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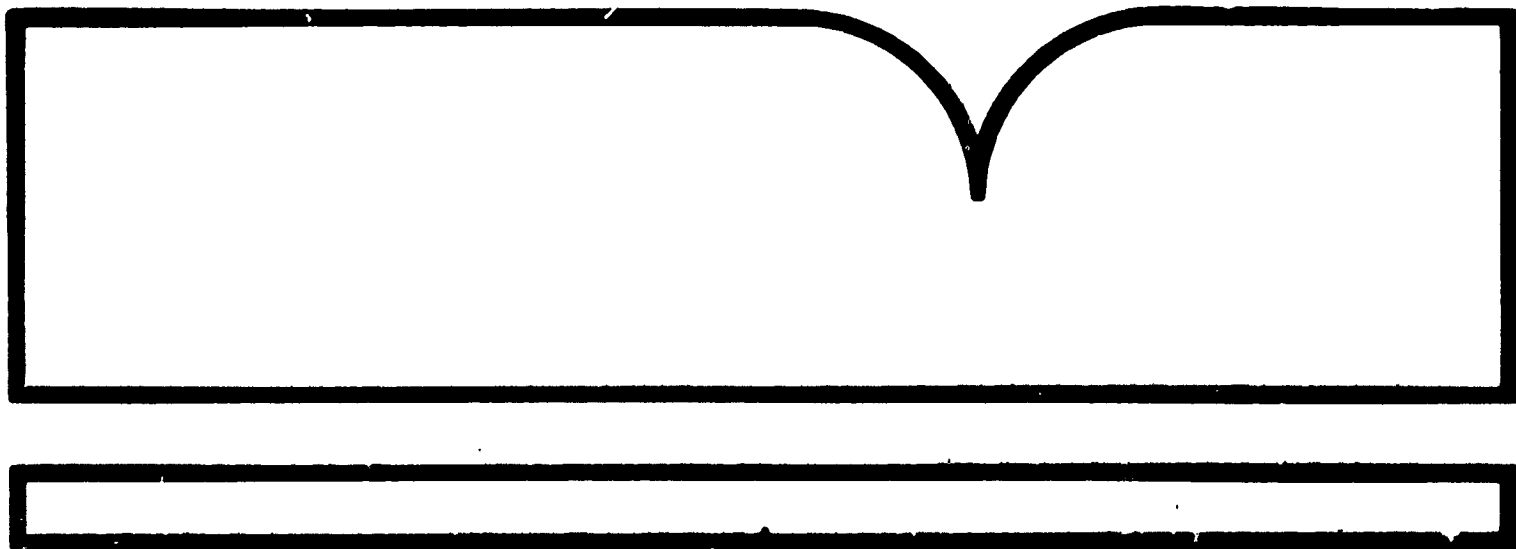
**Interactive Fortran IV Computer Programs for the
Thermodynamic and Transport Properties of
Selected Cryogens (Fluids Pack)**

**(U.S.) National Bureau of Standards
Washington, DC**

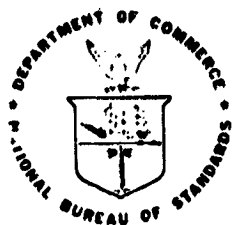
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Interactive Fortran IV Computer Programs for the Thermodynamic and Transport Properties of Selected Cryogenes (Fluids Pack)

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SPRINGFIELD, VA 22161

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Interactive Fortran IV Computer Programs for the Thermodynamic and Transport Properties of Selected Cryogenics (Fluids Pack)

R. D. McCarty

**Thermophysical Properties Division
National Engineering Laboratory
National Bureau of Standards
Boulder, Colorado 80303**



U.S. DEPARTMENT OF COMMERCE, Philip M. Klutznick, Secretary

Luther H. Hodges, Jr., Deputy Secretary

Jordan J. Baruch, Assistant Secretary for Productivity, Technology and Innovation

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, Director

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INTERACTIVE FORTRAN IV COMPUTER PROGRAMS FOR THE THERMODYNAMIC AND TRANSPORT PROPERTIES OF SELECTED CRYOGENS [FLUIDS PACK]*

R. D. McCarty

Thermophysical Properties Division
National Engineering Laboratory
National Bureau of Standards
Boulder, Colorado 80303

The thermodynamic and transport properties of selected cryogenes have been programmed into a series of computer routines. Input variables are any two of P , ρ or T in the single phase regions and either P or T for the saturated liquid or vapor state. The output is pressure, density, temperature, entropy, enthalpy for all of the fluids and in most cases specific heat capacity and speed of sound. Viscosity and thermal conductivity are also given for most of the fluids. The programs are designed for access by remote terminal; however, they have been written in a modular form to allow the user to select either specific fluids or specific properties for particular needs.

The program includes properties for hydrogen, helium, neon, nitrogen, oxygen, argon, and methane. The programs include properties for gaseous and liquid states usually from the triple point to some upper limit of pressure and temperature which varies from fluid to fluid. Computer listings of the FORTRAN IV codings are presented. Copies of the programs may be obtained from either the Thermophysical Properties Division of the National Bureau of Standards at Boulder, Colorado, or from Walter Scott at the NASA-Johnson Space Center in Houston, Texas.

Key Words: Argon; computer programs; density; enthalpy; entropy; equation of state; heat capacity at constant pressure; heat capacity at constant volume; helium; hydrogen; methane; neon; nitrogen; oxygen; thermal conductivity; velocity of sound; viscosity.

1. Introduction

Recent technological developments which made possible personal interaction with large computer systems by remote terminal has proved to be a real advantage in situations where immediate response to requests for data are important. This computer program was developed in response to a need for thermodynamic and transport property data in an interactive mode. The program makes possible the

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acquisition of thermodynamic and in some cases the transport properties of seven different cryogenic fluids. Those fluids are: hydrogen, helium, neon, nitrogen, oxygen, argon, and methane. All of the properties are calculated from empirical equations which are derived from the existing experimental data via weighted least squares fit of mathematical models to those data. The reader who is interested in the details of the correlations is referred to the sources cited for each fluid in the sections to follow.

Five of the fluids (hydrogen, nitrogen, oxygen, argon and methane) utilize the same mathematical model of the equation of state, and four of the fluids (nitrogen, oxygen, argon and methane) utilize the same correlating function for the transport properties. No transport properties for hydrogen, or neon, are given. Using the same functional form for the properties of several different fluids greatly simplifies the computer programs, since all that is needed to switch from one fluid to another is a different set of coefficients to the equations.

The properties of helium and neon are calculated from empirical functions which are different than those of the other five as well as each other. The addition of these two fluids represents approximately half of the total length (core storage) of the entire program.

The programs have been written with a dual purpose in mind. As has already been mentioned the primary purpose is to make available to the user in an interactive mode, the thermodynamic and transport properties of selected fluids. The second purpose is to provide the necessary subroutines to the user who has a very specialized need. Therefore the program has been written in a modular form which allows the user to extract almost any combination of fluids and properties.

The remainder of this report includes a section devoted to each fluid and an additional section describing the general part of the program.

2. Uncertainty of the Calculated Properties

When calculating thermodynamic properties from an empirical equation of state, one should be aware of certain problem areas where it is difficult to estimate realistically what the uncertainties really are in a given property. In the critical region ($\rho_c \pm 0.2 \rho_c$ and $T_c \pm 0.05 T_c$), the calculated density may be in error by several percent, while the calculated pressure or temperature will not be as inaccurate. Specific heat capacities and the thermal conductivity in

the critical region become very large values and no realistic estimate of the uncertainty may be made. Saturation boundaries, gas, liquid and solid are potential areas of large uncertainties for derived thermodynamic properties, especially heat capacities. In the compressed liquid, calculated pressures will have an uncertainty of several percent. This is a consequence of the nature of the surface and is in no way the fault of the equation of state.

In each of the following sections on the individual fluids, uncertainty estimates will be given for that particular fluid. These estimates have been obtained from the source documents and do not reflect the potential large uncertainties of the problem areas outlined above.

3. Computer Routines

The thermodynamic properties produced by the computer program listed in Appendix A are all calculated using a mathematical model of the equation of state of the fluid and classical thermodynamic relationships. The reader who is interested in the thermodynamics and mathematics of the problem is referred to McCarty (1975). Table 1 lists all of the subprograms with pertinent information for each.

In general eleven or twelve significant figures need to be carried in the property calculations to insure no round off errors in the result, and sample values for checking performance are included in each of the sections on the properties of a particular fluid. Performance should be checked periodically when running on a time-share system.

The program, once executed, leads the user through a series of input requests and the use of the program should be self-explanatory after the particular system requirements for access and execution are satisfied.

Upper and lower pressure and temperature limits have been imposed on each fluid according to the range of validity as claimed by the original source document. The lower pressure limit is an indication of where the program fails due to the limitations of the computer calculations. All of the functions reduce to the ideal gas in the limit of zero pressure but because of some terms in the equation which have very large exponents, the iterative solution for density fails at very low pressures. Because these models are empirical and cannot be trusted to give even reasonable results outside their ranges of pressure and temperature, the user is cautioned not to change the pressure and temperature limits originally set in the program.

4. Conclusions

The preparation of this program has demonstrated the utility of maintaining functional form when modeling properties of several different fluids. With a single functional form, the change from one fluid to another becomes a matter of switching constants and even more important the addition of more fluids to the scope of the program becomes very simple.

The author wishes to acknowledge the support of NASA, without which this work would not have been possible, and in particular the support and encouragement of Walter Scott at the Johnson Space Center.

Table 1. List of Subprograms

(Note: The list of symbols appearing in columns labeled "Arguments," "Input," and "Output" are:

P = pressure in atmospheres, D = density in moles per liter, T = temperature in Kelvin,

S = entropy in Joules per mole Kelvin, Cp and Cv = specific heat capacity at

constant pressure or volume in the same units of S, H = enthalpy in Joules per mole,

W = velocity of sound in meters per second, λ = thermal conductivity and η = viscosity.

Any deviations from the above will be noted in the text.

NAME	PURPOSE	ARGUMENTS	INPUT	OUTPUT
PROGRAM FLUIDS - MAIN PROGRAM				
SUBROUTINE DATA CH4	Sets constants for Methane.	none	none	none
SUBROUTINE DATA N2	Sets constants for Nitrogen	none	none	none
SUBROUTINE DATA O2	Sets constants for Oxygen	none	none	none
SUBROUTINE DATA PH2 with entry points NH2, OH2, EH2 and FH2	Sets constants for Hydrogen	none	none	none
SUBROUTINE PROPS	Main Property Routine of the 32 Term MBMR	P, T	D, T	P (a dummy variable)
ENTRY POINTS	Calculates pressure	P, D, T	D, T	P = press

Table 1. Continued

NAME	PURPOSE	ARGUMENTS	INPUT	OUTPUT
DPDD	Partial derivative of pressure with respect to density	P, D, T	D, T	$P = \left(\frac{\partial P}{\partial D} \right)_T$
DPDT	Partial derivative of pressure with respect to temperature	P, D, T	D, T	$P = \left(\frac{\partial P}{\partial T} \right)_D$
DSDN	One limit of the integral for entropy	P, D, T	D, T	$P = S_1$
DUDN	One limit of the integral for internal energy	P, D, T	D, T	$P = I_1$
TSDT	One limit of the integral for specific heat capacity of constant volume	P, D, T	D, T	$P = C_v$
DP2D2	Second partial derivative of pressure with respect to density of a fluid	P, D, T	D, T	$P = \left(\frac{\partial^2 P}{\partial D^2} \right)_T$
FUNCTION VPN	Calculates the vapor pressure for a fluid input of pressure	T	T	P_{SAT}
FUNCTION FINDTV	Calculates the saturation temperature given a saturation pressure of a fluid	P	P	T_{SAT}
FUNCTION CV	Calculates the specific heat capacity of constant volume of a fluid	D, T	D, T	C_v
FUNCTION FINDD	Solves the equation of state for a density given pressure and temperature	P, T	P, T	D

Table 1. Continued

NAME	PURPOSE	ARGUMENTS	INPUT	OUTPUT
SUBROUTINE REGULA	Regula-Falsi iteration, used when Newton's Iteration in FINDD fails	P, D, T	P, D, T	D
FUNCTION CP	Calculates specific heat capacity at constant volume of a fluid	D, T	D, T	C _p
FUNCTION DPDTVP	Calculates the derivative dP/dT of the vapor pressure curve of a fluid	T	T	(dP/dT) _{SAT}
FUNCTION FINDM	An alternative for D with a first guess for D as an input parameter	P, T, D	P, T, D	D
FUNCTION ENTROP	Calculates the entropy of a fluid	D, T	D, T	S
FUNCTION ENTHAL	Calculates the enthalpy of a fluid	D, T	D, T	H
FUNCTION SATL	Calculates the saturated liquid density of a fluid	T	T	D _{SATL}
ENTRY POINT SATV	Calculates the saturated vapor density of a fluid	T	T	D _{SATV}
FUNCTION SOUND	Calculates the velocity of sound of a fluid	D, T	D, T	W
FUNCTION VISC	Calculates the viscosity of a fluid	D, T	D, T	η μg/cm-s
FUNCTION THERM	Calculates the thermal conductivity of a fluid	D, T	D, T	λ mW/m-K
FUNCTION EXCESV	Calculates the "excess" viscosity of a fluid	D, g/cm ³ , T	D, g/cm ³ , T	Δη μg/cm-s

Table 1. Continued

NAME	PURPOSE	ARGUMENTS	INPUT	OUTPUT
ENTRY POINT EXCEST	Calculates the "excess" thermal conductivity of a fluid	$D, g/cm^3, T$	$D, g/cm^3, T$	$\Delta\lambda$ mm/m-K
FUNCTION FDCV	Calculates the first density correction for the viscosity of a fluid	$D, g/cm^3, T$	$D, g/cm^3, T$	$\Delta\eta$ $\mu g/cm^2-s$
ENTRY POINT FDCT	Calculates the first density correction for the thermal conductivity of a fluid	$D, g/cm^3, T$	$D, g/cm^3, T$	$\Delta\lambda$ mm/m-K x 10^{-2}
FUNCTION CRITC	Calculates the critical region enhancement for the thermal conductivity of a fluid	$D, g/cm^3, T$	$D, g/cm^3, T$	$\Delta\lambda$ mm/m-K
FUNCTION SENG	Equation of state for the critical region (used only by FUNCTION CRITC)	$D, g/cm^3, T$	$D, g/cm^3, T$	compressibility
FUNCTION DILV ENTRY DILT	Calculates the dilute gas contribution of the viscosity and thermal conductivity of a fluid	T	T	$\Delta\eta$ $\mu g/cm-s$
FUNCTION CPI	Calculates ideal gas specific heat capacity at constant pressure of a fluid	T	T	$\Delta\lambda$ mm/m-K
ENTRY POINTS HI	Calculates ideal gas enthalpy of a fluid	T	T	C_p
SI	Calculates ideal gas entropy of a fluid	T	T	H S

Table 1. Continued

NAME	PURPOSE	ARGUMENTS	INPUT	OUTPUT
FUNCTION CPO	Calculates ideal gas specific heat capacity at constant pressure for hydrogen	T	T	Cp
FUNCTION CPOH	Calculates ideal gas enthalpy for hydrogen	T	T	H
FUNCTION CPOS	Calculates ideal gas entropy for hydrogen	T	T	S
FUNCTION ATKINT	Numerical x-y interpolation routine	X, YMAT, XMAT, N, NMAX, NES, ACRCY	same	Y
		(see listing for explanation of arguments)		
SUBROUTINE REPRO	Used by Main Program to assemble properties for output			
SUBROUTINE LIMITS	Prints limits of equations of state when exceeded		P, T, IL	PRINT
SUBROUTINE DATA NE	Assembles all neon properties for printout	none	none	all neon properties
SUBROUTINE DATA HE	Assembles all helium properties for printout	none	none	all He properties
SUBROUTINE INFO	Gives general information	none	none	information
SUBROUTINE H2INFO	Gives brief description of ORT:H0-PARA states of hydrogen	none	none	information
SUBROUTINE SOURCE	Gives source of program	none	none	information

Table 1. Continued

NAME	PURPOSE	ARGUMENTS	INPUT	OUTPUT
FUNCTION FNDTHE	Solves the helium equation of state for density	P, T	P, T	D
FUNCTION FNDPHE	Main properties subprogram for helium	D, T	D, T	P
ENTRY POINTS				
DPDTHE	Calculates $(\partial P / \partial T)_\rho$ for helium	D, T	D, T	$\left(\frac{\partial P}{\partial T}\right)_\rho$
DPDDHE	Calculates $(\partial P / \partial \rho)_T$ for helium	D, T	D, T	$\left(\frac{\partial P}{\partial \rho}\right)_T$
ENTRHE	Calculates entropy for helium	D, T	D, T	S
ENTHHE	Calculates enthalpy for helium	D, T	D, T	H
CVHE	Calculates specific heat capacity at constant volume for helium	D, T	D, T	C_v
FUNCTION SOUNHE	Calculates the velocity of sound for helium	D, T	D, T	W
FUNCTION VIRB	Calculates the second virial coefficient for helium	T	T	B
FUNCTION DBDT	Calculates the temperature derivative of the second virial for helium	T	T	B
FUNCTION D2DBDT	Calculates the second temperature derivative of the second virial for helium	T	T	B
FUNCTION VPHE	Calculates the vapor pressure of helium	T	T	B
FUNCTION CPHE	Calculates specific heat capacity at constant pressure for helium	T	T	C_p

Table 1. Continued

NAME	PURPOSE	ARGUMENTS	INPUT	OUTPUT
FUNCTION DELT	Calculates a correction to the 1968 helium temperature scale	T	T	ΔT
FUNCTION VPTEHE	Solves the vapor pressure equation for temperature for helium	P	P	T
FUNCTION DVPNHE	Calculates dP/dT of the vapor pressure for helium	T	T	$\left(\frac{\partial P}{\partial T}\right)_P$
FUNCTION TRANSP	Calculates thermal conductivity and viscosity of helium	D,T	T	
ENTRY POINTS				
THREHE	Calculates the thermal conductivity for helium	D,T	T	$d \frac{mW}{cm K}$
VISCHE	Calculates viscosity for helium	D,T	T	η micropoise
FUNCTION VISCX	Calculates the dilute gas viscosity of helium from 100 K to 300 K	T	T	η micropoise
FUNCTION DELC	Calculates excess thermal conductivity for helium	D,T	D,T	$\lambda \frac{mW}{cm K}$
FUNCTION CONZ	Used with DELC	T	T	
FUNCTION VISCDDT	Calculates viscosity of helium for temperatures below 300 K	D,T	D,T	η micropoise

Table 1. Continued

NAME	PURPOSE	ARGUMENTS	INPUT	OUTPUT
FUNCTION CRITIC	Calculates critical enhancement of thermal conductivity for helium	$D, \text{gm/cm}^3, T$	D, T	$\lambda \frac{\text{mW}}{\text{cm s}}$
FUNCTION DSATV	Calculates density of saturated liquid and gaseous helium	T	T	$D, \text{g/cm}^3$
ENTRY POINTS				
DSATV	gas	T	T	$D, \text{g/cm}^3$
DSATL	liquid	T	T	$D, \text{g/cm}^3$
FUNCTION PMELT	Calculates a melting pressure for helium	T	T	F
FUNCTION FNDPNE	Redefinition of the pressure function	D, T	D, T	P
FUNCTION ENTHA	Calculates enthalpy for neon	P	P, D, T	H
FUNCTION DLIQNE	Calculates the density of saturated liquid neon	T	T	D
FUNCTION DPDDNE	Calculates $\left(\frac{\partial P}{\partial T}\right)_T$ for neon	DT	D, T	$\left(\frac{\partial P}{\partial T}\right)_T$
FUNCTION ENTR	Calculates the entropy of neon - liquid phase, i.e., $T < T_c$ and $P > P_{\text{sat}}$	D, T	D, T	$S \frac{\text{liter atm}}{\text{mol-K}}$
SUBROUTINE DATN	Sets the constants for the neon equation of state	none	none	A1 thru A14
FUNCTION PC	Calculates the pressure for neon	D, T	D, T	P
FUNCTION FNDTNE	Solves the neon equation of state for temperature	P, D	P, D	T

Table 1. continued

NAME	PURPOSE	ARGUMENTS	INPUT	OUTPUT
FUNCTION FINDP	Checks the pressure of various fluids	D, T	D, T	P
FUNCTION DPDTNE	Calculates $\left(\frac{\partial P}{\partial T}\right)_\rho$ for neon	D, T	D, T	$\left(\frac{\partial P}{\partial T}\right)_\rho$
FUNCTION FNDTHE	Solves the helium equation of state for temperature	P, D	P, D	T
FUNCTION FINDT	Solves the 32 term BWR equation of state for temperature	P, D	P, D	T
FUNCTION CPOSNE	Calculates the ideal gas entropy for neon	T	T	S
FUNCTION CPOHNE	Calculates the ideal gas enthalpy for neon	T	T	H
FUNCTION FNDNE	Solves the neon equation of state for density	P, T	P, T	D
FUNCTION ENTH	Calculates enthalpy for neon - liquid region, i.e., $T < T_c$, $P > P_{sat}$	P, D, T	P, D, T	H
FUNCTION VPTNE	Solves to vapor-pressure of neon for temperature	P	P	T
FUNCTION ENTHNE	Calculates enthalpy for neon - gaseous phase	P, D, T	P, D, T	H
FUNCTION ENTRNE	Calculate entropy for neon in the gaseous phase	D, T	D, T	S

Table 1. Continued

NAME	PURPOSE	ARGUMENTS	INPUT	OUTPUT
FUNCTION VPPNE	Calculates the saturated vapor pressure of neon	T	T	P
FUNCTION DVPNE	Calculates $\left(\frac{\partial P}{\partial T}\right)_{\text{sat}}$ for neon	T	T	$\left(\frac{\partial P}{\partial T}\right)_{\text{sat}}$

5. Properties of Hydrogen

The thermodynamic properties of hydrogen are calculated from a 32 term empirical equation of state. The source of the equation of state is NBSIR 75-814 (Roder and McCarty, 1975). The program allows the option of ortho, para, and normal hydrogen modifications. The properties for normal and ortho hydrogen are obtained by changing the ideal gas thermodynamic properties from parahydrogen to ortho or normal hydrogen. This changes the derived thermodynamic properties but does nothing to the PVT surface. Therefore the PVT for all of the hydrogen options are the same.

Table 2. Properties and Associated Estimated Uncertainties for Hydrogen

Property	All Uncertainties in Percent (Except Enthalpy)		
	Liquid (below T_c)	Gas (below T_c)	Fluid (above T_c)
pressure	5.0	0.25	0.20
density	0.1	0.25	0.2
temperature	0.1	0.25	0.2
enthalpy	1 J/mol	3 J/mol	5.10 J/mol
entropy	1.0	1.0	1
C_p	3.0	2.0	3.0
C_v	3.0	2.0	3.0
speed of sound	2.0	1.0	1.0

The above are based on the estimated average difference between calculated and true value, including problem areas as described in section 2.

Table 3. Pressure and Temperature Range for Hydrogen

Temperature range	13.8 to 400 K
	-434.83 to 260.43°F
Pressure range	0** to 1200 bar
	0 to 17404.5 psia
<u>Fixed Points</u>	
Triple Point Temperature	13.8 K*
	-434.83°F
Triple Point Pressure	0.07043101 bar**
	1.0215154 psia
Triple Point Density-Vapor	0.0632229 moles/liter
	0.007956667 lb/cu ft
Liquid	.21429 moles/liter
	4.809273 lb/cu ft
Critical Point Temperature	32.938 K*
	-459.67°F
Critical Point Pressure	12.83768 bar
	186.19481 psia
Critical Point Density	15.556 moles/liter*
	1.95774 lb/cu ft

*This particular value is used to define the point in the sense that it was used as input into the program.

**See Section 3 for more detailed explanation of the lower limits of pressure.

Table 4. Properties for Computer Program Performance Test for Hydrogen

	Density mol/L	Temp K	H J/mol	S J/mol-K	C _p J/mol-K	C _v J/mol-K	Sound Velocity m/s
	<u>Saturated Vapor at 1.01325 bar</u>						
para	.6644446	20.27686	381.4283	60.38879	24.67806	13.31149	354.0753
normal	.6644446	20.27686	1444.122	78.76558	24.67806	13.31149	354.0753
ortho	.6644446	20.27686	1798.340	78.65680	24.67806	13.31149	354.0753
	<u>Saturated Liquid at 1.01325 bar</u>						
para	35.11883	20.27686	-516.5543	16.10387	19.48814	11.42787	1100.731
normal	35.11883	20.27686	546.1399	34.48066	19.48814	11.42787	1100.731
ortho	35.11883	20.27686	900.3573	34.37187	19.48814	11.42787	1100.731
	<u>Single Phase at 300 K and 1000 bar</u>						
para	24.42809		9842.094	72.63775	31.56691	22.95644	2138.057
normal	24.42809		9897.657	84.32367	30.48744	21.87697	2152.397
ortho	24.42809		9916.192	81.98481	30.12762	21.51714	2157.474

6. Properties of Helium

The thermodynamic properties of helium are calculated from a 32 term modified Benedict-Webb-Rubin equation of state. The source of the equation of state is a paper by McCarty (1973). The transport properties for helium are from NBS Technical Note 631 (McCarty, 1972). Tabular values of the thermodynamic and transport properties of helium are given in Technical Note 531 and are identical to those produced by this computer program.

Table 5. Properties and Associated Estimated Uncertainties for Helium

Property	All Uncertainties in Percent (Except Enthalpy)		
	Liquid (below T_c)	Gas (below T_c)	Fluid (above T_c)
pressure	10.0	0.2	0.2
density	0.5	0.2	0.2
temperature	.5	0.2	0.2
enthalpy	2.0	1.0	1.0
entropy	2.0	1.0	1.0
C_p	2.0	2.0	.5
C_v	2.0	1.5	.5
speed of sound	2.0	1.0	.5
thermal conductivity	10.0	10.0	10.0
viscosity	8.0	8.0	10.0

The above are based on the estimated average difference between calculated and true value, including problem areas as described in section 2.

Table 6. Pressure and Temperature Range for Helium

Temperature range	2 to 1500 K -456.07 to 2240.33°F
Pressure range	0** to 1000 bar 0 to 14504. psia
<u>Fixed Points</u>	
Lambda Temperature	2.1720 K* -455.760°F
Lambda Pressure	.04963285 bar** .71986364 psia
Lambda Density-Vapor	.2904484 moles/liter .72575547 lb/cu ft
Liquid	36.53426 moles/liter 9.1289672 lb/cu ft
Critical Point Temperature	5.2014 K* -450.307°F
Critical Point Pressure	2.274640 bar 32.990864 psia
Critical Point Density	17.3987 moles/liter* 4.347485 lb/cu ft

*This particular value is used to define the point in the sense that it was used as input into the program, the program does not reproduce this number exactly.

**See Section 3 for more detailed explanation of the lower limits of pressure.

Table 7. Properties for Computer Program Performance Test for Helium

Density	Temp	H	S	C _p	C _v	Sound Velocity	Thermal Conductivity	Viscosity
mol/L	K	J/mol	J/mol-K	J/mol-K	J/mol-K	m/s	mW/m-K	μg/cm-s
4.219020	4.224449	120.5928	33.16956	39.12776	13.40124	100.1654	10.62098	12.46551
<u>Saturated Vapor at 1.01325 bar</u>								
31.22392	4.224449	38.86948	13.82407	19.93710	9.477176	171.9782	19.63999	31.69095
<u>Saturated Liquid at 1.01325 bar</u>								
<u>Single Phase at 300 K and 1000 bar</u>								
28.07788		7544.967	68.82269	20.89332	13.63682	1366.437	201.1403	222.7074

7. Properties of Neon

The thermodynamic properties of neon are calculated from an 18 term empirical equation of state by McCarty and Stewart (1965). No specific heat capacities are calculated for neon because the accuracy of the model of the equation of state does not warrant the calculation. Transport properties for neon are not available in the form of a mathematical model as is the case for some of the other fluids.

Table 8. Properties and Associated Estimated Uncertainties for Neon

Property	All Uncertainties in Percent (Except Enthalpy)		
	Liquid (below T_c)	Gas (below T_c)	Fluid (above T_c)
pressure	10.0	0.5	0.5
density	2.0	1.0	1.0
temperature	2.0	1.0	1.0
enthalpy	20.0	1.0	10.0
entropy	20.0	1.0	10.0

The above are based on the estimated average difference between calculated and true value, including problem areas as described in section 2.

Table 9. Pressure and Temperature Range for Neon

Temperature range	25 to 300 K -414.67 to 80.33°F
Pressure range	.1** to 200 bar 1.450 to 2901. psia

Fixed Points

Triple Point Temperature	25 K* -414.67°F
Triple Point Pressure	.5102339 bar** 7.4003172 psia
Triple Point Density-Vapor	.2528246 moles/liter .31855482 lb/cu ft
Liquid	61.45071 moles/liter 77.42688 lb/cu ft
Critical Point Temperature	44.40 K* -379.75°F
Critical Point Pressure	26.57086 bar 385.37775 psia
Critical Point Density	23.93 moles/liter* 30.151 lb/cu ft

*This particular value is used to define the point in the sense that it was used as input into the program.

**See Section 3 for more detailed explanation of the lower limits of pressure.

8. Properties of Nitrogen

The thermodynamic properties are calculated from a 32 term modified equation of state taken from Jacobsen, et al. (1973). The same functional form of the equation of state used for nitrogen has also been used here for hydrogen, oxygen, argon and methane. The transport properties are from Hanley, et al. (1974).

Table 11. Properties and Associated Estimated Uncertainties for Nitrogen

Property	All Uncertainties in Percent (Except Enthalpy)		
	Liquid (below T_c)	Gas (below T_c)	Fluid (above T_c)
pressure	5.0	0.3	0.3
density	0.5	0.3	0.2
temperature	0.5	0.3	0.2
enthalpy	3.0	1.0	1.0
entropy	2.0	1.0	1.0
C_p	5.0	5.0	5.0
C_v	5.0	5.0	5.0
speed of sound	2.0	0.25	1.0
thermal conductivity	4.0	4.0	6.0
viscosity	2.0	2.0	2.0

The above are based on the estimated average difference between calculated and true value, including problem areas as described in section 2.

Table 12. Pressure and Temperature Range for Nitrogen

Temperature range	63.15 to 1900 K 346 to 2960.33°F
Pressure range	0** to 1000 bar 0 to 145040. psia
<u>Fixed Points</u>	
Triple Point Temperature	63.15 K* 346 °F
Triple Point Pressure	.1246399 bar** 1.807749 psia
Triple Point Density-Vapor	.2396164 moles/liter .04190847 lb/cu ft
Liquid	30.57717 moles/liter 54.178504 lb/cu ft
Critical Point Temperature	126.26 K* -232.402°F
Critical Point Pressure	34.10034 bar 484.5836 psia
Critical Point Density	11.21 moles/liter* 19.606 lb/cu ft

*This particular value is used to define the point in the sense that it was used as input into the program.

**See Section 3 for more detailed explanation of the lower limits of pressure.

Table 13. Properties for Computer Program Performance Test for Nitrogen

Density	Temp	H	S	C _p	C _v	Sound	Thermal	Viscosity
mol/L	K	J/mol	J/mol-K	J/mol-K	J/mol-K	m/s	mW/m-K	μg/cm-s
<u>Saturated Vapor at 1.01325 bar</u>								
.1646146	77.36267	2163.506	151.447	31.95042	21.58560	174.8439	7.569252	52.81762
<u>Saturated Liquid at 1.01325 bar</u>								
28.86246	77.36267	-3400.812	79.53773	57.79680	27.82053	938.8844	133.6724	1515.714
<u>Single Phase at 300 K and 1000 bar</u>								
23.93016		8447.358	128.3785	37.85003	23.93016	840.4759	85.35870	523.9142

9. Properties of Oxygen

The thermodynamic properties of oxygen are calculated from a 32 term empirical equation of state given in NBSIR 78-882 by Weber (1978). The functional form of the oxygen equation of state is the same as was used for hydrogen, nitrogen, oxygen and methane. The transport properties are from Hanley et al. (1974).

Table 14. Properties and Associated Estimated Uncertainties for Oxygen

Property	All Uncertainties in Percent (Except Enthalpy)		
	Liquid (below T_c)	Gas (below T_c)	Fluid (above T_c)
pressure	5.0	0.25	0.15
density	0.1	0.25	0.15
temperature	0.1	0.2	0.1
enthalpy	0.5	0.25	0.5
entropy	0.5	0.25	0.5
C_p	3.0	5.0	3.0
C_v	3.0	5.0	3.0
speed of sound	2.0	0.5	0.5
thermal conductivity	4.0	4.0	6.0
viscosity	2.0	2.0	2.0

The above are based on the estimated average difference between calculated and true value, including problem areas as described in section 2.

Table 15. Pressure and Temperature Range for Oxygen

Temperature range	54.359 to 400 K -361.8238 to 260.33°F
Pressure range	0** to 1200 bar 0 to 17404. psia

Fixed Points:

Triple Point Temperature	54.359 K* -361.8238°F
Triple Point Pressure	.001490085 bar** .021611856 psia
Triple Point Density-Vapor	.0003275488 moles/liter 6.5431796 x 10 ⁻⁴ lb/cu ft
Liquid	40.81997 moles/liter 81.542780 lb/cu ft
Critical Point Temperature	154.481 K* -181.4242°F
Critical Point Pressure	50.42218 bar 731.31190 psia
Critical Point Density	13.63 moles/liter* 27.228 lb/cu ft

*This particular value is used to define the point in the sense that it was used as input into the program.

**See Section 3 for more detailed explanation of the lower limits of pressure.

10. Properties of Argon

The thermodynamic properties of argon have been calculated from a 32 term empirical equation of state from Hanley, et al. (1974). The functional form of the argon equation of state is the same as was used for hydrogen, nitrogen, oxygen and methane. The transport properties for argon were also taken from Hanley, et al. (1974).

Table 18. Pressure and Temperature Range for Argon

Temperature range	83.80 to 400 K -308.83 to 260.33°F
Pressure range	0** to 1000 bar 0 to 14504. psia
<u>Fixed Points</u>	
Triple Point Temperature	83.80 K* -308.83°F
Triple Point Pressure	.6890708 bar** 9.9941271 psia
Triple Point Density-Vapor	.1015395 moles/liter .25322653 lb/cu ft
Liquid	35.40018 moles/liter 88.283522 lb/cu ft
Critical Point Temperature	150.86 K* -188.122°F
Critical Point Pressure	48.98050 bar 710.40210 psia
Critical Point Density	13.41 moles/liter* 33.443 lb/cu ft

*This particular value is used to define the point in the sense that it was used as input into the program.

**See Section 3 for more detailed explanation of the lower limits of pressure.

Table 19. Properties for Computer Program Performance Test for Argon

Density	Temp	H	S	C _p	C _v	Sound	Thermal	Viscosity
mol/L	K	J/mol	J/mol-K	J/mol-K	J/mol-K	m/s	mm/m-K	μg/cm-s
.1445217	87.28153	9425.279	128.5414	23.29635	13.59023	170.3420	5.856927	72.51142
<u>Saturated Vapor at 1.01325 bar</u>								
34.87034	87.28153	2952.449	53.37806	51.00242	34.11186	608.5500	128.0897	2594.300
<u>Saturated Liquid at 1.01325 bar</u>								
24.07985	87.28153	12354.77	90.55855	31.30528	15.70327	716.8781	72.17791	750.1518
<u>Single Phase at 300 K and 1000 bar</u>								

11. Properties of Methane

The thermodynamic properties of methane are calculated from a 32 term empirical equation of state by McCarty (1974). The functional form of the methane equation of state is the same as was used for hydrogen, nitrogen, oxygen, and argon. The transport properties are from Hanley, et al. (1977).

Table 20. Properties and Associated Estimated Uncertainties for Methane

Property	All Uncertainties in Percent (Except Enthalpy)		
	Liquid (below T_c)	Gas (below T_c)	Fluid (above T_c)
pressure	5.0	0.25	0.25
density	0.1	0.25	0.25
temperature	0.1	0.25	0.25
enthalpy	1.0	0.5	0.5
entropy	0.5	0.5	0.5
C_p	2.0	5.0	2.0
C_v	2.0	5.0	2.0
speed of sound	1.0	0.3	0.3
thermal conductivity	5.0	5.0	4.0
viscosity	3.0	3.0	2.0

The above are based on the estimated average difference between calculated and true value, including problem areas as described in section 2.

Table 21. Pressure and Temperature Range for Methane

Temperature range	90.68 to 500 K -296.446 to 440.33°F
Pressure range	0** to 350 bar 0 to 5076. psia

Fixed Points

Triple Point Temperature	90.68 K* -296.446°F
Triple Point Pressure	.1174350 bar** 1.7032E07 psia
Triple Point Density-Vapor	.01569094 moles/liter .015713995 lb/cu ft
Liquid	28.15114 moles/liter 28.192503 lb/cu ft
Critical Point Temperature	190.555 K* -116.671°F
Critical Point Pressure	45.98838 bar 667.00507 psia
Critical Point Density	10.23 moles/liter* 10.245 lb/cu ft

*This particular value is used to define the point in the sense that it was used as input into the program.

**See Section 3 for more detailed explanation of the lower limits of pressure.

12. References

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- [2] McCarty, R. D., Thermodynamic Properties of Helium 4 From 2 to 1500 K at Pressures to 10^8 Pa, J. Phys. Chem. Ref. Data 2, No. 4, 923-1042 (1973).
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- [4] McCarty, R. D. and Stewart, R. B., Thermodynamic Properties of Neon from 25 to 300 K Between 0.1 and 200 Atmospheres, Advances in Thermophysical Properties at Extreme Temperatures and Pressures, The American Society of Mechanical Engineers (1965).
- [5] Jacobsen, R. T., Stewart, R. B., McCarty, R. D. and Hanley, H. J. M., Thermophysical Properties of Nitrogen from the Fusion Line to 3500 R [1944 K] for Pressures to 150,000 PSIA [10342×10^5 N/m²], Nat. Bur. Stand. (U.S.), Tech. Note 648 (Dec 1973).
- [6] Hanley, H. J. M., McCarty, R. D. and Haynes, W. M., The Viscosity and Thermal Conductivity for Dense Gaseous and Liquid Argon, Krypton, Xenon, Nitrogen and Oxygen, J. Phys. Chem. Ref. Data 3, No. 4, 979-1017 (1974).
- [7] Weber, L. A., A Modified Benedict-Webb-Rubin Equation of State for Gaseous and Liquid Oxygen, Nat. Bur. Stand. (U.S.), Interagency Report NBSIR 78-882 (1978).
- [8] McCarty, R. D., A Modified Benedict-Webb-Rubin Equation of State for Methane Using Recent Experimental Data, Cryogenics 14, No. 5, 276-80 (May 1974).
- [9] Hanley, H. J. M., Haynes, W. M. and McCarty, R. D., The Viscosity and Thermal Conductivity Coefficients for Dense Gaseous and Liquid Methane, J. Phys. Chem. Ref. Data 6, No. 2, 597-609 (1977).

Appendix 1

Example of the Use of the Program

CALL, PROGRAMS
 HI, WELCOME TO THE WORLD OF FLUID PROPERTIES. IF YOU ARE NOT FAMILIAR WITH THE
 PROGRAM PLEASE ENTER A 0

? 0
 WHEN THE PROGRAM ASKS FOR A FLUID SELECTION, ENTER THE APPROPRIATE NUMBER
 AN INAPPROPRIATE NUMBER WILL TERMINATE THE PROGRAM
 WHEN THE PROGRAM ASKS FOR A PRESSURE, DENSITY, AND
 TEMPERATURE, ENTER ANY 2 OF THE THREE AND A 0 FOR THE THIRD.
 THE ORDER MUST BE P, D, T, AND ONE OF THE THREE MUST BE 0.
 IF ALL THREE ARE 0 THE PROGRAM ASKS FOR A NEW FLUID
 IF YOU ARE INTERESTED IN A DEFINITION OF THE VARIOUS
 MODIFICATIONS OF HYDROGEN ENTER A 1, IF NOT ENTER A 0

? 0
 IF YOU ARE INTERESTED IN THE SOURCES OF THESE PROGRAMS
 ENTER A 1 IF NOT ENTER A 0.

? 0
 SELECT A FLUID FROM THE FOLLOWING LIST

- PARA HYDROGEN=1
- NORMAL HYDROGEN=10
- ORTHO HYDROGEN=11
- HELIUM=2
- NEON=3
- NITROGEN=4
- OXYGEN=5
- ARGON=6
- METHANE=7

TERMINATION=8

? 4
 THE RANGE OF TEMPERATURE FOR NITROGEN IS 63.15 TO 1900K
 WITH PRESSURES TO 10000 BAR
 DO YOU PREFER ENGINEERING UNITS OR METRIC UNITS ?
 ENTER A 0 FOR ENGINEERING UNITS OR A 1 FOR METRIC

? 1
 DO YOU WANT SATURATION PROPERTIES ?
 ENTER 0 FOR YES OR 1 FOR NO

? 1
 DO YOU WANT A SINGLE POINT OR A TABLE OF PROPERTIES ?
 ENTER A 0 FOR A SINGLE POINT OR A 1 FOR A TABLE

? 1
 ENTER A PRESSURE, A STARTING TEMPERATURE, A FINAL
 TEMPERATURE AND A TEMPERATURE INCREMENT, IN BARS, DEGREES
 K, AND IN THAT ORDER

? 10,100,200,10

PRESSURE BAR	DENSITY MOL/L	TEMP K	H J/MOL	S J/MOL-K	CP J/MOL-K	CV J/MOL-K	S SOUND M/S	COND MW/M-K	VISC M ² /M-S
10.00	24.6342	100.00	-2032.40	94.64	64.36	26.23	616.75	98.53	731.3
10.00	1.3169	110.00	2731.63	140.55	40.17	23.18	194.20	12.77	79.7
10.00	1.1452	120.00	3111.38	143.85	36.25	22.33	208.92	13.35	85.5
10.00	1.0226	130.00	3462.67	146.67	34.19	21.85	221.53	14.07	91.5
10.00	.9282	140.00	3797.88	149.15	32.94	21.56	232.83	14.73	97.5
10.00	.8523	150.00	4122.94	151.39	32.12	21.36	243.20	15.47	103.4
10.00	.7894	160.00	4441.10	153.45	31.55	21.23	252.87	16.23	109.2
10.00	.7360	170.00	4754.35	155.35	31.13	21.14	261.98	17.00	114.9
10.00	.6901	180.00	5063.95	157.12	30.81	21.07	270.64	17.76	120.6
10.00	.6499	190.00	5370.75	158.78	30.56	21.02	278.93	18.53	126.1
10.00	.6145	200.00	5675.36	160.34	30.37	20.98	286.88	19.29	131.5

ENTER A PRESSURE, A STARTING TEMPERATURE, A FINAL
 TEMPERATURE AND A TEMPERATURE INCREMENT, IN BARS, DEGREES
 K, AND IN THAT ORDER

? 0,0,0,0

SELECT A FLUID FROM THE FOLLOWING LIST

PARA HYDROGEN=1
NORMAL HYDROGEN=10
ORTHO HYDROGEN=11
HELIUM=2
NEON=3
NITROGEN=4
OXYGEN=5
ARGON=6
ETHANE=7

TERMINATION=8

0
EXIT.

Appendix 2

Program Listings

```

PROGRAM FLUIDS(INPUT=130,OUTPUT)
DIMENSION B(32),VP(9)
COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PFP,ICC,ITP,TUL,TLL,FUL,DCC
COMMON /CONT/IF
COMMON/CRIT/EM,EDK,RM,TC,DC,X,PC,BIG
100 FORMAT(* HI, WELCOME TO THE WORLD OF FLUID PROPERTIES, IF YOU ARE NOT
NOT FAMILIAR WITH THE PROGRAM PLEASE ENTER A 0 *)
PRINT 100
READ 101,1
IF(I,EQ,0)CALL INFO
101 FORMAT(11)
99 PRINT 102
PRINT 104
102 FORMAT(* SELECT A FLUID FROM THE FOLLOWING LIST*)
104 FORMAT(* PARA HYDROGEN=1** NORMAL HYDROGEN=10** ORTHO H
1YDROGEN=11** HELIUM=2** NEON=3** NITROGEN=4** OXYG
2EN=5** ARGON=6** METHANE=7**
4 TERMINATION=8*)
READ *,IF
GO TO(1,2,3,4,5,6,7,999,999,10,11),IF
1 CALL DATA PH2
GO TO 13
2 CALL DATA HE
GO TO 99
3 CALL DATA NE
GO TO 99
4 CALL DATA N2
GO TO 13
5 CALL DATA O2
GO TO 13
6 CALL DATA AR
GO TO 13
7 CALL DATA CH4
GO TO 13
10 CALL NH2
GO TO 13
11 CALL OH2
GO TO 13
13 PRINT 105
105 FORMAT(* DO YOU PREFER ENGINEERING UNITS OR METRIC UNITS ?**
1/* ENTER A 0 FOR ENGINEERING UNITS OR A 1 FOR METRIC*)
READ 101,IU
PRINT 106
106 FORMAT(* DO YOU WANT SATURATION PROPERTIES ?**
1/* ENTER 0 FOR YES OR 1 FOR NO*)
READ 101,IC
PRINT 107
107 FORMAT(* DO YOU WANT A SINGLE POINT OR A TABLE OF PROPERTIES ?**
1/* ENTER A 0 FOR A SINGLE POINT OR A 1 FOR A TABLE*)
READ 101,IV
21 IF(IC,EQ,0)GO TO 30
IF(IV,EQ,1)GO TO 40
22 IF(IU,EQ,0)GO TO 19
PRINT 103
READ *,P,D,T
P=P/1.01325
GO TO 20
19 PRINT 108
108 FORMAT(* ENTER PRESSURE IN LB/SQ IN, DENSITY IN LB/CU FT, AND*
1/* TEMPERATURE IN DEGREES F*)
READ *,P,D,T
P=P/14.695949
D=D*16.01846371/EM

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      IF(T.EQ.0.0)GO TO 20
      T=(T-32.)/1.8+273.15
20  IF(P.LE.0.0)GO TO 14
103 FORMAT(* ENTER PRESSURE IN BAR, DENSITY IN MOLES/LITER, AND TEMPER
      1ATURE IN KELVINS*)
      IF(D.LE.0.0)GO TO 17
      IF(T.LE.0.0)GO TO 12
      GO TO 22
12  IF(P.!E.0.OR.D.LE.0.0)GO TO 99
      T=FIND T(P,D)
      CALL LIMITS(P,T,IL)
      IF(IL.LE.0)GO TO 22
      GO TO 16
17  IF(T.LE.0.OR.P.LE.0)GO TO 99
      CALL LIMITS(P,T,IL)
      IF(IL.LE.0)GO TO 22
      D=FIND D(P,T)
      GO TO 16
14  IF(D.LE.0.0.OR.T.LE.0)GO TO 99
      P=FIND P(D,T)
      CALL LIMITS(P,T,IL)
      IF(IL.LE.0)GO TO 22
16  CALL REPRO(P,D,T,IU,IV,IC,IP,TF,DELT)
      GO TO 22
30  PRINT 109
109 FORMAT(* DO YOU WANT SATURATED LIQUID OR SATURATED VAPOR*
      1/* ENTER A 0 FOR LIQUID OR 1 FOR VAPOR*)
      READ 101,IP
      IF(IV.EQ.1)GO TO 40
      PRINT 111
111 FORMAT(* DO YOU WANT TO ENTER WITH TEMPERATURE OR PRESSURE *
      1/* ENTER 0 FOR TEMPERATURE OR 1 FOR PRESSURE*)
      READ 101,II
      IF(II.EQ.1)GO TO 35
211 IF(IU.EQ.1)GO TO 31
112 FORMAT(* ENTER A TEMPERATURE IN DEGREES F*)
      PRINT 112
      READ *,TI
      T=(TI-32.)/1.8+273.15
      IF(T.LE.0.0)GO TO 99
      GO TO 33
31  PRINT 113
113 FORMAT(* ENTER A TEMPERATURE IN DEGREES K*)
      READ *,T
33  IF(T.LE.0.0)GO TO 99
      IF(T.GT.TCC.OR.T.LT.TTP)GO TO 34
      P=VPN(T)
      IF(IP.EQ.0)P=P+.00001
      D=FIND D(P,T)
      CALL RE PRO(P,D,T,IU,IV,IC,IP,TF,DELT)
      GO TO 211
34  PRINT 114,TCC, TTP
114 FORMAT(* YOUR INPUT TEMPERATURE IS OUTSIDE THE RANGE OF THE*
      1/* SATURATION TEMPERATURES FOR THIS FLUID.*
      2/* TC=*,F6.2,* TTP=*,F6.2,* TRY AGAIN*)
      GO TO 211
35  IF(IU.EQ.1)GO TO 36
      PRINT 115
115 FORMAT(* ENTER A PRESSURE IN LB/SQ IN*)
      READ *,PI
      IF(PI.LE.0.0)GO TO 99
      P=PI/14.695949
      GO TO 37

```

```

36 PRINT 116
116 FORMAT(* ENTER A PRESSURE IN BAR*)
  READ *,PI
  IF(PI.LE.0.0)GO TO 99
  P=PI/1.01325
37 IF(P.GT.PCC.OR.P.LT.PTP)GO TO 38
  T=FIND IV(P)
  P=VPN(T)
  IF(IP.EQ.0)P=P+.0001
  D=FIND D(P,T)
  CALL RE PRO(P,D,T,IU,IV,IC,IP,TF,DELT)
  GO TO 35
38 PRINT 117,PCC,PTP
117 FORMAT(* YOUR INPUT PRESSURE IS OUTSIDE THE RANGE OF SATURATION*
1/* PRESSURES FOR THIS FLUID.*
2/* PC=*,F6.3,* PTP=*,F6.5,* TRY AGAIN*)
  GO TO 35
40 IF(IC.EQ.1)GO TO 50
  IF(IU.EQ.1)GO TO 41
  PRINT 118
118 FORMAT(* ENTER A STARTING TEMPERATURE, A FINAL TEMPERATURE*
1/* AND A TEMPERATURE INCREMENT, IN DEGREES F AND IN THAT ORDER*)
  READ *,TS,TF,DELT
  IF(DELT.LE.0.0)GO TO 99
  TS=(TS-32.)/1.8+273.15
  TF=(TF-32.)/1.8+273.15
  DELT=DELT/1.8
  IF(TS.LT.TTP.OR.TS.GT.TCC)GO TO 45
  IF(TF.LT.TTP.OR.TF.GT.TCC)GO TO 45
  GO TO 42
41 PRINT 119
119 FORMAT(* ENTER A STARTING TEMPERATURE, A FINAL TEMPERATURE*
1/* AND A TEMPERATURE INCREMENT IN KELVINS AND IN THAT ORDER*)
  READ *,TS,TF,DELT
  IF(DELT.LE.0.0)GO TO 99
  IF(TS.LT.TTP.OR.TS.GT.TCC)GO TO 45
  IF(TF.LT.TTP.OR.TF.GT.TCC)GO TO 45
42 T=TS
  P=VPN(T)
  IF(IP.EQ.0.0)P=P+.0001
  D=FIND D(P,T)
  CALL RE PRO(P,D,T,IU,IV,IC,IP,TF,DELT)
  GO TO 40
45 PRINT 120,TCC,TTT
120 FORMAT(* EITHER YOUR STARTING OR FINAL TEMPERATURE IS OUTSIDE*
L/* THE RANGE OF SATURATION TEMPERATURES.*
2/* TC=*,F6.2,* TTP=*,F6.2,* TRY AGAIN*)
  GO TO 40
50 IF(IU.EQ.1)GO TO 51
  PRINT 121
121 FORMAT(* ENTER PRESSURE, STARTING TEMPERATURE, FINAL TEMPERATURE*
1/* AND A TEMPERATURE INCREMENT, IN LB/CU FT, DEGREES F, AND IN*
2/* THE ABOVE ORDER*)
  READ *,PI,TS,TF,DELT
  IF(DELT.LE.0.0)GO TO 99
  P=PI/14.695949
  T=(TS-32.)/1.8+273.15
  TF=(TF-32.)/1.8+273.15
  DELT=DELT/1.8
  CALL LIMITS(P,T,IL)
  IF(IL.LE.0)GO TO 50
  CALL LIMITS(P,TF,IL)
  IF(IL.LE.0)GO TO 50

```



```

GO TO 52
51 PRINT 122
122 FORMAT(* ENTER A PRESSURE, A STARTING TEMPERATURE, A FINAL*
1/* TEMPERATURE AND A TEMPERATURE INCREMENT, IN BARS, DEGREES*
2/* K, AND IN THAT ORDER*)
READ *,PI,TS,IF,DELT
IF(DELT,IL,0.0)GO TO 99
T=TS
P=P1/1.01325
CALL LIMITS(P,T,IL)
IF(IL.LE.0)GO TO 50
CALL LIMITS(P,TF,IL)
IF(IL.LE.0)GO TO 50
52 D=FNDD(P,T)
CALL RE PRO(P,D,T,IU,IV,IC,IP,TF,DELT)
GO TO 50
999 CONTINUE
STOP
END
SUBROUTINE DATA ET
PRINT 100
100 FORMAT(* ETHANE IS SCHEDULED TO BE ADDED TO THE FLUIDS*
1/* PACK IN THE NEXT FISCAL YEAR*)
RETURN
ENTRY DATA PR
PRINT 101
101 FORMAT(* PROPANE IS SCHEDULED TO BE ADDED TO THE FLUIDS*
1/* PACK AFTER FY78*)
RETURN
ENTRY DATA NH3
PRINT 102
102 FORMAT(* AMMONIA IS SCHEDULED TO BE ADDED TO THE FLUIDS*
1/* PACK DURING FY78*)
RETURN
ENTRY DATA SH
ENTRY DATA SO
PRINT 103
103 FORMAT(* THE SLUSH PROGRAMS WILL BE ADDED TO THE FLUIDS*
1/* PACK IN FY78*)
RETURN
END
SUBROUTINE RE PRO(P,D,T,IU,IV,IQ,IP,TF,DELT)
DIMENSION G(32),VP(9)
COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,ITP,TUL,TLL,PUL
COMMON/CONT/IC
COMMON/CRIT/EM,EOK,RM,TC,DC,X,PC,SIG
N=500
IF(IV.EQ.0)TF=T-1.
PRINT 100
IF(IU.EQ.0)GO TO 1
PRINT 102
GO TO 2
1 PRINT 103
PRINT 104
2 CONTINUE
DO 10 I=1,N
IF(I.EQ.1)GO TO 3
D=FNDD(P,T)
3 H=ENTHAL(PV
S=ENTROP(D,T)
W=SOUND(D,T)
CPP=CP(D,T)
CVV=CV(D,T)

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Q=P*1.01325
IF(IU.EQ.0)GO TO 21
IF(IC.EQ.1.OR.IC.EQ.10.OR.IC.EQ.11)GO TO 20
IF(IC.EQ.9)GO TO 20
TH=THERM(D,T)
V=VISC(D,T)
PRINT 101,Q,D,T,H,S,CPP,CVV,W TH,V
GO TO 9
20 PRINT 101,Q,D,T,H,S,CPP,CVV,W
GO TO 9
101 FORMAT(F8.2,F8.4,F9.2,F9.2,F8.2,2F7.2,F8.2,F7.2,F7.1)
100 FORMAT(* PRESSURE DENSITY TEMP H S CP CV S
1 SOUND COND VISC*)
102 FORMAT(* BAR MOL/L K J/MOL J/MOL-K J/MOL-K
1M/S MW/M-K MIG/CM-5*)
103 FORMAT(* LB/SQ IN LB/CU FT DEG F BTU/LB BTU/LB-F
1 F/S BTU LB/FT-S*)
104 FORMAT(*
1 FT-HR-F E+7*)
21 H=H/(2.324445*EM)
S=S/(4.184001*EM)
CPP=CPP/(4.184001*EM)
CVV=CVV/(4.184001*EM)
W=W*3.280840
PO=P*14.695949
DO=D*EM/16.01846371
TO=T*1.8-459.67
IF(IC.EQ.1.OR.IC.GT.8)GO TO 22
TH=THERM(D,T)*.000578176
V=VISC(D,T)*.0067196897
PRINT 105,PO,DO,TO,H,S,CPP,CVV,W,TH,V
105 FORMAT(F8.1,F8.3,2F9.2,F8.2,2F7.3,F8.0,F7.4,F7.3)
GO TO 9
22 PRINT 101,PO,DO,TO,H,S,CPP,CVV,W
9 T=T+DELT
IF(T.GT.TF+.01)GO TO 11
IF(IQ.EQ.0)P=VPN(T)
IF(IP.EQ.0)P=P+.0001
10 CONTINUE
11 CONTINUE
RETURN
END

```

```

SUBROUTINE DATA CH4
DIMENSION G(32),VP(9),GI(11)
DIMENSION GV(9),GT(9),FV(4),FT(4),EV(8),ET(8)
DIMENSION A(20)
COMMON/SEN/BETA,X0,DELTA,E1, E2, AGAM
COMMON/CPID/GI
COMMON/CRIT/ EM, EOK, RM, TC, DC, X, PC, SIG
COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUI,DCC
COMMON/DATA1/GV,GT,FV,FT,EV,ET
COMMON/ISP/N,NW,NWW
COMMON/SATC/A,DTPV
NWW=0
PRINT 100
100 FORMAT(* THE RANGE OF TEMPERATURE FOR METHANE IS 90.68 TO 500 K*
1/* WITH PRESSURES TO 350 BAR*)
N=0 $ NW=0
EM=16.042 $ EOK=168. $ RM=4.101E-08 $ TC=190.555
DC=0.1627 $ X=1.7124 $ PC=45.95 $ SIG=3.68
X0=0.164 $ BETA=0.355 $ DELTA=4.352 $ E1=2.03 $ E2=0.287
AGAM=1.190
C PARAMETERS FOR TRANSPORT
C PROPERTIES - HANLEY ET. AL. JOURNAL
C OF PHY. CHEM. REF. DATA VOL 6 NO 2
C 1977
C DATA SUBROUTINE FOR METHANE
GV(1)=-2.090974/942E+2
GV(2)=2.6472692181E+2
GV(3)=-1.4728175613E+2
GV(4)=4.716/401921E+1
GV(5)=-4.4918721789E+0
GV(6)=1.2194792872E+0
GV(7)=-9.62799355746E-2
GV(8)=4.2741516570E-3
GV(9)=-8.1415307247E-05
GT(1)=-2.1476213125E+5
GT(2)=2.1904610575E+5
GT(3)=-8.61809/3719E+4
GT(4)=1.4960986936E+4
GT(5)=-4.7306603177E+2
GT(6)=-2.3311779643E+2
GT(7)=3.7784390759E+1
GT(8)=-2.3204806092E+0
GT(9)=5.3117637687E-2
EV(1)=-1.0350606586E+1
EV(2)=4.2903609488E-2
EV(3)=1.7571599671E+1
EV(4)=6.1276818706E+3
EV(5)=-3.0193918656E+3
EV(6)=1.8873011594E+2
EV(7)=1.4529023444E+2
EV(8)=0.162
FV(1)=1.6969859271
FV(2)=-.13337234608
FV(3)=1.4
FV(4)=168.
FV(4)=168.
FT(1)=-.252762921
FT(2)=.3343285931
FT(3)=1.12
FV(4)=168.
ET(1)=-7.0403639907
ET(2)=.74421462902
ET(3)=12.319512908

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ET(4)=2.2209758501E+3
 ET(5)=-8.8525979943E+2
 ET(6)=72.835897919
 ET(7)=-2.9706914540
 ET(8)=0.1628
 C
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 C
 PARAMETERS FOR THERMODYNAMIC
 PROPERTIES - MCCARTY, CRYOGENIC'S
 VOL 14 NO 5 MAY 1974 AND GOODWIN
 NBS TECH NOTE 653 APRIL 74
 R=.08205616
 GAMMA=-.0094
 GI(1)=-1.8044750507E+6
 A(1)= .183603246136E+02
 A(2)= -.182553840603E-01
 A(3)= .586623807178E+00
 A(4)= -.106005894683E+02
 A(5)= .167157622432E+03
 A(6)= -.153569173217E+03
 A(7)= .106609415023E+03
 A(8)= -.341087933790E+02
 A(9)= .973203073452E+01
 A(10)= -.388410018388E+02
 A(11)= .529573454771E+02
 A(12)= -.291075304738E+02
 A(13)= .585307647478E+01
 A(14)= -.637276532186E+00
 A(15)= .994444109622E-03
 A(16)= -.392314821657E-01
 A(17)= .728820880748E+00
 A(18)= -.625821815315E+01
 A(19)= .295561390641E+01
 A(20)= -.763972649504E+00
 GI(2)=7.7426666393E+4
 GI(3)=-1.3241658754E+3
 GI(4)=1.5438149595E+1
 GI(5)=-5.1479005257E-2
 GI(6)=1.0609172196E-4
 GI(7)=-6.5501793437E-8
 GI(8)=-6.7490056171E+0
 GI(9)=.3E+4
 GI(10)=GI(11)=0
 TU=298.15
 HU=19196.1
 GI(10)=HU-HI(TU)
 TU=300.
 SU=186.4854941
 GI(11)=SU-SI(TU)
 G(1)= -.187027997685E-01
 G(2)= .103387108009E+01
 G(3)= -.155387625619E+02
 G(4)= .772311478564E+03
 G(5)= -.377103300895E+05
 G(6)= .846818843475E-03
 G(7)= -.496415884529E+00
 G(8)= .869909352414E+02
 G(9)= -.322821592493E+05
 G(10)= -.395843026318E-04
 G(11)= .266772318035E-01
 G(12)= -.304010057839E+01
 G(13)= .191584507536E-03
 G(14)= -.195587933458E-03
 G(15)= .607479967879E+01
 G(16)= -.529609525984E-03

G(17)= .152264286004E-04
 G(18)= -.109952182842E-01
 G(19)= .191395549929E-03
 G(20)= .386470003746E+05
 G(21)= -.157930582612E+07
 G(22)= .195270144401E+03
 G(23)= .165996081629E+07
 G(24)= .603051146711E+00
 G(25)= .376485162808E+02
 G(26)= .125593680622E-02
 G(27)= -.343570032513E+02
 G(28)= -.540945094139E-05
 G(29)= .185622284663E-02
 G(30)= .770786979245E-08
 G(31)= -.286868318650E-05
 G(32)= .372376961647E-04

DTP=.2815114381423E+02
 DTPV=.1590041545160E-01

VP(1)=4.77748580
 VP(2)=1.76065363
 VP(3)=-.56788894
 VP(4)=1.32786231
 VP(5)=1.5
 VP(6)=.1158993
 VP(7)=90.68
 VP(8)=190.555
 VP(9)=0.0

TCC=VP(8)

PCC=VPN(TCC)*1.01325

PTP=VP(6)*1.01325

TTP=VP(7)

TUL=500.

TLL=TTP

PUL=350.

DCC=10.23

RETURN

END

SUBROUTINE DATA N2

DIMENSION G(32),VP(9),GI(11)

DIMENSION GV(9),GT(9),FV(4),FT(4),EV(8),ET(8)

DIMENSION A(20)

COMMON/CRIT/ EM, EOK, RM, TC, DC, X, PC, SIG

COMMON/SATC/A,DTPV

COMMON/DATA1/GV,GT,FV,FT,EV,ET

COMMON/SEN/BETA,X0,DELTA,E1, E2, AGAM

COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC

COMMON/CPID/GI

COMMON/ISP/N,NW,NWW

NWW=0

PRINT 100

100 FORMAT(* THE RANGE OF TEMPERATURE FOR NITROGEN IS 63.15 TO 1900K*
 1/* WITH PRESSURES TO 10000 BAR*)

N=0 \$ NW=1

EM=28.016 \$ EOK=118. \$ RM=3.933E-08 \$ TC=126.24

DC=.3139 \$ X=1.67108 \$ PC=33.98 \$ SIG=3.54

X0=0.164 \$ BETA=0.355 \$ DELTA=4.352 \$ E1=2.17 \$ E2=0.287

AGAM=1.190

PARAMETERS FOR TRANSPORT

PROPERTIES FROM HANLEY ET. AL.

JOUR. PHY. CHEM. REF DATA VOL3, NO 4

1974

GV(1)=-1.8224240000E+2 \$ GV(2)=1.9915327374E+2

GV(3)=-9.1542324494E+1 \$ GV(4)=2.3255484059E+1

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GV(5)=-3.6307214228 * GV(6)=3.6457506811E-1
 GV(7)=-2.2261880817E-2 * GV(8)=7.8053904895E-4
 GV(9)=-1.1894029104E-5
 GT(1)=-2.0029573972E+4 * GT(2)=4.9765746684E+3
 GT(3)=8.0188959378E+3 * GT(4)=-5.5022716888E+3
 GT(5)=1.5363738965E+3 * GT(6)=-2.2974737257E+2
 GT(7)=1.9360547346E+1 * GT(8)=-8.5677385768E-1
 GT(9)=1.5564670935E-2
 EV(1)=-9.8255690362 * EV(2)=5.7156092139E-001
 EV(3)=1.6094611148E+001 * EV(4)=3.6954086158E+003
 EV(5)=-8.0889801180E+002 * EV(6)=6.8464435640E+001
 EV(7)=-2.1241135912 * EV(8)=0.315
 FV(1)=-1.1217739623 * FV(2)=0.32912317244
 FV(3)=1.4 * FV(4)=118.
 FT(1)=.53875666637 * FT(2)=.061027911104
 FT(3)=1.2 * FT(4)=118.
 ET(1)=-2.9402951255E+1 * ET(2)=3.7201743333E+1
 ET(3)=-3.9013509079E+1 * ET(4)=-3.1826109485E+1

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THERMODYNAMIC PROPERTIES FROM
 NBS TECH NOTE 648 - DEC 77
 JACOBSEN ET. AL.

R=8.20539E-2
 GAMMA=-.0056
 GI(1)= -0.735210401157252E 03
 GI(2)= 0.342239980411978E 02
 GI(3)= -0.557648284567620E 00
 GI(4)= 0.350404228308756E 01
 GI(5)= -0.173390185081005E-04
 GI(6)= 0.174650849766463E-07
 GI(7)= -0.356892033544348E-11
 GI(8)= 0.100538722808834E 01
 GI(9)= 0.335340610000000E 04
 TO=298.15 * SO=191.502 * HO=8669.0
 GI(10)=GI(11)=0
 GI(10)=HO-HI(TO)
 GI(11)=SO-SI(TO)

G(1)= 0.136224769272827E-02
 G(2)= 0.107032469908591E 00
 G(3)= -0.243900721871413E 01
 G(4)= 0.341007449376470E 02
 G(5)= -0.422374309466167E 04
 G(6)= 0.105098600246494E-03
 G(7)= -0.112594826522081E-01
 G(8)= 0.142600789270907E-03
 G(9)= 0.184698501609007E 05
 G(10)= 0.811140082588776E-07
 G(11)= 0.233011645038006E-02
 G(12)= -0.507752586350986E 00
 G(13)= 0.485027881931214E-04
 G(14)= -0.113656764115364E-02
 G(15)= -0.707430273540575E 00
 G(16)= 0.751706648852680E-04
 G(17)= -0.111614119537424E-05
 G(18)= 0.368796562233495E-03
 G(19)= -0.201317691347729E-05
 G(20)= -0.169717444755949E 05
 G(21)= -0.119719240044192E 06
 G(22)= -0.975218272038281E 02
 G(23)= 0.554639713151823E 05
 G(24)= -0.179920450443470E 00
 G(25)= -0.256582926077184E 01
 G(26)= -0.413707715090789E-03
 G(27)= -0.256245415300293E 00

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G(28)= -0.124222373740063E-06
G(29)= 0.103556535840165E-04
G(30)= -0.538699166558303E-09
G(31)= -0.757415412839596E-08
A( 1)= -.158453465507E+02
A( 2)= .419136911423E-01
A( 3)= -.101965371660E+01
A( 4)= .134763743799E+02
A( 5)= -.109930399087E+03
A( 6)= .925518835497E+02
A( 7)= -.956233831320E+02
A( 8)= .100104366710E+03
A( 9)= -.701857937398E+02
A(10)= .900076998647E+01
A(11)= .286981120347E+02
A(12)= -.216767601780E+02
A(13)= .496558226471E+01
A(14)= .218307928477E+02
A(15)= -.126493309807E+00
A(16)= .241544188633E+01
A(17)= -.245256871794E+02
A(18)= .935925207124E+02
A(19)= -.360938251632E+02
A(20)= .757453271989E+01
G(32)= 0.585367172069521E-07
VP(1)=5.1113192094 $ VP(2)=6.482667539E-1
VP(3)=-1.5108730916E-1 $ VP(4)=7.4028493342E-1
VP(5)=1.5 $ VP(6)=.123 $ VP(7)=63.15 $ VP(8)=126.26
VP(9)=0.0
DTP=.3097717741477E+2
DTPV=.242822085710E-1
TCC=VP(8)
PCC=VP(8)*1.01325
PTP=VP(6)*1.01325
TTP=VP(7)
TLL=TTP
TUL=1900.
FUL=10000.
DCC=11.21
RETURN $ END
SUBROUTINE DATA AR
DIMENSION G(32),VP(9),GI(11)
DIMENSION GV(9),GT(9),FV(4),FT(4),EV(8),ET(8)
DIMENSION A(20)
COMMON/SEN/BET, XO, DELTA, E1, E2, AGAM
COMMON/SATC/A, DTPV
COMMON/CRIT/ EM, EOK, RM, TC, DC, X, PC, SIG
COMMON/DATA/G, R, GAMMA, VP, DTP, PCC, PTP, TCC, TTP, TUL, TLL, PUL, DCC
COMMON/DATA1/GV, GT, FV, FT, EV, ET
COMMON/CPID/GI
COMMON/ISP/N, NW, NWW
NWW=0
N=0 $ NW 1
EM=39.948 $ EOK=152.8 $ RM=3.669E-08 $ TC=150.725
DC=0.533 $ X=1.7124 $ PC=47.983 $ SIG=3.297
XO=0.183 $ BETA=0.355 $ DELTA=4.352 $ E1=2.27 $ E2=0.287
AGAM=1.190
TRANSPORT PROPERTIES
FROM HANLEY ET. AL.
J. PHY. CHEM. REF DATA VOL 3
NO 4 1974
GV(1)=6.1145472787E+1
GV(2)=-1.0394390312E+2

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GV(3)=6.7594614619E+1
 GV(4)=-2.2536509380E+1
 GV(5)=4.2593950138
 GV(6)=-4.7252671093E-1
 GV(7)=-3.1795275425E-2
 GV(8)=-1.1629083740E-3
 GV(9)=1.8043010592E-2
 GT(1)=6.2777703742E+3 * GT(2)=-9.6096376637E+3
 GT(3)=5.8887549191E+3 * GT(4)=-1.8920926320E+3
 GT(5)=3.4886571437E+2 * GT(6)=-3.8016786193E+1
 GT(7)=2.5207283167 * GT(8)=-9.1098744478E-2
 GT(9)=1.3990842942E-3
 EV(1)=-1.0010993993E+1 * EV(2)=2.0694685712E-1
 EV(3)=1.6029145122E+1 * EV(4)=1.1717461351E+3
 EV(5)=-5.6995898780E+2 * EV(6)=4.0136071933E+1
 EV(7)=3.9870122403E+1 * EV(8)=.537
 FV(1)=1.4653652433 * FV(2)=-0.77487424965
 FV(3)=1.4 * FV(4)=152.8
 FT(1)=-.2414210327 * FT(2)=.075696234255
 FT(3)=1. * FT(4)=152.8
 ET(1)=-2.4116686960E+1
 ET(2)= 3.0694859971E+1
 ET(3)=2.2956551674E+3
 ET(4)= -3.5559415848E+2

C TRANSPORT PROPERTIES FROM
 C HANLEY ET. AL. J. PHY. CHEM. REF
 C DATA VOL 3 NO 4 1974 AND
 C GOSMAN ET. AL. NSRDS MON 27 1964

R=.08205616
 GAMMA=-.0055
 GI(1)=GI(2)=GI(3)=0
 GI(4)=GI(9)=2.5
 GI(5)=GI(6)=GI(7)=0
 GI(8)=0
 GI(10)=GI(11)=0
 TO=87.28 * SO=129.1786 * HO=9504.8916
 GI(10)=HO-HI(TO)
 GI(11)=SO-SI(TO)
 G(1)=3.4342657242351E-3
 G(2)=5.7857036681387E-2
 G(3)=-2.6982470812264E+0
 G(4)=1.6481655285291E+2
 G(5)=-1.2849472420416E+4
 G(6)=-3.2636490894686E-4
 G(7)=2.4629470190841E-1
 G(8)=-6.9585445697842E+1
 G(9)=1.9196156939788E+4
 G(10)=1.6603909805594E-5
 G(11)=-1.0860316345366E-2
 G(12)=3.3231759004885E+0
 G(13)=2.1776361947053E-5
 G(14)=5.1615085812771E-3
 G(15)=-1.1366705407293E+0
 G(16)=-2.9018517618859E-4
 G(17)=3.7898289698060E-6
 G(18)=1.1030489790987E-3
 G(19)=-1.4674092942955E-5
 G(20)=-1.1479610716179E+4
 G(21)=-3.9393312963830E+5
 G(22)=-9.9620084307336E+1
 G(23)=-1.8575347046011E+4
 G(24)=-2.9393483871136E-1
 G(25)=1.6408588086762E+1


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G(26) = 4.044717423935E-4
G(27) = 2.0820007165976E+0
G(28) = 5.4769320649612E-2
G(29) = 7.5137405777667E-5
G(30) = 2.8667425518207E-10
G(31) = 8.3003722866834E-8
G(32) = 2.5287413440936E-6
A(1) = .170262973777E+02
A(2) = .131040241866E+00
A(3) = .267486438128E+01
A(4) = .300176804406E+02
A(5) = .875899149326E+02
A(6) = .408267436456E+02
A(7) = .104268066451E+03
A(8) = .671222525379E+02
A(9) = .151002937201E+02
A(10) = .331245336637E+02
A(11) = .833196217591E+01
A(12) = .427149706899E+02
A(13) = .100299900030E+02
A(14) = .137682084200E+02
A(15) = .664630363191E-01
A(16) = .133368782130E+01
A(17) = -.144371463249E+02
A(18) = .601938472000E+02
A(19) = -.230888463887E+02
A(20) = .465318358887E+01
VP(1) = 3.4151115519 $ VP(2) = 1.1910812519
VP(3) = -3.407632334E-1 $ VP(4) = 10.9515815251E-1
VP(5) = 1.5 $ VP(6) = .68005 $ VP(7) = 83.80 $ VP(8) = 150.86
VP(9) = 0.0
DTP = .3540027619188E+02
DTPV = .1029227022329
PRINT 100

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100 FORMAT(* THE TEMPERATURE RANGE FOR ARGON IS 83.8 TO 400 K*
1/* WITH PRESSURES TO 1000 BAR*)

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TCC=VP(8)
PCC=VP(10)*1.01325
PTP=VP(6)*1.01325
TTP=VP(7)
TUL=400.
TLL=TTP
PUL=1000.
DCC=13.41
RETURN $ END
SUBROUTINE DATA 02
DIMENSION G(32),VP(9),H1(11)
DIMENSION GV(9),GT(9),FV(4),FT(4),EV(8),EI(8)
DIMENSION A(20)
COMMON/SATC/A,DTPV
COMMON/DATA1/GV,GT,FV,FT,EV,EI
COMMON/SEN/BETA,XU,DELTA,E1,E2,AGAM
COMMON/CRIT/EM,EOK,RM,TC,DC,X,PC,SIG
COMMON/DATA2/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
COMMON/ISP/N,NW,NWW
COMMON/CPID/GI
NWW=0
N=0 $ NW=1
XU=0.183 $ BETA=0.355 $ DELTA=4.352 $ E1=2.21 $ E2=0.247
EM=31.9988 $ EOK=113.0 $ RM=3.8896E-08 $ TC=154.575
DC=0.4362 $ X=2.210636 $ PC=49.770 $ SIG=3.437
AGAM = 1.190

```

```

C TRANSPORT PROPERTIES

```

C
C

FROM HANLEY ET. AL.

VOL 3, NO 4, 1974

GV(1)=-7.7076378593E+1 * GV(2)=8.2801254201E+1

GV(3)=-2.4668758803E+1 * GV(4)=2.1324360243

GV(5)=3.7851049522E-1 * GV(6)=-1.0487216090E-1

GV(7)=1.1134441304E-2 * GV(8)=-5.3676093757E-4

GV(9)=1.0279379641E-5

GT(1)=-2.0395052193E+5 * GT(2)=2.4088141709E+5

GT(3)=-1.2014175183E+5 * GT(4)=3.295494919E+4

GT(5)=-5.4244239598E+3 * GT(6)=5.4734865540E+2

GT(7)=-3.2854821539E+1 * GT(8)=1.0753572103

GT(9)=-1.4610986820E-2

EV(1)=-1.2152387017E+1 * EV(2)=-3.1421728994E-1

EV(3)=1.8201161468E+1 * EV(4)=2.7390429525E+2

EV(5)=-2.7498956948E+3 * EV(6)=2.4340689667E+2

EV(7)=1.1911504104E+2 * EV(8)=.435

FV(1)=4.3526515153 * FV(2)=-2.0361263878

FV(3)=1.4 * FV(4)=100.

FT(1)=.3060 * FT(2)=.2785

FT(3)=1.12 * FT(4)=100.

ET(1)=-1.2310400765E+1 * ET(2)=1.6799504261E+1

ET(3)=-2.9944878721E+3 * ET(4)=4.7350508788E+2

C
C

THERMODYNAMIC PROPERTIES

FROM WEBER - TO BE PUBLISHED

R=8.20539E-2

GAMMA=-.0056

GI(1)= -0.498199853711943E 04

GI(2)= 0.230247779995218E 03

GI(3)= -0.345565323510732E 01

GI(4)= 0.352187677367116E 01

GI(5)= -0.435420216024420E-04

GI(6)= 0.134635345013162E-07

GI(7)= 0.162059825959105E-10

GI(8)= 0.103146851572565E 01

GI(9)= 0.223918105000000E 04

GI(10)=GI(11)=0

TO=298.15 * HO=8682. * SO=205.037

GI(10)=HO-HI(TO)

G(1)= -.4308768468E-03

G(2)= .1979591095E+00

G(3)= -.4143014968E+01

G(4)= .1853654396E+03

G(5)= -.1270637452E+05

G(6)= .1536388737E-04

G(7)= .1326068945E-02

G(8)= -.7199275123E+01

G(9)= .4705445127E+04

G(10)= .4728198017E-06

G(11)= .2430408198E-02

G(12)= -.1894759615E+00

G(13)= -.6887067207E-05

G(14)= -.6132885180E-03

G(15)= -.1836518694E+00

G(16)= .2575663871E-04

G(17)= -.2415604646E-06

G(18)= .1438680831E-03

G(19)= -.1703915986E-05

G(20)= -.2353705917E+04

G(21)= -.2271707669E+06

G(22)= -.2753815471E+02

G(23)= .9277648729E+05

G(24)= -.4114926856E-01

G(25)= .1982233262E+01

```

G(26)= -.1239651142E-03
G(27)= -.6322588664E+00
G(28)= -.2443207666E-07
G(29)= .1328704370E-04
G(30)= -.1146313812E-09
G(31)= -.1021169305E-07
G(32)= .2334998237E-06
GI(11)=80-SI(TO)
A( 1)= .581394753076E+02
A( 2)= -.490241196133E-01
A( 3)= .168328893252E+01
A( 4)= -.325161223398E+02
A( 5)= .550300989872E+03
A( 6)= -.510968506115E+03
A( 7)= .315091559049E+03
A( 8)= -.232566659258E+02
A( 9)= -.488425479359E+02
A(10)= -.150624217523E+03
A(11)= .280441603851E+03
A(12)= -.176693896861E+03
A(13)= .403247747449E+02
A(14)= .252198688365E+01
A(15)= -.136098316472E-01
A(16)= .282316159403E+00
A(17)= -.286645905341E+01
A(18)= .617024212284E+01
A(19)= -.810220795462E+00
A(20)= -.279601068969E+00
VP(1)=7.568956 * VP(2)=5.004836 * VP(3)=-2.137460
VP(4)=3.454481 * VP(5)=1.514 * VP(6)=.0014606
VP(7)=54.359 * VP(8)=154.581
VP(9)=0.0
DTP=.4081997364372E+02
DTPV=.3318894767078E-03
PRINT 100

```

```

100 FORMAT(* THE TEMPERATURE RANGE FOR OXYGEN IS 54.359 TO 400 N*
1/* WITH PRESSURES TO 1200 BAR*)

```

```

TCC=VP(8)
PCC=VPN(TCC)*1.01325
PTP=VP(6)*1.01325
ITP=VP(7)
TUL=400.
TLL=TTP
PUL=1200.
DCC=13.63
RETURN * END
SUBROUTINE DATA P H2
DIMENSION G(32),VP(9),GI(11)
DIMENSION GV(9),GT(9),FV(4),FT(4),EV(8),ET(8)
DIMENSION A(20)
COMMON/SATC/A,DTPV
COMMON/CPID/GI
COMMON/CRIT/ EM, EOK, RM, TC, DC, X, PC, SIG
COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TTP,TUL,TLL,PUL,DCC
COMMON/DATA1/GV,GT,FV,FT,EV,ET
COMMON/PARA/PERCEN
COMMON/ISP/N
N=1
GO TO 1
ENTRY N H2
N=2
GO TO 1
ENTRY O H2

```

N=3
GO TO 1
ENTR E H2
N=4
GO TO 1
ENTRY F H2
N=5

1 CONTINUE

C
C
C
C

NO TRANSPORT PROPERTIES FOR HYDROGEN
THERMODYNAMIC PROPERTIES FROM
RODER AND MCCARTY IN 75-814 AND
IR 74-357

R=.08205616

GAMMA=-.0041

G(1) = 4.614387759254E-4
G(2) = 4.233184556086E-2
G(3) = -5.096556226503E-1
G(4) = 2.923059738269E+0
G(5) = 2.987609147211E+1
G(6) = 1.883148601410E-5
G(7) = -1.322256954639E-3
G(8) = 3.016504431701E-1
G(9) = 5.093705560851E+1
G(10) = 1.973828324919E-7
G(11) = 2.858492039828E-4
G(12) = -2.228279239123E-2
G(13) = -2.257481136764E-6
G(14) = 2.414272369746E-5
G(15) = -1.695713398588E-3
G(16) = -5.393676391275E-7
G(17) = 3.998955244328E-9
G(18) = 1.142457561274E-6
G(19) = -1.252566225896E-8
G(20) = -4.917861934882E+1
G(21) = -1.585666017368E+2
G(22) = -1.901602946272E-1
G(23) = 9.198020862500E+0
G(24) = -3.180455518810E-4
G(25) = 1.191057791926E-3
G(26) = -3.791352773225E-7
G(27) = -3.983377699095E-5
G(28) = -1.234510854688E-10
G(29) = 1.950266293499E-9
G(30) = -2.380343917109E-13
G(31) = -4.073576608192E-13
A(1) = .916617720187E+02
A(2) = -.179492524446E+00
A(3) = .454671158395E+01
A(4) = -.658499589788E+02
A(5) = .734466804535E+03
A(6) = -.682501045175E+03
A(7) = .631783674710E+03
A(8) = -.539408873282E+03
A(9) = .430923811783E+03
A(10) = -.300295738811E+03
A(11) = .156567165346E+03
A(12) = -.504103608225E+02
A(13) = .720706926514E+01
A(14) = -.123944440318E+03
A(15) = .140334800142E+01
A(16) = -.211023804313E+02
A(17) = .173254622817E+03
A(18) = -.44294580871E+03

```

A(19)= .138699365355E+03
A(20)= -.235774161015E+02
G(32) = 8.80131493077E-12
VP(1)=3.05300134164
VP(2)=2.80810925813
VP(3)=-0.655461216567
VP(4)=1.59514439374
VP(5)=1.5814454428
VP(7)=13.8
VP(6)=0.0695
VP(8)=32.938
VP(9)=0
DTP=-.3821428945438E+02
DTPV=.6322296353698E-01
EM=2.01594
PRINT 100

```

```

100 FORMAT(* THE TEMPERATURE RANGE FOR HYDROGEN IS 13.8 TO 400 K*
1/* WITH PRESSURES TO 1200 BAR*)

```

```

TCC=VP(8)
PCC=VP(8)*1.01325
PTP=VP(6)*1.01325
TTP=VP(7)
TUL=400.
TLL=TTP
PUL=1200.
DCC=15.556
RETURN
END

```

```

SUBROUTINE PROPS(PP,DD,TT)

```

```

C THE 32 TERM EQUATION OF STATE, INPUT IS DENSITY(MOLFS/L.),
C TEMPERATURE(K), OUTPUT (PP) IS PRESSURE IN ATM,OR DP/DD IN
C LITER-ATM/MOLE OR DP/DT ATM/K OR S,H,OR CV AT ONE (LM) IF
C INTEGRATION

```

```

DIMENSION X(33)
DIMENSION B(33),G(32)
EQUIVALENCE (B,X)
COMMON/DATA/G,R,GAMMA
COMMON/1/B
DATA(ID=1)
DATA(IZ=1)
1 CONTINUE
IF(IZ.LE.0)GO TO 2
IZ=0
2 CONTINUE
D=DD
P=PP
T=TT
GM=GAMMA
D2=D*D
D3=D2*D
D4=D3*D
D5=D4*D
D6=D5*D
D7=D6*D
D8=D7*D
D9=D8*D
D10=D9*D
D11=D10*D
D12=D11*D
D13=D12*D
TS=SQRT (T)
T2=T*T
T3=T2*T

```

```

T4=T3*T
T5=T4*T
F=EXP (GM*D2)
GO TO (100,200,300,400,500,600,700),K
ENTRY PRESS
C ENTRY FOR PRESSURE, INPUT IS DENSITY
C AND TEMP. IN MOL/L AND K, OUTPUT IS IN ATM.
K=1
GO TO 1
100 CONTINUE
B( 1)=D2*T
B( 2)=D2*TS
B( 3)=D2
B( 4)=D2/T
B( 5)=D2/T2
B( 6)=D3*T
B( 7)=D3
B( 8)=D3/T
B( 9)=D3/T2
B(10)=D4*T
B(11)=D4
B(12)=D4/T
B(13)=D5
B(14)=D6/T
B(15)=D6/T2
B(16)=D7/T
B(17)=D8/T
B(18)=D8/T2
B(19)=D9/T2
B(20)=D3*F/T2
B(21)=D3*F/T3
B(22)=D5*F/T2
B(23)=D5*F/T4
B(24)=D7*F/T2
B(25)=D7*F/T3
B(26)=D9*F/T2
B(27)=D9*F/T4
B(28)=D11*F/T2
B(29)=D11*F/T3
B(30)=D13*F/T2
B(31)=D13*F/T3
B(32)=D13*F/T4
IF(ID.GT.0)GO TO 102
B(33)=P-R*D*T
RETURN
102 P=0
M=32
DO 101 I=1,M
101 P=P+B(I)*G(I)
P=P+R*D*T
PP=P
RETURN
ENTRY DPDD
C PARTIAL OF PRESSURE WITH RESPECT TO
C DENSITY - SEE PRESSURE
C ENTRY FOR UNITS
K=2
GO TO 1
200 CONTINUE
F1=2.00*F*GM*D
F21=3.000*F*D2 +F1*D3
F22=5.000*F*D4 +F1*D5
F23=7.000*F*D6 +F1*D7

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F24=9.000*F*D8 +F1*D9
F25=11.00*F*D10+F1*D11
F26=13.00*F*D12+F1*D13
B( 1)=2.00*D*T
B( 2)=2.00*D*TS
B( 3)=2.00*D
B( 4)=2.00*D/T
B( 5)=2.00*D/T2
B( 6)=3.00*D2*T
B( 7)=3.00*D2
B( 8)=3.00*D2/T
B( 9)=3.00*D2/T2
B(10)=4.00*D3*T
B(11)=4.00*D3
B(12)=4.00*D3/T
B(13)=5.00*D4
B(14)=6.00*D5/T
B(15)=6.00*D5/T2
B(16)=7.00*D6/T
B(17)=8.00*D7/T
B(18)=8.00*D7/T2
B(19)=9.00*D8/T2
B(20)=F21/T2
B(21)=F21/T3
B(22)=F22/T2
B(23)=F22/T4
B(24)=F23/T2
B(25)=F23/T3
B(26)=F24/T2
B(27)=F24/T4
B(28)=F25/T2
B(29)=F25/T3
B(30)=F26/T2
B(31)=F26/T3
B(32)=F26/T4
M=32
IF(ID.GT.0)GO TO 202
B(33)=P-R*T
RETURN
202 P=0
DO 201 I=1,M
201 P=P+B(I)*G(I)
P=P+R*T
PP=P
RETURN
ENTRY DPDI
C PARTIAL OF PRESSURE WITH RESPECT
C TO TEMPERATURE - SEE PRESSURE
C ENTRY FOR UNITS
K=3
GO TO 1
300 CONTINUE
X( 1)=D2
X( 2)=D2/(2.00*TS)
X( 3)=0
X( 4)=-D2/T2
X( 5)=-2.00*D2/T3
X( 6)=D3
X( 7)=0
X( 8)=-D3/T2
X( 9)=-2.00*D3/T3
X(10)=D4
X(11)=0

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```

X(12)=-D4/T2
X(13)=0
X(14)=-D6/T2
X(15)=-2.00*D6/T3
X(16)=-D7/T2
X(17)=-D8/T2
X(18)=-2.00*D8/T3
X(19)=-2.00*D9/T3
X(20)=-2.00*D5*T/T3
X(21)=-3.00*D3*F/T4
X(22)=-2.00*D5*F/T3
X(23)=-4.00*D5*F/T5
X(24)=-2.00*D7*F/T3
X(25)=-3.00*D7*F/T4
X(26)=-2.00*D9*F/T3
X(27)=-4.00*D9*F/T5
X(28)=-2.00*D11*F/T3
X(29)=-3.00*D11*F/T4
X(30)=-2.00*D13*F/T3
X(31)=-3.00*D13*F/T4
X(32)=-4.00*D13*F/T5
IF(D,GT,0)GO TO 302
X(33)=PP-R*D
RETURN
302 P=0
DO 301 I=1,32
301 P=F+G(I)*X(I)
PP=F+R*D
RETURN
ENTRY DSDN
C PARTIAL OF ENTROPY WITH
C RESPECT TO THE G COEFFICIENTS
K=4
GO TO 1
400 CONTINUE
C S=S0-R*LOGF(D*R*T/P0)+(DSDN(D)-DSDN(0))*101.325 +CPOS(T)
G1=F/(2.00*GM)
G2=(F*D2-2.00*G1)/(2.00*GM)
G3=(F*D4-4.00*G2)/(2.00*GM)
G4=(F*D6-6.00*G3)/(2.00*GM)
G5=(F*D8-8.00*G4)/(2.00*GM)
G6=(F*D10-10.00*G5)/(2.00*GM)
X( 1)=-D
X( 2)=-D/(2.00*TS)
X( 3)=0.D0
X( 4)=+D/T2
X( 5)=2.00*D/T3
X( 6)=-D2/2.00
X( 7)=0.D0
X( 8)=D2/(2.00*T2)
X( 9)=D2/T3
X(10)=-D3/3.00
X(11)=0.D0
X(12)=D3/(3.00*T2)
X(13)=0.D0
X(14)=D5/(5.00*T2)
X(15)= 2.00*D5/(5.00*T3)
X(16)=D6/(6.00*T2)
X(17)=D7/(7.00*T2)
X(18)=2.00*D7/(7.00*T3)
X(19)=D8/(4.00*T3)
X(20)=2.00*G1/T3
X(21)=3.00*G1/T4

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```

X(22)=2.00*G2/T3
X(23)=4.00*G2/T5
X(24)=2.00*G3/T3
X(25)=3.00*G3/T4
X(26)=2.00*G4/T3
X(27)=4.00*G4/T5
X(28)=2.00*G5/T3
X(29)=3.00*G5/T4
X(30)=2.00*G6/T3
X(31)=3.00*G6/T4
X(32)=4.00*G6/T5
IF(ID.GT.0)GO TO 402
RETURN
402 P=0
DO 401 I=1,32
401 P=P+G(I)*X(I)
PP=P
RETURN
ENTRY DUDN
C TERMS NEEDED FOR ENTHALPY CALCULATION
K=5
GO TO 1
500 CONTINUE
C H=H0+(I*DSDN(D)-DSDN(0))*101.325+(DUDN(D)-DUDN(0))*101.325+CPDH(T)
C +(P/D-R*T)*101.325
G1=F/(2.00*GM)
G2=(F*D2-2.00*G1)/(2.00*GM)
G3=(F*D4-4.00*G2)/(2.00*GM)
G4=(F*D6-6.00*G3)/(2.00*GM)
G5=(F*D8-8.00*G4)/(2.00*GM)
G6=(F*D10-10.00*G5)/(2.00*GM)
X( 1)=D*T
X( 2)=D*TS
X( 3)=D
X( 4)=D/T
X( 5)=D/T2
X( 6)=D2*T/2.00
X( 7)=D2/2.00
X( 8)=D2/(2.00*T)
X( 9)=D2/(2.00*T2)
X(10)=D3*T/3.00
X(11)=D3/3.00
X(12)=D3/(3.00*T)
X(13)=D4/4.00
X(14)=D5/(5.00*T)
X(15)=D5/(5.00*T2)
X(16)=D6/(6.00*T)
X(17)=D7/(7.00*T)
X(18)=D7/(7.00*T2)
X(19)=D8/(8.00*T2)
X(20)=G1/T2
X(21)=G1/T3
X(22)=G2/T2
X(23)=G2/T4
X(24)=G3/T2
X(25)=G3/T3
X(26)=G4/T2
X(27)=G4/T4
X(28)=G5/T2
X(29)=G5/T3
X(30)=G6/T2
X(31)=G6/T3
X(32)=G6/T4

```

```

      IF(ID.GT.0)GO TO 502
      RETURN
502 P=0
      DO 501 I=1,32
501  P=P+G(I)*X(I)
      PP=P
      RETURN
      ENTRY TLSDT
C     TEMP. TIMES THE PARTIAL OF
C     ENTROPY WITH RESPECT TO TEMP.
      K=6
      GO TO 1
600 CONTINUE
C     CV=CV0+(TSDSN(/)-TSDSN(D))*101.325
      G1=F/(2.00*GM)
      G2=(F*D2-2.00*G1)/(2.00*GM)
      G3=(F*D4-4.00*G2)/(2.00*GM)
      G4=(F*D6-6.00*G3)/(2.00*GM)
      G5=(F*D8-8.00*G4)/(2.00*GM)
      G6=(F*D10-10.00*G5)/(2.00*GM)
      X(1)=0
      X( 2)=-D/(4.00*TS)
      X(3)=0
      X( 4)=2.00*D/T2
      X( 5)=6.00*D/T3
      X(6)=0
      X(7)=0
      X( 8)=D2/T2
      X( 9)=3.00*D2/T3
      X(10)=0
      X(11)=0
      X(12)=(2.00*D3)/(3.00*T2)
      X(13)=0
      X(14)=(2.00*D5)/(5.00*T2)
      X(15)=(6.00*D5)/(5.00*T3)
      X(16)=D6/(3.00*T2)
      X(17)=(2.00*D7)/(7.00*T2)
      X(18)=(6.00*D7)/(7.00*T3)
      X(19)=(3.00*D8)/(4.00*T3)
      X(20)=6.000*G1/T3
      X(21)=12.00*G1/T4
      X(22)=6.000*G2/T3
      X(23)=20.00*G2/T5
      X(24)=6.000*G3/T3
      X(25)=12.00*G3/T4
      X(26)=6.000*G4/T3
      X(27)=20.00*G4/T5
      X(28)=6.000*G5/T3
      X(29)=12.00*G5/T4
      X(30)=6.000*G6/T3
      X(31)=12.00*G6/T4
      X(32)=20.00*G6/T5
      IF(ID.GT.0)GO TO 602
      RETURN
602 P=0
      DO 601 I=1,32
601  P=P+G(I)*X(I)
      PP=P
      RETURN
      ENTRY DP2D2
C     SECOND PARTIAL OF PRESSURE WITH
C     RESPECT TO DENSITY SQUARED
      K=7

```

```

GO TO 1
700 CONTINUE
F1=2.*F#GM#D
F12=2.*F1#GM#D+2.*F#GM
F212=3.*F1#D2+3.*2.*D#F+F12#D3+F1#3.*D2
F222=5.*F1#D4 +5.*4.*D3#F+5.*D4#F1+F12#D5
F232=7.*F1#D6+7.*6.*D5#F+7.*D6#F1+F12#D/
F242=9.*F1#D8+9.*8.*D7#F+9.*D8#F1+F12#D9
F252=11.*F1#D10+10.*11.*D9#F+11.*D10#F1+F12#D11
F262=13.*F1#D12+13.*12.*D11#F+13.*D12#F1+F12#D13
B(1)=2.*T $ B(2)=2.*TS $ B(3)=2.
B(4)=2./T $ B(5)=2./T2 $ B(6)=6.*D#T
B(7)=6.*D $ B(8)=6.*D/T $ B(9)=6.*D/T2
B(10)=12.*D2#T $ B(11)=12.*D2 $ B(12)=12.*D2/T
B(13)=20.*D3 $ B(14)=30.*D4/T $ B(15)=30.*D4/T2
B(16)=42.*D5/T $ B(17)=56.*D6/T $ B(18)=56.*D6/T2
B(19)=72.*D7/T2 $ B(20)=F212/T2 $ B(21)=F212/T3
B(22)=F222/T2
B(23)=F222/T4 $ B(24)=F232/T2 $ B(25)=F232/T3
B(26)=F242/T2 $ B(27)=F242/T4 $ B(28)=F252/T2
B(29)=F252/T3 $ B(30)=F262/T2 $ B(31)=F262/T3
B(32)=F262/T4
M=32
IF(ID.GT.0)GO TO 702
B(33)=PP
RETURN
702 P=0
DO 701 I=1,M
701 P=P+B(I)*G(I)
PP=P
RETURN
END
FUNCTION VPN(TT)
C CALCULATES VAPOR PRESSURE IN ATMOSPHERES
C FOR AN INPUT TEMPERATURE IN KELVIN
C DIMENSION G(32),VP(9)
COMMON/DATA/G,R,GAMMA,VP
T=TT
X=(1,-VP(7)/T)/(1,-VP(7)/VP(8))
VPN=VP(6)*EXP (VP(1)*X+VP(2)*X*X+VP(3)*X*X*X+VP(9)*X*X*X*X+VP(4)*X*X
X*(1.-X)**VP(5))
RETURN
END
FUNCTION FINDTV(POBS)
C ITERATES THE VAPOR PRESSURE EQUATION
C FOR A TEMPERATURE ( IN KELVIN)
C GIVEN AN INPUT PRESSURE IN ATMOSPHERES
COMMON/DATA/G,R,GAMMA,VP,DTP
DIMENSION G(32),VP(9)
T=VP(8)
DO 7 I=1,10
P=VPN(T)
IF(ABS (P-POBS)-.000001*POBS)8,8,6
6 CONTINUE
CORR=(POBS-P)/DPDTPVP(T)
7 T=T+CORR
8 CONTINUE
FINDTV=T
RETURN
END
FUNCTION CV(D,T)
C CALCULATES SPECIFIC HEAT CAPACITY
C AT CONSTANT VOLUME FOR AN INPUT

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```

C      OF DENSITY AND TEMPERATURE IN MOL/L AND K
      DATA(R=8.31434)
      DD=D
      TT=T
      CALL TDSD((CO,DD,TT)
      DD=0
      CALL TDSDT(CO,DD,TT)
      CV=CPI(TT)+(CO-CD)*101.325
      CV=CV-R
      RETURN
      END
      FUNCTION FIND D(P,T)
C      ITERATES EQUATION OF STATE
C      FOR DENSITY, GIVEN PRESSURE
C      AND TEMP. IN ATM. AND KELVIN. IF
C      ITERATION FAILS TRY USING
C      FUNCTION CALLED FIND M
      DIMENSION G(32),VP(9)
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,FTP,TCC,TFP,TUL,PUL,DCC
      TT=T
      IF(TT.GT.VP(8))GO TO 100
      IF( P.GT.VPN(TT))GO TO 101
      DD=SATV(TT)
      GO TO 102
100  PC=PCC/1.01325
      X=(1.1/(9.*PC))*P+.7/9.
      DD=P/(R*X)
      IF(P/PC.GT.20..AND.T/VP(8).LT.2.5)DD=DTP
      GO TO 102
101  DD=SATL(TT)
102  CONTINUE
      DO 10 I=1,50
      IF(DD.LE.0.0.OR.DD.GT.50.)GO TO 11
      CALL PRESS(PP,DD,TT)
      IF(PP.LE.0.0)GO TO 11
      P2=PP
      IF(ABS (P-P2)-1.E-7*P)20,20,1
1   CALL DPDD(PP,DD,TT)
      DP=PP
      CORR=(P2-P)/DP
      IF(ABS (CORR)-1.E-7*DD)20,20,10
10  DD=DD-CORR
11  CALL REGULA(P,DD,T)
20  FIND D=DD
      RETURN
      END
      SUBROUTINE REGULA(PI,DD,TT)
C      ITERATES EQUATION OF STATE FOR DENSITY WHEN FIND D FAILS
      DIMENSION G(32),VP(9)
      COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTP,TCC,TFP,TUL,TLL,PUL,DCC
      T=TT
      P=PI
      D2=0
      IF(T.LT.TCC)GO TO 10
      DO=DCC*TCC/T
      GO TO 20
10  PP=VPN(T)
      IF(P.GT.PP)GO TO 15
      DO=SATV(T)
      DO 11 I=1,150
      CALL PRESS(P0,DO,T)
      IF(P0.GE.P)GO TO 12
11  DO=DO+.0001*DO

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      GO TO 42
12  D1=D0
13  CALL PRESS(P1,D1,T)
     IF(P1.LT.P)GO TO 14
     IF(D1.LE..1*PTP)GO TO 42
     D0=D1
     Z=(P1-P)/P
     IF(Z.LT..1)Z=.1
     IF(Z.GT..9)Z=.7
     D1=D1-Z*D1
     GO TO 13
14  CALL PRESS(P0,D0,T)
     DO 140 I=1,50
     D=D1
     P3=P1
     IF(ABS(P-P1).LT..00001*P)GO TO 40
     P2=P-P1
     D1=D1+(D1-D0)*P2/(P1-P0)
     IF(ABS(D-D1).LE..00001*D)GO TO 40
     IF(ABS(P-P1).LT..005*P)D2=FIND M(P,T,D1)
     IF(D2.GT.0.0.AND.D2.LT.50.)D1=D2
     D2=0
     CALL PRESS(P1,D1,T)
     IF(P0.GT.P.AND.P1.GT.P)GO TO 120
     IF(P0.LT.P.AND.P1.LT.P)GO TO 120
     GO TO 140
120  P0=P3
     D0=D
140  CONTINUE
     GO TO 41
15  D0=SATL(T)
     DO 16 I=1,10
     CALL PRESS(P0,D0,T)
     IF(P0.LE.P)GO TO 17
16  D0=D0-.0001*D0
     GO TO 42
17  D1=D0
18  CALL PRESS(P1,D1,T)
     IF(D1.GE.50.)GO TO 42
     IF(P1.GT.P)GO TO 14
     D0=D1
     Z=(P-P1)/P
     Z=Z*10
     IF(T/TCC.LT..6)Z=1.
     IF(Z.LT.1.)Z=1.
     IF(Z.GT.9.)Z=9.
     D1=D1+.01*D1*Z
     GO TO 18
20  CALL PRESS(P0,D0,T)
     IF(P.LE.P0)GO TO 30
     D1=D0
21  CALL PRESS(P1,D1,T)
     IF(P1.GE.P)GO TO 14
     IF(D1.GE.50.)GO TO 42
     D0=D1
     Z=(P-P1)/P
     Z=Z*10
     IF(Z.LT.1)Z=1
     IF(Z.GT.9)Z=9
     D1=D1+.1*D1*Z
     GO TO 21
30  D1=D0
31  CALL PRESS(P1,D1,T)

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```

IF(P1.LE.P)GO TO 14
IF(D1.LE.,1#PTP)GO TO 42
D0=D1
Z=(P1-P)/P
Z=Z*10
IF(Z.L.T.1)Z=1
IF(Z.GT.9)Z=9
D1=D1-.1#D1#Z
GO TO 31
40 DD=D1
RETURN
41 PRINT 101,P,T,D
102 FORMAT(* REGULA FAILED AT P=*,F7.2,* AND T=*,F7.2)
101 FORMAT(* DENSITY ITERATION FAILED AT P=*,F7.2,* AND T=*,F7.2,
1/* DENSITY RETURNED IS*,E17.8)
RETURN
42 PRINT 102,P,T
RETURN
END
FUNCTION CP(D,T)
C CALCULATES SPECIFIC HEAT CAPACITY
C AT CONSTANT PRESSURE FOR INPUT OF
C DENSITY AND TEMPERATURE IN MOL/L AND K
C CP IS IN JOULES/MOL-K
C VEE=CV(D,T)
CALL DPDT(DPT,D,T)
CALL DPDD(DPD,D,T)
CP=CVEE+(T/(D**2))*(DPT**2)/DPD/*101.325
RETURN
END
FUNCTION DPDTVP(TT)
C CALCULATES THE DERIVATIVE OF PRESSURE
C WITH RESPECT TO TEMPERATURE AT
C SATURATION. INPUT IS TEMP. IN K, OUTPUT IS ATM/K.
COMMON/DATA/G,R,GAMMA,VP
DIMENSION G(32),VP(9)
T=TT
IF(TT.GT.VP(8))GO TO 1
X=(1.-VP(7)/T)/(1.-VP(7)/VP(8))
DXDT=(VP(7)/T**2)/(1.-VP(7)/VP(8))
DPDT=VP(1)*DXDT+2.*VP(2)*X*DXDT+VP(3)*3.*X**2*DXDT+VP(4)*
1((1.-X)**VP(5))*DXDT+VP(4)*X*((1.-X)**(VP(5)-1.))*VP(5)*(-DXDT)
DPDT=DPDT*VPN(T)
DPDTVP=DPDT
RETURN
1 DPDTVP=0
RETURN
END
FUNCTION FIND M(P,T,DD)
C ALTERNATIVE FOR FIND D, INPUT IS
C PRESSURE IN ATM., T IN KELVIN AND
C DENSITY IN MOL/L. INPUT DENSITY
C IS A STARTING VALUE FOR ITERATION
C OF EQUATION OF STATE FOR SOLUTION FOR P AND T
TT=T
DO 10 I=1,50
CALL PRESS(PP,DD,TT)
P2=PP
IF(ABS (P-P2)-1.E-7#P)20,20,1
1 CALL DPDD(PP,DD,TT)
DP=PP
CORR=(P2-P)/DP
D=DD

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      IF (ABS (CORR)-1.E-7#D)20,20,10
10 DD=DD-CORR
   FIND M=0
   RETURN
2) FIND M=DD
   RETURN
   END
   FUNCTION ENTHAL(P,D,T)
C   CALCULATES ENTHALPY FOR INPUT OF
C   PRESSURE, DENSITY AND TEMP. IN
C   ATM., MOL/L AND K.  OUTPUT IS IN
C   JOULES/MOL
   R=.08205616
   DD=D
   TT=T
   CALL DSDN(SD,DD,TT)
   CALL DUDN(U0,DD,TT)
   DD=0
   CALL DSDN(S0,DD,TT)
   CALL DUDN(U0,DD,TT)
   ENTHAL=T*(SD-S0)*101.325+(U0-U0)*101.325+HI(T)+(P/D-R*T)*101.325
   RETURN
   END
   FUNCTION ENTROP(D,T)
C   CALCULATES ENTROPY
C   FOR AN INPUT OF DENSITY AND
C   TEMP. IN MOL/L AND K.  OUTPUT IS IN
C   JOULES/MOL-K
   R=.08205616
   DD=D
   TT=T
   CALL DSDN(SD,DD,TT)
   DD=0
   CALL DSDN(S0,DD,TT)
   ENTROP=(SD-S0)*101.325-R*ALOG(D*R*T)*101.325+SI(T)
   RETURN
   END
   FUNCTION SATL(TT)
C   CALCULATES THE DENSITY OF THE
C   SATURATED LIQUID AT TEMP., T IN KELVIN.
C   OUTPUT IS IN MOL/L.
   DIMENSION A(20)
   DIMENSION G(32),VP(9)
   COMMON/DATA/G,R,GAMMA,VP,DTP,PCC,PTF,TCC,TTP,TUL,TLL,PUL,DCC
   COMMON/SATC/A,DTPV
   K=14
   KK=7
   GO TO 10
   ENTRY SATV
   K=1
   KK=13
10 IF(T.GE.TCC)GO TO 20
   T=TT
   ITT=TCC
   IF(ITT+1-T.LT.1.)T=ITT
   X=(T-TCC)/(TTP-TCC)
   D=A(K)*ALOG(X)
   DO 11 I=2,KK
   K=K+1
   MM=I
   IF (MM.GE.5)MM=MM+1
11 D=D+A(K)*(1.-X**((MM-5)/3.))
   IF(K.LT.14)GO TO 12

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D=DCC+EXP(D)*(DTP-DCC)
GO TO 13
12 D=DCC+EXP(D)*(DTPV-DCC)
13 SATL=D
IF(ITT+1-TT,LT,1, )SATL=D-(D-DCC)*(TT-T)
RETURN
20 DSATL=DCC
RETURN
END
FUNCTION SOUND(D,T)
C CALCULATES THE SPEED OF SOUND
C FOR AN INPUT OF DENSITY AND TEMP.
C IN MOL/L AND KELVIN. OUTPUT IS IN
C METERS/SECOND.
COMMON/CRIT/W
CALL DPDD(DP,D,T)
SOUND=((CP(D,T)/CV(D,T))*DP*101325./W)**.5
RETURN
END
FUNCTION VISC(DD,T)
C RETURNS VISCOSITY IN (G/CM-S)*E+6,
C T IN K, D IN MOL/L
COMMON/CRIT/EM
D=DD*EM/1000.
VISC=D(LV(T)+FD CV(D,T)+EXCESV(D,T)
RETURN
END
FUNCTION THERM(DD,T)
C RETURNS TC IN MW/M-K, T IN K, D IN MOL/L
COMMON/HAN/CR,TCI
COMMON/ISP/N,NW
COMMON/CRIT/EM
D=DD*EM/1000.
IF(NW.EQ.0 ) GO TO 3
CR=CRITC(D,T)
THER=DILT(T)+FDCT(D,T)*100.+EXCEST(D,T)+CR
TCI=THER-CR
THERM=THER
RETURN
3 CR=CRITC(D,T)
THERM=DILT(T)+FDCT(D,T)+EXCEST(D,T)+CR
TCI=THERM-CR
RETURN
END
FUNCTION EXCESV(D,T)
C CALCULATES EXCESS VISCOSITY
COMMON/DATA1/GV,GT,FV,FT,EV,ET
COMMON/ISP/N,NW
DIMENSION GV(9),GT(9),FV(4),FT(4),EV(8),E(8)
R2=D**(.5)*((D-EV(8))/EV(8))
R=D**(.1)
X=EV(1)+EV(2)*R2+EV(3)*R+EV(4)*R2/(T*T)+EV(5)*R/T**(.5)+EV(6)/T
1+EV(7)*R2/T
X1=EV(1)+EV(6)/T
EXCESV=EXP (X)-EXP (X1)
RETURN
ENTRY EXCEST
C CALCULATES EXCESS THERMAL CONDUCTIVITY
IF(NW.EQ.0 ) GO TO 3
R=D**(.1)
X=ET(1)+ET(2)*R+ET(3)*R/T**(.5)+ET(4)/T
X1=ET(1)+ET(4)/T
EXCESV=(EXP (X)-EXP (X1))/10.
RETURN

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3 R=D**(.5)*(D-ET(8))/ET(8)
R=D**(.1)
X=ET(1)+ET(2)*R2+ET(3)*R+ET(4)*R2/(T*T)+ET(5)*R/1**(.5)+ET(6)/T
1+ET(7)*R2/T
X1=ET(1)+ET(6)/T
EXLEGV=EXP(-X)-EXP(-X1)
RETURN
END
FUNCTION FDCV(D,T)
C FIRST DENSITY CORRECTION
C FOR VISCOSITY AND THERMAL CONDUCTIVITY
COMMON/DATA1/GV,G1,FV,FT,EV,ET
DIMENSION GV(9),G1(9),FV(4),F1(4),EV(8),ET(8)
FDCV=(FV(1)+FV(2))*(FV(3)-ALOG(T/FV(4)))*2)*D
RETURN
ENTRY FDC1
FDCV=(FT(1)+FT(2))*(F1(3)-ALOG(T/F1(4)))*2)*D
RETURN
END
FUNCTION CRITC(D,T)
C CALCULATES CRITICAL ENHANCEMENT
C FOR THERMAL CONDUCTIVITY
COMMON/CRIT/EM,EOK,RM,TC,DC,X,PC,SIG
COMMON/CHECK/DELD,DELT,DSTAR,TSTAR
COMMON/HJM/EPSI,CPCV,RRR,AKT
COMMON/ISP/N,NW,NWW
C D IN G/CM3 , T IN K
C OUTPUT UNITS ARE MW/M.K
AV=6.0225E+23 $ BK=1.38054E-16
DELD=ABS(D-DC)/DC $ DELT=(T-TC)/TC
C CALCULATE DISTANCE PARAMETER
R=(RM**2.5)*(D**0.5)*(AV/EM)**0.5
R=R*(EOK**0.5)*X/(T**0.5)
RRR=R
C GENERAL EQUATION
DX=D*1000.0/EM
CALL DPDT(DP1,DX,T)
C DPDT IN AT5 PER DEG.
DPT=DPT*1.01325E+6
C DPDT NOW IN DYNES PRR DEG
CALL DPDD(DPD,DX,T)
C DPDD UN AT5, MOL/L
DPD=DPD*(1.01325E+6)*(1000.0/EM)
CDPDD NOW IN DYNES, GM/CM3
IF(DPD.LT.0.0)DPD=1.0
94 VIS=VISC(DX,T)*(1.0E-06)
C VISCOSITY IN GM/CM.S
IF(DELD.EQ.0.25. OR. DELD.LT. 0.25) 8,10
8 IF(DELT.EQ.0.025. OR. DELT.LT.0.025 ) 9, 10
9 COMPRES=SENG(D,T)
GO TO 12
10 COMPRES=1.0/(D*DPD)**0.5
12 EX=BK*T**2*(DPT**2)*COMPRES
EXB=R*((BK*T)**0.5)*(D**0.5)*((AV/EM)**0.5)
CRIT=EX/(EXB*6.0*3.14159*VIS)
C PUT IN DAMPING FACTOR
BDD=((D-DC)/DC)**4
BTT=((T-TC)/TC)**2
FACT=EXP(-18.66*BTT - 4.25*BDD)
DELC=CRIT*FACT/100.0
CRITC=DELC
AKT=COMPRES*COMPRES
EPSI=RRR*BK*T*(AV*D/EM)*AKT
EPSI=EPSI**0.5

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C   CALC CP-CV
    CFCV=T*(DPT**2)*AKT/D
    RETURN
    END
    FUNCTION SENG(D,T)
C   SCALED EQUATION OF STATE FOR CRITICAL REGION
    COMMON/CRIT/ EM, EOK, RM, TC, DC, X, PC, SIG
    COMMON/BEN/BETA,XO,DELTA,E1, E2, AGAM
    COMMON/CHECK/DELD,DELT,DSTAR,TSTAR
    DSTAR= D/DC * TSTAR=T/TC
    BETA=1./BETA
    XX=DELT/DELD**BETA
    AG=AGAM-1.0
    BET2= 2.0*BETA
    AGB=AG/BET2
    DEL1=DELTA-1.0
    AGBB=(AG-BET2)/BET2
    XXO=(XX+ XO)/XO
    XXB=XXO**BET2
    BRAK=1.0 + E2**XXB
    BRAK1=BRAK**AGB
    H=E1**XXO*BRAK1
    HPRIM=(E1/XO)*BRAK1 + (AG/XO)*E1*E2*(XXB)*(BRAK**AGBB)
    RCOM=(DELD**DEL1)*(DELTA*H - (XX/BETA)*HPRIM )
    RCOMP=1.0/(RCOM*DSTAR**2)
    RCM=RCOMP/(PC*1.01325E+06)
C   RCM IN DYNES
    RCM=RCM**0.5
C
    SENG=RCM
    RETURN
    END
    FUNCTION DILV(T)
C   GIVES DILUTE GAS VISCOSITY AND THERMAL
C   CONDUCTIVITY FOR AN INPUT TEMP. IN
C   KELVIN. OUTPUT UNITS ARE SAME AS
C   THOSE IN VISC AND THERM
    COMMON/ISP/N,NW,NWV
    COMMON/DATA1/GV,GT,FV,FT,EV,ET
    DIMENSION GV(9),GT(9),FV(4),FT(4),EV(8),ET(8)
    SUM=0
    TF=T**(1./3.)
    TFF=T**(-4./3.)
    DO 10 I=1,9
    TFF=TFF*TF
10  SUM=SUM+GV(I)*TFF
    IF(NWV.EQ.7) GO TO 9
    DILV=SUM*1000.
    GO TO 11
    9  DILV=SUM
11  RETURN
    ENRY DILT
    TF=T**(1./3.)
    TFF=T**(-4./3.)
    SUM=0
    DO 20 I=1,9
    TFF=TFF*TF
20  SUM=SUM+GT(I)*TFF
    DILV=SUM
    RETURN
    END
    FUNCTION CPI(T)
C   CALCULATES IDEAL GAS THERMO PROPERTIES

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C   FOR ALL FLUIDS EXCEPT H2. INPUT IS IN
C   KELVIN, OUTPUT IS IN JOULES, MOL/L AND K
COMMON/CPID/G(11)
COMMON/ISP/N
IF(N.NE.0)GO TO 5
K=1
1  U=G(9)/T
   EU=EXP (U)
   TS=1./T**4
   GO TO (2,3,4),K
2  CPI=G(8)*U*U*EU/(EU-1.)**2
   DO 10 I=1,7
   TS=TS*T
10  CPI=CPI+G(I)*TS
   CPI=CPI*8.31434
   RETURN
5  CPI=CPO(T,N)
   RETURN
   ENTRY SI
   IF(N.NE.0)GO TO 6
K=2
GO TO 1
3  CPI=G(8)*(U/(EU-1.)-ALOG(1.-1./EU))
   1-G(1)*TS*T/3.-G(2)*TS*T*T/2.-G(3)/T+G(4)*ALOG(T)+G(5)*T+G(6)*T*T/2
   2.+G(7)*T**3/3.
   CPI=CPI*8.31434+G (11)
   RETURN
6  CPI=CPOS(T,N)
   RETURN
   ENTR HI
   IF(N.NE.0)GO TO 7
K=3
GO TO 1
4  CPI=G(8)*U*T/(EU-1.)-G(1)/(2.*T*T)-G(2)/T+G(3)*ALOG(T)+G(4)*T
   1+G(5)*T*T/2.+G(6)*T**3/3.+G(7)*T**4/4.
   CPI=CPI*8.31434+G(10)
   RETURN
7  CPI=CPOH(T,N)
   RETURN
END
FUNCTION (PO(TI,N)
DIMENSION T(58),CPP(58),CPN(58),CPO(58),CPE(58)
COMMON/PARA/PERCENT
C   CALCULATES IDESL GAS SPECIFIC HEAT FOR H2 BY INTERPOLATION
C   DATA TAKEN FROM RP 1932, UNITS OF THE TABLES ARE CAL/MOL DEG 5.
C   UNITS OF OUTPUT ARE JOULES/MOL DEG K. THE INDEX N DETERMINES THE
C   SPECIES, FOR N=1, PARAHYDROGEN, N=2 NORMAL, N=3 ORTHO, N=4 EQUILIB
C   N=5, SOME ORTHO-PARA MIXTURE SPECIFIED BY COMMON /PARA/, PERCENT
C   RANGE OF TEMP IS FROM 10 TO 5000K.
DATA(T=
1  10.0, 12.0, 14.0, 16.0, 18.0, 20.0, 25.0, 30.0, 35.0, 40.0, 45.0,
2  50.0, 55.0, 60.0, 65.0, 70.0, 75.0, 80.0, 85.0, 90.0, 95.0, 100.0,
3  105.0, 110.0, 115.0, 120.0, 125.0, 130.0, 135.0, 140.0, 145.0, 150.0, 160.0,
4  170.0, 180.0, 190.0, 200.0, 210.0, 220.0, 230.0, 240.0, 250.0, 260.0, 270.0,
5  280.0, 290.0, 300.0, 350.0, 400.0, 500.0, 600., 700., 1000., 1500., 2000.,
6  3000., 4000., 5000.)
DATA((CPE(I), I=1, 58)=4.968 , 4.96884, 4.97447, 5.01153, 5.07451, 5.208
11, 5.83508, 6.81282, 7.87989, 8.60613, 9.00231, 9.08005, 8.93278, 8.65894,
28, 33603, 8.01207, 7.71009, 7.4416, 7.21109, 7.01858, 6.85857, 6.72557, 6.6
32055, 6.53555, 6.46904, 6.42003, 6.38403, 6.36151, 6.34602, 6.33753, 6.340
401, 6.34577, 6.37276, 6.413, 6.45925, 6.50975, 6.5605, 6.6095, 6.65724,
/
6.692, 6.734, 6.771, 6.804, 6.832,
56.856, 6.877, 6.895, 6.950, 6.974, 6.993, 7.009, 7.036, 7.219, 7.720, 8.195,

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68.859,9.342,9.748)

DATA(CPO=

14.968,4.968,4.968,4.968,4.968,4.968,4.968,4.968,4.968,4.968,4.968,4.968,
24.968,4.968,4.968,4.969,4.972,4.975,4.981,4.990,5.002,5.018,5.039,
35.064,5.094,5.129,5.169,5.213,5.261,5.313,5.369,5.427,5.487,5.542,
45.741,5.868,5.992,6.109,6.219,6.320,6.411,6.493,6.566,6.629,6.684,
56.732,6.773,6.808,6.917,6.962,6.993,7.009,7.036,7.219,7.720,8.195,
68.859,9.342,9.748)

DATA(CPP=

14.968,4.968,4.968,4.968,4.968,4.968,4.968,4.968,4.969,4.972,4.983,
25.006,5.048,5.114,5.207,5.328,5.475,5.646,5.835,6.036,6.245,6.454,
36.659,6.854,7.037,7.203,7.351,7.480,7.590,7.681,7.753,7.807,7.870,
47.883,7.858,7.808,7.742,7.667,7.591,7.516,7.445,7.380,7.322,7.270,
57.225,7.186,7.152,7.050,7.010,6.998,7.010,7.037,7.219,7.720,8.159,
68.859,9.342,9.748)

DATA(CPN=

14.968,4.968,4.968,4.968,4.968,4.968,4.968,4.968,4.968,4.969,4.972,
24.977,4.988,5.005,5.029,5.061,5.100,5.147,5.201,5.261,5.325,5.393,
35.463,5.534,5.606,5.677,5.748,5.816,5.882,5.947,6.008,6.067,6.177,
46.276,6.366,6.446,6.517,6.581,6.638,6.687,6.731,6.769,6.802,6.831,
56.855,6.876,6.894,6.950,6.974,6.993,7.009,7.036,7.219,7.720,8.195,
68.859,9.342,9.748)

GO TO(1,2,3,4,5),N

1 CPO=ATKINT(TI, CPP, T, 58, 6, NES, .01)*4.184
RETURN

2 CPO=ATKINT(TI, CPN, T, 58, 6, NES, .01)*4.184
RETURN

3 CPO=ATKINT(TI, CPO, T, 58, 6, NES, .01)*4.184
RETURN

4 CPO=ATKINT(TI, CPE, T, 58, 6, NES, .01)*4.184
RETURN

5 TUP=TI+.5
TDN=TI-.5
HUP=CPOH(TUP, 5)
HDN=CPOH(TDN, 5)
CPO=(HUP-HDN)
RETURN
END

FUNCTION CPOH(TI, N)

DIMENSION T(58), HF(58), HN(58), HO(58), HE(58)

COMMON/PARA/PERCENT

C CALCULATES THE ENTHALPY OF THE IDEAL GAS FOR H2 BY INTERPOLATION
C DATA TAKEN FROM RP 1932, UNITS OF TABLES ARE CAL/MOL
C UNITS OF OUTPUT ARE JOULE/MOL. THE INDEX N DETERMINES THE SPECIES
C SPECIES, FOR N=1, PARAHYDROGEN, N=2 NORMAL, N=3 ORTHO, N=4 EQUILIB
C N=5, SOME ORTHO-PARA MIXTURE SPECIFIED BY COMMON /PARA/, PERCENT
C RANGE OF TEMP IS FROM 10 TO 5000K.

DATA(T=

1 10.0, 12.0, 14.0, 16.0, 18.0, 20.0, 25.0, 30.0, 35.0, 40.0, 45.0,
2 50.0, 55.0, 60.0, 65.0, 70.0, 75.0, 80.0, 85.0, 90.0, 95.0, 100.0,
3 105.0, 110.0, 115.0, 120.0, 125.0, 130.0, 135.0, 140.0, 145.0, 150.0, 160.0,
4 170.0, 180.0, 190.0, 200.0, 210.0, 220.0, 230.0, 240.0, 250.0, 260.0, 270.0,
5 280.0, 290.0, 300.0, 350.0, 400.0, 500.0, 600.0, 700.0, 1000.0, 1500.0, 2000.0,
6 3000.0, 4000.0, 5000.0)

DATA(HN=

1 303.67, 313.60, 323.54, 333.48, 343.41, 353.35, 378.19, 403.03,
2 427.86, 452.71, 477.56, 502.43, 527.34, 552.32, 577.40, 602.62,
3 628.02, 653.64, 679.51, 705.66, 732.13, 758.92, 786.06, 813.55,
4 841.40, 869.61, 898.17, 927.08, 956.33, 985.91, 1015.80, 1045.99,
5 1107.22, 1169.49, 1232.71, 1296.78, 1361.60, 1427.10, 1493.20, 1559.84,
6 1626.93, 1694.44, 1762.30, 1830.48, 1898.91, 1967.57, 2036.43, 2382.74,
7 2730.94, 3429.46, 4129.51, 4831.66, 5966.23, 10697.2, 14679.2,
8 23230.9, 32345.0, 41895.0)

```

DATA(HP=
1 49.68, 59.61, 69.55, 79.49, 89.42, 99.36, 124.20, 149.04,
2 173.98, 198.73, 223.61, 248.58, 273.71, 299.11, 324.90, 351.22,
3 378.22, 406.01, 434.71, 464.38, 495.09, 526.84, 559.62, 593.41,
4 628.14, 663.75, 700.14, 737.23, 774.92, 813.10, 851.69, 890.60,
5 969.04, 1047.84, 1126.58, 1204.93, 1282.69, 1359.74, 1436.03, 1511.56,
6 1586.36, 1660.49, 1733.99, 1806.95, 1879.42, 1951.47, 2023.15, 2094.83,
7 2229.17, 3429.24, 4129.48, 4831.65, 6966.23, 10697.2, 14679.2,
8 23230.9, 32345., 41895.)

```

```

DATA(HU=
1 388.63, 398.27, 408.20, 418.14, 428.07, 438.01, 462.85, 487.69,
2 512.53, 537.37, 562.21, 587.05, 611.89, 636.73, 661.57, 686.42,
3 711.29, 736.18, 761.11, 786.09, 811.14, 836.28, 861.54, 886.93,
4 912.49, 938.23, 964.18, 990.37, 1016.80, 1043.51, 1070.50, 1097.78,
5 1153.27, 1210.04, 1268.09, 1327.39, 1387.91, 1449.56, 1512.26, 1575.93,
6 1640.46, 1705.76, 1771.74, 1838.32, 1905.41, 1972.94, 2040.86, 2384.38,
7 2731.52, 3429.53, 4129.52, 4831.66, 6966.23, 10697.2, 14679.2,
8 23230.9, 32345., 41895.)

```

```

DATA(HE=
1 49.68, 59.62, 69.57, 79.56, 89.66, 99.96, 127.50, 159.12,
2 195.77, 236.90, 280.97, 326.24, 371.33, 415.35, 457.96, 498.74,
3 538.05, 575.93, 612.56, 648.13, 682.82, 716.78, 750.14, 783.03,
4 815.54, 847.76, 879.77, 911.63, 943.40, 975.11, 1006.80, 1038.52,
5 1102.11, 1166.03, 1230.39, 1295.23, 1360.58, 1426.43, 1492.76, 1559.55,
6 1626.75, 1694.32, 1762.23, 1830.43, 1898.88, 1967.55, 2036.42, 2382.74,
7 2730.94, 3429.46, 4129.51, 4831.66, 6966.23, 10697.2, 14679.2,
8 23230.9, 32345., 41895.)

```

```

GO TO(1,2,3,4,5),N
1 CPOH=ATKINT(TI,HP,T,58,6,NES,.01)*4.184
RETURN
2 CPOH=ATKINT(TI,HN,T,58,6,NES,.01)*4.184
RETURN
3 CPOH=ATKINT(TI,HO,T,58,6,NES,.01)*4.184
RETURN
4 CPOH=ATKINT(TI,HE,T,58,6,NES,.01)*4.184
RETURN
5 PERCE =PERCEN /100.
CPOH=(ATKINT(TI,HO,T,58,6,NES,.01)*(1.-PERCE )+
1ATKINT(TI,HP,T,58,6,NES,.01)*PERCE )*4.184
RETURN
END

```

```

FUNCTION CPOS(TI,N)
DIMENSION T(60),SP(60),SN(60),SD(60),SE(60)
COMMON/PARA/PERCEN

```

```

C CALCULATES THE ENTROPY OF THE IDEAL GAS FOR H2 BY INTERPOLATING
C TAKEN FROM RP 1932, UNITS OF THE TABLES ARE CAL/MOL DEG K. 1
C UNITS OF OUTPUT ARE JOULES/MOL DEG K. THE INDEX N DETERMINES THE
C SPECIES, FOR N=1, PARAHYDROGEN, N=2 NORMAL, N=3 ORTHO, N=4 EQUILIB
C N=5, SOME ORTHO-PARA MIXTURE SPECIFIED BY COMMON /PARA/, PERCENT
C RANGE OF TEMP IS FROM 10 TO 5000K.

```

```

DATA(T=
1 10.0, 12.0, 14.0, 16.0, 18.0, 20.0, 25.0, 30.0, 35.0, 40.0, 45.0,
2 50.0, 55.0, 60.0, 65.0, 70.0, 75.0, 80.0, 85.0, 90.0, 95.0, 100.0,
3 105.0, 110.0, 115.0, 120.0, 125.0, 130.0, 135.0, 140.0, 145.0, 150.0, 160.0,
4 170.0, 180.0, 190.0, 200.0, 210.0, 220.0, 230.0, 240.0, 250.0, 260.0, 270.0,
5 280.0, 290.0, 300.0, 350.0, 400.0, 450.0, 500.0, 550.0, 600.0, 700., 1000.,
6 1500., 2000., 3000., 4000., 5000.)

```

```

DATA(SP=
011.214, 12.120, 12.886, 13.54., 14.135, 14.658, 15.766, 16.672, 17.438,
118.102, 18.688, 19.214, 19.693, 20.135, 20.548, 20.938, 21.310, 21.669,
022.017, 22.356, 22.688, 23.014, 23.334, 23.648, 23.957, 24.260, 24.557,
424.848, 25.132, 25.410, 25.681, 25.945, 26.451, 26.929, 27.379, 27.802,
528.201, 28.577, 28.932, 29.268, 29.586, 29.889, 30.177, 30.452, 30.716,

```

630.969,31.212,32.305,33.244,34.069,34.806,35.473,36.082,37.165,
739.701,42.720,45.007,51.221,53.839,55.969)

DATA(SO=

115.581,16.486,17.252,17.916,18.501,19.024,20.133,21.038,21.804,
222.468,23.053,23.576,24.050,24.482,24.880,25.248,25.591,25.912,
326.215,26.500,26.771,27.029,27.275,27.512,27.739,27.958,28.170,
428.375,28.575,28.769,28.958,29.143,29.502,29.846,30.177,30.498,
530.808,31.109,31.401,31.684,31.958,32.225,32.484,32.735,32.979,
633.216,33.446,34.505,35.432,36.253,36.989,37.656,38.265,39.348,
741.884,44.903,47.190,51.221,53.839,55.969)

DATA(SN=

115.607,16.512,17.278,17.941,18.527,19.050,20.159,21.064,21.830,
222.494,23.079,23.603,24.078,24.513,24.914,25.288,25.638,25.969,
326.283,26.582,26.868,27.143,27.407,27.663,27.911,28.151,28.384,
428.611,28.832,29.047,29.256,29.461,29.856,30.234,30.595,30.942,
531.274,31.594,31.901,32.197,32.483,32.758,33.025,33.282,33.531,
733.772,34.005,35.073,36.003,36.825,37.561,38.228,38.836,39.920,
742.455,45.475,47.762,51.221,53.839,55.969)

DATA(SE=

111.215,12.120,12.887,13.554,14.149,14.692,15.918,17.069,18.196,
219.294,20.331,21.285,22.145,22.911,23.592,24.198,24.740,25.229,
325.674,26.080,26.455,26.804,27.129,27.435,27.724,27.999,28.260,
428.510,28.750,28.980,29.203,29.418,29.828,30.216,30.584,30.934,
531.269,31.591,31.899,32.196,32.482,32.758,33.024,33.282,33.531,
633.772,34.005,35.073,36.003,36.825,37.561,38.228,38.836,39.920,
742.455,45.475,47.762,51.221,53.839,55.969)

GO TO(1,2,3,4,5),N

1 CPOS=ATKINT(TI,SP,T,60,6,NES,.01)*4.184

RETURN

2 CPOS=ATKINT(TI,SN,T,60,6,NES,.01)*4.184

RETURN

3 CPOS=ATKINT(TI,SO,T,60,6,NES,.01)*4.184

RETURN

4 CPOS=ATKINT(TI,SE,T,60,6,NES,.01)*4.184

RETURN

5 PERCE =PERCEN /100.

CPOS=(ATKINT(TI,SO,T,60,6,NES,.01)*(1.-PERCE)+

1ATKINT(TI,SP,T,60,6,NES,.01)*PERCE)*4.184

C THE EXPRESSION FOR THE ENTROPY OF EQUILIBRIUM H2 IS INCORRECT,

C THE ENTROPY OF MIXING MUST BE ADDED TO MAKE IT COMPLETE

REURN

END

FUNCTION ATKINT(X,YMAT,XMAT,NELMTS,NMAX,NESSY,ACRCY)

C THIS PROGRAM HAS BEEN CHANGED SO THAT THE OSCILLATING NATURE OF
C THE MATRIX TO BE INTERPOLATED EXISTS ONLY AT THE UPPER END OF THE
C TABLE

C THIS ROUTINE WILL TAKE INPUT MATRICES OF UP TO 999 ELEMENTS EACH,

C ARRANGED SO THAT THE X MATRIX(XMAT) IS IN EITHER ASCENDING OR

C DESCENDING ORDER,SELECT NMAX OF THESE POINTS,CHOSEN SO THAT

C SUCESSIVE X VALUES OSCILATE ABOUT THE VALUE OF THE ARGUMENT X

C UNLESS THE ENDS OF THE XMATRIX INTERFERE (IN THIS CASE THE

C OSCILATORY NATURE IS LOST BUT THE PROGRAM WILL STILL PERFORM AN

C INTERPOLATION), INTERPOLATE ON THESE NMAX PAIRS OF DATA BY

C AN OSCILATING VARIABLE POINT AITKEN INTERPOLATION ALGORITHM

C EITHER UNTIL THE PERCENTAGE CHANGE IN THE INTERPOLANT IS LESS

C THAN THE ACRCY ARGUMENT(THE ARGUMENT NESSY INDICATES THE

C NUMBER OF THE POINT JUST BEFORE THE LAST ONE CHECKED) OR UNTIL

C THE NMAX POINTS ARE ALL USED. IT IS SUGGESTED THAT NMAX

C BE LESS THAN 10, AND OF COURSE LESS THAN NELMTS. NELMTS

C INDICATES THE NUMBER OF ELEMENTS IN XMAT OR YMAT.

C IF NESSY IS ZERO IT INDICATES THAT THE INTERPOLATION REQUIREMENT

C HAS NOT BEEN SATISFIED. IF NESSY IS 1 IT MEANS THAT THE VALUE OF

C X LIES OUTSIDE THE RANGE OF XMAT.

```

        DIMENSION YMAT(999), XMAT(999),A(21,20)
100 FORMAT(42HINTERPOLATION REQUIREMENT NOT SATISFIED(X=,E16.8,1H)/33H
        1LAST 2 APPROXIMATIONS OF Y ARE(Y=,E16.8,1H,,E16.8,1H))
200 FORMAT(55HTHIS REPRESENTS AN EXTRAPOLATION OF THE XMAT MATRIX(X=,
        1E16.8,1H)/33HNO CALCULATION HAS BEEN PERFORMED)
300 FORMAT(24HNELMTS IS LESS THAN NMAX)
400 FORMAT(22HNMAX IS LARGER THAN 20)
        IF(NMAX-20)71,71,69
        69 PRINT 400
           ATKINT=0.0
           RETURN
        71 IF(NMAX-NELMTS)75,75,73
        73 PRINT 300
           ATKINT=0.0
           RETURN
        75 CONTINUE
C       FIRST TWO SUCCESSIVE VALUES OF THE XMATRIX THAT STRADDLE THE
C       VALUE X WILL BE SOUGHT
        JJ1=NELMTS-1
        DO 20 I=1, JJ1
           DIF1=X-XMAT(I)
           DIF2=XMAT(I+1)-X
           IF(DIF1)16,15,16
        15 ATKINT=YMAT(I)
           NESSY =NMAX
           RETURN
        16 IF(DIF2)18,17,18
        17 ATKINT=YMAT(I+1)
           NESSY =NMAX
           RETURN
        18 RATIO=DIF1/ DIF2
           IF(RATIO)20,20,19
        19 IMID=I
           GO TO 32
        20 CONTINUE
C       AT THIS POINT ONE COULD PRINT THE FOLLOWING STATEMENT
C       WRITE OUTPUT TAPE 6,200,X
           NESSY=1
           ATKINT=0.0
           RETURN
        32 CONTINUE
C       NOTE THAT RATIO IS POSITIVE IF THE TWO POINTS STRADDLE X
C       REGARDLESS WHICH IS LARGER
        JJJ=IMID
        JUP=IMID
        JDN=IMID
        IF(JJJ+NMAX-NELMTS+1)98,58,102
        98 DO 201 J=1,NMAX
           JJJ=IMID+J-1
           A(1,J)=XMAT(JJJ)
        201 A(2,J)=YMAT(JJJ)
           GO TO 203
        102 DO 41 J=1,NMAX
           JJ=J/2
           JOE=J-2*.JJ
C       JOE IS 0 IF J IS EVEN AND 1 IF J IS ODD
           IF(J-1)33,40,33
        33 IF(JDN-1)34,36,34
        34 IF(JUP-NELMTS)35,37,35
        35 IF(JOE)37,36,37
        36 JUP=JUP+1
           JJJ=.JUP
           GO TO 40

```

```

37 JDN=JIN-1
   JJJ=JIN
   GO TO 40
40 A(1,J)=XMAT(JJJ)
   A(2,J)=YMAT(JJJ)
41 CONTINUE
203 NNN=NMAX+1
   DO 6 J=3,NNN
     L=J-1
     DO 5 K=L,NMAX
C      J IS THE COL 'MN NUMBER
C      K IS THE ROW NUMBER
       OA(J,K)=(A(J-1,K)-A(J-1,J-2))*(X-A(1,J-2))/(A(1,K)-A(1,J-2))
       1 +A(J-1,J-2)
       IF (K-L)3,2,3
       2 IF (ABS((A(J,L)-A(J-1,L-1))/A(J,L))-ACRCY/100.0)7,7,3
       3 CONTINUE
       5 CONTINUE
       6 CONTINUE
       NESSY=0
C      AT THIS POINT ONE COULD PRINT OUT THE FOLLOWING STATEMENT.
C      WRITE OUTPUT TAPE 6,100,X,A(NNN,NMAX),A(NNN-1,NMAX-1)
       ATKINT=A(NNN,NMAX)
       RETURN
7     NESSY=J-1
       ATKINT=A(J,L)
       RETURN
       END
SUBROUTINE LIMITS(P,T,IL)
  DIMENSION G(32),VP(9)
  COMMON/DATA/G,R,GAMMA,VP,DTP,FCC,PTP,ICC,ITP,TUL,TLL,PUP
  IF (P.GT.PUP)GO TO 10
  IF (T.GT.TUL.OR.T.LT.TLL)GO TO 12
  IL=1
  RETURN
10 PRINT 11,PUP
11 FORMAT(* THE INPUT PRESSURE IS OUT OF THE RANGE OF THIS EQUATION *
  1/* THE RANGE FOR THIS EQUATIONS IS FROM 0 TO *,F6.0,* BAR*)
  IL=0
  RETURN
12 PRINT 13,ILL,TUL
13 FORMAT(* THE INPUT TEMPERATURE IS OUT OF RANGE*
  1/* THE RANGE FOR THIS EQUATION IS FROM *,F6.2,* TO *,F6.0,* K*)
  IL=0
  RETURN
  LNU
SUBROUTINE DATA NE
  PRINT 105
105 FORMAT(* THE TEMPERATURE RANGE OF NEON IS 25 TO 300 KELVIN*
  1/* WITH PRESSURES TO 200 BAR*
  2/* YOU MAY ENTER THIS ROUTINE WITH ANY TWO OF THE VARIABLES*
  1/* P,D OR T, AND 0 FOR THE THIRD , FOR SATURATION ENTER WITH*
  4/* EITHER P OR T, AND 0 FOR THE OTHER TWO ,IF YOU WANT *
  5/* TO CHANGE FLUIDS ENTER 0 FOR ALL THREE INPUT VARIABLES*)
  TD=44.4
  PD=26.54
  TD=25.
  TUL=200.
  TLL=300.
  TLL=25.
  TD=20.193
  PRINT 104

```



```

100 FORMAT(* DO YOU WANT ENGINEERING UNITS OR METRIC UNITS ?*
1/* ENTER A 0 FOR ENGINEERING UNITS OR A 1 FOR METRIC*)
CALL DATA N
READ 102, IU
102 FORMAT(11)
1/* IF (IU, 10, 0) GO TO 18
PRINT 103
103 FORMAT(* ENTER PRESSURE IN BAR, DENSITY IN MOLES/LITER, AND TEMPER-
ATURE IN KELVINS*)
24 READ *, P, D, T
P=P/1.01325
GO TO 19
18 PRINT 106
106 FORMAT(* ENTER PRESSURE IN LB/SQ IN, DENSITY IN LB/CU FT AND*
1/* TEMPERATURE IN DEGREES F*)
READ *, P, D, T
P=P/14.695949
D=D*16.01846371/EM
T=(T, 10, 0) GO TO 19
T=(T-32.)/1.8+273.15
19 CONTINUE
IF (P, LE, 0, 0) GO TO 14
IF (D, LE, 0, 0) GO TO 13
IF (T, LE, 0, 0) GO TO 12
GO TO 21
12 IF (P, LE, 0, 0, OR, D, LE, 0, 0) GO TO 15
T=FNDTNE(P, D)
IF (P, GT, PUL, OR, T, GT, TUL, OR, T, LT, TLL) GO TO 25
GO TO 16
13 IF (T, LE, 0, 0, OR, P, LE, 0, 0) GO TO 15
IF (P, GT, PUL, OR, T, GT, TUL, OR, T, LT, TLL) GO TO 25
131 D=FNDUNE(P, T)
GO TO 16
14 IF (P, LE, 0, 0, OR, T, LE, 0, 0) GO TO 15
P=FNDPNE(D, T)
IF (P, GT, PUL, OR, T, GT, TUL, OR, T, LT, TLL) GO TO 25
16 H=ENTHNE(P, D, T)
S=ENTRNE(D, T)
PP=P*1.01325
IF (IU, EQ, 0) GO TO 23
PRINT 100, PP, D, T, H, S
100 FORMAT(* PRESSURE=*, F7.2, * BAR, DENSITY=*, F7.4, * MOLES/LITER, TEM-
1*PERATURE=*, F6.2, * KELVIN*
2/* ENTHALPY=*, F9.2, * JOULES/MOL, ENTROPY=*, F6.2, * JOULES/MOL-K*)
GO TO 17
23 PO=P*14.695949
IU=T*1.8-459.67
DU=D*EM/16.01846371
HU=H/(2.324445*EM)
SU=S/(4.184001*EM)
PRINT 101, PO, DU, IU, HU, SU
101 FORMAT(* PRESSURE=*, F10.3, * LB/SQ IN, DENSITY=*, F10.4, * LB/CU FT*
1/* TEMPERATURE=*, F8.2, * F, ENTHALPY=*, F9.2, * BTU/LB*
2/* ENTROPY=*, F6.2, * BTU/LB-F*)
GO TO 18
15 IF (P, LE, 0, 0, AND, T, LE, 0, 0) GO TO 21
IF (P, GT, 0, 0) GO TO 20
IF (T, GT, TC, OR, T, LT, TTF) GO TO 22
P=VPNE(T)
109 FORMAT(* DO YOU WANT SATURATED LIQUID OR VAPOR*
1/* ENTER A 1 FOR VAPOR OR A 0 FOR LIQUID*)
PRINT 109

```

```

READ *,IP
IF(IP,GT,0)P=P-.0001
IF(IP,EQ,0)P=P+.00001
GO TO 131
20 IF(P,GT,PC)GO TO 22
T=VPTENE(P)
PRINT 109
READ *,IP
IF(IP,GT,0)P=P-.0001
IF(IP,EQ,0)P=P+.00001
GO TO 131
22 PRINT 107
107 FORMAT(* YOUR INPUT PRESSURE OR TEMPERATURE IS OUT OF RANGE*
1/* OF THE SATURATION CURVE, TC=44.4, PC=26.89, T TRIPLE=25.*
2/* TRY AGAIN*)
GO TO 17
21 RETURN
25 PRINT 108
108 FORMAT(* YOUR INPUT TEMPERATURE OR PRESSURE IS OUT OF RANGE*
1/* TEMP MUST BE BETWEEN 25 AND 300K AND PRESSURE BETWEEN*
2/* 0 AND 200BAR, TRY AGAIN*)
GO TO 17
END
SUBROUTINE DATA HE
PRINT 105
105 FORMAT(* THE TEMPERATURE RANGE OF HELIUM IS 2.177 TO 1500 KELVIN*
1/* WITH PRESSURES TO 1000 BAR*
2/* YOU MAY ENTER THIS ROUTINE WITH ANY TWO OF THE VARIABLES*
3/* P,D OR T, AND 0 FOR THE THIRD, FOR SATURATION ENTER WITH*
4/* EITHER P OR T, AND A 0 FOR THE OTHER TWO , IF YOU WANT *
5/* TO CHANGE FLUIDS ENTER A 0 FOR ALL THREE INPUT VARIABLES*)
TC=5.201
PC=2.245
TTP=2.17
PUL=1000.
TUL=1500.
TLL=2.177
EM=4.0026
PRINT 104
104 FORMAT(* DO YOU WANT ENGINEERING UNITS OR METRIC UNITS ?*
1/* ENTER A 0 FOR ENGINEERING UNITS OR A 1 FOR METRIC*)
READ 102,IU'
102 FORMAT(I1)
17 IF(IU,EQ,0)GO TO 18
PRINT 103
103 FORMAT(* ENTER PRESSURE IN BAR, DENSITY IN MOLES/LITER, AND TEMPER
1ATURE IN KELVINS*)
24 READ *,P,D,T
P=P/1.01325
GO TO 19
18 PRINT 106
106 FORMAT(* ENTER PRESSURE IN LB/SQ IN, DENSITY IN LB/CU FT AND*
1/* TEMPERATURE IN DEGREES F*)
READ *,P,D,T
P=P/14.695949
D=D*16.01846371/EM
IF(T,EQ,0.0)GO TO 19
T=(T-32.)/1.8+273.15
19 CONTINUE
IF(P,LE,0.0)GO TO 14
IF(D,LE,0.0)GO TO 13
IF(T,LE,0.0)GO TO 12

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GO TO 21
12 IF(P,LE,0,0,OR,D,LE,0,0)GO TO 15
T=FNDTHE(P,D)
IF(P,GT,PUL,OR,T,GT,TUL,OR,T,LT,TLL)GO TO 25
GO TO 16
13 IF(T,LE,0,0,OR,P,LE,0,0)GO TO 15
IF(P,GT,PUL,OR,T,GT,TUL,OR,T,LT,TLL)GO TO 25
131 D=FNDDE(P,T)
GO TO 16
14 IF(D,LE,0,0,OR,T,LE,0,0)GO TO 15
P=FNDPHE(D,T)
IF(P,GT,PUL,OR,T,GT,TUL,OR,T,LT,TLL)GO TO 25
16 H=ENTHHE(D,T)
S=ENTRHE(D,T)
W=SOUNHE(D,T)
CPP=CPHE(D,T)
CVV=CVHE(D,T)
TH=THERHE(D,T)*100.
V=VISCHE(D,T)
PP=P*1.01325
IF(IU,EQ,0)GO TO 23
PRINT 100,PP,D,T,H,S,CPP,CVV,W,TH,V
100 FORMAT(* PRESSURE=*,F8.2,* BAR, DENSITY=*,F7.4,* MOLES/LITER, TE*
1*MPERATURE=*,F7.2,* KELVIN*
2/* ENTHALPY=*,F9.2,* JOULES/MOL, ENTROPY=*,F6.2,* JOULES/MOL-K*
3/* CP=*,F7.2,* JOULES/MOL-K, CV=*,F7.2,* JOULES/MOL-K*
4/* SPEED OF SOUND=*,F8.2,* METERS/SEC*
5/* THERMAL CONDUCTIVITY=*,F7.2,* M WATS/M-K*
6/* VISCOSITY=*,F7.2,* MICRO G/CM-S*)
GO TO 17
23 PO=P*14.695949
TO=T*1.8-459.67
DO=D*EM/16.01846371
HO=H/(2.3244.*EM)
SO=S/(4.184001*EM)
CPPD=CPP/(4.184001*EM)
CVVD=CVV/(4.184001*EM)
WO=W*3.260840
THO=TH*.000578176
VO=V*.0067176897
PRINT 101,PO,DO,TO,HO,SO,CPPD,CVVD,WO,THO,VO
101 FORMAT(* PRESSURE=*,F10.3,* LB/SQ IN, DENSITY=*,F10.4,* LB/CU FT*
1/* TEMPERATURE=*,F8.2,* F, ENTHALPY=*,F9.2,* BTU/LB*
2/* ENTROPY=*,F6.2,* BTU/LB-F*
3/* CP=*,F7.3,* AND CV=*,F7.3,* BTU/LB-F*
4/* SPEED OF SOUND=*,F8.1,* FT/SEC*
5/* THERMAL CONDUCTIVITY=*,F7.2,* BTU/FT-HR-F*
6/* VISCOSITY=*,F7.2,* LB/FT-S X E+7*)
GO TO 18
15 IF(P,LE,0,0,AND,T,LE,0,0)GO TO 21
IF(P,GT,0,0)GO TO 20
IF(T,GT,TC,OR,T,LT,1TP)GO TO 22
P=VPNHE(T)
PRINT 109
READ *,IP
IF(IP,GT,0)P=P-.0001
IF(IP,GE,1)P=P+.00001
109 FORMAT(* DO YOU WANT SATURATED LIQUID OR VAPOR*
1/* ENTER A 1 FOR VAPOR OR A 0 FOR LIQUID*)
GO TO 131
20 IF(P,GT,PC)GO TO 22
F=VFTEHE(P)

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PRINT 109
READ *,IP
IF (IP.GT.0)P=P-.0001
IF (IP.GE.1)P=P+.00001
GO TO 131
22 PRINT 107
107 FORMAT(* YOUR INPUT PRESSURE OR TEMPERATURE IS OUT OF RANGE*
1/* OF THE SATURATION CURVE, TC=5.201, PC=2.275, T TRIPLE=2.177*
2/* TRY AGAIN*)
GO TO 17
21 RETURN
25 PRINT 108
108 FORMAT(* YOUR INPUT TEMPERATURE OR PRESSURE IS OUT OF RANGE*
1/* TEMP MUST BE BETWEEN 2.177 AND 1500K AND PRESSURE BETWEEN*
2/* 0 AND 1000BAR, TRY AGAIN*)
GO TO 17
END
SUBROUTINE INFO
PRINT 2
2 FORMAT(* WHEN THE PROGRAM ASKS FOR A FLUID SELECTION, ENTER THE AP
1PROPRIATE NUMBER*
2/* AN INAPPROPRIATE NUMBER WILL TERMINATE THE PROGRAM*)
PRINT 1
1 FORMAT(* WHEN THE PROGRAM ASKS FOR A PRESSURE, DENSITY, AND**/ T
1TEMPERATURE, ENTER ANY 2 OF THE THREE AND A 0 FOR THE THIRD.**/ TH
2E ORDER MUST BE P, D,T, AND ONE OF THE THREE MUST BE 0. *
3/* IF ALL THREE ARE 0 THE PROGRAM ASKS FOR A NEW FLUID*)
PRINT 110
110 FORMAT(* IF YOU ARE INTERESTED IN A DEFINITION OF THE VARIOUS*
1/* MODIFICATIONS OF HYDROGEN ENTER A 1, IF NOT ENTER A 0*)
READ *,IC
IF (IC.NE.1)GO TO 111
CALL H2 INFO
111 PRINT 112
112 FORMAT(* IF YOU ARE INTERESTED IN THE SOURCES OF THESE PROGRAMS*
1/* ENTER A 1 IF NOT ENTER A 0*)
READ *,IS
IF (IS.EQ.1)CALL SOURCE
RETURN
END
SUBROUTINE H2 INFO
PRINT 100
100 FORMAT(* THE HYDROGEN MOLECULE IS MADE UP OF TWO HYDROGEN ATOMS*
1/* THERE ARE TWO POSSIBLE RELATIVE ORIENTATIONS OF THE NUCLEAR*
2/* SPIN OF THE ATOMS IN A MOLECULE OF HYDROGEN. I.E. THE SPINS*
3/* MAY BE IN THE SAME DIRECTION (ORTHO) OR IN OPPOSITE DIRECTIONS*
4/* (PARA). THE RELATIVE AMOUNTS OF ORTHO AND PARA HYDROGEN IN*
5/* A SAMPLE OF EQUILIBRIUM HYDROGEN IS TEMPERATURE DEPENDANT*)
PRINT 101
101 FORMAT(* AT ROOM TEMPERATURE EQUILIBRIUM HYDROGEN IS 75 PERCENT*
1/* ORTHO AND 25 PERCENT PARA AND IS CALLED NORMAL HYDROGEN*
2/* AT 20 KELVIN EQUILIBRIUM HYDROGEN IS 99.8 PERCENT PARA.*)
RETURN
END
SUBROUTINE SOURCE
PRINT 100
100 FORMAT(* THIS PROGRAM WAS WRITTEN BY R.D. MCCARTY AT THE NATIONAL*
1/* BUREAU OF STANDARDS IN BOULDER COLORADO UNDER A CONTRACT WITH*
2/* THE JOHNSON SPACE CENTER IN HOUSTON TEXAS. THE NASA CONTRACT*
3/* MONITOR AT JSC IS WALTER SCOTT. THE DOCUMENTATION OF THE*
4/* PROGRAM IS IN PREPARATION AND IS PLANNED AS A JOINT*
5/* NASA-NBS PUBLICATION*)

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RETURN
END
FUNCTION FNDIHE(P1,T1)
C SOLVES THE HELIUM EQUATION OF STATE FOR DENSITY IN MOL/LITER
C GIVEN A PRESSURE IN ATMOSPHERES AND A TEMPERATURE IN DEGREES K
1=11
P=P1
IF(T,LT,5.2)GO TO 6
PM=1001.
IF(T,LT,15.)PM=PMELT(T)
IF(PM,LT,P)GO TO 30
IF(T,GT,100.)GO TO 1
PC=2.2449+(T-5.2014)*1.76
IF(P,LT,PC)GO TO 1
FM=200.+(T-5.2)*12.31
D=17.399+((PM-PC)/(PM-PC+1.))*2.33*17.399
GO TO 7
2 D=.0001
IF(T,LT,4.2)GO TO 7
1 VB=VIRB(T)
RT=0.0820558*T
P1=RT/P
D=1./(P1+VB)
GO TO 7
6 IF(P,LT,VPNHE(T))GO TO 2
DS=46.18+(T-2.)*4.02
DL=HSATL(T)*1000./4.0026
DEL=DS-DL
PM=PMELT(T)
IF(P,GT,PM)GO TO 30
D=DL+DEL*P/PM
7 DO 10 I=1,50
P2=FNDPHE(D,T)
IF(ABS(P-P2)-1.E-7*P)20,20,8
8 DP=DPDIHE(D,T)
CORR=(P2-P)/DP
IF(ABS(CORR)-1.E-7*D)20,20,10
10 D=D-CORR
FNDIHE=0
RETURN
20 FNDIHE=D
RETURN
30 FNDIHE=0
RETURN
END

```

```

FUNCTION FNDPHE(DD,TT)
C THE MAIN EQUATION OF STATE ROUTINE FOR HELIUM:
C THE INPUT IS DENSITY IN MOLES/LITER AND TEMPERATURE
C IN DEGREES K, THE OUTPUT IS PRESSURE, DP/DD, DP/DT, ENTHALPY,
C ENTROPY AND CV IN ATMOSPHERES AND JOULES

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DIMENSION A(26),B(27,4)

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COMMON/IDEX/ID

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DATA(ID)=0)

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DATA((B(I),I=82,108)=

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1 5.988310109E-9,-4.9653052187E-7,-3.8116033499E-6,3.68116713
13E-5,-1.4830691828E-4,3.0596174335E-4,-3.3908190224E-4,1.962408024
22E-4,1.5527899/12E-5,-3.6110403503E-5,-1.0839/88073E-5,4.972810121
37E-5,1.938145109E-5,-4.149640896E-4,-5.7465772899E-4,-4.3470945634
4E-3,-6.838388924E-2,-2.1382474225E-2,2.7106954908E-2,-1.262796778
58E-2,2.5875/5338E-3,7.9041608815E-2,-1.4024724318E-4,-2.8278987249
6E-7,1.7336410358E-6,-2.5454187855E-6,0.0005)

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```

DATA((B(I),I=55,81)=-1.4802195348E-8,4.1721791119E-7,-2.3326553271

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```

1E-7,4.085511088E-7,1.0900567964E-5,-5.0060952775E-5,1.1312765043
2E-4,-1.2539843287E-4,1.9661380688E-6,1.7122932666E-4,2.3051000543
3E-4,-9.65647391E-4,-3.6027 735292E-5,1.6079946555E-3,-2.7441763615
4E-2,.14739506957,-.43559344838,1.3447956079,-1.7040375125,.9026267
54040,5.6875644111E-3,-1.4438146625E-1,3.3768874851E-3,1.0754201218
6E-6,-4.5264622308E-5,3.8597388864E-5,-.0005)
  DATA(B(I),I=28,54)=-4.2287454626E-8,4.4529354413E-7,-1.0246150954
1E-5,8.5254608956E-5,-2.5163069255E-4,3.2877709285E-4,-1.060195758
2E-4,-1.0687738074E-4,-3.2120950632E-5,1.415901897E-4,1.4725630701
4E-3,-2.618354941E-3,2.0461501117E-5,1.2746996288E-3,-2.0272929583
5E-2,7.4648036615E-2,-.17217966521,.51053439738,-.40178202497,
6.26829864632,7.906601204E-3,-8.9393485656E-2,-.15076580053,
72.6882494327E-6,-3.3794316835E-5,-2.4495951195E-5,-.0005)
  DATA(B(I),I=1,27)=
A      -1.5096862619E-7,6.4640898904E-7,4.1362357367E-5,
1-3.7910190353E-4,1.3806454049E-3,-2.5085412058E-3,2.3697560398E-3
2,-9.5726461066E-4,3.7405931828E-5,-6.4103220333E-4,
31.8579366177E-3,7.4007986606E-4,1.4792568148E-4,-3.2531355477E-3,
41.9518739286E-2,-.10571617135,.33164944449,-.51130022535,
53.9940004906E-1,-.15555244471,4.906264031E-3,-2.6148004377E-2,
63.4221685545E-2,5.4159662622E-6,-1.0687806777E-5,-8.9484651869E-6,
7-.0025)
  KP=1
  GO TO 10
  ENTRY DPDTHE
  KP=2
  GO TO 10
  ENTRY DPDD HE
  KP=3
  GO TO 10
  ENTRY ENTRHE
  KP=4
  GO TO 10
  ENTRY ENTHHE
  KP=5
  GO TO 10
  ENTRY CVHE
  KP=6
10 K1=0
  KH=1
  K=1
  KK=1
  K4=1
  IF(ID.NE.0)GO TO 20
  IF(TT.GE.15.)GO TO 20
  IF(TT.GT.10)GO TO 30
  IF(DD.GT.17.3987)GO TO 40
11 I=1
  T=TT
  D=DE
8 GO TO (9,100,200,300,400,500)KP
9 D2=D*I
  D3=D2*D
  D4=D3*D
  D5=D4*D
  GAMMA=B(27,1)
  EX=EXP(D2*GAMMA)
  EXD3=EX*D3
  EXD5=EX*D5
  M=1
  N=1
  A(N)=D5*I $ N=N+1

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```

A(N)=A(N-1)/T $ N=N+1
DO 2 I=1,6
FI=I
A(N)=D5*T**(.75-FI/4.)
2 N=N+1
DO 3 I=1,4
FI=I
A(N)=D4*I**(1.5-FI)
3 N=N+1
DO 1 I=1,8
FI=I
A(N)=D3*I**(1.5-FI/2.)
N=N+1
1 CONTINUE
DO 4 I=1,3
FI=I
A(N)=EXD3*I**(1.-FI)
4 N=N+1
DO 5 I=1,3
FI=I
A(N)=EXD5*I**(1.-FI)
5 N=N+1
N=N-1
I=M
7 P=0
DO 15 J=1,N
15 P=P+B(J,I)*A(J)
P=P+.0820558*D*T*(1.+VIRB(T)*D)
IF(KH.LT.1)GO TO 413
GO TO(50,50,30,40)K
100 D2=D*D
D3=D**3
D4=D3*D
D5=D4*D
D6=D5*D
T2=T*T
T3=T2*T
T4=T**4
M=I
GAMMA=B(27,M)
EX=EXP(D2*GAMMA)
N=1
R=.0820558
A(N)=0.0 $ N=N+1
A(N)=(-1.)*D6/T2 $ N=N+1
DO 102 I=1,6
FI=I
A(N)=D5*T**(.75-FI/4,-1.)*(0.75-FI/4.)
102 N=N+1
DO 103 I=1,4
FI=I
A(N)=D4*T**(.15-FI/1,-1.)*(1.5-FI)
103 N=N+1
DO 101 I=1,8
FI=I
A(N)=D3*T**(.15-FI/2,-1.)*(1.5-FI/2.)
101 N=N+1
DO 104 I=1,3
FI=I
A(N)=EX*D3*I**(1.-FI-1.)*(1.-FI)
104 N=N+1
DO 105 I=1,3

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```

      F1=1
      A(N)=EX*D1**I**C1, -F1-1, )*(C1, -F1)
105 N=N+1
      N=N-1
      P=0
      DO 115 J=1,N
115 P=P+A(J)*B(J,M)
      P=P+R*(D1, 1+VIRB(T)*D) *R*(I**D1(C1)*D)
      I=M
      GO TO(50,50,30,40)K
200 D2=D*D
      D3=D2*D
      D4=D3*D
      D5=D4*D
      M=1
      GAMMA=B(2,M)
      EX=EXP(D2*(GAMMA))
      DEX=GAMMA**2.*I**EX
      N=1
      R=.0820558
      A(N)=6.*D5 $ N=N+1
      A(N)=A(N-1)/1 $ N=N+1
      DO 202 I=1,6
      F1=I
      A(N)=5.*D4*T**(.75-F1/4.)
202 N=N+1
      DO 203 I=1,4
      F1=I
      A(N)=D3*4.*T**(.15-F1)
203 N=N+1
      DO 201 I=1,8
      F1=I
      A(N)=D2*3.*T**(.15-F1/2.)
201 N=N+1
      DO 204 I=1,3
      F1=I
      A(N)=(DEX*D3+3.*D2*EX)*T**(.1,-F1)
204 N=N+1
      DO 205 I=1,3
      F1=I
      A(N)=(DEX*D5+5.*D4*EX)*T**(.1,-F1)
205 N=N+1
      N=N-1
      P=0
      DO 215 J=1,N
215 P=P+A(J)*B(J,M)
      I=M
      P=P+R*(1.+2.*D*VIRB(T))
      GO TO(50,50,30,40)K
300 D2=D*D
      D3=D2*D
      D4=D3*D
      N=1
      R=.0820558
      M=1
      GAMMA=B(2,M)
      EX=EXP(D2*(GAMMA))
      A(N)=0.0 $ N=N+1
      A(N)=(D4*D/5.)*T**(-2.)*(-1.) $ N=N+1
      DO 302 I=1,6
      F1=I
      A(N)=(D4/4.)*T**(.75-F1/4., -1.)*(.75-F1/4.)

```



```

302 N=N+1
DO 303 I=1,4
FI=I
A(N)=(D3/3.)* T**(1.5-FI-1.)*(1.5-+1)
303 N=N+1
DO 301 I=1,8
FI=I
A(N)=(D2/2.)*T**(1.5-FI/2,-1.)*(1.5-FI/2.)
301 N=N+1
DO 304 I=1,3
FI=I
A(N)=(EX/(2.*GAMMA))*T**(1.-FI-1.)*(1.-FI)
304 N=N+1
DO 305 I=1,3
FI=I
A(N)=(D2*EX/(2.*GAMMA)-EX/(2.*GAMMA**2))*
1T**(1.-FI-1.)*(1.-FI)
305 N=N+1
N=N-1
SINT=D*R*(VIRB(T)+T*DBDT(T))
DO 306 I=1,N
306 SINT=SINT+B(I,M)*A(I)
N=21
EX=1.
D2=0
DO 310 I=1,3
FI=I
A(N)=(EX/(2.*GAMMA))*T**(1.-FI-1.)*(1.-FI)
310 N=N+1
DO 311 I=1,3
FI=I
A(N)=(D2*EX/(2.*GAMMA)-EX/(2.*GAMMA**2))*
1T**(1.-FI-1.)*(1.-FI)
311 N=N+1
N=N-1
DO 312 I=21,N
312 SINT=SINT-B(I,M)*A(I)
P=(9.371658+5.193043*ALOG(T/4.2144)-25.31469*(SINT+R*ALOG(R*T*D)))
P=P*4.0026
I=M
GO TO(50,50,30,40)K
400 KH=0
GO TO 9
413 PP=P
KH=1
D2=D*D
D3=D*D2
D4=D3*D
N=1
R=.0820558
M=I
GAMMA=B(27,M)
EX=EXP(D2*GAMMA)
A(N)=(D4*D)/5. $ N=N+1
A(N)=(D4*D/5.)*(2./T) $ N=N+1
DO 402 I=1,6
FI=I
A(N)=(D4/4.)*(T**(1.-FI/4.))-T**(1.-FI/4.)*(1.-FI/4.)
402 N=N+1
DO 403 I=1,4
FI=I
A(N)=(D3/3.)*(T**(1.5-FI)-T**(1.5-FI)*(1.5-FI))

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```

403 N=N+1
DO 401 I=1,6
  FI=I
  A(N)=(D2/2.)*(T**(1.5-FI/2.)-T**(1.5-FI/2.)*(1.5-FI/2.))
401 N=N+1
DO 404 I=1,3
  FI=I
  A(N)=(EX/(2.*GAMMA))*(T**(1.-FI)-T**(1.-FI)*(1.-FI))
404 N=N+1
DO 405 I=1,3
  FI=I
  A(N)=(D2*EX/(2.*GAMMA)-EX/(2.*GAMMA**2))*(T**(1.-FI)-T**(1.-FI)
1*(1.-FI))
405 N=N+1
  N=N-1
  HINT=R*T*T*D*DBDT(T) *(-1.)
DO 406 I=1,N
406 HINT=HINT+B(I,M)*A(I)
  N=21
  D2=0
  EX=1.
DO 410 I=1,3
  FI=I
  A(N)=(EX/(2.*GAMMA))*(T**(1.-FI)-T**(1.-FI)*(1.-FI))
410 N=N+1
DO 411 I=1,3
  FI=I
  A(N)=(D2*EX/(2.*GAMMA)-EX/(2.*GAMMA**2))*(T**(1.-FI)-T**(1.-FI)
1*(1.-FI))
411 N=N+1
  N=N-1
DO 412 I=21,N
412 HINT=HINT-B(I,M)*A(I)
  P=21.82282+5.193043*(T-4.2144)+25.31469*(HINT+PP/D-R*T)
  P=P*4.0026
  I=M
GO TO(50,50,30,40)K
500 D2=D*D
  D3=D2*D
  D4=D3*D
  N=1
  R=.0820558
  M=I
  GAMMA=B(27,M)
  EX=EXP(D2*GAMMA)
  SINT='*D*R*(2.*DBDT(T )+D2DBDT2(T)*T)
  A(N)=0.0 * N=N+1
  A(N)=(D4*D/5.)*T**(-2.)*(-1.)*(-2.) * N=N+1
DO 502 I=1,6
  FI=I
  A(N)=(D4/4.)*T**(.75-FI/4.-1.)*(.75-FI/4.)*(.75-FI/4.-1.)
502 N=N+1
DO 503 I=1,4
  FI=I
  A(N)=(D3/3.)* T**(1.5-FI-1.)*(1.5-FI)*(1.5-FI-1.)
503 N=N+1
DO 501 I=1,6
  FI=I
  A(N)=(D2/2.)*T**(1.5-FI/2.-1.)*(1.5-FI/2.)*(1.5-FI/2.-1.)
501 N=N+1
DO 504 I=1,3
  FI=I

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```

      A(N)=(EX/(2.*GAMMA))*T**(1.-FI-1.)*(1.-FI)*(1.-FI-1.)
504 N=N+1
      DO 505 I=1,3
      FI=I
      A(N)=(D2*EX/(2.*GAMMA)-EX/(2.*GAMMA**2))*
      1T**(1.-FI-1.)*(1.-FI)*(1.-FI-1.)
505 N=N+1
      N=N-1
      DO 506 I=1,N
506 SINT=SINT+B(I,M)*A(I)
      P=SINT
      EX=1.
      D2=0
      N=21
      DO 510 I=1,3
      FI=I
      A(N)=(EX/(2.*GAMMA))*T**(1.-FI-1.)*(1.-FI)*(1.-FI-1.)
510 N=N+1
      DO 511 I=1,3
      FI=I
      A(N)=(D2*EX/(2.*GAMMA)-EX/(2.*GAMMA**2))*
      1T**(1.-FI-1.)*(1.-FI)*(1.-FI-1.)
511 N=N+1
      N=N-1
      DO 512 I=21,N
512 P=P-B(I,M)*A(I)
      P=5.193043*(3./5.)*4.0026-P*101.3278
      I=M
      GO TO(50,50,30,40)K
20 K=2
      I=3
      IF(ID.NE.0)I=4
      T=TT
      D=DD
      GO TO 8
30 K=3
      GO TO(33,34,35)KK
33 D=DD
      T=TT
      KK=2
      IF(DD.GT.17.3987)GO TO 40
      I=1
      GO TO 8
34 PTI=P
      I=3
      KK=3
      T=TT
      D=DD
      GO TO 8
35 PTIII=P
38 F=(15.-T)/5.
      P=F*PTI+(1.-F)*PTIII
      IF(KH.LT.1)GO TO 413
      FNDPHE=P
      RETURN
40 IF(K.EQ.3)K1=3
      GO TO(41,42,43,44)K4
41 K=4
      I=2
      K4=2
      D=DD
      IF(K1.EQ.0)T=TT
      GO TO 8

```

```

42 PIID=P
   D=17.3987
   IF(T,LT,5,2014)D=DSATL(T)*1000./4.0026
   K4=3
   GO TO 8
43 PIIDC=P
   I=1
   K4=4
   GO TO 8
44 PIDC=P
   P=PIDC+(PIID-PIIDC)
   K4=1
   IF(K1.EQ.3)GO TO 30
   FNDPHE=P
50 FNDPHE=P
   RETURN
   END
   FUNCTION CPHE(D,T)
C CSINH(P)
C FOR HELIUM, INPUT IS DENSITY (MOLES/LITER) AND TEMPERATURE(K)
C OUTPUT IS JOULES/MOL-K
C(SEE ALSO NEXT PAGE)
   P=CVHE(D,T)+(T*(DPDTHE(D,T)**2)/((D**2)*DPDDHE(D,T)))*101.325
   CPHE=P
   END
   FUNCTION SOUNHE(D,T)
C VELOCITY OF SOUND FOR HELIUM, INPUT IS DENSITY (MOLES/LITER)
C AND TEMPERATURE (KELVIN),OUTPUT IS IN METRES/SEC
   S=((CPHE(D,T)/CVHE(D,T))*(DPDDHE(D,T)*25311.))**.5
   SOUNHE=S
   END
   FUNCTION VIRB(T)
   DIMENSION A(9),V(45)
   DATA(A=-5.0815710041E-7,-1.1168680862E-4,1.1652480354E-2,
1 7.4474587998E-2,-5.3143174768E-1,-9.5759219306E-1,
2 3.9374414843,-5.1370239224,2.0804456338)
C COEFFICIENTS FROM PROGRAM 5/28/70-1630
C THIS SUB PROGRAM CALCULATES THE SECOND VIRIAL COEFFICIENT FOR
C HELIUM. THE RANGE IS FROM 2 TO 1500 DEG K. INPUT IS TEMPERATURE
C IN DEGREES KELVIN AND IUSE, IF IUSE IS 0 OR NEGATIVE THE ROUTINE
C CALCULATES B FOR THE EQUATION PV=RT(1+BD+..., FOR OTHER VALUES OF
C IUSE, THE ROUTINE CALCULATES THE VARIANC OF B AT THE INPUT TEMP
C UNITS ARE ATM, DEG KELVIN, AND MOLES/LITER,4/3/69-1253,R.D.MCCARTY
C REVISED 2/12/70-925
1 B=0
  DO 5 I=1,9
    FI=I
5 B=B+T**((1.5-FI/2.))*A(I)
  VIRB=B
  RETURN
  END
  FUNCTION DBDT (T)
  DIMENSION A(9),V(45)
C THIS SUB PROGRAM CALCULATES THE SECOND VIRIAL COEFFICIENT FOR
C HELIUM. THE RANGE IS FROM 2 TO 1500 DEG K. INPUT IS TEMPERATURE
C IN DEGREES KELVIN AND IUSE, IF IUSE IS 0 OR NEGATIVE THE ROUTINE
C CALCULATES B FOR THE EQUATION PV=RT(1+BD+..., FOR OTHER VALUES OF
C IUSE, THE ROUTINE CALCULATES THE VARIANC OF B AT THE INPUT TEMP
  DATA(A=-5.0815710041E-7,-1.1168680862E-4,1.1652480354E-2,
1 7.4474587998E-2,-5.3143174768E-1,-9.5759219306E-1,
2 3.9374414843,-5.1370239224,2.0804456338)
C UNITS ARE ATM, DEG KELVIN, AND MOLES/LITER,5/28/70-1630,R.D.MCCARTY

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```

1 B=0
DO 5 I=1,9
FI=I
5 B=B+T**(.5-FI/2.)*A(I)*(1.5-FI/2.)
DBDT=B
RETURN
END
FUNCTION D2DBDT2(T)
DIMENSION A(9)
DATA A=-5.0815710041E-7,-1.1168680862E-4,1.1652480354E-2,
1 7.474587998E-2,-5.3143174768E-1,-9.5759219306E-1,
2 3.9374414843,-5.1370239224,2.0804456J38)
THIS SUB PROGRAM CALCULATES THE SECOND VIRIAL COEFFICIENT FOR
C HELIUM. THE RANGE IS FROM 2 TO 1500 DEG K. INPUT IS TEMPERATURE
C IN DEGREES KELVIN AND IUSE, IF IUSE IS 0 OR NEGATIVE THE ROUTINE
C CALCULATES B FOR THE EQUATION PV=RT(1+BD+...; FOR OTHER VALUES OF
C IUSE, THE ROUTINE CALCULATES THE VARIANCE OF B AT THE INPUT TEMP
C UNITS ARE ATM, DEG KELVIN, AND MOLES/LITER,5/28/70-1630,R.D.MCCARTY
1 B=0
DO 5 I=1,9
FI=I
5 B=B+T**(.5-FI/2.-1.)*(1.5-FI/2.)*(1.5-FI/2.)*A(I)
D2DBDT2=B
RETURN
END
FUNCTION VPHE(TT)
C GIVES A VAPOR PRESSURE FOR HELIUM IN ATMOSPHERES GIVEN A
C TEMPERATURE IN KELVIN. THE FUNCTION REPRODUCES THE 1968 HELIUM
C TEMPERATURE SCALE TO .0001 KELVIN
DIMENSION C(12),D(14)
DATA C=-3.9394635287,141.27497598,-1640.7741565,11974.557102,
1 -55283.309818,166219.56504,-325212.82840,398843.22750,
2 -277718.06992,83395.204183)
DATA D=-49.510540356,651.9236417,-3707.5430856,12880.673491,
1 -30048.545554,49532.267436,-59337.558548,52311.296025,
2 -33950.233134,16028.674003,-5354.1038967,1199.0301906,
3 -161.46362959,9.8811553386)
T=TT
T=T-DELT(T)
P=0
IF(T-2.1720)10,10,1
1 DO 5 I=1,10
5 P=P+C(I)*T**(2-I)
VP =EXP(P)/.76E+6
VPHE=VP
RETURN
10 DO 15 I=1,14
15 P=P+D(I)*T**(2-I)
VP =EXP(P)/.76E+6
VPHE=VP
RETURN
END
FUNCTION DELT(TT)
C ADJUSTS THE TEMPERATURE TO A NEW SCALE
T=TT
DELT=.001+.002*T
RETURN
END
FUNCTION VPTEHE(PP)
C SOLVES THE VAPOR PRESSURE EQUATION FOR TEMPERATURE GIVEN A PRESSURE
C THE FLUID IS HELIUM AND THE UNITS ARE ATMOSPHERES AND KELVINS
P=PP

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IF(P.LT..842105)GO TO 12
T=5.0
PCAL=VPNHE(T)
GO TO 13
12 PCAL=.049737
IF(ABS(P-PCAL)-.0000001*PP)11,11,1
1 T=2.1720
13 DO 10 I=1,26
DP=DVPNHE(T)
DEL=(PCAL-P)/DP
T=T-DEL
PCAL=VPNHE(T)
IF(ABS(P-PCAL)-.0000001*P)11,11,2
2 IF(ABS(DEL)-.0000001*T)11,11,10
10 CONTINUE
PRINT 100,T
11 VPTHE=T
RETURN
100 FORMAT(* TEMPERATURE ITERATION FAILED AT T=X,E14.7)
END
FUNCTION DVPNHE(TT)
C GIVES THE DERIVATIVE OF THE VAPOR PRESSURE FOR HELIUM GIVEN A
C TEMPERATURE IN KELVIN9 PRESSURE IS IN ATMOSPHERES
DIMENSION C(12),D(14)
DATA(C=-3.9394635287,141.27497598,-1640.7741565,11974.557102,
1-55283.309818,166219.56504,-325212.82840,398843.22750,
2-277718.06992,83395.204183)
DATA(D=-49.510540356,651.9236417,-3707.5430856,12880.673491,
1 -30048.545554,49532.267436,-59337.558548,52311.296025,
2-33950.233134,16028.674003,-5354.1038967,1199.0301906,
3 -161.46362959,9.8811553386)
P=0
T=TT-DELT(TT)
IF(T-2.1720)10,10,1
1 DO 5 I=1,10
5 P=P+C(I)*T**(1-I)*(2-I)
DVPNHE=P*VPNHE(T)
RETURN
10 DO 15 I=1,14
15 P=P+D(I)*T**(1-I)*(2-I)
DVPNHE=P*VPNHE(T)
RETURN
END
FUNCTION TRANSP(DD,TT)
C HELIUM
C THIS ROUTINE CALCULATES THERMAL CONDUCTIVITY AND VISCOSITY
C FOR AN INPUT OF DEGREES KELVIN AND DENSITY IN MOLES PER LITER
C THE RANGE OF TEMPERATURE IS FROM 2 TO 2000 K
C FOR TEMPERATURES BELOW 300 K FORMULAS OFD VINCE ARP AND GE STEWARD
C ARE USED, FOR TEMPERATURES ABOVE 300 THE DILUTE GAS OF A CRITICAL
C COMPILATION FROM ENGLAND IS USED FOR BOTH VISCOSITY AND
C THERMAL CONDUCTIVITY AND THE EXCESS FUNCTIONS FROM THE ROUTINES BY
C ARP AND STEWART) THE EXCESS FUNCTIONS ARE CALCULATED FOR TEMPS
C ABOVE 300 K WITH THE TEMPERATURE DEPENDENCE HELD AT 300 K
C FOR TEMPS BELOW 300 K TO 100 K THE VISCOSITY EXCESS IS CALC
C FOR STEWARTS ROUTINE BUT THE DILUTE GAS VALUES ARE TAKEN FROM
C THE ENGLISH CORRELATION FOR TEMPS BETWEEN 100 AND 110 T
C DILUTE GAS CALCULATION IS AVARAGED
ENTRY THERHE
1 D=DD
T=TT
RHO=D*4.0026E-3

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IF(T.LT.300.)GO TO 5
TH030=VISCX(300.)*.00781736
TH0300=CONZ(300.)
DEL300=DELC(300.,RHO)
TH0=VISCX(T)*.00781736+TH0300-THU30
THE=TH0300*DEL300-TH0300
TRANSP=TH0+THE
RETURN
5 TRANSP=CONZ(T)*DELC(T,RHO)+CRITIC(T,RHO)
C OUTPUT IN MW/CM.K
RETURN
ENTRY VISCHE
D=DD
T=TT
IF(T.LT.100.)GO TO 10
IF(T.LT.300.)GO TO 8
ETA0=VISCX(T)
ETO30=VISCX(300.)
ETO300=VISCDT(0.0,300.)
ETE300=VISCDT(D,300.)-ETO300
TRANSP=ETA0+ETE300
C OUTPUT UNITS ARE MICROPUISE
RETURN
8 IF(T.LT.110.)GO TO 9
ETA0=VISCX(T)
ETEB=VISCDT(D,T)-VISCDT(0.0,T)
TRANSP=ETA0+ETEB
RETURN
9 ETA1=VISCDT(0.0,100.)
ETA2=VISCX(110.)
ETA0=ETA1+(ETA2-ETA1)*(T-100.)/10.
TRANSP=ETA0+VISCDT(D,T)-VISCDT(0.0,T)
RETURN
10 TRANSP=VISCDT(D,T)
RETURN
END
FUNCTION VISCX( T )
C CALCULATES THE DILUTE GAS VISCOSITY FOR HELIUM
C FOR TEMPERATURES FROM 110K TO 300K
VISCX = 196. * T ** 0.71738 * EXP( 12.451 / T - 295.67 / T / T -
A 4.1249 )
RETURN
END
FUNCTION DELC(TEMP, RHO)
C CALCULATE THE EXCESS THERMAL CONDUCTIVITY FOR HELIUM, INPUT IS
C TEMPERATURE(K) AND DENSITY(MOLES/LITER) OF HELIUM
C K=KZERO*EXPF(B(T)*RHO + C(T)*RHO**2)
C THIS PROGRAM RETURNS EXPF(B(T)*RHO + C(T)*RHO**2)
1 BB=ALOG(TEMP) * CC=1.0/TEMP
BETTY = 4.7470660612 - 5.3641468153*BB + 3.4639703698*BB**2
2 -1.0702455443*BB**3 + 0.1571349306*BB**4 - 0.00892140047*BB**5
B=EXP(BETTY)
C = 2.2109006708 + 187.74174808*CC - 1281.0947055*CC*CC
3 +3645.2393216*CC**3 - 3486.6937948*CC**4
DELC=EXP(B*RHO+C*RHO*RHO)
RETURN
END
FUNCTION CONZ(TEMP)
C KZERO IN MILLIWATTS/CM-K, T IN KELVIN 22 JUNE 71.
1 ANNE=ALOG(TEMP)
PAT = -4.3611622157 + 1.9250159286*ANNE - 0.52544120165*ANNE**2
1+ 0.090045763885*ANNE**3 - 0.0054773874708*ANNE**4

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CONZ=EXP(PAT)
RETURN
END
FUNCTION VISCDT(DGC,T)
C W.G.STEWART,8 DATA 23 JUNE 71
C INPUT UNITS ARE KELVIN AND MOL/LITER
C OUTPUT UNITS ARE MICROPOISE
TL=ALOG(T) * R=DGC*4.0026/1000.
ANNE=-0.135311743/TL + 1.00347841 + 1.20654649*TL
1 -0.149564551*TL*TL+0.0125208416*TL**3
BETTY=R*(-47.5295259/TL + 87.6799309 -42.0741589*TL
1+8.33128289*TL*TL -0.589252385*TL**3)
CAROL = R***(547.309267/TL - 904.870586 + 431.404928*TL
1-81.4504854*TL*TL + 5.37008433*TL**3)
DAGMAR=R**3*(-1684.39324/TL + 3331.08630 - 1632.19172*TL
1+308.804413*TL*TL - 20.2956367*TL**3)
VISCDT=EXP(ANNE+ BETTY+ CAROL+ DAGMAR)
RETURN
END
FUNCTION CRITIC(TEMP,RHO)
C CRITICAL ANOMALY FOR HE THERM. CON., SCALED FROM H-2
C T IN KELVIN, REQUIRES DENSITY IN GRAMS/CC AND CP IN JOULES/MOLE
C THIS DECK OF 18 SEPT 70, I HAVE USED MCCARTY'S HE DECKS OF 7/18/70
4 T=TEMP
5 DML=RHO/0.0040026
6 IF(T .GE. 11.83) GO TO 11
IF(RHO.GT.0.12) GO TO 11
7 CP1=CPHE(DML,T)
8 CP2=CPHE(DML,11.83)
9 CRITIC=0.0026*(CP1-CP2)/4.0026
10 IF(CRITIC)11,12,12
11 CRITIC=0.0
12 RETURN
END
FUNCTION DSATV(TT)
C CALCULATES THE SATURATED LIQUID AND VAPOR DENSITIES FOR HELIUM,
C INPUT IS TEMPERATURE(K) OUTPUT IS GM/CC (SEE NEXT PAGE)
DIMENSION GV(6),GL(6)
DATA(GL=.12874326484,-.43128217346,1.7851911824,-3.3509624489,
1 3.0344215824,-1.0981289602)
DATA(GV=-.069267495322,-.1292532553,.29347470712,-.40806658212,
1 .35809505624,-.11315580397)
DATA(DC=.06964)
DATA(TC=5.2014)
T=TT
DCAL=DC
R=(1.-T/TC)
DO 1 I=1,6
FI=I
1 DCAL=DCAL+GV(I)*R**(FI/3.)
DSATV=DCAL
RETURN
ENTRY DSATL
T=TT
DCAL=DC
R=(1.-T/TC)
DO 2 I=1,6
FI=I
2 DCAL=DCAL+GL(I)*R**(FI/3.)
DSATV=DCAL
RETURN
END

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FUNCTION P MELT(TT)
C CALCULATE THE MELTING PRESSURE FOR HELIUM, INPUT IS TEMP K,
C OUTPUT IS PRESSURE IN ATMOSPHERES
DIMENSION A(5)
DATA(A=33.20,-44.156,31.799,-4.8159,0.30313)
T=TT
IF(T.LE.5.2)GO TO 7
PMELT=-17.80+17.31457*T**1.555414
PMELT=PMELT*.98066/1.01325
RETURN
7 P=0.0
DO 9 I=1,5
9 P=P+A(I)*T**(I-1)
PMELT=P*9.80665/10.1325
RETURN
END
FUNCTION FNDPNE(D,T)
C CALCULATES THE PRESSURE IN ATMOSPHERES FOR NEON,
C USES DENSITY (MOL/LITER) AND TEMPERATURE OF NEON AS INPUT
1 FNDPNE=PC(D,T)
RETURN
END
FUNCTION ENTHA(P,D,T)
COMMON A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15,A16,A17
1,A18,A19
D1=D
D2=D**2
D3=D2*D
D4=D3*D
D5=D4*D
T1=T
T2=T*T
T3=T2*T
T4=T3*T
EX=EXP(A19*D2)
EXI1=(EX-1.)/(2.*A19)
EXI3=EX*D*D/(2.*A19)-(EX-1.)/(2.*A19**2)
ENTHA =P/D-A1*T+A4*D3/3.+A5*D4/(T1*2.)
1-A6*D2*T2/2.+A9*D2/T1+3.*A10*D2/(T2*2.)
2+A17*D1+2.*A13*D1/T1+3.*A14*D1/T2
3+3.*A15*EXI1/T2+4.*A16*EXI1/T3
4+3.*A17*EXI3/T2+4.*A18*EXI3/T3
5+A2*D5/5.+A8*D2/2.
C CALCULATES ENTHALPY CHANGE FROM 0 TO FINITE DENSITIES ALONG
C ISOTHERM ACCORDING TO DTR14
C FOR NEON INPUT IS PRESSURE IN ATMOSPHERES,DENSITY IN MOLES/LITER
C AND TEMPERATURE IN K,OUTPUT IS JOULES PER MOLE.
RETURN
END
FUNCTION DLIQNE(T)
C FOR NEON
IF(T-44.4)1,2,2
1 A=-8.9200910
B=35.44150349
C=-64.720906
D=57.745619
E=-20.25961912
R=(1.0-T/44.4)**(1.0/3.0)
DENR=1.0+A*R+B*R*R+C*R**3+D*R**4+E*R**5
RSATD=10.**DENR
DLIQNE=RSATD*.484*1000.028/20.183
RETURN

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2  RSATD=1,
   DLIGNE=RSATD*.484*1000.028/20.183
   RETURN
C   UNITS ARE IN GM=MOLES/LITER
   END
   FUNCTION DPDDNE(DD,TT)
   DIMENSION G(18)
3  COMMON A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15,A16,A17
   1,A18,A19
   D1=DD
   T1=TT
   D2=D1**2
   D3=D2*D1
   D4=D3*D1
   D5=D4*D1
   T2=T1**2
   T3=T2*T1
   T4=T3*T1
   EX=EXP(A19*D2)
   EX1=EX*D1**2.*A19
   EX3=3.*D2*EX+D3*EX1
   EX5=5.*D4*EX+D5*EX1
   G(1)=D5*6.*A2
   G(2)=T1*D3*4.*A3
   G(3)=D3*4.*A4
   G(4)=D4*5.*A5/T1
   G(5)=3.*D2*T2*A6
   G(6)=3.*D2*T1*A7
   G(7)=3.*D2*A8
   G(8)=3.*D2*A9/T1
   G(9)=3.*D2*A10/T2
   G(10)=D1*2.*T1*A11
   G(11)=D1*2.*A12
   G(12)=D1*2.*A13/T1
   G(13)=D1*2.*A14/T2
   G(14)=EX3*A15/T2
   G(15)=EX3*A16/T3
   G(16)=EX5*A17/T2
   G(17)=EX5*A18/T3
   P2=A1*T1
   DO 11 K=1,17
11  P2=P2+G(K)
   DPDDNE=P2
C   CALCULATES THE FIRST DERIVATIVE OF PRESSURE WITH RESPECT TO
C   DENSITY ACCORDING TO DTR14
   RETURN
   END
   FUNCTION ENT(D,T)
   COMMON A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15,A16,A17
   1,A18,A19
   D1=D
   D2=D**2
   D3=D2*D
   D4=D3*D
   D5=D4*D
   T1=T
   T2=T*T
   T3=T2*T
   T4=T3*T
   EX=EXP(A19*D2)
   EX11=EX/(A19**2.)
   EX13=EX*D*D/(2.*A19)-(EX)/(2.*A19**2)

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ENT =A5*D4/(T2*4.)-A3*D3/3.-A6*D2*T1
1-A7*D2/2.+A9*D2/(T2*2.)+A10*D2/T3
2-A11*D1+A13*D1/T2+A14*2.*D1/T3
3+A15*2.*EXI1/T3+A16*3.*EXI1/T4
4+A17*2.*EXI3/T3+A18*3.*EXI3/T4
5-A1*ALOG(A1*T*D)
C   CALCULATES ENTROPY AT ONE LIMIT OF INTEGRATION, ISOTHERMAL,
C   ACCORDING TO DTR14
    RETURN
    END
    FUNCTION ENTR(D,T)
C FOR NEON
COMMON A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15,A16,A17
1,A18,A19
D1=D
D2=D**2
D3=D2*D
D4=D3*D
D5=D4*D
T1=T
T2=T*T
T3=T2*T
T4=T3*T
EX=EXP(A19*D2)
EXI1=(EX-1.)/(2.*A19)
EXI3=EX*D/(2.*A19)-(EX-1.)/(2.*A19**2)
ENTR =A5*D4/(T2*4.)-A3*D3/3.-A6*D2*T1
1-A7*D2/2.+A9*D2/(T2*2.)+A10*D2/T3
2-A11*D1+A13*D1/T2+A14*2.*D1/T3
3+A15*2.*EXI1/T3+A16*3.*EXI1/T4
4+A17*2.*EXI3/T3+A18*3.*EXI3/T4
5-A1*ALOG(A1*T*D)
C   CALCULATES ENTROPY ALONG AN ISOTHERM FROM 0 TO A FINITE DENSITY
C   ACCORDING TO DTR14
    RETURN
    END
C FOR NEON
SUBROUTINE DATA N
C SETS THE CONSTANTS TO THE EQUATION OF STATE FOR NEON
3 COMMON A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15,A16,A17
1,A18,A19
A1=.0820535
A2=.28010178E-07
A3=.14244722E-05
A4=-.14175051E-03
A5=-.28070869E-04
A6=-.10185146E-06
A7=.42496352E-05
A8=.25826979E-02
A9=.12417383
A10=-.62382566E-01
A11=.17237659E-02
A12=-.16730352
A13=-.61781598E+01
A14=.87257402E+02
A15=.19355993E+02
A16=-.84739643E+03
A17=-.65528926E-01
A18=.23453113E+01
A19=-.53186241E-02
    RETURN
    END

```

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FUNCTION PC(DD,TT)
C FOR NEON,P IS IN ATMOSPHERES,D IN MOLES PER LITER
C AND TT IS IN KELVIN
  DIMENSION G(18)
  3 COMMON A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15,A16,A17
  1,A18,A19
C  (CALCULATES PRESSURE ACCORDING TO DIR14
  D1=DD
  T1=TT
  D2=D1**2
  D3=D2*D1
  D4=D3*D1
  D5=D4*D1
  D6=D5*D1
  T2=T1**2
  T3=T2*T1
  T4=T3*T1
  EX=EXP(A19*D2)
  Z=D1*A1*T1
  G(1)=D6*A2
  G(2)=T1*D4*A3
  G(3)=D4*A4
  G(4)=D5*A5/T1
  G(5)=D3*T2*A6
  G(6)=D3*T1*A7
  G(7)=D3*A8
  G(8)=D3*A9/T1
  G(9)=D3*A10/T2
  G(10)=D2*T1*A11
  G(11)=D2*A12
  G(12)=D2*A13/T1
  G(13)=D2*A14/T2
  G(14)=D3*EX*A15/T2
  G(15)=D3*EX*A16/T3
  G(16)=D5*EX*A17/T2
  G(17)=D5*EX*A18/T3
  P2=Z
  DO 11 K=1,17
11 P2=P2+G(K)
  PC=P2
  RETURN
  END
FUNCTION FNDTNE(P,D)
C SOLVES THE NEON EQUATION OF STATE FOR TEMPERATURE IN KELVIN
C FOR A INPUT OF PRESSURE IN ATMOSPHERES AND DENSITY IN MOL/L
  DATA(DTP=61.78),(DC=23.93)
  PP=P
  DD=D
  IF(DD.GT.DC)GO TO 1
  TT=44.4
  GO TO 2
  1 TT=24.54+(19.86/(DTP-DC))*(DTP-DD)
  2 DO 10 I=1,10
  P?=FNDPNE(DD,TT)
  IF(ABS(PP-P2)-1.E-7*PP)20,20,22
22 DP=DPDTNE(DD,TT)
  CORR=(P2-PP)/DP
  IF(ABS(CORR)-1.E-5)20,20,10
10 TT=TT-CORR
20 FNDTNE=TT
  RETURN

```

```

END
FUNCTION FIND P(D,T)
DIMENSION G(3),VP(9)
COMMON/DATA/G,R,GAMMA,VP,DTF,PCC,PIF,ICC,ITF,TUL,ILL,PUL,DCC
DD=D
TT=T
IF(TT,LI,ICC)GO TO 10
1 CALL PRESS(PF,DD,TT)
FIND P=PF
RETURN
10 P=VPN(TT)
DV=FIND D(P-.0001,TT)
DL=FIND D(P+.0001,TT)
IF(DD,LE,DV,OR,DL,GE,DL)GO TO 1
PRINT 100,DV,ILL,DD
CALL PRESS(PF,DV,TT)
FIND P=PF
D=DV
RETURN
100 FORMAT(* THE STATE POINT YOU HAVE SPECIFIED CORRESPONDS TO A *
1/* DENSITY IN THE LIQUID VAPOR COEXISTENCE REGION*
2/* THE DENSITY OF THE SATURATED VAPOR IS *,F6.4,* MOLES/LITER*
3/* THE DENSITY OF THE SATURATED LIQUID IS *,F8.4,* MOLES/LITER*
4/* AND THE INPUT DENSITY IS *,F8.4,* MOLES/LITER*
5/* SATURATED VAPOR IS ASSUMED*)
END
FUNCTION DPTNE(D,T)
C GIVES THE FIRST DERIVATIVE OF PRESSURE WITH RESPECT TO
C TEMPERATURE FOR NEON
C INPUT PARAMETERS ARE DENSITY(MOLES/LITER) AND TEMPERATURE(K)
DIMENSION G(18)
3 COMMON A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15,A16,A17
1,A18,A19
D1=DD
T1=TT
D2=D1**2
D3=D2*D1
D4=D3*D1
D5=D4*D1
D6=D5*D1
T2=T1**2
T3=T2*T1
T4=T3*T1
EX=EXP(A19*D2)
G(1)=0
G(2)=D4*A3
G(3)=0
G(4)=-D5*A5/T2
G(5)=2.*D3*T1*A6
G(6)=D3*A7
G(7)=0
G(8)=-D3*A9/T2
G(9)=-2.*D3*A10/T3
G(10)=D2*A11
G(11)=0
G(12)=-D2*A13/T2
G(13)=-2.*D2*A14/T3
G(14)=-2.*D3*EX*A15/T3
G(15)=-3.*D3*EX*A16/T3
G(16)=-2.*D5*A17*EX/T3
G(17)=-3.*D5*A18*EX/T4
P2=D1*A1

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```

DO 11 K=1,17
1. P2=P2+Q(K)
   DPDNE=P2
   RETURN
   END
FUNCTION FNDTHE(P,D)
C SOLVES THE EQUATION OF STATE FOR HELIUM
C FOR A TEMPERATURE (IN KELVIN) GIVEN A PRESSURE IN ATM
C AND A DENSITY IN MOLES/LITER
DATA(DTP=36.514),(DC=17.399)
PP=P
DD=D
IF(DD.GT.DC)GO TO 1
TT=5.201
GO TO 2
1 TT=2.177+(3.024/(DTP-DC))*(DTP-DD)
2 DO 10 I=1,10
  P2=FNDPHE(DD,TT)
  IF(ABS(PP-P2)-1.E-7*PP)20,20,11
11 DP=DPDTHE(DD,TT)
  CORR=(P2-PP)/DP
  IF(ABS(CORR)-1.E-5)20,20,10
10 TT=TT-CORR
20 FNDTHE=TT
   RETURN
   END
FUNCTION FINDT(P,D)
C SOLVE THE THIRTY TWO TERM EQUATION OF STATE FOR TEMPERATURE
C IN KELVIN GIVEN A PRESSURE IN ATMOSPHERES AND A DENSITY IN
C MOLES/LITER
DIMENSION G(32),VP(9)
COMMON/DATA/G,R,GAMMA,VP,DIP,PCC,PTP,TCC,ITP,TUL,TLL,PUL,DCC
PP=P
DD=D
IF(P.GE.PCC/1.01325)GO TO 1
TSAT=FINDTV(PP)
DV=FINDV(PP,.00001,TSAT)
DL=FINDV(PP+.0001,TSAT)
IF(DD.GT.DV.AND.DD.LT.DL)GO TO 30
IT=TSAT
GO TO 2
1 IT=TCC
2 DO 10 I=1,10
  CALL PRESS(P2,DD,IT)
  IF(ABS(PP-P2)-1.E-7*PP)20,20,11
11 CALL DPDT(DP,DD,IT)
  CORR=(P2-PP)/DP
  IF(ABS(CORR)-1.E-5)20,20,10
10 TT=TT-CORR
20 FINDT=IT
   RETURN
30 FINDT=TSAT
   D=DV
   PRINT 100,DV,DL,DD
100 FORMAT(* THE STATE POINT YOU HAVE SPECIFIED CORRESPONDS TO*
1/* A DENSITY IN THE LIQUID VAPOR COEXISTENCE REGION*
2/* DENSITY OF THE SATURATED VAPOR IS*,F8.4,* MOLES/LITER*
3/* DENSITY OF THE SATURATED LIQUID IS*,F8.4,* MOLES/LITER*
4/* INPUT DENSITY IS*,F8.4,* MOLES/LITER*
5/* SATURATED VAPOR CONDITIONS ARE ASSUMED*)
   RETURN
   END

```

```

FUNCTION CPOSNE(T)
C CALCULATES THE INTEGRAL OF (CP/T)DT FROM ,T0, TO T FOR NEON
C TO IS 27.092 AND CP IS AT ZERO PRESSURE, 5/2R
CP =8.31434*ALOG(T/27.092)*2.5
CPOSNE=CP
RETURN
C UNITS ARE JOULES/MOLE-K
END
FUNCTION CPOHNE(T)
C CALCULATES THE INTEGRAL OF (CPT)DT FROM ,T0, TO T FOR NEON, CP AT
C ZERO PRESSURE, ,T0, IS 27.092
CP =8.31434*(T-27.092)*2.5
CPOHNE=CP
RETURN
C UNITS ARE JOULES/MOLE-K
END
FUNCTION FNDDNE(PP,TT)
C SOLVES THE EQUATION OF STATE FOR NEON FOR DENSITY (MOLES/L)
C GIVEN A PRESSURE IN ATM AND A TEMPERATURE IN KELVIN
P=PP
T=TT
D=20.
IF(T.GT.44.4)GO TO 2
PSAT=VPNNE(TT)
D=.001
IF(PSAT.GE.PP)GO TO 2
D=DLIQNE(T)+1.
2 CONTINUE
DO 10 I=1,50
P2=PC(D,T)
IF(ABS(P-P2)-1.E-6*P)11,11,1
1 DP=DPDDNE(D,T)
IF(ABS((P-P2)/DP)-1.E-6*D)11,11,10
10 D=D-(P2-P)/DP
FNDDNE=0
RETURN
11 FNDDNE=D
RETURN
END
FUNCTION ENTH (P,D,T)
COMMON A1,A2,A3,A4,A5,A6,A7,A8,A9,A10,A11,A12,A13,A14,A15,A16,A17
1,A18,A19
D1=D
D2=D**2
D3=D2*D
D4=D3*D
D5=D4*D
T1=T
T2=T*T
T3=T2*T
T4=T3*T
EX=EXP(A19*D2)
EX11=EX/(A19**2.)
EX13=EX*D*(2.*A19)-(EX)/(2.*A19**2)
ENTH =P/D+A4*D3/3.+A5*D4/(T1**2.)
1-A6*D2*T2/2.+A9*D2/T1+3.*A10*D2/(T2**2.)
2+A12*D1+2.*A13*D1/T1+3.*A14*D1/T2
3+3.*A15*EX11/T2+4.*A16*EX11/T3
4+3.*A17*EX13/T2+4.*A18*EX13/T3
6+A2*D5/5.+A8*D2/2.
C CALCULATES ENTHALPY AT ONE LIMIT OF INTEGRATION ACCORDING
C TO DTRI4, ISOTHERMAL

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RETURN
END
FUNCTION VPTNE (PP)
C SOLVES THE VAPOR PRESSURE EQUATION FOR TEMPERATURE GIVEN A PRESSURE
C THE FLUID IS NEON AND THE UNITS ARE ATMOSPHERES AND KELVINS
P=44.
REAL VPNE(1)
P=PP
1) GO TO 1.150
2) DVNE(1)=0
DLE=(P-1)/P
T=DEL
REAL VPNE(1)
IF (ABS(P-1)) .000001#(11.11.1)
3) T=ABS(DEL) .000001#(11.11.10)
10 CONTINUE
11 VPNE=T
RETURN
END
FUNCTION ENTHNE (D,T)
C CALCULATES THE ENTHALPY FOR NEON IN JOULES MOLE* GIVEN THE PRESSURE
C IN ATMOSPHERES, THE DENSITY IN MOLES/LITER, AND THE TEMPERATURE IN
C KELVINS
DATA(CHU-.18638645E+11)
IF (T.LT.44.4)GO TO 50
1) ENTHNE=H(1)*D*(T-ENTH(1))+(H(2)-H(1))*101.325
RETURN
50) PSAT=PSAT+.0001
DVAP=ENDUNE(PSAT,T)
IF (D.LE.DVAP)GO TO 1
PSAT=PSAT+.0002
DLE=D-NDUNE(PSAT,T)
H1=POLY(ENTHNE(PSAT,DVAP,T))*101.325
H2=DVNE(1)*D*(1./DVAP-1./DLE)*101.325
H3=(ENTH(D,T)-ENTH(PSAT,DLE,T))*101.325
ENTHNE=H1-H2+H3
RETURN
END
FUNCTION ENTRNE (D,T)
C CALCULATES THE ENTROPY FOR NEON GIVEN DENSITY IN MOLES PER LITER
C AND TEMPERATURE IN KELVINS, OUTPUT IS IN JOULES MOLE* K
DATA(SU-.6952101435)
IF (T.LT.44.4)GO TO 50
1) ENTRNE=SU+CP(SNE(1))ENTR(D,T)*101.325
RETURN
50) PSAT=VPNE(1)
PSAT=PSAT+.0001
DVAP=ENDUNE(PSAT,T)
IF (D.LE.DVAP)GO TO 1
PSAT=PSAT+.0002
DLE=D-NDUNE(PSAT,T)
S1=(SU+CP(SNE(1))ENTR(DVAP,T))*101.325
S2=DVNE(1)*D*(1./DVAP-1./DLE)*101.325
S3=(ENT(D,T)-ENT(DLE,T))*101.325
ENTRNE=S1-S2+S3
RETURN
END
FUNCTION VPNE (T)
C GIVES A VAPOR PRESSURE FOR NEON IN ATMOSPHERES GIVEN A TEMP IN K
D=(7.46116-106.090/T-.0356616#T+.000411092#T^2)
DVAP=(10.0#(10/760.0)

```


VPNE=HVAF
RETURN
END

L FUNCTION DVPNE(T)
DERIVATIVE OF THE VAPOR PRESSURE CURVE FOR NEON
U=106.090/T**2-.035661612.*.000411092*T
DVPNE VPNE(T)*R*2.507585093
DVPNE=DVPNE
RETURN
END

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