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THE THERMODYNAMICS OF THE GRAPHITE-CARBON VAPOR SYSTEM

F. J. Krieger

Rand Corporation
Santa Monica, California

October 1969

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PREFACE

This study was carried out at the request of the Scientific Advisor to the Physics Division, Research Directorate,* Air Force Special Weapons Center, Kirtland Air Force Base, New Mexico.

It is a contribution to a better understanding of the complex problems involved in the physics of reentry bodies. Graphite is the first of a series of ablative materials to be investigated by means of mathematical techniques similar to those used at RAND in the parametric study of certain low-molecular-weight compounds as nuclear rocket propellants.

The study was originally published in September 1962 and revised in December 1965 and June 1967. The purpose of the present revision is to make use of recently determined thermodynamic data for large gaseous polymers of carbon in order to establish a sublimation curve in a carbon phase diagram that passes through an experimentally determined triple point.

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*Now the Air Force Weapons Laboratory.

SUMMARY

The purpose of this study is the thermodynamic investigation of graphite over a range of temperatures up to 6000°K and pressures up to 10^3 atmospheres.

Two sets of equilibrium composition equations were used--one representing a pure gas phase, the other a heterogeneous system of gaseous and solid carbon. The heterogeneous chemical system is unique in that, although it involves two phases and a variety of chemical species, it comprises only one chemical element. The mathematical solution of the system of equations representing the heterogeneous chemical system was subject, therefore, to the physical constraint of one degree of freedom.

The results of the computational program are presented in both tabular and graphic form. The latter is a conventional Mollier diagram in which specific enthalpy is plotted against specific entropy, with cross plots of temperature, pressure, molecular weight, and moles of condensed carbon. A carbon phase diagram is also presented in which the computed sublimation curve terminates at an experimentally determined triple point.

ACKNOWLEDGMENTS

This study involved a considerable amount of hand and machine computation. The efforts of the following RAND Physics Department staff members are gratefully acknowledged: Donald A. Brown, for his extensive programming and machine work; and Elizabeth J. Force, for her meticulous graphical presentation of the tabulated results.

CONTENTS

PREFACE iii

SUMMARY v

ACKNOWLEDGMENTS vii

Section

I. INTRODUCTION 1

II. COMPOSITION EQUATIONS 2

III. THERMODYNAMIC EQUATIONS 7

IV. BASIC DATA 9

V. COMPUTATIONAL PROCEDURE 11

VI. RESULTS 13

REFERENCES 35

I. INTRODUCTION

This study considers a chemical system that under certain conditions of temperature and pressure is a pure gas mixture and under others is a disperse system, or smoke. In this case the smoke is a gas that contains a condensed phase, solid carbon or graphite, symbolized by C_s.

The following assumptions were made in the computations:

(1) Thermal equilibrium is maintained between the condensed particles and the gas phase.

(2) The pressure due to the thermal motion of the solid particles can be neglected.

(3) The gas phase obeys the ideal-gas law.

(4) The molar volume of solid carbon is independent of pressure.

II. COMPOSITION EQUATIONS

In this study it is assumed that the gas formed by heating carbon (graphite) at various pressures up to a temperature of 6000°K is a mixture of the following chemical species: C_s(graphite) and the thirty-three gaseous species C, C_2, C_3, ..., C_{28}, C_{29}, C_{30}, e^-, C_2^-, C^+. The presence or absence of a condensed phase makes it necessary to consider two distinct sets of chemical equations.

A. No condensed carbon present. In terms of C and e^- as primary components 1 and 2, the chemical equations for the secondary components, or derived species, are given by the expression

$$a_i C + b_i e^- = C_{a_i} e^-_{b_i} \qquad (1)$$

where the coefficients a_i and b_i, as well as the corresponding derived species, are listed in the following table:

a_i	b_i	Component i Symbol	Component i Number
2		C_2	3
3		C_3	4
4		C_4	5
.		.	.
.		.	.
.		.	.
28		C_{28}	29
29		C_{29}	30
30		C_{30}	31
2	1	C_2^-	32
1	-1	C^+	33

The mass-balance equations are

$$n_C = 1 - \sum_{3}^{33} a_i n_i, \tag{2}$$

and

$$n_{e^-} = -\sum_{3}^{33} b_i n_i, \tag{3}$$

where n_C and n_{e^-} are the numbers of moles of C and e^-, respectively, a_i and b_i are the coefficients of C and e^- on the left-hand side of Eq. (1), and n_i is the corresponding number of moles of component i.

The equilibrium equations are given by the expression

$$n_i = K_i (P/n)^{a_i+b_i-1} (n_C)^{a_i} (n_{e^-})^{b_i}, \tag{4}$$

where n is the total number of moles of gas in the equilibrium mixture, P is the total pressure in atmospheres, and K_i is the thermodynamic equilibrium constant of component i computed on the basis of Eq. (1).

B. Solid carbon present. In terms of C_s and e^- as primary components 1 and 2, the secondary components, or derived species, are given by the expression

$$a_j C_s + b_j e^- = C_{a_j} e^-_{b_j}, \tag{5}$$

where the coefficients a_j and b_j are as follows:

		Component j	
a_j	b_j	Symbol	Number
1		C	3
2		C_2	4
3		C_3	5
.		.	.
.		.	.
.		.	.
28		C_{28}	30
29		C_{29}	31
30		C_{30}	32
2	1	C_2^-	33
1	-1	C^+	34

The mass-balance equations are

$$n_{C_s} = 1 - \sum_{3}^{34} a_j n_j, \tag{6}$$

and

$$n_{e^-} = -\sum_{3}^{34} b_j n_j, \tag{7}$$

where n_{C_s} and n_{e^-} are the numbers of moles of n_{C_s} and n_{e^-}, respectively, a_j and b_j are the coefficients of C_s and e^- in Eq. (5), and n_j is the corresponding number of moles of component j.

The equilibrium equations are obtained by considering the free energy F of the system and the partial molar free energy, or chemical potential, $\mu_x = \partial F/\partial n_x$ of each component. For an ideal gas

$$\mu_x = \mu_x^o + RT \ln (n_x P/n), \tag{8}$$

where μ_x^o is the chemical potential of component x in the standard state of unit partial pressure, R is the gas constant, T is the temperature, P is the pressure, and n is the total number of moles of gaseous species in the mixture. The chemical potential for graphite is given by

$$\mu_{C_s} = \mu_{C_s}^o + (P - 1)\bar{V}_{C_s}, \tag{9}$$

where $\mu_{C_s}^o$ and $\bar{V}_{C_s}$ are the standard molar free energy and the molar volume of graphite, respectively, and P is the pressure of the system.

By combining Eqs. (8) and (9), keeping in mind that the subscript j refers to the derived species on the right-hand side of Eq. (5), the following expression is obtained

$$n_j = K_j \exp\left[a_j(P - 1)\bar{V}_{C_s}/RT\right] (P/n)^{b_j - 1} (n_{e^-})^{b_j}. \tag{10}$$

In Eq. (10), K_j is the thermodynamic equilibrium constant associated with the chemical reaction of Eq. (5) and is defined by the relation

$$\Delta F^o = \mu_j^o - a_j\mu_{C_s}^o - b_j\mu_{e^-}^o = - RT \ln K_j. \tag{11}$$

At first glance, Eqs. (6), (7), and (10) represent a mathematical system of 34 equations in 34 unknowns that, ordinarily, could be solved by simple iteration. From the standpoint of the Gibbs phase rule, however, the chemical system under consideration, consisting of one component and two phases, enjoys but one degree of freedom. This means that at an arbitrarily fixed temperature, solid and vapor are in equilibrium at a unique pressure which can be determined in the following manner.

The expression for the total pressure as the sum of the partial pressures is

$$P = \sum_{2}^{34} n_x P/n, \tag{12}$$

where n is the total number of moles of gas in the equilibrium mixture. In view of Eq. (10), the above expression becomes

$$P = P_{e^-} + \sum_{3}^{34} K_j (\exp a_j Q)(P_{e^-})^{b_j}, \tag{13}$$

where P_{e^-} is the partial pressure of e^- and Q represents the quantity $(P - 1)\bar{V}_{C_s}/RT$. In like manner, Eq. (7), when multiplied through by P/n and rearranged, becomes

$$\emptyset = P_{e^-} + \sum_{3}^{34} b_j K_j (\exp a_j Q)(P_{e^-})^{b_j}, \tag{14}$$

where $\emptyset$ represents zero. Equations (13) and (14) represent a system of two equations in two unknowns, P and P_{e^-}, which can be solved by iteration. It is then a simple matter to solve for P_j, n_j, and n.

III. THERMODYNAMIC EQUATIONS

The molecular weight of the gas-C_s mixture is given by the relation

$$M = \frac{12.011}{\bar{n}}, \tag{15}$$

where 12.011 is the formula weight of the input material C_s and $\bar{n}$ is the total number of moles in the mixture.

The specific free energy (in calories per gram) of the mixture is given by the expression

$$f = \frac{1}{12.011} \left\{ \sum^{g} n_i [\mu_i^o + RT \ln (n_i P/n)] + n_{C_s} [\mu_{C_s}^o + c(P - 1)\bar{V}_{C_s}] \right\}, \tag{16}$$

which is derived from Eqs. (8) and (9). The summation is over all gaseous species. The constant $c = 0.0242172$ converts cc-atmospheres to calories.

The specific entropy (in calories per degree per gram) of the mixture is given by the expression

$$s = \frac{1}{12.011} \left\{ \sum^{g} n_i [S_i^o - R \ln (n_i P/n)] + n_{C_s} [S_{C_s}^o - c\alpha_v (P - 1)\bar{V}_{C_s}] \right\}, \tag{17}$$

where S_i^o and $S_{C_s}^o$ are the standard molar entropy of component i and C_s, respectively, at a given temperature, and α_v is the volume coefficient of thermal expansion of C_s.

The specific enthalpy (in calories per gram) of the gas mixture is given by the expression

$$h = \frac{1}{12.011} \left\{ \sum^{g} n_i H_i^o + n_{C_s} [H_{C_s}^o + c(1 - \alpha_v T)(P - 1)\bar{V}_{C_s}] \right\}, \tag{18}$$

where H_i^o and $H_{C_s}^o$ are the standard molar heat content of component i and C_s, respectively, at a given temperature.

The specific internal energy (in calories per gram) of the mixture is given by the expression

$$u = \frac{1}{12.011}\left\{\sum^{g} n_i(H_i^o - RT) + n_{C_s}\left[H_{C_s}^o - c[1 + (P-1)\alpha_v T]\bar{V}_{C_s}\right]\right\} . \quad (19)$$

The terms representing the increase in a thermodynamic property from one atmosphere to P atmospheres for C_s, namely,

$$\Delta F = (P - 1)\bar{V}_{C_s} , \quad (20)$$

$$\Delta S = - \alpha_v(P - 1)\bar{V}_{C_s} , \quad (21)$$

$$\Delta H = (1 - \alpha_v T)(P - 1)\bar{V}_{C_s} , \quad (22)$$

$$\Delta U = - \alpha_v T(P - 1)\bar{V}_{C_s} , \quad (23)$$

are readily derived from the differential formulas relating the various thermodynamic functions. Each of the above terms must be multiplied by the factor c = 0.0242172 to convert it from cc-atmospheres to calories.

The specific volume of the mixture (in cubic centimeters per gram) is given by the expression

$$v = \frac{1}{12.011}\left\{nRT/P + n_{C_s}\bar{V}_{C_s}\right\} , \quad (24)$$

where the first term in the braces is the volume of the gas phase and the second term is that of the condensed phase.

IV. BASIC DATA

The pertinent thermodynamic properties (entropy, free energy, and heat of formation) for this study were taken from four sources: JANAF Thermochemical Data,[1] Dolton et al,[2] Kratsch et al,[3] and F. R. Gilmore.[4] The molecular weights and heats of formation of the various components are listed in the following table. The heats of formation of the carbon polymers are linear combinations of the values in Refs. 2 and 3 for the reason given in Section V.

Component	Molecular Weight	Heat of Formation at $0^{o}K$ (cal/mole)	Reference
C_s (graphite)	12.011	0	1
C	12.011	169,576	1
C_2	24.022	197,000	1
C_3	36.033	201,200	2, 3
C_4	48.044	248,900	2, 3
C_5	60.055	246,200	2, 3
C_6	72.066	286,200	2, 3
C_7	84.077	266,200	2, 3
C_8	96.088	304,900	2, 3
C_9	108.099	290,300	2, 3
C_{10}	120.110	326,700	2, 3
C_{11}	132.121	316,200	2, 3
C_{12}	144.132	350,300	2, 3
C_{13}	156.143	342,700	2, 3
C_{14}	168.154	375,400	2, 3
C_{15}	180.165	369,300	2, 3
C_{16}	192.176	401,600	2, 3
C_{17}	204.187	396,000	2, 3
C_{18}	216.198	428,200	2, 3
C_{19}	228.209	422,700	2, 3
C_{20}	240.220	455,000	2, 3
C_{21}	252.231	449,500	2, 3

Component	Molecular Weight	Heat of Formation at 0^oK (cal/mole)	Reference
C_{22}	264.242	481,800	2, 3
C_{23}	276.253	476,500	2, 3
C_{24}	288.264	508,700	2, 3
C_{25}	300.275	503,500	2, 3
C_{26}	312.286	535,700	2, 3
C_{27}	324.297	530,500	2, 3
C_{28}	336.308	562,700	2, 3
C_{29}	348.319	557,500	2, 3
C_{30}	360.330	589,800	2, 3
e^-	0.00054876	0	1
C^+	12.0105	429,623	4
C_2^-	24.0225	125,500	1

The molar volume of graphite ($\bar{V}_s$ = 5.5524 cc) was derived from a mean density of 2.1632 gm/cc based on measurements of 49 samples at the Los Alamos Scientific Laboratory.[5]

The volume coefficient of thermal expansion for graphite is given by the expression

$$\alpha_v = \frac{1}{v}\left[\frac{\partial v}{\partial T}\right]_p = (18.80 + 0.001875T) \times 10^{-6} \text{ cc/cc-deg} \qquad (25)$$

for $T > 773^oK$. This expression was derived from data on the linear coefficient of expansion of lampblack obtained at the National Carbon Research Laboratories.[6]

Two values of the gas constant were used: R = 1.98716 cal/deg-mole and R = 82.0557 cc-atm/deg-mole. Their ratio gives the conversion factor c = 0.0242172 cal/cc-atm.

V. COMPUTATIONAL PROCEDURE

The two sets of equilibrium composition equations--the one involving solid carbon and the other the gaseous species only--represent two mutually exclusive contiguous regions. It is expedient to determine the border line between the two regions, that is, the conditions of temperature and pressure under which the condensed species just vanishes. This can be done in the following manner.

Since $n_{C_s} = 0$ along the gas/condensate interface, it follows that Eqs. (4) and (10) are identical for this condition. Hence, Eq. (10) may be written in the form

$$\ln n_C + \ln (P/n) = \ln K_C + (P - 1)\bar{V}_{C_s}/RT, \qquad (26)$$

where K_C is determined on the basis of Eq. (11). The left-hand side of Eq. (26) may be regarded as the "gaseous" side, and the right-hand side as the "condensed" side. Now, if each "side" is plotted against pressure for an arbitrary temperature, the result is a graph of two curves that intersect at a unique pressure.

The computational procedure for the condensed region is not quite as straightforward as for the "pure gas" region because of the constraint imposed on the system by the single degree of freedom (Section IIB). If, however, n_{C_s} is considered as a parameter such that $0 \leq n_{C_s} \leq 1$ for arbitrary values of temperature, then the solution of the system of Eqs. (6), (7), and (10) yields a unique value of pressure for each pair of T, n_{C_s} values.

It was found that when the heats of formation of Ref. 2 were used in the calculations to determine the gas/condensate interface on a temperature versus pressure plot, i.e., the sublimation curve of the carbon phase diagram, the curve undershot the experimental triple point. But when the heats of formation of Ref. 3 were used, the curve overshot the triple point. By trial and error it was found that a 0.8915-0.1085 linear combination of the heats of formation from these two sources resulted in a sublimation curve that terminates at the triple point measured by Schoessow.[7]

VI. RESULTS

The results of this study are presented numerically in Tables 1 through 3 and graphically in Figs. 1 through 4. Figure 1 is a conventional Mollier diagram for graphite; specific enthalpy is plotted against specific entropy, with cross plots of temperature, pressure, and molecular weight in the pure gas region, and cross plots of temperature and moles of condensed carbon in the gas-solid region. The temperatures range from 6000°K to 2000°K; the pressures from 10^3 atm to 10^{-8} atm. The broken line demarcates the pure gas phase (above) from the smoke (below). The cross plots of constant molecular weight represent chemical composition and reflect the increase in concentration of the larger molecules (C_2, ..., C_{30}) with increase in temperature and pressure, particularly in the vicinity of the gas-smoke interface. Figure 2 is a detail of Fig. 1.

Figure 3 is a plot of volume versus temperature with cross plots of constant pressure and moles of condensed carbon.

Table 3 summarizes the properties of solid and gas at the graphite triple point. Of particular interest is the molecular weight of the gas phase at this point, 138.96 gm/mol.

Figure 4 is a phase diagram for graphite, i.e., a plot of temperature versus pressure in which the sublimation, vaporization, and fusion curves coincide at an experimentally determined triple point. The sublimation curve, computed by the method of Section V, shows that at 10^{-3} atm the sublimation temperature of graphite is 2968°K, and at 1 atm it is 3697°K. The vaporization curve is tentative and is derived from the curve suggested by Udy and Boulger.[8] The fusion curve is based on three experimental points, two (including the triple point) by Schoessow[7] and one by Bundy.[9]

All the computations required to obtain the results in Tables 1 and 2 were made on the RAND IBM 360/65 computer. In the tables the numbers are represented in "floating decimal" notation; the first five digits indicate the decimal form of the number, and the last two digits indicate a power of 10. Thus 12345 05 represents 0.12345×10^5 and 12345-05 represents 0.12345×10^{-5}.

Table 1

SUMMARY OF COMPUTED VALUES OF VOLUME, MOLECULAR WEIGHT, MOLES OF GAS, AND MOLES OF SOLID CARBON FOR GRAPHITE AT VARIOUS TEMPERATURES AND PRESSURES

Temperature, T (°K)	Pressure, P (atm)	Log Volume, v (cc/gm)	Molecular Weight, M	Moles of Gas, n	Moles of Solid, n_s
6000 04	10000-07	12911 02	60433 01	19875 01	
6000 04	10000-06	11890 02	63460 01	18927 01	
6000 04	10000-05	10798 02	78461 01	15308 01	
6000 04	10000-04	96898 01	10057 02	11943 01	
6000 04	10000-03	86390 01	11304 02	10625 01	
6000 04	10000-02	76212 01	11778 02	10198 01	
6000 04	10000-01	66152 01	11942 02	10057 01	
6000 04	10000 00	56110 01	12059 02	99604 00	
6000 04	10000 01	45643 01	13427 02	89456 00	
6000 04	10000 02	33094 01	24148 02	49740 00	
6000 04	10000 03	21710 01	33213 02	36164 00	
6000 04	10000 04	11016 01	38967 02	30823 00	
5500 04	10000-07	12854 02	63134 01	19025 01	
5500 04	10000-06	11766 02	77377 01	15523 01	
5500 04	10000-05	10656 02	99673 01	12050 01	
5500 04	10000-04	96027 01	11266 02	10661 01	
5500 04	10000-03	85839 01	11765 02	10209 01	
5500 04	10000-02	75777 01	11934 02	10065 01	
5500 04	10000-01	65751 01	12006 02	10004 01	
5500 04	10000 00	55648 01	12295 02	97693 00	
5500 04	10000 01	44080 01	17638 02	68097 00	
5500 04	10000 02	31806 01	29778 02	40335 00	
5500 04	10000 03	20981 01	36007 02	33357 00	
5500 04	10000 04	95491 00	50068 02	23989 00	
5000 04	10000-07	12708 02	80389 01	14941 01	
5000 04	10000-06	11604 02	10206 02	11769 01	
5000 04	10000-05	10557 02	11366 02	10567 01	
5000 04	10000-04	95412 01	11799 02	10180 01	
5000 04	10000-03	85359 01	11944 02	10056 01	
5000 04	10000-02	75340 01	11997 02	10012 01	
5000 04	10000-01	65305 01	12094 02	99316 00	
5000 04	10000 00	54672 01	13993 02	85833 00	
5000 04	10000 01	42034 01	25687 02	46760 00	
5000 04	10000 02	30811 01	34036 02	35289 00	
5000 04	10000 03	20025 01	40791 02	29445 00	
5000 04	10000 04	58297 00	10718 03	11207 00	

Table 1--continued

Temperature, T (°K)	Pressure, P (atm)	Log Volume, v (cc/gm)	Molecular Weight, M	Moles of Gas, n	Moles of Solid, n_s
4500 04	10000-07	12535 02	10762 02	11161 01	
4500 04	10000-06	11503 02	11583 02	10369 01	
4500 04	10000-05	10493 02	11872 02	10117 01	
4500 04	10000-04	94893 01	11967 02	10037 01	
4500 04	10000-03	84881 01	12001 02	10009 01	
4500 04	10000-02	74864 01	12049 02	99683 00	
4500 04	10000-01	64568 01	12898 02	93124 00	
4500 04	10000 00	52136 01	22581 02	53191 00	
4500 04	10000 01	40548 01	32549 02	36901 00	
4500 04	10000 02	29912 01	37684 02	31873 00	
4500 04	10000 03	16848 01	76294 02	15743 00	
4500 04	10000 04	26208 00	20195 03	59476-01	
4300 04	10000-07	12492 02	11373 02	10561 01	
4300 04	10000-06	11476 02	11801 02	10178 01	
4300 04	10000-05	10470 02	11944 02	10056 01	
4300 04	10000-04	94687 01	11990 02	10017 01	
4300 04	10000-03	84679 01	12012 02	99989 00	
4300 04	10000-02	74642 01	12117 02	99127 00	
4300 04	10000-01	63810 01	14676 02	81839 00	
4300 04	10000 00	51175 01	26921 02	44616 00	
4300 04	10000 01	40122 01	34305 02	35013 00	
4300 04	10000 02	29334 01	41127 02	29205 00	
4300 04	10000 03	14595 01	12250 03	98052-01	
4300 04	10000 04	17323 00	23678 03	50727-01	
4300 04	17263 03	11195 01	15523 03	77375-01	12517-05
4300 04	17263 03	10754 01	70803 02	69638-01	10000 00
4300 04	17263 03	10264 01	45861 02	61900-01	20000 00
4300 04	17263 03	97108 00	33914 02	54163-01	30000 00
4300 04	17263 03	90769 00	26905 02	46425-01	40000 00
4300 04	17263 03	83345 00	22297 02	38688-01	50000 00
4300 04	17263 03	74384 00	19036 02	30950-01	60000 00
4300 04	17263 03	63081 00	16608 02	23212-01	70000 00
4300 04	17263 03	47759 00	14729 02	15475-01	80000 00
4300 04	17263 03	23874 00	13232 02	77374-02	90000 00
4300 04	17263 03	-22965 00	12123 02	77375-03	99000 00
4300 04	17263 03	-32332 00	12022 02	77375-04	99900 00
4300 04	17263 03	-33391 00	12012 02	77375-05	99990 00
4300 04	17263 03	-33495 00	12011 02	77375-06	99999 00

Table 1--continued

Temperature, T (°K)	Pressure, P (atm)	Log Volume, v (cc/gm)	Molecular Weight, M	Moles of Gas, n	Moles of Solid, n_s
4247 04	10000-07	12482 02	11486 02	10457 01	
4247 04	10000-06	11469 02	11840 02	10145 01	
4247 04	10000-05	10465 02	11956 02	10046 01	
4247 04	10000-04	94632 01	11995 02	10014 01	
4247 04	10000-03	84624 01	12016 02	99962 00	
4247 04	10000-02	74575 01	12152 02	98836 00	
4247 04	10000-01	63511 01	15529 02	77347 00	
4247 04	10000 00	50954 01	27978 02	42930 00	
4247 04	10000 01	40017 01	34717 02	34597 00	
4247 04	10000 02	29084 01	43035 02	27910 00	
4247 04	10000 03	14055 01	13699 03	87679-01	
4247 04	10000 04	15333 00	24483 03	49059-01	
4247 04	10331 03	13851 01	13896 03	86433-01	95367-06
4247 04	10331 03	13403 01	67557 02	77789-01	10000 00
4247 04	10331 03	12903 01	44626 02	69146-01	20000 00
4247 04	10331 03	12338 01	33317 02	60503-01	30000 00
4247 04	10331 03	11688 01	26581 02	51860-01	40000 00
4247 04	10331 03	10923 01	22111 02	43216-01	50000 00
4247 04	10331 03	99942 00	18928 02	34573-01	60000 00
4247 04	10331 03	88113 00	16546 02	25930-01	70000 00
4247 04	10331 03	71804 00	14696 02	17286-01	80000 00
4247 04	10331 03	45383 00	13219 02	86432-02	90000 00
4247 04	10331 03	-15466 00	12122 02	86433-03	99000 00
4247 04	10331 03	-31329 00	12022 02	86433-04	99900 00
4247 04	10331 03	-33287 00	12012 02	86433-05	99990 00
4247 04	10331 03	-33487 00	12011 02	86432-06	99999 00
4000 04	10000-07	12444 02	11817 02	10164 01	
4000 04	10000-06	11439 02	11949 02	10052 01	
4000 04	10000-05	10437 02	11992 02	10016 01	
4000 04	10000-04	94367 01	12008 02	10003 01	
4000 04	10000-03	84355 01	12042 02	99745 00	
4000 04	10000-02	74125 01	12696 02	94602 00	
4000 04	10000-01	61805 01	21663 02	55446 00	
4000 04	10000 00	50111 01	31995 02	37540 00	
4000 04	10000 01	39509 01	36752 02	32682 00	
4000 04	10000 02	26557 01	72514 02	16564 00	
4000 04	11952 02	25286 01	81302 02	14773 00	0
4000 04	11952 02	24829 01	51558 02	13296 00	10000 00

Table 1--continued

Temperature, T (°K)	Pressure, P (atm)	Log Volume, v (cc/gm)	Molecular Weight, M	Moles of Gas, n	Moles of Solid, n_s
4000 04	11952 02	24319 01	37748 02	11819 00	20000 00
4000 04	11952 02	23740 01	29773 02	10341 00	30000 00
4000 04	11952 02	23072 01	24580 02	88639-01	40000 00
4000 04	11952 02	22282 01	20930 02	73866-01	50000 00
4000 04	11952 02	21316 01	18223 02	59093-01	60000 00
4000 04	11952 02	20071 01	16137 02	44320-01	70000 00
4000 04	11952 02	18320 01	14479 02	29546-01	80000 00
4000 04	11952 02	15339 01	13130 02	14773-01	90000 00
4000 04	11952 02	58382 00	12114 02	14773-02	99000 00
4000 04	11952 02	-97129-01	12021 02	14773-03	99900 00
4000 04	11952 02	-30451 00	12012 02	14773-04	99990 00
4000 04	11952 02	-33194 00	12011 02	14773-05	99999 00
3500 04	10000-07	12379 02	11995 02	10013 01	
3500 04	10000-06	11379 02	12006 02	10004 01	
3500 04	10000-05	10379 02	12013 02	99981 00	
3500 04	10000-04	93768 01	12061 02	99588 00	
3500 04	10000-03	83331 01	13338 02	90050 00	
3500 04	10000-02	70707 01	24404 02	49216 00	
3500 04	10000-01	59397 01	32999 02	36398 00	
3500 04	10000 00	48836 01	37546 02	31990 00	
3500 04	19685 00	45411 01	41969 02	28619 00	-19073-05
3500 04	19685 00	44954 01	33591 02	25757 00	99998-01
3500 04	19685 00	44442 01	28001 02	22895 00	20000 00
3500 04	19685 00	43862 01	24006 02	20033 00	30000 00
3500 04	19685 00	43193 01	21009 02	17171 00	40000 00
3500 04	19685 00	42401 01	18677 02	14310 00	50000 00
3500 04	19685 00	41432 01	16811 02	11448 00	60000 00
3500 04	19685 00	40182 01	15284 02	85857-01	70000 00
3500 04	19685 00	38422 01	14011 02	57238-01	80000 00
3500 04	19685 00	35412 01	12934 02	28619-01	90000 00
3500 04	19685 00	25417 01	12097 02	28619-02	99000 00
3500 04	19685 00	15468 01	12020 02	28619-03	99900 00
3500 04	19685 00	59533 00	12012 02	28619-04	99990 00
3500 04	19685 00	-91570-01	12011 02	28619-05	99999 00
3000 04	10000-07	12312 02	12012 02	99994 00	
3000 04	10000-06	11311 02	12025 02	99882 00	
3000 04	10000-05	10301 02	12320 02	97492 00	
3000 04	10000-04	91123 01	19008 02	63190 00	
3000 04	10000-03	79057 01	30586 02	39270 00	
3000 04	10000-02	68444 01	35225 02	34098 00	

Table 1--continued

Temperature, T (°K)	Pressure, P (atm)	Log Volume, v (cc/gm)	Molecular Weight, M	Moles of Gas, n	Moles of Solid, n_s
3000 04	14404-02	66781 01	35859 02	33495 00	-95367-06
3000 04	14404-02	66324 01	29919 02	30145 00	99998-01
3000 04	14404-02	65812 01	25667 02	26796 00	20000 00
3000 04	14404-02	65232 01	22473 02	23446 00	30000 00
3000 04	14404-02	64563 01	19986 02	20097 00	40000 00
3000 04	14404-02	63771 01	17995 02	16747 00	50000 00
3000 04	14404-02	62802 01	16364 02	13398 00	60000 00
3000 04	14404-02	61553 01	15005 02	10048 00	70000 00
3000 04	14404-02	59792 01	13854 02	66989-01	80000 00
3000 04	14404-02	56781 01	12867 02	33495-01	90000 00
3000 04	14404-02	46782 01	12091 02	33495-02	99000 00
3000 04	14404-02	36782 01	12019 02	33494-03	99900 00
3000 04	14404-02	26786 01	12012 02	33495-04	99990 00
3000 04	14404-02	16823 01	12011 02	33495-05	99999 00
2500 04	10000-07	12207 02	12743 02	94256 00	
2500 04	10000-06	10957 02	22641 02	53050 00	
2500 04	10000-05	98032 01	32277 02	37212 00	
2500 04	17741-05	95388 01	33439 02	35919 00	0
2500 04	17741-05	94930 01	28377 02	32327 00	99999-01
2500 04	17741-05	94419 01	24645 02	28735 00	20000 00
2500 04	17741-05	93839 01	21781 02	25143 00	30000 00
2500 04	17741-05	93170 01	19514 02	21551 00	40000 00
2500 04	17741-05	92378 01	17674 02	17960 00	50000 00
2500 04	17741-05	91409 01	16151 02	14368 00	60000 00
2500 04	17741-05	90159 01	14870 02	10776 00	70000 00
2500 04	17741-05	88398 01	13777 02	71838-01	80000 00
2500 04	17741-05	85388 01	12833 02	35919-01	90000 00
2500 04	17741-05	75388 01	12088 02	35919-02	99000 00
2500 04	17741-05	65388 01	12019 02	35919-03	99900 00
2500 04	17741-05	55388 01	12012 02	35919-04	99990 00
2500 04	17741-05	45388 01	12011 02	35919-05	99999 00
2200 04	77088-08	11884 02	30604 02	39247 00	0
2200 04	77088-08	11838 02	26502 02	35322 00	10000 00
2200 04	77088-08	11787 02	23369 02	31397 00	20000 00
2200 04	77088-08	11729 02	20899 02	27473 00	30000 00
2200 04	77088-08	11662 02	18901 02	23548 00	40000 00
2200 04	77088-08	11583 02	17251 02	19623 00	50000 00
2200 04	77088-08	11486 02	15867 02	15699 00	60000 00
2200 04	77088-08	11361 02	14688 02	11774 00	70000 00
2200 04	77088-08	11185 02	13672 02	78493-01	80000 00

Table 1--continued

Temperature, T (°K)	Pressure, P (atm)	Log Volume, v (cc/gm)	Molecular Weight, M	Moles of Gas, n	Moles of Solid, n_s
2200 04	77088-08	10884 02	12788 02	39246-01	90000 00
2200 04	77090-08	98838 01	12084 02	39247-02	99000 00
2200 04	77090-08	88838 01	12018 02	39247-03	99900 00
2200 04	77090-08	78838 01	12012 02	39247-04	99990 00
2200 04	77090-08	68838 01	12011 02	39248-05	99999 00
2000 04	94699-10	13802 02	27357 02	43904 00	0
2000 04	94699-10	13756 02	24258 02	39514 00	99999-01
2000 04	94699-10	13705 02	21789 02	35123 00	20000 00
2000 04	94699-10	13647 02	19777 02	30733 00	30000 00
2000 04	94699-10	13580 02	18105 02	26342 00	40000 00
2000 04	94699-10	13501 02	16693 02	21952 00	50000 00
2000 04	94699-10	13404 02	15486 02	17562 00	60000 00
2000 04	94699-10	13279 02	14441 02	13171 00	70000 00
2000 04	94699-10	13103 02	13529 02	87808-01	80000 00
2000 04	94699-10	12802 02	12725 02	43904-01	90000 00
2000 04	94699-10	11802 02	12079 02	43904-02	99000 00
2000 04	94699-10	10802 02	12018 02	43904-03	99900 00
2000 04	94699-10	98017 01	12012 02	43904-04	99990 00
2000 04	94699-10	88017 01	12011 02	43904-05	99999 00
4244 04	10000 03	14022 01	13795 03	87100-01	93592-06
3979 04	10000 02	26204 01	77943 02	15366 00	-91473-07
3697 04	10000 01	37699 01	49532 02	23380 00	-12659-05
3425 04	10000 00	48483 01	39215 02	29865 00	-19179-05
3184 04	10000-01	58573 01	35139 02	32552 00	-15493-05
2968 04	10000-02	68347 01	35616 02	33699 00	-88624-06
2779 04	10000-03	78194 01	34505 02	34685 00	-49133-06
2613 04	10000-04	88010 01	33855 02	35386 00	-17169-06
2465 04	10000-05	97849 01	33188 02	36182 00	18328-07
2332 04	10000-06	10776 02	32075 02	37421 00	36392-07
2213 04	10000-07	11771 02	30766 02	39036 00	44530-08

Table 2

SUMMARY OF COMPUTED VALUES OF DENSITY, ENTHALPY, ENERGY, AND ENTROPY FOR GRAPHITE AT VARIOUS TEMPERATURES AND PRESSURES

Temperature, T (°K)	Pressure, P (atm)	Density, d (gm/cc)	Enthalpy, h (cal/gm)	Energy, u (cal/gm)	Entropy, s (cal/deg-gm)
6000 04	10000-07	12275-12	40443 05	38470 05	12253 02
6000 04	10000-06	12890-11	38166 05	36287 05	11128 02
6000 04	10000-05	15937-10	29475 05	27955 05	90197 01
6000 04	10000-04	20427-09	21392 05	20207 05	71611 01
6000 04	10000-03	22961-08	18227 05	17172 05	62082 01
6000 04	10000-02	23923-07	17201 05	16188 05	56420 01
6000 04	10000-01	24257-06	16870 05	15871 05	52015 01
6000 04	10000 00	24493-05	16700 05	15711 05	47917 01
6000 04	10000 01	27271-04	15401 05	14513 05	42068 01
6000 04	10000 02	49047-03	10308 05	98138 04	30954 01
6000 04	10000 03	67460-02	85786 04	82196 04	26498 01
6000 04	10000 04	79148-01	79495 04	76435 04	24171 01
5500 04	10000-07	13989-12	38004 05	36273 05	11823 02
5500 04	10000-06	17145-11	29658 05	28246 05	96390 01
5500 04	10000-05	22085-10	21382 05	20286 05	76165 01
5500 04	10000-04	24964-09	18071 05	17101 05	65865 01
5500 04	10000-03	26068-08	16995 05	16066 05	59949 01
5500 04	10000-02	26443-07	16652 05	15736 05	55468 01
5500 04	10000-01	26602-06	16525 05	15615 05	51417 01
5500 04	10000 00	27242-05	16216 05	15327 05	47070 01
5500 04	10000 01	39082-04	12435 05	11815 05	36881 01
5500 04	10000 02	65982-03	88721 04	85050 04	28457 01
5500 04	10000 03	79785-02	80077 04	77042 04	25504 01
5500 04	10000 04	11094 00	68574 04	66391 04	22274 01
5000 04	10000-07	19594-12	27952 05	26716 05	98937 01
5000 04	10000-06	24875-11	20450 05	19477 05	78923 01
5000 04	10000-05	27703-10	17609 05	16735 05	69027 01
5000 04	10000-04	28759-09	16692 05	15850 05	63255 01
5000 04	10000-03	29112-08	16401 05	15569 05	58823 01
5000 04	10000-02	29240-07	16302 05	15474 05	54804 01
5000 04	10000-01	29477-06	16189 05	15368 05	50775 01
5000 04	10000 00	34107-05	14476 05	13766 05	43712 01
5000 04	10000 01	62608-04	94645 04	90777 04	31237 01
5000 04	10000 02	82958-03	80048 04	77129 04	26805 01
5000 04	10000 03	99424-02	73012 04	70576 04	24153 01
5000 04	10000 04	26123 00	49032 04	48105 04	18567 01

Table 2--continued

Temperature, T (°K)	Pressure, P (atm)	Density, d (gm/cc)	Enthalpy, h (cal/gm)	Energy, u (cal/gm)	Entropy, s (cal/deg-gm)
4500 04	10000-07	29145-12	18764 05	17933 05	79735 01
4500 04	10000-06	31370-11	16907 05	16135 05	71536 01
4500 04	10000-05	32152-10	16315 05	15561 05	66327 01
4500 04	10000-04	32409-09	16127 05	15379 05	62073 01
4500 04	10000-03	32500-08	16064 05	15319 05	58117 01
4500 04	10000-02	32632-07	16006 05	15263 05	54180 01
4500 04	10000-01	34930-06	15175 05	14482 05	48604 01
4500 04	10000 00	61153-05	10054 05	96575 04	34401 01
4500 04	10000 01	88150-04	79611 04	76864 04	28112 01
4500 04	10000 02	10206-02	73452 04	71079 04	25439 01
4500 04	10000 03	20662-01	52556 04	51384 04	19817 01
4500 04	10000 04	54691 00	39185 04	38743 04	16492 01
4300 04	10000-07	32232-12	17263 05	16511 05	76331 01
4300 04	10000-06	33447-11	16366 05	15642 05	70309 01
4300 04	10000-05	33851-10	16082 05	15366 05	65798 01
4300 04	10000-04	33983-09	15991 05	15279 05	61765 01
4300 04	10000-03	34045-08	15955 05	15244 05	57869 01
4300 04	10000-02	34341-07	15845 05	15139 05	53812 01
4300 04	10000-01	41595-06	13643 05	13061 05	45110 01
4300 04	10000 00	76298-05	88586 04	85412 04	31681 01
4300 04	10000 01	97224-04	76319 04	73828 04	27353 01
4300 04	10000 02	11656-02	69191 04	67114 04	24453 01
4300 04	10000 03	34717-01	43456 04	42759 04	17733 01
4300 04	10000 04	67107 00	36910 04	36550 04	15955 01
4300 04	17263 03	75947-01	40613 04	40063 04	16993 01
4300 04	17263 03	84057-01	38441 04	37944 04	16488 01
4300 04	17263 03	94107-01	36269 04	35825 04	15983 01
4300 04	17263 03	10689 00	34097 04	33706 04	15478 01
4300 04	17263 03	12368 00	31925 04	31586 04	14973 01
4300 04	17263 03	14674 00	29752 04	29467 04	14468 01
4300 04	17263 03	18037 00	27580 04	27348 04	13962 01
4300 04	17263 03	23399 00	25408 04	25229 04	13457 01
4300 04	17263 03	33297 00	23236 04	23110 04	12952 01
4300 04	17263 03	57712 00	21064 04	20991 04	12447 01
4300 04	17263 03	16969 01	19109 04	19084 04	11992 01
4300 04	17263 03	21053 01	18913 04	18893 04	11947 01
4300 04	17263 03	21573 01	18894 04	18874 04	11942 01
4300 04	17263 03	21626 01	18892 04	18872 04	11942 01

Table 2--continued

Temperature, T (°K)	Pressure, P (atm)	Density, d (gm/cc)	Enthalpy, h (cal/gm)	Energy, u (cal/gm)	Entropy, s (cal/deg-gm)
4247 04	10000-07	32959-12	16995 05	16260 05	75703 01
4247 04	10000-06	33974-11	16265 05	15552 05	70070 01
4247 04	10000-05	34309-10	16034 05	15328 05	65684 01
4247 04	10000-04	34419-09	15960 05	15256 05	61690 01
4247 04	10000-03	34479-08	15927 05	15225 05	57802 01
4247 04	10000-02	34872-07	15784 05	15090 05	53669 01
4247 04	10000-01	44560-06	13044 05	12500 05	43706 01
4247 04	10000 00	80284-05	86175 04	83159 04	31115 01
4247 04	10000 01	99620-04	75559 04	73128 04	27174 01
4247 04	10000 02	12349-02	67282 04	65321 04	24003 01
4247 04	10000 03	39309-01	41757 04	41141 04	17331 01
4247 04	10000 04	70253 00	36400 04	36055 04	15831 01
4247 04	10331 03	41198-01	41585 04	40978 04	17286 01
4247 04	10331 03	45679-01	39287 04	38739 04	16745 01
4247 04	10331 03	51253-01	36989 04	36501 04	16204 01
4247 04	10331 03	58377-01	34691 04	34263 04	15663 01
4247 04	10331 03	67802-01	32394 04	32025 04	15122 01
4247 04	10331 03	80856-01	30096 04	29786 04	14581 01
4247 04	10331 03	10013 00	27798 04	27548 04	14040 01
4247 04	10331 03	13148 00	25500 04	25310 04	13499 01
4247 04	10331 03	19141 00	23202 04	23071 04	12958 01
4247 04	10331 03	35170 00	20904 04	20833 04	12417 01
4247 04	10331 03	14278 01	18836 04	18819 04	11930 01
4247 04	10331 03	20572 01	18630 04	18617 04	11881 01
4247 04	10331 03	21521 01	18609 04	18597 04	11876 01
4247 04	10331 03	21621 01	18607 04	18595 04	11876 01
4000 04	10000-07	36002-12	16199 05	15526 05	73780 01
4000 04	10000-06	36405-11	15937 05	15272 05	69280 01
4000 04	10000-05	36535-10	15854 05	15192 05	65251 01
4000 04	10000-04	36584-09	15826 05	15164 05	61366 01
4000 04	10000-03	36687-08	15787 05	15127 05	57463 01
4000 04	10000-02	38682-07	15137 05	14511 05	52091 01
4000 04	10000-01	65999-06	10118 05	97512 04	36616 01
4000 04	10000 00	97479-05	78133 04	75648 04	29170 01
4000 04	10000 01	11197-03	72073 04	69911 04	26326 01
4000 04	10000 02	22093-02	51072 04	49976 04	20052 01
4000 04	11952 02	29605-02	48660 04	47682 04	19403 01
4000 04	11952 02	32889-02	45526 04	44646 04	18619 01

Table 2--continued

Temperature, T (°K)	Pressure, P (atm)	Density, d (gm/cc)	Enthalpy, h (cal/gm)	Energy, u (cal/gm)	Entropy, s (cal/deg-gm)
4000 04	11952 02	36993-02	42391 04	41609 04	17835 01
4000 04	11952 02	42268-02	39257 04	38572 04	17052 01
4000 04	11952 02	49296-02	36123 04	35536 04	16268 01
4000 04	11952 02	59129-02	32988 04	32499 04	15485 01
4000 04	11952 02	73860-02	29854 04	29462 04	14701 01
4000 04	11952 02	98369-02	26720 04	26426 04	13918 01
4000 04	11952 02	14722-01	23585 04	23389 04	13134 01
4000 04	11952 02	29245-01	20451 04	20352 04	12350 01
4000 04	11952 02	26072 00	17630 04	17619 04	11645 01
4000 04	11952 02	12506 01	17348 04	17346 04	11575 01
4000 04	11952 02	20161 01	17320 04	17319 04	11568 01
4000 04	11952 02	21475 01	17317 04	17316 04	11567 01
3500 04	10000-07	41766-12	15627 05	15047 05	72274 01
3500 04	10000-06	41805-11	15605 05	15026 05	68399 01
3500 04	10000-05	41830-10	15595 05	15016 05	64560 01
3500 04	10000-04	41995-09	15545 05	14969 05	60615 01
3500 04	10000-03	46443-08	14334 05	13812 05	53456 01
3500 04	10000-02	84975-07	90852 04	88002 04	35840 01
3500 04	10000-01	11490-05	74313 04	72205 04	29547 01
3500 04	10000 00	13073-04	68768 04	66915 04	26657 01
3500 04	19685 00	28767-04	64442 04	62785 04	25079 01
3500 04	19685 00	31963-04	59473 04	57981 04	23659 01
3500 04	19685 00	35958-04	54503 04	53178 04	22239 01
3500 04	19685 00	41095-04	49534 04	48374 04	20819 01
3500 04	19685 00	47944-04	44564 04	43570 04	19399 01
3500 04	19685 00	57532-04	39594 04	38766 04	17979 01
3500 04	19685 00	71915-04	34625 04	33962 04	16560 01
3500 04	19685 00	95886-04	29655 04	29158 04	15140 01
3500 04	19685 00	14383-03	24686 04	24354 04	13720 01
3500 04	19685 00	28764-03	19716 04	19550 04	12300 01
3500 04	19685 00	28729-02	15243 04	15227 04	11022 01
3500 04	19685 00	28390-01	14796 04	14794 04	10894 01
3500 04	19685 00	25390 00	14751 04	14751 04	10881 01
3500 04	19685 00	12347 01	14747 04	14747 04	10880 01
3000 04	10000-07	48795-12	15378 05	14882 05	71511 01
3000 04	10000-06	48850-11	15364 05	14869 05	67656 01
3000 04	10000-05	50047-10	15063 05	14579 05	62870 01
3000 04	10000-04	77215-09	10658 05	10344 05	44973 01
3000 04	10000-03	12425-07	75661 04	73712 04	32832 01
3000 04	10000-02	14309-06	68993 04	67301 04	29231 01

Table 2--continued

Temperature, T (°K)	Pressure, P (atm)	Density, d (gm/cc)	Enthalpy, h (cal/gm)	Energy, u (cal/gm)	Entropy, s (cal/deg-gm)
3000 04	14404-02	20982-06	68226 04	66563 04	28771 01
3000 04	14404-02	23314-06	62624 04	61128 04	26903 01
3000 04	14404-02	26228-06	57023 04	55693 04	25036 01
3000 04	14404-02	29975-06	51421 04	50257 04	23169 01
3000 04	14404-02	34970-06	45819 04	44822 04	21302 01
3000 04	14404-02	41965-06	40217 04	39386 04	19434 01
3000 04	14404-02	52456-06	34616 04	33951 04	17567 01
3000 04	14404-02	69941-06	29014 04	28515 04	15700 01
3000 04	14404-02	10491-05	23412 04	23080 04	13833 01
3000 04	14404-02	20982-05	17810 04	17644 04	11965 01
3000 04	14404-02	20982-04	12769 04	12752 04	10285 01
3000 04	14404-02	20980-03	12265 04	12263 04	10117 01
3000 04	14404-02	20962-02	12214 04	12214 04	10100 01
3000 04	14404-02	20781-01	12209 04	12209 04	10098 01
2500 04	10000-07	62119-12	14433 05	14043 05	67867 01
2500 04	10000-06	11037-10	91149 04	88955 04	43748 01
2500 04	10000-05	15734-09	70604 04	69065 04	33892 01
2500 04	17741-05	28920-09	68923 04	67438 04	32873 01
2500 04	17741-05	32133-09	63001 04	61664 04	30504 01
2500 04	17741-05	36149-09	57079 04	55891 04	28135 01
2500 04	17741-05	41314-09	51158 04	50118 04	25766 01
2500 04	17741-05	48199-09	45236 04	44344 04	23398 01
2500 04	17741-05	57839-09	39314 04	38571 04	21029 01
2500 04	17741-05	72299-09	33392 04	32797 04	18660 01
2500 04	17741-05	96399-09	27470 04	27024 04	16291 01
2500 04	17741-05	14460-08	21547 04	21250 04	13923 01
2500 04	17741-05	28920-08	15625 04	15477 04	11554 01
2500 04	17741-05	28920-07	10296 04	10281 04	94218 00
2500 04	17741-05	28920-06	97627 03	97612 03	92086 00
2500 04	17741-05	28919-05	97094 03	97093 03	91873 00
2500 04	17741-05	28919-04	97041 03	97041 03	91852 00
2200 04	77088-08	13069-11	71788 04	70359 04	37447 01
2200 04	77088-08	14521-11	65431 04	64145 04	34557 01
2200 04	77088-08	16336-11	59074 04	57931 04	31668 01
2200 04	77088-08	18670-11	52717 04	51717 04	28778 01
2200 04	77088-08	21781-11	46360 04	45503 04	25889 01
2200 04	77088-08	26137-11	40003 04	39289 04	23000 01
2200 04	77088-08	32672-11	33646 04	33075 04	20110 01
2200 04	77088-08	43562-11	27290 04	26861 04	17221 01
2200 04	77088-08	65344-11	20933 04	20647 04	14331 01

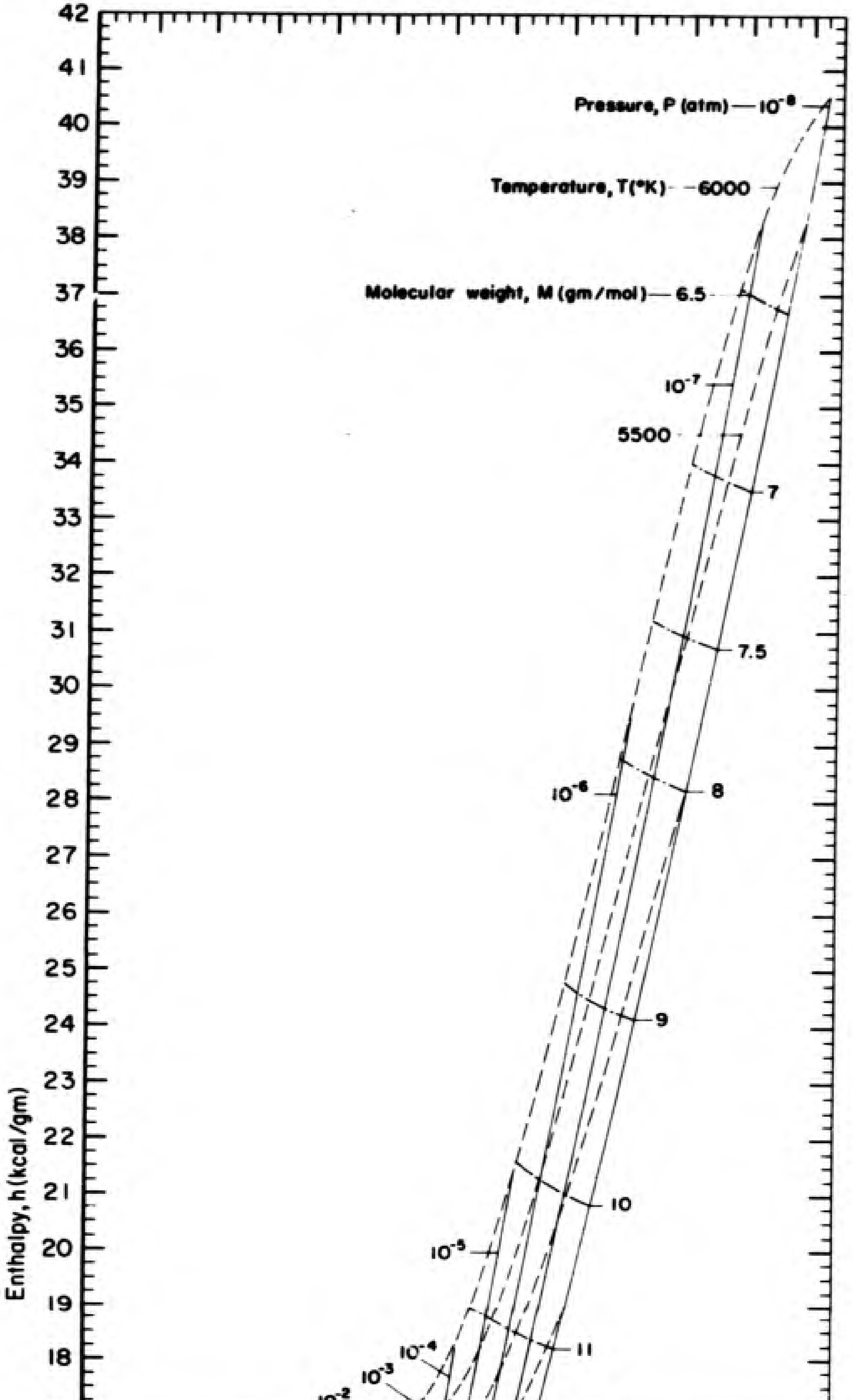
Table 2--continued

Temperature, T (°K)	Pressure, P (atm)	Density, d (gm/cc)	Enthalpy, h (cal/gm)	Energy, u (cal/gm)	Entropy, s (cal/deg-gm)
2200 04	77088-08	13069-10	14576 04	14433 04	11442 01
2200 04	77090-08	13069-09	88547 03	88404 03	88411 00
2200 04	77090-08	13069-08	82826 03	82812 03	85811 00
2200 04	77090-08	13069-07	82254 03	82252 03	85551 00
2200 04	77090-08	13069-06	82197 03	82196 03	85525 00
2000 04	94699-10	15786-13	76911 04	75458 04	42921 01
2000 04	94699-10	17540-13	69943 04	68636 04	39438 01
2000 04	94699-10	19733-13	62976 04	61814 04	35954 01
2000 04	94699-10	22552-13	56009 04	54992 04	32470 01
2000 04	94699-10	26310-13	49042 04	48170 04	28987 01
2000 04	94699-10	31572-13	42074 04	41348 04	25503 01
2000 04	94699-10	39466-13	35107 04	34526 04	22020 01
2000 04	94699-10	52621-13	28140 04	27704 04	18536 01
2000 04	94699-10	78931-13	21173 04	20882 04	15052 01
2000 04	94699-10	15786-12	14205 04	14060 04	11569 01
2000 04	94699-10	15786-11	79350 03	79204 03	84335 00
2000 04	94699-10	15786-10	73079 03	73065 03	81199 00
2000 04	94699-10	15786-09	72452 03	72451 03	80886 00
2000 04	94699-10	15786-08	72389 03	72389 03	80854 00
4244 04	10000 03	39613-01	41659 04	41047 04	17308 01
3979 04	10000 02	23967-02	49345 04	48334 04	19624 01
3697 04	10000 01	16988-03	58553 04	57131 04	22798 01
3425 04	10000 00	14181-04	65694 04	63998 04	25738 01
3184 04	10000-01	13890-05	67965 04	66240 04	27569 01
2968 04	10000-02	14631-06	68330 04	66674 04	29000 01
2779 04	10000-03	15156-07	68679 04	67079 04	30385 01
2613 04	10000-04	15812-08	68776 04	67244 04	31763 01
2465 04	10000-05	16409-09	69091 04	67616 04	33275 01
2332 04	10000-06	16757-10	70053 04	68609 04	35058 01
2213 04	10000-07	16935-11	71575 04	70145 04	37181 01

Table 3

SUMMARY OF PROPERTIES OF SOLID AND GAS
AT THE GRAPHITE TRIPLE POINT

	Solid	Gas
Temperature, T (^{o}K)	4247	4247
Pressure, P (atm)	103.31	103.31
log P	2.0142	2.0142
Enthalpy, h (cal/gm)	1860.7	4158.5
Entropy, s (cal/deg-gm)	1.1876	1.7286
Energy, u (cal/gm)	1859.5	4097.8
Free Energy, f (cal/gm)	-3183.0	-3182.9
Molecular Wt., M (gm/mol)	12.011	138.96
Density, d (gm/cc)	2.1621	0.041198
Volume, v (cc/gm)	0.46251	24.273
log v	-0.33487	1.3851
n_{solid} (moles)	1.0000	0
n_{gas} (moles)	0	0.086433



Enthalpy, h (kcal/gm)
42
41
40
39
38
37
36
35
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
Pressure, P (atm) — 10^-8
Temperature, T(°K) — 6000
Molecular weight, M (gm/mol) — 6.5
10^-7
5500
7
7.5
10^-6
8
9
10
10^-5
11
10^-4
10^-3

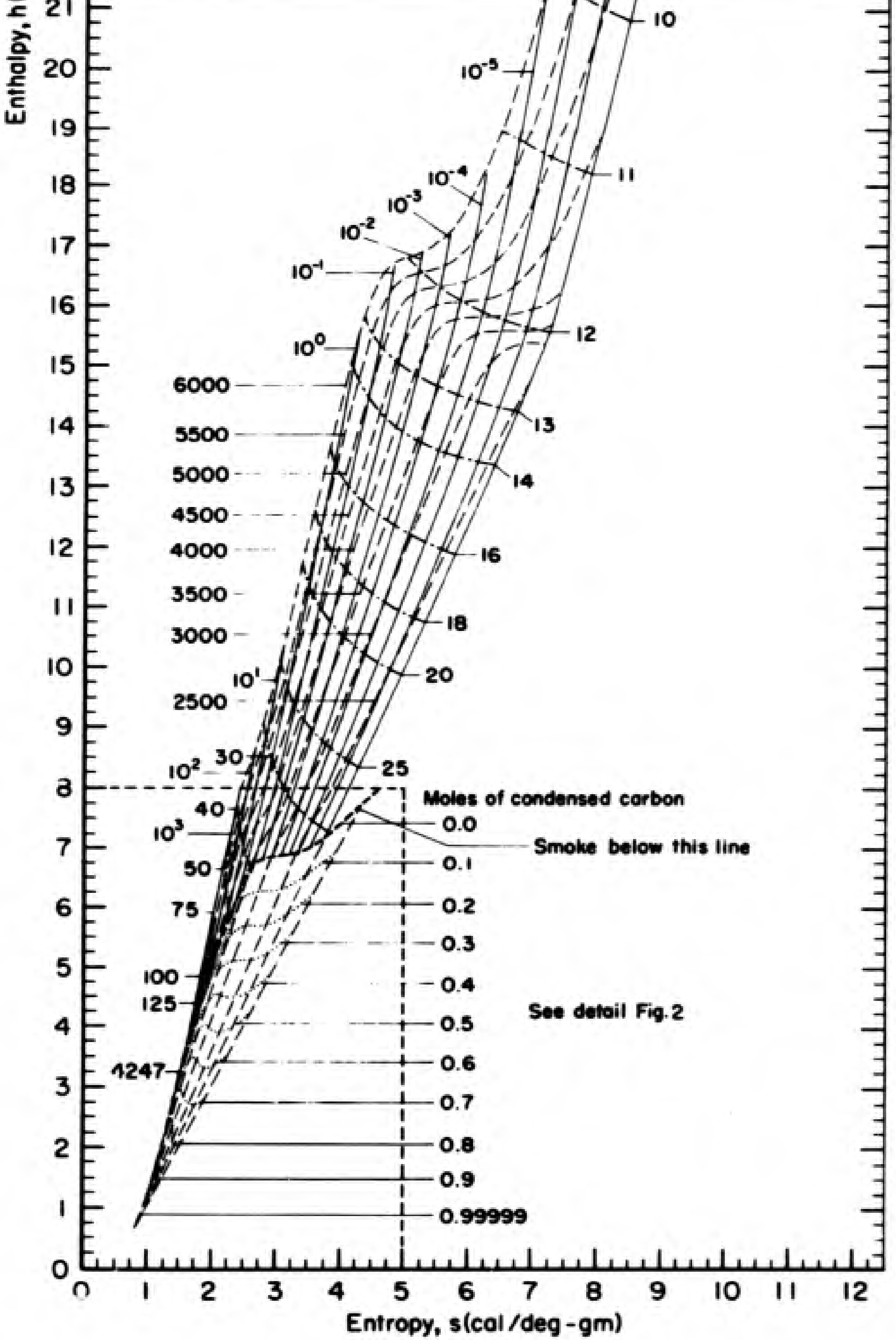
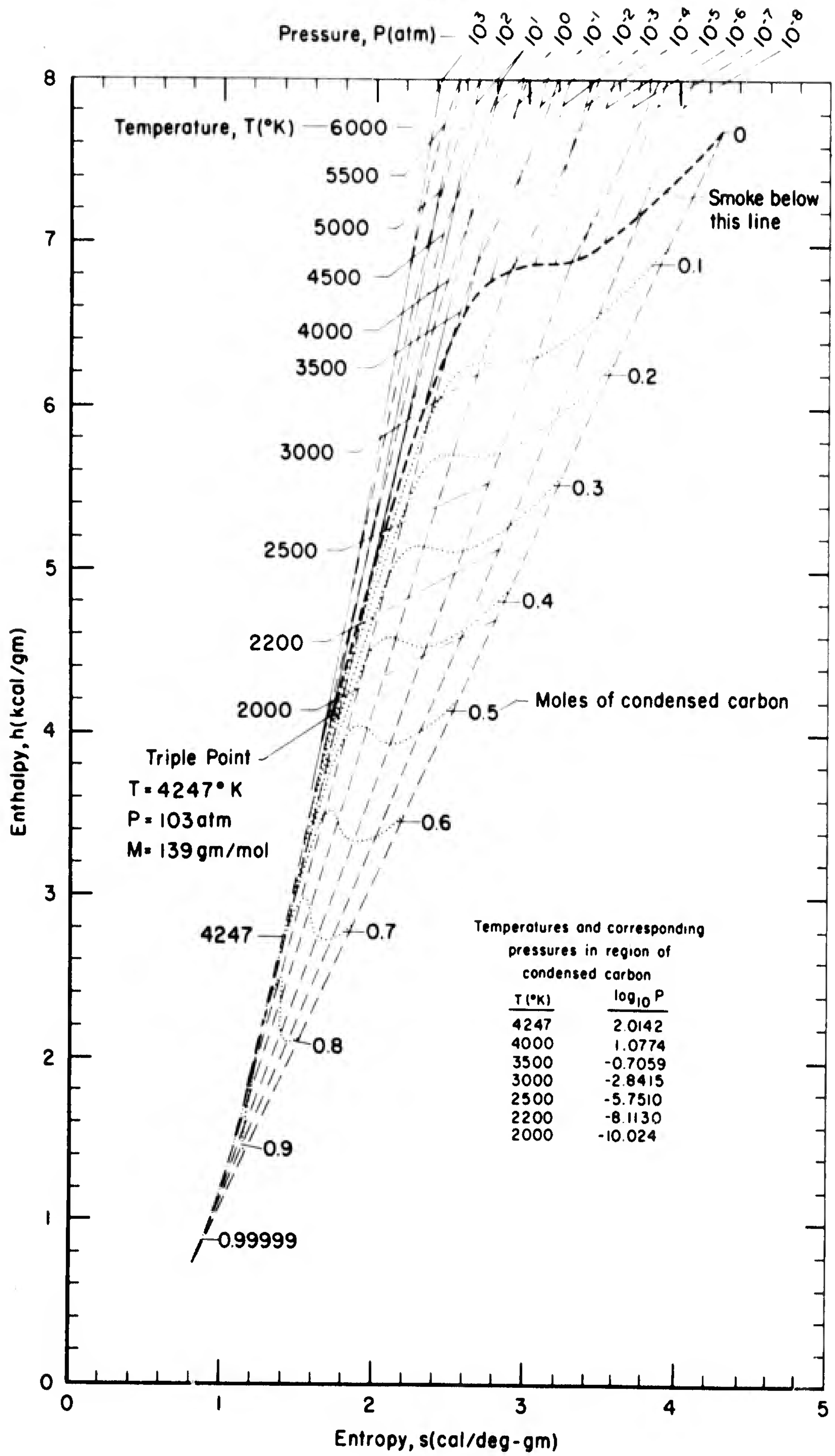


Fig. 1—Enthalpy versus entropy for graphite with cross plots of temperature, pressure, molecular weight, and moles of condensed carbon



T (°K)	$log_{10}P$
4247	2.0142
4000	1.0774
3500	-0.7059
3000	-2.8415
2500	-5.7510
2200	-8.1130
2000	-10.024

Fig.2—Detail of Fig.1

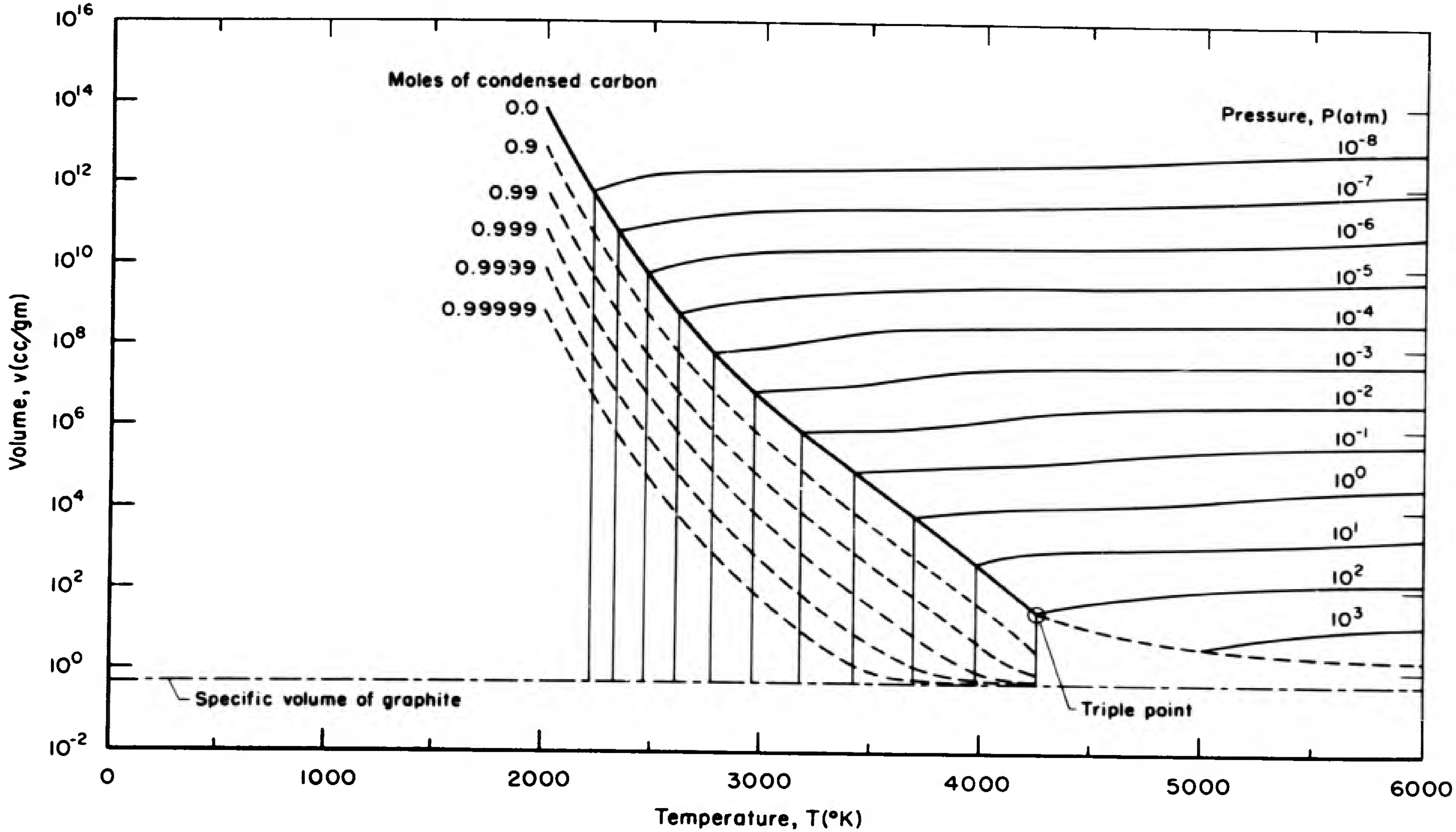


Fig.3—Volume versus temperature for graphite with cross plots of constant pressure and moles of condensed carbon

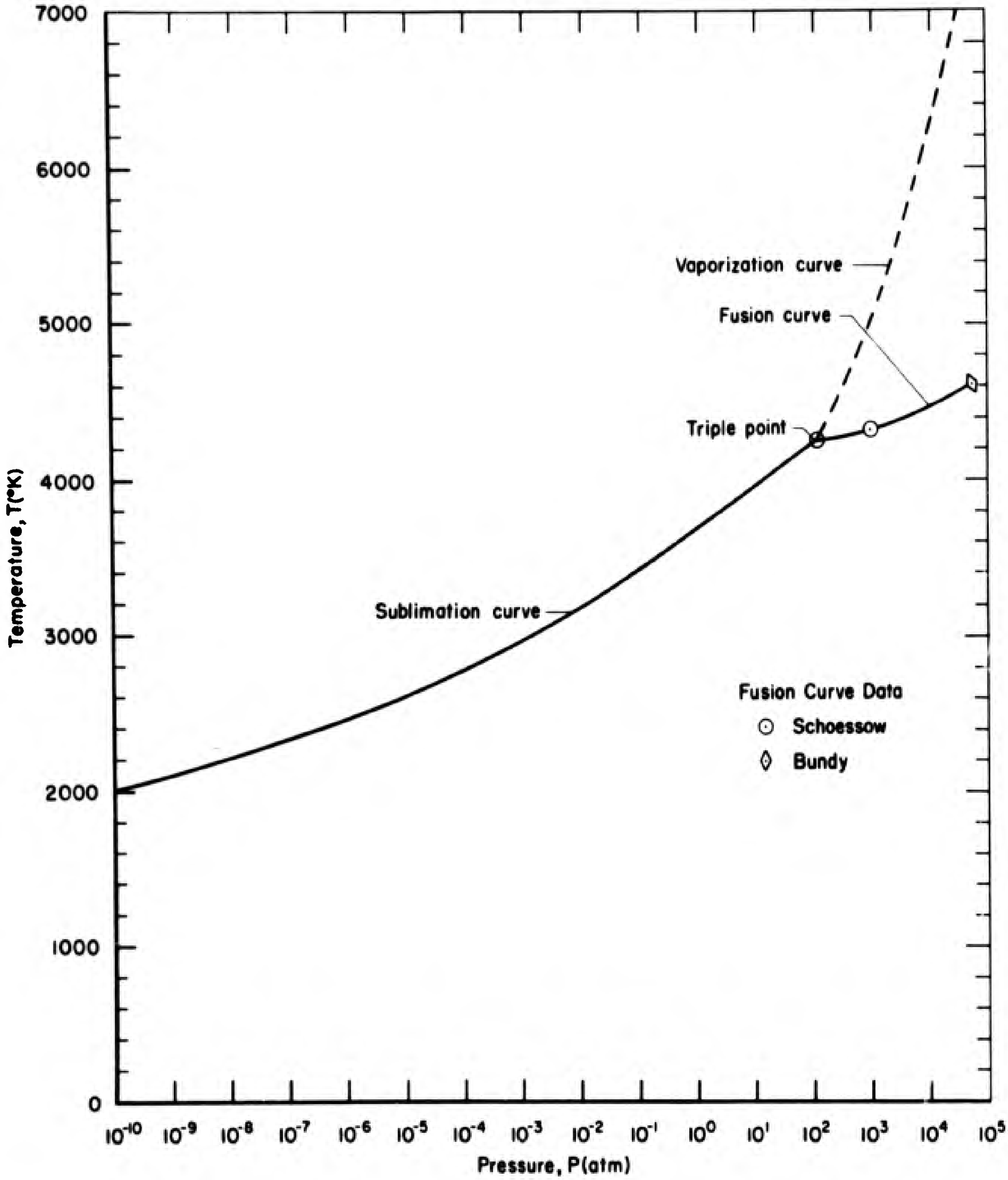


Fig.4—Phase diagram for graphite

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