    FUNC=AAVE*D(1)*BB*DEN+DENSQ*(D(2)+D(3)/(TMEAN-9.0))
    CONC=0.1*EXP(FUNC)
    RETURN
20 IF (TMEAN .GT. 2000.) RETURN
    CONC=2.8971E-3*TMEAN**.72872
    RETURN
    END

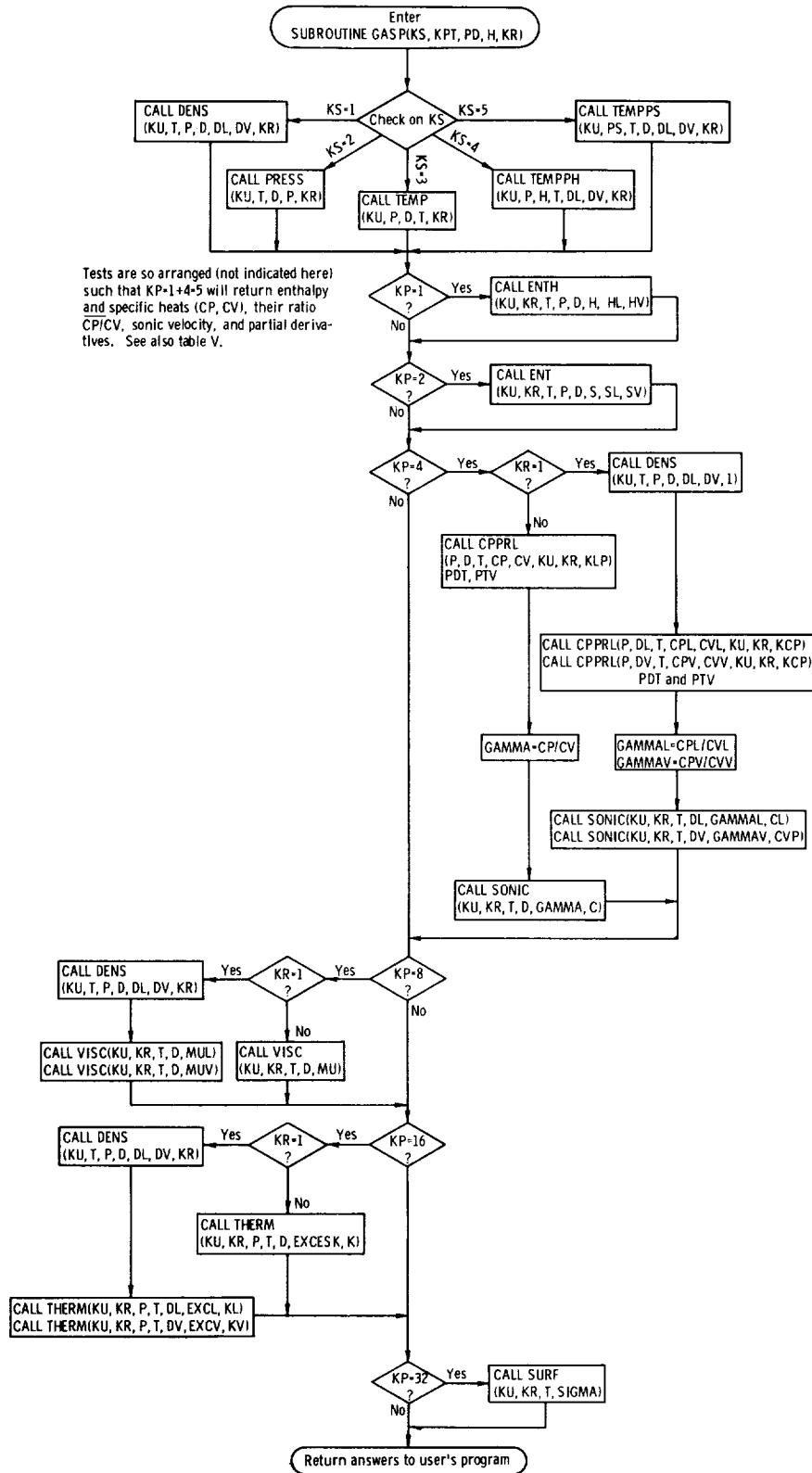
```

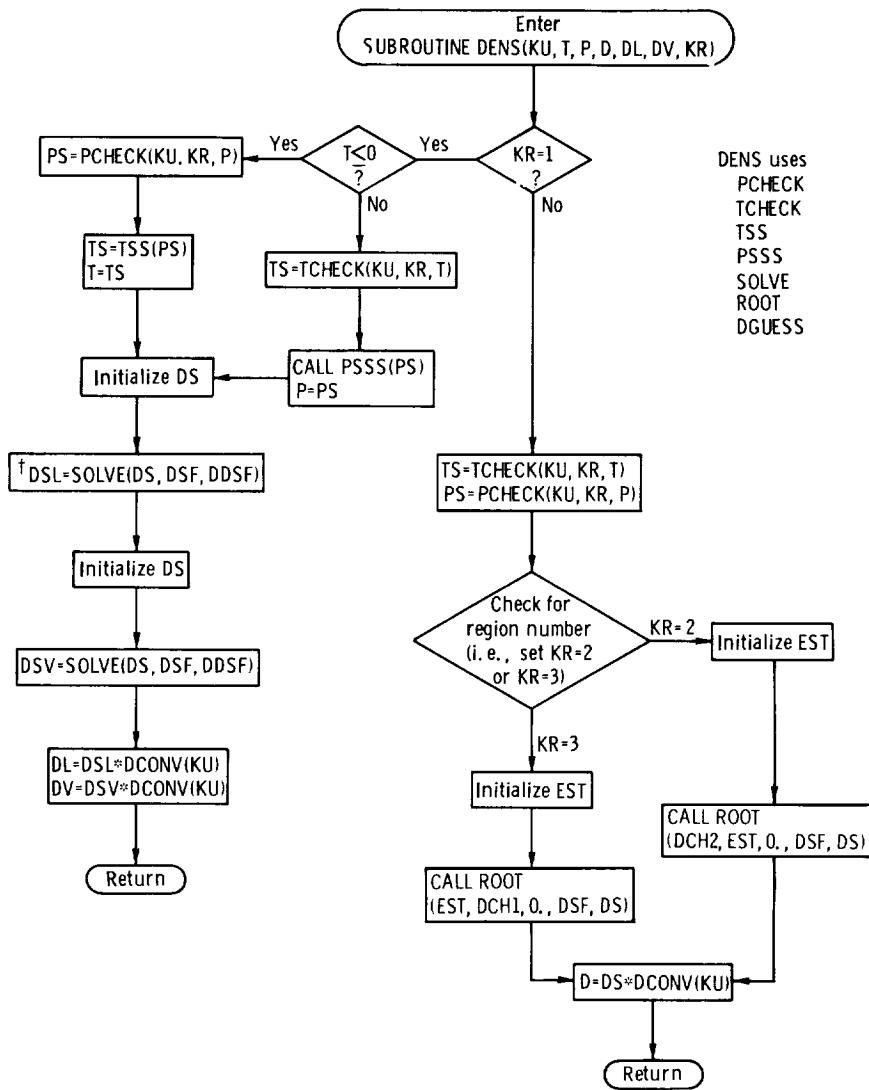
```

C      SURFACE TENSION  DYNE/CM
C
      SUBROUTINE SURF(KU,KR,T,SIGMA)
      COMMON/SURCON/PCTC,TCRIT,FIXIT,ZET
      COMMON/HELFLU/IHE,IFL,IHY
      COMMON /IERRDR/IROUT
      DIMENSION STCONV(5)
      DATA STCONV/2*1.,6.8521766E-5,2*1./
      IROUT=13
      SIGMA=0.
      TS=TCHECK(KU,1,T)
      IF ( TS .GT. TCRIT) RETURN
      IF(IHY.EQ.1 .OR. IHE.EQ.1) GOTO 10
      SIG=PCTC*(1.-TS/TCRIT)**1.22222*(.432/ZET-.951)*FIXIT
      SIGMA=SIG *STCONV(KU)
      RETURN
10 TR=TS/TCRIT
      C1=5.3C8
      IF(IHY.EQ.1) C1=5.369
      SIGMA=C1*(1.0-TR)**1.065*STCONV(KU)
      RETURN
      END

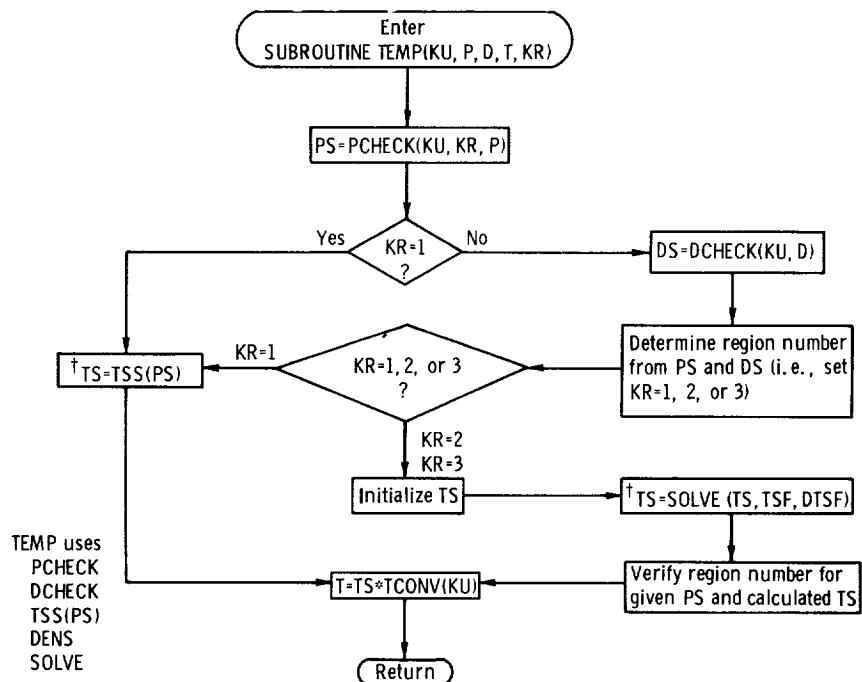
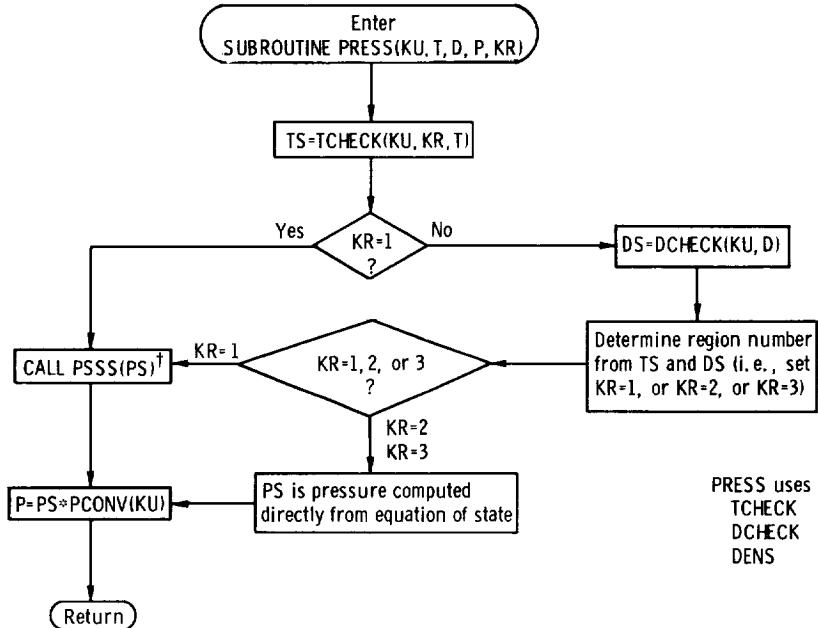
```

COMPACT FLOW CHART FOR GASP

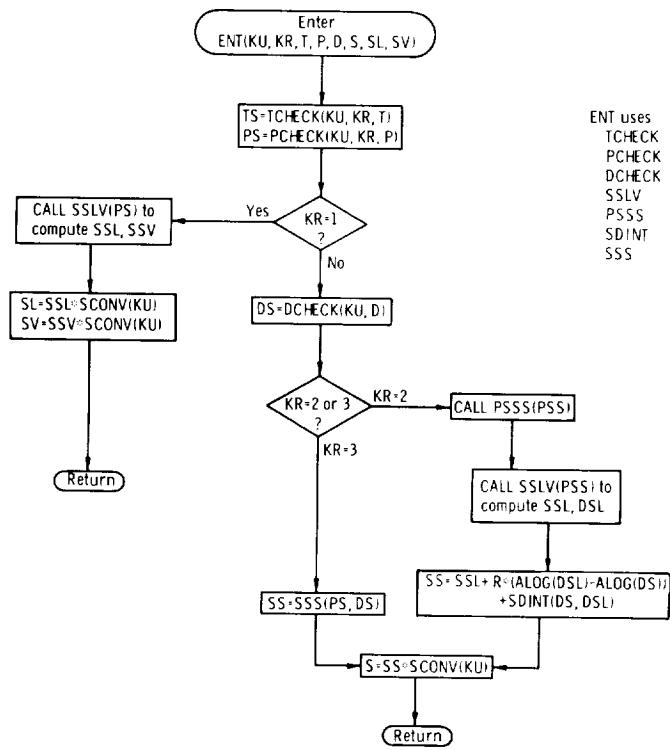
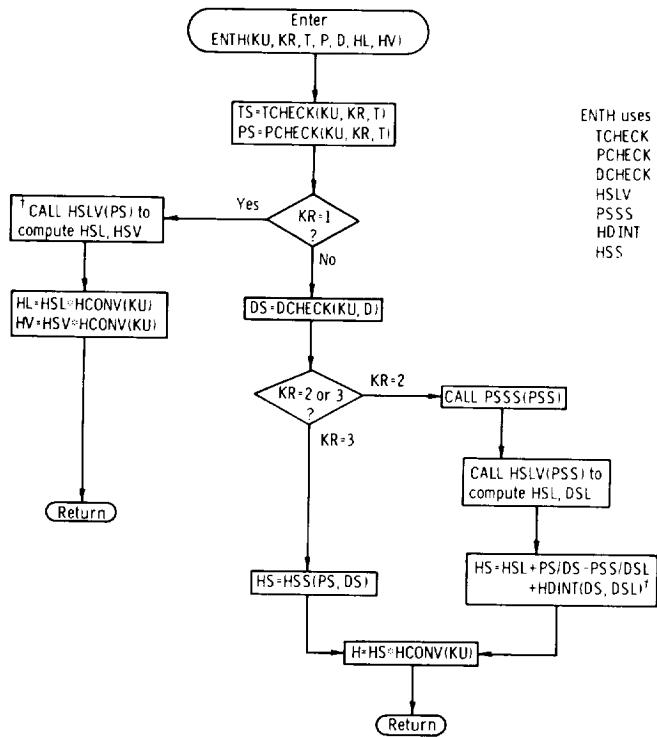




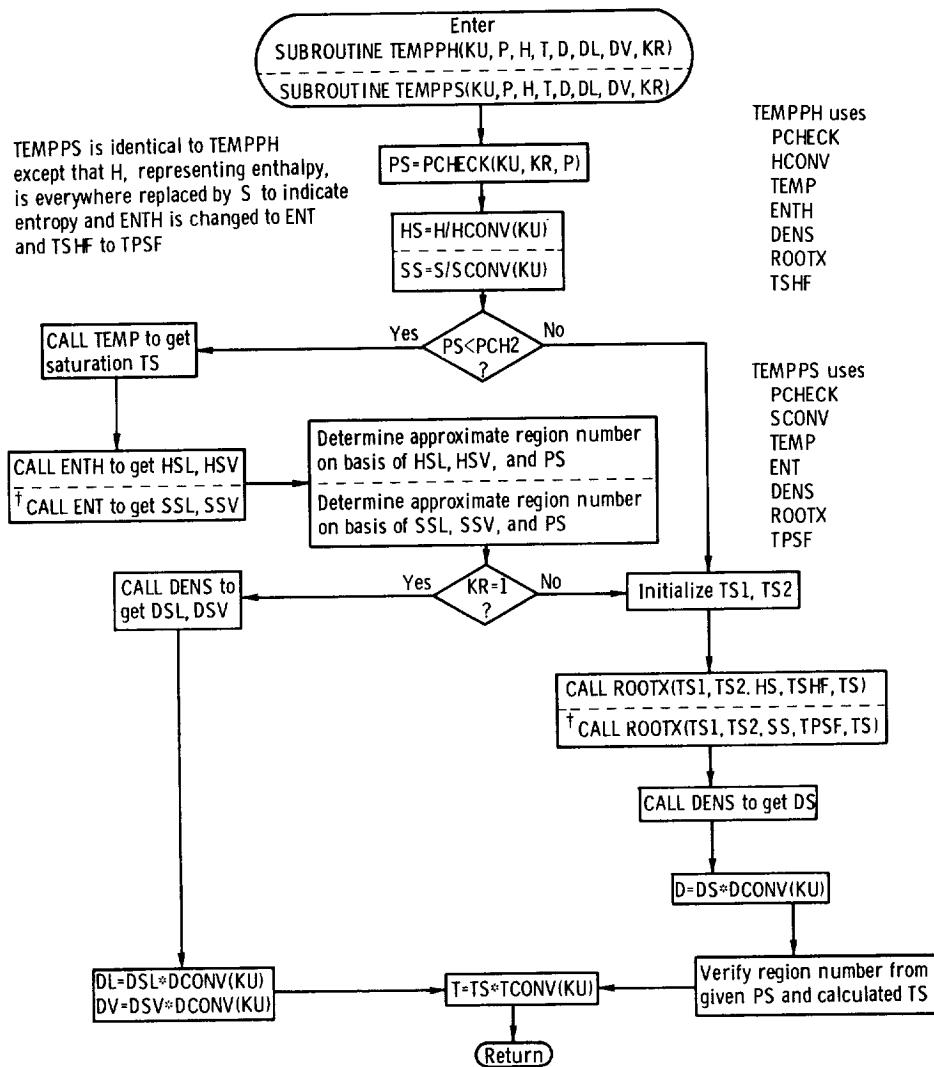
<sup>†</sup> See appendix F for details of subroutine or function specified.



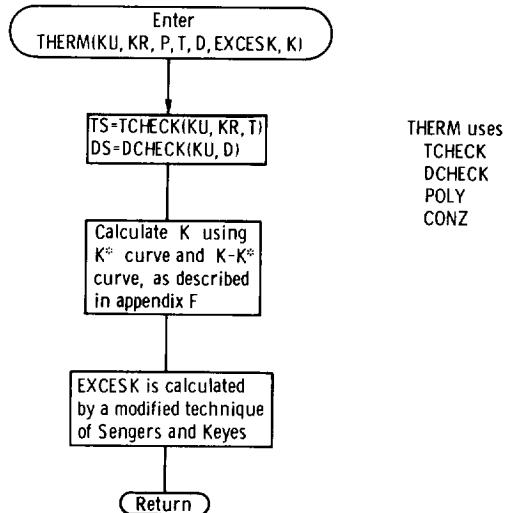
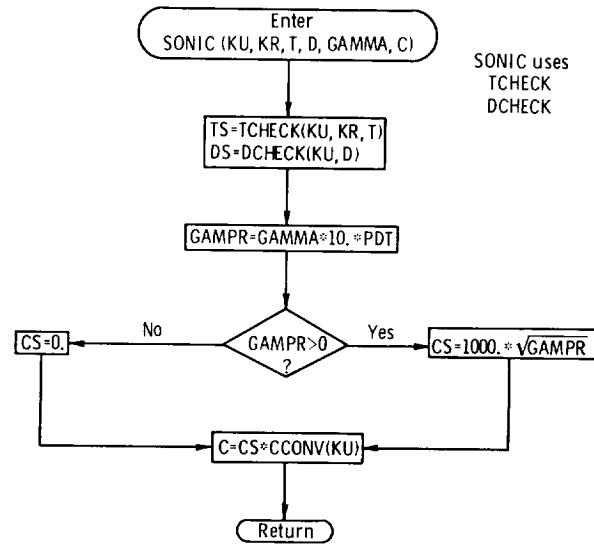
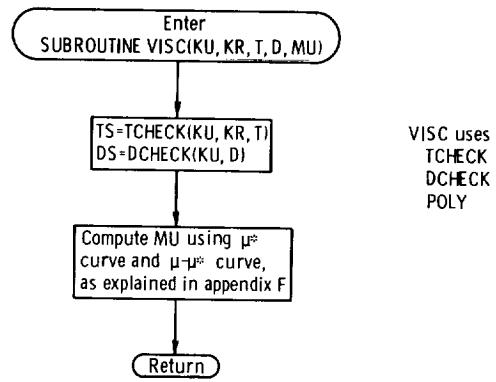
<sup>†</sup> See appendix F for details of subroutine or function specified.

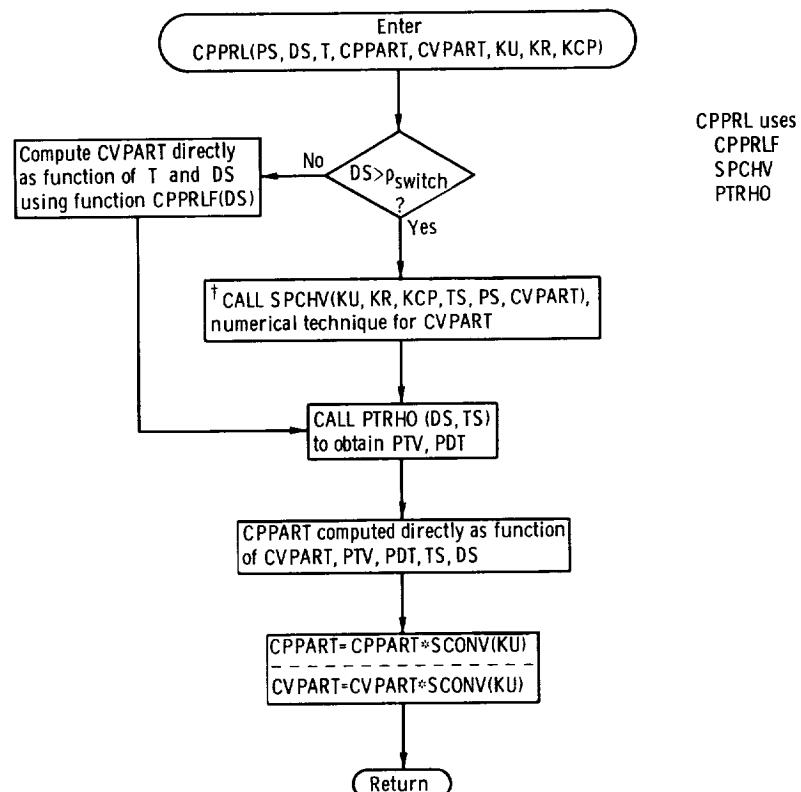
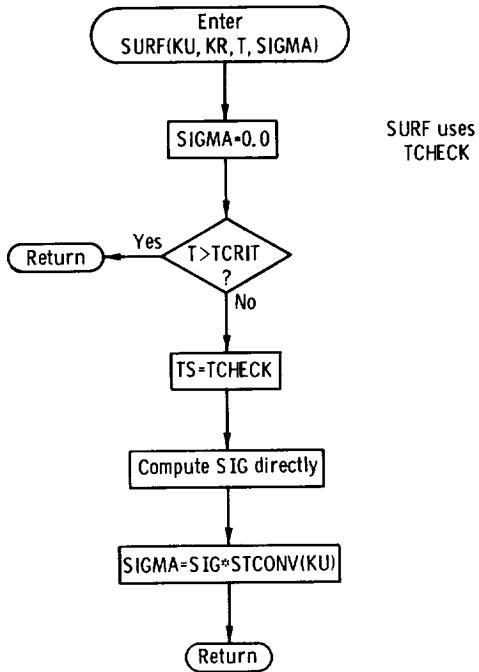


<sup>†</sup> See appendix F for details of subroutine or function specified.



† See appendix F for details of subroutine or function specified.





<sup>†</sup> See appendix F for details of subroutine or function specified.

## APPENDIX I

### TEST PROGRAM WITH OUTPUT

This appendix contains a short isobar test program with sample output for each of the 10 fluids in GASP. It is not intended to be used as a set of property tables but rather as an aid to checking out the operation of GASP. The user can produce similar output by using the following driver-deck

- (1) To verify the GASP calling procedure
- (2) To check user output against expected output
- (3) To serve as a rapid means of providing the user with results

All parameters that are produced by GASP, with the exception of surface tension and saturation properties, are listed as output for three pressures:

- (1) 0.101325 MPa (1 atm)
- (2) Critical pressure of the fluid
- (3) 10.1325 MPa (100 atm)

```
C
C      TEST PROGRAM  PREPARES TABLES FOR EACH FLUID OVER A RANGE OF PVT
C
COMMON/PROPTY/KU,DL,DV,HL,HV,S,SL,SV,CV,CVL,CVV,CP,CPL,CPV,GAMMA,
1GAMMAL,GAMMAV,C,CL,CVP,MU,MUL,MUV,K,KL,KV,SIGMA,EXCESK,EXCL,EXCV
COMMON/DER IV/PDT,PTV,PDTL,PDTV,PTVL,PTVV
REAL    MU,MUL,MUV,K,KL,KV
COMMON/CHECKS/DCH1,DCH2,PCH1,PCH2,PCH3,TCH1,TCH2,TCH3,DST,TST,H
ISCH1,FSCH2
DATA NAM/3HC4,2HN2,2HO2,2HAR,3HC02,2HNE,2HCO,2HHE,2HF2,2HH2/
DIMENSION NAM(10),P(3),T(250),YPL(250,10),TSTART(3,10),DTA(3,10)
DATA P/1.,1.,100./
DATA TSTART/95.,295.,400.,65.,200.,400.,60.,225.,400.,85.,225.,400
*,220.,420.,500.,25.,80.,400.,70.,200.,400.,3.,10.,100.,70.,200.,
*400.,16.,40.,200./
DATA DTA/10.,20.,100.,10.,20.,100.,10.,20.,100.,10.,20.,100.,
* 10.,20.,100.,10.,20.,100.,10.,20.,100.,5,10.,100.,5.,20.,100.,
* 2.,10.,100./
KS=1
KP=31
KU=1
WRITE(6,1)
1 FORMAT(1H1)
DO 100C L=1,10
CALL SETUP (NAM(L))
P(2)=PCT2/.101325
T(1)=TSTART(1,L)
DT=DTA(1,L)
TS=TSTART(2,L)
N=2
KPT=0
DO 20 J=1,50
KPT=J
T(J+1)=T(J)+DT
```

```

TJ=T(J+1)
IF(TJ.GE.TCH3) GOTO 25
IF(L.EQ.10 .AND. TJ.GE.1999.5) GOTO 25
IF(TJ-TS+.05) 20,210,210
210 T(J+1)=TS
DT=DTA(N,L)
N=N+1
TS=TCH3
IF(N.LT.4) TS=TSTART(N,L)
20 CONTINUE
25 KPT=KPT+1
T(KPT)=TCH3
DO 100 I=1,3
Z= P(I)*.101325
DO 50 J=1,KPT
KR=0
CALL GASP (KS,KP,T(J),Z,D,H,KR)
YPL(J,1)=D
YPL(J,2)=H
YPL(J,3)=S
YPL(J,4)=CP
YPL(J,5)=CV
YPL(J,6)=C
YPL(J,7)=K
YPL(J,8)=MU
YPL(J,9)=PDT
YPL(J,10)=PTV
46 FORMAT(1H ,I6,6E14.6)
50 CONTINUE
C          TABLE      OF
C          CENSITY, ENTROPY, ENTHALPY, CP, CV,           SONIC VELOCITY
C          THERMAL CONDUCTIVITY, VISCOSITY AND PARTIAL DERIVATIVES
C          FOR EACH  T P
C
      WRITE(6,800) NAM(L),KU
800 FORMAT(1H1 ,45X,34H THERMODYNAMIC PROPERTY TABLE -- ,A4 ,3X,3HKU=
1 I3)
      WRITE(6,801) P(I)
801 FORMAT(1H0 ,5X, F10.2 ,1H ATM ISOBAR)
      WRITE(6,701)
      WRITE(6,702)
701 FORMAT(3H0 ,4HTEMP,5X,7HDENSITY,4X,8HENHALPY,4X,7HENENTROPY,7X,2HC
*P,10X,2HCV,9X,7HSON VEL,4X,10HTHERM COND,5X,4HVISC,7X,5HDP/DD,7X,5
*HCP/DT,/ )
702 FORMAT(4X,1HK ,8X,4HG/CC,8X,3HJ/G,8X,5HJ/G-K,7X,5HJ/G-K,7X,5HJ/G-K,
*8X,4HCM/S,7X,8HJ/CM-S-K,5X,6HG/CM-S,4X,10HMN-CC/G-M2,3X,7HMN/K-M2,
*/ )
      DO 150 J=1,KPT
      WRITE (6,803) T (J),(YPL(J, N),N=1,10)
      IF (MOD(J,50).NE.0) GO TO 150
      IF ( J.EQ. KPT) GO TO 150
      WRITE(6,800) NAM(L)
      WRITE(6,801) P(I)
803 FORMAT (1H ,F6.1,2X,10(1X,G11.4))
150 CONTINUE
100 CONTINUE
51 FORMAT(12H ISOBARS = 5F10.3 )
1000 CONTINUE
      RETURN
      END

```

THERMODYNAMIC AND TRANSPORT PROPERTIES FOR METHANE PC=45.66 ATM, TC=190.77 K, ROC=.162 G/CC  
 -0.30279E+00 IS OUT OF RANGE OF CURVE FIT VALUE IS EXTRAPOLATED.  
 THERMODYNAMIC PROPERTY TABLE — CH4 KU = 1

1.00 ATM ISOBAR							1.00 ATM ISOBAR						
TEMP K	DENSITY G/CC	ENTHALPY J/G	ENTROPY J/G-K	CP J/G-K	CV J/G-K	SON VEL CM/S	COND J/CH-M2-K	COND J/CH-S-K	VISC G/CH-S	DP/DD MN-CC/G-M2	DP/DD MN/K-M2		
95.0	0.4469	231.00	4.3982	2.6952	1.2469	0.1819E+06	0.2269E+02	0.1725E+02	1.530.4	2.1588			
105.0	0.4327	261.80	4.7058	3.3877	1.9143	0.1492E+06	0.2065E+02	0.1372E+02	1.258.5	1.8182			
115.0	0.1761E-02	803.93	9.5664	2.2001	1.6037	0.2759E+05	0.1238E+03	0.4742E+04	55.498	0.9447E-03			
125.0	0.1607E-02	825.76	9.7485	2.1688	1.5916	0.2891E+05	0.1348E+03	0.5138E+04	61.361	0.8552E-03			
135.0	0.1479E-02	847.33	9.9145	2.1465	1.5824	0.3015E+05	0.1456E+03	0.5533E+04	67.033	0.7829E-03			
145.0	0.1371E-02	868.71	10.067	2.1304	1.5757	0.3133E+05	0.1564E+03	0.5926E+04	72.617	0.7228E-03			
155.0	0.1279E-02	889.95	10.209	2.1190	1.5712	0.3246E+05	0.1672E+03	0.6316E+04	78.123	0.6720E-03			
165.0	0.1199E-02	911.10	10.341	2.1112	1.5686	0.3354E+05	0.1780E+03	0.6701E+04	83.570	0.6283E-03			
175.0	0.1128E-02	932.19	10.465	2.1065	1.5678	0.3457E+05	0.1888E+03	0.7082E+04	88.973	0.5902E-03			
185.0	0.1065E-02	953.24	10.582	2.1044	1.5689	0.3557E+05	0.1997E+03	0.7458E+04	96.341	0.5567E-03			
195.0	0.1010E-02	974.28	10.693	2.1048	1.5717	0.3654E+05	0.2108E+03	0.7827E+04	99.683	0.5270E-03			
205.0	0.9593E-03	995.34	10.798	2.1074	1.5763	0.3747E+05	0.2220E+03	0.8191E+04	105.00	0.5003E-03			
215.0	0.9140E-03	1016.4	10.899	2.1123	1.5828	0.3837E+05	0.2334E+03	0.8549E+04	110.30	0.4763E-03			
225.0	0.8728E-03	1037.6	10.995	2.1192	1.5911	0.3924E+05	0.2420E+03	0.8901E+04	115.59	0.4546E-03			
235.0	0.8351E-03	1058.8	11.087	2.1283	1.6013	0.4008E+05	0.2568E+03	0.9246E+04	120.87	0.4348E-03			
245.0	0.80C7E-03	1080.2	11.176	2.1394	1.6133	0.4090E+05	0.2689E+03	0.9585E+04	126.13	0.4167E-03			
255.0	0.7689E-03	1101.6	11.262	2.1526	1.6273	0.4169E+05	0.2813E+03	0.9948E+04	131.39	0.4000E-03			
265.0	0.7397E-03	1123.2	11.345	2.1678	1.6431	0.4246E+05	0.2939E+03	0.1024E+03	136.64	0.3847E-03			
275.0	0.7126E-03	1145.0	11.426	2.1849	1.6609	0.4320E+05	0.3068E+03	0.1057E+03	141.88	0.3705E-03			
285.0	0.6874E-03	1166.9	11.504	2.2040	1.6805	0.4393E+05	0.3201E+03	0.1088E+03	147.12	0.3573E-03			
295.0	0.6639E-03	1189.1	11.581	2.2250	1.7019	0.4463E+05	0.3333E+03	0.1119E+03	152.35	0.3451E-03			
315.0	0.6215E-03	1234.0	11.728	2.2724	1.7501	0.4598E+05	0.3620E+03	0.1179E+03	162.81	0.3229E-03			
335.0	0.5842E-03	1280.0	11.869	2.3267	1.8049	0.4726E+05	0.3915E+03	0.1238E+03	173.25	0.3035E-03			
355.0	0.5512E-03	1327.1	12.006	2.3869	1.8655	0.4848E+05	0.4217E+03	0.1294E+03	183.68	0.2863E-03			
375.0	0.5217E-03	1375.5	12.139	2.4521	1.9311	0.4964E+05	0.4531E+03	0.1350E+03	194.10	0.2709E-03			
395.0	0.4952E-03	1425.3	12.268	2.5211	2.005	0.5077E+05	0.4855E+03	0.1403E+03	204.52	0.2571E-03			
400.0	0.4890E-03	1437.9	12.300	2.5388	2.0182	0.5104E+05	0.4937E+03	0.1417E+03	207.12	0.2539E-03			
500.0	0.3910E-03	1709.5	12.904	2.8815	2.3618	0.5623E+05	0.6676E+03	0.1671E+03	259.12	0.2029E-03			
600.0	0.3258E-03	2006.8	13.446	2.9988	2.4796	0.6134E+05	0.8531E+03	0.1899E+03	311.07	0.1690E-03			

-0.30279E+00 IS OUT OF RANGE OF CURVE FIT VALUE IS EXTRAPOLATED.

THERMODYNAMIC PROPERTY TABLE — CH<sub>4</sub> KU= 1

TEMP K	DENSITY G/CC	ENTHALPY J/G	ENTROPY J/G-K	CP J/G-K	CV J/G-K	SOL VEL CM/S	THERM COND J/CM-S-K	VISC G/CM-S	DP/DD MN-CC/G-M2	DP/DT MN/K-M2
95.0	0.4498	238.13	4.3679	2.6724	1.2802	0.1833E+06	0.2316E-02	0.1811E-02	1609.8	2.1847
105.0	0.4261	268.66	4.6720	3.3556	1.9493	0.1520E+06	0.2116E-02	0.1449E-02	1342.3	1.8494
115.0	0.4222	303.49	4.9887	3.5609	2.1227	0.1366E+06	0.1932E-02	0.1174E-02	1111.6	1.5741
125.0	0.4077	339.14	5.2859	3.5585	2.0590	0.1254E+06	0.1762E-02	0.9624E-03	909.75	1.3469
135.0	0.2925	374.75	5.5600	3.5479	1.9487	0.1154E+06	0.1601E-02	0.7961E-03	730.87	1.1548
145.0	0.3760	411.33	5.8213	3.6880	1.9375	0.1042E+06	0.1447E-02	0.6630E-03	570.57	0.9867
155.0	0.3576	450.32	6.0812	3.8992	1.9204	0.9297E+05	0.1226E-02	0.5244E-03	425.72	0.8337
165.0	0.2363	492.27	6.3434	4.2502	1.9033	0.8104E+05	0.1145E-02	0.4631E-03	294.07	0.6878
175.0	0.3096	536.93	6.6061	4.9550	1.8949	0.6745E+05	0.9880E-03	0.3817E-03	173.96	0.5400
185.0	0.2688	590.87	6.9053	7.4219	1.9184	0.4964E+05	0.7934E-03	0.2262E-03	63.701	0.3701
195.0	0.8744E-01	815.08	8.0822	8.7809	1.9995	0.2803E+05	0.3415E-03	0.1091E-03	17.884	0.6896E-01
205.0	0.676E-01	875.12	8.3833	4.6272	1.8822	0.3107E+05	0.3192E-03	0.1016E-03	39.271	0.4841E-01
215.0	0.5740E-01	915.99	8.5781	3.6903	1.8188	0.3328E+05	0.3156E-03	0.1010E-03	54.571	0.3956E-01
225.0	0.5136E-01	950.50	8.7351	3.2567	1.7792	0.3508E+05	0.3175E-03	0.1020E-03	67.228	0.3413E-01
235.0	0.4654E-01	981.72	8.8708	3.0065	1.7542	0.3664E+05	0.3223E-03	0.1038E-03	78.319	0.3032E-01
245.0	0.4347E-01	1010.9	8.9926	2.8461	1.7395	0.3802E+05	0.3289E-03	0.1084E-03	88.361	0.2746E-01
255.0	0.4064E-01	1038.8	9.1041	2.7376	1.7325	0.3928E+05	0.3369E-03	0.1084E-03	97.646	0.2521E-01
265.0	0.3826E-01	1065.8	9.2079	2.6623	1.7318	0.4044E+05	0.3459E-03	0.1109E-03	106.36	0.2338E-01
275.0	0.3622E-01	1092.1	9.3055	2.6097	1.7361	0.4151E+05	0.3557E-03	0.1134E-03	114.63	0.2185E-01
285.0	0.3443E-01	1118.0	9.3980	2.5736	1.7448	0.4251E+05	0.3663E-03	0.1161E-03	122.54	0.2055E-01
295.0	0.3285E-01	1143.6	9.4864	2.5501	1.7573	0.4346E+05	0.3776E-03	0.1187E-03	130.15	0.1943E-01
315.0	0.2016E-01	1194.4	9.6528	2.5305	1.7917	0.4521E+05	0.4020E-03	0.1240E-03	144.69	0.1757E-01
335.0	0.2754E-01	1245.0	9.8087	2.5372	1.8367	0.4680E+05	0.4284E-03	0.1292E-03	158.53	0.1609E-01
355.0	0.2606E-01	1296.0	9.9565	2.5624	1.8903	0.4826E+05	0.4562E-03	0.1344E-03	171.84	0.1487E-01
375.0	0.2445E-01	1347.6	10.098	2.6009	1.9507	0.4963E+05	0.4855E-03	0.1395E-03	184.75	0.1384E-01
395.0	0.2305E-01	1400.1	10.234	2.6492	2.0161	0.5092E+05	0.5161E-03	0.1445E-03	197.33	0.1296E-01
400.0	0.2273E-01	1413.4	10.268	2.6624	2.0330	0.5123E+05	0.5239E-03	0.1458E-03	200.44	0.1276E-01
500.0	0.1784E-01	1694.1	10.893	2.9500	2.3673	0.5692E+05	0.6926E-03	0.1701E-03	260.04	0.9819E-02
600.0	0.1475E-01	1997.0	11.445	3.0430	2.4820	0.6232E+05	0.8531E-03	0.1923E-03	316.81	0.8026E-02

-0.30279E+00 IS OUT OF RANGE OF CURVE FIT VALUE IS EXTRAPOLATED.

## 100.00 ATM ISOBAR

THERMODYNAMIC PROPERTY TABLE -- CH<sub>4</sub> KU= 1

TEMP K	DENSITY G/CC	ENTHALPY J/G	ENTROPY J/G-K	CP J/G-K	CV J/G-K	SON VEL CM/S	THERM COND J/CM-S-K	VISC G/CM-S	DP/DD MN/CM-G-M2	DP/DT MN/K-M2
95.0	0.4531	246.92	4.3312	2.6497	1.3181	0.1851E+06	0.2371E-02	0.1918E-02	1703.8	2.2143
105.0	0.4401	277.19	4.6335	3.3246	1.9882	0.1552E+06	0.2175E-02	0.1544E-02	1440.9	1.8847
115.0	0.4269	311.64	4.9468	3.5159	2.1612	0.1406E+06	0.1996E-02	0.1280E-02	1214.8	1.6150
125.0	0.4134	346.74	5.2395	3.4918	2.0958	0.1302E+06	0.1831E-02	0.1040E-02	1017.9	1.3940
135.0	0.3995	381.53	5.5073	3.4483	1.9834	0.1212E+06	0.1677E-02	0.8690E-03	844.31	1.2091
145.0	0.3847	416.87	5.7597	3.5350	1.9695	0.1113E+06	0.1531E-02	0.7306E-03	690.01	1.0501
155.0	0.3689	453.91	6.0067	3.6528	1.9489	0.1017E+06	0.1391E-02	0.6195E-03	552.17	0.9091
165.0	0.3516	492.58	6.2484	3.8172	1.9263	0.9221E+05	0.1258E-02	0.5223E-03	429.04	0.7798
175.0	0.3323	530.98	6.4744	4.0537	1.9057	0.8249E+05	0.1128E-02	0.4521E-03	319.86	0.6585
185.0	0.3101	568.65	6.6837	4.4057	1.8927	0.7235E+05	0.9997E-03	0.3866E-03	224.89	0.5420
195.0	0.2835	617.44	6.9403	4.9480	1.8924	0.6177E+05	0.8710E-03	0.3219E-03	145.93	0.4288
205.0	0.2506	670.73	7.2067	5.7519	1.9098	0.5126E+05	0.7421E-03	0.2723E-03	87.250	0.3205
215.0	0.2168	732.38	7.5002	6.4879	1.9401	0.4283E+05	0.6220E-03	0.2351E-03	54.855	0.2271
225.0	0.1719	797.08	7.7943	6.2693	1.9493	0.3876E+05	0.530E-03	0.1922E-03	46.702	0.1627
235.0	0.1425	855.56	8.0488	5.3951	1.9245	0.3794E+05	0.4843E+05	0.1658E-03	51.350	0.1241
245.0	0.1224	905.30	8.2562	4.5932	1.8895	0.3847E+05	0.451E-03	0.1516E-03	60.887	0.1004
255.0	0.1085	948.24	8.4280	4.0309	1.8597	0.3944E+05	0.4471E-03	0.1441E-03	71.802	0.8483E-01
265.0	0.9823E-01	986.53	8.5754	3.6519	1.8387	0.4055E+05	0.4455E+05	0.1402E-03	82.785	0.7393E-01
275.0	0.9030E-01	1021.7	8.7056	3.3919	1.8262	0.4165E+05	0.4423E-03	0.1383E-03	93.417	0.6586E-01
285.0	1.8293E-01	1054.6	8.8233	3.2092	1.8210	0.4273E+05	0.4451E-03	0.1377E-03	103.59	0.5962E-01
295.0	0.7867E-01	1086.0	8.9316	3.0782	1.8221	0.4375E+05	0.4501E-03	0.1378E-03	113.32	0.5465E-01
315.0	0.7037E-01	1145.8	9.1276	2.9146	1.8395	0.4566E+05	0.4650E-03	0.1394E-03	131.59	0.4716E-01
335.0	0.6403E-01	1203.1	9.3042	2.8315	1.8726	0.4740E+05	0.4843E-03	0.1422E-03	148.56	0.4175E-01
355.0	0.5896E-01	1259.4	9.4672	2.7956	1.9178	0.4898E+05	0.5064E-03	0.1456E-03	164.55	0.3763E-01
375.0	0.5478E-01	1315.2	9.6203	2.7925	1.9722	0.5045E+05	0.5311E-03	0.1494E-03	179.77	0.3436E-01
395.0	0.5126E-01	1371.2	9.7657	2.8096	2.0329	0.5183E+05	0.5578E-03	0.1534E-03	194.37	0.3169E-01
400.0	0.5046E-01	1385.3	9.8011	2.8163	2.0489	0.5216E+05	0.5648E-03	0.1544E-03	197.94	0.3109E-01
500.0	0.3885E-01	1677.0	10.451	3.0296	2.3730	0.5813E+05	0.7205E-03	0.1758E-03	264.69	0.2291E-01
600.0	0.2189E-01	1986.2	11.015	3.0933	2.4844	0.6372E+05	0.8956E-03	0.1965E-03	326.13	0.1834E-01

## THERMODYNAMIC AND TRANSPORT PROPERTIES FOR NITROGEN PC=33.72ATM, TC=126.3 K, ROC=.3105G/CC

0.44490E+00 IS OUT OF RANGE OF CURVE FIT VALUE IS EXTRAPOLATED.

0.41877E+00 IS OUT OF RANGE OF CURVE FIT VALUE IS EXTRAPOLATED.

THERMODYNAMIC PROPERTY TABLE -- N2 KU= 1

## 1.00 ATM ISOBAR

TEMP K	DENSITY G/GC	ENTHALPY J/G	ENTROPY J/G-K	CP J/G-K	CV J/G-K	SPEC VEL CM/S	THERM COND J/CM-S-K	VISC G/CM-S	DP/DD MN-CC/G-M2	UP/DT MN/K-M2
65.0	0.8570	4.1979	0.6452E-01	2.0200	1.2105	0.9647E+05	0.1543E-02	0.2586E-02	557.67	2.2584
75.0	0.8144	24.776	0.3589	2.0622	1.167	0.8119E+05	0.1408E-02	0.1778E-02	42.15	1.876
85.0	0.4158E-02	236.49	3.0914	1.1050	0.7632	0.1845E+05	0.7800E-04	0.6094E-04	23.511	0.1279E-02
95.0	0.3682E-02	247.43	3.2231	1.0852	0.7572	0.1961E+05	0.8718E-04	0.6780E-04	26.844	0.1121E-02
105.0	0.2309E-02	258.21	3.3211	1.0725	0.7530	0.2070E+05	0.9636E-04	0.7458E-04	30.072	0.1001E-02
115.0	0.2008E-02	268.89	3.4182	1.0639	0.7501	0.2171E+05	0.1055E-03	0.8126E-04	33.234	0.9006E-03
125.0	0.2759E-02	279.50	3.5067	1.0580	0.7480	0.2268E+05	0.1147E-03	0.8780E-04	36.350	0.8285E-03
135.0	0.2549E-02	290.06	3.5879	1.0538	0.7465	0.2359E+05	0.1219E-03	0.9420E-04	39.435	0.7637E-03
145.0	0.2369E-02	300.58	3.6631	1.0507	0.7453	0.2448E+05	0.1297E-03	0.1004E-03	42.497	0.7088E-03
155.0	0.2214E-02	311.08	3.7331	1.0483	0.7445	0.2532E+05	0.1377E-03	0.1056E-03	45.542	0.6614E-03
165.0	0.2077E-02	321.55	3.7986	1.0465	0.7438	0.2614E+05	0.1460E-03	0.1124E-03	48.575	0.6202E-03
175.0	0.1957E-02	332.01	3.8601	1.0451	0.7433	0.2694E+05	0.1544E-03	0.1182E-03	51.597	0.5839E-03
185.0	0.1850E-02	342.45	3.9182	1.0440	0.7429	0.2770E+05	0.1629E-03	0.1238E-03	54.612	0.5517E-03
195.0	0.1755E-02	352.89	3.9731	1.0431	0.7426	0.2845E+05	0.1716E-03	0.1292E-03	56.620	0.5229E-03
200.0	0.1710E-02	358.10	3.9995	1.0428	0.7424	0.2882E+05	0.1759E-03	0.1319E-03	59.122	0.5096E-03
220.0	0.1554E-02	378.95	4.0989	1.0416	0.7421	0.3023E+05	0.1933E-03	0.1422E-03	65.120	0.4627E-03
240.0	0.1424E-02	399.77	4.1895	1.0409	0.7419	0.3159E+05	0.2107E-03	0.1521E-03	71.106	0.4238E-03
260.0	0.1314E-02	420.59	4.2728	1.0406	0.7420	0.3288E+05	0.2278E-03	0.1616E-03	77.382	0.3909E-03
280.0	0.1220E-02	441.40	4.3499	1.0406	0.7422	0.3412E+05	0.2447E-03	0.1709E-03	83.051	0.3628E-03
300.0	0.1138E-02	462.21	4.4217	1.0408	0.7427	0.3532E+05	0.2610E-03	0.1779E-03	89.015	0.3385E-03
320.0	0.1067E-02	483.03	4.4889	1.0413	0.7433	0.3647E+05	0.2755E-03	0.1885E-03	94.975	0.3172E-03
340.0	0.1004E-02	503.86	4.5520	1.0420	0.7442	0.3759E+05	0.2879E-03	0.1972E-03	100.93	0.2958E-03
360.0	0.9418E-02	524.71	4.6116	1.0430	0.7453	0.3867E+05	0.3002E-03	0.2058E-03	106.89	0.2819E-03
380.0	0.8982E-02	545.58	4.6680	1.0442	0.7466	0.3973E+05	0.3123E-03	0.2131E-03	112.84	0.2670E-03
400.0	0.8532E-02	566.48	4.7216	1.0457	0.7482	0.4075E+05	0.3242E-03	0.2209E-03	118.79	0.2536E-03
500.0	0.6825E-02	671.56	4.9560	1.0510	0.7597	0.4546E+05	0.3814E-03	0.2576E-03	148.52	0.2028E-03
600.0	0.5687E-02	778.08	5.1502	1.0745	0.7774	0.4963E+05	0.4356E-03	0.2916E-03	178.24	0.1690E-03
700.0	0.4875E-02	886.62	5.3175	1.0970	0.8003	0.5340E+05	0.4875E-03	0.3233E-03	207.94	0.1448E-03
800.0	0.4226E-02	997.57	5.4656	1.1222	0.8253	0.5685E+05	0.5373E-03	0.3533E-03	237.64	0.1267E-03
900.0	0.3792E-02	1111.0	5.5992	1.1467	0.8498	0.6006E+05	0.5855E-03	0.3818E-03	267.33	0.1126E-03
1000.0	0.3413E-02	1226.7	5.7211	1.1657	0.8688	0.6322E+05	0.6322E-03	0.4090E-03	297.02	0.1013E-03

0.44382E+00 IS OUT OF RANGE OF CURVE FIT VALUE IS EXTRAPOLATED.  
0.42279E+00 IS OUT OF RANGE OF CURVE FIT VALUE IS EXTRAPOLATED.

THERMODYNAMIC PROPERTY TABLE -- N2

32.72 ATM 1 SOBAR							N2	KU= 1		
TEMP K	DENSITY G/CC	ENTHALPY J/G	ENTROPY J/G-K	CP J/G-K	CV J/G-K	SON VEL CM/S	T+TERM COND J/CM-S-K	VISC G/CM-S	DP/DD MN-CG-M2	DP/DT MN/K-M2
65.0	0.8627	6.8952	0.4666E-01	1.9970	1.2147	0.9830E+05	0.1563E-02	0.2732E-02	587.81	2.2947
75.0	0.8220	27.215	0.3374	2.0319	1.1278	0.9405E+05	0.1433E-02	0.1895E-02	453.64	1.9221
85.0	0.7779	47.252	0.5883	1.9779	0.9770	0.8271E+05	0.1301E-02	0.1339E-02	337.92	1.5518
95.0	0.7295	67.173	0.8098	2.0345	0.9097	0.7300E+05	0.1166E-02	0.9660E-03	238.28	1.2253
105.0	0.6736	88.517	1.0232	2.2923	0.9582	0.6027E+05	0.1022E-02	0.7062E-03	151.83	0.9355
115.0	0.6017	113.11	1.2467	2.7691	0.9493	0.4716E+05	0.8562E-03	0.5102E-03	76.236	0.6609
125.0	0.4571	152.24	1.5707	7.7254	0.9661	0.2722E+05	0.5763E-03	0.3032E-03	9.2633	0.3235
135.0	0.1319	243.23	2.2835	2.6072	0.9285	0.2004E+05	0.1937E-03	0.11179E-03	14.302	0.5561E-01
145.0	0.1059	264.69	2.4372	1.8476	0.8738	0.2203E+05	0.1836E-03	0.11171E-03	22.945	0.4156E-01
155.0	0.9149E-01	281.62	2.5502	1.5738	0.8402	0.2357E+05	0.1825E-03	0.11199E-03	29.966	0.3428E-01
165.0	0.8169E-01	296.57	2.6437	1.4292	0.8174	0.2488E+05	0.1849E-03	0.1237E-03	35.414	0.2960E-01
175.0	0.7435E-01	310.39	2.7250	1.3396	0.8011	0.2604E+05	0.1890E-03	0.1289E-03	40.561	0.2627E-01
185.0	0.6853E-01	323.46	2.7977	1.2790	0.7890	0.2710E+05	0.1943E-03	0.1325E-03	45.299	0.2374E-01
195.0	0.6375E-01	336.02	2.8638	1.2356	0.7799	0.2807E+05	0.2003E-03	0.1371E-03	49.741	0.2173E-01
200.0	0.6165E-01	342.16	2.8949	1.2183	0.7761	0.2854E+05	0.2035E-03	0.1394E-03	51.876	0.2088E-01
220.0	0.5468E-01	365.98	3.0085	1.1681	0.7650	0.3026E+05	0.2173E-03	0.1488E-03	59.978	0.1813E-01
240.0	0.4932E-01	389.00	3.1087	1.1367	0.7581	0.3183E+05	0.2320E-03	0.1577E-03	67.580	0.1610E-01
260.0	0.4502E-01	411.52	3.1988	1.1158	0.7537	0.3329E+05	0.2470E-03	0.1666E-03	74.843	0.1453E-01
280.0	0.4147E-01	433.68	3.2809	1.1012	0.7509	0.3465E+05	0.2621E-03	0.1752E-03	81.866	0.1327E-01
300.0	0.3848E-01	455.59	3.3565	1.0998	0.7492	0.3594E+05	0.2771E-03	0.1838E-03	88.711	0.1223E-01
320.0	0.3562E-01	477.33	3.4266	1.0833	0.7484	0.3717E-05	0.2904E-03	0.1922E-03	95.421	0.1135E-01
340.0	0.3370E-01	498.94	3.4921	1.0779	0.7481	0.3834E-05	0.3018E-03	0.2006E-03	102.02	0.1060E-01
360.0	0.3175E-01	520.45	3.5536	1.0740	0.7484	0.3947E-05	0.3132E-03	0.2090E-03	108.54	0.948E-02
380.0	0.3002E-01	541.91	3.6116	1.0713	0.7491	0.4055E-05	0.3245E-03	0.2160E-03	114.99	0.9374E-02
400.0	0.2848E-01	563.31	3.6665	1.2696	0.7502	0.4160E-05	0.3357E-03	0.2236E-03	121.38	0.8866E-02
500.0	0.2270E-01	670.23	3.9051	1.0712	0.7605	0.4639E-05	0.3905E-03	0.2598E-03	152.76	0.6993E-02
600.0	0.1890E-01	777.91	4.1014	1.0640	0.7777	0.5058E-05	0.4432E-03	0.2933E-03	183.55	0.5786E-02
700.0	0.1621E-01	887.26	4.2699	1.1038	0.8001	0.5434E+05	0.4990E-03	0.3248E-03	214.02	0.4938E-02
800.0	0.1419E-01	998.80	4.4188	1.1274	0.8254	0.5777E+05	0.5420E-03	0.3545E-03	244.29	0.4309E-02
900.0	0.1262E-01	1112.7	4.5530	1.1508	0.8498	0.6096E-05	0.5906E-03	0.3828E-03	274.42	0.3823E-02
1000.0	0.1137E-01	1228.8	4.6752	1.1690	0.8688	0.6400E+05	0.6322E-03	0.4100E-03	304.47	0.3436E-02

0.4492E+00 IS OUT OF RANGE OF CURVE FIT VALUE IS EXTRAPOLATED.

0.43006E+00 IS OUT OF RANGE OF CURVE FIT VALUE IS EXTRAPOLATED.

0.40886E+00 IS OUT OF RANGE OF CURVE FIT VALUE IS EXTRAPOLATED.

THERMODYNAMIC PROPERTY TABLE -- N2 KU= 1

100.00 ATM ISOBAR				CP J/G-K	CV J/G-K	SOL VEL CM/S	THERM COND J/CM-S-K	VISC G/CM-S	DP/DJ MN-CC/G-M2	DP/DT MN/K-M2	
TEMP K	DENSITY G/CC	ENTHALPY J/G	ENTROPY J/G-K	0.1306E-31	1.9576	1.2223	0.1018E+06	0.1602E-02	3.025E-02	646.67	
65.0	3.8736	12.444	0.2978	1.9848	1.1483	0.9447E+05	0.1479E-02	0.2139E-02	516.24	2.3629	
75.0	0.8358	32.345	0.5415	1.9059	1.0023	0.8774E+05	0.1358E-02	0.1539E-02	404.86	1.6515	
85.0	0.7960	51.803	0.7525	1.9102	0.9368	0.7955E+05	0.1238E-02	0.1136E-02	310.38	1.3446	
95.0	0.7540	70.776	0.9485	2.0194	0.9557	0.6976E+05	0.1117E-02	0.8599E-03	230.31	1.0830	
105.0	0.7090	90.371	1.1371	2.1625	0.9726	0.6021E+05	0.9953E-03	0.6644E-03	164.07	0.8565	
115.0	0.6594	111.11	1.3434	2.3280	0.9565	0.5133E+05	0.8685E-03	0.5204E-03	108.32	0.6571	
125.0	0.6031	134.34	1.5165	2.5564	0.9431	0.4271E+05	0.7333E-03	0.4089E-03	67.302	0.4817	
135.0	0.5371	158.55	1.7074	2.7651	0.9354	0.3541E+05	0.5976E-03	0.3192E-03	42.408	0.3371	
145.0	0.4608	185.27	2.1297	1.8922	0.9271	0.3098E+05	0.4819E-03	0.2628E-03	32.656	0.2360	
155.0	0.3835	212.97	2.3902	2.0551	0.9091	0.2927E+05	0.4029E-03	0.2247E-03	31.604	0.1744	
165.0	0.3195	239.02	2.6216	2.1914	2.1676	0.8848	0.2903E+05	0.3553E-03	0.2021E-03	34.401	0.1368
175.0	0.2724	262.16	2.8255	2.3047	0.8610	0.2944E+05	0.3275E-03	0.1891E-03	38.848	0.1125	
185.0	0.2384	285.66	3.0078	2.4007	1.7361	0.8404	0.3011E+05	0.3114E-03	0.1833E-03	43.890	0.9577E-01
195.0	0.2133	300.78	3.0928	2.4438	1.6636	0.8314	0.3049E+05	0.3062E-03	0.1814E-03	46.473	0.8929E-01
200.0	0.2031	309.28	3.4034	2.5919	1.4625	0.8039	0.3210E+05	0.2965E-03	0.1794E-03	56.640	0.7087E-01
220.0	0.1721	340.34	3.6833	2.7138	1.3460	0.7858	0.3368E+05	0.2969E-03	0.1819E-03	66.221	0.5935E-01
240.0	0.1510	368.33	3.9446	2.8184	1.2728	0.7739	0.3517E+05	0.3022E-03	0.1865E-03	75.208	0.5141E-01
260.0	0.1353	394.46	4.1940	2.9108	1.2239	0.7663	0.3657E+05	0.3101E-03	0.1921E-03	83.708	0.4557E-01
280.0	0.1231	419.40	4.4352	2.9941	1.1897	0.7606	0.3790E+05	0.3199E-03	0.1944E-03	91.821	0.4105E-01
300.0	0.1133	443.52	4.6705	3.0700	1.1650	0.7571	0.3915E+05	0.3289E-03	0.2051E-03	99.629	0.3745E-01
320.0	0.1051	467.05	4.9016	3.1401	1.1466	0.7549	0.4035E+05	0.3369E-03	0.2121E-03	107.19	0.3449E-01
340.0	0.9814E-01	490.16	5.1295	3.2052	1.1328	0.7538	0.4149E+05	0.3454E-03	0.2194E-03	114.56	0.3200E-01
360.0	0.9214E-01	512.95	5.3550	3.2661	1.1223	0.7534	0.4259E+05	0.3538E-03	0.2256E-03	121.77	0.2988E-01
380.0	0.8691E-01	535.50	557.86	3.3235	1.1143	0.7536	0.4365E+05	0.3634E-03	0.2224E-03	128.84	0.2805E-01
400.0	0.8228E-01	568.20	3.5698	1.0974	0.7618	0.4484E+05	0.4111E-03	0.2659E-03	162.79	0.2159E-01	
500.0	0.6532E-01	668.20	3.7700	1.1015	0.7783	0.5258E+05	0.4595E-03	0.2808E-03	195.31	0.1764E-01	
600.0	0.5439E-01	778.03	3.9408	1.1166	0.8004	0.5628E+05	0.5074E-03	0.3286E-03	227.05	0.1495E-01	
700.0	0.4668E-01	888.87	4.0912	1.0015	0.8255	0.5965E+05	0.5555E-03	0.3571E-03	258.28	0.1298E-01	
800.0	0.4093E-01	1001.5	4.2264	1.1585	0.8499	0.6278E+05	0.6066E-03	0.3856E-03	289.19	0.1148E-01	
900.0	0.3646E-01	1116.3	4.3494	1.1752	0.8689	0.6578E+05	0.6457E-03	0.4124E-03	319.86	0.1029E-01	

THERMODYNAMIC AND TRANSPORT PROPERTIES FOR OXYGEN PC=50.16 ATM, TC=154.78 K, RDC=.4325G/CC  
THERMODYNAMIC PROPERTY TABLE -- 02 KU= 1

1.00 ATM 1SNBAR							1.00 ATM 1SNBAR						
TEMP K	DENSITY G/CC	ENTHALPY J/G	ENTROPY J/G-K	CP J/G-K	CV J/G-K	SON VEL CM/S	THERM COND J/CM-S-K	VISC G/CM-S	DP/DD MN-CC/G-M2	DP/DT MN-K-M2			
60.0	1.2823	94.017	2.3124	1.1303	0.5437	0.1312E+06	0.1504E+02	0.4913E-02	827.82	3.6480			
70.0	1.2371	107.40	2.5179	1.5190	0.8610	0.1093E+06	0.1429E-02	0.3599E-02	677.81	3.1225			
80.0	1.1903	123.67	2.7349	1.7112	1.0093	0.964E+05	0.1355E-02	0.2675E-02	548.49	2.6113			
90.0	1.1416	141.11	2.9403	1.7612	1.0094	0.8726E+05	0.1279E-02	0.2023E-02	436.41	2.1797			
100.0	0.4000E-02	363.60	5.4022	0.9504	0.6636	0.1880E+05	0.9317E-04	0.107E-04	24.685	0.1664E-02			
110.0	2.3613E-02	373.04	5.4923	0.9392	0.6596	0.1979E+05	0.1022E-03	0.8879E-04	27.511	0.9544E-03			
120.0	3.2297E-02	382.40	5.5736	0.9319	0.6573	0.2072E+05	0.1113E-03	0.9641E-04	30.279	0.8844E-03			
130.0	0.3034E-02	391.69	5.6480	0.9268	0.6552	0.2161E+05	0.1204E-03	0.1039E-03	33.009	0.7969E-03			
140.0	0.2811E-02	400.94	5.7166	0.9233	0.6540	0.2245E+05	0.1295E-03	0.1113E-03	35.713	0.7368E-03			
150.0	0.2619E-02	410.16	5.7802	0.9207	0.6531	0.2327E+05	0.1386E-03	0.1185E-03	38.396	0.6855E-03			
160.0	0.2452E-02	419.36	5.8395	0.9188	0.6525	0.2405E+05	0.1461E-03	0.1255E-03	41.065	0.6411E-03			
170.0	0.2306E-02	428.54	5.8952	0.9174	0.6521	0.2480E+05	0.1537E-03	0.1323E-03	43.722	0.6023E-03			
180.0	0.2176E-02	437.71	5.9476	0.9164	0.6518	0.2553E+05	0.1616E-03	0.1390E-03	46.371	0.5680E-03			
190.0	0.2060E-02	446.87	5.9971	0.9156	0.6517	0.2624E+05	0.1696E-03	0.1456E-03	49.013	0.5375E-03			
200.0	0.1956E-02	456.02	6.0441	0.9151	0.6517	0.2693E+05	0.1779E-03	0.1519E-03	51.649	0.5101E-03			
210.0	0.1862E-02	465.17	6.0887	0.9148	0.6518	0.2760E+05	0.1862E-03	0.1581E-03	54.281	0.4854E-03			
220.0	0.1777E-02	474.31	6.1313	0.9147	0.6520	0.2825E+05	0.1947E-03	0.1642E-03	56.909	0.4331E-03			
225.0	0.1737E-02	478.89	6.1518	0.9147	0.6522	0.2858E+05	0.1990E-03	0.1672E-03	58.222	0.4226E-03			
245.0	0.1594E-02	497.18	6.2297	0.9151	0.6531	0.2982E+05	0.2162E+03	0.1787E-03	63.466	0.4153E-03			
265.0	0.1473E-02	515.57	6.3016	0.9163	0.6546	0.3101E+05	0.2336E-03	0.1898E-03	68.702	0.3837E-03			
285.0	0.1369E-02	533.84	6.3683	0.9182	0.6569	0.3215E+05	0.2510E-03	0.2005E-03	73.931	0.3566E-03			
305.0	0.1279E-02	552.23	6.4307	0.9211	0.6599	0.3324E+05	0.2683E-03	0.2109E-03	79.156	0.3330E-03			
325.0	0.1200E-02	570.69	6.4893	0.9250	0.6640	0.3428E+05	0.2854E-03	0.2211E-03	84.377	0.3124E-03			
345.0	0.1131E-02	589.24	6.5447	0.9301	0.6693	0.3529E+05	0.3021E-03	0.2310E-03	89.594	0.2942E-03			
365.0	0.1069E-02	607.90	6.5973	0.9366	0.6759	0.3625E+05	0.3185E-03	0.2408E-03	94.809	0.2781E-03			
385.0	0.1013E-02	626.71	6.6474	0.9448	0.6842	0.3716E+05	0.3344E-03	0.2506E-03	100.32	0.2636E-03			
400.0	0.9749E-03	640.94	6.6837	0.9522	0.6916	0.3783E+05	0.3431E-03	0.2579E-03	103.93	0.2537E-03			
500.0	0.7798E-03	739.79	6.9039	1.0362	0.7763	0.4166E+05	0.4037E-03	0.3000E-03	129.97	0.2028E-03			

THERMODYNAMIC PROPERTY TABLE -- 02 KU= 1

5C.17 ATM ISOBAR											
TEMP K	DENSITY C/C	ENTHALPY J/G	ENTROPY J/G-K	CP J/G-K	CV J/G-K	SOL VEL CM/S	THERM COND J/CM-S-K	VISC G/CM-S	DP/DD MN-CG /G-M2	DP/DT MN/K-M2	
60.0	1.2892	97.106	2.2993	1.1196	0.5453	0.1330E+06	0.1515E-02	0.5126E-02	860.99	3.6981	
70.0	1.2443	110.39	2.5032	1.5086	0.8673	0.1113E+06	0.1442E-02	0.3776E-02	712.26	3.1793	
80.0	1.1991	126.54	2.7186	1.6967	1.0157	0.9881E+05	0.1370E-02	0.2824E-02	584.53	2.6747	
90.0	1.1526	143.80	2.9219	1.7386	1.0157	0.9014E+05	0.1298E-02	0.2151E-02	474.35	2.2507	
100.0	1.1039	161.10	3.1042	1.7179	0.9384	0.8317E+05	0.1225E-02	0.1666E-02	377.81	1.8944	
110.0	1.058	178.26	3.2677	1.7221	0.8668	0.7618E+05	0.1149E-02	0.1311E-02	292.36	1.5850	
120.0	0.9946	195.81	3.4204	1.7965	0.8344	0.6807E+05	0.1069E-02	0.1045E-02	215.17	1.3063	
130.0	0.9289	214.57	3.5705	1.9515	0.8229	0.5882E+05	0.9799E-03	0.8408E-03	145.88	1.0454	
140.0	0.8475	235.44	3.7250	2.2776	0.8237	0.4801E+05	0.8743E-03	0.6740E-03	83.346	0.7885	
150.0	0.7210	262.53	3.9114	3.5754	0.8503	0.3354E+C5	0.7202E-03	0.5097E-03	26.760	0.5027	
160.0	0.2162	359.75	4.5393	3.3344	0.8569	0.1953E+05	0.2559E-03	0.1677E-03	9.8054	0.8424E-01	
170.0	0.168	383.79	4.6854	1.9027	0.7834	0.2611E+05	0.1599E-03	0.1599E-03	19.221	0.5933E-01	
180.0	0.1431	400.69	4.7821	1.5323	0.7457	0.2313E+05	0.2273E-03	0.1607E-03	26.038	0.4824E-01	
190.0	0.1276	415.04	4.8598	1.3559	0.7222	0.2440E+05	0.2269E-03	0.1638E-03	31.708	0.4148E-01	
200.0	0.1161	428.04	4.9265	1.2522	0.7063	0.2551E+05	0.2291E-03	0.1677E-03	36.708	0.3674E-01	
210.0	0.1012	440.20	4.9858	1.1842	0.6950	0.2651E+05	0.2368E-03	0.1722E-03	41.265	0.3323E-01	
220.0	0.9984E-01	451.79	5.0398	1.1364	0.6889	0.2744E+05	0.2376E-03	0.1769E-03	45.506	0.3044E-01	
225.0	0.9663E-01	457.43	5.0651	1.1176	0.6836	0.2788E+05	0.2403E-03	0.1793E-03	47.534	0.2926E-01	
245.0	0.8599E-01	479.19	5.1578	1.0636	0.6746	0.2950E+05	0.2523E-03	0.1890E-03	55.190	0.2544E-01	
265.0	0.7781E-01	500.11	5.2399	1.0307	0.6698	0.3097E+05	0.2658E-03	0.1988E-03	62.315	0.2267E-01	
285.0	0.7124E-01	520.50	5.3140	1.0095	0.6679	0.3231E+05	0.2801E-03	0.2085E-03	69.079	0.2050E-01	
305.0	0.6582E-01	540.54	5.3820	0.9960	0.6681	0.3357E+05	0.2949E-03	0.2181E-03	75.584	0.1876E-01	
325.0	0.6124E-01	560.37	5.4450	0.9877	0.6702	0.3474E+05	0.3099E-03	0.2276E-03	81.893	0.1732E-01	
345.0	0.5710E-01	580.08	5.5038	0.9836	0.6741	0.3584E+05	0.3249E-03	0.2370E-03	88.051	0.1611E-01	
365.0	0.5338E-01	599.74	5.5592	0.9829	0.6797	0.3689E+05	0.3398E-03	0.2464E-03	94.089	0.1500E-01	
385.0	0.5077E-01	619.41	5.6117	0.9852	0.6872	0.3787E+05	0.3544E-03	0.2557E-03	100.03	0.1416E-01	
400.0	0.4844E-01	634.22	5.6494	0.9890	0.6941	0.3857E+05	0.3624E-03	0.2628E-03	104.43	0.1355E-01	
500.0	0.3899E-01	735.90	5.8760	0.7769	1.0581	0.4256E+05	0.4187E-03	0.3037E-03	132.97	0.1058E-01	

THERMODYNAMIC PROPERTY TABLE -- 02 KU= 1

170.00 ATM ISOBAR		DENSITY G/CC	ENTHALPY J/G	ENTROPY J/G-K	CP J/G-K	CV J/G-K	SCN VEL CM/S	THERM COND J/CM-S	VISC G/CM-S	DP/DD MN/CC-G-M2	DP/DT MN/K-M2
60.0	1.2940	100.25	2.2865	1.1396	0.5469	0.1347E+06	0.1526E+02	0.5345E+02	893.89	3.7465	
70.0	1.2512	113.43	2.4890	1.4995	0.8729	0.1132E+06	0.1455E+02	0.3958E+02	746.29	3.2339	
80.0	1.2075	129.48	2.7029	1.6842	1.0221	0.1011E+06	0.1385E+02	0.2977E+02	619.93	2.7353	
90.0	1.1628	146.59	2.9044	1.7198	1.0295	0.9283E+05	0.1316E+02	0.2280E+02	511.32	2.3177	
100.0	1.1166	163.65	3.0842	1.6889	0.9425	0.8640E+05	0.1246E+02	0.1778E+02	416.60	1.9689	
110.0	1.0680	180.44	3.2443	1.6761	0.8691	0.8014E+05	0.1175E+02	0.1410E+02	332.98	1.6692	
120.0	1.0159	197.40	3.3918	1.7194	0.8342	0.7302E+05	0.1102E+02	0.1135E+02	258.69	1.4033	
130.0	0.9589	215.10	3.5334	1.8079	0.8188	0.6523E+05	0.1024E+02	0.9275E+02	192.70	1.1610	
140.0	0.8944	233.79	3.6719	1.9487	0.8113	0.5686E+05	0.9294E+02	0.7653E+02	134.62	0.9353	
150.0	0.8178	254.21	3.8126	2.1863	0.8112	0.4780E+05	0.8436E+02	0.6333E+03	84.79	0.7210	
160.0	0.7157	278.17	3.9672	2.6408	0.8212	0.3805E+05	0.7263E+02	0.5158E+03	45.028	0.5150	
170.0	0.5831	308.34	4.1499	3.4103	0.8425	0.2897E+05	0.5780E+03	0.3805E+03	20.737	0.3263	
180.0	0.4329	343.12	4.3487	3.2820	0.8399	0.2497E+05	0.4389E+03	0.2836E+03	15.95	0.2014	
190.0	0.3372	371.73	4.5036	2.4651	0.8028	0.2491E+05	0.3664E+03	0.2374E+03	20.205	0.1418	
200.0	0.2827	393.53	4.6155	1.9463	0.7682	0.2577E+05	0.3335E+03	0.2190E+03	13.208	0.1111	
210.0	0.2478	411.41	4.7028	1.6564	0.7426	0.2677E+05	0.3173E+03	0.2114E+03	32.123	0.9265E+01	
220.0	0.2231	427.03	4.7755	1.4819	0.7243	0.2775E+05	0.3092E+03	0.2087E+03	37.648	0.8028E+01	
225.0	0.2131	434.27	4.8080	1.4178	0.7167	0.2822E+05	0.3070E+03	0.2084E+03	40.263	0.7547E+01	
245.0	0.1828	460.81	4.9211	1.2540	0.6962	0.2998E+05	0.3053E+03	0.2101E+03	49.914	0.6161E+01	
265.0	0.1617	484.91	5.0157	1.1645	0.6846	0.3157E+05	0.3102E+03	0.2162E+03	58.588	0.5268E+01	
285.0	0.1459	507.61	5.0984	1.1100	0.6785	0.3301E+05	0.3186E+03	0.2220E+03	66.593	0.4634E+01	
305.0	0.1335	529.44	5.1724	1.0748	0.6759	0.3433E+05	0.3229E+03	0.2305E+03	74.121	0.4155E+01	
325.0	0.1233	550.68	5.2399	1.0517	0.6763	0.3556E+05	0.3406E+03	0.2384E+03	81.295	0.3778E+01	
345.0	0.1147	571.56	5.3022	1.0368	0.6785	0.3671E+05	0.3528E+03	0.2466E+03	88.198	0.3472E+01	
365.0	0.1074	592.20	5.3604	1.0281	0.6831	0.3779E+05	0.3654E+03	0.2550E+03	94.888	0.3216E+01	
385.0	0.1011	612.71	5.4151	1.0242	0.6898	0.3880E+05	0.3782E+03	0.2636E+03	101.41	0.2999E+01	
400.0	0.9683E-01	628.07	5.4542	1.0242	0.6964	0.3952E+05	0.3849E+03	0.2701E+03	106.20	0.2857E+01	
500.0	0.7615E-01	732.42	5.6868	1.0785	0.7776	0.4355E+05	0.4088E+03	0.3088E+03	136.74	0.2185E+01	

THERMODYNAMIC AND TRANSPORT PROPERTIES FOR ARGON PC= 48.014ATM, TC=150.7 K, RCC=.531 G/CC  
THERMODYNAMIC PROPERTY TABLE -- AR KU= 1

1.00 ATM ISOBAR						1.00 ATM ISOBAR					
TEMP K	DENSITY G/CC	ENTHALPY J/G	ENTROPY J/G-K	CP J/G-K	CV J/G-K	SON VEL CM/S	THERM COND J/CM-S-K	VISC G/CM-S	DP/DD MN-CC/FG-M2	DP/DT MN/K-M2	
85.0	1.4059	71.587	1.33337	1.2398	0.7560	0.7390E+05	0.1369E-02	0.2794E-02	333.04	1.9355	
95.0	0.5262E-02	240.53	3.2683	0.5442	0.3160	0.1796E+05	0.609E-04	0.8241E-04	18.739	0.1116E-02	
105.0	0.4730E-02	245.95	3.3225	0.5396	0.3162	0.1893E+05	0.6630E-04	0.9078E-04	20.993	0.9997E-03	
115.0	0.4299E-02	251.33	3.3714	0.5358	0.3158	0.1984E+05	0.7250E-04	0.9914E-04	23.207	0.9059E-03	
125.0	0.3942E-02	256.67	3.4160	0.5328	0.3152	0.2072E+05	0.8311E-04	0.1074E-03	25.394	0.8288E-03	
135.0	0.3641E-02	261.99	3.4569	0.5305	0.3147	0.2155E+05	0.8811E-04	0.1157E-03	27.560	0.7642E-03	
145.0	0.3384E-02	267.28	3.4947	0.5287	0.3143	0.2236E+05	0.9442E-04	0.1238E-03	29.710	0.7093E-03	
155.0	0.3161E-02	272.56	3.5299	0.5273	0.3139	0.2313E+05	0.995E-04	0.1318E-03	31.849	0.6619E-03	
165.0	0.2966E-02	277.83	3.5629	0.5262	0.3136	0.2388E+05	0.1054E-03	0.1397E-03	33.978	0.6206E-03	
175.0	0.2794E-02	283.09	3.5938	0.5253	0.3134	0.2460E+05	0.1107E-03	0.1474E-03	36.103	0.5843E-03	
185.0	0.2641E-02	288.34	3.6230	0.5246	0.3132	0.2530E+05	0.1160E-03	0.1550E-03	38.217	0.5520E-03	
195.0	0.2505E-02	293.58	3.6506	0.5240	0.3130	0.2598E+05	0.1212E-03	0.1625E-03	40.329	0.5222E-03	
205.0	0.2381E-02	298.82	3.6768	0.5236	0.3129	0.2665E+05	0.1264E-03	0.1698E-03	42.437	0.4973E-03	
215.0	0.2270E-02	304.05	3.7017	0.5232	0.3128	0.2729E+05	0.1314E-03	0.1769E-03	44.542	0.4738E-03	
225.0	0.2168E-02	309.28	3.7255	0.5229	0.3127	0.2793E+05	0.1365E-03	0.1839E-03	46.644	0.4525E-03	
245.0	0.1990E-02	319.73	3.7700	0.5223	0.3126	0.2915E+05	0.1463E-03	0.1975E-03	50.843	0.4152E-03	
265.0	0.1839E-02	330.18	3.8109	0.5220	0.3125	0.3032E+05	0.1559E-03	0.2105E-03	55.035	0.3836E-03	
285.0	0.1710E-02	340.61	3.8489	0.5217	0.3124	0.3145E+05	0.1653E-03	0.2230E-03	59.222	0.3555E-03	
305.0	0.1597E-02	351.05	3.8843	0.5215	0.3124	0.3253E+05	0.1745E-03	0.2351E-03	63.405	0.3330E-03	
325.0	0.1499E-02	361.47	3.9174	0.5213	0.3124	0.3359E+05	0.1835E-03	0.2467E-03	67.586	0.3114E-03	
345.0	0.1412E-02	371.90	3.9485	0.5212	0.3123	0.3461E+05	0.1924E-03	0.2581E-03	71.764	0.2942E-03	
365.0	0.1334E-02	382.32	3.9779	0.5211	0.3123	0.3560E+05	0.2010E-03	0.2692E-03	75.940	0.2780E-03	
385.0	0.1265E-02	392.74	4.0057	0.5210	0.3123	0.3656E+05	0.2095E-03	0.2803E-03	80.115	0.2655E-03	
400.0	0.1217E-02	400.56	4.0256	0.5210	0.3123	0.3726E+05	0.2158E-03	0.2880E-03	83.245	0.2516E-03	
500.0	0.9735E-03	452.64	4.1418	0.5207	0.3123	0.4166E+05	0.2558E-03	0.3381E-03	104.10	0.2028E-03	
600.0	0.8112E-03	504.71	4.2368	0.5206	0.3123	0.4564E+05	0.2928E-03	0.3838E-03	124.94	0.1690E-03	
700.0	0.6933E-03	556.76	4.3170	0.5205	0.3123	0.4930E+05	0.3275E-03	0.4265E-03	145.77	0.1448E-03	
800.0	0.5084E-03	608.82	4.3865	0.5205	0.3123	0.5270E+05	0.3601E-03	0.4668E-03	166.60	0.1297E-03	
900.0	0.5086E-03	660.86	4.4478	0.5205	0.3123	0.5589E+05	0.3909E-03	0.5052E-03	187.42	0.1124E-03	
1000.0	0.4867E-03	712.91	4.5026	0.5205	0.3123	0.5891E+05	0.4202E-03	0.5419E-03	208.24	0.1033E-03	

DENSITY SOLUTION IS BEYOND THE GRASP OF GASP. ANSWER IS ON SOLID SIDE OF MELTING LOCUS FOR T = 85. P = 4.865 MN.

## 48.01 ATM ISOTHERM

THERMODYNAMIC PROPERTY TABLE -- AR KU = 1

TEMP K	DENSITY G/CC	ENTHALPY J/G	ENTROPY J/G-K	COP J/G-K	CV J/G-K	SCN VEL CM/S	THERM COND J/CM-S-K	VISC G/CM-S	DP/DD MN-CC/G-M2	DP/DT MN/K-M2
85.0	1.4197	73.808	1.32201	1.2149	0.7533	0.7585E+05	0.1400E-02	0.2996E-02	356.73	1.9760
95.0	1.3611	85.730	1.4528	1.1711	0.6073	0.7492E+05	0.1200E-02	0.2260E-02	290.92	1.7889
105.0	1.2968	97.347	1.5691	1.1540	0.5091	0.7207E+05	0.1158E-02	0.1717E-02	229.14	1.5384
115.0	1.2262	108.91	1.6743	1.1775	0.4456	0.6744E+05	0.1035E-02	0.1319E-02	172.14	1.2834
125.0	1.1462	120.83	1.7736	1.2892	0.4339	0.5964E+05	0.9135E-03	0.1022E-02	119.72	1.0374
135.0	1.0489	134.20	1.8764	1.5159	0.4287	0.5023E+05	0.7771E-03	0.8722E-03	71.353	0.7951
145.0	0.9503	152.74	2.0085	2.3185	0.4332	0.3745E+05	0.6060E-05	0.5104E-03	26.208	0.5284
155.0	0.2717	226.13	2.4964	2.6253	0.4521	0.1991E+05	0.1795E-03	0.1796E-03	6.8670	0.8430E-01
165.0	0.2056	243.56	2.6058	1.3047	0.4073	0.2171E+05	0.1629E-03	0.1699E-03	14.714	0.5816E-01
175.0	0.1756	254.89	2.6725	1.3057	0.3834	0.2304E+05	0.1593E-03	0.1710E-03	20.237	0.4710E-01
185.0	0.1562	264.18	2.7241	0.8667	0.3678	0.2417E+05	0.1590E-03	0.1748E-03	24.785	0.4038E-01
195.0	0.1420	272.41	2.7675	0.7855	0.3566	0.2518E+05	0.1603E-03	0.1796E-03	28.771	0.3572E-01
205.0	0.1309	279.98	2.8054	0.7321	0.3482	0.2610E+05	0.1624E-03	0.1850E-03	32.390	0.3223E-01
215.0	0.1218	287.10	2.8393	0.6945	0.3418	0.2695E+05	0.1651E-03	0.1906E-03	35.750	0.2950E-01
225.0	0.1142	293.90	2.8702	0.6667	0.3369	0.2775E+05	0.1681E-03	0.1964E-03	38.917	0.2728E-01
245.0	0.1020	306.82	2.9253	0.6286	0.3297	0.2924E+05	0.1748E-03	0.2082E-03	44.837	0.2386E-01
265.0	0.9254E-01	319.14	2.9736	0.6042	0.3250	0.3060E+05	0.1820E-03	0.2198E-03	50.375	0.2132E-01
285.0	0.8488E-01	331.04	3.0169	0.5874	0.3217	0.3188E+05	0.1895E-03	0.2313E-03	55.650	0.1933E-01
305.0	0.7851E-01	342.66	3.0563	0.5754	0.3194	0.3308E+05	0.1971E-03	0.2426E-03	60.738	0.1773E-01
325.0	0.7312E-01	356.08	3.0926	0.5664	0.3178	0.3422E+05	0.2047E-03	0.2536E-03	65.684	0.1639E-01
345.0	0.6847E-01	365.33	3.1262	0.5595	0.3166	0.3531E+05	0.2124E-03	0.2644E-03	70.522	0.1526E-01
365.0	0.6442E-01	376.47	3.1575	0.5542	0.3157	0.3635E+05	0.2201E-03	0.2750E-03	75.274	0.1429E-01
385.0	0.6085E-01	387.51	3.1870	0.5499	0.3150	0.3736E+05	0.2277E-03	0.2854E-03	79.957	0.1344E-01
400.0	0.5843E-01	395.73	3.2080	0.5472	0.3146	0.3809E+05	0.2334E-03	0.2932E-03	83.431	0.1287E-01
500.0	0.4636E-01	449.83	3.3287	0.3131	0.3131	0.4261E+05	0.2703E-03	0.3420E-03	106.02	0.1008E-01
600.0	0.3949E-01	503.15	3.4259	0.5309	0.3126	0.4662E+05	0.3C54E-03	0.3869E-03	127.99	0.8305E-02
700.0	0.3255E-01	556.08	3.5075	0.5280	0.3124	0.5029E+05	0.3386E-03	0.4291E-03	149.64	0.7073E-02
800.0	0.2883F-01	608.78	3.5779	0.5261	0.3123	0.5368E+05	0.3701E-03	0.4691E-03	171.08	0.6162E-02
900.0	0.2533E-01	661.33	3.6398	0.5249	0.3123	0.5686E+05	0.4001E-03	0.5072E-03	192.39	0.5462E-02
1000.0	0.2237F-01	713.78	3.6951	0.5240	0.3123	0.5987E+05	0.4287E-03	0.5436E-03	213.60	0.4901E-02

SOLUTION IS BEYOND THE GRASP GASPL. ANSWER IS ON SOLID SIDE OF MELTING LOCUS FOR T = 85. P = 10.132 MN.

THERMODYNAMIC PROPERTY TABLE -- AR KU= 1

TEMP K	DENSITY G/CC	ENTHALPY J/G	ENTROPY J/G-K	CP J/G-K	CV J/G-K	SOL VEL C/S	THERM COND J/CM-S-K	VISC G/CM-S	DP/DD MN-CC/G-M2	DP/DT MN/K-M2
85.0	1.4339	76.311	1.3062	1.1911	0.7505	0.7784E+05	0.1432E-02	3.8179	2.0172	
95.0	1.3784	87.985	1.4361	1.1444	0.6115	0.7713E+05	0.1316E-02	317.87	1.8406	
105.0	1.3184	99.291	1.5492	1.1170	0.5177	0.7467E+05	0.1200E-02	258.36	1.6012	
115.0	1.2542	110.39	1.6502	1.1185	0.4562	0.7074E+05	0.1085E-02	234.12	1.3598	
125.0	1.1846	121.51	1.7429	1.1823	0.4453	0.6418E+05	0.9752E-03	155.14	1.1330	
135.0	1.1071	133.28	1.8335	1.2795	0.4386	0.5698E+05	0.8598E-03	111.32	0.9219	
145.0	1.0169	147.30	1.9335	1.4381	0.4340	0.4915E+05	0.7400E-03	72.901	0.7225	
155.0	0.9044	162.88	2.0374	1.7300	0.4339	0.4049E+05	0.6106E-03	41.118	0.5303	
165.0	0.7523	182.58	2.1604	2.2324	0.4437	0.3164E+05	0.4667E-03	19.894	0.3494	
175.0	0.5747	206.14	2.2990	2.3289	0.4517	0.2643E+05	0.3386E-03	13.548	0.2191	
185.0	0.4456	227.07	2.4155	1.8293	0.4352	0.2553E+05	0.2700E-03	15.513	0.1523	
195.0	0.3691	243.08	2.4998	1.4056	0.4121	0.2603E+05	0.2393E-03	19.861	0.1174	
205.0	0.3209	255.76	2.5633	1.1524	0.3927	0.2683E+05	0.2244E-03	24.524	0.9675E-01	
215.0	0.2873	266.45	2.6143	0.9982	0.3776	0.2768E+05	0.2167E-03	28.972	0.8310E-01	
225.0	0.2622	275.90	2.6572	0.8977	0.3660	0.2851E+05	0.2127E-03	33.127	0.7335E-01	
245.0	0.2261	292.52	2.7281	0.7772	0.3496	0.3001E+05	0.2040E-03	40.672	0.6023E-01	
265.0	0.2007	303.32	2.7862	0.7091	0.3391	0.3104E+05	0.2120E-03	47.458	0.5167E-01	
285.0	0.1815	321.05	2.8361	0.6661	0.3321	0.3288E+05	0.2156E-03	53.719	0.4555E-01	
305.0	0.1663	334.06	2.8803	0.6371	0.3272	0.3401E+05	0.2203E-03	59.608	0.4092E-01	
325.0	0.1538	346.38	2.9200	0.6163	0.3237	0.3524E+05	0.2258E-03	65.222	0.3727E-01	
345.0	0.1432	358.75	2.9564	0.6010	0.3212	0.3635E+05	0.2317E-03	70.628	0.3428E-01	
365.0	0.1342	370.65	2.9899	0.5892	0.3193	0.3744E+05	0.2319E-03	75.871	0.3180E-01	
385.0	0.1264	382.33	3.0211	0.5800	0.3178	0.3844E+05	0.2444E-03	80.986	0.2968E-01	
400.0	0.1211	390.99	3.0431	0.5743	0.3170	0.3919E+05	0.2493E-03	84.752	0.2829L-01	
500.0	0.9541E-31	447.13	3.1685	0.5517	0.3140	0.4372E+05	0.2826E-03	108.81	0.2170E-01	
600.0	0.7906E-01	501.72	3.2681	0.5412	0.3130	0.4773E+05	0.3355E-03	131.78	0.1770L-01	
700.0	0.6764E-01	555.53	3.3510	0.5354	0.3126	0.5138E+05	0.3473E-03	154.16	0.1498L-01	
800.0	0.5911E-01	608.88	3.4223	0.5318	0.3124	0.5476E+05	0.3778E-03	176.17	0.1301E-01	
900.0	0.5262E-01	661.93	3.4848	0.5294	0.3123	0.5792E+05	0.4070E-03	197.93	0.1150E-01	
1000.0	0.4740E-01	714.79	3.5404	0.5277	0.3123	0.6090E+05	0.4350E-03	219.52	0.1031E-01	

THERMODYNAMIC AND TRANSPORT PROPERTIES FOR CO<sub>2</sub> PC=72.869 ATM, TC=304.21 K, ROC=464 G/CC  
THERMODYNAMIC PROPERTY TABLE — CO<sub>2</sub> KU=1

1.00 ATM ISOBAR		ENTROPY J/G-K		CP J/G-K		CV J/G-K		SCN VEL CM/S		THERM COND J/CM-S-K		VISC G/CM-S		DP/DD MN-CG-M2	
TEMP K	DENSITY G/CC	ENTHALPY J/G	ENTROPY J/G-K	CP	CV	SCN VEL	THERM COND	VISC	DP/DD	MN-CG-M2	DP/DD	MN-CG-M2	DP/DD	MN-CG-M2	
220.0	0.2472E-02	743.79	4.6035	0.7856	0.5854	0.2330E+05	0.1097E-03	0.1154E-03	40.407	0.4753E-03	40.407	0.4753E-03	40.407	0.4753E-03	
230.0	0.2260E-02	751.69	4.6386	0.7941	0.5946	0.2380E+05	0.1165E-03	0.1204E-03	42.409	0.4526E-03	42.409	0.4526E-03	42.409	0.4526E-03	
240.0	0.2258E-02	759.67	4.6726	0.8020	0.6040	0.2428E+05	0.1234E-03	0.1254E-03	44.396	0.4322E-03	44.396	0.4322E-03	44.396	0.4322E-03	
250.0	0.2165E-02	767.73	4.7055	0.8113	0.6135	0.2475E+05	0.1304E-03	0.1303E-03	46.369	0.4137E-03	46.369	0.4137E-03	46.369	0.4137E-03	
260.0	0.2080E-02	775.88	4.7374	0.8188	0.6230	0.2520E+05	0.1375E-03	0.1351E-03	48.332	0.3968E-03	48.332	0.3968E-03	48.332	0.3968E-03	
270.0	0.2001E-02	784.11	4.7685	0.8275	0.6324	0.2565E+05	0.1446E-03	0.1399E-03	50.286	0.3813E-03	50.286	0.3813E-03	50.286	0.3813E-03	
280.0	0.1928E-02	792.43	4.7987	0.8352	0.6418	0.2609E+05	0.1518E-03	0.1447E-03	52.232	0.3671E-03	52.232	0.3671E-03	52.232	0.3671E-03	
290.0	0.1860E-02	800.84	4.8282	0.8450	0.6512	0.2651E+05	0.1590E-03	0.1494E-03	54.173	0.3559E-03	54.173	0.3559E-03	54.173	0.3559E-03	
300.0	0.1797E-02	809.33	4.8570	0.8558	0.6605	0.2693E+05	0.1663E-03	0.1540E-03	56.108	0.3416E-03	56.108	0.3416E-03	56.108	0.3416E-03	
310.0	0.1738E-02	817.91	4.8852	0.8625	0.6697	0.2734E+05	0.1736E-03	0.1766E-03	58.039	0.3303E-03	58.039	0.3303E-03	58.039	0.3303E-03	
320.0	0.1683E-02	826.58	4.9127	0.8713	0.6788	0.2774E+05	0.1809E-03	0.1632E-03	59.965	0.3196E-03	59.965	0.3196E-03	59.965	0.3196E-03	
330.0	0.1631E-02	835.34	4.9396	0.8719	0.6877	0.2814E+05	0.1883E-03	0.1677E-03	61.889	0.3097E-03	61.889	0.3097E-03	61.889	0.3097E-03	
340.0	0.1583E-02	844.18	4.9660	0.8835	0.6966	0.2853E+05	0.1958E-03	0.1721E-03	63.809	0.3004E-03	63.809	0.3004E-03	63.809	0.3004E-03	
350.0	0.1537E-02	853.11	4.9919	0.8970	0.7054	0.2891E+05	0.2032E-03	0.1765E-03	65.727	0.2916E-03	65.727	0.2916E-03	65.727	0.2916E-03	
360.0	0.1494E-02	862.12	5.0173	0.9054	0.7142	0.2929E+05	0.2107E-03	0.1808E-03	67.662	0.2833E-03	67.662	0.2833E-03	67.662	0.2833E-03	
370.0	0.1453E-02	871.22	5.0422	0.9138	0.7225	0.2966E+05	0.2182E-03	0.1851E-03	68.556	0.2755E-03	68.556	0.2755E-03	68.556	0.2755E-03	
380.0	0.1415E-02	880.39	5.0667	0.9220	0.7303	0.3003E+05	0.2258E-03	0.1893E-03	71.467	0.2682E-03	71.467	0.2682E-03	71.467	0.2682E-03	
390.0	0.1378E-02	889.65	5.0907	0.9301	0.7392	0.3039E+05	0.2333E-03	0.1935E-03	73.377	0.2612E-03	73.377	0.2612E-03	73.377	0.2612E-03	
400.0	0.1343E-02	899.00	5.1144	0.9331	0.7473	0.3074E+05	0.2409E-03	0.1976E-03	75.286	0.2546E-03	75.286	0.2546E-03	75.286	0.2546E-03	
410.0	0.1310E-02	908.42	5.1377	0.9450	0.7554	0.3109E+05	0.2485E-03	0.2016E-03	77.193	0.2483E-03	77.193	0.2483E-03	77.193	0.2483E-03	
420.0	0.1279E-02	917.92	5.1605	0.9538	0.7633	0.3144E+05	0.2561E-03	0.2056E-03	79.099	0.2423E-03	79.099	0.2423E-03	79.099	0.2423E-03	
430.0	0.1221E-02	937.15	5.2053	0.9691	0.7787	0.3212E+05	0.2714E-03	0.2135E-03	82.908	0.2312E-03	82.908	0.2312E-03	82.908	0.2312E-03	
440.0	0.1167E-02	956.68	5.2487	0.9839	0.7937	0.3279E+05	0.2866E-03	0.2212E-03	86.713	0.2210E-03	86.713	0.2210E-03	86.713	0.2210E-03	
450.0	0.1118E-02	976.50	5.2909	0.9933	0.8082	0.3344E+05	0.3020E-03	0.2287E-03	90.516	0.2117E-03	90.516	0.2117E-03	90.516	0.2117E-03	
460.0	0.1074E-02	996.61	5.3319	1.0122	0.8222	0.3407E+05	0.3173E-03	0.2361E-03	94.315	0.2032E-03	94.315	0.2032E-03	94.315	0.2032E-03	
470.0	0.8942E-03	1101.1	5.5222	1.0751	0.8856	0.3709E+05	0.3938E-03	0.2710E-03	113.29	0.1692E-03	113.29	0.1692E-03	113.29	0.1692E-03	
480.0	0.1662E-03	1211.3	5.6920	1.1279	0.9385	0.3986E+05	0.4694E-03	0.3036E-03	132.23	0.1449E-03	132.23	0.1449E-03	132.23	0.1449E-03	
490.0	0.6704E-03	1326.3	5.8455	1.1716	0.9823	0.4246E+05	0.5436E-03	0.3354E-03	151.16	0.1268E-03	151.16	0.1268E-03	151.16	0.1268E-03	
500.0	0.5558E-03	1445.3	5.9857	1.2075	1.3183	0.4491E+05	0.6160E-03	0.3627E-03	170.08	0.1127E-03	170.08	0.1127E-03	170.08	0.1127E-03	
500.0	0.5362E-03	1567.6	6.1145	1.2358	1.4077	0.4732E+05	0.6863E-03	0.3901E-03	188.99	0.1014E-03	188.99	0.1014E-03	188.99	0.1014E-03	
500.0	0.0	ANSWER IS REYND THE GRASP OF GASP.	ANSWER IS ON SOLID SIDE OF MELTING LOCUS FOR T = 220. P = 7.383 MN.												

THERMODYNAMIC PROPERTY TABLE -- CO<sub>2</sub> KU = 1

TEMP K	72.87 ATM ISOBAR		ENTROPY J/G	ENTHALPY J/G	CP J/G-K	CV J/G-K	SON VEL CM/S	THERM COND J/CM-S-K	VISC G/CM-S	DP/DD MN/CM-M2	DP/DT MN/K-M2
	DENSITY G/CC	ENTHALPY J/G									
220.0	1.1820	390.31	2.6478	2.0253	1.0463	0.9783E+05	0.1603E-02	0.2134E-02	4.94E-21	1.7539	1.5447
230.0	1.1454	410.30	2.7367	1.9732	1.979	0.9194E+05	0.1513E-02	0.1821E-02	418.69	1.3579	1.3579
240.0	1.1080	430.30	2.8206	2.0144	0.9817	0.8663E+05	0.1423E-02	0.1565E-02	349.02	1.1873	1.1873
250.0	1.0678	449.86	2.9016	2.0337	0.9470	0.7816E+05	0.1333E-02	0.1353E-02	284.43	1.0280	1.0280
260.0	1.0241	470.36	2.9820	2.0920	0.9242	0.7126E+05	0.1241E-02	0.1175E-02	224.33	0.8756	0.8756
270.0	0.9754	491.91	3.0633	2.2040	0.9111	0.6380E+05	0.1144E-02	0.1022E-02	168.28	0.5689	0.5689
280.0	0.9187	514.99	3.1473	2.4123	0.9067	0.5553E+05	0.1038E-02	0.8850E-03	115.92	0.3798	0.3798
290.0	0.8466	540.93	3.2382	2.8706	0.9135	0.485E+05	0.9158E-03	0.7542E-03	66.94	0.7829E-01	0.7829E-01
300.0	0.7286	576.86	3.3599	4.9155	0.9485	0.3263E+05	0.7390E-03	0.5973E-03	20.545	0.1380	0.1380
310.0	0.6434	712.43	3.8051	4.1119	0.9597	0.2088E+05	0.2833E-03	0.2038E-03	10.174	0.5836E-01	0.5836E-01
320.0	0.1972	742.10	3.8994	3.3273	0.8912	0.2258E+05	0.2655E-03	0.2066E-03	19.524	0.4872E-01	0.4872E-01
330.0	0.1739	762.56	3.9624	1.8357	0.8558	0.2381E+05	0.2610E-03	0.2032E-03	26.432	0.4257E-01	0.4257E-01
340.0	0.1583	779.61	4.0134	1.5930	0.8344	0.2482E+05	0.2609E-03	0.2028E-03	32.175	0.3817E-01	0.3817E-01
350.0	0.1467	794.84	4.0575	1.4577	0.8210	0.2570E+05	0.2629E-03	0.2038E-03	37.198	0.3481E-01	0.3481E-01
360.0	0.1375	808.93	4.0972	1.3659	0.8127	0.2648E+05	0.2661E-03	0.2055E-03	41.726	0.3214E-01	0.3214E-01
370.0	0.1298	822.25	4.1337	1.3020	0.8079	0.2720E+05	0.2701E-03	0.2078E-03	45.889	0.2996E-01	0.2996E-01
380.0	0.1234	835.03	4.1678	1.2556	0.8054	0.2786E+05	0.2748E-03	0.2103E-03	49.770	0.2812E-01	0.2812E-01
390.0	0.1177	847.40	4.1999	1.2212	0.8048	0.2847E+05	0.2798E-03	0.2131E-03	53.427	0.2654E-01	0.2654E-01
400.0	0.1128	859.48	4.2305	1.1950	0.8056	0.2905E+05	0.2852E-03	0.2160E-03	56.902	0.2518E-01	0.2518E-01
410.0	0.1084	871.32	4.2598	1.1749	0.8073	0.2969E+05	0.2909E-03	0.2191E-03	60.226	0.2393E-01	0.2393E-01
420.0	0.1044	882.99	4.2879	1.1595	0.8099	0.3013E+05	0.2968E-03	0.2222E-03	63.421	0.2196E-01	0.2196E-01
440.0	0.9748E-01	905.95	4.3413	1.1333	0.8169	0.3112E+05	0.3091E-03	0.2285E-03	69.497	0.2032E-01	0.2032E-01
460.0	0.9164E-01	928.58	4.3916	1.1251	0.8253	0.3204E+05	0.3219E-03	0.2350E-03	75.239	0.1895E-01	0.1895E-01
480.0	0.8660E-01	951.33	4.4394	1.1136	0.8343	0.3290E+05	0.3351E-C3	0.2415E-03	80.723	0.1779E-01	0.1779E-01
500.0	0.8220E-01	973.39	4.4850	1.1172	0.8443	0.3312E+05	0.3486E-03	0.2480E-03	85.998	0.1380E-01	0.1380E-01
600.0	0.6618E-01	1085.7	4.6896	1.1334	0.8969	0.3734E+05	0.4185E-03	0.2799E-03	110.33	0.7638E-02	0.7638E-02
700.0	0.5593E-01	1200.6	4.8667	1.1652	0.9443	0.4045E+05	0.4899E-03	0.3108E-03	132.68	0.1140E-01	0.1140E-01
800.0	0.4845E-01	1318.7	5.0244	1.1975	0.9863	0.4324E+05	0.5611E-03	0.3414E-03	153.99	0.9768E-02	0.9768E-02
900.0	0.4287E-01	1439.9	5.1672	1.2256	1.0239	0.4581E+05	0.6313E-03	0.3679E-03	174.67	0.8565E-02	0.8565E-02
1000.0	0.3849E-01	1563.9	5.2977	1.2516	1.0496	0.4822E+05	0.6998E-03	0.3947E-03	194.96	0.7638E-02	0.7638E-02

DENSITY IS BEYOND THE GRASP OF GASP. ANSWER IS ON SOLID SIDE OF MELTING LOCUS FOR T = 220. P = 10.132 MN.

THERMODYNAMIC PROPERTY TABLE -- CO<sub>2</sub> KU= 1

TEMP K	DENSITY G/CC	ENTHALPY J/G	ENTROPY J/G-K	CP J/G-K	CV J/G-K	SUN VEL CM/S	THERM COND J/CM-S-K	VISC G/CM-S	DP/DD MN-C <sub>2</sub> /G-M <sub>2</sub>	DP/DT MN-K-M <sub>2</sub>
220.0	1.1875	391.12	2.6410	2.0128	1.0514	0.9916E+05	0.1618E-02	0.2189E-02	513.57	1.7790
230.0	1.1523	410.96	2.7292	1.9538	0.9845	0.9347E-05	0.1530E-02	0.182E-02	438.90	1.5720
240.0	1.1157	430.44	2.8121	1.9438	0.9405	0.8747E-05	0.1442E-02	0.1613E-02	370.19	1.3879
250.0	1.0771	449.99	2.8919	1.9972	0.9502	0.8029E-05	0.1355E-02	0.139E-02	305E-02	1.2207
260.0	1.0358	470.24	2.9705	2.0372	0.9265	0.7383E-05	0.1267E-02	0.1219E-02	247.90	1.0659
270.0	0.9907	490.89	3.0492	2.1152	0.9123	0.6698E-05	0.1176E-02	0.106E-02	193.46	0.9198
280.0	0.9399	512.77	3.1287	2.2436	0.9051	0.5964E-05	0.1080E-02	0.9336E-03	143.18	0.7791
290.0	0.8803	536.19	3.2109	2.4838	0.9063	0.5160E-05	0.9748E-03	0.8128E-03	97.121	0.6399
300.0	0.8045	563.58	3.3037	2.9673	0.9173	0.4249E-05	0.8534E-03	0.65948E-03	55.807	0.4968
310.0	0.6888	598.72	3.4189	4.4038	0.9507	0.3167E-05	0.6917E-03	0.5517E-03	21.652	0.3383
320.0	0.4691	659.07	3.6102	6.8823	1.0104	0.2274E-05	0.4550E-03	0.3612E-03	7.5891	0.1751
330.0	0.3230	711.76	3.7726	3.7941	0.9603	0.2268E-05	0.3479E-03	0.2655E-03	1.3020	0.1080
340.0	0.2655	742.28	3.8628	2.5235	0.9112	0.2381E-05	0.3180E-03	0.2436E-03	20.426	0.8277E-01
350.0	0.2335	764.69	3.9288	2.0150	0.8799	0.2486E-05	0.3074E-03	0.2239E-03	26.981	0.6907E-01
360.0	0.2119	783.37	3.9814	1.7453	0.8595	0.2579E-05	0.3030E-03	0.2297E-03	32.754	0.6014E-01
370.0	0.1958	799.94	4.0268	1.5810	0.8463	0.2662E-05	0.3020E-03	0.2280E-03	37.936	0.5373E-01
380.0	0.1831	815.17	4.0675	1.4710	0.8376	0.2738E-05	0.3031E-03	0.2278E-03	42.668	0.4885E-01
390.0	0.1726	829.48	4.1046	1.3948	0.8322	0.2808E-05	0.3054E-03	0.2286E-03	47.049	0.4497E-01
400.0	0.1638	843.13	4.1392	1.3334	0.8292	0.2873E-05	0.3087E-03	0.2299E-03	51.151	0.4180E-01
410.0	0.1562	856.29	4.1717	1.2950	0.8280	0.2935E-05	0.3126E-03	0.2317E-03	55.024	0.3914E-01
420.0	0.1495	869.78	4.2025	1.2633	0.8281	0.2993E-05	0.3171E-03	0.2337E-03	58.707	0.3387E-01
440.0	0.1382	893.86	4.2602	1.2178	0.8313	0.3100E-05	0.3221E-03	0.2285E-03	65.614	0.3319E-01
460.0	0.1290	917.91	4.3136	1.1894	0.8371	0.3200E+05	0.3382E-03	0.2437E-03	72.045	0.3030E-01
480.0	0.1212	941.51	4.3638	1.1716	0.8445	0.3292E-05	0.3500E-03	0.2493E-03	78.110	0.2797E-01
500.0	0.1146	964.82	4.4114	1.1617	0.8533	0.3379E+05	0.3624E-03	0.2550E-03	83.887	0.2603E-01
600.0	0.9114E-01	1080.2	4.6218	1.1555	0.9009	0.3756E-05	0.4228E-03	0.2847E-03	109.98	0.1969E-01
700.0	0.7649E-01	1196.8	4.8015	1.1738	0.9472	0.4075E-05	0.4946E-03	0.3144E-03	133.43	0.1607E-01
800.0	0.6621E-01	1316.1	4.9607	1.2058	0.9878	0.4359E+05	0.5633E-03	0.3443E-03	155.50	0.1366E-01
900.0	0.5852E-01	1438.1	5.1044	1.2334	1.0219	0.4619E-05	0.6378E-03	0.3703E-03	176.76	0.1193E-01
1000.0	0.5250E-01	1562.7	5.2356	1.2558	1.0552	0.4861E-05	0.7554E-03	0.3968E-03	197.48	0.1060E-01

THERMODYNAMIC AND TRANSPORT PROPERTIES FOR NEON P<sub>0</sub> = 26.19 ATM, T<sub>C</sub> = 44.4 K, RHO<sub>C</sub> = .483 G/CC  
THERMODYNAMIC PROPERTY TABLE — NE KU = 1

1.00 ATM ISOBAR						1.00 ATM ISOBAR					
TEMP K	DENSITY GCC	ENTHALPY J/G	ENTROPY J/G-K	CP J/G-K	CV J/G-K	SON VEL CM/S	THERM COND J/CM-S-K	VISC G/CM-S	DP/DD MN-CC/G-M2	DP/DT MN/K-M2	
25.0	1.2406	0.9672	0.3769E-01	1.8944	1.3053	0.4454E+05	0.1289E-02	0.1520E-02	136.68	2.2264	
35.0	0.7219E-02	9.9557	3.6448	1.0614	0.6154	0.1535E+05	0.8688E-04	0.6032E-04	13.657	0.302E-02	
45.0	0.5542E-02	110.11	3.9100	1.0502	0.6187	0.1750E+05	0.1146E-03	0.7636E-04	18.033	0.235E-02	
55.0	0.408F-02	120.58	4.1201	1.0435	0.6191	0.1939E+05	0.1357E-03	0.9143E-04	22.307	0.1810E-02	
65.0	0.3802E-02	130.99	4.2941	1.0395	0.6190	0.2111E+05	0.1559E-03	0.1054E-03	26.528	0.157E-02	
75.0	0.3289E-02	141.37	4.4426	1.0369	0.6188	0.2269E+05	0.1752E-03	0.1184E-03	30.720	0.1361E-02	
80.0	0.2062E-02	146.55	4.5095	1.0359	0.6187	0.2344E+05	0.1846E-03	0.1246E-03	32.808	0.125E-02	
100.0	0.2422E-02	167.24	4.7404	1.0335	0.6184	0.2622E+05	0.2204E-03	0.1475E-03	41.128	0.1017E-02	
120.0	0.2050E-02	187.90	4.9287	1.0323	0.6183	0.2872E+05	0.2540E-03	0.1688E-03	49.417	0.846E-03	
140.0	0.1577E-02	208.54	5.0878	1.0316	0.6182	0.3103E+05	0.2857E-03	0.1881E-03	57.690	0.7251E-03	
160.0	0.1537E-02	229.17	5.2255	1.0311	0.6181	0.3317E+05	0.3158E-03	0.2023E-03	65.953	0.6341E-03	
180.0	0.1366E-02	249.78	5.3469	1.0308	0.6181	0.3518E+05	0.3444E-03	0.2237E-03	74.210	0.5635E-03	
200.0	0.1229E-02	270.40	5.4555	1.0306	0.6181	0.3708E+05	0.3718E-03	0.2404E-03	82.462	0.5010E-03	
220.0	0.1118E-02	291.01	5.5537	1.0305	0.6181	0.3889E+05	0.3980E-03	0.2563E-03	90.711	0.4609E-03	
240.0	0.1025E-02	311.62	5.6434	1.0304	0.6181	0.4062E+05	0.4233E-03	0.2717E-03	98.958	0.4224E-03	
260.0	0.9457E-03	332.22	5.7258	1.0303	0.6180	0.4227E+05	0.4476E-03	0.2866E-03	107.20	0.3899E-03	
280.0	0.8782E-03	352.83	5.8022	1.0302	0.6180	0.4387E+05	0.4710E-03	0.3011E-03	115.45	0.3620E-03	
300.0	0.8196E-03	373.43	5.8733	1.0302	0.6180	0.4551E+05	0.4937E-03	0.3151E-03	123.69	0.3379E-03	
320.0	0.7684E-03	394.04	5.9398	1.0301	0.6180	0.4689E+05	0.5157E-03	0.3288E-03	131.93	0.3167E-03	
340.0	0.7232E-03	414.64	6.0022	1.0301	0.6180	0.4834E+05	0.5370E-03	0.3421E-03	140.17	0.2981E-03	
360.0	0.6831E-03	435.24	6.0611	1.0301	0.6180	0.4974E+05	0.5582E-03	0.3551E-03	148.42	0.2815E-03	
380.0	0.6471E-03	455.84	6.1168	1.0300	0.6180	0.5110E+05	0.5776E-03	0.3678E-03	156.66	0.2667E-03	
400.0	0.6148E-03	476.44	6.1696	1.0300	0.6180	0.5242E+05	0.5966E-03	0.3803E-03	164.90	0.2534E-03	
500.0	0.4918E-03	579.44	6.3994	1.0300	0.6180	0.5861E+05	0.6868E-03	0.4393E-03	206.09	0.2027E-03	
600.0	0.4099E-03	682.43	6.5872	1.0299	0.6180	0.6420E+05	0.7705E-03	0.4938E-03	247.29	0.1687E-03	
DENSITY SOLUTION IS BEYOND THE GRASP OF GASP. ANSWER IS ON SOLID SIDE OF MELTING LOCUS FOR T = 25. P = 2.654 MN.											

## THERMODYNAMIC PROPERTY TABLE -- NE KU= 1

26.19 ATM ISOBAR

TEMP K	DENSITY G/CC	ENTHALPY J/G	ENTROPY J/G-K	CP J/G-K	CV J/G-K	SOL VEL CM/S	THERM COND J/CM-S-K	VISC G/CM-S	DP/DD MN-CC /G-M2	DP/DT MN/K-M2
25.0	1.2581	2.3562	0.1155E-01	1.8500	1.2408	0.4823E+05	0.1330E-02	0.1667E-02	156.01	2.4528
35.0	1.0712	23.177	0.7083	2.2454	1.0109	0.4215E+05	0.9681E-03	0.7396E-03	79.986	1.7994
45.0	0.2862	80.249	2.0587	7.4539	0.8882	0.1485E+05	0.2103E-03	0.1120E-03	2.6292	0.1773
55.0	0.1449	106.45	2.5960	1.6447	0.6861	0.1889E+05	0.1796E-03	0.1032E-03	0.7380E-01	0.7383
65.0	0.1107	121.02	2.4401	1.3330	0.6518	0.2112E+05	0.1895E-03	0.1133E-03	21.806	0.5291E-01
75.0	0.9146E-01	133.73	3.0223	1.2227	0.6398	0.2296E+05	0.2031E-03	0.1244E-03	27.589	0.4235E-01
80.0	0.8446E-01	139.77	3.1002	1.1907	0.6363	0.2380E+05	0.2101E-03	0.1300E-03	30.273	0.3868E-01
100.0	0.6532E-01	162.79	3.2573	1.1206	0.6286	0.2680E+05	0.2413E-03	0.1513E-03	40.280	0.2908E-01
120.0	0.5364E-01	184.85	3.5585	1.0886	0.6248	0.2941E+05	0.2718E-03	0.1718E-03	49.640	0.2350E-01
140.0	0.4566E-01	206.44	3.7250	1.0709	0.6226	0.3176E+05	0.3013E-03	0.1905E-03	58.661	0.1979E-01
160.0	0.3981E-01	227.75	3.8673	1.0601	0.6213	0.3393E+05	0.3297E-03	0.2084E-03	67.475	0.1712E-01
180.0	0.2532E-01	248.89	3.9917	1.0531	0.6204	0.3592E+05	0.3571E-03	0.2255E-03	76.156	0.1511E-01
200.0	0.2176E-01	269.90	4.1024	1.0482	0.6198	0.3785E+05	0.3834E-03	0.2419E-03	84.745	0.1338E-01
220.0	0.2886E-01	290.83	4.2022	1.0446	0.6194	0.3966E+05	0.4089E-03	0.2578E-03	93.267	0.1226E-01
240.0	0.2646E-01	311.70	4.2930	1.0420	0.6191	0.4138E+05	0.4334E-03	0.2730E-03	101.74	0.1120E-01
260.0	0.2443E-01	332.53	4.3763	1.0401	0.6189	0.4303E+05	0.4571E-03	0.2878E-03	110.18	0.1032E-01
280.0	0.2269E-01	353.31	4.4534	1.0385	0.6187	0.4461E+05	0.4801E-03	0.3022E-03	118.58	0.9567E-02
300.0	0.2118E-01	374.08	4.5250	1.0373	0.6186	0.4614E+05	0.5023E-03	0.3161E-03	126.96	0.8917E-02
320.0	0.1981E-01	394.81	4.5919	1.0363	0.6185	0.4762E+05	0.5239E-03	0.3297E-03	135.33	0.8351E-02
340.0	0.1871E-01	415.54	4.6547	1.0355	0.6184	0.4905E+05	0.5448E-03	0.3433E-03	143.68	0.7853E-02
360.0	0.1767E-01	436.24	4.7139	1.0348	0.6184	0.5044E+05	0.5657E-03	0.3559E-03	152.01	0.7411E-02
380.0	0.1675E-01	456.94	4.7698	1.0343	0.6183	0.5179E+05	0.5844E-03	0.3686E-03	160.34	0.7017E-02
400.0	0.1595E-01	477.62	4.8229	1.0338	0.6183	0.5310E+05	0.6035E-03	0.3810E-03	168.65	0.6663E-02
500.0	0.1275E-01	580.93	5.0534	1.0323	0.6181	0.5524E+05	0.6927E-03	0.4399E-03	210.14	0.5321E-02
600.0	0.1064E-01	684.12	5.2416	1.0315	0.6181	0.6479E+05	0.7757E-03	0.4943E-03	251.52	0.4431E-02
DENSITY	SOLUTION IS BEYOND THE GRASP OF GASP. ANSWER IS ON SOLID SIDE OF MELTING LOCUS FOR T = 23.731	IS OUT OF RANGE FOR P IN SUB.-ENTH								10.132 MN.

THERMODYNAMIC PROPERTY TABLE --- NE KU= 1

TEMP K	DENSITY G/CC	ENTHALPY J/G	ENTROPY J/G-K	CP J/G-K	CV J/G-K	SOL VEL CM/S	THERM COND J/CM-S-K	VISC G/CM-S	DP/DD MN-CC/G-M2	DP/DT MN/K-M2
25.0	1.2993	6.4718	-0.5762E-01	1.7612	1.0986	0.5780E+05	0.1430E-02	0.2210E-02	208.38	3.0533
35.0	1.1415	25.825	0.5913	1.9771	0.9284	0.5388E+05	0.1102E-02	0.9738E-03	136.34	2.3070
45.0	0.5533	45.203	1.0756	2.0238	0.5498	0.4906E+05	0.8025E-03	0.5247E-03	65.376	1.3950
55.0	0.7085	69.692	1.5648	2.6779	0.7013	0.3191E+05	0.5211E-03	0.2732E-03	26.639	0.6936
65.0	0.4966	94.924	1.9875	2.2294	0.7168	0.2690E+05	0.3660E-03	0.2016E-03	23.272	0.3654
75.0	1.3783	115.07	2.2765	1.7965	0.6913	0.2670E+05	0.3147E-03	0.1771E-03	27.425	0.2405
80.0	0.3397	123.72	2.3881	1.6441	0.6793	0.2709E+05	0.3047E-03	0.1729E-03	30.333	0.2055
100.0	0.2481	153.05	2.7167	1.3280	0.6510	0.2944E+05	0.3005E-03	0.1755E-03	42.485	0.1331
120.0	0.1997	178.41	2.9483	1.2111	0.6388	0.3184E+05	0.3161E-03	0.1883E-03	53.466	0.1008
140.0	0.1686	202.12	3.1311	1.1543	0.6323	0.3407E+05	0.3372E-03	0.2030E-03	63.579	0.8207E-01
160.0	0.1464	224.94	3.2835	1.1214	0.6283	0.3615E+05	0.3602E-03	0.2184E-03	73.205	0.6955E-01
180.0	0.1297	247.23	3.4148	1.1003	0.6258	0.3810E+05	0.3837E-03	0.2338E-03	82.532	0.6052E-01
200.0	0.1166	269.15	3.5303	1.0858	0.6240	0.3994E+05	0.4072E-03	0.2490E-03	91.657	0.5366E-01
220.0	0.1060	290.82	3.6336	1.0754	0.6227	0.4169E+05	0.4303E-03	0.2639E-03	100.64	0.4826E-01
240.0	0.9728E-01	312.31	3.7271	1.0676	0.6218	0.4336E+05	0.4531E-03	0.2784E-03	109.50	0.4388E-01
260.0	0.8990E-01	333.65	3.8125	1.0616	0.6210	0.4497E+05	0.4753E-03	0.2926E-03	118.28	0.4025E-01
280.0	0.8359E-01	354.89	3.8912	1.0569	0.6205	0.4651E+05	0.4970E-03	0.3069E-03	127.00	0.3719E-01
300.0	0.7812E-01	376.03	3.9641	1.0532	0.6201	0.4800E+05	0.5182E-03	0.3201E-03	135.65	0.3457E-01
320.0	0.7334E-01	397.11	4.0321	1.0501	0.6198	0.4944E+05	0.5388E-03	0.3333E-03	144.26	0.3231E-01
340.0	0.6913E-01	418.13	4.0958	1.0476	0.6195	0.5084E+05	0.5590E-03	0.3463E-03	152.83	0.3033E-01
360.0	0.6538E-01	439.10	4.1558	1.0456	0.6193	0.5220E+05	0.5792E-03	0.3590E-03	161.36	0.2858E-01
380.0	0.6202E-01	460.03	4.2124	1.0438	0.6191	0.5352E+05	0.5976E-03	0.3715E-03	169.87	0.2703E-01
400.0	0.5900E-01	480.93	4.2660	1.0423	0.6190	0.5480E+05	0.6158E-03	0.3838E-03	178.35	0.2563E-01
500.0	0.4747E-01	585.05	4.4983	1.0375	0.6185	0.6082E+05	0.7028E-03	0.4419E-03	220.49	0.2040E-01
600.0	0.3974E-01	688.79	4.6875	1.0349	0.6183	0.6626E+05	0.7845E-03	0.4960E-03	262.34	0.1696E-01

THE RMODYNAMIC AND TRANSPORT PROPERTIES FOR CO PC=34.529ATM, TC=132.91 K, RHOC=.2997 G/CC  
 0.44549E+CO IS OUT OF RANGE OF CURVE FIT VALUE IS EXTRAPOLATED.  
 0.42396E+CO IS OUT OF RANGE OF CURVE FIT VALUE IS EXTRAPOLATED.  
 0.44816E+00 IS OUT OF RANGE OF CURVE FIT VALUE IS EXTRAPOLATED.

THERMODYNAMIC PROPERTY TABLE -- CO KU= 1

1.00 ATM ISOBAR

TEMP K	DENSITY G/CC	ENTHALPY J/G	ENTROPY J/G-K	CP J/G-K	CV J/G-K	SOLID VEL CM/S	THERM COND J/CM-S-K	VISC G/C-M-S	DP/DD MN-CC /G-M2	DP/DT MN-K-M2
70.0	0.8359	124.42	2.6639	2.2570	1.3056	0.1054E+06	0.1474E-02	0.2358E-02	642.98	2.4712
80.0	0.7955	146.68	2.9612	2.2084	1.1415	0.9541E+05	0.1348E-02	0.1673E-02	470.48	1.9927
90.0	0.390E-02	374.36	5.7460	1.0775	0.7469	0.1903E+05	0.7905E-04	0.6166E-04	25.101	0.1187E-02
100.0	0.3491E-02	385.10	5.8591	1.0696	0.7472	0.2015E+05	0.8783E-04	0.6827E-04	28.359	0.1056E-02
110.0	0.3116E-02	395.76	5.9607	1.0634	0.7468	0.2120E+05	0.9622E-04	0.7486E-04	31.549	0.9512E-03
120.0	0.2882E-02	406.37	6.0530	1.0588	0.7462	0.2219E+05	0.1054E-03	0.8141E-04	34.692	0.8653E-03
130.0	0.2622E-02	416.94	6.1376	1.0552	0.7456	0.2313E+05	0.1142E-03	0.8787E-04	37.801	0.7988E-03
140.0	0.2458E-02	427.48	6.2157	1.0524	0.7451	0.2403E+05	0.1212E-03	0.9425E-04	40.884	0.7363E-03
150.0	0.2290E-02	437.99	6.2883	1.0503	0.7447	0.2490E+05	0.1286E-03	0.1005E-03	43.947	0.6853E-03
160.0	0.2144E-02	448.48	6.3560	1.0496	0.7443	0.2573E+05	0.1363E-03	0.1067E-03	46.995	0.6410E-03
170.0	0.2016E-02	458.96	6.4195	1.0472	0.7441	0.2654E+05	0.1441E-03	0.1127E-03	50.031	0.6022E-03
180.0	0.1903E-02	469.43	6.4793	1.0461	0.7439	0.2732E+05	0.1521E-03	0.1186E-03	53.058	0.5680E-03
190.0	0.1801E-02	479.88	6.5359	1.0452	0.7437	0.2807E+05	0.1603E-03	0.1243E-03	56.077	0.5374E-03
200.0	0.1710E-02	490.33	6.5895	1.0445	0.7436	0.2881E+05	0.1685E-03	0.1300E-03	59.089	0.5101E-03
220.0	0.1554E-02	511.21	6.6890	1.0435	0.7434	0.3023E+05	0.1851E-03	0.1409E-03	65.099	0.4630E-03
240.0	0.1424E-02	532.08	6.7797	1.0428	0.7433	0.3158E+05	0.2018E-03	0.1513E-03	71.094	0.4240E-03
260.0	0.1314E-02	552.93	6.8632	1.0423	0.7434	0.3288E+05	0.2183E-03	0.1613E-03	77.077	0.3911E-03
280.0	0.1219E-02	573.77	6.9404	1.0421	0.7434	0.3412E+05	0.2347E-03	0.1709E-03	83.053	0.3629E-03
300.0	0.1138E-02	594.61	7.0123	1.0419	0.7435	0.3532E+05	0.2507E-03	0.1801E-03	89.023	0.3386E-03
320.0	0.1067E-02	615.45	7.0796	1.0418	0.7437	0.3648E+05	0.2662E-03	0.1891E-03	94.987	0.3173E-03
340.0	0.1004E-02	636.28	7.1427	1.0419	0.7439	0.3760E+05	0.2794E-03	0.1978E-03	100.95	0.2985E-03
360.0	0.9478E-03	657.12	7.2023	1.0419	0.7441	0.3869E+05	0.2913E-03	0.2064E-03	106.91	0.2819E-03
380.0	0.8979E-03	677.96	7.2586	1.0421	0.7444	0.3975E+05	0.3030E-03	0.2148E-03	112.86	0.2670E-03
400.0	0.8530E-03	698.80	7.3121	1.0423	0.7447	0.4078E+05	0.3146E-03	0.2231E-03	118.81	0.2536E-03
500.0	0.6823E-03	803.13	7.5448	1.0437	0.7464	0.4558E+05	0.3702E-03	0.2611E-03	148.56	0.2028E-03
600.0	0.5685E-03	907.58	7.7353	1.0459	0.7487	0.4990E+05	0.4228E-03	0.2961E-03	178.28	0.1689E-03

DENSITY SOLUTION IS BEYOND THE GRASP OF GASP. ANSWER IS EN SOLID SIDE OF MELTING LOCUS FOR T = 70. P = 3.499 MN.

0.44816E+00 IS OUT OF RANGE OF CURVE FIT VALUE IS EXTRAPOLATED.

0.42396E+CO IS OUT OF RANGE OF CURVE FIT VALUE IS EXTRAPOLATED.

0.44549E+CO IS OUT OF RANGE OF CURVE FIT VALUE IS EXTRAPOLATED.

THERMODYNAMIC PROPERTY TABLE — CO KU= 1

34.53 ATM ISOBAR											
TEMP K	DENSITY G/CC	ENTHALPY J/G	ENTROPY J/G-K	CP J/G-K	CV J/G-K	SOL VEL CM/S	THERM COND J/CM-S-K	VISC G/CM-S	DP/DD MN-CC / G-H2	DP/DD MN-K-H2	
70.0	0.841	127.20	2.6457	2.2318	1.3225	0.1066E+06	0.1491E-02	0.2472E-02	673.76	2.4884	
80.0	0.8025	149.17	2.9393	2.1754	1.1619	0.9725E+05	0.1371E-02	0.1771E-02	505.26	2.0302	
90.0	0.7617	170.88	3.1950	2.1724	1.0833	0.8611E+05	0.1249E-02	0.1291E-02	369.70	1.6090	
100.0	0.7149	192.71	3.42249	2.1996	1.0156	0.7479E+05	0.1123E-02	0.9618E-03	258.27	1.2502	
110.0	0.6627	215.15	3.6387	2.3152	0.9646	0.6299E+05	0.9913E-03	0.7303E-03	165.33	0.9441	
120.0	0.5972	239.98	3.8545	2.7416	1.0031	0.4879E+05	0.8418E-03	0.5564E-03	87.105	0.6709	
130.0	0.4870	274.60	4.1305	4.8340	0.9065	0.3324E+05	0.6244E-03	0.3906E-03	20.723	0.3854	
140.0	0.1358	375.0	4.8874	2.8359	0.9064	0.2043E+05	0.1943E-03	0.1210E-03	13.343	0.5825E-01	
150.0	0.1077	398.27	5.0434	1.9051	0.8537	0.2233E+05	0.1824E-03	0.1119E-03	22.426	0.4271E-01	
160.0	0.9274E-01	415.63	5.1556	1.6071	0.8272	0.2388E+05	0.1807E-03	0.1212E-03	29.359	0.3509E-01	
170.0	0.8265E-01	430.88	5.2481	1.4562	0.8105	0.2511E+05	0.1826E-03	0.1250E-03	35.268	0.3025E-01	
180.0	0.7513E-01	444.95	5.3285	1.3642	0.7988	0.2632E+05	0.1863E-03	0.1292E-03	40.555	0.2682E-01	
190.0	0.6920E-01	458.26	5.4005	1.3022	0.7901	0.2736E+05	0.1912E-03	0.1338E-03	45.420	0.2421E-01	
200.0	0.6435E-01	471.05	5.4661	1.2575	0.7833	0.2833E+05	0.1968E-03	0.1385E-03	49.976	0.2215E-01	
210.0	0.5676E-01	495.55	5.6829	1.1979	0.7734	0.3009E+05	0.2095E-03	0.1480E-03	58.439	0.1906E-01	
220.0	0.5101E-01	519.11	5.6854	1.1603	0.7667	0.3168E+05	0.2233E-03	0.1575E-03	66.303	0.1682E-01	
230.0	0.46645E-01	542.05	5.7772	1.1348	0.7619	0.3314E+05	0.2376E-03	0.1667E-03	73.760	0.1511E-01	
240.0	0.4272E-01	564.55	5.8606	1.1166	0.7585	0.3452E+05	0.2522E-03	0.1758E-03	80.927	0.1375E-01	
250.0	0.3960E-01	586.74	5.9372	1.1033	0.7559	0.3581E+05	0.2667E-03	0.1846E-03	87.880	0.1263E-01	
260.0	0.3694E-01	608.70	6.0081	1.0932	0.7540	0.3705E+05	0.2811E-03	0.1932E-03	94.668	0.1170E-01	
270.0	0.3463E-01	630.48	6.0741	1.0853	0.7525	0.3823E+05	0.2933E-03	0.2016E-03	101.33	0.1091E-01	
280.0	0.3261E-01	652.13	6.1359	1.0792	0.7514	0.3936E+05	0.3043E-03	0.2099E-03	107.89	0.1022E-01	
290.0	0.3082E-01	673.66	6.1942	1.0744	0.7506	0.4046E+05	0.3152E-03	0.2180E-03	114.36	0.9621E-02	
300.0	0.2923E-01	695.11	6.2492	1.0704	0.7501	0.4152E+05	0.3261E-03	0.2262E-03	120.77	0.9092E-02	
310.0	0.2792E-01	801.52	6.4867	1.0595	0.7492	0.4638E+05	0.3792E-03	0.2634E-03	152.14	0.7156E-02	
320.0	0.2329E-01	907.25	6.6794	1.0559	0.7504	0.5072E+05	0.4303E-03	0.2979E-03	182.86	0.5916E-02	
330.0	0.1939E-01								10.132 MN.		
340.0									70. P =		

0.45301E+00 IS OUT OF RANGE OF CURVE FIT VALUE IS EXTRAPOLATED.

0.43438E+CO IS OUT OF RANGE OF CURVE FIT VALUE IS EXTRAPOLATED.

0.41379E+CO IS OUT OF RANGE OF CURVE FIT VALUE IS EXTRAPOLATED.

DENSITY SOLUTION IS BEYOND THE GRASP OF GASP. ANSWER IS ON SOLID SIDE OF MELTING LOCUS FOR T =

THERMODYNAMIC PROPERTY TABLE -- CO KU# 1

100.00 AT& 1 SIBAR							CO						
TEMP K	DENSITY G/CC	ENTHALPY J/G	ENTROPY J/G-K	CP J/G-K	CV J/G-K	SUN VEL CM/S	THERM COND J/CM-S-K	VISC G/CM-S	DP/DD MN-CC/G-M2	DP/DT MN/K-M2			
70.0	0.8505	1.3273	2.6127	2.1900	1.3497	0.1090E+06	0.1524E-02	0.2700E-02	732.27	2.5217			
80.0	0.8148	1.5426	2.9003	2.1257	1.1951	0.1007E-06	0.1411E-02	0.1964E-02	570.35	2.0988			
90.0	0.7771	1.7538	3.1490	2.1000	1.1182	0.9096E-05	0.1299E-02	0.1456E-02	440.59	1.7036			
100.0	0.7374	1.9627	3.3692	2.0795	1.0501	0.8143E-05	0.1187E-02	0.1107E-02	334.82	1.3690			
110.0	0.6950	2.1706	3.5673	2.0898	0.9966	0.7210E-05	0.1077E-02	0.8643E-03	247.89	1.0909			
120.0	0.6489	2.3845	3.7534	2.2185	1.0291	0.6169E-05	0.9652E-03	0.6911E-03	176.57	0.8584			
130.0	0.5970	2.6185	3.9406	2.2538	0.9152	0.5416E+05	0.8501E-03	0.5631E-03	119.10	0.6612			
140.0	0.5368	2.8542	4.1149	2.5932	1.0265	0.4360E+05	0.7276E-03	0.6344E-03	75.234	0.4925			
150.0	0.4657	3.1233	4.3005	2.8008	0.9468	0.3699E+05	0.6006E-03	0.3803E-03	46.177	0.3518			
160.0	0.3884	3.4102	4.4856	2.8808	0.9151	0.3210E+05	0.4334E-03	0.2195E-03	32.739	0.2463			
170.0	0.2209	3.6842	4.6536	2.6180	0.8949	0.2999E+05	0.3990E-03	0.2349E-03	30.725	0.1791			
180.0	0.2717	3.9310	4.7931	2.2640	0.8753	0.2958E+05	0.2988E-03	0.2089E-03	33.835	0.1388			
190.0	0.2369	4.1427	4.9076	1.9844	0.8577	0.2991E+05	0.3203E-03	0.1948E-03	38.681	0.1135			
200.0	0.2116	4.3306	5.0040	1.7860	0.8428	0.3053E+05	0.3641E-03	0.875E-03	43.994	0.9638E-01			
220.0	0.1770	4.6609	5.1616	1.5420	0.8201	0.3202E+05	0.2901E-03	0.1829E-03	54.533	0.7487E-01			
240.0	0.1541	4.9543	5.2893	1.4042	0.8039	0.3354E+05	0.2884E-03	0.1844E-03	64.415	0.6184E-01			
260.0	0.1375	5.2259	5.3981	1.3180	0.7921	0.3500E+05	0.2926E-03	0.1887E-03	73.630	0.5304E-01			
280.0	0.1247	5.4834	5.4935	1.2598	0.7833	0.3638E+05	0.2998E-03	0.1942E-03	82.297	0.4666E-01			
300.0	0.1145	5.7310	5.5789	1.2186	0.7766	0.3769E+05	0.3089E-03	0.2005E-03	90.528	0.4180E-01			
320.0	0.1060	5.9715	5.6565	1.181	0.7714	0.3893E+05	0.3389E-03	0.2071E-03	98.414	0.3796E-01			
340.0	0.9891E-01	6.2067	5.7278	1.1649	0.7673	0.4012E+05	0.3276E-03	0.2140E-03	106.02	0.3483E-01			
360.0	0.5280E-01	6.4378	5.7939	1.1469	0.7641	0.4126E+05	0.3358E-03	0.2211E-03	113.41	0.3222E-01			
380.0	0.8748E-01	6.6657	5.8555	1.1326	0.7615	0.4235E+05	0.3443E-03	0.2283E-03	120.61	0.3002E-01			
400.0	0.8280E-01	6.8910	5.9133	1.1210	0.7595	0.4344E+05	0.3531E-03	0.2355E-03	127.66	0.2813E-01			
500.0	0.6569E-01	7.9929	6.1593	1.0877	0.7543	0.4824E+05	0.3992E-03	0.2699E-03	161.35	0.2155E-01			
600.0	0.5469E-01	9.0726	6.3562	1.0737	0.7534	0.5251E+05	0.4461E-03	0.3030E-03	193.51	0.1757E-01			

THERMODYNAMIC AND TRANSPORT PROPERTIES FOR HE PC = 2.245ATM, TC = 5.2K, RHOC = .0693G/CC  
THERMODYNAMIC PROPERTY TABLE -- HE KU= 1

1.00 ATM ISORAP							1.00 ATM ISORAP						
TEMP K	DENSITY G/CC	ENTHALPY J/G	ENTROPY J/G-K	CP J/G-K	CV J/G-K	SON VEL CM/S	THERM COND J/CM-S-K	VISC G/CM-S	DP/DD MN=CC/G-M2	DP/DT MN/K-M2			
3.0	0.1430	5.7589	2.3795	2.7207	2.2248	0.2181E+05	0.1685E-03	0.3833E-04	38.882	0.3626			
3.5	0.1376	7.0390	2.7745	2.5503	1.6519	0.2158E+05	0.1899E-03	0.3610E-04	30.173	0.3829			
4.0	2.1299	8.5660	3.1805	3.8433	2.1457	0.1907E+05	0.2069E-03	0.3329E-04	20.306	0.3814			
4.5	0.1446E-01	32.886	8.9422	6.7033	2.8267	0.1093E+05	0.1059E-03	0.1295E-04	5.0371	0.3013E-01			
5.0	0.1207E-01	36.162	9.6329	6.4023	2.9443	0.1193E+05	0.1147E-03	0.1392E-04	6.6519	0.2659E-01			
5.5	0.1044E-01	39.297	10.231	6.1488	3.0578	0.1281E+05	0.1229E-03	0.1488E-04	8.1572	0.2336E-01			
6.0	0.9251E-02	42.322	10.757	5.9612	3.0852	0.1360E+05	0.1312E-03	0.1582E-04	9.5738	0.1982E-01			
6.5	0.8333E-02	45.266	11.229	5.8229	3.0982	0.1433E+05	0.1386E-03	0.1674E-04	10.923	0.1783E-01			
7.0	0.7567E-02	48.151	11.656	5.7191	3.1048	0.1500E+05	0.1461E-03	0.1764E-04	12.222	0.1623E-01			
7.5	0.6991E-02	50.990	12.048	5.6394	3.1085	0.1564E+05	0.1528E-03	0.1851E-04	13.481	0.1591E-01			
8.0	0.6482E-02	52.793	12.410	5.5770	3.1106	0.1624E+05	0.1597E-03	0.1937E-04	14.710	0.1380E-01			
8.5	0.6047E-02	56.569	12.746	5.5271	3.1119	0.1681E+05	0.1659E-03	0.2020E-04	15.914	0.1886E-01			
9.0	0.5669E-02	59.322	13.061	5.4867	3.1127	0.1736E+05	0.1721E-03	0.2102E-04	17.098	0.1246E-01			
9.5	0.5339E-02	62.056	13.357	5.4534	3.1133	0.1789E+05	0.1779E-03	0.2181E-04	18.266	0.1133E-01			
10.0	0.5047E-02	64.776	13.636	5.4256	3.1137	0.1840E+05	0.1837E-03	0.2260E-04	19.420	0.1069E-01			
20.0	0.2447E-02	117.83	17.320	5.282	3.1155	0.2637E+05	0.2717E-03	0.3582E-04	41.269	0.5314E-02			
30.0	0.1625E-02	170.13	19.441	5.2176	3.1157	0.3233E+05	0.3490E-03	0.4634E-04	62.400	0.3398E-02			
40.0	0.1288E-02	222.24	20.940	5.2069	3.1158	0.3732E+05	0.4182E-03	0.5542E-04	83.354	0.2542E-02			
50.0	0.9788E-03	274.29	22.102	5.2020	3.1158	0.4172E+05	0.4812E-03	0.6360E-04	104.24	0.2031E-02			
60.0	0.8115E-03	326.29	23.050	5.1993	3.1158	0.4569E+05	0.5410E-03	0.7117E-04	125.08	0.1691E-02			
70.0	0.6966E-03	378.28	23.851	5.1976	3.1158	0.4934E+05	0.5977E-03	0.7827E-04	145.91	0.1449E-02			
80.0	0.6076E-03	430.25	24.545	5.1966	3.1158	0.5273E+05	0.6519E-03	0.8503E-04	166.72	0.1268E-02			
90.0	0.5422E-03	482.21	25.157	5.1958	3.1158	0.5592E+05	0.7040E-03	0.9152E-04	187.52	0.1127E-02			
100.0	0.4811E-03	534.16	25.704	5.1953	3.1158	0.5894E+05	0.7547E-03	0.9778E-04	208.32	0.1014E-02			
200.0	0.2437E-03	1033.6	29.305	5.1936	3.1158	0.8329E+05	0.1195E-02	0.1537E-03	416.15	0.5067E-03			
300.0	0.1625E-03	1572.9	31.411	5.1933	3.1158	0.1020E+06	0.1571F-02	0.2043E-03	623.91	0.3318E-03			
400.0	0.1219E-03	2092.3	32.905	5.1932	3.1158	0.1177E+06	0.1933E-02	0.2531E-03	831.66	0.2533E-03			
500.0	0.9752E-04	2611.6	34.063	5.1932	3.1158	0.1316E+06	0.2230E-02	0.3015E-03	1039.4	0.2022E-03			
600.0	0.8127E-04	3130.9	35.010	5.1931	3.1158	0.1442E+06	0.2506E-02	0.3499E-03	1247.1	0.1669E-03			

2.24 ATM ISOBAR		THERMODYNAMIC PROPERTY TABLE -- HE KU= 1									
TEMP K	DENSITY G/CC	ENTHALPY J/G	ENTROPY J/G-K	CP J/G-K	CV J/G-K	SON VEL CM/S	TERM COND J/CH-S-K	VISC G/CM-S	DP/DD MN-CC/G-M2	DP/DT MN/K-M2	
3.0	0.1460	6.4735	2.3268	2.6099	2.1799	0.2335E+05	0.1712E-03	0.4100E-04	45.538	0.3730	
3.5	0.1413	6.6794	2.6992	2.3482	1.5981	0.2343E+05	0.1931E-03	0.3876E-04	37.359	0.3999	
4.0	0.1351	9.0480	3.0632	3.3529	2.0621	0.2146E+05	0.2111E-03	0.3615E-04	28.318	0.4084	
4.5	0.1264	11.193	3.5661	5.3902	3.0049	0.1815E+05	0.2249E-03	0.3316E-04	18.364	0.3943	
5.0	0.1111	14.638	4.2888	-4.7647	-11.181	54.777	0.2317E-03	0.2909E-04	7.0414	0.3341	
5.5	0.3219E-01	32.881	7.7951	9.3522	2.6123	0.1178E+05	0.1440E-03	0.1748E-04	3.8771	0.7015E-01	
6.0	0.2572E-01	37.104	8.5310	7.8010	2.8959	0.1274E+05	0.1461E-03	0.1789E-04	6.0282	0.509E-01	
6.5	0.2190E-01	40.810	9.1247	7.0939	3.0042	0.1363E+05	0.1504E-03	0.1852E-04	7.8706	0.4817E-01	
7.0	0.1927E-01	4.264	9.6337	6.6698	3.0533	0.1444E+05	0.1560E-03	0.1922E-04	9.5416	0.4227E-01	
7.5	0.1731E-01	4.7503	10.084	6.3855	3.0780	0.1517E+05	0.1615E-03	0.1994E-04	11.098	0.3829E-01	
8.0	0.1577E-01	5.0642	10.489	6.1823	3.0914	0.1586E+05	0.1674E-03	0.2068E-04	12.570	0.3444E-01	
8.5	0.1451E-01	53.694	10.859	6.0306	3.0992	0.1649E+05	0.1729E-03	0.2142E-04	13.980	0.3186E-01	
9.0	0.1347E-01	56.679	11.200	5.9136	3.1039	0.1710E+05	0.1785E-03	0.2216E-04	15.341	0.2947E-01	
9.5	0.1258E-01	59.611	11.517	5.8210	3.1069	0.1767E+05	0.1838E-03	0.2289E-04	16.662	0.2744E-01	
10.0	0.1181E-01	62.503	11.814	5.7463	3.1089	0.1822E+05	0.1892E-03	0.2361E-04	17.951	0.2669E-01	
20.0	0.5514E-02	1.1699	15.607	5.3149	3.1150	0.2645E+05	0.2744E-03	0.3633E-04	41.012	0.1171E-01	
30.0	0.3644E-02	16.973	17.746	5.2471	3.1156	0.3246E+05	0.3508E-03	0.4669E-04	62.549	0.7882E-02	
40.0	0.2728E-02	22.220	19.252	5.2236	3.1157	0.3746E+05	0.4197E-03	0.5570E-04	83.711	0.5129E-02	
50.0	0.2181E-02	27.425	20.416	5.2128	3.1158	0.4186E+05	0.4824E-03	0.6385E-04	104.72	0.4511E-02	
60.0	0.1818E-02	32.634	21.366	5.2058	3.1158	0.4582E+05	0.5421E-03	0.7138E-04	125.65	0.3804E-02	
70.0	0.1558E-02	37.839	22.168	5.2032	3.1158	0.4947E+05	0.5986E-03	0.7847E-04	146.54	0.2577E-02	
80.0	0.1364E-02	43.041	22.863	5.2009	3.1158	0.5286E+05	0.6527E-03	0.8522E-04	167.40	0.2849E-02	
90.0	0.1213E-02	48.241	23.476	5.1992	3.1158	0.5605E+05	0.7048E-03	0.9169E-04	188.24	0.2331E-02	
100.0	0.1092E-02	53.440	24.023	5.1981	3.1158	0.5906E+05	0.7554E-03	0.9794E-04	209.07	0.2277E-02	
200.0	0.5465E-03	1054.0	27.625	5.1943	3.1158	0.8388E+05	0.1195E-02	0.1538E-03	417.04	0.1138E-02	
300.0	0.3645E-03	1573.3	29.731	5.1946	3.1158	0.1021E+06	0.1571E-02	0.2043E-03	624.85	0.7583E-03	
400.0	0.2735E-03	2092.7	31.225	5.1934	3.1158	0.1178E+06	0.1933E-02	0.2531E-03	832.61	0.5687E-03	
500.0	0.2188E-03	2612.0	32.384	5.1933	3.1158	0.1317E+06	0.2230E-02	0.3014E-03	1040.4	0.4550E-03	
600.0	0.1824E-03	3131.3	33.330	5.1932	3.1158	0.1442E+06	0.2506E-02	0.3498E-03	1248.1	0.3791E-03	

SOLUTION OUT OF RANGE

SOLUTION	OUT OF RANGE	IN SUB.-ENTH
10.181	IS OUT OF RANGE	FOR P
10.253	IS OUT OF RANGE	FOR P
10.326	IS OUT OF RANGE	FOR P
10.205	IS OUT OF RANGE	FOR P
10.278	IS OUT OF RANGE	FOR P
10.351	IS OUT OF RANGE	FOR P
10.424	IS OUT OF RANGE	FOR P
10.206	IS OUT OF RANGE	FOR P
10.279	IS OUT OF RANGE	FOR P
10.354	IS OUT OF RANGE	FOR P
10.428	IS OUT OF RANGE	FOR P
10.207	IS OUT OF RANGE	FOR P
10.283	IS OUT OF RANGE	FOR P
10.359	IS OUT OF RANGE	FOR P
10.436	IS OUT OF RANGE	FOR P
10.210	IS OUT OF RANGE	FOR P
10.288	IS OUT OF RANGE	FOR P
10.212	IS OUT OF RANGE	FOR P
10.293	IS OUT OF RANGE	FOR P
10.214	IS OUT OF RANGE	FOR P
10.297	IS OUT OF RANGE	FOR P
10.216	IS OUT OF RANGE	FOR P
10.301	IS OUT OF RANGE	FOR P
10.218	IS OUT OF RANGE	FOR P
10.303	IS OUT OF RANGE	FOR P
10.219	IS OUT OF RANGE	FOR P
10.305	IS OUT OF RANGE	FOR P
10.219	IS OUT OF RANGE	FOR P
10.306	IS OUT OF RANGE	FOR P
10.219	IS OUT OF RANGE	FOR P
10.306	IS OUT OF RANGE	FOR P
10.219	IS OUT OF RANGE	FOR P
10.306	IS OUT OF RANGE	FOR P
10.218	IS OUT OF RANGE	FOR P
10.304	IS OUT OF RANGE	FOR P

THERMODYNAMIC PROPERTY TABLE -- HE KU= 1

100.00 ATM ISOBAR		HE KU= 1									
TEMP K	DENSITY G/CC	ENTHALPY J/G	ENTROPY J/G-K	CP J/G-K	CV J/G-K	SOL VEL CM/S	THERM COND J/CH-S-K	VISC G/CM-S	DP/DD MN-CC/G-M2	DP/DT MN/K-M2	
3.0	0.2100	56.762	1.3311	1.6103	1.4870	0.5540E+05	0.4984E-03	0.3307E-03	283.41	0.7167	
3.5	0.2100	57.376	1.5214	1.1654	1.0201	0.5740E+05	0.5710E-03	0.2928E-03	288.43	0.7267	
4.0	0.2091	57.988	1.6842	1.5212	1.3545	0.5683E+05	0.6152E-03	0.2244E-03	287.58	0.7238	
4.5	0.2078	58.947	1.9032	2.3308	2.1352	0.5568E+05	0.6421E-03	0.2189E-03	284.03	0.7302	
5.0	0.2065	60.127	2.1580	-12.002	-12.236	0.5238E+05	0.6632E-03	0.1932E-03	279.67	0.7473	
5.5	0.2051	62.604	2.6077	-0.8067E-01	-0.3630	0.2471E+05	0.6746E-03	0.1313E-03	274.63	0.7702	
6.0	0.2037	62.845	2.6490	0.9816	0.6424	0.6412E+05	0.6819E-03	0.1571E-03	269.05	0.7945	
6.5	0.2022	63.535	2.7591	1.7413	1.3378	0.5852E+05	0.6881E-03	0.1441E-03	263.10	0.8171	
7.0	0.2006	64.554	2.9098	2.3079	1.8345	0.5685E+05	0.6832E-03	0.1334E-03	256.90	0.8361	
7.5	0.1989	65.821	3.0845	2.7448	2.1975	0.5595E+05	0.6793E-03	0.1245E-03	250.59	0.8507	
8.0	0.1972	67.283	3.2731	3.0906	2.4670	0.5532E+05	0.6737E-03	0.1170E-03	244.27	0.8605	
8.5	0.1954	68.901	3.4691	3.3699	2.6689	0.5482E+05	0.6644E-03	0.1106E-03	238.02	0.8658	
9.0	0.1936	70.645	3.6684	3.5993	2.8209	0.5440E+05	0.6585E-03	0.1052E-03	231.89	0.8669	
9.5	0.1917	72.494	3.8683	3.7903	2.9353	0.5401E+05	0.6500E-03	0.1005E-03	225.94	0.8643	
10.0	0.1897	74.430	4.0669	3.9513	3.0212	0.5366E+05	0.6416E-03	0.9648E-04	220.19	0.8586	
20.0	0.1494	121.57	7.2889	5.1616	3.1730	0.4966E+05	0.5961E-03	0.7031E-04	0.5797	0.1330	
30.0	0.1162	175.39	9.4660	5.5256	3.1237	0.4975E+05	0.6164E-03	0.7079E-04	139.92	0.3889	
40.0	0.5320E-01	231.00	11.066	5.5671	3.1157	0.5195E+05	0.6634E-03	0.7534E-04	151.05	0.2835	
50.0	0.7751E-01	286.45	12.303	5.5180	3.1148	0.5479E+05	0.6975E-03	0.8087E-04	169.43	0.2212	
60.0	0.6636E-01	341.35	13.304	5.4621	3.1149	0.5773E+05	0.7284E-03	0.8665E-04	190.04	0.1809	
70.0	J.5806E-01	395.73	14.142	5.4155	3.1151	0.6062E+05	0.7597E-03	0.9244E-04	211.37	0.1530	
80.0	0.5164E-01	449.69	14.863	5.3789	3.1153	0.6341E+05	0.7927E-03	0.9817E-04	232.91	0.1326	
90.0	0.4653E-01	503.33	15.495	5.3503	3.1154	0.6611E+05	0.8276E-03	0.1038E-03	254.48	0.1170	
100.0	0.4235E-01	556.72	16.057	5.3278	3.1155	0.6870E+05	0.8642E-03	0.1093E-03	276.02	0.1047	
200.0	0.2247E-01	1088.8	19.714	5.2376	3.1158	0.9065E+05	0.1243E-02	0.1605E-03	488.81	0.5118E-01	
300.0	0.1537E-01	1676.2	21.833	5.2152	3.1158	0.1082E+06	0.1601E-02	0.2075E-03	698.95	0.3394E-01	
400.0	0.1166E-01	2127.2	23.332	5.2063	3.1158	0.1232E+06	0.1955E-02	0.2532E-03	908.08	0.2541E-01	
500.0	0.9407E-02	2647.6	24.493	5.2019	3.1158	0.1365E+06	0.2247E-02	0.2986E-03	1116.7	0.2030E-01	
600.0	0.7883E-02	3167.7	25.441	5.1993	3.1158	0.1487E+06	0.2521E-02	0.3441E-03	1325.1	0.1691E-01	

THE REGION 125-145K FOR T AND P GREATER THAN 10 ATM YIELDS POOR RESULTS FOR THE DERIVED PROPERTIES--BEWARE  
 THERMODYNAMIC AND TRANSPORT PROPERTIES FOR FLUORINE PC=51.47ATM, TC=144.31K, RHOC=.57386/CC  
 THERMODYNAMIC PROPERTY TABLE -- F2 KU= 1

1.00 ATM ISOBAR						1.00 ATM ISOBAR					
TEMP K	DENSITY G/C.C	ENTHALPY J/J	ENTROPY J/G-K	CP J/G-K	CV J/G-K	SON VEL CM/S	THERM COND J/CM-S-K	VISC G/CM-H-S	DP/DD MN-CG-M2	DP/DT MN/K-M2	
70.0	1.6023	-134.25	1.9989	1.4998	2.8925	0.9483E+05	0.1632E-02	0.2700E-02	535.12	3.4523	
75.0	1.5696	-126.75	2.1023	1.4976	2.8673	0.9057E+05	0.1549E-02	0.2300E-02	575.11	3.1365	
80.0	1.5362	-119.29	2.1987	1.4856	2.8305	0.8668E+05	0.1470E-02	0.1967E-02	419.75	2.8502	
85.0	0.5622E-02	61.3779	4.3278	0.8159	2.5654	0.1585E+05	0.9589E-04	0.7815E-04	17.382	0.1277E-02	
90.0	0.5289E-02	65.4338	4.3742	0.8072	2.5618	0.1636E+05	0.1016E-03	0.8264E-04	18.620	0.1192E-02	
95.0	0.4939E-02	69.4555	4.4177	0.8000	2.5592	0.1684E+05	0.1073E-03	0.8715E-04	19.833	0.1119E-02	
100.0	0.4723E-02	73.4441	4.4585	0.7945	2.5572	0.1731E+05	0.1130E-03	0.9168E-04	21.026	0.1055E-02	
105.0	0.4485E-02	77.402	4.4972	0.7903	2.5558	0.1777E+05	0.1187E-03	0.9621E-04	22.204	0.9877E-03	
110.0	0.4272E-02	81.345	4.5339	0.7871	2.5548	0.1821E+05	0.1244E-03	0.1007E-03	23.370	0.9488E-03	
115.0	0.4078E-02	85.2774	4.5688	0.7847	2.5542	0.1863E+05	0.1305E-03	0.1053E-03	24.526	0.9041E-03	
120.0	0.3902E-02	89.193	4.6022	0.7829	2.5533	0.1905E+05	0.1357E-03	0.1098E-03	25.674	0.8637E-03	
125.0	0.3719E-02	93.103	4.6341	0.7816	2.5538	0.1945E+05	0.1413E-03	0.1142E-03	26.815	0.8289E-03	
130.0	0.3553E-02	97.009	4.6647	0.7807	2.5539	0.1985E+05	0.1469E-03	0.1187E-03	27.951	0.7934E-03	
135.0	0.3457E-02	100.91	4.6942	0.7801	2.5542	0.2023E+05	0.1520E-03	0.1231E-03	29.082	0.7625E-03	
140.0	0.3331E-02	104.81	4.7226	0.7798	2.5547	0.2061E+05	0.1580E-03	0.1275E-03	30.209	0.7341E-03	
145.0	0.3224E-02	108.71	4.7499	0.7798	2.5553	0.2098E+05	0.1636E-03	0.1319E-03	31.333	0.7018E-03	
150.0	0.3105E-02	112.61	4.7764	0.7800	2.5563	0.2134E+05	0.1691E-03	0.1362E-03	32.454	0.6834E-03	
155.0	0.3003E-02	116.51	4.8019	0.7824	2.5568	0.2169E+05	0.1746E-03	0.1450E-03	33.573	0.6607E-03	
160.0	0.2907E-02	120.41	4.8267	0.7809	2.5578	0.2204E+05	0.1801E-03	0.1447E-03	34.689	0.6395E-03	
165.0	0.2818E-02	124.32	4.8508	0.7816	2.5588	0.2238E+05	0.1856E-03	0.1489E-03	35.804	0.6196E-03	
170.0	0.2734E-02	128.23	4.8741	0.7824	2.5599	0.2271E+05	0.1911E-03	0.1531E-03	36.916	0.6009E-03	
175.0	0.2659E-02	132.14	4.8968	0.7833	2.5611	0.2304E+05	0.1966E-03	0.1572E-03	38.028	0.5834E-03	
180.0	0.2581E-02	136.06	4.9189	0.7843	2.5624	0.2336E+05	0.2020E-03	0.1612E-03	39.138	0.5669E-03	
185.0	0.2505E-02	139.99	4.9404	0.7854	2.5637	0.2368E+05	0.2075E-03	0.1652E-03	40.247	0.5513E-03	
190.0	0.2444E-02	143.92	4.9613	0.7866	2.5651	0.2399E+05	0.2129E-03	0.1692E-03	41.355	0.5366E-03	
195.0	0.2380E-02	147.85	4.9818	0.7879	2.5665	0.2427E+05	0.1911E-03	0.1731E-03	42.462	0.5226E-03	
200.0	0.2320E-02	151.79	5.0018	0.7892	2.5681	0.2460E+05	0.2237E-03	0.1770E-03	43.568	0.5093E-03	
220.0	0.2108E-02	167.64	5.0772	0.7952	2.5745	0.2577E+05	0.2452E-03	0.1920E-03	47.986	0.4625E-03	
240.0	0.1932E-02	183.61	5.1467	0.8021	2.5818	0.2688E+05	0.2666E-03	0.2064E-03	52.395	0.4236E-03	
260.0	0.1782E-02	199.72	5.2112	0.8095	2.5894	0.2793E+05	0.2878E-03	0.2201E-03	56.798	0.3908E-03	
280.0	0.1655E-02	215.99	5.2715	0.8173	2.5975	0.2893E+05	0.3088E-03	0.2333E-03	61.197	0.3627E-03	
300.0	0.1544E-02	232.42	5.3282	0.8255	2.6058	0.2990E+05	0.3297E-03	0.2460E-03	65.593	0.3384E-03	
320.0	0.1447E-02	249.01	5.3817	0.8338	2.6142	0.3082E+05	0.3504E-03	0.2582E-03	69.985	0.3172E-03	
340.0	0.1362E-02	265.77	5.4325	0.8422	2.6227	0.3172E+05	0.3711E-03	0.2701E-03	74.376	0.2985E-03	
360.0	0.1286E-02	282.70	5.4809	0.8506	2.6312	0.3258E+05	0.3915E-03	0.2817E-03	78.765	0.2818E-03	
380.0	0.1219E-02	299.79	5.5271	0.8599	2.6395	0.332E+05	0.4118E-03	0.2931E-03	83.152	0.2670E-03	
400.0	0.1158E-02	317.05	5.5713	0.8670	2.6477	0.3423E+05	0.4220E-03	0.3043E-03	87.538	0.2536E-03	
500.0	0.9259E-03	405.64	5.7689	0.9034	0.6843	0.3801E+05	0.5292E-03	0.3559E-03	109.46	0.2028E-03	

THERMODYNAMIC PROPERTY TABLE — F2 KU= 1

51•47 ATM ISOBAR

TEMP K	DENSITY G/CC	ENTHALPY J/G	ENTROPY J/G-K	CP J/G-K	CV J/G-K	SOL VEL CM/S	THERM COND J/CM-S-K	VISC G/CM-S	DP/UD MN-CC/G-M2	DP/DT MN/K-M2
70.0	1.6116	-131.95	1.9863	1.4895	0.8964	0.9689E+05	0.1658E-02	0.2831E-02	564.99	3.5261
75.0	1.5801	-124.51	2.0890	1.4818	0.8736	0.9281E+05	0.1517E-02	0.2420E-02	505.73	3.2156
80.0	1.5479	-117.11	2.1844	1.4703	0.8329	0.8924E+05	0.1499E-02	0.2078E-02	451.17	2.9348
85.0	1.5150	-109.80	2.2731	1.4554	0.7923	0.8580E+05	0.1424E-02	0.1792E-02	400.64	2.6790
90.0	1.4810	-102.54	2.3561	1.4490	0.7564	0.8231E+05	0.1552E-02	0.1552E-02	353.62	2.4431
95.0	1.4458	-95.27	2.4347	1.4583	0.7328	0.7850E+05	0.1281E-02	0.1350E-02	309.70	2.2234
100.0	1.4091	-87.91	2.5101	1.4870	0.7244	0.7425E+05	0.1212E-02	0.1180E-02	268.58	2.0166
105.0	1.3706	-80.36	2.5838	1.5350	0.7298	0.6956E+05	0.1144E-02	0.1036E-02	230.02	1.8203
110.0	1.3298	-72.54	2.6566	1.5977	0.7426	0.6458E+05	0.1078E-02	0.9131E-03	193.84	1.6326
115.0	1.2861	-64.37	2.7292	1.6639	0.7523	0.5955E+05	0.1011E-02	0.8083E-03	159.91	1.4517
120.0	1.2286	-55.84	2.8018	1.7176	0.7234	0.5515E+05	0.9445E-03	0.7112E-03	128.12	1.2761
125.0	1.1859	-46.94	2.8745	1.8216	0.7207	0.4987E+05	0.8764E-03	0.6397E-03	98.399	1.1040
130.0	1.1253	-37.55	2.9481	1.9852	0.7222	0.4409E+05	0.8053E-03	0.5700E-03	70.668	0.9328
135.0	1.0512	-27.25	3.0258	2.2937	0.7392	0.3753E+05	0.7272E-03	0.5057E-03	44.86	0.7575
140.0	0.9466	-14.22	3.1205	3.1523	0.7523	0.2900E+05	0.6311E-03	0.4397E-03	20.763	0.5647
145.0	0.3883	44.82	3.5315	10.37	0.8307	0.1605E+05	0.2958E-03	0.2288E-03	2.0632	0.1431
150.0	0.2728	66.90	3.6818	2.6655	0.7432	0.1751E+05	0.2523E-03	0.1914E-03	8.5464	0.9028E-01
155.0	0.2344	77.96	3.7542	1.8898	0.7025	0.1852E+05	0.2423E-03	0.1825E-03	12.756	0.7322E-01
160.0	0.2108	86.50	3.8086	1.5682	0.6762	0.1936E+05	0.2384E-03	0.1789E-03	16.153	0.6327E-01
165.0	0.1938	93.85	3.8538	1.3833	0.6570	0.2008E+05	0.2374E-03	0.1778E-03	19.086	0.5638E-01
170.0	0.1837	100.49	3.8935	1.2725	0.6429	0.2013E+05	0.2379E-03	0.1780E-03	21.710	0.5122E-01
175.0	0.1690	106.64	3.9291	1.1917	0.6323	0.2132E+05	0.2394E-03	0.1790E-03	24.111	0.4719E-01
180.0	0.1609	112.44	3.9618	1.1321	0.6235	0.2187E+05	0.2415E-03	0.1805E-03	26.343	0.4390E-01
185.0	0.1532	117.98	3.9922	1.0856	0.6168	0.2238E+05	0.2442E-03	0.1825E-03	28.442	0.4116E-01
190.0	0.1464	123.32	4.0207	1.0538	0.6116	0.2287E+05	0.2473E-03	0.1847E-03	30.434	0.3882E-01
195.0	0.1403	128.50	4.0476	1.0222	0.6074	0.2333E+05	0.2506E-03	0.2376E-03	32.337	0.3600E-01
200.0	0.1349	133.55	4.0732	0.9938	0.6042	0.2377E+05	0.2542E-03	0.1898E-03	34.166	0.3503E-01
220.0	0.1117	152.96	4.1652	0.9334	0.5975	0.2535E+05	0.2701E-03	0.2012E-03	40.932	0.2950E-01
240.0	0.1051	171.28	4.2454	0.9072	0.5970	0.2675E+05	0.2877E-03	0.2132E-03	47.099	0.2554E-01
260.0	0.9531E-01	189.24	4.3172	0.8950	0.5993	0.2802E+05	0.3011E-03	0.2255E-03	52.884	0.2317E-01
280.0	0.6252E-01	295.02	4.6518	0.8874	0.6069	0.2918E+05	0.3250E-03	0.2376E-03	58.405	0.2101E-01
300.0	0.5944E-01	296.95	4.3829	0.8820	0.6074	0.3027E+05	0.3443E-03	0.2496E-03	63.736	0.1925E-01
310.0	0.8079E-01	224.55	4.4436	0.8734	0.6111	0.3129E+05	0.3638E-03	0.2614E-03	68.923	0.1780E-01
320.0	0.7521E-01	242.11	4.5003	0.8731	0.6182	0.3226E+05	0.3833E-03	0.2730E-03	73.999	0.1656E-01
340.0	0.7040E-01	259.69	4.5535	0.8739	0.6257	0.3319E+05	0.4029E-03	0.2844E-03	78.985	0.1550E-01
360.0	0.6621E-01	277.32	4.6039	0.8832	0.6334	0.3407E+05	0.4225E-03	0.2957E-03	83.900	0.1457E-01
380.0	0.6252E-01	295.02	4.6518	0.8874	0.6413	0.3493E+05	0.4421E-03	0.3069E-03	88.755	0.1376E-01
510.0	0.4706E-01	403.34	4.8993	0.9134	0.6491	0.3883E+05	0.5375E-03	0.3586E-03	112.42	0.1079E-01
20.848	IS OUT OF RANGE FOR P	IN SUB-E <sup>NTH</sup>								
24.393	IS OUT OF RANGE FOR P	IN SUB-E <sup>NTH</sup>								
23.238	IS OUT OF RANGE FOR P	IN SUB-E <sup>NTH</sup>								
22.135	IS OUT OF RANGE FOR P	IN SUB-E <sup>NTH</sup>								
21.154	IS OUT OF RANGE FOR P	IN SUB-E <sup>NTH</sup>								

THERMODYNAMIC PROPERTY TABLE — F2 KU= 1

100.00 ATW ISOBAR											
TEMP K	DENSITY G/C	ENTHALPY J/G	ENTROPY J/G-K	CP J/G-K	CV J/G-K	SOL VEL CM/S	THERM COND J/CM-S-K	VISC G/CM-S	DP/DD MN-CG/M2	DP/DT MN/K-M2	
70.0	1.6200	-129.72	1.9747	1.4828	0.8999	0.9878E+05	0.1682E-02	0.2958E-02	593.03	3.5940	
75.0	1.5895	-122.32	2.0767	1.4741	0.8736	0.9496E+05	0.1602E-02	0.2536E-02	534.39	3.2880	
80.0	1.5585	-114.99	2.1714	1.4510	0.8351	0.9156E+05	0.1526E-02	0.2184E-02	480.48	3.0120	
85.0	1.5268	-107.75	2.2592	1.4388	0.7934	0.8837E+05	0.1453E-02	0.1889E-02	384.63	2.7609	
90.0	1.4943	-100.58	2.3412	1.4292	0.7563	0.8516E+05	0.1382E-02	0.1642E-02	384.33	2.5301	
95.0	1.4609	-93.43	2.4184	1.4180	0.7323	0.8168E+05	0.1313E-02	0.1434E-02	341.18	2.3158	
100.0	1.4264	-86.24	2.4924	1.4056	0.7228	0.7779E+05	0.1247E-02	0.1258E-02	300.88	2.1151	
105.0	1.3905	-78.86	2.5642	1.3910	0.7270	0.7350E+05	0.1182E-02	0.1109E-02	263.21	1.9256	
110.0	1.3531	-71.28	2.6347	1.3513	0.7384	0.6899E+05	0.1118E-02	0.9825E-03	228.02	1.7457	
115.0	1.3139	-63.45	2.7043	1.3594	0.7466	0.6452E+05	0.1056E-02	0.8749E-03	195.19	1.5742	
120.0	1.2723	-55.37	2.7731	1.6347	0.7395	0.6033E+05	0.9952E-03	0.7830E-03	164.65	1.4101	
125.0	1.2280	-47.12	2.8404	1.6676	0.7087	0.5656E+05	0.9347E-03	0.7042E-03	136.36	1.2527	
130.0	1.1802	-38.74	2.9062	1.7311	0.7048	0.5205E+05	0.8744E-03	0.6362E-03	110.32	1.1013	
135.0	1.1278	-30.17	2.9709	1.8231	0.7037	0.4736E+05	0.8138E-03	0.5771E-03	86.575	0.9955	
140.0	1.0691	-20.87	3.0385	1.9520	0.7056	0.4248E+05	0.7521E-03	0.5249E-03	65.239	0.8148	
145.0	1.0018	-10.20	3.1134	2.1417	0.7113	0.3743E+05	0.6881E-03	0.4780E-03	46.54	0.6788	
150.0	0.9216	1.184	3.1905	2.4343	0.7214	0.3231E+05	0.6204E-03	0.4346E-03	30.935	0.5477	
155.0	0.8227	1.4386	3.2771	2.8634	0.7360	0.2744E+05	0.5478E-03	0.3927E-03	19.311	0.4441	
160.0	0.7043	29.84	3.3752	3.2658	0.7492	0.2371E+05	0.4740E-03	0.3516E-03	12.899	0.3172	
165.0	0.5883	46.08	3.4752	3.1275	0.7472	0.2196E+05	0.4135E-03	0.3157E-03	11.525	0.2999	
170.0	0.4998	60.53	3.5615	2.6396	0.7299	0.2161E+05	0.3744E-03	0.2893E-03	12.919	0.1904	
175.0	0.4379	72.59	3.6314	2.2033	0.7085	0.2183E+05	0.3510E-03	0.2715E-03	15.320	0.1584	
180.0	0.3936	82.78	3.6889	1.8926	0.6891	0.2223E+05	0.3366E-03	0.2596E-03	17.990	0.1365	
185.0	0.3604	91.67	3.7376	1.6764	0.6727	0.2269E+05	0.3275E-03	0.2516E-03	20.665	0.1207	
190.0	0.3333	99.65	3.7801	1.5222	0.6593	0.2317E+05	0.3218E-03	0.2460E-03	23.258	0.1086	
195.0	0.3131	106.96	3.8181	1.4036	0.6445	0.2365E+05	0.3182E-03	0.2422E-03	25.744	0.9948E-01	
200.0	0.2954	113.78	3.8527	1.3223	0.6397	0.2411E+05	0.3163E-03	0.2397E-03	28.123	0.9520E-01	
220.0	0.2455	137.95	3.9680	1.1225	0.6185	0.2582E+05	0.3173E-03	0.2371E-03	36.731	0.7120E-01	
240.0	0.2133	159.36	4.0612	1.0236	0.6102	0.2732E+05	0.3259E-03	0.2407E-03	44.286	0.5228E-01	
260.0	0.1902	179.38	4.1413	0.9779	0.6087	0.2867E+05	0.3381E-03	0.2472E-03	51.157	0.5227E-01	
280.0	0.1724	198.61	4.2126	0.9436	0.6103	0.2990E+05	0.3525E-03	0.2552E-03	57.559	0.4563E-01	
300.0	0.1582	217.40	4.2774	0.9313	0.6154	0.3103E+05	0.3682E-03	0.2640E-03	63.623	0.4095E-01	
320.0	0.1464	235.92	4.3372	0.9214	0.6212	0.3209E+05	0.3848E-03	0.2733E-03	69.434	0.3373E-01	
340.0	0.1365	254.28	4.3929	0.9161	0.6273	0.3309E+05	0.4020E-03	0.2829E-03	75.048	0.3443E-01	
360.0	0.1280	272.58	4.4452	0.9140	0.6351	0.3404E+05	0.4197E-03	0.2927E-03	80.507	0.3196E-01	
380.0	0.1205	290.86	4.4946	0.9140	0.6425	0.3495E+05	0.4376E-03	0.3027E-03	85.839	0.2985E-01	
400.0	0.1140	309.15	4.5415	0.9155	0.6503	0.3581E+05	0.4557E-03	0.3127E-03	91.067	0.2803E-01	
500.0	0.9012E-01	401.46	4.7474	0.9320	0.6849	0.3975E+05	0.5461E-03	0.3611E-03	116.13	0.2159E-01	

THERMODYNAMIC AND TRANSPORT PROPERTIES FOR HYDROGEN PC=12.759 ATM, TC=32.976 K, RHOC=.031436/CC

0.9185E-0515 OUT OF RANGE FOR D IN SUB-ENTH  
 0.7326E-01 -291.95  
 0.8185E-0515 OUT OF RANGE FOR D IN SUB-ENTH  
 0.81F5E-0515 OUT OF RANGE FOR D IN SUB-ENTH  
 0.9185E-0515 OUT OF RANGE FOR D IN SUB-ENTH  
 0.8185E-0515 OUT OF RANGE FOR D IN SUB-VISC  
 0.8185E-0515 OUT OF RANGE FOR D IN SUB-THERM

THERMODYNAMIC PROPERTY TABLE -- H2 KU= 1

1.00 ATM ISOBAR

TEMP K	DENSITY G/CC		ENTHALPY J/G		ENTROPY J/G-K		CP J/G-K		CV J/G-K		SON VEL CM/S		THERM COND J/CM-S-K		VISC G/CM-S		DP/DD MN-CC/G-M2		DP/DT MN/K-M2	
	ENTROPY	CP	ENTROPY	CP	ENTROPY	CP	ENTROPY	CP	ENTROPY	CP	SON VEL	THRM COND	VISC	DP/DD	DP/DT	DP/DD	DP/DT	DP/DD	DP/DT	
16.0	0.7519E-01	-291.95	6.0160	8.2828	5.8330	0.1205E+06	0.8900E-03	0.1995E-03	1022.8	0.9410										
18.0	0.7326E-01	-274.86	7.0220	8.8288	5.7932	0.1150E+06	0.9555E-03	0.1620E-03	967.85	0.8863										
20.0	0.7108E-01	-256.62	9.4205	5.5421	0.1109E+06	0.9838E-03	0.1364E-03	722.97	0.8616											
22.0	0.1209E-02	210.80	31.003	11.416	6.2346	0.3753E+05	0.1762E-03	0.1220E-04	76.930	0.5148E-02										
24.0	0.1090E-02	233.44	31.987	11.200	6.2363	0.3952E+05	0.1919E-03	0.1324E-04	86.969	0.4623E-02										
26.0	0.9940E-03	255.64	32.877	11.044	6.2360	0.4138E+05	0.2075E-03	0.1425E-04	96.669	0.4203E-02										
28.0	0.9145E-03	277.61	33.691	10.926	6.2342	0.4313E+05	0.2231E-03	0.1522E-04	106.112	0.3856E-02										
30.0	0.8475E-03	299.36	34.441	10.834	6.2315	0.4479E+05	0.2387E-03	0.1622E-04	115.38	0.3566E-02										
32.0	0.7901E-03	320.96	35.138	10.761	6.2254	0.4638E+05	0.2544E-03	0.1717E-04	124.49	0.3318E-02										
34.0	0.7403E-03	342.42	35.789	10.702	6.2254	0.4790E+05	0.2662E-03	0.1811E-04	133.47	0.3104E-02										
36.0	0.6967E-03	363.77	36.399	10.654	6.2223	0.4937E+05	0.2802E-03	0.1902E-04	142.37	0.2917E-02										
38.0	0.6581E-03	385.04	36.974	10.614	6.2193	0.5079E+05	0.2942E-03	0.1992E-04	151.18	0.2752E-02										
40.0	0.6236E-03	406.23	37.518	10.616	6.2153	0.5211E+05	0.3081E-03	0.2080E-04	159.93	0.2605E-02										
50.0	0.4951E-03	511.39	39.865	10.484	6.2183	0.5850E+05	0.3776E-03	0.2498E-04	202.98	0.2061E-02										
60.0	0.4111E-03	617.08	41.791	10.703	6.4858	0.6363E+05	0.4479E-03	0.2888E-04	245.36	0.1707E-02										
70.0	0.2517E-03	726.30	43.474	11.178	6.9884	0.6780E+05	0.5251E-03	0.3245E-04	287.37	0.1459E-02										
80.0	0.3074E-03	841.24	45.008	11.834	7.6161	0.7131E+05	0.6027E-03	0.3585E-04	329.17	0.1274E-02										
90.0	0.2730E-03	963.37	46.445	12.604	8.4428	0.7444E+05	0.7017E-03	0.3908E-04	370.84	0.1131E-02										
100.0	0.2456E-03	1093.5	47.815	13.425	9.2708	0.7728E+05	0.8007E-03	0.4116E-04	412.42	0.1017E-02										
110.0	0.2232E-03	1231.8	49.133	14.235	10.086	0.8004E+05	0.9033E-03	0.4427E-04	455.93	0.9237E-03										
120.0	0.2046E-03	1378.0	50.404	14.975	10.831	0.8276E+05	0.1006E-02	0.4697E-04	495.39	0.8463E-03										
130.0	0.1888E-03	1530.9	51.628	15.589	11.448	0.8550E+05	0.1092E-02	0.4961E-04	536.82	0.7809E-03										
140.0	0.1753E-03	1689.1	52.801	16.021	11.882	0.8830E+05	0.1172E-02	0.5218E-04	578.22	0.7249E-03										
150.0	0.1636E-03	1850.6	53.914	16.217	12.080	0.9120E+05	0.1252L-02	0.5469E-04	61.9.60	0.6764E-03										
160.0	0.1534E-03	2011.3	54.952	16.237	12.101	0.9417E+05	0.1335E-02	0.5715E-04	660.97	0.6340E-03										
170.0	0.1444E-03	2173.6	55.936	16.220	12.085	0.9709E+05	0.1415E-02	0.6068E-04	702.32	0.5966E-03										
180.0	0.1363E-03	2335.6	56.862	16.173	12.039	0.9995E+05	0.1491E-02	0.6419E-04	743.66	0.5634E-03										
190.0	0.1292E-03	2497.0	57.734	16.101	11.963	0.1028E+06	0.1562E-02	0.6824E-04	784.99	0.5337E-03										
200.0	0.1227E-03	2657.6	58.538	16.010	11.878	0.1055E+06	0.1639E-02	0.6665E-04	826.32	0.5070E-03										
300.0	0.8181E-04	4198.9	64.824	14.846	10.717	0.1310E+06	0.2160E-02	0.8716E-04	1239.3	0.3379E-03										
400.0	0.6136E-04	566.0.9	69.031	14.591	10.464	0.1518E+06	0.2664E-02	0.1068E-03	1652.1	0.2534E-03										
500.0	0.4909E-04	7126.9	72.303	14.516	10.389	0.1699E+06	0.3134E-02	0.1244E-03	2064.8	0.2027E-03										
600.0	0.4091E-04	8698.8	74.944	14.544	10.417	0.1860E+06	0.3579E-02	0.1410E-03	2477.5	0.1689E-03										
700.0	0.3507E-04	10101.0	77.193	14.652	10.526	0.2006E+06	0.4005E-02	0.1625E-03	2890.1	0.1448E-03										
800.0	0.3069E-04	0.1163E+05	79.158	14.778	10.652	0.2143E+06	0.4414E-02	0.1716E-03	3302.8	0.1267E-03										
900.0	0.2728E-04	0.1311E+05	80.907	14.919	10.793	0.2266E+06	0.4810E-02	0.1860E-03	3715.4	0.1126E-03										
1000.0	0.2455E-04	0.1461E+05	82.486	15.074	10.948	0.2384E+06	0.5194E-02	0.1998E-03	4128.0	0.1013E-03										
1100.0	0.2232E-04	0.1613E+05	83.931	15.239	11.113	0.2495E+06	0.5561E-02	0.2133E-03	4540.7	0.9212E-04										
1200.0	0.2046E-04	0.1766E+05	85.264	15.414	11.288	0.2601E+06	0.5931E-02	0.2264E-03	4953.3	0.8444E-04										
1300.0	0.1889E-04	0.1921E+05	86.505	15.596	11.470	0.2701E+06	0.6208E-02	0.2391E-03	5365.9	0.7794E-04										
1400.0	0.1754E-04	0.2078E+05	87.668	15.783	11.657	0.2797E+06	0.6537E-02	0.2515E-03	5778.5	0.7238E-04										
1500.0	0.1637E-04	0.2237E+05	88.763	15.974	11.848	0.2889E+06	0.6919E-02	0.2637E-03	6191.1	0.6755E-04										
1600.0	0.1535E-04	0.2398E+05	89.800	16.167	12.041	0.2978E+06	0.7315E-02	0.2755E-03	6603.7	0.6333E-04										
1700.0	0.1444E-04	0.2560E+05	90.786	16.361	12.234	0.3063E+06	0.7645E-02	0.2872E-03	7016.4	0.5960E-04										
1800.0	0.1364E-04	0.2725E+05	91.727	16.554	12.427	0.3144E+06	0.7970E-02	0.2986E-03	7429.0	0.5629E-04										
1900.0	0.1229E-04	0.2891E+05	92.627	16.745	12.619	0.3226E+06	0.8291E-02	0.3099E-03	7841.6	0.5333E-04										
3000.0	0.8185E-05	0.4836E+05	100.67	18.484	14.358	0.3992E+06	0.4234E-03	0.4234E-03	0.1238E+05	0.3378E-04										

THERMODYNAMIC PROPERTY TABLE -- H2 KU= 1

## 12.76 ATM ISOBAR

TEMP K	DENSITY G/CC	ENTHALPY J/G	ENTROPY J/G-K	CP J/G-K	CV J/G-K	SON VEL CM/S	THERM COND J/CM-S-K	VI SC G/CM-S	DP/DD MN-CC/G-H2	DP/DD MN-K-H2
16.0	0.7630E+01	-279.14	5.8338	8.0870	5.9072	0.1244E+06	0.2077E-03	0.2161E-03	1130.6	0.9469
18.0	0.7455E+01	-262.54	6.8103	8.5080	5.8103	0.1200E+06	0.9815E-03	0.1765E-03	983.18	0.9049
20.0	0.7260E+01	-245.09	8.9401	5.5373	5.4777	0.1167E+06	0.1018E-02	0.485E-02	845.92	0.8710
22.0	0.7041E+01	-226.44	8.6176	9.7592	7.7296	0.1127E+06	0.1050E-02	0.1272E-03	713.34	0.8296
24.0	0.6792E+01	-205.64	9.5219	2.3858	2.7785	0.1379E+06	0.1053E-02	0.1052E-03	777.75	0.7775
26.0	0.6504E+01	-181.48	9.6610	2.7785	2.7785	0.1258E+06	0.1037E-02	0.9595E-04	455.13	0.7139
28.0	0.6156E+01	-152.80	11.549	3.4954	3.4954	0.1089E+06	0.9974E-03	0.8328E-04	327.92	0.6374
30.0	0.5702E+01	-117.46	12.767	4.2584	4.2584	0.9161E+05	0.9313E-03	0.7108E-04	200.83	0.5428
32.0	0.4954E+01	-64.70	14.461	5.0282	5.0282	0.7076E+05	0.6042E-03	0.5681E-04	71.195	0.4070
34.0	0.1684E+01	169.34	21.557	41.54	6.6030	0.4233E+05	0.3879E-03	0.2439E-04	28.484	0.9111E-01
36.0	0.1311E+01	228.83	23.261	23.443	6.6478	0.4489E+05	0.3717E-03	0.2315E-04	57.153	0.6768E-01
38.0	0.1128E+01	270.42	24.386	18.824	6.6325	0.4720E+05	0.3723E-03	0.2324E-04	78.494	0.5658E-01
40.0	0.1006E+01	305.63	25.290	16.640	6.6394	0.4918E+05	0.3779E-03	0.2366E-04	96.516	0.4944E-01
50.0	0.6983E+02	448.02	12.888	6.4698	6.4698	0.5754E+05	0.4227E-03	0.2687E-04	166.19	0.3225E-01
60.0	0.5521E+02	571.95	30.744	12.072	6.6508	0.6351E+05	0.4884E-03	0.3034E-04	222.19	0.2474E-01
70.0	0.4613E+02	692.24	32.599	12.074	7.1013	0.6810E+05	0.5602E-03	0.3371E-04	272.75	0.2030E-01
80.0	0.3979E+02	814.71	34.234	12.468	7.7420	0.7184E+05	0.6337E-03	0.3694E-04	320.48	0.1731E-01
90.0	0.3571E+02	942.31	35.36	13.077	8.0519	0.7508E+05	0.7304E+03	0.4005E-03	366.51	0.1514E-01
100.0	0.3139E+02	1076.6	37.150	9.3155	12.888	0.7804E+05	0.8224E-03	0.2336E-04	411.45	0.1347E-01
110.0	0.2844E+02	1218.2	38.459	14.526	10.121	0.8087E+05	0.9233E-03	0.4506E-04	455.64	0.1215E-01
120.0	0.2601E+02	1366.9	39.793	15.212	10.858	0.8364E+05	0.1029E-02	0.4770E-04	499.29	0.1107E-01
130.0	0.2397E+02	1522.1	41.034	15.786	11.473	0.8664E+05	0.1114E-02	0.5028E-04	542.53	0.1017E-01
140.0	0.2223E+02	1682.1	42.220	16.187	11.902	0.8924E+05	0.1193E-02	0.5281E-04	585.46	0.9414E-02
150.0	0.2074E+02	1845.0	43.344	16.359	12.095	0.9217E+05	0.1272E-02	0.5528E-04	628.16	0.8763E-02
160.0	0.1943E+02	2007.1	44.350	16.359	12.113	0.9517E+05	0.1353E-02	0.5770E-04	670.66	0.8197E-02
170.0	0.1828E+02	2170.6	45.381	16.327	12.096	0.9810E+05	0.1431E-02	0.6009E-04	713.00	0.7701E-02
180.0	0.1726E+02	2333.6	46.313	16.267	12.048	0.1010E+06	0.1504E-02	0.6243E-04	755.22	0.7262E-02
190.0	0.1635E+02	2495.8	47.190	16.185	11.976	0.1038E+06	0.1574E-02	0.6473E-04	797.33	0.6872E-02
200.0	0.1553E+02	2657.2	48.018	16.084	11.884	0.1066E+06	0.1640E-02	0.6700E-04	839.35	0.6552E-02
300.0	0.1037E+02	4203.4	54.303	14.876	10.652	0.1321E+06	0.2148E-02	0.8808E-04	1256.7	0.4325E-02
400.0	0.7783E+03	56.675	58.518	14.608	10.464	0.1528E+06	0.2664E-02	0.1074E-02	1671.6	0.3239E-02
500.0	0.6232E+03	71.348	61.792	14.526	10.390	0.1708E+06	0.3134E-02	0.1246E-03	2085.6	0.2589E-02
600.0	0.5197E+03	87.076	64.434	14.551	10.418	0.1858E+06	0.3579E-02	0.1411E-03	2499.1	0.2157E-02
700.0	0.4457E+03	101.7E+05	66.685	14.657	10.526	0.2014E+06	0.4045E-02	0.1567E-03	2912.3	0.1848E-02
800.0	0.3902E+03	116.4E+05	68.650	14.782	10.676	0.2148E+06	0.4414E-02	0.1717E-02	3325.4	0.1617E-02
900.0	0.3470E+03	131.2E+05	70.399	14.922	10.793	0.2273E+06	0.4810E-02	0.1861E-03	3738.4	0.1437E-02
1000.0	0.3124E+03	146.2E+05	71.979	15.076	10.948	0.2391E+06	0.5194E-02	0.1999E-03	4151.3	0.1293E-02
1100.0	0.2840E+03	161.4E+05	73.424	15.241	11.113	0.2502E+06	0.5567E-02	0.2134E-03	4564.1	0.1176E-02
1200.0	0.2604E+03	176.7E+05	74.757	15.416	11.288	0.2607E+06	0.5931E-02	0.2264E-03	4916.9	0.1078E-02
1300.0	0.2404E+03	192.2E+05	75.999	15.597	11.473	0.2707E+06	0.6288E-02	0.2399E-03	5389.7	0.9946E-02
1400.0	0.2233E+03	207.9E+05	77.161	15.784	11.657	0.2803E+06	0.6637E-02	0.2514E-03	5802.4	0.9236E-02
1500.0	0.2084E+03	223.8E+05	78.257	15.775	11.848	0.2895E+06	0.6979E-02	0.2637E-03	6215.2	0.8620E-02
1600.0	0.1954E+03	239.9E+05	79.294	16.168	12.041	0.2983E+06	0.7315E-02	0.2756E-03	6627.9	0.8081E-02
1700.0	0.1840E+03	256.1E+05	80.280	16.361	12.234	0.3068E+06	0.7645E-02	0.2875E-03	7040.6	0.7605E-02
1800.0	0.1738E+03	272.6E+05	81.221	16.554	12.427	0.3151E+06	0.7970E-02	0.2987E-03	743.3	0.7183E-03
1900.0	0.1646E+03	289.3E+05	82.121	16.745	12.619	0.3231E+06	0.8291E-02	0.3099E-03	7866.0	0.6805E-03
3000.0	0.1043E+03	448.38E+05	90.167	14.358	14.358	0.3996E+06	0.4235E-05	0.4309E-03	0.1241E+05	

0.41836E+C0 IS OUT OF RANGE OF CURVE FIT VALUE IS EXTRAPOLATED.

0.41239E+C0 IS OUT OF RANGE OF CURVE FIT VALUE IS EXTRAPOLATED.

0.40580E+00 IS OUT OF RANGE OF CURVE FIT VALUE IS EXTRAPOLATED.

THERMODYNAMIC PROPERTY TABLE -- H2 KU= 1

100.00 ATM ISOBAR						DP/DD MN-CC/G-M2						DP/DT MN/K-M2					
TEMP K	DENSITY G/CC	ENTHALPY J/G	FNTROPY J/G-K	CP J/G-K	CV J/G-K	SON VEL CM/S	THERM COND J/CM-S-K	VISC G/CM-S	DP/DD MN-CC/G-M2	DP/DT MN/K-M2							
16.0	3.8236E-01	-1.82-.83	4.9059	7.2316	5.9901	0.1479E+06	0.1007E-02	0.3526E-03	1.812.9	0.9768							
18.0	0.8122E-01	-1.68.28	5.7627	7.2710	5.6823	0.1471E+06	0.2834E-03	0.1124E-02	1.691.2	0.9925							
20.0	0.8001E-01	-1.53.62	6.5349	7.3588	5.3682	0.1470E+06	0.1198E-03	0.2367E-02	1.576.4	1.0022							
22.0	0.7889E-01	-1.38.54	7.2533	7.7460	5.3315	0.1459E+06	0.1269E-02	0.2032E-03	1.465.9	0.9981							
24.0	0.7729E-01	-1.22.35	7.9572	8.5174	5.6692	0.1429E+06	0.1313E-02	0.1781E-03	1.359.2	0.9816							
26.0	0.7581E-01	-1.04.41	8.6744	9.4875	6.1985	0.1381E+06	0.1536E-02	0.1558E-03	1.265.4	0.9557							
28.0	0.7425E-01	-8.4.640	9.4067	10.295	6.5572	0.1348E+06	0.1345E-02	0.1429E-03	1.157.9	0.9231							
30.0	0.7262E-01	-6.3.496	10.136	10.426	6.2288	0.1355E+06	0.1342E-02	0.1300E-03	1.064.0	0.8860							
32.0	0.7092E-01	-4.0.724	10.870	9.0235	4.3546	0.1421E+06	0.1322E-02	0.1192E-03	975.00	0.8458							
34.0	0.6915E-01	-2.0.892	11.471	10.630	5.4749	0.1315E+06	0.1297E-02	0.1100E-03	891.19	0.8038							
36.0	0.6731E-01	-1.3541	12.107	11.589	5.9363	0.1260E+06	0.1269E-02	0.1021E-03	812.90	0.7605							
38.0	0.6541E-01	25.406	12.757	12.449	6.2859	0.1211E+06	0.1239E-02	0.9517E-04	740.48	0.7168							
40.0	0.6344E-01	51.095	13.416	13.263	6.5875	0.1165E+06	0.1208E-02	0.8906E-04	674.27	0.6730							
50.0	0.5300E-01	1.98.67	16.697	15.947	7.1179	0.9986E+05	0.1052E-02	0.6746E-04	445.08	0.4698							
60.0	0.4318E-01	362.66	19.686	16.519	7.3829	0.9094E+05	0.9461E-03	0.5650E-04	369.60	0.3239							
70.0	0.2566E-01	525.45	22.196	15.994	7.7334	0.8789E+05	0.9144E-03	0.5204E-04	373.51	0.2367							
80.0	0.3021E-01	683.01	24.301	15.574	8.2433	0.8753E+05	0.9220E-03	0.5083E-04	405.50	0.1845							
90.0	0.2635E-01	838.11	26.128	15.501	8.8907	0.8833E+05	0.9181E-03	0.5113E-04	447.55	0.1511							
100.0	0.2339E-01	993.95	27.769	15.704	9.6176	0.8974E+05	0.1052E-02	0.5152E-04	493.26	0.1282							
110.0	0.2101E-01	1152.7	29.282	16.064	10.358	0.9152E+05	0.1133E-02	0.5284E-04	540.11	0.1116							
120.0	0.1922E-01	1315.4	30.698	16.474	11.047	0.9357E+05	0.1218E-02	0.5446E-04	587.10	0.9988E-01							
130.0	0.1767E-01	1482.0	32.031	16.839	11.622	0.9583E+05	0.1289E-02	0.5823E-04	633.83	0.8911E-01							
140.0	0.1688E-01	1651.8	33.289	17.079	12.025	0.9829E+05	0.1356E-02	0.5817E-04	680.18	0.8115E-01							
150.0	0.1527E-01	1823.0	34.470	17.126	12.198	0.1010E+06	0.1427E-02	0.6016E-04	726.12	0.7457E-01							
160.0	0.1431E-01	1992.2	35.562	17.026	12.203	0.1038E+06	0.1495E-02	0.6219E-04	771.69	0.6904E-01							
170.0	0.1347E-01	2161.9	36.591	16.912	12.169	0.1066E+06	0.1562E-02	0.6424E-04	816.91	0.6431E-01							
180.0	0.1233E-01	2330.4	37.554	16.786	12.111	0.1093E+06	0.1627E-02	0.6630E-04	861.81	0.6023E-01							
190.0	0.1120E-01	2497.6	38.458	16.648	12.030	0.1120E+06	0.1689E-02	0.6836E-04	906.44	0.5665E-01							
200.0	0.1148E-01	2663.4	39.308	16.501	11.931	0.1147E+06	0.1746E-02	0.7042E-04	950.83	0.5349E-01							
300.0	0.7736E-02	4237.2	45.710	15.063	10.734	0.1394E+06	0.2195E-02	0.9029E-04	1385.7	0.3499E-01							
400.0	0.5876E-02	5715.6	49.966	14.715	10.471	0.1596E+06	0.2688E-02	0.1029E-03	181.87	0.2588E-01							
500.0	0.4717E-02	7191.7	53.259	14.597	10.393	0.1771E+06	0.3154E-02	0.1259E-03	223.3	0.2464E-01							
600.0	0.3922E-02	8770.4	55.913	14.601	10.420	0.1928E+06	0.3597E-02	0.1422E-03	2652.4	0.1699E-01							
700.0	0.3401E-02	1023E+05	58.170	14.695	14.527	0.2070E+06	0.4022E-02	0.1577E-03	3070.0	0.1454E-01							
800.0	0.2955E-02	1171E+05	60.140	14.811	10.653	0.2202E+06	0.4414E-02	0.1725E-03	3486.5	0.1271E-01							
900.0	0.2661E-02	1320E+05	61.892	14.946	10.794	0.2324E+06	0.4810E-02	0.1868E-03	3902.2	0.1129E-01							
1000.0	0.2400E-02	1470E+05	63.474	15.095	10.948	0.2440E+06	0.5194E-02	0.2006E-03	4317.4	0.1015E-01							
1100.0	0.2166E-02	1622E+05	64.920	15.257	11.114	0.2652E+06	0.5567E-02	0.2140E-03	4732.2	0.9228E-02							
1200.0	0.2007E-02	1775E+05	66.255	15.429	11.288	0.2852E+06	0.5932E-02	0.2270E-03	5146.6	0.857E-02							
1300.0	0.1855E-02	1930E+05	67.497	15.609	11.473	0.2751E+06	0.6288E-02	0.2397E-03	5560.8	0.7804E-02							
1400.0	0.1724E-02	2087E+05	68.661	15.794	11.657	0.2845E+06	0.66337E-02	0.2521E-03	5974.8	0.7246E-02							
1500.0	0.1611E-02	2246E+05	69.757	15.984	11.848	0.2936E+06	0.6979E-02	0.2642E-03	6388.6	0.6762E-02							
1600.0	0.1512E-02	2407E+05	70.795	16.176	12.061	0.3023E+06	0.7315E-02	0.2760E-03	6802.3	0.6338E-02							
1700.0	0.1424E-02	2570E+05	71.781	16.368	12.235	0.3107E+06	0.7645E-02	0.2877E-03	7215.9	0.5965E-02							
1800.0	0.1346E-02	2734E+05	72.722	16.560	12.428	0.3189E+06	0.7970E-02	0.2991E-03	7629.3	0.5633E-02							
1900.0	0.1276E-02	2901E+05	73.623	16.751	12.619	0.3267E+06	0.8291E-02	0.3103E-03	8042.7	0.5336E-02							
30000.0	0.8117E-03	0.4846E+05	81.671	14.358	14.358	0.4026E+06	0.4237E-03	0.4237E-03	0.3378E-02	0.1259E+05							

## APPENDIX J

### SAMPLE PROBLEMS WITH OUTPUT

It is often instructive to present a few examples as an aid to the user. In this appendix, we have chosen four rather simple problems in order to demonstrate how to make calls to GASP.

#### PROBLEM 1

Calculate the heat-transfer coefficient for liquid hydrogen flowing turbulently through a tube for these conditions:

- (1) Tube diameter, 0.8 cm
- (2) Average bulk velocity, 60 m/sec
- (3) Average bulk temperature, 25 K
- (4) Average bulk pressure, 6 megapascals
- (5) Tube wall temperature, 450 K

$$Nu = 0.021 Re_f^{0.8} Pr_f^{0.4} \left( 1 + 0.01453 \frac{\nu_w}{\nu_b} \right)$$

where

Nu Nusselt number,  $hd/k$

Re Reynolds number,  $\rho Vd/u$

Pr Prandtl number,  $\mu C_p/k$

h desired heat-transfer coefficient

d tube diameter

k thermal conductivity

$\rho$  density

$\mu$  dynamic viscosity

$\nu$  kinematic viscosity,  $\mu/\rho$

$C_p$  specific heat

u average bulk velocity

and the subscripts b, f, and w denote bulk, film, and wall conditions, respectively.

```

C
C DO NOT USE K AS AN INDEX IT MEANS THERMAL CONDUCTIVITY
C DO NOT FORGET YOUR COMMON STATEMENT
C
C COMMON/PROPTY/KU,DL,DV,HL,HV,S,SL,SV,CV,CVL,CVV,CPL,CPV,GAMMA,
C 1GAMMA,L,GAMMAV,C,CL,CVP,MU,MUL,MUV,K,KL,KV,SIGMA,EXCESK,EXCL,EXCV
C
C DECLARE THE FOLLOWING VARIABLES AS REAL
C
C REAL MU,MUL,MUV,K,KL,KV
C
C DO NOT FORGET TO CALL SETUP
C
      DATA DIA,VB,TB,PB,TW/0.8,60.,25.,6.,450./
      DATA NAM/2MHZ/
      CALL SETUP(NAM)
C SELECT UNITS OF CALCULATION - SET KU=1
      KU=1
C SELECT BULK PROPERTIES DENSITY,VISCOSITY - SET KS=1,KP=8
      KS=1
      KP=8
C DETERMINE THE REGION OF CALCULATION - ASSUME UNKNOWN - SET KR=0
      KR=0
      CALL GASPI(KS,KP,TB,PB,DB,HB,KR)
      ANUB=MU/DB
C DETERMINE WALL PROPERTIES DENSITY,VISCOSITY - SET
C DETERMINE WALL PROPERTIES DENSITY,VISCOSITY - (KS=1,KP=8)
      KR=0
      CALL GASPI(KS,KP,TW,PB,DW,HW,KR)
      ANUW=MU/DW
C DETERMINE FILM PROPERTIES, DENSITY,SPECIFIC HEAT,VISCOSITY
C THERMAL CONDUCTIVITY, SET KS=1, KP=4+8*16 = 28
      KP=28
      KR=0
      TF=(TW+TB)/2.
      CALL GASPI(KS,KP,TF,PB,DF,HF,KR)
      REF=DF*VB*100.*DIA/MU
      PRF=CP*MU/K
      ANUF=0.021*REF**.8*PRF**.4*(1.+0.01453*ANUW/ANUB)
      HCOF=ANUF*K/DIA
      WRITE(6,1000) DIA,VB,TB,PB,TW,REF,PRF,ANUF,HCOF
      WRITE(6,1001) ANUW,ANUR,K,MU,DB,DW
      1000 FORMAT (1H1,5H DIA=,F5.2,5H VB=,F5.1,5H TB=,F5.2,5H PB=,F5.1,
      15H TW=,F5.1,6H REF=,F8.0,6H PRF=,F5.3,6H NUF=,F5.1,10H H.T.C
      20F=F5.3,///)
      1001 FORMAT(6(3X,E13.7))
      STOP
      END

```

THE RMODYNAMIC AND TRANSPORT PROPERTIES FOR HYDROGEN PC=L2.759 AT M, TC=32.976 K, RHOC=.03143 G/CC  
 DIA= 0.80 VB= 60.0 TR=25.00 PB= 6.0 TW=450.0 REF= 369005. PRF=0.645 NUF=643.0 H.T.COF=1.508  
 0.3710686E-01 0.1900674E-02 0.1876238E-02 0.7069401E-04 0.7292893E-01 0.3147296E-02

## PROBLEM 2

Calculate the end point (exhaust conditions) of fluid properties for a methane expander with inlet conditions of 100 atm and 200 K and exhaust conditions at the critical pressure. Assume the expansion is isentropic.

```

C      DO NOT USE K AS AN INDEX IT MEANS THERMAL CONDUCTIVITY
C      DO NOT FORGET YOUR COMMON STATEMENT
C
C      COMMON/PROPRTY/KU,DL,DV,HL,HV,S,SL,SV,CV,CVL,CVV,CP,CPL,CPV,GAMMA,
C      1GAMMAL,GAMMAV,C,CL,CVP,MU,MUL,MUV,K,KL,KV,SIGMA,EXCESK,EXCL,EXCV
C
C      DECLARE THE FOLLOWING VARIABLES AS REAL
C
C      REAL MU,MUL,MUV,K,KL,KV
C
C      DO NOT FORGET TO CALL SETUP
C
C      DATA PIN,TIN/100.,200./
C      DATA NAM/3MH4/
C      CALL SETUP(NAM)
C
C      SELECT UNITS OF CALCULATION - SET KU=2
C      KU=2
C      DETERMINE THE REGION OF CALCULATION - ASSUME UNKNOWN - SET KR=0
C      KR=0
C      SELECT PROPERTIES DENSITY,ENTHALPY,ENTROPY,SPECIFIC HEATS,SONIC
C      VELOCITY,VISCOSITY, THERMAL CONDUCTIVITY   KP=1+2+4+8+16 = 31
C      KS=1
C      KP=31
C      CALL GASPI(KS,KP,TIN,PIN,DIN,HIN,KR)
C      SIN=S
C      CPIN=CP
C      CVIN=CV
C      SONIN=C
C      VISIN=MU
C      CONIN=K
C      UIN=PIN-PIN*.101325/DIN
C      AKRIN=KR
C
C      ISENTROPIC EXPANSION TO OUTLET SOUT=SIN=S,P=POUT - SET KS=5
C      KS=5
C
C      THE CRITICAL PRESSURE OF METHANE IS 45.66 ATMOSPHERES
C      P=45.66
C      CALL GASPI(KS,KP,TOUT,P,DOU,HOUP,KR)
C      SOUT=S
C      CPDOUT=CP
C      CWOUT=CV
C      SONOUT=C
C      VISOUT=MU
C      CONOUT=K
C      UOUP=HOUT-P*.101325/DIN
C      AKROUT=KR
C
C      WRITE(6,1000)TIN,PIN,DIN,HIN,SIN,CPIN,CVIN,SONIN,VISIN,CONIN,AKRIN
C      WRITE(6,1001)TOUT,P,DOU,HOUP,SOUT,CPDOUT,CWOUT,SONOUT,VISOUT,
C      1 CONOUT,AKROUT
1000 FORMAT(1H1,5H TIN=,F5.0,5H PIN=,F5.0,5H DIN=,F5.3,5H HIN=,F6.1,
1 5H SIN=,F5.2,6H CPIN=,F5.2,6H CVIN=,F5.2,9H SONICIN=,F6.3,8H VISC
2IN=,F7.6,7H CONIN=,F6.5,6H KRIN=,F2.0,///)
1001 FORMAT(1H TOUT=,F5.2,6H POUT=,F5.2,6H DOU=,F5.3,6H HOUT=, F6.2,6H
1 SOUT=,F4.2,7H CPDOUT=,F4.2,7H CWOUT=,F4.2,10H SONICOUT=,F6.0,9H VI
2SCOUT=,F7.6, RH CONOUT=,F6.5,7H KROUT=,F2.0)
      STOP
      END

THERMODYNAMIC AND TRANSPORT PROPERTIES FOR METHANE PC=45.66 ATM,TC=190.77 K,ROC=.162 G/CC
190.77   IS OUT OF RANGE FOR T IN SUB-ENT
190.77   IS OUT OF RANGE FOR T IN SUB-DENS
TIN= 200. PIN= 100. DIN=0.268 HIN= 643.1 SIN= 7.07 CPIN= 5.32 CVIN= 1.90 SONICIN=56429. VISCIN=.000300 CONIN=.00081 KRIN=3.
TOUT=88.43 POUT=45.66 DOU=0.243 HOUT=621.66 SOUT=7.07 CPDOUT=1.84 CWOUT=1.96 SONICOUT=40593. VISCOUT=.000270 CONOUT=.00069 KROUT=2.

```

### PROBLEM 3

Determine a temperature-entropy (T-S) diagram for fluorine from 55 to 200 K with pressure as a parameter. Also determine the isoquality lines from 0 to 1 in increments of 0.1. Let the pressures be as given in the following table:

Pressure, MPa	
0.1	5.215
1	6
2	7
3	8
4	10

The problem can be solved by incrementing temperature (KS=1) or entropy (KS=5). However, it is faster to increment temperatures. Therefore, select the temperature increment to be 5 K.

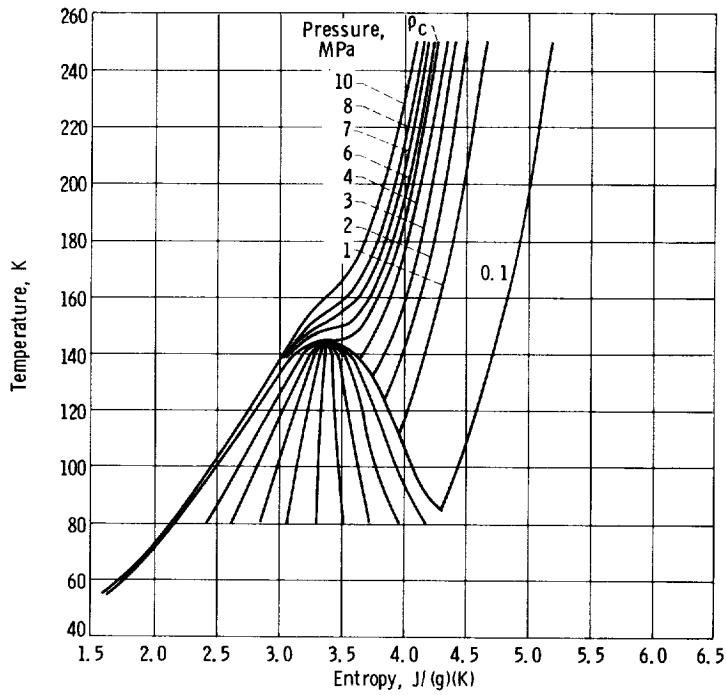
```

COMMON/PROMPT/KU,DL,DV,HL,HV,S,SL,SV,CV,CVL,CVV,CP,CPL,CPV,GAMMA,
1GAMMAL,GAMMAV,C,CL,CVP,MU,MUL,MUV,K,KL,KV,SIGMA,EXCESK,EXCL,EXCV
REAL H,L,MUL,MUV,K,KL,KV
      DIMENSION P(10),TITLE(7),X(2000),Y(2000)
      DATA TITL/42H TEMPERATURE-ENTROPY DIAGRAM FOR FLUORINE /
      DATA P/.1,1.,2.,3.,4.,5.215,6.,7.,8.,10./
      DATA TSTART,PC,N/55.,5.215,40/
      DATA TSTART,PC,N/80.,5.215,14/
      DATA NAM/2HF2/
      CALL SETUP(NAM)
      CALL GASP(KS,KP,TSAT,P(1),D,H,KR)
      KS=1
      KP=2
      KS=1
      M=0
      DO 3 I=1,10
      T=TSTART
      IF(P(I).GT.PC) GO TO 5
      KR=1
      TSAT=0.
      CALL GASP(KS,KP,TSAT,P(I),D,H,KR)
      K=M+1
      X(M)=SL
      Y(M)=TSAT
      X(M+1)=SV
      Y(M+1)=TSAT
      DO 2 J=1,9
      NN=M+J+1
      XX=0.1*FLOAT(IJ)
      X(NN)=XX*SV+(1.-XX)*SL
      Y(NN)=TSAT
      M=M+1
      2   DO 3 J=1,N
      IF(T.EQ.TSAT) GO TO 3
      KR=0
      CALL GASP(KS,KP,T,P(I),D,H,KR)
      M=M+1
      X(M)=S
      Y(M)=T
      3   T=T+5.
      WRITE(6,1000) (X(J),Y(J), J=1,M)
1000 FORMAT (10(2X,F7.3))
      CALL LRPLOT (X,Y,M)
      STOP
      END

```

THE REGION 125-145K FOR T AND P GREATER THAN 10 ATM YIELDS POOR RESULTS FOR THE DERIVED PROPERTIES--BEWARE.

THERMODYNAMIC AND TRANSPORT PROPERTIES FOR FLUORINE PC=51.47ATM, TC=144.31K, RHOC=.5738G/CC							
144.31 IS OUT OF RANGE FOR T IN SUB.-ENT							
144.31 IS OUT OF RANGE FOR T IN SUB.-DENS							
2.286	84.845	2.490	84.845	2.695	84.845	2.899	84.845
3.308	84.845	3.512	84.845	3.716	84.845	3.921	84.845
4.329	84.845	2.199	80.000	4.331	85.000	4.377	90.000
4.462	100.000	4.500	105.000	4.537	110.000	4.572	115.000
4.637	125.000	4.668	130.000	4.697	135.000	4.725	140.000
4.706	111.834	2.833	111.834	2.960	111.834	3.087	111.834
3.342	111.834	3.469	111.834	3.596	111.834	3.723	111.834
3.977	111.834	2.196	80.000	2.286	85.000	2.370	90.000
2.527	100.000	2.603	105.000	2.678	110.000	4.007	115.000
4.089	125.000	4.125	130.000	4.159	135.000	4.191	140.000
2.884	123.771	2.981	123.771	3.077	123.771	3.174	123.771
3.368	123.771	3.464	123.771	3.561	123.771	3.658	123.771
3.851	123.771	2.193	80.000	2.283	85.000	2.367	90.000
2.523	100.000	2.598	105.000	2.673	110.000	2.748	115.000
3.865	125.000	3.915	130.000	3.959	135.000	3.998	140.000
3.008	131.917	3.083	131.917	3.158	131.917	3.233	131.917
3.382	131.917	3.457	131.917	3.532	131.917	3.606	131.917
3.756	131.917	2.191	80.000	2.280	85.000	2.363	90.000
2.519	100.000	2.593	105.000	2.668	110.000	2.742	115.000
2.894	125.000	2.975	130.000	3.798	135.000	3.854	140.000
3.119	138.218	3.173	138.218	3.226	138.218	3.280	138.218
3.388	138.218	3.442	138.218	3.496	138.218	3.550	138.218
3.658	138.218	2.188	80.000	2.277	85.000	2.360	90.000
2.515	100.000	2.589	105.000	2.662	110.000	2.736	115.000
2.885	125.000	2.962	130.000	3.047	135.000	3.698	140.000
3.378	144.312	3.378	144.312	3.378	144.312	3.378	144.312
3.378	144.312	3.378	144.312	3.378	144.312	3.378	144.312
3.378	144.312	2.184	80.000	2.273	85.000	2.356	90.000
2.510	100.000	2.584	105.000	2.657	110.000	2.729	115.000
2.874	125.000	2.948	130.000	3.026	135.000	3.120	140.000
2.182	80.000	2.271	85.000	2.354	90.000	2.432	95.000
2.581	105.000	2.653	110.000	2.725	115.000	2.797	120.000
2.940	130.000	3.015	135.000	3.100	140.000	3.224	145.000
2.268	85.000	2.351	90.000	2.429	95.000	2.504	100.000
2.648	110.000	2.720	115.000	2.791	120.000	2.861	125.000
3.002	135.000	3.081	140.000	3.178	145.000	2.177	80.000
2.348	90.000	2.425	95.000	2.500	100.000	2.572	105.000
2.715	115.000	2.785	120.000	2.854	125.000	2.922	130.000
3.065	140.000	3.151	145.000	2.172	80.000	2.260	85.000
2.419	95.000	2.493	100.000	2.565	105.000	2.635	110.000
2.774	120.000	2.841	125.000	2.907	130.000	2.972	135.000
3.115	145.000						3.040



## PROBLEM 4

Suppose you are asked to design a liquid-oxygen-cooled, copper-liner-type thrust chamber where it is required to know the variation of enthalpy with pressure at nearly constant temperature. Given the proposed design parameters of an inlet temperature of 172° R and an inlet pressure of 6700 psia, it is necessary to find  $(\partial H/\partial P)_T$  over a range in temperature and pressure for use in a solution matrix.

The  $(\partial H/\partial P)_T$  is not directly available from GASP; however,  $(\partial P/\partial T)_\rho$  and  $(\partial P/\partial \rho)_T$  are available and with a little manipulation one can find  $(\partial H/\partial P)_T$ . From appendix E

$$\left(\frac{\partial H}{\partial P}\right)_T = V - T \left(\frac{\partial V}{\partial T}\right)_P$$

where  $V = 1/\rho$ , and from the Bridgeman Tables

$$\left(\frac{\partial V}{\partial T}\right)_P = (-\partial P)_V = -\frac{(\partial P)_V}{(\partial T)_V} \times (\partial T)_V = -\left(\frac{\partial P}{\partial T}\right)_V \times \left(\frac{\partial V}{\partial P}\right)_T$$

$$= \frac{1}{\rho^2} \left[ \begin{array}{l} \left(\frac{\partial P}{\partial T}\right)_\rho \\ \hline \left(\frac{\partial P}{\partial \rho}\right)_T \end{array} \right]$$

$$\left(\frac{\partial H}{\partial P}\right)_T = \frac{1}{\rho} \left[ 1 - \frac{T}{\rho} \frac{\left(\frac{\partial P}{\partial T}\right)_\rho}{\left(\frac{\partial P}{\partial \rho}\right)_T} \right]$$

The latter term is the volume expansivity multiplied by  $T$  or

$$T \left[ \frac{1}{V} \frac{\partial V}{\partial T} \right]$$

The  $(\partial H/\partial P)_T$  can now be found from GASP as follows:

- (1) The desired units are psia, °R, and lbm/ft<sup>3</sup> (KU=3).
- (2) The input is  $T$  and  $P$ . The output will be  $(\partial P/\partial T)_\rho$ ,  $(\partial P/\partial \rho)_T$ , and  $\rho$ . Set KS=1, KP=4, and KR=0.

(3) The units of  $\partial H/\partial P$  will be  $ft^3/lbm$ , and  $\partial H/\partial P$  must be multiplied by 144/778.161 to return the KU=3 units, that is,

$$\frac{ft^3}{lbm} \times \frac{144 \text{ in.}^2}{ft^2} \times \frac{\text{Btu}}{778.161 \text{ ft-lbf}} = \frac{\text{Btu}}{lbm\text{-psia}}$$

An alternate procedure is to use the units of the program since

$$\frac{T \left( \frac{\partial P}{\partial T} \right)_P}{\rho \left( \frac{\partial P}{\partial \rho} \right)_T}$$

is dimensionless, that is,

- (1) Assign KU=1, with KP and KR as before.
- (2) Convert P and T prior to calling GASP.

$$P1=P/14.696; T1=T/1.8$$

CALL GASP(KU, KP, T1, P1, D, H, KR)

(3) Then convert to the desired units. Note that the units of  $(\partial H/\partial P)_T$  are  $cm^3/g$  and  $J/(g)(MPa)$  with no further conversion required.

```

DIMENS(3N, P(5), 1(4), HPT(9)
COMMON/NPROPTY/KU, DL, NV, HL, HV, S, SL, SV, CV, C_VL, CPL, CPV, GAMMA,
GAMMAL, GAMMAV, C, CL, CVP, MH, MUL, MU_UV, K, KL, KV, S1, MA, XC_ESK, EXCL, EXCV
COMMON/DEF/IV/PDT, PTV, PDTL, PDTV, PTVV, PTVV
COMMON/CUN123/DCUNV(5), TCUNV(5), PCUNV(5)
REAL MU, MUL, MU_UV, K, KL, KV
DATA P /4000., 5000., 6000., 6700., 7000.
DATA T /172., 200., 225., 250., 275., 300., 325., 350., 372.
DATA NAMGAS /2H2/
CALL SETUP(NAMGAS)
KU=3
KP=4
KS=1
WRITE(6, 100)
WRITE(6, 101) (T(J), J=1, 9)
DO 102 I=1, 5
DO 103 J=1, 9
  KP=0
  CALL GASP (KS, KP, T(J), P(I), D, H, KR)
  HPT(IJ)=1.-T(I))D*PTV(PDT*(DCUNV(I)/TCUNV(I))/D
102  WRITE(6, 134) P(I), (HPT(J), J=1, 9)
100  FORMAT(1H, 58H TABLE OF (DH/DT) FOR SELECTED TEMPERATURES AND
1D PRESSURES //)
101  FORMAT(4X, 9(6X, F6.11) //)
104  FORMAT(1X, F6.1, 9(2X, F10.4) /)
STOP
END

```

	172.0	200.0	225.0	250.0	275.0	300.0	325.0	350.0	372.0
4000.0	0.1422	0.1949	0.2587	0.3448	0.4613	0.6175	0.8185	1.0558	1.2764
5000.0	0.1328	0.1788	0.2322	0.3005	0.3874	0.4959	0.6267	0.7758	0.9149
6000.0	0.1248	0.1657	0.2116	0.2684	0.3376	0.4202	0.5160	0.6223	0.7210
7000.0	0.1199	0.1579	0.1998	0.2506	0.3112	0.3819	0.4623	0.5503	0.6317
7000.0	0.1180	0.1548	0.1952	0.2438	0.3014	0.3680	0.4432	0.5251	0.6006

## PROBLEM 5

Suppose that an odd set of units such as that given here are, for some unknown reason, required in a user's program and that the user also requires the use of GASP for PVT values.

Quantity	New system of units	Equivalent in SI system of units
Length	Cubit (cb)	45.72 cm
Mass	Stone (st)	14 lbm or $6350.29318 \text{ g}$
Time	Millenium	$1000 \text{ yr} \text{ or } 3.1556926 \times 10^{10} \text{ sec}$
Energy	Megaton	$4.2 \times 10^{16} \text{ J}$
Temperature	Electron volt equivalent (eVe)	$1.6021 \times 10^{-19}$ $= 1.16419 \times 10^4 \text{ K}$
Force	Megapoundal	$1.380622 \times 10^{-22}$ $0.1382549121376 \text{ MN}$

Converting this system of units so that GASP can calculate PVT values requires the following conversion factors:<sup>15</sup>

To convert from -	To -	Multiply by -
Pressure, megapoundal/cb <sup>2</sup>	MN/m <sup>2</sup> (or MPa)	$\frac{0.138254954376}{(0.4572)^2} = 0.661406197$
Temperature, eVe	K	$1.16419 \times 10^4$
Density, st/cb <sup>3</sup>	g/cm <sup>3</sup>	$\frac{6350.29318}{(45.72)^3} = 3.037955$
Enthalpy, megaton/st	J/g	$\frac{4.2 \times 10^{16}}{6350.29318} = 6.6138679 \times 10^{12}$
Entropy and specific heats, megaton/st-eVe	J/g-K	$\frac{4.2 \times 10^{16}}{6350.29318 \times 1.16419 \times 10^4} = 5.6810897 \times 10^8$
Sonic velocity, cb/millenium	cm/sec	$\frac{45.72}{3.1556926 \times 10^{10}} = 1.4488103 \times 10^{-9}$
Surface tension, megapoundal/cb	dyne/cm	$\frac{0.138254954376 \times 10^{11}}{45.72} = 3.30239491 \times 10^9$
Thermal conductivity, megaton/cb-eVe-millenium	W/cm-sec	$\frac{4.2 \times 10^{16}}{45.72 \times 1.16419 \times 10^4 \times 3.1556926 \times 10^{10}} = 2.500486$
Viscosity, st/cb-millenium	g/cm-sec	$\frac{6350.29318}{45.72 \times 3.1556926 \times 10^{10}} = 4.4014205 \times 10^{-9}$

<sup>15</sup>A convenient source for units conversion is  
Mechtly, E. A.: The International System of Units, Physical Constants and Conversion Factors.  
NASA SP-7012 (revised), 1973.

The following DATA statements in GASP must now be altered:

(1) DATA statements to be altered in BLOCK DATA

```
DATA TCONV/1., 1., 1.8, 8.5896632E-5, 1.  
DATA PCONV/1., 9.8692327, 145.03774, 1.5119302, 1.  
DATA DCONV/2* 1., 62.42796, .3291688, 1.  
DATA SCONV/2* 1., .23900574, 1.7602257E-9, 1.  
DATA CCONV/2* 1., .0328084, .69022149E9, 1.  
DATA HCONV/2* 1., .4302103, 1.5119746E-13, 1.
```

(2) Other DATA statements to be altered if these properties are to be completed

SUBROUTINE SURF

```
DATA STCONV/2* 1., 6.8521766E-5, .3306934E-8, 1.
```

SUBROUTINE VISC

```
DATA MU CONV/2* 1., .67196899E-1, .22719938E9, 1.
```

SUBROUTINE THERM

```
DATA KCONV/2* 1., .01606044, .39992226, 1.
```

The program for the units conversion is as follows:

```
COMMON/PROMPT/KU,DL,DV,HL,HV,S,SL,SV,CV,CVL,CVV,CPL,CPL,GAMMA,  
ICAMMAL,GAMMAV,C,CL,CVP,MU,MUL,MUV,K,KL,KV,SIGMA,EXCESK,EXCL,EXCV  
REAL MU,MUL,MUV,K,KL,KV  
DATA NAM/2MH2/  
CALL SETUP(NAM)  
TC=2.832527E-3  
PC=1.9546319  
KU=4  
KS=1  
KP=63  
J=0  
TSTART=1.7179326E-3  
DT=.2147416E-4  
DP=.303926E1  
TSTOP=TC  
DO 102 I=1,52  
P=FLOAT(I)*DP  
WRITE(6,101) P  
101 FORMAT(1H1,F10.3)  
T=0.  
KR=1  
CALL GASP(KS,KP,T,P,D,H,KR)  
IF(KR.EQ.1) WRITE(6,333) P,T,DL,HL,SL,CPL,CL,KL,MUL,SIGMA  
IF(KR.EQ.1) WRITE(6,333) P,T,DV,HV,SV,CPL,CVP,KV,MUV  
WRITE(6,1000)  
WRITE(6,1001)  
1001 FORMAT(1X,9HMPD/(CB)2,6X,3HEVE,8X,8HST/(CB)3,4X,5HMT/ST,7X,9HMT/ST  
1-EVE,2X,9HMT/ST-EVE,3X,5ICR/ML,6X,12HMT/CB-EVE-ML,2X,8HST/CB-ML )  
1000 FORMAT(3X,1H ,10X,1HT,12X,1HD,10X,1HH,11X,1HS,11X,2HC,12X,1HC,10X,4HV1SC  
1,4HV1SC,8X,4HCND / )  
T=TSTART+DT  
DO 100 J=1,100  
IF (T.GE.TSTOP) GO TO 102  
T=T+DT  
KR=0  
CALL GASP(KS,KP,T,P,D,H,KR)  
100          WRITE(6,333) P,T,D,H,S,CPL,C,K,MU  
333 FORMAT(10G12.4)  
102 CONTINUE  
STOP  
END
```

```

C      STORES THE COEFFICIENTS FOR ALL FLUIDS FOR THE EQUATION OF STATE
C      AND THE TRANSPORT EQUATIONS.
C      STORES CONVERSION CONSTANTS NEEDED BY ALL FLUIDS
C
BLOCK DATA
COMMON/GASES/MATCH(10),MESSAG(15,10)
COMMON/CON123/ DCONV(5),TCONV(5),PCONV(5)
COMMON/CONV4/SCONV(5)
COMMON/CONV5/CCONV(5)
COMMON/CONV6/HCONV(5)
COMMON/ALLCOF/COF(53,10),TCCOF(15,10),AKSTCO(18,4),DIST(10),
IHTMOL(10),EPSOK(10),ZETA(10),FF(10),SH(10),KSWT(10),DIFTT(10),
2RHOSWT(10),DTRIP(10),AMUC(10),BMUC(10)
DIMENSION MCH4(15),MN2(15),MAR(15),MC02(15),MNE(15),MCO(15
1),MHE(15),MF2(15),MH2(15)
EQUIVALENCE(MESSAG(1,1),MCH4(1)),(MESSAG(1,2),MN2(1)),(MESSAG(1,3)
1,MN2(1)),(MESSAG(1,4),MAR(1)),(MESSAG(1,5),MC02(1)),(MESSAG(1,6),
2MNE(1)),(MESSAG(1,7),MCO(1)),(MESSAG(1,8),MHE(1)),(MESSAG(1,9),MF2
3(1)),(MESSAG(1,10),MH2(1))
DATA MATCH(1,I=1,8)/3HCH4,2HN2,2H2O ,2HAR,3HCO2,2HNE,2HCO,2H2/
DATA MATCH(9)/2HF2/
DATA MATCH(10)/2H2/
DATA MCH4(1) /9OH THERMODYNAMIC AND TRANSPORT PROPERTIES FOR ME
ITHANE PC=45.66 ATM, TC=190.77 K, ROC=.162 G/CC /
DATA MN2(1) /9OH THERMODYNAMIC AND TRANSPORT PROPERTIES FOR N
ITITROGEN PC=33.72ATM, TC=126.3 K, ROC=.3105G/CC /
DATA MAR(1) /9OH THERMODYNAMIC AND TRANSPORT PROPERTIES FOR AR
IGON PC= 48.0L1ATM, TC=150.7 K, ROC=.531 G/CC /
DATA MC02(1) /9OH THERMODYNAMIC AND TRANSPORT PROPERTIES FOR CO
1 2 PC=72.869ATM, TC=304.21 K, ROC=.464 G/CC /
DATA MNE(1) /9OH THERMODYNAMIC AND TRANSPORT PROPERTIES FOR NE
ION PC= 26.19ATM, TC=44.4 K, RHOC=.483 G/CC /
DATA MCO(1) /9OH THERMODYNAMIC AND TRANSPORT PROPERTIES FOR CO
1 PC=34.529ATM, TC=132.91 K, RHOC=.2997 G/CC /
DATA MHE(1) /9OH THERMODYNAMIC AND TRANSPORT PROPERTIES FOR HE
1 PC = 2.245ATM, TC = 5.2K, RHOC = .0693G/CC /
DATA MF2(1) /9OTH THERMODYNAMIC AND TRANSPORT PROPERTIES FOR FLU
IDRINE PC=51.47ATM, TC=144.31K,RHOC=.5738G/CC /
DATA MH2(1) / 9OH THERMODYNAMIC AND TRANSPORT PROPERTIES FOR HYDRO
1GENPC=12.759ATM,TC=32.976K,RHOC=.03143G/CC /
DATA TCONV/1.,1.,1.8,8.5896632E-5,1./
DATA PCONV/1.,9.8692327,145.03774,1.5119302,1./
DATA DCONV/2*1.,62.42796,0.3291688,1./
DATA SCONV/2*1.,.23900574,1.7602257E-9,1./
DATA MC0NV/2*1.,.4302103,1.5119746E-13,1./
DATA CCONV/2*1.,.0328084,.69022149E9,1./
(The remainder of BLOCK DATA is unchanged.)

```

```

C      COMPUTE VISCOSITY MU GIVEN TEMPERATURE T AND DENSITY D.
C      UNITS ARE SPECIFIED BY KU. REGION IS SPECIFIED BY KR.
C
C      (U-U*1Z PARAMETER IS CALCULATED FROM JOSSI,STIEL,AND THODOS
C      VOL.8 NO.1 A.I.CHE.JOURNAL PAGE 60
C
SUBROUTINE VISC(KU,KR,T,D,MU)
DIMENSION COMEGA(15),MC0NV(5)
REAL MUS,MCONV,MU,MUM2
DATA (COMEGA(I),I=1,15)/2.,4.,-.52288,-1.33115022,.56160244,
11.49894829,-1.84681526,1.58946684,.60206,.32481334E-1,
2-.23524079,-65223929,-1.03095995,1.40383078,2.60206/
COMMON/COFMU/EPSK,WM,DIS,RHOCRT,ZETA ,AMUX,BMUX
DATA MCONV/2*1.,.67196899E-1,.22719938E9,1./
(The remainder of VISC is unchanged.)

```

```

C      COMPUTE THERMAL CONDUCTIVITY K GIVEN TEMPERATURE T AND
C      DENSITY D. UNITS ARE SPECIFIED BY KU. REGION IS SPECIFIED
C      BY KR.
C
SUBROUTINE THERM (KU,KR,P,T,D,EXCESK, K)
COMMON/HEFLU/ IHE, IFL, IHY
COMMON/TCOND/CKMKST(9), XLAMB,ZC5, RHOGR, TCR, TCSTAR, CKSTAR(18)
COMMON/BEND/R,DMYU(28)
COMMON/COFMU/EPSK,WM,DIS,RHOCRT,ZETA ,AMUX,BMUX
COMMON/REFND/SOT0,HOTO,CPOCOR,HTERM,STERM
COMMON/CCOPD/TO,CCOP1,CCOP2,CCOP3,CCOP4,CCOP5
DIMENSION OMEGA1(9),OMEGA2(15)
REAL KMKS, KSRAT, K, KCONV ,KZERO
DIMENSION KCONV(5)
DATA (OMEGA1(I),I=1,9)/1.,4.,-.52288,.82359030E-1,-.53982316,
11.28552553,-1.53509592,1.44223760,2.602 /
DATA (OMEGA2(I),I=1,15)/2.,4.,-.52288,-1.33115022,.56160244,
11.49894829,-1.84681526,1.58946684,.60206,.32481334E-1,
2-.23524079,-65223929,-1.03095995,1.40383078,2.60206/
DATA KCONV/2*1.,.01606044,.3999226 ,1./
(The remainder of THERM is unchanged.)

```



## APPENDIX K

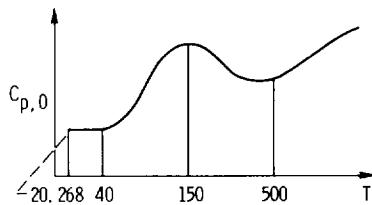
### SPECIFIC HEAT, ENTHALPY, AND ENTROPY OF PARAHYDROGEN AT ZERO PRESSURE

The dilute-gas heat capacity of parahydrogen at constant pressure is significantly different than for other gases and had to be handled separately.

The associated sketch is used to aid in defining the regions and the appropriate constants to compute  $C_{p,0}$ . The form of equation (B19)

$$C_{p,0} = \sum_{i=1}^5 m_i T^{i-1} \quad (B19)$$

had to be retained to maintain flexibility. Therefore, the parahydrogen  $C_{p,0}$  curve was broken into four regions as indicated by the sketch. Subroutine SETCP0(T) was added to define the appropriate values of  $m_i$ ,  $\Delta H$ , and  $\Delta S$  for each region. Recall that evaluation of  $H$  and  $S$  requires  $\int C_{p,0} dT$  and  $\int C_{p,0} d \ln T$ , respectively (see eqs. (B24) and (B25)).



For hydrogen, these integrals are region dependent:

$$\int_{T_0}^T C_{p,0} dT = \left( \int_{T_0}^{T_x} C_{p,0} dT \equiv \Delta H \right) + \int_{T_x}^T C_{p,0} dT$$

$$\int_{T_0}^T C_{p,0} d \ln T = \left( \int_{T_0}^{T_x} C_{p,0} d \ln T \equiv \Delta S \right) + \int_{T_x}^T C_{p,0} d \ln T$$

where  $T_x$  represents the lower bound of a region.

The values of  $m_i$ ,  $\Delta H$ , and  $\Delta S$  are as follows:

	$20.268 \leq T < 40$	$40 \leq T < 150$	$150 \leq T < 500$	$T \geq 500$
$m_1$	10.3121	4.759936	6.6557899	$4.4114861 \times 10^{-3}$
$m_2$	0	-0.21977388	0.15621077	$-0.7176787 \times 10^{-5}$
$m_3$		$0.32100769 \times 10^{-2}$	$-0.8613643 \times 10^{-3}$	$0.18638538 \times 10^{-5}$
$m_4$		$-0.120615002 \times 10^{-4}$	$0.18972274 \times 10^{-5}$	$-0.5306547 \times 10^{-9}$
$m_5$		$0.57121808 \times 10^{-8}$	$-0.14418461 \times 10^{-8}$	$0.46649305 \times 10^{-13}$
$\Delta H$		-62.9775	-147.6	61.7
$\Delta S$		-9.9313	5.361	-16.707

As one might anticipate, stepwise integration produces small discontinuities in  $S$  and  $H$  and irregularities in other derived properties at these boundaries.

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TABLE I. - PVT RANGES<sup>a</sup> AND CRITICAL PARAMETERS USED IN GASP

Fluid	Temperature range, K		Pressure range, MPa		Critical temperature, $T_c$ , K	Critical pressure, $P_c$ , MPa	Critical density, $\rho_c$ , g/cm <sup>3</sup>
	$T_{\min}$	$T_{\max}$	$P_{\min}$	$P_{\max}$			
P-H <sub>2</sub>	13.8	3000	$0.101325 \times 10^{-3}$	100	32.976	1.2928	0.03143
He	3.0	600	.010132	10.1325	5.2	.2274644	.0693
Ne	24.54		.0101325	20.29	44.4	2.6537	.483
CH <sub>4</sub>	90.66		.01167	50.67	190.77	4.627	.1620
CO	68.14		.0101325	20.27	132.91	3.4986	.2997
N <sub>2</sub>	64	1000	.0101325	50.67	126.3	3.417	.3105
O <sub>2</sub>	70 <sup>b</sup>	500	.0101325	100	154.78	5.083	.4325
F <sub>2</sub>	53.48	500	.011	20.3	144.31	5.215	.57375
Ar	83.78	1000	.0101325	50.65	150.7	4.865	.5310
CO <sub>2</sub>	216.56	1000	.0101325	50.67	304.21	7.3835	.4640

<sup>a</sup>As a general rule, the PVT ranges may be extended with some confidence; however, derived properties do not usually follow.

<sup>b</sup>Ranges to 54.35 K; however, derived values below 70 K are questionable.

TABLE II. - COEFFICIENTS FOR EQUATION OF STATE (B2) FOR TEN FLUIDS

Coeff- icient	Fluid				
	CH <sub>4</sub>	N <sub>2</sub>	O <sub>2</sub>	Ar	CO <sub>2</sub>
R	0.51825100E+00	0.29679700E+00	0.25983199E+00	0.20812800E+00	0.18891799E+00
n <sub>1</sub>	0.17191020E+01	0.48058175E+00	0.34811077E+00	0.19825920E+00	0.22488558E+00
n <sub>2</sub>	-0.86366402E+03	-0.15047010E+03	-0.14070678E+03	-0.81733119E+02	-0.13717965E+03
n <sub>3</sub>	0.25005236E+05	0.26071365E+04	0.25061744E+04	0.17777470E+04	-0.14430214E+05
n <sub>4</sub>	-0.12533848E+08	-0.12792742E+07	-0.10081345E+07	-0.82406544E+06	-0.29630491E+07
n <sub>5</sub>	0.34169547E+09	0.29436228E+08	0.19074164E+08	0.31666098E+08	-0.20606039E+09
n <sub>6</sub>	0.75523689E+00	0.37500264E+00	-0.40134966E-02	-0.44202671E-01	0.45554393E-01
n <sub>7</sub>	-0.12111233E+03	-0.50738465E+02	0.65172112E+02	0.62161422E+02	0.77042840E+02
n <sub>8</sub>	0.20547188E+06	0.14499236E+05	0.10962206E+05	0.11443248E+04	0.40602371E+05
n <sub>9</sub>	0.32337540E+02	0.14409980E+01	0.69721580E+00	0.47797520E+00	0.40029509E+00
n <sub>10</sub>	-0.61948317E+04	-0.24136776E+03	-0.26242449E+03	-0.19645227E+03	-0.39436077E+03
n <sub>11</sub>	-0.25603803E+02	0.28954771E+00	0.19137800E+00	-0.21572754E+00	0.12115286E+00
n <sub>12</sub>	0.11556713E+04	-0.27613799E+02	0.29416771E+02	0.16544141E+03	0.10783386E+03
n <sub>13</sub>	0.27425297E+05	0.36048264E+03	0.78932076E+02	-0.28142112E+02	0.43962336E+02
n <sub>14</sub>	0.49499630E+08	-0.20083357E+07	-0.19231580E+07	0.82532058E+05	-0.36505545E+08
n <sub>15</sub>	-0.11956135E+11	0.43265184E+09	0.46108240E+09	-0.91538377E+07	0.19490511E+11
n <sub>16</sub>	0.88302981E+12	-0.16513521E+11	-0.39362633E+11	-0.18340752E+10	-0.29186718E+13
n <sub>17</sub>	-0.31713486E+10	-0.12141439E+08	-0.56689950E+07	-0.33858136E+07	0.24358627E+08
n <sub>18</sub>	0.12302028E+13	0.47216396E+10	0.13644286E+10	0.15532886E+10	-0.37546530E+11
n <sub>19</sub>	-0.64499294E+14	-0.12016418E+12	0.91977197E+11	-0.67479568E+11	0.11898141E+14
n <sub>20</sub>	0.37000000E+02	0.10000000E+02	0.54000000E+01	0.35000000E+01	0.50000000E+01
n <sub>21</sub>	0.	0.	0.	0.	0.
n <sub>22</sub>	0.	0.	0.	0.	0.
n <sub>23</sub>	0.	0.	0.	0.	0.
n <sub>24</sub>	0.	0.	0.	0.	0.

Coeff- icient	Fluid				
	Ne	CO	He	F <sub>2</sub>	H <sub>2</sub>
R	0.41185435E+00	0.29692807E+00	0.29772224E+01	0.21881590E+00	0.41260486E+01
n <sub>1</sub>	0.42879277E+00	0.36547544E+00	0.84470245E+01	0.21051539E+00	0.44446150E+02
n <sub>2</sub>	-0.41617333E+02	-0.80241533E+02	-0.23405643E+03	-0.81175243E+02	-0.38659604E+04
n <sub>3</sub>	-0.15368388E+04	-0.16713841E+05	0.47857662E+02	0.23064630E+04	-0.10966551E+06
n <sub>4</sub>	0.21705583E+05	0.13129095E+06	-0.11937548E+03	-0.63183150E+06	0.12080022E+07
n <sub>5</sub>	0.	0.	0.	0.96908966E+07	-0.54747655E+07
n <sub>6</sub>	0.52377780E-01	0.65308710E+00	0.20230185E+02	0.25933660E+00	-0.33278647E+03
n <sub>7</sub>	0.31832376E+02	-0.80131497E+02	0.14653521E+04	-0.63689419E+02	0.81345734E+05
n <sub>8</sub>	0.15304725E+04	0.	0.	0.68240310E+04	0.26294257E+06
n <sub>9</sub>	0.86991276E+00	0.73365157E+00	0.	-0.13779899E+00	0.30063983E+05
n <sub>10</sub>	-0.86565802E+02	0.	-0.11186866E+05	0.74842154E+02	-0.33024955E+07
n <sub>11</sub>	0.	0.	0.	0.30516478E+00	-0.24686707E+06
n <sub>12</sub>	0.	0.	0.	-0.13304028E+03	0.47555234E+08
n <sub>13</sub>	0.41994280E+02	0.41363247E+03	-0.70728125E+05	0.50315749E+02	-0.12064332E+09
n <sub>14</sub>	0.23856729E+06	0.18061147E+07	-0.79046072E+04	0.40392186E+06	-0.49289827E+08
n <sub>15</sub>	-0.10444366E+08	0.63943277E+09	0.54530768E+05	-0.27610459E+08	0.15925894E+10
n <sub>16</sub>	0.	-0.66472139E+11	0.15941147E+06	-0.42709623E+10	-0.87182365E+10
n <sub>17</sub>	-0.19828098E+07	-0.24767075E+08	-0.18259780E+07	-0.33659737E+07	0.66330266E+11
n <sub>18</sub>	0.70965701E+08	0.96546154E+10	0.41462568E+07	0.65832302E+09	0.16366622E+11
n <sub>19</sub>	0.	-0.47286423E+12	-0.16887829E+08	-0.61907880E+09	-0.12954419E+14
n <sub>20</sub>	0.13590153E+02	0.74632444E+01	0.40570426E+03	0.30600000E+01	0.10500000E+04
n <sub>21</sub>	0.	0.58725319E+09	0.30308251E+03	0.	0.
n <sub>22</sub>	-0.12553439E-02	0.	0.	0.	0.
n <sub>23</sub>	-0.7688021E+03	0.	0.	0.	0.
n <sub>24</sub>	-0.84938358E+03	0.	0.	0.	0.

TABLE III. - PRIMARY REFERENCES USED IN DERIVED AND  
TRANSPORT PROPERTY CALCULATIONS

Calculation	Fluid									
	CH <sub>4</sub>	N <sub>2</sub>	O <sub>2</sub>	Ar	CO <sub>2</sub>	Ne	CO	He	F <sub>2</sub>	H <sub>2</sub>
	Reference									
Saturation curve	14	8	39	68	41	69	9	70	42	8, 19
Specific-heat-at-zero-pressure C <sub>p, 0</sub> curve	71	7	72	73	71	10	9	17	42	19
Reference values of temperature T <sub>0</sub> , enthalpy, H <sub>0</sub> , and entropy, S <sub>0</sub>	71	7	39	73	71	10	9	17	42	8, 19
Thermal conductivity:										
k*/k* <sub>T<sub>c</sub></sub>	74	75	75	76	77	76	75	28	(a, b)	<sup>a</sup> 27
k - k*	74	75	75	76	77	76	--	<sup>a</sup> 28	(a, b)	<sup>a</sup> 27
Surface-tension data	43	43	43	43	43	43	43	17	78	19
k*, k Data	79	79	79	79	79	79	79	28	(b)	27
$\mu^*$ , $\mu$ Data	79	79	79	79	79	79	79	28	(b)	22

<sup>a</sup>Special forms, not general.

<sup>b</sup>Private communication with H. J. M. Hanley, of National Bureau of Standards, Boulder, Colorado.

TABLE IV. - SUMMARY OF PVT RELATIVE ERRORS - FROM FIGURES 1 TO 17

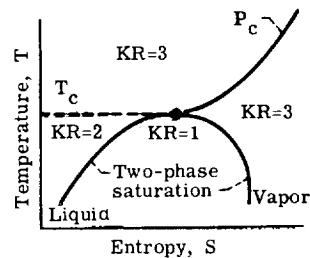
[See also PVT comparisons to other equations of state.]

Fluid	Investigator	Reference	Estimated relative error, <sup>a</sup> [(Calculated - Experimental)/Experimental] × 100, percent			Range of data			How acquired
			Temperature	Pressure	Density	Temperature, K	Pressure	Density or volume	
CH <sub>4</sub>	Jansoone, Gielen, DeBoelpaep, Verbeeke	34	±0.1 (1(a))	-0.5 to 1.0 (1(b))	-2.5 to 10 (1(c))	188.946 to 193.601	44.738 to 49.995 atm	68.5926 to 132.4392 cm <sup>3</sup> /g-mole	Incrementing volume
	Vennix (four points with errors > 10 percent)	35	±0.25 (2(a))	±1.0 (2(b))	±1.5 (2(c))	150.03 to 273.38	214.03 to 9935.55 psia	0.04088 to 0.36 g/cm <sup>3</sup>	Incrementing volume
	Vennix <sup>b</sup>	35	±0.5 (3(a))	±0.005 (3(b))	±0.2 (3(c))	150.03 to 273.38	214.03 to 9935.55 psia	0.04088 to 0.36 g/cm <sup>3</sup>	Incrementing volume
	Goodwin	13	-0.8 to 0.2 (4(a))	1 to 3 (with a few points to 20) (4(b))	±0.5 (4(c))	176 to 300	2.7962 to 35.2726 MPa	2.990 to 25.829 g-mole/cm <sup>3</sup>	Isobaric incrementing temperature
N <sub>2</sub>	Strobridge	7	c -4 to 0.5 (6(a))	c -10 to 2 (much higher values at high densities) (6(b))	c -1.3 to 0.8 (6(c))	-----	-----	-----	-----
	Coleman and Stewart	37	Higher differences <sup>d</sup> at lower tem- peratures (7(a))	Very large differ- ences <sup>d</sup> at high densities (7(b))	d -1.8 to 1.2 (7(c))	-----	-----	-----	-----
	Weber	36	-----	-----	±0.4 (9(b))	80 to 140	2.508 to 27.019 atm	0.2653 to 0.8071 g/cm <sup>3</sup>	Isobaric incrementing temperature
O <sub>2</sub>	Weber	39	±0.15 (11(a))	±2 (with a few points at much larger values) (11(b))	±0.2 (with maximum deviation of ±2) (11(c))	54.5 to 300	0.438 to 357.53 atm	6.44×10 <sup>-5</sup> to 4.11341×10 <sup>-2</sup> g-mole/cm <sup>3</sup>	Incrementing temperature
Ar	Van Itterbeck, Verbeke, Staes	40	±0.3 (13(a))	±5 (with some higher scatter) (13(b))	-0.3 to 0.4 (13(c))	90.15 to 148.25	10 to 288 atm	0.795 to 1.439 g/cm <sup>3</sup>	Various isotherms
CO <sub>2</sub>	Michels, Blaisse, and Michels	41	±0.1 (14(a))	±0.5 (with a few points to 5 percent (14(b))	f 4 (14(c))	276.003 to 313.237	36.318 to 98.497 atm	0.10336 to 0.91507 g/cm <sup>3</sup>	Various isotherms
He	McCarty	16, 17	±1 (with greater error close to critical point and to ±10 for sub- critical) (15(a))	±0.1 (with errors to ±10 for sub- critical) (15(b))	±1 (with errors to 20 in critical region) (15(c))	(e)	(e)	(e)	-----
F <sub>2</sub>	Prydz and Straty	18, 42	±0.2 (with scat- ter to ±20 near critical) (16(a))	±0.5 (with some scatter to 4) (16(b))	±0.2 (with scatter to ±5 near critical) (16(c))	54 to 300	0.03 to 24 atm	0.038 to 45.1 mol/liter	Isochoric
H <sub>2</sub>	Goodwin	19	±0.15 (with scat- ter to ±0.4) (17(a))	±0.4 (with scat- ter to 2 at low pressure) (17(b))	±0.3 (with scatter to ±2 near critical) (17(c))	13.8 to 100	0.07 to 340 atm	0.006 to 0.016 mol/cm <sup>3</sup>	Isochoric

<sup>a</sup>The figure number is in parentheses next to the value of the error.<sup>b</sup>A comparison of Vennix's data to Vennix's equation of state.<sup>c</sup>The Strobridge equation has been overextended to 1000 K and 100 MPa.<sup>d</sup>Equation of Coleman and Stewart should not be used below 77 K.<sup>e</sup>"Data" from the program of McCarty (ref. 17).

TABLE V. - OPERATIONS SHEET FOR SUBROUTINE GASP<sup>a</sup>

COMMON/PROPTY/KU, DL, DV, HL, HV, S, SL, SV, CV, CVL, CVV, CP, CPL, CPV, GAMMA, GAMMAL, GAMMAV, C, CL, CVP, MU, MUL, MUV, K, KL, KV, SIGMA. EXCL, EXCV, EXCESK	
COMMON/DERIV/PDT, PTV, PDTL, PDTV, PTVL, PTVV	
REAL MU, MUL, MUV, K, KL, KV	
CALL SETUP(NAMGAS): Name fluid - HE for helium, CH4 for methane, NE for neon, N2 for nitrogen, CO for carbon monoxide, O2 for oxygen, AR for argon, CO2 for carbon dioxide, F2 for fluorine, H2 for parahydrogen	
CALL WASP (KS, KP, T, P, D, H, KR)	<p style="text-align: center;">Region</p> <ul style="list-style-type: none"> <li>KR=0 Unknown, check KR returned</li> <li>KR=1 Saturation</li> <li>KR=2 Liquid</li> <li>KR=3 Gas and/or fluid</li> </ul> <p style="text-align: center;">Enthalpy, J/g      Density, g/cm<sup>3</sup>      Pressure, MN/m<sup>2</sup>      Temperature, K</p> <p style="text-align: center;">Thermodynamic and transport properties<sup>b</sup></p> <ul style="list-style-type: none"> <li>KP=0 Only P, <math>\rho</math>, and T returned</li> <li>KP=1 H Enthalpy, J/g; (H), (HL), (HV)</li> <li>KP=2 S Entropy, J/(g)(K); (S), (SL), (SV)</li> <li>KP=4 <math>C_v</math> Specific heat at constant volume, J/(g)(K); (CV), (CVL), (CVV)</li> <li><math>C_p</math> Specific heat at constant pressure, J/(g)(K); (CP), (CPL), (CPV)</li> <li><math>\gamma</math> Ratio of specific heats, <math>C_p/C_v</math>; (GAMMA), (GAMMAL), (GAMMAV)</li> <li>c Sonic velocity, cm/sec; (C), (CL), (CVP)</li> <li><math>\partial P/\partial \rho</math> Slope of PVT surface along an isotherm, MPa/(g/cm<sup>3</sup>); (PDT), (PDTL), (PDTV)</li> <li><math>\partial P/\partial T</math> Slope of PVT surface along an isochore, MPa/K; (PTV), (PTVL), (PTVV)</li> <li>KP=8 <math>\mu</math> Dynamic viscosity, g/(cm)(sec); (MU), (MUL), (MUV)</li> <li>KP=16 k Thermal conductivity, W/(cm)(K); (K), (KL), (KV)</li> <li>KP=32 <math>\sigma</math> Surface tension, dyne/cm; (SIGMA)</li> </ul> <p style="text-align: center;">Input specification of independent properties</p> <ul style="list-style-type: none"> <li>KS=1 <math>\rho = f(T, P)</math>; given T, P find <math>\rho</math></li> <li>KS=2 <math>P = f(T, \rho)</math>; given T, <math>\rho</math> find P</li> <li>KS=3 <math>T = f(P, \rho)</math>; given P, <math>\rho</math> find T</li> <li>KS=4 <math>T, \rho = f(P, H)</math>; given P, H find T, <math>\rho</math></li> <li>KS=5 <math>T, \rho = f(P, S)</math>; given P, S find T, <math>\rho</math></li> </ul>



<sup>a</sup>Notes:

1. The units indicator, KU, must be set such that  $1 \leq KU \leq 5$  or no valid property values can be determined. See table VIII.
2. Reset KR≠1 for each call to GASP to be assured of nonsaturation calculations (unless  $T = T_{sat}$  and  $P = P_{sat}$ ).
3. Sample call:

COMMON/PROPTY (as indicated above)

COMMON/DERIV/ (as indicated above)

REAL (as indicated above)

DATE NAMGAS/2HO2/

CALL SETUP(NAMGAS)

KR=0

CALL GASP(2, 7, 100., P, .39996 E-2, H, KP)

Returns: P = 1 atm;  $C_v = 0.6636$ ;  $\gamma = 1.43$ .

<sup>b</sup>KP input is  $\sum$  KP options if more than one property is requested. For example, if enthalpy and entropy are desired, set KP equal to 3.

TABLE VI. - UNITS SPECIFICATION KU<sup>a</sup>

Physical quantity	KU=1	KU=2	KU=3
Temperature	K	K	°R
Density	g/cm <sup>3</sup>	g/cm <sup>3</sup>	lbm/ft <sup>3</sup>
Pressure	MPa	atm	psia
Enthalpy	J/g	J/g	Btu/lbm
Entropy, specific heat	J/g-K	J/g-K	Btu/lbm-°R
Sonic velocity	cm/sec	cm/sec	ft/sec
Dynamic viscosity	g/cm-sec	g/cm-sec	lbm/ft-sec
Thermal conductivity	J/cm-sec-K	J/cm-sec-K	Btu/ft-sec-°R
Surface tension	dyne/cm	dyne/cm	lbf/ft
$\left(\frac{\partial P}{\partial \rho}\right)_T$	(MPa) $\left(\frac{cm^3}{g}\right)$	(atm)(cm <sup>3</sup> )/g	(psia)(ft <sup>3</sup> )/lbm $\approx \left(\frac{144}{788.161}\right)\left(\frac{Btu}{lbm}\right)$
	J/g	0.101325 J/g	psia/°R
$\left(\frac{\partial P}{\partial T}\right)_\rho$	MPa/K	atm/K	psia/°R

<sup>a</sup>KU=4 and KU=5 permit the user to work in other units; however, the proper conversions must be entered into BLOCK DATA. See appendix I, problem 5.

User's program must have

```
COMMON/CONV123/DConv(5), TConv(5), PConv(5)
COMMON/CONV4/SConv(5)
COMMON/CONV5/CConv(5)
COMMON/CONV6/HConv(5)
```

Store proper conversion in

```
DConv(4), etc., for KU=4
DConv(5), etc., for KU=5
```

such that

```
DINput/DConv(4) = g/cm3
TINput/TConv(4) = K
PINput/PConv(4) = MPa
HINput/HConv(4) = J/g
SINput/SConv(4) = J/g-K
```

when using KU=4 or KU=5. Transport properties such as dynamic viscosity, thermal conductivity, and surface tension will be in units of KU=1 (same as KU=2), i.e., (Units of KU=1) × (Conversion factor) = (Desired unit of input/output).

TABLE VII. - COMPUTER TIME ESTIMATES FOR

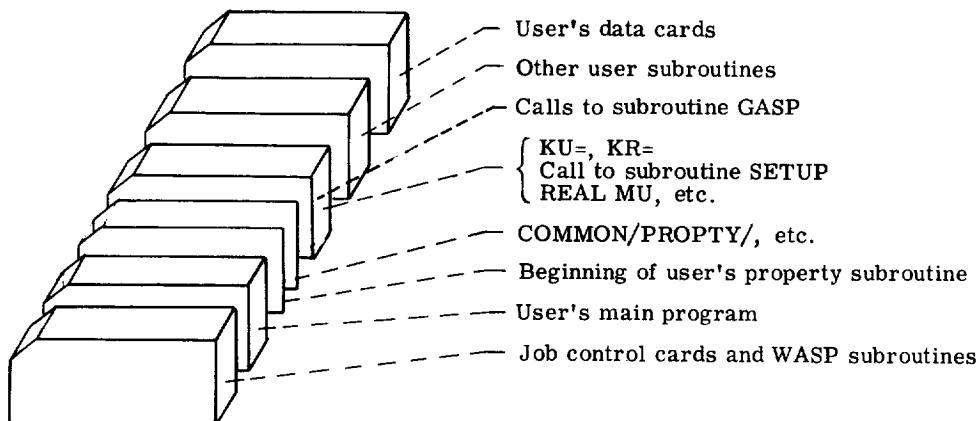
VARIOUS SINGLE CALLS TO GASP ON

IBM 7094-7044

Fluid	Type of call					
	KS=1	KS=2	KS=3	KS=4	KS=5	KS=1, KS=63
Property						
Density	Pressure	Temperature	Pressure, enthalpy	Pressure, entropy	All properties	
Time <sup>a</sup> , sec						
CH <sub>4</sub>	0.008	0.0025	0.0037	0.09	0.12	0.031
N <sub>2</sub>	.006	.0016	.0035	.098	.11	.025
O <sub>2</sub>	.0056	.0028	.0045	.097	.13	.036
Ar	.0071	.0016	.0038	.11	.12	.023
CO <sub>2</sub>	.0055	.0018	.0045	.092	.13	.021
Ne	.0058	.0015	.004	.091	.098	.021
CO	.0056	.0020	.0048	.091	.11	.031
He	.0076	.0012	.0032	.081	.12	.022
F <sub>2</sub>	.0056	.0028	.006	.11	.12	.038
H <sub>2</sub>	.0098	.0013	.0032	.11	.13	.022

<sup>a</sup>Times are for single calls based on times for 100 calls averaged over the PVT range.

TABLE VIII. - PROGRAM ASSEMBLY



The subroutines in GASP may be loaded in any order with respect to the user's program. To run successfully, there must appear in at least one user subroutine the following:

- (1) COMMON/PROPTY/, etc.  
REAL MU, etc.
  - (2) KU=1 (or 2, 3, 4, 5)
  - (3) Other input variable specifications
  - (4) Call to subroutine SETUP
  - (5) Calls to subroutine GASP
- The COMMON/PROPTY/, of course, must be in the main program or subroutine where the user expects answers to be returned from GASP. It could be in several or all user subroutines.

TABLE IX. - COEFFICIENTS FOR  $P_{\text{sat}} = F(T)$  AND  $C_{p,0} = F(T)$ ; REFERENCE VALUES OF TEMPERATURE, ENTROPY, AND ENTHALPY; AND RANGE DERIVATIVES

	Fluid				
	$\text{CH}_4$	$\text{C}_2$	$\text{C}_3$	$\text{Ar}$	$\text{N}_2$
Constants in vapor-pressure curve equation:					
$J_1$	-0.32097996E+02	-0.66669126E+01	-0.51504618E+01	-0.13914448E+02	-0.78913112E+02
$J_2$	-0.29476493E+03	-0.20086668E+03	-0.25626822E+03	-0.57316331E+03	-0.26133653E+03
$J_3$	-0.75773219E+00	-0.37077481E+00	-0.42620757E+00	-0.18276203E+02	-0.11405373E+01
$J_4$	-0.77349172E+02	-0.62602129E+02	-0.56222081E+02	-0.18302925E+02	-0.67265955E+02
$J_5$	-0.47651151E+04	-0.56187159E+04	-0.26516635E+04	-0.10957549E+04	-0.21749217E+04
$J_6$	-0.12130439E+36	-0.25848436E+36	-0.13904384E+36	-0.36123787E+37	-0.37153631E+37
$J_7$	-0.19484937E+09	-0.49725676E+09	-0.15423155E+09	-0.50097228E+10	-0.262275674E+12
Constants in specific-heat-at-zero-pressure equation:					
$m_1$	-0.77498625E+01	-0.29092035E+02	-0.29145184E+02	-0.26000000E+01	-0.41420200E+01
$m_2$	-0.39225023E+02	-0.89317172E+03	-0.56919860E+03	-0.	-0.19227000E+01
$m_3$	-0.56781803E+04	-0.92294239E+05	-0.68732634E+05	-0.	-0.76012221E+05
$m_4$	-0.34426075E+36	-0.26204592E+07	-0.4484566045E+07	-0.	-0.73132222E+04
$m_5$	-0.23950075E+09	-0.14124266E+10	-0.13282647E+09	-0.	-0.
Reference temperature, $T_0$ , K	0.11167200E+03	0.77364000E+02	0.90000000E+02	0.87400000E+02	0.19471200E+03
Reference entropy, $S_0$ , J/(K)(mol)	0.83551735E+01	0.23351167E+01	0.47242894E+01	0.27571720E+01	0.48821219E+01
Reference enthalpy, $H_0$ , J/mol	0.81329700E+03	0.23118865E+03	0.35642127E+03	0.23743200E+03	0.76654175E+03
Specific-heats units correction factor, CP000R	0.26781491E+00	0.35693888E+01	0.31251170E+01	0.29815200E+00	0.69667300E+01
Lower pressure limit, $P_{\text{min}}$ , MPa	0.11672000E+01	0.13132200E+01	0.12132500E+01	0.12132500E+01	0.12132500E+01
Pressure at thermodynamic critical point, $P_c$ , MPa	0.44279320E+01	0.34172000E+01	0.50830000E+01	0.86922000E+01	0.73815000E+01
Upper pressure limit, $P_{\text{max}}$ , MPa	0.50672000E+02	0.50672000E+02	0.12000000E+03	0.56660000E+02	0.56660000E+02
Lower temperature limit, $T_{\text{min}}$ , K	0.97660000E+02	0.66400000E+02	0.45350700E+02	0.37842000E+02	0.21656200E+03
Temperature of thermodynamic critical point, $T_0$ , K	0.19772200E+03	0.12632000E+03	0.15478200E+03	0.15070320E+03	0.32421200E+03
Upper temperature limit, $T_{\text{max}}$ , K	0.60000000E+03	0.10000000E+04	0.50000000E+03	0.10000000E+04	0.10000000E+04
Lower density limit, $\rho_{\text{min}}$ , g/cm <sup>3</sup>	0.14494000E+04	0.16494000E+04	0.16000000E+04	0.16000000E+04	0.14444000E+04
Density at thermodynamic critical point, $\rho_0$ , g/cm <sup>3</sup>	0.10298600E+00	0.10298600E+01	0.12166700E+02	0.43250000E+02	0.43120000E+02
Upper density limit, $\rho_{\text{max}}$ , g/cm <sup>3</sup>	0.57000000E+00	0.11204000E+01	0.15000000E+01	0.14800000E+01	0.12500000E+01

	Fluid				
	$\text{He}$	$\text{CO}$	$\text{Br}$	$F_7$	$F_1$
Constants in vapor-pressure curve equation:					
$J_1$	0.679222985E+01	0.131728485E+02	-0.211200826E+01	0.511212186E+00	-0.10593817E+01
$J_2$	-0.117864375E+04	-0.52442818E+03	-0.3225748E+01	-0.35538649E+03	-0.35249570E+02
$J_3$	-0.19946843E+00	-0.18207888E+00	-0.23561801E+01	-0.16184764E+01	-0.17777397E+02
$J_4$	-0.69681779E+02	-0.20345068E+02	-0.95994925E+02	-0.28461699E+02	-0.23601614E+01
$J_5$	-0.14623832E+03	-0.13659320E+04	-0.22307327E+03	-0.25041457E+04	-0.85529568E+03
$J_6$	-0.17229114E+05	-0.51448454E+01	-0.26197460E+01	-0.111746000E+06	-0.16187257E+04
$J_7$	-0.83733535E+06	-0.16769321E+13	-0.12166700E+02	-0.19876899E+09	-0.125000233E+06
Constants in specific-heat-at-zero-pressure equation:					
$m_1$	0.10298600E+01	0.10392600E+01	0.51930624E+01	0.7981845E+01	0.14759936E+02
$m_2$	0.	-0.53332200E+05	0.	-0.37629101E+02	-0.21977387E+02
$m_3$	0.	0.26032523E+07	0.	0.26888018E+04	-0.32100176E+02
$m_4$	0.	0.	0.	-0.38658913E+77	-0.12616192E+04
$m_5$	0.	0.	0.	0.17515391E+10	0.57121808E+08
Reference temperature, $T_0$ , K	0.27040000E+02	0.68140000E+02	0.42146000E+02	0.84953000E+02	0.22268000E+02
Reference entropy, $S_0$ , J/(K)(mol)	0.24540781E+01	0.47528763E+01	0.45953227E+01	0.38416000E+01	0.21176619E+02
Reference enthalpy, $H_0$ , J/mol	0.59234824E+02	0.35387320E+03	0.36558202E+02	0.63235000E+02	0.20994360E+03
Specific-heats units correction factor, CP000R	0.10000000E+01	0.10000000E+01	0.11000000E+01	0.11000000E+01	0.10000000E+01
Lower pressure limit, $P_{\text{min}}$ , MPa	0.10132500E+01	0.10132500E+01	0.10132500E+01	0.11000000E+01	0.10132500E+01
Pressure at thermodynamic critical point, $P_c$ , MPa	0.26537000E+01	0.39860000E+01	0.22764400E+02	0.52150000E+01	0.12924000E+01
Upper pressure limit, $P_{\text{max}}$ , MPa	0.20900000E+02	0.29272200E+02	0.13132500E+02	0.23000000E+02	0.13000000E+02
Lower temperature limit, $T_{\text{min}}$ , K	0.24540000E+02	0.68140000E+02	0.30000000E+01	0.53480000E+02	0.13000000E+02
Temperature of thermodynamic critical point, $T_0$ , K	0.60000000E+03	0.60000000E+03	0.60000000E+03	0.50000000E+03	0.33000000E+02
Upper temperature limit, $T_{\text{max}}$ , K	0.15000000E+03	0.50000000E+04	0.40000000E+04	0.10000000E+05	0.10000000E+04
Lower density limit, $\rho_{\text{min}}$ , g/cm <sup>3</sup>	0.48330000E+00	0.29970000E+00	0.69300000E+01	0.57175000E+00	0.31430000E+01
Density at thermodynamic critical point, $\rho_0$ , g/cm <sup>3</sup>	0.13500000E+01	0.86000000E+00	0.21000000E+00	0.22500000E+01	0.11000000E+02
Upper density limit, $\rho_{\text{max}}$ , g/cm <sup>3</sup>	0.	0.	0.	0.	0.

TABLE X. - CONSTANTS AND COEFFICIENTS USED IN TRANSPORT EQUATIONS FOR DILUTE-GAS CONDUCTIVITY

$$(a) \log_{10} \left( \frac{k^*}{k_T} \right) = \sum_{i=1}^5 b_i T_R^i \quad (\text{eq. (B39)})$$

Fluid structure	Range delimiter ( $\log_{10} T_R$ )		$b_1$	$b_2$	$b_3$	$b_4$	$b_5$
	Low	High					
Inerts (He, Ne, Ar)	-4 -0.96910013×10 <sup>-1</sup> .903089987	-0.96910013×10 <sup>-1</sup> .903089987 1.778	0.3891166×10 <sup>-2</sup> 0.1751783×10 <sup>-1</sup> .136720567	0.983 0.85181928 .631	0 0	0 -84178805×10 <sup>-1</sup> 0	0 -16491245×10 <sup>-1</sup> 0
Diatomics <sup>a</sup> (N <sub>2</sub> , O <sub>2</sub> , F <sub>2</sub> , CO ≈ N <sub>2</sub> )	-4 0 .39794	0 .39794 1.0	0 -21370471×10 <sup>-2</sup> .08170270	1.0 .80465632 .729	0 .79352374 0	0 -1.1239895 0	0 0
Triatomics (CO <sub>2</sub> )	-0.22	1.0	0.16196636×10 <sup>-2</sup>	1.31584644	-0.21522105	-0.10587949	0
CH <sub>4</sub>	-0.280 .238	0.238 .71948992	-0.30757470 -.26396826	1.0243779 .4865031	0.26550054 2.7281748	0.86187039 -.3.6259505	0 1.6717516

$$(b) \log_{10} [k \cdot k^* \cdot Z_c^5] = \sum_{i=0}^4 a_i \rho_R^i \quad (\text{eq. (B41)})^b$$

	Fluid						
	CH <sub>4</sub>	N <sub>2</sub>	O <sub>2</sub>	Ar	CO <sub>2</sub>	Ne	CO
Critical temperature, T <sub>c</sub> , K	190.77	126.3	154.78	150.70	304.2	44.4	132.91
Critical density, ρ <sub>c</sub> , g/cm <sup>3</sup>	0.1820	0.3105	0.4325	0.5310	0.4640	0.483	0.2997
Thermal conductivity at T <sub>c</sub> , k <sub>T</sub> <sup>*</sup>	1.10 <sup>-4</sup>	2.77×10 <sup>-5</sup>	3.40×10 <sup>-5</sup>	2.24×10 <sup>-5</sup>	4.03×10 <sup>-5</sup>	2.6×10 <sup>-5</sup>	2.75×10 <sup>-5</sup>
Molecular weight	16.04	28.016	31.9988	39.94	44.01	20.183	28.01
Compressibility factor at critical point, Z <sub>5</sub> <sup>c</sup>	0.0020119504	0.002086587	0.0021320779	0.0021277034	0.0016279794	0.00244676	0.00226934
Conductivity parameter, λ	0.75226444	1.1425961	0.96364877	1.1037087	0.98614941	0.95859	1.127527
Potential parameter, k <sub>c</sub>	0.00713	0.0103	1×10 <sup>-2</sup>	0.00837	0.005	0.030488	0.009066
Hard-sphere collision diameter, σ <sub>d</sub>	3.822	3.681	3.499	3.421	3.952	2.82	3.59
Compressibility factor at critical point, Z <sub>c</sub>	0.046890513	0.040786245	0.030115154	0.027628636	0.022407394	0.047495	0.0402544
Equation of k = k <sup>*</sup> :							
Low range (LB)	-0.9586073	-1.39794	-2.6383	-1.744727	-4.699	-1.744727	-1.39794
High range	0.617	0.39697	0.5132176	0.45108	0.4226	0.45108	0.4625
a <sub>0</sub>	-7.0146457	-6.8539532	-6.86562723	-6.94782507	-6.98446882	-6.94782507	-6.94782507
a <sub>1</sub>	1.2990797	1.5602809	1.39461538	1.56855570	1.56855570	1.56855570	1.56855570
a <sub>2</sub>	0.07042136	0.39312380	0.23878721	0.72199889	0.59310573	0.72199889	0.72199889
a <sub>3</sub>	1.55004671	0.17155947	0.058701320	0.28823104	0.29305409	0.17155947	0.29305409
a <sub>4</sub>	0.92583319	0.051372790	0	0.047325357	0.025170328	0.047325357	0.051372790

<sup>a</sup>Parahydrogen handled separately.

<sup>b</sup>See also eq. (B28) which is general for all fluid with the exception of hydrogen (B36).

<sup>c</sup>Special equations for hydrogen thermal conductivity.

TABLE XI. - MODULAR STRUCTURE OF GASP

## (a) Necessary routines

Subroutine (* indicates multiple entry)	Reason
SETUP	Overlays coefficients into COMMON blocks
BLOCK	Contains coefficients for all fluids
*(CHECK, TCHECK, PCHECK, DCHECK)	Performs region and limit checks for all subroutines; converts user's units to internal program units
ROOT ROOTX SOLVE	POLY SPLINA Mathematical routines used in all iterative solutions necessary to calculation of properties
DENS PSSS	* (DSF, DDSF) DGUESS Used for KS=1 request and to determine region number for most other KS and KP options

## (b) Optional routines

Name	Subroutine (* indicates multiple entry)	KS or KP option involved	Statement numbers in subroutine GASP to be modified	Additional conditions for removal
Pressure	PRESS	KS=2	20	Also remove derived property B and modify statements 110 and 140
Temperature	TEMP, TSS *(TSSF, DTSSF) *(TSF, DTSF)	KS=3 (also KS=4 and KS=5)	30	Must also remove "Derived input" module and modify statements 40 and 45
Derived input	TEMPPH, TEMPPS *(TSHF, TPSF)	KS=4 (also KS=5)	40 45	None
Derived property A	ENTH ENT HSSLVF *(HSS, SSS) *(HSLV, SSLV) *(HDINT, SDINT) *(HDINTF, SDINTF)	KP=1 (also KP=2) KS=4 KS=5	60 to 110	Must also remove "Derived input," modify statements 40 and 45, remove "Derived property B," and modify statements 110 to 140
Derived property B	CPPRL CPPRLF SPCHV CVPS PTRHO SETCPO	KP=4	110 to 140	None
Transport modules	VISC, VISCD	KP=8	160 to 170	May be removed individually or as a whole module
	THERM, CONZ, CONC	KP=16	180 to 190	
	SURF	KP=32	240	

TABLE XII. - GASP DISASSEMBLY AND STORAGE REDUCTIONS<sup>a</sup>

To eliminate-	Remove decks	Substitute a dummy for -	Storage saved (base 8)
1. Nine of the ten gases	Change SETUP and BLOCD accordingly	-----	(2147) <sub>8</sub>
2. $T, \rho = f(P, H)$	TEMPPH	TEMPPH	(314) <sub>8</sub>
3. $T, \rho = f(P, S)$	TEMPPS	TEMPPS	(263) <sub>8</sub>
4. $T, \rho = f(P, H)$ or $f(P, S)$	TEMPPH, TEMPPS, TSHF, ROOTX	TEMPPH, TEMPPS	(1430) <sub>8</sub>
5. Enthalpy (also $T, \rho = f(P, H)$ and $CV, CP$ for $\rho > \rho_{switch}$ )	ENTH, TEMPPH, SPCHV, CVPS, SPLINA	ENTH, TEMPPH, SPCHV	(2135) <sub>8</sub>
6. Entropy (also $T, \rho = f(P, S)$ )	ENT, TEMPPS	ENT, TEMPPS	(475) <sub>8</sub>
7. $CV, CP, \gamma, C, \partial\rho/\partial T,$ $\partial P/\partial \rho$ , for all $\rho$	CPPRL, CPPRLF, PTRHO, SPCHV, CVPS, SPLINA	CPPRL	(3314) <sub>8</sub>
8. $CV, CP, \gamma, C, \partial\rho/\partial T,$ $\partial P/\partial \rho$ , for all $\rho$ ; Enthalpy, entropy; $T, \rho = f(P, H)$ or $f(P, S)$	Decks in 4 and 7; also ENTH, ENT, HSS, HSSLVF, HSLV, SETCPO, HDINT, HDINTF	TEMPPH, TEMPPS, CPPRL, ENTH, ENT	(7341) <sub>8</sub>
9. Viscosity	VISC, VISCD	VISC	(1127) <sub>8</sub>
10. Thermal conductivity	THERM, CONC, CONZ	THERM	(1530) <sub>8</sub>
11. Viscosity and thermal conductivity	VISC, THERM, CONC, CONZ, POLY, VISCD	VISC, THERM	(3104) <sub>8</sub>
12. Surface tension	SURF	SURF	(151) <sub>8</sub>

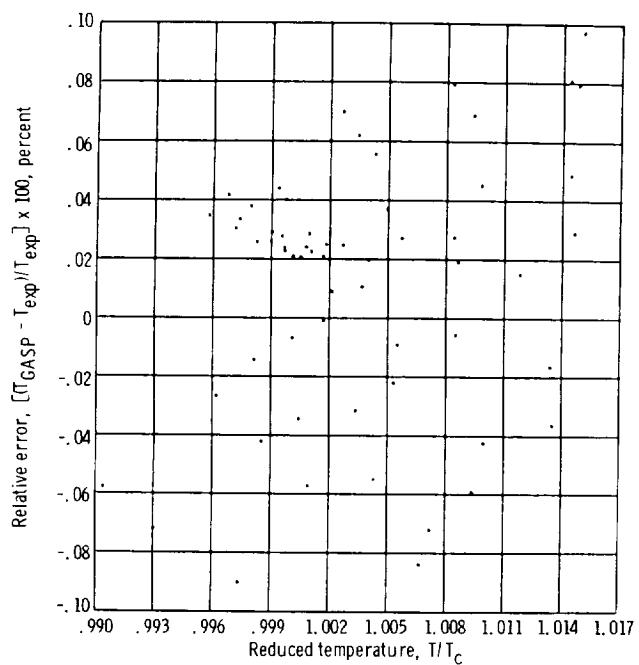
<sup>a</sup>Certain portions of GASP may be eliminated to gain more space for the user's own program. This table gives the amount of storage space to be saved when calculations which are not of interest to the user are omitted. The second column lists the decks to be physically removed from GASP. The third column shows the deck names for which dummy entry points must be prepared. A dummy entry point consists of no more than the deck name with argument list, followed by a RETURN and END. For example, to omit the viscosity calculation remove VISC and insert a dummy deck in its place:

```
SUBROUTINE VISC(K1,K2,X1,X2,X3)
```

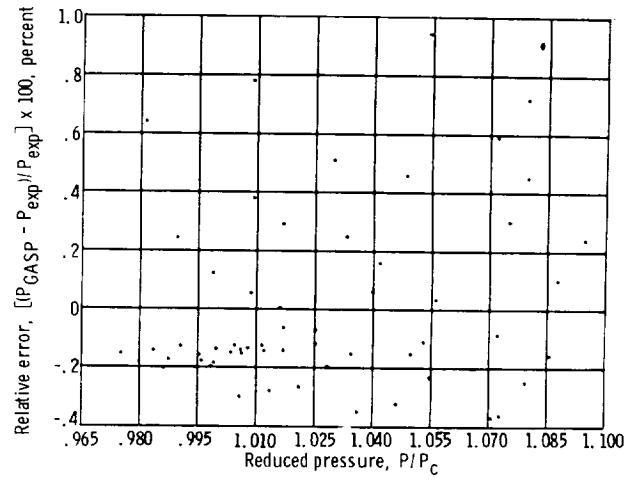
```
RETURN
```

```
END
```

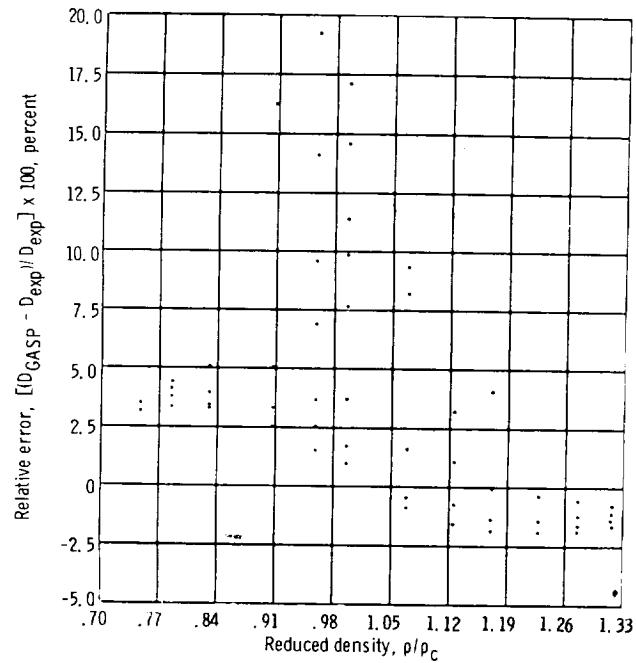
See also example appendix G.



(a) Temperature.



(b) Pressure.



(c) Density.

Figure 1. - Percent relative error in temperature, pressure, and density for methane data of Jansoone, Gielen, DeBoelpaep, and Verbeeke (ref. 34) as function of reduced data, based on calculated values from Bender's equation of state (ref. 4).

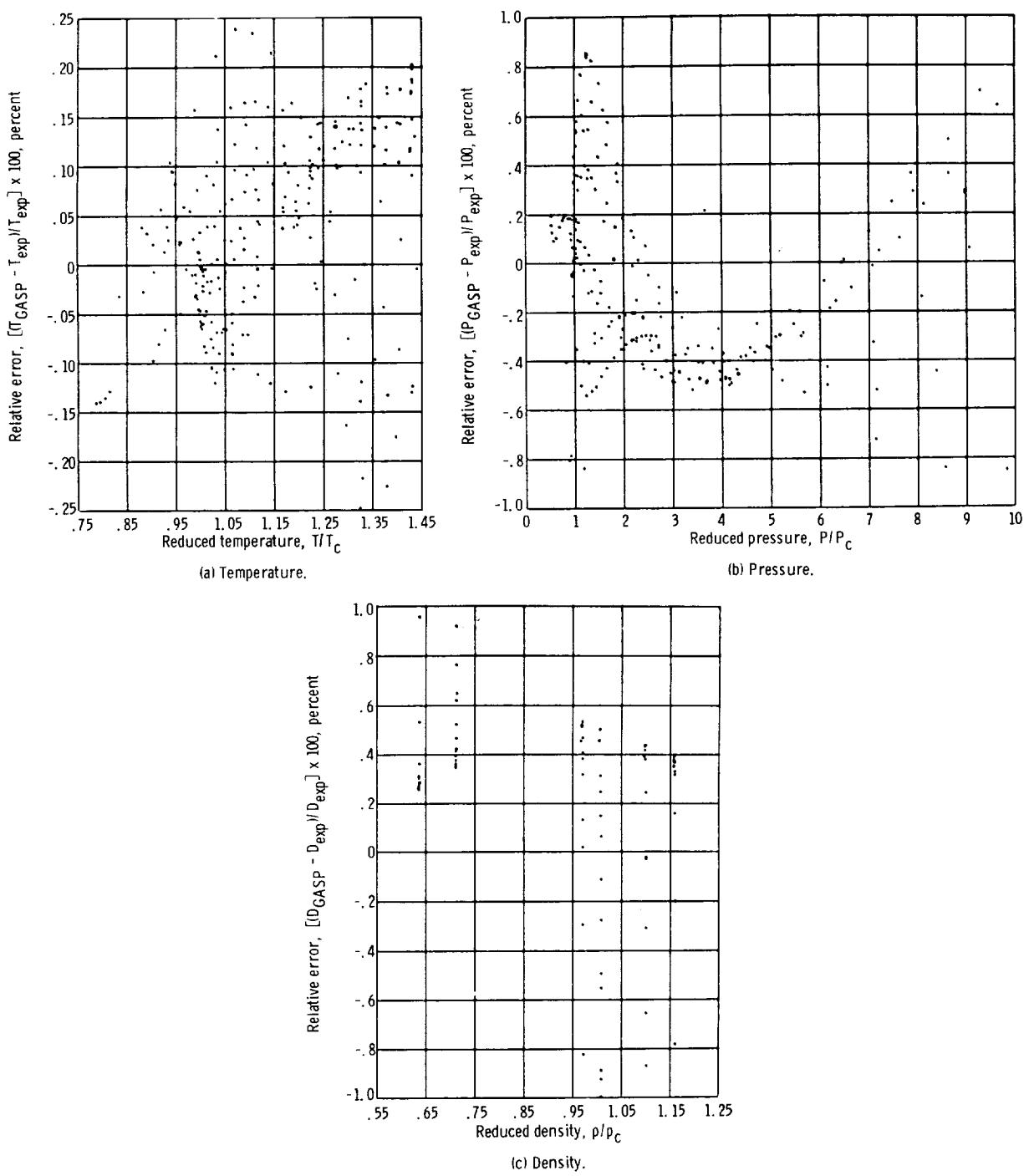
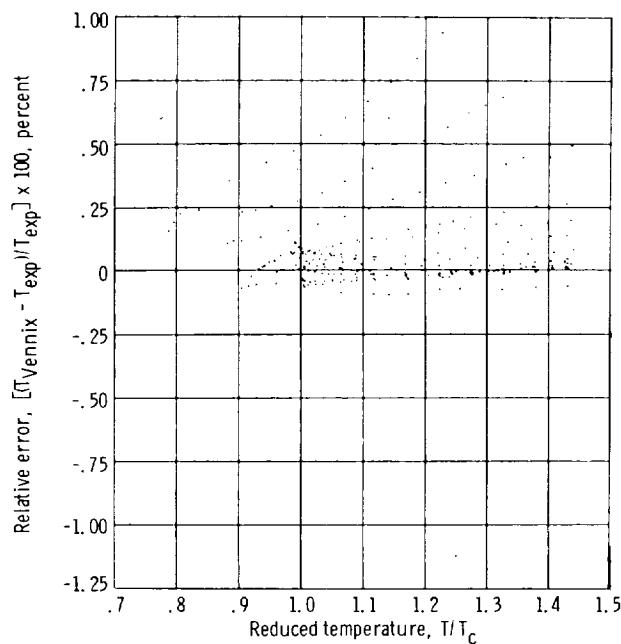
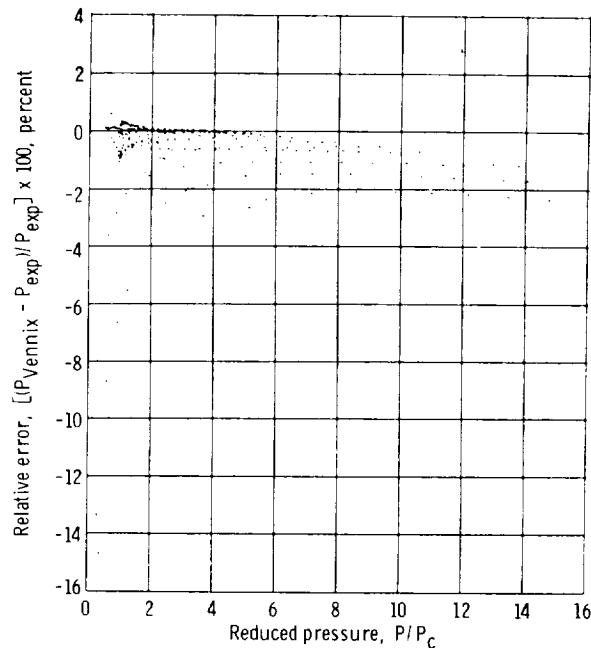


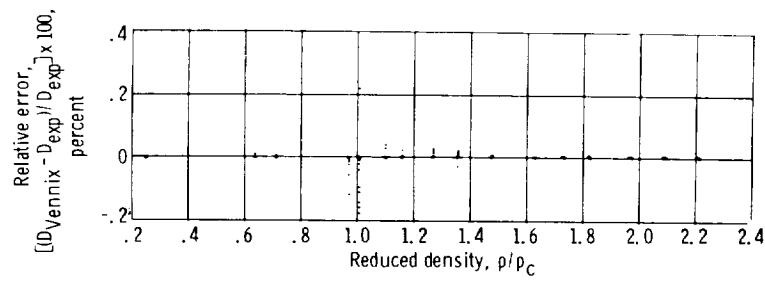
Figure 2. - Percent relative error in temperature, pressure, and density for methane data of Vennix (ref. 35) as function of reduced data, based on calculated values from Bender's equation of state (ref. 4).



(a) Temperature.



(b) Pressure.



(c) Density.

Figure 3. - Percent relative error in temperature, pressure, and density for methane data of Vennix (ref. 35) as function of reduced data, based on calculated values from Vennix's equation of state (ref. 35).

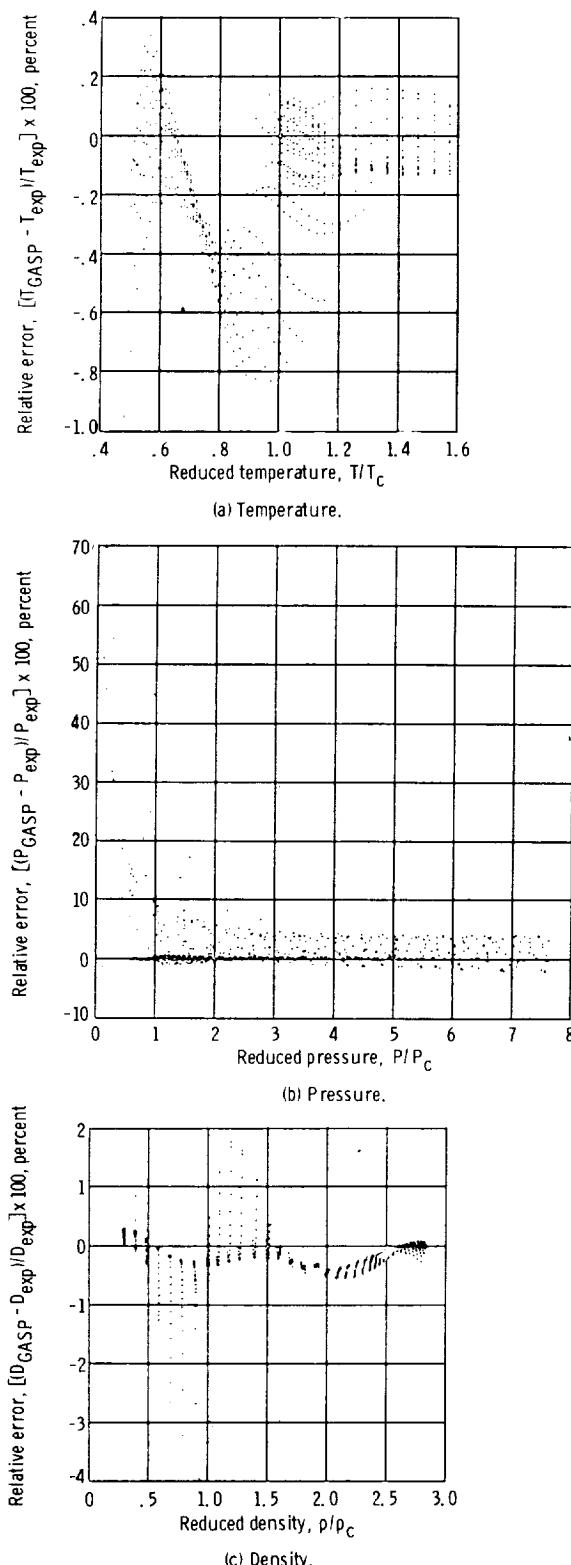


Figure 4. - Percent relative error in temperature, pressure, and density for methane data of Goodwin (ref. 13) as function of reduced data, based on calculated values from Bender's equation of state (ref. 4).

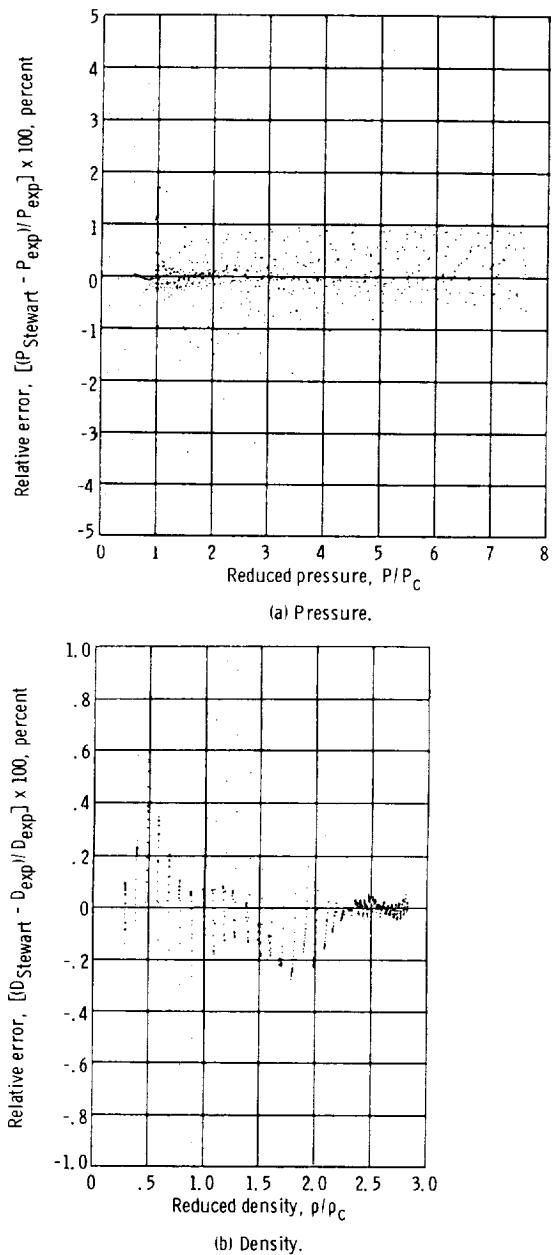
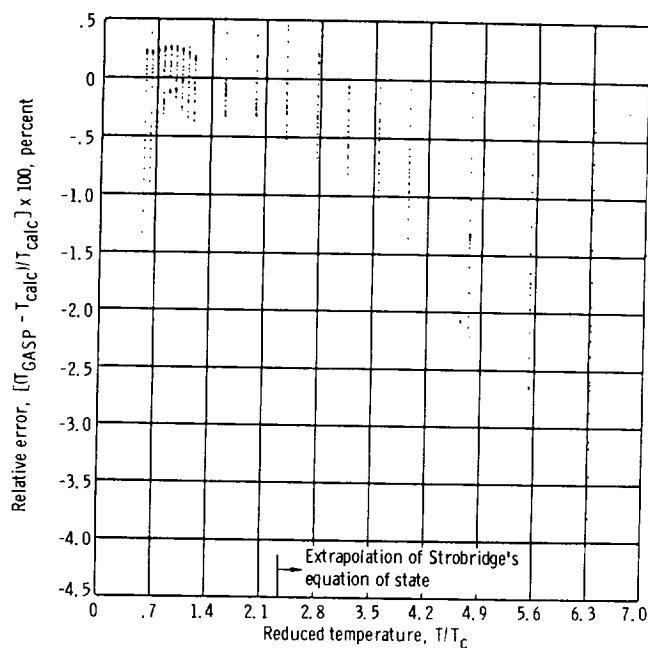
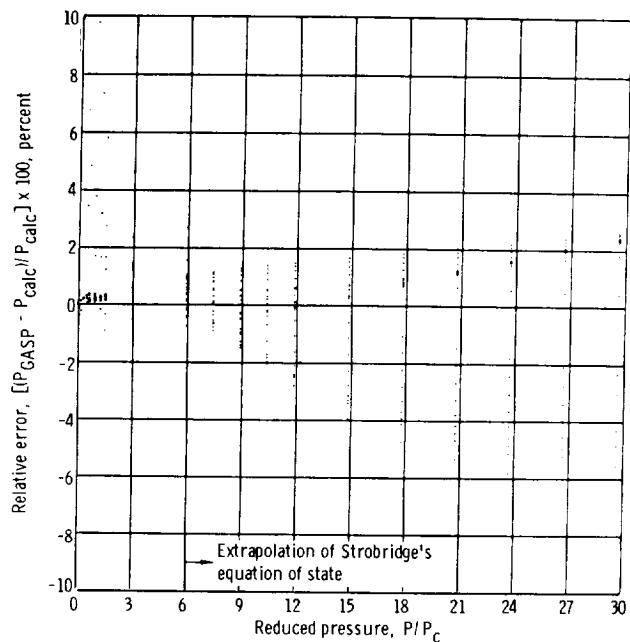


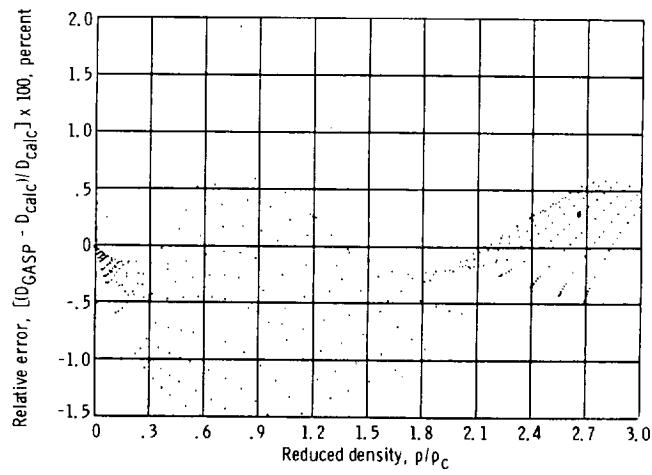
Figure 5. - Percent relative error in pressure and density for methane data of Goodwin (ref. 13) as function of reduced data, based on calculated values from Stewart-type equation (ref. 44) fit by McCarty (ref. 46).



(a) Temperature.



(b) Pressure.



(c) Density.

Figure 6. - Percent relative deviation in temperature, pressure, and density for nitrogen data of Strobridge (ref. 7) as function of reduced data, based on calculated values from Bender's equation of state (ref. 4).

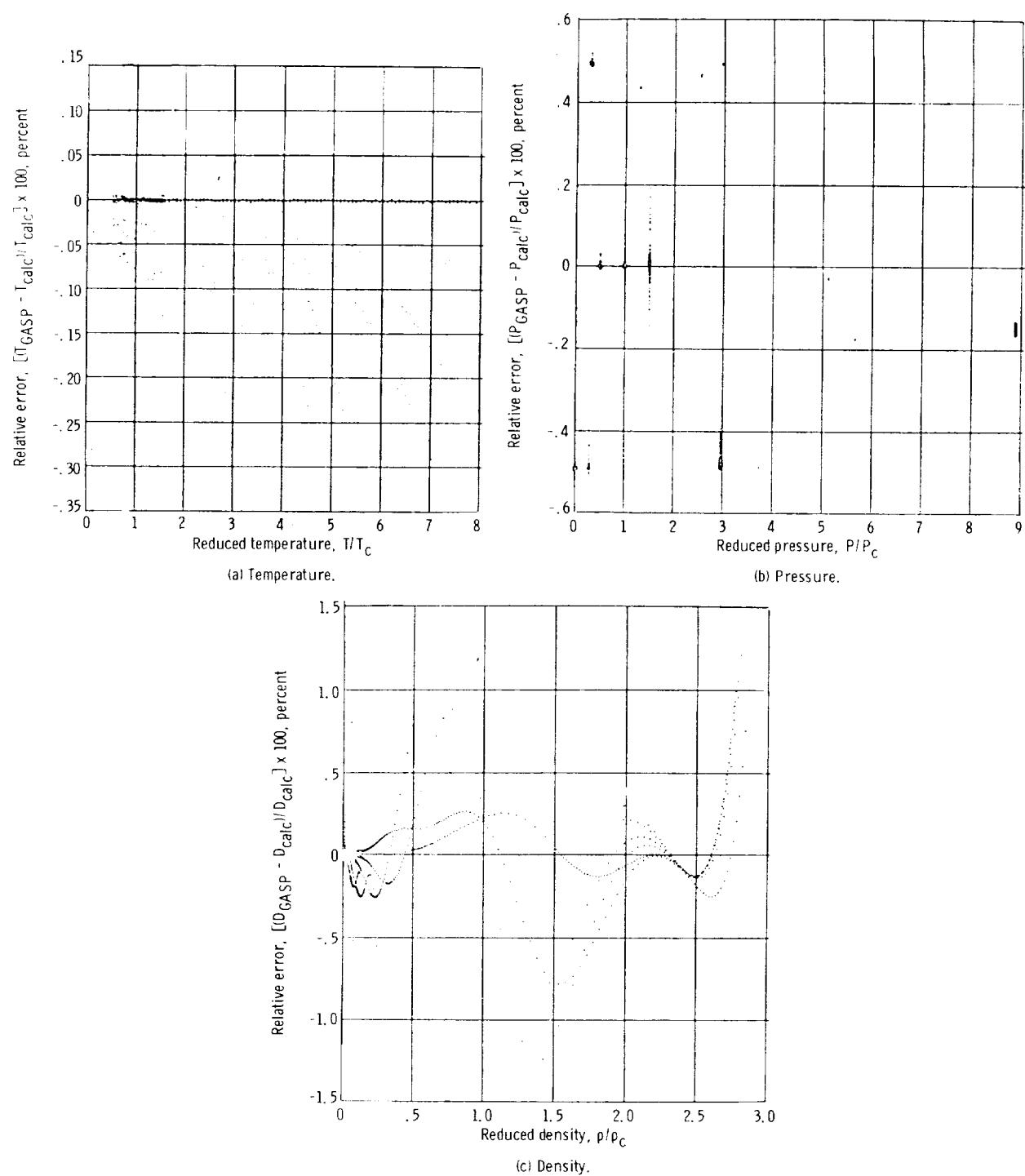


Figure 7. - Percent relative deviation in temperature, pressure, and density for nitrogen data of Coleman and Stewart (ref. 37) as function of reduced data, based on calculated values from Bender's equation of state (ref. 4).

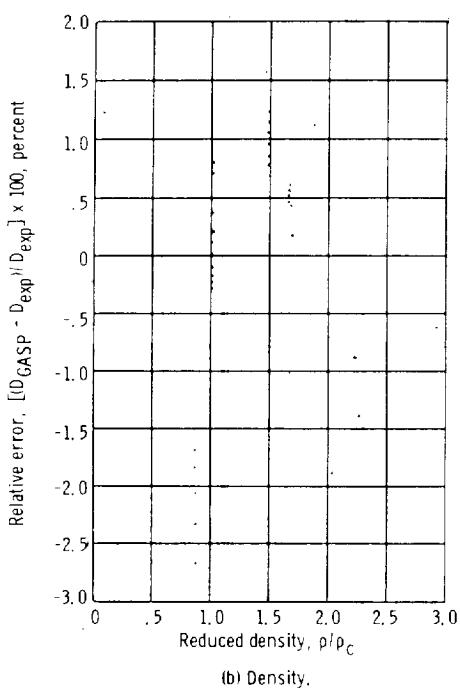
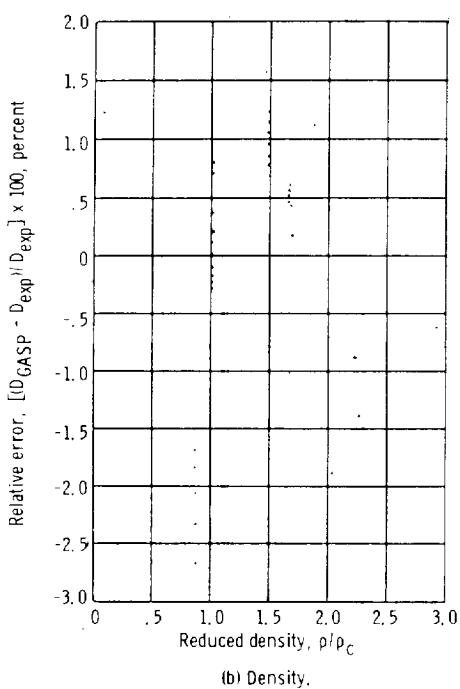
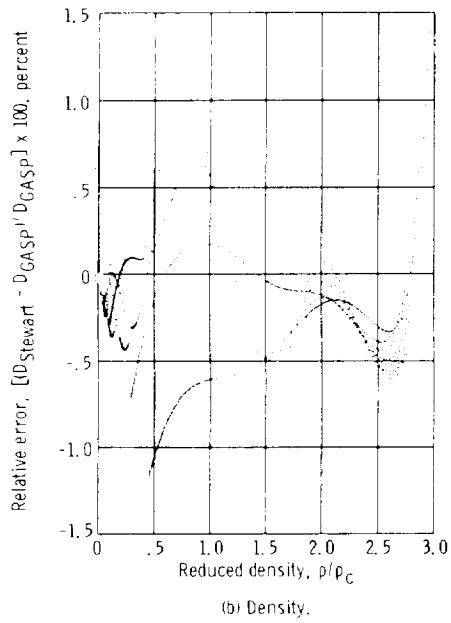
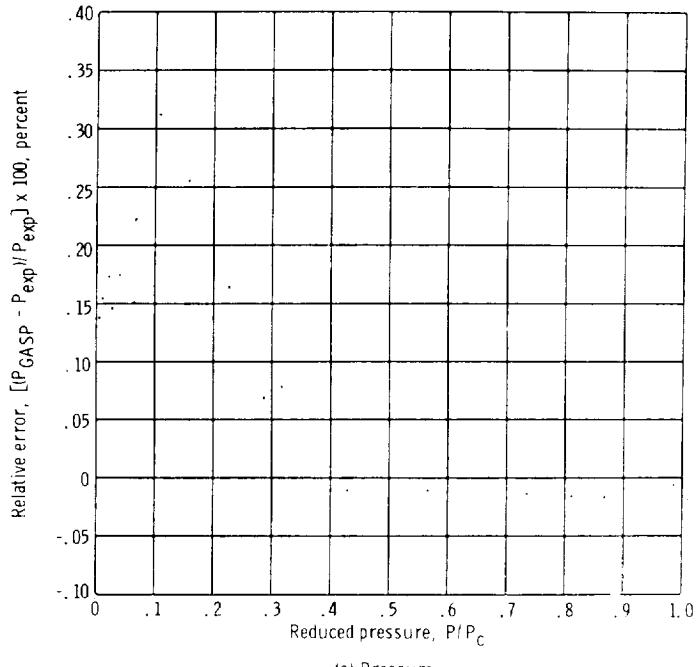
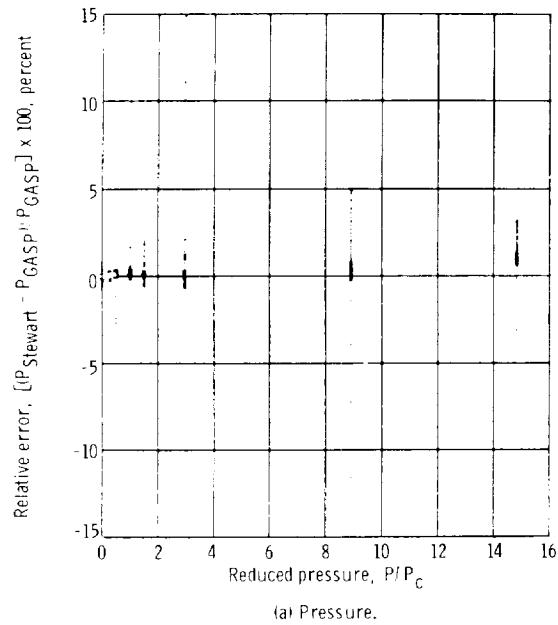
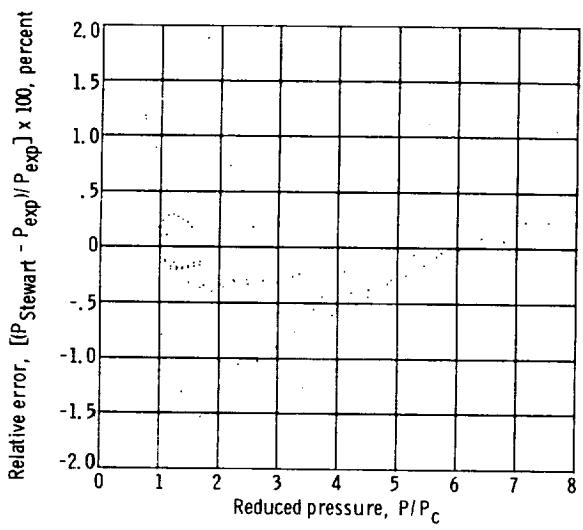
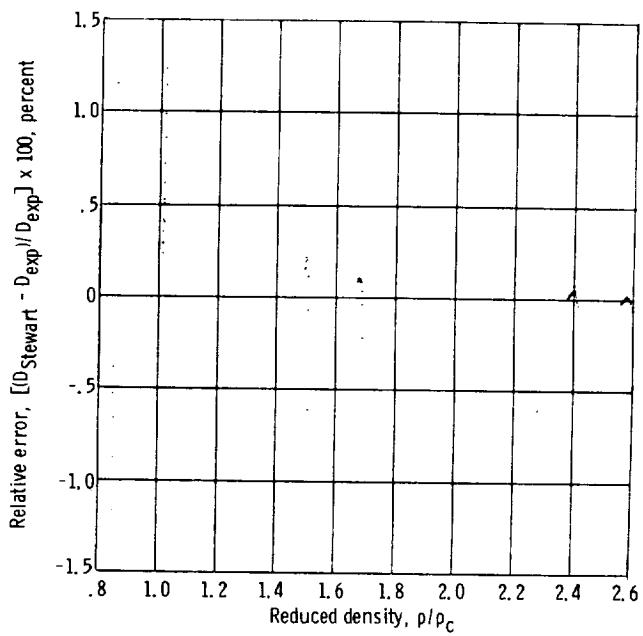


Figure 8. - Percent relative deviation in pressure and density for nitrogen data generated by GASP as function of reduced data, based on calculated values obtained from Stewart-type equation (ref. 44).

Figure 9. - Percent relative error in pressure and density for nitrogen data of Weber (ref. 36) as function of reduced data, based on calculated values from Bender's equation of state (ref. 4).



(a) Pressure.



(b) Density.

Figure 10. - Percent relative error in pressure and density for nitrogen data of Weber (ref. 36) as function of reduced data, based on calculated values obtained from Stewart-type equation (ref. 44).

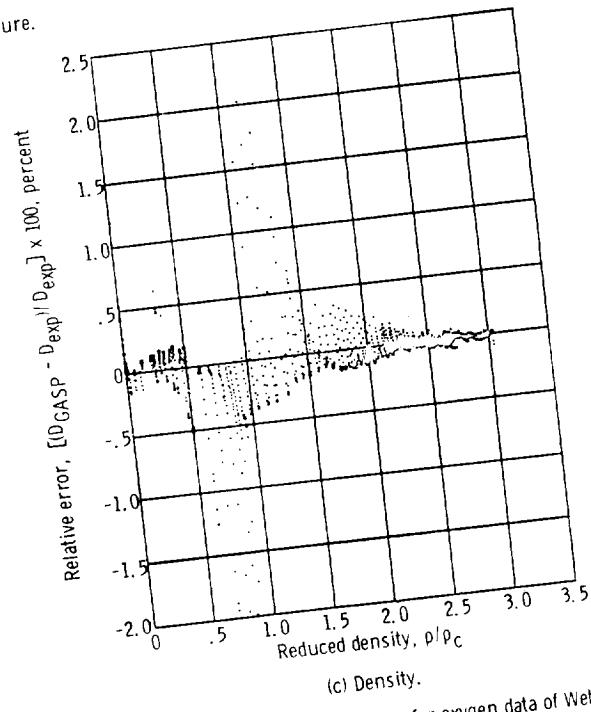
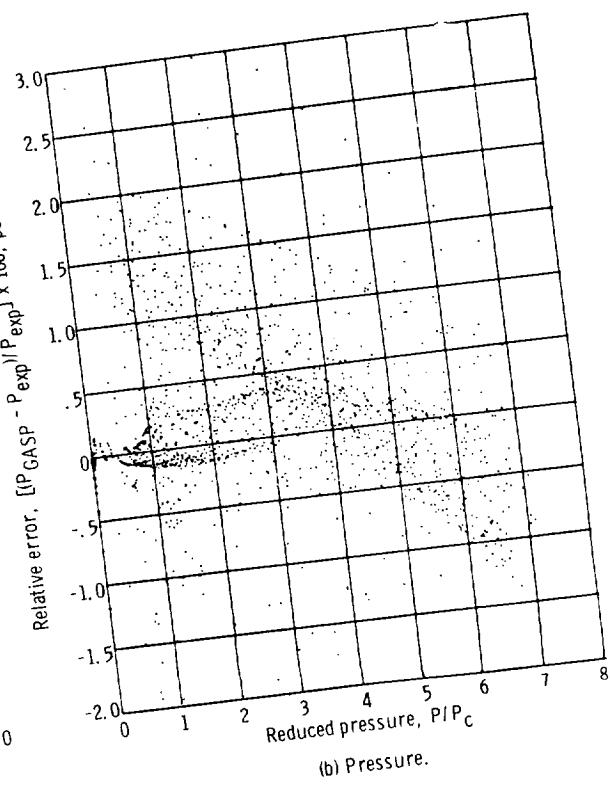
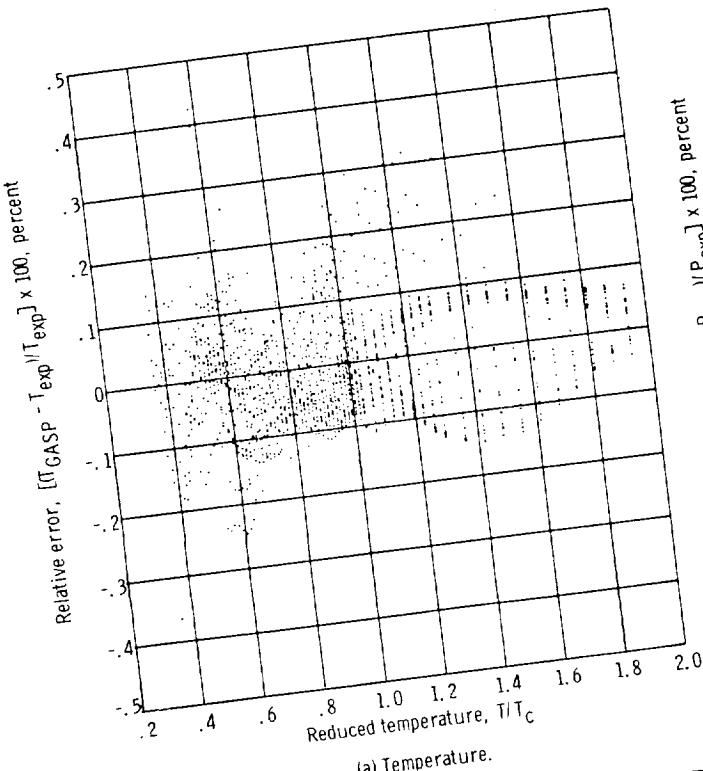


Figure 11. - Percent relative error in temperature, pressure, and density for oxygen data of Weber (ref. 39) as function of reduced data, based on calculated values from Bender's equation of state (ref. 4).

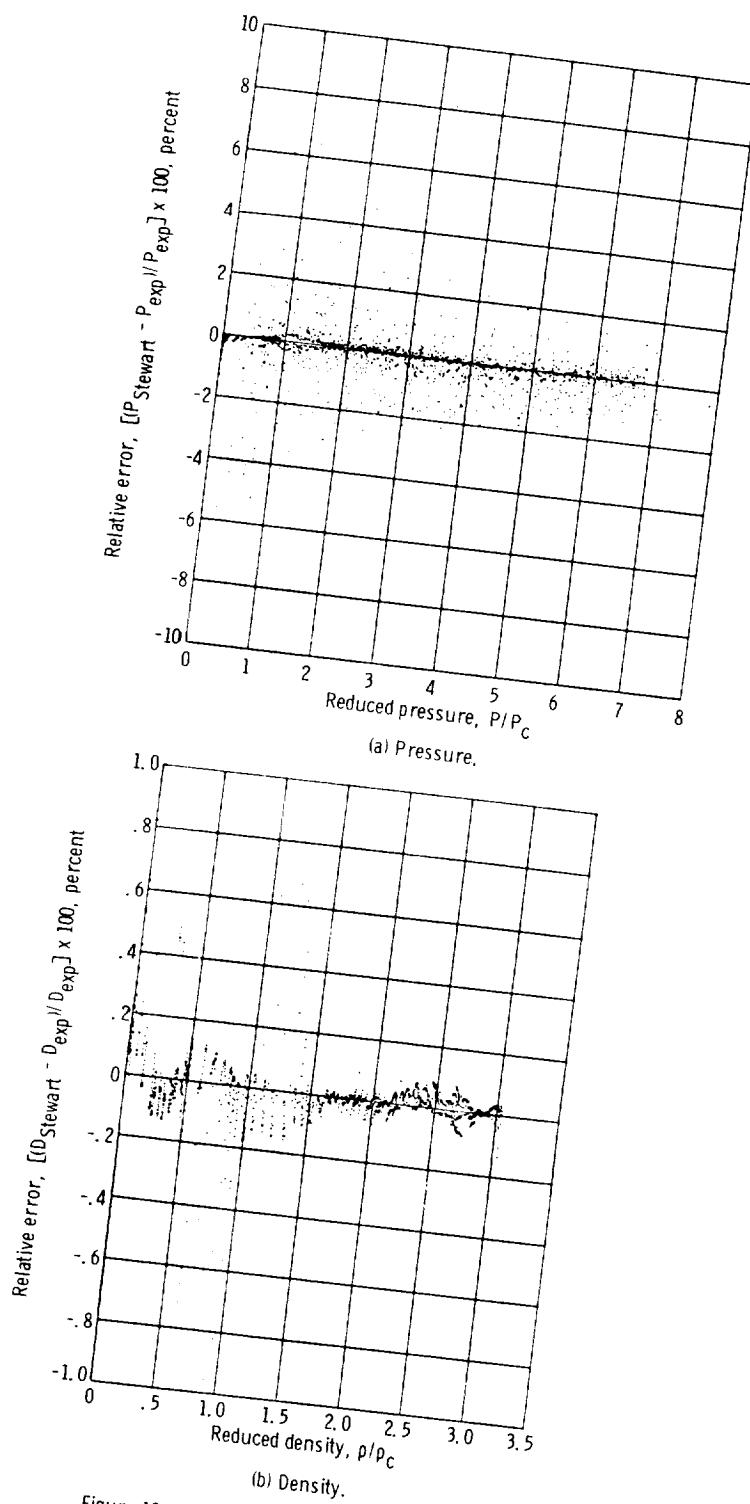


Figure 12. - Percent relative error in pressure and density for oxygen data of Weber (ref. 39) as function of reduced data, based on calculated values obtained from Stewart-type equation (ref. 44).

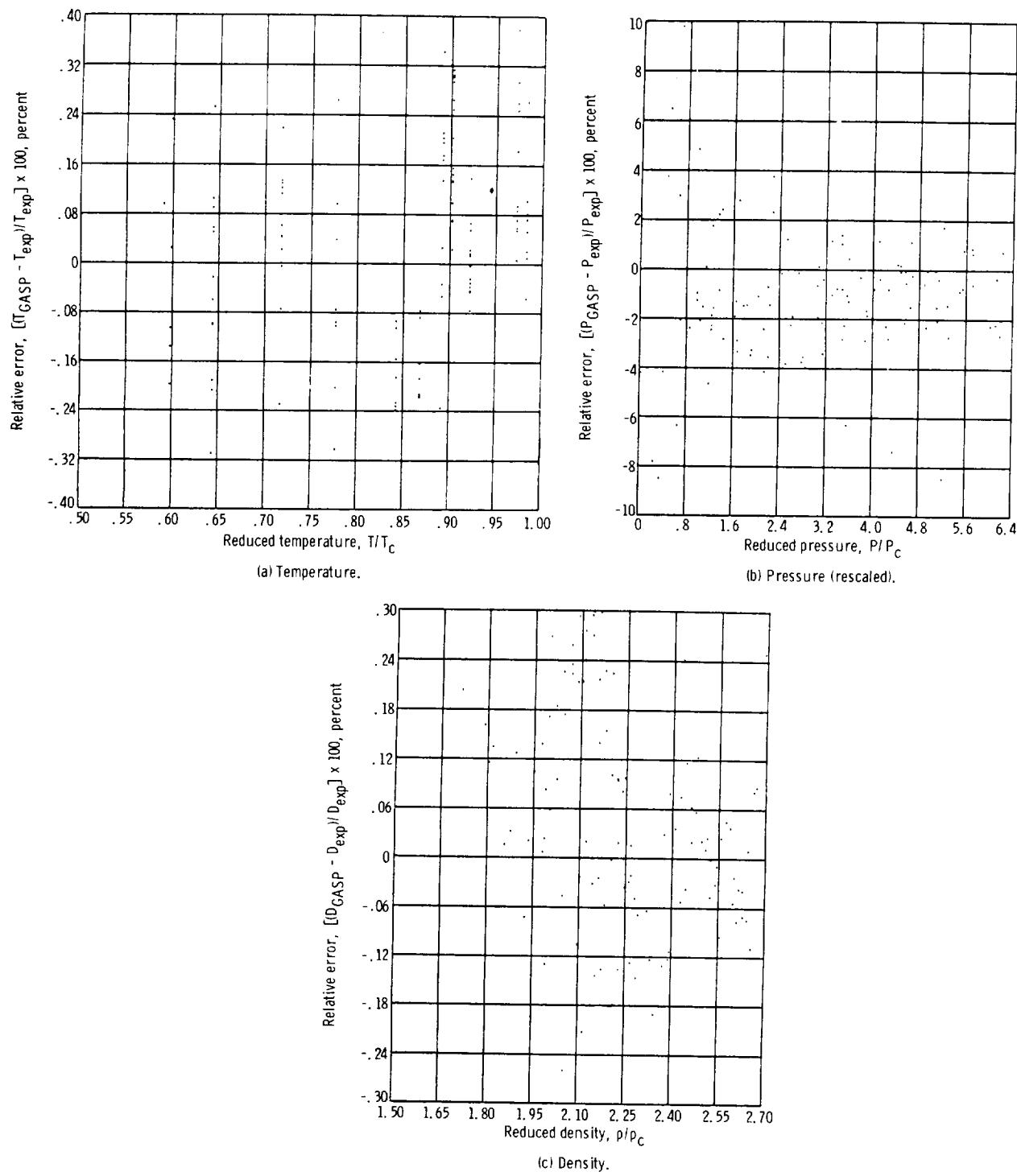


Figure 13. - Percent relative error in temperature, pressure, and density for argon data of Van Itterbeek, Verbeeke, and Staes (ref. 40) as function of reduced data, based on calculated values from Bender's equation of state (ref. 4).

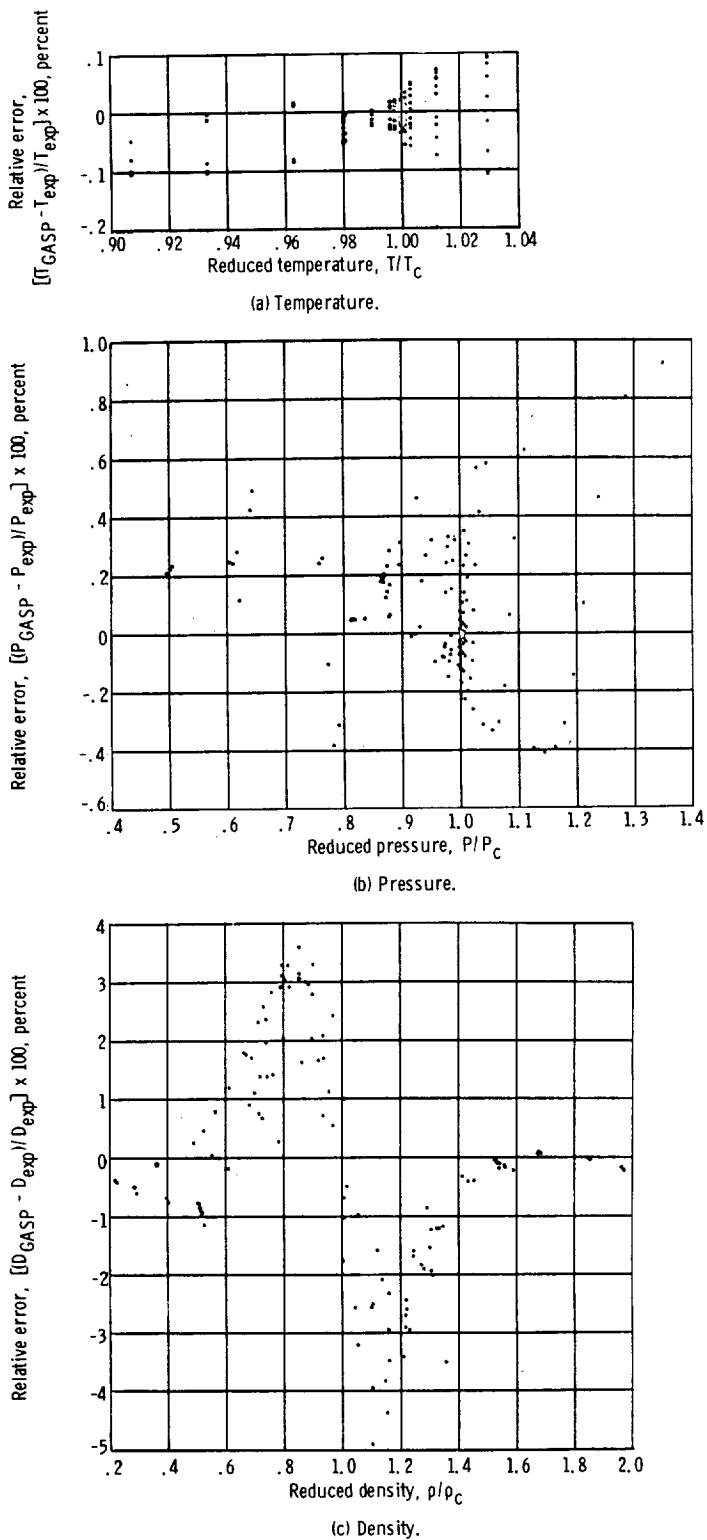


Figure 14. - Percent relative error in temperature, pressure, and density for carbon dioxide data of Michels, Blaisse, and Michels (ref. 41) as function of reduced data, based on calculated values from Bender's equation of state (ref. 4).

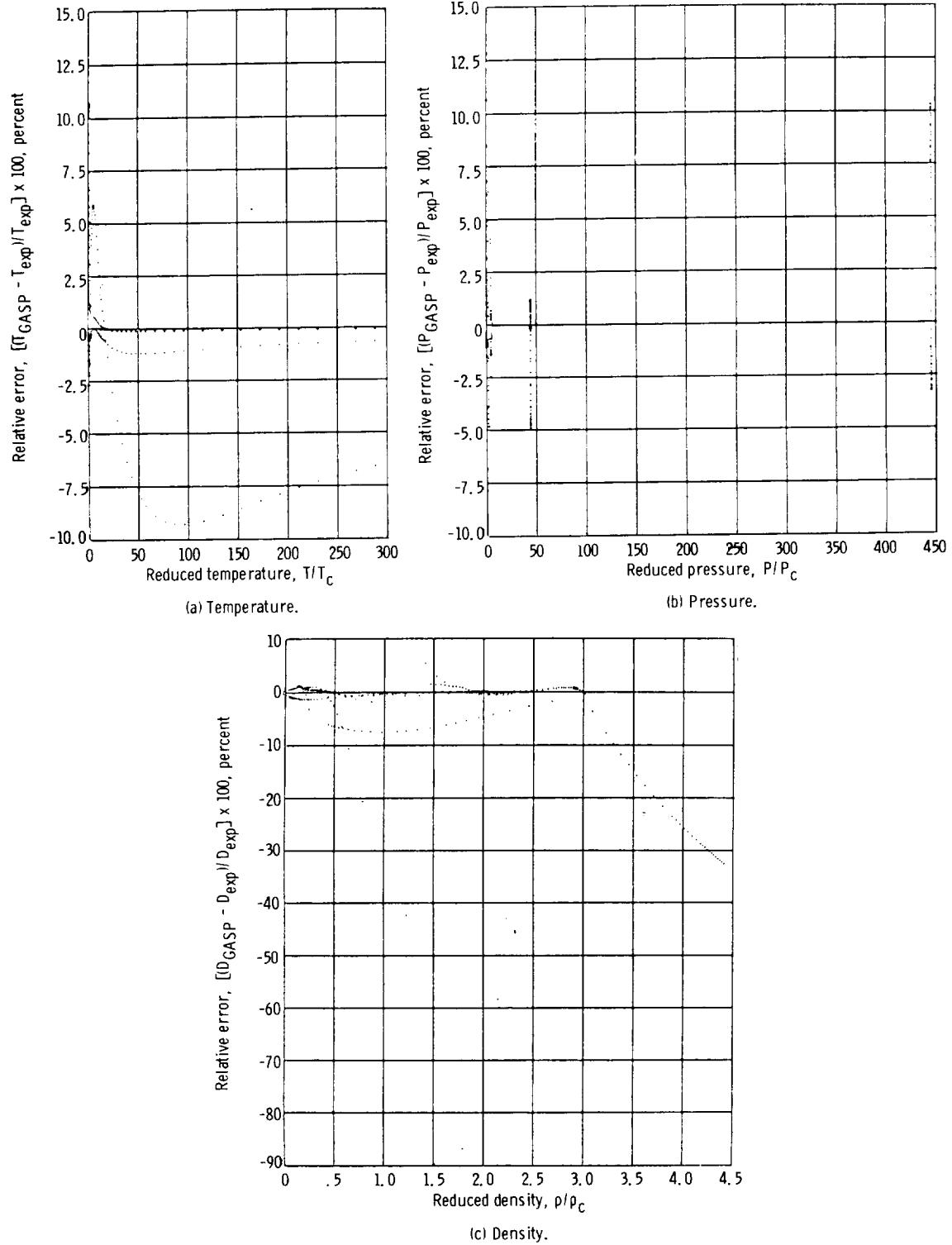


Figure 15. - Percent relative error in temperature, pressure, and density for helium data of Mann (ref. 11) as function of reduced data, based on calculated values from McCarty (ref. 17).

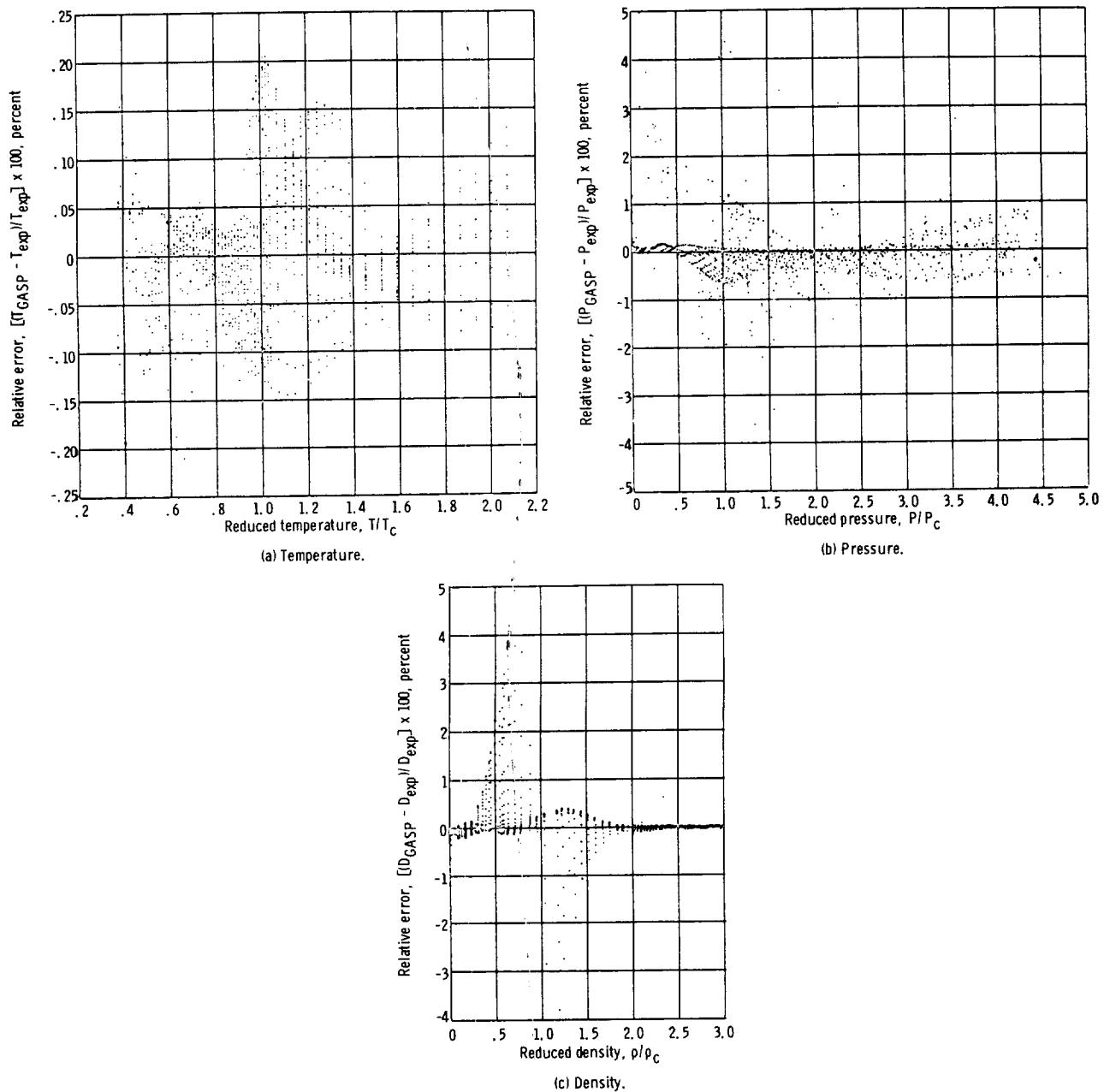
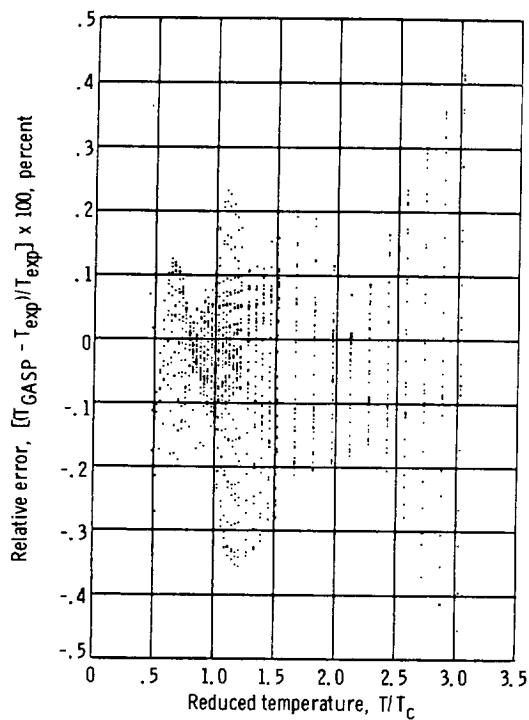
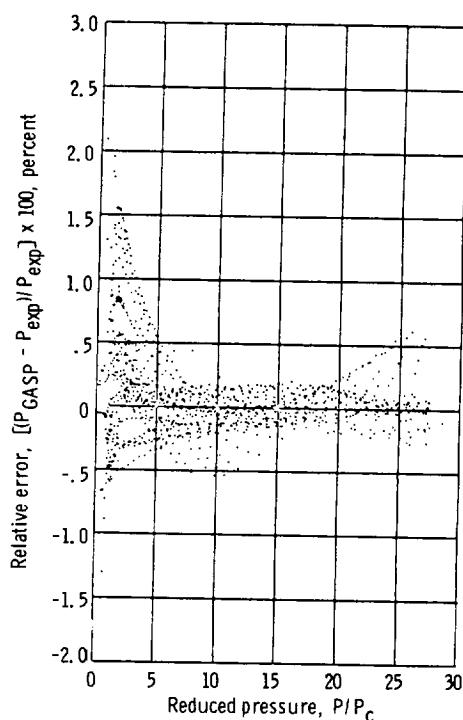


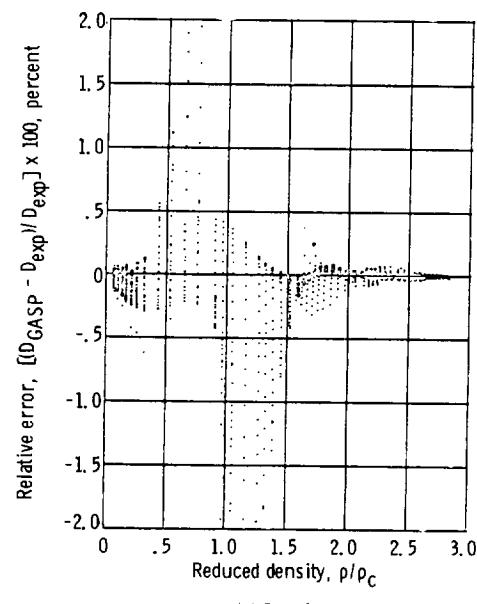
Figure 16. - Percent relative error in temperature, pressure, and density for fluorine data of Prydz and Straty (ref. 18) as function of reduced data, based on calculated values from Bender's equation of state in GASP, fit by authors.



(a) Temperature.



(b) Pressure.



(c) Density.

Figure 17. - Percent relative error in temperature, pressure, and density for parahydrogen data of Roder, Weber, and Goodwin (ref. 19) as function of reduced data, based on calculated values from Bender's equation in GASP, fit by authors.

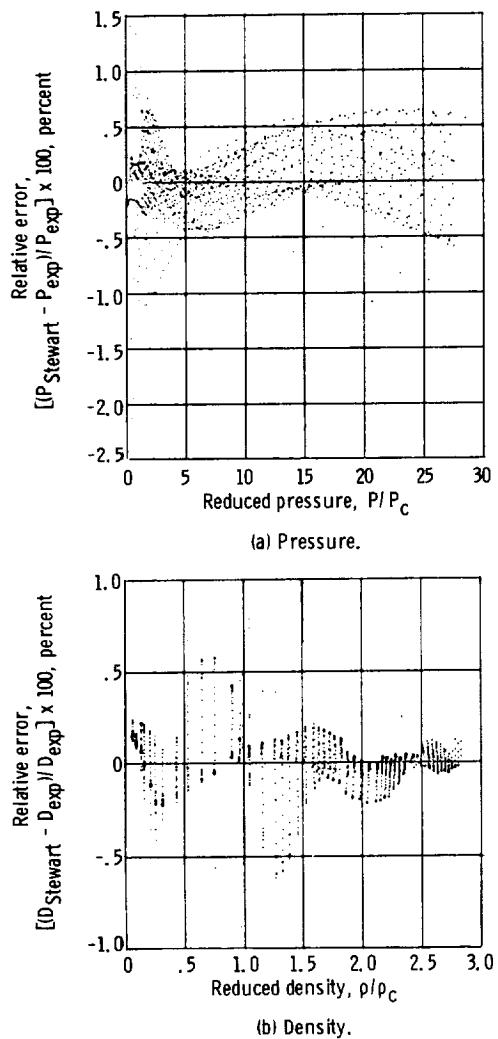


Figure 18. - Percent relative error in temperature, pressure, and density for parahydrogen data of Roder, Weber, and Goodwin (refs. 8 and 19) as function of reduced data, based on calculated values obtained from Stewart-type equation (ref. 44).

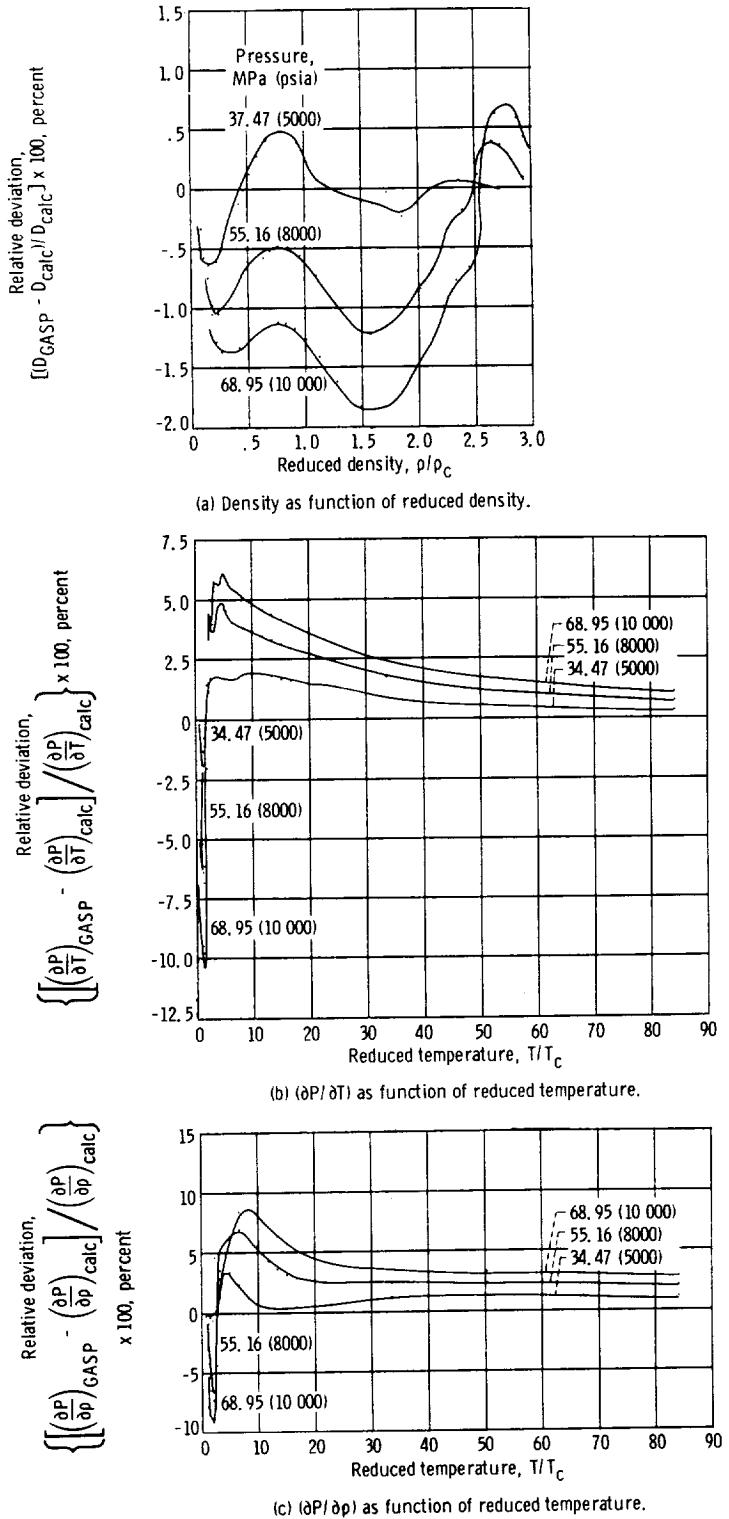
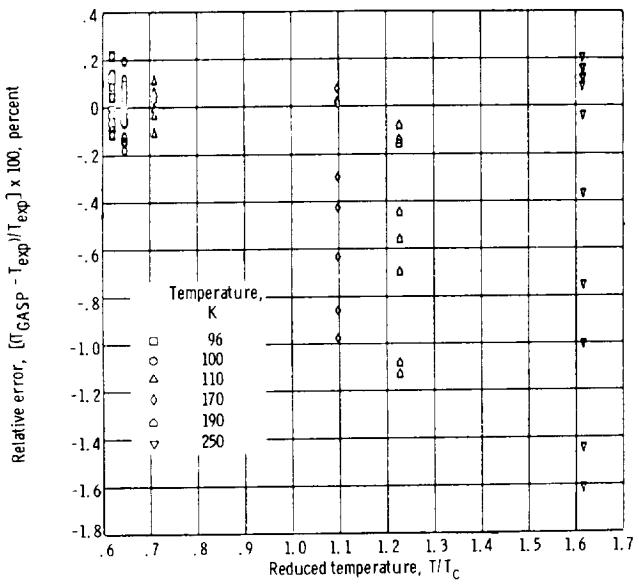
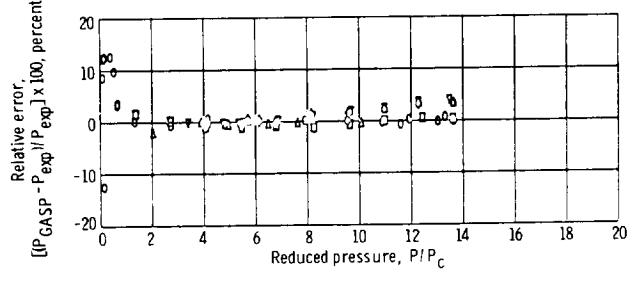


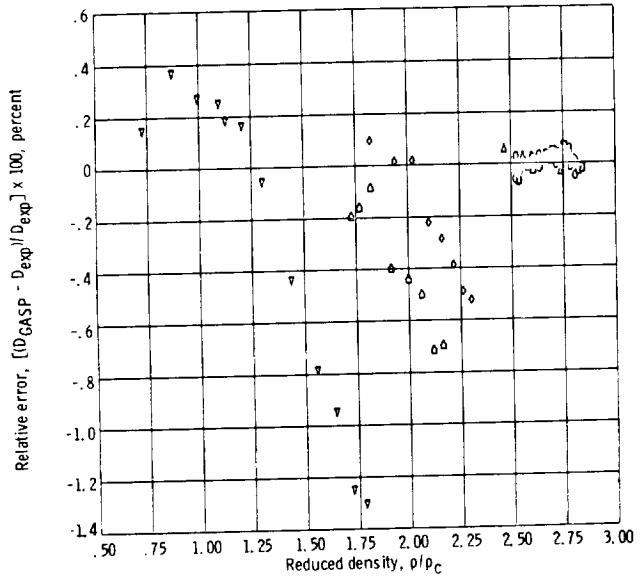
Figure 19. - Percent relative deviation in temperature, pressure, and density for parahydrogen results of McCarty and Weber (ref. 20) as function of reduced data, based on calculated values obtained from Bender's equation in GASP, fit by authors.



(a) Temperature.



(b) Pressure.



(c) Density.

Figure 20. - Percent relative error in temperature, pressure, and density for oxygen data of Streett (unpublished data) as function of reduced data, based on calculated values from Bender's equation of state (ref. 4).

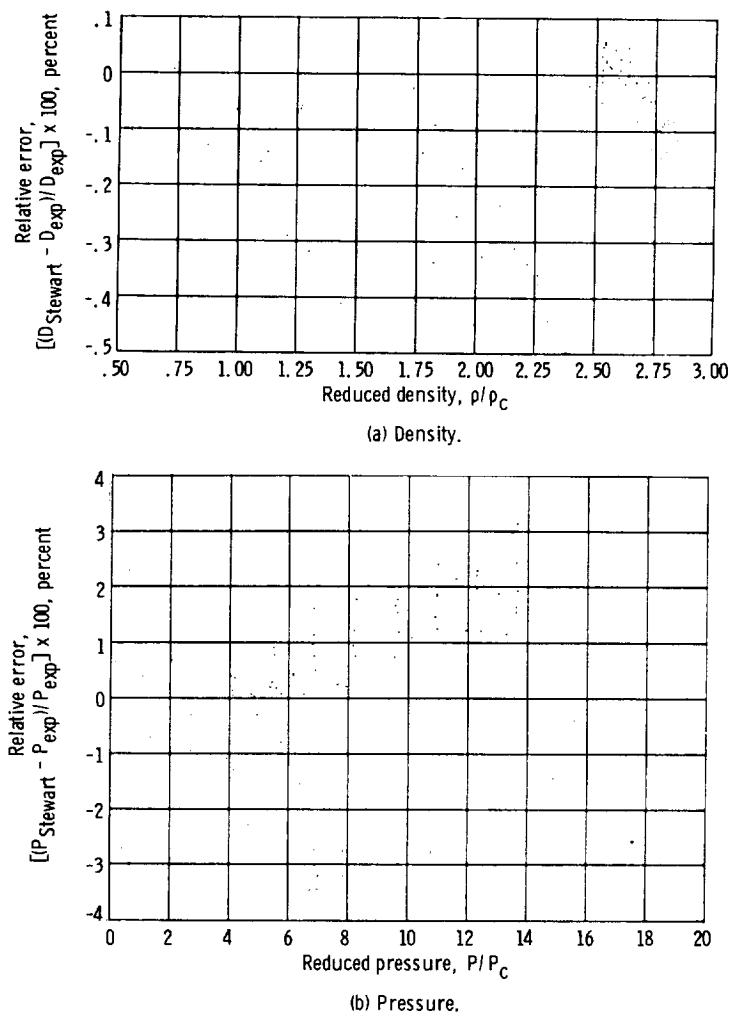


Figure 21. - Percent relative error in density and pressure for oxygen data of Streett (unpublished data) as function of reduced data, based on calculated values obtained from Stewart-type equation (ref. 44).

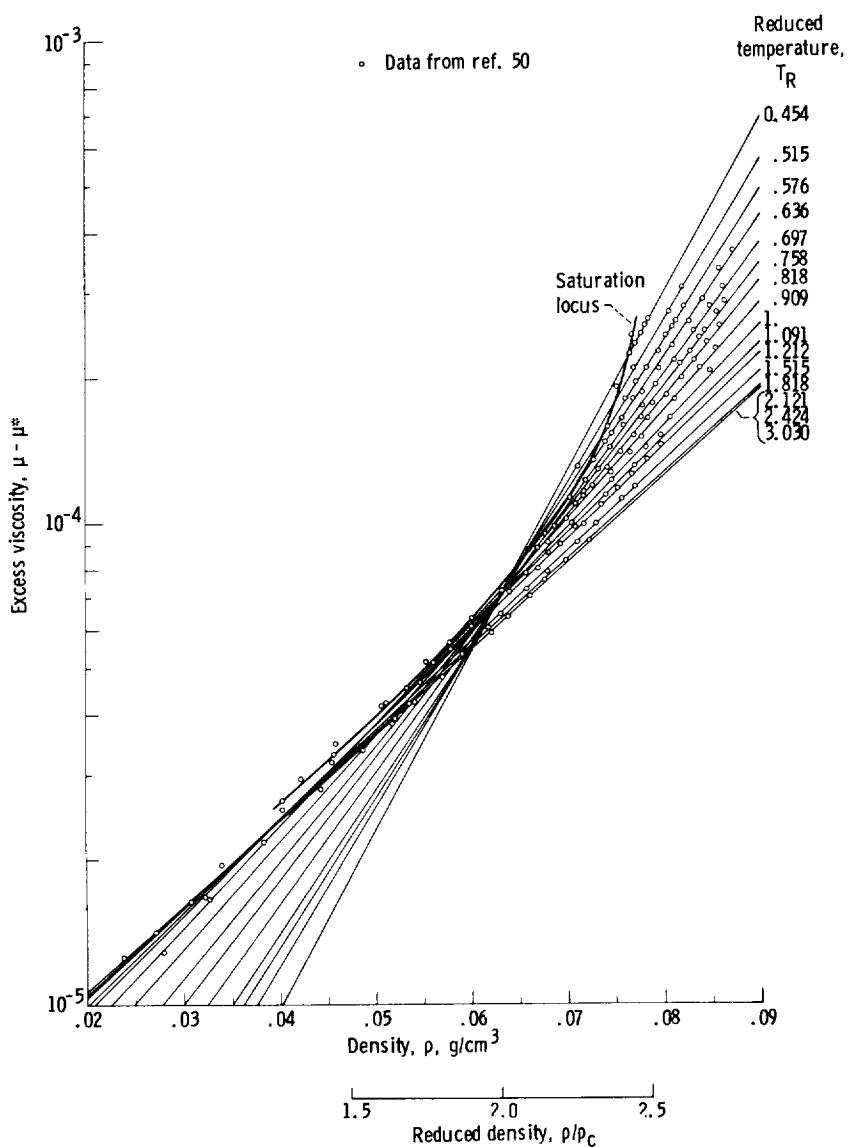


Figure 22. - Viscosity data of Diller (ref. 50) as function of reduced density.  
Critical temperature, 32.976 K; critical density,  $\rho_c$ , 0.0314 g/cm<sup>3</sup>.

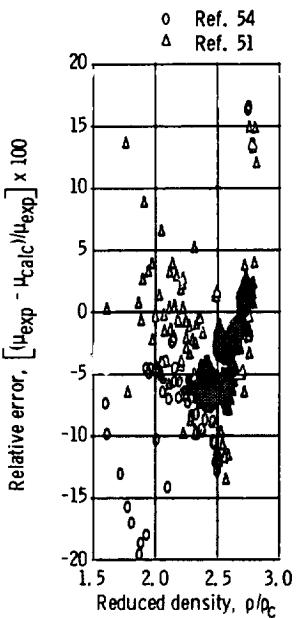


Figure 23. - Percent relative error in viscosity as function of reduced density for nitrogen data of Hellemans (ref. 54) and DeBock (ref. 51) compared with calculated values.

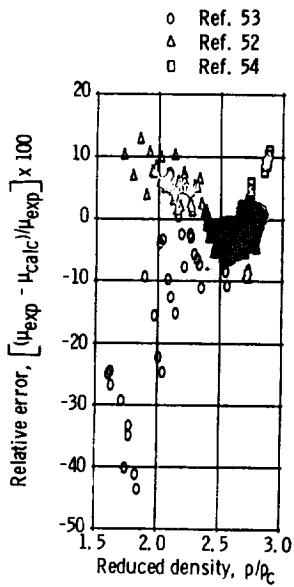


Figure 24. - Percent relative error in viscosity as function of reduced density for oxygen data of Van Itterbeek (ref. 53), Grevendijk (ref. 52), and Hellemans (ref. 54) compared with calculated values.

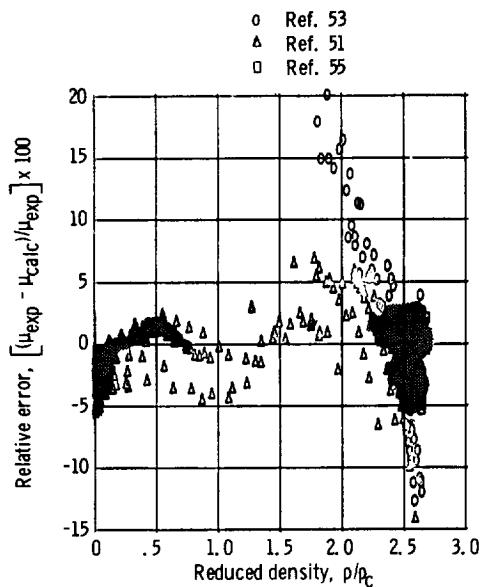


Figure 25. - Percent relative error in viscosity as function of reduced density for argon data of Van Itterbeek (ref. 53), DeBock (ref. 51), and Haynes (ref. 55) compared with calculated values.

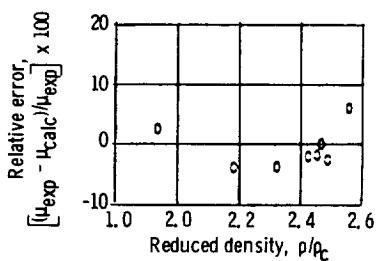


Figure 26. - Percent relative error in viscosity as function of reduced density for neon data of Forster (ref. 62) compared with calculated values.

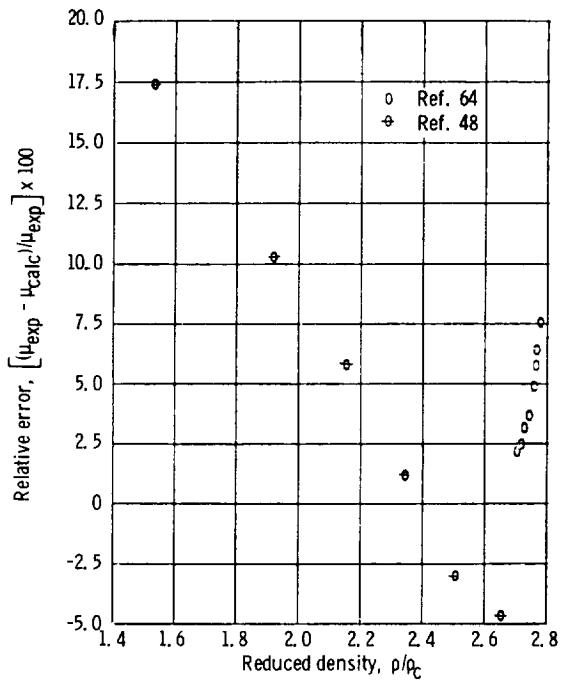


Figure 27. - Percent relative error in viscosity as function of reduced density for carbon monoxide data of Boon (ref. 64) compared with calculated values.

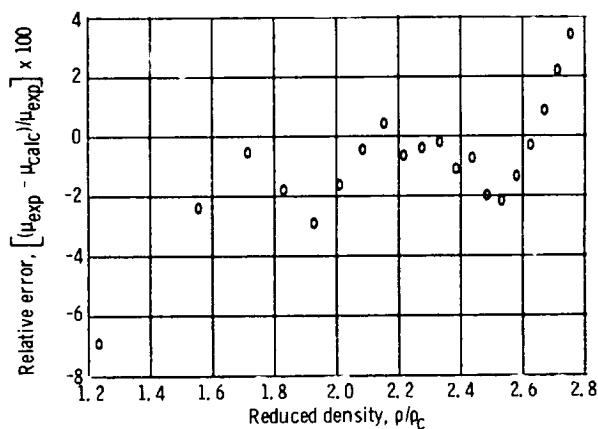


Figure 28. - Percent relative error in viscosity as function of reduced density for methane data of Haynes (ref. 59) compared with calculated values.

Region	Characteristic
I	Numerical
II	Numerical for CO, Ne, and He
III	Analytical
IV	For $P < P_c$ , $T_c \pm 0.5$ for CO, Ne, and He; $T_c \pm 0.1$ for Bender fluids. Near critical region of uncertain results in derived properties and possibly density. At very high pressure extensions ( $>500$ atm), deviations in properties at $T_c$ have been noticed.

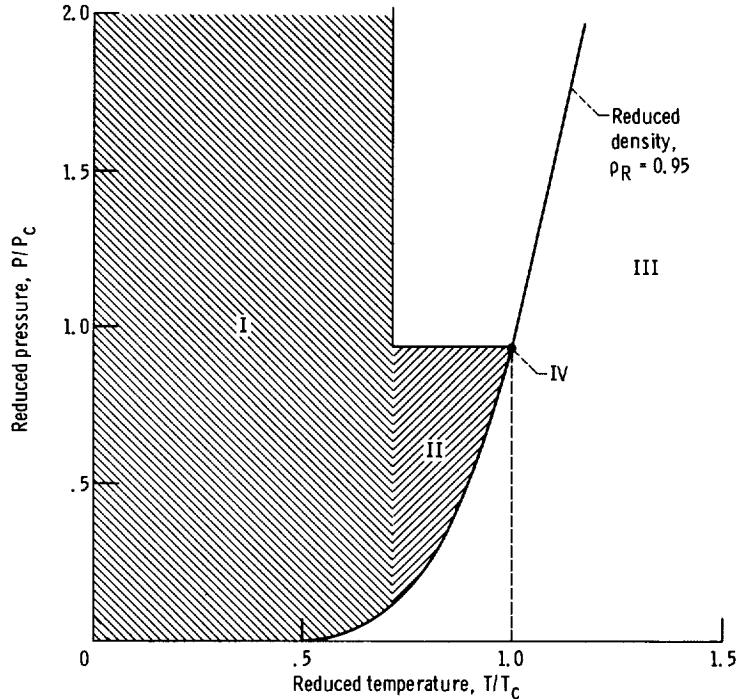


Figure 29. - Analytic and numeric computation regions for specific heat at constant volume  $C_v$ . Reduced density,  $\rho/\rho_c$ : 2.5 for methane, 2.2 for nitrogen, and 2.4 for all other fluids.