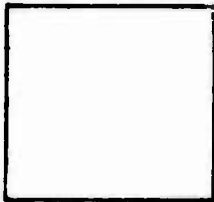


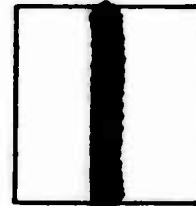
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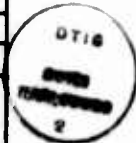
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The TPRC Data Series
VOLUME 8

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SPECIFIC HEAT

Nonmetallic Liquids and Gases

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SPECIFIC HEAT

Nonmetallic Liquids and Gases

THERMOPHYSICAL PROPERTIES OF MATTER
The TPRC Data Series

A Comprehensive Compilation of Data by the
Thermophysical Properties Research Center (TPRC), Purdue University

Y. S. Touloukian, Series Editor
C. Y. Ho, Series Technical Editor

-
- Volume 1. Thermal Conductivity—Metallic Elements and Alloys
 - Volume 2. Thermal Conductivity—Nonmetallic Solids
 - Volume 3. Thermal Conductivity—Nonmetallic Liquids and Gases
 - Volume 4. Specific Heat—Metallic Elements and Alloys
 - Volume 5. Specific Heat—Nonmetallic Solids
 - Volume 6. Specific Heat—Nonmetallic Liquids and Gases
 - Volume 7. Thermal Radiative Properties—Metallic Elements and Alloys
 - Volume 8. Thermal Radiative Properties—Nonmetallic Solids
 - Volume 9. Thermal Radiative Properties—Coatings
 - Volume 10. Thermal Diffusivity
 - Volume 11. Viscosity
 - Volume 12. Thermal Expansion—Metallic Elements and Alloys
 - Volume 13. Thermal Expansion—Nonmetallic Solids

New data on thermophysical properties are being constantly accumulated at TPRC. Contact TPRC and use its interim updating services for the most current information.

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oxygen--pentanol--pentane--phenyl compounds--phosgene--propene--propanol--
propyl compounds--propylene compounds--

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Volume 6 in this 14 volume TPRC Data Series covers nonmetallic substances
which are in the fluid state at normal temperature and pressure, including 12
elements, 10 inorganic compounds, 33 organic compounds, and air. Recommended
specific heat values for all these fluids are presented for saturated liquid,
saturated vapor, and gaseous states.

383 pages, 1970

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THERMOPHYSICAL PROPERTIES OF MATTER
VOLUME 6

SPECIFIC HEAT

Nonmetallic Liquids and Gases

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Nonmetallic Liquids and Gases

Y. S. Touloukian

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"In this work, when it shall be found that much is omitted, let it not be forgotten that much likewise is performed..."

SAMUEL JOHNSON, A.M.

From last paragraph of Preface to his two-volume *Dictionary of the English Language*.
Vol. I, page 5, 1755, London, Printed by Strahan.

Foreword

In 1957, the Thermophysical Properties Research Center (TPRC) of Purdue University, under the leadership of its founder, Professor Y. S. Touloukian, began to develop a coordinated experimental, theoretical, and literature review program covering a set of properties of great importance to science and technology. Over the years, this program has grown steadily, producing bibliographies, data compilations and recommendations, experimental measurements, and other output. The series of volumes for which these remarks constitute a foreword is one of these many important products. These volumes are a monumental accomplishment in themselves, requiring for their production the combined knowledge and skills of dozens of dedicated specialists. The Thermophysical Properties Research Center deserves the gratitude of every scientist and engineer who uses these compiled data.

The individual nontechnical citizen of the United States has a stake in this work also, for much of the science and technology that contributes to his well-being relies on the use of these data. Indeed, recognition of this importance is indicated by a mere reading of the list of the financial sponsors of the Thermophysical Properties Research Center; leaders of the technical industry of the United States and agencies of the Federal Government are well represented.

Experimental measurements made in a laboratory have many potential applications. They might be used, for example, to check a theory, or to help design a chemical manufacturing plant, or to compute the characteristics of a heat exchanger in a nuclear power plant. The progress of science and technology demands that results be published in the open literature so that others may use them. Fortunately for progress, the useful data in any single field are not scattered throughout the tens of thousands of technical journals published throughout the world. In most fields, fifty percent of the useful work appears in no more than thirty or forty journals. However, in the case of TPRC, its field is so broad

that about 100 journals are required to yield fifty percent. But that other fifty percent! It is scattered through more than 3500 journals and other documents, often items not readily identifiable or obtainable. Nearly 50,000 references are now in the files.

Thus, the man who wants to use existing data, rather than make new measurements himself, faces a long and costly task if he wants to assure himself that he has found all the relevant results. More often than not, a search for data stops after one or two results are found—or after the searcher decides he has spent enough time looking. Now with the appearance of these volumes, the scientist or engineer who needs these kinds of data can consider himself very fortunate. He has a single source to turn to; thousands of hours of search time will be saved, innumerable repetitions of measurements will be avoided, and several billions of dollars of investment in research work will have been preserved.

However, the task is not ended with the generation of these volumes. A critical evaluation of much of the data is still needed. Why are discrepant results obtained by different experimentalists? What undetected sources of systematic error may affect some or even all measurements? What value can be derived as a "recommended" figure from the various conflicting values that may be reported? These questions are difficult to answer, requiring the most sophisticated judgment of a specialist in the field. While a number of the volumes in this Series do contain critically evaluated and recommended data, these are still in the minority. The data are now being more intensively evaluated by the staff of TPRC as an integral part of the effort of the National Standard Reference Data System (NSRDS). The task of the National Standard Reference Data System is to organize and operate a comprehensive program to prepare compilations of critically evaluated data on the properties of substances. The NSRDS is administered by the National Bureau of Standards under a directive from the Federal Council for Science

and Technology, augmented by special legislation of the Congress of the United States. TPRC is one of the national resources participating in the National Standard Reference Data System in a united effort to satisfy the needs of the technical community for readily accessible, critically evaluated data.

As a representative of the NBS Office of Standard Reference Data, I want to congratulate Professor Touloukian and his colleagues on the accomplishments represented by this Series of reference data

books. Scientists and engineers the world over are indebted to them. The task ahead is still an awesome one and I urge the nation's private industries and all concerned Federal agencies to participate in fulfilling this national need of assuring the availability of standard numerical reference data for science and technology.

EDWARD L. BRADY
Associate Director for Information Programs
National Bureau of Standards

Preface

Thermophysical Properties of Matter, the TPRC Data Series, is the culmination of twelve years of pioneering effort in the generation of tables of numerical data for science and technology. It constitutes the restructuring, accompanied by extensive revision and expansion of coverage, of the original *TPRC Data Book*, first released in 1960 in loose-leaf format, 11" x 17" in size, and issued in June and December annually in the form of supplements. The original loose-leaf *Data Book* was organized in three volumes: (1) metallic elements and alloys, (2) nonmetallic elements, compounds, and mixtures which are solid at N.T.P., and (3) nonmetallic elements, compounds, and mixtures which are liquid or gaseous at N.T.P. Within each volume, each property constituted a chapter.

Because of the vast proportions the *Data Book* began to assume over the years of its growth and the greatly increased effort necessary in its maintenance by the user, it was decided in 1967 to change from the loose-leaf format to a conventional publication. Thus, the December 1966 supplement of the original *Data Book* was the last supplement disseminated by TPRC.

While the manifold physical, logistic, and economic advantages of the bound volume over the loose-leaf oversize format are obvious and welcome to all who have used the unwieldy original volumes, the assumption that this work will no longer be kept on a current basis because of its bound format would not be correct. Fully recognizing the need of many important research and development programs which require the latest available information, TPRC has instituted a *Data Update Plan* enabling the subscriber to inquire, by telephone if necessary, for specific information and receive, in many instances, same-day response on any new data processed or revision of published data since the latest edition. In this context, the TPRC Data Series departs drastically from the conventional handbook and giant multivolume classical works, which are no longer adequate media for the dissemination of

numerical data of science and technology without a continuing activity on contemporary coverage. The loose-leaf arrangements of many works fully recognize this fact and attempt to develop a combination of bound volumes and loose-leaf supplement arrangements as the work becomes increasingly large. TPRC's *Data Update Plan* is indeed unique in this sense since it maintains the contents of the TPRC Data Series current and live on a day-to-day basis between editions. In this spirit, I strongly urge all purchasers of these volumes to complete in detail and return the *Volume Registration Certificate* which accompanies each volume in order to assure themselves of the continuous receipt of annual listing of corrigenda during the life of the edition.

The TPRC Data Series consists initially of 13 independent volumes. The initial ten volumes will be published in 1970, and the remaining three by 1972. It is also contemplated that subsequent to the first edition, each volume will be revised, updated, and reissued in a new edition approximately every fifth year. The organization of the TPRC Data Series makes each volume a self-contained entity available individually without the need to purchase the entire Series.

The coverage of the specific thermophysical properties represented by this Series constitutes the most comprehensive and authoritative collection of numerical data of its kind for science and technology.

Whenever possible, a uniform format has been used in all volumes, except when variations in presentation were necessitated by the nature of the property or the physical state concerned. In spite of the wealth of data reported in these volumes, it should be recognized that all volumes are not of the same degree of completeness. However, as additional data are processed at TPRC on a continuing basis, subsequent editions will become increasingly more complete and up to date. Each volume in the Series basically comprises three sections, consisting of a text, the body of numerical data with source references, and a material index.

The aim of the textual material is to provide a complementary or supporting role to the body of numerical data rather than to present a treatise on the subject of the property. The user will find a basic theoretical treatment, a comprehensive presentation of selected works which constitute reviews, or compendia of empirical relations useful in estimation of the property when there exists a paucity of data or when data are completely lacking. Established major experimental techniques are also briefly reviewed.

The body of data is the core of each volume and is presented in both graphical and tabular format for convenience of the user. Every single point of numerical data is fully referenced as to its original source and no secondary sources of information are used in data extraction. In general, it has not been possible to critically scrutinize all the original data presented in these volumes, except to eliminate perpetuation of gross errors. However, in a significant number of cases, such as for the properties of liquids and gases and the thermal conductivity of all the elements, the task of full evaluation, synthesis, and correlation has been completed. It is hoped that in subsequent editions of this continuing work, not only new information will be reported but the critical evaluation will be extended to increasingly broader classes of materials and properties.

The third and final major section of each volume is the material index. This is the key to the volume, enabling the user to exercise full freedom of access to its contents by any choice of substance name or detailed alloy and mixture composition, trade name, synonym, etc. Of particular interest here is the fact that in the case of those properties which are reported in separate companion volumes, the material index in each of the volumes also reports the contents of the other companion volumes.* The sets of companion volumes are as follows:

Thermal conductivity:	Volumes 1, 2, 3
Specific heat:	Volumes 4, 5, 6
Radiative properties:	Volumes 7, 8, 9
Thermal expansion:	Volumes 12, 13

The ultimate aims and functions of TPRC's Data Tables Division are to extract, evaluate, reconcile, correlate, and synthesize all available data for the thermophysical properties of materials with

*For the first edition of the Series, this arrangement was not feasible for Volume 7 due to the sequence and the schedule of its publication. This situation will be resolved in subsequent editions.

the result of obtaining internally consistent sets of property values, termed the "recommended reference values." In such work, gaps in the data often occur, for ranges of temperature, composition, etc. Whenever feasible, various techniques are used to fill in such missing information, ranging from empirical procedures to detailed theoretical calculations. Such studies are resulting in valuable new estimation methods being developed which have made it possible to estimate values for substances and/or physical conditions presently unmeasured or not amenable to laboratory investigation. Depending on the available information for a particular property and substance, the end product may vary from simple tabulations of isolated values to detailed tabulations with generating equations, plots showing the concordance of the different values, and, in some cases, over a range of parameters presently unexplored in the laboratory.

The TPRC Data Series constitutes a permanent and valuable contribution to science and technology. These constantly growing volumes are invaluable sources of data to engineers and scientists, sources in which a wealth of information heretofore unknown or not readily available has been made accessible. We look forward to continued improvement of both format and contents so that TPRC may serve the scientific and technological community with ever-increasing excellence in the years to come. In this connection, the staff of TPRC is most anxious to receive comments, suggestions, and criticisms from all users of these volumes. An increasing number of colleagues are making available at the earliest possible moment reprints of their papers and reports as well as pertinent information on the more obscure publications. I wish to renew my earnest request that this procedure become a universal practice since it will prove to be most helpful in making TPRC's continuing effort more complete and up to date.

It is indeed a pleasure to acknowledge with gratitude the multisource financial assistance received from over fifty of TPRC's sponsors which has made the continued generation of these tables possible. In particular, I wish to single out the sustained major support being received from the Air Force Materials Laboratory-Air Force Systems Command, the Office of Standard Reference Data-National Bureau of Standards, and the Office of Advanced Research and Technology-National Aeronautics and Space Administration. TPRC is indeed proud to have been designated as a National Information Analysis Center for the Department of Defense as well as a component of the National

Standard Reference Data System under the cognizance of the National Bureau of Standards.

While the preparation and continued maintenance of this work is the responsibility of TPRC's Data Tables Division, it would not have been possible without the direct input of TPRC's Scientific Documentation Division and, to a lesser degree, the Theoretical and Experimental Research Divisions. The authors of the various volumes are the senior staff members in responsible charge of the work. It should be clearly understood, however, that many have contributed over the years and their contributions are specifically acknowledged in each volume. I wish to take this opportunity to personally

thank those members of the staff, research assistants, graduate research assistants, and supporting graphics and technical typing personnel without whose diligent and painstaking efforts this work could not have materialized.

Y. S. TOULOUKIAN

Director

*Thermophysical Properties Research Center
Distinguished Atkins Professor of Engineering*

Purdue University
Lafayette, Indiana
July 1969

Introduction to Volume 6

This volume of *Thermophysical Properties of Matter*, the TPRC Data Series, covering the specific heat of fluids, presents the data on nonmetallic materials which are in the liquid or gaseous state at normal temperature and pressure. It is not as comprehensive as its two companion volumes, Volumes 4 and 5, primarily because we have not been able to cover an extensive number of fluids due to lack of technological interest.

The volume comprises three major sections: the front text material together with its bibliography, the main body of numerical data with its references, and the material index.

The text material is intended to assume a role complementary to the main body of numerical data which is the primary purpose of this volume. It is felt that a concise discussion of the theoretical nature of the property under consideration together with a review of predictive procedures and recognized experimental techniques will be appropriate in a major reference work of this kind. The extensive reference citations given in the text should lead the interested reader to a highly comprehensive literature for a detailed study. It is hoped, however, that enough detail is presented for this volume to be self-contained for the practical user.

The main body of the volume consists of the presentation of numerical data compiled over the years in a most meticulous manner. The coverage includes a selected number of pure substances, identical to those covered in Volume 3 of this Series, which are felt to be of greatest engineering importance. The extraction of all data directly from their original sources ensures freedom from errors of transcription. Furthermore, some gross errors appearing in the original source documents have been corrected. The organization and presentation of the data together with other pertinent information on the use of the tables and figures are discussed in detail in the text of the section entitled *Numerical Data*.

All the data presented in this volume have been critically reviewed and analyzed, and "recommended reference values" are presented.

As stated earlier, all data have been obtained from their original sources and each data set is so referenced. TPRC has in its files all documents cited in this volume. Those that cannot readily be obtained elsewhere are available from TPRC in microfiche form.

The material index at the end of the volume covers the contents of all three companion volumes (Volumes 4, 5, and 6) on specific heat. It is hoped that the user will find these comprehensive indices helpful.

This volume has grown out of the activities made possible principally through the support of the Air Force Materials Laboratory-Air Force Systems Command, under the monitorship of Mr. John H. Charlesworth, and the Office of Standard Reference Data-National Bureau of Standards, under the monitorship of Dr. Howard J. White, Jr. The authors wish to acknowledge the contributions made by Dr. K. Hamanoue and Messrs. O. Takagi, K. Kamata, and K. Ueda of TPRC's Kobe Affiliate Group.

Inherent to the character of this work is the fact that in the preparation of this volume we have drawn most heavily upon the scientific literature and feel a debt of gratitude to the authors of the referenced articles. While their often discordant results have caused us much difficulty in reconciling their findings, we consider this to be our challenge and our contribution to negative entropy of information, as an effort is made to create from the randomly distributed data a condensed, more orderly state.

While this volume is primarily intended as a reference work for the designer, researcher, experimentalist, and theoretician, the teacher at the graduate level may also use it as a teaching tool to point out to his students the topography of the state of knowledge on the specific heat of fluids. We believe there is also much food for reflection by the specialist and the academician regarding the meaning of "original" investigation and its "information content."

The authors and their contributing associates are keenly aware of the possibility of omissions or

errors which may be encountered in a work of this scope. We hope that these faults will not be judged too harshly and that we will receive the benefit of suggestions regarding references omitted, additional material groups needing more detailed treatment, improvements in presentation, and, most important, any inadvertent errors. If the *Volume Registration*

Certificate accompanying this volume is returned, the reader will assure himself of receiving annually a list of corrigenda as possible errors come to our attention.

Lafayette, Indiana
July 1969

Y. S. TOULOUKIAN
T. MAKITA

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GROUPING OF MATERIALS AND LIST OF FIGURES AND TABLES

1. ELEMENTS

Figure and/or Table No.	Name	Symbol	Physical State*	Page No.
1	Argon	A	L, G	1
2	Bromine	Br ₂	L, G	7
3	Chlorine	Cl ₂	L, G	11
4	Deuterium	D ₂	L, G	15
5	Fluorine	F ₂	L, G	19
6	Helium	He	-, G	23
7	Hydrogen	H ₂	L, G	26
8	Krypton	Kr	L, G	34
9	Neon	Ne	-, G	37
10	Nitrogen	N ₂	L, G	39
11	Oxygen	O ₂	L, G	48
12	Xenon	Xe	L, G	57

2. INORGANIC COMPOUNDS

13	Ammonia	NH ₃	L, G	61
14	Boron Trifluoride	BF ₃	L, G	67
15	Hydrogen Chloride	HCl	L, G	72
16	Hydrogen Iodide	HI	-, G	76
17	Hydrogen Sulfide	H ₂ S	L, G	78
18	Nitric Oxide	NO	L, G	83
19	Nitrogen Peroxide	NO ₂	L, -	90
20	Nitrous Oxide	N ₂ O	L, G	92
21	Sulfur Dioxide	SO ₂	L, G	97
22	Water	H ₂ O	L, G	102

3. ORGANIC COMPOUNDS

23	Acetone	(CH ₃) ₂ CO	L, G	113
24	Acetylene	CHCH	-, G	117
25	Benzene	C ₆ H ₆	L, G	121
26	i-Butane	i-C ₄ H ₁₀	L, G	129
27	n-Butane	n-C ₄ H ₁₀	L, G	136
28	Carbon Dioxide	CO ₂	L, G	143
29	Carbon Monoxide	CO	L, G	152
30	Carbon Tetrachloride	CCl ₄	L, G	159

* L = liquid, G = gas.

xviii *Grouping of Materials and List of Figures and Tables*

3. ORGANIC COMPOUNDS (continued)

Figure and/or Table No.	Name	Formula	Physical State*	Page No.
31	Chloroform	CHCl_3	L, G	166
32	n-Decane	$\text{C}_{10}\text{H}_{22}$	L, G	170
33	Ethane	C_2H_6	L, G	174
34	Ethyl Alcohol	$\text{C}_2\text{H}_5\text{OH}$	L, G	180
35	Ethylene	CH_2CH_2	L, G	185
36	Ethylene Glycol	$\text{CH}_2\text{OHCH}_2\text{OH}$	L, -	192
37	Ethyl Ether	$(\text{C}_2\text{H}_5)_2\text{O}$	L, G	194
38	Freon 11	Cl_3CF	L, G	200
39	Freon 12	Cl_2CF_2	L, G	204
40	Freon 13	ClCF_3	-, G	210
41	Freon 21	Cl_2CHF	L, G	212
42	Freon 22	ClCHF_2	L, G	218
43	Freon 113	$\text{CCl}_2\text{FCClF}_2$	L, G	224
44	Freon 114	$\text{CClF}_2\text{CClF}_2$	-, G	228
45	Glycerol	$\text{CH}_2\text{OHCHOHCH}_2\text{OH}$	L, -	230
46	n-Heptane	C_7H_{16}	L, G	232
47	n-Hexane	C_6H_{14}	L, G	238
48	Methane	CH_4	L, G	244
49	Methyl Alcohol	CH_3OH	L, G	252
50	Methyl Chloride	CH_3Cl	L, G	257
51	n-Nonane	C_9H_{20}	L, G	261
52	n-Octane	C_8H_{18}	L, G	266
53	n-Pentane	C_5H_{12}	L, G	272
54	Propane	C_3H_8	L, G	279
55	Toluene	$\text{C}_6\text{H}_5\text{CH}_3$	L, G	285

4. MIXTURES

56	Air	-, G	293
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Theory, Estimation, and Measurement

Notation

a	Velocity of sound	n_A	Number of atoms in a molecule
a_r	Total number of phase cells in the phase space	n_r	Number of molecules in r th phase cell
B	A constant in rotational energy states, $B = h/8\pi^2 CI$	P	Pressure, in atm
b	Conversion factor from atmospheres to dynes cm^{-2} , $b = 1.0132 \times 10^6$	Q	Partition function (sum of states); Heat energy exchanged with system
C	Constant temperature coefficient; A constant in Boltzmann statistics, equation (38)	q_r	General designation for statistical weight
c	Velocity of light, $c = 2.997925 \times 10^{10}$ cm sec^{-1}	R	Universal gas constant
C_p	Specific heat at constant pressure	S	Entropy
C_s	Specific heat under saturated conditions	T	Absolute equilibrium temperature
C_v	Specific heat at constant volume	v	Vibrational statistical weight
$(C_v)_{el}$	Specific heat due to electronic configurations	V	Total volume
$(C_v)_{nu}$	Specific heat due to nuclear spins	W	Number of different complexions corre- sponding to a statistical state of a gas
$(C_v)_{rot}$	Specific heat due to rotation of molecule as a whole	Wk	Work done on or by system
$(C_v)_{tr}$	Specific heat due to translation of center of gravity of the molecule	x	Reduced temperature, $x = \theta_{vib}/T = hv/kT$
$(C_v)_{vib}$	Specific heat due to vibration of atoms inside the molecule	Z	Compressibility, $Z = PV/RT$
E	Total energy of all n molecules; Internal energy of system; Electrical voltage	α	Exponent in expression $PV^\alpha = \text{constant}$ in expansion of real gases, see equation (89)
e	Base of Napierian logarithms	β	Volumetric coefficient of expansion
f	Number of degrees of freedom	γ	Specific heat ratio, C_p/C_v
F	Flow rate of fluid through calorimeter	Δ	Volume of a phase cell
g_{el}	Electronic statistical weight	$\bar{\epsilon}$	Average energy of a molecule
g_{nu}	Nuclear spin statistical weight	θ_{vib}	Vibrational characteristic temperature, $\theta_{vib} = hv/k$
H	Enthalpy	κ_T	Isothermal compressibility
h	Planck constant, $h = 6.6262 \times 10^{-27}$ erg sec	λ	Wavelength, in cm
I	Moment of inertia of a molecule; Electrical current	μ_J	Joule-Thomson coefficient
i_s	Number of units of spin of the nucleus of an atom	v	Frequency of vibration, in cycles sec^{-1} , $v = c\omega$
J	Rotational quantum weight; Electrical equi- valent of heat	π	A mathematical constant, $\pi = 3.14159...$
k	Boltzmann constant (gas constant per molecule), $k = 1.3806 \times 10^{-16}$ erg K^{-1}	$\prod_i$	Mathematical symbol indicating product of a series of i terms
$\ln$	Logarithm to the base e	ρ	Density
m	Mass of a molecule	$\sum_i$	Mathematical symbol indicating summation of a series of i terms
N	Avogadro's number; Total number of molecules	σ	Symmetry number in rotational states for the different spatial orientations of a molecule which are physically indistinguishable
		ϕ	Volume of the phase space in which repre- sentative molecules may be found
		ω	Wave number, in cm^{-1} , $\omega = 1/\lambda$

Specific Heat of Liquids and Gases

1. INTRODUCTION

The specific heat is one of the most important thermodynamic properties of pure substances, and at the same time it is one of those measurable in the laboratory to a degree of confidence proportional to the expenditure of care and the refinement of technique. In the particular case of gases, accurate heat-capacity measurements, at several pressures and over a range of temperature, are valuable in at least two ways: (a) They may be extrapolated to zero pressure at the several temperatures to obtain a set of values of ideal-gas specific heat. For gases of any complexity, the specific heats thus obtained frequently may be used to decide questions of structure or vibrational frequency. Once a reliable set of molecular constants is available, the zero-pressure thermodynamic properties may be calculated over a temperature range far larger than that of the specific heat experiments. (b) The values obtained for the change of specific heat with pressure may be an order of magnitude more accurate than the same quantity calculated from data of state of good accuracy. Thus there is provided an opportunity to check or modify existing equations of state.

In the past two decades it has become accepted that ideal-gas specific heat of diatomic molecules and others of very simple structure can be calculated statistically with at least as good reliability as they can be obtained from experimental measurements. This does not mean, however, that gas specific heat measurements are no longer necessary; on the contrary, they are becoming more important both in regard to C_p^0 and equation of state for the vast majority of substances in the vapor state which are too complex for reliable statistical calculations.

In this introductory presentation a brief review of the basic nature of the specific heat or heat capacity is given, together with the thermodynamic relations for its derivation from data of state and various experimental and theoretical methods. These thermodynamic equations are perfectly general

and apply to both the liquid and gaseous state except where the relations are for the dilute or perfect gas. The treatment also presents a very brief exposition to the calculation of zero-pressure specific heat of gases because of its basic importance. For a more detailed exposition on the subject, the reader may refer to a number of excellent texts or original articles cited herein.

As to the liquid state, it has long been customary to classify liquids into two classes, *normal liquids* and *associated liquids*, based on the general guidelines whether their physical properties obeyed certain empirical relationships or not. Those liquids whose properties exhibited anomalies were referred to as associated liquids because their deviation from empirical rules were thought to be due to association of the molecules in the vapor phase to form larger molecules in the condensed phase. In present day, because of our better understanding of the molecular state, we define normal liquids as the state in which the internal degrees of freedom of each molecule are not seriously disturbed by the close proximity of the other molecules in the liquid. In such a state the partition functions will be the product of a partition function for the translations of the molecules and a partition function for the internal degrees of freedom of each single molecule, the latter being very similar to those for gaseous molecules. In an associated liquid, on the other hand, the originally gaseous molecules interact so intimately that the rotational and vibrational degrees of freedom are seriously modified; some rotations may become frozen, and atoms from different molecules may become bound to each other so tightly that one speaks of the formation of new chemical links.

The study of associated liquids has only been started and few liquids have been examined by modern methods. Even when we exclude association there are incomparably greater difficulties in applying statistical mechanics to a liquid than to a dilute gas or to a crystal. For in a dilute gas we have complete randomness of configuration and in a crystal we

have almost complete order; in a liquid we have neither and it is this fact which makes it so difficult to find a useful model.

Until recent years all attempts to discuss the liquid state have been based on the theory of dense gases. However, more recently, we have reached the conclusion that a liquid is much more like a crystal than like a dense gas and the structure is conveniently referred to as quasi-crystalline. Whereas in a crystal each molecule is surrounded by a definite invariable number of nearest neighbors, this number is not definite in a liquid. Nevertheless, at temperatures well below the critical temperature, the number of nearest neighbors has a fairly well defined average value, and although there are fluctuations about this average, these fluctuations are not serious, and the geometrical relationship of each molecule to its immediate neighbors is on the average very similar to that in a crystal.

2. DEFINITION OF SPECIFIC HEATS

In thermodynamics, the specific heats at constant pressure and at constant volume are given by definition as

$$C_p = \left(\frac{\partial H}{\partial T} \right)_p \quad (1)$$

and

$$C_v = \left(\frac{\partial E}{\partial T} \right)_v \quad (2)$$

Furthermore, the property enthalpy, H , is given by definition as $H = U + PV$. Based on these three definitions, and using the First Law of thermodynamics we shall interrelate C_p and C_v to the heat-energy quantities measured experimentally in their determination.

For a unit mass of a substance undergoing a change of state, we can write the First Law of thermodynamics as

$$dQ = dE + d(Wk) \quad (3)$$

Let us select two specific constant-pressure processes for the unit mass to undergo, between the same identical end states in each process:

First process: Heat is exchanged but no shaft work crosses the boundaries of the constant-pressure system.

Under these conditions the above First Law relationship reduces to

$$dQ = dE + PdV$$

or

$$\begin{aligned} dQ &= d(E + PV) \\ &= dH \end{aligned} \quad (4)$$

Second process: The process is adiabatic but shaft work is done on the constant-pressure system.

Under these conditions the First Law relationship reduces to

$$\begin{aligned} 0 &= dE + PdV - d(Wk) \\ d(Wk) &= dE + PdV \\ &= d(E + PV) \\ &= dH \end{aligned} \quad (5)$$

When the magnitude of the heat exchanged in the first process is made equal to the shaft work done in the second process $|dQ| = |d(Wk)|$, then the enthalpy changes, dH , in the two processes would have been the same and the system would have undergone an identical change of state between the same end states irrespective of the process. Therefore, we have shown that for a constant-pressure process where no shaft work is involved, $dH = dQ$ and therefore $C_p = (dQ/dT)_p$. Hence the term "specific heat" is a misnomer unless its definition includes a sufficiently circumscribed description of the process in which at constant pressure $dH = dQ$.

A very similar type of treatment is made to show that for a constant-volume process $dE = dQ$, and hence $C_v = (dQ/dT)_v$ under specified conditions only.

In addition to the constant-pressure and constant-volume processes which are of primary interest in the evaluation of the specific heat, the specific heat of saturated liquids and solids, $C_s = (dQ/dT)_s$, is also of importance in a number of engineering applications. This definition implies that during the addition of heat the solid or liquid is kept in equilibrium with an infinitesimal amount of its saturated vapor. Strictly speaking, the heat capacity of a saturated liquid or solid cannot be measured at constant pressure, because the temperature rises during the absorption of heat and the pressure varies according to the vapor pressure relation. If the pressure were kept constant the liquid or solid would evaporate and one would measure the latent heat effect and not the specific heat. Since the difference between C_p and C_s is usually negligibly small, many investigators have

This is
terrible.

What are

U PV

E Q

Wk

used C_p instead of C_v for the liquid or solid under saturated vapor pressure. In this volume, the symbol C_p is maintained for liquids under saturated vapor pressures, and the designation "saturated liquid" is specified in the departure plots.

3. USEFUL RELATIONSHIPS BETWEEN C_p , C_v AND OTHER THERMODYNAMIC PROPERTIES [11]

A. The Difference between C_p and C_v

Although there is no apparent connection between the two heat capacities C_p and C_v , we may develop several relations without any limiting assumptions by simply using the First and Second Laws of thermodynamics. Several useful relationships are summarized as follows:

$$C_p - C_v = \left[P + \left(\frac{\partial E}{\partial V} \right)_T \right] \left(\frac{\partial V}{\partial T} \right)_p \quad (6)$$

$$C_p - C_v = \left[V + \left(\frac{\partial H}{\partial P} \right)_T \right] \left(\frac{\partial P}{\partial T} \right)_v \quad (7)$$

$$C_p - C_v = \left[V + \left(\frac{\partial H}{\partial T} \right)_p \left(\frac{\partial T}{\partial P} \right)_h \right] \left(\frac{\partial P}{\partial T} \right)_v \quad (8)$$

$$C_p - C_v = T \left(\frac{\partial V}{\partial T} \right)_p \left(\frac{\partial P}{\partial T} \right)_v \quad (9)$$

$$C_p - C_v = -T \left(\frac{\partial V}{\partial T} \right)_p^2 / \left(\frac{\partial V}{\partial P} \right)_T \quad (10)$$

$$C_p - C_v = -T \left(\frac{\partial P}{\partial T} \right)_v^2 / \left(\frac{\partial P}{\partial V} \right)_T \quad (11)$$

$$\left(\frac{C_p - C_v}{R} \right) = \frac{[Z - T(\partial Z / \partial T)_p]^2}{[Z - P(\partial Z / \partial P)_T]} \quad (12)$$

As there is no restriction in the derivation of these equations, they are applicable to any substance in any physical state. Equations (9) and (10) are especially convenient in practical use, because the difference between the two heat capacities may be represented by P - V - T relation only. Furthermore, substituting in equation (10) the volumetric coefficient of thermal expansion $\beta = [(1/V)(\partial V / \partial T)_p]$ and the coefficient of isothermal compressibility $\kappa_T = -[(1/V)(\partial V / \partial P)_T]$, we may obtain for the ideal-gas state

$$C_p - C_v = \frac{\beta^2}{\kappa_T} VT \quad (13)$$

The value of $C_p - C_v$ for most solids is relatively

small, and values for the elements in the solid state range up to ten percent of the values of C_v . The value of $C_p - C_v$ for a substance in the liquid state is usually larger than for the same substance in the solid state, since the value of the coefficient of expansion is usually larger in the liquid state. For an ideal gas, the difference between C_p and C_v can be simply derived from any one of equations (5) through (10), in using the condition that defines the ideal gas:

$$C_p - C_v = R \quad (14)$$

where R is the universal gas constant, 1.9872 cal g-mole⁻¹ K⁻¹. For the real gas at 1 atm, the value of $C_p - C_v$ is not greatly different from R .

In general, if we know the value of either C_p or C_v for a substance, the other may be derived from the above equations, using the P - V - T data, an appropriate equation of state for the substance concerned, or the compressibility. This volume concerns itself only with the specific heat at constant pressure.

Similarly, the difference between C_p and C_s is represented in the same form as equation (9) as follows:

$$C_p - C_s = T \left(\frac{\partial V}{\partial T} \right)_p \left(\frac{\partial P}{\partial T} \right)_s \quad (15)$$

B. The Ratio of C_p over C_v

The ratio of the heat capacities at constant pressure and constant volume, designated by γ , is also important in reversible adiabatic processes. The fundamental relation used to express this ratio is given by

$$\gamma = \frac{C_p}{C_v} = \left(\frac{\partial V}{\partial P} \right)_s / \left(\frac{\partial V}{\partial P} \right)_T \quad (16)$$

where the subscript s refers to an isentropic process. The adiabatic compressibility is defined as

$$\kappa_s = -\frac{1}{V} \left(\frac{\partial V}{\partial P} \right)_s \quad (17)$$

and after using the isothermal compressibility κ_T as defined by equation (17), equation (16) may be written as

$$\gamma = \frac{\kappa_s}{\kappa_T} \quad (18)$$

The propagation of sound compresses the fluid adiabatically. The velocity of sound a at low frequency

and low amplitudes in a fluid of density ρ is given by the following exact relation:

$$a = \left(\frac{\partial P}{\partial \rho} \right)_s^{1/2} = (\kappa_s \rho)^{1/2} \quad (19)$$

Substituting this relation into equation (16), we obtain

$$\gamma = -\frac{a^2}{V^2} \left(\frac{\partial V}{\partial P} \right)_T \quad (20)$$

Consequently, the ratio of heat capacities may be derived from experimental values of velocity of sound together with the knowledge of P - V - T relations. Furthermore, combining equation (20) with equation (9) or (10), we can obtain the values of C_p or C_v for fluids:

$$C_v = \frac{T(\partial P/\partial T)_v^2 (\partial V/\partial P)_T}{(a^2/V^2) + (\partial P/\partial V)_T} \quad (21)$$

$$C_p = -\frac{T(\partial P/\partial T)_v^2}{1 + (V^2/a^2)} \quad (22)$$

This procedure is frequently used as one method of indirect experimental determination of specific heat.

C. General Thermodynamic Relations for C_p and C_v

The indirect determination of C_p and C_v as a function of pressure and temperature are based on the formulation of well known general thermodynamic relations for pure substances which involve the definitions of these two properties, knowledge of a valid equation of state or data of state (P - V - T data), and one other auxiliary set of data such as the Joule-Thomson coefficient $\mu_J = (\partial T/\partial P)_h$ or the constant-temperature coefficient $C = (\partial H/\partial P)_T$. In fact the interrelationship

$$C_p = -\frac{C}{\mu_J} \quad (23)$$

is often used in comparing experimental data from various sources. Through the use and manipulation of the Maxwell relations one obtains relations for C_p as a function of (H , S , T) or (P , V , T); such as

$$C_p = T \left(\frac{\partial S}{\partial T} \right)_p \quad (24)$$

or

$$\left(\frac{\partial C_p}{\partial P} \right)_T = T \left(\frac{\partial^2 V}{\partial T^2} \right)_p \quad (25)$$

Using these relationships C_p may be derived through

thermodynamic functions or tabulations. However, in normal practice C_p is used in the formulation of these derived thermodynamic functions (i.e., enthalpy, entropy, free energies, etc.) and its determination is based on statistical mechanical deductions or experimental calorimetry.

4. PREDICTION OF ZERO-PRESSURE SPECIFIC HEAT OF GASES [11, 12, 13]

A. General Considerations

The study of specific heats at vanishingly low pressures (zero pressure) is of importance because numerical calculations can be performed with extreme accuracy through theoretical considerations of the internal energy of matter. As in the statistical mechanical theory of matter the quantity calculated is the internal energy; therefore, the specific heat at constant volume is obtained directly from these calculations from the definition $C_v = (\partial E/\partial T)_v$. At vanishingly low pressures (perfect gas) $C_p = R - C_v$.

From classical statistical mechanics and Maxwell's law of equipartition of energy the average energy per degree of freedom for a molecule consisting of a point mass with no intermolecular forces, is given by

$$\bar{\epsilon} = \frac{1}{2} RT, \text{ per degree of freedom} \quad (26)$$

and the specific heat

$$C_v = \left(\frac{\partial \bar{\epsilon}}{\partial T} \right)_v = \frac{1}{2} R, \text{ per degree of freedom} \quad (27)$$

The classical statistical mechanics assumes only translational and rotational energies to exist and on this basis leads to C_v values shown in column 5 in the following table. As is well known, equations (26) and (27) apply with great accuracy to monatomic gases but are quite inadequate for diatomic and polyatomic gases as they predict C_v to be independent of temperature and to be an integral multiple of $\frac{1}{2}R$. Actually, C_v for diatomic* and polyatomic gases

*For diatomic molecules at about room temperature C_v is approximately 5 although such gases really fall into 3 groups: (1) For one gas, H_2 , C_v is appreciably less than 5 at room temperature and decreases fairly rapidly with decreasing temperature. (2) For a group of diatomic gases (O_2 , N_2 , CO , NO , HCl , HBr , HI) C_v is nearly 5 over a wide range of temperatures, the members of this group showing small but well established differences in C_v . (3) The halogen gases (Cl_2 , Br_2 , and I_2) have higher values of C_v , about 6 at ordinary temperatures, but are more dependent on temperature than those of group (2). Polyatomic gases have values of C_v almost always greater than 6.

1	2	3	4	5	6
Molecule	f Translation	f Rotation	f Vibration*	$\frac{1}{2}Rf$, cal/mol C from classical mechanics	C_v Observed
Monatomic	3	0	0	$\frac{3}{2}R \approx 3$	3
Diatomic	3	2	1	$\frac{5}{2}R \approx 5$	5
Triatomic	3	3	3	$\frac{9}{2}R \approx 6$	>6
n_A -atomic	3	3	$3n_A - 6$	$\frac{3}{2}R \approx 6$	>6

*The number of vibrational degrees of freedom of a molecule containing n_A atoms is calculated as follows:

$$f_{\text{vib}} = 3n_A - f_{\text{tr}} - f_{\text{ro}} = 3n_A - 3 - 3 = 3n_A - 6$$

increases with increasing temperature. The variation of C_v with temperature may be explained, at least qualitatively, on the basis of the acquisition of additional degrees of freedom by the molecule. However, this is not generally successful, and in the case of H_2 it is necessary to assume that the two degrees of "rotational" freedom disappear at lower temperatures, a result quite incompatible with the classical theory.

The above results and discussion indicate the very limited validity of classical mechanics and it is only by abandoning the "general" validity of the theorem of equipartition that the specific heats of gases can be satisfactorily explained. The proper mechanics to use in dealing with atomic and molecular systems has been discovered in the process of development of the quantum theory.

For our present purpose, the total energy of a molecule can be divided into energies of translation, rotation, vibration, electronic excitation, and nuclear spin. We may describe the state of affairs with a considerable degree of accuracy by the statement that these energies can be assumed to be independent of each other and additive. Strictly speaking, vibrational and rotational energies cannot be separated into two parts since actual molecules are not perfectly rigid structures and the equilibrium distance will vary somewhat with the state of rotation. In other words, there will be an interaction between vibrational and rotational states. We must also say that even the energy of translation is "quantized," but for any actual gas the temperature at which a deviation from the classical laws could be observed is so close to the absolute zero that the relatively large departures from ideal-gas behavior due to intermolecular forces make it impossible to detect the deviation

predicted by the quantum theory. The only exception to this statement is the "electron gas" in metals.

We can therefore write in symbolic form

$$\epsilon = \epsilon_{\text{tr}} + \epsilon_{\text{ro}} + \epsilon_{\text{vib}} + \epsilon_{\text{el}} + \epsilon_{\text{nu}} \quad (28)$$

or

$$C_v^0 = \frac{\partial \epsilon}{\partial T} \quad (29)$$

$$= (C_v)_{\text{tr}} + (C_v)_{\text{ro}} + (C_v)_{\text{vib}} + (C_v)_{\text{el}} + (C_v)_{\text{nu}}$$

But

$$C_v^0 = C_p^0 - R$$

Hence

$$C_p^0 = R + (C_v)_{\text{tr}} + (C_v)_{\text{ro}} + (C_v)_{\text{vib}} + (C_v)_{\text{el}} + (C_v)_{\text{nu}} \quad (30)$$

B. Statistical Mechanical Definitions

a. The Phase Space and Phase Cell

In studying a system of N identical molecules, each possessing f degrees of freedom, it is convenient to imagine a $2f$ -dimensional phase space. Each molecule of the gas can then be represented by a point in the phase space. The phase space is divided into equal volume elements of size Δ where the element Δ is supposed to be very small but nevertheless finite. The following discussion is restricted to a system of monatomic gas.

If then our system of molecules is contained in a volume V and if the greatest energy any molecule can possess is ϵ , then it can be shown that the volume of the "phase space" accessible to representative points is given by the equation

$$\phi = \frac{1}{h^3} V (2m\epsilon)^{3/2} \quad (31)$$

For points which represent molecules with energies in the range ϵ to $\epsilon + \delta\epsilon$, where $\delta\epsilon$ is small but finite, the available volume $\delta\phi$ of the phase space is obtained from equation (31) with sufficient accuracy by the equation

$$\delta\phi = 2\pi V(2m)^{3/2}\epsilon^{1/2}\delta\epsilon \quad (32)$$

If we denote by a_r the number of "cells," each of volume Δ , which corresponds to energies in the range ϵ_r to $\epsilon_r + \delta\epsilon$, we find from equation (32)

$$a_r = \frac{\delta\phi}{\Delta} = \frac{2\pi V}{\Delta}(2m)^{3/2}\epsilon_r^{1/2}\delta\epsilon \quad (33)$$

b. Boltzmann Statistics

In classical statistics we have no information about the proper size of the phase cell. For a monatomic gas whose total energy is E , the value of ϕ can be obtained from equation (31) by replacing ϵ by E . This phase volume ϕ we imagine divided up into a large number of cells, the volumes of which are equal but otherwise arbitrary. A statistical state of the whole gas is specified by giving the number of representative points in each phase cell; a complexion is described by specifying the individual molecules in each cell. This, of course, assumes that identical molecules can be distinguished for the purpose of enumerating the number of complexions which correspond to a given statistical state. If we assume that the probability of a statistical state is proportional to the number of complexions corresponding to this state, we can show that the most probable statistical state is the one that occurs in the equilibrium state of the gas.

Based on these considerations and the conditions that:

$$\sum n_r = N = \text{const}, \quad \sum \delta n_r = 0 \quad (34)$$

$$\sum \epsilon_r n_r = E = \text{const}, \quad \sum \epsilon_r \delta n_r = 0 \quad (35)$$

$$\ln W \text{ is a maximum,} \quad \delta \ln W = 0 \quad (36)$$

We obtain the most important result of Boltzmann's statistics; namely,

$$n_r = \frac{1}{C} \exp(-\epsilon_r/kT) \quad (37)$$

where n_r = number of molecules in the r th phase cell of volume Δ , ϵ_r = the energy of a molecule in the r th phase cell, and C = a constant (to be evaluated later).

c. Quantum Weights

If the possible energy states (levels) of a molecule

are arranged in an increasing order, it may be possible that these energy levels can be divided into groups, such that the energy difference between any two levels in a group is small compared with the energy difference between two successive groups. If q_r is the number of levels in such a group and if we can assign without appreciable error the energy ϵ_r to each level in the group as the same, then it is convenient to treat such a group of states as a single state of "quantum" or "statistical" weight q_r .^{*} Under these conditions equation (37) of Boltzmann's statistics is written in the form*

$$n_r = \frac{q_r}{C} \exp(-\epsilon_r/kT) \quad (38)$$

d. Sum of States—The Partition Function

Corresponding to each of the types of energy into which we have divided the total energy of a molecule, equation (28), there is a certain function Q , called the "sum of states" or the "partition function," which is frequently used in calculating the thermodynamic properties of an ideal gas. If $\epsilon_0, \epsilon_1, \dots, \epsilon_r$ denote the energy levels for the type of energy considered, and if the level of energy ϵ_r has a quantum statistical weight q_r , then the sum of states Q is given by the expression

$$Q = q_0 \exp(-\epsilon_0/kT) + q_1 \exp(-\epsilon_1/kT) + \dots + q_r \exp(-\epsilon_r/kT) = \sum q_r \exp(-\epsilon_r/kT) \quad (39)$$

Q in equation (39) stands for any one of the functions Q_{tr} , Q_{rot} , Q_{vib} , Q_{el} , Q_{nu} . Each of these is a function of T only, except Q_{tr} , which is a function of T and P . If we restrict our considerations to conditions of temperature and pressure under which the Boltzmann statistics is valid, we find, in view of equation (38),

$$N = \sum n_r = \frac{1}{C} \sum q_r \exp(-\epsilon_r/kT) = Q/C \quad (40)$$

Hence,

$$C = \frac{Q}{N} \quad n_r = \frac{N}{Q} q_r \exp(-\epsilon_r/kT) \quad (41)$$

$$E = \sum \epsilon_r n_r = \frac{N}{Q} \sum \epsilon_r q_r \exp(-\epsilon_r/kT)$$

*It can be shown that the value of the constant C in equation (38) is very large for all gases (except the "electron gas" in metals), even at very low temperature, if the pressure of the gas is moderately low. On this basis we can conclude that the Boltzmann statistics is sufficiently accurate for all usual applications to gases and we need not consider any other types of statistics (i.e., Fermi-Dirac or Bose-Einstein statistics).

$$= \frac{N \sum \epsilon_r q_r \exp(-\epsilon_r/kT)}{\sum q_r \exp(-\epsilon_r/kT)} \quad (42)$$

$$E = -Nk \left[\frac{\partial \ln Q}{\partial (1/T)} \right]_v = Nk T^2 \left(\frac{\partial \ln Q}{\partial T} \right)_v$$

$$E = RT^2 \left(\frac{\partial \ln Q}{\partial T} \right)_v \quad (43)$$

where $Nk = R$.

From equation (43)

$$C_v = \left(\frac{\partial E}{\partial T} \right)_v = R \frac{\partial}{\partial T} \left(T^2 \frac{\partial \ln Q}{\partial T} \right)_v$$

$$C_v = RT \left[\frac{\partial^2 (T \ln Q)}{\partial T^2} \right]_v \quad (44)$$

The complete partition function Q of a molecule is defined by the equation

$$Q = Q_{tr} \times Q_{rot} \times Q_{vib} \times Q_{el} \times Q_{nu} \quad (45)$$

Since, $\ln Q = \ln Q_{tr} + \ln Q_{rot} + \dots$, it is seen that equations (43) and (44) can be applied to any one of the various partition functions to give the corresponding values of energy and specific heat.

C. Contributions of the Various Forms of Energy to the Total Energy of a Molecule and the Specific Heat

a. Translational Energy

The translational energy of a molecule is obtained with great accuracy from classical statistics by considering the center of gravity of the molecule to have a kinetic energy of translation as given by equation (26),

$$\bar{\epsilon} = \frac{1}{2} RT, \text{ per degree of freedom} \quad (26)$$

Therefore for the three degrees of freedom of translation

$$E_{tr} = \frac{3}{2} RT$$

and

$$(C_v)_{tr} = \frac{3}{2} R \quad (46)$$

The translational energy may also be quantized leading to the translational partition function

$$Q_{tr} = \frac{(2\pi mkT)^{3/2} NkT}{Pbh^3} \quad (47)$$

when the pressure P is expressed in atmospheres and $b = 1.0132 \times 10^6$ is the factor that converts atmospheres into dynes per cm^2 . Q_{tr} is seen to be a function of T and P . For one mole of a gas, equations (43) and (47) give

$$E_{tr} = RT^2 \frac{(\partial \ln Q_{tr})}{\partial T} = \frac{3}{2} RT \quad (48)$$

and from equations (44) and (47) or differentiating equation (48) with respect to T

$$(C_v)_{tr} = RT \left[\frac{\partial^2 (T \ln Q_{tr})}{\partial T^2} \right] = \frac{3}{2} R \quad (49)$$

b. Electronic Energy (Excited States)

If the electronic levels of energy are represented in ascending order by $\epsilon_0, \epsilon_1, \epsilon_2, \dots$ with corresponding statistical weights $g_0, g_1, g_2, \dots$, the electronic partition function is given by the expression

$$Q_{el} = g_0 \exp(-\epsilon_0/kT) + g_1 \exp(-\epsilon_1/kT) + \dots$$

$$= g_e \exp(-\epsilon_0/kT) \quad (50)$$

where,

$$g_e = g_0 + g_1 \exp[-(\epsilon_1 - \epsilon_0)/kT] + \dots$$

From equation (50),

$$\ln Q_{el} = \ln g_e - \frac{\epsilon_0}{kT} \quad (51)$$

$$T \ln Q_{el} = T \ln g_e - \frac{\epsilon_0}{k} \quad (52)$$

From equations (43) and (51)

$$E_{el} = RT^2 \left[\frac{d \ln g_e}{dT} - \frac{d(\epsilon_0/kT)}{dT} \right]$$

$$= RT^2 \left(\frac{d \ln g_e}{dT} \right) + (E_0)_{el} \quad (53)$$

where $(E_0)_{el}$ is the electronic energy per mole when all the molecules are in their lowest electronic level.

$$(C_v)_{el} = R \frac{d}{dT} \left(\frac{T^2 d \ln g_e}{dT} \right) = RT \left[\frac{d^2 (T \ln g_e)}{dT^2} \right] \quad (54)$$

At low temperatures, all the atoms or molecules will be in the lowest level ϵ_0 ; the same statement can be made for room temperature or even moderately high temperatures if the difference $(\epsilon_1 - \epsilon_0)$ is very large compared with kT . Under these circumstances, the partition function given by equation (50) can be represented with sufficient accuracy by the equation

$$Q_{el} = g_0 \exp(-\epsilon_0/kT) \quad (55)$$

Under these conditions it can be seen that in equations (53) and (54) the derivatives of $\ln g_e$ with respect to T are negligibly small. For the case of equation (55) [where g_e from equation (50) reduces

to $g_0 = \text{constant}$] equations (53) and (54) reduce to

$$E_{e1} = (E_0)_{e1} \quad (56)$$

$$(C_v)_{e1} = 0 \quad (57)$$

In most calculations, except at very high temperatures, C_{e1} is assumed negligible.

c. Vibrational Energy

From quantum mechanics it is found that the energy ϵ_{vib} of a harmonic oscillator in a diatomic molecule (linear oscillator) or polyatomic molecule (nonlinear oscillator) is given as a whole multiple of a quantum ($h\nu$) by the equation

$$\epsilon_{vib} = h\nu[\nu + \frac{1}{2}] \quad (58)$$

where,

$$h\nu = hc\omega_1 \quad (59)$$

An expression for the partition function Q_{vib} (for strictly harmonic vibration) is

$$\begin{aligned} Q_{vib} &= \sum_{\nu=0}^{\infty} \exp[-h\nu/kT(\nu + \frac{1}{2})] \\ &= \exp(-h\nu/2kT)[1 + \exp(-h\nu/kT) \\ &\quad + \exp(-2h\nu/kT) + \dots] \\ &= \frac{\exp(-h\nu/2kT)}{[1 - \exp(-h\nu/kT)]} \end{aligned} \quad (60)$$

Letting

$$x_1 = h\nu_1/kT$$

from equation (60) we can write

$$\ln Q_{vib} = -\frac{x_1}{2} - \ln(1 - e^{-x_1}) \quad (61)$$

From equations (43) and (61) we get

$$E_{vib} = \frac{RTx_1}{e^{x_1} - 1} + \frac{1}{2}RTx_1 = \frac{RTx_1}{e^{x_1} - 1} + (E_0)_{vib} \quad (62)$$

and from equation (62)

$$(C_v)_{vib} = \frac{Rx_1^2 e^{x_1}}{(e^{x_1} - 1)^2} \quad (63)$$

In equations (62) and (63) ν_1 are independent of pressure and temperature and are obtained from spectroscopic measurements of the gas at rather very low pressures to reduce the effect of molecular encounters and thus obtain sharper spectrograms.

d. Vibrational Characteristic Temperature

For a linear (diatomic) harmonic oscillator the

characteristic vibrational temperature is defined as

$$\theta_{vib} = \frac{h\nu_1}{k} = \frac{hc\omega}{k} \quad (64)$$

then x becomes

$$x = \frac{\theta_{vib}}{T}$$

Hence, if θ_{vib} is given for a particular vibration, we can calculate E_{vib} and $(C_v)_{vib}$ from equations (62) and (63) by using values of the Einstein functions:

$$(E - E_0)_{vib} = \frac{3RTx}{e^x - 1}, \quad \text{Einstein} \quad (65)$$

$$(C_v)_{vib} = \frac{3Rx^2 e^x}{(e^x - 1)^2}, \quad \text{Einstein} \quad (66)$$

Since the Einstein functions [equations (65) and (66)] refer to an oscillator with three degrees of freedom, then for a given vibration in a gas molecule we shall have the relations

$$E_{vib} = \frac{1}{3}(E)_{\text{Einstein}} \quad (67)$$

$$(C_v)_{vib} = \frac{1}{3}(C_v)_{\text{Einstein}} \quad (68)$$

Einstein functions are found tabulated (for both E_{vib} and C_{vib}) as a function of x or θ_{vib} .

e. Rotational Energy

Here we have to distinguish between linear (diatomic) molecules and nonlinear (polyatomic) molecules. We must also introduce the "symmetry number" σ , which is the number of different spatial orientations of a molecule which are physically indistinguishable. For example, the molecules AB, AAB, ABC, have each a symmetry number equal to 1; the molecule AA and ABA have each a symmetry number 2. Molecules like CH_4 and CCl_4 possess a symmetry number 12.

Since the moments of inertia of a molecule are functions of the vibrational and rotational states, an exact expression for the rotational energy is somewhat complicated. We shall consider here the simple case where the moment of inertia I of a diatomic molecule is assumed to be constant. On this assumption the rotational energy is obtained from the relation

$$\epsilon_j/hC = J(J+1)B \quad (69)$$

where B is a constant, $B = h/8\pi^2 CI$. For diatomic molecules, quantum mechanics gives for the statistical weight of the energy level ϵ_j the quantity $(2J+1)$. The partition function of the states Q_{rot} can be

expressed then by the relation

$$Q_{\text{rot}} = \sum_{J=0}^{\infty} (2J+1) \exp \left[-\sigma J(J+1) \frac{hcB}{kT} \right] \quad (70)$$

A sufficiently accurate value of the summation of equation (70) is

$$Q_{\text{rot}} = \frac{kT}{\sigma hcB} = \frac{8\pi^2 IkT}{\sigma h^2} \quad (71)$$

Therefore from equations (43) and (71)

$$E_{\text{rot}} = RT^2 \left(\frac{d \ln \frac{8\pi^2 IkT}{\sigma h^2}}{dT} \right) = RT \quad (72)$$

and

$$(C_v)_{\text{rot}} = \frac{d(RT)}{dT} = R \quad (73)$$

At very low temperatures Q_{rot} will be represented by the first two terms of the above sum [equation (70)]; and it can be shown that both E_{rot} and $(C_v)_{\text{rot}}$ approach zero exponentially as T approaches zero. Equations (72) and (73) are for the case of a diatomic molecule, where it is regarded as a small "dumbbell." Rotation about the axis joining the two molecules is not affected by collisions and is not effective, but the two rotations of the molecule about its center of gravity in two planes at right angles can be changed by collisions, and hence the molecule has two effective rotational degrees of freedom. A rigid molecule containing more than two atoms will have one more additional effective rotational degree of freedom. Hence for a polyatomic molecule, equations (72) and (73) become

$$E_{\text{rot}} = \frac{3}{2} RT \quad (74)$$

$$(C_v)_{\text{rot}} = \frac{3}{2} R \quad (75)$$

f. Combined Rotational and Vibrational Energies

Since actual molecules are not perfectly rigid structures, the equilibrium distance between any two vibrating nuclei in a rotating molecule will vary somewhat with the state of rotation. Hence the vibration frequencies and moments of inertia will not be strictly constant. In other words, there will be an interaction between the rotational and vibrational states, and the complete expression for the rotational-vibrational energy cannot be strictly separated into two parts, one containing only the rotational quantum number J , the second containing only the vibrational quantum number v .

An approximate value of $Q_{v,J}$ which includes both vibrational and rotational states of a diatomic molecule is obtained by multiplying Q_{vib} of equation (60) by Q_{rot} of equation (71). Thus we find

$$Q_{v,J} = \left[\frac{\frac{8\pi^2 IkT}{\sigma h^2} \exp(hcB/3kT) \cdot \exp(-x/2)}{(1 - e^{-x})} \right] \quad (76)$$

Equation (76) can be used for ordinary temperatures and above and would replace the partition functions given by equations (60) and (71). The term $\exp(hcB/3kT)$ can be replaced by unity except when the moment of inertia of the molecule is exceptionally small.

For nonlinear polyatomic molecules which have no internal rotations, we shall merely write down the partition function which corresponds to equation (76) for diatomic (linear) molecules. If we let I_1, I_2 , and I_3 be the three principal moments of inertia about the three mutually perpendicular axis, then, when the moments of inertia are large and the temperatures are high, the following expression is valid:

$$Q_{v,J} = \frac{8\pi^2 (8\pi^3 I_1 \cdot I_2 \cdot I_3)^{1/2}}{\sigma h^3} (kT)^{3/2} \prod_i \frac{\exp(-x_i/2)}{1 - \exp(-x_i)} \quad (77)$$

g. Nuclear Spin Energy

If the nucleus of an atom has i_s units of spin (unit of spin = $h/2\pi$) there are $(2i_s + 1)$ different orientations of the spin axis which make $(2i_s + 1)$ different contributions to the energy of the atom. We may represent these $(2i_s + 1)$ nuclear energy levels by $\epsilon_0, \epsilon_1, \epsilon_2$, etc. The nuclear partition function can be expressed then

$$Q_{\text{nu}} = \exp(-\epsilon_0/kT) + \exp(-\epsilon_1/kT) + \cdots \quad (78)$$

However, it is to be noted that the difference between $\epsilon_0, \epsilon_1, \epsilon_2$, etc., are exceedingly small, so that, for any temperature even a few degrees above absolute zero equation (78) can be written as

$$Q_{\text{nu}} = g_{\text{nu}} \exp(-\epsilon_0/kT) \quad (79)$$

where $g_{\text{nu}} = (2i_s + 1)$, called sometimes the nuclear multiplicity.

From equation (79):

$$\ln Q_{\text{nu}} = \ln g_{\text{nu}} - \epsilon_0/kT \quad (80)$$

and

$$T \ln Q_{\text{nu}} = T \ln g_{\text{nu}} - \epsilon_0/k \quad (81)$$

From equations (43) and (80)

$$E_{\text{nu}} = RT^2 \frac{d(\ln g_{\text{nu}})}{dT} + (E_0)_{\text{nu}} \quad (82)$$

and from equations (44) and (81)

$$(C_v)_{\text{nu}} = RT \frac{d^2(T \ln g_{\text{nu}})}{dT^2} \quad (83)$$

The magnitude of equations (82) and (83) are negligibly small for all gases except H_2 and D_2 . It is only for H_2 and D_2 that we need to concern ourselves about nuclear spin contributions in applying functions calculated by statistical mechanical methods.

h. Summary

In concluding the discussion of the previous pages we see that for most gases (except H_2 and D_2 , and the "electron gas" in metals)

$$(C_v)_{\text{el}} \approx 0$$

$$(C_v)_{\text{nu}} \approx 0$$

Therefore we can write equation (30) in the form:

Diatomic Gases

$$C_v = C_p^0 - R = \left(\frac{3}{2}R\right)_{\text{tr}} + (R)_{\text{rot}} + \left[R \sum_{v_i} \frac{x_i^2 \exp(x_i)}{[\exp(x_i) - 1]^2}\right]_{\text{vib}} \quad (84)$$

or

$$C_p^0 = \frac{7}{2}R + \left[R \sum_{v_i} \frac{x_i^2 \exp(x_i)}{[\exp(x_i) - 1]^2}\right] \quad (85)$$

Polyatomic Gases:

$$C_v = C_p^0 - R = \left(\frac{3}{2}R\right)_{\text{tr}} + \left(\frac{3}{2}R\right)_{\text{rot}} + \left(R \sum_{v_i} \frac{x_i^2 \exp(x_i)}{[\exp(x_i) - 1]^2}\right)_{\text{vib}} \quad (86)$$

or

$$C_p^0 = 4R + \left[R \sum_{v_i} \frac{x_i^2 \exp(x_i)}{[\exp(x_i) - 1]^2}\right] \quad (87)$$

Example: For the molecule CF_3H (consisting of 5 atoms) we see that the number of vibrational degrees of freedom are: $f = (3 \times 5 - 6) = 9$. Therefore there are 9 frequencies of vibration, ν_1 to ν_9 , which can be obtained from spectroscopic studies. For CF_3H the values of ν_1 are [13]:

$$\begin{aligned} \nu_1 &= 3100 \text{ cycles cm}^{-1} \\ \nu_2 &= 1100 \text{ cycles cm}^{-1} \\ \nu_3 &= 700 \text{ cycles cm}^{-1} \\ \nu_4 &= \nu_5 = 1250 \text{ cycles cm}^{-1} \\ \nu_6 &= \nu_7 = 900 \text{ cycles cm}^{-1} \\ \nu_8 &= \nu_9 = 500 \text{ cycles cm}^{-1} \end{aligned}$$

Using equation (87), where $x = h\nu_i/kT$, C_p^0 can be calculated.

5. EXPERIMENTAL DETERMINATION OF SPECIFIC HEAT OF FLUIDS

A. General Considerations

The specific heat of gases and liquids has been studied extensively by a variety of methods and their multivariants. Several comprehensive works have authoritatively reviewed the experimental methods and techniques on specific heat measurements; therefore, this section constitutes only a brief review of the general features of the more important method in use and for study in depth, the reader should refer to the major reference works [1-9].

An important milestone in the history of gas heat capacities was the publication in 1924 of Partington and Shilling's *Specific Heat of Gases* [1]. That volume not only gave a detailed description of each worker's method and apparatus, but also tabulated the results obtained by all workers, for a large number of gases. The reader should consult this work for discussion of some of the classical experiments and detailed description of apparatus and methods.

In 1968, an extensive publication appeared under the series title *Experimental Thermodynamics*. Volume I of this series entitled *Calorimetry of Non-reacting Systems*, edited by McCullough and Scott [2], constitutes a most exhaustive coverage of all aspects of experimental calorimetry with the exception of microcalorimetry. This work in essence upgrades the earlier review of Partington and Shilling, except that no experimental data are reported or reviewed. The specialized field of microcalorimetry is well covered by references [4, 5] while reacting systems is reviewed in references [7, 8].

For the purpose of this review, direct determinations of the specific heat at constant pressure are those which involve a calorimeter. The major methods that come under this category are:

- | | |
|--------------------------------|--------|
| a. Constant-flow calorimeter | gas |
| b. Isothermal drop calorimeter | liquid |

- c. Conduction calorimeter liquid
- d. Mixing method calorimeter gas, liquid
- e. Heat-exchanger calorimeter gas, liquid

Indirect determinations of specific heat are those in which another variable is measured, and C_p may be derived only with knowledge of the equation of state or the specific heat of a calibrating fluid. The major methods in the category are:

- a. Isentropic expansion method gas
- b. Velocity of sound method gas, liquid
- c. Joule-Thomson effect method gas

The above methods of direct or indirect calorimetry are named after the phenomenological process associated with the method. Other calorimeters are named after the scientist who first used it extensively. Examples are:

- a. Bunsen ice-calorimeter—isothermal
- b. Nernst calorimeter—isothermal shield (also referred to as isoperibol)
- c. Joule twin calorimeter—also referred to as twin or differential calorimeter
- d. Dewar low-temperature calorimeter—also referred to as cryostat
- e. Calvet calorimeter—twin isothermal micro-calorimeter
- f. Callendar radiation balance—also referred to as radio balance microcalorimeter

The names of several calorimeters also describe a characteristic property or function of the calorimeter. Examples are: *microcalorimeter*, *flow calorimeter*, *aneroid calorimeter* (*copper block calorimeter*), *radiation calorimeter*, *receiving calorimeter*, etc.

B. Choice of the Calorimetric Method

The first question raised in undertaking a calorimetric project is the choice of the method to be used. There are a large number of factors to be considered (both scientific and fiscal) some of which are briefly touched upon below.

Two of the primary decisions to be made at the very outset are the desired accuracy of results and financial and personnel commitments. These factors while seemingly unrelated are very much interconnected indeed since an order of magnitude improvement in accuracy implies several orders of magnitude increase in effort but also the type of expertise the personnel should have to undertake the task. Most calorimetric determinations at moderate temperatures can be made with reasonable effort to within 1 percent accuracy. Accuracies of the order of

0.1 percent are obtained with sophisticated instrumentation and techniques while accuracies of 0.001 percent are very seldom encountered if at all justifiable from the standpoint of effort required. An important factor related to accuracy is the factor of absolute or relative measurements. The latter leads to simpler methods if adequate standard reference samples are available for calibration purposes commensurate with the accuracy desired. It should be clear that in the design of relative measurements the accuracy of the results obtained will be approximately one order of magnitude less than the accuracy with which the property of the reference samples are known.

The temperature and pressure range involved as well as the amount of sample available are also key factors in the selection of the method to be used. For instance, flow calorimeters are suitable when a large volume of the gas is available while the drop technique will do best for small samples of liquids where ease of sample replacement will be advantageous for measurements on a large number of samples. However, in the final analysis, in most practical instances limitations of available instrumentations, time, and qualifications of personnel force at times drastic compromises with the resultant deficiencies in the results.

In general, there is no such thing as a *best method*. For a given situation several methods may yield the same overall performance. Once sample size is determined for a liquid or gas and the accuracy required specified, based on their degree of sophistication, the personnel involved will optimize the resources at their disposal with such other parameters as heat leak characteristics of shields and thermal lag of calorimeter components for the temperature range under consideration. Above all one should never lose sight of the fact that equilibrium thermodynamics requires both the initial and final states of the sample to be well known. When one suspects strong temperature dependence of the specific heat, the determinations should be carried out at as small temperature increments as feasible. This latter practice will also assure that any phase changes that may take place either in the sample or the calorimeter material will be detected.

C. Standard Reference Materials

It was mentioned earlier that relative measurements are easier to perform as compared to absolute measurements, should standard reference samples be available to calibrate the calorimeter. By this

statement it should not be inferred that a calorimeter can be calibrated to yield results of accuracy comparable to the accuracy of the values established for the standard reference samples.

One of the prime uses of standard reference samples is to ascertain the performance of any absolute calorimeter, to establish periodic checks on the stability of a calorimeter, or to intercompare calorimeters at various laboratories. In such instances the availability of well characterized high-purity stable samples whose properties are determined with great care on well proven instrumentation is essential. Such materials may be procured from special sources, the most prominent of which is the Office of Standard Reference Materials, National Bureau of Standards, Washington, D.C. 20234. A list of available standard reference materials, together with prices, is given in NBS-Miscellaneous Publication 260 "Standard Reference Materials."*

In 1949, the Fourth Calorimetry Conference [10] recommended three substances to be used as "reference standard" materials for heat capacity measurements. These are benzoic acid and *n*-heptane in the low- to moderate-temperature range and aluminum oxide primarily for the high-temperature range. Near room temperature, water has long been used as a reference material. Because of its low cost, reproducibility in extreme purity, and the very large number of determinations made on liquid water, its specific heat is known within 0.01 percent in the range of 0 to 100 C.

D. Brief Description of Typical Calorimeters

As discussed earlier, there are few basic methods for the practical and precise determination of the specific heat of fluids, and especially of gases, because of their low heat capacities at normal and moderate pressures. Although there are many variants and minor modifications or improvements described in the various references cited below, the most important ones are described in references [1] and [2] and are briefly reviewed below.

a. Direct Methods

(i) *Constant-Flow Calorimeter.* The constant-flow electric-heating method is the only way yet devised of measuring directly absolute values of C_p . The first

apparatus was designed for measurements on liquid samples by H. L. Callender in 1902, and K. Scheele and H. Heuse made measurements on gases in 1912. This method has since been considered as the most accurate and the standard method in the determinations of C_p for vapors and gases, because the specific heat of a gas is so low that a closed system, such as an adiabatic calorimeter, cannot be used reliably on account of the comparatively large heat capacity of the container.

In simplest terms, the method consists in obtaining a constant, measured rate of flow through a tube, then measuring the temperature of the fluid at two points along the tube between which a constant measured electric power is being applied. Obtaining and measuring a constant flow rate to the desired precision, measuring temperatures which accurately represent the state of the fluid, and reducing the heat leak of the calorimeter to manageable proportions are only three of the problems which are encountered and which tend to make any flow calorimeter built for precision work extremely complicated.

The specific heat is calculated from the flow rate and the energy supplied, by the equation

$$C_p = \frac{EI}{JF(T_2 - T_1)} \quad (88)$$

where E is the voltage applied to the heater, I is the heating current, T_2 is the temperature at the outlet, T_1 is the temperature at the inlet, F is the flow rate of the sample fluid, and J is the electrical equivalent of heat, 4.1833 int. joule cal⁻¹.

Several improved modern flow calorimeters, which can be used for vapors which are liquid at room temperature, have been developed and used for a number of extensive measurements of organic vapors [14-17]. In this type of calorimeter, the vapor produced in a vaporizer, which is immersed in a thermostat about 0.2 C higher than the boiling point of the sample, is passed through the preheating coil in the calorimeter thermostat and then into the calorimeter, where a measured amount of heat is supplied electrically. The temperatures before and after the calorimeter are measured by platinum resistance thermometers. The flow rate of the vapor is known accurately from the measurement of the electrical energy input to the vaporizer and the known heat of vaporization of the substance. The heat loss of the vapor during the passage from the calorimeter to the outlet thermometer can be accounted for by measurements at several flow rates and the extrapolation to infinite flow, where the heat loss would

*Standard samples of hydrocarbons of certified purity which were prepared by NBS in cooperation with the American Petroleum Institute are now available only as API Standard Samples from: API Samples, Carnegie-Mellon University, Schenley Park, Pittsburgh, Penn. 15213.

become zero. This apparatus has been employed in the range of 50 to 200 C and 100 to 800 mm Hg, with an error of less than 0.1 percent.

Metal calorimeters of this type have been also developed at the National Bureau of Standards [18, 19]. One of the most refined of this type of apparatus was built by Osborne, Stimson and Sligh [18]. A simplified version of this apparatus was described by Wacker, Cheney, and Scott [20].

A small-scale flow calorimeter with a vaporizer was reported by Reynolds and De Vries [21]. Only a 25-ml liquid sample is required and the error would be about 1 percent.

Waddington, Todd, and Huffman [16] described an all-glass flow calorimeter which has been employed extensively by the Bartlesville group of the United States Bureau of Mines for investigations, with an accuracy of 0.1 to 0.2 percent, of vapors of hydrocarbons and related compounds. McCullough *et al.* have published revisions of this calorimeter [25]. Other flow calorimeters are those of De Vries and co-workers [26, 27] and Pitzer [14]. These are also of glass, operating generally at 1 atm or below, with somewhat less precision than the Bartlesville apparatus.

A flow calorimeter for high temperatures was designed by Bennewitz and Schultz [22] and improved by Dailey and Felsing [23]. A temperature difference is produced along the flow tube between two blocks of copper through which the sample fluid flows. A thermopile of copper-constantan placed between two copper blocks detects the temperature drop due to the stream of gas. Electric power which is necessary to compensate the temperature drop is measured. The specific heat can be calculated from the flow rate, temperature difference, and electric power supplied, by use of equation (88). Precision is somewhat lower with this method.

A typical high-pressure flow calorimeter was designed by Krase and Mackey [24], who measured the specific heat of gases at pressures up to 700 atm and temperatures to 150 C. The sample gas passed through a thermostat, a calorimeter, an expansion valve, a flowmeter, a humidifier, and a wet-test meter. The calorimeter consisted of a coil of steel tube embedded in a copper casting and placed in a dewar flask. The copper casting contained an electric resistance heater and a thermometer. The compressed gas is passed through the apparatus at a steady rate, between 0.7 and 1.5 moles min^{-1} . The rate is regulated manually by an expansion valve. The wires for the thermocouples, reading the inlet

and outlet temperatures of the gas stream, are introduced through vertical steel tubings. The heat loss due to conduction of heat through each tubing is corrected for by the measurement of the temperature gradient along the tubing. Other corrections were made for inductive heating of the calorimeter by the winding and for the temperature change due to the Joule-Thomson effect resulting from the pressure drop in the calorimeter.

(ii) *Isothermal Drop Calorimeter.* In a calorimeter of this type, it is possible to measure the evolution of heat under conditions where there is no temperature change, and the heat capacity of the material undergoing phase change and the calorimeter are not involved. The temperature is maintained constant by using the equilibrium between the melting solid and liquid phases of a suitable substance. The change in temperature of a liquid sample which is introduced in the calorimeter can be measured by the change in volume of the melting equilibrium system. The "ice calorimeter" was first designed by Bunsen, and various calorimeters using ice-water equilibrium have been designed since [28, 29]. Calorimeters using the melting equilibria of diphenyl ether [30], phenol [31], and naphthalene [32] are also employed along the same principle. The change in volume of the equilibrium system is measured by direct reading of a graduated glass tube, or indirectly by the weight of mercury. Therefore, precise electric measurements are not necessary. However, the isothermal calorimeter is limited to one temperature. Since it is difficult to introduce the liquid sample at a temperature much different from that of the equilibrium system, this calorimeter is not extensively used.

(iii) *Conduction Calorimeter.* This calorimetric method depends upon the relative rate of temperature rise when a liquid sample is heated indirectly by the conduction of heat from a low-pressure gas. A gas, at a fixed pressure, is introduced between the sample container and the heating cylinder around which an electric wire is wound. Heat evolved by the heater conducts to the sample container across a constant small temperature difference (2 to 3 C). When the stationary state of heat flow is attained, the heat flux is a function of thermal conductivity and pressure of the gas, the temperature difference between heating cylinder and sample container, and the dimensions of the apparatus. However, it is not necessary to know the absolute value of the heat flux if the rate of temperature rise of a standard reference substance, whose heat capacity is known, would be measured

under the same condition. Although this method is relatively simple in instrumental and experimental procedures, it would be difficult to expect high accuracy. Therefore, the application of this method is also limited [33–35].

(iv) *Mixing Method Calorimeter* [36]. Two parts of a fluid at different temperatures are mixed in a calorimeter, and the change in temperature of the calorimeter is measured. This method is simple and applicable to both liquid and gas. Although it has been used at considerable high temperatures, the results obtained represent a mean specific heat over a wide range of temperature. The accuracy of the method is not good because of the difficulty in correcting for various sources of errors.

(v) *Heat-Exchanger Calorimeter*. This method was devised by Workman [37] and was used to measure the ratio of the heat capacity at a selected high pressure to that at some standard pressure (e.g. 1 atm) for hydrogen, oxygen, and nitrogen. The method involves exchanging heat between the flow gas at high pressure and the same gas stream after throttling to the lower pressure. The only measurements required are the temperatures and pressures of the high- and low-pressure gas before and after the heat-exchanger. Although the procedure is simple and the sources of heat loss are cancelled out in this method, only the relative values of specific heat at two pressures are obtained.

b. Indirect Methods

The indirect determination of the specific heat depends mostly upon both experimental measurements and thermodynamic calculations. Therefore, the knowledge of P - V - T relations is always essential to calculate the specific heat. Hence the accuracy of the results in these methods should be evaluated considering both the experimental techniques and the reliability of the basic values used in the calculation. The following are representative of the major methods used.

(i) *Isentropic Expansion Method*. In reversible adiabatic (isentropic) expansion of an ideal gas, the quantity $PT^{\gamma/(1-\gamma)}$ is a constant, and the value of γ can be obtained from an experiment in which the pressure and temperature are measured carefully just before and just after an adiabatic expansion. In the case of a real gas, however, the exponent α in the expression $PT^\alpha = \text{constant}$ can be shown readily to be

$$\alpha = -\frac{C_p}{R[Z + (\partial Z/\partial T)_p]} \quad (89)$$

where $Z = PV/RT$.

Using such an expression, or equivalent ones involving γ or C_p , and appropriate equations of state, various workers have investigated the isentropic expansion of a number of gases. In these experiments the volume of gas involved should be large and the container and temperature-measuring device should have as little mass as possible. Consequently, nearly all work has been done near 1 atm. Brinkworth [38, 39], Eucken and von Lude [40], and Kistiakowsky and Rice [41] are among the main workers with this method. Other workers are Partington and Shilling [42], Eucken and Parts [43], and Sage, Webster, and Lacey [44].

(ii) *Velocity of Sound Method*. The measurement of velocity of sound is the most useful indirect method which is applicable to both gases and liquids. The velocity of the propagation of the ultrasonic waves generated by a piezoelectric quartz crystal is measured by the interferometric method [45–50], the pulse technique [51, 52], and the optical diffraction method [53, 54]. The values of the ratio of the specific heats γ and the specific heat at constant pressure C_p can be calculated using the knowledge of the P - V - T relations as shown in the following equations:

$$\gamma = -(a^2/V^2)(\partial V/\partial P)_T \quad (90)$$

$$C_p = -T(\partial P/\partial T)_v^2[1 + V^2/a^2] \quad (91)$$

where a is the velocity of sound in the fluid sample. The velocity of sound must be measured at sufficiently low frequency so that dispersion is not encountered. The specific heat obtained by this method is not of the highest accuracy because of possible accumulated errors in both the experimental measurement and the P - V - T data available.

Partington and Shilling and their co-workers [55–59] were advocates of this method. Sherratt and Griffiths [60, 61], Hubbard and Hodge [62], and Cornish and Eastman [63] have worked with improved version of this method and obtained good precision. In the latter reference there is a detailed discussion of the method.

The resonance method developed by Clark and Katz [64] and the self-sustained oscillation method developed by Koehler [65] are closely akin to the sound velocity method.

(iii) *Joule-Thomson Effect Method*. The adiabatic Joule-Thomson experiment for a gas gives C_p

by means of the following equations:

$$C_p = -\frac{1}{\mu_J} [V - T(\partial V / \partial T)_p] \quad (92)$$

where μ_J is the Joule-Thomson coefficient, defined by

$$\mu_J = (\partial T / \partial P)_h$$

When a gas expands through a porous plug or a throttle under adiabatic conditions, the enthalpy of the gas remains constant. The changes in tempera-

ture and pressure before and after the expansion are measured by a differential thermocouple and manometers, respectively. If the final pressure is atmospheric and the pressure difference across the plug is plotted against the temperature difference, the slope on the straight line gives the Joule-Thomson coefficient μ_J . The procedures in this method are described in references [66-69]. Burlew [70] reported an interesting application of the Joule-Thomson effect to the accurate determination of the heat capacity of liquids.

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Numerical Data

Data Presentation and Related General Information

1. SCOPE OF COVERAGE

The selection of the 56 substances reported in this volume was based on considerations of scientific and technological importance, current interest, and the needs of the engineering and scientific community. In this sense the substance coverages in Volumes 3, 6, and 11 (thermal conductivity, specific heat, and viscosity, respectively) are identical to the extent made possible by the availability of the data. Substances investigated are organized in alphabetical order by name and are assigned consecutive substance numbers. All textual discussions, tables, and plots concerning a substance carry the same substance number irrespective of its physical state. For a given substance, the liquid state appears first followed by the gaseous state. For each physical state the sequence of presentation consists of text, table, and figure. While the coverage of the world literature reported in this volume is extensive, it is far from complete. This is due to the inability of the authors and their associates to extract and scrutinize all data available to them. It is felt, however, that the recommended values for the substances covered would not be affected appreciably in the light of the additional data which will be incorporated in the second edition.

2. PROCESSING AND PRESENTATION OF DATA

As in the case of each volume of this series, the source information used was made available by TPRC's Scientific Documentation Division. With very rare exceptions, all data were extracted from the original reference sources. In addition to the numerical data, the extraction process retrieves all pertinent information concerning the experimental or theoretical method used, estimated accuracy, reported error, purity of the sample used, and other specifications

which are necessary in the critical evaluation of the data.

The data correlation procedure varies with the substance, physical state, and, in special cases, with the temperature and pressure ranges considered. Usually the values are first plotted to indicate the approximate concordance of the available information. Depending on this representation, as well as the reliability of the original data, all the reported values are critically evaluated. Data points and data sets are assigned appropriate, equal or unequal, weight. The data are then fitted by means of a least mean square polynomial using a digital computer. In rare cases, simple empirical fits or graphical smoothing procedures are used when justified. In the use of polynomial fits, the simplest formula is selected which gives the best fit compatible with the estimated accuracy of the input data. In the analysis method used, every polynomial equation is followed by the mean and maximum deviations, as well as the temperature range in which the correlation is applicable. The extrapolation of the equation beyond the limits specified is not recommended since it would be frequently unreliable.

Subsequent to the establishment of the correlating equation, the tabulated recommended values at preselected temperature increments are generated by the computer. The computed values are further rounded off and differenced to check for consistency and compatibility of the values with the estimated limits of error. These values are accompanied by indications of phase transition temperatures where these fall within the range of the tabulation.

All original experimental data and major theoretical calculations are compared with the tabulated recommended values irrespective of the weight given to these data in the original critical evaluation process. In preparing the departure plots the following definition is used:

$$\text{percent Departure} = \frac{(\text{Value})_{\text{exper}} - (\text{Value})_{\text{tab}}}{(\text{Value})_{\text{tab}}} \times 100$$

By the above definition, departures are positive if the original experimental or theoretical data are greater than the tabulated values and vice versa. Again, the extrapolation of the values beyond the limits of the tables is not recommended. If however, this must be done, the departure plots should be examined to obtain an indication of the probable trend in the values in regions yet undocumented.

3. SYMBOLS AND ABBREVIATIONS USED IN THE FIGURES AND TABLES

Most abbreviations and symbols used in this volume are those generally accepted in engineering and scientific practice and convention.

The abbreviation NTP signifies "normal temperature and pressure." The notations, "n.m.p.," "n.b.p.," and "c.p." refer to normal melting point, normal boiling point, and critical point, respectively.

In the discussion of the data, numbers in parentheses and those signified by the notation "Reference" on the departure plots correspond to the *References to Data Sources* listed at the end of the *Numerical Data Section*. In the tabulation of recommended values, the notation $\bar{5}$ sometimes appears as the last digit of a value if the actual value of the next significant figure is less than 5. If no bar appears above the 5, in further rounding off the preceding figure can be increased by unity.

In the departure plots, curve numbers are surrounded either by circles or squares, the latter being used to indicate a single data point or a cluster of points. Solid lines are used in the plots to connect experimental data joints and dotted lines indicate major correlations or calculated values. For clarity in presentation, sometimes bands are indicated when many curves are crowded together or coincide.

When percent departures for some of the original data fall outside the limits given in the departure plot, the numerical value of the departure is indicated correctly on the temperature axis and a vertical arrow, up or down, points to the fact that the value is beyond the limits of the plot.

4. CONVENTION FOR BIBLIOGRAPHIC CITATION

For the following types of documents the biblio-

graphic information is cited in the sequences given below.

Journal Article:

- a. Author(s)—The names and initials of all authors are given. The last name is written first, followed by the initials.
- b. Title of article—In this volume the titles of the articles listed in the *References to Text* are given, but not those listed in the *References to Data Sources*.
- c. Journal title—The abbreviated title of the journal as in *Chemical Abstracts* is given.
- d. Series, volume, and number—If the series is designated by a letter, no comma is used between the letter for series and the numeral for volume, and they are underlined together. In case series is also designated by a numeral, a comma is used between the numeral for series and the numeral for volume, and only the numeral representing volume is underlined. No comma is used between the numerals representing volume and number. The numeral for number is enclosed in parentheses.
- e. Pages—The inclusive page numbers of the article.
- f. Year—The year of publication.

Report:

- a. Author(s).
- b. Title of report—In this volume, the titles of the reports listed in the *Reference to Text* are given, but not of those listed in the *References to Data Sources*.
- c. Name of the responsible organization.
- d. Report, or bulletin, circular, technical note, etc.
- e. Number.
- f. Part.
- g. Pages.
- h. Year.
- i. ASTIA's AD number—This is given in square brackets whenever available.

Book:

- a. Author(s).
- b. Title.
- c. Volume.
- d. Edition.
- e. Publisher.
- f. Place of publication.
- g. Pages.
- h. Year.

NAME, FORMULA, MOLECULAR WEIGHT, TRANSITION TEMPERATURES, AND PHYSICAL CONSTANTS
OF ELEMENTS AND COMPOUNDS

Name	Formula	Molecular Weight	Density (25°C), g cm ⁻³	Melting (or Triple) Point, K	Normal Boiling Point, K	Critical Temp., K	C (25°C), cal g ⁻¹ K ⁻¹	C (25°C), cal g ⁻¹ K ⁻¹	Dipole Moment, Debyes
Acetone	C ₃ H ₆ O	58.081	0.933 (l)†	178	329	508	0.528 (l)		2.88
Acetylene	C ₂ H ₂	26.039	1.077 -3**	179	191	309	0.407	0.329	0
Air		28.966	1.184 -3	60	796.82d	133	0.240	0.172	
Ammonia	NH ₃	17.031	0.601 -3	195	240	405	0.515	0.387	1.47
Argon	Ar	39.948	1.634 -3	84	88	151	0.125	0.075	0
Benzene	C ₆ H ₆	78.117	0.876 (l)	279	353	563	0.415 (l)	--	0
Boron Trifluoride	BF ₃	67.807		146	172	261	--	--	0
Bromine	Br ₂	159.818		266	332	584	0.113	--	0
i-Butane	i-C ₄ H ₁₀	58.126		114	262	408	0.404		0.132
n-Butane	n-C ₄ H ₁₀	58.126	2.491 -3	137	273	426	0.409	0.358	≤0.05
Carbon Dioxide	CO ₂	44.010	1.811 -3	216(5 atm)	195	304	0.203	0.158	0
Carbon Monoxide	CO	28.011	1.145 -3	68	81	134	0.249	0.177	0.112
Carbon Tetrachloride	CCl ₄	153.824	1.589 (l)	250	350	556	0.204 (l)	--	0
Chlorine	Cl ₂	70.906	2.944 -3	172	239	417	0.114*	0.084	0
Chloroform	CHCl ₃	119.378	1.469 (l)	210	334	535	0.228 (l)	--	1.01
n-Decane	C ₁₀ H ₂₂	142.290	0.728 (l)	243	446	619	0.527 (l)	--	
Deuterium	D ₂	4.028	0.165 -3	19(16 at)	23	38	1.731*	1.241	0
Diethylamine	C ₄ H ₁₁ N	73.143	0.711 (l)	233	329	496	0.516 (l)	--	1.11
Ethane	C ₂ H ₆	30.070	1.243 -3	95±6	185	305	0.422	0.335	0
Ethyl Alcohol	C ₂ H ₅ O	46.070	0.789 (l)	159±3	351	516	0.580 (l)	--	1.69
Ethyl Ether	C ₄ H ₁₀ O	74.125	0.716 (l)	157(α), 150(β)	308	467	0.559 (l)	--	1.15
Ethylene	C ₂ H ₄	28.055	1.155 -3	104	170	283	0.374	0.297	0
Ethylene Glycol	C ₂ H ₄ O ₂	62.070	1.100 (l)	258	471		0.575 (l)	--	2.28
Fluorine	F ₂	37.997	1.553 -3	54	86	144	0.197*	0.152	0
Freon 11	CCl ₃ F	137.369	5.840 -3	162	297	471	0.136*	0.125	0.45
Freon 12	CCl ₂ F ₂	120.914	5.045 -3	116	243	385	0.146	0.128	0.51
Freon 13	CClF ₃	104.460	4.388 -3	91	191	302	0.153*	0.138	0.50
Freon 21	CHCl ₂ F	102.924	4.284 -3	133	282	451	0.141*	0.119	1.29
Freon 22	CHClF ₂	86.469	3.588 -3	113	233	369	0.151	0.133	1.42
Freon 113	C ₂ Cl ₃ F ₃	187.377	1.564 (l)	238	321	481	0.225 (l)		
Freon 114	C ₂ Cl ₂ F ₄	170.922	7.012 -3	179	276	419	0.170	0.157	0.5
Glycerol	C ₃ H ₈ O ₃	92.096	1.263 (l)	291	563		0.567 (l)		
Helium	He	4.003	0.164 -3	3, 5	4	5, 4	1.240*	0.748	0
n-Heptane	C ₇ H ₁₆	100.208	0.681 (l)	183	371	540	0.536 (l)	--	
n-Hexane	C ₆ H ₁₄	86.181	0.657 (l)	179	342	508	0.543 (l)	--	
Hydrogen	H ₂	2.016	0.082 -3	14	20	33	3.420	2.438	0
Hydrogen Chloride	HCl	36.461	1.502 -3	166	188	325	0.191*	0.140	1.08
Hydrogen Iodide	HI	127.913 127.913		223	237	423	0.054*		
Hydrogen Sulfide	H ₂ S	34.080	1.409 -3	190	214	374	0.240*	0.157	0.97
Iodine	I ₂	253.809	4.93 (s)	387	458	785	0.052 (s)	--	0
Krypton	Kr	83.80	3.429 -3	117	120	210	0.059*	0.035	0
Methane	CH ₄	16.043	0.657 -3	90	112	190	0.533	0.409	0
Methyl Alcohol	CH ₃ O	32.043	0.789 (l)	175	338	513	0.602 (l)		1.70
Methyl Chloride	CH ₃ Cl	50.488		175	249	416	0.193		
Methyl Formate	C ₂ H ₄ O ₂	60.054	0.974 (l)	174	305	487	0.516	--	
Neon	Ne	20.183	0.824 -3	25	27	44	0.246*	0.150	0
Nitric Oxide	NO	30.006	1.228 -3	111	121	180	0.238	0.167	0.153
Nitrogen	N ₂	28.018	1.146 -3	63	78	126	0.249	0.178	0
Nitrogen Per oxide	NO ₂	46.006	1.44 (l)	263	295	431	0.369 (l)		0.316
Nitrous Oxide	N ₂ O	44.013		176±7	184	310	0.209*	0.170	0.167
n-Nonane	C ₉ H ₂₀	128.262	0.714 (l)	220	424	594	0.529 (l)	--	
n-Octane	C ₈ H ₁₈	114.234	0.701 (l)	216	399	569	0.530 (l)	--	
Oxygen	O ₂	31.999	1.310 -3	55	90	155	0.220	0.157	0
n-Pentane	C ₅ H ₁₂	72.154	0.621 (l)	144	309	470	0.561 (l)		
Cyclopropane	42.080 C ₃ H ₆ 44.098	44.098	1.854 -3 0.61(l)	146	240		--		
Propane	C ₃ H ₈	44.098	1.854 -3	86	231	369	0.400	0.350	0.084
Propylene	C ₃ H ₆	42.082	0.514 (l)	87	226	365	0.370	0.310	
Radon	Rn	226		202	211	377			0
Sulfur Dioxide	SO ₂	64.063	2.679 -3	198	263	430	0.149*	0.081	1.63
Toluene	C ₇ H ₈	92.144	1.028 (l)	178	394	594	0.410 (l)	--	0.36
Tritium	T ₂			21	28	44			0
Water	H ₂ O	18.015	1.000 (l) 0.997	273	373	647	0.998 (l)	--	1.85
Xenon	Xe	131.30	5.397 -3	161	165	289	0.0378*	0.0227*	0

* For ideal gas state.

** The notation -3 signifies 10⁻³, so that 1.077 -3 means 1.077 x 10⁻³, etc.

† (l) and (s) designate liquid and solid state, respectively.

CONVERSION FACTORS FOR UNITS OF SPECIFIC HEAT

MULTIPLY by appropriate factor to OBTAIN	$\text{cal}_{\text{th}} \text{ g-mol}^{-1} \text{ C}^{-1}$	$\text{cal}_{\text{th}} \text{ g}^{-1} \text{ C}^{-1}$	$\text{cal}_{\text{IT}} \text{ g-mol}^{-1} \text{ C}^{-1}$	$\text{cal}_{\text{IT}} \text{ g}^{-1} \text{ C}^{-1}$	$\text{J g-mol}^{-1} \text{ K}^{-1}$	$\text{J g}^{-1} \text{ K}^{-1}$	$\text{J kg-mol}^{-1} \text{ K}^{-1}$	$\text{J kg}^{-1} \text{ K}^{-1}$	$\text{Btu}_{\text{th}} \text{ lb}^{-1} \text{ F}^{-1}$	$\text{Btu}_{\text{IT}} \text{ lb}^{-1} \text{ F}^{-1}$
$\text{cal}_{\text{th}} \text{ g-mol}^{-1} \text{ C}^{-1}$	1	1/M	0.999331	0.999331/M	4.184	4.184/M	4.184×10^3	$4.184/\text{M} \times 10^3$	0.999331/M	0.999331
$\text{cal}_{\text{th}} \text{ g}^{-1} \text{ C}^{-1}$	M	1	0.999331M	0.999331	4.184M	4.184	4.184×10^3	4.184×10^3	1	0.999331
$\text{cal}_{\text{IT}} \text{ g-mol}^{-1} \text{ C}^{-1}$	1.00067	1.00067/M	1	1/M	4.1868	4.1868/M	$(4.1868/\text{M}) \times 10^3$	$(4.1868/\text{M}) \times 10^3$	1.00067/M	1/M
$\text{cal}_{\text{IT}} \text{ g}^{-1} \text{ C}^{-1}$	1.00067M	1.00067	M	1	4.1868M	4.1868	4.1868×10^3	4.1868×10^3	1.00067	1
$\text{J g-mol}^{-1} \text{ K}^{-1}$	0.239006	0.239006/M	0.238946	0.238946/M	1	1/M	1×10^3	$1 \times 10^3/\text{M}$	0.239006/M	0.238946/M
$\text{J g}^{-1} \text{ K}^{-1}$	0.239006M	0.239006	0.238946M	0.238946	M	1	$\text{M} \times 10^3$	10^3	0.239006	0.238946
$\text{J kg-mol}^{-1} \text{ K}^{-1}$	2.39006×10^{-4}	$(2.39006/\text{M}) \times 10^{-4}$	2.38946×10^{-4}	$(2.38946/\text{M}) \times 10^{-4}$	10^{-3}	$10^{-3}/\text{M}$	1	1/M	$(2.39006/\text{M}) \times 10^{-4}$	$(2.38946/\text{M}) \times 10^{-4}$
$\text{J kg}^{-1} \text{ K}^{-1}$	2.39006×10^{-4}	2.39006×10^{-4}	2.38946×10^{-4}	2.38946×10^{-4}	$\text{M} \times 10^{-3}$	10^{-3}	M	1	2.39006×10^{-4}	2.38946×10^{-4}
$\text{Btu}_{\text{th}} \text{ lb}^{-1} \text{ F}^{-1}$	M	1	0.999331M	0.999331	4.184M	4.184	4.184×10^3	4.184×10^3	1	0.999331
$\text{Btu}_{\text{IT}} \text{ lb}^{-1} \text{ F}^{-1}$	1.00067M	1.00067	M	1	4.1868M	4.1868	4.1868×10^3	4.1868×10^3	1.00067	1

5. NAME, FORMULA, MOLECULAR WEIGHT, TRANSITION TEMPERATURES, AND PHYSICAL CONSTANTS OF ELEMENTS AND COMPOUNDS

The table on page 25a contains information on the molecular weight, transition temperatures, and physical constants of the elements and compounds included in this volume and of a few selected compounds in addition. This information is very useful in data analysis and synthesis. The electric dipole moment values are quoted from the recent compilation of Nelson, ~~1962~~, and Maryott, National Standard Reference Data Series—National Bureau of Standards, NSRDS-NBS, 10, 1967.

6. CONVERSION FACTORS FOR UNITS OF SPECIFIC HEAT

The conversion factors given in the table on

page 26a are based upon the following basic definitions:

$$\begin{aligned} 1 \text{ lb} &= 0.45359237 \text{ kg}^* \\ 1 \text{ cal}_{\text{th}} &= 4.184 \text{ (exactly) J}^* \\ 1 \text{ cal}_{\text{IT}} &= 4.1868 \text{ (exactly) J}^* \\ 1 \text{ Btu}_{\text{th}} \text{ lb}^{-1} \text{ F}^{-1} &= 1 \text{ cal}_{\text{th}} \text{ g}^{-1} \text{ C}^{-1} \dagger \\ 1 \text{ Btu}_{\text{IT}} \text{ lb}^{-1} \text{ F}^{-1} &= 1 \text{ cal}_{\text{IT}} \text{ g}^{-1} \text{ C}^{-1} \dagger \end{aligned}$$

The subscripts "th" and "IT" designate "thermochemical" and "International Steam Table," respectively.

In the table, the symbol M is the molecular weight.

*National Bureau of Standards, "New Values for the Physical Constants Recommended by NAS-NRC," *NBS Tech. News Bull.* 47(10), 175-7, 1963.

†Mueller, E. F. and Rossini, F. D., "The Calory and the Joule in Thermodynamics and Thermochemistry," *Am. J. Phys.* 12(1), 1-7, 1944.

TABLE 1 SPECIFIC HEAT AT CONSTANT PRESSURE OF ARGON

DISCUSSION		RECOMMENDED VALUES	
LIQUID		[Temperature, T, F; Specific Heat, C _p , B lb ⁻¹ F ⁻¹]	
		LIQUID	
		T	C _p
		-305	0.2564
		-300	0.2683
		-295	0.2771
		-290	0.2834
		-285	0.2878
		-280	0.2907
		-275	0.2927
		-270	0.2944
		-265	0.2964
		-260	0.2991
		-255	0.3032
		-250	0.3091
		-245	0.3174
		-240	0.3288
		-235	0.3437
		-230	0.3626
		-225	0.3862

DISCUSSION

Six sources of information are available for the specific heat of liquid argon. Among them, a set of recent data of Van Isterbeek (259), who derived the values from experimental P-V-T relations at temperatures between 90 K and 130 K, nearly along the saturated vapor pressure curve, are considered to be reliable and are given weight in this analysis. A single-point calorimetric value of Drain and Morrison (312) at 85 K is also given weight. However, early calorimetric data of Eucken and Hauck (55) and of Clusius (289) are given no weight, as well as two sources of theoretical work (216, 503).

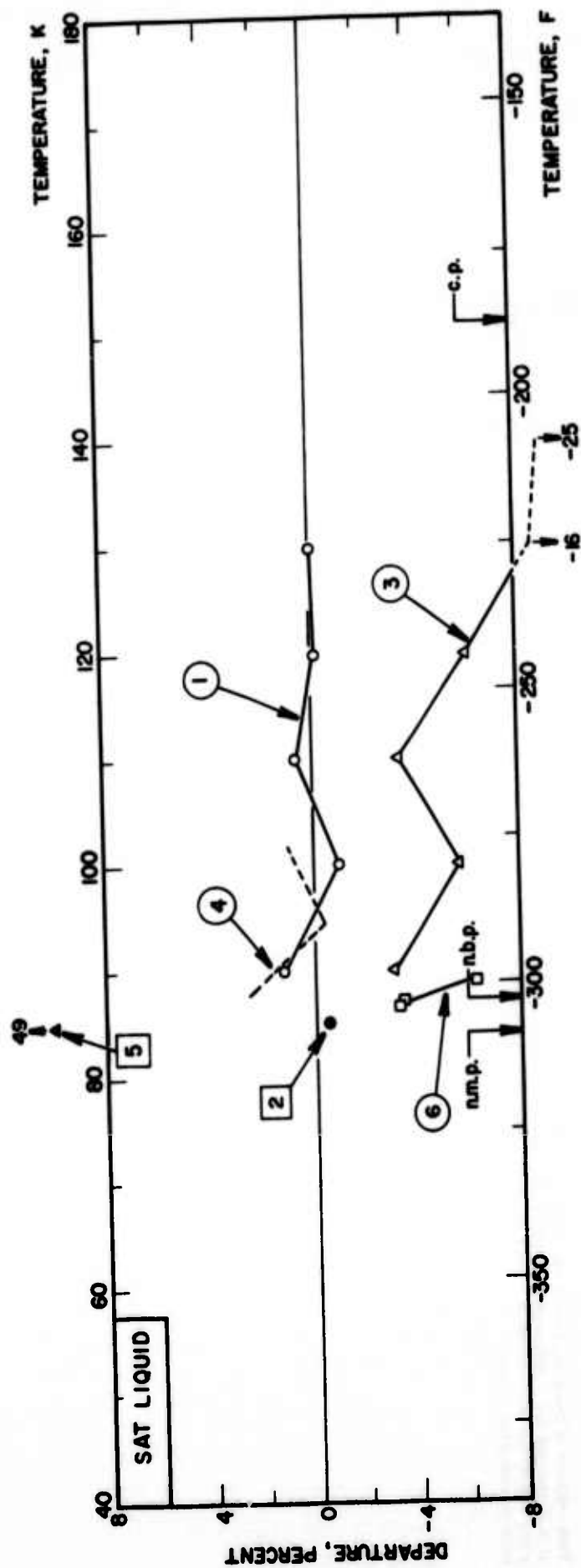
The correlation formula obtained for the temperature range between 85 K and 130 K is

$$C_p \text{ (cal g}^{-1} \text{ K}^{-1}\text{)} = -4.61633 + 0.140126 T - 1.33870 \times 10^{-3} T^2 + 4.28176 \times 10^{-6} T^3 \quad (T \text{ in K})$$

This equation is found to fit the above enumerated values with a mean deviation of 0.57 percent and a maximum of 1.1 percent. The recommended values are generated by the above formula. The tabulated values should be substantially correct within two percent.

n. b. p. = -302 F

FIGURE 1 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID ARGON



Curve	Reference
1	259
2	312
3	55
4	503
5	216
6	289

TABLE 1 SPECIFIC HEAT AT CONSTANT PRESSURE OF ARGON

DISCUSSION

GAS

Twenty-two sources of information are available on the constant pressure specific heat of gaseous argon. Since argon is a monatomic gas and the molecules possess translational energy only, its molar heat capacity at the ideal gas state is represented by $C_p = (5/2)R$, (R is the gas constant) and remains constant with temperature over a wide temperature range. A number of reliable theoretical calculations (100, 137, 265, 335, 362, 389, 435), using spectroscopic and molecular data, show that C_p remains constant up to 6000 K or more. Therefore the specific heat at the ideal gas state is given as follows:

$$C_p^0 (\text{cal g}^{-1}\text{K}^{-1}) = \frac{5}{2} \frac{R}{M} = \frac{5}{2} \frac{1.98719}{39.948} = 0.12436, \quad (1)$$

where M is the molecular weight. The extrapolated values of Michels, et al., (463, 464, 465) from the specific heat at high pressures agree very well with Equation (1) in the temperature range from 133 K to 423 K. The recommended value for the ideal gas specific heat is represented by Equation (1) or

$$C_p^0 (\text{B lb}^{-1}\text{F}^{-1}) = 0.12428.$$

at temperatures between 10 K and 6000 K. In the departure plot for $P = 0$, all the above enumerated values and early experimental data (56, 319) are compared with Equation (1). A set of theoretical values at higher temperatures (569) are not used in this analysis.

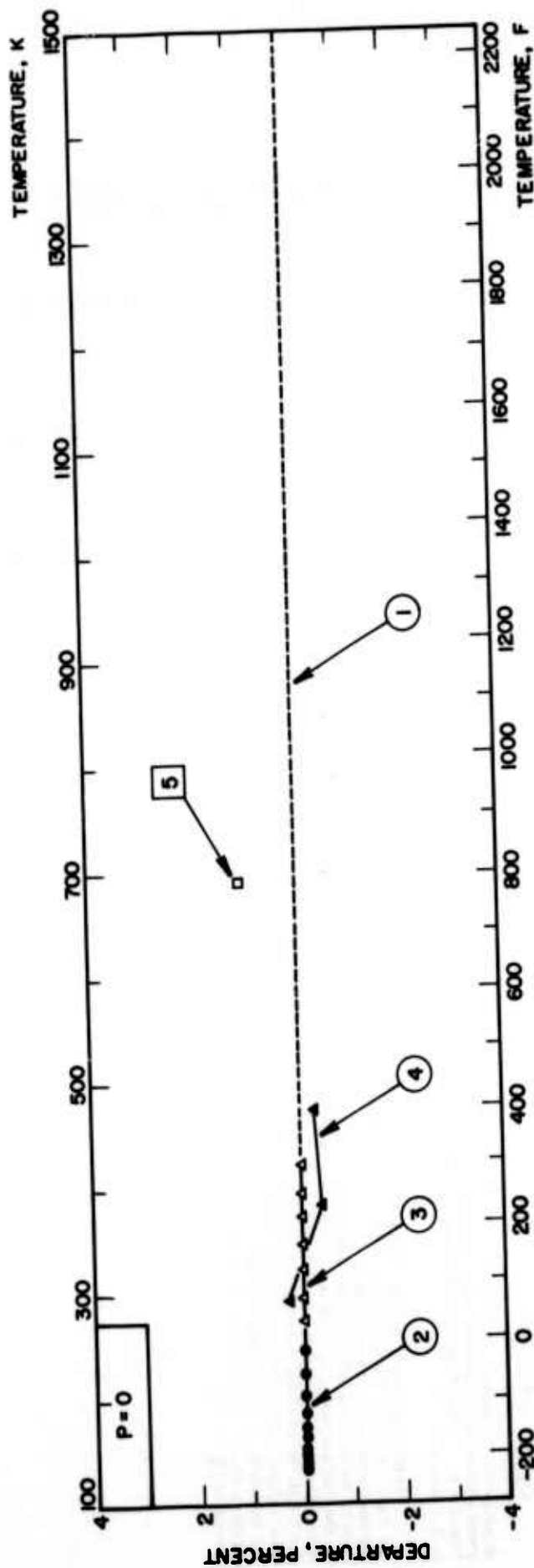
On the other hand, the specific heat at the real gas state are derived by Beckett and Fano (265) from the virial coefficients and theoretical values of C_p . Their values are also compiled in several reports (274, 454, 575). Since their values are considered to be the most reliable over the wide temperature range, the recommended values for the real gas state, C_p , are obtained by graphical interpolation. The experimental values obtained by adiabatic expansion (56) and P - V - T relations (464, 465) are compared with the tabulated values in the departure plot for $P = 1$ atm, as well as two sets of correlated values (251, 556). Cited values (216, 557) are not plotted in this figure. The calorimetric data of argon adsorbed on titanium oxide (474) and carbon (521) are not taken into consideration in this analysis. The third departure plot shows a comparison of C_p with C_p^0 .

RECOMMENDED VALUES

[Temperature, T , F; Specific Heat, C_p , B lb⁻¹F⁻¹]

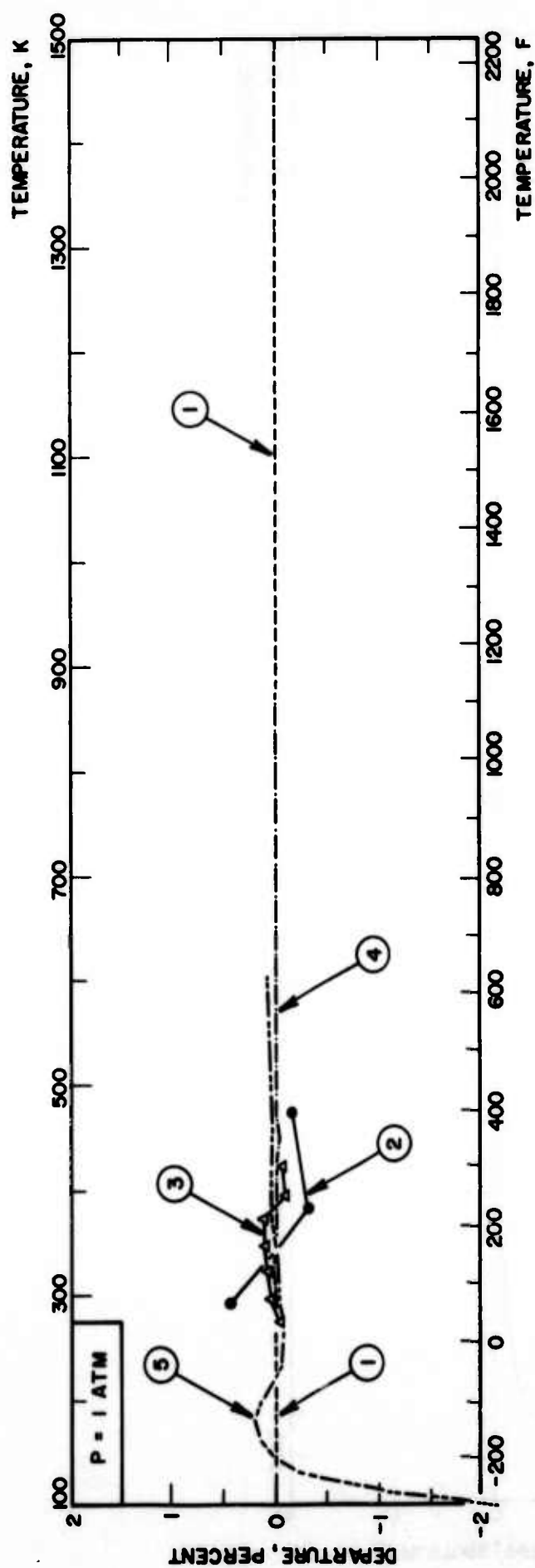
GAS			
T	C _p	T	C _p
280	0.12968	500	0.12437
260	0.12814	520	0.12437
240	0.12714	540	0.12436
220	0.12653	560	0.12436
200	0.12610	580	0.12436
180	0.12577	600	0.12435
160	0.12553	620	0.12435
140	0.12534	640	0.12435
120	0.12518	660	0.12435
100	0.12506	680	0.12434
80	0.12496	700	0.12434
60	0.12488	720	0.12434
40	0.12481	740	0.12434
20	0.12474	760	0.12434
0	0.12470	780	0.12434
20	0.12466	800	0.12433
40	0.12463	820	0.12433
60	0.12460	840	0.12433
80	0.12457	860	0.12433
100	0.12454	880	0.12433
120	0.12453	900	0.12433
140	0.12452	920	0.12433
160	0.12450	940	0.12433
180	0.12448	960	0.12432
200	0.12447	980	0.12432
220	0.12446	1000	0.12432
240	0.12445	1100	0.12432
260	0.12444	1200	0.12432
280	0.12443	1300	0.12431
300	0.12441	1400	0.12431
320	0.12441	1500	0.12431
340	0.12441	1600	0.12431
360	0.12440	1700	0.12431
380	0.12440	1800	0.12430
400	0.12440	1900	0.12430
420	0.12439	2000	0.12430
440	0.12438		
460	0.12438		
480	0.12437		

FIGURE 1 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS ARGON



Curve	Reference
1	100, 137, 265, 335,
2	362, 389, 435
3	463
4	464, 465
5	56
	319

FIGURE 1 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS ARGON



Curve	Reference
1	265, 274, 454, 575
2	56
3	484, 485
4	556
5	261

FIGURE 1 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS ARGON

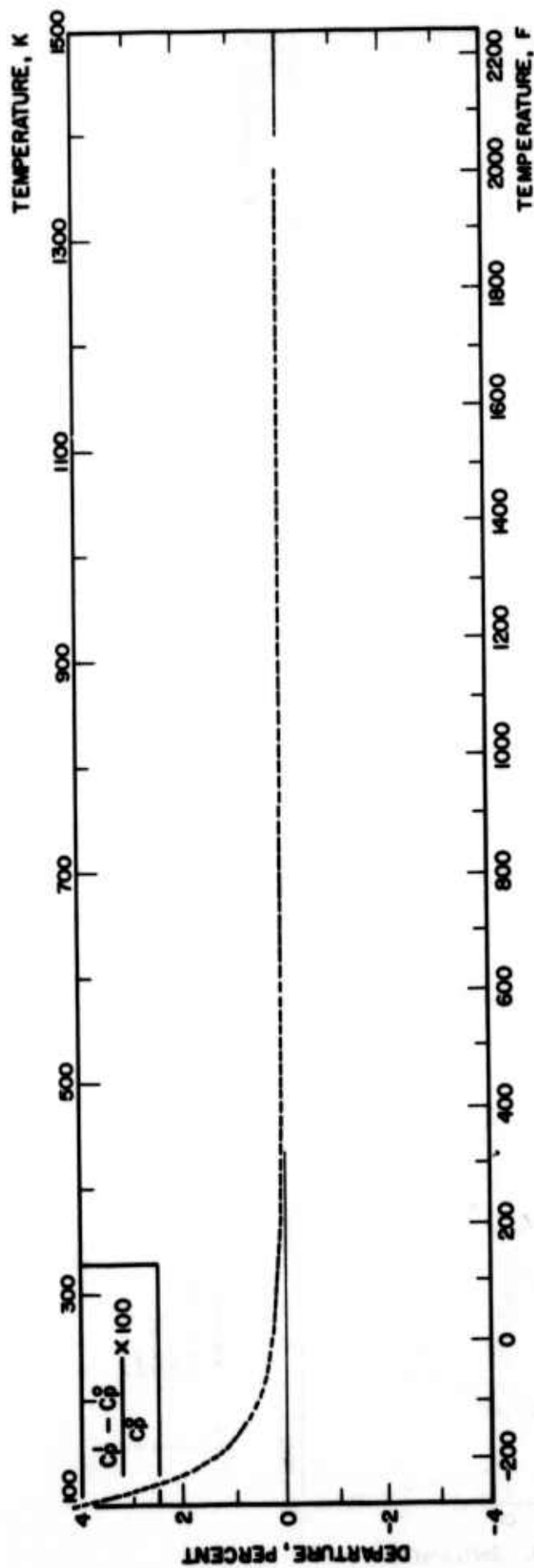


TABLE 2 SPECIFIC HEAT AT CONSTANT PRESSURE OF BROMINE

DISCUSSION		RECOMMENDED VALUES	
LIQUID		[Temperature, T, F; Specific Heat, C _p , B lb ⁻¹ F ⁻¹]	
		LIQUID	
T	C _p ¹	T	C _p ¹
20	0.1161	20	0.1161
30	0.1153	30	0.1153
40	0.1147	40	0.1147
50	0.1141	50	0.1141
60	0.1137	60	0.1137
70	0.1133	70	0.1133
80	0.1130	80	0.1130
90	0.1129	90	0.1129

Only two sources of information are available for the specific heat at constant pressure of liquid bromine. The extensive calorimetric measurement of Hildebrand et al. (381), covering temperatures from 265.9 K to 300 K, should be reliable from the standpoint of the experimental procedures and the purity of liquid sample used. Therefore, full weight is given to the reported data points in the present analysis. Another source is the work of Tsien (216), who derived a single point value at 270 K by means of an empirical method from the gas specific heat. The value is too low, and is given no weight.

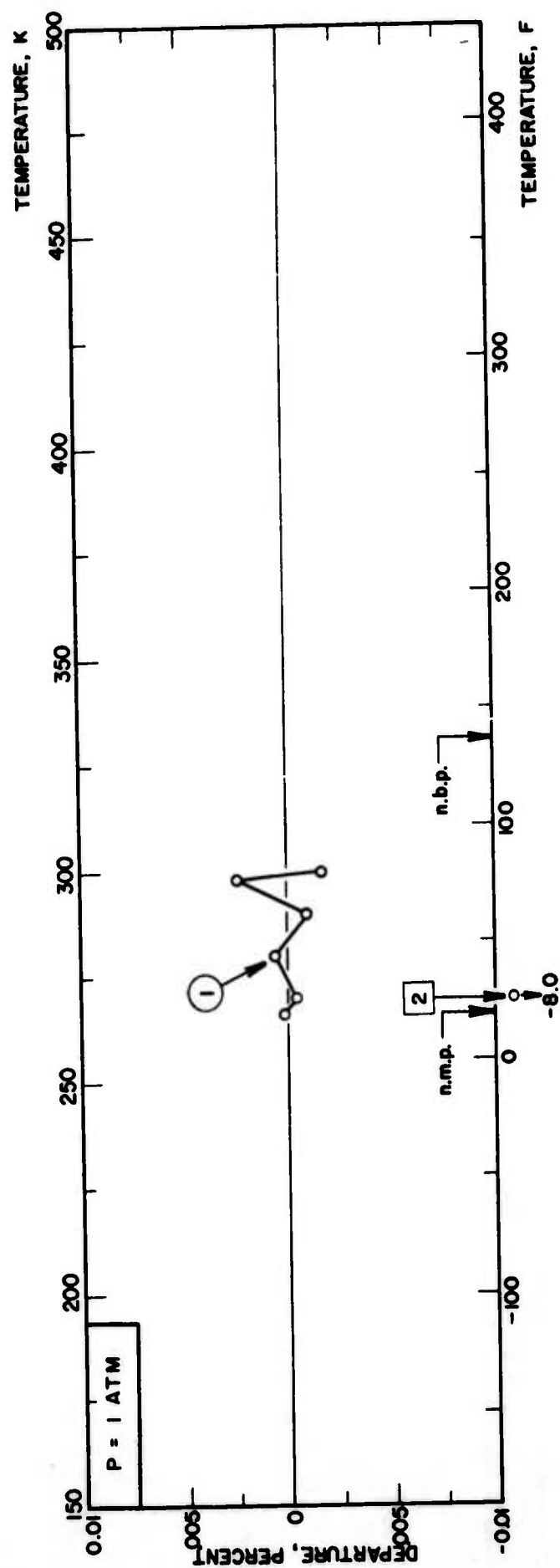
The correlation formula obtained for the temperature range between 265.9 K and 300 K is

$$C_p (\text{cal g}^{-1}\text{K}^{-1}) = 0.244162 - 7.47918 \times 10^{-4}T + 7.43415 \times 10^{-7}T^2 + 9.78071 \times 10^{-10}T^3$$

(T in K).

This equation is found to fit the above enumerated data within a maximum deviation of 0.002 percent. The recommended values are computed from the above equation. The tabulated values should be substantially correct within 0.1 percent over the whole temperature range.

FIGURE 2 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID BROMINE



Curve	Reference
1	381
2	216

TABLE 2 SPECIFIC HEAT AT CONSTANT PRESSURE OF BROMINE

GAS	DISCUSSION		RECOMMENDED VALUES	
	[Temperature, T, F; Specific Heat, C _p , B lb ⁻¹ F ⁻¹]		GAS	
	T	C _p	T	C _p
	-100	0.05169	600	0.05561
	-80	0.05200	620	0.05564
	-60	0.05229	640	0.05566
	-40	0.05257	660	0.05569
	-20	0.05282	680	0.05571
	0	0.05306	700	0.05574
	20	0.05328	720	0.05576
	40	0.05348	740	0.05578
	60	0.05367	760	0.05581
	80	0.05385	780	0.05583
	100	0.05401	800	0.05585
	120	0.05415	820	0.05587
	140	0.05428	840	0.05589
	160	0.05441	860	0.05591
	180	0.05452	880	0.05593
	200	0.05462	900	0.05595
	220	0.05471	920	0.05597
	240	0.05479	940	0.05599
	260	0.05487	960	0.05601
	280	0.05493	980	0.05603
	300	0.05499	1000	0.05605
	320	0.05505	1100	0.05613
	340	0.05510	1200	0.05621
	360	0.05514	1300	0.05628
	380	0.05518	1400	0.05634
	400	0.05522	1500	0.05640
	420	0.05526	1600	0.05645
	440	0.05529	1700	0.05650
	460	0.05533	1800	0.05655
	480	0.05536	1900	0.05659
	500	0.05539	2000	0.05663
	520	0.05543		
	540	0.05547		
	560	0.05551		
	580	0.05556		

GAS

Seven sources of information are available for the specific heat at constant pressure of gaseous bromine. A few sets of theoretical values for the ideal gas heat capacity are also found in the literature. The values of Gordon and Barnes (355) and Evans et al. (321) were derived from spectroscopic and molecular structural data. Three sets of compiled values (254, 428, 508) are also considered to be reliable. Therefore all the reported values are given equal weight in the present analysis. The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 200 K and 590 K:

$$C_p^0 (\text{cal g}^{-1}\text{K}^{-1}) = 0.0418420 + 7.34557 \times 10^{-5}T - 1.38188 \times 10^{-7}T^2 + 9.04413 \times 10^{-10}T^3 \quad (1)$$

For temperatures between 590 K and 1500 K:

$$C_p^0 (\text{cal g}^{-1}\text{K}^{-1}) = 0.0535106 + 5.16046 \times 10^{-5}T - 2.97904 \times 10^{-7}T^2 + 6.51581 \times 10^{-10}T^3 \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.12 and 0.24 percent, and maximum deviations of 0.26 and 0.55 percent, respectively. These formulas are used to generate the recommended values, which should be substantially correct within one percent over the entire temperature range. The percent departures of all the reported values from the tabulated values are given in the departure plot. An empirical equation (532) is not plotted.

On the other hand, only a single-point value obtained by an empirical method (216) is available for the real gas state. Since no correlation is presented for the real gas specific heat at the present time the single value (216) is compared with Equation (1) and is shown in the departure plot for $P = 0$.

n.m.p. = 19 F
n.b.p. = 138 F

FIGURE 2 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS BROMINE

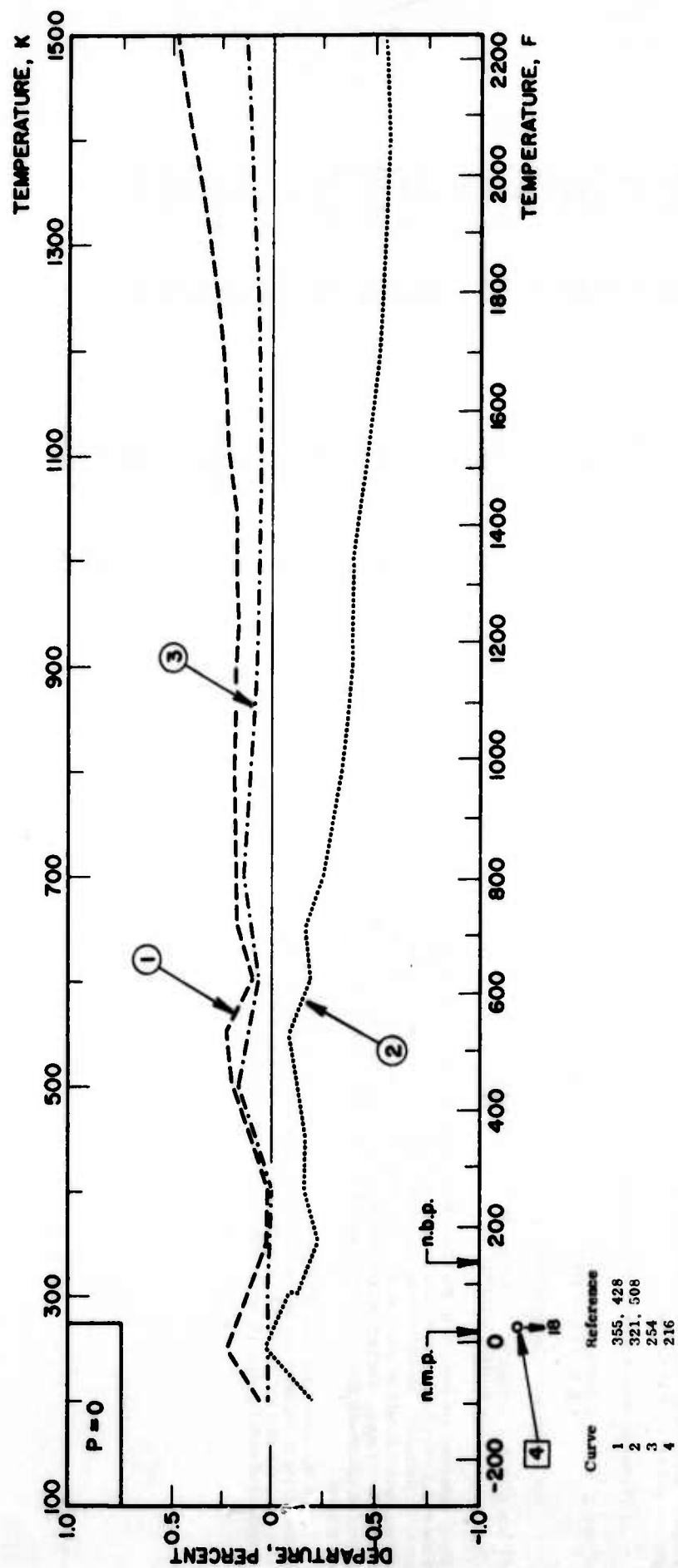


TABLE 3 SPECIFIC HEAT AT CONSTANT PRESSURE OF CHLORINE

DISCUSSION		RECOMMENDED VALUES	
LIQUID		[Temperature, T, F; Specific Heat, C _p , B lb ⁻¹ F ⁻¹]	
T	C _p	T	C _p
-145	0.2258	-145	0.2258
-143	0.2258	-143	0.2258
-135	0.2257	-135	0.2257
-130	0.2256	-130	0.2256
-125	0.2255	-125	0.2255
-120	0.2254	-120	0.2254
-115	0.2253	-115	0.2253
-110	0.2251	-110	0.2251
-105	0.2249	-105	0.2249
-100	0.2248	-100	0.2248
-95	0.2246	-95	0.2246
-90	0.2244	-90	0.2244
-85	0.2241	-85	0.2241
-80	0.2239	-80	0.2239
-75	0.2237	-75	0.2237
-70	0.2235	-70	0.2235
-65	0.2232	-65	0.2232
-60	0.2230	-60	0.2230
-55	0.2228	-55	0.2228
-50	0.2225	-50	0.2225
-45	0.2223	-45	0.2223
-40	0.2220	-40	0.2220
-30	0.2216	-30	0.2216

n. b. p. = -30 F

DISCUSSION

LIQUID

Two sets of calorimetric data are available for the specific heat at constant pressure of liquid chlorine within the temperature range between the normal melting point and the normal boiling point. The extensive data of Glaue and Powell (343) are considered to be more reliable from the standpoint of the experimental procedure and the purity of the liquid used, and are given full weight in the present analysis. However, earlier experimental data of Eucken and Karwat (317) are found to be several percent higher than those of Glaue and Powell, and are given no weight.

The correlation formula obtained for the temperature range between 179 K and 237 K is

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.132589 + 1.36826 \times 10^{-3}T - 6.42353 \times 10^{-6}T^2 + 9.44876 \times 10^{-9}T^3 \quad (T \text{ in K}).$$

This equation is found to fit the above enumerated values with a mean deviation of 0.05 percent and a maximum of 0.15 percent. The above formula is used to generate the recommended values, which should be substantially correct within one percent.

FIGURE 3 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID CHLORINE

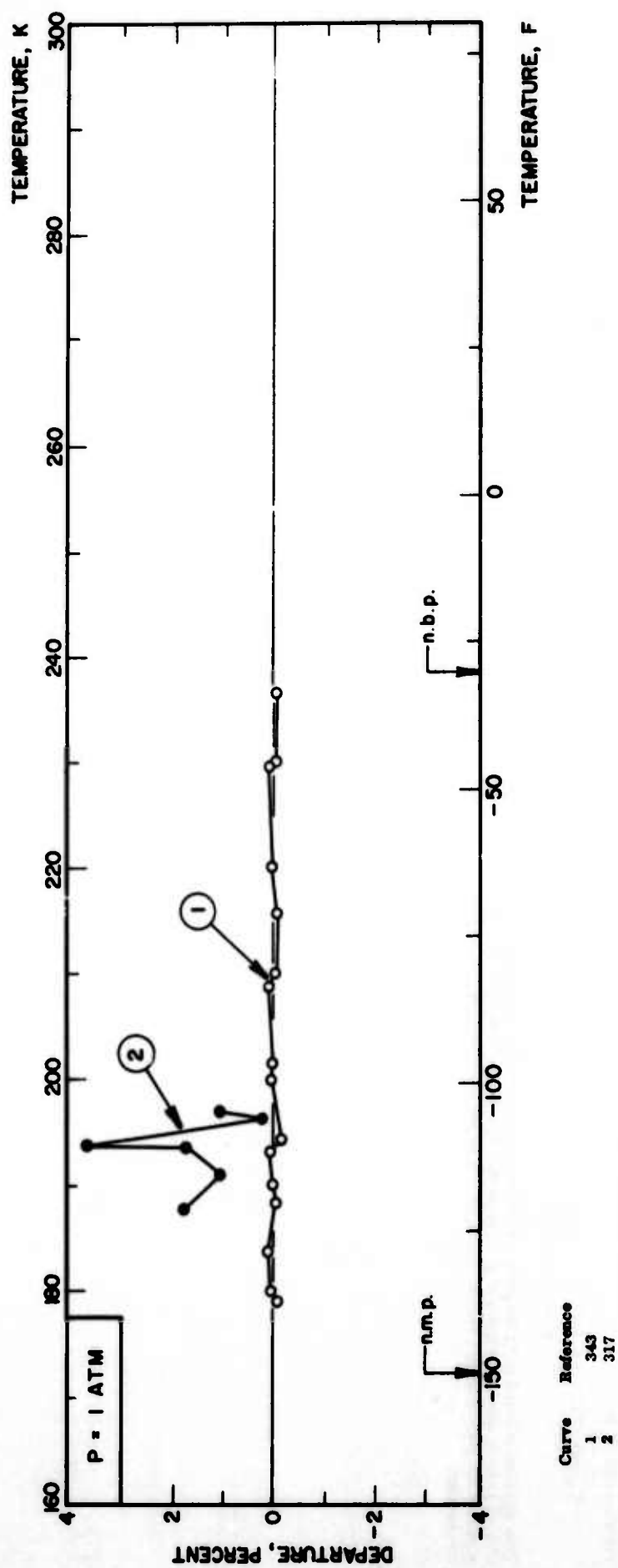


TABLE 3 SPECIFIC HEAT AT CONSTANT PRESSURE OF CHLORINE

DISCUSSION

GAS

There exist 17 sources of information on the specific heat at constant pressure of gaseous chlorine. Many extensive values for the ideal gas state are available, which were derived from spectroscopic and molecular structural data. Results of Faltin (59), Gordon (72, 73), McBride et al. (137), Ribaud (167), Sinke (192), Evans et al. (321), Furukawa et al. (335), Hildenbrand (380), Huff, et al. (389) and Rossini et al. (508) are considered to be reliable as well as compilation tables (254, 428, 479), and are given equal weight in this analysis. However no weight is given to earlier statistical calculations (278, 532). The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 200 K and 640 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}) = 0.0799006 + 1.84257 \times 10^{-4} T - 2.75383 \times 10^{-7} T^2 + 1.47322 \times 10^{-10} T^3 \quad (1)$$

For temperatures between 640 K and 1500 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}) = 0.111175 + 3.01054 \times 10^{-4} T - 1.94702 \times 10^{-8} T^2 + 4.54431 \times 10^{-12} T^3 \quad (T \text{ in K}) \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.10 and 0.14 percent and maximum deviations of 0.81 and 0.52 percent, respectively. These formulas are used to calculate the recommended values, which should be substantially correct within one percent over the entire temperature range. The percent departures of all the reported values from the tabulated values are given in the departure plot for $P = 0$. An empirical equation (346) is not plotted in this figure.

No information is available in the literature on the specific heat of this gas in the real gas state.

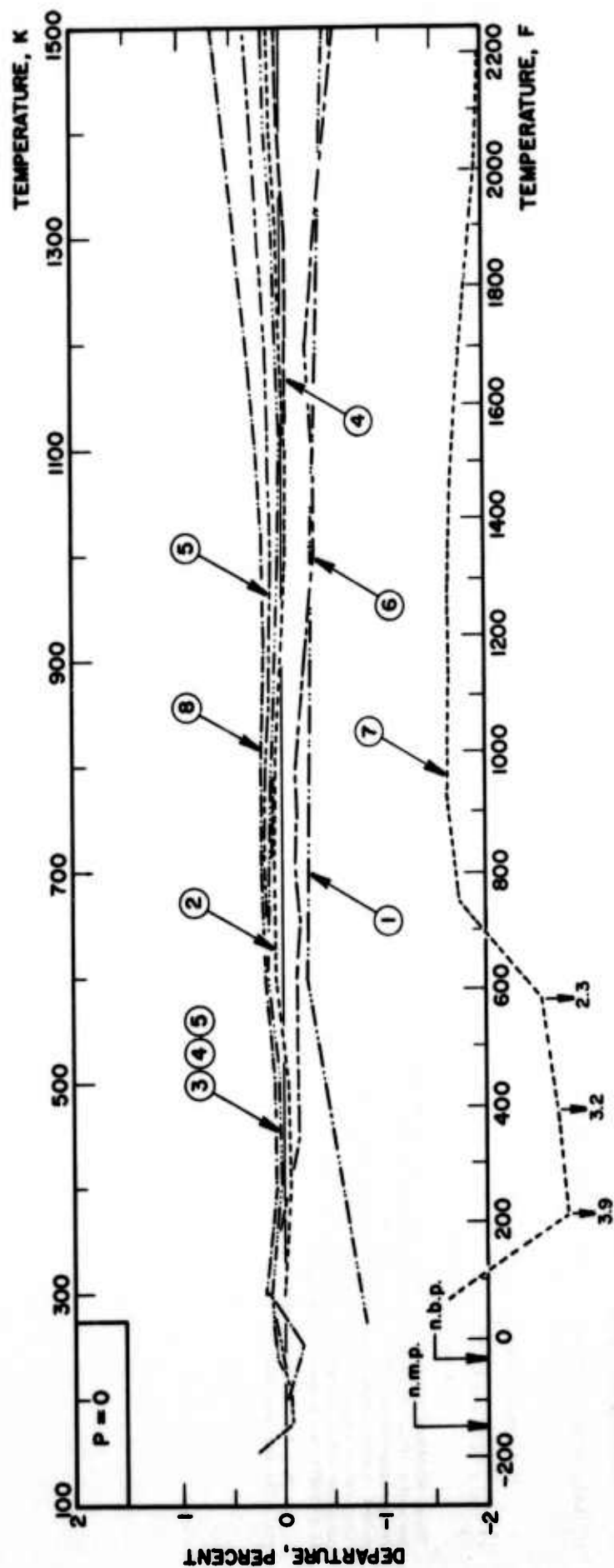
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p , B lb⁻¹ F⁻¹]

GAS		RECOMMENDED VALUES	
T	C_p^0	T	C_p^0
-100	0.1068	600	0.1229
-80	0.1078	620	0.1231
-60	0.1088	640	0.1232
-40	0.1097	660	0.1233
-20	0.1106	680	0.1235
0	0.1114	700	0.1236
20	0.1122	720	0.1237
40	0.1129	740	0.1239
60	0.1136	760	0.1240
80	0.1143	780	0.1241
100	0.1149	800	0.1242
120	0.1155	820	0.1243
140	0.1161	840	0.1244
160	0.1166	860	0.1245
180	0.1171	880	0.1246
200	0.1176	900	0.1247
220	0.1181	920	0.1248
240	0.1185	940	0.1249
260	0.1189	960	0.1250
280	0.1193	980	0.1250
300	0.1196	1000	0.1251
320	0.1199	1100	0.1255
340	0.1202	1200	0.1259
360	0.1205	1300	0.1262
380	0.1208	1400	0.1264
400	0.1211	1500	0.1267
420	0.1213	1600	0.1269
440	0.1215	1700	0.1270
460	0.1217	1800	0.1272
480	0.1219	1900	0.1273
500	0.1221	2000	0.1275
520	0.1223		
540	0.1224		
560	0.1226		
580	0.1228		

n. b. p. = -30 F

FIGURE 3 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS CHLORINE



Curve	Reference
1	59
2	72, 380
3	73, 137, 167, 192,
	321, 389, 423, 479
4	254
5	335
6	508
7	278
8	532

TABLE 4 SPECIFIC HEAT AT CONSTANT PRESSURE OF n-DEUTERIUM

DISCUSSION		RECOMMENDED VALUES	
		[Temperature, T, F; Specific Heat, C_p , B lb ⁻¹ F ⁻¹]	
LIQUID		LIQUID	
		T	C_p^1
		-426	1.188
		-424	1.253
		-422	1.315
		-420	1.382
		-418	1.464

LIQUID

Seven sources of information are available for the specific heat at constant pressure of liquid deuterium. Two sets of experimental results for the normal deuterium were reported by Chusius and Bartholome (288, 290), who measured the specific heat of 99.7 percent pure liquid by a vacuum calorimeter covering temperatures from 19.42 K to 21.71 K. Chelton and Mann (283, 457) and Woolley et al. (571) reported the compilations of existing data covering the temperature range between 18.43 K and 23 K. Good agreement is found among these values, and, therefore, equal weight is given to these works in the present analysis. Although another set of theoretical values (515) were derived from the vapor pressure equation and the equation of state by use of the Debye theory, no weight is given to this work. A set of experimental data (417) for 97.8 percent ortho-deuterium is not analyzed at this time.

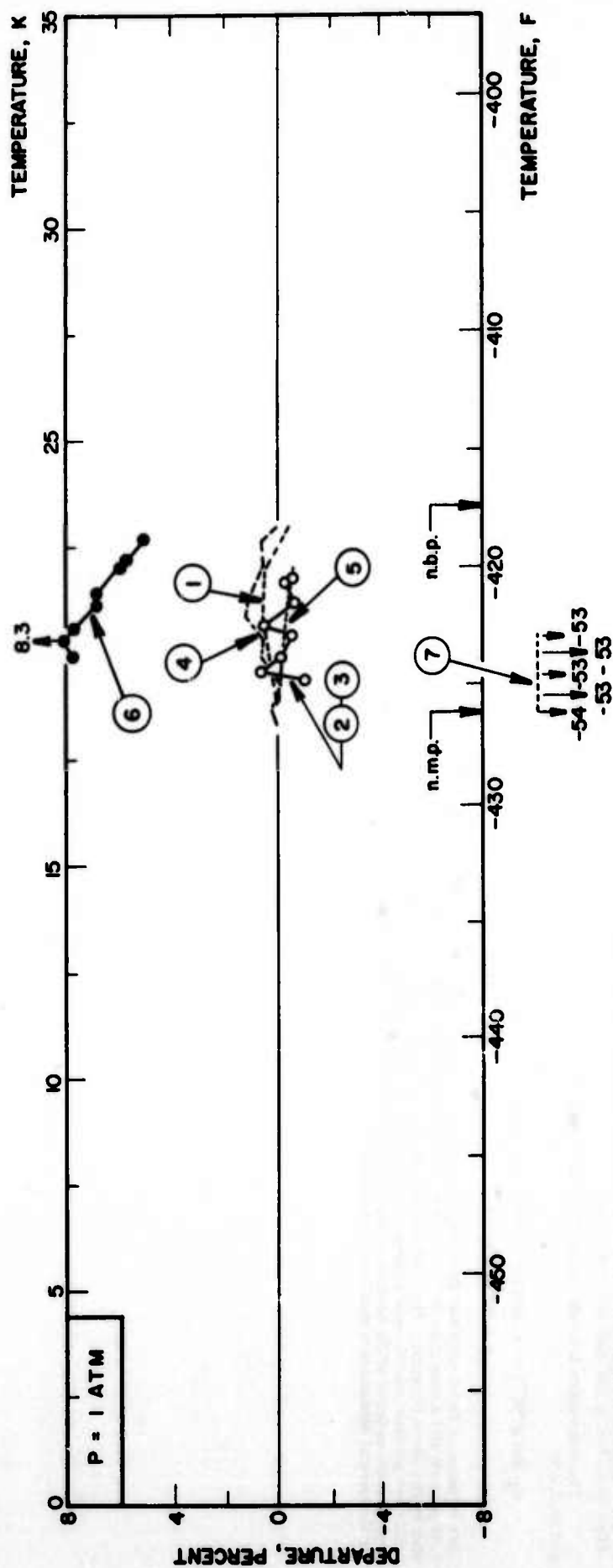
The correlation formula obtained for the temperature range between 18.43 K and 23.0 K is

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = -8.90612 + 1.39803 T - 6.63011 \times 10^{-3} T^2 + 1.09123 \times 10^{-5} T^3$$

(T in K).

This equation is found to fit the above enumerated values with a mean deviation of 0.46 percent and a maximum of 1.1 percent. The recommended values are generated by the above equation. The tabulated values should be substantially correct within two percent over the whole temperature range. In the departure plot, the experimental data for ortho-deuterium (417) are compared with the above equation for the normal deuterium without any correction.

FIGURE 4 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID DEUTERIUM



Curve	Reference
1	283
2	286
3	290
4	487
5	571
6	417
7	516

TABLE 4 SPECIFIC HEAT AT CONSTANT PRESSURE OF n-DEUTERIUM

DISCUSSION		RECOMMENDED VALUES	
GAS		[Temperature, T, F; Specific Heat, C_p , B lb ⁻¹ F ⁻¹]	
T	C_p^0	T	C_p^0
-100	1.7318	600	1.7544
- 80	1.7316	620	1.7565
- 60	1.7315	640	1.7588
- 40	1.7313	660	1.7611
- 20	1.7312	680	1.7636
0	1.7311	700	1.7662
20	1.7311	720	1.7688
40	1.7311	740	1.7715
60	1.7311	760	1.7743
80	1.7311	780	1.7772
100	1.7312	800	1.7801
120	1.7313	820	1.7831
140	1.7315	840	1.7861
160	1.7317	860	1.7893
180	1.7319	880	1.7924
200	1.7323	900	1.7957
220	1.7326	920	1.7989
240	1.7331	940	1.8023
260	1.7336	960	1.8057
280	1.7341	980	1.8091
300	1.7347	1000	1.8126
320	1.7354	1100	1.8306
340	1.7362	1200	1.8494
360	1.7371	1300	1.8689
380	1.7380	1400	1.8886
400	1.7390	1500	1.9083
420	1.7401	1600	1.9278
440	1.7413	1700	1.9468
460	1.7426	1800	1.9651
480	1.7440	1900	1.9823
500	1.7454	2000	1.9982
520	1.7470		
540	1.7487		
560	1.7505		
580	1.7524		

GAS

Only four sources of information are available on the specific heat at constant pressure of gaseous normal deuterium in the ideal gas state. The most reliable values were derived from spectroscopic and molecular structural data by Woolley et al. (571). Heavy weight is given to their results. Another theoretical investigation of Johnston and Long (396) and a set of values derived from experimental compressibility data (461) are also given weight in the present analysis. However, no weight is given to a set of values obtained by earlier statistical calculation (83). The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 200 K and 620 K

$$C_p^0 (\text{cal g}^{-1}\text{K}^{-1}) = 1.73486 + 9.63364 \times 10^{-6}T - 1.69942 \times 10^{-7}T^2 + 3.62210 \times 10^{-9}T^3 \quad (T \text{ in K}) \quad (1)$$

For temperatures between 620 K and 1500 K

$$C_p^0 (\text{cal g}^{-1}\text{K}^{-1}) = 1.81328 - 4.84626 \times 10^{-6}T + 8.08487 \times 10^{-7}T^2 - 2.59126 \times 10^{-9}T^3 \quad (T \text{ in K}) \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.01 and 0.03 percent, and maximum deviations of 0.03 and 0.04 percent, respectively. These formulas are used to generate the recommended values, which should be substantially correct within 0.2 percent over the entire temperature range. The percent departures of all the reported values from the tabulated values are given in the departure plot. An empirical equation (196) is not plotted in this figure.

Although Woolley et al. (571) and Johnston and Long (396) also reported the heat capacity values of ortho- and para-deuterium, covering temperatures from 10 K to 300 K, these values are not correlated at this time.

No information is available on the specific heat in the real gas state.

FIGURE 4 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS n-DEUTERIUM

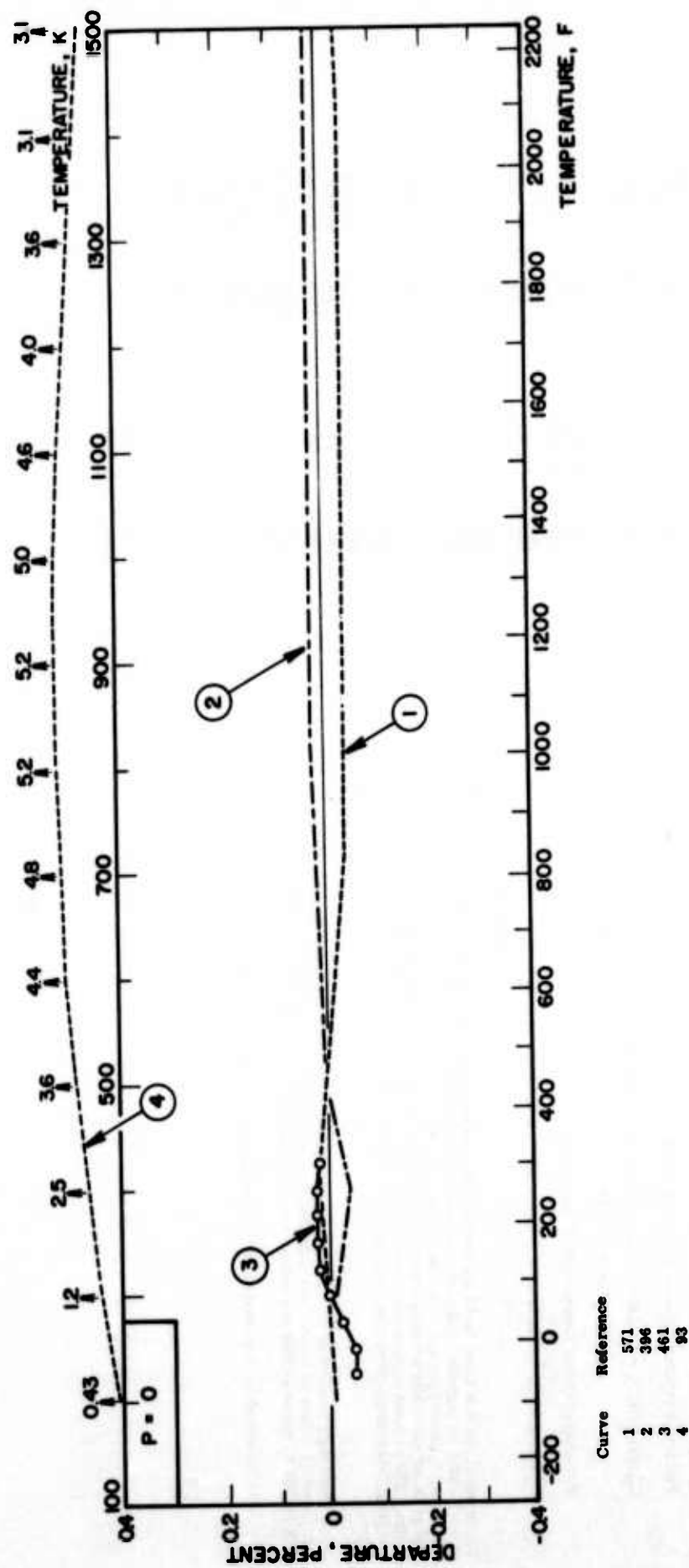


TABLE 5 SPECIFIC HEAT AT CONSTANT PRESSURE OF FLUORINE

DISCUSSION		RECOMMENDED VALUES	
LIQUID		[Temperature, T, F; Specific Heat, C_p , B lb ⁻¹ F ⁻¹]	
		LIQUID	
		T	C_p
		-360	0.362
		-355	0.360
		-350	0.359
		-345	0.358
		-340	0.357
		-335	0.357
		-330	0.358
		-325	0.359
		-320	0.360
		-315	0.362
		-310	0.365
		-305	0.369

Only three sources of information are available for the specific heat at constant pressure for liquid fluorine. The most extensive experimental data are reported by Hu et al., (387, 388), who used a condensed gas calorimeter and covered temperatures from the melting point to the normal boiling point at the normal pressure. Their data are considered to be reliable from the standpoint of the experimental procedures and the purity of liquid sample used, and all the reported experimental points are given weight in this analysis. Another source of information (280) is a compilation of an earlier experimental work which should be less reliable, and therefore, no weight is given to this work.

The correlation formula applicable over the temperatures from 58 K to 82 K is

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.360180 + 2.11636 \times 10^{-3}T - 6.32015 \times 10^{-5}T^2 + 4.63308 \times 10^{-7}T^3 \quad (T \text{ in K}).$$

This equation is found to fit the above enumerated data with a mean deviation of 0.24 percent and a maximum of 0.38 percent. The recommended values are calculated by the above formula. The tabulated values should be substantially correct within one percent over the whole temperature range. In the departure plot, the smoothed values reported by Hu et al. (387, 388) are not given.

n. b. p. = -305 F

FIGURE 5 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID FLUORINE

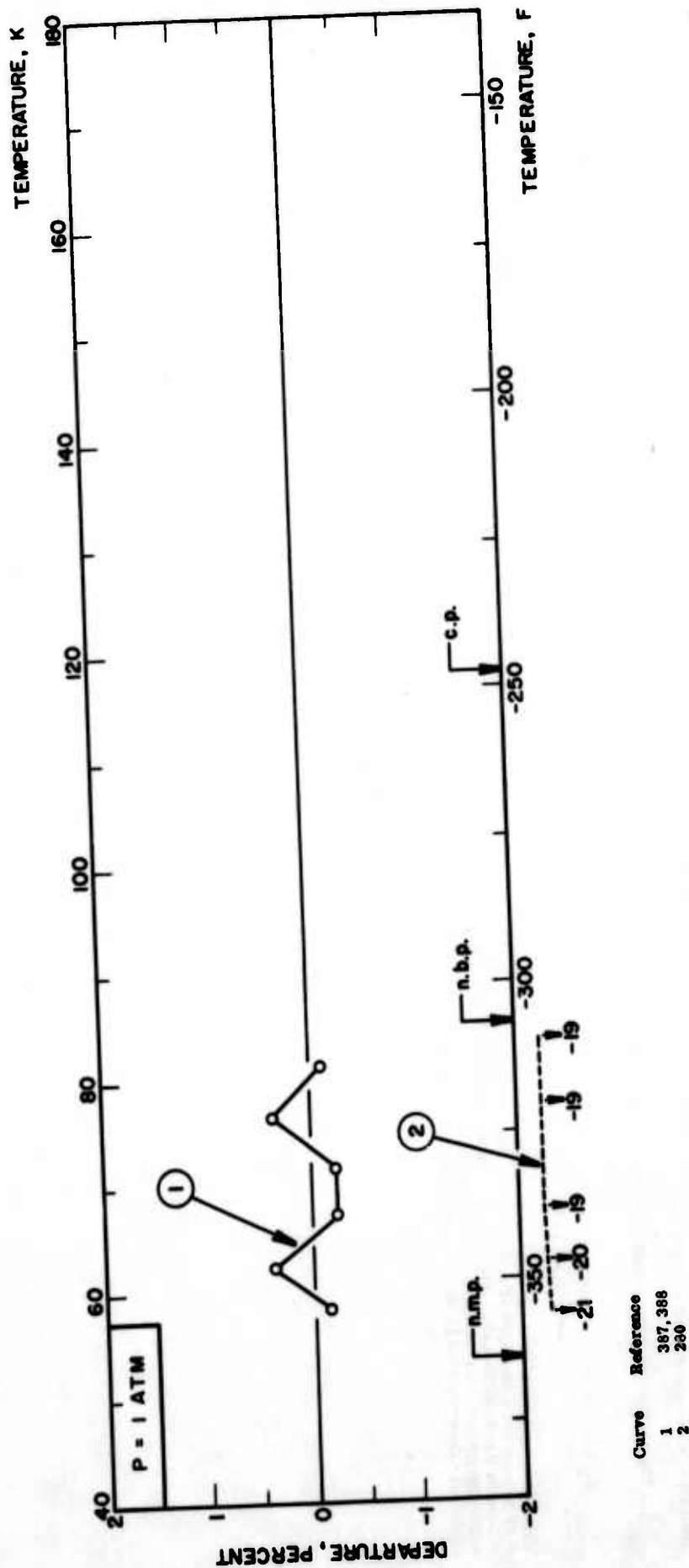


TABLE 5 SPECIFIC HEAT AT CONSTANT PRESSURE OF FLUORINE

DISCUSSION

GAS

There exist 17 sources of information on the constant pressure specific heat of gaseous fluorine. A number of extensive values for the ideal gas state have been derived from spectroscopic and molecular structural data. Results of Gordon (72), McBride et al. (137), Sinks (192), Cole et al. (298), Evans et al. (321), Furukawa et al. (335), Hildebrand (380) and Potter (493) are considered to be reliable as well as compilation tables (254, 479, 508). Equal weight is given to these works in this analysis. However, other sets of theoretical derivations (476, 477) and correlations (389, 428, 486) are given no weight. The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 200 K and 770 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}) = 0.157376 + 1.60907 \times 10^{-4} T - 8.94787 \times 10^{-6} T^2 - 6.18535 \times 10^{-8} T^3 \quad (1)$$

For temperatures between 770 K and 1500 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}) = 0.183543 + 9.52742 \times 10^{-4} T - 5.95103 \times 10^{-6} T^2 + 1.38398 \times 10^{-11} T^5 \quad (2)$$

(T in K)

These equations are found to fit the above enumerated values with mean deviations of 0.15 and 0.17 percent, and maximum deviations of 0.44 and 0.42 percent, respectively. These formulas are used to generate the recommended values, which should be substantially correct within one percent over the entire temperature range. The percent departures of all the reported values from the tabulated values are given in the departure plot. An empirical equation (346) is not plotted in this figure.

No information is available in literature on the specific heat of fluorine in the real gas state.

RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p , B lb⁻¹F⁻¹]

GAS

T	C_p^0	T	C_p^0
-100	0.1858	600	0.2208
-80	0.1872	620	0.2214
-60	0.1886	640	0.2220
-40	0.1899	660	0.2226
-20	0.1912	680	0.2231
0	0.1925	700	0.2236
20	0.1938	720	0.2241
40	0.1950	740	0.2245
60	0.1962	760	0.2250
80	0.1974	780	0.2254
100	0.1986	800	0.2258
120	0.1998	820	0.2262
140	0.2009	840	0.2265
160	0.2020	860	0.2269
180	0.2031	880	0.2272
200	0.2042	900	0.2275
220	0.2052	920	0.2277
240	0.2062	940	0.2280
260	0.2072	960	0.2283
280	0.2082	980	0.2286
300	0.2092	1000	0.2289
320	0.2101	1100	0.2303
340	0.2110	1200	0.2315
360	0.2119	1300	0.2326
380	0.2128	1400	0.2336
400	0.2136	1500	0.2344
420	0.2144	1600	0.2352
440	0.2152	1700	0.2359
460	0.2160	1800	0.2366
480	0.2168	1900	0.2372
500	0.2175	2000	0.2378
520	0.2182		
540	0.2189		
560	0.2196		
580	0.2202		

FIGURE 5 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS FLUORINE

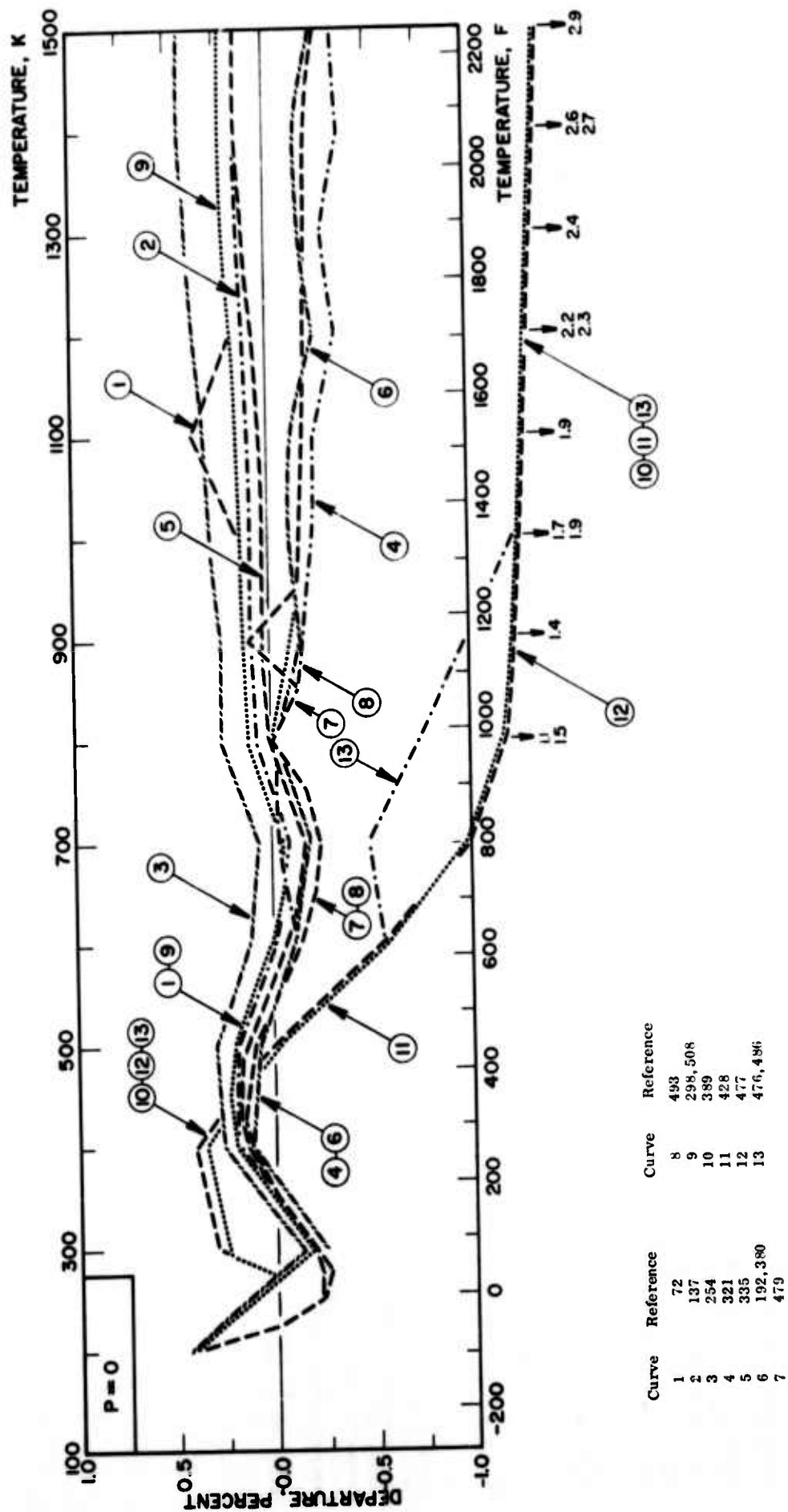


TABLE SPECIFIC HEAT AT CONSTANT PRESSURE OF HELIUM

DISCUSSION

GAS

There exist 24 sources of information in the literature for the constant pressure specific heat of gaseous helium. A number of reliable calculations (100, 137, 335, 362, 435) using spectroscopic and molecular data, show that the ideal gas heat capacity for helium is represented by $(5/2)R$, (R is the gas constant) and it remains constant with temperature up to 6000 K or more because helium is a monatomic gas and the molecules possess translational energy only. This fact is also verified by experimental works (383, 560). Therefore, the isobaric specific heat at the ideal gas state is given by

$$C_p^0 (\text{cal g}^{-1} \text{K}^{-1}) = \frac{5}{2} \frac{R}{M} = \frac{5}{2} \frac{1.98719}{4.0026} = 1.2412, \quad (1)$$

where M is molecular weight. The recommended value of C_p^0 is given by Equation (1) or

$$C_p^0 (\text{Btu lb}^{-1} \text{°R}^{-1}) = \frac{F-1}{F} = 1.2404.$$

No tables and plots concerning the above enumerated works for C_p^0 are given in this analysis, as well as three compilations (313, 454, 481).

On the other hand, many sets of data at the real gas state are available. These include experimental data reported from P-V-T relations (391, 545), adiabatic expansion (319) and velocity of sound measurements (306, 547, 548). As these data fail to cover a wide temperature range, it is difficult to correlate the specific heat in the real gas state. In the departure plot for $P = 1$ atm, the above experimental data, as well as some sets of compilations or correlations (283, 442, 446, 452, 564), are compared with the values at the ideal gas state, namely, Equation (1). Cited values (457, 557) and higher temperature values (282) are not plotted in this figure.

FIGURE 6 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS HELIUM

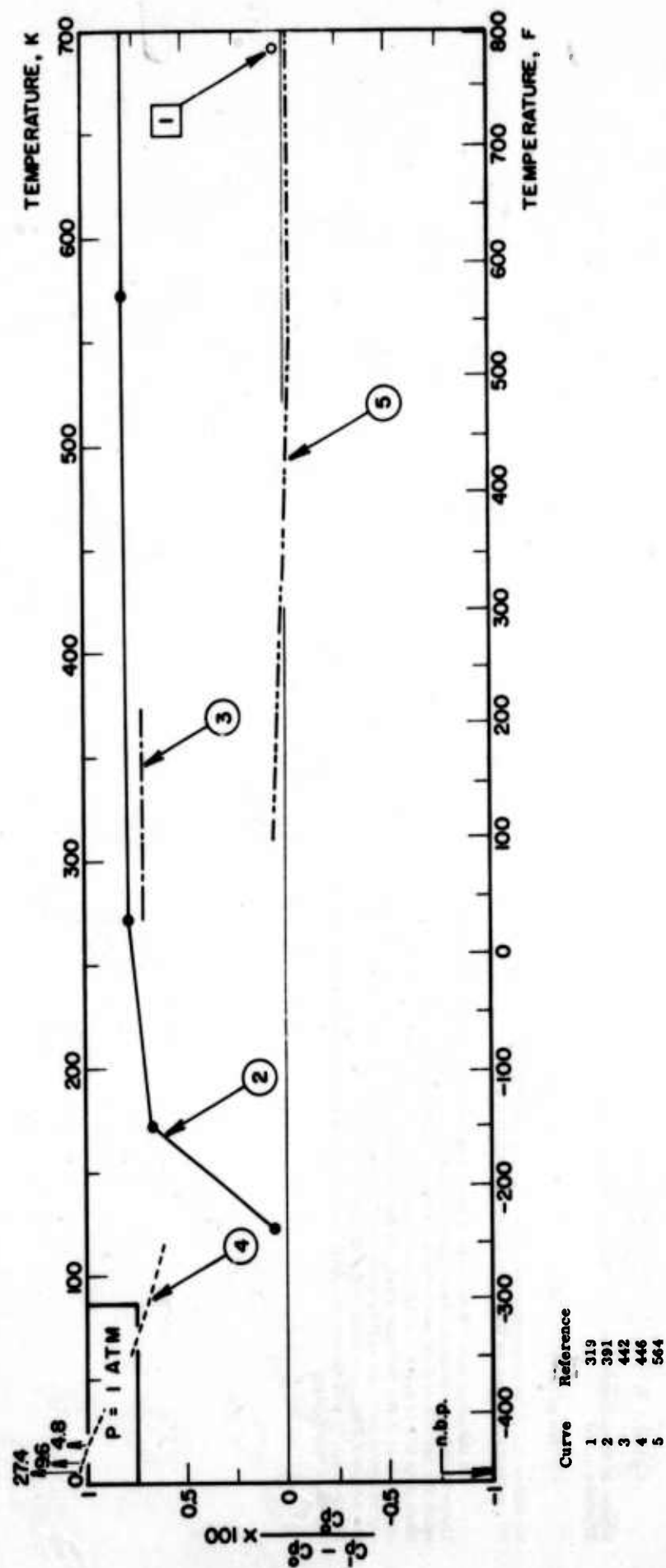


FIGURE 6 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS HELIUM (continued)

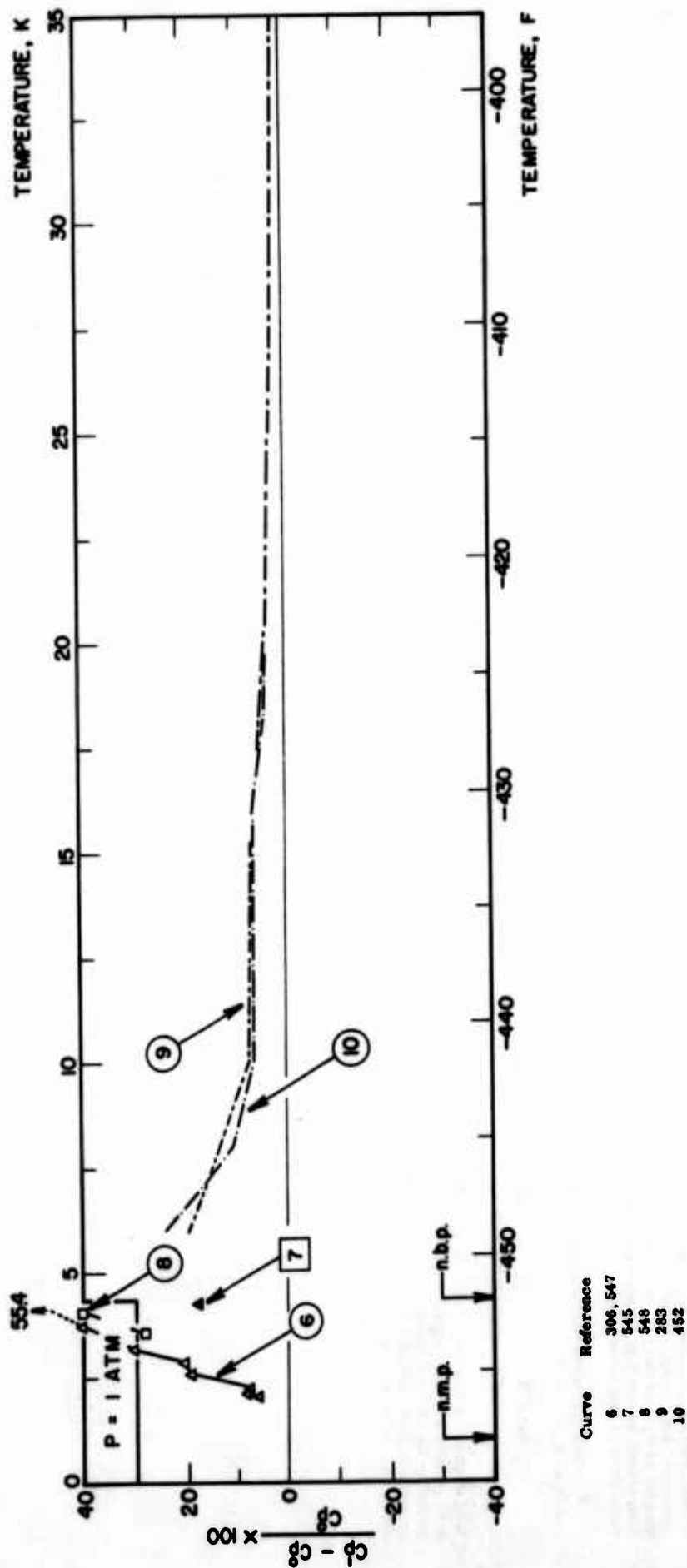


TABLE 7 SPECIFIC HEAT AT CONSTANT PRESSURE OF HYDROGEN

DISCUSSION

RECOMMENDED VALUES
[Temperature, T, F; Specific Heat, C_p , B lb⁻¹F⁻¹]

LIQUID	
T	C_p
-434	1.668
-432	1.748
-430	1.844
-428	1.956
-426	2.084
-424	2.223
-422	2.374
-420	2.536
-418	2.708
-416	2.887
-414	3.074
-412	3.266

LIQUID

There exist ten sources of information for the specific heat at constant pressure of liquid hydrogen. Among them, three reliable sets of calorimetric data of Clusius and Hiller (293), Johnston et al. (394) and Smith et al. (530) were obtained for para-hydrogen. These data agree well with the compilation for normal-hydrogen by Woolley et al. (571). Therefore, equal weight are given to these four works covering temperatures from 14 K to 26 K under saturated vapor pressures. However, three compilations (283, 446, 457) given in graphical forms are given no weight, as well as two sets of theoretical values (472, 515). Another set of calorimetric data reported by Gutsche (363) was obtained under high pressures and is not considered in this correlation.

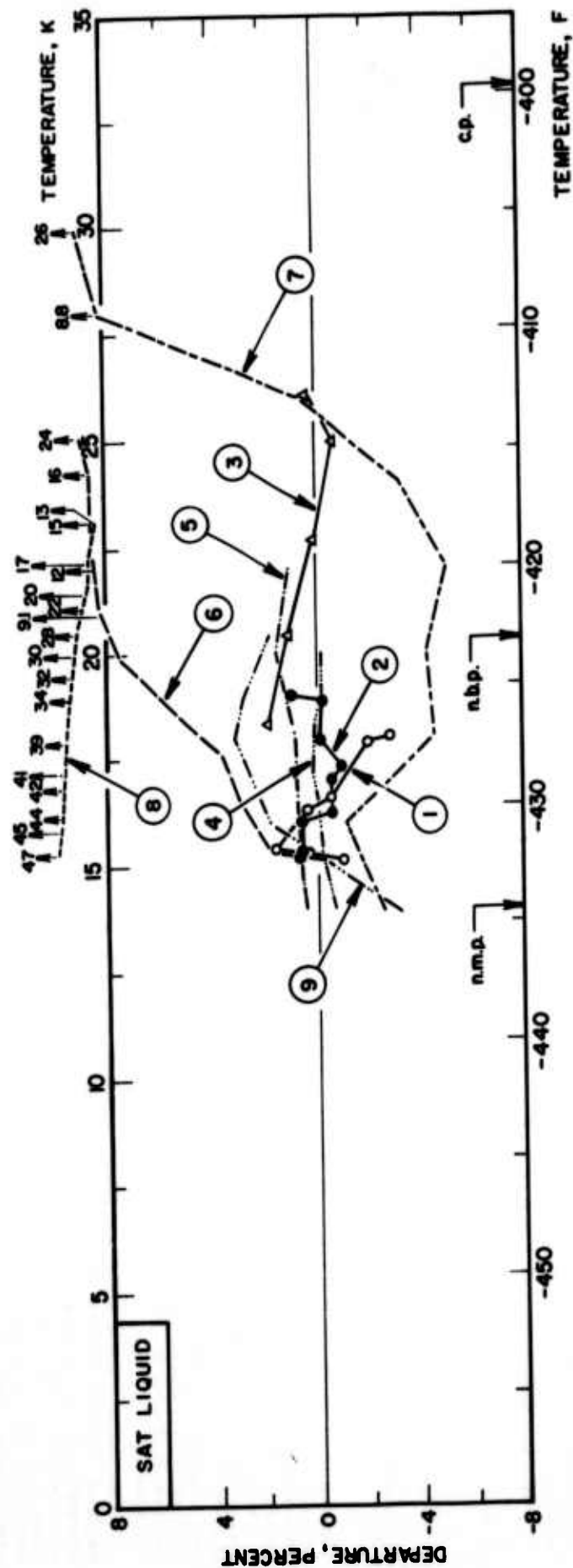
The correlation formula obtained for the temperature range between 14 K and 26 K is

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 2.64317 - 0.230392 T + 1.34355 \times 10^{-5} T^2 - 1.45134 \times 10^{-7} T^3 \quad (T \text{ in K}).$$

This equation is found to fit the above enumerated values with a mean deviation of 0.67 percent and a maximum of 2.8 percent. The recommended values are generated by the above formula. The tabulated values should be substantially correct within four percent. The calorimetric data under high pressures (363) are not plotted in the departure plot.

n.m.p. = -431 F
n.b.p. = -423 F

FIGURE 7 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID HYDROGEN



Curve	Reference
1	283
2	394
3	530
4	571
5	283
6	457
7	446
8	472
9	515

TABLE 7 SPECIFIC HEAT AT CONSTANT PRESSURE OF HYDROGEN

DISCUSSION

GAS

There exist 66 sources of information on the specific heat at constant pressure of gaseous hydrogen. Many sets of extensive values for the ideal gas state have been derived from spectroscopic and molecular structural data by statistical mechanics. The results presented by Brickwedde et al. (22), Gordon (72), Keyes (100), McBride et al. (137), Ribaud (167), Sinks (192), Wagman, et al. (226), Hildenbrand (380), Huff et al. (389), Kallman (403), Pack and Hill (486) and Woolley et al. (571) are considered to be reliable as well as three compilation tables (253, 254, 575), and are given equal weight in the present analysis. A set of derived values from P-V-T data (461) is also taken into consideration. However, other sets of correlated values (59, 357) and various earlier statistical calculations (24, 93, 278, 285, 304, 339, 426, 501) are given no weight as well as a set of extrapolated values from calorimetric measurement (319). The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 100 K and 400 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 1.46910 + 1.60057 \times 10^{-2}T - 4.44048 \times 10^{-4}T^2 + 4.21220 \times 10^{-4}T^3 \quad (1)$$

For temperatures between 400 K and 1500 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 3.56903 - 4.89590 \times 10^{-4}T + 6.22549 \times 10^{-7}T^2 - 1.19686 \times 10^{-10}T^3 \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.17 and 0.07 percent, and maximum deviations of 0.34 and 0.17 percent, respectively. The recommended values are generated from the above formulas. The tabulated values of C_p^0 should be substantially correct within 0.5 percent over the entire temperature range. The percent departures of all the reported values from the recommended values are given in two departure plots for $P = 0$. However, mean specific heat values (92), cited values (421), low temperature data (263, 433) and empirical equations (25, 205, 377, 532) are not shown in these figures. Furthermore, Woolley et al. (571) presented the heat capacity of ortho- and para-hydrogen, but no correlation is presented on them in this work.

Meanwhile, a number of extensive theoretical values are also available for the specific heat in the real gas state. The most reliable values are derived by Hilsenrath et al. (575) by means of the real gas correction of the ideal gas specific heat. Therefore, heavy weight is given to their results. Other sets of theoretical values of Edse (314) and Heck (375, 376) are also given weight, as well as the extrapolated values from calorimetric data (65) and a set of correlated values (249). However, several compilations (78, 132, 283, 374, 446, 454, 457, 481,

541) and earlier statistical calculations (354) are given no weight, as well as the experimental data obtained by the adiabatic expansion (277) and by a flow calorimeter (482). The correlation formulas obtained for the specific heat in the real gas state, independently of the ideal gas values, are as follows:

For temperatures between 100 K and 420 K:

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 1.53950 + 1.50825 \times 10^{-2}T - 4.02449 \times 10^{-4}T^2 + 3.63544 \times 10^{-4}T^3 \quad (3)$$

For temperatures between 420 K and 1500 K:

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 3.58927 - 5.55096 \times 10^{-4}T + 6.94235 \times 10^{-7}T^2 - 1.45155 \times 10^{-10}T^3 \quad (4)$$

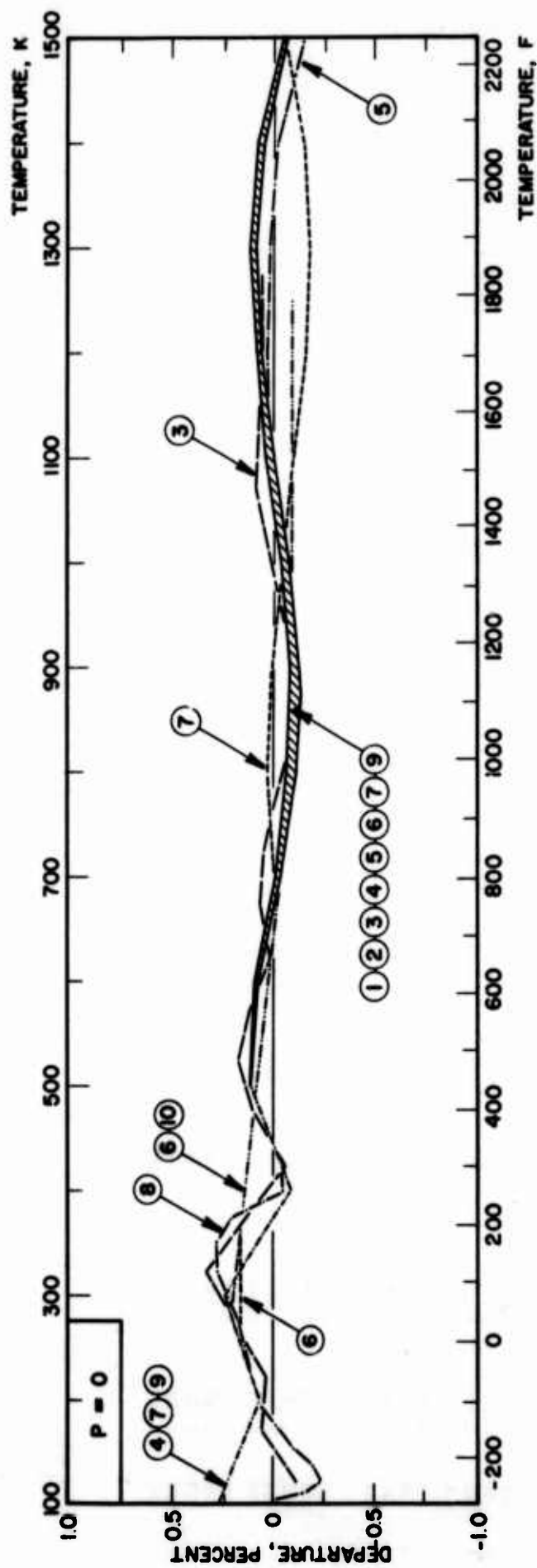
These equations are found to fit the above enumerated values with mean deviations of 0.10 and 0.08 percent, and maximum deviations of 0.37 and 0.24 percent, respectively. The recommended values of C_p are generated from the above formulas. The tabulated values should be substantially correct within 0.5 percent over the entire temperature range. Equations (3) and (4) are used to calculate the departures of all the reported values in the real gas state, which are shown in the departure plot for $P = 1$ atm. However, empirical equations (184, 185, 346), cited values (71, 127, 279, 421, 442, 557), and data outside the present temperature range (544, 559, 563) are not given in this figure. A set of data of hydrogen adsorbed on carbon (533) is not taken into consideration in this correlation.

The comparison of Equations (3) and (4) with Equations (1) and (2) is also given in the last plot.

TABLE 7 SPECIFIC HEAT AT CONSTANT PRESSURE OF HYDROGEN (continued)

RECOMMENDED VALUES				RECOMMENDED VALUES			
[Temperature, T, F; Specific Heat, C_p^0 and C_p , B lb ⁻¹ F ⁻¹]				[Temperature, T, F; Specific Heat C_p^0 and C_p , B lb ⁻¹ F ⁻¹]			
GAS							
T	C_p^0	C_p	T	C_p^0	C_p	T	C_p^0
-280	2.664	2.678	300	3.462	3.465	900	3.501
-260	2.754	2.765	320	3.462	3.465	920	3.504
-240	2.836	2.845	340	3.462	3.465	940	3.507
-220	2.911	2.918	360	3.462	3.464	960	3.510
-200	2.978	2.985	380	3.462	3.464	980	3.513
-180	3.040	3.046	400	3.462	3.464	1000	3.516
-160	3.095	3.101	420	3.462	3.465	1100	3.533
-140	3.145	3.150	440	3.463	3.465	1200	3.552
-120	3.189	3.195	460	3.463	3.465	1300	3.571
-100	3.228	3.234	480	3.464	3.466	1400	3.593
-80	3.263	3.269	500	3.465	3.466	1500	3.618
-60	3.293	3.300	520	3.465	3.467	1600	3.643
-40	3.319	3.327	540	3.466	3.468	1700	3.669
-20	3.341	3.350	560	3.467	3.469	1800	3.696
0	3.360	3.370	580	3.469	3.470	1900	3.725
20	3.376	3.387	600	3.470	3.471	2000	3.755
40	3.389	3.401	620	3.471	3.472		
60	3.400	3.412	640	3.473	3.474		
80	3.409	3.421	660	3.474	3.475		
100	3.417	3.429	680	3.476	3.477		
120	3.423	3.435	700	3.478	3.479		
140	3.428	3.439	720	3.480	3.481		
160	3.433	3.443	740	3.482	3.482		
180	3.437	3.446	760	3.484	3.484		
200	3.442	3.449	780	3.486	3.487		
220	3.447	3.451	800	3.488	3.489		
240	3.453	3.454	820	3.490	3.491		
260	3.460	3.458	840	3.493	3.493		
280	3.462	3.462	860	3.495	3.496		
			880	3.498	3.499		

FIGURE 7 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS HYDROGEN



Curve	Reference
1	22, 285
2	72, 167, 192, 380
3	389, 426, 486
4	100
5	137, 571
6	226, 403
7	253
8	254
9	461
10	575
	59

FIGURE 7 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS HYDROGEN (continued)

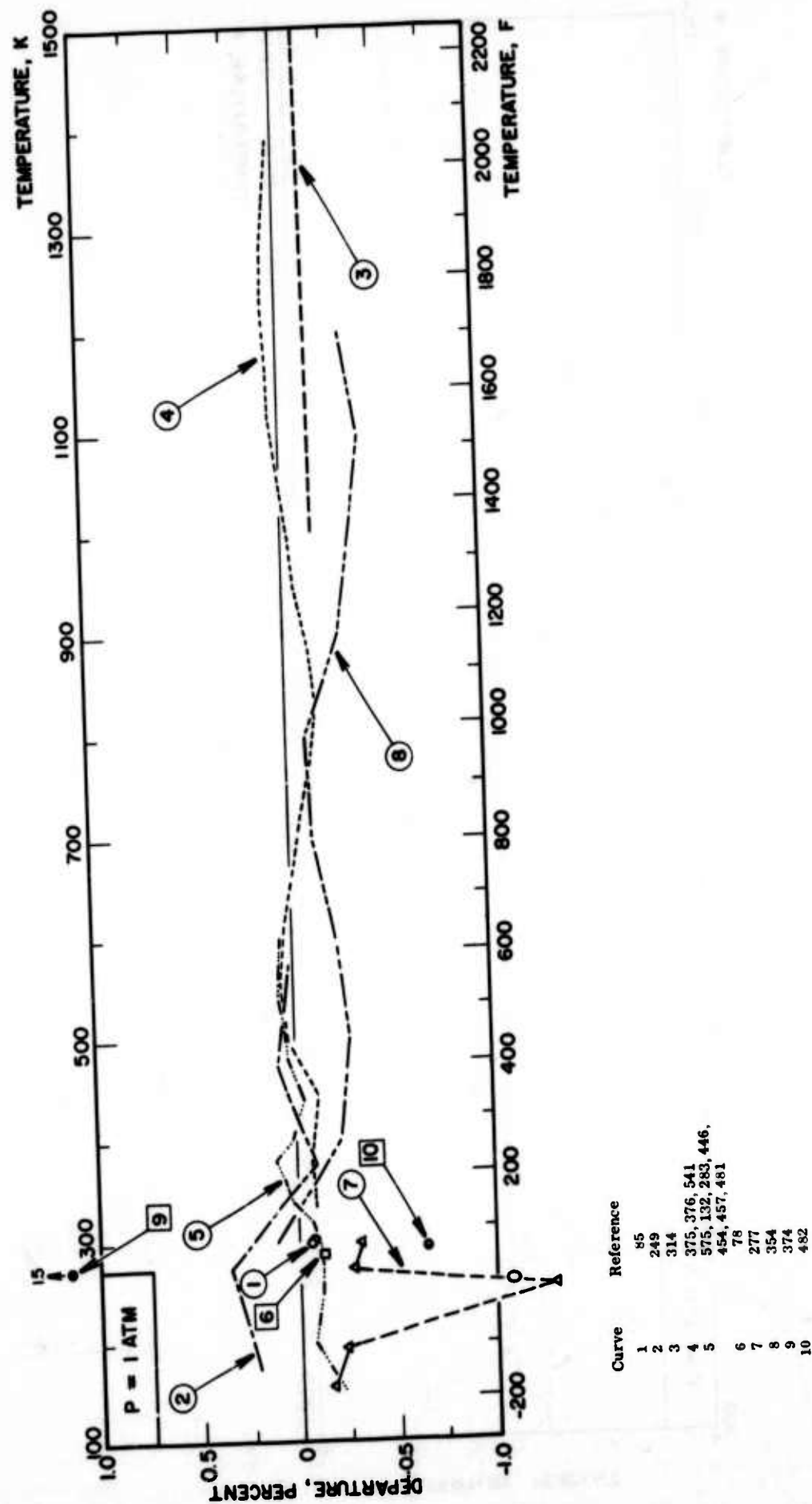


FIGURE 7 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS HYDROGEN (continued)

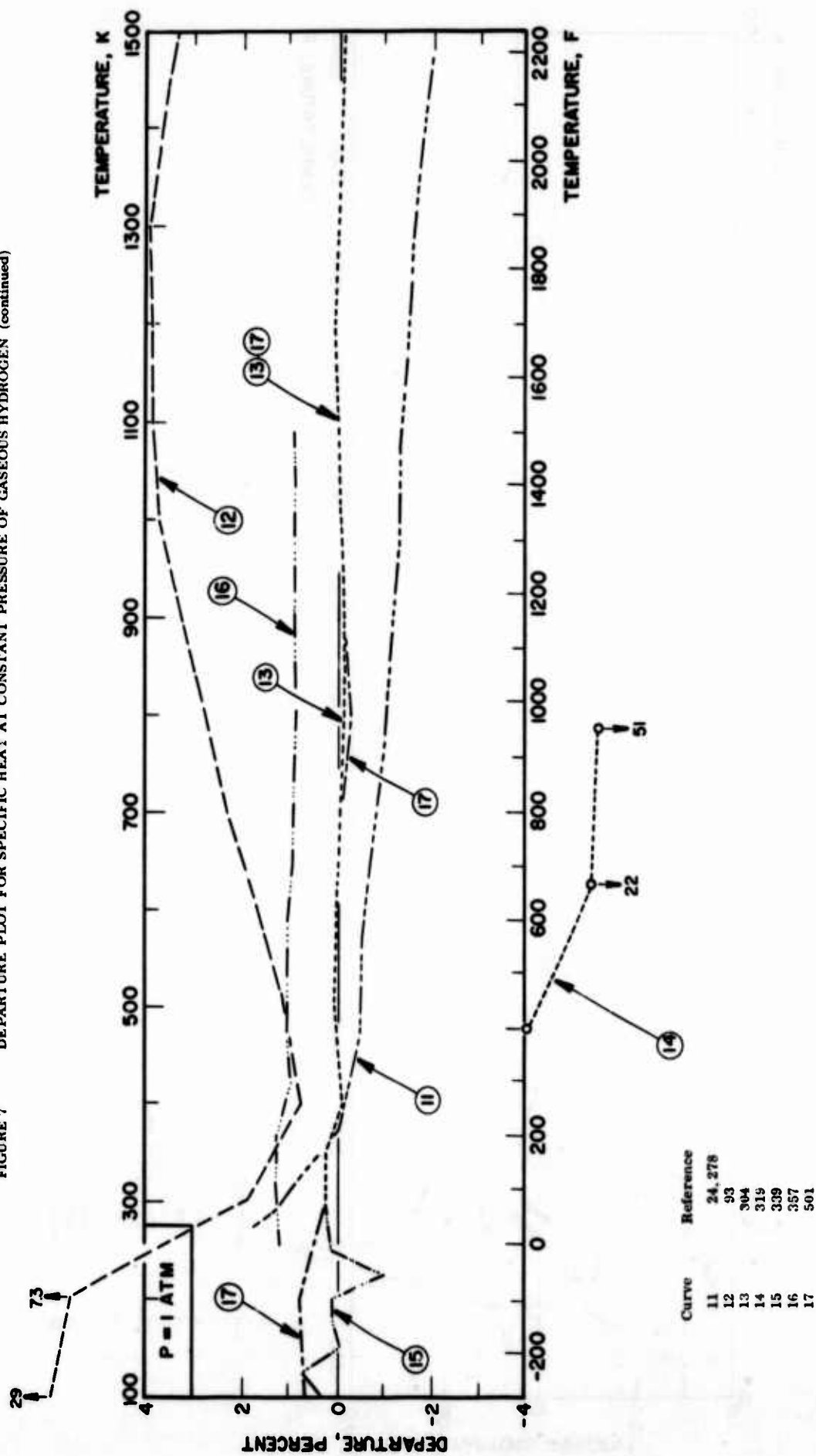


FIGURE 7 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS HYDROGEN

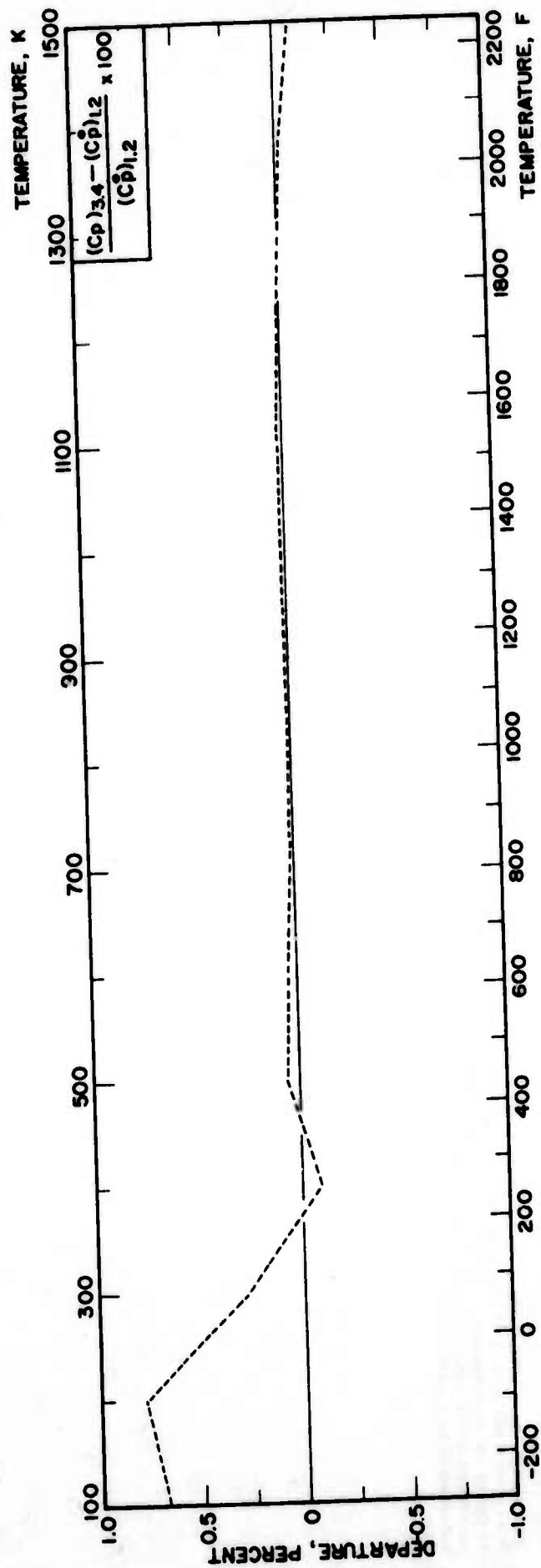


TABLE 8 SPECIFIC HEAT AT CONSTANT PRESSURE OF KRYPTON

DISCUSSION		RECOMMENDED VALUES	
		[Temperature, T, °F; Specific Heat, C _p , B lb ⁻¹ F ⁻¹]	
LIQUID		LIQUID	
		T	C _p
		-250	0.1259
		-245	0.1276
		-240	0.1278

LIQUID

Three experimental works are available for the specific heat at constant pressure of liquid krypton. Two sets of calorimetric data for the purified krypton of Clusius et al. (289, 294), covering temperatures from 117.13 K to 123.07 K, agree within two percent. Equal weight is given to all the reported data points in the present analysis. Another set of calorimetric data is reported by Pace et al. (485), who measured the specific heat of krypton adsorbed on titanium dioxide at the temperature range between 20 K and 140 K. Their work is given no weight in this analysis for the pure liquid.

The correlation formula obtained for the temperature range from 117 K to 123 K is

$$C_p \text{ (cal } ^\circ\text{K}^{-1}\text{)} = 0.107272 - 1.21811 \times 10^{-2}T + 2.05761 \times 10^{-4}T^2 - 8.56821 \times 10^{-7}T^3 \quad (T \text{ in K}).$$

This equation is found to fit the above enumerated data with a mean deviation of 0.49 percent and a maximum of 1.2 percent. The recommended values are generated by the above equation. The tabulated values should be substantially correct within two percent. The data of krypton adsorbed on titanium dioxide are not shown in the departure plot.

n. b. p. = -244 °F

FIGURE 8 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID KRYPTON

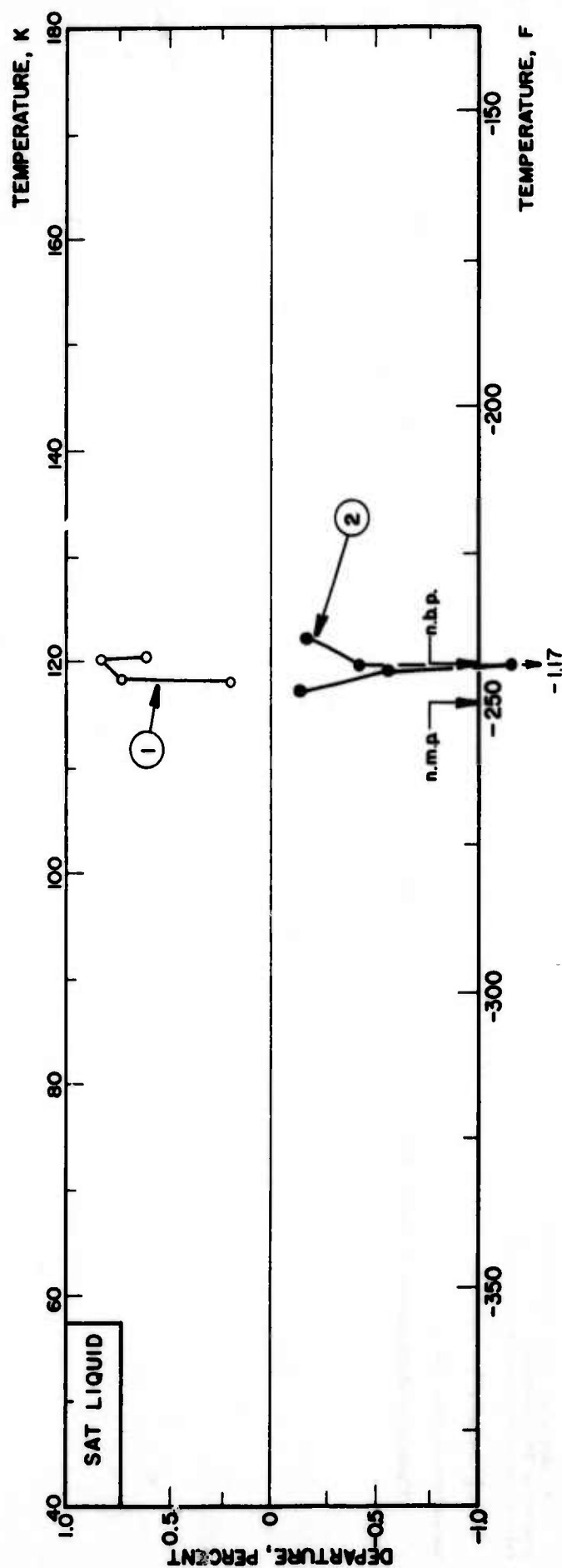


TABLE 8 SPECIFIC HEAT AT CONSTANT PRESSURE OF KRYPTON

DISCUSSION

GAS

Information on the constant pressure specific heat of gaseous krypton is nearly nonexistent in the literature. Since krypton is a monatomic gas and the molecules possess translational energy only, its molar heat capacity at the ideal gas state is represented by $C_p^0 = (5/2)R$, (R is the universal gas constant) and remains constant with temperature over a wide temperature range. Therefore, the specific heat of this gas is:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}) = \frac{5R}{2M} = \frac{5}{2} \frac{1.98719}{83.90} = 0.059284, \quad (1)$$

where M is the molecular weight.

Kolsky, et al. (435) showed from statistical calculations that the C_p^0 remains constant in the temperature range from 10 K to 6200 K. Therefore, the recommended value of the isobaric specific heat at the ideal gas state is given by Equation (1), or

$$C_p^0 \text{ (Btu lb}^{-1}\text{F}^{-1}) = 0.059245.$$

and no table is given in the present analysis.

There is no information on the specific heat of krypton in the real gas state.

TABLE 9 SPECIFIC HEAT AT CONSTANT PRESSURE OF NEON

DISCUSSION

GAS

Few sources of information are available for the specific heat of gaseous neon. As neon is a monatomic gas and the molecules do not possess any internal degrees of freedom, the molar heat capacity at the ideal gas state is given by $C_p = (5/2)R$, (R is the universal gas constant) and remains constant with temperature over a wide temperature range. Therefore, the isobaric specific heat of this gas is given as follows:

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = \frac{5R}{2M} = \frac{5 \times 1.98719}{2 \times 20.183} = 0.24615, \quad (1)$$

where M is the molecular weight.

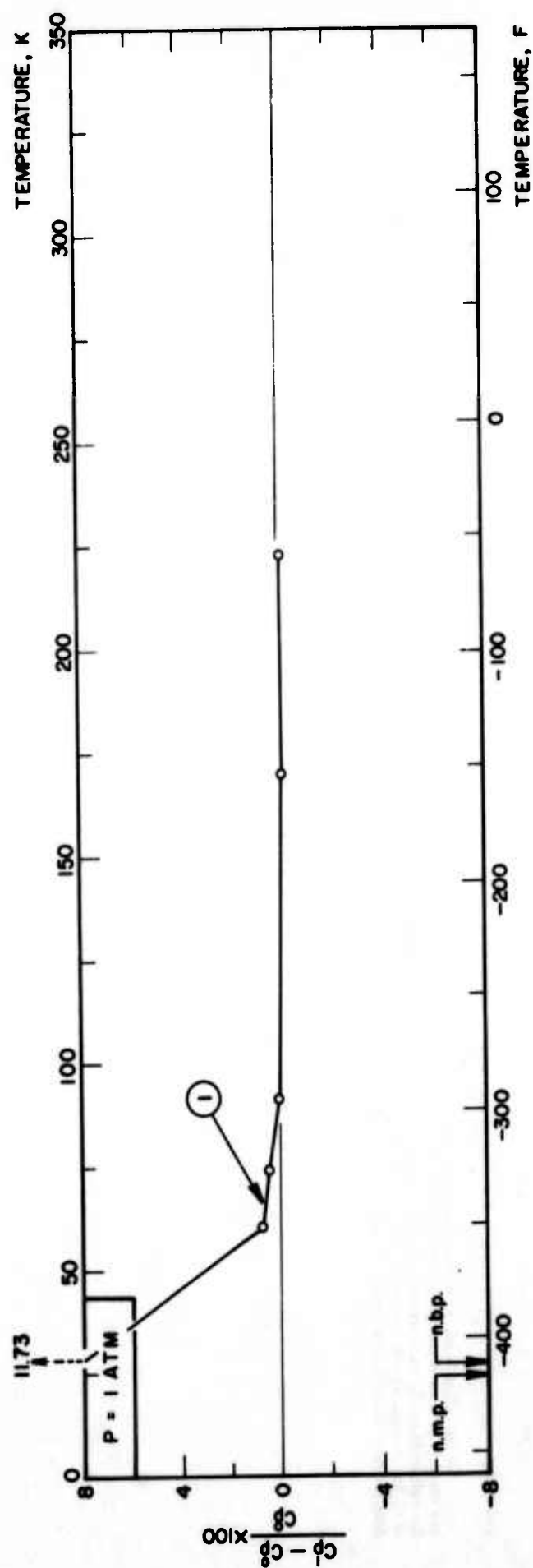
Statistical mechanical calculations (335, 435) showed that C_p should be constant in the temperature range from 10 K to 8000 K. The recommended value of the isobaric specific heat at the ideal gas state is given by Equation (1), or

$$C_p^0 \text{ (Btu lb}^{-1}\text{F}^{-1}\text{)} = 0.24599$$

and therefore, no tabulation is made in the present analysis.

On the other hand, available information for the specific heat at the real gas state, C_p , was reported only by Keesom and Van Lammeren (413), who derive the values from the measurement of the velocity of sound in the gas. Their values of C_p are compared with Equation (1) in the departure plot. A set of calorimetric data for neon adsorbed on titanium oxide (542) is not used in the present analysis.

FIGURE 9 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS NEON



Curve Reference
1 413

TABLE 10 SPECIFIC HEAT AT CONSTANT PRESSURE OF NITROGEN

RECOMMENDED VALUES	
[Temperature, T, °F; Specific Heat, C _p , B lb ⁻¹ F ⁻¹]	
LIQUID	
T	C _p
-340	0.4794
-335	0.4829
-330	0.4855
-325	0.4877
-320	0.4899
-315	0.4922
-310	0.4949
-305	0.4984
-300	0.5028
-295	0.5065
-290	0.5157
-285	0.5248
-280	0.5360
-275	0.5495
-270	0.5658
-265	0.5850
-260	0.6074
-255	0.6334
-250	0.6630
-245	0.6968
-240	0.7349

DISCUSSION

LIQUID

Seven sources of information are available for the constant pressure specific heat of liquid nitrogen. Among them, three sets of experimental data are considered to be reliable. These are the calorimetric data of Clusius (240) covering temperatures from 66.9 K to 73.5 K within an experimental error of 0.7 percent, the work of Glaue and Clayton (241) at temperatures between 65.02 K and 77.74 K which agrees with that of Clusius within 0.8 percent, and the data of Wiebe and Brevoort (242) obtained along the saturated vapor pressure curve up to 117 K. Therefore, equal weight is given to these sets of data. However, a compilation of existing data (446) and a theoretical work (216) are given no weight. Two sets of calorimetric data of this liquid adsorbed on titanium dioxide (262, 473) are also not analyzed at the present time.

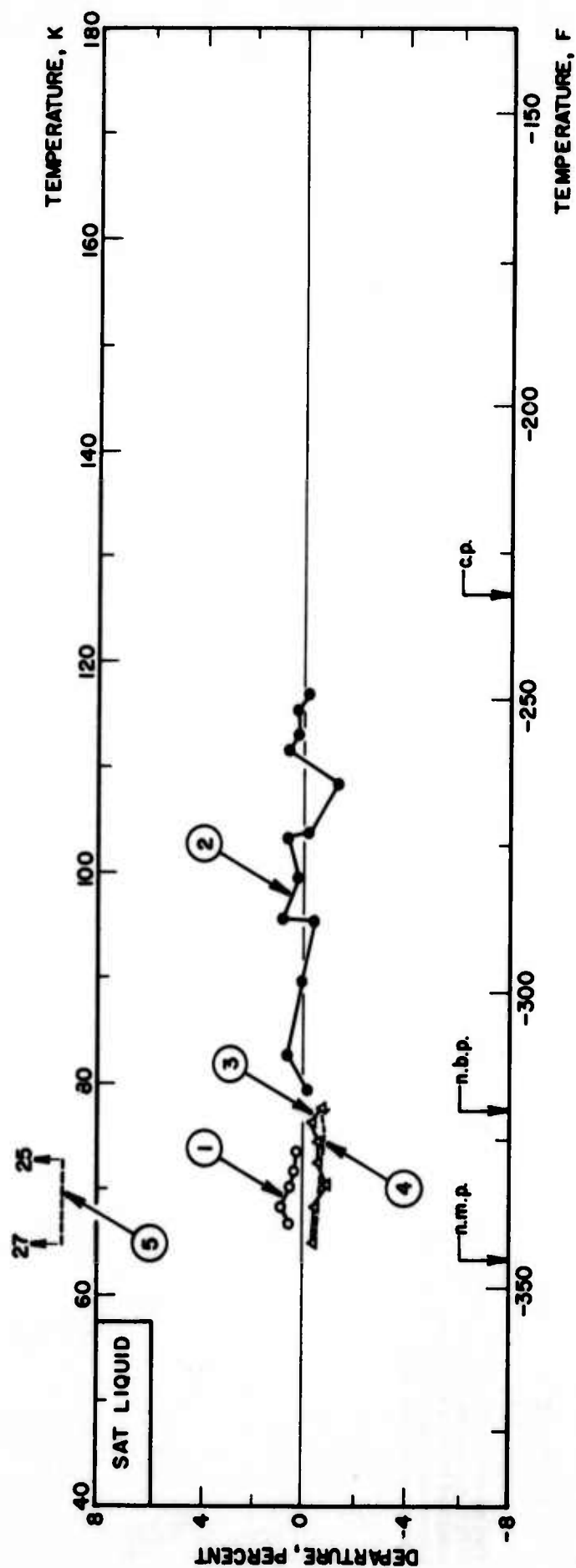
The correlation formula obtained for the temperature range between 67 K and 117 K is

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = -0.530224 + 3.96307 \times 10^{-3}T - 4.97385 \times 10^{-4}T^2 + 2.17816 \times 10^{-6}T^3 \quad (T \text{ in K})$$

This equation is found to fit the above enumerated values with a mean deviation of 0.53 percent and a maximum of 1.4 percent. The recommended values are generated by the above formula. The tabulated values should be substantially correct within two percent. In the departure plot, two sets of data for adsorbed nitrogen on titanium dioxide are not given.

n. b. p. = -320 °F

FIGURE 10 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID NITROGEN



Curve	Reference
1	240
2	248
3	341
4	446
5	216

TABLE 10 SPECIFIC HEAT AT CONSTANT PRESSURE OF NITROGEN

DISCUSSION

GAS

Seventy-nine sources of information are available for the specific heat at constant pressure of gaseous nitrogen. A number of extensive theoretical values for the ideal gas state have been derived from spectroscopic and molecular structural data. The values presented by Faltin (59), Gordon (72), Ribaud (467), Wagman et al. (226), Goff and Gratch (351), Gratch (362), Hildenbrand (380), Huff et al. (389), Kobe et al. (426, 429) and Woolley (568) are considered to be reliable, as well as three compilation tables (253, 254, 575). Therefore, equal weight is given to these works in the present analysis. However, other sets of extensive derivations (100, 266, 403), correlations (360, 368) and earlier statistical calculations (24, 93, 178, 278, 395, 501) are given no weight, as well as three sets of extrapolated values to zero pressure from adiabatic expansion experiments (56, 319, 466). The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 250 K and 775 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.259934 - 8.42119 \times 10^{-6}T + 1.72117 \times 10^{-9}T^2 - 6.72914 \times 10^{-13}T^3 \quad (1)$$

For temperatures between 775 K and 1500 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.201678 + 1.09013 \times 10^{-6}T - 3.32212 \times 10^{-9}T^2 + 2.45228 \times 10^{-13}T^3 \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.03 and 0.01 percent, and maximum deviations of 0.10 and 0.05 percent, respectively. The recommended values are generated from the above formulas. The tabulated values of C_p^0 should be substantially correct within 0.2 percent over the entire temperature range. The percent departures of all the works mentioned above from the tabulated values are given in two departure plots for $P = 0$. Several empirical equations (25, 196, 205, 532) are not shown in these figures, as well as a set of mean specific heat data (92).

Meanwhile, many sets of experimental and derived values are also available for the specific heat in the real gas state. However, several sets of direct calorimetric data are considered to be not so reliable. A number of theoretical values have been derived by statistical mechanics and the correction of imperfect gas. Among them, theoretical results presented by Curtiss and Hirschfelder (302), Heck (375, 376, 541) and Woolley (568, 575, 446, 457) are thought to be reliable, as well as the values derived by the theory of association (553) and by experimental P-V-T data (449). Therefore, these works are given equal weight in the present analysis. However, no weight is given to various experimental data obtained by flow calorimeters (286, 451, 482), by adiabatic expansion (56), by

Joule-Thomson effect (307, 507), by velocity of sound (46, 309, 520) and by use of equilibrium constant (519). Many sets of correlated values (78, 127, 252, 274, 279, 283, 350, 374, 481, 512) are also given no weight. The correlation formulas obtained for the specific heat in the real gas state are as follows:

For temperatures between 250 K and 780 K:

$$C_p \text{ (Cal g}^{-1}\text{K}^{-1}\text{)} = 0.261365 - 9.01034 \times 10^{-6}T + 1.60323 \times 10^{-9}T^2 - 7.08987 \times 10^{-13}T^3 \quad (3)$$

For temperatures between 780 K and 1500 K:

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.200469 + 1.10194 \times 10^{-6}T - 3.37414 \times 10^{-9}T^2 + 2.21178 \times 10^{-13}T^3 \quad (4)$$

These equations are found to fit the above enumerated values with mean deviations of 0.04 and 0.04 percent, and maximum deviations of 0.25 and 0.13 percent, respectively. The recommended values of C_p are generated using the above formulas. The tabulated values should be substantially correct within 0.5 percent over the entire temperature range. Equations (3) and (4) are used to calculate the departures of all the values mentioned above in the real gas state, which are shown in two departure plots for $P = 1$ atm. However, various empirical equations (184, 185, 275, 346, 377, 436, 528), cited values (71, 454, 460, 557) and values outside the present temperature range (216, 270, 559, 563) are not plotted in these figures, as well as a set of data of adsorbed nitrogen on solids (475).

The comparison of Equations (3) and (4) with Equations (1) and (2) is also given in the last plot.

TABLE 1C SPECIFIC HEAT AT CONSTANT PRESSURE OF NITROGEN (continued)

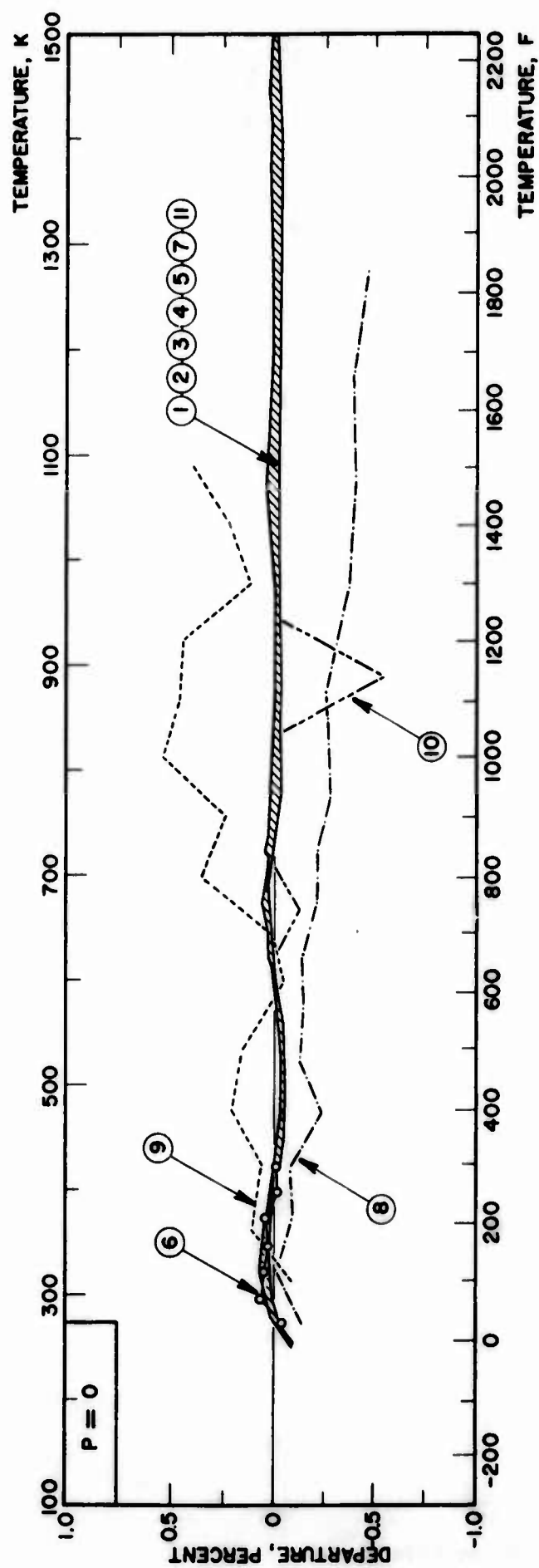
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p^0 and C_p , B lb⁻¹ F⁻¹]

GAS

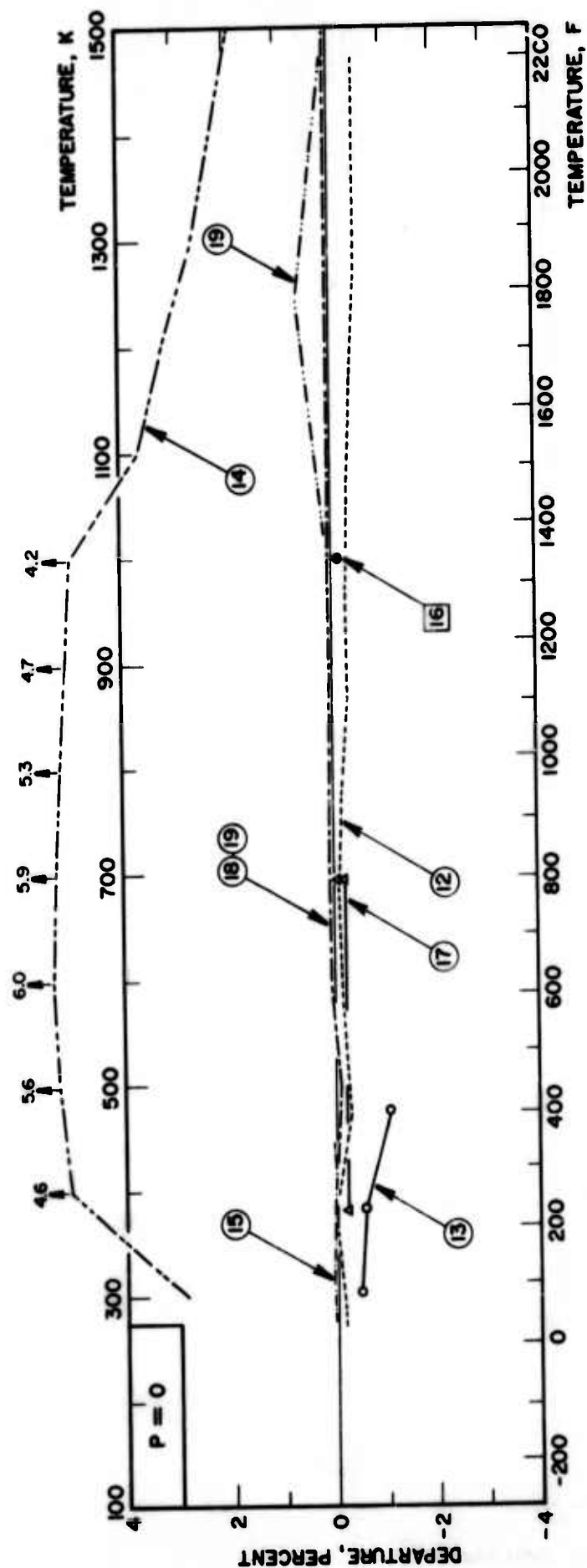
T	C_p^0	C_p	T	C_p^0	C_p
0	0.24837	0.2488	700	0.25896	0.2590
20	0.24828	0.2487	720	0.25956	0.2596
40	0.24822	0.2486	740	0.26017	0.2603
60	0.24819	0.2485	760	0.26079	0.2609
80	0.24818	0.2485	780	0.26142	0.2615
100	0.24820	0.2485	800	0.26206	0.2622
120	0.24825	0.2485	820	0.26271	0.2628
140	0.24833	0.2486	840	0.26336	0.2635
160	0.24843	0.2487	860	0.26402	0.2641
180	0.24856	0.2488	880	0.26468	0.2648
200	0.24871	0.2489	900	0.26535	0.2655
220	0.24889	0.2491	920	0.26603	0.2661
240	0.24909	0.2493	940	0.26656	0.2668
260	0.24931	0.2495	960	0.26723	0.2673
280	0.24956	0.2497	980	0.26790	0.2680
300	0.24983	0.2500	1000	0.26855	0.2686
320	0.25012	0.2502	1100	0.27174	0.2719
340	0.25043	0.2505	1200	0.27477	0.2749
360	0.25076	0.2509	1300	0.27763	0.2778
380	0.25111	0.2512	1400	0.28033	0.2806
400	0.25148	0.2516	1500	0.28288	0.2831
420	0.25187	0.2520	1600	0.28526	0.2855
440	0.25227	0.2524	1700	0.28750	0.2877
460	0.25270	0.2528	1800	0.28958	0.2898
480	0.25314	0.2532	1900	0.29152	0.2917
500	0.25360	0.2537	2000	0.29331	0.2935
520	0.25407	0.2541			
540	0.25456	0.2546			
560	0.25506	0.2551			
580	0.25558	0.2557			
600	0.25611	0.2562			
620	0.25666	0.2567			
640	0.25721	0.2573			
660	0.25778	0.2579			
680	0.25836	0.2584			

FIGURE 10 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS NITROGEN



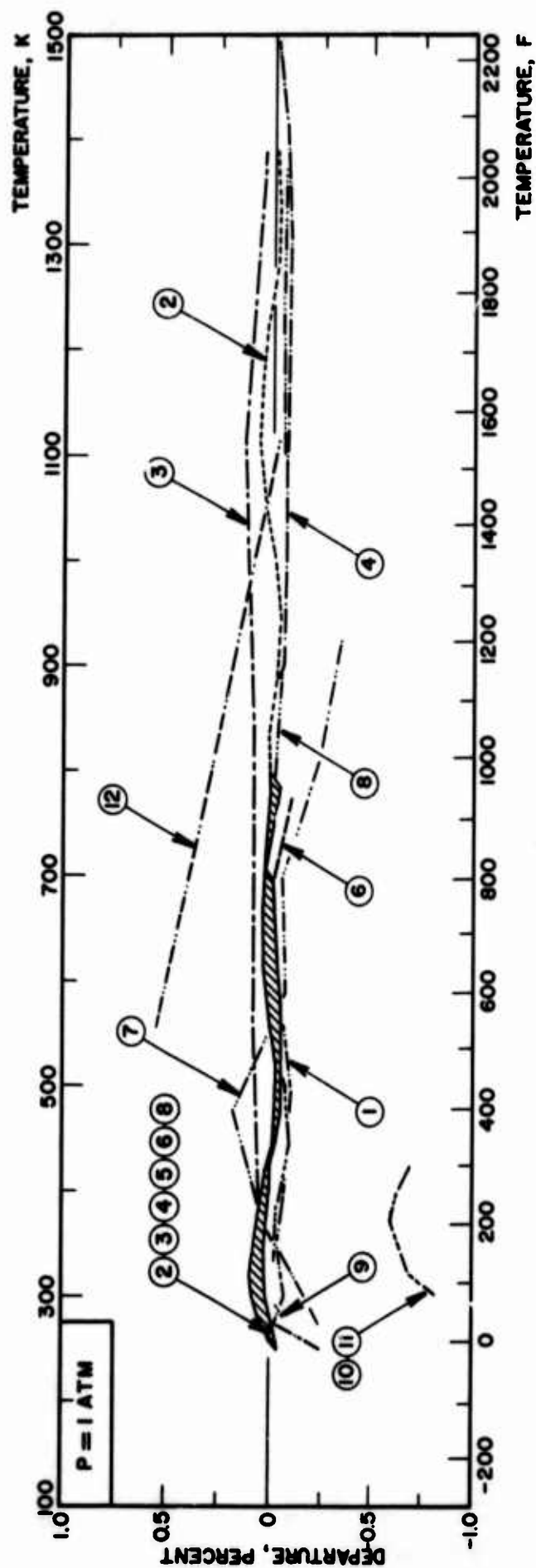
Curve	Reference
1	59, 167, 226,
2	426, 429
3	72, 254, 380, 389
4	253
5	351
6	362
7	466
8	568, 575
9	100
10	360
11	368
	403

FIGURE 10 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS NITROGEN (continued)



Curve	Reference
12	24, 278
13	56
14	93
15	178
16	266
17	319
18	395
19	501

FIGURE 10 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS NITROGEN



Curve	Reference
1	302
2	375, 541
3	376
4	446, 457, 568, 575
5	449
6	553
7	127
8	274
9	283
10	350
11	451
12	512

FIGURE 10 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF ASEOUS NITROGEN (continued)

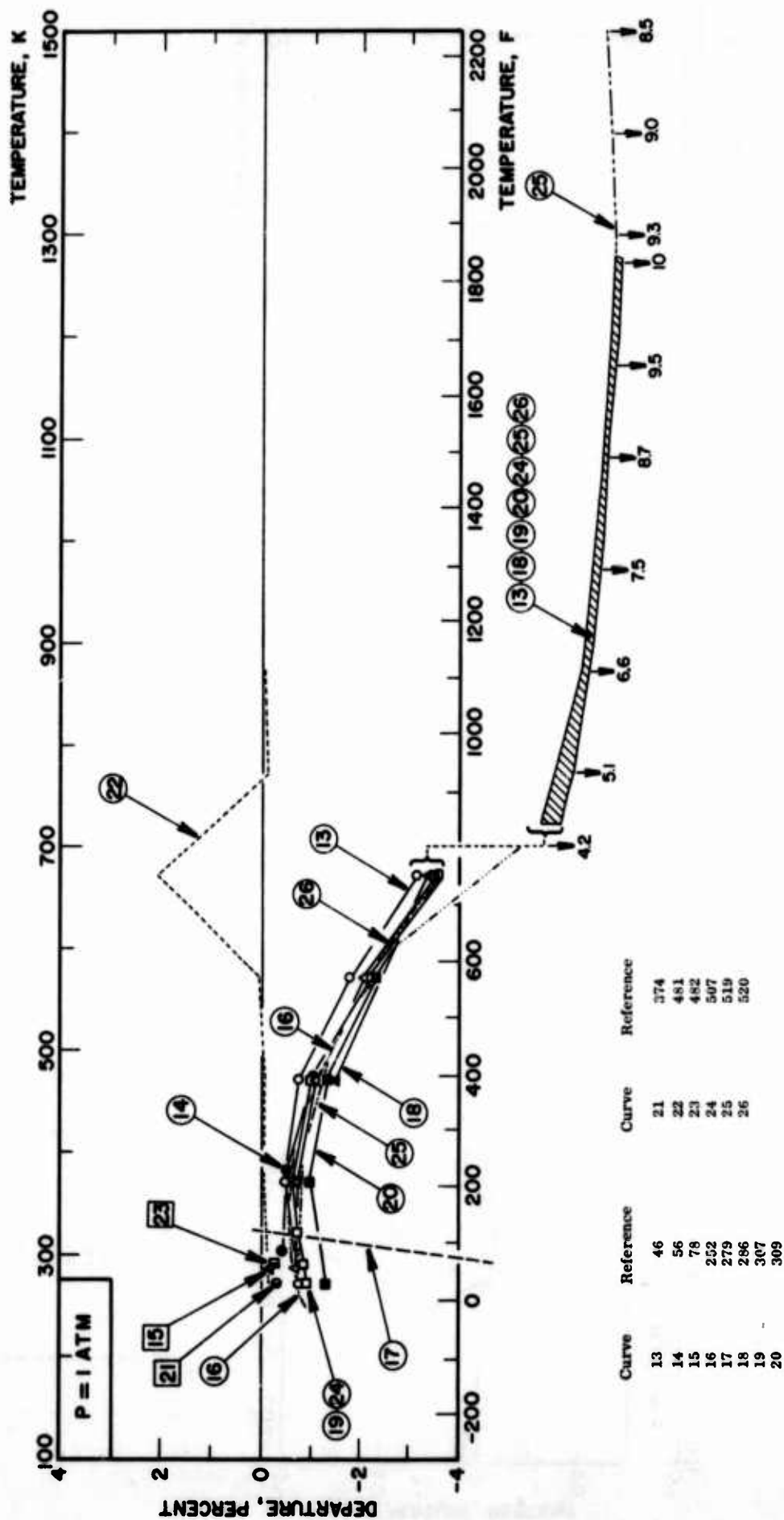


FIGURE 10 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS NITROGEN

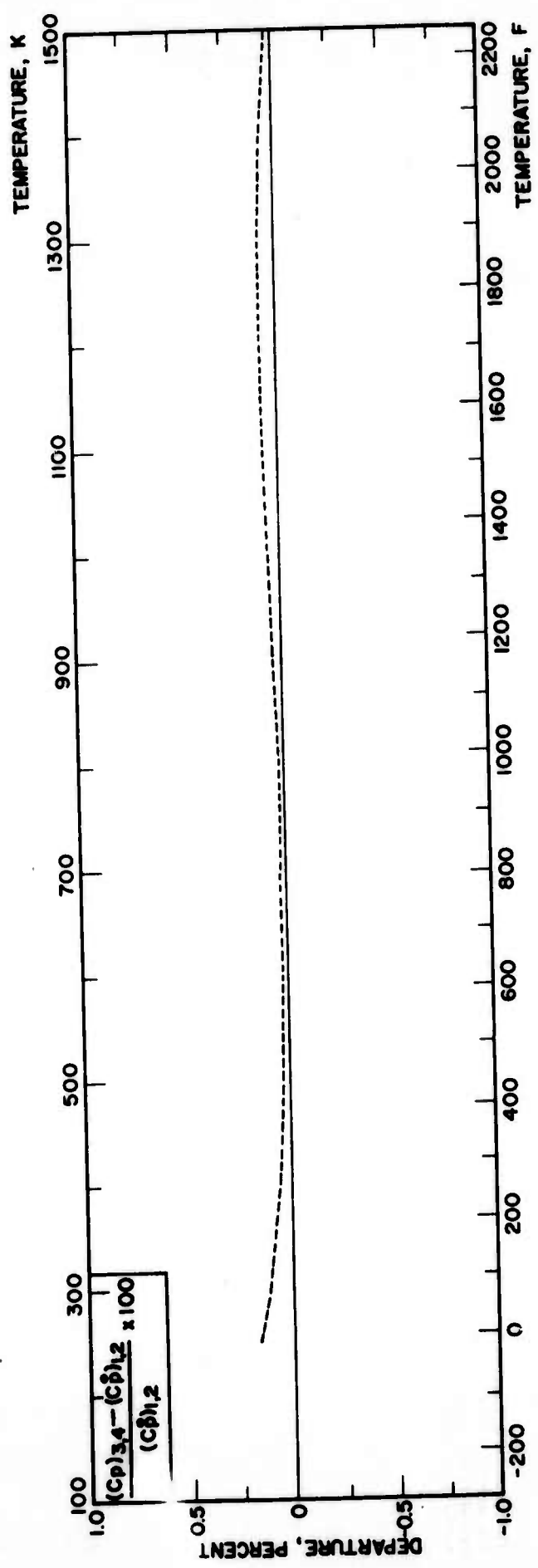


TABLE 11 SPECIFIC HEAT AT CONSTANT PRESSURE OF OXYGEN

DISCUSSION

LIQUID

Three sources of information are available for the constant pressure specific heat of liquid oxygen. All the reported values fall within the temperature range from the normal melting point to the normal boiling point. Among them, the two sets of calorimetric data of Clusius (240) obtained by means of two kinds of apparatus are considered to be the most reliable from the standpoint of experimental procedures and therefore, are given full weight in the present analysis. Another set of experimental values (552) derived from measurements of the sound velocity are very low, and are given no weight, as well as a single point value (216) derived by an empirical method.

The correlation formula obtained for the temperature range between 56.6 K and 72.8 K is

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.391168 + 4.98693 \times 10^{-7}T \quad (T \text{ in K}).$$

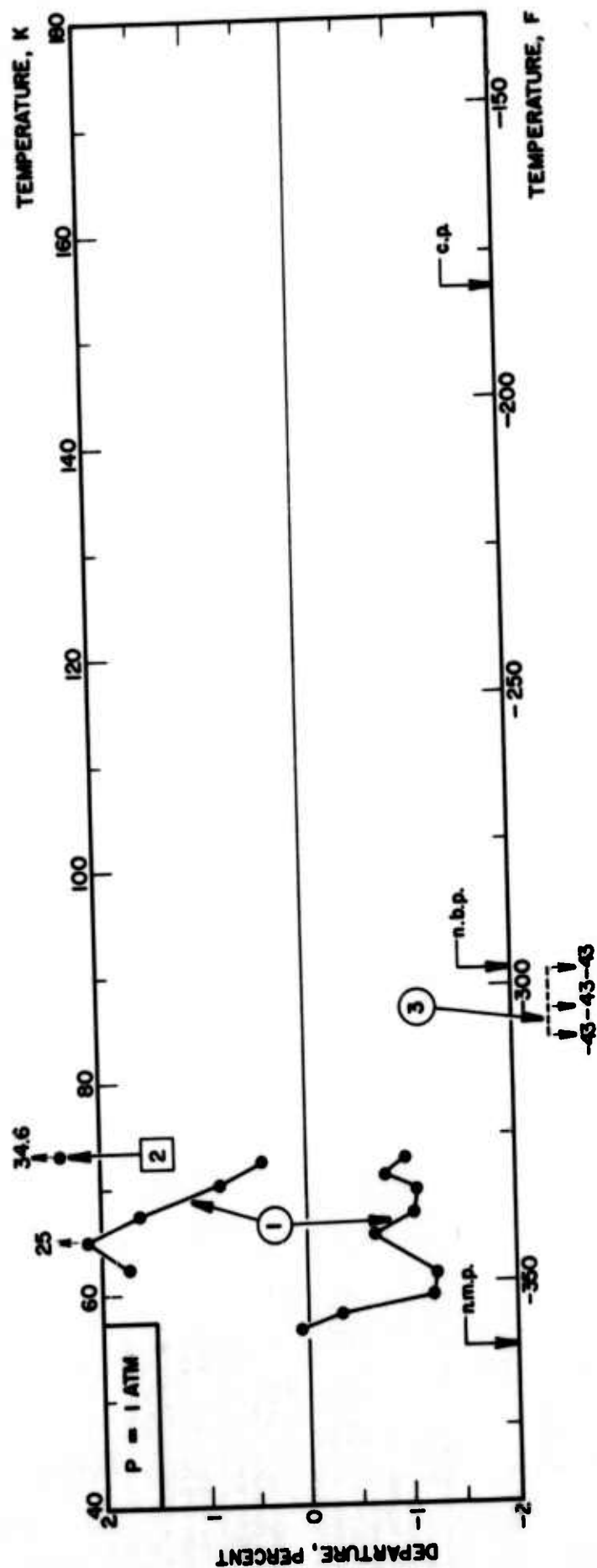
This equation is found to fit the above enumerated values with a mean deviation of 1.0 percent and a maximum of 2.5 percent. The recommended values are generated by the above formula. The tabulated values should be substantially correct within three percent.

RECOMMENDED VALUES

(Temperature, T, F; Specific Heat, C_p , B lb⁻¹F⁻¹)

LIQUID	
T	C_p
-360	0.3937
-355	0.3938
-350	0.3939
-345	0.3941
-340	0.3942
-335	0.3944
-330	0.3945
-325	0.3946
-320	0.3948
-315	0.3949

FIGURE 11 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID OXYGEN



Curve	Reference
1	240
2	216
3	552

TABLE 11 SPECIFIC HEAT AT CONSTANT PRESSURE OF OXYGEN

DISCUSSION

GAS

There exist 70 sources of information on the specific heat at constant pressure of gaseous oxygen. A number of extensive heat capacity values for the ideal gas state have been derived from spectroscopic and molecular structural data. The values presented by Brickwedde et al. (22), Fatin (59), Gordon (72), Ribaud (167), Sinke (192), Wagman et al. (226), Hildenbrand (380), Huff et al. (389), Kallman (403), Wintle (561) and Woolley (565, 566, 567) are considered to be reliable, as well as three compilation tables (253, 254, 575). Therefore, equal weight is given to these works in the present analysis. However, other sets of extensive correlations (100, 266, 368) and earlier statistical calculations (24, 93, 278, 397, 398, 426, 501) are given no weight. Three sets of extrapolated values from the calorimetric measurements (56, 319, 453) are also given no weight. The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 250 K and 760 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.222081 - 7.69230 \times 10^{-5}T + 2.78765 \times 10^{-7}T^2 - 1.70107 \times 10^{-10}T^3 \quad (1)$$

For temperatures between 760 K and 1500 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.177100 + 1.49509 \times 10^{-4}T - 8.44940 \times 10^{-8}T^2 + 1.83236 \times 10^{-11}T^3 \quad (T \text{ in K}) \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.07 and 0.03 percent, and maximum deviations of 0.73 and 0.37 percent, respectively. The recommended values are generated using the above formulas. The tabulated values of C_p^0 should be substantially correct within one percent over the entire temperature range. The percent departures of all the works mentioned above from the tabulated recommended values are shown in two plots for $P = 0$. A number of empirical equations (25, 196, 205, 532) as well as a set of mean specific heat data (92), are not plotted in these figures.

On the other hand, a number of experimental and derived values are available for the specific heat in the real gas state. Among them, experimental data obtained by flow calorimetry (144, 223, 482) and by an explosion method (444) are thought to be reliable, as well as the numerical correlations (274, 567, 575) and a theoretical derivation (553). Therefore, equal weight is given to these works in this analysis. However, no weight is given to other experimental data obtained by flow calorimeters (56, 453), by the velocity of sound (422, 520, 551) and by use of equilibrium constants (519). Several sets of statistical calculations (375, 376, 512) and empirical correlations (78, 374, 541) are also given no weight. The correlation formulas obtained for the specific heat in the real gas state are as follows:

For temperatures between 243 K and 790 K:

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.227218 - 1.06392 \times 10^{-4}T + 3.33354 \times 10^{-7}T^2 - 2.02242 \times 10^{-10}T^3 \quad (3)$$

For temperatures between 790 K and 1500 K:

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.160484 + 1.96817 \times 10^{-4}T - 1.28451 \times 10^{-7}T^2 + 3.17949 \times 10^{-11}T^3 \quad (T \text{ in K}) \quad (4)$$

These equations are found to fit the above enumerated values with mean deviations of 0.09 and 0.14 percent, and maximum deviations of 0.41 and 0.82 percent, respectively. The recommended values of C_p are generated from the above formulas. The tabulated values should be substantially correct within one percent over the entire temperature range. Equations (3) and (4) are used to calculate the departure of all the values mentioned above in the real gas state, which are shown in the departure plots for $P = 1$ atm. The cited values (71, 127, 460, 557) and values at higher temperatures (270, 281, 559, 563) and at lower temperatures (216, 550) are not given in the figures, as well as empirical equations (194, 185, 275, 346, 377, 528).

The comparison of Equations (3) and (4) with Equations (1) and (2) is also given in the last plot.

TABLE 11 SPECIFIC HEAT AT CONSTANT PRESSURE OF OXYGEN (continued)

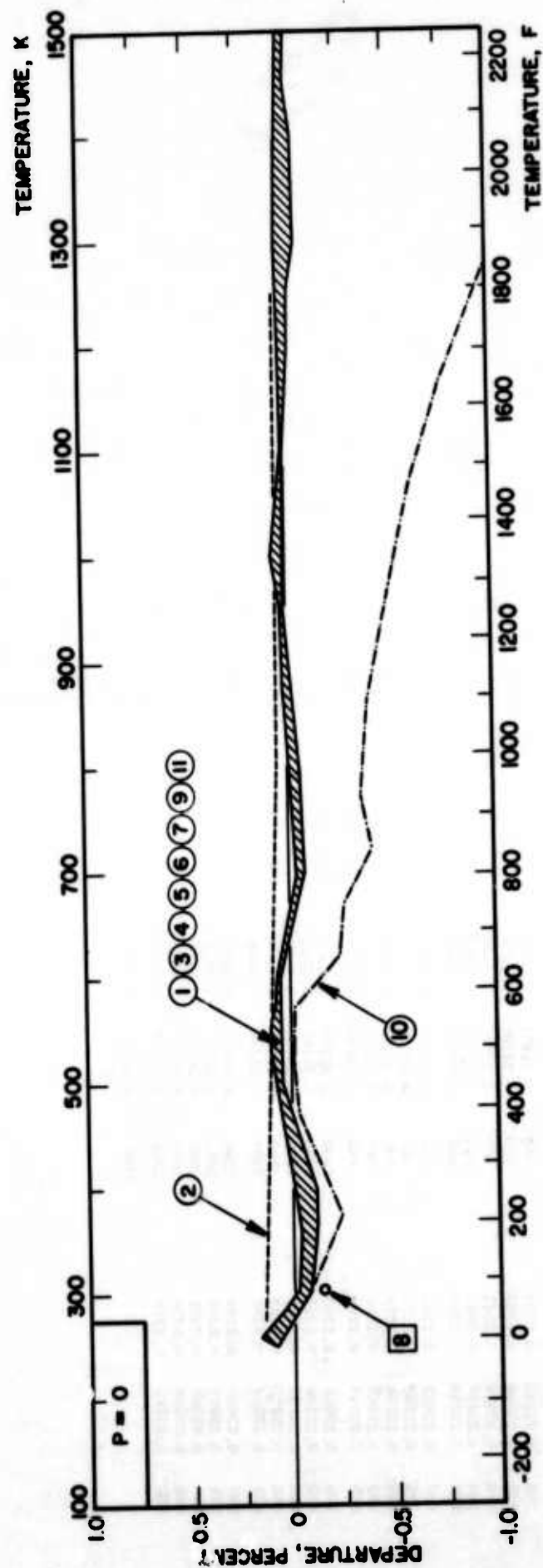
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p^0 and C_p , B lb⁻¹F⁻¹]

GAS

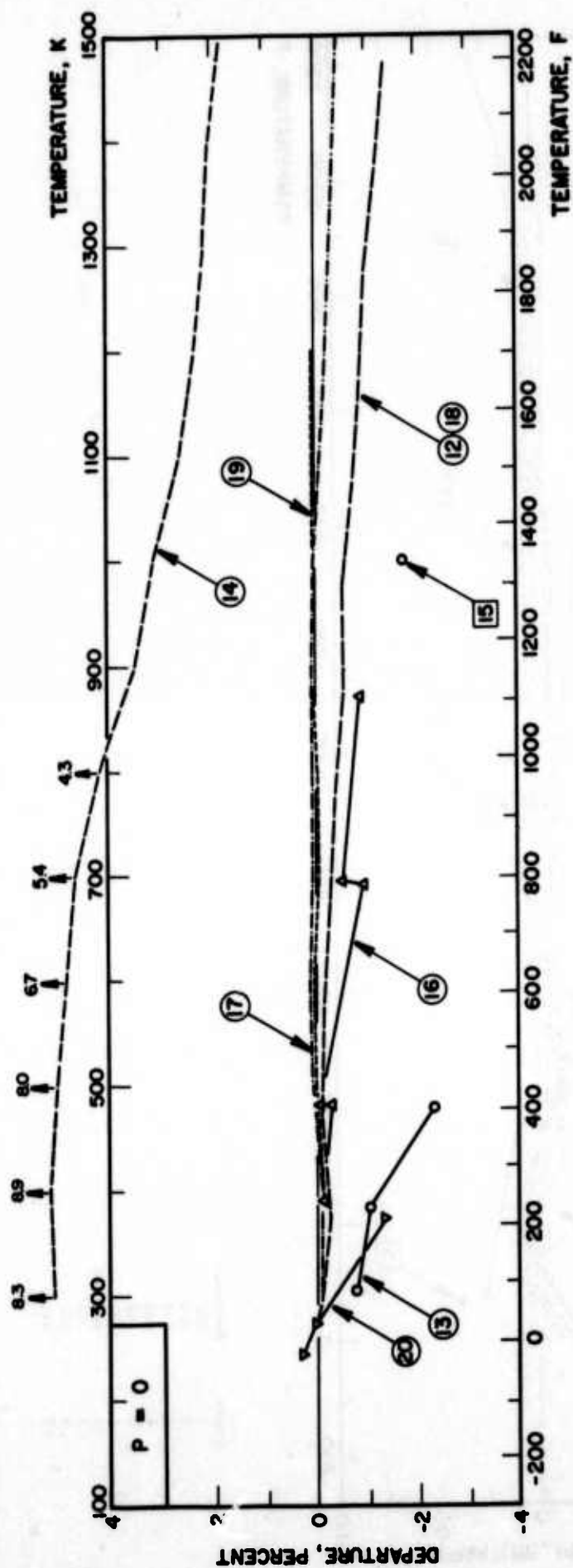
T	C_p^0	C_p	T	C_p^0	C_p
0	0.21764	0.2183	600	0.23855	0.2387
20	0.21802	0.2186	620	0.23937	0.2395
40	0.21843	0.2189	640	0.24019	0.2404
60	0.21887	0.2193	660	0.24100	0.2412
80	0.21935	0.2197	680	0.24179	0.2420
100	0.21986	0.2201	700	0.24258	0.2428
120	0.22039	0.2206	720	0.24336	0.2436
140	0.22096	0.2211	740	0.24412	0.2444
160	0.22155	0.2217	760	0.24487	0.2451
180	0.22217	0.2223	780	0.24560	0.2458
200	0.22281	0.2229	800	0.24631	0.2465
220	0.22348	0.2235	820	0.24700	0.2472
240	0.22416	0.2242	840	0.24768	0.2479
260	0.22487	0.2249	860	0.24833	0.2485
280	0.22559	0.2256	880	0.24895	0.2491
300	0.22633	0.2263	900	0.24956	0.2497
320	0.22709	0.2271	920	0.25014	0.2503
340	0.22786	0.2279	940	0.25072	0.2508
360	0.22865	0.2286	960	0.25128	0.2513
380	0.22944	0.2294	980	0.25184	0.2518
400	0.23025	0.2303	1000	0.25238	0.2524
420	0.23106	0.2311	1100	0.25496	0.2551
440	0.23188	0.2319	1200	0.25732	0.2575
460	0.23271	0.2328	1300	0.25946	0.2597
480	0.23354	0.2336	1400	0.26141	0.2616
500	0.23438	0.2344	1500	0.26320	0.2634
520	0.23521	0.2353	1600	0.26483	0.2650
540	0.23605	0.2362	1700	0.26632	0.2665
560	0.23688	0.2370	1800	0.26771	0.2679
580	0.23772	0.2379	1900	0.26900	0.2692
			2000	0.27021	0.2705

FIGURE 11 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS OXYGEN



Curve	Reference
1	22
2	59
3	72, 254, 380, 389
4	192
5	167, 226
6	253
7	403
8	561
9	565, 566, 567, 575
10	100
11	368

FIGURE 11 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS OXYGEN (continued)



Curve	Reference
12	24, 278
13	56
14	93
15	266
16	319
17	397, 501
18	398
19	426
20	453

FIGURE 11 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS OXYGEN

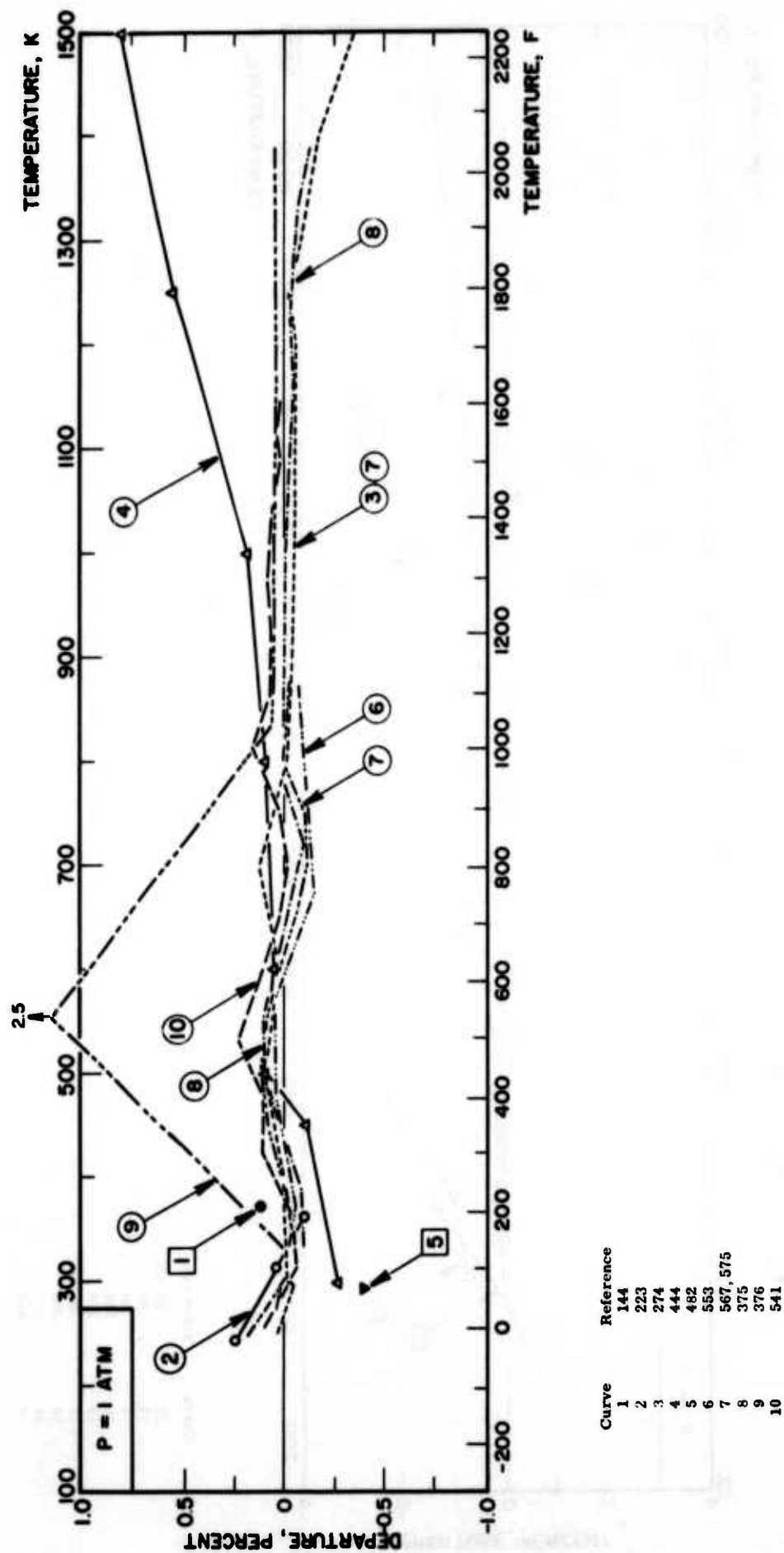


FIGURE 11 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS OXYGEN (continued)

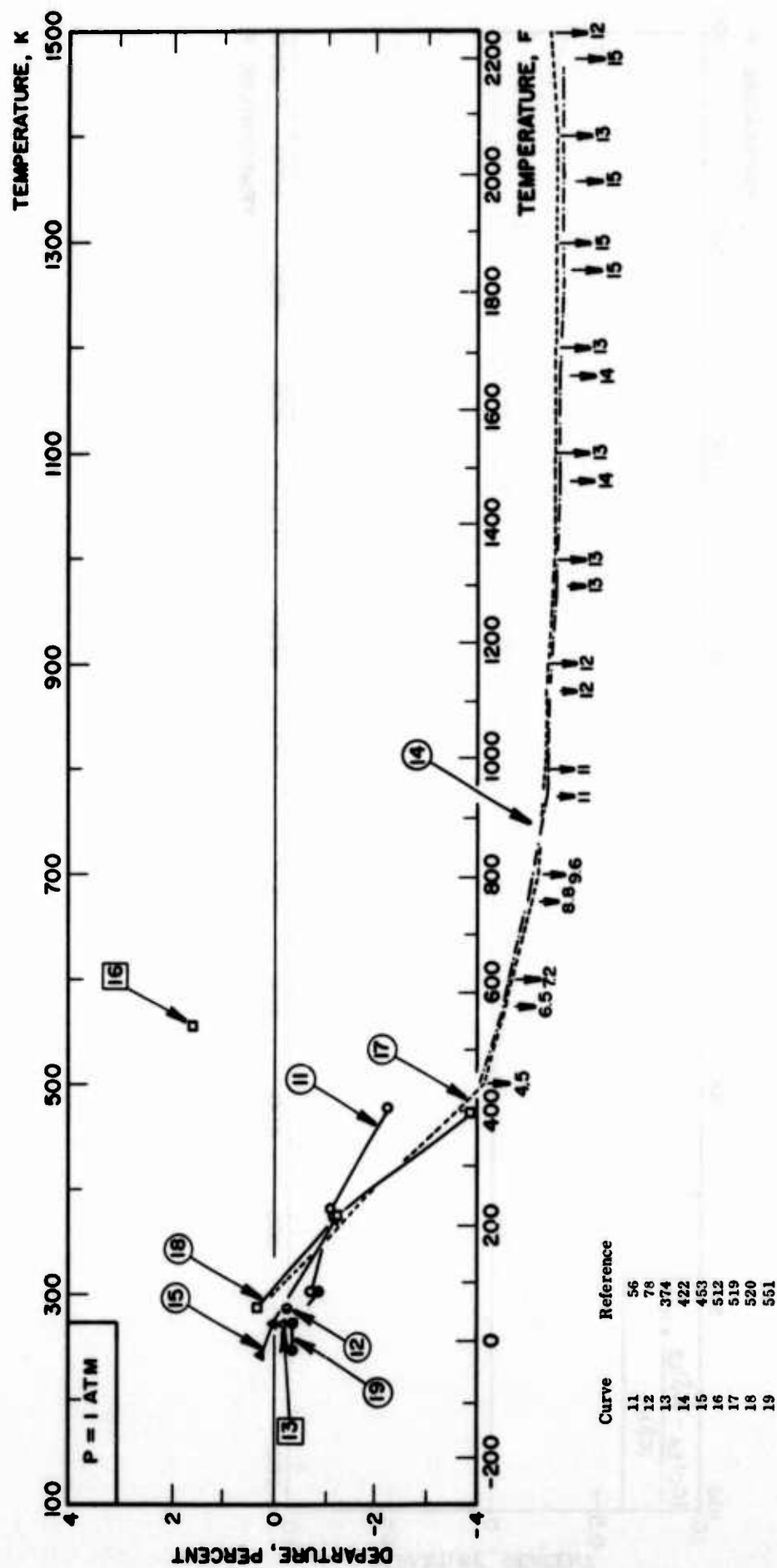


FIGURE 11 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS OXYGEN

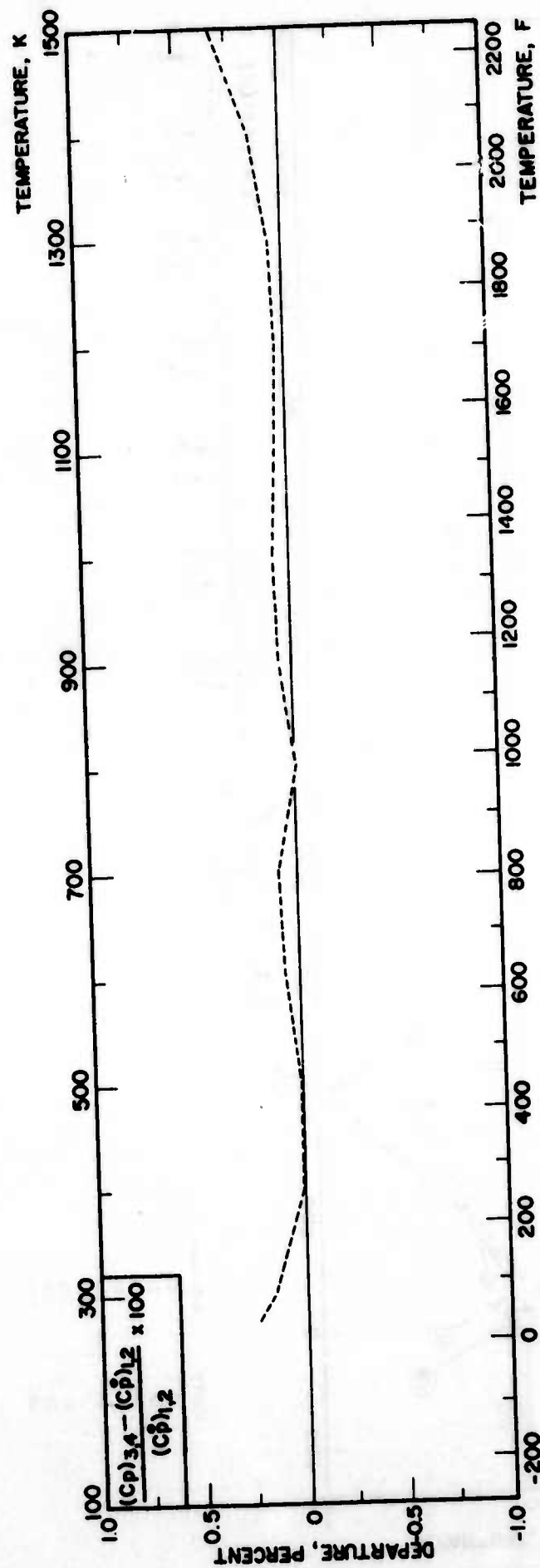


TABLE 12 SPECIFIC HEAT AT CONSTANT PRESSURE OF XENON

DISCUSSION		RECOMMENDED VALUES	
LIQUID		[Temperature, T, F; Specific Heat, C_p , B lb ⁻¹ F ⁻¹]	
		LIQUID	
		T	C_p
		-166	0.0813
		-165	0.0813
		-164	0.0813
		-163	0.0813
		-162	0.0813
		-161	0.0813
		-160	0.0813

LIQUID

The only information available for the constant pressure specific heat of liquid xenon is the calorimetric work of Clusius and Riccoboni (295). Their data covering temperatures from 163.2 K to 165.9 K, is for a liquid with a purity from 98 to 99 percent, where the balance is krypton. All the reported data points are fitted with the following correlation formula:

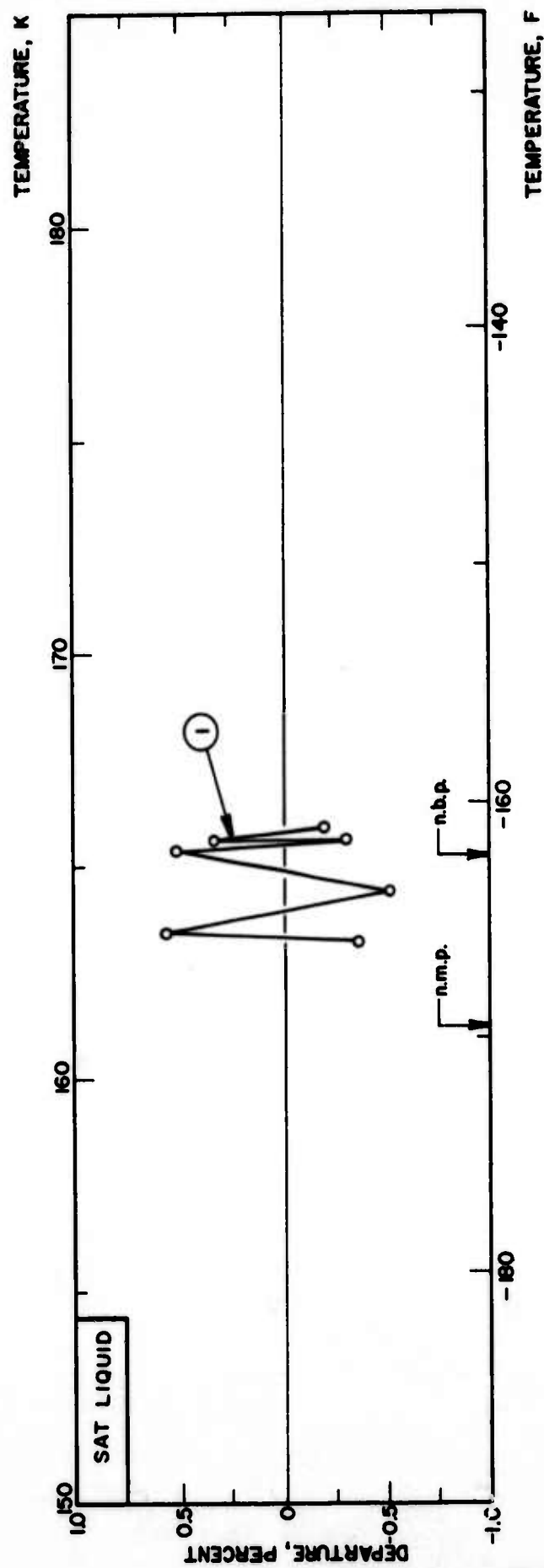
$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = -0.120482 + 2.31711 \times 10^{-4}T + 1.91008 \times 10^{-6}T^2 \quad (T \text{ in K}).$$

$$- 8.04351 \times 10^{-9}T^3$$

This equation is found to fit the above enumerated values with a mean deviation of 0.40 percent and a maximum of 0.52 percent. The recommended values are generated by the above formula. The tabulated values should be substantially correct within one percent.

n. b. p. = -162 F

FIGURE 12 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID XENON



Curve Reference
1 295

TABLE 12 SPECIFIC HEAT AT CONSTANT PRESSURE OF XENON

DISCUSSION

GAS

The available information on the specific heat at constant pressure of gaseous xenon is few in the literature. Since xenon is a monatomic gas and the molecules possess translational energy only, its molar heat capacity at the ideal gas state is represented by $C_p^0 = (5/2)R$, (R is the universal gas constant) and remains constant with temperature over a wide temperature range. Therefore, the specific heat of this gas is given as follows:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}) = \frac{5R}{2M} = \frac{5}{2} \frac{1.98719}{131.30} = 0.037837, \quad (1)$$

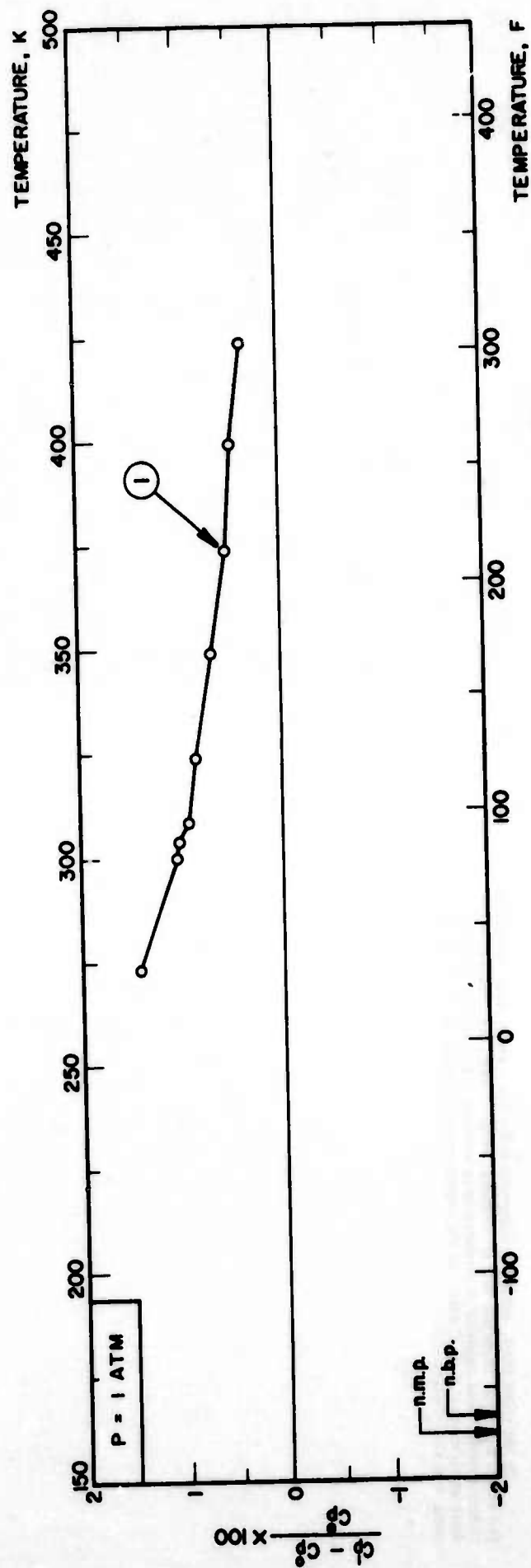
where M is the molecular weight.

Kolaty, et al. (435) showed that C_p^0 remains constant in the temperature range from 10 K to 5300 K. Therefore, the recommended value of C_p^0 is Equation (1), or

$$C_p^0 \text{ (Btu lb}^{-1}\text{F}^{-1}) = 0.037812.$$

On the other hand, available information for the specific heat in the real gas state, C_p , was reported only by Michels, et al., (469), who derived the isobaric molar heat capacity at temperatures between 273 K and 423 K from their experimental P-V-T data. In the departure plot, their values of C_p are compared with Equation (1).

FIGURE 12 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS XENON



Curve Reference
1 469

TABLE 13 SPECIFIC HEAT AT CONSTANT PRESSURE OF AMMONIA

DISCUSSION

LIQUID

Seven sources of information are available for the specific heat at constant pressure of liquid ammonia. A set of calorimetric data reported by Overstreet and Glaue (484), covering temperatures from 197.84 K to 238.33 K, are considered to be the most reliable and are given heavy weight. The correlated values obtained by Koch (249) and the detailed compilation of the U. S. National Bureau of Standards (478) are also considered to be reliable under higher vapor pressures, and are given weight in the present analysis. However, two sets of earlier calorimetric data (43, 317) are given no weight, as well as theoretical values (216) and a compilation (198) given in a graphical form.

The correlation formula obtained for the temperature range between 197 K and 377 K is

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = -0.904418 + 2.26685 \times 10^{-3}T - 8.91777 \times 10^{-5}T^2 + 1.20944 \times 10^{-7}T^3 \quad (T \text{ in K}).$$

This equation is found to fit the above enumerated works with a mean deviation of 0.51 percent and a maximum of 2.7 percent. The recommended values are generated by the above formula. The tabulated values should be correct within two percent below 273 K, and the uncertainty would increase above this temperature.

RECOMMENDED VALUES

(Temperature, T, F; Specific Heat, C_p , B lb⁻¹F⁻¹)

LIQUID

T	C_p
-100	1.029
-80	1.044
-60	1.056
-40	1.065
-20	1.074
0	1.082
20	1.092
40	1.10
60	1.12
80	1.13
100	1.16
120	1.19
140	1.22
160	1.26
180	1.32
200	1.38
220	1.45

n. s. p. = -28 F

TABLE 13 SPECIFIC HEAT AT CONSTANT PRESSURE OF AMMONIA

DISCUSSION

GAS

Twenty-six sources of information are available on the specific heat at constant pressure of gaseous ammonia. A number of extensive values for the ideal gas state have been derived from spectroscopic and molecular data. Among them, the values presented by Gordon (72), Keyes (100), Kobe and Harrison (107, 371), Ribaud (167) are considered to be reliable and are given equal weight in the present analysis. However, other sets of compiled values (59, 254), early statistical calculations (24, 213, 350, 372, 407, 535) and an empirical correlation (18) are given no weight. The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 223 K and 630 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.465750 - 1.96818 \times 10^{-4}T + 1.30052 \times 10^{-6}T^2 - 8.66281 \times 10^{-10}T^3 \quad (1)$$

For temperatures between 630 K and 1500 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.320795 + 5.72260 \times 10^{-4}T - 9.24803 \times 10^{-6}T^2 - 1.27816 \times 10^{-10}T^3 \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.24 and 0.23 percent, and maximum deviations of 0.94 and 1.04 percent, respectively. These formulas are used to generate the recommended values, which should be substantially correct within 1.5 percent over the entire temperature range. The percent departures of all the reported values from the recommended values are given in the departure plot for $P = 0$. Empirical equations (25, 197) and values outside the present temperature range (73, 349) are not plotted in this figure.

Concerning the specific heat in the real gas state, two sets of theoretical values (132, 250) at temperatures from 300 K to 600 K are considered to be the most reliable and, therefore, are fitted to the following equation:

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.645706 - 1.24500 \times 10^{-3}T + 3.45991 \times 10^{-6}T^2 - 2.34833 \times 10^{-9}T^3 \quad (3)$$

This equation is found to reproduce the original values with a mean deviation of 0.10 percent and a maximum one of 0.23 percent. Experimental values obtained from velocity of sound measurements (46), earlier theoretical values (48), empirical correlations (249), and derived values from equilibrium constants (519) and the equation of state (535) are also compared with Equation (3) and are shown in the departure plot for $P = 1$ atm. A set of cited values from earlier experimental data (216) is not plotted in this figure.

In the third departure plot, Equation (3) is compared with Equation (1) in the common temperature range.

RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p , B lb⁻¹ F⁻¹]

GAS

T	C_p^0	T	C_p^0
-60	0.4764	600	0.6235
-40	0.4793	620	0.6282
-20	0.4823	640	0.6330
0	0.4856	660	0.6376
20	0.4889	680	0.6424
40	0.4925	700	0.6473
60	0.4962	720	0.6521
80	0.5000	740	0.6569
100	0.5039	760	0.6617
120	0.5080	780	0.6664
140	0.5122	800	0.6712 0.6712
160	0.5164	820	0.6759
180	0.5208	840	0.6805
200	0.5253	860	0.6852
220	0.5299	880	0.6898
240	0.5345	900	0.6943
260	0.5392	920	0.6989
280	0.5440	940	0.7034
300	0.5488	960	0.7079
320	0.5537	980	0.7123
340	0.5587	1000	0.7168
360	0.5636	1100	0.7384
380	0.5686	1200	0.7593
400	0.5736	1300	0.7794
420	0.5787	1400	0.7987
440	0.5837	1500	0.8172
460	0.5888	1600	0.8348
480	0.5938	1700	0.8516
500	0.5988	1800	0.8676
520	0.6038	1900	0.8827
540	0.6088	2000	0.8969
560	0.6137		
580	0.6186		

n. b. p. = -28 F

FIGURE 13 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS AMMONIA

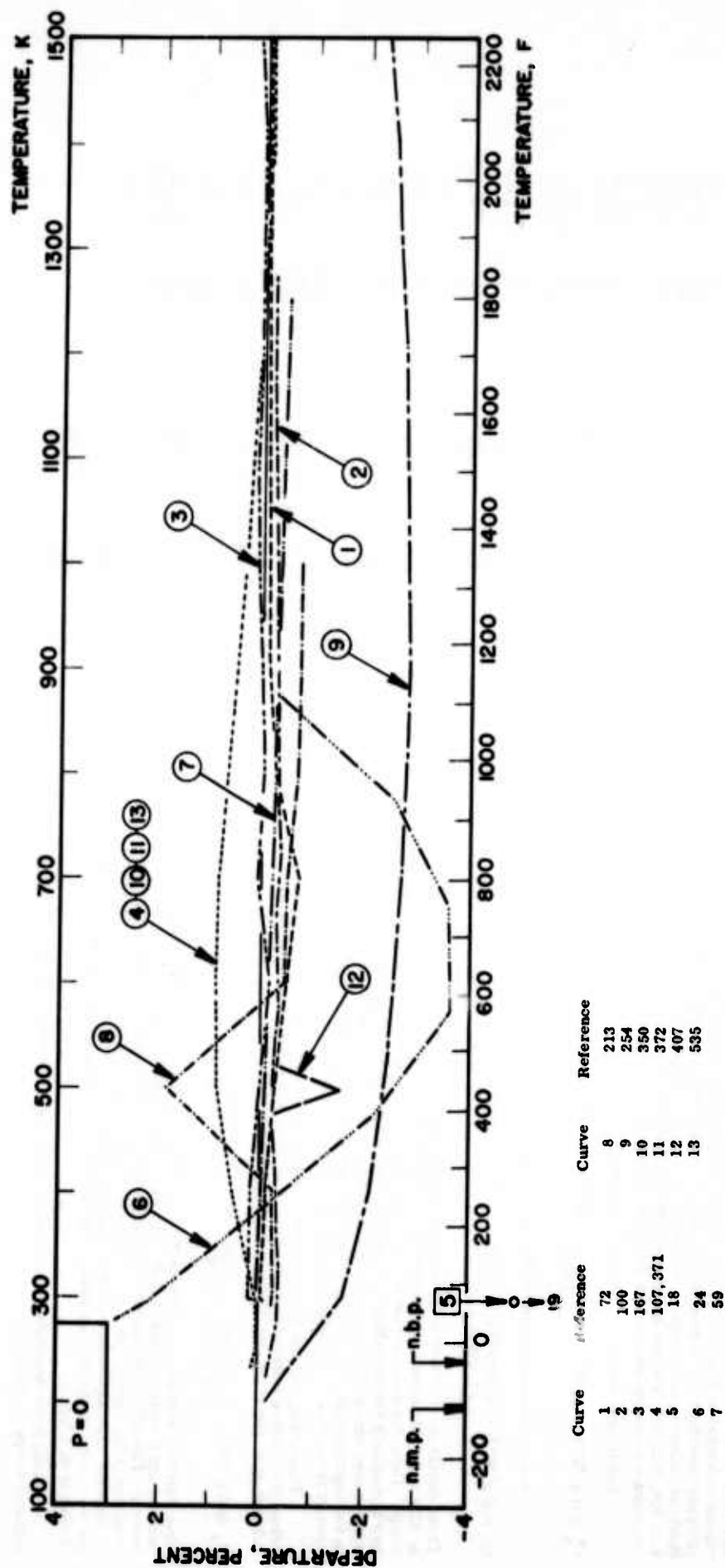
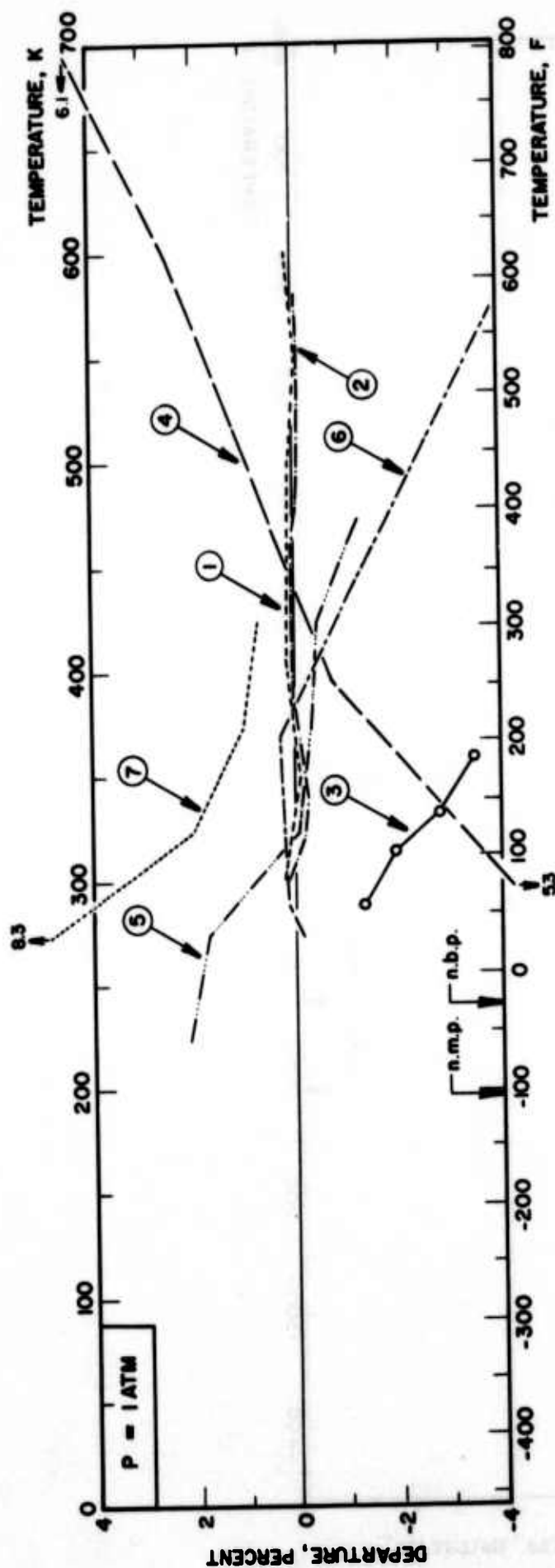


FIGURE 13 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS AMMONIA



Curve	Reference
1	132
2	250
3	46
4	48
5	249
6	519
7	535

FIGURE 13 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS AMMONIA

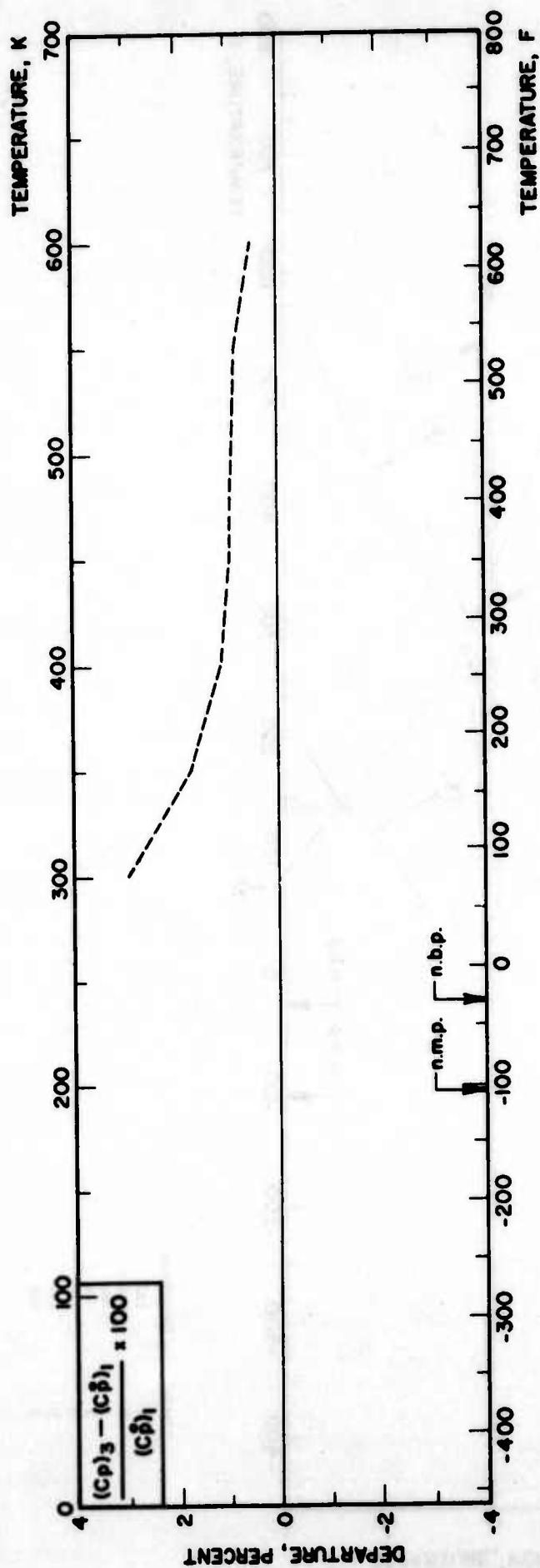


TABLE 14 SPECIFIC HEAT AT CONSTANT PRESSURE OF BORON TRIFLUORIDE

LIQUID	DISCUSSION		RECOMMENDED VALUES	
	Only one experimental work is available for the specific heat at constant pressure of liquid boron trifluoride. Eucken and Schröder (320) made measurements of the liquid, having a purity of 99.3 percent, by means of an adiabatic calorimeter, covering temperatures from 145 K to 173 K along the saturated vapor pressure curve. All the reported data points are fitted with the following correlation formula:		[Temperature, T, F; Specific Heat, C _p , B lb ⁻¹ F ⁻¹]	
	$C_p \text{ (cal g}^{-1}\text{K}^{-1}) = 0.326803 + 5.58265 \times 10^{-4}T + 2.05148 \times 10^{-6}T^2 - 5.35251 \times 10^{-8}T^3$ (T in K).		LIQUID	
			T	C _p
			-200	0.3612
			-195	0.3621
			-190	0.3630
			-185	0.3638
			-180	0.3647
			-175	0.3655
			-170	0.3664
			-165	0.3672
			-160	0.3680
			-155	0.3688
			-150	0.3696
			-145	0.3704

Only one experimental work is available for the specific heat at constant pressure of liquid boron trifluoride. Eucken and Schröder (320) made measurements of the liquid, having a purity of 99.3 percent, by means of an adiabatic calorimeter, covering temperatures from 145 K to 173 K along the saturated vapor pressure curve. All the reported data points are fitted with the following correlation formula:

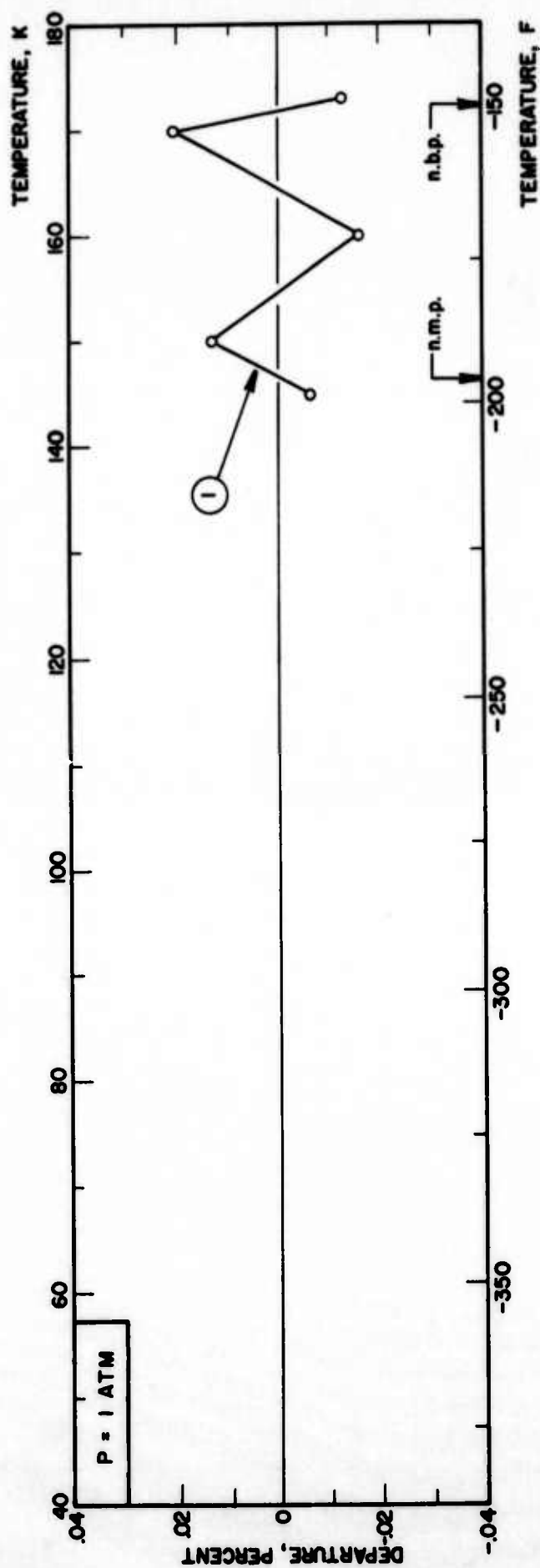
$$C_p \text{ (cal g}^{-1}\text{K}^{-1}) = 0.326803 + 5.58265 \times 10^{-4}T + 2.05148 \times 10^{-6}T^2 - 5.35251 \times 10^{-8}T^3$$

(T in K).

This equation is found to fit the above enumerated values with a mean deviation of 0.01 percent and a maximum of 0.02 percent. The above formula is used to generate the recommended values, which should be substantially correct within one percent.

n. m. p. = -197 F
n. b. p. = -150 F

FIGURE 14 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID BORON TRIFLUORIDE



Curve	Reference
1	320

TABLE 14 SPECIFIC HEAT AT CONSTANT PRESSURE OF BORON TRIFLUORIDE

DISCUSSION

GAS

There exist 13 sources of information for the specific heat at constant pressure of gaseous boron trifluoride. A number of extensive values for the ideal gas state have been derived from spectroscopic and molecular structural data. Results of Gordon (72), McBride et al. (137), Evans et al. (323, 324), Farber et al. (327), Hildenbrand (380), Huff et al. (389), Pack and Hill (486) and Spencer (531) are considered to be reliable as well as a compilation table (254). Therefore, equal weight is given to these works in the present analysis. The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 150 K and 600 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.0717530 + 4.41685 \times 10^{-4}T - 2.99299 \times 10^{-7}T^2 + 3.42705 \times 10^{-11}T^3 \quad (1)$$

For temperatures between 600 K and 1500 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.111803 + 3.16988 \times 10^{-4}T - 2.11623 \times 10^{-7}T^2 + 5.02322 \times 10^{-11}T^3 \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.09 and 0.06 percent, and maximum deviations of 0.44 and 0.15 percent, respectively. These formulas are used to generate the recommended values, which should be substantially correct within one percent over the entire temperature range. The percent departures of all the reported values from the tabulated values are given in the departure plot for $P = 0$. Empirical equations (195, 346) are not plotted in this figure.

Only one experimental work is available on the specific heat in the real gas state. Millar (142) made measurements by a cooling method, at two temperatures, 189 K and 278 K. His results are felt to be not too reliable. Therefore, no correlation for the real gas specific heat is given at the present time. His data are compared with Equation (1) in the departure plot for $P = 1$ atm.

RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p , B lb⁻¹ F⁻¹]

GAS

T	C_p^0	T	C_p^0
-200	0.1293	600	0.2349
-180	0.1332	620	0.2362
-160	0.1371	640	0.2376
-140	0.1409	660	0.2390
-120	0.1446	680	0.2403
-100	0.1482	700	0.2415
-80	0.1518	720	0.2426
-60	0.1553	740	0.2438
-40	0.1588	760	0.2449
-20	0.1622	780	0.2460
0	0.1655	800	0.2471
20	0.1687	820	0.2481
40	0.1719	840	0.2491
60	0.1750	860	0.2501
80	0.1781	880	0.2510
100	0.1811	900	0.2520
120	0.1840	920	0.2529
140	0.1868	940	0.2538
160	0.1896	960	0.2547
180	0.1923	980	0.2555
200	0.1950	1000	0.2563
220	0.1976	1100	0.2601
240	0.2001	1200	0.2634
260	0.2026	1300	0.2662
280	0.2050	1400	0.2686
300	0.2073	1500	0.2707
320	0.2096	1600	0.2725
340	0.2118	1700	0.2741
360	0.2139	1800	0.2754
380	0.2160	1900	0.2767
400	0.2180	2000	0.2778
420	0.2200		
440	0.2219		
460	0.2237		
480	0.2255		
500	0.2272		
520	0.2289		
540	0.2305		
560	0.2320		
580	0.2335		

n.m.p. = -197 F
n.b.p. = -150 F

FIGURE 14 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS BORON TRIFLUORIDE

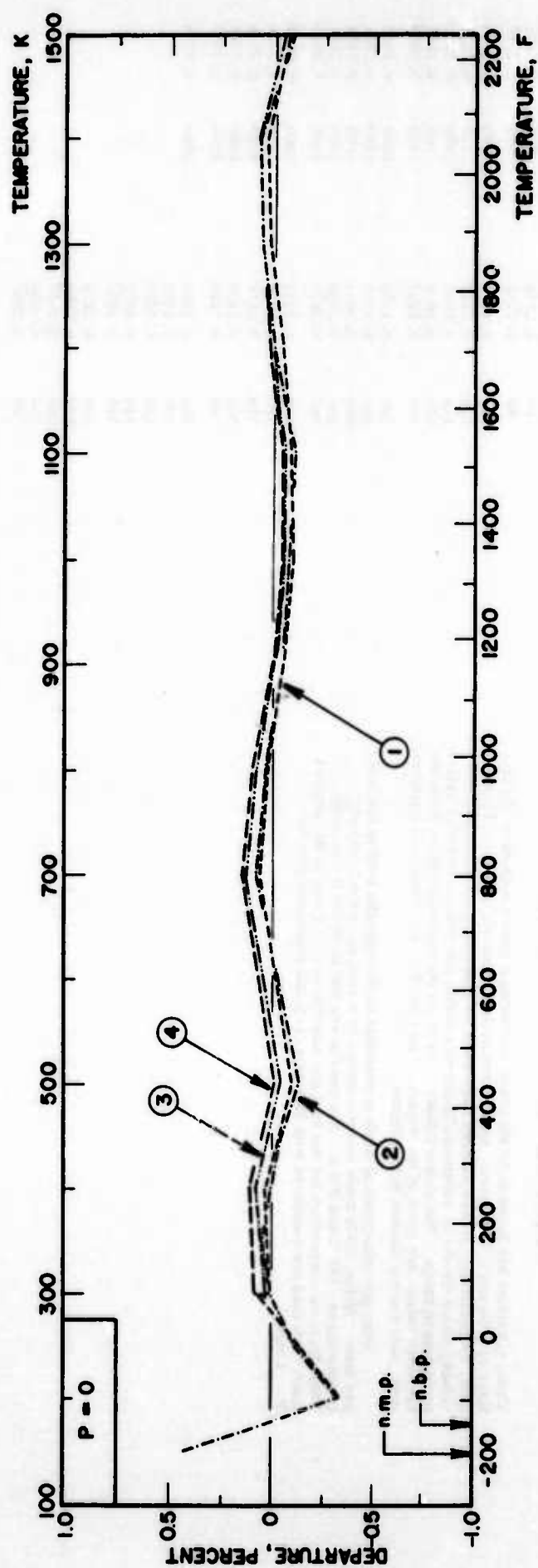
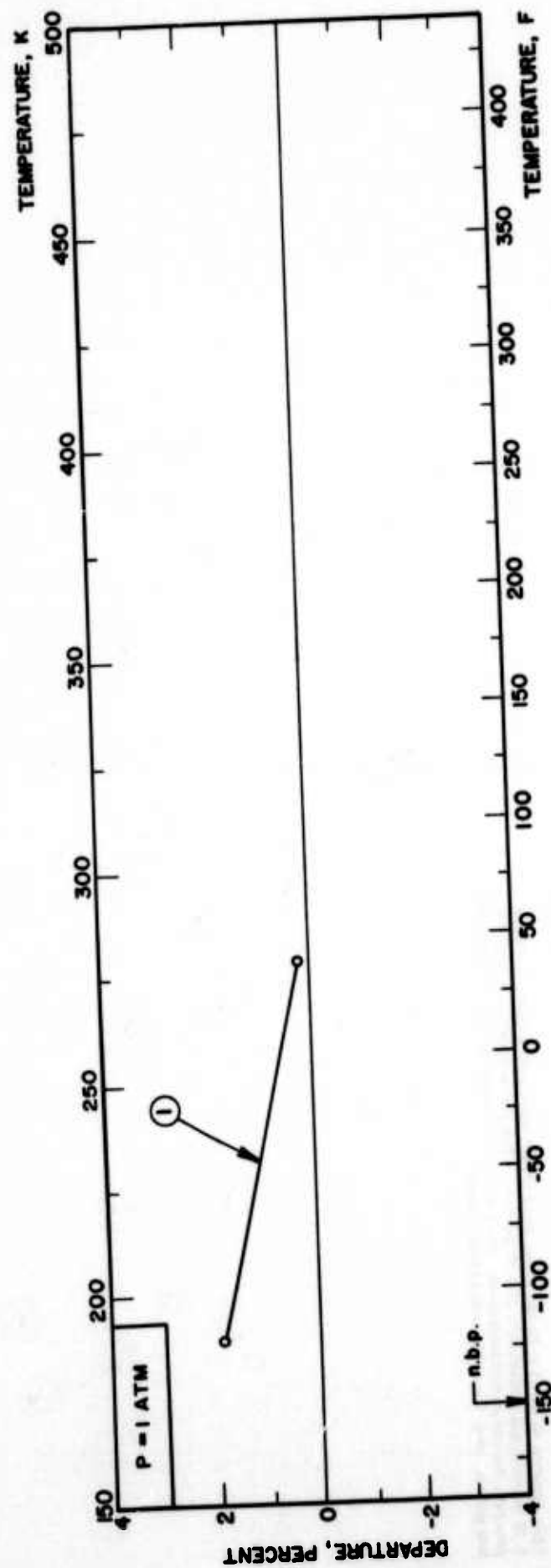


FIGURE 14 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS BORON TRIFLUORIDE



Curve	Reference
1	142

TABLE 15 SPECIFIC HEAT AT CONSTANT PRESSURE OF HYDROGEN CHLORIDE

DISCUSSION		RECOMMENDED VALUES	
		[Temperature, T, F; Specific Heat, C _p , B lb ⁻¹ F ⁻¹]	
LIQUID		LIQUID	
	T		C _p
	-165		0.3943
	-160		0.3946
	-155		0.3950
	-150		0.3955
	-145		0.3963
	-140		0.3973
	-135		0.3987
	-130		0.4005

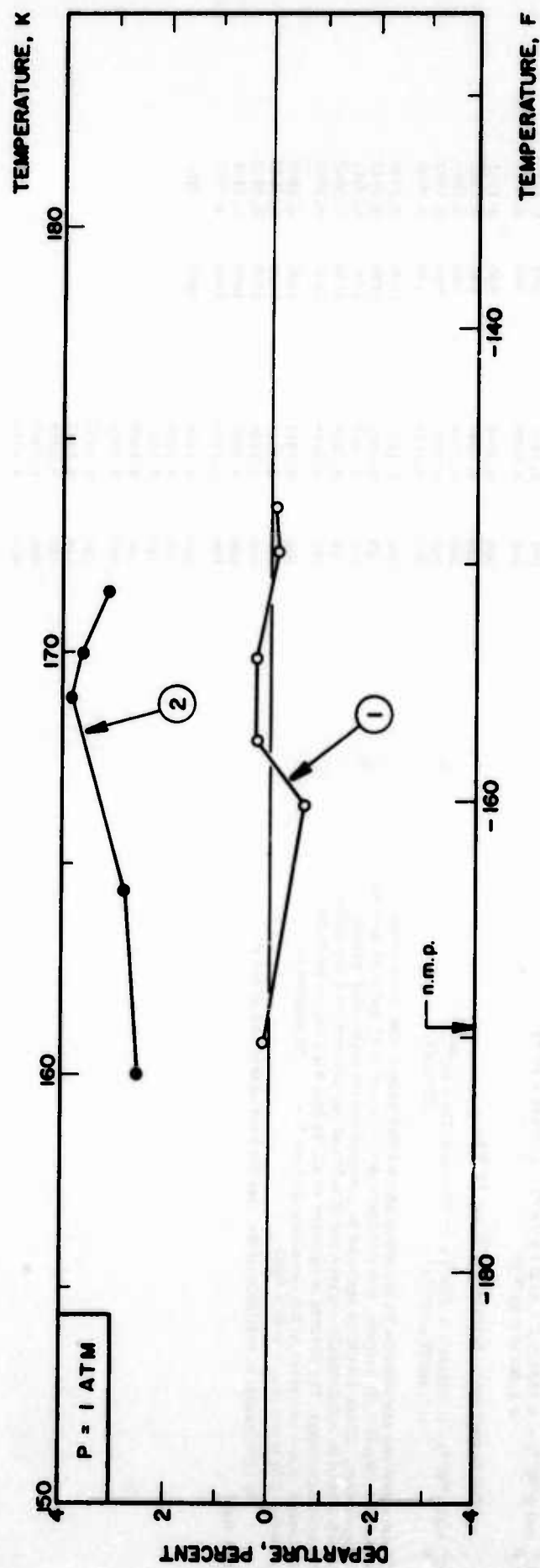
Only two sets of calorimetric data are available for the specific heat of liquid hydrogen chloride. Clusius (240) measured the purified liquid with an error of 0.7 percent at temperatures between 163 K and 173.4 K. His data are considered to be reliable and equal weight is given to all the reported data. Another set of experimental data (317), covering temperature from 164.3 K and 188.2 K along the saturated vapor pressure curve, are thought to be less reliable from the standpoint of the reported accuracy, and are given no weight in the present analysis.

The correlation formula obtained for the temperature range between 163.0 K and 173.4 K is

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = -1.33043 + 3.20880 \times 10^{-2}T - 1.99437 \times 10^{-4}T^2 + 4.14111 \times 10^{-6}T^3 \quad (T \text{ in K}).$$

This equation is found to fit the above enumerated work with a mean deviation of 0.26 percent and a maximum of 0.62 percent. The above equation is used to generate the recommended values, which should be substantially correct within two percent over the whole temperature range.

FIGURE 15 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID HYDROGEN CHLORIDE



Curve	Reference
1	240
2	317

TABLE 15 SPECIFIC HEAT AT CONSTANT PRESSURE OF HYDROGEN CHLORIDE

GAS	RECOMMENDED VALUES		
	[Temperature, T, F; Specific Heat, C _p , B lb ⁻¹ F ⁻¹]		
	GAS		
	T	C _p	T
	0	0.1908	700
	20	0.1908	720
	40	0.1907	740
	60	0.1907	760
	80	0.1907	780
	100	0.1907	800
	120	0.1907	820
	140	0.1907	840
	160	0.1907	860
	180	0.1908	880
	200	0.1908	900
	220	0.1909	920
	240	0.1909	940
	260	0.1910	960
	280	0.1911	980
	300	0.1912	1000
	320	0.1912	1100
	340	0.1913	1200
	360	0.1914	1300
	380	0.1916	1400
	400	0.1917	1500
	420	0.1918	1600
	440	0.1920	1700
	460	0.1921	1800
	480	0.1923	1900
	500	0.1924	2000
	520	0.1926	
	540	0.1928	
	560	0.1930	
	580	0.1932	
	600	0.1935	
	620	0.1937	
	640	0.1939	
	660	0.1942	
	680	0.1944	

Thirteen sources of information are available on the specific heat at constant pressure of gaseous hydrogen chloride. A number of extensive values for the ideal gas state have been derived from spectroscopic and molecular structural data. The values presented by Gordon (72, 73), McBride et al. (137), Sinke (192), Furukawa et al. (335), Hildenbrand (360), Huff et al. (389) and Rossini et al. (508) are considered to be reliable as well as the compilation table (254). Therefore, equal weight is given to these works in the present analysis. The correlated values (39, 426) are given no weight as well as an earlier statistical work (532). The correlation formulas obtained for the ideal gas specific heat are as follows:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}) = 0.193329 - 1.51244 \times 10^{-6}T + 1.89621 \times 10^{-9}T^2 + 1.26710 \times 10^{-11}T^3 \quad (1)$$

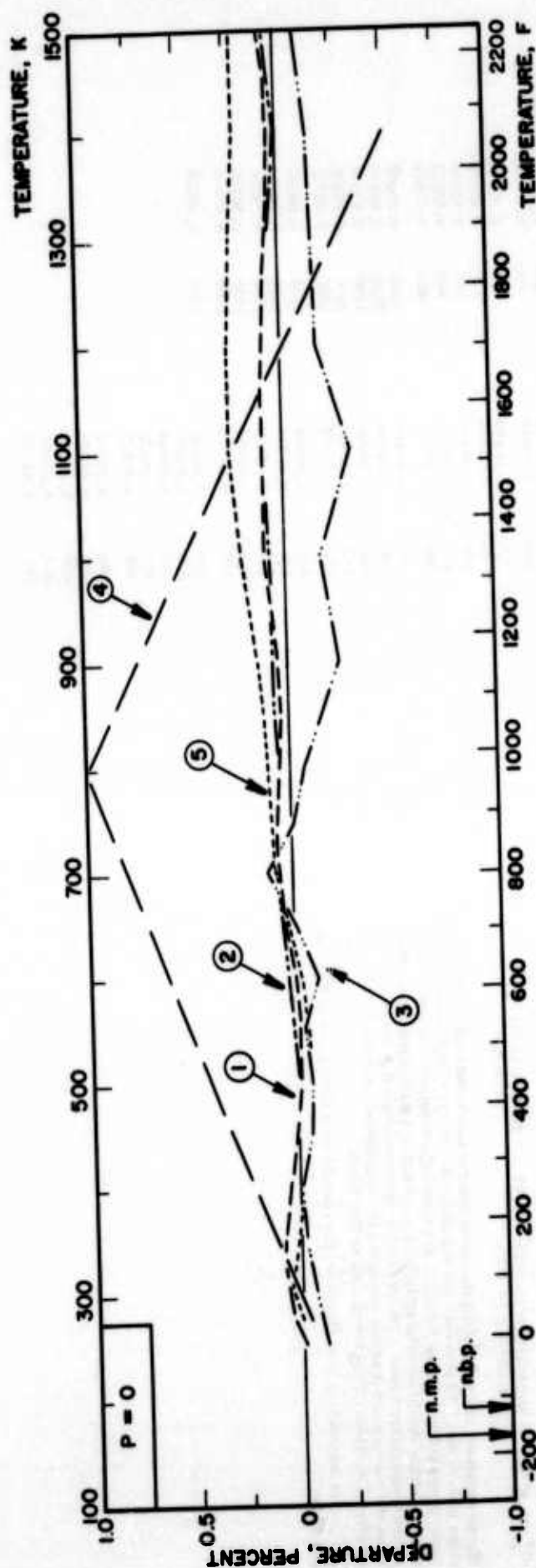
For temperatures between 770 K and 1500 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}) = 0.180499 + 3.49075 \times 10^{-6}T + 3.61248 \times 10^{-9}T^2 - 1.30027 \times 10^{-11}T^3 \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.05 and 0.09 percent, and maximum deviations of 0.12 and 0.33 percent, respectively. These formulas are used to generate the recommended values, which should be substantially correct within half and one percent over the entire temperature range. The percent departures of all the reported values from the tabulated values are given in the departure plot for $P = 0$. An empirical equation (25) is not shown in this figure.

No information is available on the specific heat of this gas in the real gas state.

FIGURE 15 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS HYDROGEN CHLORIDE



Curve	Reference
1	72, 73, 137, 192,
2	335, 380, 389
3	254
4	508
5	59
	428, 532

TABLE 16 SPECIFIC HEAT AT CONSTANT PRESSURE OF HYDROGEN IODIDE

DISCUSSION		RECOMMENDED VALUES	
GAS		[Temperature, T, F; Specific Heat, C _p , B lb ⁻¹ F ⁻¹]	
GAS		GAS	
T	C _p	T	C _p
0	0.05439	700	0.05726
20	0.05439	720	0.05742
40	0.05439	740	0.05758
60	0.05440	760	0.05774
80	0.05441	780	0.05789
100	0.05443	800	0.05805
120	0.05445	820	0.05820
140	0.05448	840	0.05835
160	0.05451	860	0.05851
180	0.05455	880	0.05866
200	0.05459	900	0.05881
220	0.05464	920	0.05896
240	0.05470	940	0.05911
260	0.05475	960	0.05925
280	0.05482	980	0.05940
300	0.05488	1000	0.05955
320	0.05496	1100	0.06026
340	0.05504	1200	0.06094
360	0.05512	1300	0.06160
380	0.05521	1400	0.06223
400	0.05530	1500	0.06282
420	0.05540	1600	0.06336
440	0.05550	1700	0.06390
460	0.05561	1800	0.06439
480	0.05573	1900	0.06484
500	0.05584	2000	0.06525
520	0.05597		
540	0.05610		
560	0.05623		
580	0.05637		
600	0.05651		
620	0.05666		
640	0.05682		
660	0.05694		
680	0.05710		

There exist only five sources of information for the constant pressure specific heat of gaseous hydrogen iodide. Four sets of extensive values for the ideal gas state have been presented by Gordon (73), Kobe and Long (428), Rossini et al. (508) and JANAF Thermochemical Tables (254). Excellent agreement is found among these values. Therefore equal weight is given to these works in the present analysis. The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 250 K and 620 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.0559084 - 1.1109 \times 10^{-4}T + 2.09174 \times 10^{-6}T^2 - 3.27269 \times 10^{-10}T^3 \quad (1)$$

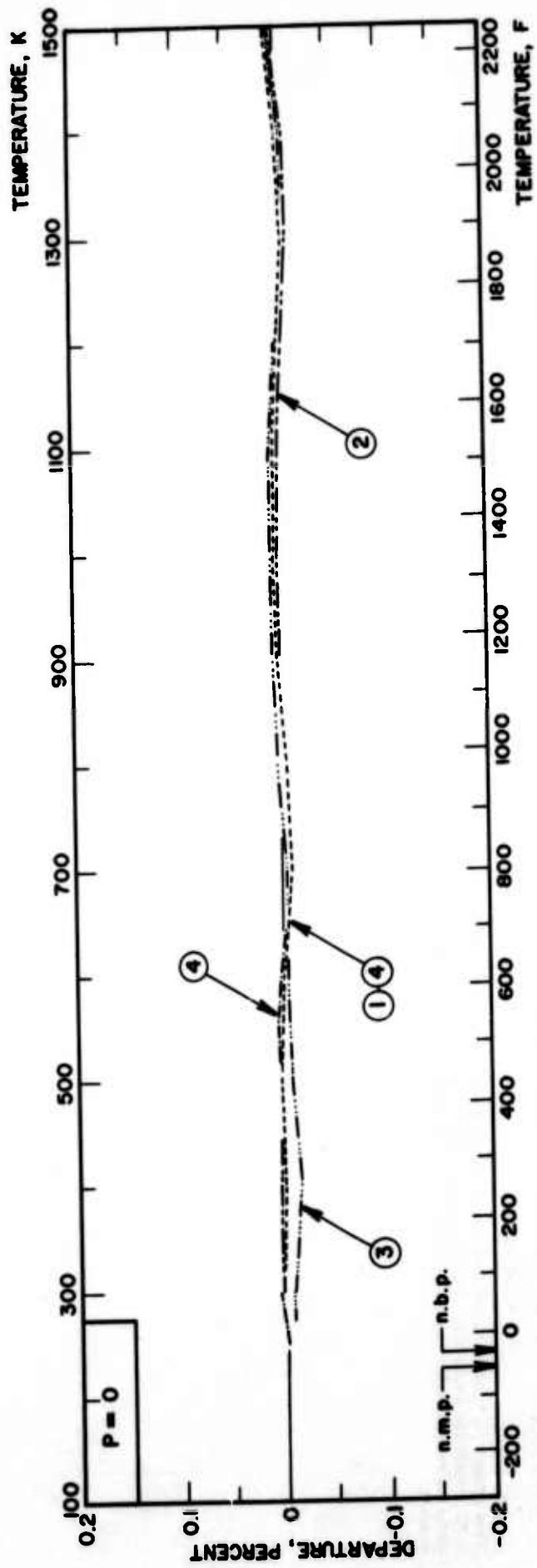
For temperatures between 620 K and 1500 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.0471113 + 1.66509 \times 10^{-4}T - 2.70113 \times 10^{-6}T^2 - 1.59501 \times 10^{-10}T^3 \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.04 and 0.05 percent, and maximum deviations of 0.15 and 0.10 percent, respectively. These formulas are used to generate the recommended values, which should be substantially correct within a half percent over the entire temperature range. The percent departures of all the reported values from the recommended values are given in the departure plot for P = 0. An empirical equation (25) is not plotted in this figure.

No information is available on the specific heat of this gas in the real gas state.

FIGURE 15 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS HYDROGEN-IODIDE



Curve	Reference
1	73
2	254
3	428
4	508

TABLE 17 SPECIFIC HEAT AT CONSTANT PRESSURE OF HYDROGEN SULFIDE

DISCUSSION		RECOMMENDED VALUES	
LIQUID		[Temperature, T, F; Specific Heat, C _p , B lb ⁻¹ F ⁻¹]	
		LIQUID	
		T	C _p
		-115	0.4750
		-110	0.4752
		-105	0.4762
		-100	0.4776
		-95	0.4791
		-90	0.4801
		-85	0.4803
		-80	0.4791

Two sets of calorimetric data are available for the constant pressure specific heat of liquid hydrogen sulfide within the temperature range between the normal melting point and the normal boiling point. Giauque and Blue (349) reported data with an experimental error of 0.2 percent covering temperatures from 189.95 K to 210.99 K, and Chuska and Frank (292) made measurements between 193.6 K and 208.9 K. Agreement is good at low temperatures, but the discrepancy increases at higher temperature. However, both sets of data are considered to be sufficiently reliable, and are given equal weight in the present analysis.

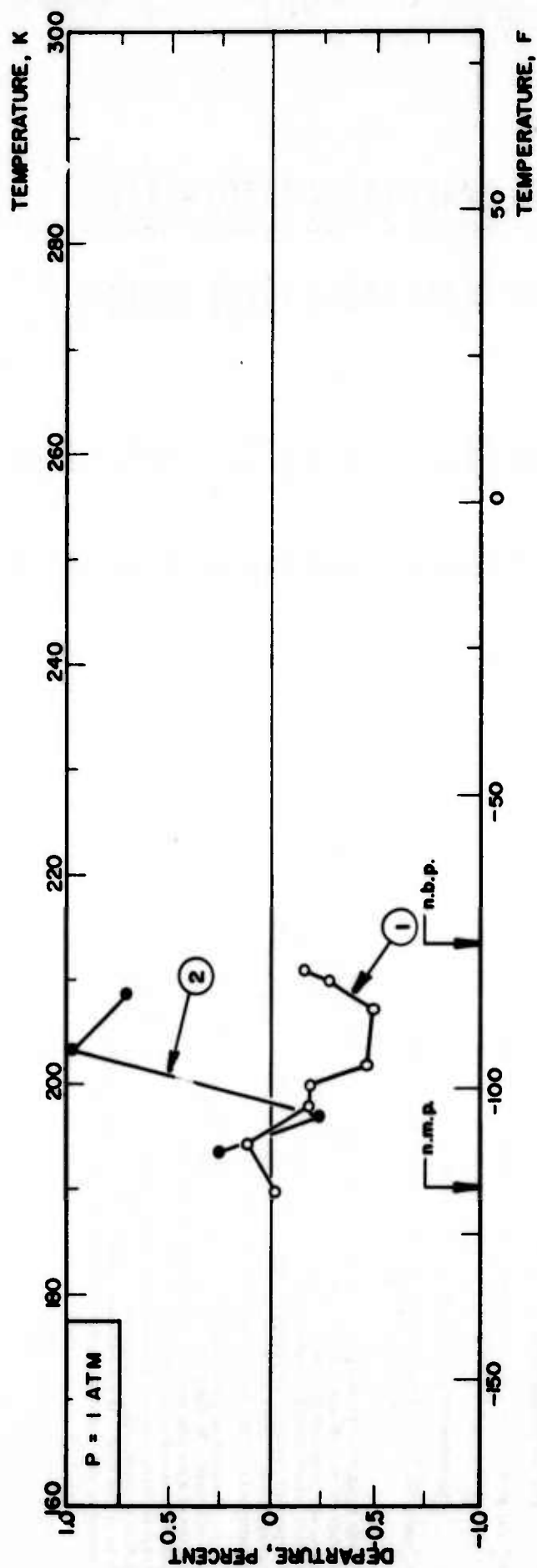
The correlation formula obtained for the temperature range between 189.95 K and 210.99 K is

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 27.6057 - 0.408452 T + 2.04719 \times 10^{-3} T^2 - 3.41558 \times 10^{-6} T^3$$

(T in K).

This equation is found to fit the above enumerated data with a mean deviation of 0.32 percent and a maximum of 0.98 percent. The above formula is used to generate the recommended values, which should be substantially correct within two percent.

FIGURE 17 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID HYDROGEN SULFIDE



Curve	Reference
1	292
2	34C

TABLE 17 SPECIFIC HEAT AT CONSTANT PRESSURE OF HYDROGEN SULFIDE

DISCUSSION

GAS

There exist 20 sources of information for the constant pressure specific heat of gaseous hydrogen sulfide. Several sets of extensive values in the ideal gas state have been derived by statistical mechanics from spectroscopic and molecular structural data. Results presented by McBride et al. (137, 458), Sinke (192), Evans and Wagman (322) and Haar et al. (364, 365) are considered to be reliable as well as a compilation table (254). Therefore, these values are given equal weight in this analysis. Other sets of theoretical values (59, 264) and earlier statistical calculations (24, 300) are given no weight as well as the compiled values (72, 427) based on the earlier work (300) and a single point value obtained by empirical correlation (18). The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 200 K and 620 K:

$$C_p^0 (\text{cal g}^{-1} \text{K}^{-1}) = 0.239144 - 9.51950 \times 10^{-5} T + 4.04069 \times 10^{-7} T^2 - 2.49695 \times 10^{-10} T^3 \quad (1)$$

For temperatures between 620 K and 1500 K:

$$C_p^0 (\text{cal g}^{-1} \text{K}^{-1}) = 0.184201 + 1.58423 \times 10^{-4} T - 9.60009 \times 10^{-7} T^2 - 1.12799 \times 10^{-10} T^3 \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.07 and 0.15 percent, and maximum deviations of 0.29 and 0.39 percent, respectively. These formulas are used to generate the recommended values, which should be substantially correct within one percent over the entire temperature range. The percent departures of all the reported values from the recommended values are given in the departure plot for $P = 0$. Empirical equations (25, 196, 197) are not plotted in this figure.

Concerning the specific heat in the real gas state, only three sets of data are available. Millar (442) reported results between 216 K and 278 K obtained by means of a cooling method. Felsing and Drake (328) reported flow-calorimetric data at temperatures from 305 K to 385 K. However, large discrepancies are found between these works. A single point value obtained from a correlation (78) is also felt to be unreliable. Therefore, no correlation is given for the real gas specific heat at this time. In the departure plot for $P = 1$ atm, these reported data are compared with Equation (1) for the ideal gas specific heat.

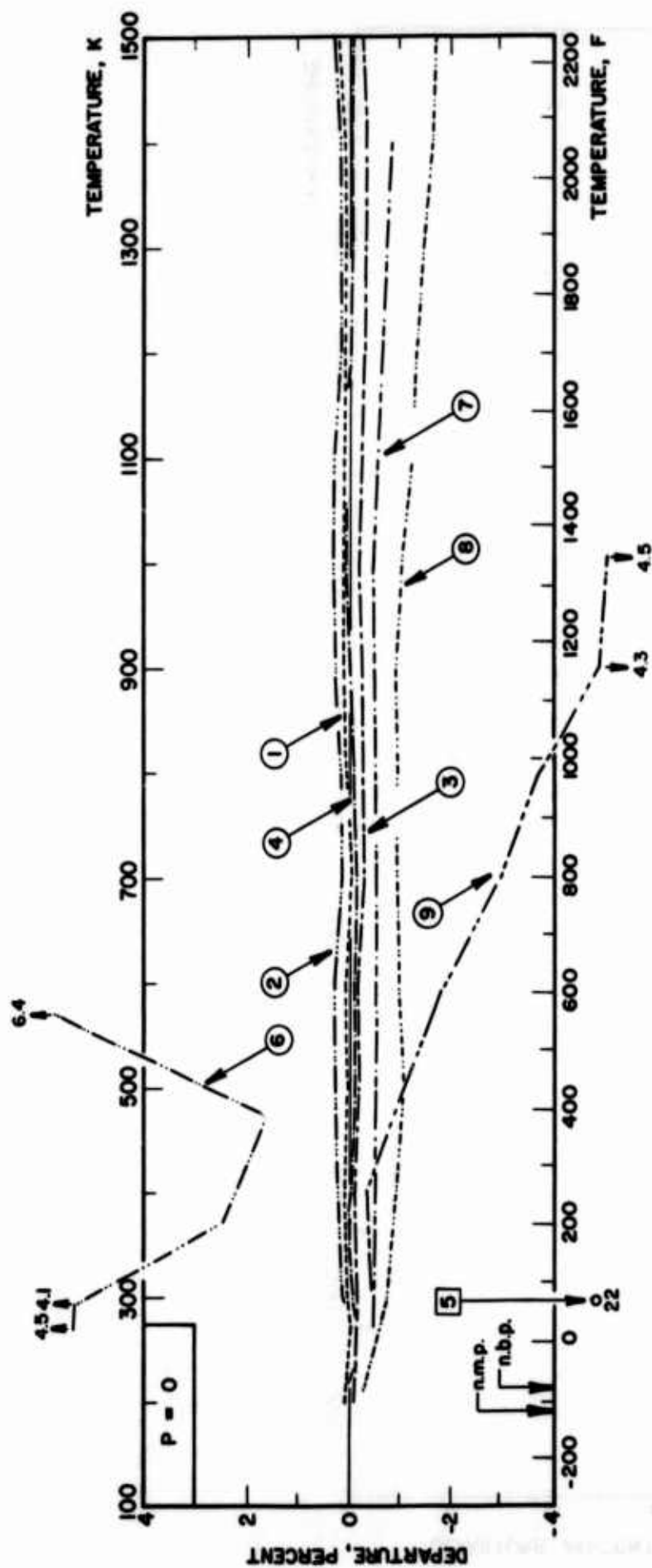
RECOMMENDED VALUES
[Temperature, T, F; Specific Heat, C_p , B lb⁻¹ F⁻¹]

GAS

T	C_p^0	T	C_p^0
-100	0.2341	600	0.2720
-80	0.2345	620	0.2734
-60	0.2350	640	0.2747
-40	0.2356	660	0.2761
-20	0.2362	680	0.2776
0	0.2369	700	0.2791
20	0.2376	720	0.2805
40	0.2384	740	0.2820
60	0.2392	760	0.2834
80	0.2400	780	0.2849
100	0.2409	800	0.2863
120	0.2419	820	0.2877
140	0.2429	840	0.2891
160	0.2439	860	0.2906
180	0.2450	880	0.2919
200	0.2461	900	0.2933
220	0.2472	920	0.2947
240	0.2484	940	0.2961
260	0.2496	960	0.2974
280	0.2508	980	0.2988
300	0.2520	1000	0.3001
320	0.2533	1100	0.3067
340	0.2545	1200	0.3131
360	0.2558	1300	0.3192
380	0.2572	1400	0.3250
400	0.2585	1500	0.3305
420	0.2598	1600	0.3358
440	0.2612	1700	0.3408
460	0.2625	1800	0.3454
480	0.2639	1900	0.3497
500	0.2652	2000	0.3537
520	0.2666		
540	0.2680		
560	0.2693		
580	0.2707		

n. b. p. = -75 F

FIGURE 17 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS HYDROGEN SULFIDE



Curve	Reference
1	137, 458
2	192, 322
3	254
4	364, 365
5	18
6	24
7	59
8	72, 300, 427
9	264

FIGURE 17 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS HYDROGEN SULFIDE

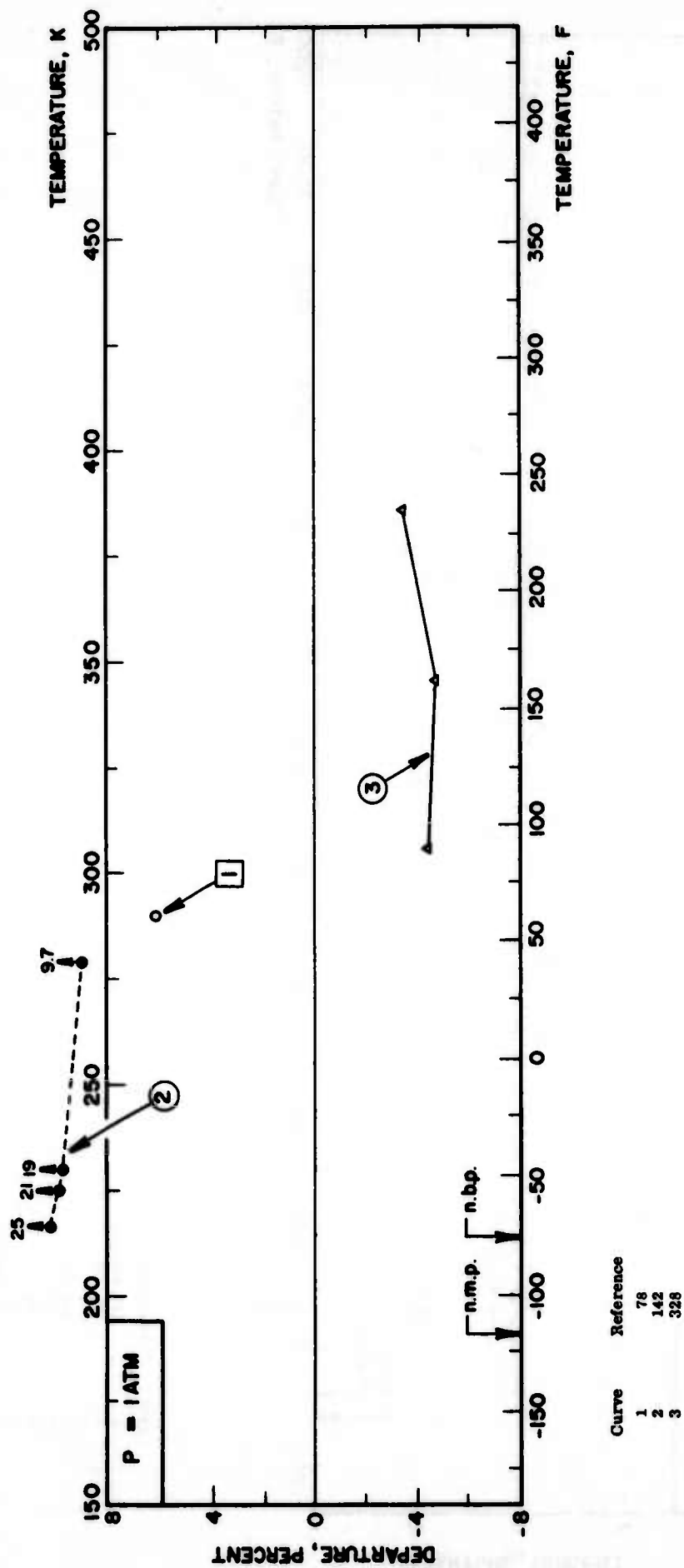


TABLE 18 SPECIFIC HEAT AT CONSTANT PRESSURE OF NITRIC OXIDE

DISCUSSION

LIQUID

Three sources of information are available for the specific heat at constant pressure of liquid nitric oxide. A set of extensive calorimetric data were reported by Kerr (416), who made measurements of the very pure liquid, covering temperatures between 113.41 K and 155.69 K along the saturated vapor pressure curve. His data are considered to be the most reliable and his experimental data, except for one point at the highest temperature (155.69 K), are given full weight in this analysis. A set of earlier calorimetric data of Eucken and Karwat (217) in a narrow temperature range (115.4 K to 117.0 K) are given lesser weight. However, a single point value (216) derived by an empirical theory is given no weight.

The correlation formula obtained for the temperature range between 113 K and 150 K is

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = -24.9374 + 0.638340 T - 5.41689 \times 10^{-3} T^2 + 1.56010 \times 10^{-5} T^3$$

(T in K).

This equation is found to fit the above enumerated values with a mean deviation of 0.68 percent and a maximum of 1.8 percent. The recommended values are generated by the above formula. The tabulated values should be substantially correct within two percent.

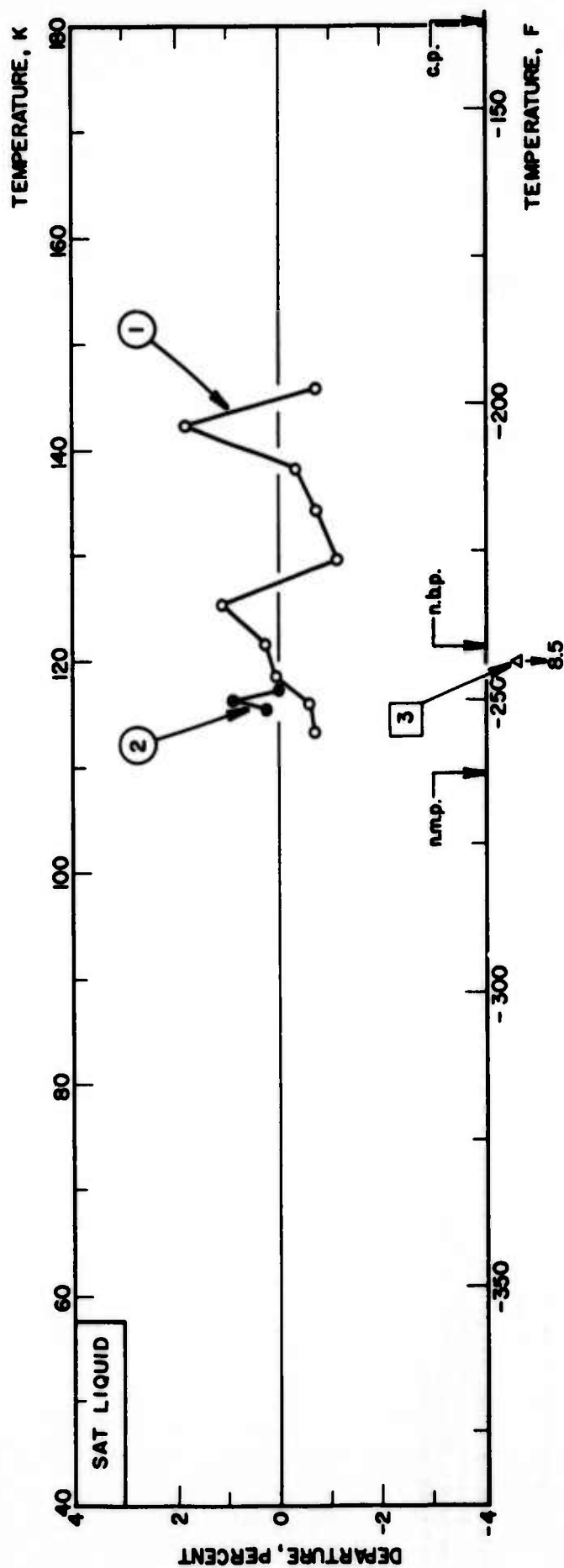
RECOMMENDED VALUES
[Temperature, T, °F; Specific Heat, C_p , B lb⁻¹F⁻¹]

LIQUID

T	C_p
-255	0.545
-250	0.577
-245	0.609
-240	0.644
-235	0.684
-230	0.730
-225	0.784
-220	0.849
-215	0.927
-210	1.02
-205	1.13
-200	1.26
-195	1.40
-190	1.57

n. b. p. = -241 °F

FIGURE 18 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID NITRIC OXIDE



Curve	Reference
1	416
2	317
3	216

TABLE 18 SPECIFIC HEAT CONSTANT PRESSURE OF NITRIC OXIDE

DISCUSSION

GAS

Twenty-six sources of information are available on the specific heat at constant pressure of gaseous nitric oxide. A number of extensive values for the ideal gas state have been derived from spectroscopic and molecular structural data. Results of Faltin (59), Gordon (72), Keyes (100), Ribaud (167), Sinks (192), Beckett and Haar (266), Glatt et al. (348), Hildenbrand (390), Huff et al. (399) and Kallman (403) are considered to be reliable, as well as compilation tables (253, 254, 429). Therefore, equal weight is given to these works in the present analysis. However, earlier statistical calculations (93, 278, 393, 562) and an empirical correlation (18) are given no weight. The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 100 K and 590 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.282183 - 3.16841 \times 10^{-4} T + 6.88734 \times 10^{-7} T^2 - 4.22833 \times 10^{-10} T^3 \quad (1)$$

For temperatures between 590 K and 1500 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.192074 + 1.22287 \times 10^{-4} T - 5.05602 \times 10^{-7} T^2 + 6.90346 \times 10^{-10} T^3 \quad (2)$$

These equations are found to fit the above referred to values with mean deviations of 0.08 and 0.04 percent, and maximum deviations of 0.29 and 0.20 percent, respectively. These formulas are used to calculate the recommended values, which should be substantially correct within one percent over the entire temperature range. The percent departures of all the reported values from the tabulated values are given in the departure plot for $P = 0$. Empirical equations (25, 188) are not plotted in this figure.

On the other hand, several works are available for the specific heat in the real gas state. The theoretical results of Masi (132), which are cited by McKown (469), are considered to be the most reliable, and are fitted to the following equations, independently of the ideal gas values:

For temperatures between 150 K and 580 K:

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.309760 - 5.23433 \times 10^{-4} T + 1.18484 \times 10^{-7} T^2 - 8.04772 \times 10^{-10} T^3 \quad (3)$$

For temperatures between 580 K and 1500 K:

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.192096 + 1.23339 \times 10^{-4} T - 5.24720 \times 10^{-7} T^2 + 7.70996 \times 10^{-10} T^3 \quad (4)$$

These equations are found to fit the original values with mean deviations of 0.29 and 0.03 percent and maximum deviations of 0.79 and 0.07 percent, respectively. The recommended values of C_p are generated by Equations (3) and (4). The tabulated values should be substantially correct within one percent. In the departure plot for $P = 1$ atm, experimental values obtained through velocity of sound measurements (488), derived values from the equilibrium constants (519) and a correlated value (216) are also compared with Equations (3) and (4). A set of values obtained at higher temperatures is not given in this figure.

The comparison of Equations (3) and (4) with Equations (1) and (2) is also given in the third plot.

TABLE 18 SPECIFIC HEAT CONSTANT PRESSURE OF NITRIC OXIDE (continued)

RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p° and C_p , B lb⁻¹ F⁻¹]

GAS					RECOMMENDED VALUES					RECOMMENDED VALUES				
T	C_p°	C_p	T	C_p°	C_p	T	C_p°	C_p	T	C_p°	C_p	T	C_p°	C_p
-260	0.2548		300	0.2392	0.2392	900	0.2584	0.2585	1000	0.2615	0.2615	1500	0.2740	0.2740
-240	0.2528		320	0.2396	0.2398	920	0.2590	0.2591	1100	0.2644	0.2644	1600	0.2760	0.2759
-220	0.2510		340	0.2401	0.2403	940	0.2597	0.2597	1200	0.2671	0.2671	1700	0.2778	0.2777
-200	0.2494		360	0.2406	0.2409	960	0.2603	0.2603	1300	0.2696	0.2696	1800	0.2794	0.2793
-180	0.2478		380	0.2412	0.2416	980	0.2609	0.2610	1400	0.2719	0.2718	1900	0.2809	0.2808
-160	0.2464		400	0.2417	0.2422	1000	0.2615	0.2615	1500	0.2740	0.2740	2000	0.2822	0.2821
-140	0.2451	0.2516	420	0.2423	0.2428	1100	0.2644	0.2644	1600	0.2760	0.2759			
-120	0.2439	0.2476	440	0.2429	0.2435	1200	0.2671	0.2671	1700	0.2778	0.2777			
-100	0.2428	0.2459	460	0.2435	0.2441	1300	0.2696	0.2696	1800	0.2794	0.2793			
-80	0.2419	0.2444	480	0.2442	0.2448	1400	0.2719	0.2718	1900	0.2809	0.2808			
-60	0.2410	0.2430	500	0.2448	0.2454	1500	0.2740	0.2740	2000	0.2822	0.2821			
-40	0.2402	0.2418	520	0.2454	0.2459	1600	0.2760	0.2759						
-20	0.2396	0.2407	540	0.2461	0.2465	1700	0.2778	0.2777						
0	0.2390	0.2398	560	0.2467	0.2470	1800	0.2794	0.2793						
20	0.2385	0.2390	580	0.2473	0.2475	1900	0.2809	0.2808						
40	0.2381	0.2384	600	0.2479	0.2479	2000	0.2822	0.2821						
60	0.2378	0.2379	620	0.2486	0.2487									
80	0.2375	0.2375	640	0.2493	0.2495									
100	0.2374	0.2372	660	0.2501	0.2502									
120	0.2373	0.2370	680	0.2508	0.2509									
140	0.2373	0.2370	700	0.2516	0.2517									
160	0.2373	0.2370	720	0.2523	0.2524									
180	0.2374	0.2371	740	0.2530	0.2531									
200	0.2376	0.2373	760	0.2537	0.2538									
220	0.2378	0.2376	780	0.2544	0.2545									
240	0.2381	0.2379	800	0.2551	0.2552									
260	0.2384	0.2383	820	0.2558	0.2559									
280	0.2388	0.2387	840	0.2564	0.2565									
			860	0.2571	0.2572									
			880	0.2578	0.2578									

n. m. p. = 260 ± 2 F

n. b. p. = -241 F

FIGURE 18 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS NITRIC OXIDE

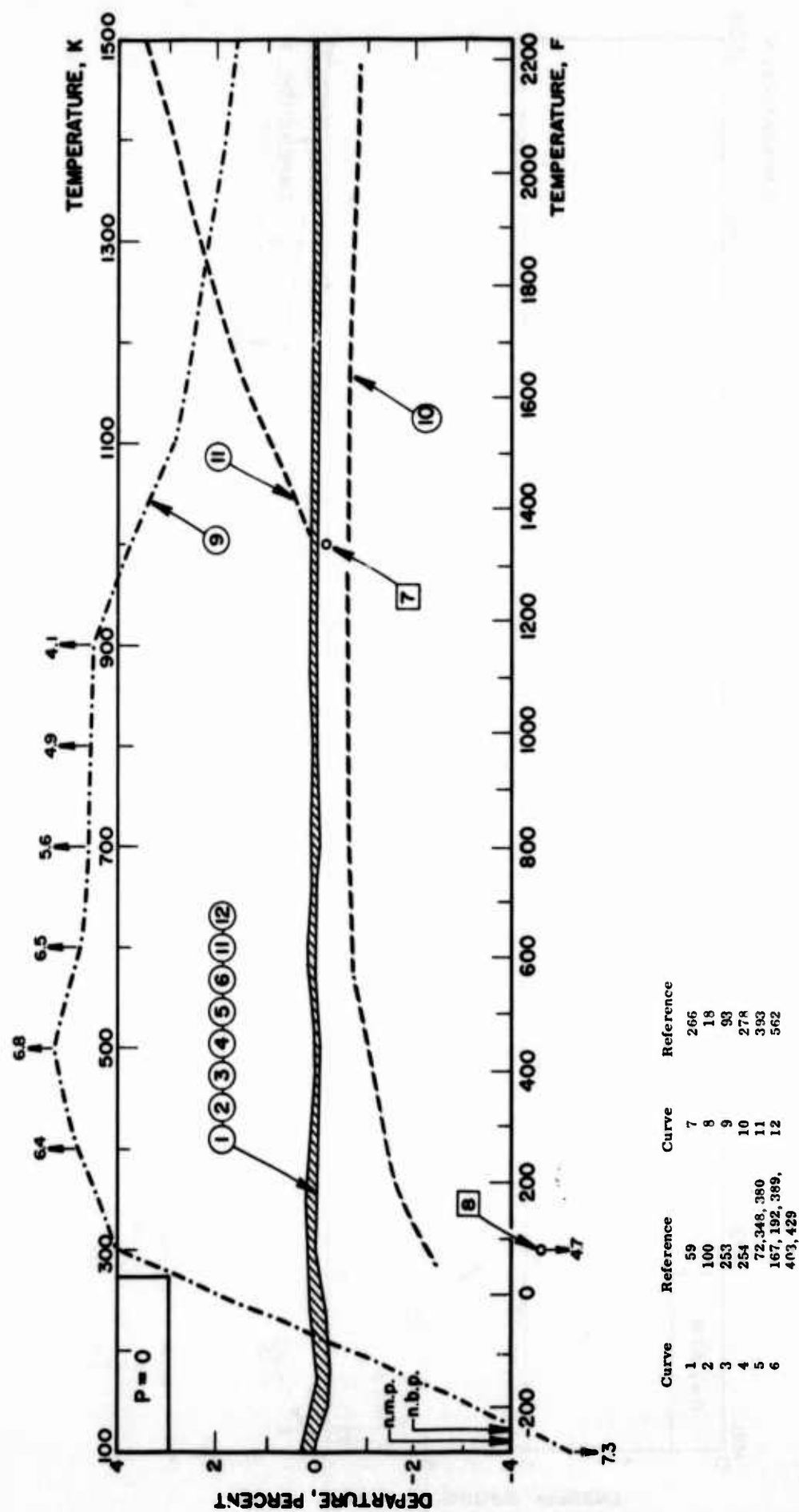
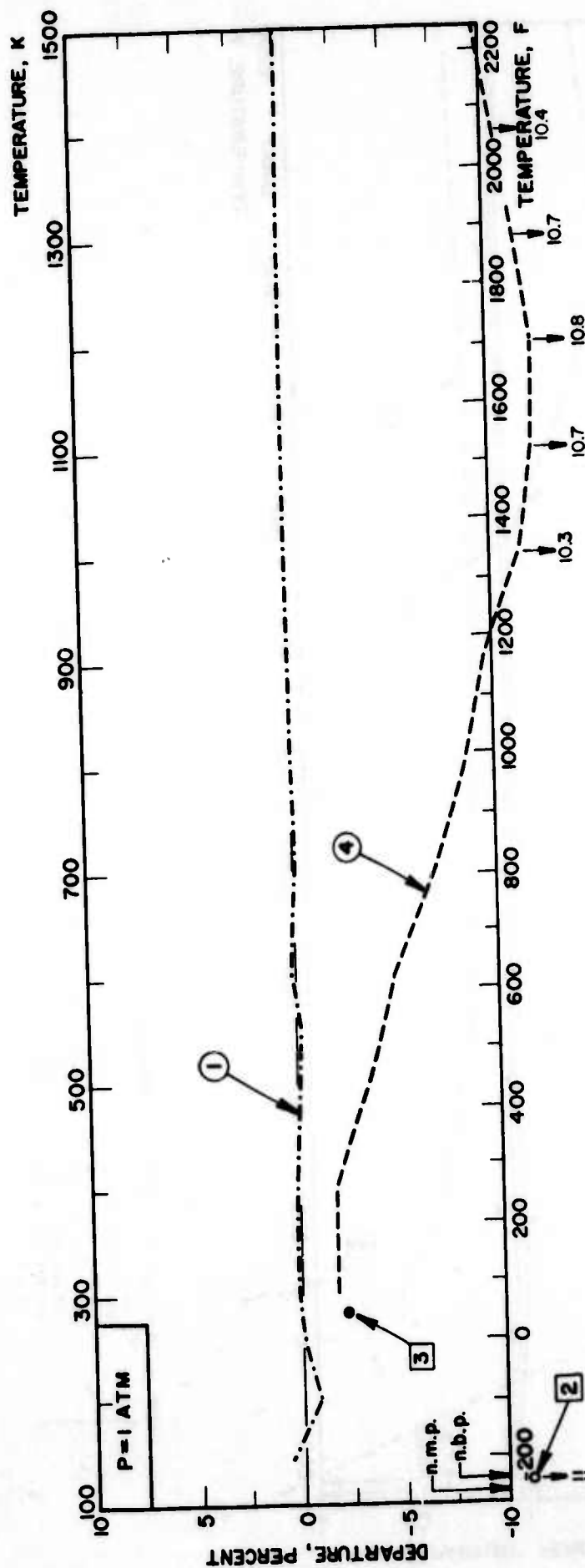


FIGURE 13 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS NITRIC OXIDE



Curve	Reference
1	132, 460
2	216
3	488
4	519

FIGURE 18 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS NITRIC OXIDE

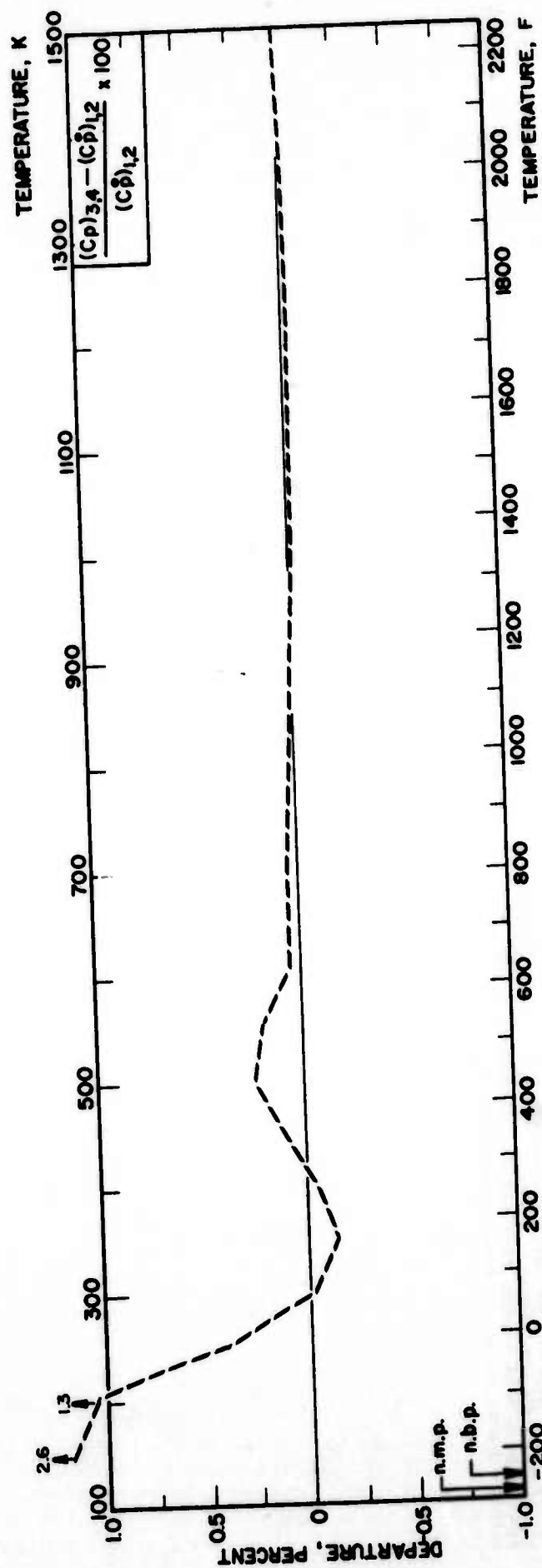


TABLE 19 SPECIFIC HEAT AT CONSTANT PRESSURE OF NITROGEN PEROXIDE

DISCUSSION	RECOMMENDED VALUES	
	[Temperature, T, F; Specific Heat, Cp, B lb ⁻¹ F ⁻¹]	
LIQUID	LIQUID	
	T	Cp
Only one experimental work on the constant pressure specific heat of liquid nitrogen peroxide was reported by Giaque and Kemp (342). They measured the specific heat of pure nitrogen tetraoxide covering temperatures from 265 K to 291 K. A compilation based on their data was recently published by Liberto (445). All the reported data points are given equal weight in the present analysis. The correlation formula obtained at temperatures between 265 K and 291 K is $C_p (\text{cal g}^{-1}\text{K}^{-1}) = 1.97538 - 1.76174 \times 10^{-2}T + 6.25487 \times 10^{-5}T^2 - 7.21761 \times 10^{-8}T^3$ (T in K). This equation is found to fit the above enumerated values with a mean deviation of 0.04 percent and a maximum of 0.13 percent. The recommended values are generated by the above formula. The tabulated values should be substantially correct within one percent over the whole temperature range.	20	0.3563
	30	0.3584
	40	0.3606
	50	0.3631
	60	0.3655
	70	0.3680
	80	0.3705
	90	0.3727

n. b. p. = 71 F

FIGURE 19 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID NITROGEN PEROXIDE

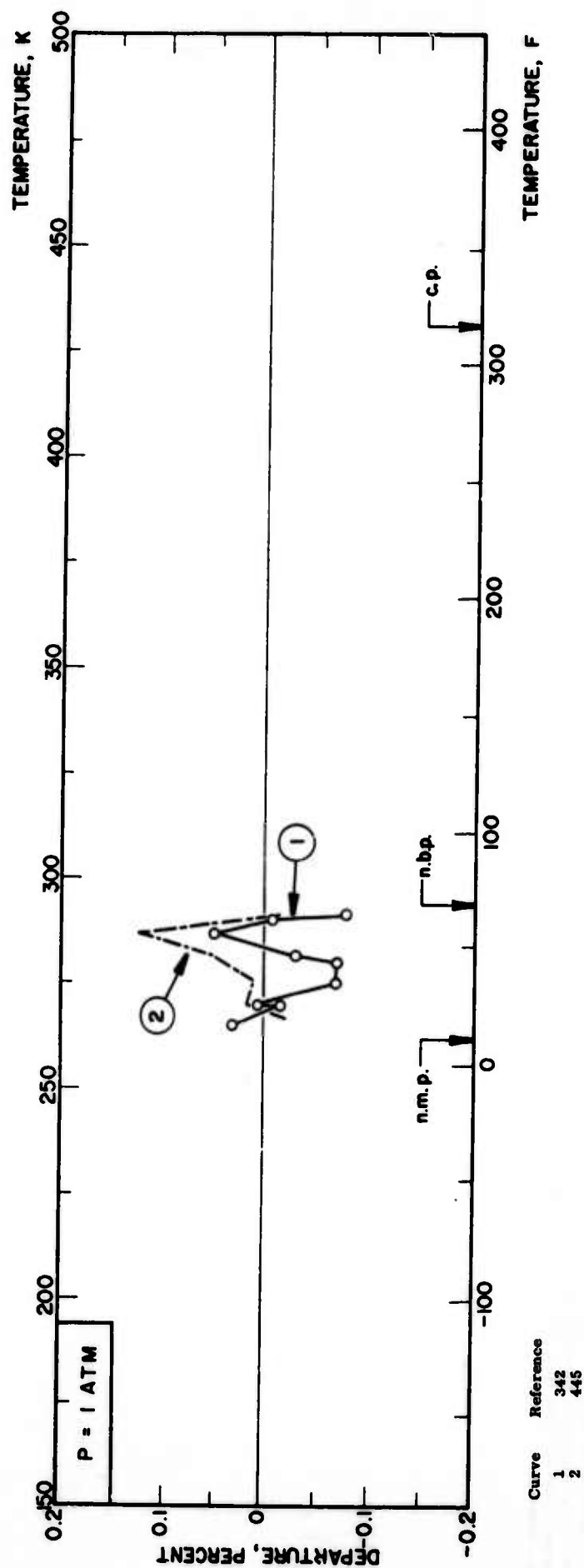


TABLE 20 SPECIFIC HEAT AT CONSTANT PRESSURE OF NITROUS OXIDE

DISCUSSION

LIQUID

Only one experimental work is available on the specific heat of liquid nitrous oxide reported by Blue and Giauque (271). Their data were obtained by a gold calorimeter, covering temperatures from 183.55 K and 187.13 K. All the reported data points are given full weight and are fitted to the following correlation formula:

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.368113 + 2.89976 \times 10^{-6}T \quad (T \text{ in K}).$$

This equation is found to fit the above enumerated values with a mean deviation of 0.10 percent and a maximum of 0.21 percent. The above formula is used to generate the recommended values, which should be substantially correct within one percent.

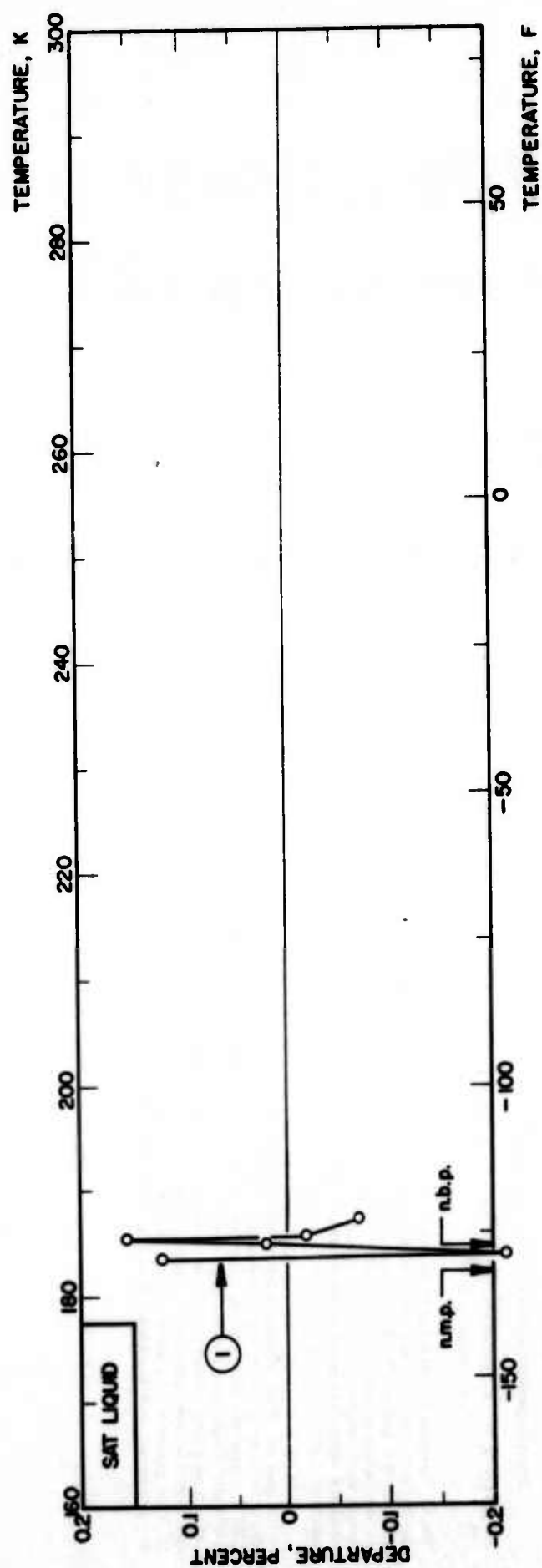
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p , B. lb.⁻¹F.⁻¹]

LIQUID	
T	C_p
-130	0.4209
-128	0.4213
-126	0.4216
-124	0.4219
-122	0.4222
-120	0.4226

n. b. p. = -130 F

FIGURE 20 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID NITROUS OXIDE



Curve Reference
1 271

TABLE 20 SPECIFIC HEAT AT CONSTANT PRESSURE OF NITROUS OXIDE

GAS	DISCUSSION			RECOMMENDED VALUES		
	[Temperature, T, F; Specific Heat, C_p , B lb ⁻¹ F ⁻¹]			GAS		
	T	C_p°	T	C_p°	T	C_p°
	-100	0.1823	600	0.2613		
	-80	0.1857	620	0.2628		
	-60	0.1890	640	0.2642		
	-40	0.1923	660	0.2655		
	-20	0.1954	680	0.2668		
	0	0.1985	700	0.2681		
	20	0.2015	720	0.2694		
	40	0.2044	740	0.2706		
	60	0.2072	760	0.2718		
	80	0.2099	780	0.2730		
	100	0.2126	800	0.2742		
	120	0.2152	820	0.2753		
	140	0.2177	840	0.2765		
	160	0.2202	860	0.2776		
	180	0.2226	880	0.2787		
	200	0.2249	900	0.2798		
	220	0.2272	920	0.2808		
	240	0.2294	940	0.2818		
	260	0.2316	960	0.2829		
	280	0.2337	980	0.2839		
	300	0.2357	1000	0.2848		
	320	0.2377	1100	0.2895		
	340	0.2396	1200	0.2937		
	360	0.2415	1300	0.2975		
	380	0.2434	1400	0.3009		
	400	0.2452	1500	0.3040		
	420	0.2470	1600	0.3068		
	440	0.2487	1700	0.3093		
	460	0.2504	1800	0.3116		
	480	0.2520	1900	0.3137		
	500	0.2537	2000	0.3156		
	520	0.2552				
	540	0.2568				
	560	0.2583				
	580	0.2598				

GAS

There exist 20 sources of information on the constant pressure specific heat of gaseous nitrous oxide. Several sets of extensive values have been derived from the spectroscopic and molecular structural data. Among them, results of Gordon (72), McBride and Gordon (488) and Pennington and Kobe (491) are considered to be reliable as well as the JANAF Thermochemical Tables (254). Therefore, these values are given equal weight in this analysis. However, other sets of correlated values (18, 59, 100, 167, 429, 543) are given no weight as well as earlier statistical calculations (93, 278, 403). The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 200 K and 600 K:

$$C_p^\circ (\text{cal g}^{-1}\text{K}^{-1}) = 0.103451 + 4.89293 \times 10^{-4}T - 5.19278 \times 10^{-7}T^2 + 2.44839 \times 10^{-10}T^3 \quad (1)$$

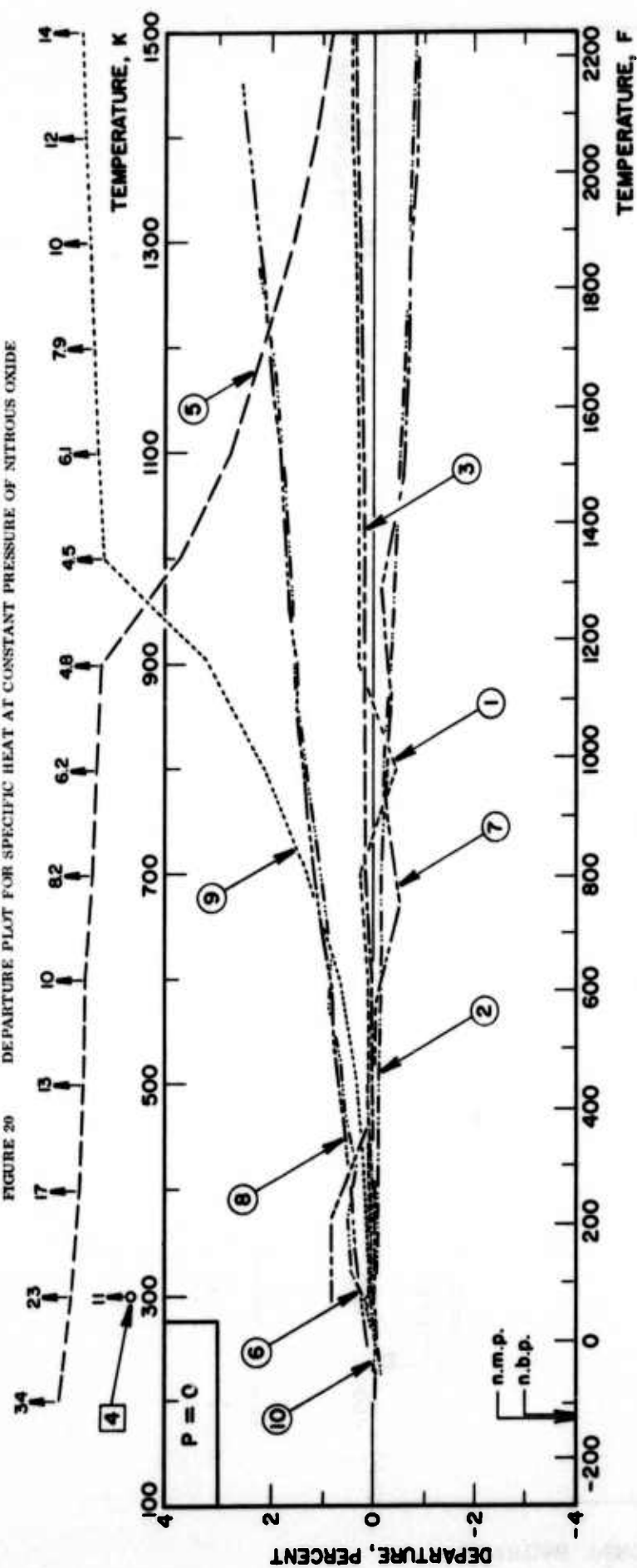
For temperatures between 600 K and 1500 K:

$$C_p^\circ (\text{cal g}^{-1}\text{K}^{-1}) = 0.149343 + 2.67192 \times 10^{-4}T - 1.47619 \times 10^{-7}T^2 + 3.01604 \times 10^{-11}T^3 \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.04 and 0.34 percent, and maximum deviations of 0.16 and 0.84 percent, respectively. These formulas are used to calculate the recommended values, which should be substantially correct within one percent over the entire temperature range. The percent departures of all the reported values from the tabulated values are given in the departure plot for $P = 0$. However, empirical equations (185, 195, 197, 346) are not plotted in this figure.

Meanwhile, three experimental works are available on the specific heat in the real gas state. Huetz-Aubert (85) obtained the specific heat at 296 K and 301 K from the isothermal and isentropic compressibility. Eucken and Lude (56) reported the data between 272 K and 390 K by the adiabatic expansion experiment. Partington and Shilling (488) derived the values at 285 K from the velocity of sound. However, these results are considered to be less reliable, covering a narrow temperature range. Therefore, no correlation is given for the real gas state. In the departure plot for $P = 1$ atm, the reported values are compared with Equation (1) for the ideal gas state.

FIGURE 20 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF NITROUS OXIDE



Curve	Reference
1	72, 491
2	254
3	458
4	18
5	93
6	100
7	278
8	59, 167, 405
9	429
10	543

FIGURE 20 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF NITROUS OXIDE

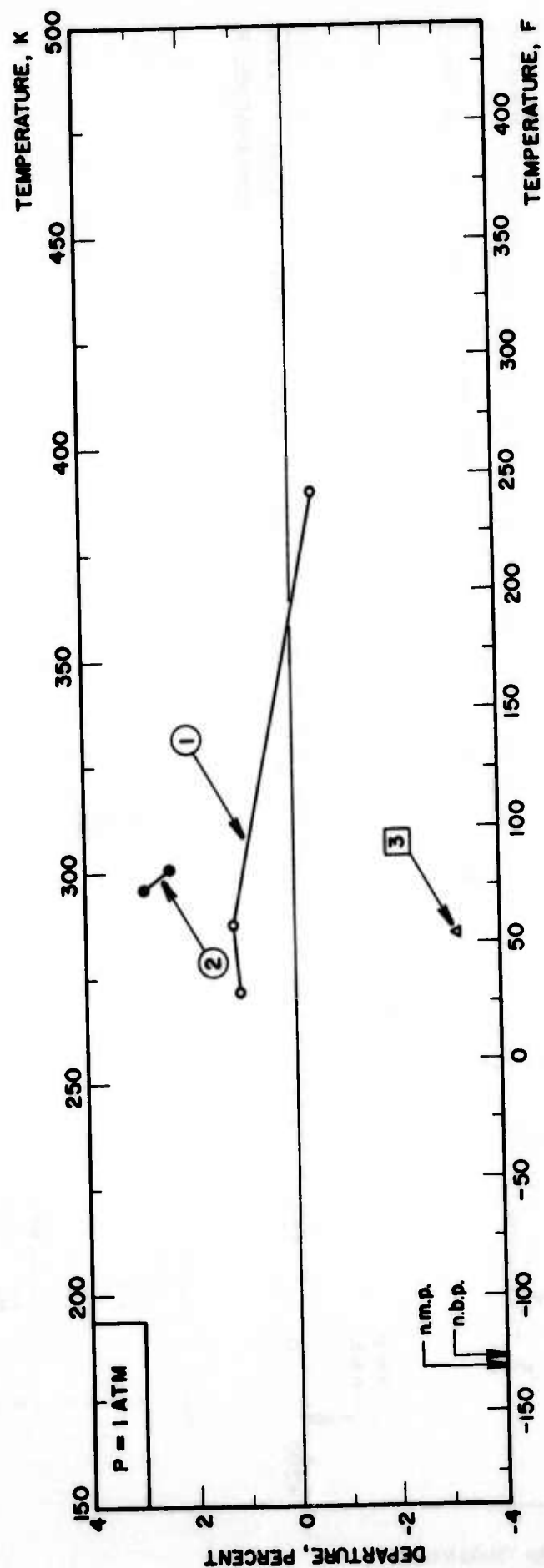


TABLE 21 SPECIFIC HEAT AT CONSTANT PRESSURE OF SULFUR DIOXIDE

DISCUSSION

LIQUID

Four sources of information are available for the specific heat at constant pressure of liquid sulfur dioxide. Riedel (504) made calorimetric measurements for the very pure substance and covered the temperature range between 233.65 K to 273.95 K along the saturated vapor pressure curve. His data are considered to be reliable and are given full weight. A compilation table by Koch (249), while it agrees with the above work, is given lesser weight in this analysis. However, a set of calorimetric data reported by Giauque and Stephenson (344), covering temperatures from 201.74 K to 260.86 K, has a negative slope with respect to temperature, and therefore no weight is given to their work, as well as a single point value (216) derived by an empirical method.

The correlation formula obtained for the temperature range between 223.15 K and 323.15 K is

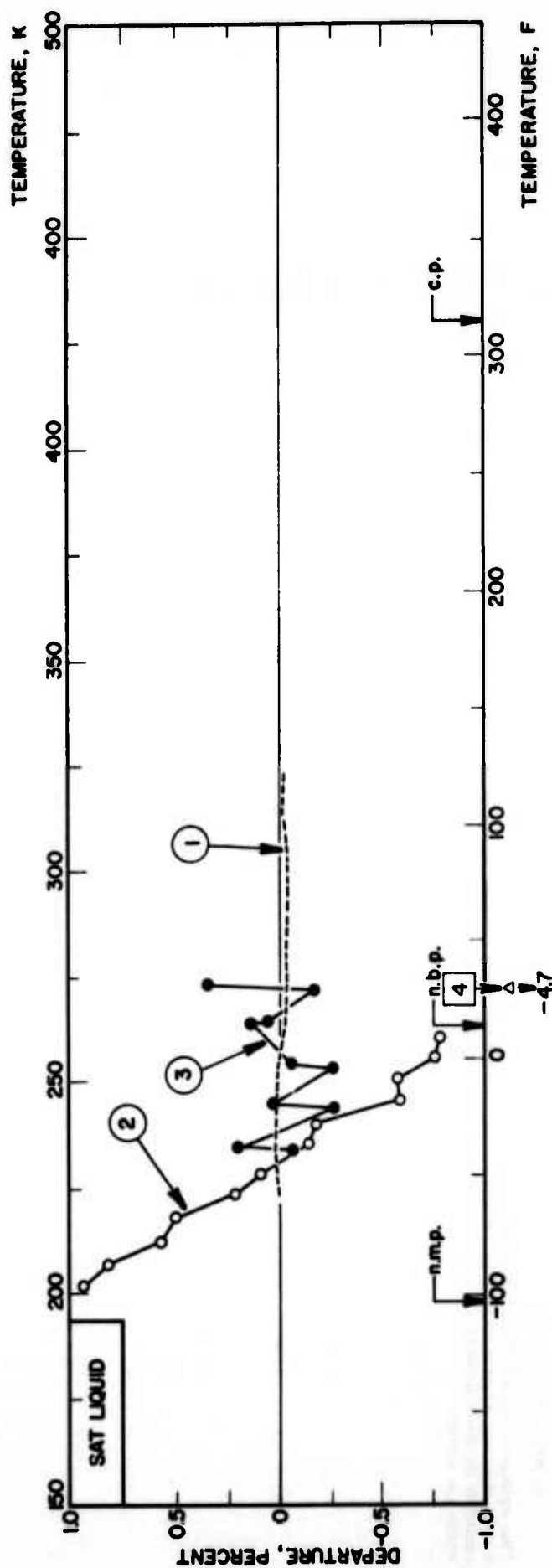
$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.319900 + 2.14297 \times 10^{-5}T \quad (T \text{ in K}).$$

This equation is found to fit the above enumerated values with a mean deviation of 0.09 percent and a maximum of 0.35 percent. The recommended values are generated by the above formula. The tabulated values should be substantially correct within one percent.

RECOMMENDED VALUES	
[Temperature, T, °F; Specific Heat, C_p , Btu ⁻¹ F ⁻¹]	
LIQUID	
T	C_p
-100	0.3240
-95	0.3240
-90	0.3241
-85	0.3241
-80	0.3242
-75	0.3243
-70	0.3243
-65	0.3244
-60	0.3244
-55	0.3245
-50	0.3246
-45	0.3246
-40	0.3247
-30	0.3248
-20	0.3249
-10	0.3250
0	0.3252
10	0.3253
20	0.3254
30	0.3255
40	0.3256
50	0.3258
60	0.3259
70	0.3260
80	0.3261
90	0.3262
100	0.3263
110	0.3265
120	0.3266
130	0.3267

n. b. p. = 13 °F

FIGURE 21 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID SULFUR DIOXIDE



Curve	Reference
1	249
2	344
3	504
4	216

TABLE 21 SPECIFIC HEAT AT CONSTANT PRESSURE OF SULFUR DIOXIDE

GAS	DISCUSSION			RECOMMENDED VALUES		
	[Temperature, T, F; Specific Heat, C _p , B lb ⁻¹ F ⁻¹]			[Temperature, T, F; Specific Heat, C _p , B lb ⁻¹ F ⁻¹]		
	T	C _p ^o	T	T	C _p ^o	T
	80	0.1488		700	0.1858	
	100	0.1503		720	0.1866	
	120	0.1519		740	0.1873	
	140	0.1534		760	0.1881	
	160	0.1549		780	0.1888	
	180	0.1564		800	0.1895	
	200	0.1578		820	0.1902	
	220	0.1593		840	0.1909	
	240	0.1607		860	0.1915	
	260	0.1620		880	0.1921	
	280	0.1634		900	0.1927	
	300	0.1647		920	0.1932	
	320	0.1660		940	0.1938	
	340	0.1672		960	0.1943	
	360	0.1685		980	0.1948	
	380	0.1697		1000	0.1953	
	400	0.1709		1100	0.1977	
	420	0.1721		1200	0.1997	
	440	0.1732		1300	0.2015	
	460	0.1743		1400	0.2031	
	480	0.1754		1500	0.2045	
	500	0.1765		1600	0.2057	
	520	0.1775		1700	0.2068	
	540	0.1785		1800	0.2078	
	560	0.1795		1900	0.2086	
	580	0.1805		2000	0.2094	
	600	0.1814				
	620	0.1824				
	640	0.1832				
	660	0.1841				
	680	0.1850				

Twenty sources of information are available on the constant pressure specific heat of gaseous sulfur dioxide. Concerning the ideal gas specific heat, several reliable values have been derived by statistical mechanics from molecular data. Results presented by Faltin (59), Gordon (72), Ribaud (167), Sinks (192), Barrow and Pitzer (264), Evans and Wagman (322), Kobe and Long (427) and McBride and Gordon (458) are given equal weight in this analysis. However, no weight is given to the earlier statistical calculations (93, 301) and an empirical correlation (18). The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 298 K and 770 K:

$$C_p^o \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.0961779 + 2.09023 \times 10^{-4}T - 1.13480 \times 10^{-7}T^2 + 8.07944 \times 10^{-12}T^3 \quad (1)$$

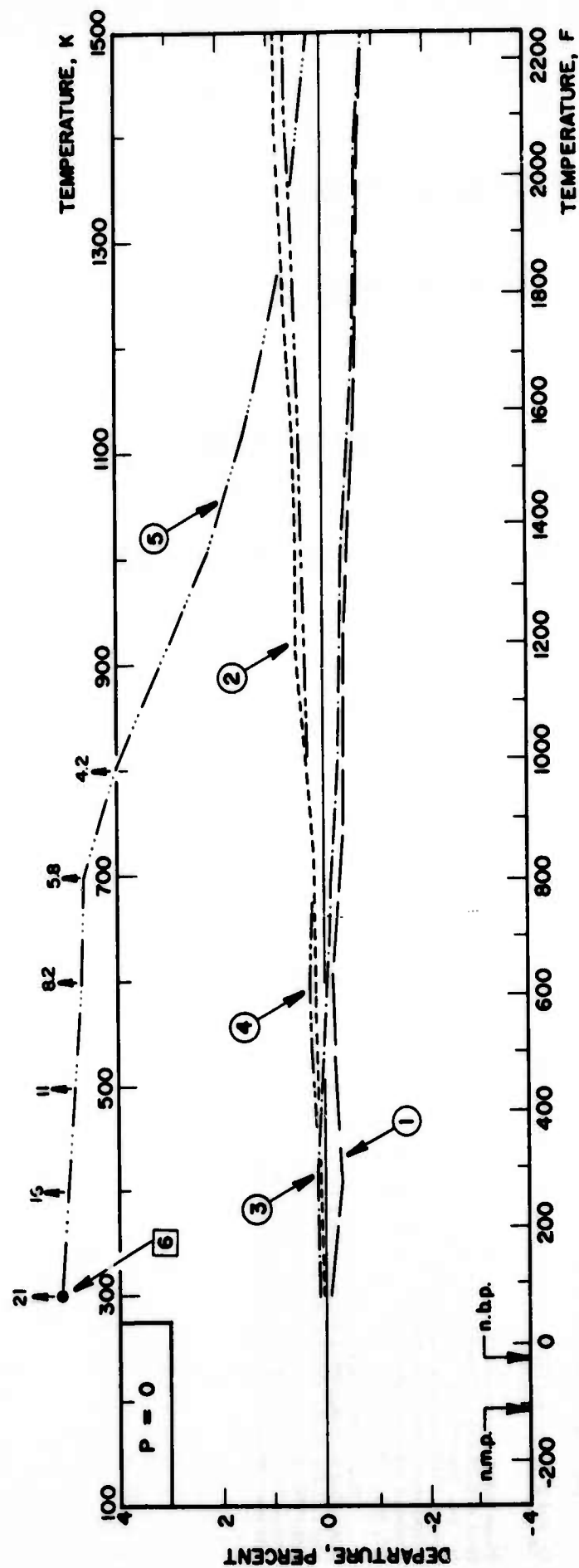
For temperatures between 770 K and 1500 K:

$$C_p^o \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.116719 + 1.64753 \times 10^{-4}T - 1.01758 \times 10^{-7}T^2 + 2.26034 \times 10^{-11}T^3 \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.16 and 0.57 percent, and maximum deviations of 0.38 and 0.89 percent, respectively. These formulas are used to generate the recommended values, which should be substantially correct within one percent over the entire temperature range. The percent departures of all the reported values from the tabulated values are given in the departure plot for $P = 0$. Empirical equations (25, 194, 197, 346, 377) are not plotted in this figure.

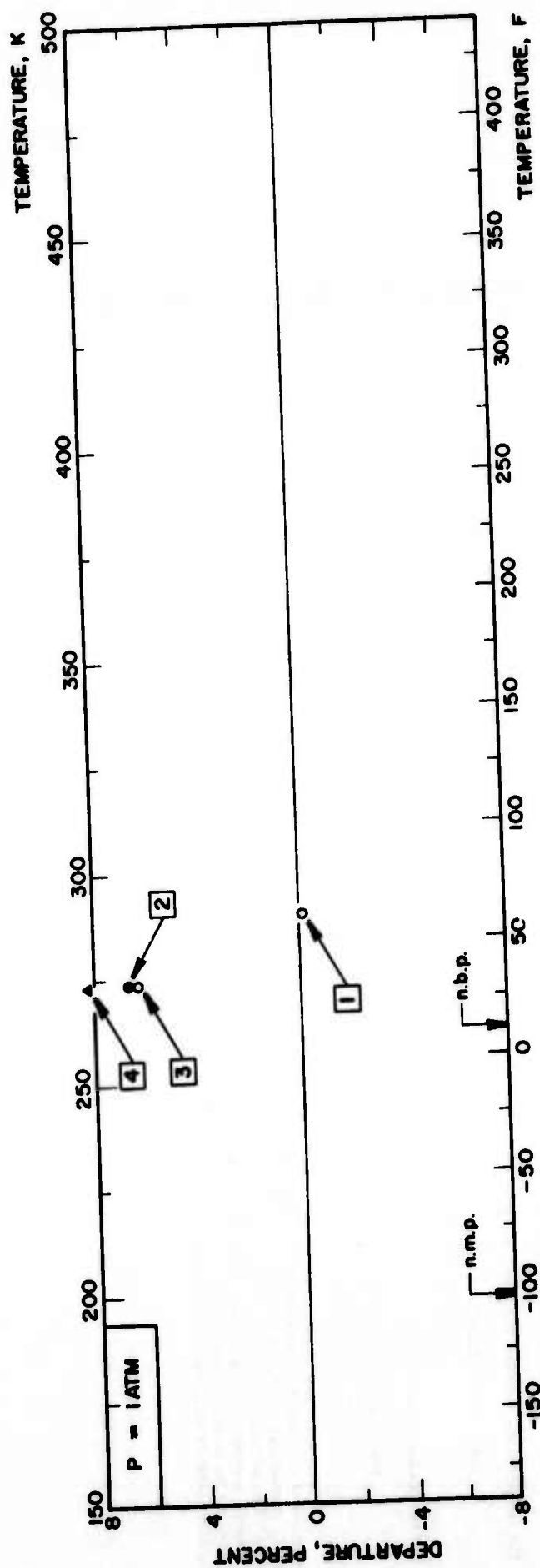
Meanwhile, concerning the specific heat in the real gas state, a single point value by Riedel (504), derived from a P-V-T relation, is thought to be the only reliable value. Other single point values (78, 216, 374) were obtained by empirical correlations. As the temperature range covered is too narrow, no correlation is given for the real gas specific heat at this time. The reported data are compared with Equation (1) in the departure plot for $P = 1$ atm.

FIGURE 21 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS SULFUR DIOXIDE



Curve	Reference
1	59, 72, 167,
2	264, 301
3	192, 322
4	427
5	458
6	93
	18

FIGURE 21 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS SULFUR DIOXIDE (continued)



Curve	Reference
1	78
2	216
3	374
4	504

TABLE 22 SPECIFIC HEAT AT CONSTANT PRESSURE OF WATER

DISCUSSION		RECOMMENDED VALUES	
		[Temperature, T, F; Specific Heat, C _p , B lb ⁻¹ F ⁻¹]	
LIQUID		LIQUID	
	T		C _p
	40		1.003
	60		0.9996
	80		0.9977
	100		0.9971
	120		0.9976
	140		0.9988
	160		1.001
	180		1.003
	200		1.006
	220		1.009
	240		1.011
	260		1.013
	280		1.017
	300		1.031
	320		1.042
	340		1.051
	360		1.060
	380		1.069
	400		1.080
	420		1.093
	440		1.110
	460		1.131
	480		1.159
	500		1.192
	520		1.234
	540		1.285
	560		1.346
	580		1.417
	600		1.501
	620		1.598

DISCUSSION

LIQUID

There exist 20 sources of information available for the isobaric specific heat of liquid water. As water has been the most extensively studied reference substance in the measurement of heat capacity, the discrepancy among the reported data is rather small. The calorimetric data of Ginnings and Furukawa (68), Osborne, et al. (483) and Schrock, et al. (181) are considered to be the most reliable from the viewpoint of the experimental procedures. Therefore, heavy weight is given to these data. To obtain the correlation at higher temperatures, weight is also given to several sets of compiled values (249, 336, 406, 480, 529) under the present analysis. However, no weight is given to early calorimetric data (172, 296, 329, 392), single point data (492), derived values from P-V-T data (303) and several sets of correlated or compiled values (78, 198, 442, 509, 564).

The correlation formulas obtained are as follows:

For temperatures between 273 K and 410 K:

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 2.13974 - 9.68137 \times 10^{-3}T + 2.68536 \times 10^{-5}T^2 - 2.42139 \times 10^{-7}T^3 \quad (T \text{ in K}), (1)$$

For temperatures between 410 K and 590 K:

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = -11.1558 + 7.96443 \times 10^{-2}T - 1.74799 \times 10^{-4}T^2 + 1.29156 \times 10^{-7}T^3 \quad (T \text{ in K}), (2)$$

These equations are found to fit the above enumerated data with mean deviations of 0.14 and 0.59 percent and maximum deviations of 1.83 and 2.42 percent, respectively. The recommended values are generated from the above formulas. The tabulated values below 400 F should be substantially correct within one percent, however, the uncertainty would increase above 400 F. In the departure plots, all the available data are compared with Equations (1) and (2). An empirical equation (346) is not given in this figure.

n. b. p. = 212 F

FIGURE 22 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID WATER

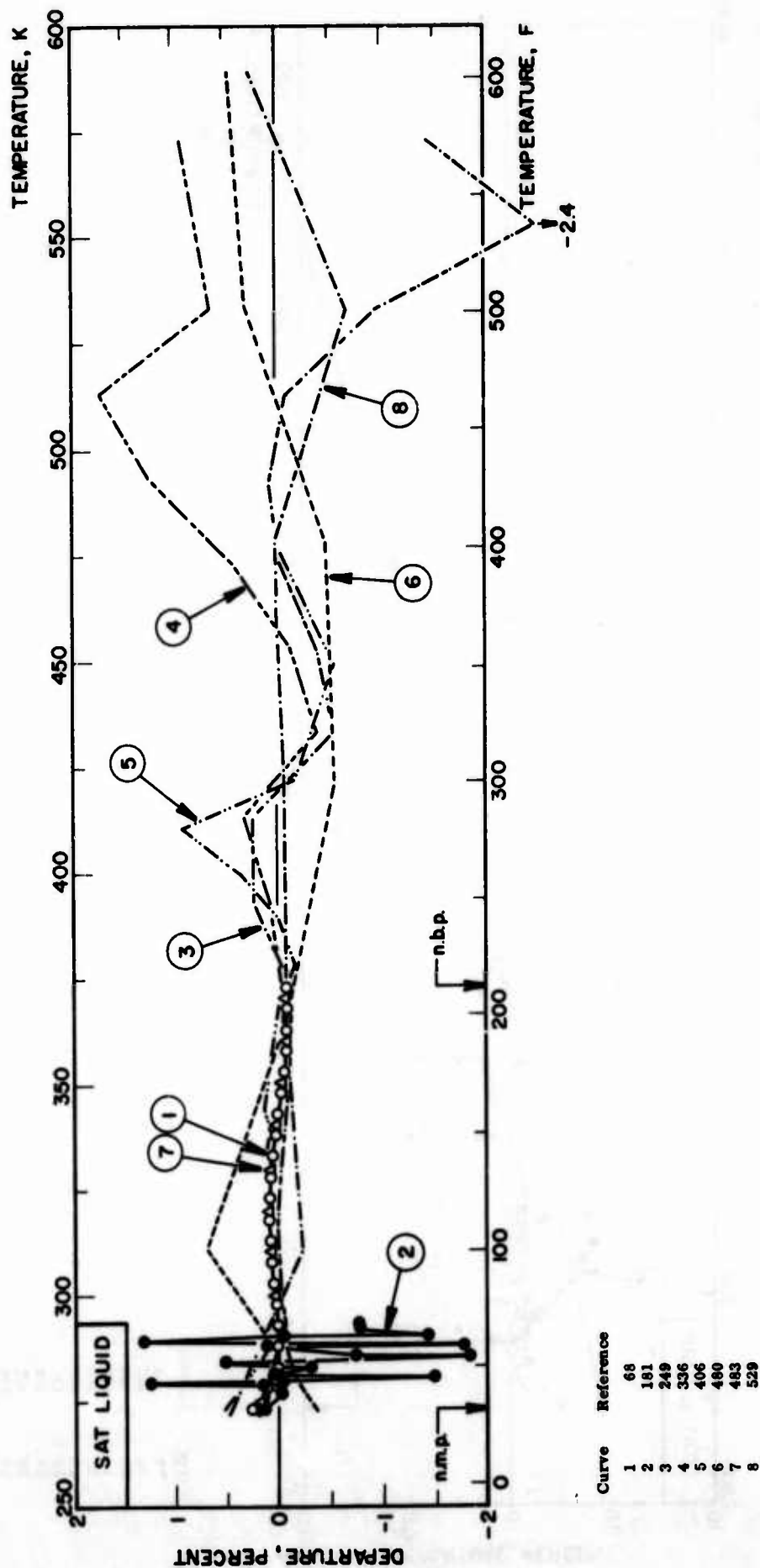


FIGURE 22 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID WATER (continued)

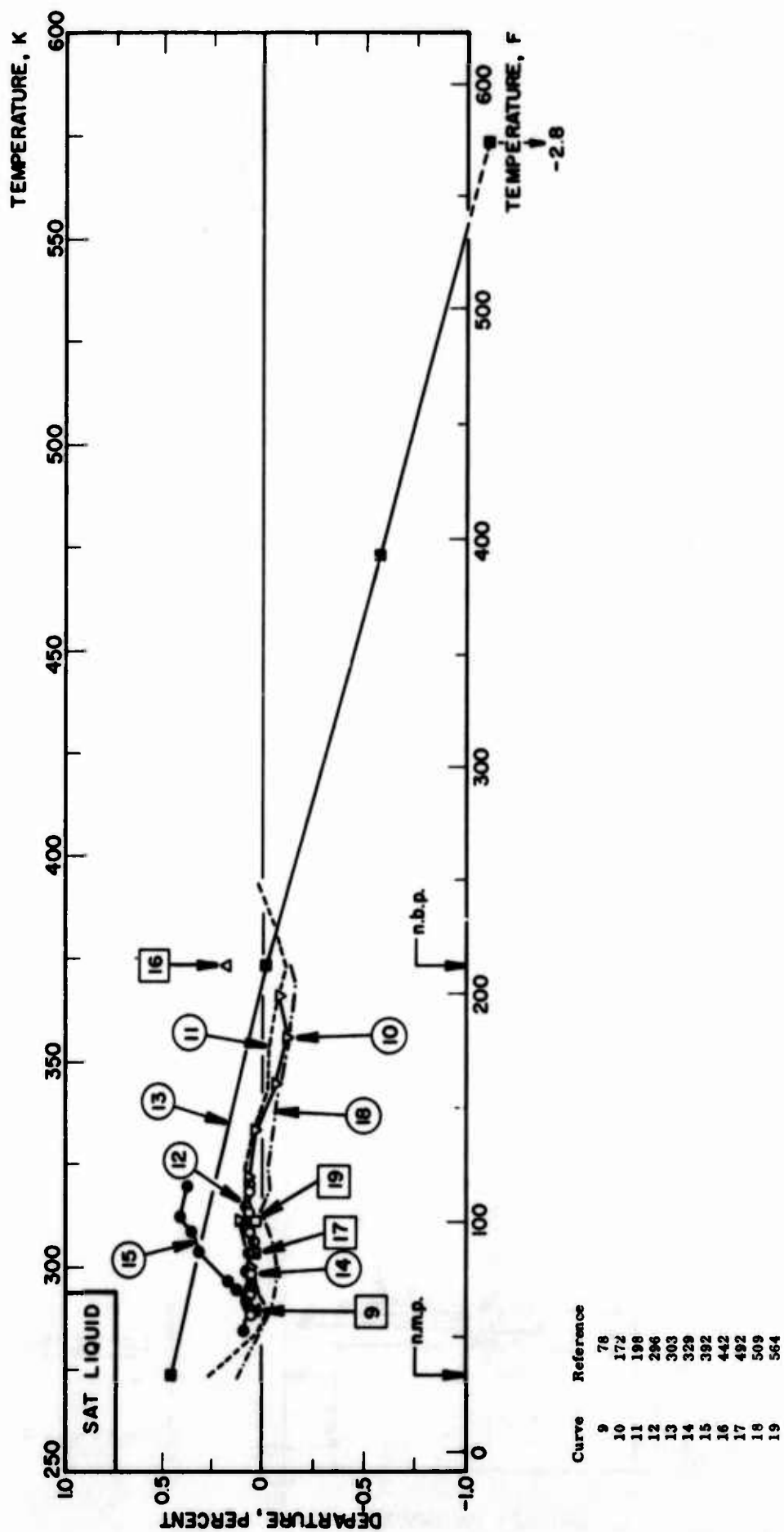


TABLE 22 SPECIFIC HEAT AT CONSTANT PRESSURE OF WATER (continued)

RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p^0 and C_p , B lb⁻¹ F⁻¹]

GAS			
T	C_p^0	C_p	T
0			700
20			720
40	0.44390		740
60	0.44456		760
80	0.44527		780
100	0.44604		800
120	0.44687		820
140	0.44775		840
160	0.44868		860
180	0.44967		880
200	0.45071		900
220	0.45180	0.4864	920
240	0.45293	0.4815	940
260	0.45411	0.4777	960
280	0.45533	0.4747	980
300	0.45659	0.4726	1000
320	0.45790	0.4712	1100
340	0.45924	0.4703	1200
360	0.46062	0.4700	1300
380	0.46204	0.4702	1400
400	0.46349	0.4706	1500
420	0.46497	0.4713	1600
440	0.46648	0.4721	1700
460	0.46802	0.4729	1800
480	0.46959	0.4736	1900
500	0.47118	0.4742	2000
520	0.47280	0.4755	
540	0.47443	0.4769	
560	0.47609	0.4784	
580	0.47777	0.4798	
600	0.47947	0.4814	
620	0.48118	0.4829	
640	0.48290	0.4844	
660	0.48464	0.4860	
680	0.48639	0.4876	

n. b. p. = 212 F

TABLE 22 SPECIFIC HEAT AT CONSTANT PRESSURE OF WATER

DISCUSSION

GAS

There exist 75 sources of information on the specific heat at constant pressure of water vapor. A number of extensive heat capacity values for the ideal gas state have been derived from spectroscopic and molecular structural data. The values presented by Gordon (72), McBride et al. (137), Fano et al. (326), Friedman and Haar (332, 333), Hilsenrath (380), McBride and Gordon (458), are considered to be reliable, as well as three compilation tables (253, 254, 575). Therefore, equal weight is given to these works in this analysis. However, other sets of extensive theoretical values (22, 59, 100, 167, 226, 325, 347, 389, 403, 513, 575) and earlier statistical calculations (24, 93, 278, 352, 353, 419, 426) are given no weight as well as a single point value obtained by empirical correlation (13). The extrapolated values to zero pressure from the calorimetric measurements (334, 459) also are not used in this correlation. The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 270 K and 800 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.452219 - 1.29224 \times 10^{-4}T + 4.17008 \times 10^{-7}T^2 - 2.00401 \times 10^{-10}T^3 \quad (1)$$

For temperatures between 800 K and 1500 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.378278 + 1.53443 \times 10^{-4}T + 3.31531 \times 10^{-7}T^2 - 1.78435 \times 10^{-10}T^3 \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.03 and 0.13 percent, and maximum deviations of 0.07 and 0.73 percent, respectively. The recommended values are generated from the above formulas. The tabulated values of C_p^0 should be substantially correct well within one percent over the entire temperature range. The percent departures of all the works mentioned above the recommended values are shown in two plots for $P = 0$. Various empirical equations (25, 196, 197, 205, 377, 420, 532) as well as a set of mean specific heat data (92), are not plotted in these figures.

On the other hand, a number of experimental and theoretical values are available for the specific heat in the real gas state. The theoretical values derived by statistical mechanics and the correction of gas imperfection have been presented by many investigators. Among them, results of Masi (132), Fano et al. (325, 326), Heck (375, 376), Keyes et al. (419), and Hilsenrath et al. (575) are considered to be reliable, as well as a set of correlated values (349). These values are given equal weight in the present analysis. Two sets of calorimetric data (425, 459) are also reliable and are given weight. However, no weight is given to the calorimetric data (162, 334), theoretical values (354), derived values from P-V-T data (303), empirical correlations (13, 18, 78, 274, 366, 555) and compilations (71, 127, 269, 529). The correlation formulas

obtained for the specific heat in the real gas state, independently of the ideal gas specific heat, are as follows:

For temperatures between 373 K and 535 K:

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 1.94480 - 8.92530 \times 10^{-5}T + 1.78830 \times 10^{-8}T^2 - 1.18442 \times 10^{-11}T^3 \quad (3)$$

For temperatures between 535 K and 1500 K:

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.443222 - 2.85391 \times 10^{-5}T + 1.98477 \times 10^{-8}T^2 - 6.63724 \times 10^{-11}T^3 \quad (T \text{ in K}) \quad (4)$$

These equations are found to fit the above enumerated values with mean deviations of 0.46 and 0.43 percent, and maximum deviations of 1.4 and 1.9 percent, respectively. The recommended values of C_p are generated from the above formulas. The tabulated values should be substantially correct within two percent over the entire temperature range. Equations (3) and (4) are used to calculate the departure percents of all the values mentioned above in the real gas state, which are shown in the departure plots for $P = 1$ atm. Various empirical equations (184, 185, 275, 346, 528), values at higher temperatures (270, 456, 559, 563) and at lower temperatures (48), and high pressure data (418, 518, 523) are not plotted in these figures.

The comparison of Equations (3) and (4) with Equations (1) and (2) is also given in the last plot.

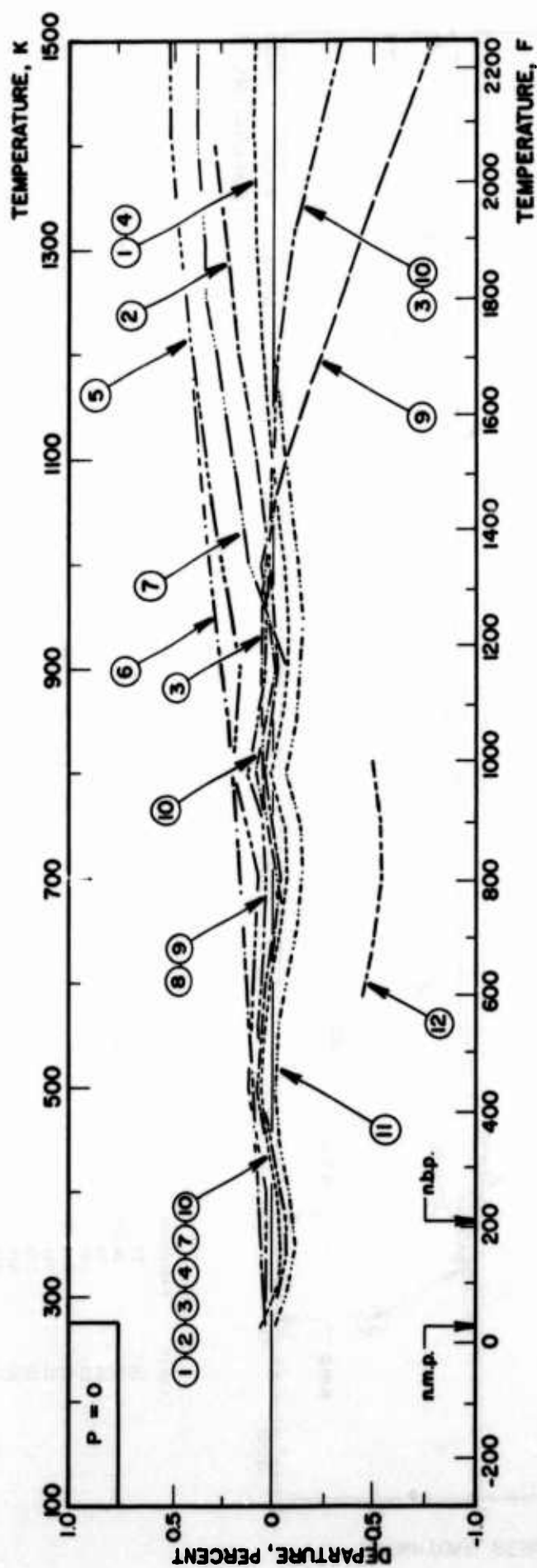
TABLE 22 SPECIFIC HEAT AT CONSTANT PRESSURE OF WATER(continued)

RECOMMENDED VALUES
[Temperature, T, F; Specific Heat, C_p^0 and C_p , B lb⁻¹ F⁻¹]

GAS					
T	C _p ⁰	C _p	T	C _p ⁰	C _p
0			700	0.48814	0.4891
20			720	0.48991	0.4908
40	0.44390		740	0.49168	0.4924
60	0.44456		760	0.49345	0.4940
80	0.44527		780	0.49523	0.4957
100	0.44604		800	0.49700	0.4974
120	0.44687		820	0.49878	0.4991
140	0.44775		840	0.50055	0.5008
160	0.44868		860	0.50232	0.5025
180	0.44967		880	0.50409	0.5042
200	0.45071		900	0.50584	0.5060
220	0.45180	0.4864	920	0.50759	0.5077
240	0.45293	0.4815	940	0.50932	0.5095
260	0.45411	0.4777	960	0.51105	0.5113
280	0.45533	0.4747	980	0.51276	0.5131
300	0.45659	0.4726	1000	0.51466	0.5149
320	0.45790	0.4712	1100	0.52417	0.5240
340	0.45924	0.4703	1200	0.53361	0.5333
360	0.46062	0.4700	1300	0.55294	0.5426
380	0.46204	0.4702	1400	0.55216	0.5520
400	0.46349	0.4706	1500	0.56124	0.5614
420	0.46497	0.4713	1600	0.57016	0.5706
440	0.46648	0.4721	1700	0.57891	0.5797
460	0.46802	0.4729	1800	0.58747	0.5885
480	0.46959	0.4736	1900	0.59582	0.5970
500	0.47118	0.4742	2000	0.60394	0.6051
520	0.47280	0.4755			
540	0.47443	0.4769			
560	0.47609	0.4784			
580	0.47777	0.4798			
600	0.47947	0.4814			
620	0.48118	0.4829			
640	0.48290	0.4844			
660	0.48464	0.4860			
680	0.48639	0.4876			

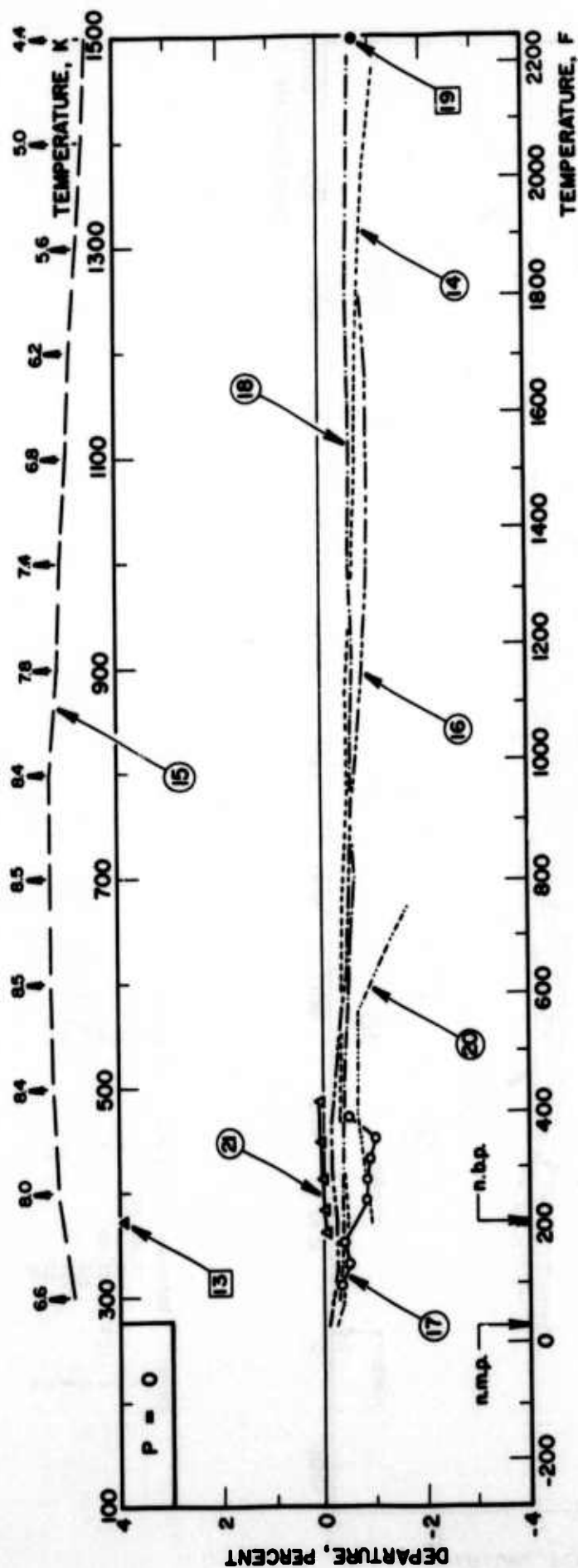
n.b.p. = 212 F

FIGURE 22 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS WATER



Curve	Reference	Curve	Reference
1	72, 326, 332,	7	167, 226
2	333, 390, 575	8	325
3	137, 458	9	347
4	253	10	389, 403, 426
5	254	11	513
6	22	12	573
	59		

FIGURE 22 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS WATER (continued)



Curve	Reference
13	13
14	24, 278
15	93
16	100
17	334
18	352
19	353
20	419
21	459

FIGURE 22 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS WATER

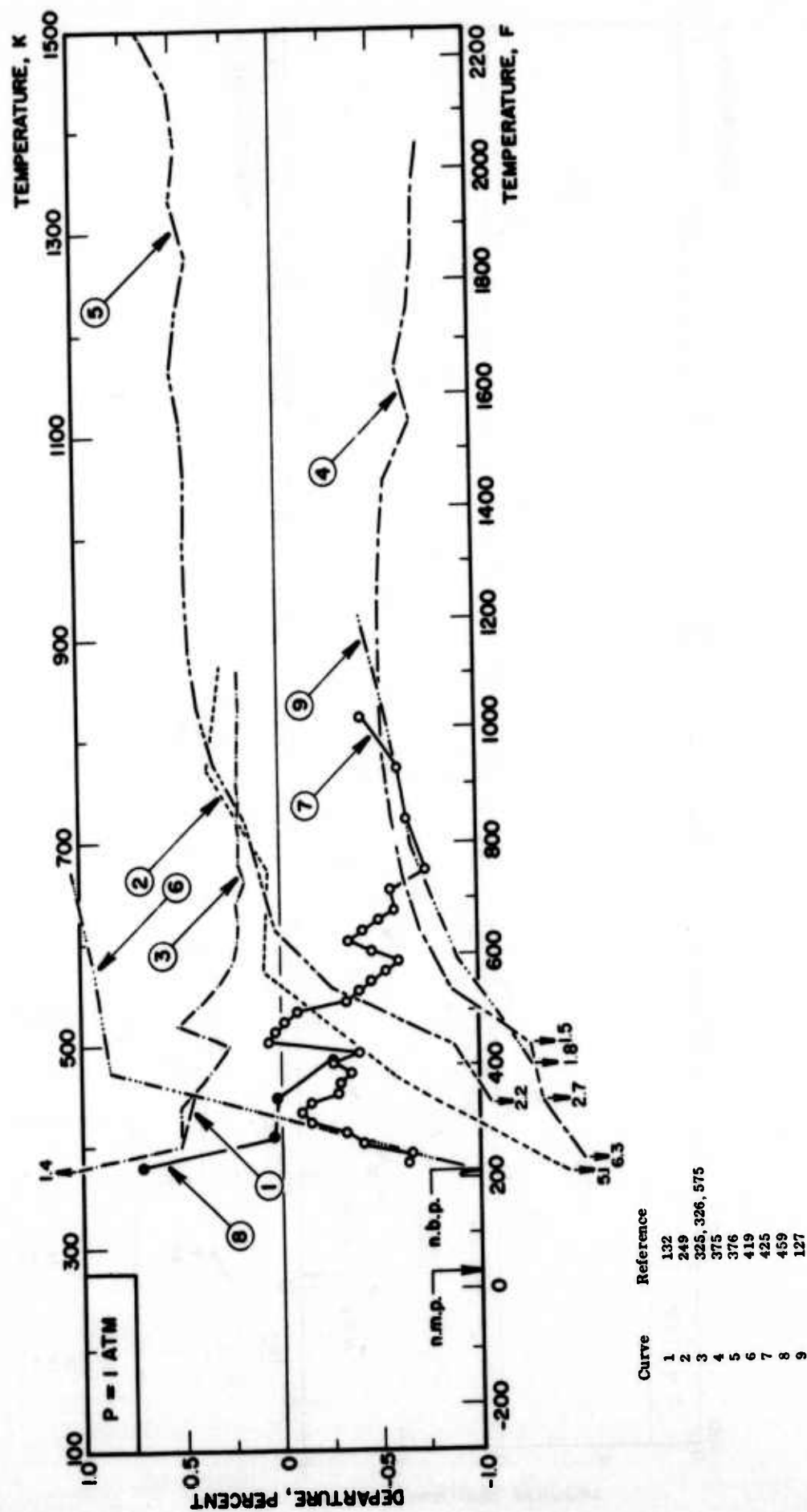


FIGURE 22 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS WATER (continued)

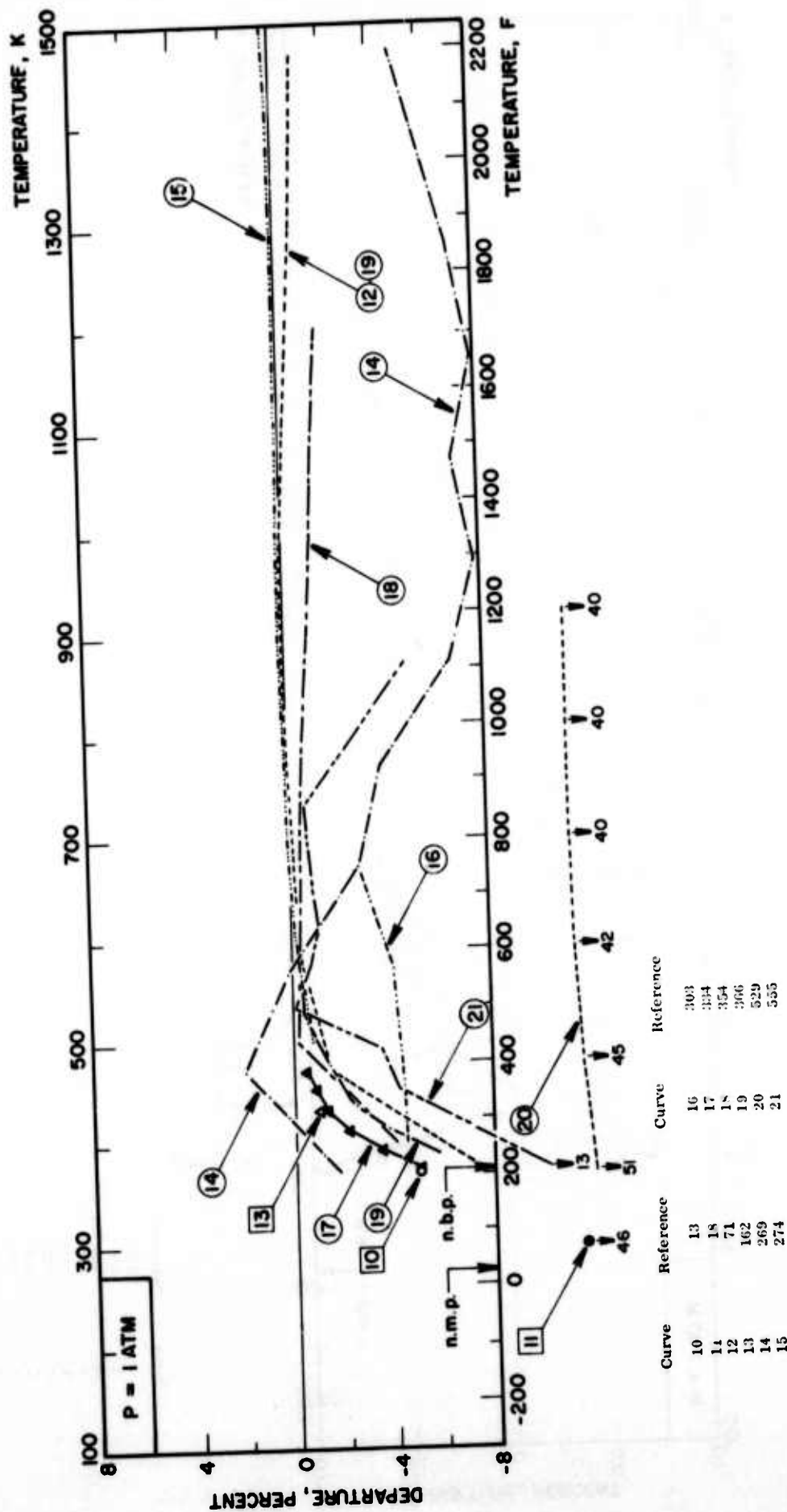


FIGURE 22 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS WATER

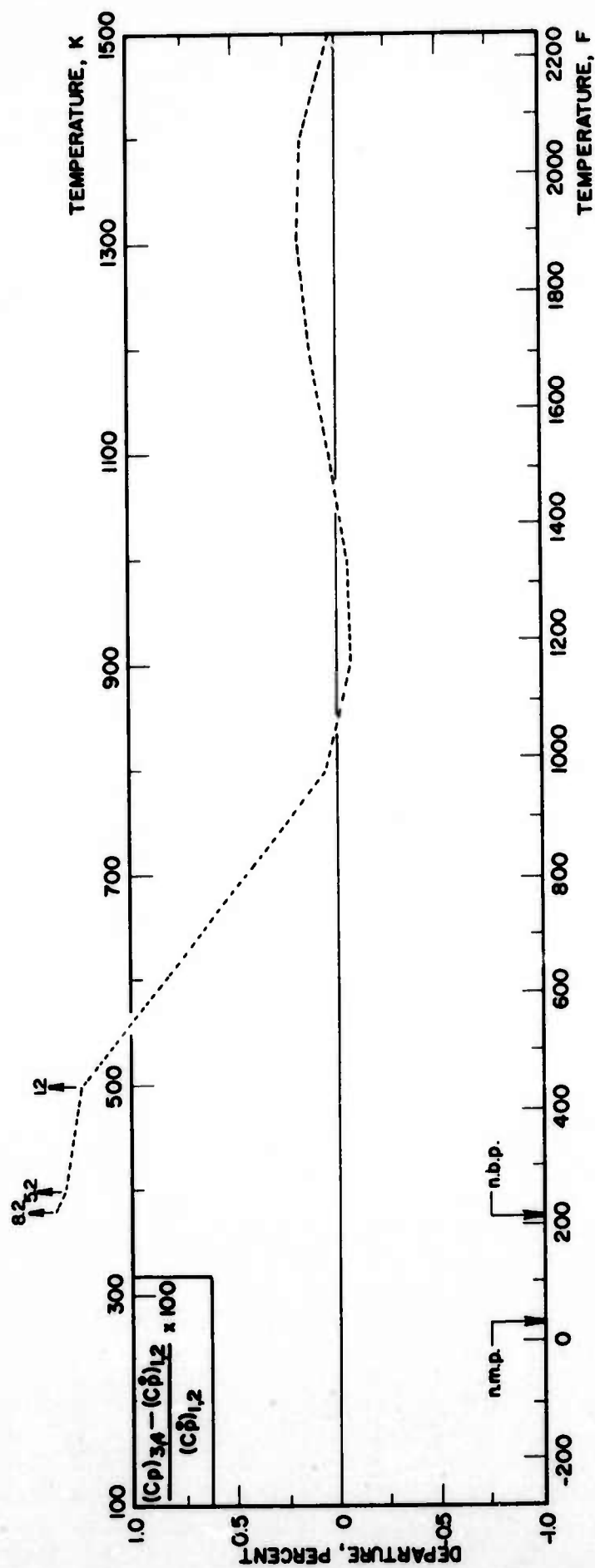


TABLE 23 SPECIFIC HEAT AT CONSTANT PRESSURE OF ACETONE

DISCUSSION

LIQUID

Nine sources of information are available for the specific heat at constant pressure of liquid acetone. The latest experimental measurements were made by Staveley et al. (199), using an adiabatic calorimeter within an error of one percent. His data covering the temperature range from 287 K to 324 K are considered to be the most reliable. Early calorimetric data of Kelley (244) at temperatures from 180 to 297 K and Mitsuhashi and Hara (143) between 204 and 256 K are also reliable from the standpoint of their experimental procedures. Therefore, equal weight is given to the three sets of data in this analysis. No weight is given to the derived or correlated values (23, 36, 216), as well as a single-point experimental observation (215).

The correlation formula obtained for the temperature range between 180 K and 324 K is

$$C_p (\text{cal g}^{-1} \text{K}^{-1}) = 0.839890 - 4.60183 \times 10^{-3} T + 1.82400 \times 10^{-4} T^2 - 2.11716 \times 10^{-6} T^3$$

(T in K).

This equation is found to fit the 58 data points enumerated above with a mean deviation of 0.8 percent and a maximum of 2.7 percent.

The recommended values are computed by the above formula. The tabulated values between the n. m. p. and the n. b. p. should be correct within two percent. In the departure plot, two sets of cited data (63, 186) are not shown.

RECOMMENDED VALUES
[Temperature, T, F; Specific Heat, C_p , B lb⁻¹ F⁻¹]
LIQUID

T	C_p
-140	0.4790 [†]
-120	0.4784
-100	0.4794
-80	0.4817
-60	0.4853
-40	0.4898
-20	0.4952
0	0.5013
20	0.5079
40	0.5148
60	0.5218
80	0.5288
100	0.5357
120	0.5421

[†]Extrapolated for the liquid phase ignoring pressure dependence (n. m. p. = -139 F).

FIGURE 23 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID ACETONE

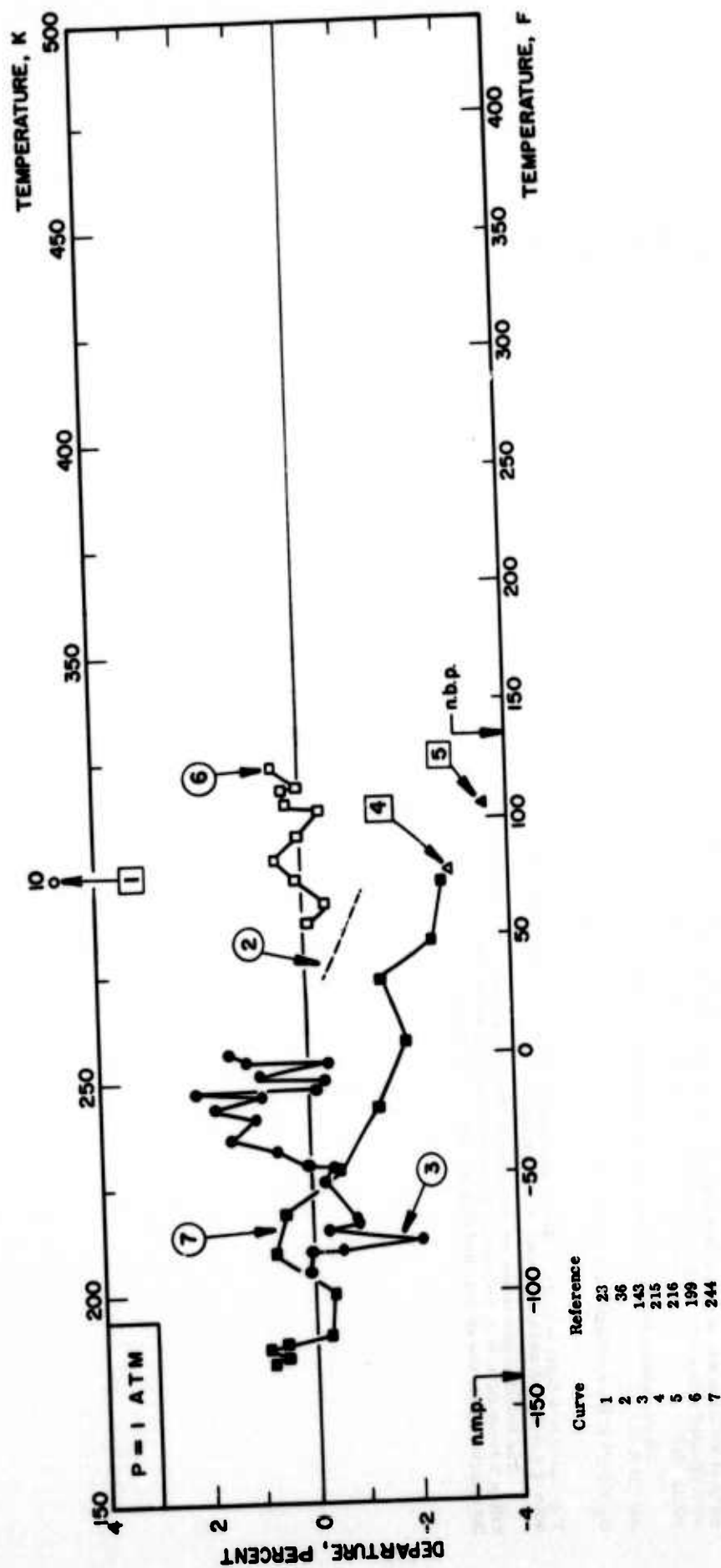


TABLE 23 SPECIFIC HEAT AT CONSTANT PRESSURE OF ACETONE (continued)

DISCUSSION			RECOMMENDED VALUES		
GAS			[Temperature, T, F; Specific Heat, C _p , B lb ⁻¹ F ⁻¹]		
T	C _p ^a	T	C _p ^a	T	C _p ^a
40	0.2961*	600	0.5033		
60	0.3046*	620	0.5095		
80	0.3129*	640	0.5156		
100	0.3213*	660	0.5215		
120	0.3295*	680	0.5274		
140	0.3377	700	0.5332		
160	0.3458	720	0.5389		
180	0.3538	740	0.5445		
200	0.3617	760	0.5500		
220	0.3696	780	0.5554		
240	0.3774	800	0.5607		
260	0.3851	820	0.5659		
280	0.3927	840	0.5710		
300	0.4003	860	0.5760		
320	0.4077	880	0.5808		
340	0.4151	900	0.5856		
360	0.4224	920	0.5903		
380	0.4296	940	0.5949		
400	0.4368	960	0.5994		
420	0.4438	980	0.6038		
440	0.4508	1000	0.6085		
460	0.4577	1100	0.6291		
480	0.4645	1200	0.6485		
500	0.4712	1300	0.6667		
520	0.4778	1400	0.6837		
540	0.4843	1500	0.6995		
560	0.4907	1600	0.7142		
580	0.4971	1700	0.7278		
		1800	0.7403		
		1900	0.7517		
		2000	0.7622		

*n.b.p. = 133 F

GAS

A number of extensive heat capacity values for the ideal gas state have been derived from spectroscopic and molecular structural data. The values of Kobe and Harrison (106) and of Pennington and Kobe (157, 158), who also took into consideration their experimental results, are thought to be the most reliable, although the discrepancy between them is found to be substantial at temperatures below 1000 K. In the present analysis, equal weight is given to both works. Two sets of earlier statistical values (48, 105) are given no weight. The correlation formulas obtained for the ideal gas specific heat between 273 K and 1500 K is as follows:

$$C_p^0 (\text{cal g}^{-1} \text{K}^{-1}) = 6.33525 \times 10^{-3} + 9.05719 \times 10^{-4} T - 2.14992 \times 10^{-7} T^2 - 9.00590 \times 10^{-11} T^3 \quad (T \text{ in K}),$$

and for the temperature range between 500 K and 1500 K:

$$C_p^0 (\text{cal g}^{-1} \text{K}^{-1}) = 0.144995 + 7.79868 \times 10^{-4} T - 2.80143 \times 10^{-7} T^2 + 2.84348 \times 10^{-11} T^3 \quad (T \text{ in K}).$$

These equations are found to fit the above referenced values with a mean deviation of 1.0 and 0.2 percent and a maximum of 1.7 and 0.5 percent, respectively. The above formulas are used to compute the recommended values, which should be substantially correct within two percent at temperatures below 1000 K. The tabulated values above 1000 K should be correct within one percent. Spencer (196) presented two empirical equations for the ideal gas heat capacity. However, these results, as well as three other sets of cited values (78, 216, 236), are not given in the departure plot.

Several experimental works are also available for the specific heat in the real gas state. Collins et al. (38) reported the calorimetric measurements at temperatures from 333 K to 438 K with the error of one percent. Pennington and Kobe (157, 158) used a flow calorimeter having a reported accuracy of 99.8 percent and covered the temperature range between 338 K and 439 K. Another flow-calorimetric work was reported by Bennowitz and Rosner (15) at 410 K with a reported error of 0.6 percent. Jalkar (89) also derived specific heat values through measurements of the velocity of sound at temperatures from 341 K to 454 K. Empirical values (18) were also obtained at 293 K by the additive scheme. Since the discrepancy among these results is considerable no correction is made for the real gas specific heat.

FIGURE 23 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS ACETONE

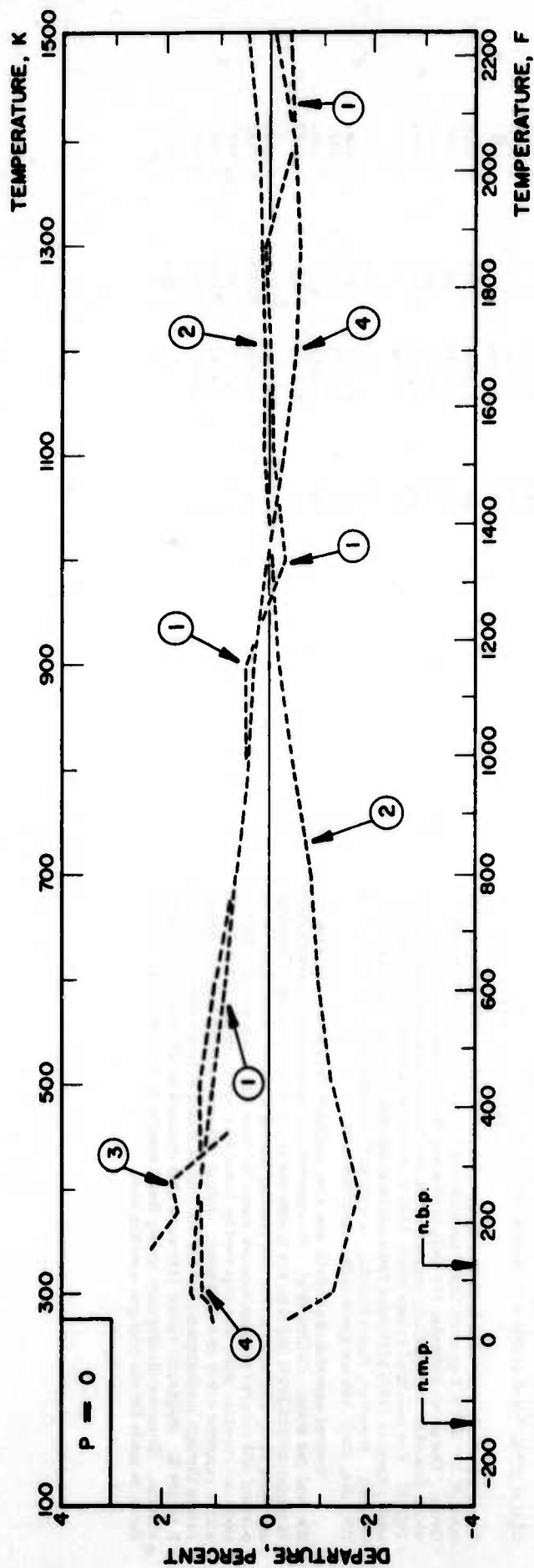


TABLE 24 SPECIFIC HEAT AT CONSTANT PRESSURE OF ACETYLENE

DISCUSSION

GAS

There exist 25 sources of information available on the specific heat at constant pressure of gaseous acetylene. A number of tabulations of the ideal gas state have been presented based on statistical calculations from the spectroscopic data. The values presented by Kobe and Long (111), McBride et al. (137), Ribaud (167), Rossini et al. (171), Sinke (192) and Wagman et al. (227) are considered to be reliable from the viewpoint of the molecular data used, as well as several compiled tables (59, 72, 253, 255). Among them, the recent work of McBride et al. (137) gives somewhat higher values with increasing temperature. However, in the present analysis, equal weight is given to the above enumerated works. No weight is given to early statistical calculations (93, 203, 222), as well as a single point value empirically derived (18). The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 273 K and 750 K:

$$C_p^0 \text{ (cal } g^{-1}K^{-1}) = 0.0956720 + 1.48788 \times 10^{-3}T - 1.77657 \times 10^{-6}T^2 + 8.36237 \times 10^{-10}T^3 \quad (1)$$

For temperatures between 750 K and 1500 K:

$$C_p^0 \text{ (cal } g^{-1}K^{-1}) = 0.312637 + 4.64654 \times 10^{-4}T - 1.98142 \times 10^{-7}T^2 + 3.62564 \times 10^{-11}T^3 \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.42 and 1.0 percent and maximum ones of 1.5 and 2.5 percent, respectively. The recommended values are computed using the above formulas. The tabulated values should be substantially correct within 2.5 percent. In the departure plot at $P = 0$, all the above mentioned works are compared with the above formulas. Although several polynomial equations for the ideal heat capacity have been reported (25, 47, 194, 195, 197), these equations are not shown in the departure plot, as well as two sets of cited values (210, 236).

On the other hand, no calorimetric data are found in the literature. The values for the specific heat at the real gas state were derived by means of equations of state (14, 202) and empirical correlations (78, 251). Among them, two sets of values (14, 251), covering temperatures from 160 K to 573 K, are fitted to the following formula:

$$C_p \text{ (cal } g^{-1}K^{-1}) = 0.260749 + 2.53184 \times 10^{-4}T + 1.25051 \times 10^{-6}T^2 - 1.53877 \times 10^{-9}T^3 \quad (3)$$

In the departure plot at $P = 1$ atm, the values at the real gas state are compared with the above formula. Furthermore, the comparison between Equation (3) and Equation (1) is given in the third departure plot of $[C_p]_3 - (C_p)_1/(C_p)_1$ over the common temperature range.

RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p , B lb⁻¹ F⁻¹]

GAS

T	C_p^0	T	C_p^0
40	0.3894	700	0.5401
60	0.3970	720	0.5428
80	0.4043	740	0.5454
100	0.4114	760	0.5480
120	0.4182	780	0.5505
140	0.4248	800	0.5531
160	0.4312	820	0.5556
180	0.4373	840	0.5582
200	0.4432	860	0.5608
220	0.4489	880	0.5633
240	0.4544	900	0.5659
260	0.4597	920	0.5684
280	0.4648	940	0.5709
300	0.4697	960	0.5733
320	0.4745	980	0.5757
340	0.4791	1000	0.5781
360	0.4835	1100	0.5897
380	0.4877	1200	0.6007
400	0.4918	1300	0.6110
420	0.4958	1400	0.6208
440	0.4996	1500	0.6301
460	0.5033	1600	0.6389
480	0.5069	1700	0.6472
500	0.5103	1800	0.6551
520	0.5137	1900	0.6626
540	0.5169	2000	0.6698
560	0.5201		
580	0.5232		
600	0.5262		
620	0.5291		
640	0.5319		
660	0.5347		
680	0.5374		

FIGURE 24 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS ACETYLENE

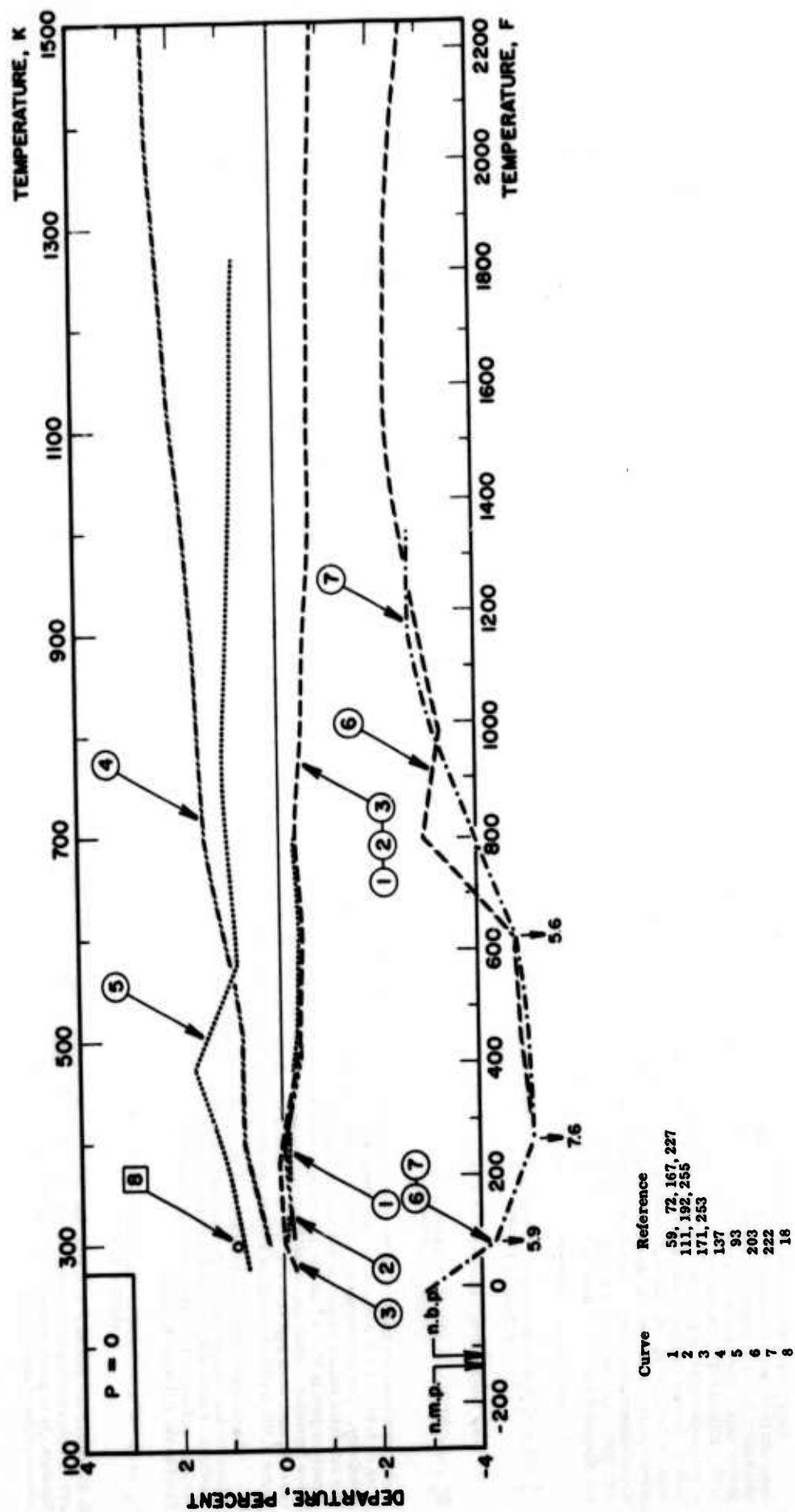


FIGURE 24 DEPARTURE FROM IDEALITY FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS ACETYLENE

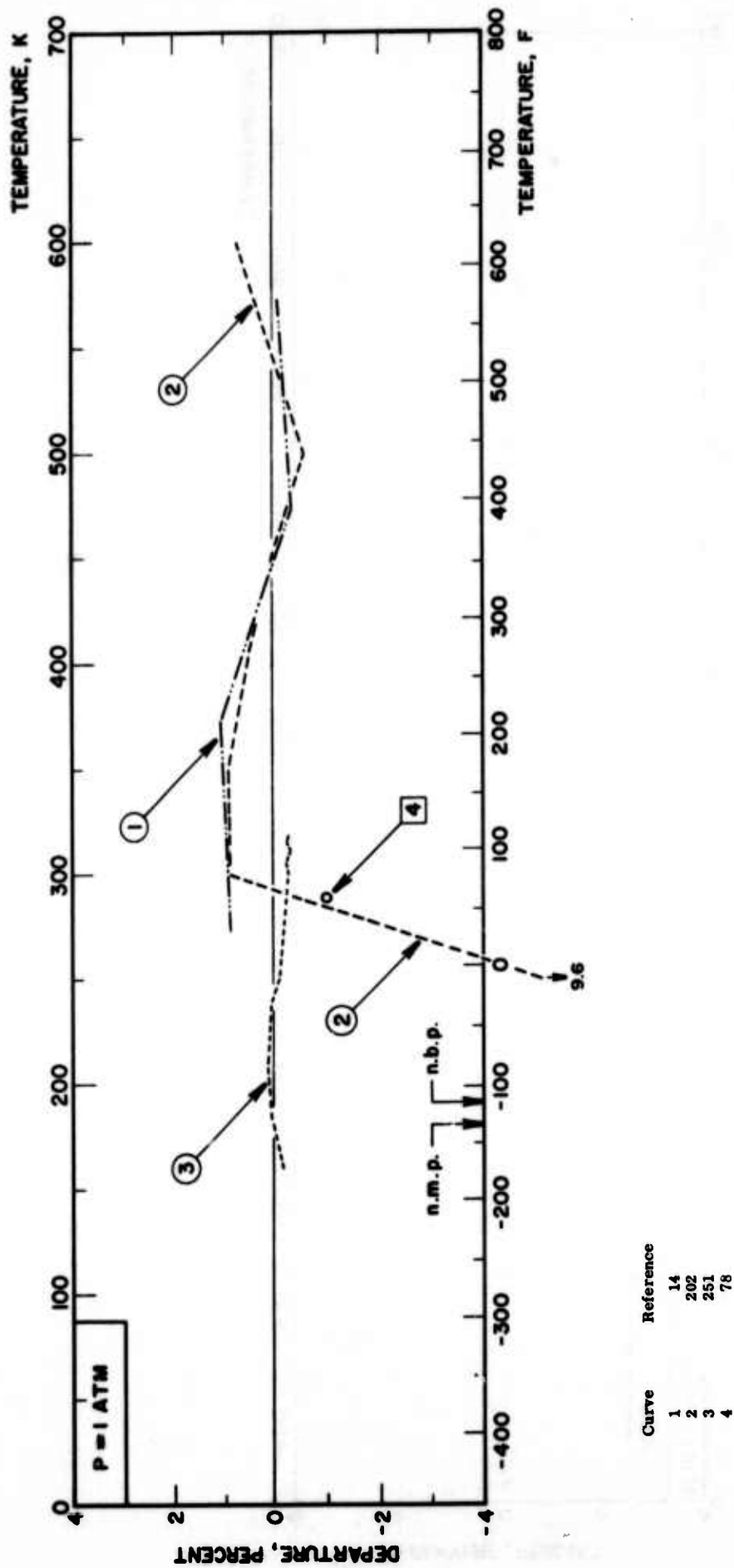


FIGURE 24 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS ACETYLENE

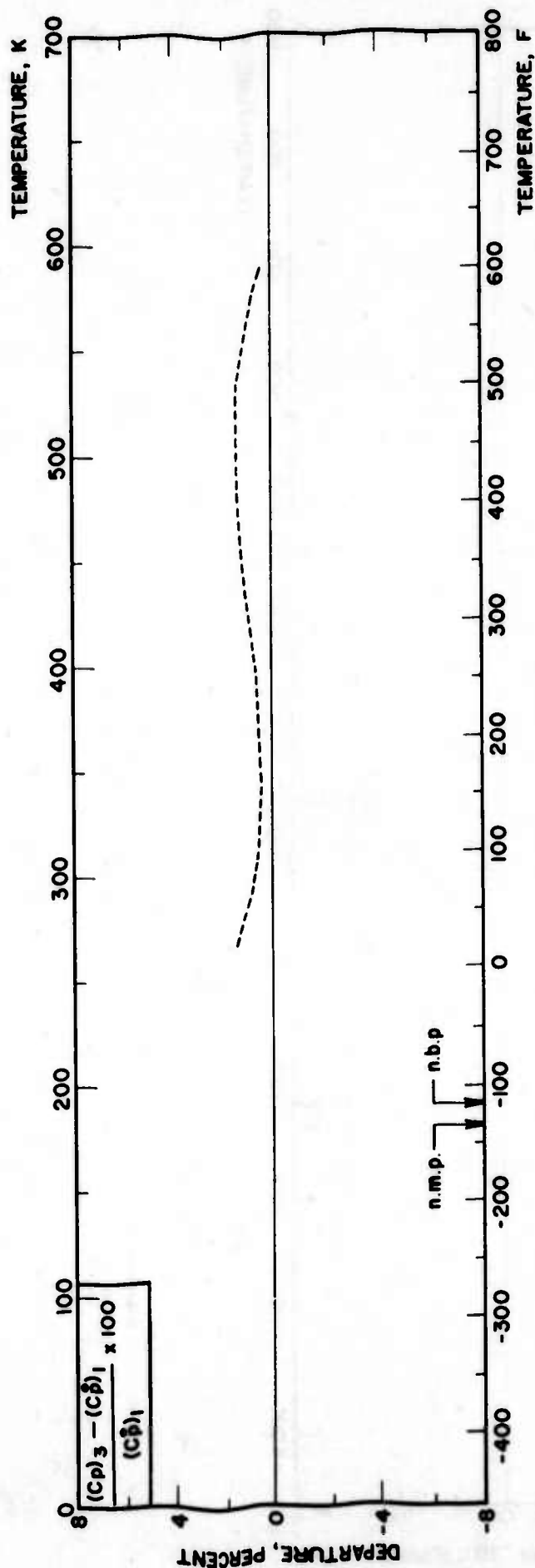


TABLE 25 SPECIFIC HEAT AT CONSTANT PRESSURE OF BENZENE

DISCUSSION

LIQUID

A number of experimental works are available for the constant pressure specific heat of liquid benzene, covering the temperature range between the n. m. p. and the n. b. p. The latest calorimetric measurement was made by Alwood (9), who used 99.96 mole percent benzene and reported that the standard deviation of his results was one percent. Oliver et al. (148) measured the specific heat by an adiabatic calorimeter with a reported error of 0.2 percent. The agreement between them is found to be excellent. The data of Burlew (31) obtained by a piezo-thermometric method show a slightly steeper change with temperature than those of (9). The results reported by Slaveley et al. (199), with an experimental error of one percent, are found to be slightly lower than those of (9) in the middle of the temperature range. The earlier careful determination of Flock et al. (62) consists of only one experimental data point at the saturated vapor pressure beyond the n. b. p. These five sets of data are considered to be reliable from the view point of the experimental methods and procedures, and are given equal weight in this analysis. Although Williams and Daniels (232) found a minimum near 293 K, indicating a change in molecular structure of the liquid, the recent results give no indication of such a minimum. Therefore no weight is given to their work. The earlier experimental works (60, 96, 115, 117, 168, 200, 201, 231, 237), the single point data (190, 238) and two sets of empirically calculated values (36, 216) are given no weight in this correlation.

The correlation formula obtained for the temperature range between 278 K and 383 K is

$$C_p(\text{cal g}^{-1} \text{K}^{-1}) = 0.283708 + 2.75787 \times 10^{-4}T + 2.34387 \times 10^{-7}T^2 + 1.06981 \times 10^{-9}T^3$$

(T in K).

This equation is found to fit the 96 data points selected with a mean deviation of 0.3 percent and a maximum of 1.4 percent.

The recommended values are generated by the above equation. The tabulated values between the n. m. p. and the n. b. p. should be correct within one percent, and above the n. b. p. the uncertainty would increase. Five additional sets of data (21, 63, 77, 188, 221) are not represented in the departure plot.

RECOMMENDED VALUES
[Temperature, T, °F; Specific Heat, C_p , B lb⁻¹ F⁻¹]
LIQUID

T	C_p
40	0.4009 [†]
60	0.4083
80	0.4160
100	0.4240
120	0.4323
140	0.4409
160	0.4498
180	0.4590 [‡]
200	0.469 [‡]
220	0.479 [‡]
240	0.489 [‡]
260	0.499 [‡]

[†]Extrapolated for the liquid phase ignoring pressure dependence (n. m. p. = 42 °F)

[‡]n. b. p. = 176 °F

FIGURE 25 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID BENZENE

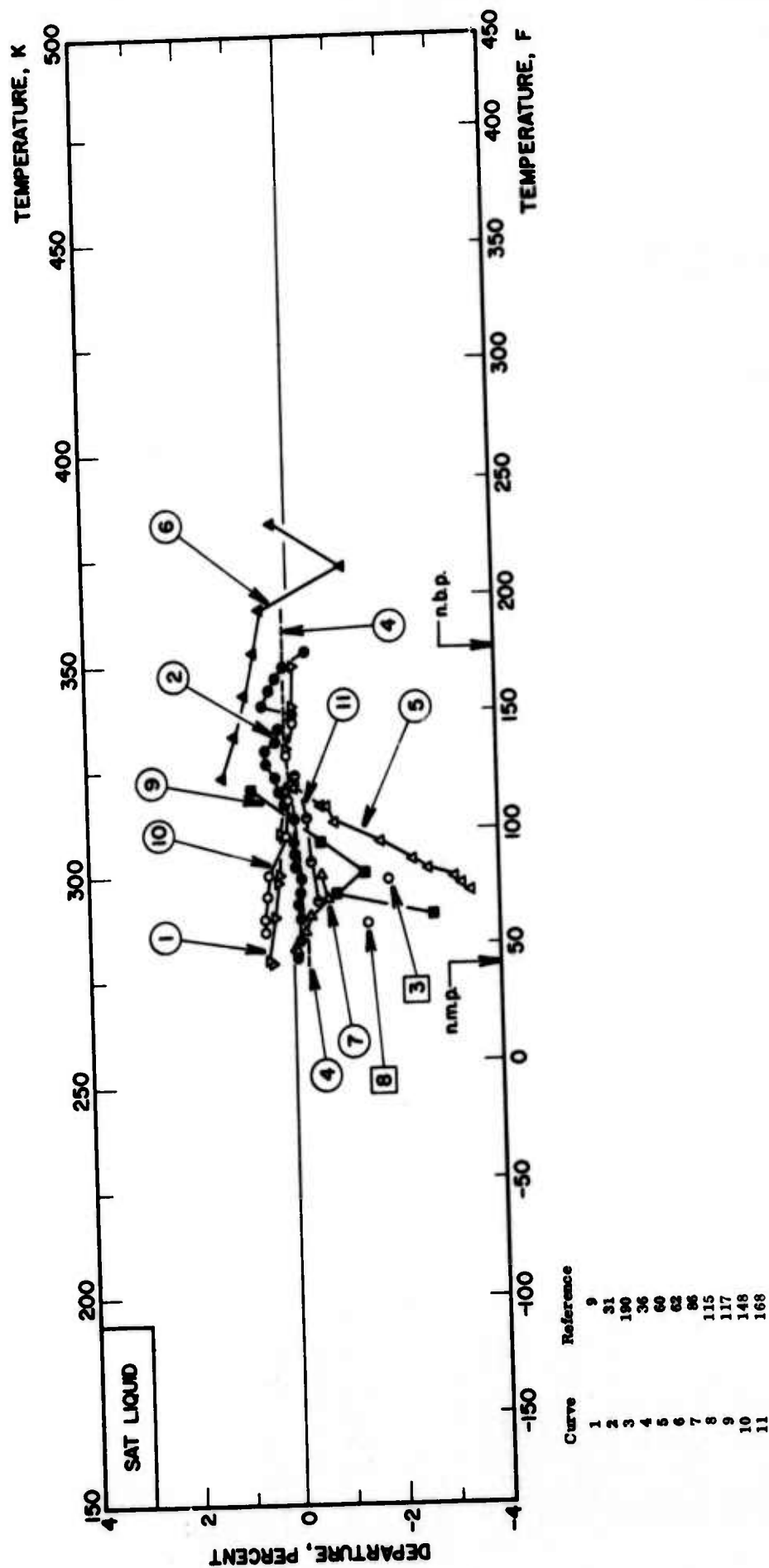


FIGURE 25 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID BENZENE

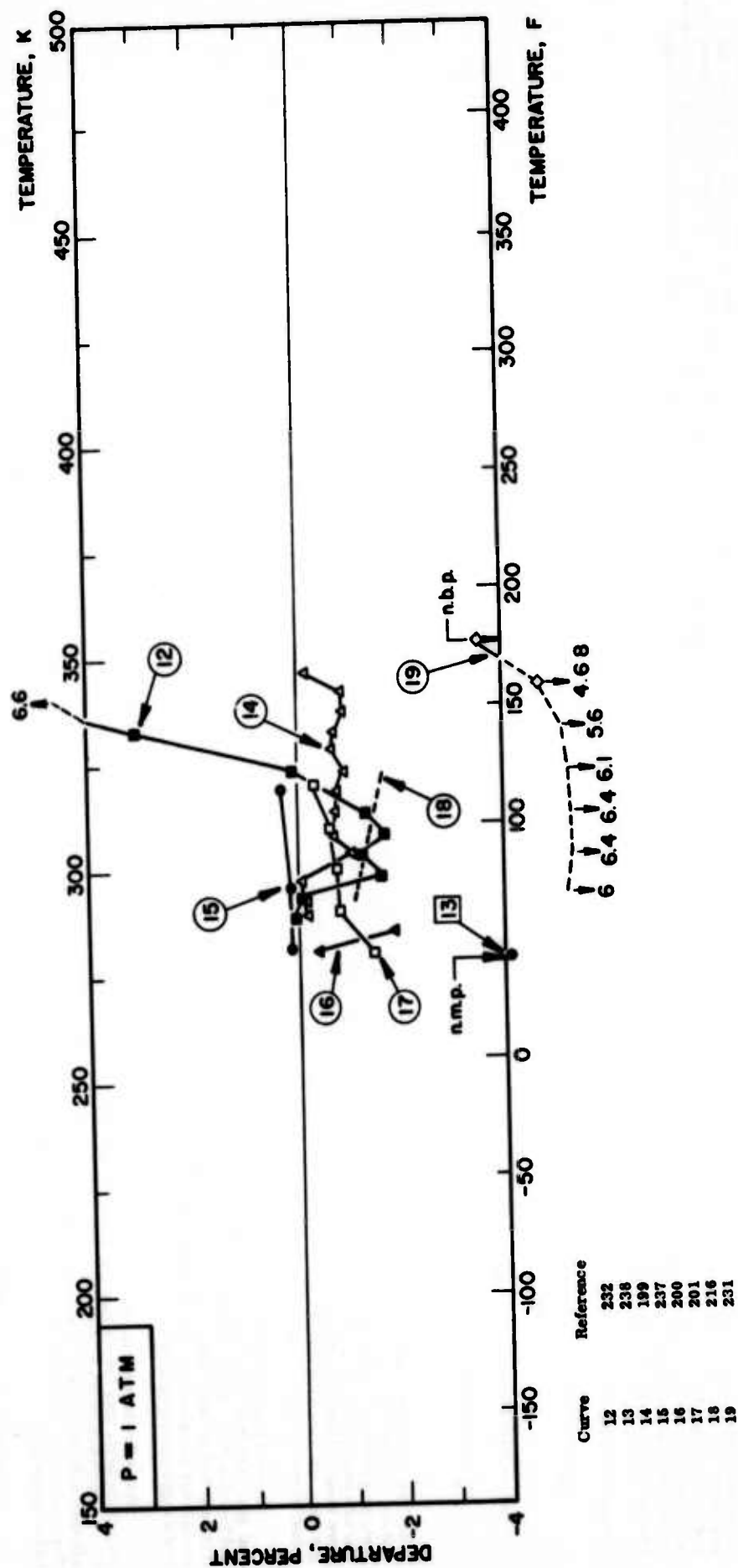


TABLE 25 SPECIFIC HEAT AT CONSTANT PRESSURE OF BENZENE

DISCUSSION

GAS

There exist 31 sources of information on the isobaric specific heat of gaseous benzene. Among a number of extensive calculations for the ideal gas state, derived from spectroscopic and molecular structural data, the results of Brickwedde et al. (22), Faltin (59), Kobe and Long (110), Ribaud (167), Rossini et al. (171, 253), and Taylor (208), are found to agree well with each other and are considered to be reliable. Therefore, equal weight is given to these values in the present analysis. Several sets of early statistical calculations (24, 92, 202, 222), as well as the results of empirical calculations (13, 18), are given no weight. The correlation formulas obtained for the ideal gas state are as follows:

For temperatures between 273 K and 770 K:

$$C_p^i (\text{cal g}^{-1} \text{K}^{-1}) = -0.115011 + 1.49459 \times 10^{-3} T - 9.26795 \times 10^{-7} T^2 + 1.89526 \times 10^{-10} T^3 \quad (T \text{ in K}), (1)$$

For temperatures between 770 K and 1500 K:

$$C_p^i (\text{cal g}^{-1} \text{K}^{-1}) = 0.0510547 + 1.00015 \times 10^{-3} T - 5.04836 \times 10^{-7} T^2 + 9.57398 \times 10^{-11} T^3 \quad (T \text{ in K}), (2)$$

These two equations are found to fit the above enumerated values with mean deviations of 0.14 and 0.04 percent, and maximum deviations of 0.68 and 0.47 percent, respectively. The recommended values are generated by the above formulas. The tabulated values should be accurate within one percent over the entire temperature range. In the departure plot at $P = 0$, all the reported values at the ideal gas state are compared with the above formulas. The empirical equations obtained by Spencer et al. (195, 196) are not shown in this figure.

Several experimental works are also available for the specific heat of the real gas. The flow-calorimetric data of Eucken and Sarstedt (58), Montgomery and DeVries (145), Pitzer and Scott (165), Scott et al. (186), Sinke and DeVries (191) and Welner and Pitzer (229), and the single data point obtained from compressibility measurement (85) are considered to be reliable from the viewpoint of the experimental procedures used.

Since the theoretical values for the ideal gas state are more reliable than the calorimetric data for the real gas state, the specific heat for the real gas state, C_p^r , is computed from the ideal gas values, C_p^i , using known thermodynamic relations together with the Berthelot's equation of state which corrects for gas imperfection. The resulting C_p^r values for the temperatures range 300 K to 610 K are fitted to the following equation:

$$C_p^r (\text{cal g}^{-1} \text{K}^{-1}) = -0.0518635 + 1.15983 \times 10^{-3} T - 3.44023 \times 10^{-6} T^2 - 1.67132 \times 10^{-10} T^3 \quad (T \text{ in K}), (3)$$

The recommended values of C_p^i are calculated from the above formula. The calorimetric data mentioned above (58, 85, 145, 165, 186, 191, 229), as well as the earlier calorimetric data (15) and derived values from the velocity of sound (46, 89) and several sets of compiled values (48, 65, 78, 202, 216) are compared with Equation (3) in the departure plot for $P = 1$ atm. In the third departure plot, C_p^i given by Equation (3) is compared with C_p^r given by Equation (1) over their common temperature range.

TABLE 25 SPECIFIC HEAT AT CONSTANT PRESSURE OF BENZENE (continued)

RECOMMENDED VALUES
[Temperature, T, F; Specific Heat, C_p , B lb⁻¹F⁻¹]

T	GAS		T	C_p
	C_p	C_p		
40	0.2296		700	0.5071
60	0.2408		720	0.5129
80	0.2517	0.260	740	0.5185
100	0.2625	0.270	760	0.5240
120	0.2731	0.280	780	0.5294
140	0.2835	0.290	800	0.5347
160	0.2938	0.300	820	0.5398
180	0.3038	0.309	840	0.5447
200	0.3137	0.319	860	0.5496
220	0.3234	0.328	880	0.5543
240	0.3329	0.337	900	0.5589
260	0.3423	0.346	920	0.5634
280	0.3515	0.355	940	0.5682
300	0.3605	0.364	960	0.5724
320	0.3693	0.372	980	0.5767
340	0.3780	0.381	1000	0.5808
360	0.3865	0.389	1100	0.6005
380	0.3948	0.397	1200	0.6187
400	0.4030	0.405	1300	0.6354
420	0.4110	0.413	1400	0.6506
440	0.4189	0.421	1500	0.6647
460	0.4266	0.428	1600	0.6775
480	0.4341	0.436	1700	0.6892
500	0.4415	0.443	1800	0.7000
520	0.4487	0.450	1900	0.7098
540	0.4558	0.457	2000	0.7189
560	0.4627	0.464		
580	0.4695	0.471		
600	0.4761	0.477		
620	0.4826	0.484		
640	0.4890			
660	0.4952			
680	0.5012			

n.m.p. = 42 F
n.b.p. = 176 F

FIGURE 25 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS BENZENE

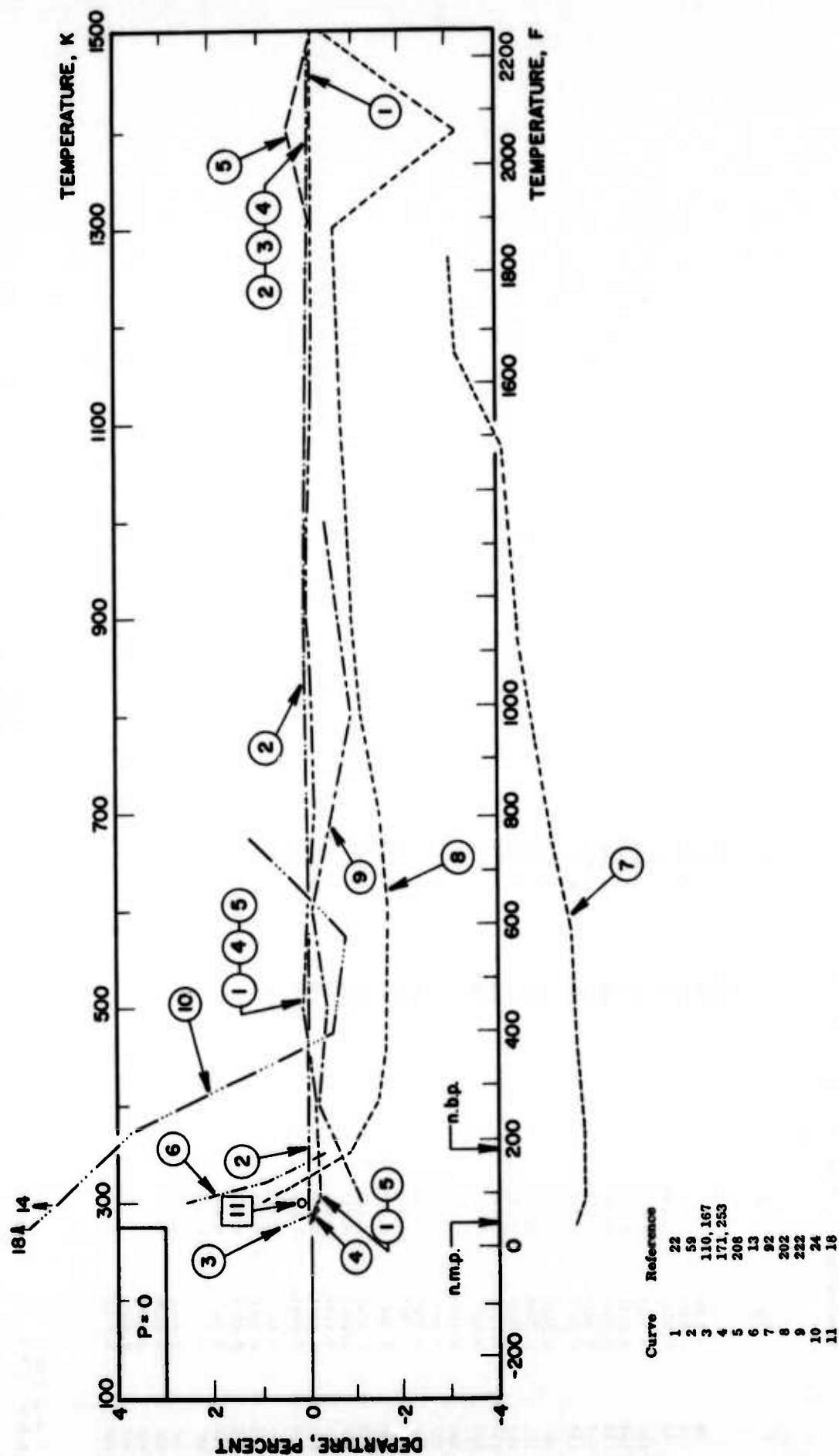


FIGURE 25 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS BENZENE

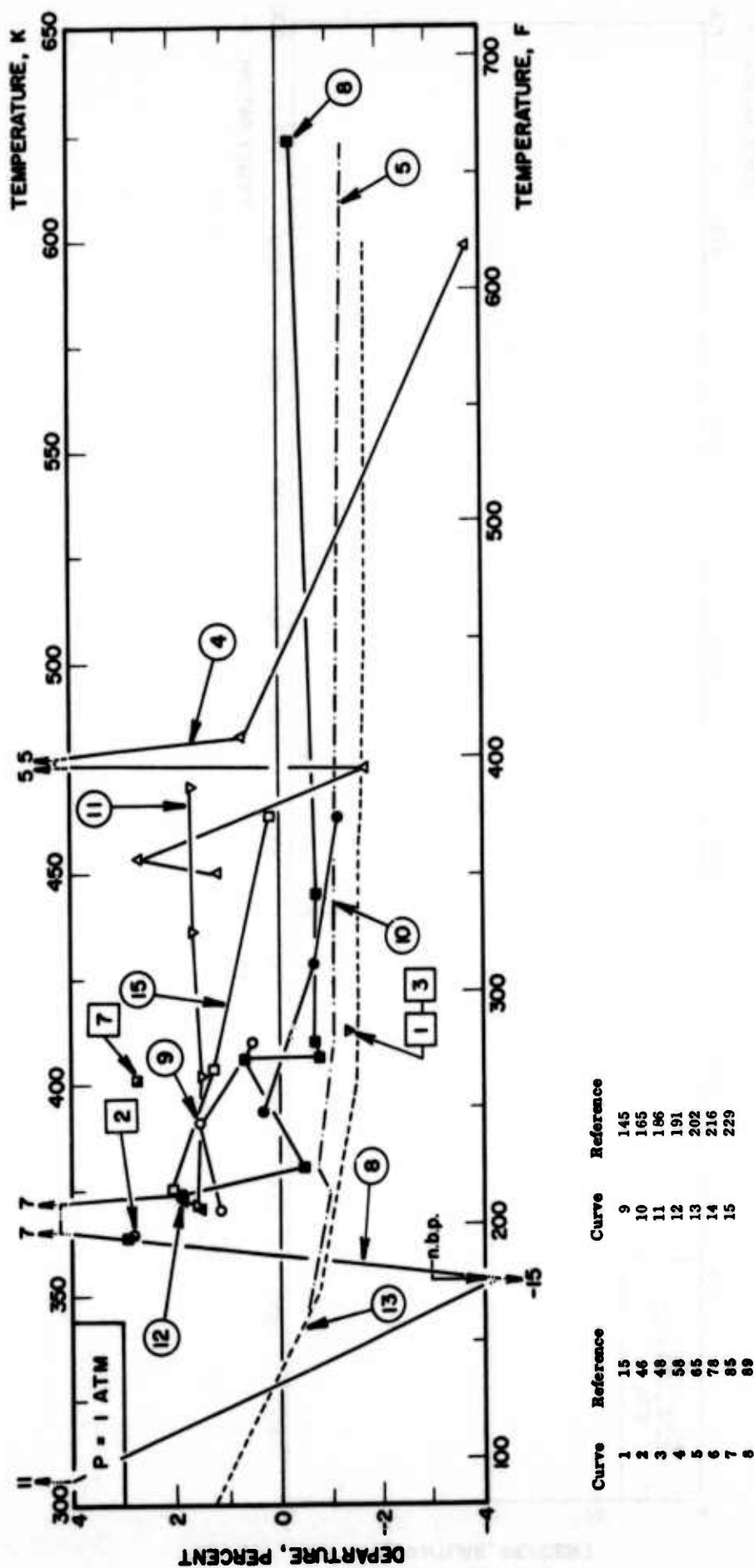


FIGURE 25 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS BENZENE

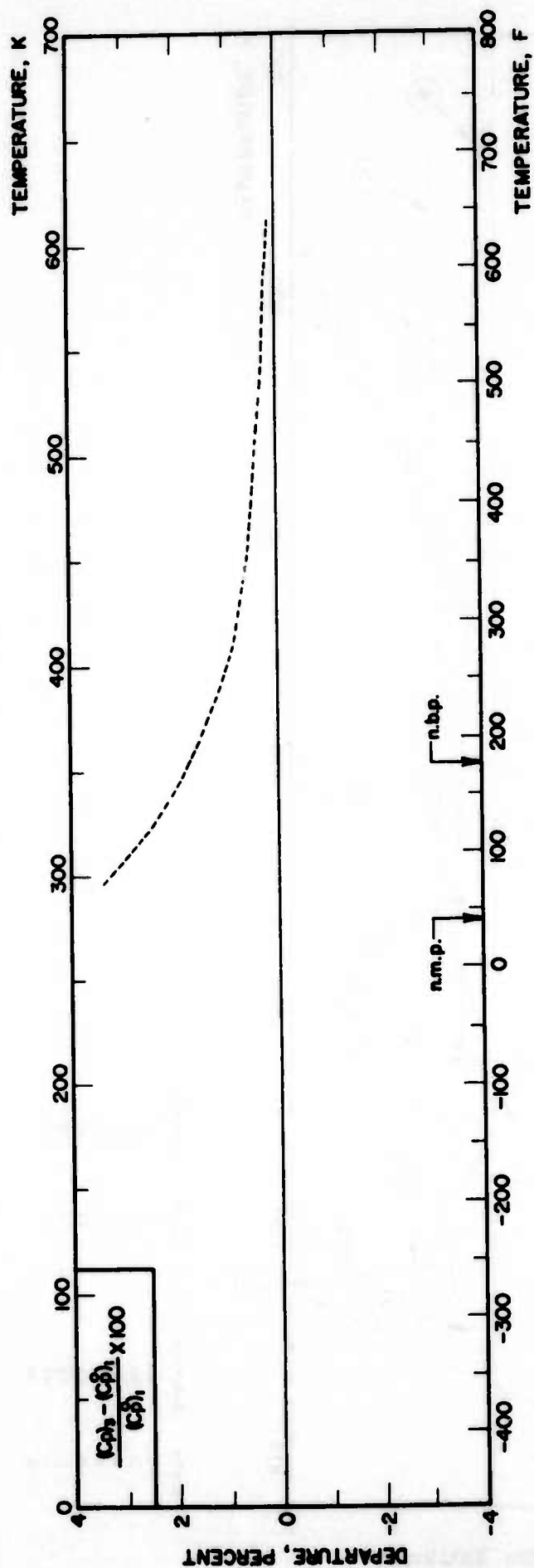


TABLE 26 SPECIFIC HEAT AT CONSTANT PRESSURE OF Iso-BUTANE

DISCUSSION

LIQUID

There exist six sets of data on the constant pressure specific heat of liquid isobutane. In the temperature range between the n.m.p. and n.b.p., two sets of data (7, 155) obtained by calorimetric measurements agree very well with each other, and both would be considered to be reliable from the standpoint of the specimen and experimental method used. On the other hand, Sage and Lacey (175), made calorimetric measurements above the n.b.p. at saturation vapor pressures with a reported accuracy of one percent. Their results are also considered reliable, taking into account their experimental procedures. Therefore, the above three sets of data are given equal weight in this analysis. Earlier experimental data (43) showed considerable scattering, and two sets of correlated values (32, 83) are considered to be less reliable. No weight is given to these data.

The correlation formula obtained from 65 data points is

$$C_p (\text{cal g}^{-1}\text{K}^{-1}) = 0.145617 + 3.70016 \times 10^{-3}T - 1.61531 \times 10^{-5}T^2 + 2.90403 \times 10^{-8}T^3 \quad (T \text{ in K})$$

This equation is found to fit the above 65 data points with a mean deviation of 0.7 percent and a maximum of 4.6 percent in the temperature range from 115 K to 378 K.

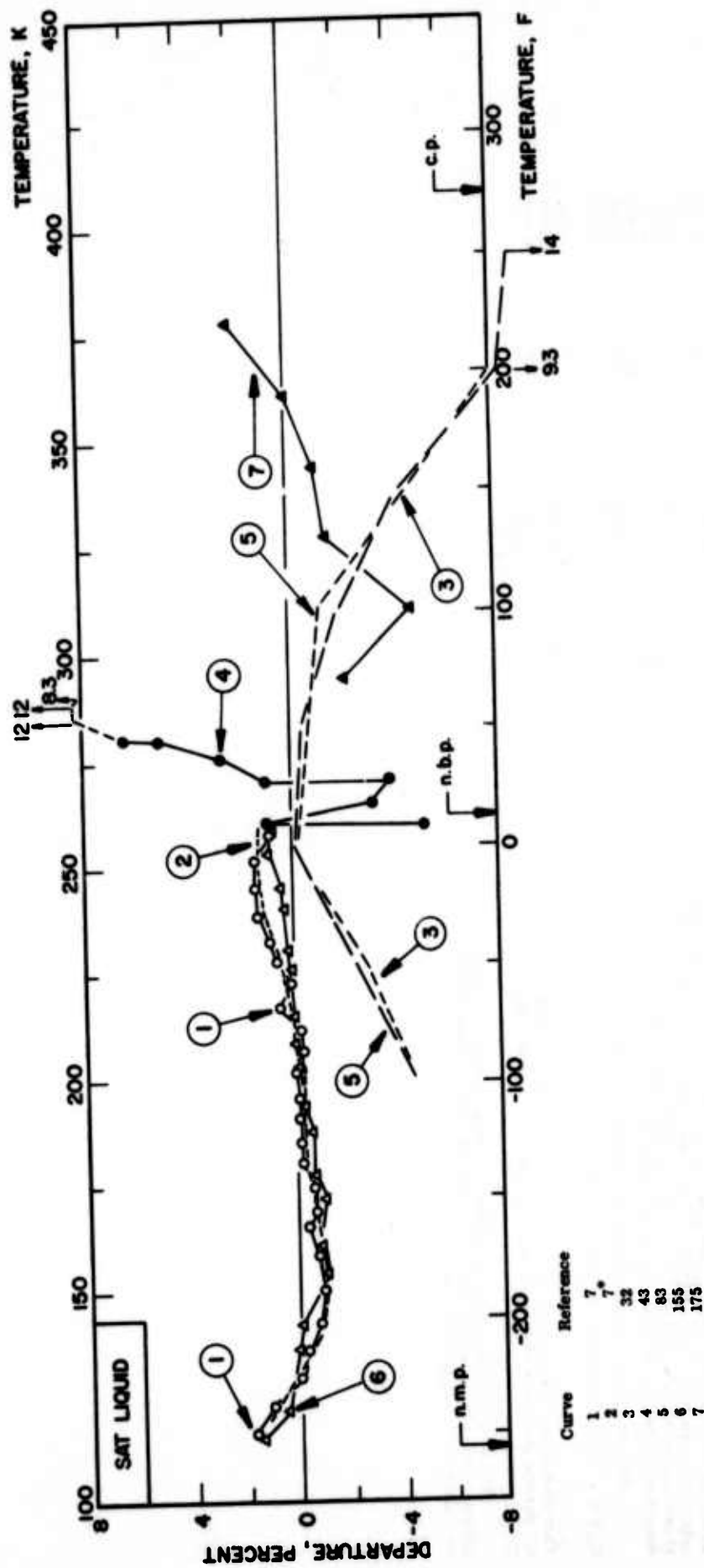
The recommended values are generated using the above formula. The tabulated values between the n.m.p. to n.b.p. should be correct within 1.5 percent, and values above n.b.p. within four percent.

RECOMMENDED VALUES

LIQUID			
[Temperature, T, F; Specific Heat, C_p , Btu ⁻¹ F ⁻¹]			
T	C_p	T	C_p
-240	0.4091	0	0.5204
-220	0.4202	20	0.5338
-200	0.4301	40	0.549
-180	0.4392	60	0.566
-160	0.4476	80	0.585
-146	0.4556	100	0.607
-120	0.4635	120	0.631
-100	0.4714	140	0.659
-80	0.4796	160	0.689
-60	0.4884	180	0.723
-40	0.4980	200	0.761
-20	0.5086	220	0.803
		240	0.848

n.b.p. = 12 F

FIGURE 26 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID ISO-BUTANE



*Smoothed values

TABLE 26 SPECIFIC HEAT AT CONSTANT PRESSURE OF ISOBUTANE

DISCUSSION

GAS

Eleven sources of information are available for the isobaric specific heat of gaseous isobutane. Extensive values of the ideal-gas heat capacity, obtained from spectroscopic and molecular structural data, are presented by Kobe and Long (109), Pitzer and Kilpatrick (164) and Rossini et al. (171), covering the temperature range 273 K to 1500 K. As agreement is excellent among these extensive values, equal weight is given to these works in this analysis. Although Anton et al. (7) also reported the heat capacity at the ideal gas state based on spectroscopic data, the molecular data used by them are less reliable and therefore no weight is given to their values (7), as well as a set of empirically derived values (18). The correlation formulas obtained for the ideal gas state are as follows:

For temperatures from 273 K to 785 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = -0.0202539 + 1.62434 \times 10^{-3}T - 7.69141 \times 10^{-7}T^2 + 9.64716 \times 10^{-11}T^3 \quad (T \text{ in K}), (1)$$

For temperatures from 785 K to 1500 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.127560 + 1.26105 \times 10^{-3}T - 5.36522 \times 10^{-7}T^2 + 1.39621 \times 10^{-10}T^3 \quad (T \text{ in K}), (2)$$

These equations are found to fit the above referenced data with mean deviations of 0.18 and 0.06 percent, and maximum deviations of 0.65 and 0.62 percent, respectively. The recommended values are computed from the above formulas. The tabulated values should be correct within one percent over the entire temperature range. In the departure plot at $P = 0$, all the existing values mentioned above are compared with the above equations.

On the other hand, concerning the specific heat in the real gas state, the calorimetric data between 347 K and 693 K reported by Dailey and Feising (41) is thought to be reliable. However, their data are not found to be realistic in comparison with the values for the ideal gas state, C_p^0 . Therefore, in the present analysis, the specific heat at the real gas state, C_p , is calculated from C_p^0 and corrected for gas imperfection, using the Berthelot's equation of state. The resulting C_p values for temperatures from 233 K to 710 K are represented by the following formula:

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.0342741 + 1.33934 \times 10^{-3}T - 2.62434 \times 10^{-7}T^2 - 2.04162 \times 10^{-10}T^3 \quad (T \text{ in K}), (3)$$

The recommended values of C_p^0 are generated by the above equation. In the departure plot at $P = 1$ atm, calorimetric data (41, 223), derived values from Joule-Thomson coefficient (75, 178) and a compilation (78) are compared with Equation (3). The comparison between Equation (3) and Equation (1) is shown in the third departure plot.

Kazavchinskii (96) gave the difference of heat capacity between the real gas state and the ideal gas state based on an equation of state. However, his results are not used in the present analysis.

TABLE 26 SPECIFIC HEAT AT CONSTANT PRESSURE OF ISOBUTANE (continued)

RECOMMENDED VALUES				
[Temperature, T, F; Specific Heat, C_p , B lb ⁻¹ F ⁻¹]				
GAS				
T	C_p	C_p	T	C_p
40	0.3732	0.381	700	0.7323
60	0.3867	0.394	720	0.7406
80	0.4000	0.406	740	0.7488
100	0.4131	0.419	760	0.7568
120	0.4260	0.431	780	0.7646
140	0.4388	0.444	800	0.7724
160	0.4514	0.456	820	0.7800
180	0.4639	0.468	840	0.7874
200	0.4762	0.480	860	0.7947
220	0.4883	0.491	880	0.8019
240	0.5003	0.503	900	0.8089
260	0.5121	0.514	920	0.8158
280	0.5237	0.526	940	0.8226
300	0.5352	0.537	960	0.8291
320	0.5465	0.548	980	0.8354
340	0.5577	0.559	1000	0.8416
360	0.5687	0.570	1100	0.8715
380	0.5795	0.581	1200	0.8994
400	0.5902	0.591	1300	0.9254
420	0.6007	0.602	1400	0.9497
440	0.6111	0.612	1500	0.9723
460	0.6213	0.622	1600	0.9932
480	0.6314	0.632	1700	1.0126
500	0.6413	0.642	1800	1.0305
520	0.6511	0.652	1900	1.0471
540	0.6607	0.662	2000	1.0625
560	0.6702	0.671		
580	0.6795	0.681		
600	0.6887	0.690		
620	0.6977	0.699		
640	0.7066	0.708		
660	0.7153	0.716		
680	0.7239	0.725		

FIGURE 26 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS ISO-BUTANE

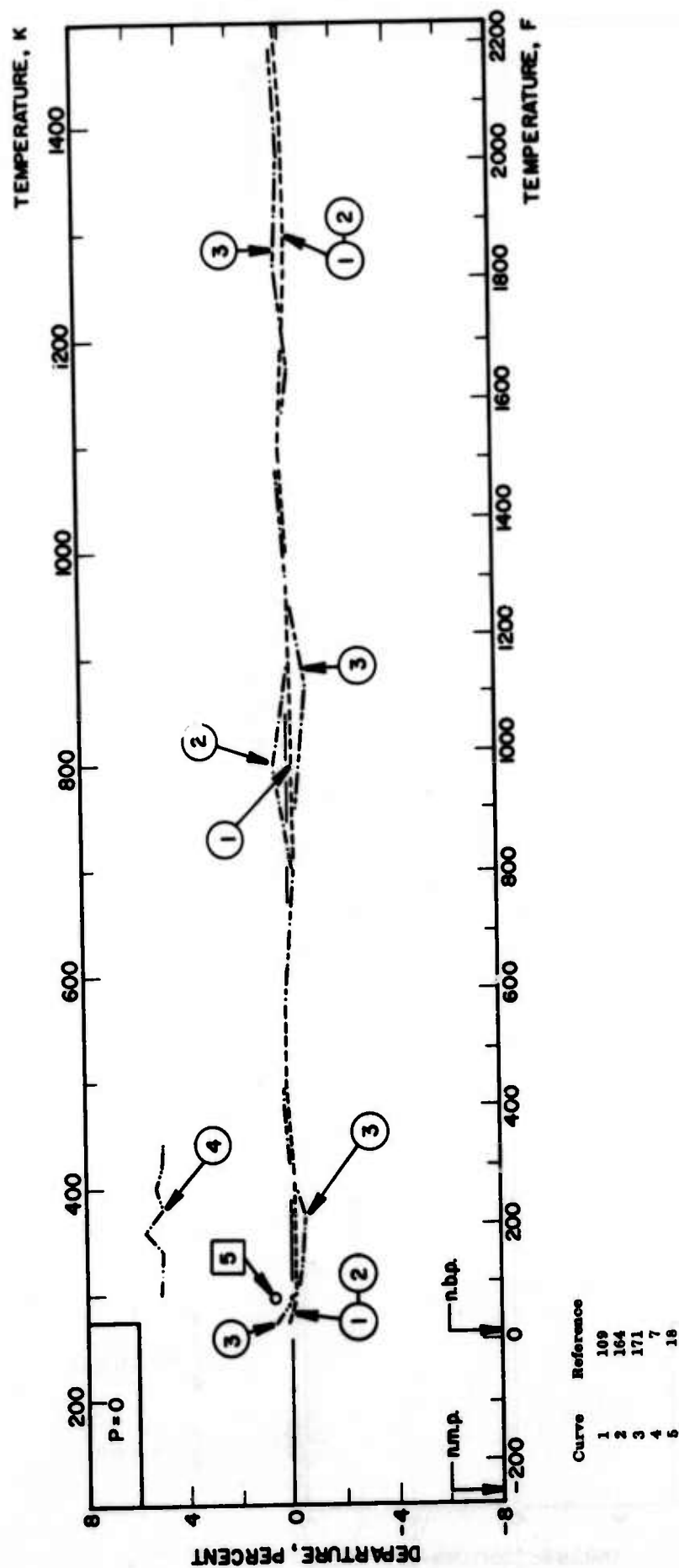


FIGURE 26 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS *iso*-BUTANE

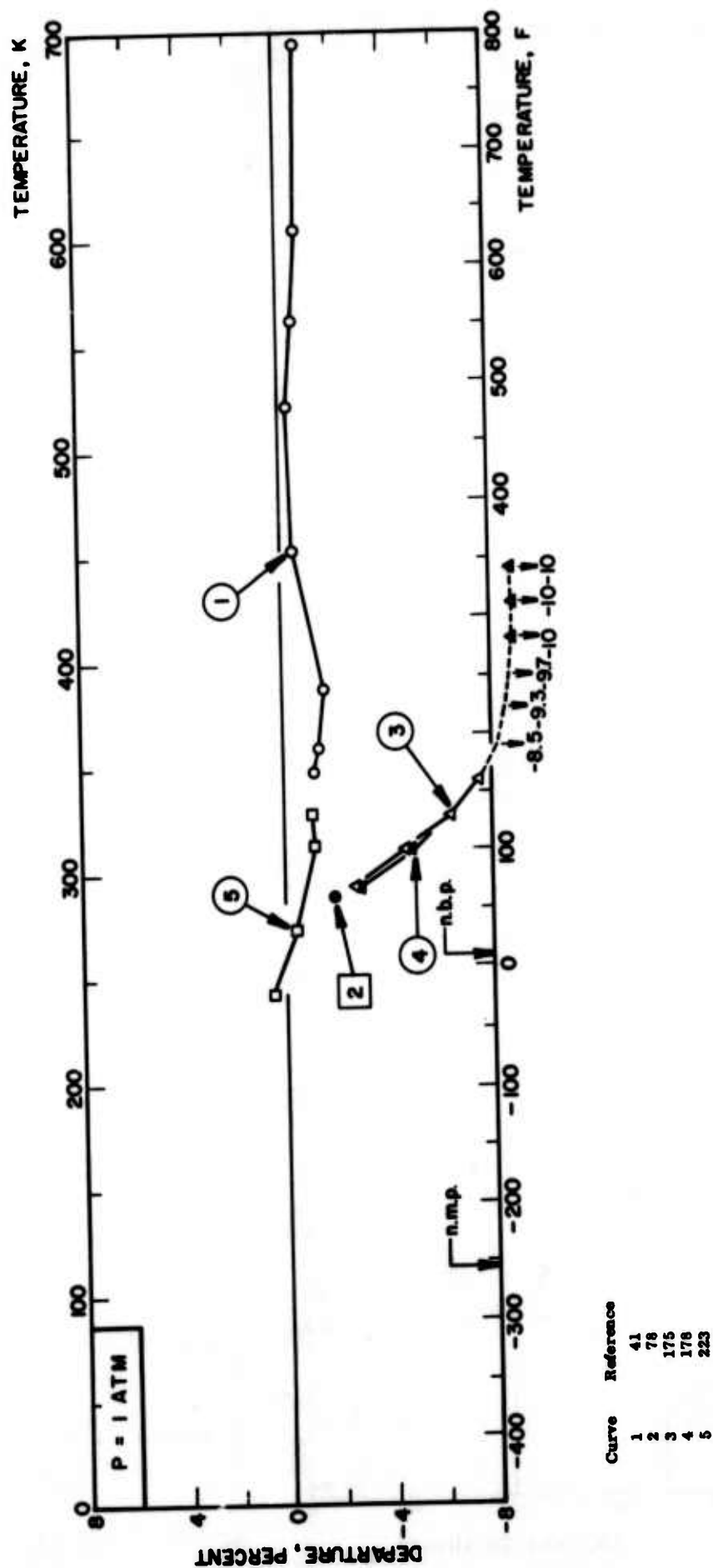


FIGURE 26 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS *iso*-BUTANE

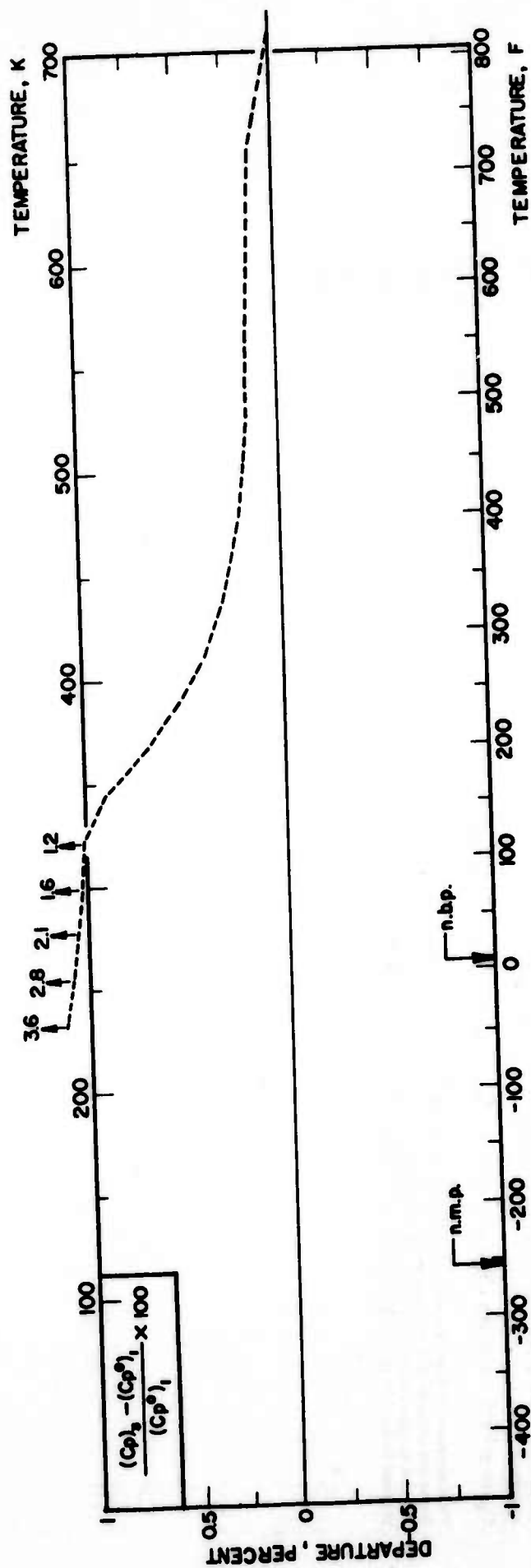


TABLE 27 SPECIFIC HEAT AT CONSTANT PRESSURE OF n-BUTANE

DISCUSSION

LIQUID

Seven works are available on the specific heat at constant pressure of liquid n-butane. In the range between the n. m. p. and the n. b. p., calorimetric measurements of Aston and Messerly (8) and Huffman et al. (87) are considered to be the most reliable from the standpoint of careful procedures used. The early data of Dana et al. (43) show considerable scattering near the n. b. p. Sage and Lacey (172) made measurements along the saturation vapor pressure curve covering temperatures from 297 K to 368 K. Their data, which are taken from figures presented, are also considered reliable. The extensive values (32, 83) are the result of correlations of these authors who do not give source information for their data. These are thought to be less reliable in comparison with the careful measurements mentioned above. A set of derived values (36) is also less reliable.

In this analysis, the three sets of data (8, 87, 172) covering temperatures from 140 K to 366 K are given equal weight and are fitted by the following equation:

$$C_p (\text{cal g}^{-1} \text{K}^{-1}) = 0.353969 + 1.57717 \times 10^{-3} T - 7.93132 \times 10^{-6} T^2 + 1.73737 \times 10^{-8} T^3 \quad (T \text{ in K}).$$

This equation is found to reproduce the 35 data points enumerated above with a mean deviation of 0.4 percent and a maximum of 1.8 percent. The above equation is used to generate the recommended values which should be correct within one percent below 278 K and two percent above 288 K.

RECOMMENDED VALUES
[Temperature, T, °F; Specific Heat, C_p , B lb⁻¹ °F⁻¹]

T	C_p
-220	0.4641†
-200	0.4683
-180	0.4724
-160	0.4766
-140	0.4809
-120	0.4856
-100	0.4907
-80	0.4965
-60	0.5030
-40	0.5104
-20	0.5188
0	0.5285
20	0.5385
40	0.5519
60	0.566
80	0.582
100	0.599
120	0.619
140	0.641
160	0.665
180	0.692

† Extrapolated for the liquid phase ignoring pressure dependence (n. m. p. = -213 ± 4 °F).

n. b. p. = 32 °F

FIGURE 27 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID n-BUTANE

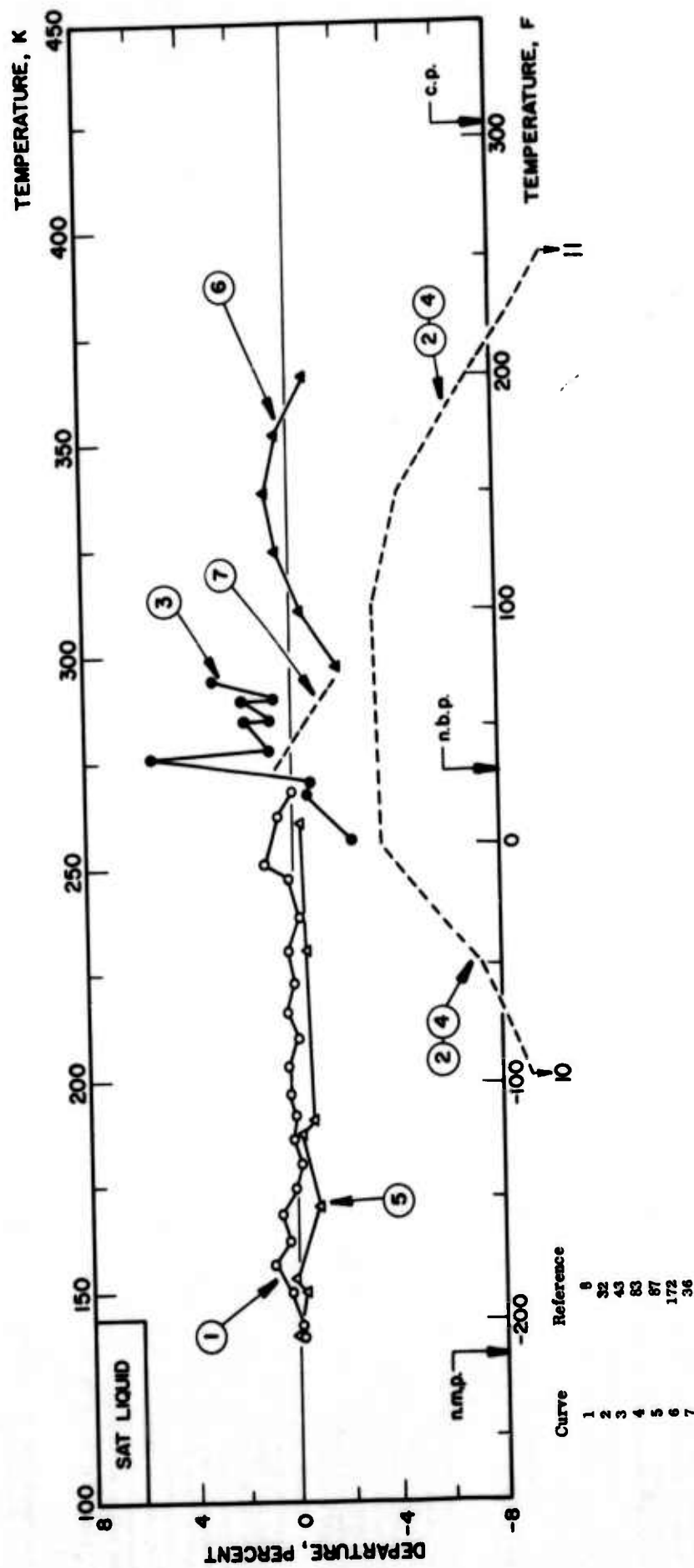


TABLE 27 SPECIFIC HEAT AT CONSTANT PRESSURE OF n-BUTANE (continued)

DISCUSSION

GAS

There exist 28 papers on the isobaric specific heat of gaseous n-butane. A number of extensive heat capacity values for the ideal gas state have been derived from spectroscopic and molecular structural data. The values presented by Person (159), Pitzer and Kilpatrick (164), whose values are also compiled in references (59, 109, 167), and API Research Project 44 (253) are considered to be the most reliable. Therefore, equal weight is given to these works in the present analysis. Some early statistical calculations (48, 161, 171, 203) are given no weight, as well as a number of empirically correlated values (133, 134, 222). The correlation formulas obtained for the ideal gas specific heat are as follows:

$$C_p^0 (\text{cal g}^{-1} \text{K}^{-1}) = 0.0564796 + 1.22083 \times 10^{-3} T - 1.00571 \times 10^{-7} T^2 \quad (1)$$

$$- 2.72977 \times 10^{-10} T^3 \quad (T \text{ in K})$$

For temperatures between 790 K and 1500 K:

$$C_p^0 (\text{cal g}^{-1} \text{K}^{-1}) = 0.0507543 + 1.43941 \times 10^{-3} T - 6.79897 \times 10^{-7} T^2 \quad (2)$$

$$+ 1.22485 \times 10^{-10} T^3 \quad (T \text{ in K}).$$

The equations are found to fit the above enumerated values with the mean deviations of 0.4 and 0.02 percent and maximum deviations of 1.3 and 0.07 percent, respectively. The above formulas are used to generate the recommended values, which should be substantially correct within 1.5 percent. The percent departure of all the values mentioned above from the tabulated recommended values are shown in the departure plot for $P = 0$. Although Spencer, et al. (195, 196, 197) presented various empirical equations for the ideal gas heat capacity, their results are not plotted in this figure.

On the other hand, several sets of experimental data are available for the specific heat in the real gas state. Among them, the most reliable work is that of Dailey and Felsing (41), who used a flow calorimeter and covered temperatures from 345 K to 693 K. Their results are considered to be appropriate for this analysis in view of the close interrelation they exhibit with the extensive values of the ideal gas state described above. The data of Sage, et al. (172, 176) which are derived from measurements of adiabatic expansion are found to be too low, and are given no weight, as well as the experimental values in a narrow temperature range (85, 209) and empirically derived values (13, 14, 18, 32, 83, 202). The correlation formula for the real gas state between 345 K and 693 K obtained, independently of the values at the ideal gas state, is as follows:

$$C_p (\text{cal g}^{-1} \text{K}^{-1}) = 0.0703903 + 1.11291 \times 10^{-3} T + 2.44476 \times 10^{-7} T^2 \quad (3)$$

$$- 5.82753 \times 10^{-10} T^3 \quad (T \text{ in K}).$$

This equation fits the above enumerated data (41) with a mean deviation of 0.1 percent and a maximum of 0.2 percent. Equation (3) is used to calculate the departures

of all the above mentioned values in the real gas state which are shown in the departure plot for $P = 1$ atm. The third plot is the comparison of Equation (3) with the values for the temperature range where Equation (3) is valid. In this figure percent is calculated by

$$\frac{(C_p)_2 - (C_p)_1}{(C_p)_1} \times 100$$

TABLE 27 SPECIFIC HEAT AT CONSTANT PRESSURE OF n-BUTANE (continued)

RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p , B lb⁻¹ F⁻¹]
GAS

T	C_p^0	T	C_p^0
20	0.3693*	600	0.6842
40	0.3815	620	0.6932
60	0.3937	640	0.7021
80	0.4058	660	0.7108
		680	0.7194
100	0.4179	700	0.7278
120	0.4298	720	0.7361
140	0.4417	740	0.7442
160	0.4534	760	0.7521
180	0.4651	780	0.7599
200	0.4766	800	0.7675
220	0.4881	820	0.7750
240	0.4995	840	0.7823
260	0.5107	860	0.7894
280	0.5219	880	0.7963
300	0.5329	900	0.8031
320	0.5439	920	0.8097
340	0.5547	940	0.8161
360	0.5654	960	0.8223
380	0.5760	980	0.8292
400	0.5865	1000	0.8357
420	0.5968	1100	0.8666
440	0.6071	1200	0.8954
460	0.6172	1300	0.9220
480	0.6271	1400	0.9466
500	0.6370	1500	0.9694
520	0.6467	1600	0.9905
540	0.6563	1700	1.0099
560	0.6657	1800	1.0279
580	0.6750	1900	1.0446
		2000	1.0600

*n.b.p. = 32 F

FIGURE 27 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS n-BUTANE

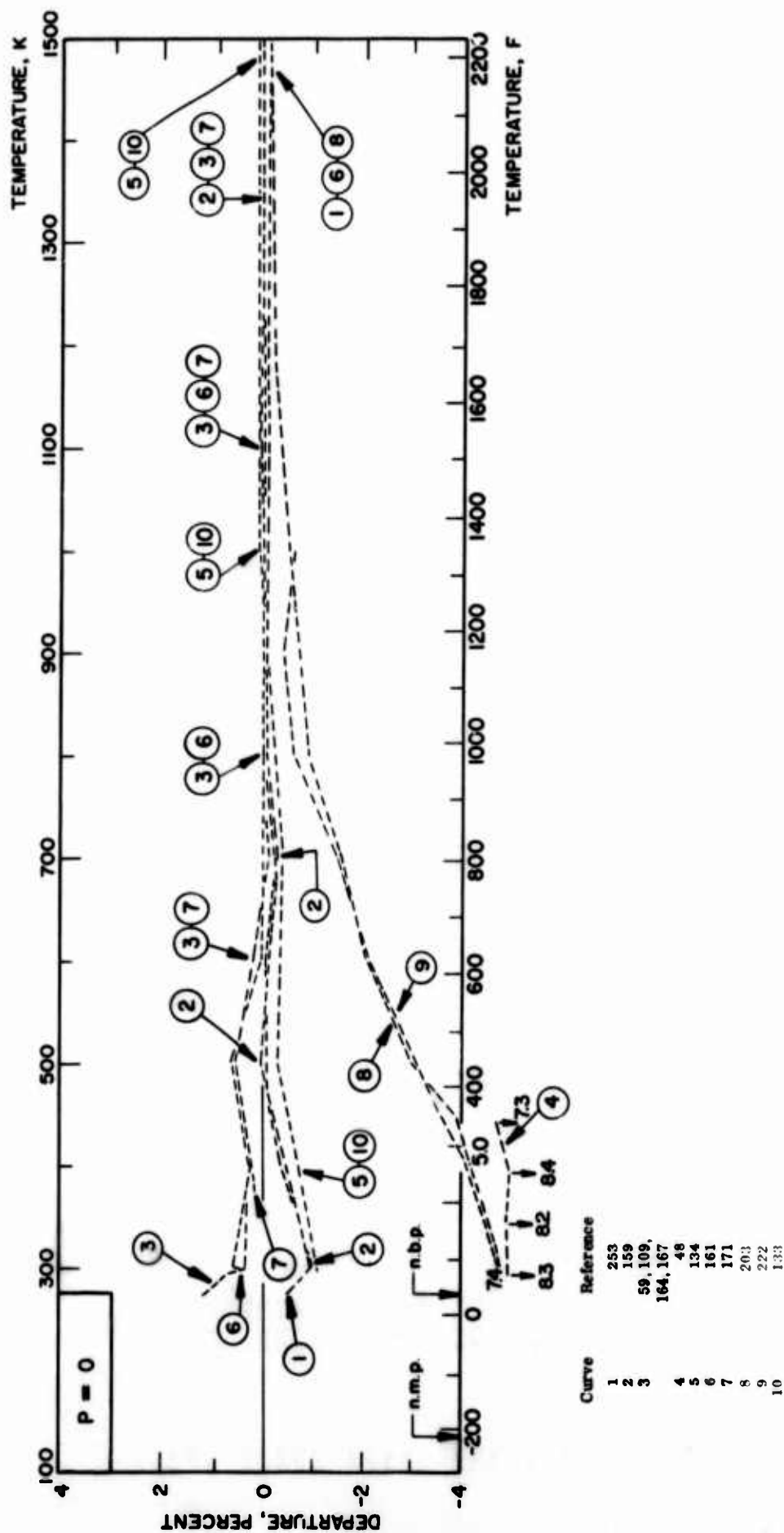


FIGURE 27 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS n-BUTANE

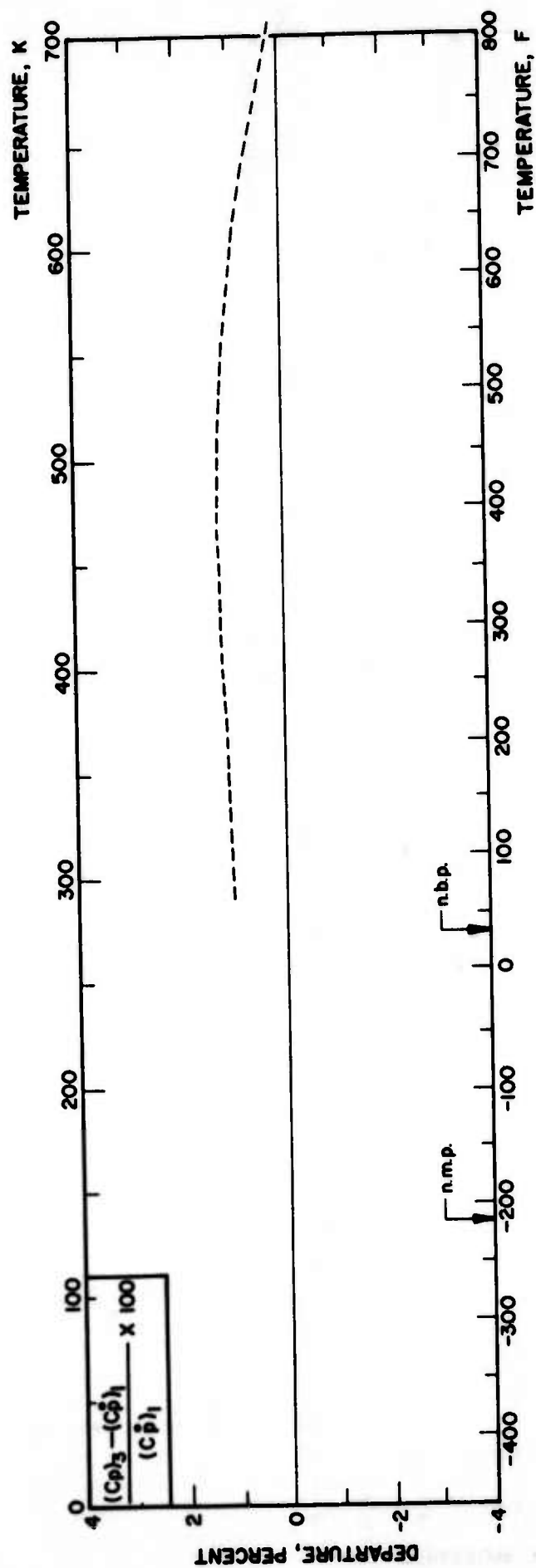
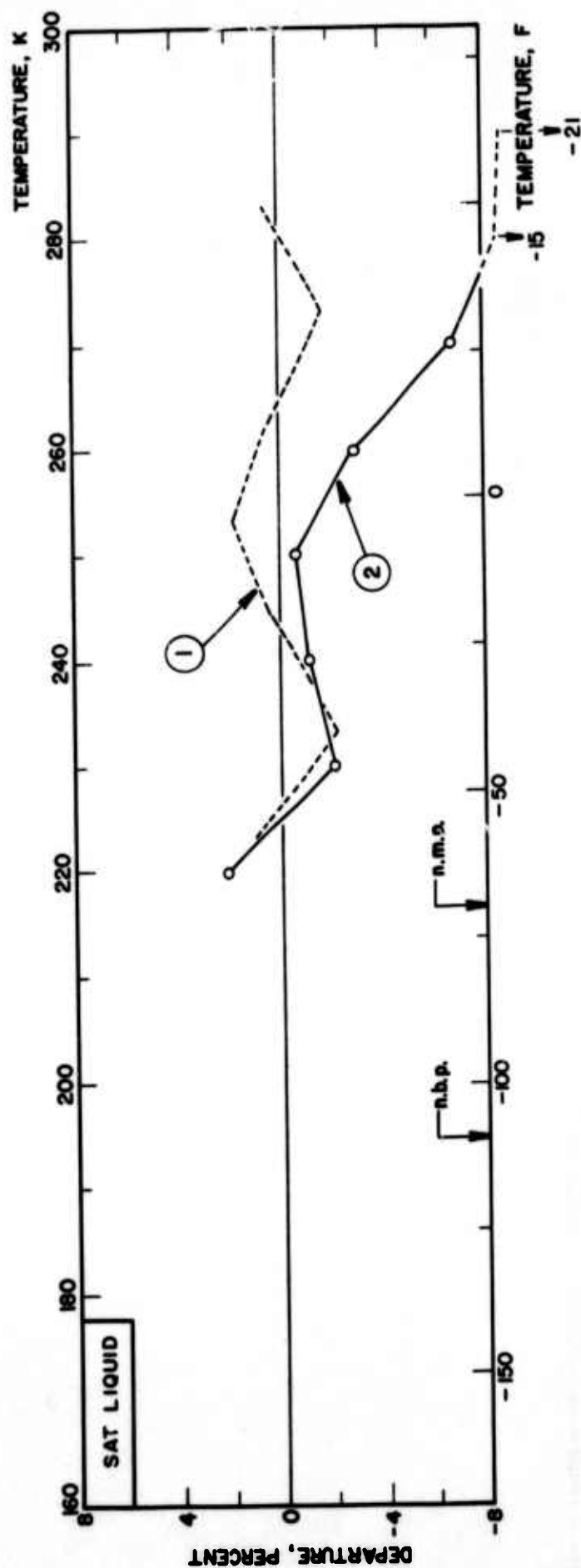


TABLE 28 SPECIFIC HEAT AT CONSTANT PRESSURE OF CARBON DIOXIDE

LIQUID	DISCUSSION		RECOMMENDED VALUES	
			[Temperature, T, F; Specific Heat, C _p , B lb ⁻¹ F ⁻¹]	
			LIQUID	
			T	C _p
Only two sources of information are available for the constant pressure specific heat of liquid carbon dioxide. The early calorimetric data of Eucken and Hauck (55) are not considered to be so reliable based on their work on other liquids. Therefore, the correlated values obtained by Koch (249), covering temperatures from 223 K to 283 K along the saturated vapor pressure curve, are used in the present analysis. The equation used to fit Koch's correlation is: $C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = -46.6258 + 0.584679 T - 2.42252 \times 10^{-3} T^2 + 3.34972 \times 10^{-6} T^3$ (T in K). This equation is found to fit Koch's correlation with a mean deviation of 1.1 percent and a maximum of 2.2 percent. The above formula is used to generate the recommended values, which should be substantially correct within four percent.			-60	0.4308
			-55	0.4414
			-50	0.4494
			-45	0.4554
			-40	0.4598
			-30	0.4632
			-20	0.4692
			-10	0.4752
			0	0.4865
			10	0.5068
			20	0.5393
			30	0.5877
			40	0.6551
			50	0.7453

FIGURE 28 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID CARBON DIOXIDE



Curve	Reference
1	249
2	55

TABLE 28 SPECIFIC HEAT AT CONSTANT PRESSURE OF CARBON DIOXIDE

DISCUSSION

GAS

There exist 78 sources of information on the specific heat at constant pressure of gaseous carbon dioxide. A number of extensive heat capacity values for the ideal gas state have been derived from spectroscopic and molecular structural data. Among them, the results of Gordon (72), McBride et al. (137), Gratch (361, 362), Hildenbrand (380), McBride and Gordon (458), Price (495, 496) and Woolley (570) are considered to be reliable, as well as three compilation tables (253, 254, 575). Therefore, equal weight is given to these works in the present analysis. However, other sets of derived values by statistical calculations (167, 226), by equations of state (284, 403, 462) and by empirical correlations (18, 59, 100, 359, 389, 450, 494, 514) are given no weight, as well as earlier statistical calculations (24, 93, 278, 285, 405, 426, 532). Extrapolated values to zero pressure from the measurement of sound velocity (561) also are not taken into consideration. The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 200 K and 590 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.105914 + 4.03552 \times 10^{-4}T - 3.03235 \times 10^{-7}T^2 + 8.29431 \times 10^{-11}T^3 \quad (1)$$

For temperatures between 590 K and 1500 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.135069 + 2.89483 \times 10^{-4}T - 1.64998 \times 10^{-7}T^2 + 3.53157 \times 10^{-11}T^3 \quad (2) \quad (T \text{ in K})$$

These equations are found to fit the above enumerated values with mean deviations of 0.12 and 0.09 percent, and maximum deviations of 0.32 and 0.29 percent, respectively. The recommended values are generated from the above formulas. The tabulated values of C_p should be substantially correct within 0.5 percent over the entire temperature range. The percent departures of all the values mentioned above from the tabulated values are given in two departure plots for $P = 0$. However, several empirical equations (25, 196, 197, 205, 377, 536) and a set of mean specific heat values (92) are not plotted in these figures.

On the other hand, many sets of theoretical values and experimental data are available for the specific heat in the real gas state. The reliable values derived by statistical mechanics and the imperfect gas correction were presented by Heck (375, 376) and Hilsenrath et al. (575). Among a number of experimental works, flow calorimetric data of Eucken and Sarstedt (58) and Masi and Petkof (453), adiabatic expansion data of Kistiakowsky and Rice (103) and derived values from compressibility data of De Groot and Michels (305) and McCormack and Schneider (450) are considered to be reliable. Therefore, equal weight is given to these works in the present analysis. However, other sets of theoretical values (354) and correlation results (249, 250, 494, 519) are given no weight, as well as several

experimental data obtained by flow calorimeters (482, 514), by adiabatic expansion (56), by compressibility data (65) and by velocity of sound (46, 241, 422). The correlation formulas obtained for the specific heat in the real gas state are as follows:

For temperatures between 220 K and 540 K:

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.136812 + 2.15312 \times 10^{-4}T + 7.25177 \times 10^{-7}T^2 - 1.57146 \times 10^{-10}T^3 \quad (3)$$

For temperatures between 540 K and 1500 K:

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.144592 + 2.58445 \times 10^{-4}T - 1.31976 \times 10^{-7}T^2 + 2.42548 \times 10^{-10}T^3 \quad (4) \quad (T \text{ in K})$$

These equations are found to fit the above enumerated values with mean deviations of 0.24 and 0.19 percent, and maximum deviations of 1.0 and 0.30 percent, respectively. The recommended values of C_p are calculated from the above formulas. The tabulated values should be substantially correct within one to two percent over the entire temperature range. Equations (3) and (4) are used to calculate the departures of all the values mentioned above the real gas state, which are shown in two departure plots for $P = 1$ atm. However, cited values (71, 78, 127, 279, 374, 442, 454, 481, 541), higher temperature values (270, 559), high pressure data (319) and mean specific heat values (286) are not plotted in these figures, as well as several empirical equations (184, 185, 275, 299, 346, 454, 528).

The comparison of Equations (3) and (4) with Equations (1) and (2) is given in the last plot.

TABLE 28 SPECIFIC HEAT AT CONSTANT PRESSURE OF CARBON DIOXIDE (continued)

RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p^0 and C_p , B lb⁻¹ F⁻¹]

GAS					
T	C _p ⁰	C _p	T	C _p ⁰	C _p
100	0.17499	0.1814	600	0.25515	0.2558
-80	0.17821	0.1839	620	0.25680	0.2572
-60	0.18136	0.1864	640	0.25822	0.2596
-40	0.18445	0.1888	660	0.25963	0.2600
-20	0.18748	0.1913	680	0.26100	0.2613
0	0.19045	0.1938	700	0.26236	0.2626
20	0.19336	0.1962	720	0.26369	0.2639
40	0.19622	0.1987	740	0.26499	0.2654
60	0.19901	0.2011	760	0.26628	0.2665
80	0.20175	0.2035	780	0.26754	0.2677
100	0.20443	0.2059	800	0.26878	0.2690
120	0.20706	0.2083	820	0.26999	0.2702
140	0.20963	0.2106	840	0.27118	0.2713
160	0.21215	0.2130	860	0.27235	0.2725
180	0.21461	0.2153	880	0.27350	0.2737
200	0.21702	0.2176	900	0.27463	0.2748
220	0.21938	0.2198	920	0.27574	0.2759
240	0.22169	0.2221	940	0.27683	0.2770
260	0.22394	0.2243	960	0.27789	0.2781
280	0.22615	0.2265	980	0.27894	0.2791
300	0.22830	0.2286	1000	0.27997	0.2801
320	0.23041	0.2308	1100	0.28481	0.2850
340	0.23247	0.2328	1200	0.28920	0.2895
360	0.23448	0.2349	1300	0.29318	0.2936
380	0.23644	0.2369	1400	0.29678	0.2973
400	0.23836	0.2389	1500	0.30004	0.3006
420	0.24023	0.2409	1600	0.30299	0.3037
440	0.24206	0.2428	1700	0.30567	0.3064
460	0.24384	0.2446	1800	0.30812	0.3088
480	0.24558	0.2465	1900	0.31036	0.3110
500	0.24728	0.2482	2000	0.31245	0.3130
520	0.24894	0.2499			
540	0.25055	0.2514			
560	0.25212	0.2529			
580	0.25366	0.2543			

n.m.p. (5 atm) = -70 F
 n.b.p. = -109 F

FIGURE 28 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS CARBON DIOXIDE

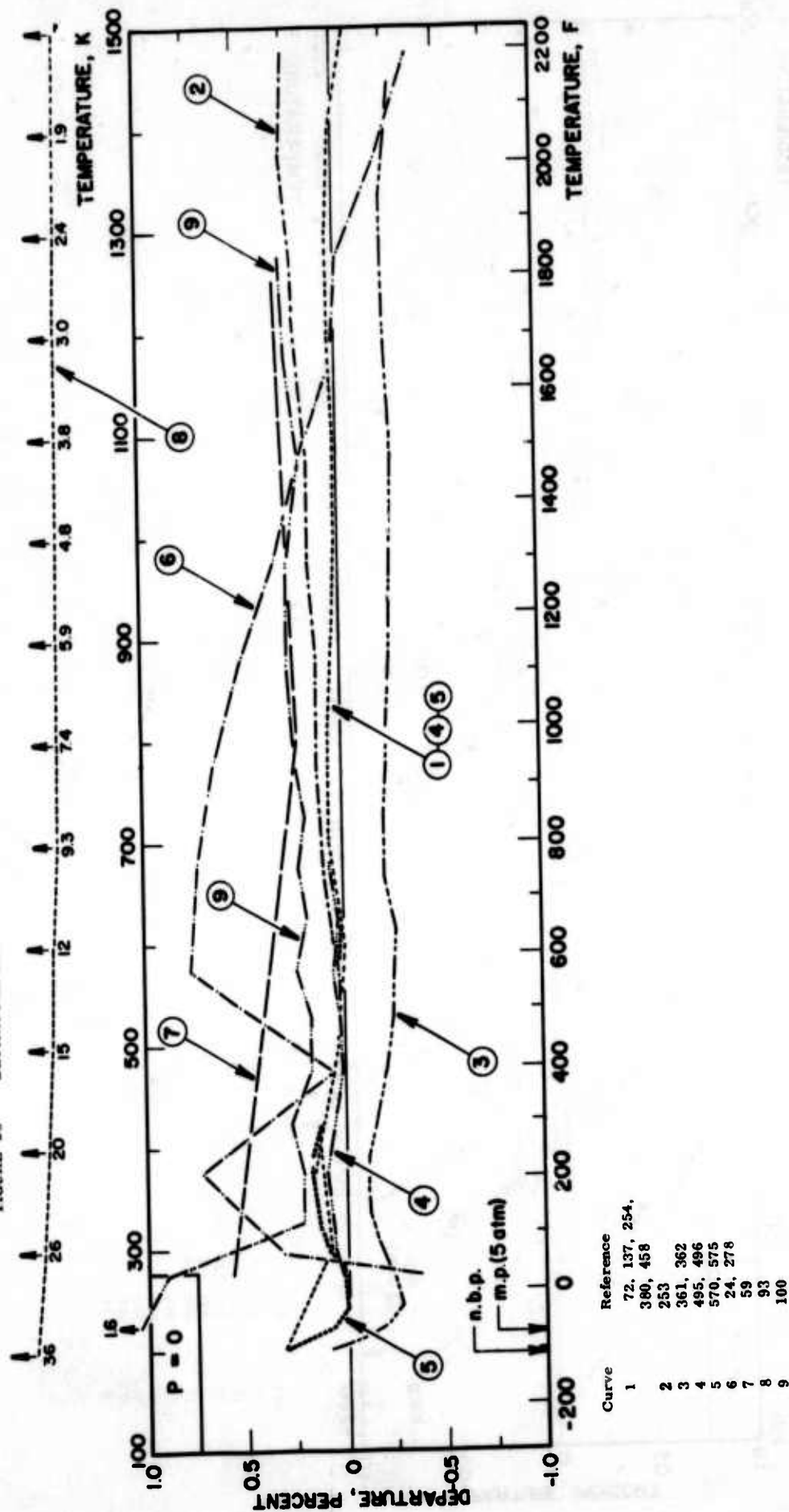


FIGURE 29 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS CARBON DIOXIDE (continued)

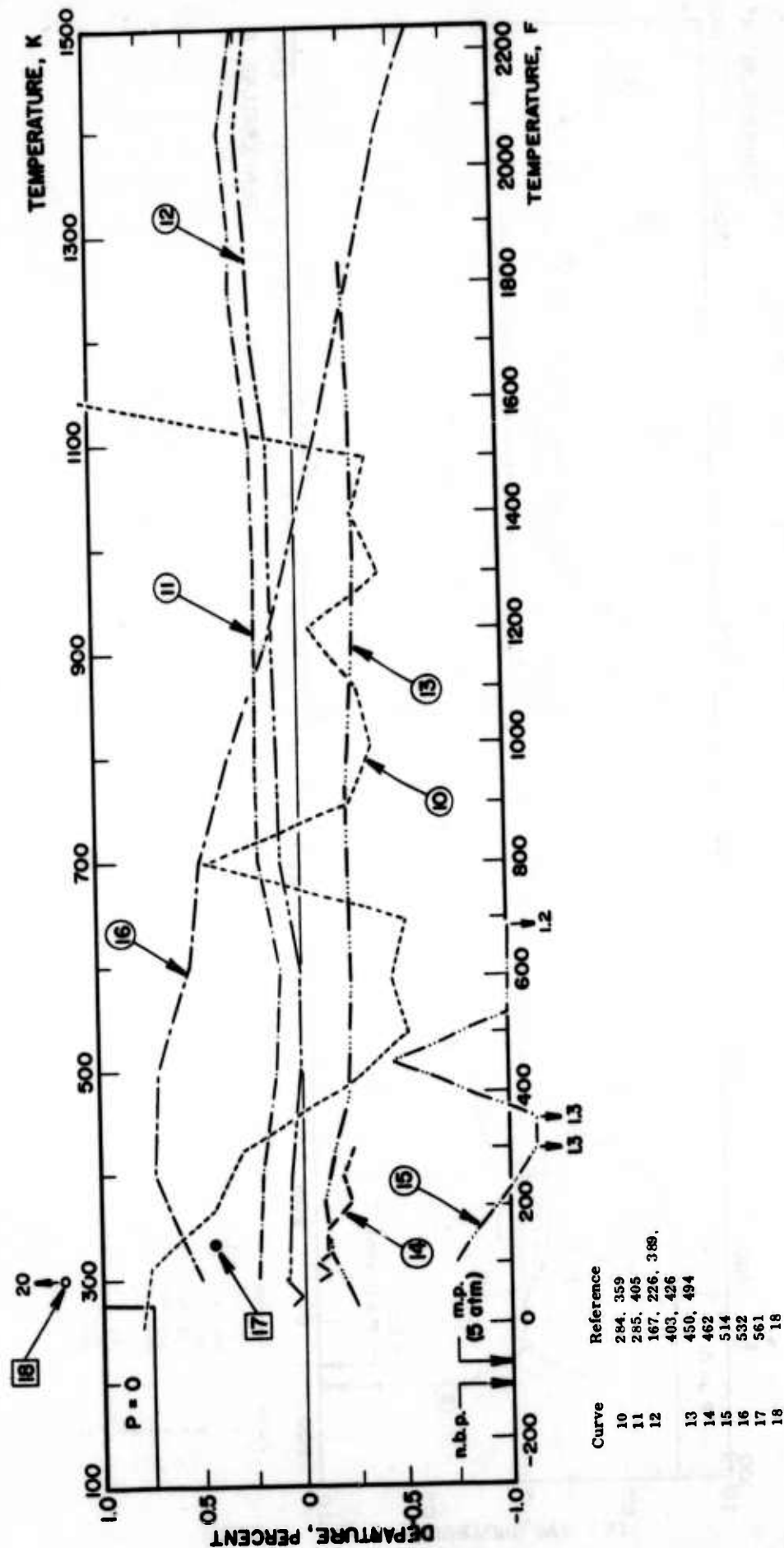


FIGURE 28 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS CARBON DIOXIDE

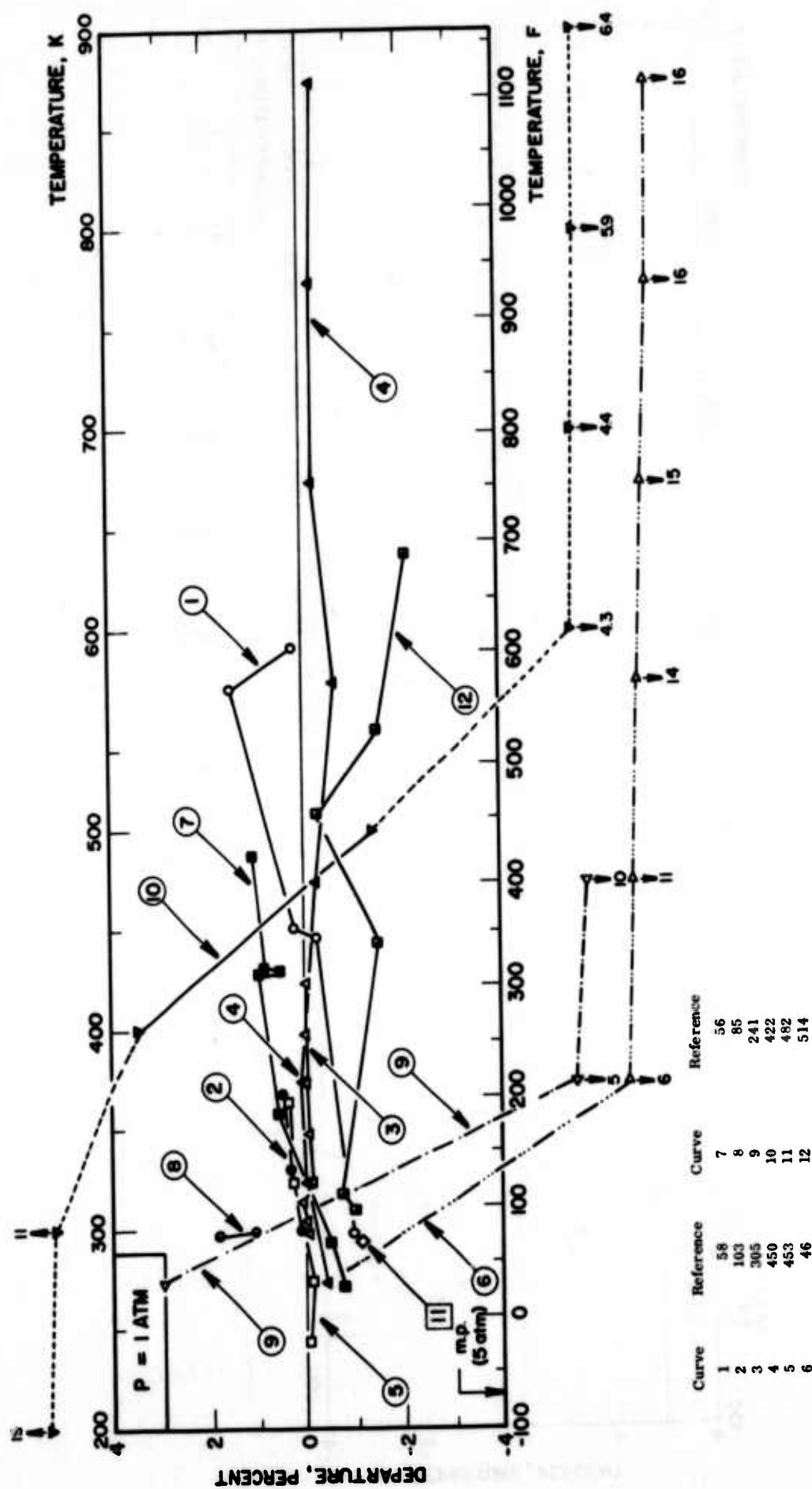


FIGURE 28 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS CARBON DIOXIDE (continued)

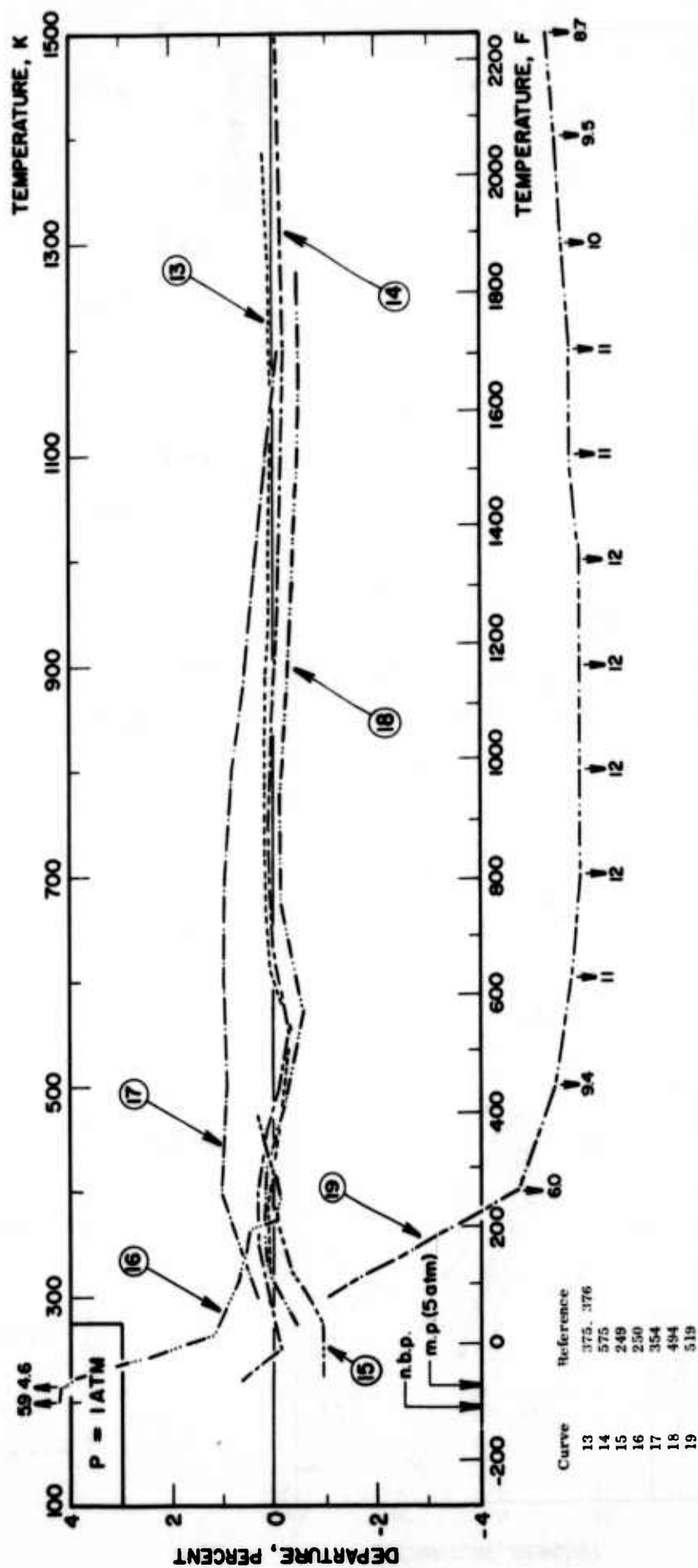


FIGURE 28 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS CARBON DIOXIDE

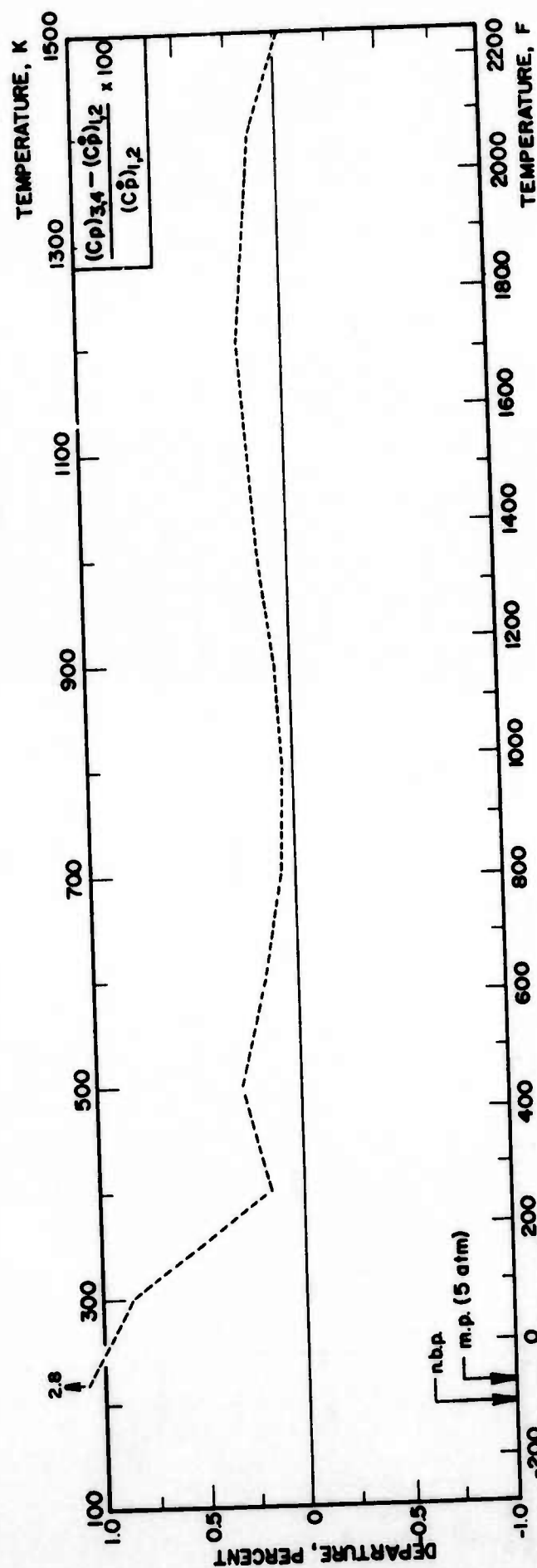


TABLE 29 SPECIFIC HEAT AT CONSTANT PRESSURE OF CARBON MONOXIDE

DISCUSSION		RECOMMENDED VALUES	
		[Temperature, T, F; Specific Heat, C_p , B lb ⁻¹ F ⁻¹]	
LIQUID		LIQUID	
	T		C_p
	-335		0.5132
	-330		0.5145
	-325		0.5158
	-320		0.5171
	-315		0.5185
	-310		0.5198

LIQUID

Two sets of calorimetric data and a single-point theoretical value are available for the specific heat of liquid carbon monoxide. Clausius (240) made measurements with a reported error of 0.7 percent at temperatures from 70.1 K to 81.3 K. Clayton and Giauque (287) reported the data of the very pure liquid in the temperature range between 70.02 K to 83.39 K. These calorimetric works show good agreement with each other and, therefore, are given equal weight. However, no weight is given to the theoretical calculation (216).

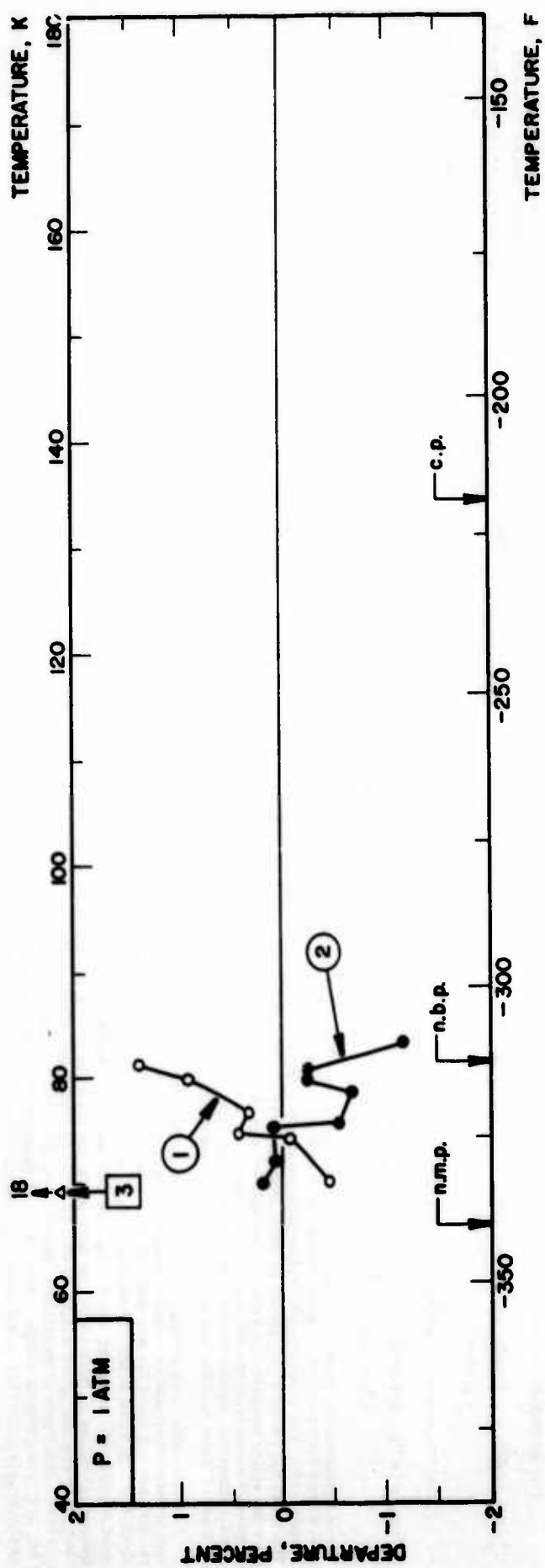
The correlation formula obtained for the temperature range from 70.02 K to 83.39 K is

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.480696 + 4.74088 \times 10^{-4}T \quad (T \text{ in K}).$$

This equation is found to fit the above enumerated works with a mean deviation of 0.49 percent and a maximum of 1.4 percent. The above formula is used to generate the recommended values, which should be substantially correct within two percent.

n. b. p. = -313 F

FIGURE 29 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID CARBON MONOXIDE



Curve	Reference
1	240
2	287
3	216

TABLE 29 SPECIFIC HEAT AT CONSTANT PRESSURE OF CARBON MONOXIDE

DISCUSSION

GAS

Fifty-five sources of information are available on the constant pressure specific heat of gaseous carbon monoxide. Many sets of extensive values for the ideal gas state have been derived from spectroscopic and molecular structural data. Among them, results presented by Gordon (72), McBride et al. (137), Ribaud (167), Sinke (192), Wagman et al. (226), Belzer et al. (267), Goff and Gratch (351), Gratch (362), Hildenbrand (380), Huff et al. (389), Kallman (403) and Touloukian (538) are considered to be reliable, as well as the compilation tables (253, 254, 575). Therefore equal weight is given to these works in this analysis. However, other sets of derived values (59, 100, 467, 468) and a single point value of empirical correlation (18) are given no weight, as well as earlier statistical calculations (24, 93, 278, 285, 395, 404, 426, 501). The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 250 K and 615 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.256859 - 6.46329 \times 10^{-4} T + 1.31865 \times 10^{-7} T^2 - 2.65440 \times 10^{-11} T^3 \quad (1)$$

For temperatures between 615 K and 1500 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.210345 + 9.44224 \times 10^{-4} T - 1.94071 \times 10^{-7} T^2 - 2.35385 \times 10^{-12} T^3 \quad (2)$$

These equations are found to fit the above cited values with mean deviations of 0.01 and 0.03 percent, and maximum deviations of 0.05 and 0.10 percent, respectively. The recommended values are generated using the above formulas. The tabulated values of C_p^0 should be substantially correct within 0.5 percent over the entire temperature range. The percent departures of all the values mentioned above from the tabulated values are given in the departure plot for $P = 0$. However, various empirical equations (25, 196, 205, 377, 532) as well as a set of mean specific heat values (92), are not plotted in this figure.

Meanwhile, concerning the specific heat in the real gas state, several sets of theoretical and correlated values are available, but reliable calorimetric data are not found for this gas. The theoretical results of Touloukian (538), which are also cited in the literatures (132, 575), are considered to be the most reliable and are given heavy weight in this analysis. Another set of theoretical values of Heck (375) and derived values from the P-V-T relations (467, 468) are also given weight as well as a set of correlated values (250). However, other sets of theoretical values (354, 553) and correlated values (78, 374) are given no weight. Also, a set of experimental data obtained by adiabatic expansion (56) is not taken into consideration. The correlation formulas obtained for the specific heat in the real gas state are as follows:

For temperatures between 273 K and 635 K:

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.261531 - 9.32244 \times 10^{-5} T + 1.93514 \times 10^{-7} T^2 - 7.14562 \times 10^{-11} T^3 \quad (3)$$

For temperatures between 635 K and 1500 K:

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.212217 + 8.82394 \times 10^{-5} T - 1.26583 \times 10^{-8} T^2 - 4.68276 \times 10^{-12} T^3 \quad (4)$$

These equations are found to fit the above enumerated values with mean deviations of 0.03 and 0.04 percent, and maximum deviations of 0.17 and 0.09 percent, respectively. The recommended values of C_p are calculated from the above formulas, independently of the values of C_p^0 . The tabulated values should be substantially correct within one percent over the entire temperature range. Equations (3) and (4) are used to calculate the departures of all the values mentioned above in the real gas state, which are shown in the departure plot for $P = 1$ atm. However, three sets of cited values (71, 127, 541), higher temperature data (559) and lower temperature values (216) are not plotted in this figure, as well as several empirical equations (184, 185, 346, 528).

The comparison of Equations (3) and (4) with Equations (1) and (2) is given in the third plot.

TABLE 29 SPECIFIC HEAT AT CONSTANT PRESSURE OF CARBON MONOXIDE (continued)

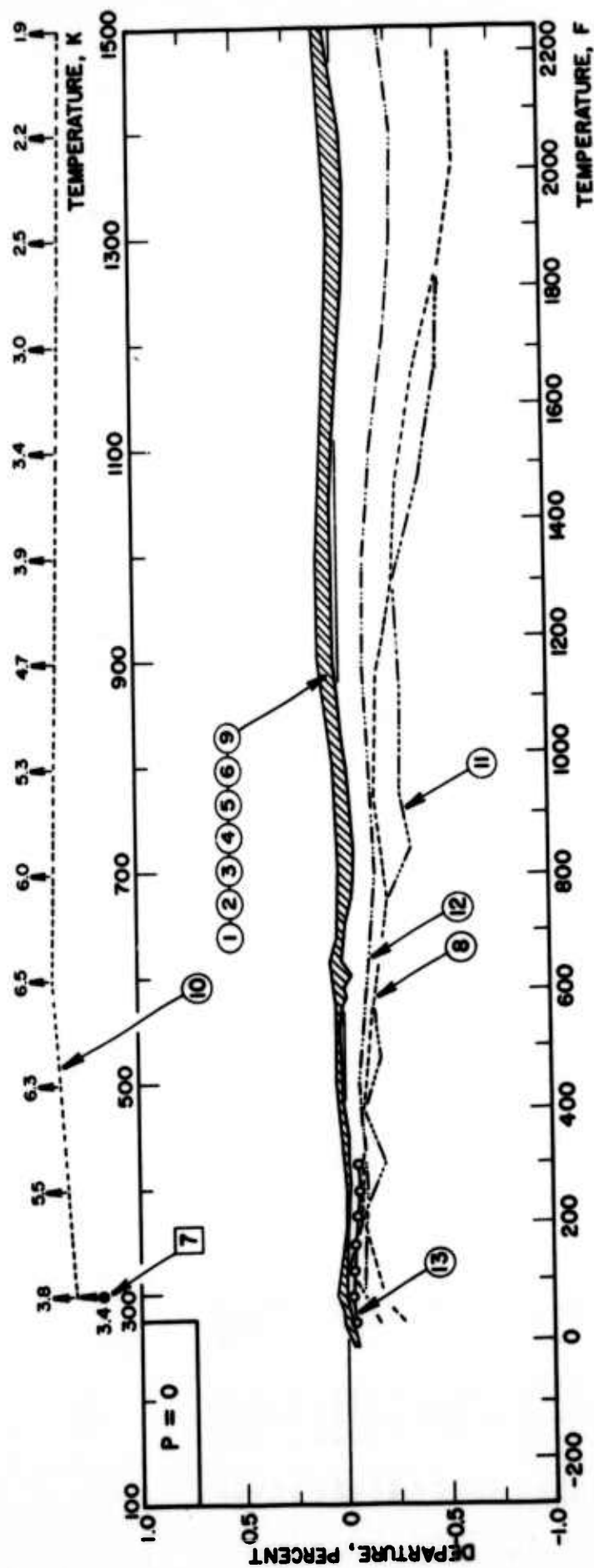
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p^0 and C_p , B lb⁻¹F⁻¹]

GAS

T	C_p^0	C_p	T	C_p^0	C_p
0	0.24835		600	0.25893	0.2590
20	0.24834		620	0.25964	0.2596
40	0.24835	0.2489	640	0.26037	0.2603
60	0.24839	0.2489	660	0.26083	0.2610
80	0.24846	0.2489	680	0.26158	0.2618
100	0.24855	0.2489	700	0.26232	0.2624
120	0.24867	0.2490	720	0.26306	0.2631
140	0.24882	0.2491	740	0.26379	0.2638
160	0.24899	0.2493	760	0.26451	0.2646
180	0.24919	0.2495	780	0.26523	0.2653
200	0.24941	0.2497	800	0.26594	0.2660
220	0.24966	0.2499	820	0.26664	0.2667
240	0.24994	0.2502	840	0.26734	0.2674
260	0.25024	0.2505	860	0.26804	0.2681
280	0.25056	0.2508	880	0.26872	0.2688
300	0.25091	0.2511	900	0.26940	0.2695
320	0.25128	0.2515	920	0.27008	0.2701
340	0.25168	0.2519	940	0.27075	0.2708
360	0.25210	0.2523	960	0.27141	0.2715
380	0.25254	0.2527	980	0.27207	0.2721
400	0.25301	0.2532	1000	0.27272	0.2728
420	0.25350	0.2537	1100	0.27588	0.2759
440	0.25402	0.2542	1200	0.27888	0.2790
460	0.25455	0.2547	1300	0.28172	0.2818
480	0.25511	0.2553	1400	0.28440	0.2845
500	0.25569	0.2558	1500	0.28692	0.2870
520	0.25630	0.2564	1600	0.28926	0.2894
540	0.25692	0.2570	1700	0.29144	0.2916
560	0.25757	0.2577	1800	0.29345	0.2936
580	0.25824	0.2583	1900	0.29528	0.2954
			2000	0.29693	0.2970

FIGURE 29 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS CARBON MONOXIDE



Curve	Reference	Curve	Reference
1	72, 167, 192, 254,	8	24, 278
2	267, 380, 389, 403,	9	59, 285, 395, 501
3	426	10	93
4	137, 575	11	100
5	226	12	404
6	253	13	467, 468
7	351, 362		
	538		
	18		

FIGURE 29 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS CARBON MONOXIDE

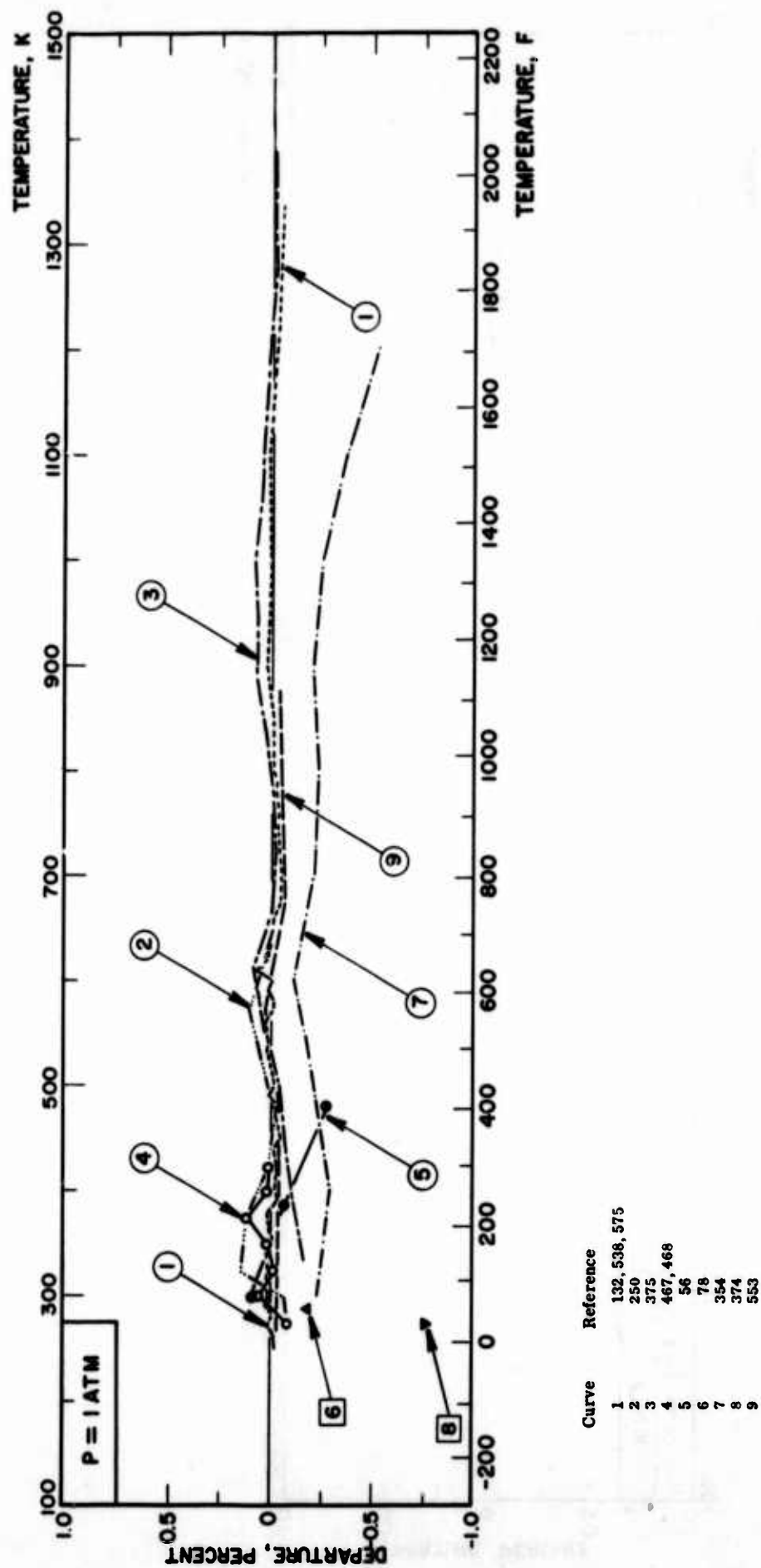


FIGURE 25 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS CARBON MONOXIDE

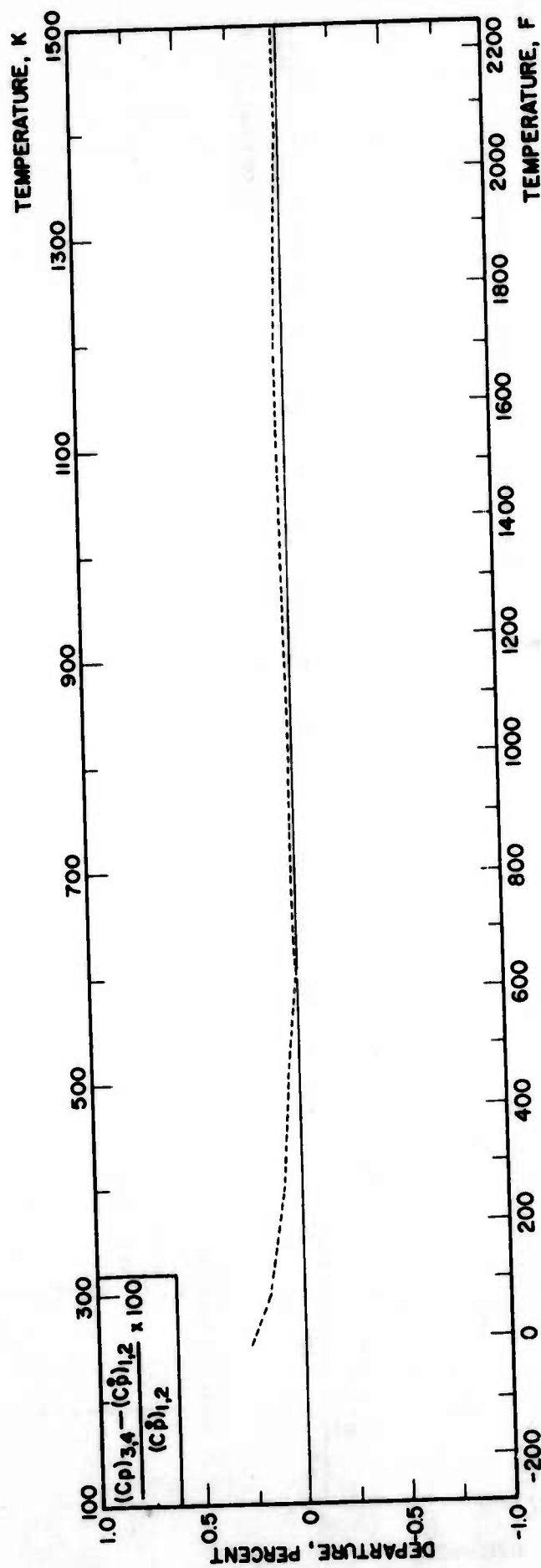


TABLE 30 SPECIFIC HEAT AT CONSTANT PRESSURE OF CARBON TETRACHLORIDE

RECOMMENDED VALUES
[Temperature, T, F; Specific Heat, C_p , B lb⁻¹ F⁻¹]

LIQUID

T	C_p
-40	0.194 [†]
-20	0.198 [†]
0	0.2007
20	0.2024
40	0.2033
60	0.2038
80	0.2043
100	0.2052
120	0.2068
140	0.2096
160	0.2140 [‡]
180	0.220 [‡]
200	0.229 [‡]
220	0.240 [‡]
240	0.254 [‡]

DISCUSSION

LIQUID

There exist 20 sources of information on the specific heat at constant pressure of liquid carbon tetrachloride. Most of the experimental data are concentrated between the n. m. p. and the n. b. p. However, the discrepancy among them is rather small. The recent calorimetric data of Harrison and McElvyn-Hughes (79) and Staveley, et al (199) are considered to be the most reliable in view of their careful experimental procedures. Four sets of experimental data (82, 168, 201, 232) are also thought to be of reasonable accuracy. Therefore, equal weight is given to the above six works in the present analysis. Meanwhile, several experimental works (115, 118, 123, 128, 221, 231, 237), which are considered to be less reliable, are given no weight, as well as a set of correlated values (36) and a set of empirically derived values (216).

The correlation formula obtained between 250 K and 339 K is

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = -0.911601 + 1.15185 \times 10^{-3} T - 3.97844 \times 10^{-5} T^2 + 4.59652 \times 10^{-7} T^3 \quad (T \text{ in K}).$$

This equation is found to fit the 51 data points enumerated above with a mean deviation of 0.5 percent and a maximum of 1.4 percent. The recommended values are computed using the above formula. The tabulated values in the temperature range from 0 F to 140 F should be correct within one percent. Outside this range the uncertainty would increase.

In the departure plot, as a set of empirically derived values (21) shows very large deviation from the above equation. These departures are not plotted, as well as the cited values of (63, 188, 236) and a set of data (42) obtained at 26 atm.

[†] Extrapolated for the liquid phase ignoring pressure dependence (n. m. p. = -9 F).

[‡] Extrapolated for the liquid phase ignoring pressure dependence (n. b. p. = 170 F).

FIGURE 30 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID CARBON TETRACHLORIDE

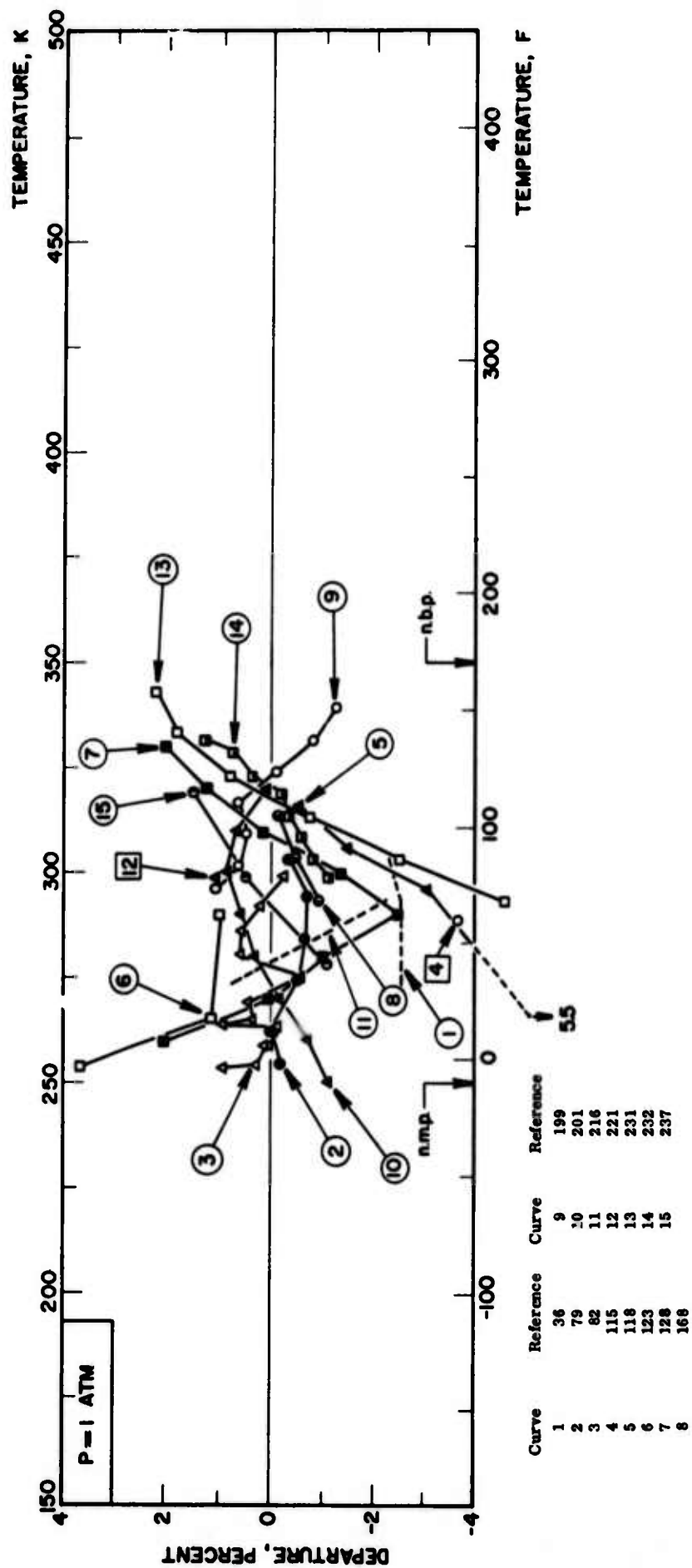


TABLE 30 SPECIFIC HEAT AT CONSTANT PRESSURE OF CARBON TETRACHLORIDE

DISCUSSION

GAS

Twenty-five sources of information are available for the constant pressure specific heat of gaseous carbon tetrachloride. A number of extensive theoretical values for the ideal gas state have been derived from spectroscopic and molecular structural data. The values presented by Albright et al. (2), Bernstein (19), Cerny and Erdos (34,35), Gelles and Pitzer (66), Gordon (73,242), Madigan and Cleveland (130) and McBride et al. (137) are considered to be reliable, as well as the compilation tables (108,113,254). Therefore, equal weight is given to these works in the present analysis. Several sets of earlier statistical calculations (48, 220,236) are given no weight as well as empirically derived values (20,69). The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 100 K and 590 K

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.0223810 + 6.07856 \times 10^{-4}T - 1.01085 \times 10^{-6}T^2 + 6.12155 \times 10^{-10}T^3 \quad (T \text{ in K}), \quad (1)$$

For temperatures between 590 K and 1500 K

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.109265 + 1.26510 \times 10^{-4}T - 9.86439 \times 10^{-8}T^2 + 2.62643 \times 10^{-11}T^3 \quad (T \text{ in K}), \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.35 and 0.34 percent, and maximum deviations of 0.82 and 1.5 percent, respectively. The recommended values are generated using the above formulas. The tabulated values should be substantially correct within 1.5 percent. The percent departures of all the original values mentioned above from the recommended values are plotted in the departure plot for $P = 0$. A set of cited values (216) as well as an empirical equation (197) are not shown in this figure.

Several sets of calorimetric data (58,144, 162,163,165,191) are available for the specific heat in the real gas state over a limited temperature range. Since the discrepancy among these data is rather large, the specific heat in the real gas state, C_p , is calculated by the usual thermodynamic relations, taking into account the ideal gas values, C_p^0 , mentioned above, which are more reliable. The correction for the gas imperfection is calculated using Berthelot's equation of state. Resulting C_p values obtained over the temperature range from 344 K to 478 K are expressed by the following formula:

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.0548174 + 4.39770 \times 10^{-4}T - 7.04750 \times 10^{-7}T^2 + 4.21167 \times 10^{-10}T^3 \quad (T \text{ in K}), \quad (3)$$

The recommended values for C_p are generated using the above equation. The percent departures of all the available data enumerated above from Equation (3) are shown in the departure plot for $P = 1$ atm. The comparison between Equation (3) and Equation (1) is given in the third departure plot.

TABLE 30 SPECIFIC HEAT AT CONSTANT PRESSURE OF CARBON TETRACHLORIDE (continued)

RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p , B lb⁻¹F⁻¹]

GAS				
T	C_p	C_p^l	T	C_p^g
-280	0.0735		500	0.1518
-260	0.0782		520	0.1524
-240	0.0826		540	0.1529
-220	0.0868		560	0.1535
-200	0.0908		580	0.1541
-180	0.0947		600	0.1547
-160	0.0983		620	0.1552
-140	0.1018		640	0.1556
-120	0.1051		660	0.1560
-100	0.1083		680	0.1564
-80	0.1113		700	0.1567
-60	0.1141		720	0.1571
-40	0.1168		740	0.1574
-20	0.1194		760	0.1578
0	0.1218		780	0.1581
20	0.1241		800	0.1584
40	0.1262		820	0.1587
60	0.1283		840	0.1590
80	0.1302		860	0.1592
100	0.1320		880	0.1595
120	0.1337		900	0.1598
140	0.1352		920	0.1600
160	0.1367	0.140	940	0.1602
180	0.1381	0.141	960	0.1605
200	0.1394	0.142	980	0.1607
220	0.1406	0.143	1000	0.1609
240	0.1418	0.144	1100	0.1618
260	0.1429	0.145	1200	0.1625
280	0.1439	0.146	1300	0.1631
300	0.1448	0.146	1400	0.1635
320	0.1457	0.147	1500	0.1639
340	0.1465	0.148	1600	0.1641
360	0.1473	0.149	1700	0.1643
380	0.1480	0.149	1800	0.1645
400	0.1487	0.150	1900	0.1647
420	0.1494		2000	0.1649
440	0.1500			
460	0.1506			
480	0.1512			

n.m.p. = -9 F

n.b.p. = 170 F

FIGURE 30 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS CARBON TETRACHLORIDE

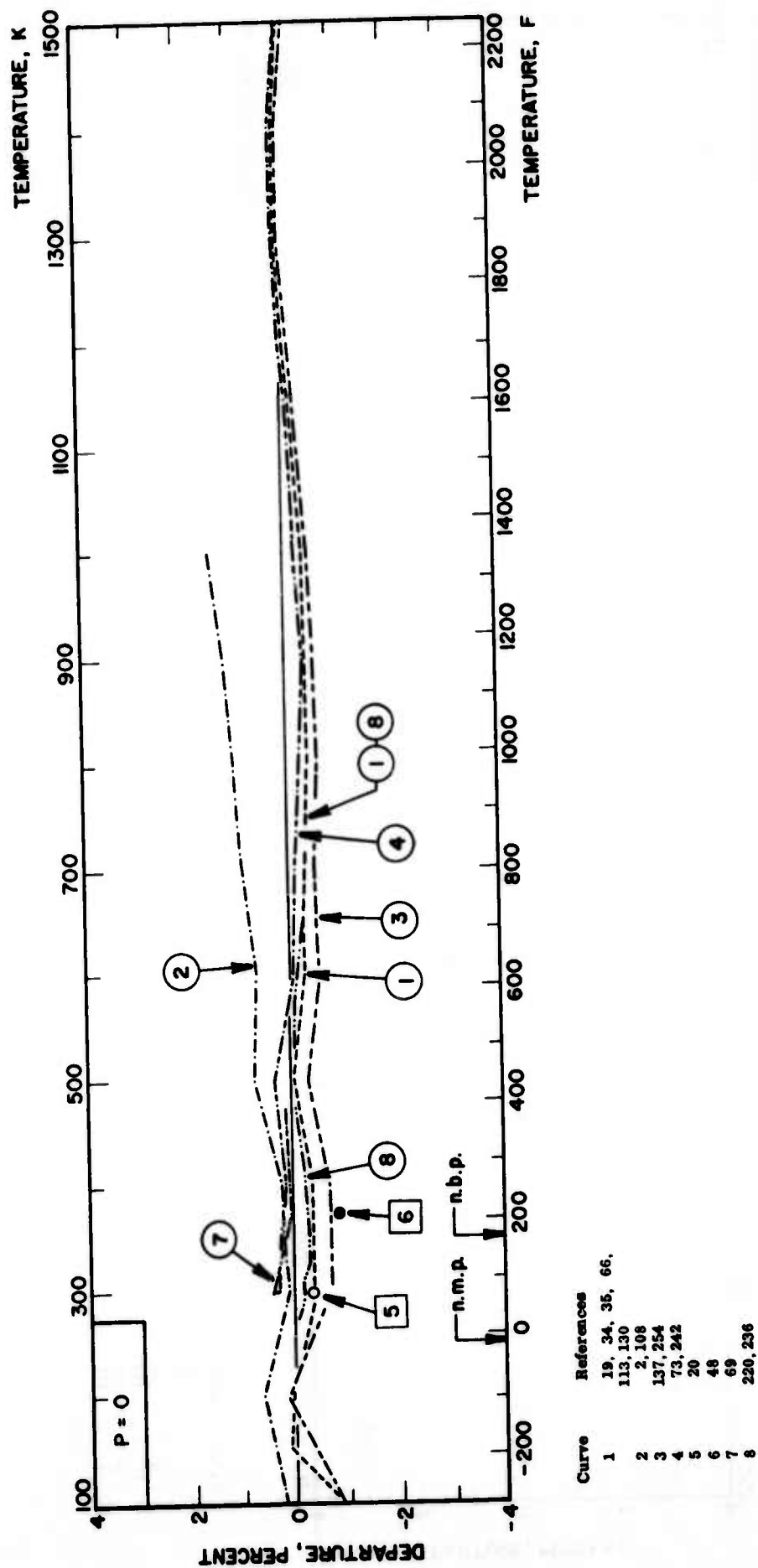


FIGURE 30 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS CARBON TETRACHLORIDE

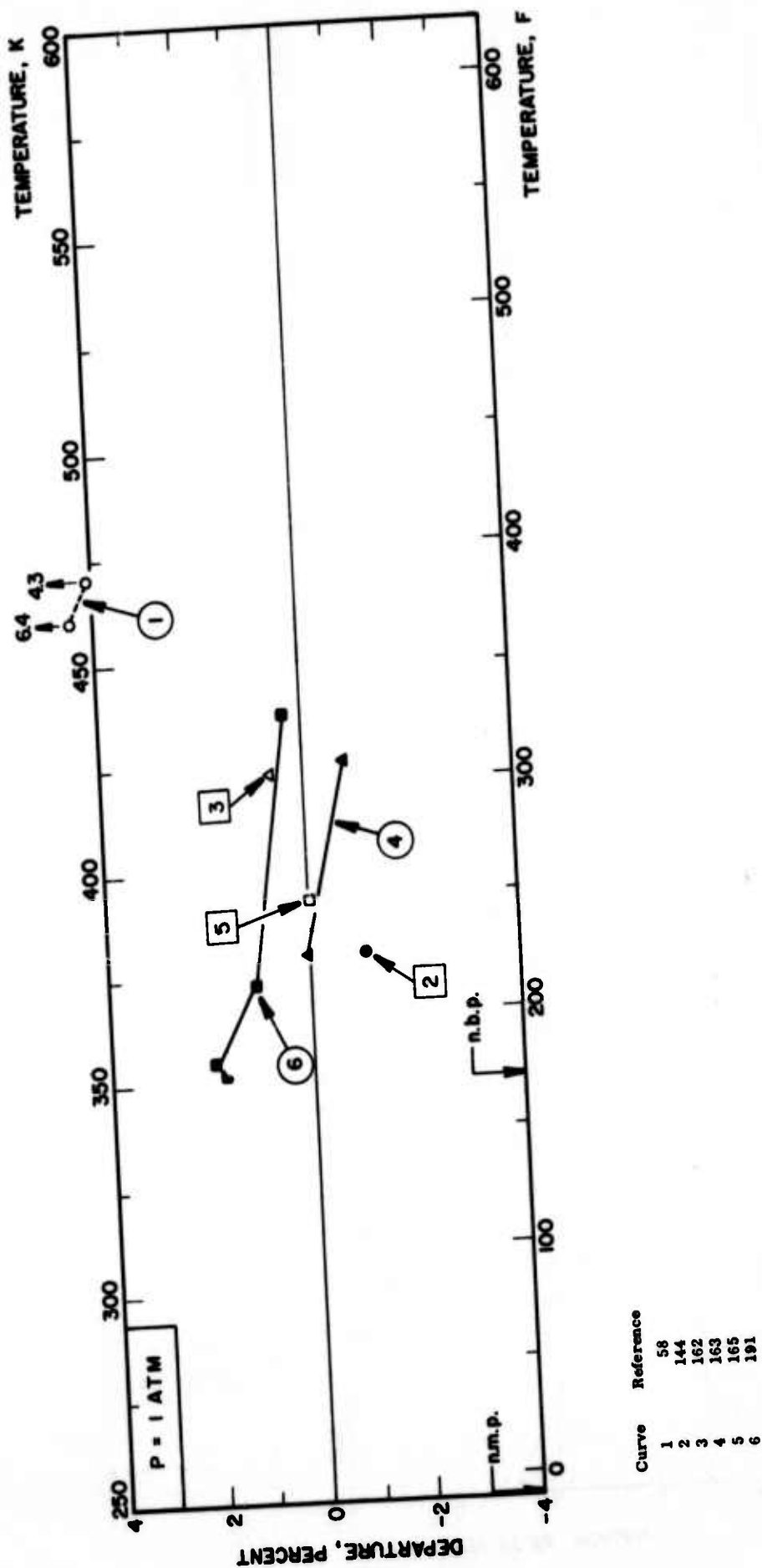


FIGURE 30 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS CARBON TETRACHLORIDE

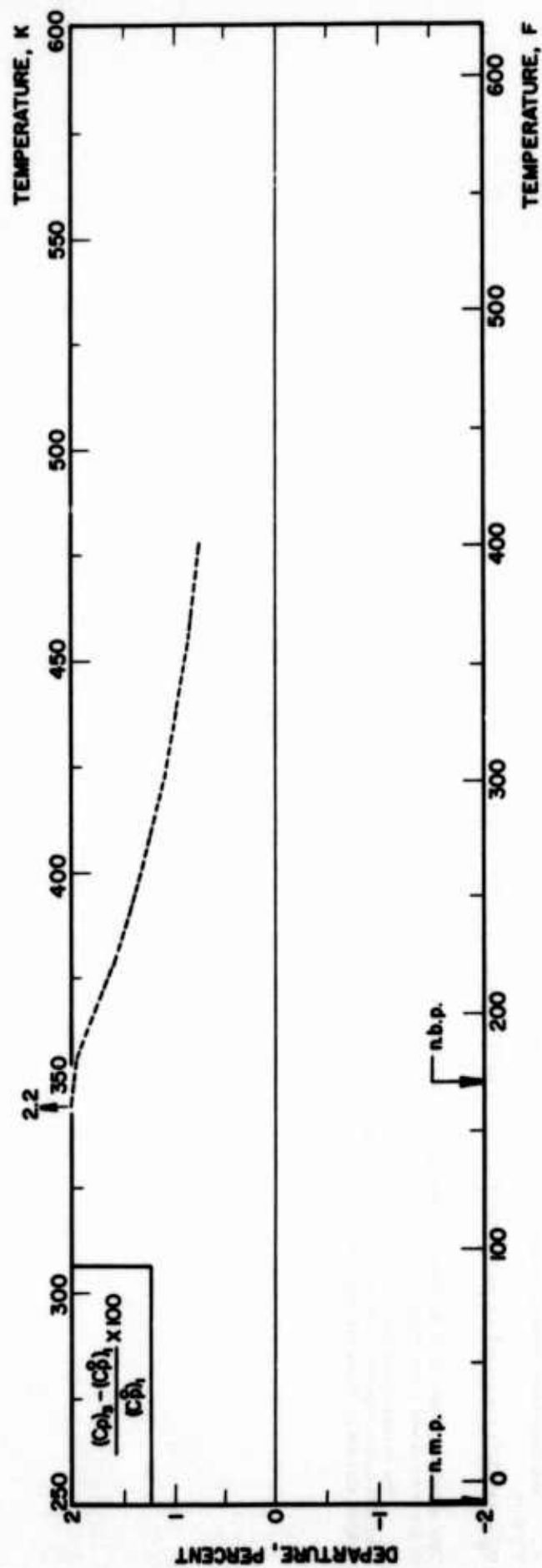


TABLE 31 SPECIFIC HEAT AT CONSTANT PRESSURE OF CHLOROFORM

DISCUSSION

LIQUID

Eight sources of information are available for the specific heat at constant pressure of liquid chloroform. Most of the calorimetric measurements were made between the n. m. p. and the n. b. p. The recent careful determinations by Harrison and MacLennan-Hughes (79) and Staveley et al. (139) are considered to be the most reliable from the standpoint of the purity of specimens and the experimental procedure. Furthermore, experimental data obtained from adiabatic temperature-pressure coefficients by Richards and Wallace (168) seem also reliable in view of the reported accuracy. Therefore, all the data-points reported in the above three works are given equal weight in this analysis. The experimental results of an earlier adiabatic calorimetric measurement (231), of a mixing method (118) and of an expansion method (26) are thought to be less reliable and are given no weight, as well as two sets of correlated results (63, 216) covering a short range of temperature.

The correlation formula obtained in the temperature range from 240 K to 329 K is

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.189615 + 2.66488 \times 10^{-4}T - 1.09053 \times 10^{-6}T^2 + 2.12180 \times 10^{-9}T^3 \quad (T \text{ in K})$$

This equation is found to fit the above 29 experimental data with a mean deviation of 0.4 percent and a maximum of 2.1 percent.

The recommended values are generated by the above equation. The tabulated values should be correct within one percent between -20 F and 140 F. Outside this range the uncertainty would increase.

RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p , B lb⁻¹ F⁻¹]

T	C_p
-40	0.219
-20	0.2201
0	0.2213
20	0.2228
40	0.2243
60	0.2261
80	0.2280
100	0.2301
120	0.2324
140	0.2350
160	0.2382
180	0.2412
200	0.2442

‡ Extrapolated for the liquid phase ignoring pressure dependence (n. b. p. = 142 F).

FIGURE 31 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID CHLOROFORM

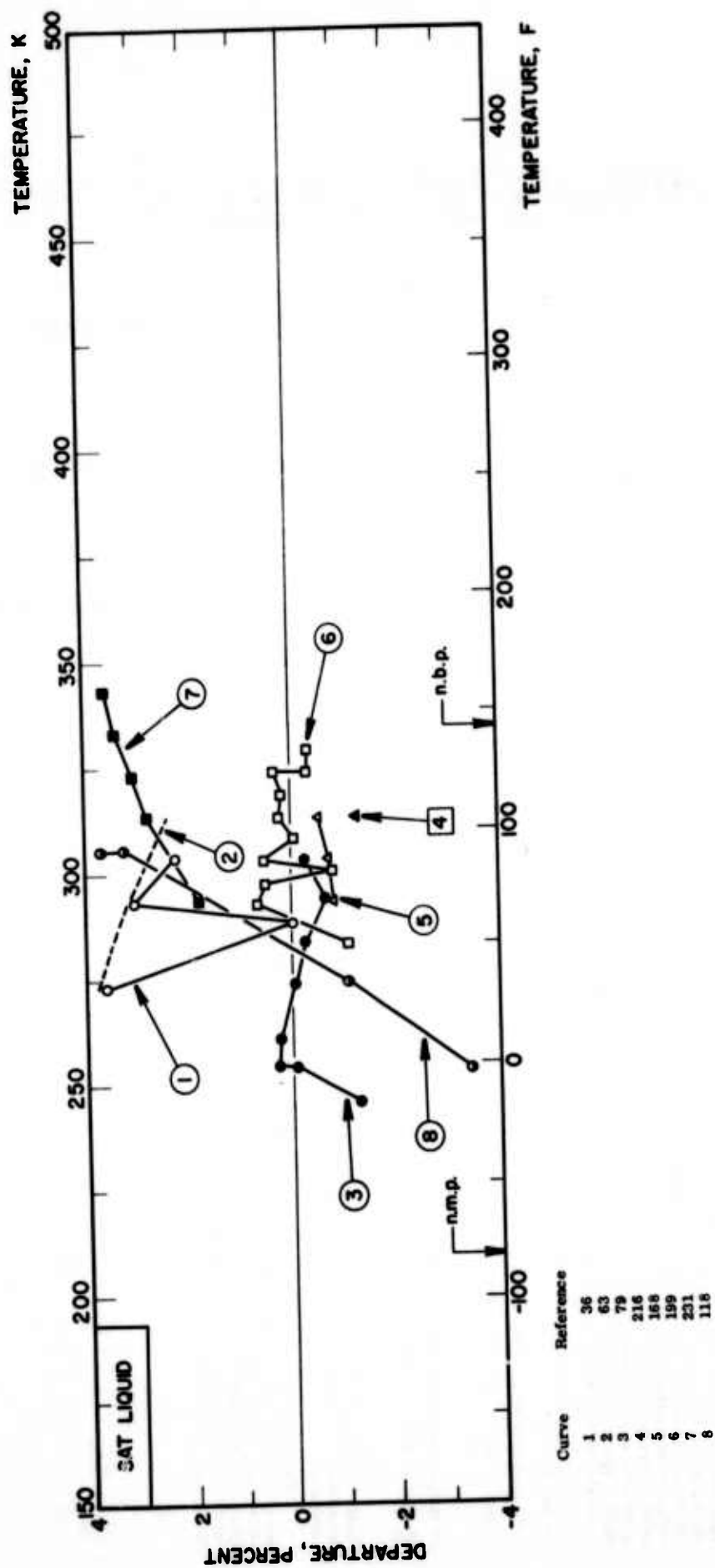


TABLE 31 SPECIFIC HEAT AT CONSTANT PRESSURE OF CHLOROFORM

DISCUSSION

GAS

There exist 10 sources of information for the constant pressure specific heat of gaseous chloroform. A number of derived values from spectroscopic and molecular structural data have been presented covering a wide range of temperature. The extensive results of Cerny and Erdos (34), Gelles and Pitzer (66) and Madigan and Cleveland (130) are thought to be the most reliable in view of the molecular data used. Kobe and Long (113) compiled heat capacity values from various sources covering temperature from 273 K to 1500 K. The latest compilation appeared in JANAF Thermochemical Tables (254) in the temperature range up to 6000 K. Good agreement is found among them. Therefore, all the works cited above are given equal weight in the present analysis. The earlier derived values (220) are given no weight, as well as the values obtained by the additive scheme (20, 69).

The correlation formulas obtained for the specific heat of the ideal gas state are as follows:

For temperatures from 100 K to 590 K:

$$C_p^0 \text{ (cal g}^{-1} \text{ K}^{-1}) = 4.45764 \times 10^{-2} + 3.92388 \times 10^{-4} T - 3.758357 \times 10^{-7} T^2 + 1.217041 \times 10^{-10} T^3 \quad (T \text{ in K})$$

for temperatures from 590 K to 1500 K:

$$C_p^0 \text{ (cal g}^{-1} \text{ K}^{-1}) = 9.74324 \times 10^{-2} + 1.82053 \times 10^{-4} T - 1.14528 \times 10^{-7} T^2 + 2.65931 \times 10^{-11} T^3 \quad (T \text{ in K})$$

These equations are found to fit the above enumerated values with mean deviations of 0.2 and 0.1 percent and a maximum of 0.5 and 0.3 percent, respectively.

The recommended values are generated using the above formulas. The tabulated values should be substantially correct within one percent over the entire temperature range. Spencer and Flannagan (197) presented a heat capacity equation by the correlation of earlier existing values. Their results are not plotted on the departure plot, as well as a set of cited values (236). No direct calorimetric measurements are found in the literature.

RECOMMENDED VALUES			
[Temperature, T, F; Specific Heat, C_p , B lb ⁻¹ F ⁻¹]			
T	C_p^0	T	C_p^0
-280	0.08007*	500	0.1653
-260	0.08359*	520	0.1663
-240	0.08703*	540	0.1673
-220	0.09039*	560	0.1683
-200	0.09366*	580	0.1692
-180	0.09686*	600	0.1700
-160	0.09998*	620	0.1711
-140	0.1030*	640	0.1719
-120	0.1060*	660	0.1727
-100	0.1089*	680	0.1734
-80	0.1117*	700	0.1742
-60	0.1144*	720	0.1749
-40	0.1171*	740	0.1757
-20	0.1197*	760	0.1764
0	0.1222*	780	0.1771
20	0.1247*	800	0.1777
40	0.1271*	820	0.1784
60	0.1294*	840	0.1791
80	0.1316*	860	0.1797
100	0.1338*	880	0.1803
120	0.1359	900	0.1809
140	0.1380*	920	0.1815
160	0.1400	940	0.1821
180	0.1419	960	0.1827
200	0.1438	980	0.1833
220	0.1456	1000	0.1838
240	0.1474	1100	0.1864
260	0.1491	1200	0.1886
280	0.1507	1300	0.1907
300	0.1523	1400	0.1925
320	0.1538	1500	0.1941
340	0.1553	1600	0.1955
360	0.1567	1700	0.1968
380	0.1581	1800	0.1980
400	0.1594	1900	0.1991
420	0.1607	2000	0.2001
440	0.1619		
460	0.1631		
480	0.1642		

* n.b.p. 142 F

FIGURE 31 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS CHLOROFORM

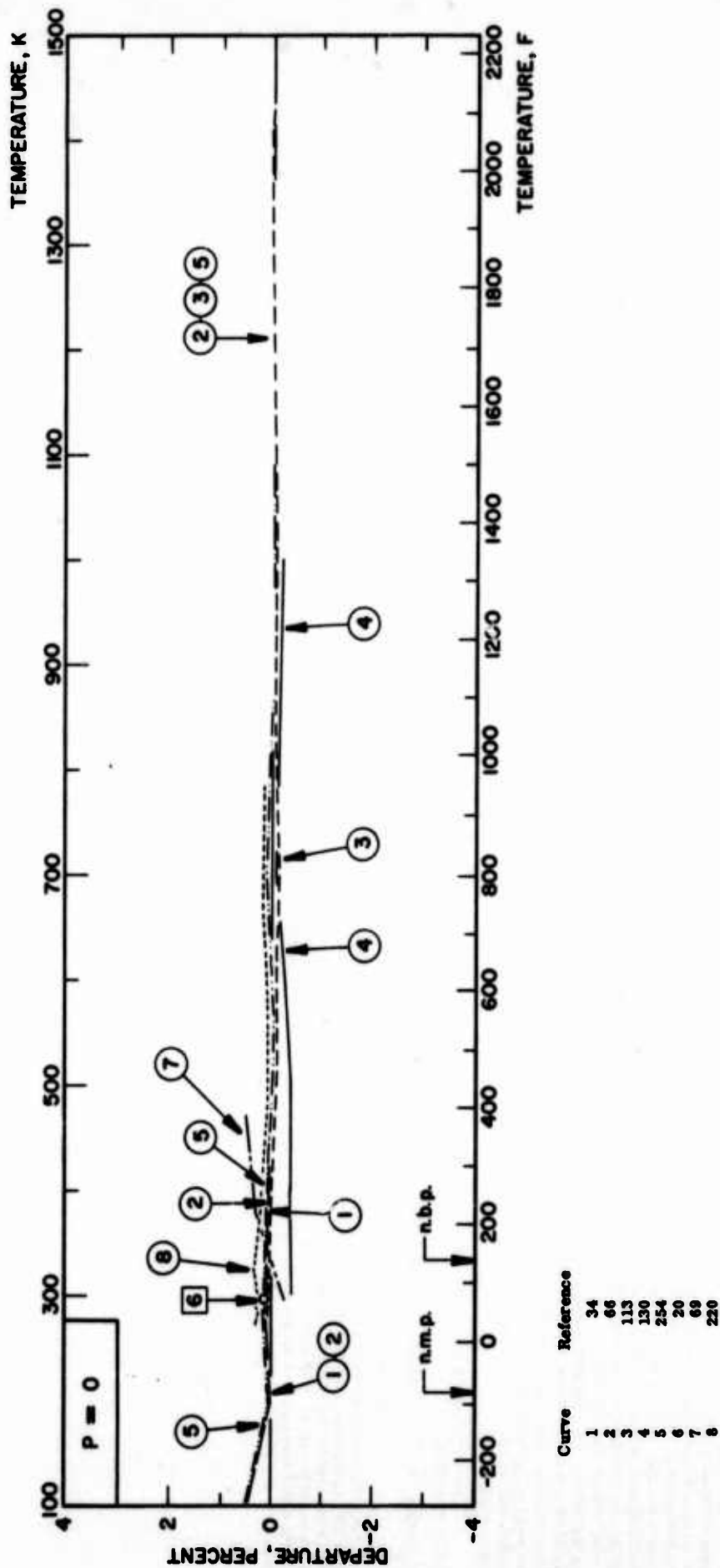


TABLE 32 SPECIFIC HEAT AT CONSTANT PRESSURE OF n-DECANE

RECOMMENDED VALUES		
LIQUID		
[Temperature, T, F; Specific Heat, C_p , B lb ⁻¹ F ⁻¹]		
T	C_p	
-20	0.4970	
0	0.5014	
20	0.5068	
40	0.5131	
60	0.5204	
80	0.5287	
100	0.5380	
120	0.5485	
140	0.560	
160	0.573	
180	0.587	
200	0.602	
220	0.618	

DISCUSSION

LIQUID

Five experimental works are available for the constant pressure specific heat of liquid n-decane. All the data fall within a temperature range between the n.m.p. and the n.b.p. The latest calorimetric measurement, which was made by Finke, et al (61) with a reported error of 0.1 percent using 99.91 mole percent n-decane, is considered to be the most reliable and therefore is given heavy weight in the present analysis. Another careful determination was reported by Osborne and Ginnings (149) with the same accuracy. As the agreement between them is found to be very good, nearly equal weight is also given to the latter. An extensive calorimetric measurement up to 366 K (179) was made at saturation vapor pressure for 99.7 percent n-decane. However, since the trend with temperature is somewhat different from that of (61) and (149), no weight is given to this work. The same holds true for two sets of earlier calorimetric data (87, 153) and a single-point value obtained from an empirical relation (36).

The correlation formula obtained for the temperature range between

245 K and 320 K is

$$C_p (\text{cal g}^{-1} \text{K}^{-1}) = 0.581718 - 8.44526 \times 10^{-4} T + 1.21946 \times 10^{-6} T^2 + 3.37247 \times 10^{-9} T^3 \quad (T \text{ in K}).$$

This equation is found to fit the 35 selected data points with a mean deviation of 0.06 percent and a maximum of 0.1 percent. The recommended values are computed by the above formula. The tabulated values below 120 F are substantially correct within 0.5 percent. Above this temperature the uncertainty would increase. A single-point value (78) is not shown in the departure plot.

FIGURE 32 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID n-DECANE

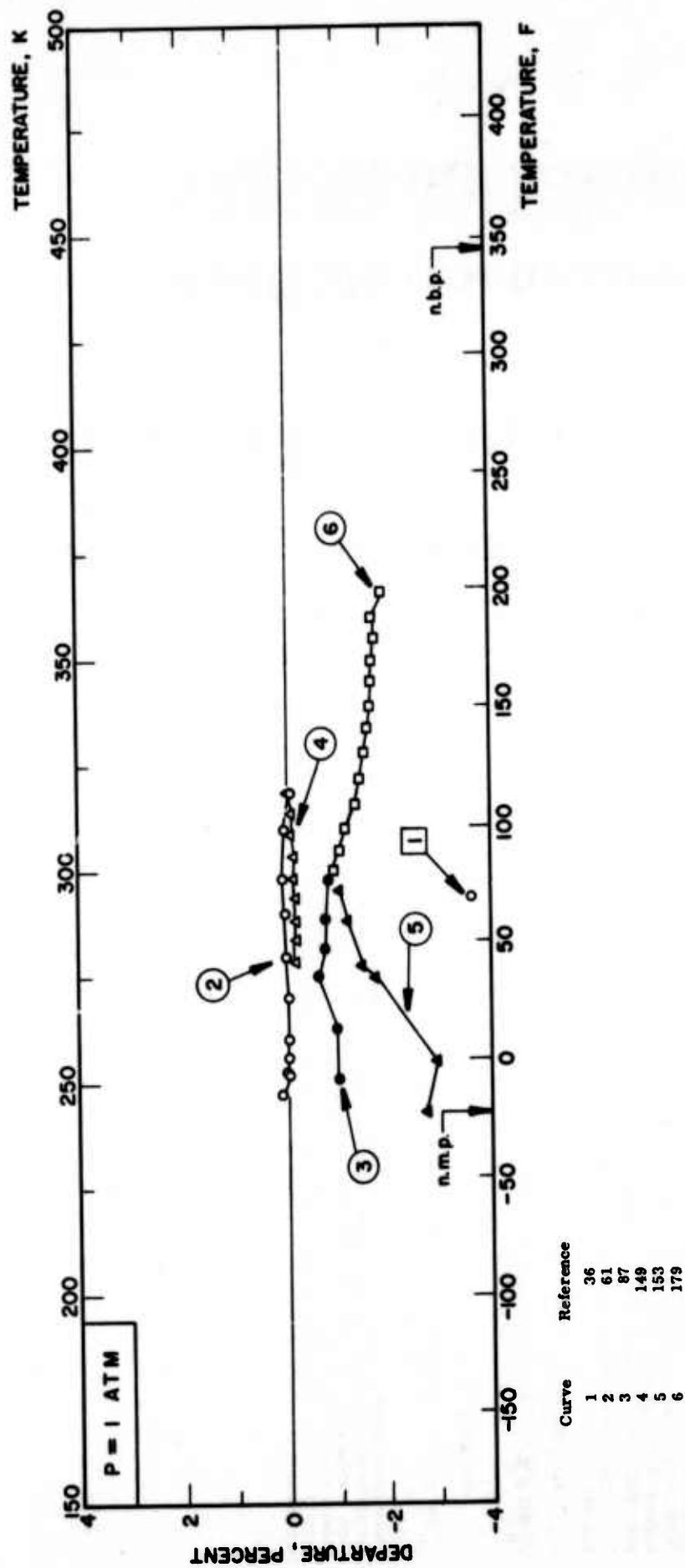


TABLE 32 SPECIFIC HEAT AT CONSTANT PRESSURE OF n-DECANE

DISCUSSION

GAS

Six sources of information are available on the specific heat at constant pressure of n-decane. No calorimetric work at the real gas state is found in the literature. The theoretical values at the ideal gas state have been derived by the statistical calculations from spectroscopic and molecular data. The extensive values of Person and Pimentel (159), Rossini et al. (171) and API Research Project 44 (253) are considered to be reliable, and therefore equal weight is given to these works in this analysis. Two sets of empirically estimated values (133, 134) and a single-point compiled value (76) are given no weight.

The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 298 K and 785 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.0572925 + 1.22049 \times 10^{-3}T - 1.53983 \times 10^{-6}T^2 \quad (1)$$

$$- 2.53576 \times 10^{-10}T^3 \quad (T \text{ in K})$$

For temperatures between 785 K and 1500 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.056093 + 1.41072 \times 10^{-3}T - 6.96289 \times 10^{-7}T^2 \quad (2)$$

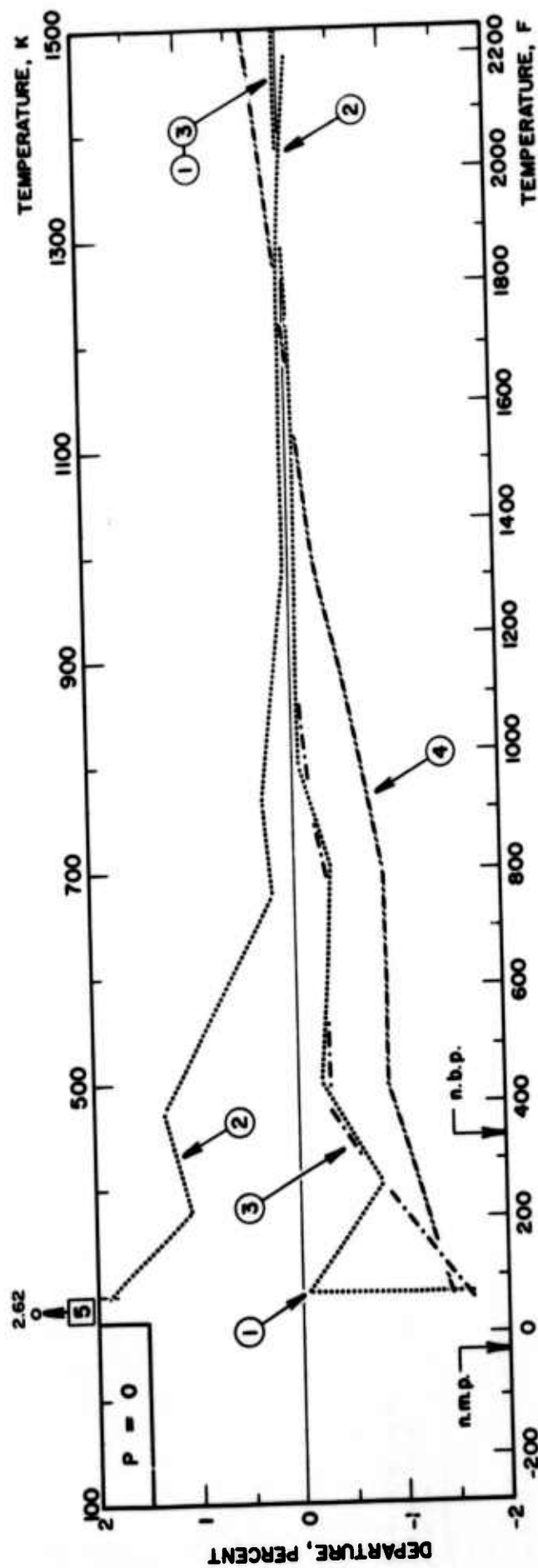
$$+ 1.31224 \times 10^{-10}T^3 \quad (T \text{ in K})$$

These equations are found to fit the above enumerated values with the mean deviations of 0.86 and 0.05 percent and the maximum ones of 1.9 and 0.20 percent, respectively. The above formulas are used to generate the recommended values, which should be substantially correct within two percent. The departure percent of all the values mentioned above from the tabulated recommended values are shown in the departure plot.

RECOMMENDED VALUES			
[Temperature, T, F; Specific Heat, C _p , B lb ⁻¹ F ⁻¹]			
GAS			
T	C _p ^o	T	C _p ^o
80	0.4023	700	0.7114
100	0.4140	720	0.7192
120	0.4256	740	0.7268
140	0.4371	760	0.7342
160	0.4486	780	0.7415
180	0.4599	800	0.7486
200	0.4711	820	0.7555
220	0.4822	840	0.7623
240	0.4932	860	0.7689
260	0.5041	880	0.7753
280	0.5149	900	0.7815
300	0.5256	920	0.7876
320	0.5361	940	0.7935
340	0.5465	960	0.7994
360	0.5568	980	0.8056
380	0.5670	1000	0.8116
400	0.5771	1100	0.8405
420	0.5870	1200	0.8671
440	0.5968	1300	0.8917
460	0.6065	1400	0.9144
480	0.6160	1500	0.9353
500	0.6254	1600	0.9546
520	0.6346	1700	0.9723
540	0.6438	1800	0.9887
560	0.6527	1900	1.0038
580	0.6616	2000	1.0178
600	0.6703		
620	0.6788		
640	0.6872		
660	0.6954		
680	0.7035		

n. b. p. = 344 F

FIGURE 32 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS n-DECANE



Curve	Reference
1	159
2	171
3	253
4	133, 134
5	78

TABLE 33 SPECIFIC HEAT AT CONSTANT PRESSURE OF ETHANE

DISCUSSION

LIQUID

Six sources of information are available for the specific heat at constant pressure of liquid ethane. The early calorimetric data of Eucken and Hauck (55) at temperatures from 100 K to 270 K are thought to be not too reliable because of the impure ethane used. Extensive calorimetric measurements of Wiebe, et al (230) and Witt and Kemp (233) should be more reliable from the standpoint of the experimental procedures and the purity of liquid samples used. Therefore, equal weight is given to the reported data points below 230 K of (230, 233). Above this temperature, the specific heat increases rapidly with increasing temperature up to the critical point. The reported data between 236 K and 295 K (230) are not considered adequate to produce a single correlation equation. Similarly, three sets of correlated values (32, 78, 83) as well as the data of (55), are given no weight.

The correlation formula obtained for the temperature range between 91 K and 230 K is

$$C_p (\text{cal g}^{-1} \text{K}^{-1}) = 0.471189 + 1.57503 \times 10^{-3} T - 1.20173 \times 10^{-5} T^2 + 3.60166 \times 10^{-8} T^3 \quad (T \text{ in K}).$$

This equation is found to fit the above enumerated 69 data points with a mean deviation of 0.3 percent and a maximum of 1 percent. The recommended values are computed from the above equation. The tabulated values should be substantially correct within two percent.

RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p , B lb⁻¹ F⁻¹]

LIQUID	
T	C_p
-300	0.5411
-280	0.5441
-260	0.5468
-240	0.5495
-220	0.5525
-200	0.5561
-180	0.5605
-160	0.5661
-140	0.5732
-120	0.5821
-100	0.5931
-80	0.6063
-60	0.6223
-40	0.6412
-20	0.6634

n. m. p. = -288 ± 11 F

n. b. p. = -127 F

FIGURE 33 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID ETHANE

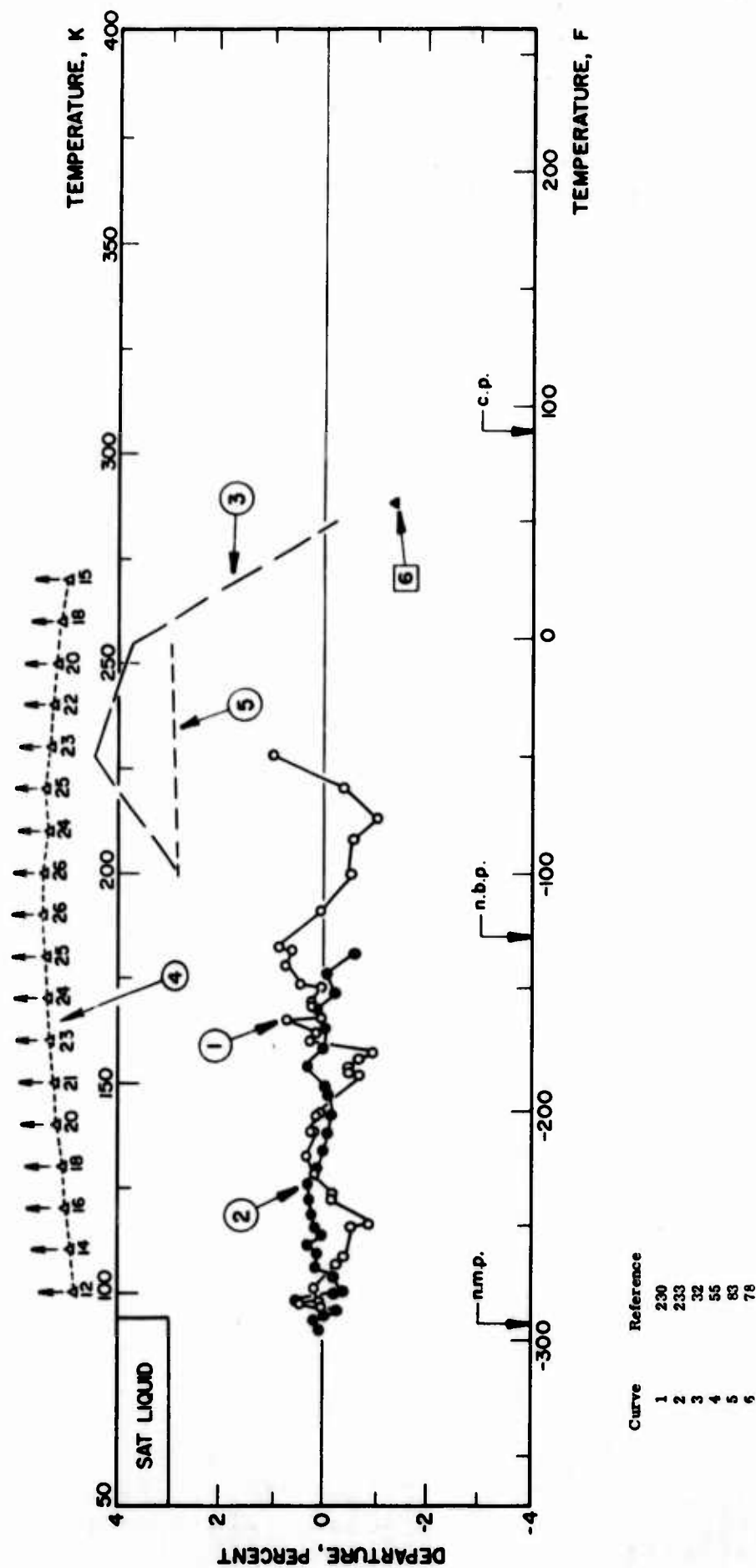


TABLE 33 SPECIFIC HEAT AT CONSTANT PRESSURE OF ETHANE

GAS	RECOMMENDED VALUES		
	[Temperature, T, F; Specific Heat, C _p , B lb ⁻¹ F ⁻¹]		
	T	C _p	T
			GAS
	40	0.3981	700
	60	0.4094	720
	80	0.4207	740
	100	0.4320	760
	120	0.4433	780
	140	0.4545	800
	160	0.4658	820
	180	0.4770	840
	200	0.4882	860
	220	0.4993	880
	240	0.5104	900
	260	0.5215	920
	280	0.5325	940
	300	0.5435	960
	320	0.5544	980
	340	0.5653	1000
	360	0.5761	1100
	380	0.5868	1200
	400	0.5975	1300
	420	0.6081	1400
	440	0.6186	1500
	460	0.6290	1600
	480	0.6394	1700
	500	0.6496	1800
	520	0.6598	1900
	540	0.6699	2000
	560	0.6798	
	580	0.6896	
	600	0.6994	
	620	0.7090	
	640	0.7185	
	660	0.7279	
	680	0.7371	

DISCUSSION

GAS

Thirty-eight sources of information are available for the isobaric specific heat of gaseous ethane. For the heat capacity at the ideal gas state, several sets of extensive tabulations have been derived from spectroscopic and molecular structural data. The values derived by Brickwedde et al. (22), Pitzer (161), Ribaud (167) and Rossini et al. (171) are considered to be the most reliable, as well as the compiled values (59, 109, 253). These values, covering temperatures between 273 K and 1500 K, are given equal weight in this analysis. Some early statistical calculations (99, 203, 213) and several sets of empirically correlated values (18, 24, 127, 133, 134, 222) are given no weight, as well as the extrapolated data to zero pressure from experimental measurements (28, 57, 141). The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 273 K and 780 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.127300 + 8.96790 \times 10^{-6}T + 4.29320 \times 10^{-7}T^2 - 5.10678 \times 10^{-10}T^3 \quad (1)$$

For temperatures between 780 K and 1500 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.0188191 + 1.51573 \times 10^{-5}T - 6.71170 \times 10^{-7}T^2 + 1.12362 \times 10^{-10}T^3 \quad (2)$$

These equations are found to fit the above enumerated data with mean deviations of 0.17 and 0.01 percent and maximum ones of 0.54 and 0.04 percent, respectively. The recommended values are generated by these formulas. The tabulated values should be substantially correct within one percent. In the departure plot at zero pressure, the existing values at the ideal gas state are compared with the above equations. Several empirical equations (184, 195, 196, 197, 205) are not plotted in this figure.

On the other hand, among a number of works for the real gas state, calorimetric data of Dailey (40) and Eucken and Parts (57) are thought to be the most reliable. Furthermore, Din (252) presented the correlated tables of thermodynamic properties and gave heat capacity values between 200 K and 500 K. Good agreement is found among the above three works. Therefore, equal weight is given to these works in this analysis. Some experimental data obtained by a flow calorimeter (212), by P-V-T relations (65, 141, 177), by adiabatic expansion (103) and by velocity of sound (46, 241) are given no weight, as well as the empirically derived values (13, 14, 32, 83, 182) and an early statistical calculation (202). The correlation formula obtained for the real gas state between 189 K and 603 K is

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.326541 - 4.89639 \times 10^{-6}T + 3.53571 \times 10^{-9}T^2 - 2.73616 \times 10^{-13}T^3 \quad (3)$$

This equation fits the above enumerated data with a mean deviation of 0.46 percent and a maximum of 1.9 percent. In the departure plot at one atm, all the reported data for the real gas state are compared with the above equation. In the third departure plot, the interrelation between Equations (1) and (3) is shown over the common temperature range.

FIGURE 33 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS ETHANE

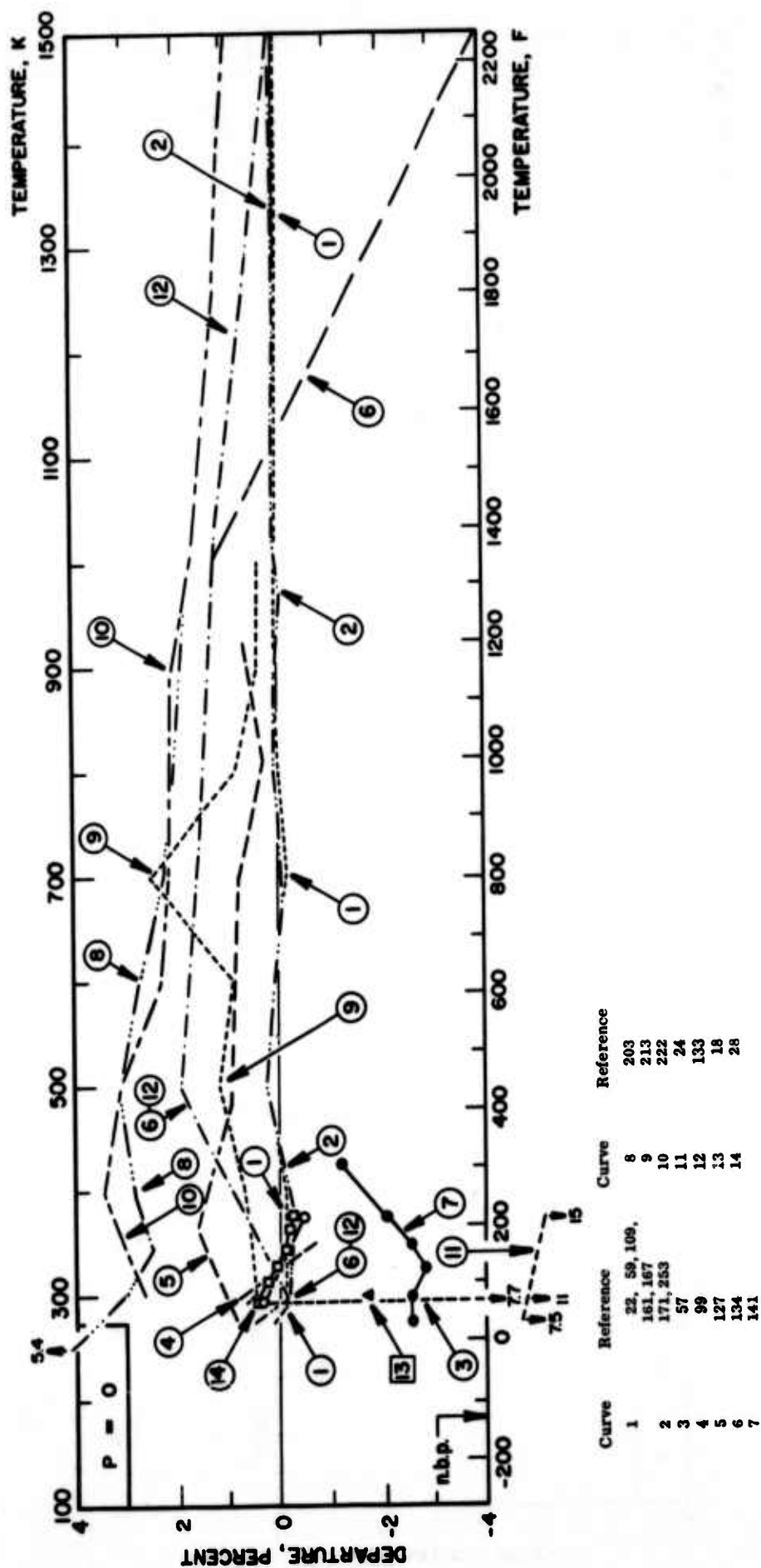
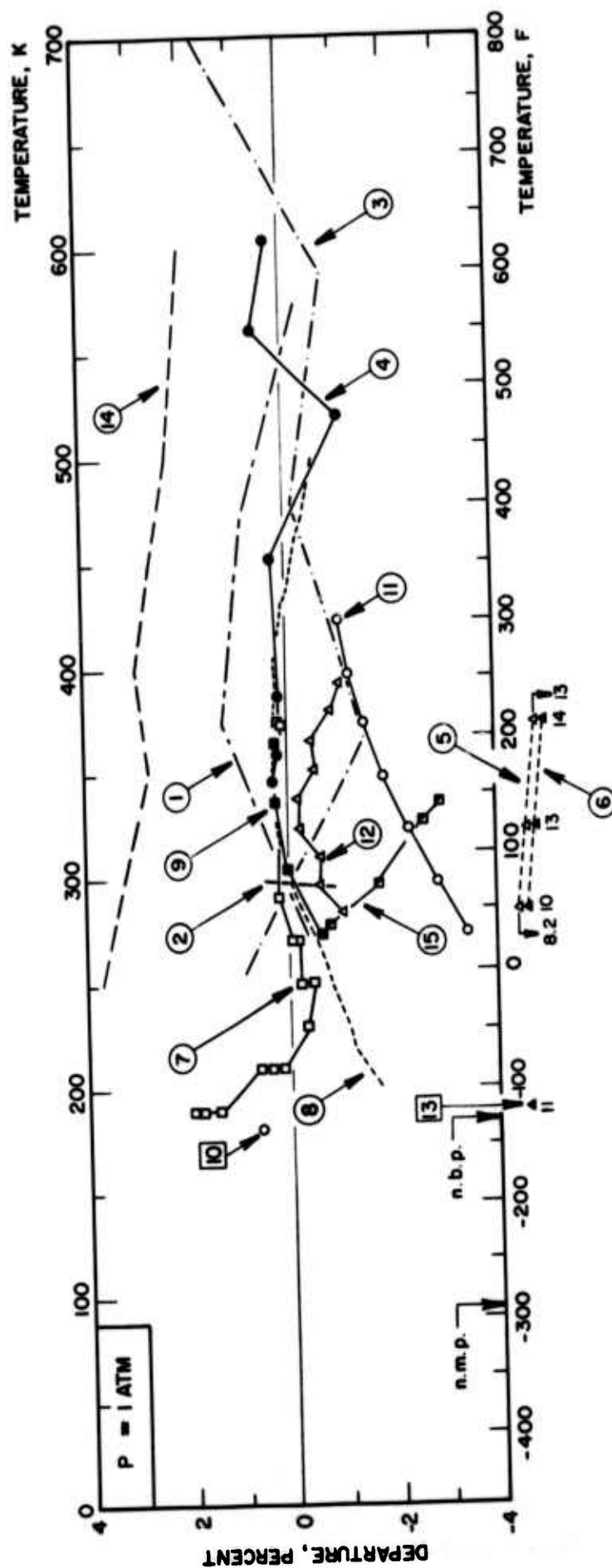


FIGURE 33 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS ETHANE



Curve	Reference	Curve	Reference
1	14	11	141
2	85	12	177
3	32, 83	13	182
4	40	14	202
5	241	15	212
6	46		
7	57		
8	252		
9	103		
10	13		

FIGURE 33 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS ETHANE

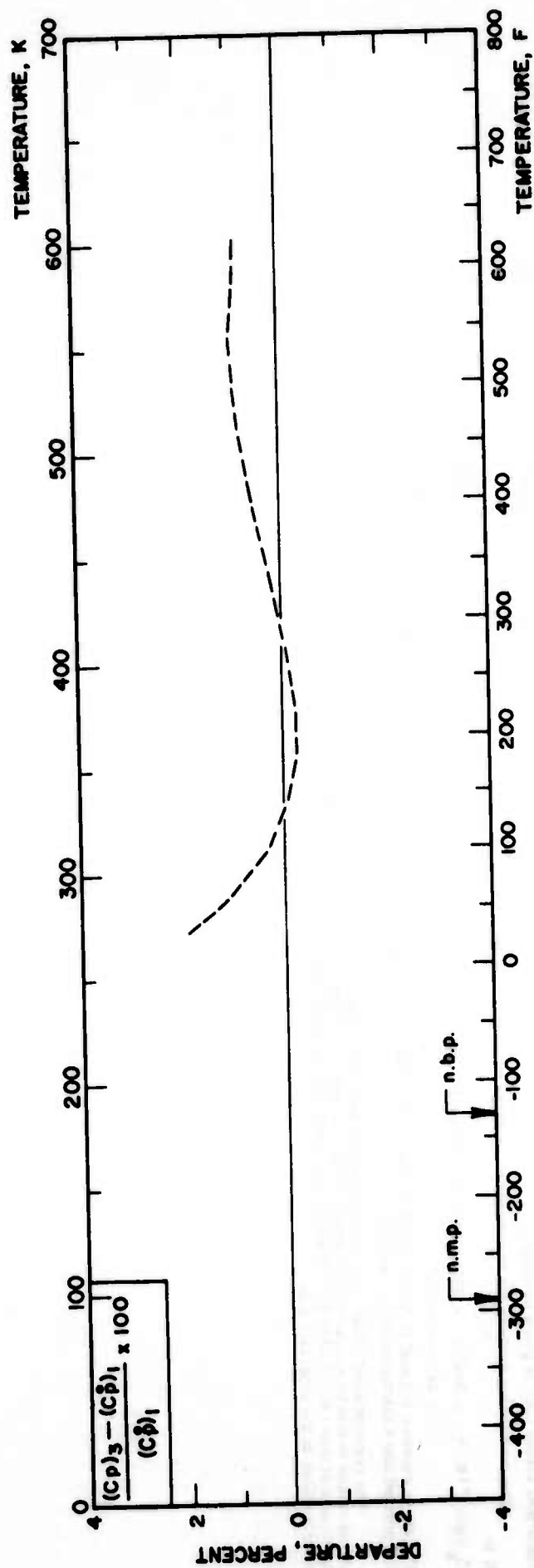


TABLE 34 SPECIFIC HEAT AT CONSTANT PRESSURE OF ETHYL ALCOHOL

DISCUSSION

LIQUID

Five experimental works are available on the constant pressure specific heat of liquid ethyl alcohol over the temperature range between 180 K and 576 K. A careful calorimetric determination reported by Flock, et al (62), covering the temperature range from 313 K to 383 K, at saturation vapor pressures, is considered to be the most reliable in view of the purity of the sample and the reported accuracy of measurements. A set of low temperature data (143) are not so reliable, as well as an earlier calorimetric work (231). Two sets of data (4, 187) at high pressures and temperatures, were also reported for a 95 or 96 percent alcohol solution. No weight is given to these works. Meanwhile, a number of correlations (74, 151, 198) were made of existing data. Among them, the latest work of Green (74) is considered to be the most reasonable. Therefore, the experimental data (62) for temperatures between 313 K and 383 K described above and the correlated values below 313 K are used in the present analysis. A set of empirical values (36) is given no weight.

The correlation formula for the temperature range between 158 K and 383 K is

$$C_p (\text{cal g}^{-1} \text{K}^{-1}) = 0.504351 - 4.81584 \times 10^{-4} T - 9.21631 \times 10^{-7} T^2 + 1.14379 \times 10^{-9} T^3 \quad (T \text{ in K})$$

The above equation is found to fit the selected values with a mean deviation of 0.3 percent and a maximum of 0.7 percent.

The recommended values are computed by the above formula. The tabulated values should be substantially correct within one percent. Three additional sets of data (63, 78, 188) as well as the extensive high pressure data (4) are not shown in the departure plot.

RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p , B lb⁻¹ F⁻¹]

LIQUID

T	C_p	T	C_p
-160	0.4511	100	0.6089
-140	0.4535	120	0.6353
-120	0.4572	140	0.6641
-100	0.4623	160	0.6955 ^{††}
-80	0.4688	180	0.7297
-60	0.4769	200	0.7666 ^{††}
-40	0.4866	220	0.8063 ^{††}
-20	0.4981	240	0.8491 ^{††}
0	0.5114	260	0.8949
20	0.5267		
40	0.5440		
60	0.5634		
80	0.5850		

^{††}n.d.p. = 173 F

FIGURE 34 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID ETHYL ALCOHOL

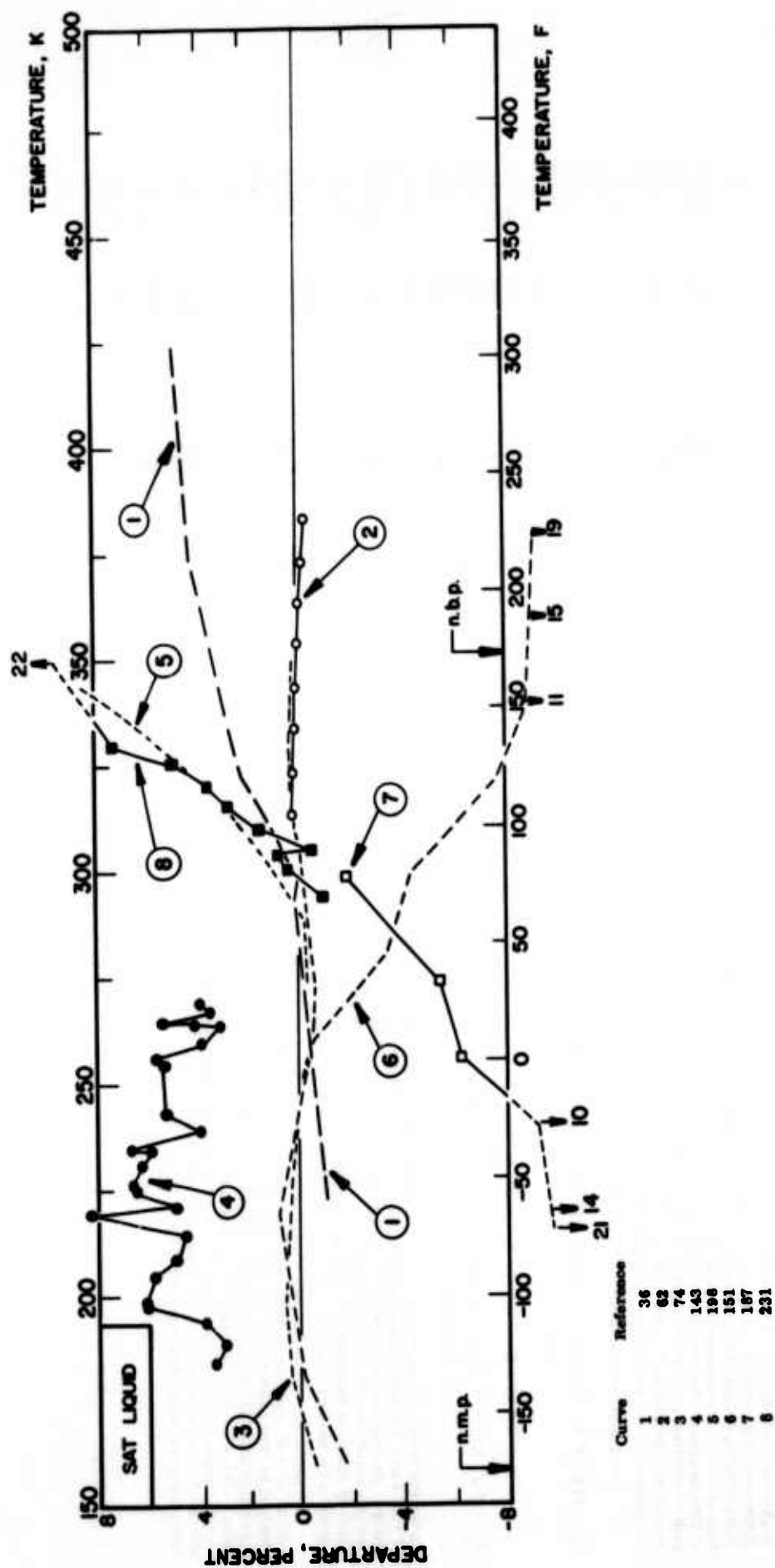


TABLE 34 SPECIFIC HEAT AT CONSTANT PRESSURE OF ETHYL ALCOHOL

DISCUSSION

GAS

Fifteen sources of information are available for the isobaric specific heat of gaseous ethyl alcohol. Concerning the heat capacity at the ideal gas state, three sets of theoretical values, which are derived from spectroscopic and molecular structural data, by Brickwedde et al. (22), Kobe and Pennington (114) and Ribaud (167), are considered to be the most reliable and are given equal weight in this analysis. The results of an early statistical calculation (235) and a recent correlation (74) are thought to be less reliable, and are given no weight, as well as a single point value from empirical correlation (18). The correlation formulas obtained for the ideal gas specific heat are as follows;

For temperatures between 273 K and 785 K:

$$C_p^0 (\text{cal g}^{-1} \text{K}^{-1}) = 0.131122 + 9.18566 \times 10^{-4} T - 2.35957 \times 10^{-7} T^2 - 7.19165 \times 10^{-11} T^3, \quad (1)$$

For temperatures between 785 K and 1500 K:

$$C_p^0 (\text{cal g}^{-1} \text{K}^{-1}) = 0.136067 + 9.84955 \times 10^{-4} T - 4.44996 \times 10^{-7} T^2 + 7.63654 \times 10^{-11} T^3, \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.07 and 0.004 percent and maximum ones of 0.20 and 0.01 percent, respectively. The recommended values, which should be correct within 0.5 percent, are generated from the above equations. In the departure plot at $p = 0$, all the existing values at the ideal gas state are compared with the above equations. Empirical equations (151, 195, 197) are not shown in this figure.

Meanwhile, several experimental works are available for the specific heat at the real gas state. Large discrepancies are found between the results obtained by flow calorimetry (11, 191) and by velocity of sound (46, 90). As correlated data (48, 78) are thought to be less reliable no great weight can be given to these values. Because of the difficulty to resolve these discrepancies, no correlation formula is presented for the real gas specific heat. All the available works enumerated above are compared with Equation (1) for the ideal gas state, as given in the departure plot of $p = 1$ atm.

RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p , Btu ¹ F ⁻¹]			
GAS			
T	C_p^0	T	C_p^0
0	0.3489	600	0.5751
20	0.3576	620	0.5813
40	0.3661	640	0.5875
60	0.3747	660	0.5935
80	0.3831	680	0.5995
100	0.3915	700	0.6054
120	0.3998	720	0.6111
140	0.4080	740	0.6168
160	0.4162	760	0.6224
180	0.4242	780	0.6279
200	0.4322	800	0.6333
220	0.4402	820	0.6386
240	0.4480	840	0.6439
260	0.4558	860	0.6490
280	0.4634	880	0.6540
300	0.4711	900	0.6589
320	0.4786	920	0.6637
340	0.4860	940	0.6685
360	0.4934	960	0.6731
380	0.5006	980	0.6778
400	0.5078	1000	0.6824
420	0.5149	1100	0.7046
440	0.5220	1200	0.7253
460	0.5289	1300	0.7445
480	0.5358	1400	0.7624
500	0.5425	1500	0.7790
520	0.5492	1600	0.7944
540	0.5558	1700	0.8086
560	0.5623	1800	0.8218
580	0.5687	1900	0.8340
		2000	0.8454

n.b.p. = 173 F

FIGURE 34 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS ETHYL ALCOHOL

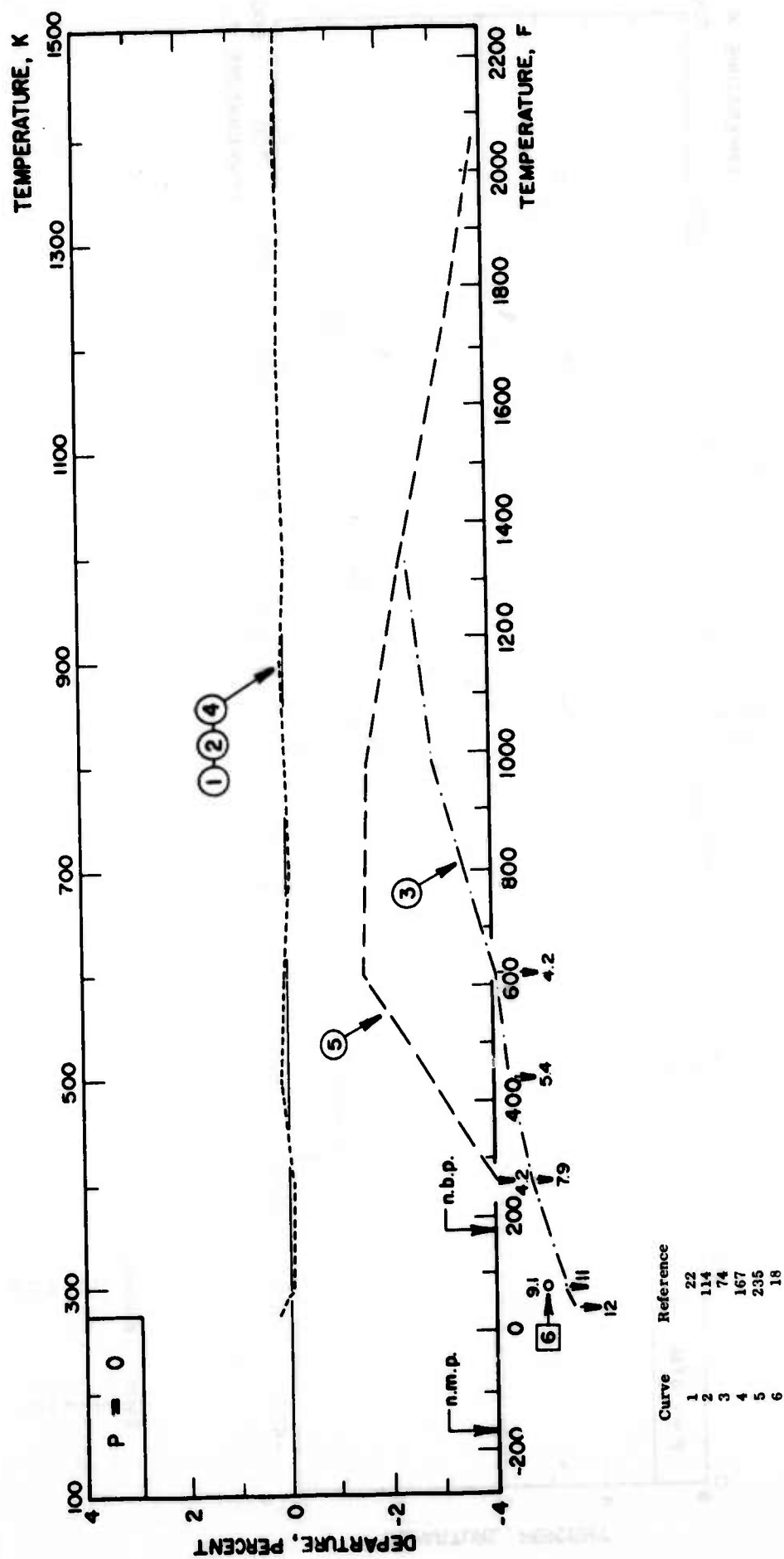
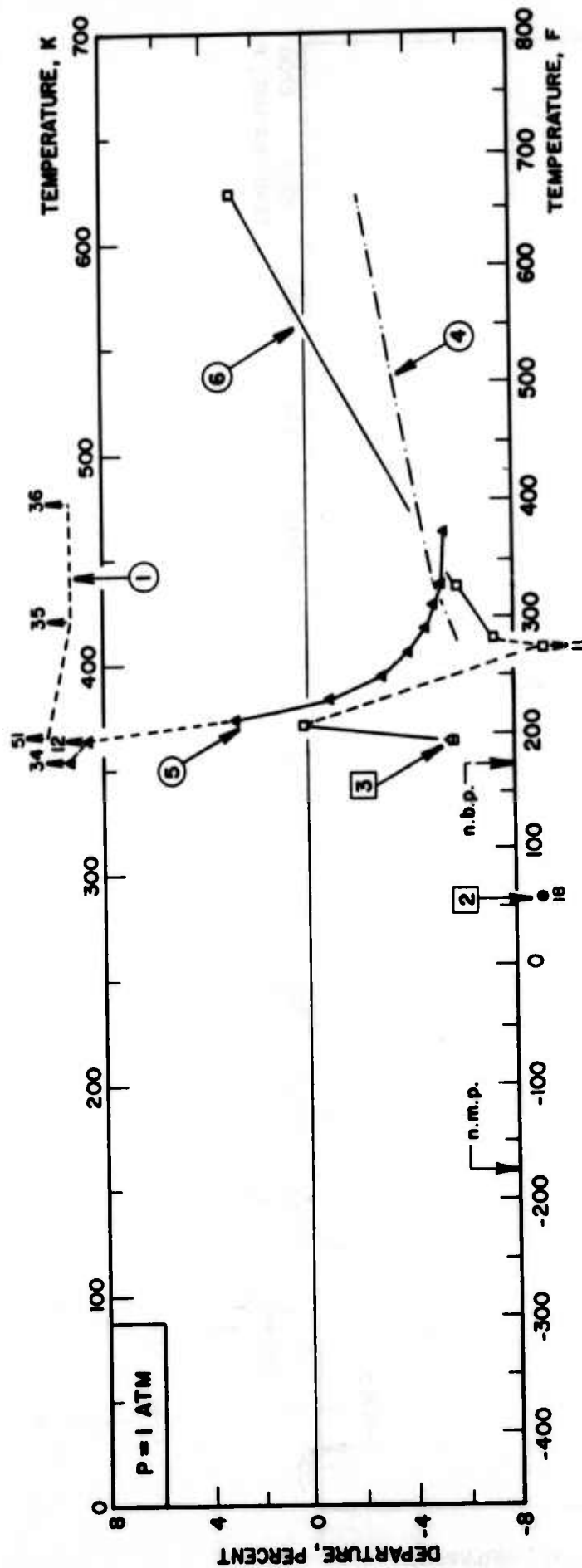


FIGURE 34 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS ETHYL ALCOHOL



Curve	Reference
1	11
2	78
3	46
4	48
5	191
6	90

TABLE 35 SPECIFIC HEAT AT CONSTANT PRESSURE OF ETHYLENE

DISCUSSION		RECOMMENDED VALUES	
LIQUID		LIQUID	
[Temperature, T, F; Specific Heat, C _p , B lb ⁻¹ F ⁻¹]		[Temperature, T, F; Specific Heat, C _p , B lb ⁻¹ F ⁻¹]	
T	C _p †	T	C _p †
-280	0.5914	-280	0.5914
-260	0.5861	-260	0.5861
-240	0.5811	-240	0.5811
-220	0.5766	-220	0.5766
-200	0.5733	-200	0.5733
-180	0.5717	-180	0.5717
-160	0.5722‡	-160	0.5722‡
-140	0.5753‡	-140	0.5753‡
-120	0.5816	-120	0.5816

DISCUSSION

LIQUID

Three sets of experimental works are available for the specific heat at constant pressure of liquid ethylene. In the temperature range from the n.m.p. to the n.b.p., the careful calorimetric measurements of Egan and Kemp (53) are considered to be the most reliable in view of the purity of sample used and of the experimental procedure employed. Another work in the same temperature range is that of Eucken and Hauck (55). However, their results are thought to be less reliable as found in measurements reported for other substances. The reported data of Eucken and Hauck are from three to 17 percent higher than those of Egan and Kemp. Therefore, no weight is given to the data of Eucken and Hauck in this analysis. Pall and Maass (150) made measurements of specific heat of ethylene near the critical point. Between 281.9 K and 282.5 K, below the critical point, they reported several data points at a constant density of 0.2255 g cm⁻³. Since it would be difficult to extrapolate these data down to the n.b.p., no weight is given to this work.

The formula correlating the 20 data points presented by Egan and Kemp

$$(53) \text{ is as follows: } C_p (\text{cal g}^{-1} \text{K}^{-1}) = 0.562894 + 1.64465 \times 10^{-3} T - 1.96469 \times 10^{-5} T^2 + 6.07683 \times 10^{-8} T^3 \quad (T \text{ in K}).$$

This equation is found to be able to reproduce the data with a mean deviation of 0.07 percent and a maximum of 0.16 percent in the temperature range from 105 K to 170 K.

The recommended values are computed from the above equation. The tabulated values between -280 F and -120 F should be correct within 0.2 percent. The applicability of the above equation up to higher temperature is unknown, and the results of Pall and Maass (150) are not shown in the departure plot.

† Extrapolated for the liquid phase ignoring pressure dependence (n.m.p. = -273 F).

‡ Extrapolated for the liquid phase under saturation vapor pressure ignoring pressure dependence (n.b.p. = -155 F).

FIGURE 35 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID ETHYLENE

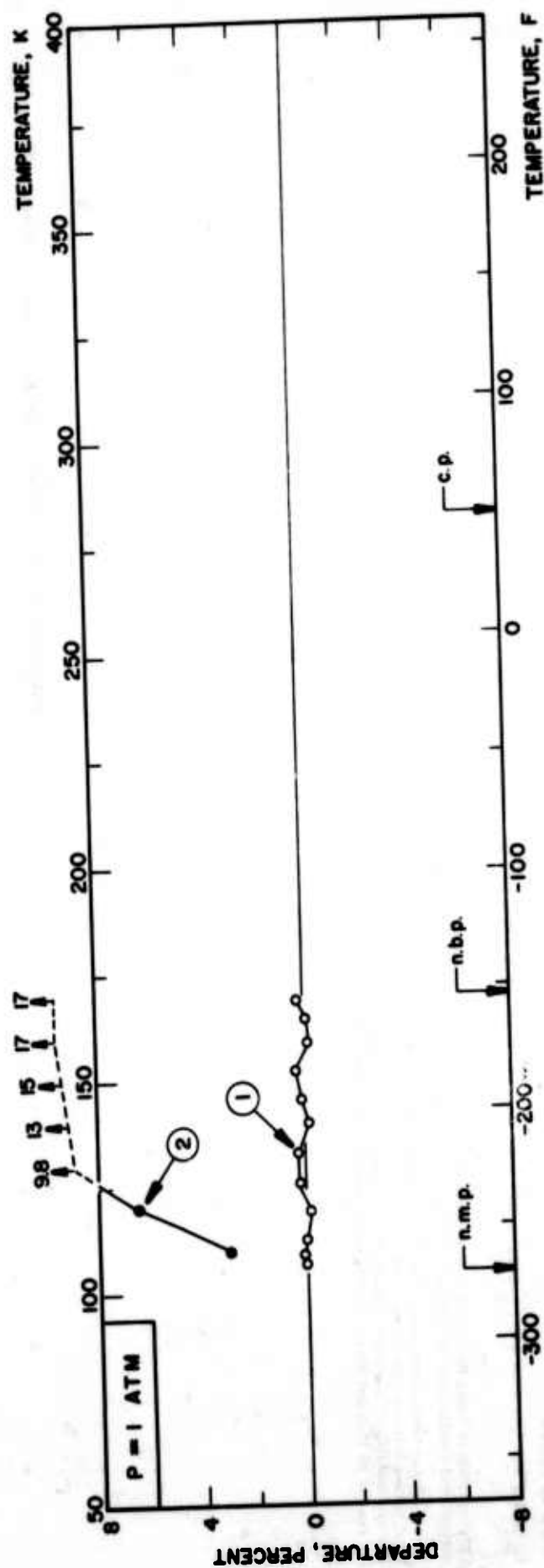


TABLE 35 SPECIFIC HEAT AT CONSTANT PRESSURE OF ETHYLENE

DISCUSSION

GAS

Thirty-three sources of information are available for the isobaric specific heat of gaseous ethylene. Among a number of works on the heat capacity in the ideal gas state, several sets of extensive values have been derived from spectroscopic and molecular data. The results of Brickwedde et al. (22), Kilpatrick and Pitzer (101), Ribaud (168) and Rossini et al. (171), are felt to be the most reliable as well as the compiled tables (59, 72, 112, 137, 253). These values are given equal weight in this analysis. Some early statistical calculations (93, 203, 213, 222) and three sets of empirically derived values (18, 24, 133) are given no weight, as well as the extrapolated data to zero pressure from experimental results (15, 30, 57, 140). The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures from 273 K to 785 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.0594797 + 1.16218 \times 10^{-3}T - 3.74170 \times 10^{-7}T^2 - 5.78817 \times 10^{-11}T^3 \quad (T \text{ in K}), \quad (1)$$

For temperatures from 785 K to 1500 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.103519 + 1.12042 \times 10^{-3}T - 5.06926 \times 10^{-7}T^2 + 8.79117 \times 10^{-11}T^3 \quad (T \text{ in K}), \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.10 and 0.06 percent and maximum deviations of 0.28 and 0.13 percent, respectively. The recommended values are generated from the above equations. The tabulated values should be substantially accurate to within one percent. In the departure plot for $P = 0$ all the existing values of the ideal gas state are compared with the above equations. Several empirical equations (184, 195, 197) are not plotted in this figure, as well as a set of cited values (236).

With regards to the specific heat of the real gas, calorimetric data of Eucken and Parts (57) and results derived from P-V-T measurements of Michels et al. (140) are considered to be reliable from the standpoint of the experimental procedures used. Din (251) presented heat capacity values between 273 K and 423 K. Some sets of data obtained by flow calorimetry (15, 77) and from velocity of sound measurements (46) are thought to be less reliable, as well as certain empirically derived values (14, 85, 202).

However, these data are not always found to be realistic in comparison with the values for the ideal gas state. In general, the theoretical values for the ideal gas state are thought to be more reliable than the calorimetric data obtained for the real gas. Therefore, the specific heat of the real gas, C_p , was computed using the ideal gas values, C_p^0 , and a correction for gas imperfection was applied, using the usual thermodynamic relations and the Berthelot's equation of state. The resulting C_p values for temperatures from 178 K to 610 K are fitted to the following equation:

$$C_p^1 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.111919 + 8.27703 \times 10^{-4}T + 3.44484 \times 10^{-7}T^2 - 5.69197 \times 10^{-10}T^3 \quad (T \text{ in K}), \quad (3)$$

The recommended values of C_p are generated by the above formula. In the departure plot at $P = 1$ atm, all the reported data for the real gas state enumerated above are compared with Equation (3). Furthermore, the comparison between C_p given by Equation (3) and C_p^0 as given by Equation (1) over their common temperature range is shown in the third departure plot.

TABLE 35 SPECIFIC HEAT AT CONSTANT PRESSURE OF ETHYLENE (continued)

RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p , B lb⁻¹F⁻¹]

GAS			
T	C_p	T	C_p
40	0.3518	700	0.6370
60	0.3622	720	0.6437
80	0.3725	740	0.6503
		760	0.6567
		780	0.6631
100	0.3827	800	0.6693
120	0.3928	820	0.6754
140	0.4027	840	0.6813
160	0.4126	860	0.6872
180	0.4224	880	0.6929
200	0.4320	900	0.6985
220	0.4416	920	0.7039
240	0.4510	940	0.7093
260	0.4603	960	0.7145
280	0.4695	980	0.7199
300	0.4787	1000	0.7252
320	0.4877	1100	0.7504
340	0.4965	1200	0.7740
360	0.5053	1300	0.7960
380	0.5140	1400	0.8164
400	0.5225	1500	0.8354
420	0.5310	1600	0.8530
440	0.5393	1700	0.8693
460	0.5475	1800	0.8845
480	0.5556	1900	0.8996
500	0.5636	2000	0.9117
520	0.5715		
540	0.5792		
560	0.5869		
580	0.5944		
600	0.6018		
620	0.6091		
640	0.6162		
660	0.6233		
680	0.6302		

FIGURE 35 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS ETHYLENE

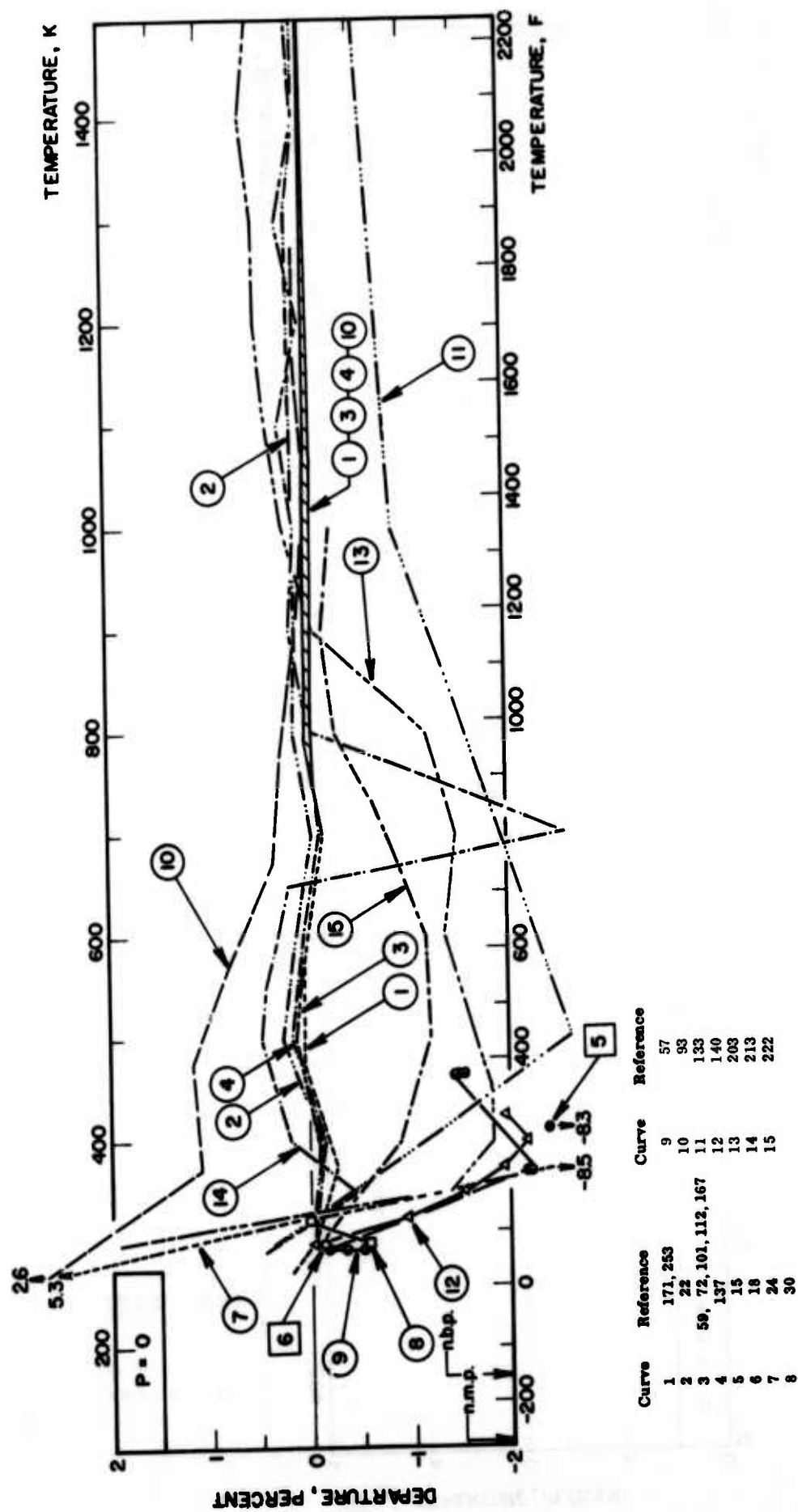


FIGURE 35 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS ETHYLENE

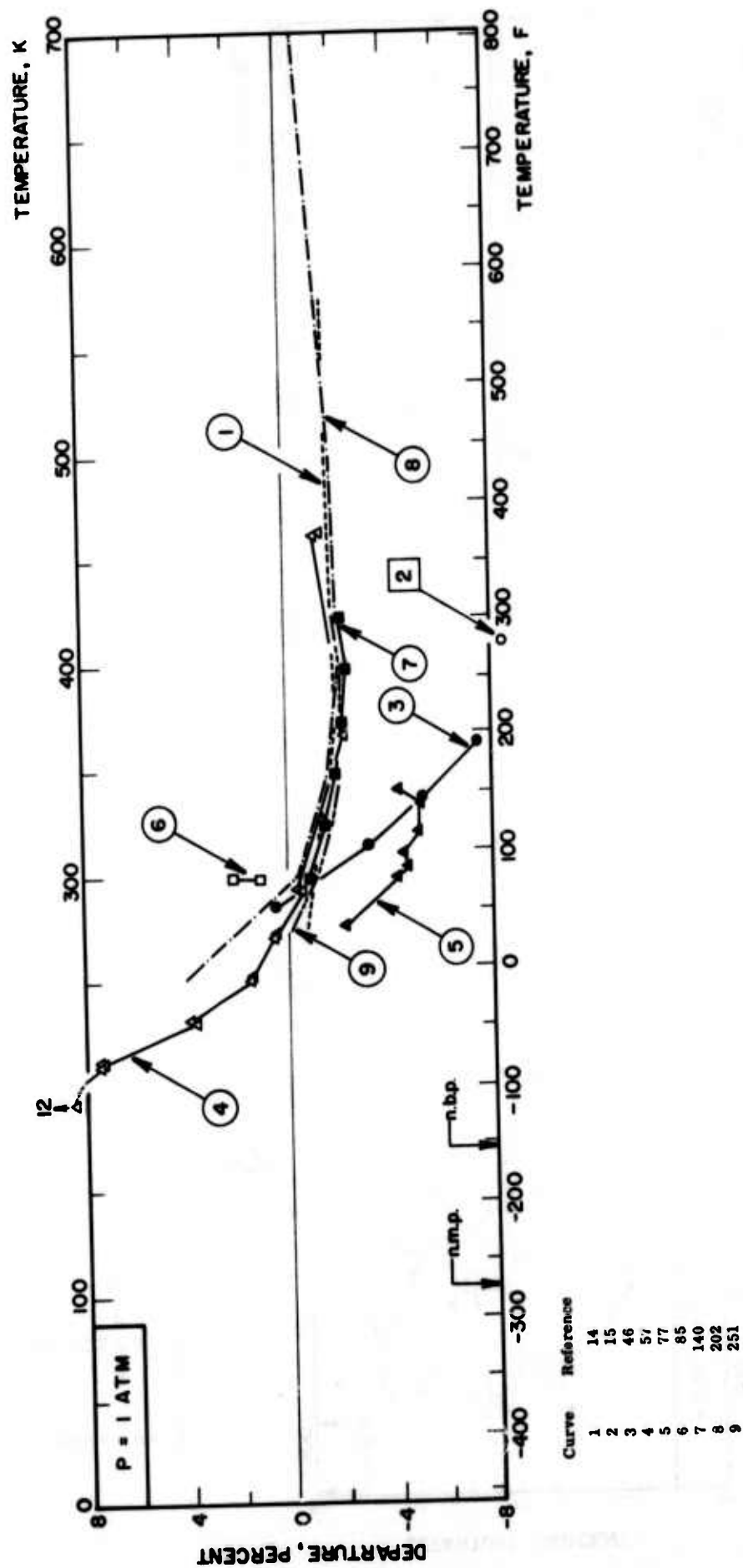


FIGURE 35 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS ETHYLENE

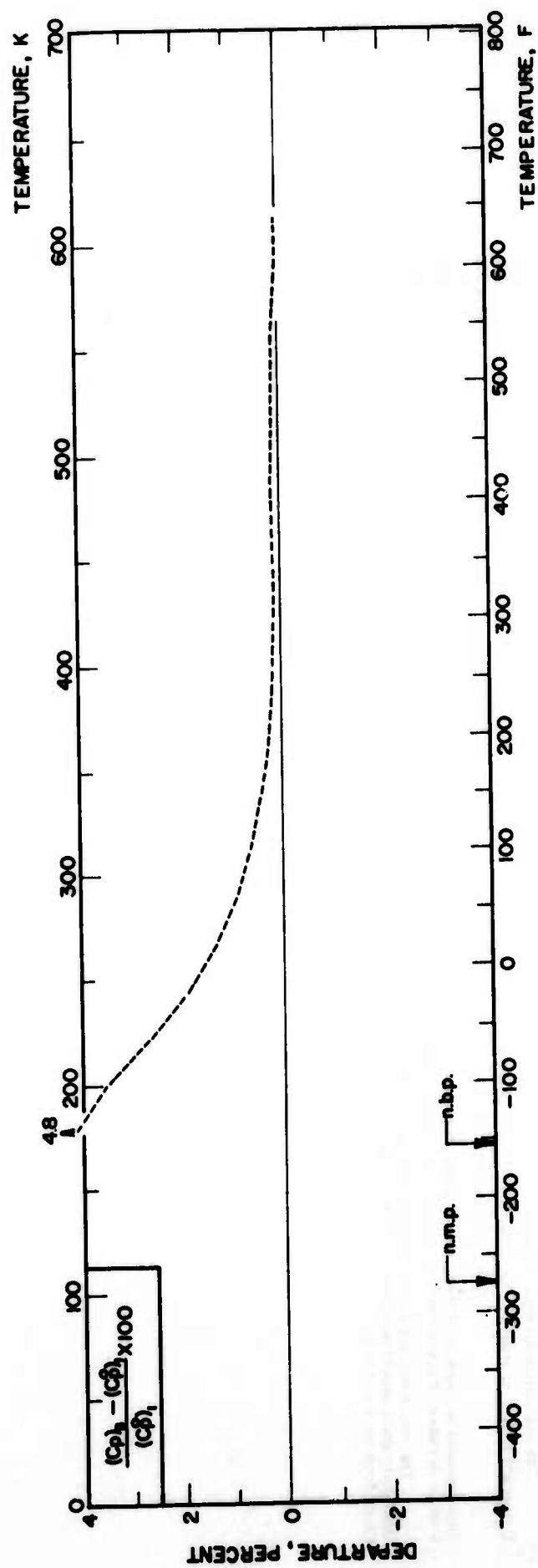


TABLE 36 SPECIFIC HEAT AT CONSTANT PRESSURE OF ETHYLENE GLYCOL

DISCUSSION

LIQUID

Five sets of data are available on the constant pressure specific heat of liquid ethylene glycol. However, extensive calorimetric measurements have not yet been made. The only reliable experimental data were reported over a short temperature range between 262 K and 293 K by Parks and Kelley (194) in 1925. Their results were mainly used in a correlation by Taylor and Rinkenbach (207), together with other existing old data. The correlated results were fitted by a straight line, from which the new values were calculated. An unpublished NBS report (256) gives data on ethylene glycol containing three percent of triethanolamine phosphate, the effect of which on specific heat was thought to be negligible. Koch (249) also gave correlated values between 273 K and 373 K. All the data points enumerated above are given equal weight in this analysis.

The correlation formula obtained is

$$C_p(\text{cal g}^{-1} \text{K}^{-1}) = 0.0168840 + 3.35083 \times 10^{-5}T - 7.22400 \times 10^{-6}T^2 + 7.61748 \times 10^{-8}T^3 \quad (T \text{ in K})$$

This equation is found to fit the above 42 points between 262 K and 468 K with a mean deviation of approximately 1 percent and a maximum of 2.9 percent.

The recommended values are generated by the above formula. The tabulated values should be correct within two percent in the temperature range from 20 F to 380 F.

RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p , B lb⁻¹ F⁻¹]
LIQUID

T	C_p
20	0.5406
40	0.5530
60	0.5651
80	0.5771
100	0.5890
120	0.6008
140	0.6127
160	0.6247
180	0.6368
200	0.6492
220	0.6618
240	0.6748
260	0.6882
280	0.7021
300	0.7165
320	0.7315
340	0.7472
360	0.7636
380	0.7807

n. b. p. = 388 F
n. m. p. = 4 F

FIGURE 36 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID ETHYLENE GLYCOL

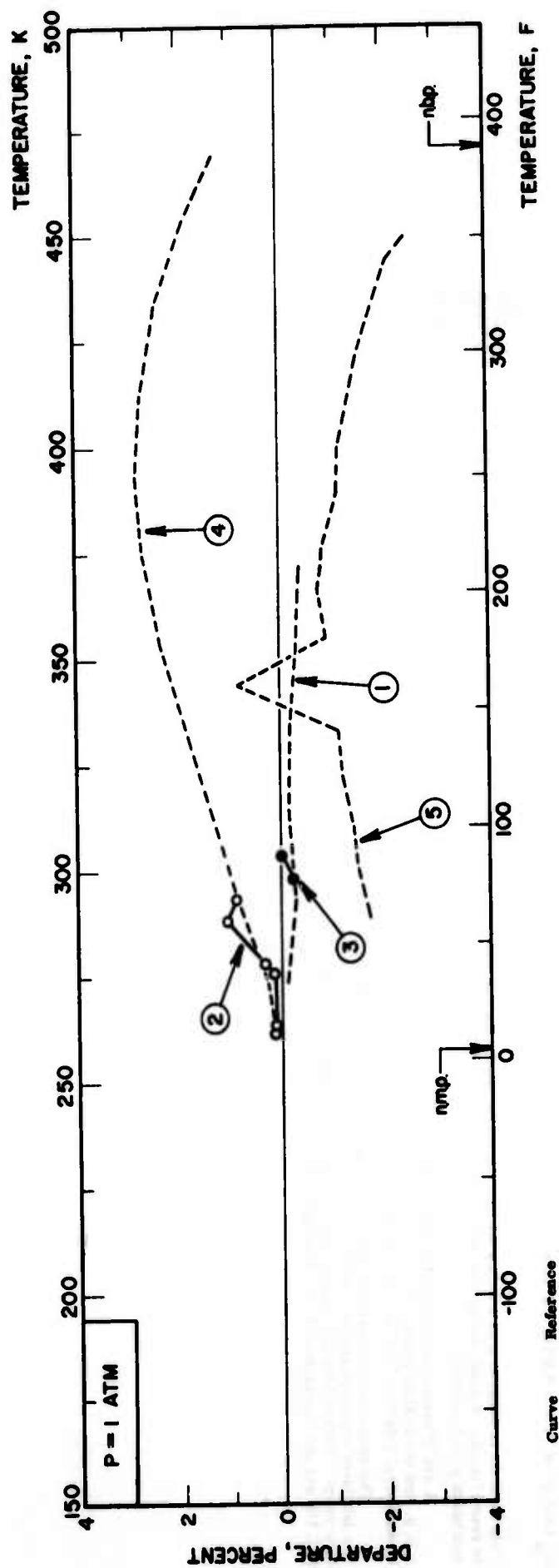


TABLE 37 SPECIFIC HEAT AT CONSTANT PRESSURE OF ETHYL-ETHER

DISCUSSION		RECOMMENDED VALUES	
LIQUID		LIQUID	
Five experimental works published before 1940 fall within the temperature range from the a.m.p. to the a.b.p. Among them, two sets of extensive results were obtained by Mazur (135, 136) using an adiabatic calorimeter, who gave a linear equation		[Temperature, T, F; Specific Heat, C_p , B lb ⁻¹ F ⁻¹]	
C_p (cal g ⁻¹ K ⁻¹) = 0.54239 + 0.00059563 t	(t in C).	T	C_p
Since his results are considered to be reliable in comparison with earlier measurements (5, 245, 247) all the data points reported in (135, 136) are used to generate the correlation formula in this analysis. The cubic equation obtained for the temperature range between 155 K and 295 K is		-160	0.4778
C_p (cal g ⁻¹ K ⁻¹) = 0.232794 + 2.59892 x 10 ⁻³ T - 8.92565 x 10 ⁻⁶ T ² + 1.30136 x 10 ⁻⁹ T ³		-140	0.4854
(T in K).		-120	0.4925
This formula is found to give a better fit than the above cited equation, and is able to reproduce the original data points with a mean deviation of 0.1 percent and a maximum of 0.3 percent.		-100	0.4992
A set of extensive calorimetric data obtained at temperatures between the a.b.p. and the critical point at 40 atm (239) and two sets of derived values obtained by empirical relations (36, 216) are not given any weight in the present correlation.		-80	0.5057
The above cubic equation is used to compute the recommended values. The tabulated values should be correct within one percent over the whole temperature range. Data at high pressures (239) and two additional sets of values (63, 78) are not represented in the departure plot.		-60	0.5119
		-40	0.5181
		-20	0.5244
		0	0.5308
		20	0.5374
		40	0.5445
		60	0.5520
		80	0.5600

FIGURE 37 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID ETHYL-ETHER

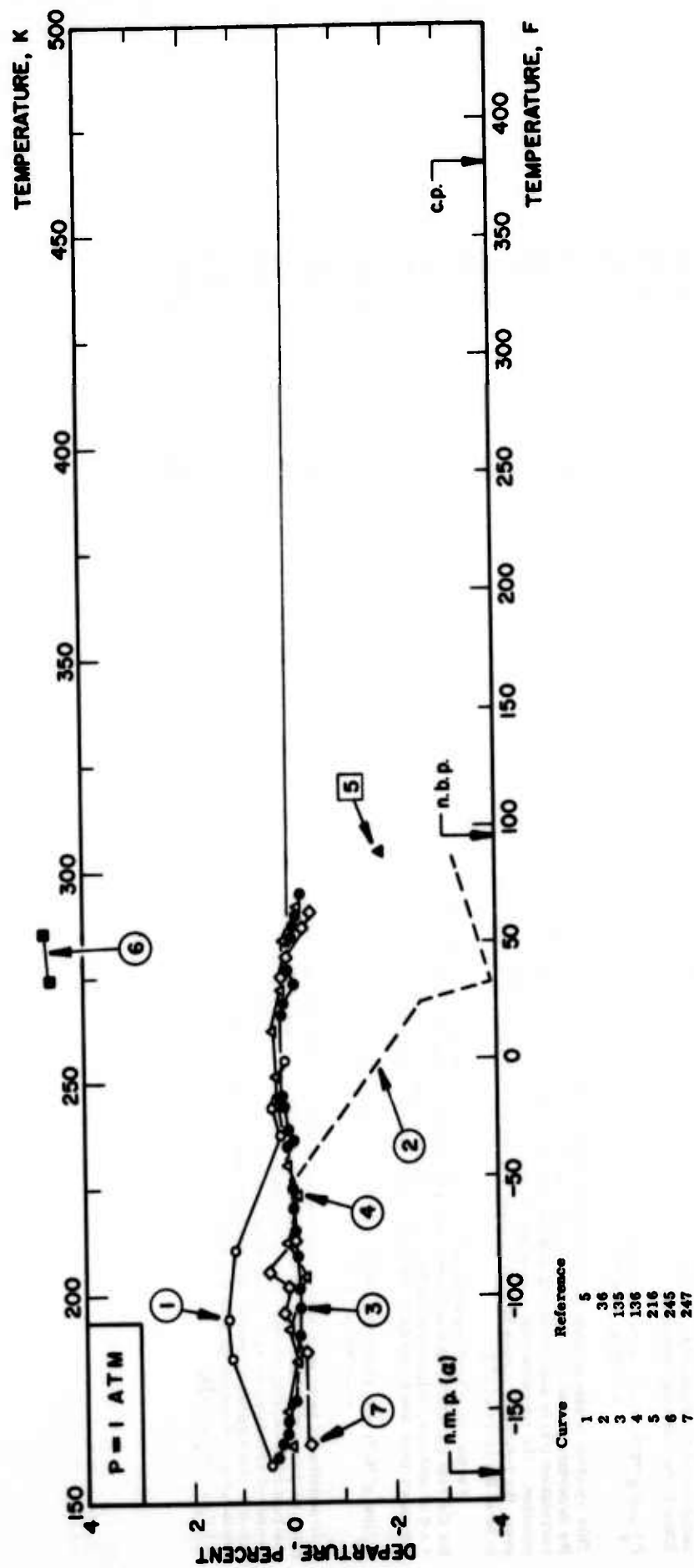


TABLE 37 SPECIFIC HEAT AT CONSTANT PRESSURE OF ETHYL ETHER

DISCUSSION

GAS

There exist 10 sources of information for the specific heat at constant pressure of gaseous ethyl ether. Only one set of values for zero-pressure specific heat were derived by Valentin (217), using the equilibrium constants at temperatures from 372 K to 500 K. No work is found on the statistical calculation at the ideal gas state. In the present analysis, Valentin's values are fitted to the following formula:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}) = -0.967148 + 7.98827 \times 10^{-3}T - 1.61408 \times 10^{-5}T^2 + 1.21565 \times 10^{-7}T^3 \quad (1)$$

This equation is able to reproduce his values within 0.001 percent, as shown in the departure plot at $P = 0$, where a single point value obtained by an empirical correlation (18) is also compared with the extrapolated value of the above equation. The recommended values are generated by the above formula. However, the reliability cannot be fully assessed at the present time. It is estimated to be of the order of 15%.

On the other hand, several sets of experimental data have been reported for the real gas state. Among them, two sets of calorimetric data (58, 91) and a set of extensive values derived from the velocity of sound (89) covering temperatures from 308 K and 623 K are fitted to the following equation:

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}) = 0.192557 + 3.28575 \times 10^{-4}T + 1.70641 \times 10^{-6}T^2 - 1.89605 \times 10^{-8}T^3 \quad (2)$$

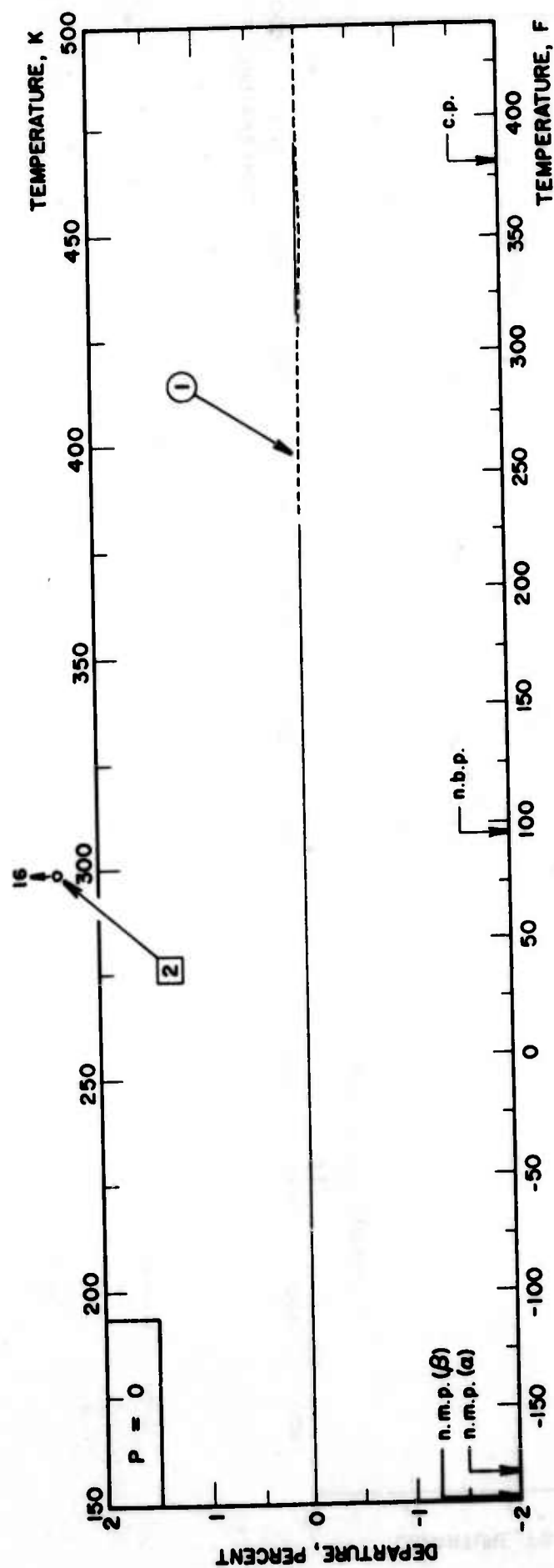
This equation is found to be able to reproduce the above enumerated data with a mean deviation of 3.7 percent. In the departure plot at $P = 1$ atm, early values obtained from velocity of sound (46) and compiled values (78, 216) are also compared with Equation (2). A set of calorimetric data at 40 atm (239) is not shown in this figure, as well as an empirical equation (180). Furthermore, the comparison of Equation (2) with Equation (1) is given in the third departure plot of $[(C_p)_1 - (C_p)_2]/(C_p)_1$.

RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p , B lb⁻¹ F⁻¹]

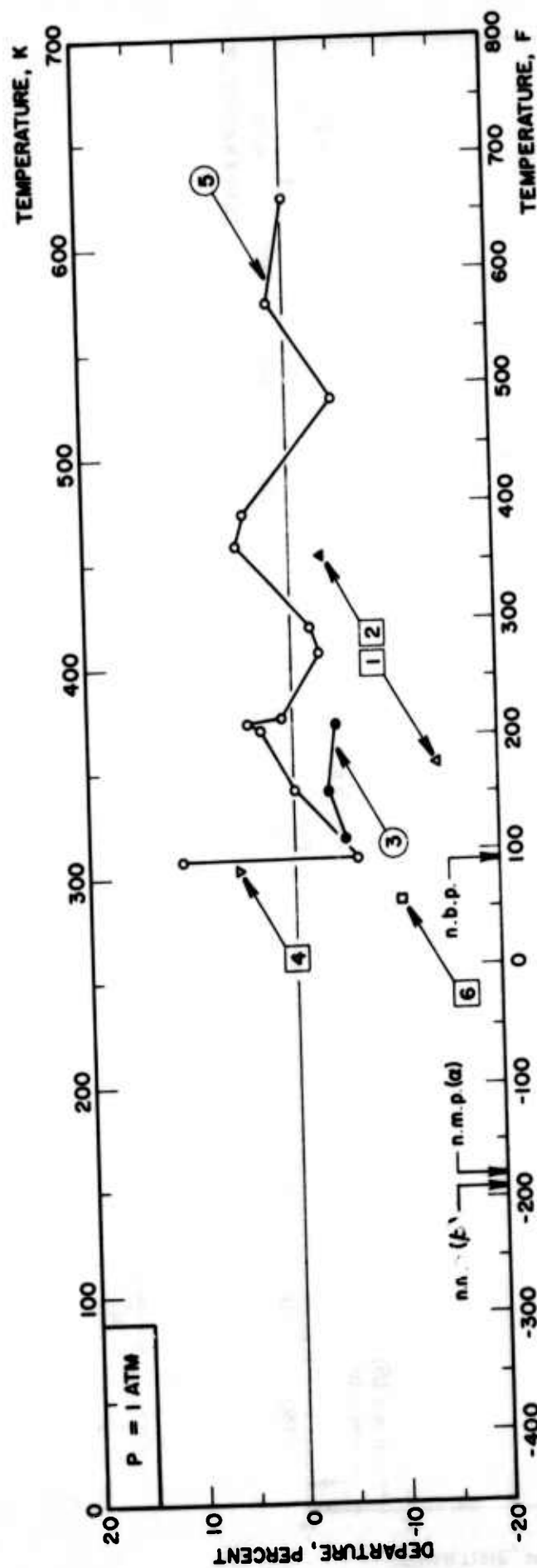
GAS	
T	C_p^0
100	0.3214
120	0.3372
140	0.3520
160	0.3657
180	0.3786
200	0.3907
220	0.4021
240	0.4129
260	0.4232
280	0.4331
300	0.4428
320	0.4523
340	0.4617
360	0.4711
380	0.4806
400	0.4903
420	0.5004
440	0.5108
460	0.5218
480	0.5334
500	0.5457
520	0.5588
540	0.5729
560	0.5879
580	0.6041
600	0.6215
620	0.6402

FIGURE 37 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS ETHYL ETHER



Curve	Reference
1	217
2	18

FIGURE 37 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS ETHYL ETHER



Curve	Reference
1	46
2	58
3	91
4	216
5	89
6	78

FIGURE 37 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS ETHYL ETHER

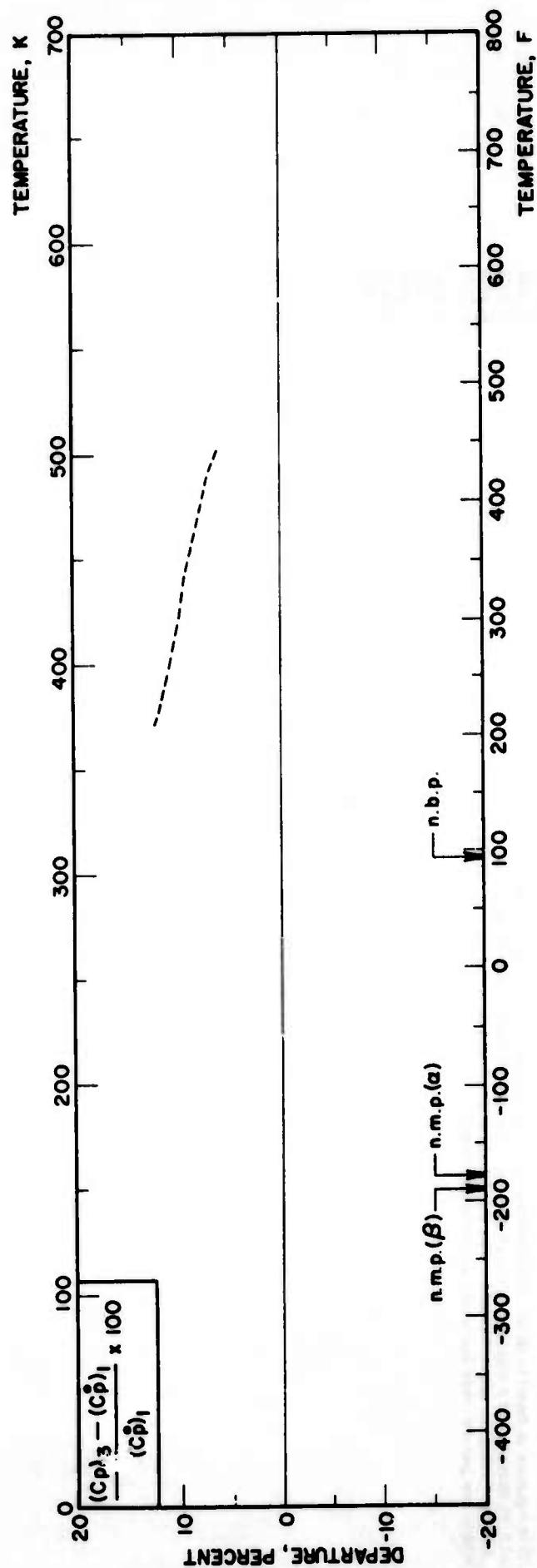


TABLE 38 SPECIFIC HEAT AT CONSTANT PRESSURE OF FREON-11

DISCUSSION

LIQUID

Only three experimental works have been reported on the specific heat at constant pressure of liquid Freon-11. Osborne et al (246) made measurements covering the temperature range from the n.m.p. to the n.b.p. by means of an adiabatic calorimeter with an experimental error of 0.1 percent. Their results are considered to be the most reliable and the reported data are given equal weight in this analysis. Meanwhile, two sets of calorimetric data of Benning et al (16,17) between 253 K and 347 K under saturation vapor pressure are thought to be less reliable, and no weight is given to these works.

The correlation formula obtained for the temperature range between 179 K and 288 K is

$$C_p(\text{cal g}^{-1} \text{K}^{-1}) = 0.159171 + 2.68130 \times 10^{-4}T - 7.30278 \times 10^{-7}T^2 + 1.41282 \times 10^{-9}T^3 \quad (T \text{ in K}).$$

This equation is found to fit the above enumerated data points with a mean deviation of 0.02 percent and a maximum of 0.05 percent. The recommended values are computed using the above formula. The tabulated values should be substantially correct within one percent over the whole temperature range.

RECOMMENDED VALUES	
[Temperature, T, °F; Specific Heat, C_p , B lb ⁻¹ °F ⁻¹]	LIQUID
T	C_p
-160	0.1900
-140	0.1915
-120	0.1931
-100	0.1947
-80	0.1964
-60	0.1980
-40	0.1998
-20	0.2016
0	0.2034
20	0.2054
40	0.2074
60	0.2096
80*	0.2119
100*	0.2143
120*	0.2168
140	0.2195
160	0.2224
180	0.2255

* Extrapolated for the liquid phase ignoring pressure dependence (n. b. p. = 75 °F).

FIGURE 38 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID FREON-11

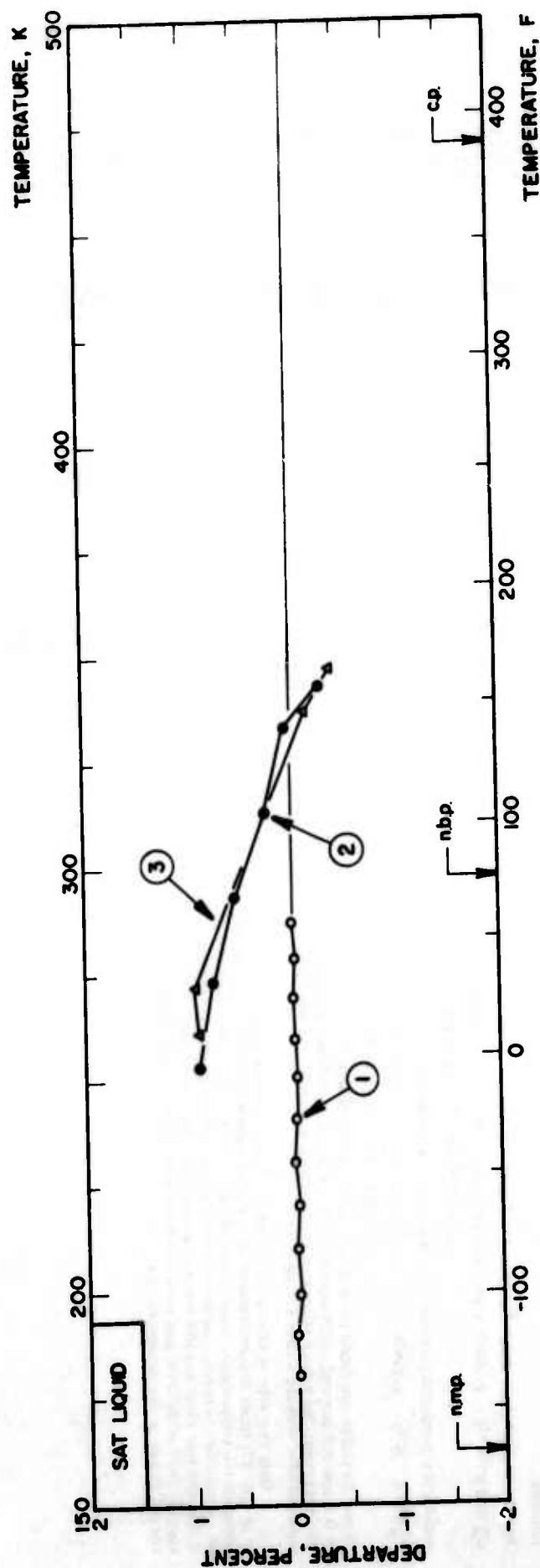


TABLE 38 SPECIFIC HEAT AT CONSTANT PRESSURE OF FREON-11 (continued)

GAS	DISCUSSION			RECOMMENDED VALUES		
	[Temperature, T, F; Specific Heat, C _p , B lb ⁻¹ F ⁻¹]			GAS		
	T	C _p ^a	T	C _p ^a	T	C _p ^a
	-300	0.07001*	500	0.1646		
	-280	0.07503*	520	0.1654		
	-260	0.07985*	540	0.1661		
	-240	0.08448*	560	0.1668		
	-220	0.08892*	580	0.1675		
	-200	0.09318*	600	0.1681		
	-180	0.09726*	620	0.1688		
	-160	0.1012	640	0.1694		
	-140	0.1049*	660	0.1700		
	-120	0.1085*	680	0.1706		
	-100	0.1119*	700	0.1711		
	-80	0.1152*	720	0.1717		
	-60	0.1183*	740	0.1722		
	-40	0.1213*	760	0.1727		
	-20	0.1241*	780	0.1732		
	0	0.1268*	800	0.1737		
	20	0.1294*	820	0.1741		
	40	0.1318*	840	0.1745		
	60	0.1342*	860	0.1750		
	80	0.1364	880	0.1754		
	100	0.1385	900	0.1758		
	120	0.1405	920	0.1761		
	140	0.1424	940	0.1765		
	160	0.1442	960	0.1768		
	180	0.1459	980	0.1772		
	200	0.1476	1000	0.1775		
	220	0.1491	1100	0.1788		
	240	0.1506	1200	0.1799		
	260	0.1520	1300	0.1807		
	280	0.1533	1400	0.1814		
	300	0.1546	1500	0.1818		
	320	0.1558	1600	0.1821		
	340	0.1570	1700	0.1824		
	360	0.1581	1800	0.1826		
	380	0.1592	1900	0.1829		
	400	0.1603	2000	0.1832		
	420	0.1613				
	440	0.1622				
	460	0.1631				
	480	0.1639				

* n. b. p. = 75 F

GAS

There are 11 sources of information available in the literature for the constant pressure specific heat of gaseous Freon-11. The ideal gas specific heat is derived from spectroscopic and molecular structural data by several investigators. The extensive values of Albright et al (2), Cleveland et al (37) and Gelles and Pitzer (66) are considered to be the most reliable from the standpoint of the molecular data used. Kice and Kobe (108) presented correlated results after an analysis of existing values. The discrepancy between these sets of values is somewhat large and amounts to a maximum error of 1.7 percent. Two sets of earlier derived results (95, 214) lie between the recent values mentioned above. In the present analysis, all the reported values enumerated are given equal weight. However, no weight is given to the two sets of derived values covering narrow temperature ranges (20, 49).

The correlation formulas obtained for the ideal gas specific heat are as follows:

For the temperature range between 100 K and 490 K:

$$C_p^0 (\text{cal g}^{-1} \text{K}^{-1}) = 2.23277 \times 10^{-2} + 6.19827 \times 10^{-6} T - 9.74217 \times 10^{-9} T^2 + 5.89557 \times 10^{-12} T^3, \quad (T \text{ in K})$$

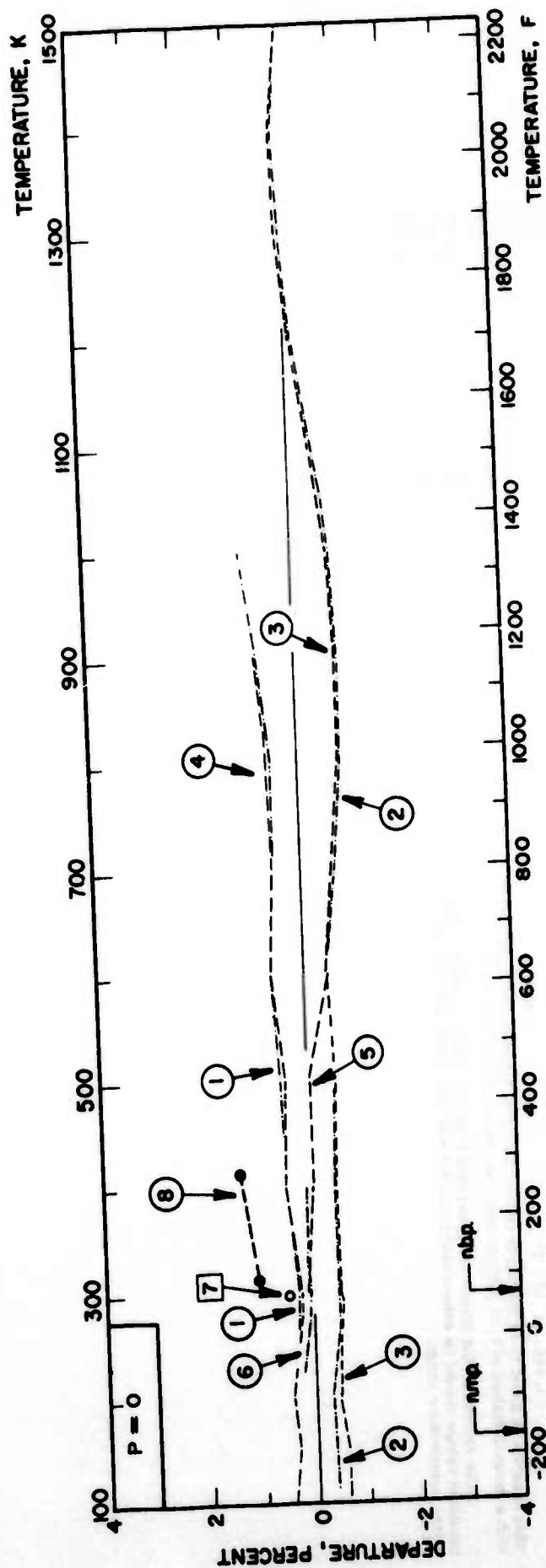
and for the temperature range between 490 K and 1500 K:

$$C_p^0 (\text{cal g}^{-1} \text{K}^{-1}) = 9.61600 \times 10^{-2} + 2.51180 \times 10^{-6} T - 1.58863 \times 10^{-9} T^2 + 4.26581 \times 10^{-11} T^3, \quad (T \text{ in K})$$

These formulas are found to fit the above cited data with a mean deviation of 0.3 and 0.5 percent and a maximum of 0.6 and 1.1 percent, respectively. The recommended values generated by the above two equations should be substantially correct within 1.5 percent.

Only two sets of direct experimental measurements exist. Benning et al (16, 17) made determinations at 1 atm by means of a flow calorimeter, covering the temperature range from 311 K to 413 K. The reported error was within five percent, and their results showed considerable scattering. It appears that their results are not adequate for the correlation of the specific heat of the real gas state and their data together with those of (236) are not shown in the departure plot.

FIGURE 3S DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS FREON-11



Curve	Reference
1	2
2	37
3	66
4	108
5	214
6	95
7	20
8	48

TABLE 39 SPECIFIC HEAT AT CONSTANT PRESSURE OF FREON-12

DISCUSSION		RECOMMENDED VALUES	
LIQUID		LIQUID	
Only four sources of information are available in the literature for the specific heat at constant pressure of liquid Freon-12. Among them, the most reliable experimental work would be that of Riedel (170), who measured the specific heat of purified liquid Freon-12 by means of an adiabatic calorimeter with an error of one percent, covering temperatures from 194 K to 294 K under saturation vapor pressures. Another calorimetric data (29) near 290 K is considered to be less reliable from standpoint of the experimental procedure used. A set of correlated values of Koch (249) are found to agree with those of Riedel (170). Another set of correlated values (33) under saturation vapor pressure showed a different trend with temperature. Therefore, the correlation formula below is obtained by giving equal weight to all the reported data of Riedel (170), $C_p (\text{cal g}^{-1} \text{K}^{-1}) = 0.00963113 + 2.32124 \times 10^{-3} T - 9.72940 \times 10^{-6} T^2 + 1.49532 \times 10^{-8} T^3$ (T in K). This equation is found to fit the above enumerated data between 194 K and 294 K with a mean deviation of 0.35 percent and a maximum of 0.97 percent. The recommended values are generated from the above equation. The tabulated values should be substantially correct within 1.5 percent over the entire temperature range.		[Temperature, T, F; Specific Heat, C_p, B lb⁻¹ F⁻¹]	
T	C_p	T	C_p
-140	0.1986	100	0.2401
-120	0.2016	120	0.2474
-100	0.2042	140	0.2558
-80	0.2066	160	0.2656
-60	0.2089	180	0.2767
-40	0.2113		
-20	0.2139		
0	0.2168		
20	0.2201		
40	0.2240		
60	0.2285		
80	0.2338		

n. b. p. = -22 F

FIGURE 39 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID FREON-12

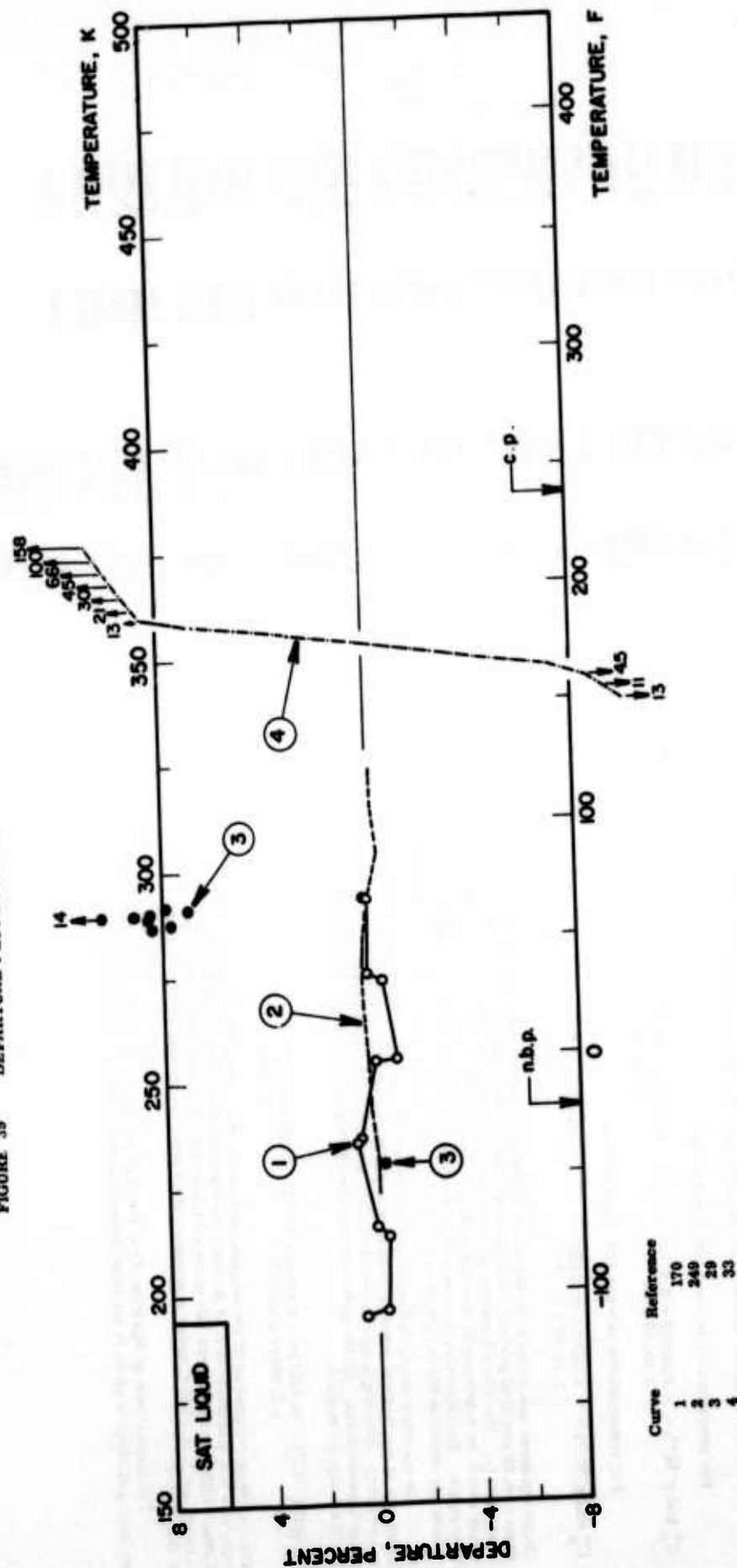


TABLE 39 SPECIFIC HEAT AT CONSTANT PRESSURE OF FREON-12

GAS	RECOMMENDED VALUES			
	[Temperature, T, F; Specific Heat, C_p , B lb ⁻¹ F ⁻¹]			
	GAS		GAS	
	T	C_p	T	C_p
	-280	0.0779	500	0.1805
	-260	0.0827	520	0.1815
	-240	0.0873	540	0.1826
	-220	0.0918	560	0.1835
	-200	0.0962	580	0.1845
	-180	0.1004	600	0.1854
	-160	0.1045	620	0.1863
	-140	0.1084	640	0.1871
	-120	0.1123	660	0.1879
	-100	0.1160	680	0.1887
	-80	0.1195	700	0.1894
	-60	0.1230	720	0.1901
	-40	0.1263	740	0.1908
	-20	0.1295	760	0.1915
	0	0.1326	780	0.1921
	20	0.1356	800	0.1927
	40	0.1384	820	0.1934
	60	0.1412	840	0.1939
	80	0.1438	860	0.1945
	100	0.1464	880	0.1951
	120	0.1489	900	0.1956
	140	0.1512	920	0.1962
	160	0.1535	940	0.1967
	180	0.1557	960	0.1972
	200	0.1578	980	0.1976
	220	0.1598	1000	0.1981
	240	0.1617	1100	0.2002
	260	0.1635	1200	0.2019
	280	0.1653	1300	0.2034
	300	0.1670	1400	0.2046
	320	0.1686	1500	0.2056
	340	0.1702	1600	0.2065
	360	0.1717	1700	0.2072
	380	0.1731	1800	0.2079
	400	0.1745	1900	0.2085
	420	0.1758	2000	0.2091
	440	0.1770		
	460	0.1782		
	480	0.1794		

n. m. p. = -252 F
n. b. p. = -22 F

DISCUSSION

There exist 12 sources of information on the specific heat at constant pressure of gaseous Freon-12. Several sets of extensive heat capacity values for the ideal gas state have been derived from spectroscopic and molecular data. The values presented by Albright et al. (2), Faltin (39), Gelles and Pitzer (66), Kobe and Kobe (108) and Masi (131) are thought to be reliable and are given equal weight in this analysis. Some early statistical calculations (94, 214) are given no weight, as well as a single point value obtained by an empirical correlation (20). The correlation formulas obtained for the ideal gas state are as follows:

For temperatures between 100 K and 600 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.0278828 + 5.68820 \times 10^{-6}T - 7.04559 \times 10^{-9}T^2 + 3.28112 \times 10^{-12}T^3 \quad (1)$$

For temperatures between 600 K and 1500 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.102099 + 2.24224 \times 10^{-6}T - 1.64846 \times 10^{-9}T^2 + 4.25588 \times 10^{-12}T^3 \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.29 and 0.62 percent, and maximum ones of 0.75 and 1.47 percent, respectively. The above formulas are used to compute the recommended values, which should be substantially correct within 1.5 percent over the whole temperature range. The departure percents of all the reported values from the tabulated values are shown in the departure plot at $P = 0$, excluding a set of cited values (236).

On the other hand, Buffington and Fleischner (29) and Masi (131) made measurements of the isobaric specific heat of this gas at one atm by means of flow calorimetry, covering temperatures from 273 K and 363 K. Good agreement is found between them. All the reported data are fitted to the following equation by the least square method:

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.133136 - 3.87835 \times 10^{-6}T + 2.31512 \times 10^{-9}T^2 - 2.90113 \times 10^{-12}T^3 \quad (3)$$

This equation is found to fit the original data points with a mean deviation of 0.20 percent and a maximum of 0.45 percent, as shown in the departure plot at $P = 1$ atm. Although Calcaterra (33) presented correlated results at temperatures between 398 K and 530 K under a pressure of 40 atm, his results are not shown in this figure.

The comparison of Equation (3) at the real gas state with Equation (1) at the ideal gas state is given in the third departure plot of $[(C_p)_1 - (C_p^0)_1]/(C_p^0)_1$.

FIGURE 39 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS FREON-12

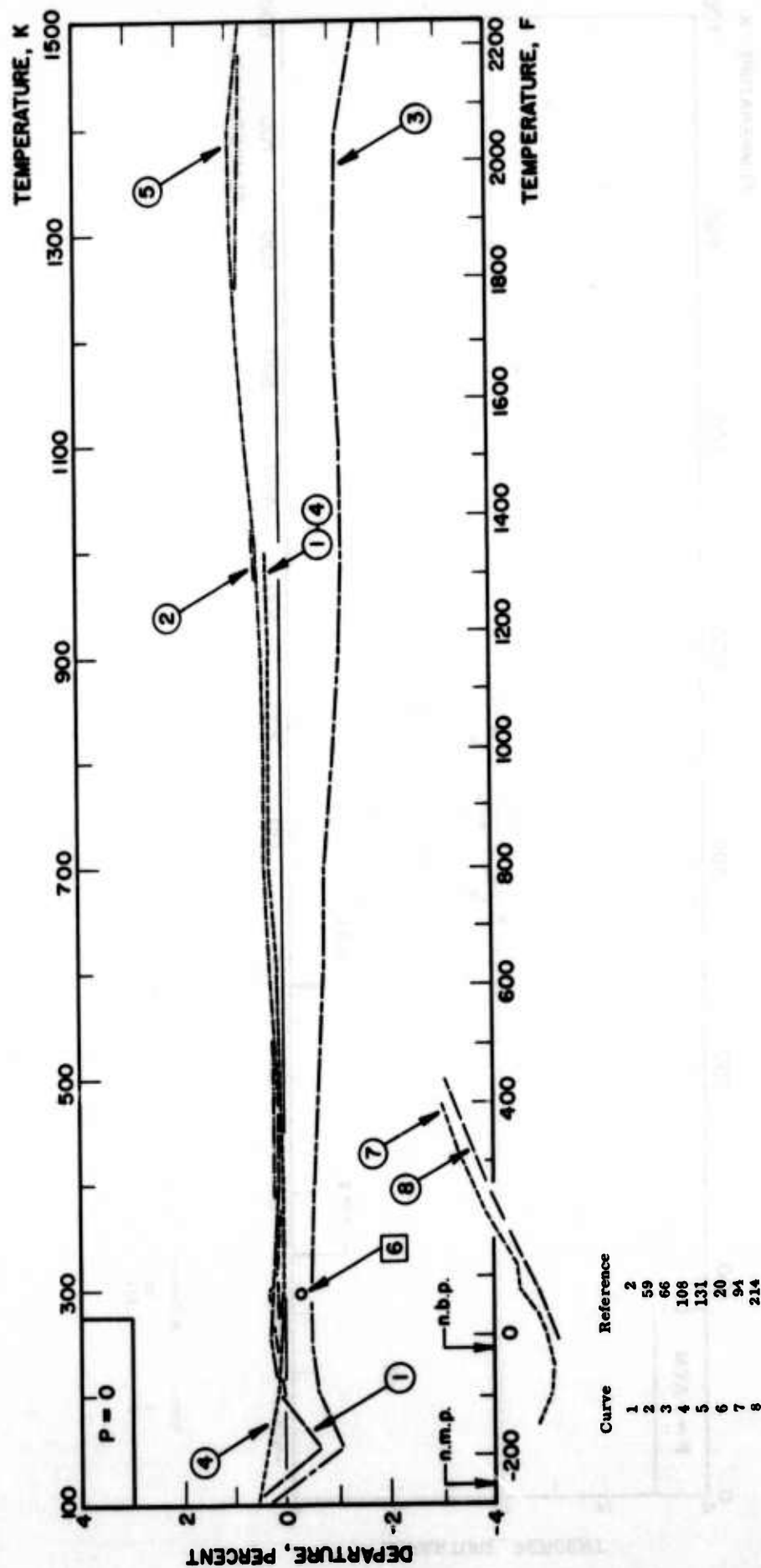


FIGURE 39 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS FREON-12

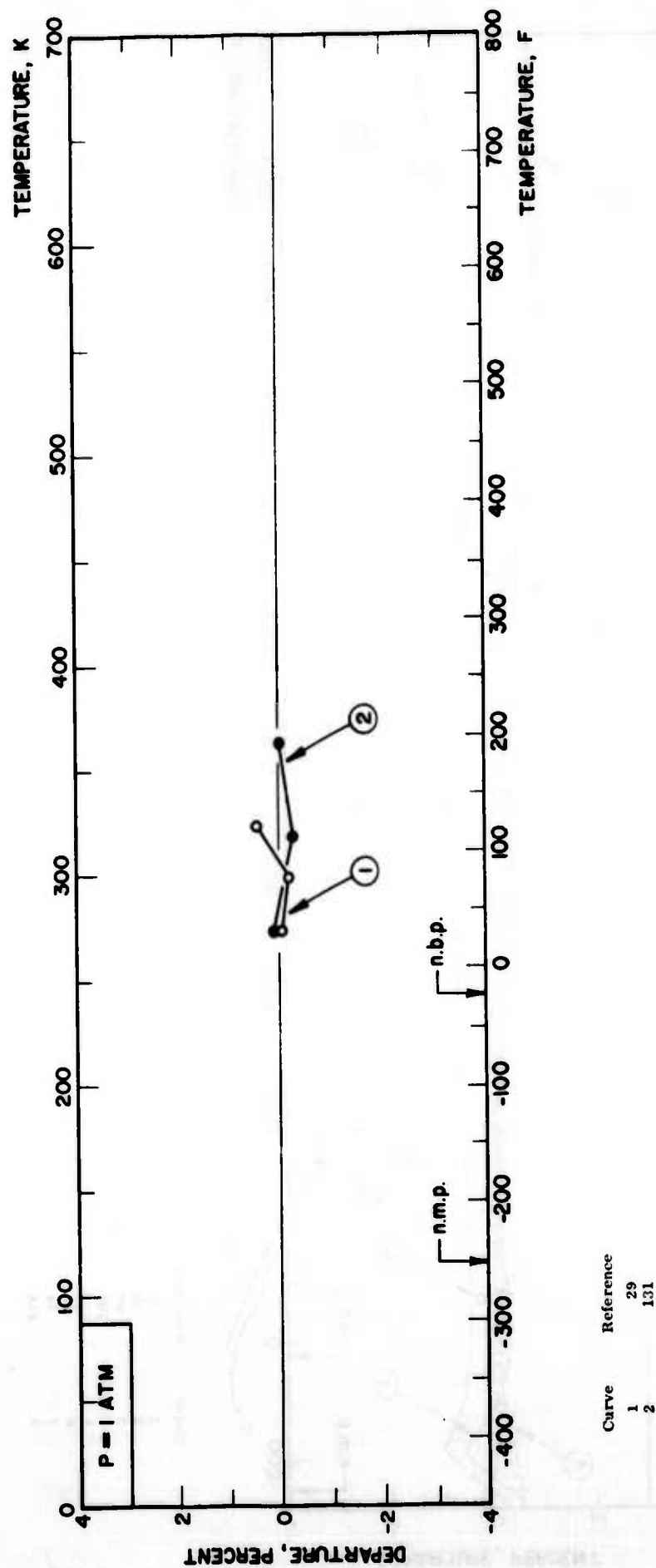


FIGURE 39 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS FREON-12

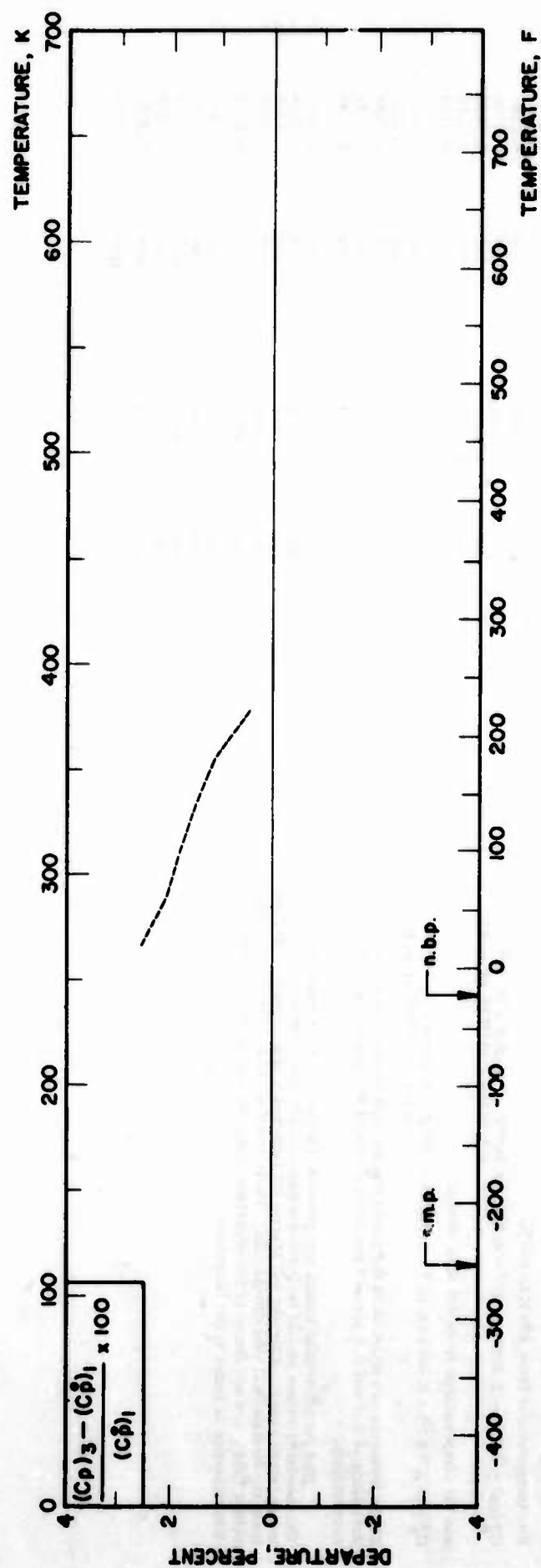


TABLE 40 SPECIFIC HEAT AT CONSTANT PRESSURE OF FREON-13

DISCUSSION

GAS

Eight sources of information are available for the constant pressure specific heat of gaseous Freon-13. Extensive values derived from spectroscopic and molecular structural data have been presented by Albright et al. (2), Gelles and Pitzer (66), Justi and Langer (95), and Thompson and Temple (214). Kobe and Kobe (108) compiled existing values and presented heat capacity tables and equations. The agreement among the derived values enumerated above is found to be within one percent. Therefore, all the reported values are given equal weight in the present analysis. A single-point value (20) obtained by the additive scheme is given no weight.

The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures from 200 K to 600 K:

$$C_p^g (\text{cal g}^{-1} \text{K}^{-1}) = 2.26848 \times 10^{-3} + 6.22016 \times 10^{-4} T - 7.05220 \times 10^{-7} T^2 + 3.04164 \times 10^{-10} T^3 \quad (T \text{ in K}).$$

and for temperatures from 600 K to 1000 K:

$$C_p^g (\text{cal g}^{-1} \text{K}^{-1}) = 8.46943 \times 10^{-3} + 3.32099 \times 10^{-4} T - 2.50256 \times 10^{-7} T^2 + 6.50464 \times 10^{-10} T^3 \quad (T \text{ in K}).$$

These formulas are found to fit the above enumerated values with mean deviations of 0.3 and 0.4 percent and a maximum of 0.8 and 0.8 percent, respectively.

The recommended values are generated using the above equations. The tabulated values should be correct within one percent over the entire temperature range. Albright and Martin (3) reported a heat capacity equation from the fundamental vibrational data. Their results, as well as a set of cited values (236), are not shown in the departure plot. No direct experimental determination is found in the literature.

RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p , B lb⁻¹ F⁻¹]
GAS

T	C_p^g	T	C_p^g
-100	0.1212	500	0.1998
-80	0.1253	520	0.2012
-60	0.1293	540	0.2026
-40	0.1331	560	0.2039
-20	0.1369	580	0.2052
0	0.1405	600	0.2064
20	0.1440	620	0.2076
40	0.1474	640	0.2089
60	0.1507	660	0.2100
80	0.1539	680	0.2110
100	0.1569	700	0.2120
120	0.1599	720	0.2130
140	0.1628	740	0.2140
160	0.1655	760	0.2149
180	0.1682	780	0.2158
200	0.1708	800	0.2167
220	0.1733	820	0.2175
240	0.1757	840	0.2184
260	0.1780	860	0.2191
280	0.1802	880	0.2199
300	0.1823	900	0.2206
320	0.1844	920	0.2214
340	0.1864	940	0.2221
360	0.1883	960	0.2227
380	0.1901	980	0.2234
400	0.1919	1000	0.2240
420	0.1936	1100	0.2267
440	0.1953	1200	0.2290
460	0.1968	1300	0.2308
480	0.1984	1400	0.2323
		1500	0.2334

FIGURE 40 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS FREON-13

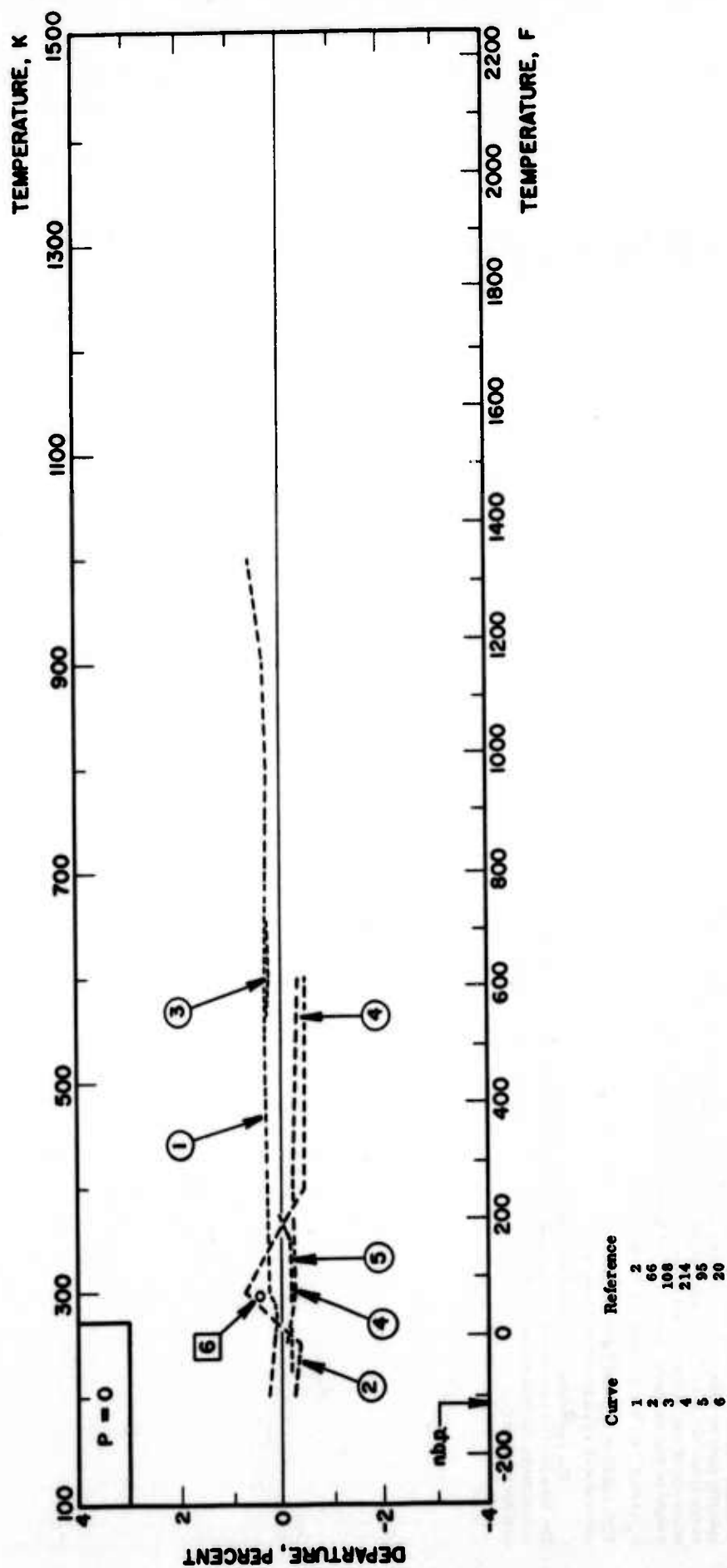


TABLE 41 SPECIFIC HEAT AT CONSTANT PRESSURE OF FREON-21

DISCUSSION		RECOMMENDED VALUES	
LIQUID		LIQUID	
		T	C_p
Only two experimental determinations are available for the specific heat of liquid Freon-21, being those of Benning et al (16, 17). They measured the specific heat by means of an adiabatic calorimeter, covering the temperature range from 253 K to 353 K under saturation vapor pressures, with a reported accuracy of five percent. All of the 10 data points reported are given equal weight in this analysis, and are fitted to the following linear equation $C_p (\text{cal g}^{-1} \text{K}^{-1}) = 0.19531 + 1.8896 \times 10^{-4} T \quad (T \text{ in K}).$ This equation is found to fit the above 10 points with a mean deviation of 0.2 percent and a maximum of 0.4 percent. The recommended values are calculated from the above equation. The tabulated values should be substantially correct within 5 percent in the temperature range between 273 K and 353 K. The uncertainty increases outside this range.		-40	0.2394
		-20	0.2415
		0	0.2436
		20	0.2457
		40	0.2478
		60	0.2499
		80	0.2520
		100	0.2541
		120	0.2562
		140	0.2583
		160	0.2604
		180	0.2625
		200	0.2646

DISCUSSION

LIQUID

Only two experimental determinations are available for the specific heat of liquid Freon-21, being those of Benning et al (16, 17). They measured the specific heat by means of an adiabatic calorimeter, covering the temperature range from 253 K to 353 K under saturation vapor pressures, with a reported accuracy of five percent. All of the 10 data points reported are given equal weight in this analysis, and are fitted to the following linear equation

$$C_p (\text{cal g}^{-1} \text{K}^{-1}) = 0.19531 + 1.8896 \times 10^{-4} T \quad (T \text{ in K}).$$

This equation is found to fit the above 10 points with a mean deviation of 0.2 percent and a maximum of 0.4 percent.

The recommended values are calculated from the above equation. The tabulated values should be substantially correct within 5 percent in the temperature range between 273 K and 353 K. The uncertainty increases outside this range.

n.b.p. = 48 F

FIGURE 41 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID FREON-21

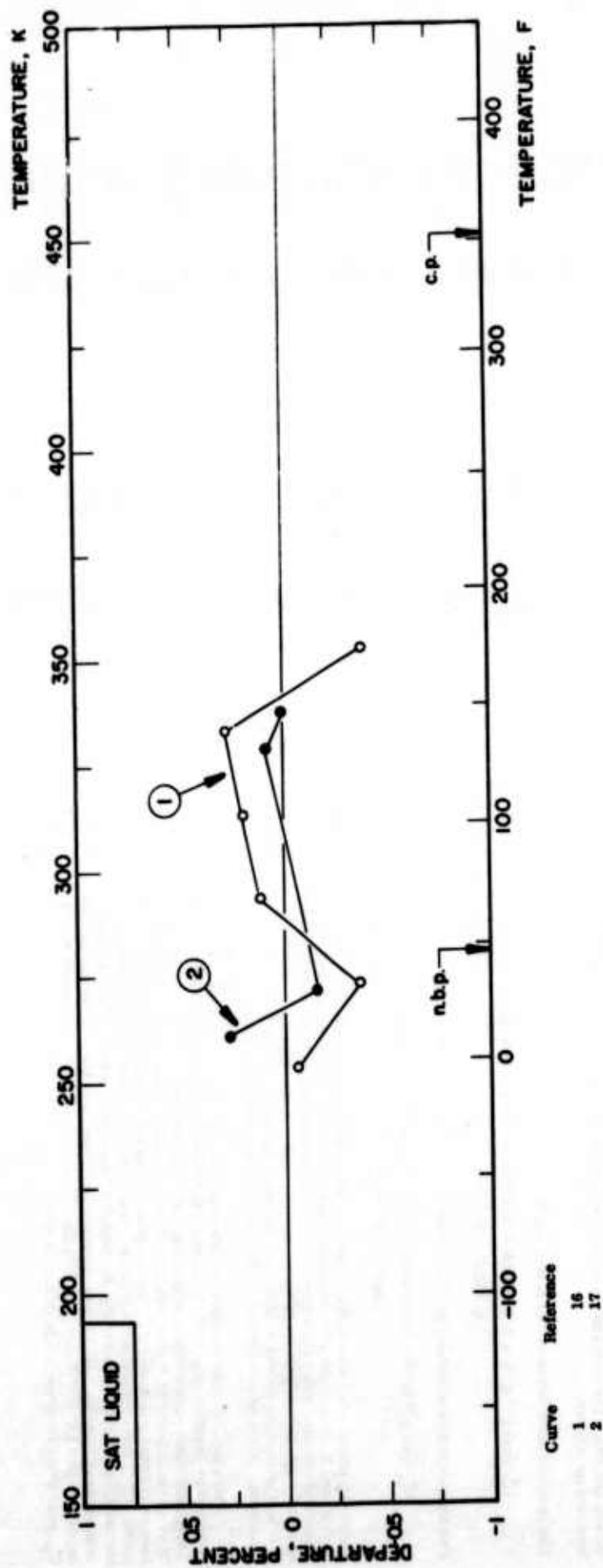


TABLE 41 SPECIFIC HEAT AT CONSTANT PRESSURE OF FREON-21

DISCUSSION

GAS

Ten sources of information are available for the isobaric specific heat of gaseous Freon-21. Concerning the heat capacity in the ideal gas state, several sets of extensive calculations have been presented based on spectroscopic and molecular structural data. The values derived by Gellies and Pitzer (66), Glockler and Edgell (70) and Weissman et al. (228), and compiled values in the JANAF Thermochemical Tables (254), covering the temperature range between 100 K up to 6000 K, are considered to be the most reliable. Therefore, these works are given equal weight in the present analysis. A set of early statistical calculation (48) is given no weight, as well as two sets of empirically estimated values (20, 69). The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 100 K and 590 K:

$$C_p^0 \text{ (cal g}^{-1} \text{ K}^{-1}) = 0.0537464 + 3.47156 \times 10^{-4} T - 1.58035 \times 10^{-7} T^2 - 6.39583 \times 10^{-11} T^3 \quad (T \text{ in K}), \quad (1)$$

For temperatures between 590 K and 1500 K:

$$C_p^0 \text{ (cal g}^{-1} \text{ K}^{-1}) = 0.0919903 + 2.47070 \times 10^{-4} T - 1.56916 \times 10^{-7} T^2 + 3.66968 \times 10^{-11} T^3 \quad (T \text{ in K}). \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.27 and 0.08 percent and maximum ones of 2.6 and 0.28 percent, respectively. The recommended values are generated by these formulas. The tabulated values should be substantially correct within one percent. In the departure plot for $P = 0$, the existing values at the ideal gas state are compared with the above equations. A set of cited values (236) is not shown in this figure.

Meanwhile, only two sets of flow-calorimetric data of the real gas are reported by Benning et al. (16, 17), covering temperatures from 311 K to 413 K. Their data show considerable scattering, and are not thought to be so reliable from the standpoint of the accuracy of measurements. Therefore, the specific heat in the real gas state, C_p^1 , is computed using the ideal gas values described above, C_p^0 , and corrections are made for gas imperfections using the usual thermodynamic relations and the Berthelot's equation of state. The calorimetric data of Benning et al. (16, 17) are compared with the computed C_p^1 in the second departure plot for $P = 1$ atm. In the third departure plot, C_p^1 is compared with C_p^0 over their common temperature range.

RECOMMENDED VALUES

[Temperature, T, K; Specific Heat, C_p^0 , B lb⁻¹ F⁻¹]

GAS

T	C_p^0	C_p^1	T	C_p^0
-280	0.0867		500	0.1841
-260	0.0902		520	0.1854
-240	0.0936		540	0.1867
-220	0.0970		560	0.1879
			580	0.1891
-200	0.1003		600	0.1902
-180	0.1036		620	0.1915
-160	0.1068		640	0.1926
-140	0.1100		660	0.1937
-120	0.1131		680	0.1947
-100	0.1162		700	0.1957
-80	0.1193		720	0.1967
-60	0.1223		740	0.1977
-40	0.1252		760	0.1986
-20	0.1281		780	0.1996
0	0.1309		800	0.2005
20	0.1337		820	0.2014
40	0.1365		840	0.2023
60	0.1392		860	0.2031
80	0.1418		880	0.2040
100	0.1444	0.147	900	0.2048
120	0.1469	0.150	920	0.2056
140	0.1494	0.152	940	0.2063
160	0.1518	0.154	960	0.2071
180	0.1542	0.156	980	0.2079
200	0.1565	0.158	1000	0.2086
220	0.1588	0.160	1100	0.2120
240	0.1609	0.162	1200	0.2150
260	0.1631	0.164	1300	0.2177
280	0.1652	0.166	1400	0.2201
300	0.1672		1500	0.2222
320	0.1692		1600	0.2241
340	0.1711		1700	0.2258
360	0.1729		1800	0.2273
380	0.1747		1900	0.2287
400	0.1764		2000	0.2301
420	0.1781			
440	0.1797			
460	0.1812			
480	0.1827			

n. m. p. = -221 F
n. b. p. = 48 F

FIGURE 41 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS FREON-21

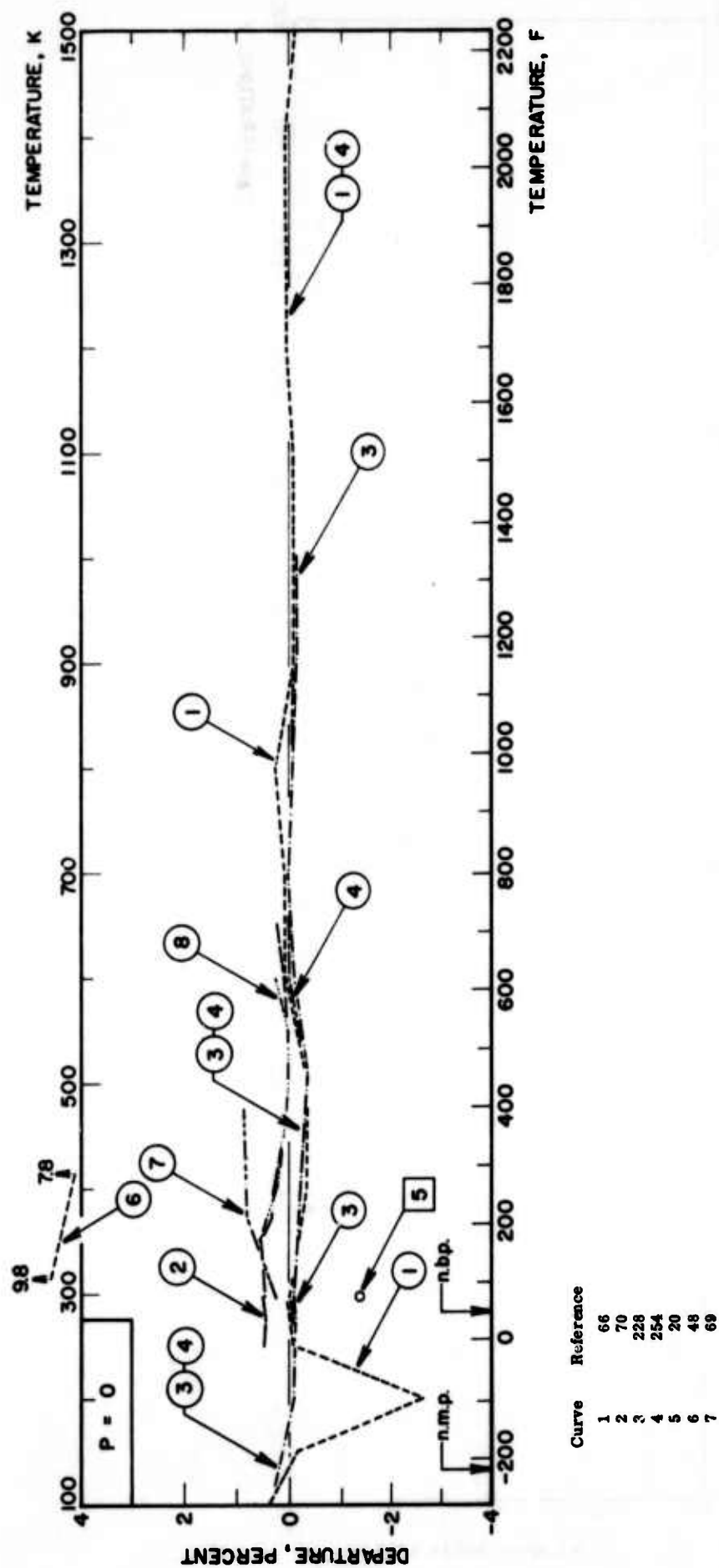


FIGURE 41 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS FREON-21

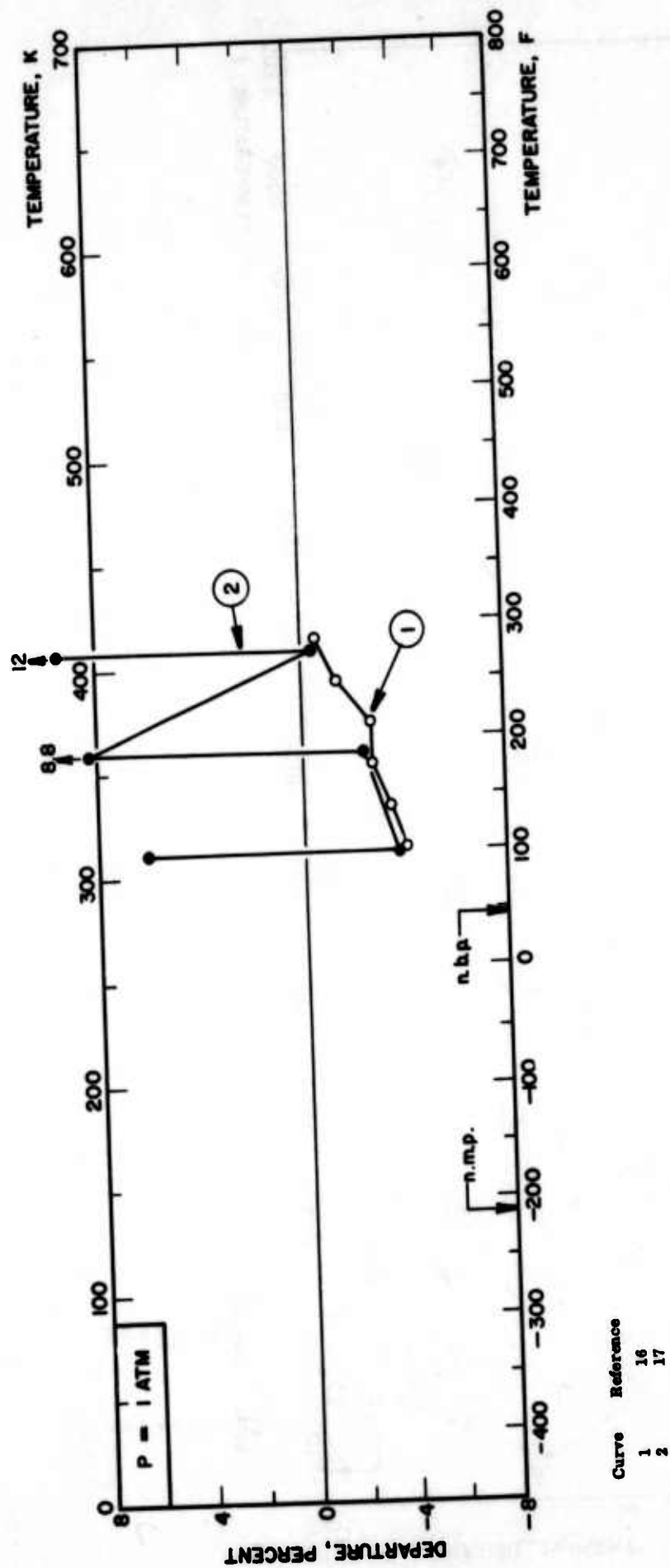


FIGURE 41 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS FREON-21

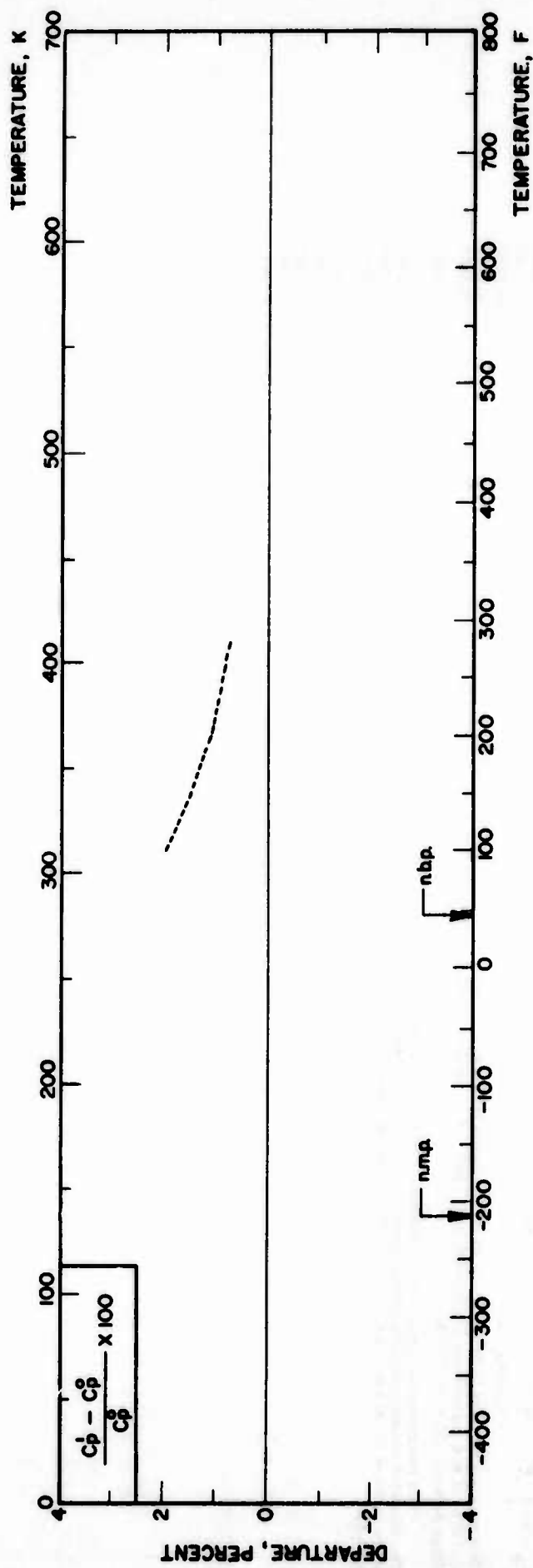


TABLE 42 SPECIFIC HEAT AT CONSTANT PRESSURE OF FREON-22

DISCUSSION		RECOMMENDED VALUES	
LIQUID		LIQUID	
Three sets of calorimetric data are available for the specific heat of liquid Freon-22. The latest data were reported by Neilson and White (146), who measured the specific heat of 99.98 mole percent Freon-22 by means of an adiabatic calorimeter with a reported accuracy of 0.5 percent, covering the temperature range from 122 K to 226 K at 1 atm. Their results showed a slight temperature dependence of the specific heat within this temperature range. The rest of the measurements (16, 17) were made under saturation vapor pressure above the n. b. p. All the data points can be considered to be continuous, and are given equal weight in the present analysis. The correlation formula obtained is $C_p \text{ (cal g}^{-1} \text{ K}^{-1}) = 0.267165 + 3.22637 \times 10^{-5} T - 1.93112 \times 10^{-6} T^2 + 7.26552 \times 10^{-9} T^3 \quad (T \text{ in K}).$ This equation is found to fit the above 21 experimental points with a mean deviation of 0.6 percent and a maximum of 1.5 percent in the temperature range between 122 K and 333 K. The recommended values are calculated from the above equation. The tabulated values should be substantially correct in the temperature range between 125 K and 335 K. Outside this range the uncertainty would increase.		[Temperature, T, F; Specific Heat, C_p, B lb⁻¹ F⁻¹]	
T	C_p	T	C_p
-240	0.2554	100	0.3087
-220	0.2542	120	0.3197
-200	0.2533	140	0.3320
-180	0.2526	160	0.346
-160	0.2524	180	0.361
-140	0.2525		
-120	0.2531		
-100	0.2543		
-80	0.2561		
-60	0.2585		
-40	0.2616		
-20	0.2655		
0	0.2703		
20	0.2759		
40	0.2825		
60	0.2902		
80	0.2989		

n. b. p. = -41 F

FIGURE 42 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID FREON-22

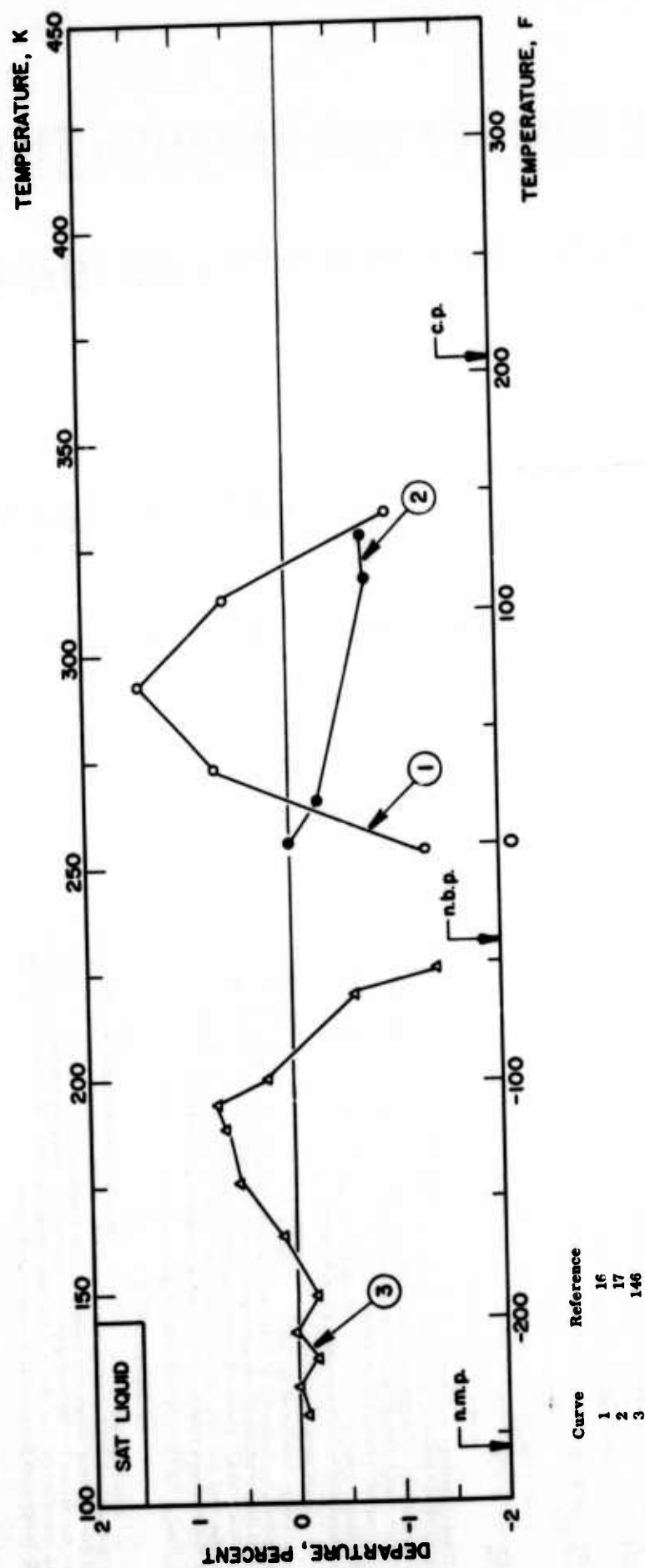


FIGURE 42 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS FREON-22

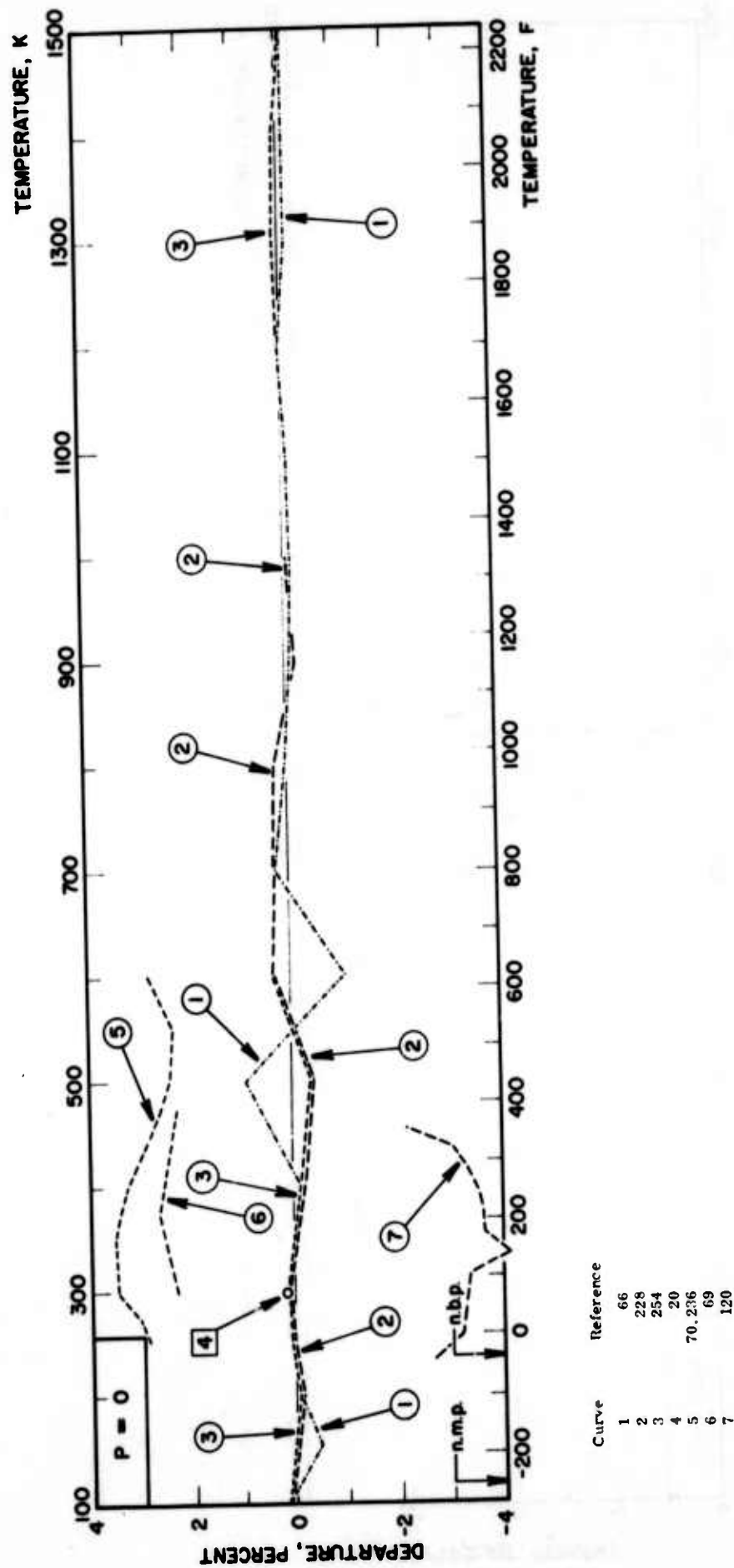


FIGURE 42 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS FREON-22

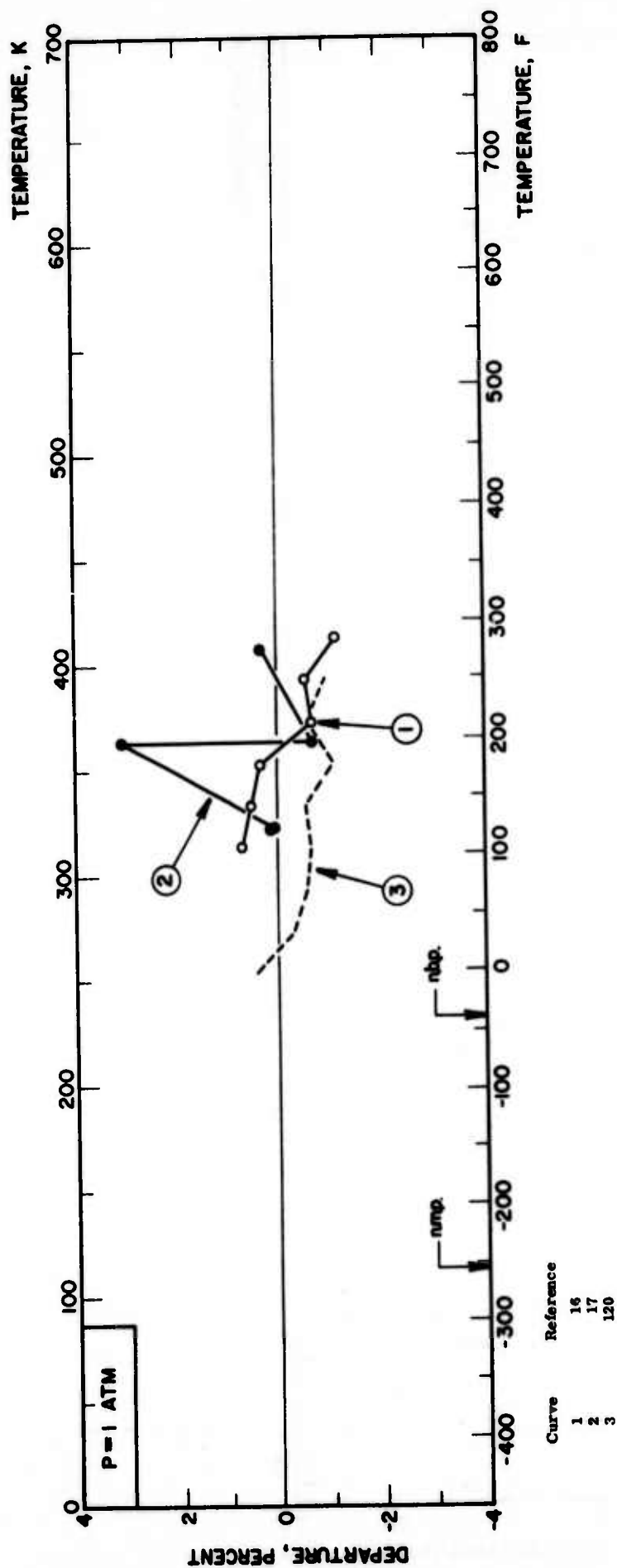


FIGURE 42 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS FREON 22

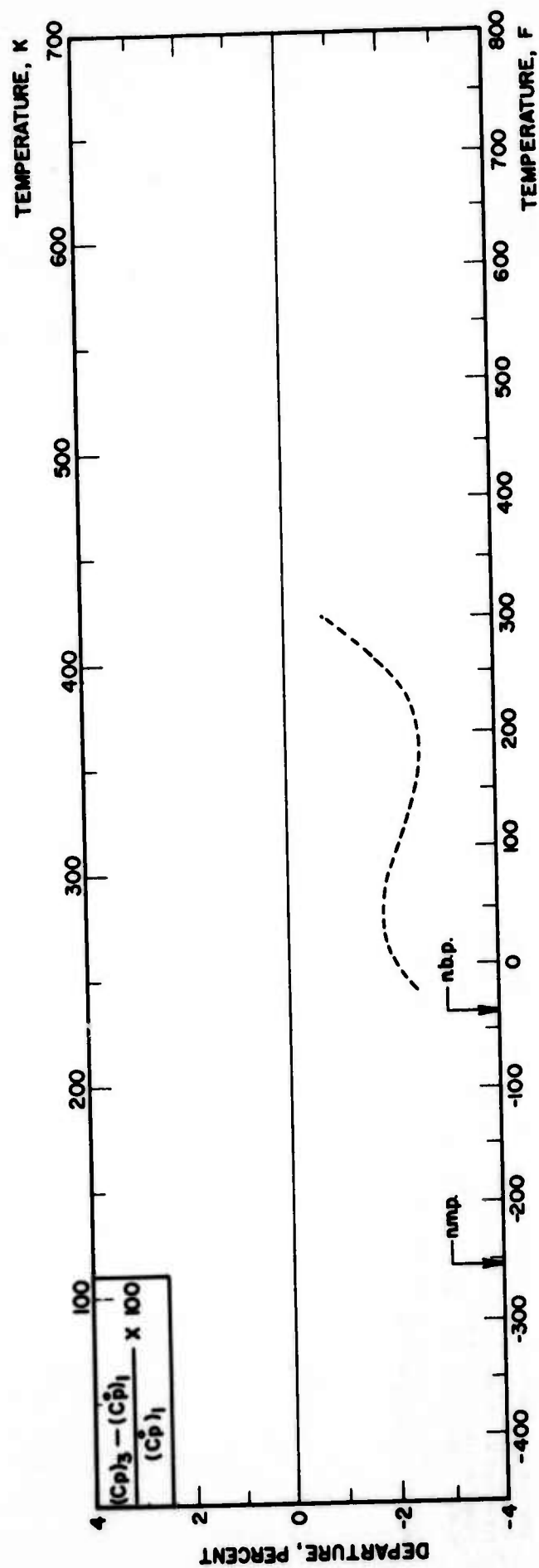


TABLE 43 SPECIFIC HEAT AT CONSTANT PRESSURE OF FREON-113

RECOMMENDED VALUES
[Temperature, T, F; Specific Heat, C_p , B lb⁻¹ F⁻¹]
LIQUID

T	C_p
-20	0.2076
0	0.2107
20	0.2140
40	0.2176
60	0.2213
80	0.2252
100	0.2292
120	0.2333
140	0.237
160	0.241
180	0.245

DISCUSSION

LIQUID

Only three sets of experimental data are available for the specific heat at constant pressure of liquid Freon-113. Riedel (169) made calorimetric measurements, covering temperatures from 243 K to 334 K, with a reported error of 0.5 percent. His results are thought, to be the most reliable and are given heavy weight in this analysis. Two sets of data were reported by Benning et al (16, 17), obtained by an adiabatic calorimeter and covering temperatures between 243 K and 353 K. Their data show a different trend with temperature from those of Riedel. Therefore, lesser weight is given to the results of Benning et al.

The correlation formula obtained between 243 K and 353 K is

$$C_p(\text{cal g}^{-1}\text{K}^{-1}) = 0.299591 - 1.33126 \times 10^{-3}T + 5.21678 \times 10^{-6}T^2 - 5.34447 \times 10^{-9}T^3$$

(T in K).

This equation fits the 55 data points with a mean deviation of 1.1 percent and a maximum of 4.6 percent at the highest temperature of Benning et al. The recommended values are generated using the above equation. The tabulated values should be correct within one percent in the temperature range from the n.m.p. to the n.b.p. Above the n.b.p., the uncertainty would increase.

Zeise (236) presented an empirical linear equation using the data of Benning et al (17). This equation is not plotted in the departure plot.

n.b.p. = 118 F

FIGURE 43 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID FREON-113

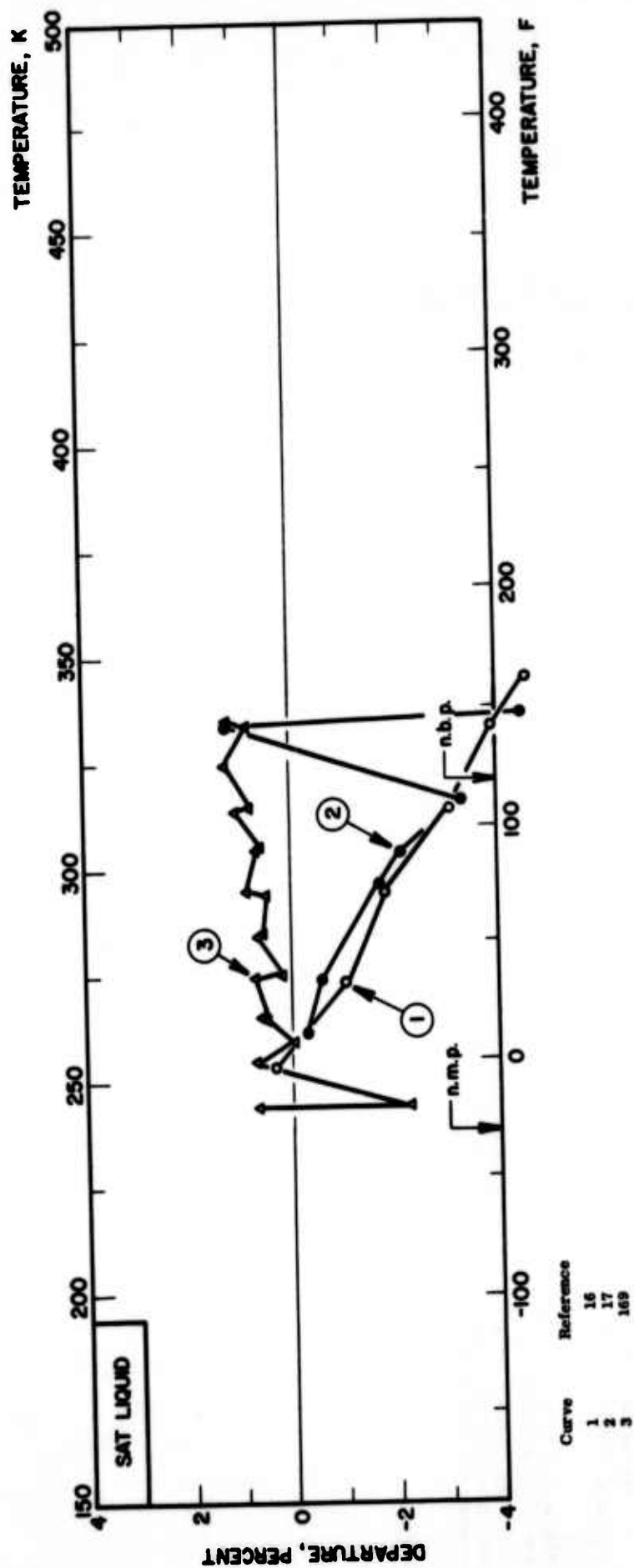


TABLE 43 SPECIFIC HEAT AT CONSTANT PRESSURE OF FREON-113 (continued)

DISCUSSION		RECOMMENDED VALUES	
GAS	T	[Temperature, T, F; Specific Heat, C _p , B lb ⁻¹ F ⁻¹]	
		GAS	
	T	C _p	
	120	0.1585	
	140	0.1608	
	160	0.1632	
	180	0.1655	
	200	0.1678	
	220	0.1701	
	240	0.1722	
	260	0.1742	
	280	0.1761	
	300	0.1778	
	320	0.1793	
	340	0.1805	
	360	0.1815	
	380	0.1822	

Only two sets of calorimetric measurements are available on the isobaric specific heat of gaseous Freon-113, both being those of Beming, et al (16,17). These authors used a flow calorimeter and obtained specific heat data within an experimental error of five percent, covering temperatures from 333 K to 413 K. Their results are not considered to be too reliable from the standpoint of experimental procedure used. Nevertheless, the 10 data points reported are given equal weight in the present analysis.

The correlation formula obtained for the real gas state is

$$C_p \text{ (cal g}^{-1} \text{ K}^{-1}) = 0.234595 - 1.05032 \times 10^{-3} T + 3.68350 \times 10^{-6} T^2 - 3.58501 \times 10^{-9} T^3 \quad (T \text{ in K}).$$

This equation is found to fit the reported data with a mean deviation of 0.3 percent and a maximum of 1.2 percent.

The recommended values are calculated using the above formula. The tabulated values should be substantially correct within five percent, the uncertainty resulting from the experimental error of the original data.

FIGURE 43 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS FREON-113

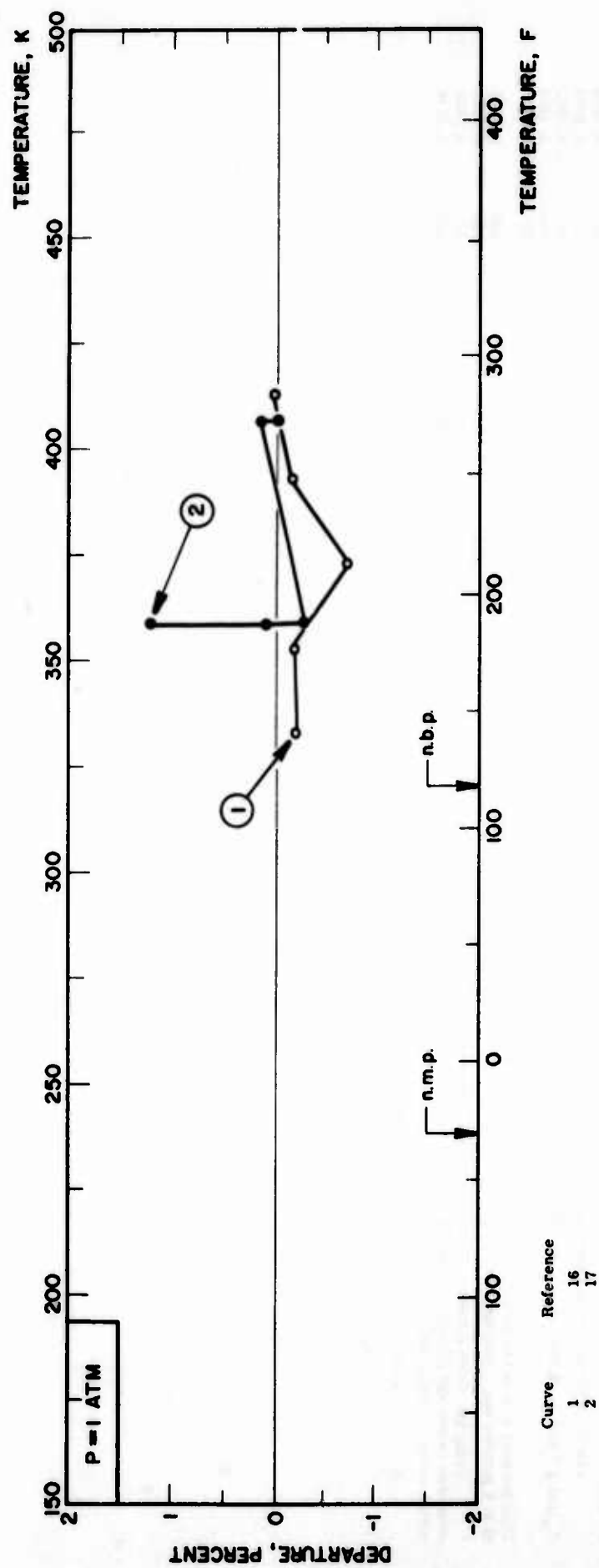


FIGURE 44 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS FREON-114

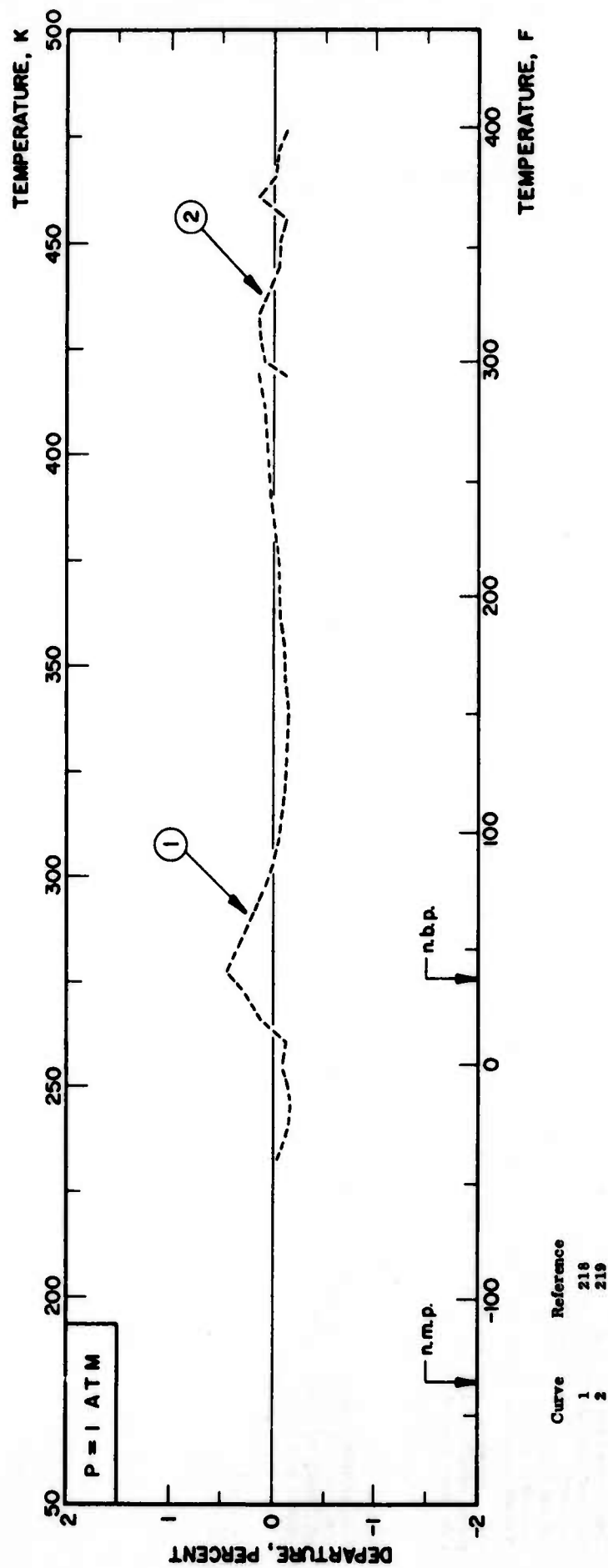


TABLE 45 SPECIFIC HEAT AT CONSTANT PRESSURE OF GLYCEROL

DISCUSSION

LIQUID

Seven sources of information are available for the specific heat at constant pressure of liquid glycerol, of which three (593, 594, 595) contain original experimental data. The recent calorimetric data of Blaha (595) and of Rabinovich and Nikolaev (593) are in good agreement with one another, whereas the ancient single data point of Weber (594) is higher by 7 percent. In their extensive tabulation of physical properties of volatile components of alcoholic mashes and crude alcohols, Stage et al. (198) included a set of values for the specific heat of liquid glycerol. These values are also in good agreement with the data of (593, 595). Schumann and Voss (592) and Wilke (590) have each given a single value without indicating the source. These two values are slightly lower than the data of (593, 595) by 1.5 and 3 percent. A single value given in (591) was taken from Handbook of Chemistry and Physics, 1953 Edition, Chemical Rubber Publishing Co. This value is much lower than all the others and is considered incorrect.

By giving no weight to the handbook value of (591) and Weber's data point and giving equal weight to the others, a correlation formula is obtained for the temperature range from 283 to 511 K:

$$C_p(\text{cal g}^{-1}\text{K}^{-1}) = 0.098645 + 1.88655 \times 10^{-3}T - 1.36428 \times 10^{-6}T^2 + 1.03166 \times 10^{-9}T^3$$

(T in K).

This equation is found to fit the above enumerated data points with a mean deviation of 0.7 percent and a maximum of 4 percent. The recommended values are computed from the above equation. The tabulated values should be substantially correct within 2 percent.

RECOMMENDED VALUES
[Temperature, T, °F; Specific Heat, C_p , B lb⁻¹F⁻¹]

LIQUID	
T	C_p
50	0.5468
60	0.5544
80	0.5694
100	0.5843
120	0.5992
140	0.6139
160	0.6285
180	0.6430
200	0.6576
220	0.6720
240	0.6864
260	0.7008
280	0.7151
300	0.7294
320	0.7437
340	0.7580
360	0.7722
380	0.7865
400	0.8008
420	0.8152
440	0.8296
460	0.8440

n. m. p. = 65 °F (solidifies at much lower temperature)

n. b. p. = 554 °F

FIGURE 45 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID GLYCEROL

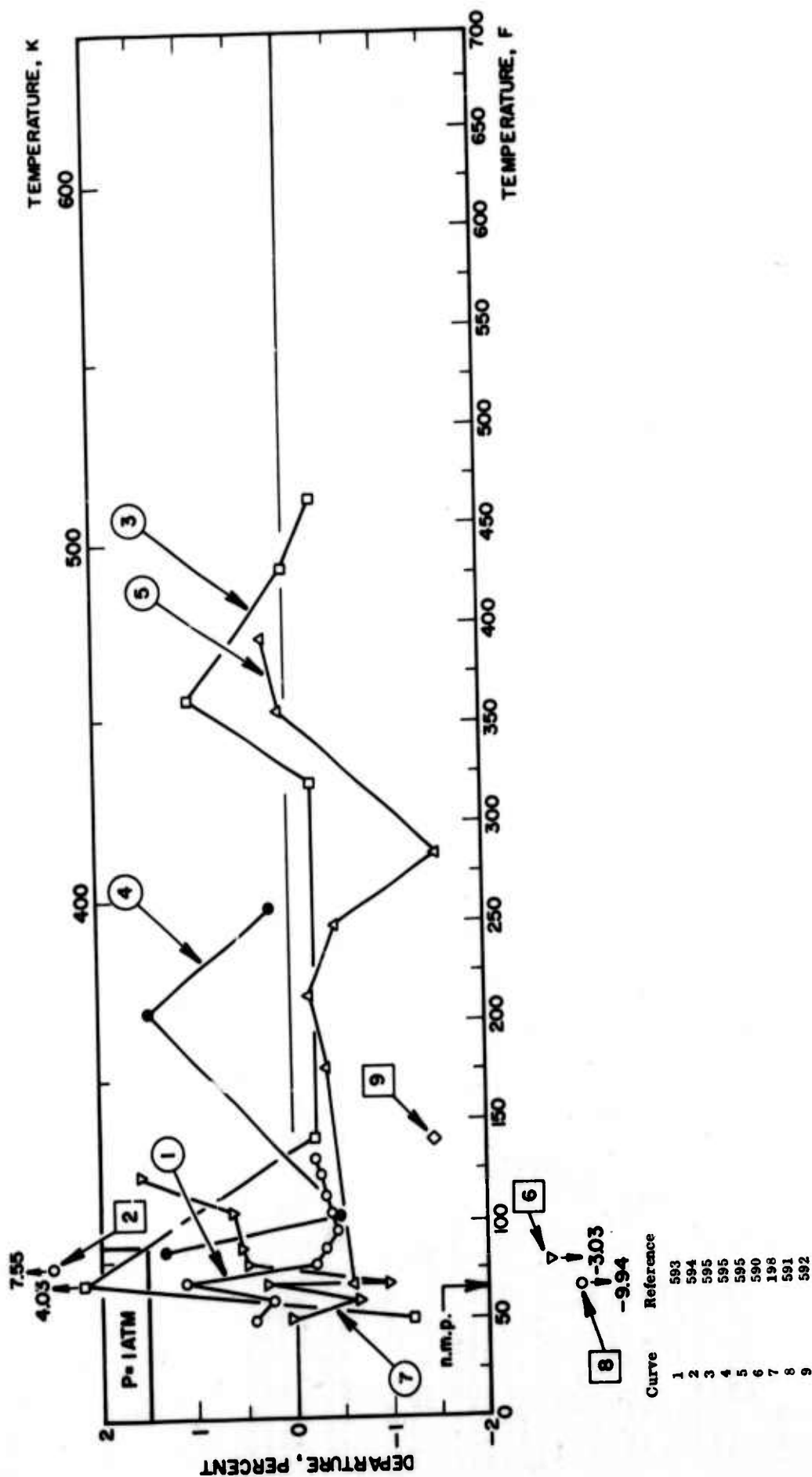


TABLE 46 SPECIFIC HEAT AT CONSTANT PRESSURE OF n-HEPTANE

DISCUSSION

LIQUID

There exist 12 sources of information on the specific heat at constant pressure of liquid n-heptane. The agreement among most of the experimental data is rather good. The most extensive works were reported by Douglas, et al (49) and Gilling and Furukawa (68), who employed the drop method by means of an ice calorimeter and obtained the specific heat of 99.997 percent n-heptane with an error of 0.2 percent covering temperatures from 183 K to 520 K under saturation vapor pressures. They found a minimum value of the specific heat in the liquid phase near 200 K, confirming the trend that had been suggested in an earlier calorimetric work (153). Another set of careful calorimetric data were obtained by Osborne and Gilling (149) covering the temperature range between 278 K and 318 K. These works are considered to be the most reliable and therefore the reported data, excluding those near the minimum and those near the critical point, are given equal weight in order to produce a single correlation formula in the present analysis. Meanwhile, two sets of extensive calorimetric works (80, 162) showed a little different trend from the above enumerated works (49, 68, 149), and are given no weight, as well as the mean specific heat between 294 K and 369 K (257) and four sets of early calorimetric works (153, 168, 221, 231). Also no weight is given to the correlated values in narrow temperature ranges (36, 78).

The correlation formula obtained for the temperature range between 230 K and 480 K is

$$C_p (\text{cal g}^{-1} \text{K}^{-1}) = 0.454958 - 3.46073 \times 10^{-4} T + 2.14820 \times 10^{-6} T^2 - 2.48653 \times 10^{-10} T^4$$

(T in K).

This equation is found to fit the above enumerated 70 data points with a mean deviation of 0.08 percent and a maximum of 0.3 percent.

The recommended values between 233 K and 480 K are generated by the above equation. The values outside this temperature range are determined by the graphical interpolation of the reported data (49, 68). The tabulated values should be correct within one percent over the whole temperature range.

RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p , B lb⁻¹ F⁻¹]

LIQUID

T	C_p	T	C_p
-120	0.482	200	0.6040
-100	0.490	220	0.6168
-80	0.482	240	0.6300
-60	0.484	260	0.6437
-40	0.4876	280	0.6578
-20	0.4946	300	0.6724
0	0.5022	320	0.6874
20	0.5102	340	0.7029
40	0.5188	360	0.7189
60	0.5278	380	0.7353
80	0.5373	400	0.7521
100	0.5472	420	0.773
120	0.5576	440	0.799
140	0.5685	460	0.838
160	0.5799	480	0.939
180	0.5917		

n. b. p. = 209 F

FIGURE 46 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID n-HEPTANE

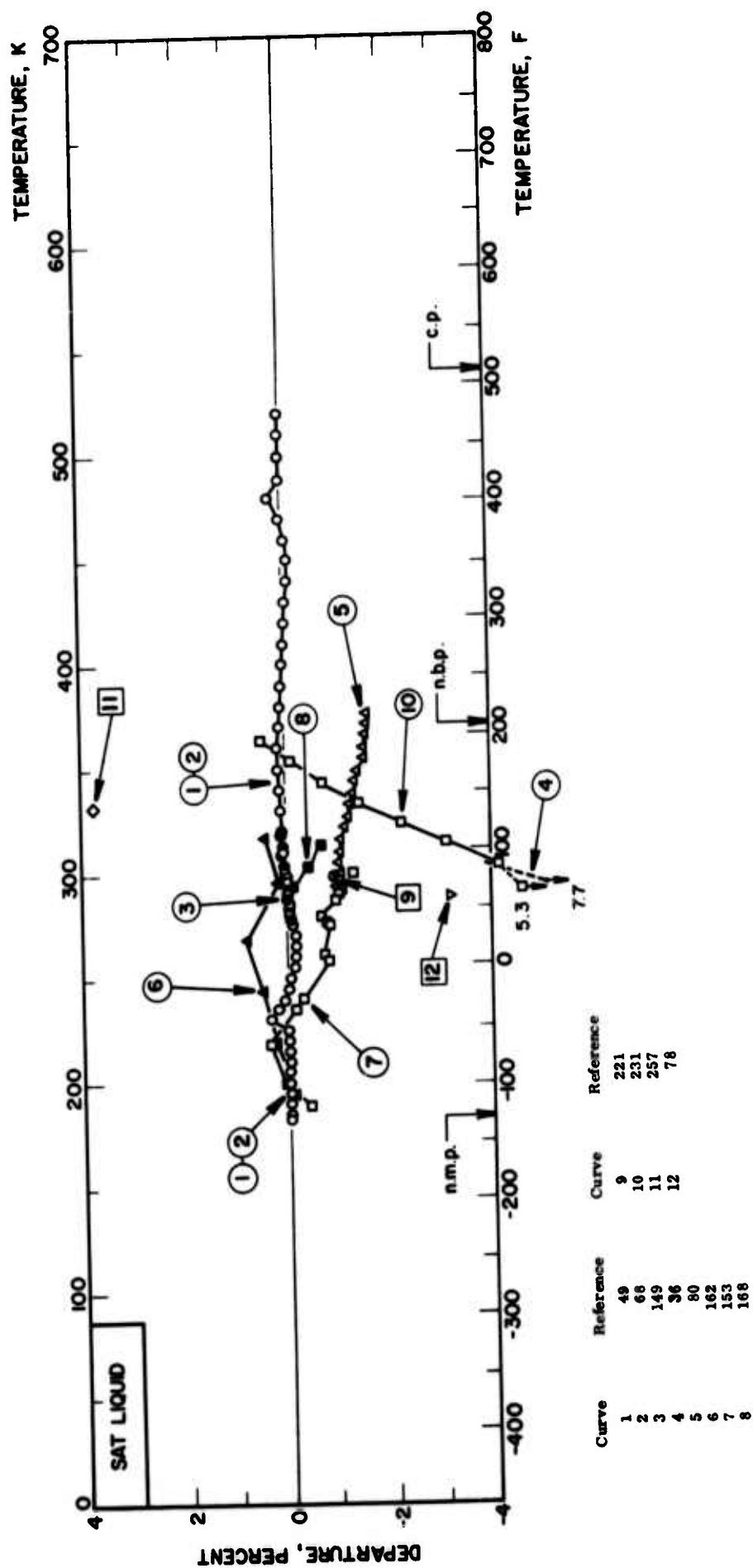


TABLE 46 SPECIFIC HEAT AT CONSTANT PRESSURE OF n-HEPTANE

GAS

DISCUSSION

There exist 26 sources of information for the isobaric specific heat of gaseous n-heptane. A number of extensive values have been derived from spectroscopic and molecular structural data. The results of Person and Pimentel (150), Pitzer (161), Ribaud (167), Rossini et al. (171, 253) are considered to be the most reliable, and are given equal weight in this analysis at temperatures between 298 K and 1500 K, although some discrepancy is found among them at temperatures below the n. b. p. Other sets of values derived from an equation of state (13), modified simple formulas (133, 134), and early statistical calculations (203, 222) are given no weight, as well as the correlated values from published experimental data (49). The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperature range from 298 K and 800 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.0254671 + 1.37666 \times 10^{-3} T - 4.00040 \times 10^{-7} T^2 - 1.13314 \times 10^{-10} T^3, \quad (1)$$

For temperature range from 800 K and 1500 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.0982018 + 1.30398 \times 10^{-3} T - 5.92804 \times 10^{-7} T^2 + 1.01054 \times 10^{-10} T^3 \quad (T \text{ in K}) \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.45 and 0.04 percent and maximum ones of 2.4 and 0.16 percent, respectively. The recommended values are computed by the above formulas. The tabulated values should be substantially correct within one percent above 500 K and two percent at lower temperatures. In the departure plot at $P = 0$, all the above mentioned values are compared with the Equations (1) and (2). The extrapolated values to zero pressure from the calorimetric data (225) are also shown in this figure. Several empirical equations (195, 196, 197) are not given.

On the other hand, several sets of experimental data are available on the specific heat in the real gas state. The flow-calorimetric data of Eucken and Sarstedt (58), Pitzer (162) and Waddington et al. (225) are considered to be reliable, as well as a single point data obtained by isothermal and isentropic compressibility (85). Therefore, these data covering temperatures from 357 K to 466 K are fitted by the least square method to the following equation:

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 4.62354 - 3.27676 \times 10^{-2} T + 8.38934 \times 10^{-5} T^2 - 6.91452 \times 10^{-8} T^3 \quad (T \text{ in K}) \quad (3)$$

[Temperature, T, F; Specific Heat, C_p , B lb⁻¹ F⁻¹]

RECOMMENDED VALUES

GAS

T	C_p^0	T	C_p^0
80	0.3989	680	0.7075
100	0.4112	700	0.7156
120	0.4233	720	0.7235
140	0.4352	740	0.7313
160	0.4471	760	0.7389
180	0.4588	780	0.7463
200	0.4704	800	0.7536
220	0.4818	820	0.7608
240	0.4932	840	0.7678
260	0.5044	860	0.7746
280	0.5154	880	0.7812
300	0.5264	900	0.7877
320	0.5372	920	0.7944
340	0.5478	940	0.8007
360	0.5583	960	0.8070
380	0.5687	980	0.8131
400	0.5790	1000	0.8192
420	0.5891	1100	0.8482
440	0.5991	1200	0.8752
460	0.6089	1300	0.9003
480	0.6186	1400	0.9235
500	0.6281	1500	0.9450
520	0.6375	1600	0.9649
540	0.6468	1700	0.9833
560	0.6559	1800	1.0002
580	0.6649	1900	1.0159
		2000	1.0303

n. b. p. = 209 F

GAS

There exist 26 sources of information for the isobaric specific heat of gaseous n-heptane. A number of extensive values have been derived from spectroscopic and molecular structural data. The results of Person and Pimentel (150), Pitzer (161), Ribaud (167), Rossini et al. (171, 253) are considered to be the most reliable, and are given equal weight in this analysis at temperatures between 298 K and 1500 K, although some discrepancy is found among them at temperatures below the n. b. p. Other sets of values derived from an equation of state (13), modified simple formulas (133, 134), and early statistical calculations (203, 222) are given no weight, as well as the correlated values from published experimental data (49). The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperature range from 298 K and 800 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.0254671 + 1.37666 \times 10^{-3} T - 4.00040 \times 10^{-7} T^2 - 1.13314 \times 10^{-10} T^3, \quad (1)$$

For temperature range from 800 K and 1500 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.0982018 + 1.30398 \times 10^{-3} T - 5.92804 \times 10^{-7} T^2 + 1.01054 \times 10^{-10} T^3 \quad (T \text{ in K}) \quad (2)$$

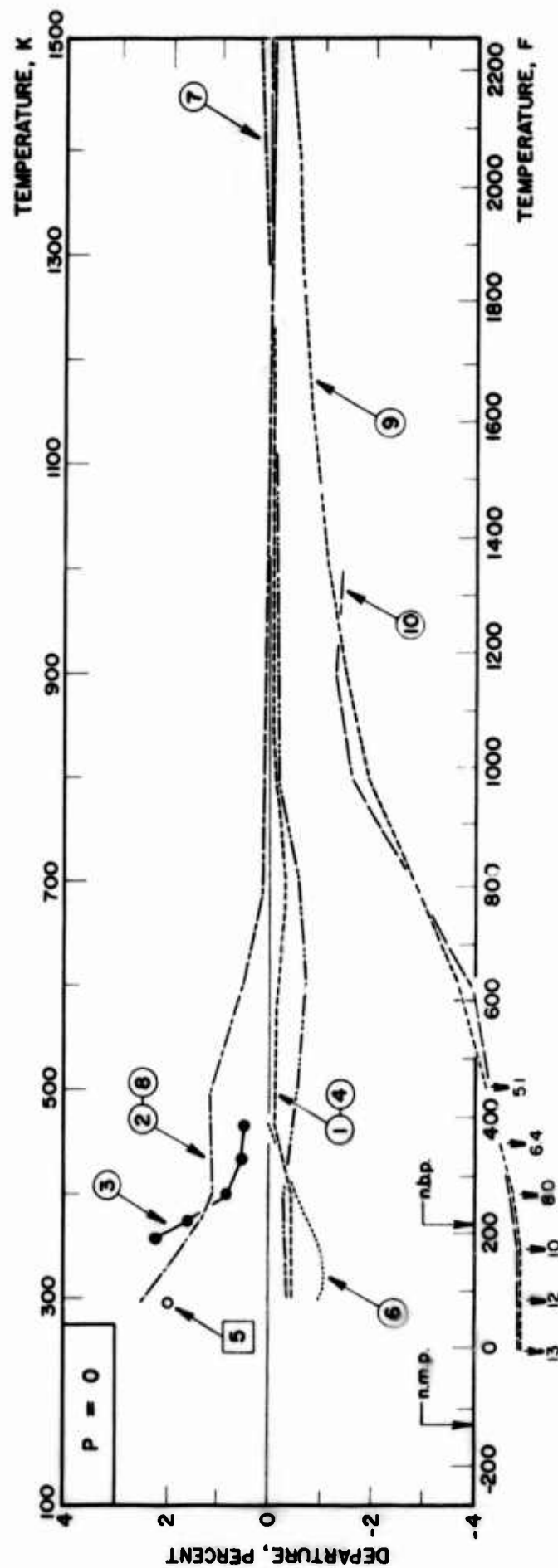
These equations are found to fit the above enumerated values with mean deviations of 0.45 and 0.04 percent and maximum ones of 2.4 and 0.16 percent, respectively. The recommended values are computed by the above formulas. The tabulated values should be substantially correct within one percent above 500 K and two percent at lower temperatures. In the departure plot at $P = 0$, all the above mentioned values are compared with the Equations (1) and (2). The extrapolated values to zero pressure from the calorimetric data (225) are also shown in this figure. Several empirical equations (195, 196, 197) are not given.

On the other hand, several sets of experimental data are available on the specific heat in the real gas state. The flow-calorimetric data of Eucken and Sarstedt (58), Pitzer (162) and Waddington et al. (225) are considered to be reliable, as well as a single point data obtained by isothermal and isentropic compressibility (85). Therefore, these data covering temperatures from 357 K to 466 K are fitted by the least square method to the following equation:

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 4.62354 - 3.27676 \times 10^{-2} T + 8.38934 \times 10^{-5} T^2 - 6.91452 \times 10^{-8} T \quad (T \text{ in K}) \quad (3)$$

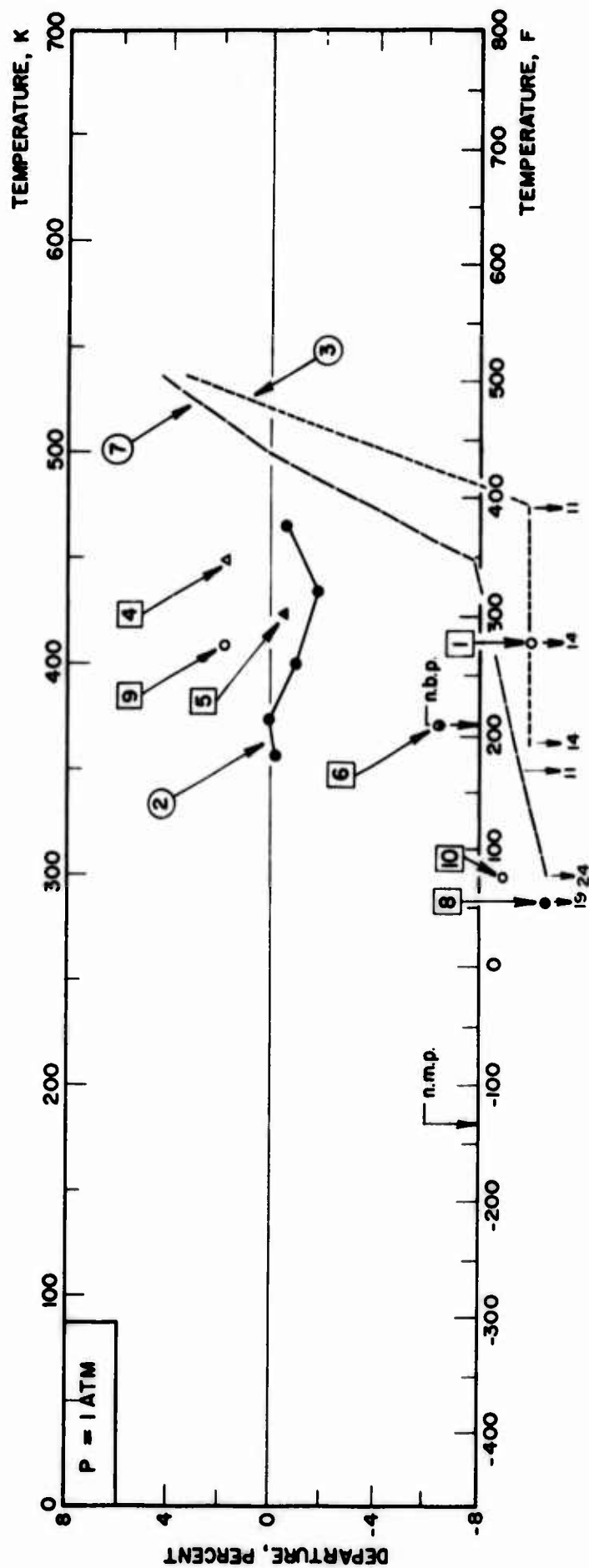
This equation is found to fit the above enumerated data with a mean deviation of 0.96 percent and a maximum of 1.9 percent. In the departure plot at $P = 1$ atm, early calorimetric data (15), derived values using equations of state (13, 14, 203) and empirically correlated values (78, 182) are compared with the above equation. Furthermore, the comparison between Equation (3) and (1) over the common temperature range is shown in the third departure plot of $[(C_p)_3 - (C_p^0)_3]/(C_p^0)_1$.

FIGURE 46 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS n-HEPTANE



Curve	Reference
1	159
2	161, 167
3	225
4	253
5	13
6	49
7	133, 134
8	171
9	203
10	222

FIGURE 46 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS n-HEPTANE



Curve	Reference
1	15
2	225
3	14
4	58
5	162
6	182
7	203
8	78
9	85
10	13

FIGURE 46 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS n-HEPTANE

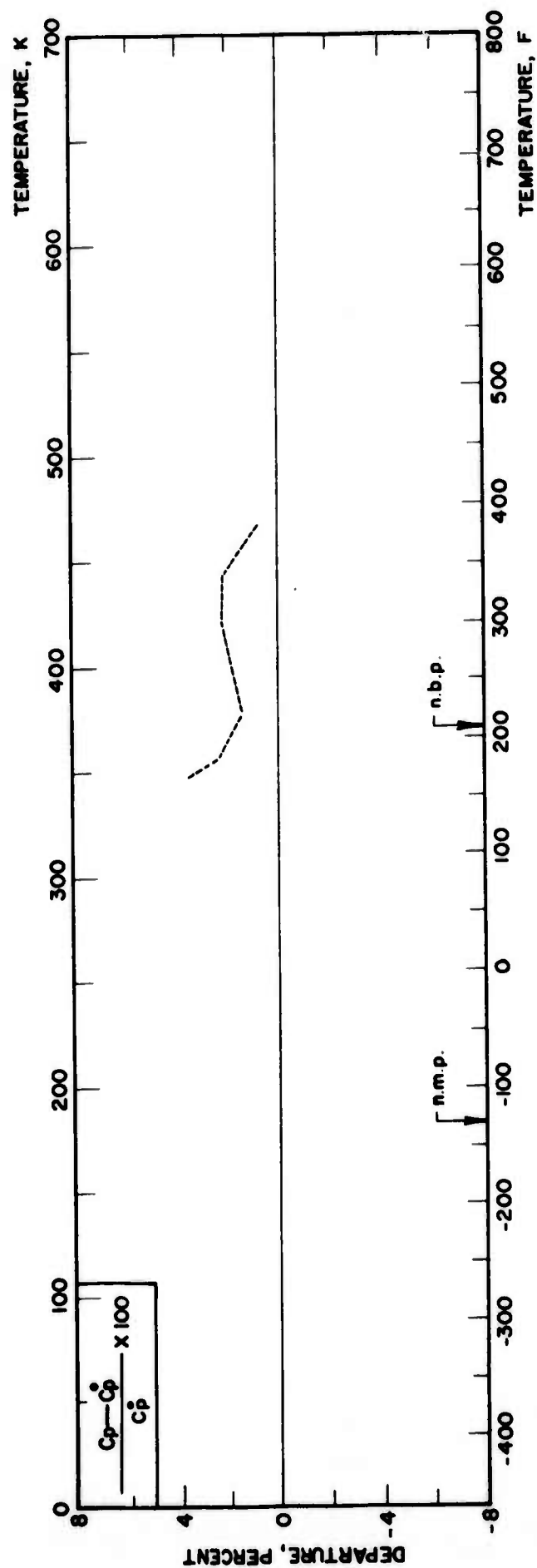


TABLE 47 SPECIFIC HEAT AT CONSTANT PRESSURE OF n-HEXANE

LIQUID	DISCUSSION	RECOMMENDED VALUES	
		Temperature, T, °F; Specific Heat, C _p , B lb ⁻¹ F ⁻¹	LIQUID
		T	C _p
		-140	0.4699
		-120	0.4721
		-100	0.4753
		-80	0.4795
		-60	0.4845
		-40	0.4904
		-20	0.4973
		0	0.5050
		20	0.5135
		40	0.5229
		60	0.5332
		80	0.5442
		100	0.5560
		120	0.5686
		140	0.5819
		160	0.5960
		180	0.6108
		200	0.6263
		220	0.6424
		240	0.6593
		260	0.6768
		280	0.6950

n. m. p. = -138 F
n. b. p. = +156 F

LIQUID

Nine sources of information are available on the specific heat at constant pressure of liquid n-hexane. In the temperature range from the n. m. p. to the n. b. p., the calorimetric work of Douslin and Huffman (50) is considered to be the most reliable in view of their experimental procedure with a reported error of 0.2 percent. Huffman et al (87) made careful measurements by the Nernst method, and their results show good agreement with those of Douslin and Huffman. Beyond the n. b. p., the calorimetric data of Connolly et al (39) is thought to be also reliable. Equal weight is given to the above three works in this analysis. Meanwhile, Stull (201) reported that a hump was observed with a maximum at about 260 K and with a minimum near 300 K. However, other investigators did not find such a hump. Therefore no weight is given to Stull's results, as well as some early calorimetric data (153) and correlated results (32, 36, 83).

The correlation formula obtained in the temperature range between 180 K to 366 K is

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}\text{)} = 0.577652 - 1.43082 \times 10^{-3} T + 5.00921 \times 10^{-6} T^2 - 2.01933 \times 10^{-9} T^3$$

(T in K).

This equation fits the 55 data points enumerated above with a mean deviation of 0.1 percent and a maximum of 0.5 percent. The recommended values are computed by the above equation. The tabulated values should be substantially correct within one percent. In the departure plot, a set of cited data (188) are not shown.

FIGURE 47 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID n-HEXANE

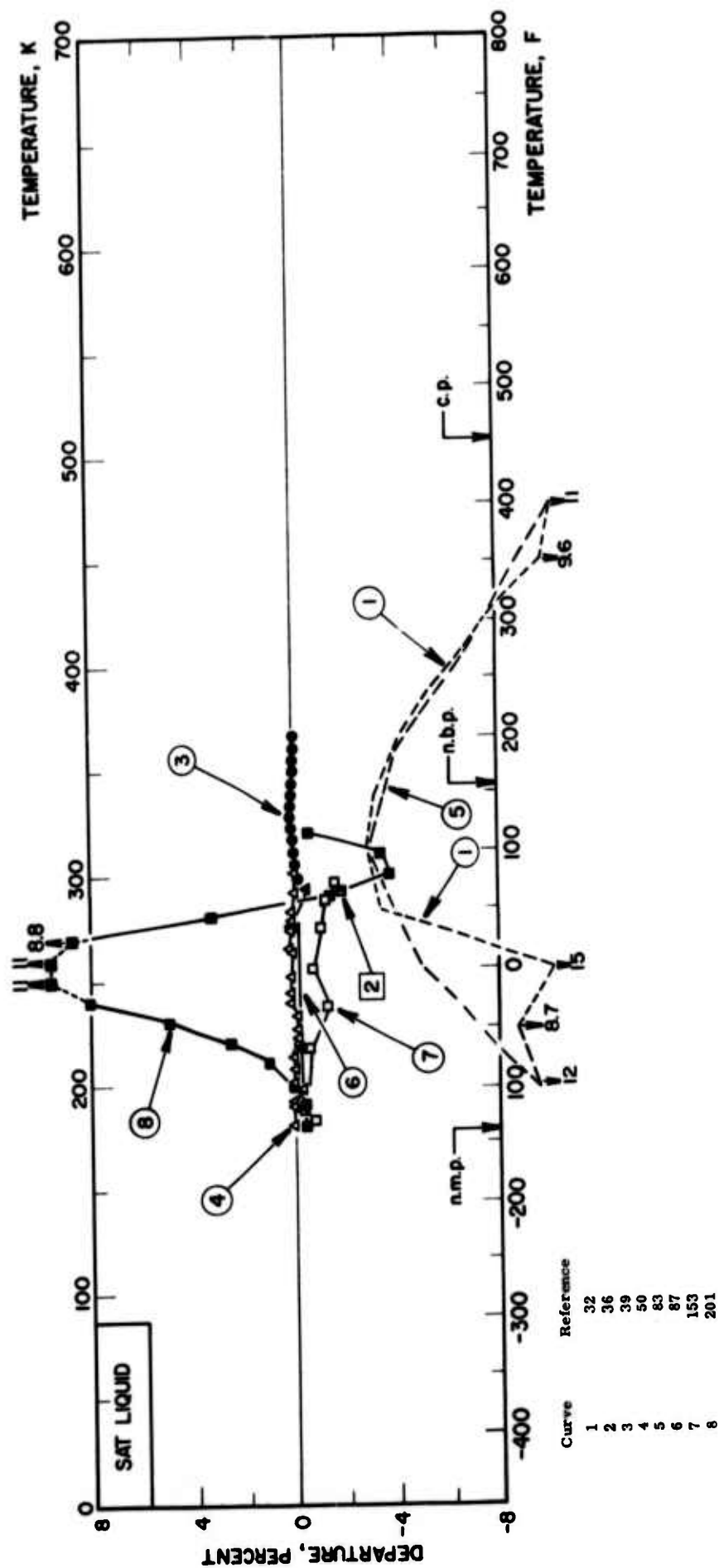


TABLE 47 SPECIFIC HEAT AT CONSTANT PRESSURE OF n-HEXANE

DISCUSSION

GAS

There exist 24 sources of information on the isobaric specific heat of gaseous n-hexane. A number of intensive formulations for the ideal gas state have been derived from spectroscopic and molecular structural data. Among them, the works of Person and Pimentel (159), Pitzer et al. (161, 164), Ribaud (167), Rossini et al. (171) are thought to be the most reliable, as well as the compilations (109, 253). Therefore, equal weight is given to these works in the present correlation. However, no weight is given to the early statistical calculations (203, 222) and the empirical derivations (133, 134). The correlation formulas obtained for the ideal gas state are as follows:

For temperatures between 273 K and 790 K:

$$C_p^0 (\text{cal g}^{-1}\text{K}^{-1}) = 0.0586880 + 1.21316 \times 10^{-3} T - 1.21609 \times 10^{-7} T^2 - 2.63815 \times 10^{-10} T^3 \quad (1)$$

For temperatures between 790 K and 1500 K:

$$C_p^0 (\text{cal g}^{-1}\text{K}^{-1}) = 0.0650063 + 1.39341 \times 10^{-3} T - 6.62474 \times 10^{-7} T^2 + 1.19713 \times 10^{-10} T^3 \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.75 and 0.93 percent and maximum ones of 2.2 and 0.15 percent, respectively. The above formulas are used to generate the recommended values, which should be substantially correct within one percent. The departure of all the values mentioned above from the tabulated recommended values are shown in the departure plot at $P = 0$. A set of the extrapolated values to zero pressure from the calorimetric data (224) is also given in this figure. Several empirical equations (195, 196, 197) are not plotted.

Meanwhile, concerning the specific heat at the real gas state, two sets of experimental data of Waddington and Dougan (224) and Eucken and Sarstedt (59) were obtained by means of flow calorimeters covering the temperature range from 333 K to 574 K. These data show good agreement with each other over the common temperature range, and are considered to be the most reliable from the standpoint of experimental procedures used. In this analysis for the real gas state, these data are given equal weight and are fitted to the following equation:

$$C_p (\text{cal g}^{-1}\text{K}^{-1}) = 0.649840 - 2.81865 \times 10^{-3} T + 8.92647 \times 10^{-6} T^2 - 6.88679 \times 10^{-9} T^3 \quad (3)$$

This equation is found to fit the original data with a mean deviation of 0.46 percent and a maximum of 1.3 percent. In the departure plot at $P = 1$ atm, early experimental data by a flow calorimeter (15) and by the velocity of sound (46, 89), and theoretically derived values (13, 14, 85, 182, 202) are compared with the above Equation (3). Furthermore, the comparison of Equation (3) with Equation (1) over the common temperature range is shown in the third departure plot of $[(C_p)_3 - (C_p)_1]/(C_p)_1$.

RECOMMENDED VALUES

[Temperature, T, °F; Specific Heat, C_p , B lb ⁻¹ F ⁻¹]			
GAS			
T	C_p^0	T	C_p^0
40	0.3402	600	0.6765
60	0.3922	620	0.6852
80	0.4041	640	0.6938
100	0.4159	660	0.7023
120	0.4277	680	0.7106
140	0.4393	700	0.7188
160	0.4509	720	0.7268
180	0.4623	740	0.7346
200	0.4737	760	0.7423
220	0.4849	780	0.7499
240	0.4961	800	0.7572
260	0.5071	820	0.7644
280	0.5180	840	0.7714
300	0.5289	860	0.7783
320	0.5396	880	0.7850
340	0.5502	900	0.7915
360	0.5606	920	0.7978
380	0.5710	940	0.8039
400	0.5812	960	0.8099
420	0.5913	980	0.8164
440	0.6013	1000	0.8226
460	0.6112	1100	0.8523
480	0.6209	1200	0.8798
500	0.6305	1300	0.9053
520	0.6400	1400	0.9289
540	0.6493	1500	0.9507
560	0.6585	1600	0.9708
580	0.6676	1700	0.9873
		1800	1.0064
		1900	1.0222
		2000	1.0368

n. b. p. = 156 F

FIGURE 47 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS n-HEXANE

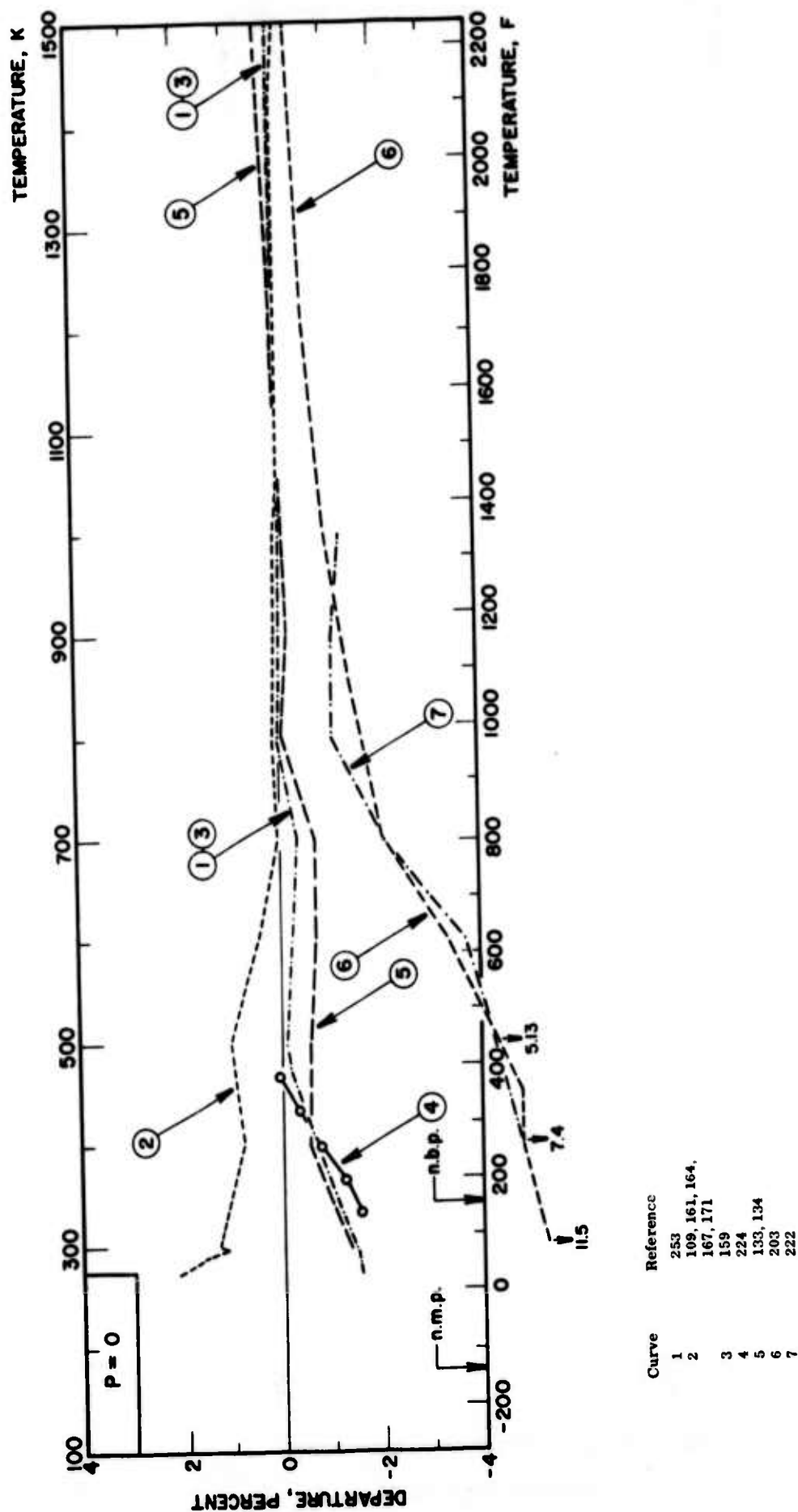


FIGURE 47 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS n-HEXANE

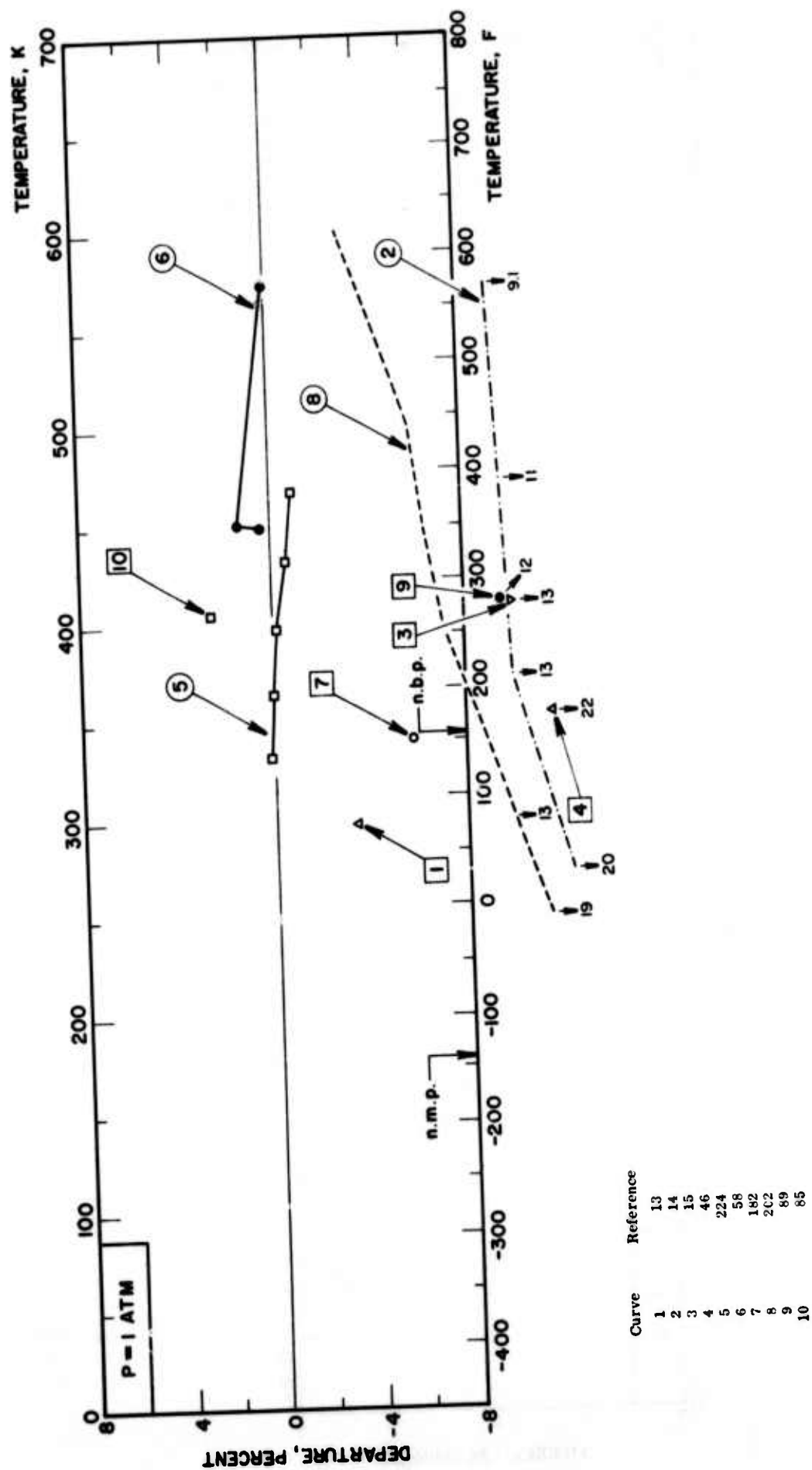


FIGURE 47 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS n-HEXANE

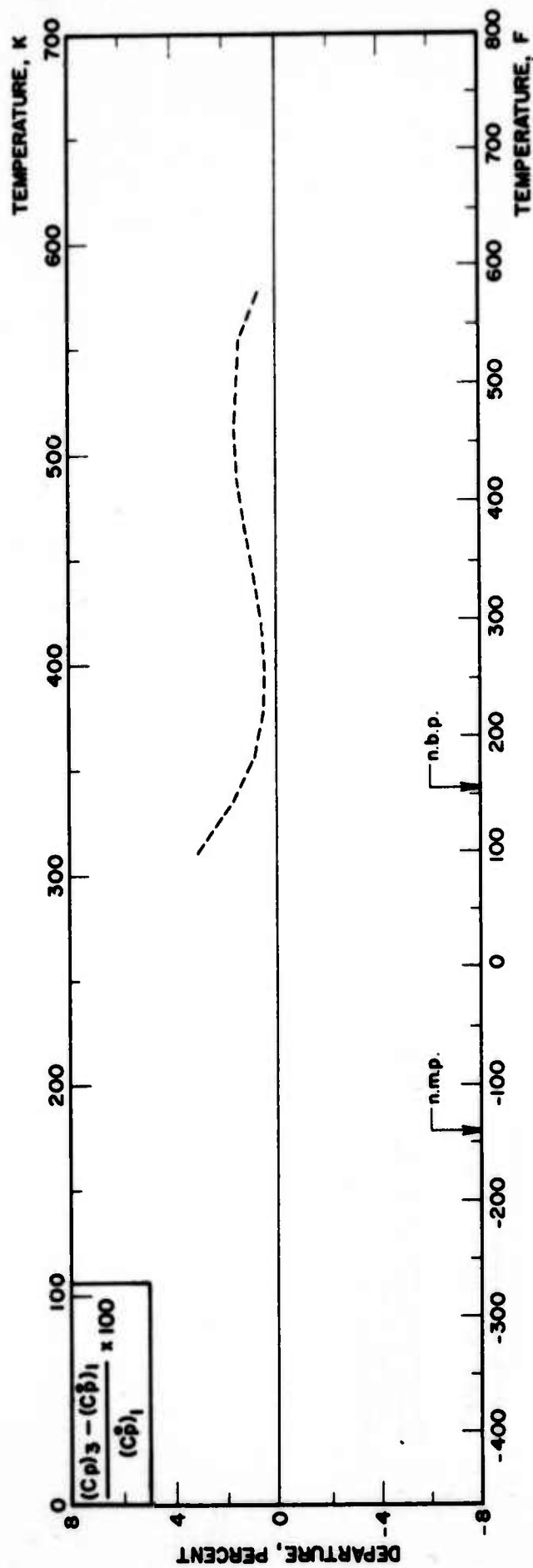


TABLE 48 SPECIFIC HEAT AT CONSTANT PRESSURE OF METHANE

DISCUSSION		RECOMMENDED VALUES	
LIQUID		[Temperature, T, F; Specific Heat, C_p , B lb ⁻¹ F ⁻¹]	
		T	C_p
		-300	0.8064
		-280	0.8058
		-260	0.8183
		-240	0.8422
		-220	0.8755
		-200	0.9163
		-180	0.963
		-160	1.012
		-140	1.064

DISCUSSION

LIQUID

Six sources of information are available for the specific heat at constant pressure of liquid methane. A calorimetric work between the n. m. p. and the n. b. p. was reported by Clusius (240) with an error of 0.2 to 0.7 percent. Wiebe and Brevoort (248) made calorimetric measurements with an error of one percent covering the temperature range from 98 K to 191 K under saturation vapor pressures. Another calorimetric work was that of Hestermans and White (81) covering temperatures between 115 K and 188 K. Recently, Van Isterbeek et al (259) reported derived values at various pressures from PVT relations. These works are considered to be reliable from the standpoint of experimental procedures used. All the reported data points below 150 K enumerated above are given equal weight in this analysis. As the specific heat near the critical point increases rapidly with temperature, the data points above 150 K are not used to produce a single correlation equation. Meanwhile, a set of calorimetric data (52) and a single point value (216) calculated by an empirical method is considered to be less reliable, and therefore no weight is given to these works.

The correlation formula obtained for the temperature range between 95 K and 150 K under saturation vapor pressures is

$$C_p (\text{cal g}^{-1} \text{K}^{-1}) = 1.51754 - 1.71493 \times 10^{-2} T + 1.23794 \times 10^{-4} T^2 - 2.34165 \times 10^{-7} T^3$$

(T in K).

This equation is found to fit the above enumerated data points with a mean deviation of 1 percent and a maximum of 3 percent. The recommended values below 140 K are generated using the above formula, and those above 140 K are obtained graphically. The tabulated values should be correct within four percent.

n. m. p. = -297 F
n. b. p. = -258 F

FIGURE 48 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID METHANE

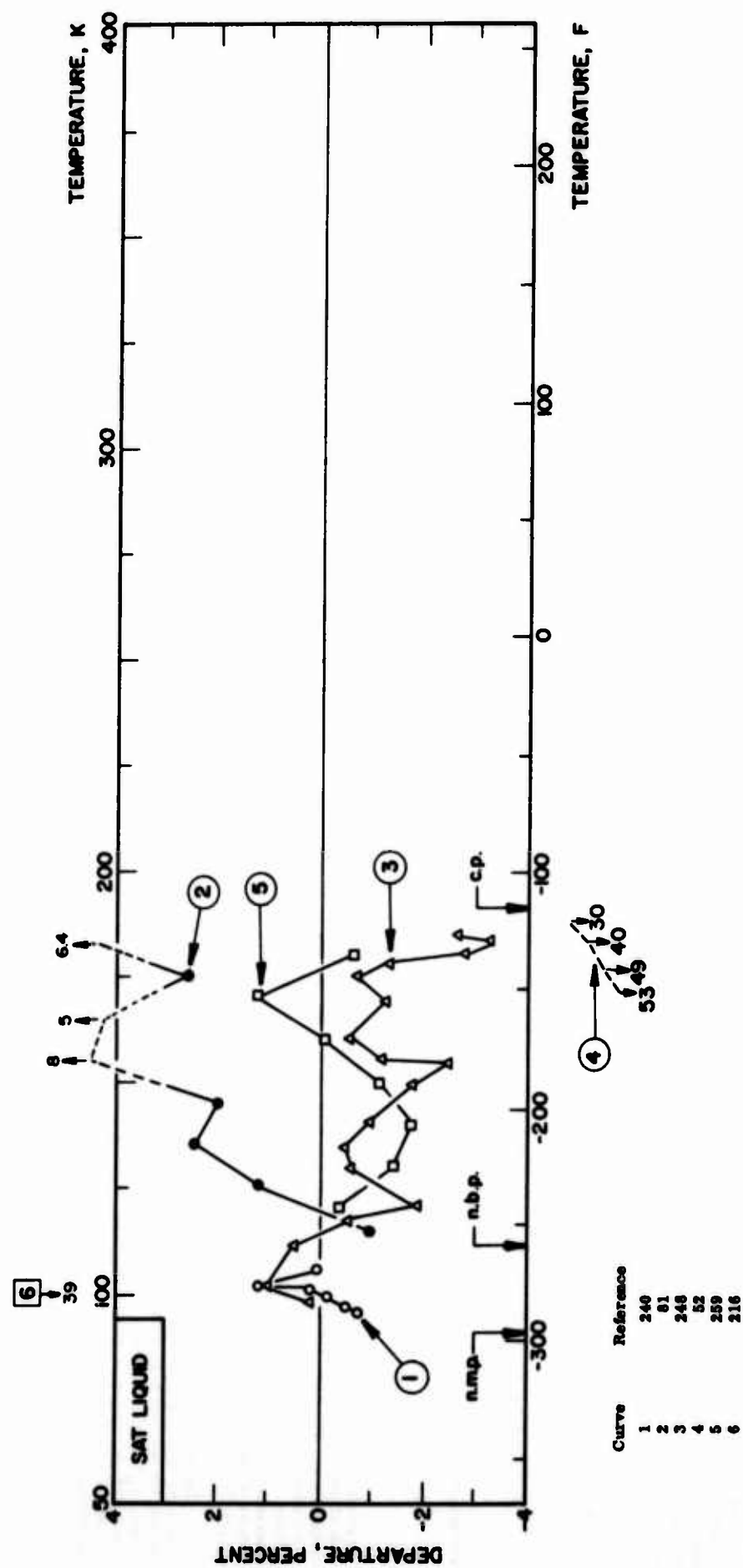


TABLE 48 SPECIFIC HEAT AT CONSTANT PRESSURE OF METHANE

DISCUSSION

GAS

There exist 56 sources of information on the specific heat at constant pressure of gaseous methane. A number of extensive heat capacity values for the ideal gas state have been derived from spectroscopic and molecular structural data. The values presented by Cerny and Erdos (34, 35), Faltin (59), Gordon (72), Kobe and Long (109, 113), McBride et al. (137), Pitzer (161), Ribaud (167) and Rossini et al. (171) are considered to be reliable, as well as two compilation tables (253, 254). Therefore, equal weight is given to these works in the present analysis. However, other sets of extensive correlations (100, 133, 134) and the earlier statistical calculations (24, 93, 178, 202, 213, 220, 222, 226) are given no weight as well as single-point values obtained by empirical correlations (18, 20). The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 270 K and 790 K

$$C_p^0 \text{ (cal g}^{-1} \text{ K}^{-1}) = 0.458066 - 2.61341 \times 10^{-4} T + 2.07904 \times 10^{-6} T^2 - 1.25017 \times 10^{-9} T^3 \quad (T \text{ in K}), \quad (1)$$

For temperatures between 790 K and 1500 K

$$C_p^0 \text{ (cal g}^{-1} \text{ K}^{-1}) = 0.0258866 + 1.60802 \times 10^{-3} T - 6.67069 \times 10^{-7} T^2 + 1.06432 \times 10^{-10} T^3 \quad (T \text{ in K}), \quad (2)$$

These equations are found to fit the above referenced values with mean deviations of 0.23 and 0.39 percent, and maximum deviations of 0.79 and 1.9 percent, respectively. The above formulas are used to generate the recommended values, which should be substantially accurate within two percent over the entire temperature range. The percent departure of all the values mentioned above from the tabulated recommended values are shown in the departure plot for $p = 0$. A number of empirical equations (25, 47, 185, 195, 197, 205, 377) as well as cited values (71, 236), are not plotted in this figure.

There are several sets of experimental data available for the specific heat in the real gas state, but the discrepancy between them is large. For this reason, the specific heat of the real gas, C_p^1 , is calculated from the ideal gas values, C_p^0 , and a correction for gas imperfection was applied using the usual thermodynamic relations and the Berthelot's equation of state. The C_p^1 values obtained for the temperature range from 178 K to 511 K are fitted to the following formula:

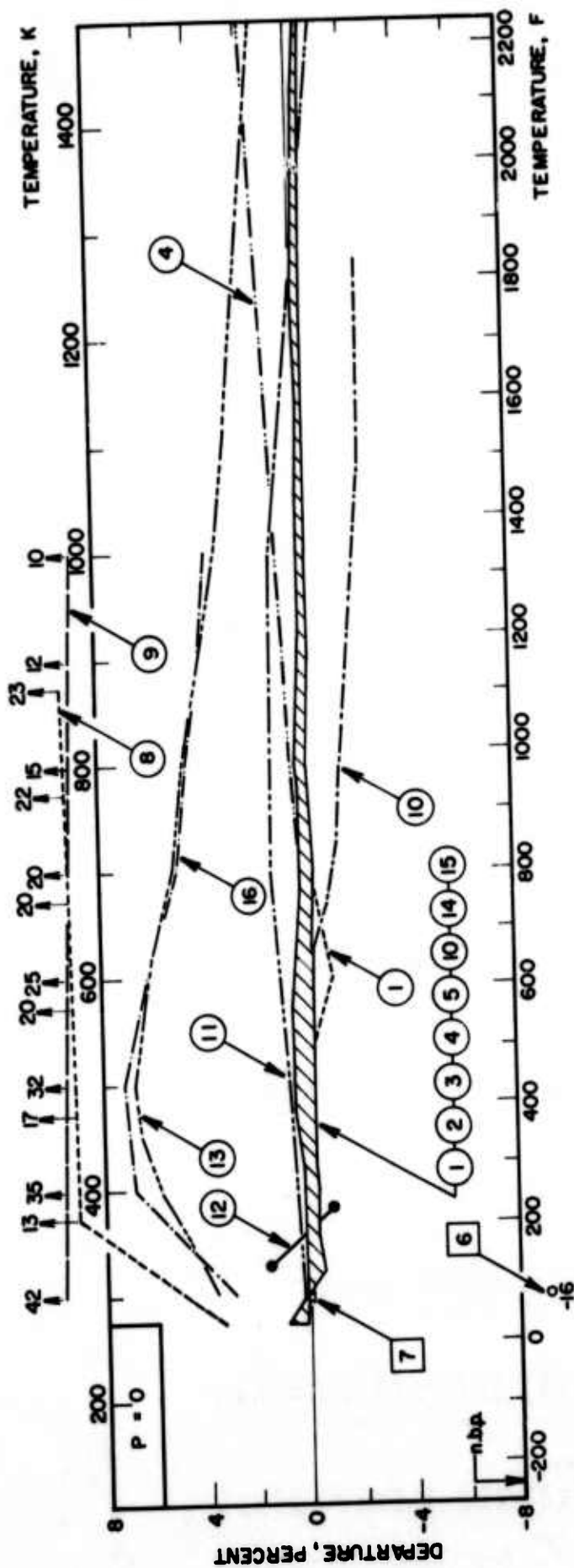
$$C_p^1 \text{ (cal g}^{-1} \text{ K}^{-1}) = 0.495585 - 5.25602 \times 10^{-4} T + 2.71563 \times 10^{-6} T^2 - 1.76417 \times 10^{-9} T^3 \quad (T \text{ in K}), \quad (3)$$

The recommended values of C_p^1 tabulated are generated by the above equation. The experimental data obtained by calorimetry (142), the velocity of sound (46, 241) measurements, p - V - T relations (27, 51, 85, 252) and adiabatic expansion (54, 56, 132) are compared with Equation (3) in the departure plot for $p = 1$ atm. The set of theoretical values (203) and a number of empirically correlated values (13, 14, 32, 78, 125, 182) are also compared with Equation (3) in the figure. The values cited in references (52, 83, 127, 216) as well as those obtained from an empirical equation (184) are not shown in this figure. In the third departure plot, the relative comparison between C_p^1 given by Equation (3) and C_p^0 given by Equation (1) is shown over their common temperature range.

TABLE 48 SPECIFIC HEAT AT CONSTANT PRESSURE OF METHANE (continued)

RECOMMENDED VALUES				
[Temperature, T, F; Specific Heat, C_p , B lb ⁻¹ F ⁻¹]				
T	C_p°	C_p^1	T	C_p°
40	0.5186	0.521	600	0.7692
60	0.5255	0.527	620	0.7790
80	0.5326	0.534	640	0.7888
100	0.5399	0.541	660	0.7985
120	0.5474	0.549	680	0.8082
140	0.5552	0.556	700	0.8178
160	0.5631	0.564	720	0.8273
180	0.5713	0.572	740	0.8367
200	0.5796	0.580	760	0.8460
220	0.5881	0.589	780	0.8553
240	0.5968	0.598	800	0.8643
260	0.6056	0.606	820	0.8733
280	0.6146	0.615	840	0.8821
300	0.6237	0.624	860	0.8907
320	0.6329	0.634	880	0.8992
340	0.6423	0.643	900	0.9075
360	0.6517	0.652	920	0.9156
380	0.6612	0.662	940	0.9235
400	0.6708	0.671	960	0.9313
420	0.6805	0.681	980	0.9391
440	0.6903	0.691	1000	0.9473
460	0.7001	0.700	1100	0.9870
480	0.7099		1200	1.0242
500	0.7198		1300	1.0591
520	0.7297		1400	1.0918
540	0.7395		1500	1.1225
560	0.7494		1600	1.1512
580	0.7593		1700	1.1780
			1800	1.2031
			1900	1.2265
			2000	1.2484

FIGURE 4b DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS METHANE



Curve	Reference	Curve	Reference
1	34, 35	11	133, 134
2	59, 109, 113,	12	178
3	161, 167, 226	13	202
4	72, 171, 254	14	213
5	137	15	220
6	253	16	222
7	18		
8	20		
9	24		
10	93		
	100		

FIGURE 48 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS METHANE

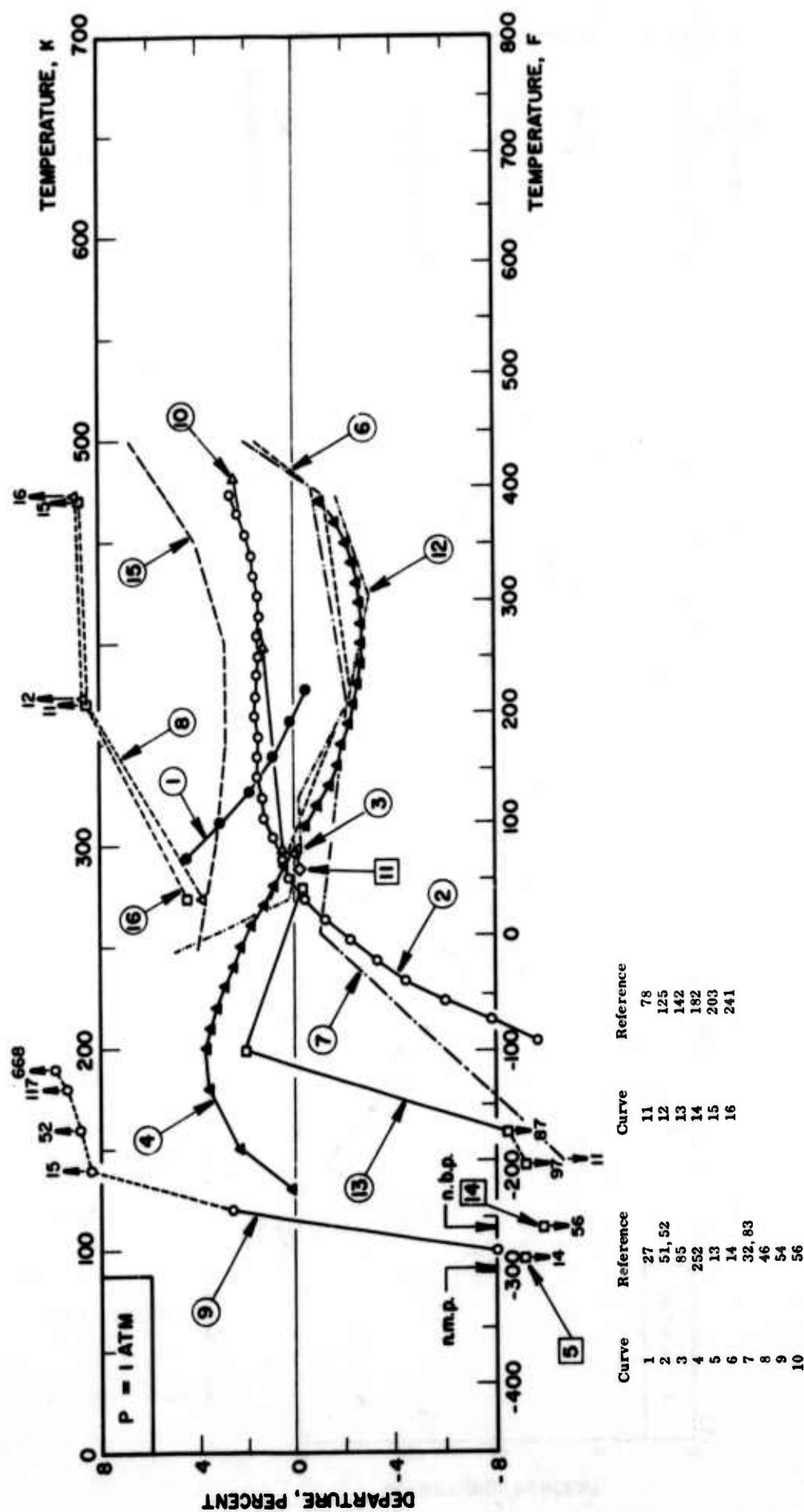


FIGURE 48 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS METHANE (continued)

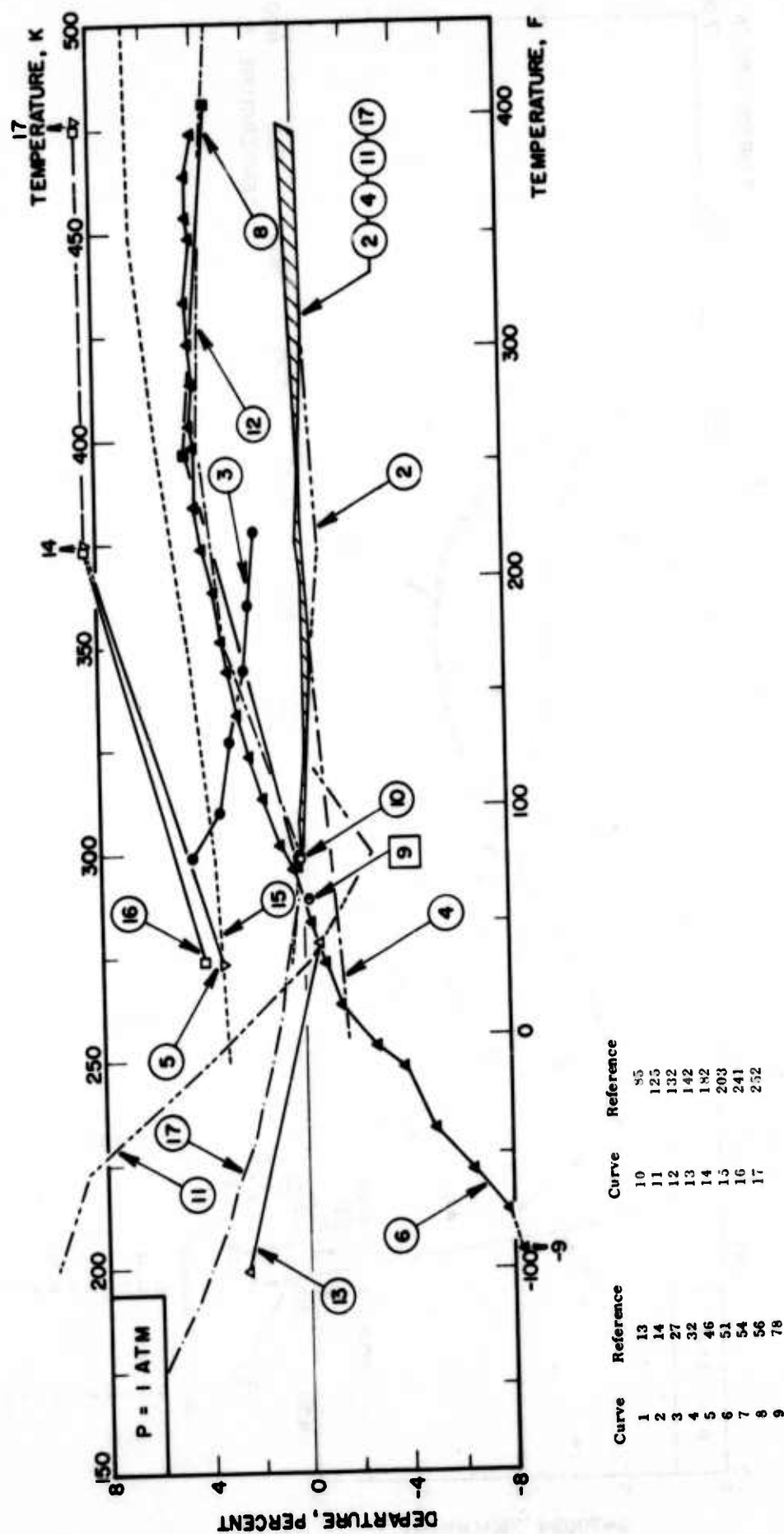


FIGURE 48 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS METHANE

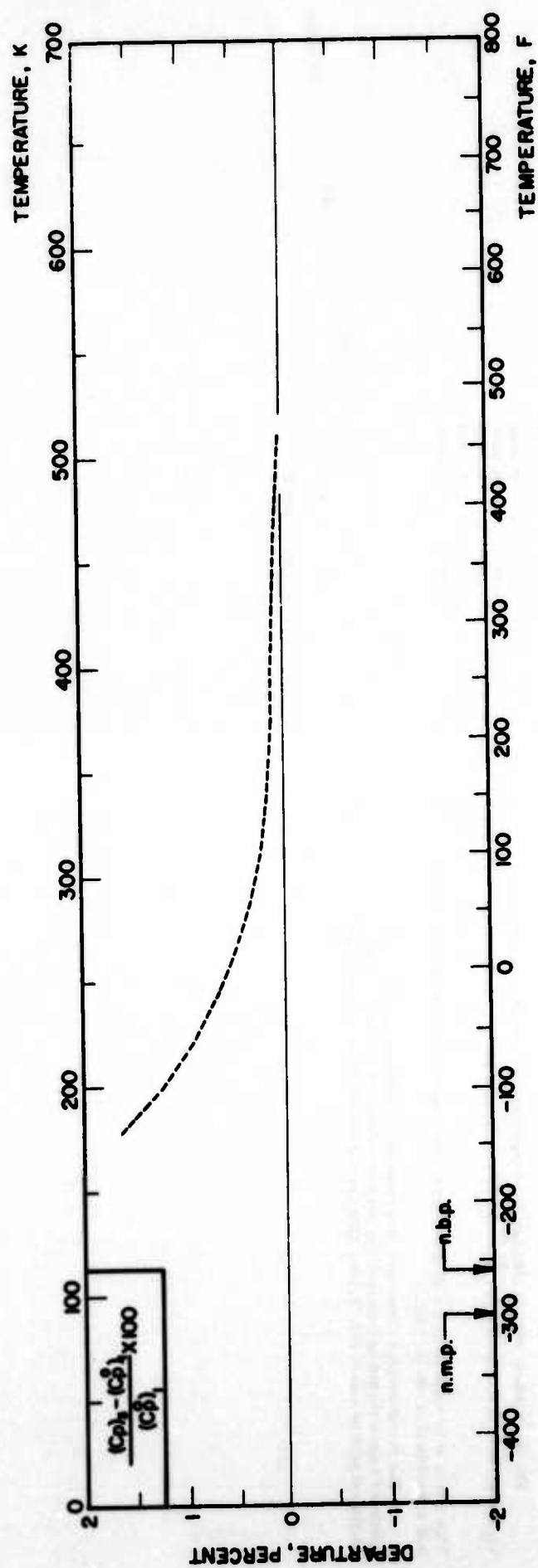


TABLE 49 SPECIFIC HEAT AT CONSTANT PRESSURE OF METHYL ALCOHOL

DISCUSSION

LIQUID

Ten sources of information are available on the constant pressure specific heat of liquid methyl alcohol. Among them, the latest experimental work covering a temperature range between 313 K and 363 K, was reported by Hough et al (84), who used 99.8 mole percent methyl alcohol and stated that the experimental error was within 0.4 percent. A careful measurement was made by Flock et al (62), with a reported error of 0.1 percent, at saturated vapor pressures, up to 383 K. Kelley (243) measured the specific heat of the purified liquid at low temperatures with an experimental error of one percent down to 181 K. These three sets of data are considered to be reliable from the standpoint of their experimental procedures, and are given equal weight in this analysis. Another early calorimetric work (143) shows considerable scattering of the data, and therefore no weight is given, as well as the compiled values (198) and values derived using empirical methods (36).

The correlation formula obtained for temperatures from 181 K to 383 K is

$$C_p (\text{cal g}^{-1} \text{K}^{-1}) = 0.582485 - 3.75646 \times 10^{-4} T - 1.67844 \times 10^{-6} T^2 + 1.06214 \times 10^{-8} T^3$$
(T in K)

This equation is found to fit the 28 data points with a mean deviation of 0.4 percent and a maximum of one percent.

The recommended values are generated by the above equation. The tabulated values should be substantially correct within two percent. Four additional sets of values (63, 78, 188, 193) are not shown on the departure plot.

RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p , Btu⁻¹ F⁻¹]
 LIQUID

T	C_p	T	C_p
-140	0.5220	100	0.6223
-120	0.5229	120	0.6418
-100	0.5248	140	0.6634
-80	0.5279	160	0.6871**
-60	0.5323	180	0.7132**
-40	0.5379	200	0.7417†
-20	0.5450	220	0.7726**
0	0.5536	240	0.8062**
20	0.5638		
40	0.5757		
60	0.5893		
80	0.6048		

††: n.b.p. = 148 F

FIGURE 49 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID METHYL ALCOHOL

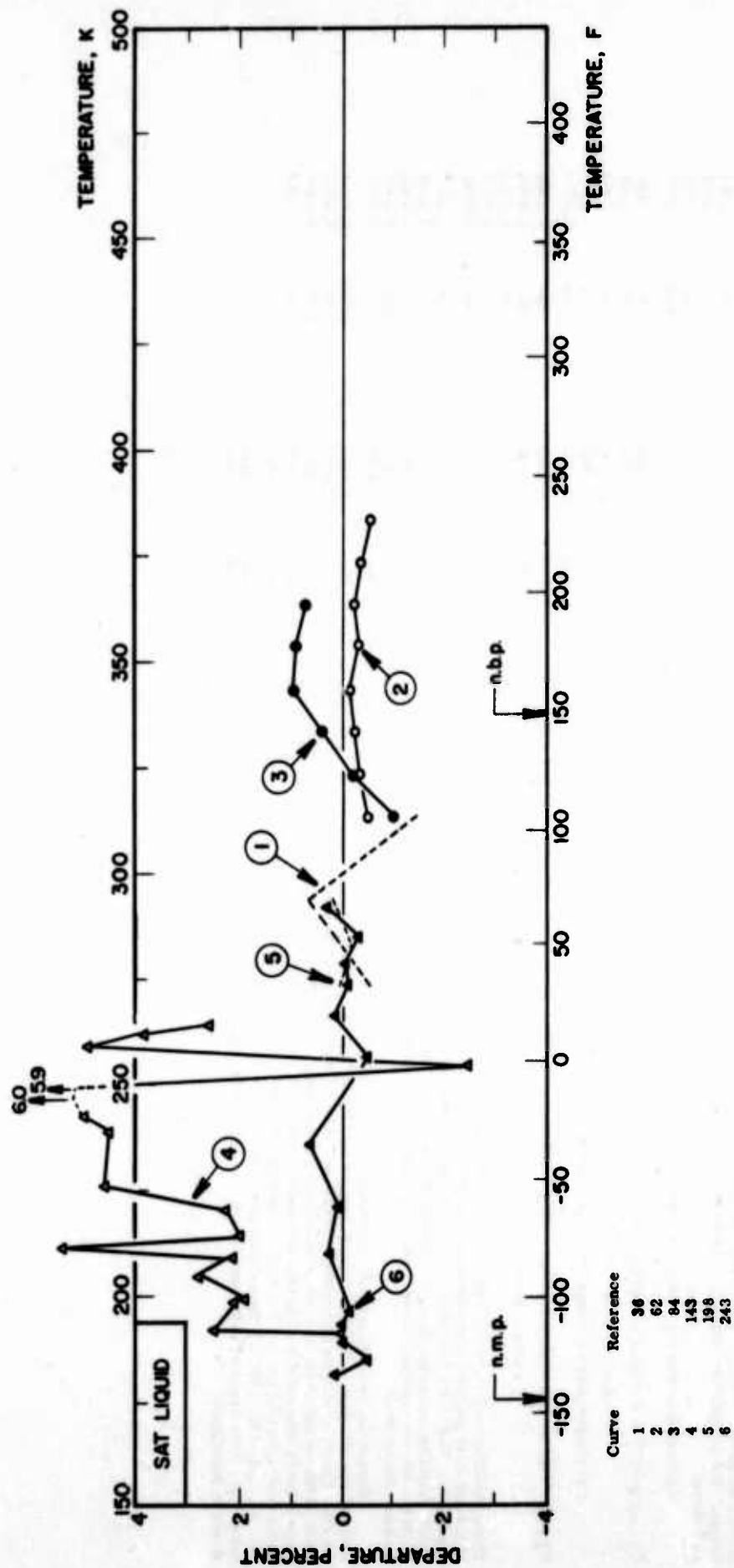


TABLE 49 SPECIFIC HEAT AT CONSTANT PRESSURE OF METHYL ALCOHOL

DISCUSSION

GAS

Thirteen sources of information are available on the specific heat at constant pressure of gaseous methyl alcohol. Only three sets of theoretical values for the heat capacity in the ideal gas state are found in the literature, covering temperatures up to 1000 K. These are the works of Ivash et al. (88), Kobe and Pennington (114) and Smith (193). Equal weight is given to these works in the present analysis. A single point value obtained empirically (18) is given no weight. The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 273 K and 785 K:

$$C_p^0 (\text{cal g}^{-1} \text{K}^{-1}) = 0.189431 + 3.61729 \times 10^{-4} T + 5.40825 \times 10^{-7} T^2 - 4.43004 \times 10^{-9} T^3 \quad (1)$$

For temperatures between 785 K and 1000 K

$$C_p^0 (\text{cal g}^{-1} \text{K}^{-1}) = 0.376893 - 9.77068 \times 10^{-6} T + 5.70656 \times 10^{-7} T^2 - 2.65182 \times 10^{-9} T^3 \quad (T \text{ in K}) \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 1.1 and 0.48 percent, and maximum deviations of 2.5 and 0.79 percent, respectively. The above formulas are used to generate the recommended values, which should be substantially correct within 2.5 percent. The percent departures of all the values mentioned above from the tabulated values are shown in the departure plot for $P = 0$.

Meanwhile, several sets of experimental data are also available for the real gas specific heat within a relatively narrow temperature range. However, the discrepancy among these results is large, and it is difficult to determine the trend of the specific heat with temperature using these data. Therefore, no correlation is attempted for the real gas specific heat at the present time. In the departure plot for $P = 1$ atm, the reported data obtained by flow calorimetry (15, 45, 144, 191, 229), by the velocity of sound (46, 90), as well as a correlated value (78), are compared with Equation (1). A set of cited values (236) is not shown in this figure.

RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p , B lb⁻¹ F⁻¹]

GAS		GAS	
T	C_p^0	T	C_p^0
40	0.3218	600	0.4991
60	0.3281	620	0.5051
80	0.3343	640	0.5109
100	0.3406	660	0.5167
120	0.3470	680	0.5225
140	0.3534	700	0.5281
160	0.3597	720	0.5337
180	0.3662	740	0.5392
200	0.3726	760	0.5447
220	0.3790	780	0.5500
240	0.3855	800	0.5552
260	0.3919	820	0.5604
280	0.3984	840	0.5654
300	0.4049	860	0.5704
320	0.4113	880	0.5752
340	0.4178	900	0.5799
360	0.4242	920	0.5846
380	0.4306	940	0.5890
400	0.4370	960	0.5937
420	0.4434	980	0.5981
440	0.4497	1000	0.6024
460	0.4560	1100	0.6239
480	0.4623	1200	0.6447
500	0.4686	1300	0.6645
520	0.4748		
540	0.4809		
560	0.4870		
580	0.4931		

n. b. p. = 148 F

FIGURE 49 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS METHYL ALCOHOL

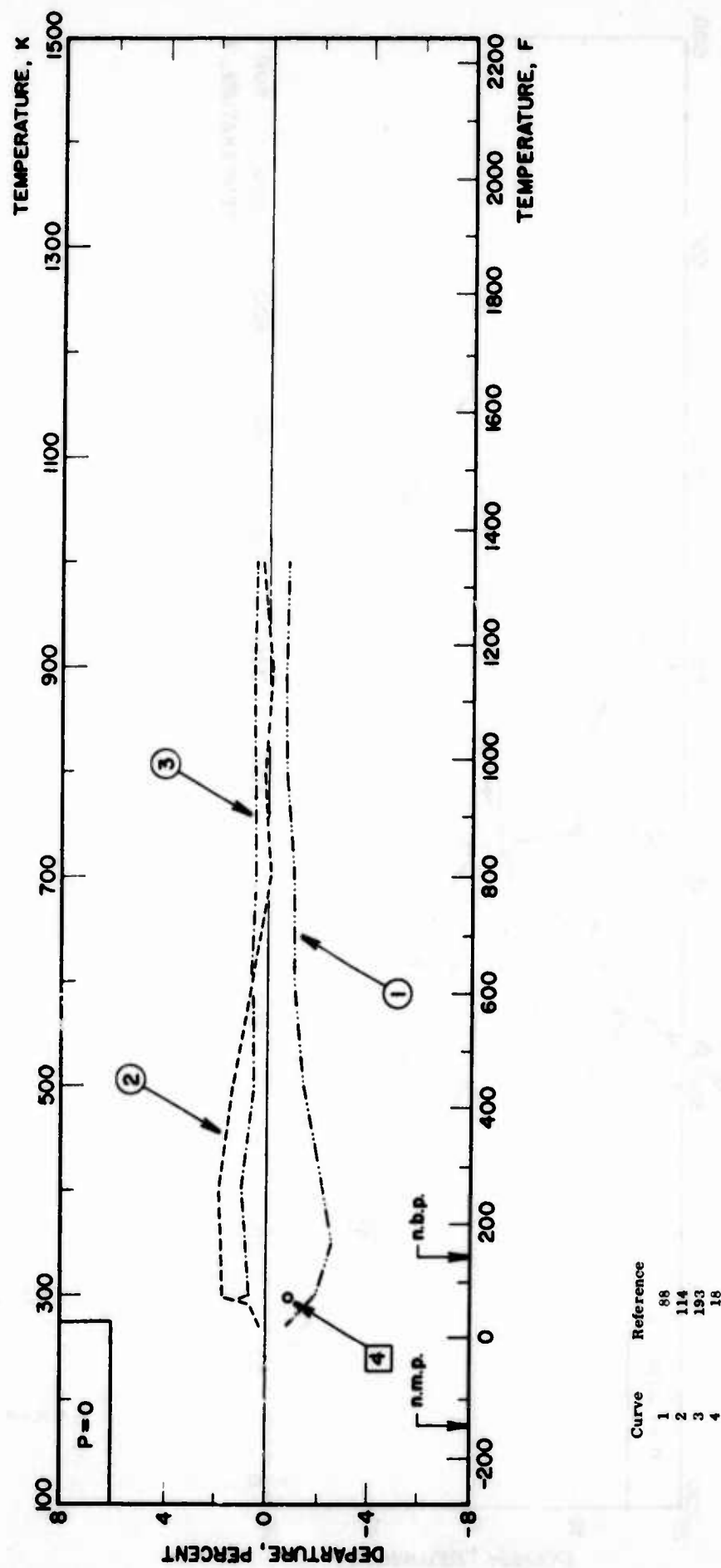


FIGURE 49 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS METHYL ALCOHOL

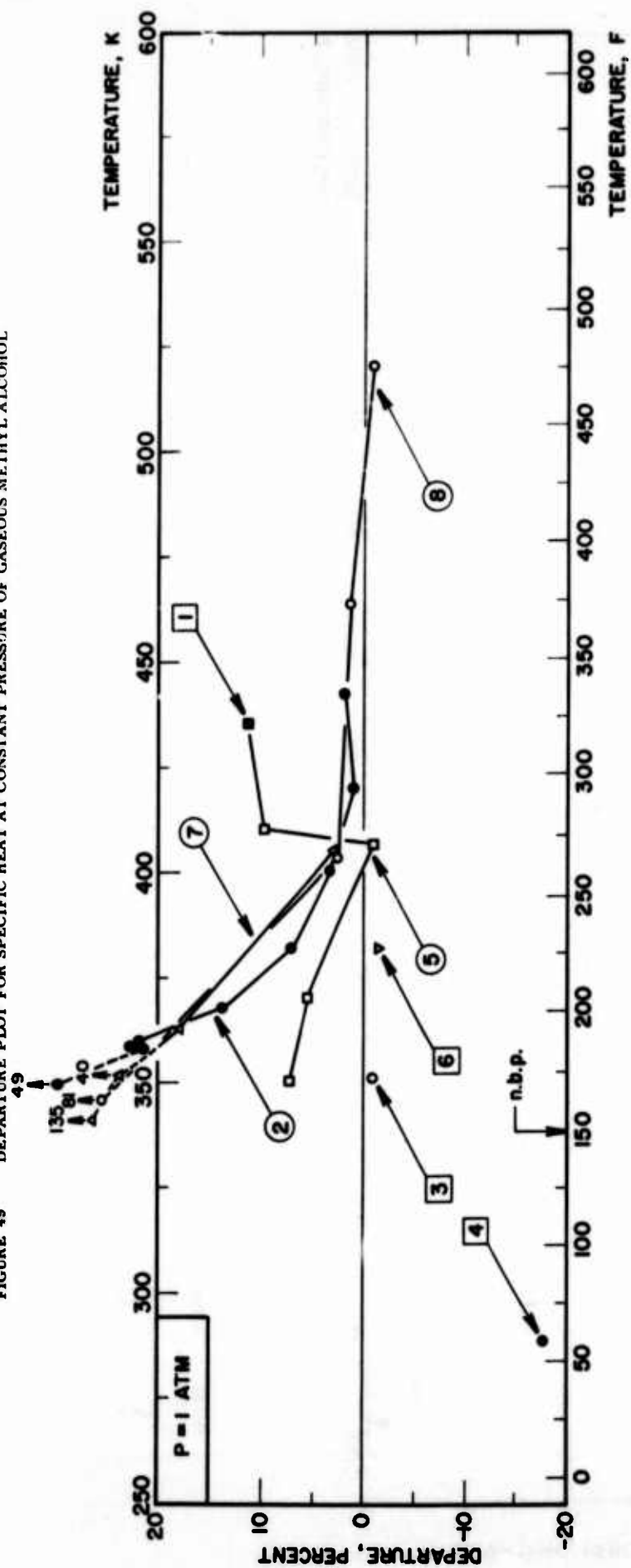


TABLE 50 SPECIFIC HEAT AT CONSTANT PRESSURE OF METHYL CHLORIDE

DISCUSSION		RECOMMENDED VALUES	
LIQUID		[Temperature, T, F; Specific Heat, C _p , B lb ⁻¹ F ⁻¹]	
		T	C _p
		-140	0.352
		-120	0.3515
		-100	0.3515
		-80	0.3521
		-60	0.3533
		-40	0.3553
		-20	0.3580
		0	0.3615
		20	0.3659
		40	0.3712
		60	0.3775
		80	0.3848
		100	0.3931
		120	0.4026
		140	0.413

DISCUSSION

LIQUID

Six sets of data are available on the specific heat at constant pressure of liquid methyl chloride. Most of the data points fall between the n.m.p. and n.b.p. The discrepancy between the reported calorimetric data is rather small. From the standpoint of the experimental method and procedure, the data of Awbery and Griffiths (10) and Messerly and Aston (138) are considered to be the most reliable. Awbery and Griffiths (10) reported also recommended values of the specific heat, taking into account other investigators' data. Koch (249) also gave correlated values from 223 K to 323 K, including the values above the n.b.p. at saturation vapor pressures.

The correlation equation obtained is

$$C_p(\text{cal g}^{-1} \text{K}^{-1}) = 0.395562 - 2.12562 \times 10^{-4} T - 1.28431 \times 10^{-6} T^2 + 6.25660 \times 10^{-9} T^3$$

(T in K).

This equation is found to fit the above 40 points between 182 K and 323 K with a mean deviation of 0.3 percent and a maximum of 0.7 percent.

The recommended values are calculated from the above equation. The tabulated values should be substantially correct in the temperature range between -120 F and +120 F. The uncertainty increases outside this range.

n. b. p. = -11 F

FIGURE 50 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID METHYL CHLORIDE

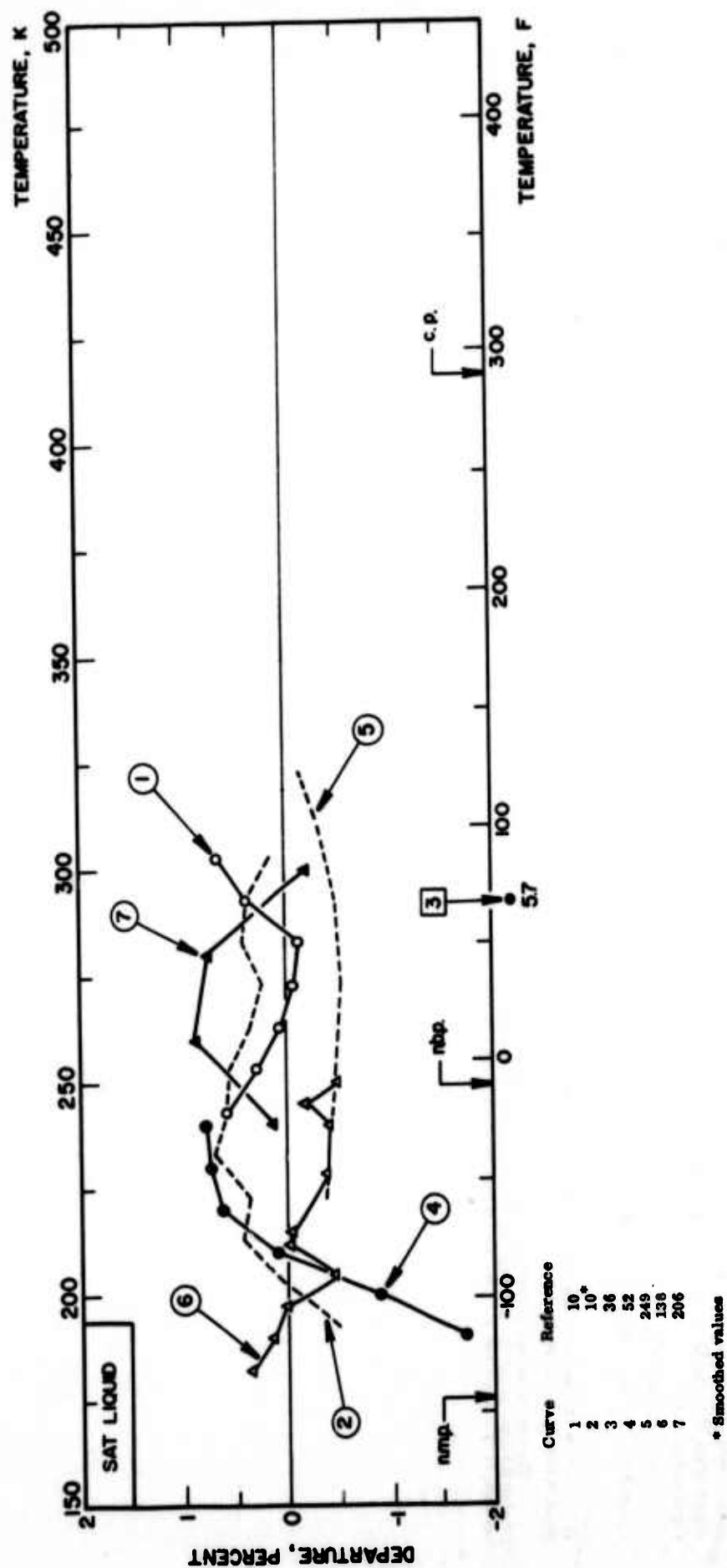


TABLE 50 SPECIFIC HEAT AT CONSTANT PRESSURE OF METHYL CHLORIDE (continued)

GAS	RECOMMENDED VALUES			
	[Temperature, T, F; Specific Heat, C_p , B lb ⁻¹ F ⁻¹]			
	T	C_p	T	C_p
	0	0.1771	600	0.2868
	20	0.1812	620	0.2899
	40	0.1853	640	0.2929
	60	0.1893	660	0.2959
	80	0.1933	680	0.2989
	100	0.1973	700	0.3018
	120	0.2012	720	0.3046
	140	0.2052	740	0.3074
	160	0.2091	760	0.3102
	180	0.2129	780	0.3129
	200	0.2168	800	0.3155
	220	0.2206	820	0.3181
	240	0.2244	840	0.3207
	260	0.2282	860	0.3232
	280	0.2319	880	0.3256
	300	0.2356	900	0.3280
	320	0.2393	920	0.3303
	340	0.2429	940	0.3326
	360	0.2465	960	0.3349
	380	0.2501	980	0.3372
	400	0.2536	1000	0.3394
	420	0.2571	1100	0.3502
	440	0.2606	1200	0.3603
	460	0.2640	1300	0.3697
	480	0.2674	1400	0.3784
	500	0.2707	1500	0.3865
	520	0.2740	1600	0.3940
	540	0.2773	1700	0.4009
	560	0.2805	1800	0.4073
	580	0.2836	1900	0.4133
			2000	0.4188

DISCUSSION

GAS

There exist eleven sources of information on the constant pressure specific heat of gaseous methyl chloride. A number of derived values for the ideal gas state are presented using statistical formulas based on spectroscopic and molecular structural data. Among them, the values of Cerny and Erdos (34), covering temperatures from 100 K to 1000 K, and of Gelles and Pitzer (66), covering up to 1500 K, are the most reliable from the standpoint of the molecular data used. A table compiled by Kobe and Long (113), ranging from 273 K to 1500 K, and JANAF Thermochemical Tables (254) up to 6000 K are also found to be reliable. Therefore, the values between 270 K and 1500 K reported in these works (34, 66, 113, 254) are given equal weight in this analysis. The earlier statistical results (220) are given no weight, as well as three sets of empirically estimated values covering narrow temperature ranges (20, 48, 69).

The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 270 K and 782 K:

$$C_p^0 (\text{cal g}^{-1} \text{K}^{-1}) = 7.95197 \times 10^{-2} + 3.91691 \times 10^{-4} T - 1.07495 \times 10^{-7} T^2 - 9.51899 \times 10^{-11} T^3 \quad (T \text{ in K}),$$

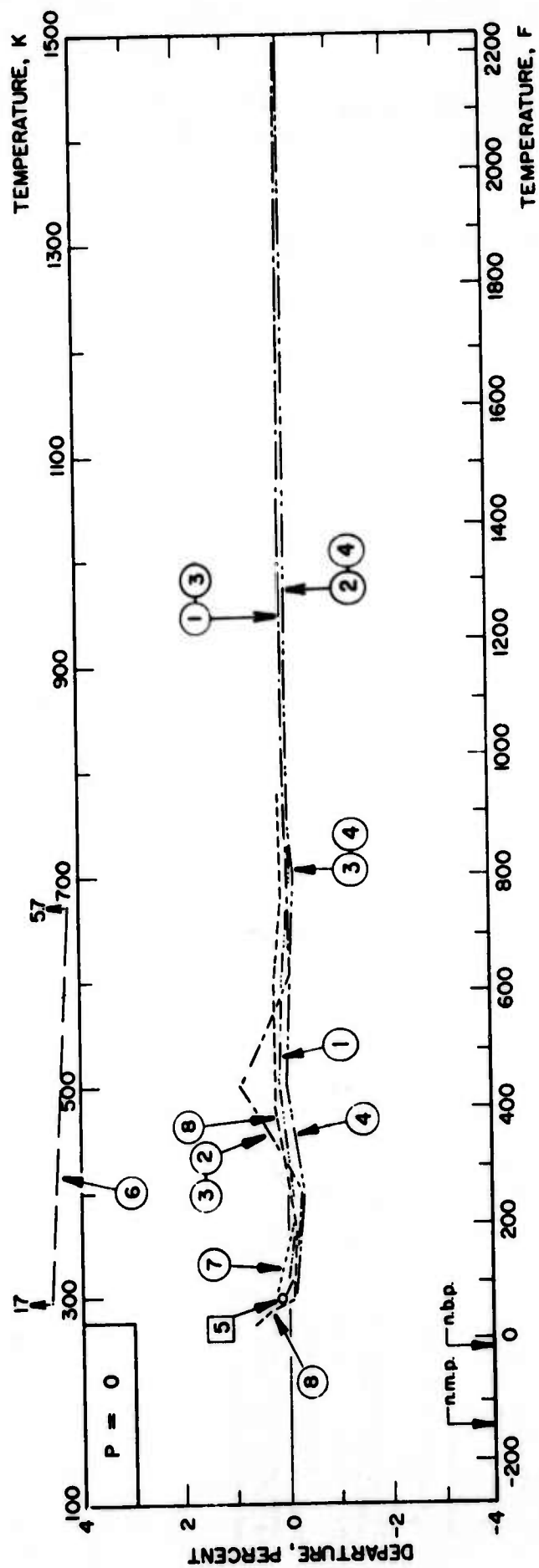
and for temperatures between 782 K and 1500 K:

$$C_p^0 (\text{cal g}^{-1} \text{K}^{-1}) = 7.14539 \times 10^{-2} + 4.84503 \times 10^{-4} T - 2.20685 \times 10^{-7} T^2 + 3.82628 \times 10^{-11} T^3 \quad (T \text{ in K}).$$

The former equation is found to fit the above referenced values with a mean deviation of 0.1 percent and a maximum of 0.8 percent. The latter fits with a mean error of 0.01 percent and a maximum of 0.03 percent.

The recommended values are calculated from the above equations. The tabulated values should be substantially correct within one percent over the entire temperature range. The only available experimental data (142), the cited values of (236), as well as the correlated equations of Spencer and Flannagan (197), are not shown in the departure plot.

FIGURE 50 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS METHYL CHLORIDE



Curve	Reference
1	34
2	66
3	113
4	254
5	20
6	48
7	69
8	220

TABLE 51 SPECIFIC HEAT AT CONSTANT PRESSURE OF n-NONANE

DISCUSSION

LIQUID

There exist seven sources of information available on the specific heat at constant pressure of liquid n-nonane. All the reported values are obtained at temperatures from the n. m. p. to the n. b. p.. Finke et al. (61) made calorimetric measurements with an error of 0.1 percent covering temperatures between 225 K and 314 K. Osborne and Glimings (149) reported calorimetric results between 278 K and 318 K also with a reported error of 0.1 percent. These sets of data are considered to be the most reliable from the standpoint of the experimental procedures and the purity of liquids used. As Finke (61) found a minimum in the specific heat in the neighborhood of 230 K, the correlation formula in this analysis is obtained by giving equal weight to the reported data points between 240 K and 318 K. Meanwhile, two sets of earlier calorimetric data (87, 153), and two sets of correlated results (36, 78) are thought to be less reliable and are given no weight, as well as a mean calorimetric value between 295 K and 402 K (257).

The correlation formula obtained for the temperature range between 240 K and 318 K is:

$$C_p (\text{cal g}^{-1} \text{K}^{-1}) = 0.970146 - 5.32528 \times 10^{-3} T + 1.80857 \times 10^{-4} T^2 - 1.73755 \times 10^{-4} T^3 \quad (T \text{ in K}).$$

This equation is found to fit the above enumerated data points with a mean deviation of 0.05 percent and a maximum of 0.1 percent.

The recommended values above 240 K are generated using the above equation. The tabulated values at -60 F and -40 F are obtained by a graphical interpolation of Finke's results (61). The tabulated values between 240 K and 325 K should be substantially correct within one percent. Outside this temperature range the uncertainty would increase.

RECOMMENDED VALUES
[Temperature, T, F; Specific Heat, C_p , B lb⁻¹ F⁻¹]

T	C_p
-60	0.489
-40	0.491
-20	0.4949
0	0.5000
20	0.5062
40	0.5135
60	0.5217
80	0.5306
100	0.5402
120	0.5502
140	0.5605
160	0.5710
180	0.5815
200	0.5920

FIGURE 51 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID n-NONANE

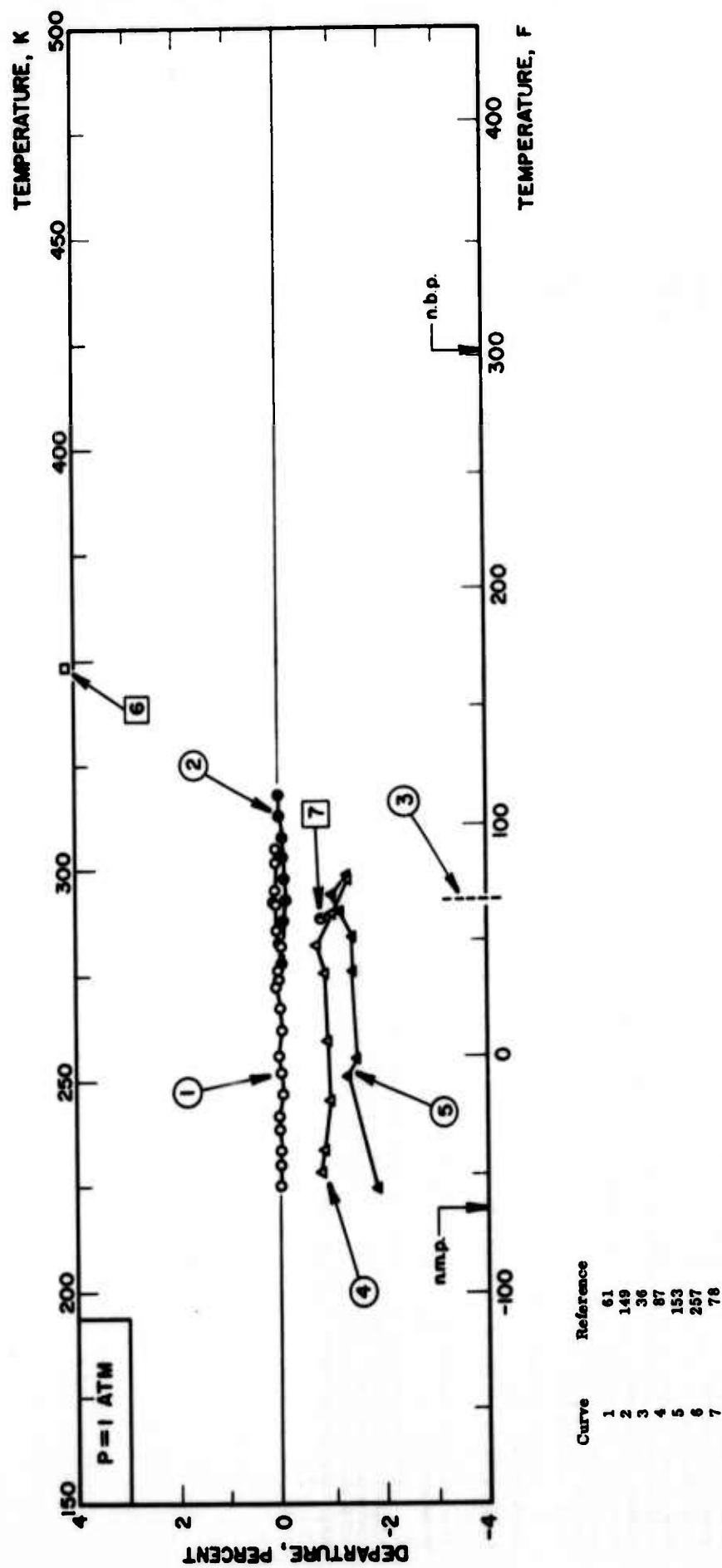


TABLE 51 SPECIFIC HEAT AT CONSTANT PRESSURE OF n-NONANE

DISCUSSION

GAS

Seven sources of information are available on the specific heat at constant pressure of gaseous n-nonane. The extensive theoretical values in the ideal gas state have been derived from spectroscopic and molecular structural data. Among them, the results reported by Person and Pimental (159) and Rossini et al. (171, 253) are considered to be reliable, and are given equal weight in the present analysis. A set of values obtained by simple formulas (133, 134) is given no weight. The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 273 K and 780 K:

$$C_p^0 (\text{cal g}^{-1} \text{K}^{-1}) = 0.0851799 + 1.22834 \times 10^{-3} T - 1.64406 \times 10^{-5} T^2 - 2.46534 \times 10^{-8} T^3 \quad (1)$$

For temperatures between 780 K and 1500 K:

$$C_p^0 (\text{cal g}^{-1} \text{K}^{-1}) = 0.0721002 + 1.36989 \times 10^{-3} T - 6.58734 \times 10^{-5} T^2 + 1.20639 \times 10^{-8} T^3 \quad (T \text{ in K}) \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.86 and 0.05 percent, and maximum deviations of 3.2 and 0.19 percent, respectively. The recommended values are generated using the above formulas. The tabulated values should be correct within two percent excluding temperatures below 300 K. The percent departures of all the values mentioned above from the tabulated values are given in the departure plot for $P = 0$.

On the other hand, no direct experimental determination in the real gas state is found in the literature. Only two empirical values (78, 182) are presented. No correlation is given for the real gas state. The reported values are compared with Equation (1) in the departure plot at $P = 1 \text{ atm}$.

RECOMMENDED VALUES

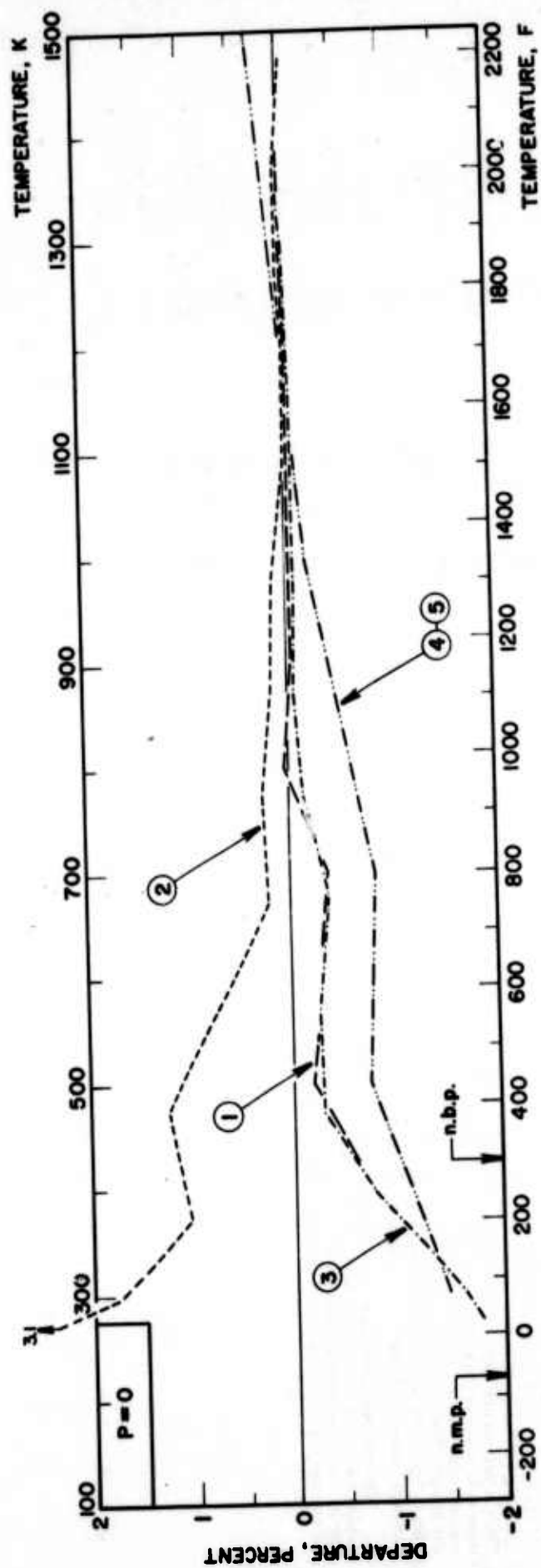
[Temperature, T, F; Specific Heat, C_p , Btu⁻¹ F⁻¹]

GAS

T	C_p^0	T	C_p^0
40	0.3787	600	0.6713
60	0.3906	620	0.6799
80	0.4025	640	0.6883
100	0.4142	660	0.6966
120	0.4259	680	0.7047
140	0.4375	700	0.7126
160	0.4489	720	0.7204
180	0.4603	740	0.7281
200	0.4715	760	0.7355
220	0.4827	780	0.7429
240	0.4937	800	0.7500
260	0.5046	820	0.7570
280	0.5154	840	0.7638
300	0.5261	860	0.7704
320	0.5367	880	0.7769
340	0.5472	900	0.7832
360	0.5575	920	0.7893
380	0.5677	940	0.7952
400	0.5778	960	0.8014
420	0.5878	980	0.8076
440	0.5976	1000	0.8136
460	0.6073	1100	0.8424
480	0.6168	1200	0.8692
500	0.6263	1300	0.8939
520	0.6356	1400	0.9167
540	0.6447	1500	0.9378
560	0.6537	1600	0.9572
580	0.6626	1700	0.9752
		1800	0.9917
		1900	1.0070
		2000	1.0211

n, b, p. = 303 F

FIGURE 51 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS n-NONANE



Curve	Reference
1	159
2	171
3	253
4	134
5	133

FIGURE 51 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS n-NONANE

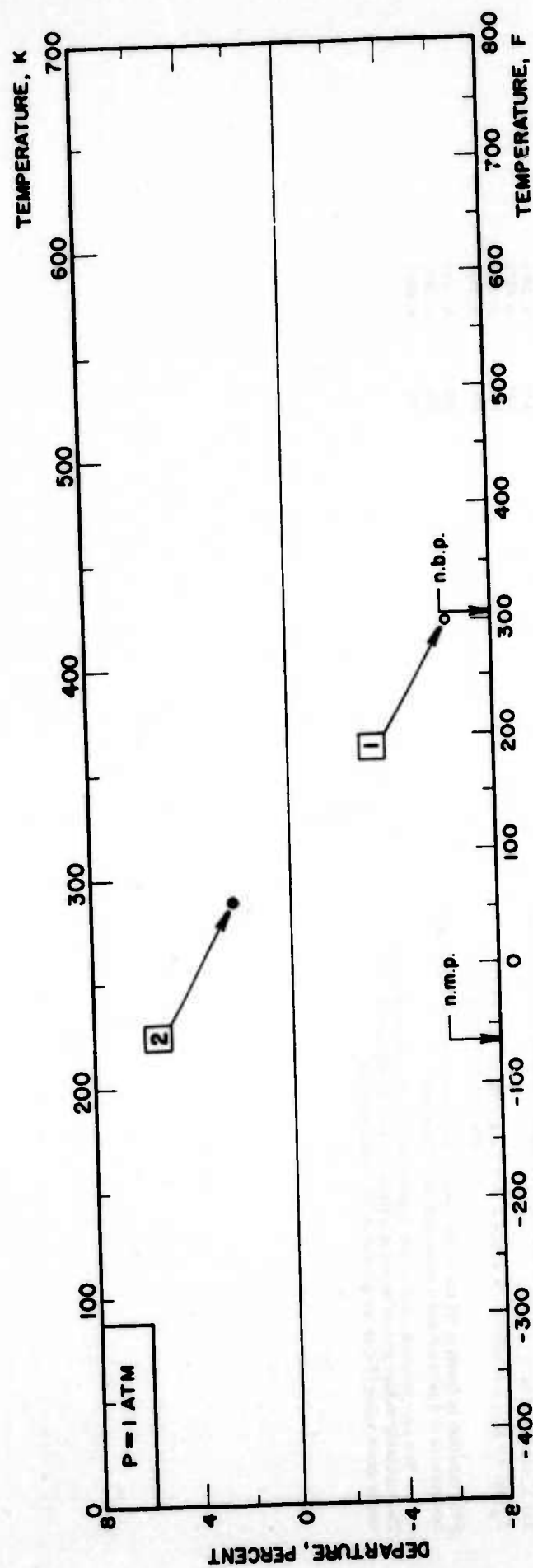


TABLE 52 SPECIFIC HEAT AT CONSTANT PRESSURE OF n-OCTANE

DISCUSSION

LIQUID

Five experimental works are available on the constant pressure specific heat of liquid n-octane within the temperature range between the n. m. p. and the n. b. p.. The latest calorimetric measurement for 99.94 mole percent n-octane was made by Fiske et al. (61) with an experimental error of 0.1 percent. Connolly et al. (39) measured the specific heat of purified saturated liquid using an isothermal calorimeter. Another careful determination was reported by Osborne and Ginnings (149) with an error of 0.1 percent. These three sets of data are considered to be reliable from the standpoint of their experimental procedures, and are given equal weight in this analysis. Two sets of earlier calorimetric data (87, 153), as well as a single-point value derived by an empirical relation (36), are found to be less reliable and are given no weight.

The correlation formula obtained for the temperature range between 220 K and 370 K is

$$C_p (\text{cal g}^{-1} \text{K}^{-1}) = 0.526048 - 9.57018 \times 10^{-4} T + 4.07363 \times 10^{-4} T^2 - 2.74978 \times 10^{-5} T^3 \quad (T \text{ in K}).$$

This equation is found to fit the 47 data points referred to above with a mean deviation of 0.2 percent and a maximum of 0.6 percent.

The recommended values are generated using the above formula. The tabulated values should be substantially correct within one percent. A single-point value (78) is not plotted on the departure plot.

RECOMMENDED VALUES
[Temperature, T, °F; Specific Heat, C_p , B lb⁻¹ °F⁻¹]
LIQUID

T	C_p
-60	0.4840
-40	0.4892
-20	0.4949
0	0.5012
20	0.5079
40	0.5151
60	0.5228
80	0.5308
100	0.5393
120	0.5481
140	0.5573
160	0.5668
180	0.5766
200	0.5867
220	0.5971
240	0.6077

FIGURE 52 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID n-OCTANE

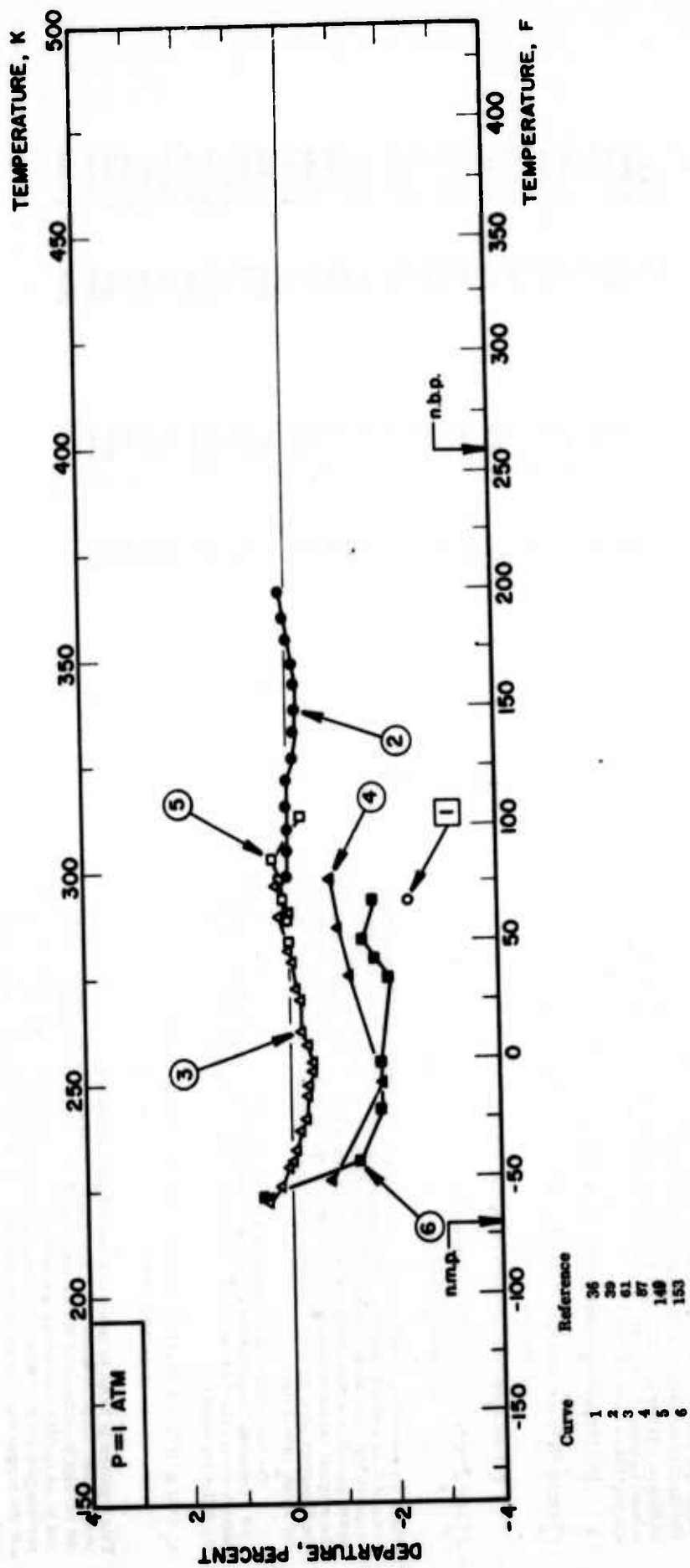


TABLE 52 SPECIFIC HEAT AT CONSTANT PRESSURE OF n-OCTANE

DISCUSSION

GAS

Twenty sources of information are available for the specific heat at constant pressure of gaseous n-octane. Extensive theoretical values for the ideal gas state derived from spectroscopic data were reported by Person and Pimentel (159), Pitzer (161), Ribaud (167) and Rossini et al. (171, 253). These sets of values are thought to be reliable and are given equal weight in the present analysis. The theoretical values derived by simple formulas (133, 134) and by the earlier statistical calculation (202, 222) are given no weight as well as empirically correlated values (13, 18). The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 273 K and 780 K:

$$C_p^0 (\text{cal g}^{-1}\text{K}^{-1}) = 0.0511050 + 1.28099 \times 10^{-3} T - 2.81774 \times 10^{-7} T^2 - 1.66703 \times 10^{-10} T^3 \quad (1)$$

For temperatures between 780 K and 1500 K:

$$C_p^0 (\text{cal g}^{-1}\text{K}^{-1}) = 0.0873567 + 1.33119 \times 10^{-3} T - 6.20477 \times 10^{-7} T^2 + 1.08914 \times 10^{-10} T^3 \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.88 and 0.05 percent, and maximum deviations of 2.7 and 0.14 percent, respectively. The above formulas are used to generate the recommended values, which should be substantially correct within two percent. The departures of all the original values mentioned above from the recommended values are plotted in the departure plot for $P = 0$. Several empirical equations (195, 196, 197, 205) are not shown in this figure.

The only calorimetric data for the real gas state was reported by Barrow (12), covering temperatures from 405 K to 523 K. He also presented a single point derived value (13) at 298 K. Therefore, all the reported data are fitted to the following equation:

$$C_p (\text{cal g}^{-1}\text{K}^{-1}) = 0.361819 - 1.10474 \times 10^{-3} T + 5.77902 \times 10^{-6} T^2 - 5.21314 \times 10^{-9} T^3 \quad (3)$$

This equation is found to reproduce the original data within 0.01 percent over the temperature range between 298 K and 523 K. Equation (3) is used to calculate the percent departures of the values obtained by empirical correlations (78, 182) and by an earlier theoretical calculation (203). The results are shown in the departure plot for $P = 1$ atm. The comparison of Equation (3) with Equation (1) for the temperature range where Equation (3) is valid are given in the third plot.

RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p , B lb ⁻¹ F ⁻¹]			
GAS			
T	C_p^0	T	C_p^0
40	0.3812	600	0.6731
60	0.3932	620	0.6817
80	0.4051	640	0.6901
100	0.4169	660	0.6983
120	0.4286	680	0.7064
140	0.4401	700	0.7144
160	0.4516	720	0.7222
180	0.4630	740	0.7299
200	0.4742	760	0.7374
220	0.4853	780	0.7447
240	0.4963	800	0.7519
260	0.5072	820	0.7590
280	0.5180	840	0.7659
300	0.5287	860	0.7726
320	0.5392	880	0.7792
340	0.5496	900	0.7856
360	0.5599	920	0.7918
380	0.5701	940	0.7979
400	0.5801	960	0.8042
420	0.5900	980	0.8103
440	0.5998	1000	0.8164
460	0.6094	1100	0.8453
480	0.6189	1200	0.8721
500	0.6283	1300	0.8969
520	0.6375	1400	0.9199
540	0.6466	1500	0.9411
560	0.6556	1600	0.9607
580	0.6644	1700	0.9788
		1800	0.9955
		1900	1.0109
		2000	1.0250

n. b. p. = 258 F

FIGURE 52 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS n-OCTANE

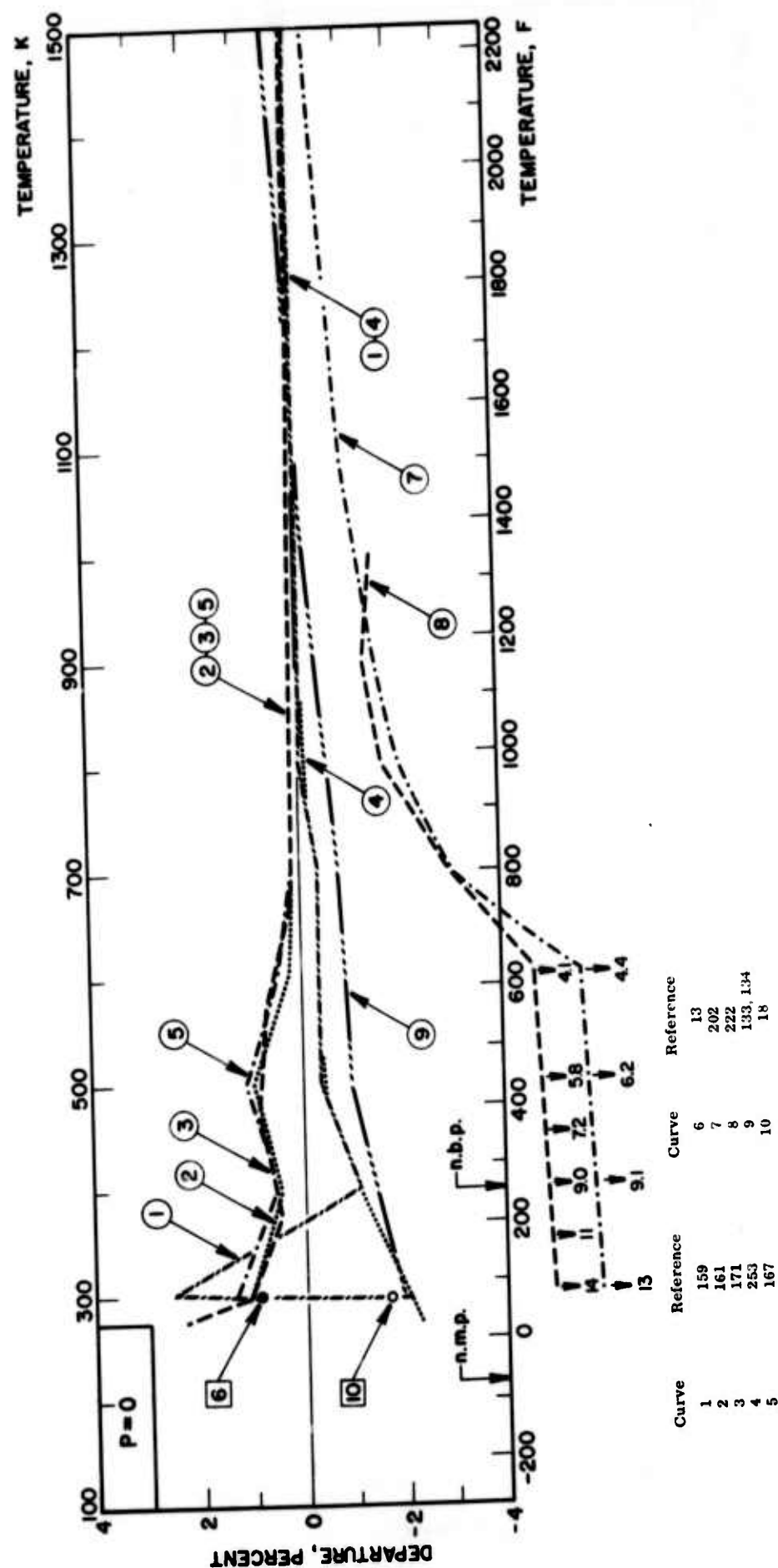


FIGURE 52 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS n-OCTANE

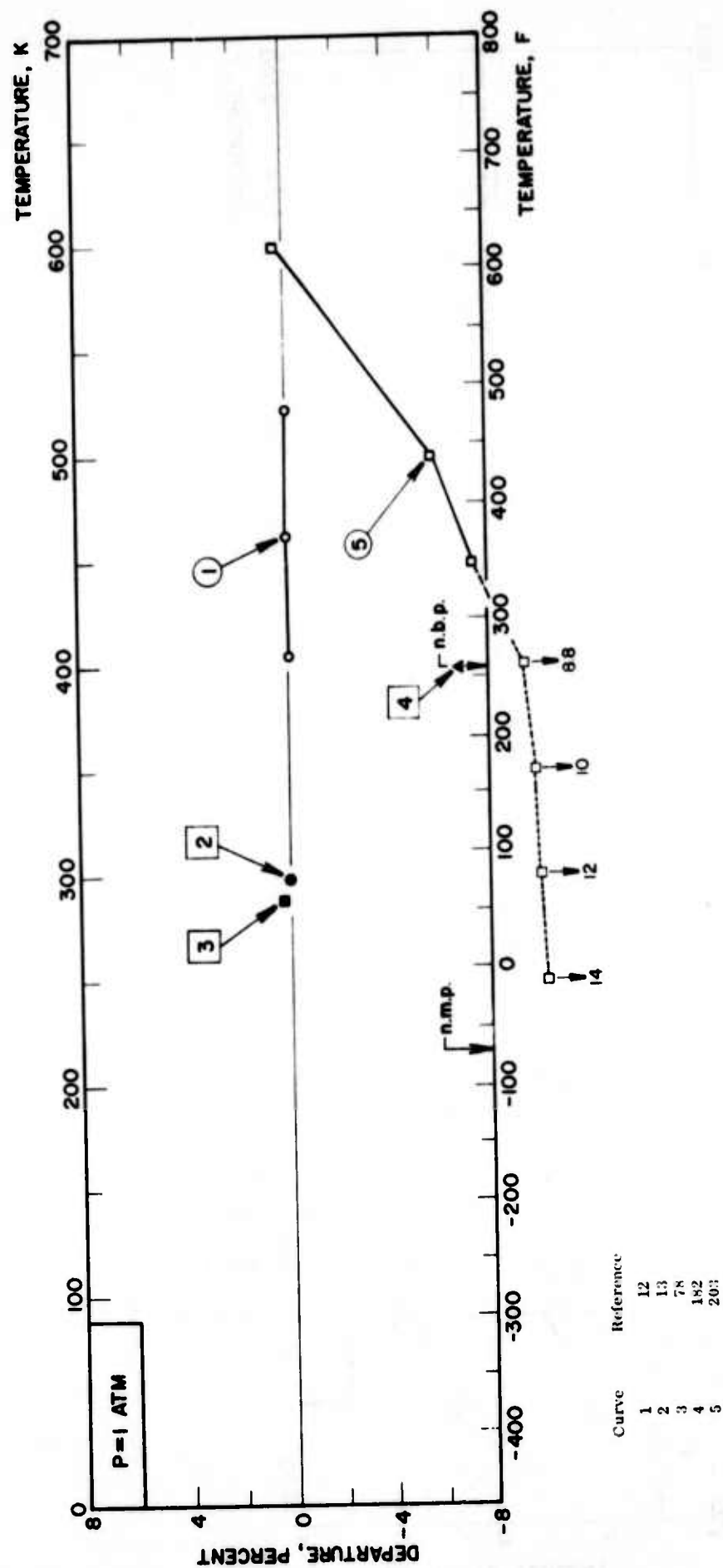


FIGURE 52 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS n-OCTANE

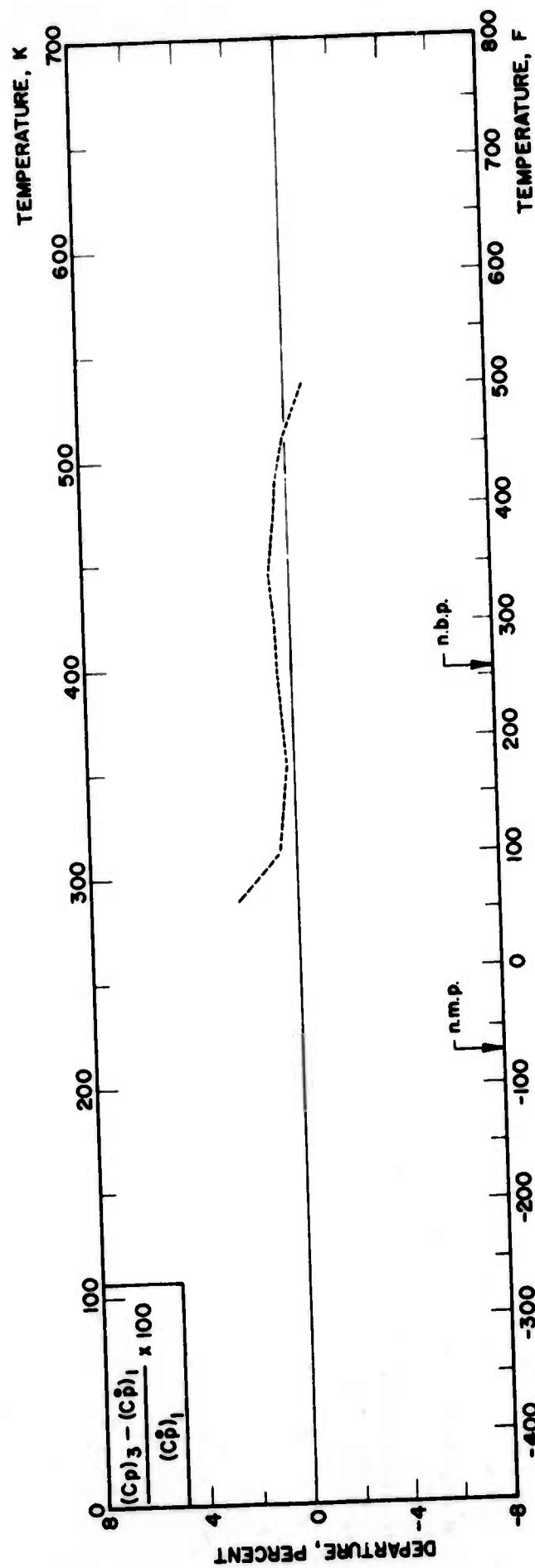


TABLE 53 SPECIFIC HEAT AT CONSTANT PRESSURE OF n-PENTANE

DISCUSSION

LIQUID

Six works are available on the specific heat at constant pressure of liquid n-pentane. Calorimetric data of Messerly and Kennedy (139), covering temperatures from 150 K to 290 K, are considered to be the most reliable in view of their experimental procedure and purity of sample. Results of Parks and Huffman (152), covering the same temperature range, show that the agreement with (139) is well within the experimental error at temperatures below 200 K, but the deviation increases above this temperature and becomes about two percent at the highest temperature. In this analysis, equal weight is given to both (139) and (152). Sage et al. (174) have made measurements at temperatures between 297 K and 378 K at a pressure of 1000 lb in.⁻² by an adiabatic expansion method. As it is difficult to extrapolate their data to one atm., no weight is given to their work, as well as the correlated results of (32, 36, 83).

The correlation formula obtained in the temperature range from 150 K to 290 K is

$$C_p (\text{cal g}^{-1} \text{K}^{-1}) = 0.463639 + 1.23858 \times 10^{-4} T - 2.17509 \times 10^{-6} T^2 + 9.57025 \times 10^{-9} T^3 \quad (T \text{ in K}).$$

This equation fits the 48 data points enumerated above with a mean deviation of 0.3 percent and a maximum of 1.8 percent.

The recommended values are computed using the above equation. The tabulated values below 20 F should be correct within one percent. Above this temperature, the uncertainty would increase. In the departure plot, the high pressure data (174) is not shown.

RECOMMENDED VALUES
[Temperature, T, F; Specific Heat, C_p , B lb⁻¹ F⁻¹]

T	C_p
-200	0.4647
-180	0.4660
-160	0.4678
-140	0.4703
-120	0.4736
-100	0.4776
-80	0.4825
-60	0.4884
-40	0.4952
-20	0.5033
0	0.5125
20	0.5229
40	0.535
60	0.548
80	0.563
100	0.579*
120	0.597*
140	0.617*
160	0.638*
180	0.662*
200	0.688*

* Extrapolated for the liquid phase ignoring pressure dependence (n. b. p. = 97 F).

FIGURE 53 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID n-PENTANE

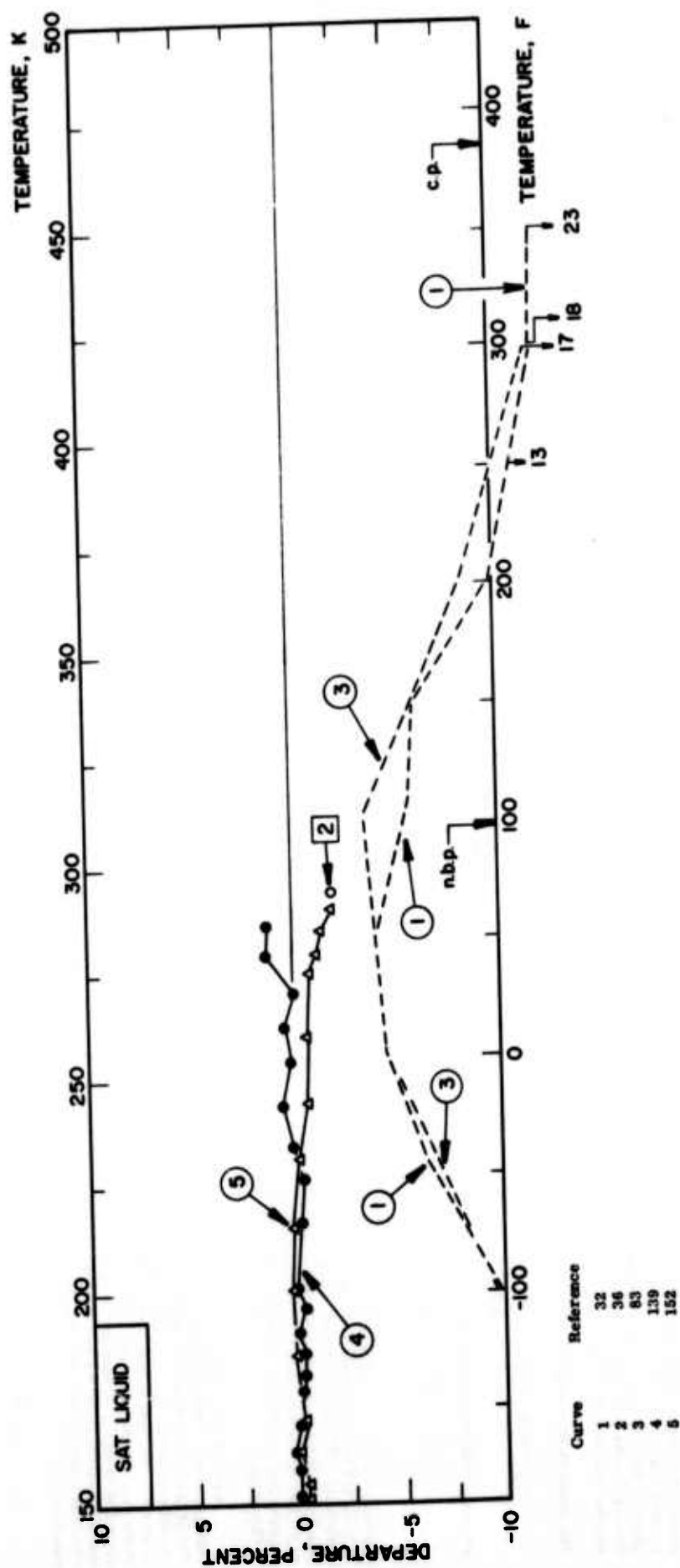


TABLE 53 SPECIFIC HEAT AT CONSTANT PRESSURE OF n-PENTANE

DISCUSSION

GAS

There exist 29 papers on the specific heat at constant pressure of gaseous n-pentane. A number of extensive heat capacity values for the ideal gas state have been derived from spectroscopic and molecular structural data. The values presented by Kobe and Long (109), Kiaslov (133, 134), Person (159), Pitzer and Kilpatrick (161, 164) and Ribaud (167) are considered to be reliable, as well as a compilation table (253). Therefore equal weight is given to these works in the present analysis. Some earlier statistical calculations (48, 139, 172, 202, 222) are given no weight, as well as the values extrapolated to zero pressure from experimental results (46, 163). The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 273 K and 780 K

$$C_p^0 (\text{cal g}^{-1} \text{K}^{-1}) = 0.0651968 + 1.16432 \times 10^{-3} T - 1.53714 \times 10^{-4} T^2 - 3.22752 \times 10^{-10} T^3 \quad (1)$$

(T in K),

For temperatures between 780 K and 1500 K

$$C_p^0 (\text{cal g}^{-1} \text{K}^{-1}) = 0.0635648 + 1.40263 \times 10^{-3} T - 6.63570 \times 10^{-4} T^2 + 1.19788 \times 10^{-10} T^3 \quad (2)$$

(T in K),

These equations are found to fit the above enumerated values with mean deviations of 0.63 and 0.93 percent, and maximum deviations of 2.4 and 0.18 percent, respectively. The above formulas are used to generate the recommended values, which should be substantially correct within two percent. The percent departures of all the values mentioned above from the tabulated values are shown in the departure plot for $P = 0$. Various empirical equations (195, 196, 197) are not plotted in this figure.

Several sets of experimental data are available for the specific heat in the real gas state. Among them, calorimetric data of Eucken and Sarstedt (58) and Pitzer (163) are considered to be reliable from the viewpoint of experimental procedures used. However, the general trend of their data is not always found to be realistic, taking into account the ideal gas values, C_p^0 , discussed above. In the present analysis, therefore, the specific heat of the real gas, C_p^1 , is computed from C_p^0 values and the gas imperfection correction, using the usual thermodynamic relations and Berthelot's equation of state. Resulting C_p^1 values obtained at temperatures from 244 K and 610 K are represented by the following equation:

$$C_p^1 (\text{cal g}^{-1} \text{K}^{-1}) = 0.147363 + 7.02528 \times 10^{-4} T + 8.79322 \times 10^{-7} T^2 - 9.07666 \times 10^{-10} T^3 \quad (3)$$

(T in K),

The recommended values of C_p^1 are generated from the above formula. Equation (3) is also used to calculate the percent departures of all the available calorimetric data (15, 58, 163, 178), theoretical calculation (203) and correlations (6, 13, 32, 78, 83, 182), which are shown in the departure plot for $P = 1$ atm. The third departure plot shows the comparison between Equation (3) and Equation (1) over their common temperature range.

TABLE 53 SPECIFIC HEAT AT CONSTANT PRESSURE OF n-PENTANE (continued)

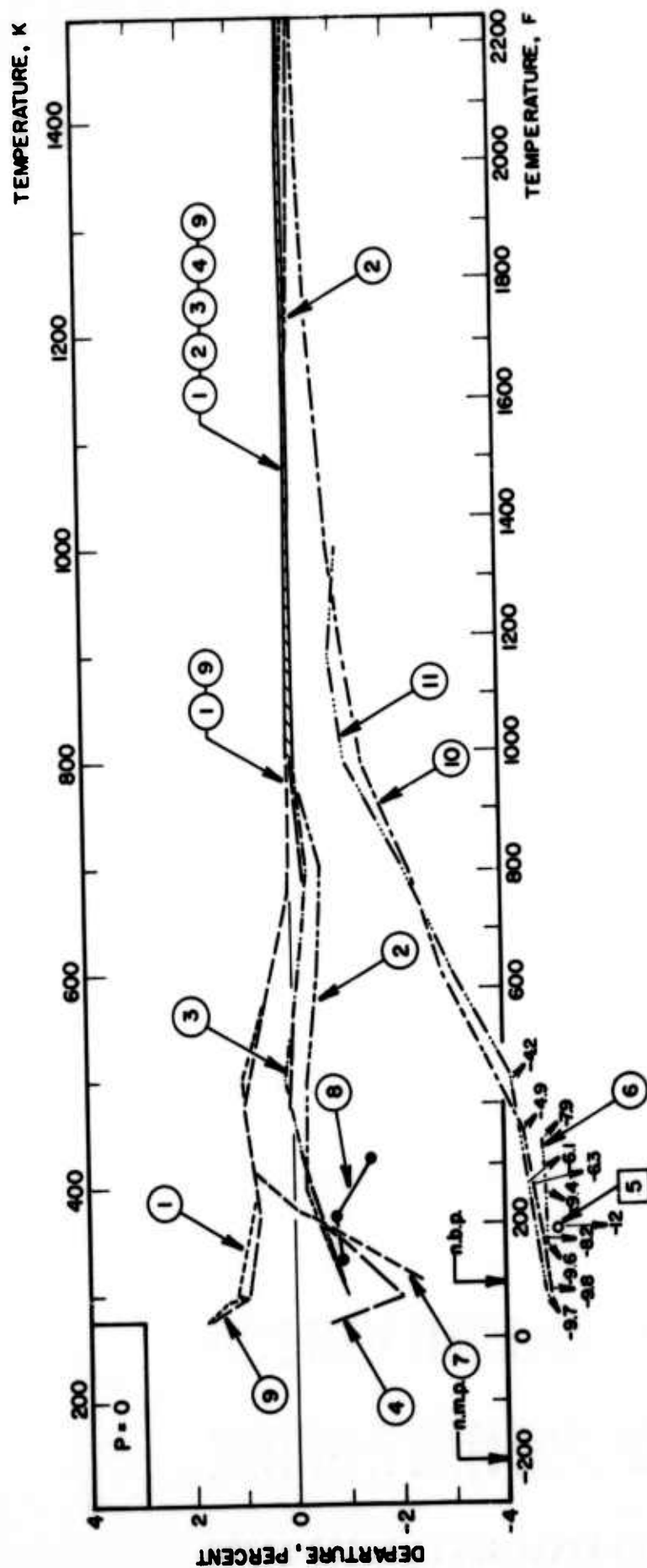
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p , B lb⁻¹ F⁻¹]

T	C_p^0	C_p^1	T	C_p^0	C_p^1
40	0.3801	0.390	600	0.6790	0.630
60	0.3920	0.401	620	0.6879	0.689
80	0.4039	0.412	640	0.6967	0.697
100	0.4158	0.423	660	0.7054	
120	0.4275	0.434	680	0.7138	
140	0.4392	0.445	700	0.7222	
160	0.4507	0.456	720	0.7303	
180	0.4622	0.467	740	0.7383	
200	0.4736	0.478	760	0.7462	
220	0.4849	0.489	780	0.7539	
240	0.4962	0.500	800	0.7614	
260	0.5073	0.510	820	0.7687	
280	0.5183	0.521	840	0.7759	
300	0.5292	0.532	860	0.7829	
320	0.5401	0.543	880	0.7897	
340	0.5508	0.553	900	0.7963	
360	0.5614	0.564	920	0.8027	
380	0.5718	0.574	940	0.8090	
400	0.5822	0.584	960	0.8153	
420	0.5925	0.594	980	0.8217	
440	0.6026	0.604	1000	0.8280	
460	0.6126	0.614	1100	0.8581	
480	0.6225	0.624	1200	0.8860	
500	0.6323	0.634	1300	0.9119	
520	0.6419	0.643	1400	0.9359	
540	0.6514	0.653	1500	0.9580	
560	0.6607	0.662	1600	0.9785	
580	0.6699	0.671	1700	0.9975	
			1800	1.0150	
			1900	1.0311	
			2000	1.0461	

n.b.p. = 97 F

FIGURE 53 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS n-PENTANE



Curve	Reference
1	109, 161, 164, 167
2	133, 134
3	159
4	253
5	46
6	48
7	139
8	163
9	172
10	202
11	222

FIGURE 53 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS n-PENTANE

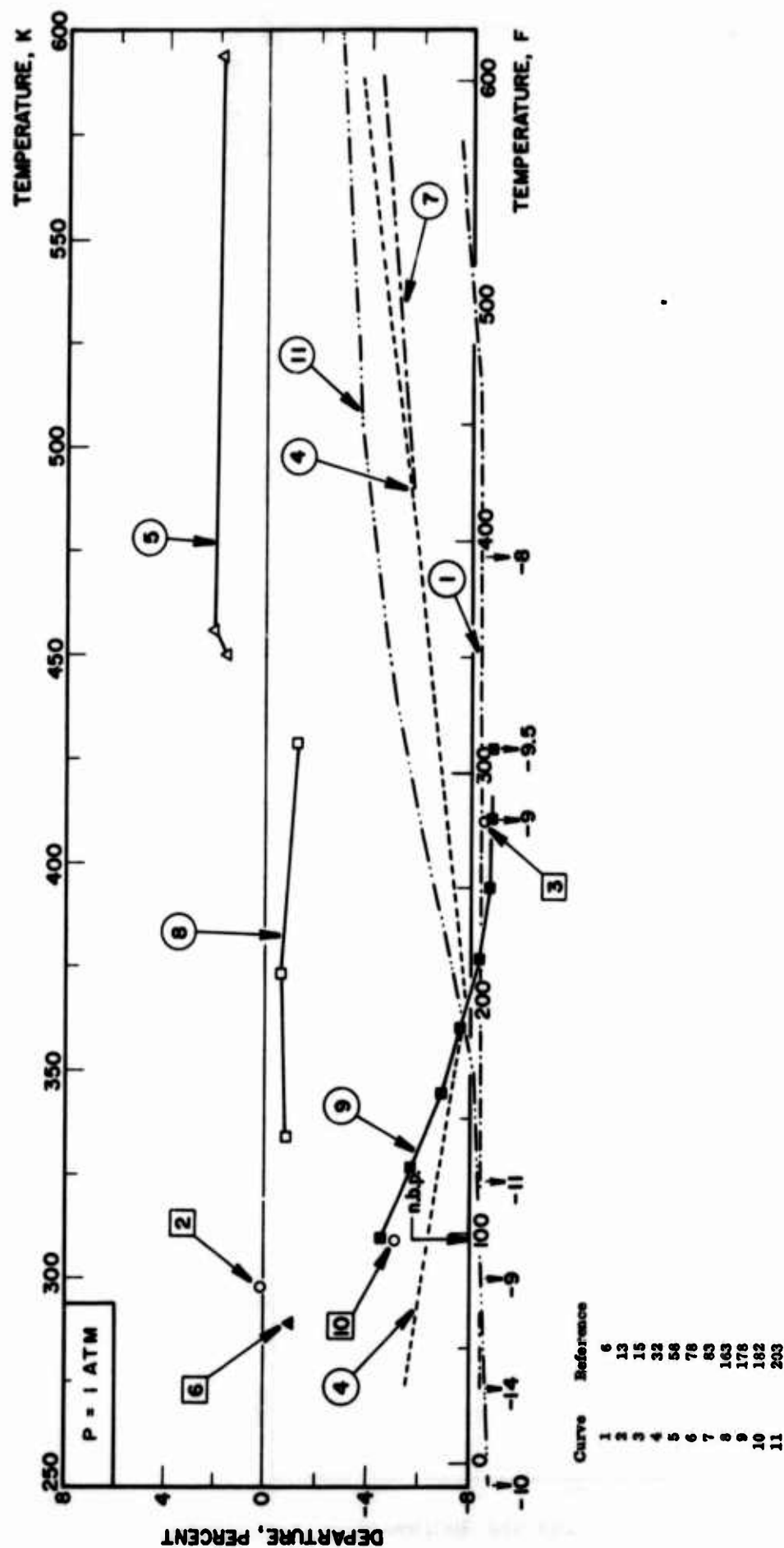


FIGURE 53 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS n-PENTANE

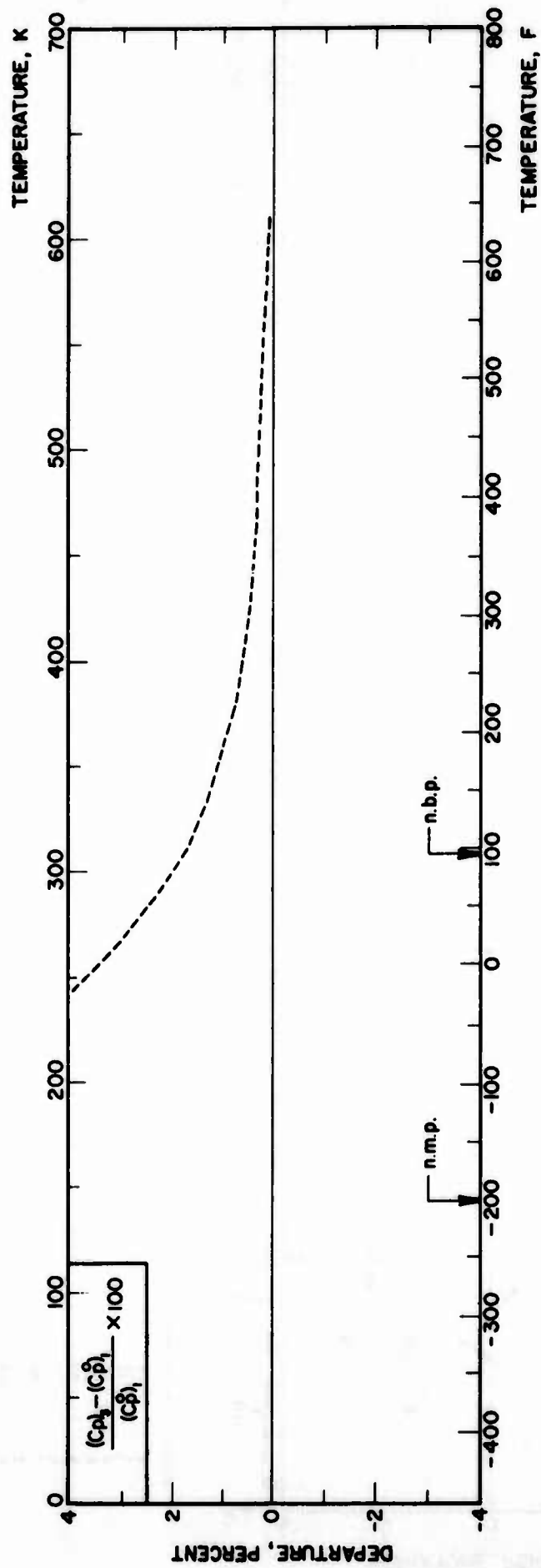


TABLE 54 SPECIFIC HEAT AT CONSTANT PRESSURE OF PROPANE

DISCUSSION

LIQUID

Eight works are available on the specific heat at constant pressure of liquid propane. In the temperature range from the n. m. p. to the n. b. p., only one set of calorimetric data was reported by Kemp and Egan (98). Their results are considered to be the most reliable from the standpoint of the experimental procedures, and all the reported data points are given equal weight in order to produce the recommended formula. At temperatures above the n. b. p., under saturation vapor pressures, Dana et al. (43) presented calorimetric data covering temperatures from 242 K to 292 K, Sage and Lacey (172) made measurements by means of an adiabatic calorimeter between 297 K and 347 K and Sage et al. (173) also reported results derived from Joule-Thomson experiments at temperatures from 294 K to 344 K. These sets of data, all under saturation vapor pressure, are given no weight in this analysis, as well as three sets of correlated values (32, 75, 83).

The correlation formula obtained in the temperature range from 89 K to 230 K is

$$C_p (\text{cal g}^{-1} \text{K}^{-1}) = 0.433027 + 3.91635 \times 10^{-4} T - 2.18185 \times 10^{-6} T^2 + 1.02882 \times 10^{-8} T^3 \quad (T \text{ in K}).$$

This equation is found to fit the above enumerated data points with a mean deviation of 0.09 percent and a maximum of 0.3 percent. The recommended values are calculated from the above equation. The tabulated values should be substantially correct within one percent at temperatures below the n. b. p. Above this temperature the uncertainty would increase.

In the departure plot, the reported data above the n. b. p. are compared with the values extrapolated by the above equation. A set of data at 900 psi pressure (176) is not shown in this plot.

RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p , B lb⁻¹ F⁻¹]

LIQUID			
T	C _p	T	C _p
-300	0.4575	0	0.5617*
-280	0.4603	20	0.5768*
-260	0.4634	40	0.5933*
-240	0.4667	60	0.6114*
-220	0.4705	80	0.6312*
-200	0.4747	100	0.6527*
-180	0.4795	120	0.6760*
-160	0.4849	140	0.7013*
-140	0.4911	160	0.7286*
-120	0.4980	180	0.7579*
-100	0.5059		
-80	0.5148		
-60	0.5247		
-40	0.5358*		
-20	0.5481*		

* Extrapolated for the liquid phase ignoring pressure dependence (n. b. p. = -44 F)

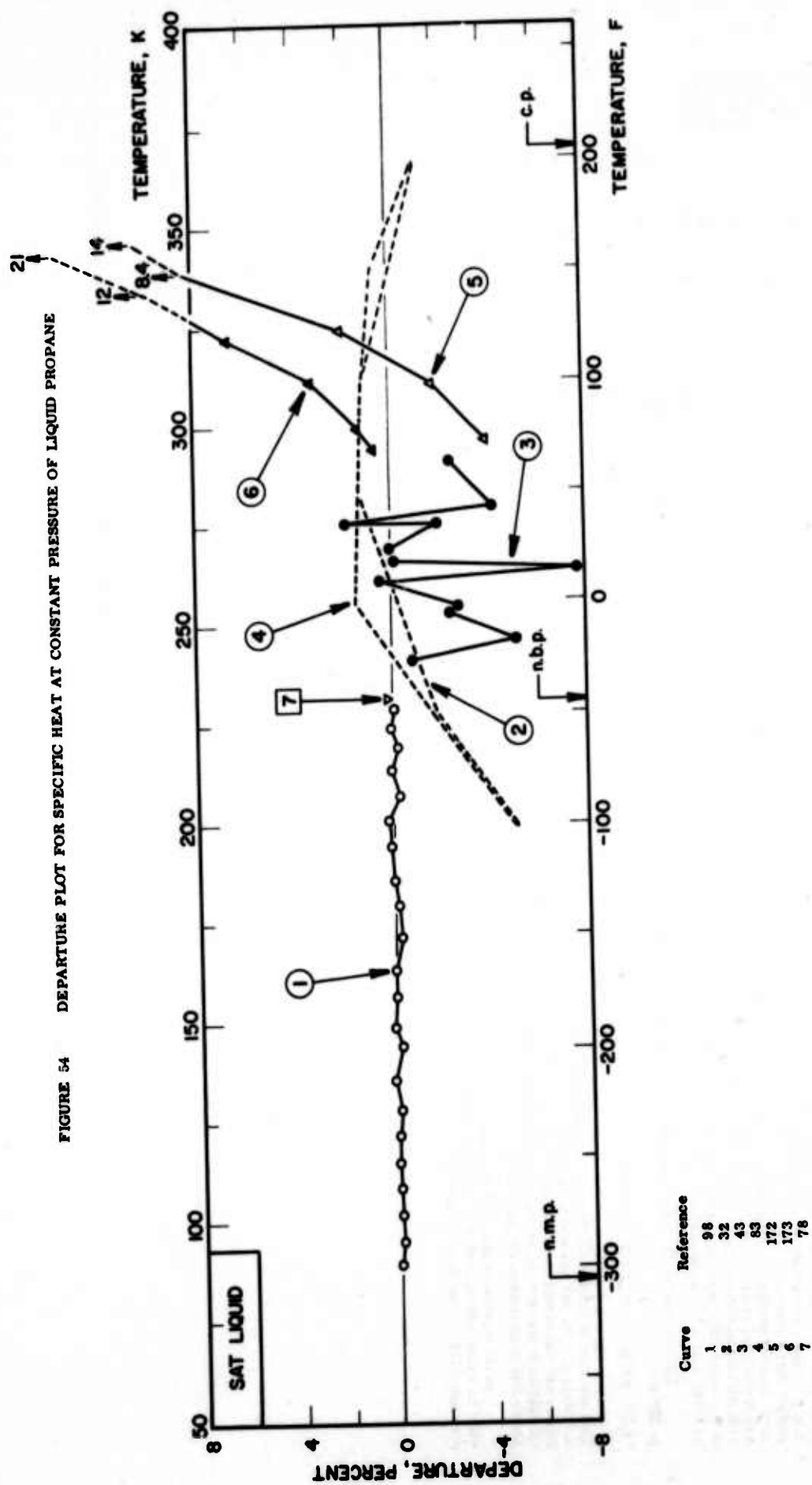


TABLE 54 SPECIFIC HEAT AT CONSTANT PRESSURE OF PROPANE

DISCUSSION

GAS

There exist 32 sources of information on the constant pressure specific heat of gaseous propane. A number of extensive values for the ideal gas state have been derived from spectroscopic and molecular structural data. The values presented by Pitzer (161), Rihard (167) and Rossini et al. (171) are considered to be reliable, as well as the compilation tables (59, 109, 253). Therefore, equal weight is given to these works in this analysis. The statistical values by modified simple formulas (133, 134) and by earlier calculation (160, 203, 222) are given no weight as well as a single point value obtained empirically (18). The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 273 K and 780 K:

$$C_p^0 (\text{cal g}^{-1} \text{K}^{-1}) = 0.0198573 + 1.38072 \times 10^{-3} T - 3.12097 \times 10^{-7} T^3 - 1.65153 \times 10^{-10} T^6 \quad (1)$$

For temperatures between 780 K and 1500 K:

$$C_p^0 (\text{cal g}^{-1} \text{K}^{-1}) = 0.0391462 + 1.46886 \times 10^{-3} T - 6.78173 \times 10^{-7} T^3 + 1.18767 \times 10^{-10} T^6 \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.17 and 0.01 percent, and maximum deviations of 0.66 and 0.02 percent, respectively. The above formulas are used to generate the recommended values, which should be substantially correct within one percent over the entire temperature range. The percent departures of all the reported values mentioned above from the tabulated values are shown in the departure plot for $P = 0$. Although Spencer et al. (195, 196, 197) presented various empirical equations, their results are not plotted in this figure, as well as a set of cited values (236) and a set of experimentally derived values at lower temperatures (102).

On the other hand, several sets of experimental data are available for the specific heat in the real gas state. Among them, flow calorimetric data of Dailey (40) and derived data from adiabatic expansion (104) are thought to be the most reliable, as well as a set of compiled values from P - V - T data (251). These works are given equal weight in this analysis. Other sets of experimental data (85, 172, 178) and a number of correlated values (13, 14, 32, 48, 78, 83, 182, 202) are given no weight. The correlation formula obtained for the real gas specific heat between 240 K and 653 K is:

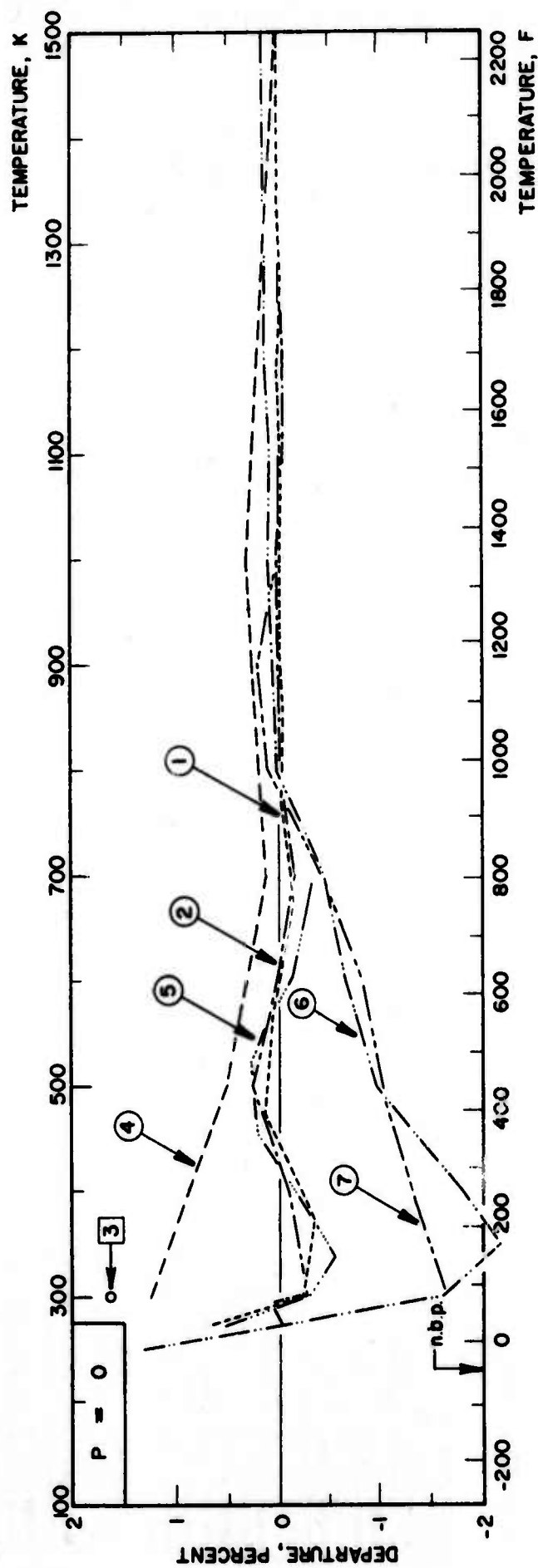
$$C_p (\text{cal g}^{-1} \text{K}^{-1}) = 0.147658 + 4.62079 \times 10^{-4} T + 1.90565 \times 10^{-7} T^2 - 1.73337 \times 10^{-9} T^3 \quad (3)$$

This equation is found to fit the above enumerated data with a mean deviation of 0.37 percent and a maximum of 1.4 percent. Equation (3) is used to calculate the percent departures of all the above mentioned values in the real gas state, which are shown in the departure plot for $P = 1$ atm. A set of experimental data under high pressure (173) is not given in this figure. The third plot is the comparison of Equation (3) with Equation (1) within their common temperature range.

RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p , B lb ⁻¹ F ⁻¹]			
GAS			
T	C_p^0	T	C_p^0
40	0.3753	600	0.6904
60	0.3882	620	0.6997
80	0.4011	640	0.7088
100	0.4138	660	0.7177
120	0.4263	680	0.7266
140	0.4388	700	0.7352
160	0.4512	720	0.7437
180	0.4634	740	0.7521
200	0.4755	760	0.7603
220	0.4875	780	0.7683
240	0.4994	800	0.7762
260	0.5111	820	0.7839
280	0.5227	840	0.7914
300	0.5342	860	0.7988
320	0.5456	880	0.8060
340	0.5568	900	0.8130
360	0.5679	920	0.8199
380	0.5789	940	0.8266
400	0.5897	960	0.8335
420	0.6004	980	0.8404
440	0.6110	1000	0.8471
460	0.6214	1100	0.8794
480	0.6317	1200	0.9094
500	0.6418	1300	0.9373
520	0.6518	1400	0.9632
540	0.6617	1500	0.9871
560	0.6714	1600	1.0092
580	0.6810	1700	1.0297
		1800	1.0486
		1900	1.0661
		2000	1.0823

FIGURE 54 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS PROPANE



Curve	Reference
1	171, 253
2	52, 109, 161, 167
3	18
4	133, 134
5	160
6	203
7	222

FIGURE 54 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS PROPANE

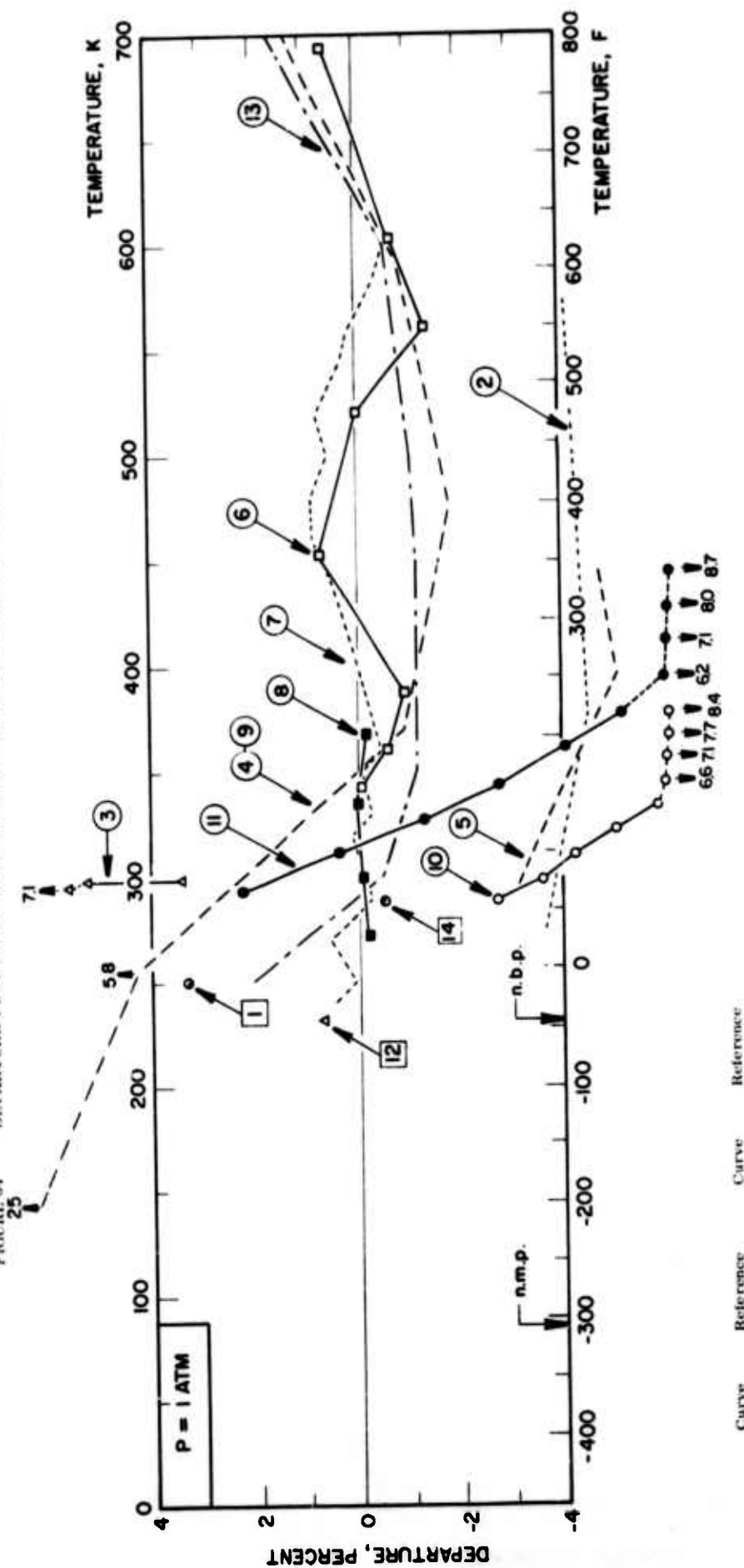


FIGURE 54 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS PROPANE

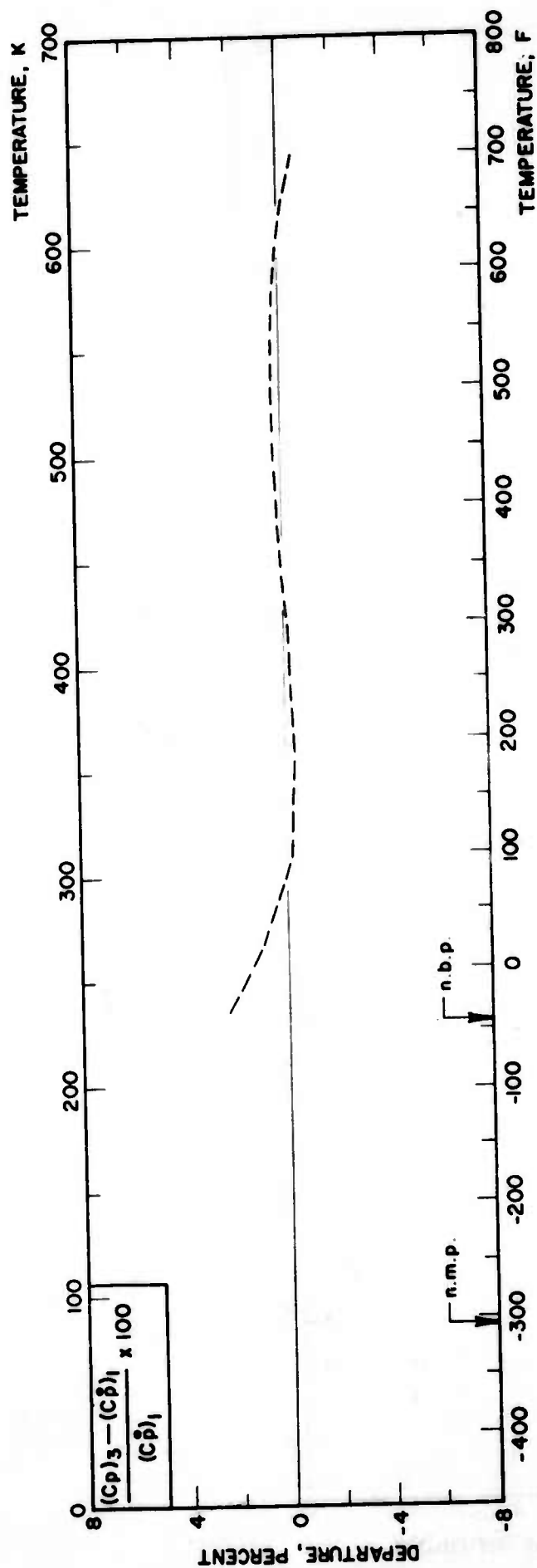


TABLE 55 SPECIFIC HEAT AT CONSTANT PRESSURE OF TOLUENE

DISCUSSION

LIQUID

There exist 17 works on the constant pressure specific heat of liquid toluene. Most of the experimental measurements were made within the temperature range between the n.m.p. and the n.b.p. The calorimetric results of Barlew (31), Kelley (97), Kurbatov (117), Richards and Wallace (168), Schrock et al (181), Zhdanov (237) and Swietoslawski and Zielenkiewicz (258) are considered to be reliable from the standpoint of the experimental procedures used and the reported accuracy of their measurements. Therefore, equal weight is given to these works in the present analysis. Meanwhile, four sets of calorimetric data in narrow temperature ranges (5, 200, 221, 231) and three sets of derived or correlated values (23, 36, 78) are not given any weight, as well as two sets of cited data (63, 188). The only calorimetric work beyond the n.b.p. was performed by Nesselmann et al (147) under various pressures between 3 and 19 atm. However, the results showed considerable scattering and are given no weight.

The correlation formula obtained for the temperature range between 183 K and

$$C_p(\text{cal g}^{-1} \text{K}^{-1}) = 0.451594 - 1.65686 \times 10^{-3} T + 7.12868 \times 10^{-6} T^2 - 6.82620 \times 10^{-9} T^3$$

(T in K)

This equation is found to fit the above enumerated 69 data points with a mean deviation of 0.9 percent and a maximum of 3.3 percent. The recommended values are calculated using the above formula. The tabulated values should be correct within four percent. In the departure plot two sets of cited values (63, 188) are not shown.

RECOMMENDED VALUES

[Temperature, T, °F; Specific Heat, C_p , B lb⁻¹ F⁻¹]
LIQUID

T	C_p	T	C_p
-140	0.3437 [†]	100	0.4201
-120	0.3467	120	0.4291
-100	0.3505	140	0.4381
-80	0.3550	160	0.4472
-60	0.3602	180	0.4564
-40	0.3660	200	0.4655
-20	0.3725	220	0.4745
0	0.3794	240	0.4834 0.4934
20	0.3869	260	0.492 [‡]
40	0.3947	280	0.500 [‡]
60	0.4029	300	0.509 [‡]
80	0.4114	320	0.516 [‡]

[†]Extrapolated for the liquid phase ignoring pressure dependence
(n.m.p. = -139 °F)

[‡]Extrapolated for the liquid phase ignoring pressure dependence
(n.b.p. = 231 °F)

FIGURE 55 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID TOLUENE

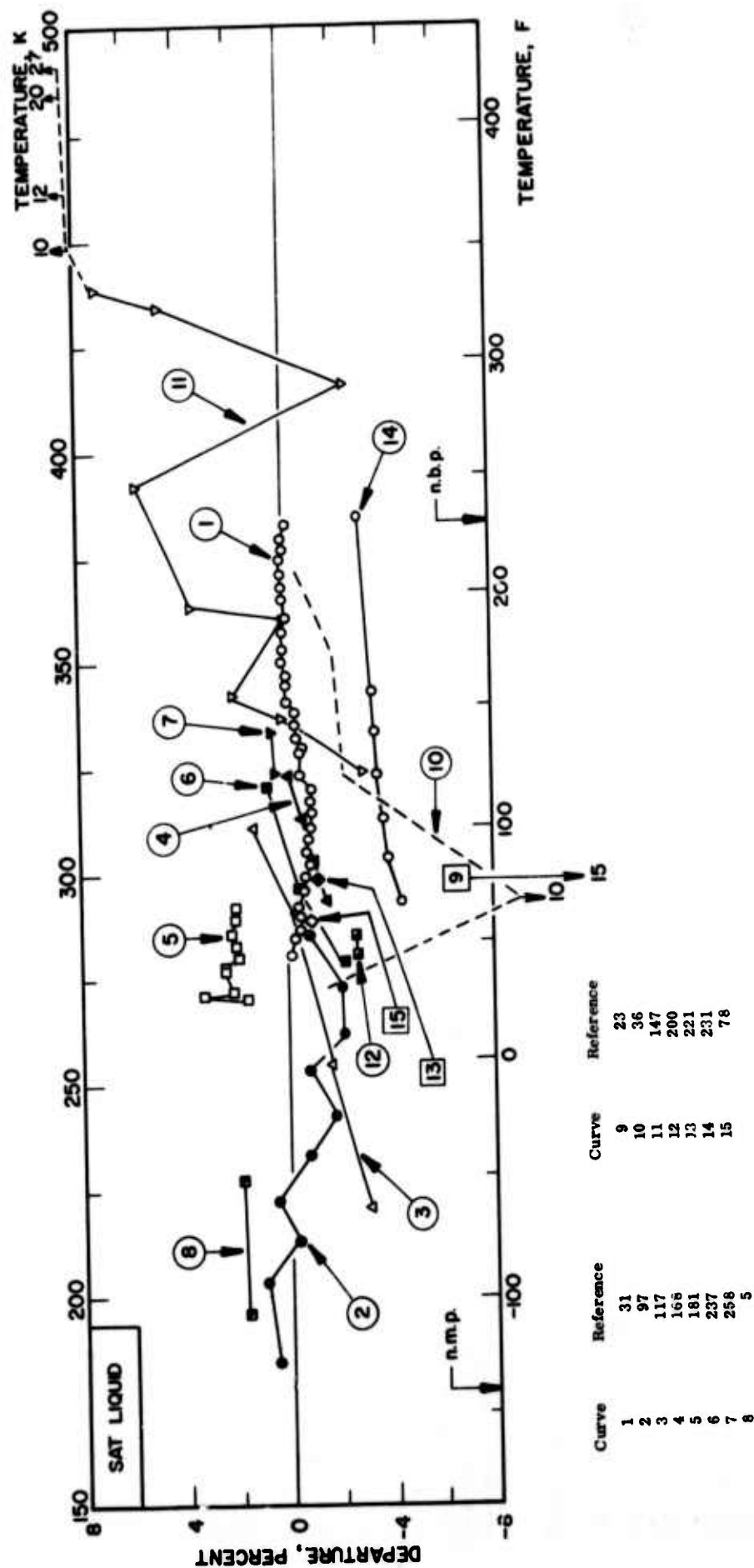


TABLE 55 SPECIFIC HEAT AT CONSTANT PRESSURE OF TOLUENE

DISCUSSION

GAS

Sixteen sources of information are available for the specific heat at constant pressure of gaseous toluene. Extensive theoretical values for the ideal gas state derived from spectroscopic data were presented by several authors. The results of Kobe and Long (110), Ribaud (167), Rossini et al. (171), and Taylor et al. (208) are considered to be reliable. Excellent agreement is found among them. Therefore, full weight is given to these works in this analysis. The earlier statistical calculations (202, 222) are given no weight as well as a single point value obtained empirically (18). The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 273 K and 760 K

$$C_p^0 (\text{cal g}^{-1} \text{K}^{-1}) = -0.0744426 + 1.34989 \times 10^{-3} T - 6.75927 \times 10^{-7} T^2 + 6.15416 \times 10^{-11} T^3 \quad (T \text{ in K}), \quad (1)$$

For temperatures between 760 K and 1500 K

$$C_p^0 (\text{cal g}^{-1} \text{K}^{-1}) = 0.0286835 + 1.10456 \times 10^{-3} T - 5.69020 \times 10^{-7} T^2 + 1.10798 \times 10^{-10} T^3 \quad (T \text{ in K}), \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.15 and 0.01 percent, and maximum deviations of 0.54 and 0.02 percent, respectively. The recommended values are generated using the above formulas. The tabulated values should be substantially correct within a half percent. The percent departures of all the reported values from the above equations are shown in the departure plot for $P = 0$. Some empirical equations (195, 196) are not plotted in this figure.

Several experimental works are available for the specific heat in the real gas state. The flow calorimetric data of Montgomery and DeVries (145) and Pitzer and Scott (165) are thought to be reliable from the standpoint of the experimental procedures used. However, the general trend of their data is not always found to be realistic in comparison with the ideal gas values, C_p^0 , mentioned above, which are thought to be more reliable. In the present analysis, therefore, the specific heat at the real gas, C_p^1 , is calculated by means of the usual thermodynamic relations. The correction for gas imperfection is computed from Berthelot's equation of state. The C_p^1 values obtained for temperatures from 299 K to 610 K are fitted to the following formula:

$$C_p^1 (\text{cal g}^{-1} \text{K}^{-1}) = -1.41207 \times 10^{-4} + 9.66922 \times 10^{-4} T + 1.27754 \times 10^{-4} T^2 - 3.60844 \times 10^{-10} T^3 \quad (T \text{ in K}), \quad (3)$$

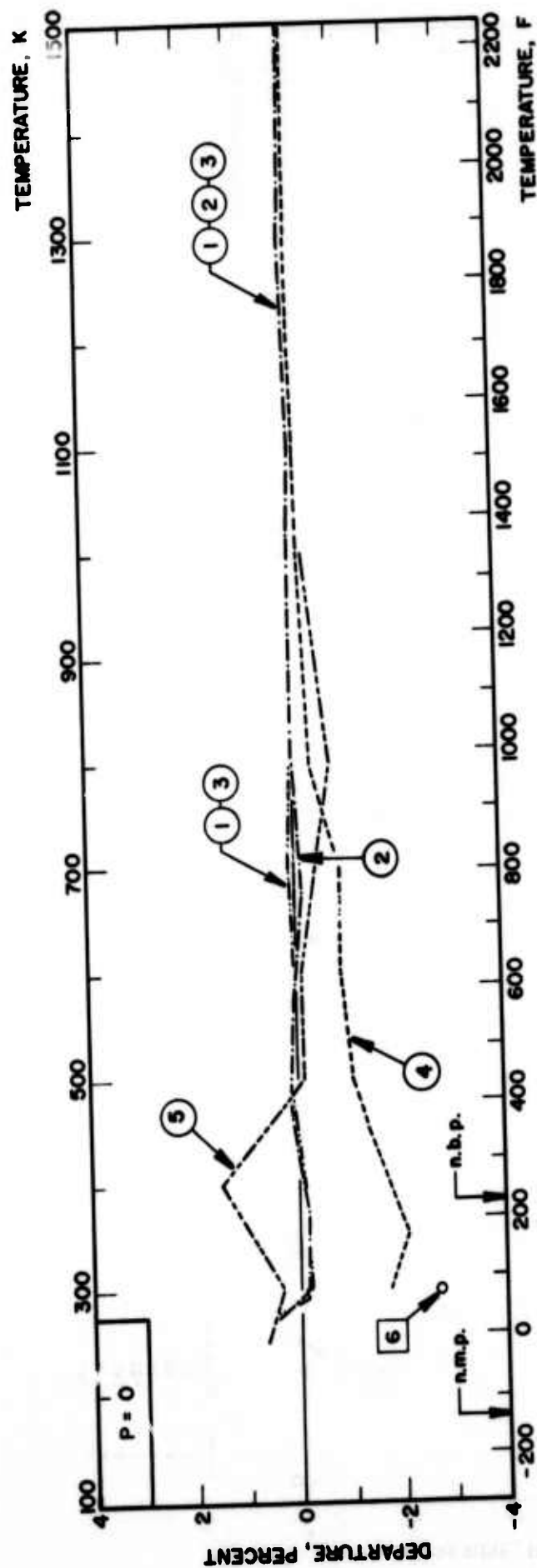
The recommended values for C_p^1 are generated using the above equation. In the departure plot for $P = 1 \text{ atm}$, all the available data obtained by calorimetry (15, 145, 147, 165), theoretical calculation (203) and empirical correlation (48, 78) are compared with Equation (3). Furthermore, the comparison between Equation (3) and Equation (1) is given in the third departure plot.

TABLE 55 SPECIFIC HEAT AT CONSTANT PRESSURE OF TOLUENE (continued)

RECOMMENDED VALUES				
[Temperature, T, F; Specific Heat, C_p , B lb ⁻¹ F ⁻¹]				
T	C_p^0	C_p^1	T	C_p^0 C_p^1
40	0.2493		600	0.4982 0.500
60	0.2603		620	0.5050 0.506
80	0.2710	0.281	640	0.5117 0.513
100	0.2816	0.291	660	0.5182
120	0.2920	0.300	680	0.5246
140	0.3023	0.310	700	0.5308
160	0.3125	0.319	720	0.5369
180	0.3225	0.329	740	0.5429
200	0.3323	0.338	760	0.5487
220	0.3420	0.347	780	0.5544
240	0.3515	0.356	800	0.5599
260	0.3609	0.365	820	0.5654
280	0.3702	0.374	840	0.5706
300	0.3792	0.383	860	0.5758
320	0.3882	0.391	880	0.5808
340	0.3970	0.400	900	0.5857
360	0.4056	0.408	920	0.5905
380	0.4141	0.417	940	0.5952
400	0.4225	0.425	960	0.5999
420	0.4307	0.433	980	0.6044
440	0.4388	0.441	1000	0.6089
460	0.4467	0.449	1100	0.6302
480	0.4545	0.456	1200	0.6498
500	0.4621	0.464	1300	0.6678
520	0.4696	0.471	1400	0.6842
540	0.4770	0.479	1500	0.6993
560	0.4842	0.486	1600	0.7131
580	0.4913	0.493	1700	0.7257
			1800	0.7373
			1900	0.7479
			2000	0.7577

n.b.p. = 231 F

FIGURE 55 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS TOLUENE



Curve	Reference
1	110
2	167, 171
3	208
4	202
5	222
6	18

FIGURE 55 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS TOLUENE

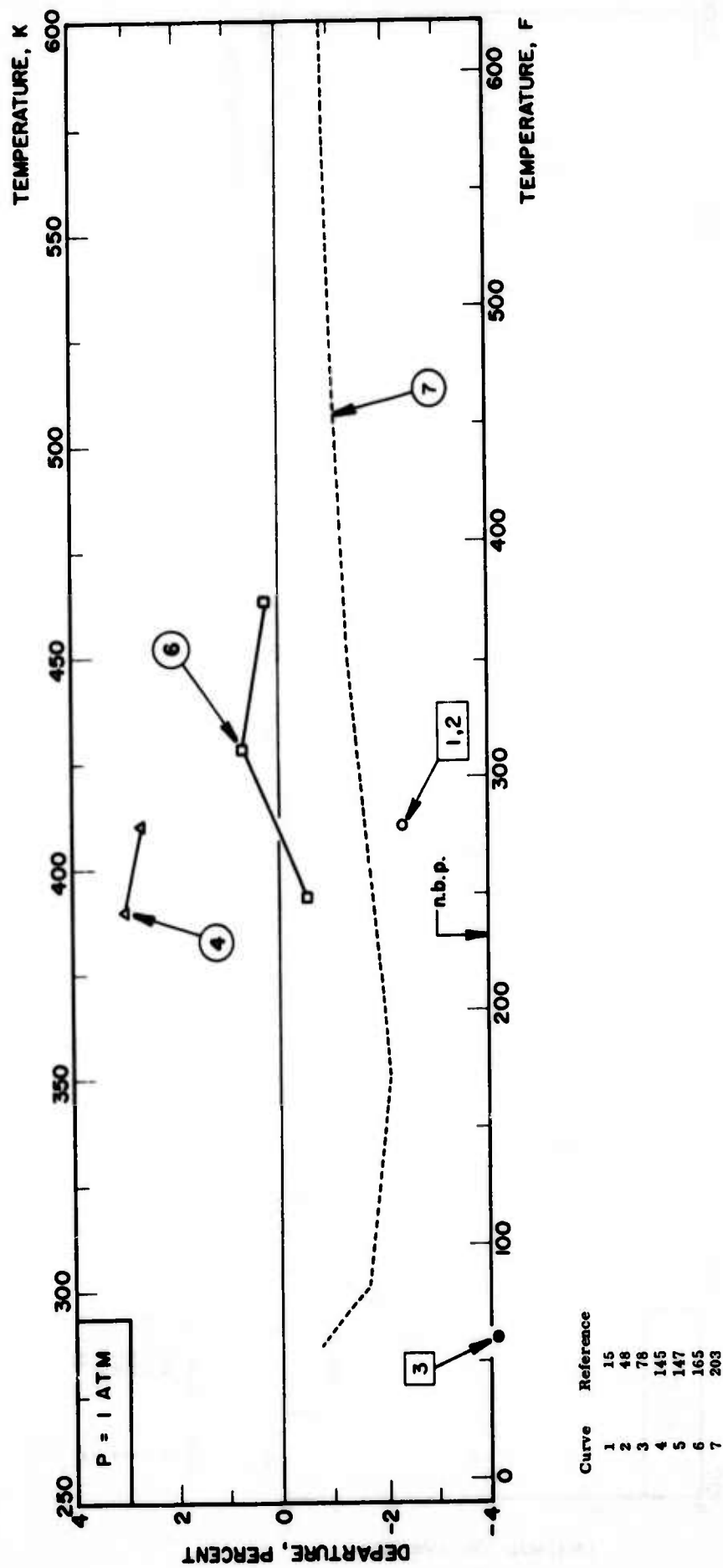


FIGURE 55 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS TOLUENE

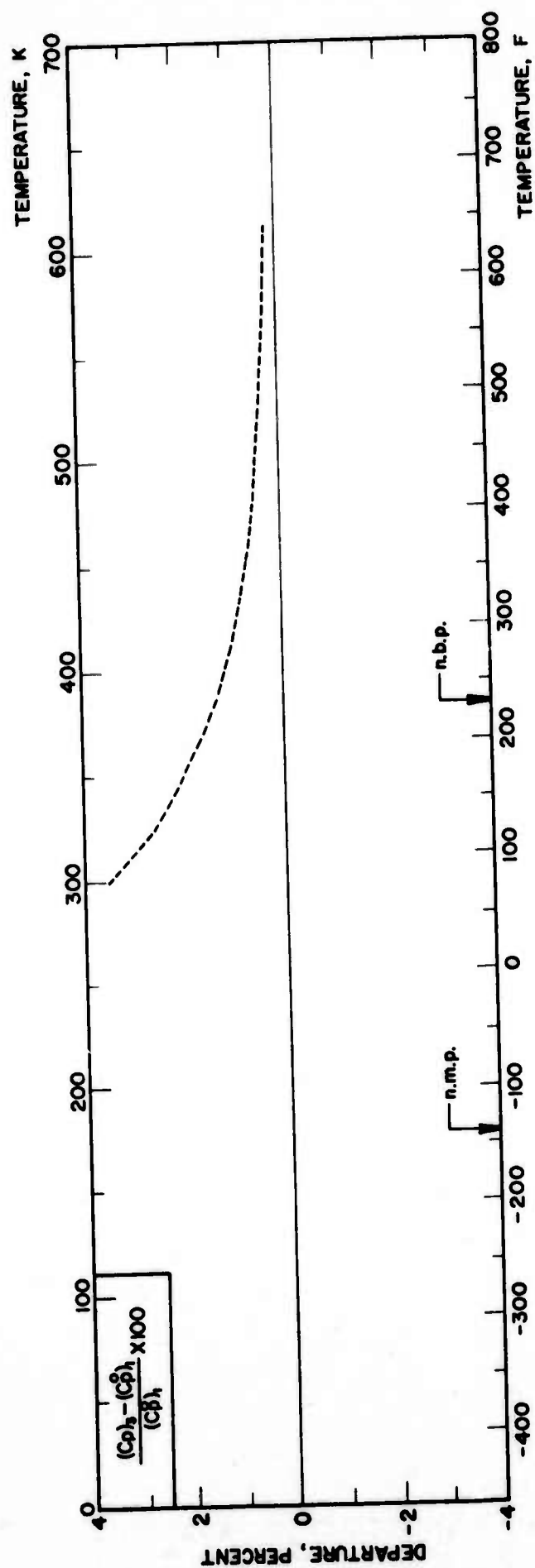


TABLE 56 SPECIFIC HEAT AT CONSTANT PRESSURE OF AIR

DISCUSSION

GAS

Seventy-six sources of information are available on the specific heat at constant pressure of air. Several extensive values have been derived from spectroscopic and molecular structural data. The results of Dommett (311), Kallman (403), and Hilsenrath et al. (575) are considered to be reliable, and are given equal weight in this analysis. Other sets of correlations (59, 100, 358, 368) and earlier statistical calculations (24, 93, 103, 338, 350, 402, 426) are given no weight, as well as the extrapolated values to zero pressure from experimental P - V - T data (470). The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 250 K and 600 K

$$C_p^0 \text{ (cal g}^{-1} \text{ K}^{-1}) = 0.244388 - 4.20419 \times 10^{-5} T + 9.61128 \times 10^{-8} T^2 - 1.16383 \times 10^{-11} T^3 \quad (T \text{ in K}), \quad (1)$$

For temperatures between 600 K and 1500 K

$$C_p^0 \text{ (cal g}^{-1} \text{ K}^{-1}) = 5.208831 + 7.71027 \times 10^{-5} T - 8.56726 \times 10^{-9} T^2 - 4.75772 \times 10^{-12} T^3 \quad (T \text{ in K}). \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.03 and 0.04 percent, and maximum deviations of 0.28 and 0.22 percent, respectively. The recommended values are generated using the above formulas. The tabulated values of C_p^0 should be substantially correct within 0.5 percent over the entire temperature range. The percent departures of all the values mentioned above from the tabulated values are given in the departure plot for $P = 0$. The lower temperature data (497, 549), cited values (454) and the mean specific heat values (92) are not plotted.

A number of experimental and theoretical values are also available for the specific heat in the real gas state. Among them, the derived values of Hilsenrath et al. (575), which are also compiled in various reports (132, 260, 323, 454, 481), are considered to be the most reliable in the temperature range from 260 K up to 900 K. Therefore, their values are fitted to the following equations in the present analysis of the real gas specific heat,

For temperatures between 260 K and 610 K:

$$C_p \text{ (cal g}^{-1} \text{ K}^{-1}) = 0.249679 - 7.55179 \times 10^{-5} T + 1.69194 \times 10^{-7} T^2 - 6.46128 \times 10^{-11} T^3 \quad (T \text{ in K}), \quad (3)$$

For temperatures between 610 K and 900 K

$$C_p \text{ (cal g}^{-1} \text{ K}^{-1}) = 0.239496 - 3.89538 \times 10^{-5} T + 1.36120 \times 10^{-7} T^2 - 6.40730 \times 10^{-11} T^3 \quad (T \text{ in K}). \quad (4)$$

These equations are found to fit the above enumerated values (575) with mean deviations of 0.01 and 0.008 percent, and maximum deviations of 0.01 and 0.02 percent, respectively. The recommended values of the specific heat at the real gas state C_p are generated using the above formulas. In the departure plots at $P = 1$ atm, all the available data obtained by theoretical calculations (302, 330, 368, 369, 370, 376, 490, 497, 512, 553), correlations (71, 249, 251, 274, 315, 366, 367, 403, 406, 541), calorimetry (40, 85, 209, 268, 378), adiabatic expansion (56, 103, 277), Joule-Thomson experiments (505, 506), the velocity of sound measurements (489, 520) and heat transfer measurements (297) are compared with Equation (3) and (4). However, cited values (71, 78, 127, 269, 279, 350, 374, 442, 528, 534, 557, 564), high temperature data (385, 447), low temperature data (549) and mean specific heat values (377) are not plotted in the figures, as well as empirical equations (184, 272).

A comparison of Equation (3) and (4) with Equation (1) and (2) is also given in the last departure plot.

TABLE 56 SPECIFIC HEAT AT CONSTANT PRESSURE OF AIR

RECOMMENDED VALUES				RECOMMENDED VALUES				
[Temperature, T, F; Specific Heat, C _p , B lb ⁻¹ F ⁻¹]				[Temperature, T, F; Specific Heat, C _p , B lb ⁻¹ F ⁻¹]				
T	C _p ⁰	C _p ¹	T	GAS		T	GAS	
				C _p ⁰	C _p ¹		C _p ⁰	C _p ¹
-280	0.24098		300	0.24273	0.2429	900	0.25996	0.2600
-260	0.24073		320	0.24311	0.2433	920	0.26058	0.2606
-240	0.24051		340	0.24350	0.2437	940	0.26120	0.2612
-220	0.24031		360	0.24392	0.2441	960	0.26181	0.2618
-200	0.24013		380	0.24435	0.2445	980	0.26241	0.2625
-180	0.23998		400	0.24480	0.2450	1000	0.26301	0.2631
-160	0.23984		420	0.24528	0.2455	1100	0.26594	0.2660
-140	0.23973		440	0.24577	0.2460	1200	0.26873	
-120	0.23964		460	0.24628	0.2465	1300	0.27140	
-100	0.23958		480	0.24682	0.2470	1400	0.27392	
-80	0.23953		500	0.24737	0.2476	1500	0.27630	
-60	0.23951		520	0.24794	0.2481	1600	0.27853	
-40	0.23951		540	0.24853	0.2487	1700	0.28061	
-20	0.23953		560	0.24914	0.2493	1800	0.28252	
0	0.23957	0.2402	580	0.24976	0.2499	1900	0.28428	
20	0.23963	0.2402	600	0.25041	0.2505	2000	0.28587	
40	0.23972	0.2402	620	0.25107	0.2511			
60	0.23982	0.2403	640	0.25149	0.2517			
80	0.23995	0.2403	660	0.25217	0.2523			
100	0.24010	0.2405	680	0.25284	0.2530			
120	0.24027	0.2406	700	0.25351	0.2536			
140	0.24046	0.2408	720	0.25418	0.2542			
160	0.24067	0.2409	740	0.25484	0.2549			
180	0.24091	0.2412	760	0.25549	0.2555			
200	0.24116	0.2414	780	0.25615	0.2561			
220	0.24143	0.2417	800	0.25679	0.2568			
240	0.24173	0.2419	820	0.25744	0.2574			
260	0.24204	0.2422	840	0.25808	0.2580			
280	0.24238	0.2426	860	0.25871	0.2587			
			880	0.25934	0.2593			

FIGURE 56 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS AIR

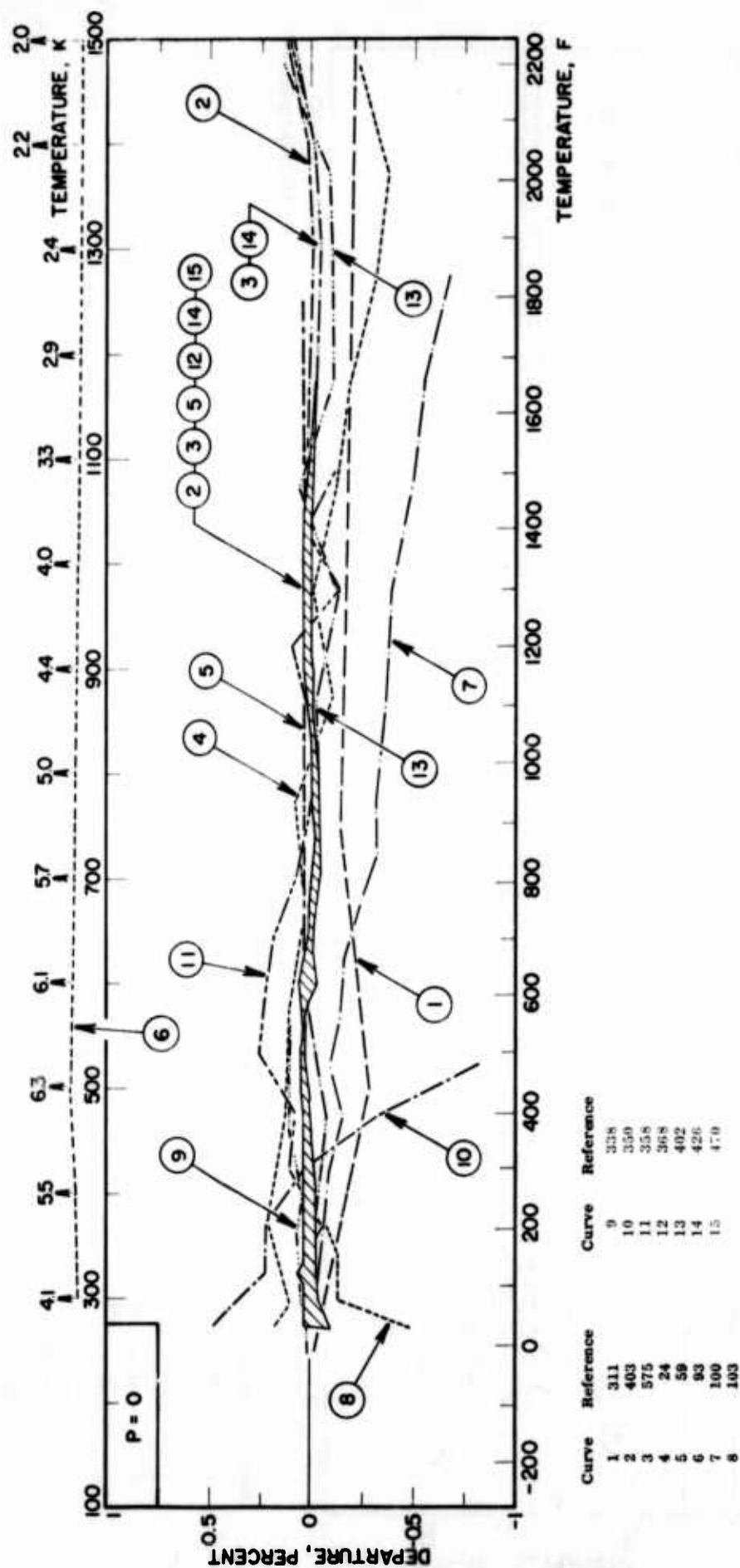


FIGURE 56 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS AIR

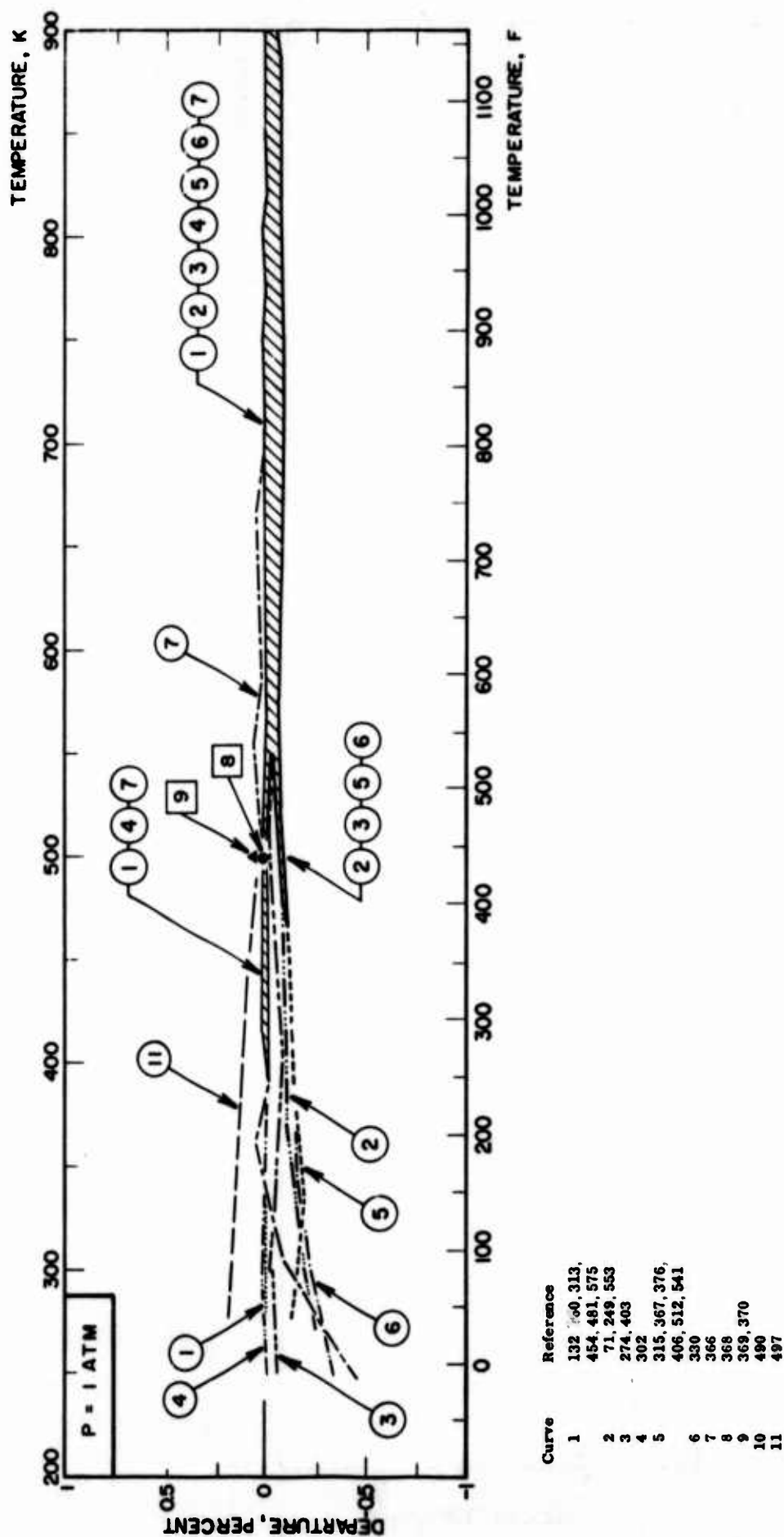
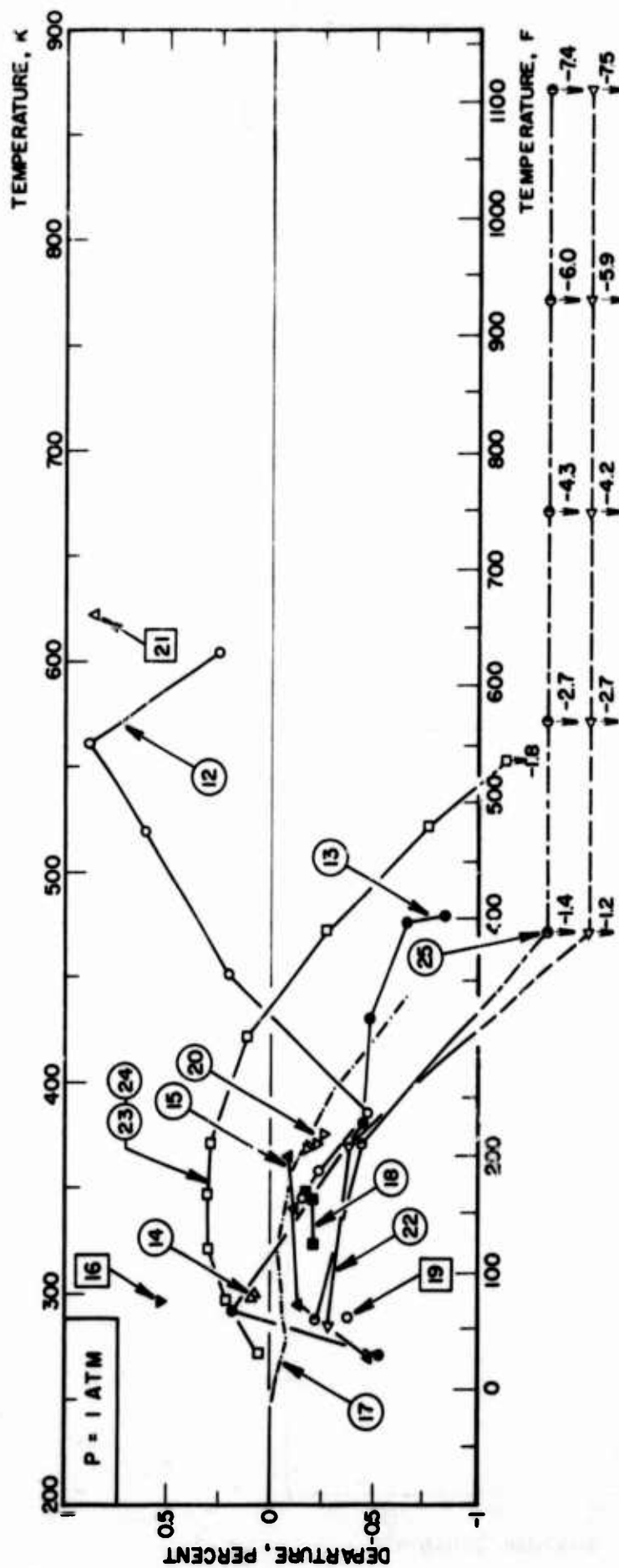
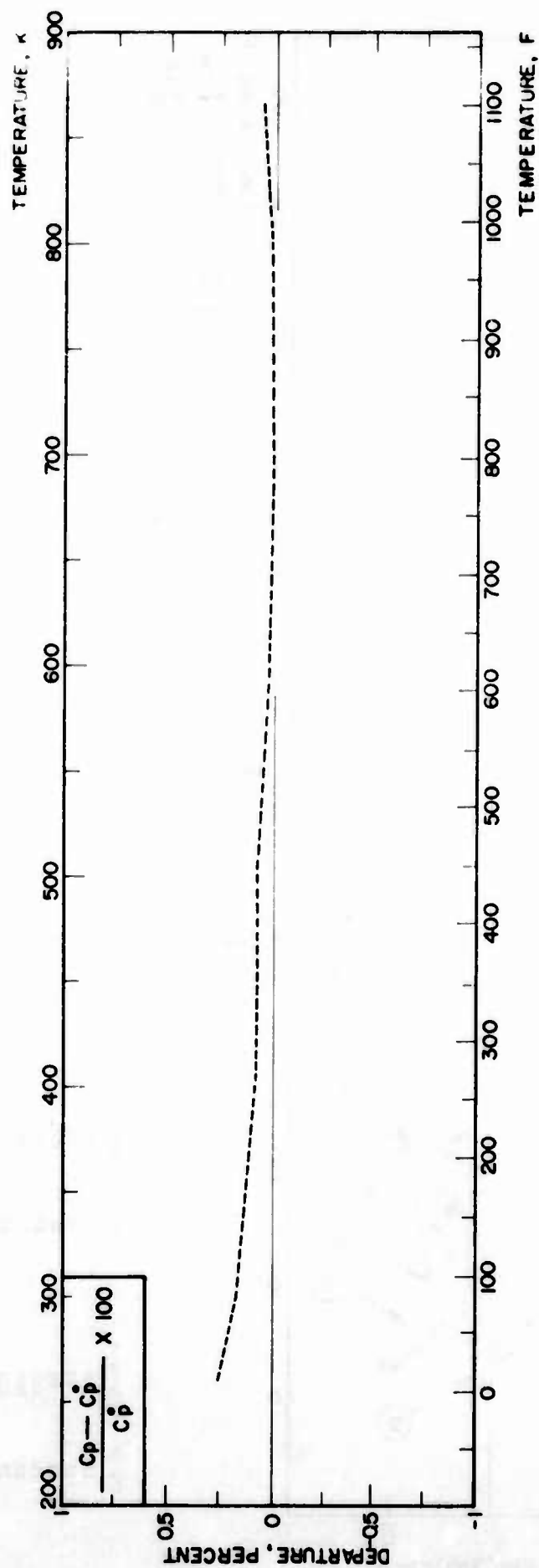


FIGURE 56 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS AIR (continued)



Curve	Reference	Curve	Reference
12	40	19	277
13	56	20	297
14	85	21	378
15	103	22	489
16	209	23	505
17	251	24	506
18	268	25	520

FIGURE 56 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS AIR



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- | Ref.
No. | TPRC
No. | |
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Aluminum	4	1	NH ₄ Al(SO ₄) ₂ · 12H ₂ O	5	1173
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Aluminum + Zinc + ΣX _i	4	514	Ammonium aluminum disulfate dodecahydrate [NH ₄ Al(SO ₄) ₂ · 12H ₂ O]	5	1173
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75 S (same as 7075)	4	514	Antimonic acid anhydride (see Diantimony pentaoxide)		
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QMV	5	1243	Boron nitride + Diboron trioxide + ΣX_1 , cermet ($\text{BN} + \text{B}_2\text{O}_3 + \Sigma X_1$)	5	1270
YB 9052	5	1243	Boron nitride + Carbon, cermet (BN + C)	5	1273
YB 9054	5	1243	Boron sesquioxide (B_2O_3)	5	51
Beryllium difluoride (BeF_2)	5	921	Diboron trioxide (see Boron sesquioxide)		
Beryllium oxide (BeO)	5	45	Borosilicate glass ($\text{SiO}_2 + \text{B}_2\text{O}_3 + \Sigma X_1$)	5	1230
Beryllium oxide + Beryllium, cermet ($\text{BeO} + \text{Be}$)	5	1246	Brass	4	346
Beryllium oxide + Beryllium + Molybdenum, cermet ($\text{BeO} + \text{Be} + \text{Mo}$)	5	1249	Brimstone (see Sulfur)		
Beryllium oxide + Molybdenum, cermet ($\text{BeO} + \text{Mo}$)	5	1252	Bromine	6	7
Beryllium oxide + Molybdenum dodecaberyllide, cermet ($\text{BeO} + \text{MoBe}_{12}$)	5	1255	1-Butane ($1-\text{C}_4\text{H}_{10}$)	6	129
Beryllium oxide + Niobium dodecaberyllide, cermet ($\text{BeO} + \text{NbBe}_{12}$)	5	1258	n-Butane ($n-\text{C}_4\text{H}_{10}$)	6	136
Beryllium oxide + Tantalum dodecaberyllide, cermet ($\text{BeO} + \text{TaBe}_{12}$)	5	1261	Butter of zinc (see Zinc dichloride)		
Beryllium oxide + Titanium dodecaberyllide, cermet ($\text{BeO} + \text{TiBe}_{12}$)	5	1264	Cadmium	4	29
Beryllium oxide + Zirconium 13-beryllide, cermet ($\text{BeO} + \text{ZrBe}_{13}$)	5	1267	Cadmium + Magnesium (MgCd)	4	294
Diberyllium silicon tetraoxide (Be_2SiO_4)	5	1329	Cadmium + Magnesium (Mg_3Cd)	4	297
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Bimethyl (see Ethane)			Cadmium dibromide (CdBr_2)	5	759
Bismuth	4	21	Cadmium dichloride (CdCl_2)	5	791
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Bismuth glance (see Dibismuth tritelluride)			Cadmium diiodide (CdI_2)	5	491
Bismuth sesquioxide (Bi_2O_3)	5	48	Cadmium oxide (CdO)	5	54
Dibismuth trioxide (see Bismuth sesquioxide)			Cadmium sulfide (CdS)	5	650
Dibismuth trisulfide (Bi_2S_3)	5	647	Cadmium telluride (CdTe)	5	720
Dibismuth tritelluride (Bi_2Te_3)	5	717	Calcia (see Calcium oxide)		
Bitter spar (see Calcium magnesium carbonate)			Calcium	4	32
Boralloy (see Boron nitride)			Calcium aluminates:		
Boron	4	25	CaAl_2O_4	5	1332
	5	1	CaAl_4O_7	5	1335
			$\text{Ca}_3\text{Al}_2\text{O}_8$	5	1338
			$\text{Ca}_{12}\text{Al}_{14}\text{O}_{33}$	5	1341
			Calcium dialuminum tetraoxide (CaAl_2O_4)	5	1332

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Tricalcium dialuminum hexaoxide ($\text{Ca}_3\text{Al}_2\text{O}_6$)	5	1338	Calcium difluoride (CaF_2)	5	924
Dodecacalcium 14-aluminum 33-oxide ($\text{Ca}_{12}\text{Al}_{14}\text{O}_{33}$)	5	1341	Calcium diiron tetroxide (CaFe_2O_4)	5	1356
Calcium aluminum silicates:			Dicalcium diiron pentaoxide ($\text{Ca}_2\text{Fe}_2\text{O}_5$)	5	1359
$\text{CaAl}_2\text{Si}_2\text{O}_8$	5	1404	Calcium magnesium dicarbonate [$\text{CaMg}(\text{CO}_3)_2$]	5	1115
$\text{Ca}_3\text{Al}_2\text{SiO}_7$	5	1401	Calcium magnesium silicates:		
$\text{CaAl}_2\text{Si}_2\text{O}_8 \cdot 2\text{H}_2\text{O}$	5	1407	$\text{CaMgSi}_2\text{O}_6$	5	1413
$\text{Ca}_2\text{Al}_4\text{Si}_5\text{O}_{24} \cdot 7\text{H}_2\text{O}$	5	1410	$\text{Ca}_2\text{MgSi}_2\text{O}_7$	5	1416
Calcium dialuminum disilicon octaoxide ($\text{CaAl}_2\text{Si}_2\text{O}_8$)	5	1404	$\text{Ca}_3\text{MgSi}_2\text{O}_8$	5	1419
Dicalcium dialuminum silicon heptaoxide ($\text{Ca}_2\text{Al}_2\text{SiO}_7$)	5	1401	$\text{Ca}_2\text{Mg}_3\text{Si}_5\text{O}_{23} \cdot \text{H}_2\text{O}$	5	1422
Calcium dialuminum disilicon octaoxide dihydrate ($\text{CaAl}_2\text{Si}_2\text{O}_8 \cdot 2\text{H}_2\text{O}$)	5	1407	Calcium magnesium disilicon hexaoxide ($\text{CaMgSi}_2\text{O}_6$)	5	1413
Dicalcium tetraaluminum octasilicon 24-oxide heptahydrate ($\text{Ca}_2\text{Al}_4\text{Si}_8\text{O}_{24} \cdot 7\text{H}_2\text{O}$)	5	1410	Dicalcium magnesium disilicon heptaoxide ($\text{Ca}_2\text{MgSi}_2\text{O}_7$)	5	1416
Calcium borates:			Tricalcium magnesium disilicon octaoxide ($\text{Ca}_3\text{MgSi}_2\text{O}_8$)	5	1419
CaB_2O_4	5	1344	Dicalcium pentamagnesium octasilicon 23- oxide monohydrate ($\text{Ca}_2\text{Mg}_5\text{Si}_8\text{O}_{23} \cdot \text{H}_2\text{O}$)	5	1422
CaB_4O_7	5	1347	Calcium molybdate (see Calcium molybde- num tetroxide)	5	1362
$\text{Ca}_2\text{B}_2\text{O}_5$	5	1350	Calcium molybdenum tetroxide (CaMoO_4)	5	1362
$\text{Ca}_3\text{B}_2\text{O}_6$	5	1353	Calcium oxide (CaO)	5	57
Calcium metaborate (see Calcium diboron tetroxide)			Calcium silicates:		
Monocalcium borate (see Calcium diboron tetroxide)			CaSiO_3	5	1365
Calcium diboron tetroxide (CaB_2O_4)	5	1344	Ca_2SiO_4	5	1368
Calcium tetraboron heptaoxide (CaB_4O_7)	5	1347	Ca_3SiO_5	5	1371
Dicalcium diboron pentaoxide ($\text{Ca}_2\text{B}_2\text{O}_5$)	5	1350	$\text{Ca}_3\text{Si}_2\text{O}_7$	5	1374
Tricalcium diboron hexaoxide ($\text{Ca}_3\text{B}_2\text{O}_6$)	5	1353	Calcium metasilicate (see Calcium silicon trioxide)		
Calcium dicarbide (CaC_2)	5	405	Calcium orthosilicate (see Dicalcium silicon tetroxide)		
Calcium carbonate (CaCO_3)	5	1112	Calcium silicon trioxide (CaSiO_3)	5	1365
Calcium dichloride (CaCl_2)	5	794	Dicalcium silicon tetroxide (Ca_2SiO_4)	5	1368
Calcium ferrites:			Tricalcium silicon pentaoxide (Ca_3SiO_5)	5	1371
CaFe_2O_4	5	1356	Tricalcium disilicon heptaoxide ($\text{Ca}_3\text{Si}_2\text{O}_7$)	5	1374
$\text{Ca}_2\text{Fe}_2\text{O}_5$	5	1359	Calcium sulfates:		
Calcium metaferrite (see Calcium diiron tetroxide)			CaSO_4	5	1182
Calcium orthoferrite (see Dicalcium diiron pentaoxide)			$\text{CaSO}_4 \cdot 1/2\text{H}_2\text{O}$	5	1185

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Calcium sulfate (CaSO ₄)	5	1182	Carbon steel (Group II)	4	623
Calcium sulfate hemihydrate (CaSO ₄ ·1/2H ₂ O)	5	1185	Carbon steel (Group II), eutectoid	4	623
Calcium sulfate dihydrate (CaSO ₄ ·2H ₂ O)	5	1188	Carbon steel (Group II), hyper eutectoid	4	623
Calcium sulfide (CaS)	5	653	Carbon steel (Group II), U-8	4	623
Calcium titanates:			Cassiopeium (see Lutetium)		
CaTiO ₃	5	1377	Celtium (see Hafnium)		
Ca ₃ Ti ₂ O ₇	5	1380	Cerium	4	36
Calcium titanium trioxide (CaTiO ₃)	5	1377	Cerium trifluoride (CeF ₃)	5	927
Tricalcium dititanium heptaoxide (Ca ₃ Ti ₂ O ₇)	5	1380	Cerium oxides:		
Calcium tungstate (see Calcium tungsten tetraoxide)			CeO	5	60
Calcium tungsten tetraoxide (CaWO ₄)	5	1383	Ce ₂ O ₃	5	64
Calcium uranate (see Calcium uranium tetraoxide)			Cerium dioxide (CeO ₂)	5	60
Calcium uranium tetraoxide (CaUO ₄)	5	1386	Cerium sesquioxide (Ce ₂ O ₃)	5	64
Calcium vanadates:			Dicerium trioxide (see Cerium sesquioxide)		
CaV ₂ O ₆	5	1389	Cerium sulfides:		
Ca ₂ V ₂ O ₇	5	1392	CeS	5	656
Ca ₃ V ₂ O ₈	5	1395	Ce ₂ S ₃	5	659
Calcium divanadium hexaoxide (CaV ₂ O ₆)	5	1389	Cerium sulfide (CeS)	5	656
Dicalcium divanadium heptaoxide (Ca ₂ V ₂ O ₇)	5	1392	Dicerium trisulfide (Ce ₂ S ₃)	5	659
Tricalcium divanadium octaoxide (Ca ₃ V ₂ O ₈)	5	1395	Cermets:		
Calcium wolframite (see Calcium tungsten tetraoxide)			Be + BeO	5	1243
Calcium zirconate (see Calcium zirconium trioxide)			BeO + Be	5	1246
Calcium zirconium trioxide (CaZrO ₃)	5	1398	BeO + Be + Mo	5	1249
Carbon, diamond	5	4	BeO + Mo	5	1252
Carbon, graphite	5	9	BeO + MoBe ₁₂	5	1255
Carbon + Silicon carbide, cermet (C + SiC)	5	1276	BeO + NbBe ₁₂	5	1258
Carbon tetrachloride (CCl ₄)	6	159	BeO + TaBe ₁₂	5	1261
Carbon oxides:			BeO + TiBe ₁₂	5	1264
CO	6	152	BeO + ZrBe ₁₃	5	1267
CO ₂	6	143	BN + B ₂ O ₃ + ΣX ₁	5	1270
Carbon monoxide (CO)	6	152	BN + C	5	1273
			C + SiC	5	1276
			SiC + C + ΣX ₁	5	1279

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ZrO ₂ + Ti	5	1285	Pentachromium dicarbide (Cr_5C_2)	5	411
Cesium	4	40	Heptachromium tricarbonide (Cr_7C_3)	5	417
Cesium aluminum disulfate dodecahydrate [$\text{CsAl}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$]	5	1191	Chromium chlorides:		
Cesium chloride (CsCl)	5	797	CrCl ₂	5	800
Cesium monohydrogen difluoride (CsHF_2)	5	931	CrCl ₃	5	803
Cesium iodide (CsI)	5	494	Chromium dichloride (CrCl_2)	5	800
Chlorine	6	11	Chromium trichloride (CrCl_3)	5	803
Chlorodifluoromethane (see Freon 22)			Chromium sesquioxide (Cr_2O_3)	5	67
Chlorotrifluoromethane (see Freon 13)			Dichromium trioxide (see Chromium sesquioxide)		
Chloroform (CHCl_3)	6	166	Chromium silicides:		
Chloromethane (see Methyl chloride)			CrSi	5	565
Chromel A (see Nichrome V)			CrSi ₂	5	568
Chromel P	4	392	Cr ₃ Si	5	559
Chromium	4	44	Cr ₅ Si ₃	5	562
Chromium + Aluminum	4	304	Chromium silicide (CrSi)	5	565
Chromium + Aluminum + ΣX_1	4	517	Chromium disilicide (CrSi_2)	5	568
Chromium + Iron	4	307	Trichromium silicide (Cr_3Si)	5	559
Chromium + Iron + ΣX_1	4	520	Pentachromium trisilicide (Cr_5Si_3)	5	562
Chromium + Manganese	4	311	Cobalt	4	48
Chromium alloys (specific types)			Cobalt + Chromium + ΣX_1	4	523, 526
Aluminothermic chromium	4	520	Cobalt + Dysprosium (DyCo_5)	4	314
Ferrochromium	4	520	Cobalt + Iron	4	317
Chromium borides:			Cobalt + Nickel	4	320
CrB	5	335	Cobalt alloy, HE 1049	4	526
CrB ₂	5	338	Cobalt chlorides:		
Chromium monoboride (CrB)	5	335	CoCl ₂	5	806
Chromium diboride (CrB_2)	5	338	CoCl ₂ · 6H ₂ O	5	809
Chromium carbides:			Cobalt dichloride (CoCl_2)	5	806
Cr ₃ C ₂	5	408	Cobalt dichloride hexahydrate ($\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$)	5	809
Cr ₄ C	5	414	Cobalt ferrites:		
Cr ₅ C ₂	5	411	CoFe ₂ O ₄	5	1425
Cr ₇ C ₃	5	417	Co _x Fe _y O ₄ (nonstoichiometric)	5	1428

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Cobalt diiron tetraoxide (CoFe_2O_4)	5	1425	Copper alloys (specific types)		
Cobalt iron tetraoxide, nonstoichiometric ($\text{Co}_x\text{Fe}_y\text{O}_4$)	5	1428	Manganin	4	338
Cobalt difluoride (CoF_2)	5	934	Monel	4	562
Cobalt oxides:			Copper bromide (CuBr)	5	762
CoO	5	70	Copper chlorides:		
Co_3O_4	5	73	CuCl_2	5	812
Cobalt monoxide (CoO)	5	70	$\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$	5	815
Tricobalt tetraoxide (Co_3O_4)	5	73	Copper dichloride (CuCl_2)	5	812
Cobalto-cobaltic oxide (see Tricobalt tetraoxide)			Copper dichloride dihydrate ($\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$)	5	815
Cobaltosic oxide (see Tricobalt tetraoxide)			Copper ferrites:		
Cobaltouscobaltic oxide (see Tricobalt tetraoxide)			CuFe_2O_4	5	1437
Cobalt silicide (CoSi)	5	571	$\text{Cu}_x\text{Fe}_y\text{O}_4$ (nonstoichiometric)	5	1434
Cobalt sulfate heptahydrate ($\text{CoSO}_4 \cdot 7\text{H}_2\text{O}$)	5	1194	Copper diiron tetraoxide (CuFe_2O_4)	5	1437
Cobalt tungstate (see Cobalt tungsten tetraoxide)			Copper iron tetraoxide, nonstoichiometric ($\text{Cu}_x\text{Fe}_y\text{O}_4$)	5	1434
Cobalt tungsten tetraoxide (CoWO_4)	5	1431	Copper hemioxide (see Copperous oxide)		
Columbium (see Niobium)			Dicopper monoxide (see Copperous oxide)		
Constantan	4	341	Copper oxides:		
Copper	4	51	CuO	5	80
Copper, electrolytic	4	51	Cu_2O	5	76
Copper, electrolytic tough pitch (Fed. Spec. QQC-502)	4	51	Copperas (see Iron sulfate heptahydrate)		
Copper, electrolytic tough pitch (Fed. Spec. QQC-576)	4	51	Copperic oxide (CuO)	5	80
Copper, OFHC	4	51	Copperous oxide (Cu_2O)	5	76
Copper + Aluminum	4	323	Copper protoxide (see Copperous oxide)		
Copper + Chromium + Bk	4	506	Copper suboxide (see Copperous oxide)		
Copper + Gallium	4	327	Copper sulfides:		
Copper + Iron	4	331	CuS	5	662
Copper + Magnesium	4	335	Cu_2S	5	665
Copper + Magnesium + Aluminum ($\text{MgCu}_{2-x}\text{Al}_x$)	4	529	Copper sulfide (CuS)	5	662
Copper + Magnesium + Silicon ($\text{MgCu}_{2-x}\text{Si}_x$)	4	532	Dicopper sulfide (Cu_2S)	5	665
Copper + Manganese	4	338	Cordierite (see Dimagnesium tetraaluminum pentasilicon 18-oxide)		
Copper + Nickel	4	341	Corning 1723 glass	5	1227
Copper + Zinc	4	346	Corundum (see Aluminum oxide)		
			Crucible HMM HNM	4	714
			Cuprum (see Copper)		

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n-Decane (C ₁₀ H ₂₂)	6	170	Ethylene alcohol (see Ethylene glycol)		
Deuterium	6	15	Ethylene glycol (CH ₂ OHCH ₂ OH)	6	192
Diamond (see Carbon, diamond)			Ethyne (see Acetylene)		
Dichlorodifluoromethane (see Freon 12)			Europium	4	68
Dichlorofluoromethane (see Freon 21)			Europium oxide (Eu ₂ O ₃)	5	89
1,2-Dichloro-1,1,2,2-tetrafluoroethane (see Freon 114)			Dieuropium trisulfate octahydrate (Eu ₂ (SO ₄) ₃ ·8H ₂ O)	5	1197
Dimethyl (see Ethane)			Ferric oxide [see Iron (ic) oxide]		
Dimethyl ketone (see Acetone)			Ferroniobium	4	574
Dimethylmethane (see Propane)			Ferrous chloride (see Iron dichloride)		
Dysprosia (see Dysprosium oxide)			Ferrous ferric oxide (see Triiron tetraoxide)		
Dysprosium	4	62	Ferrous fluoride (see Iron difluoride)		
Dysprosium trichloride hexahydrate (DyCl ₃ ·6H ₂ O)	5	818	Ferrous oxide [see Iron (ous) oxide]		
Dysprosium oxide (Dy ₂ O ₃)	5	83	Ferrum (see Iron)		
Dysprosium sesquioxide (see Dysprosium oxide)			Flowers of tin (see Tin dioxide)		
Didysprosium trioxide (see Dysprosium oxide)			Fluorine	6	19
Erbia (see Erbium oxide)			Freon 10 (see Carbon tetrachloride)		
Erbium	4	65	Freon 11 (Cl ₃ CF)	6	200
Erbium trichloride hexahydrate (ErCl ₃ ·6H ₂ O)	5	822	Freon 12 (Cl ₂ CF ₂)	6	204
Erbium gallate (see Trierbium pentagallium dodecaoxide)			Freon 13 (ClCF ₃)	6	210
Trierbium pentagallium dodecaoxide [Er ₃ Ga ₅ O ₁₂ (Garnet)]	5	1440	Freon 20 (see Chloroform)		
Erbium oxide (Er ₂ O ₃)	5	86	Freon 21 (Cl ₂ CHF)	6	212
Erbium sesquioxide (see Erbium oxide)			Freon 22 (ClCHF ₂)	6	218
Erbium trioxide (see Erbium oxide)			Freon 113 (CCl ₂ FCClF ₂)	6	224
Ethane (C ₂ H ₆)	6	174	Freon 114 (CClF ₂ CClF ₂)	6	228
1,2-Ethanediol (see Ethylene glycol)			Gadolinia (see Gadolinium oxide)		
Ethene (see Ethylene)			Gadolinium	4	72
Ethyne (see Acetylene)			Gadolinium trichloride hexahydrate (GdCl ₃ ·6H ₂ O)	5	826
Ethoxyethane (see Ethyl ether)			Gadolinium trinitrate hexahydrate (Gd(NO ₃) ₃ ·6H ₂ O)	5	1142
Ethyl Alcohol (C ₂ H ₅ OH)	6	180	Gadolinium oxide (Gd ₂ O ₃)	5	92
Ethyl ether [(C ₂ H ₅) ₂ O]	6	194	Gadolinium sesquioxide (see Gadolinium oxide)		
Ethyl oxide (see Ethyl ether)			Digadolinium trioxide (see Gadolinium oxide)		
Ethylene (CH ₂ CH ₂)	6	185	Gallium	4	75
			Gallium antimonide (GaSb)	5	300

Material Name	Vol.	Page	Material Name	Vol.	Page
Gallium arsenide (GaAs)	5	307	Graphites (specific types) continued		
Gallium oxide (Ga ₂ O ₃)	5	95	Canadian natural CNG	5	9
Gallium sesquioxide (see Gallium oxide)			Canadian natural boronated CNG-B	5	9
Digallium trioxide (see Gallium oxide)			Ceylon natural graphite		
Gallium phosphide (GaP)	5	520	Graphitized lampblack SA-25	5	9
Gallium telluride (see Digallium tritelluride)			Natural Madagascan	5	9
Digallium tritelluride (Ga ₂ Te ₃)	5	723	Pile H-CS II	5	9
Genetron 11 (see Freon 11)			Pyro	5	9
Genetron 12 (see Freon 12)			Hafnia (see Hafnium dioxide)		
Genetron 13 (see Freon 13)			Hafnium	4	87
Genetron 22 (see Freon 22)			Hafnium + Zirconium	4	356
Genetron 113 (see Freon 113)			Hafnium beryllide (see Dihafnium 21-beryllide)		
Genetron 114 (see Freon 114)			Dihafnium 21-beryllide (Hf ₂ Be ₂₁)	5	313
Germanium	4	79	Hafnium diboride (HfB ₂)	5	341
Germanium tetrahydride (GeH ₄)	5	1033	Hafnium carbide (HfC)	5	420
Germanium oxide (see Germanium dioxide)			Hafnium tetrafluoride (HfF ₄)	5	937
Germanium dioxide (GeO ₂)	5	98	Hafnium nitride (HfN)	5	1081
Germanium silicide, nonstoichiometric (Ge _x Si _y)	5	574	Hafnium dioxide (HfO ₂)	5	101
Glass ceramics (see pyroceram)			Hastelloy B	4	571
Glasses (see individual glass)			Hastelloy C	4	556
Glucinum (see Beryllium)			Hastelloy R-235	4	553
Glucinum sulfate (see Beryllium sulfate)			Haynes stellite, HE 1049	4	526
Glycerin (see Glycerol)			Heavy hydrogen (see Deuterium)		
Glycerol (CH ₂ OHCHOHCH ₂ OH)	6	230	Helium	6	23
Glycol (see Ethylene glycol)			n-Heptane (C ₇ H ₁₆)	6	232
Glycyl alcohol (see Glycerol)			n-Hexane (C ₆ H ₁₄)	6	238
Gold	4	83	High silica glass (SiO ₂ + ΣX _i)	5	1234
Gold + Nickel	4	353	Holmia (see Holmium oxide)		
Graphites (specific types)			Holmium	4	90
Grade 3474 D	5	9	Holmium trichloride hexahydrate (HoCl ₃ ·6H ₂ O)	5	829
Grade 7087	5	9	Holmium oxide (Ho ₂ O ₃)	5	104
Grade ATJ	5	9	Holmium sesquioxide (see Holmium oxide)		
Grade CS	5	9	Diholmium trioxide (see Holmium oxide)		
Grade GBH	5	9	Hydrargyrum (see Mercury)		
Acheson	5	9			

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Hydrogen	6	26	Iron + Chromium, Group I ($25 \leq \text{Cr} < 50$)	4	635
Hydrogen chloride (HCl)	6	72	Iron + Chromium + Manganese, Group I	4	638
Hydrogen iodide (HI)	6	76	Iron + Chromium + Manganese + ΣX_i , Group II ($\text{Cr} < 5.0$)	4	687
Hydrogen sulfide (H_2S)	6	78	Iron + Chromium + Manganese + ΣX_i , Group II ($14 \leq \text{Cr} \leq 27$)	4	690
Inco 713 C	4	550	Iron + Chromium + Nickel + ΣX_i , Group II (15-16 Cr, 4-5 Ni)	4	717
Incoloy	4	726	Iron + Chromium + Nickel + ΣX_i , Group II (17-20 Cr, 8-14 Ni)	4	699
Incoloy 901	4	565	Iron + Chromium + ΣX_i , Group II	4	678
Incoloy alloy 800 (see Incoloy)			Iron + Cobalt + ΣX_i , Group I	4	641
Incoloy alloy 901 (see Incoloy 901)			Iron + Cobalt + ΣX_i (Group I), eutectoid	4	641
Inconel 702 alloy	4	553	Iron + Copper + ΣX_i , Group I	4	644
Inconel alloy	4	553	Iron + Manganese + Carbon, Group I	4	655
Inconel alloy 600 (see Inconel alloy)			Iron + Manganese + Carbon (Group I), eutectoid	4	655
Inconel alloy 702 (see Inconel 702 alloy)			Iron + Manganese + ΣX_i , Group I	4	647
Inconel alloy X-750 (see Inconel X alloy)			Iron + Manganese + ΣX_i , Group I ($10 < \text{Mn} \leq 50$)	4	650
Inconel X alloy	4	553	Iron + Manganese + ΣX_i , Group II	4	723
Indium	4	95	Iron + Nickel, Group II	4	726
Indium + Tin	4	359	Iron + Nickel + Carbon, Group I	4	665
Indium antimonide (InSb)	5	303	Iron + Nickel + Chromium + ΣX_i , Group II	4	729
Indium arsenide (InAs)	5	310	Iron + Nickel + ΣX_i , Group I	4	660
Indium phosphide (InP)	5	523	Iron + Silicon + ΣX_i , Group I	4	668
Diindium sulfide, nonstoichiometric (In_2S_x)	5	668	Iron + Silicon + ΣX_i , Group II	4	732
Inquartation silver	4	208	Iron + Tin, Group I	4	672
Invar	4	660	Iron + Titanium, Group I (TiFe_2)	4	675
Iodide titanium	4	257	Iron + Titanium + ΣX_i , Group II	4	735
Iodide zirconium	4	268	Iron + Tungsten + ΣX_i , Group II	4	738
Iodine	5	15	Iron aluminate (see Iron dialuminum tetraoxide)		
Iridium	4	99	Iron dialuminum tetraoxide (FeAl_2O_4)	5	1443
Iron	4	102	Iron carbide (see Triiron carbide)		
Iron, Armco	4	102	Triiron carbide (Fe_3C)	5	424
Iron, electrolytic	4	102	Iron dichloride (FeCl_2)	5	832
Iron + Aluminum, Group I	4	626	Ironous chloride (see Iron dichloride)		
Iron + Antimony, Group I	4	629			
Iron + Carbon + ΣX_i , Group I	4	619			
Iron + Carbon + ΣX_i , Group II	4	623			
Iron + Chromium, Group I ($8 \leq \text{Cr} < 25$)	4	632			

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Iron chromite (see Iron dichromium tetraoxide)			Iron sulfide (FeS)	5	674
Iron dichromium tetraoxide (FeCr ₂ O ₄)	5	1446	Iron disulfide (FeS ₂)	5	677
Iron cobaltite (see Iron dicobalt tetraoxide)			Iron sulfide, nonstoichiometric (Fe _x S)	5	671
Iron dicobalt tetraoxide (FeCo ₂ O ₄)	5	1449	Iron tellurides:		
Iron difluoride (FeF ₂)	5	940	FeTe ₂	5	729
Iron oxides:			Fe _x Te (nonstoichiometric)	5	726
FeO	5	107	Iron ditelluride (FeTe ₂)	5	729
Fe ₂ O ₃	5	110	Iron telluride, nonstoichiometric (Fe _x Te)	5	726
Fe ₃ O ₄	5	114	Iron titanate (see Iron titanium trioxide)		
Diiron trioxide [see Iron(III) oxide]			Iron titanium trioxide (FeTiO ₃)	5	1455
Triiron tetraoxide (Fe ₃ O ₄)	5	114	Iron vitriol (see Iron sulfate heptahydrate)		
Iron selenides:			Iron(II) oxide (FeO)	5	110
FeS ₂	5	527	Iron(III) oxide (Fe ₂ O ₃)	5	107
Fe ₃ S ₄	5	536	Isotron 11 (see Freon 11)		
Fe ₇ Se ₈	5	533	Isotron 12 (see Freon 12)		
Fe _x Se (nonstoichiometric)	5	530	Isotron 13 (see Freon 13)		
Iron diselenide (FeSe ₂)	5	527	Isotron 22 (see Freon 22)		
Triiron tetraselenide (Fe ₃ Se ₄)	5	536	Isotron 113 (see Freon 113)		
Heptairon octaselenide (Fe ₇ Se ₈)	5	533	Isotron 114 (see Freon 114)		
Iron selenide, nonstoichiometric (Fe _x Se)	5	530	Jodium (see Iodine)		
Iron silicides:			Kallium (see Potassium)		
FeSi	5	577	Krypton	6	34
Fe ₃ Si	5	583	Lanthana (see Lanthanum oxide)		
Fe ₅ Si ₃	5	580	Lanthanum	4	110
Iron silicide (FeSi)	5	577	Lanthanum oxide (La ₂ O ₃)	5	118
Triiron silicide (Fe ₃ Si)	5	583	Lanthanum sesquioxide (see Lanthanum oxide)		
Pentairon trisilicide (Fe ₅ Si ₃)	5	580	Dilanthanum trioxide (see Lanthanum oxide)		
Iron orthosilicate (see Diiron silicon tetraoxide)			Laughing gas (see Nitrous oxide)		
Diiron silicon tetraoxide (Fe ₂ SiO ₄)	5	1452	Lead	4	113
Iron sulfate heptahydrate (FeSO ₄ ·7H ₂ O)	5	1200	Lead + Tin	4	363
Iron sulfides:			Lead - tin solder (Sn + Pb)	4	446
FeS	5	674	Lead glance (see Lead sulfide)		
FeS ₂	5	677	Lead diiodide (PbI ₂)	5	497
Fe _x S (nonstoichiometric)	5	671	Lead molybdate (see Lead molybdenum tetraoxide)		

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Lead molybdenum tetraoxide (PbMoO_4)	5	1458	Lithium fluoride (LiF)	5	943
Lead oxides:			Lithium hexafluoroaluminate (see Trilithium aluminum hexafluoride)		
PbO	5	122	Lithium hydride (LiH)	5	1036
PbO_2	5	125	Lithium monohydrogen difluoride (LiHF_2)	5	953
Pb_2O_3	5	128	Lithium iron dioxide (LiFeO_2)	5	1467
Pb_3O_4	5	131	Lithium iron tetraoxide, nonstoichiometric ($\text{Li}_x\text{Fe}_y\text{O}_4$)	5	1470
Lead oxide (PbO)	5	122	Lithium oxide (Li_2O)	5	134
Lead dioxide (PbO_2)	5	125	Dilithium oxide (see Lithium oxide)		
Lead monoxide (see Lead oxide)			Lithium titanate (see Dilithium titanium trioxide)		
Lead peroxide (see Lead dioxide)			Lithium metatitanate (see Dilithium titanium trioxide)		
Lead protoxide (see Lead oxide)			Dilithium titanium trioxide (Li_2TiO_3)	5	1473
Lead sesquioxide (Pb_2O_3)	5	128	Lithium zinc ferrite [see Lithium zinc iron tetraoxide (nonstoichiometric)]		
Lead superoxide (see Lead dioxide)			Lithium zinc iron tetraoxide, nonstoichiometric ($\text{Li}_x\text{Zn}_y\text{Fe}_z\text{O}_4$)	5	1476
Dilead trioxide (see Lead sesquioxide)			Lutetia (see Lutetium sesquioxide)		
Trilead tetraoxide (Pb_3O_4)	5	131	Lutetium	4	121
Lead sulfide (PbS)	5	681	Lutetium sesquioxide (Lu_2O_3)	5	137
Lead tungstate (see Lead tungsten tetraoxide)			Dilutetium trioxide (see Lutetium sesquioxide)		
Lead tungsten tetraoxide (PbWO_4)	5	1461	Magnesia (see Magnesium oxide)		
Lead wolframate (see Lead tungsten tetraoxide)			Magnesium	4	124
Libbey-Owens-Ford plate glass No. 9330	5	1240	Magnesium + Aluminum + ΣX_i	4	535
Lithia (see Lithium oxide)			Magnesium + Silicon	4	369
Lithium	4	117	Magnesium + Thorium + ΣX_i	4	538
Lithium + Magnesium	4	366	Magnesium + Zinc + ΣX_i	4	541
Lithium aluminate (see Lithium aluminum dioxide)			Magnesium alloys (specific types)		
Lithium metaaluminate (see Lithium aluminum dioxide)			AN-M-29	4	535
Trilithium aluminum hexafluoride (Li_3AlF_6)	5	947	AZ-31B	4	535
Lithium aluminum dioxide (LiAlO_2)	5	1464	AZ-80	4	535
Dilithium beryllium tetrafluoride (Li_2BeF_4)	5	950	HK-31A	4	538
Dilithium carbonate (Li_2CO_3)	5	1118	HM-21XA	4	538
Lithium chloride (LiCl)	5	835	HM-31XA	4	538
Lithium ferrites:			ZK-60A	4	541
LiFeO_2	5	1467			
$\text{Li}_x\text{Fe}_y\text{O}_4$ (nonstoichiometric)	5	1470			

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Magnesium aluminate (see Magnesium dialuminum tetraoxide)			Magnesium germanide (see Dimagnesium germanide)		
Magnesium metaaluminate (see Magnesium dialuminum tetraoxide)			Dimagnesium germanide (Mg_2Ge)	5	481
Magnesium dialuminum tetraoxide (MgAl_2O_4)	5	1479	Magnesium diiron tetraoxide (MgFe_2O_4)	5	1485
Magnesium aluminum silicate (see Dimagnesium tetraaluminum pentasilicon 18-oxide)			Magnesium iron tetraoxide, nonstoichiometric ($\text{Mg}_x\text{Fe}_y\text{O}_4$)	5	1488
Dimagnesium tetraaluminum pentasilicon 18-oxide ($\text{Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$)	5	1503	Magnesium molybdate (see Magnesium molybdenum tetraoxide)		
Magnesium borides:			Magnesium molybdenum tetraoxide (MgMoO_4)	5	1491
MgB_2	5	345	Magnesium nitride (see Trimagnesium dinitride)		
MgB_4	5	348	Trimagnesium dinitride (Mg_3N_2)	5	1084
Magnesium diboride (MgB_2)	5	345	Magnesium oxide (MgO)	5	140
Magnesium tetraboride (MgB_4)	5	348	Magnesium silicates:		
Magnesium cadmium alloys:			MgSiO_3	5	1494
MgCd	4	294	Mg_2SiO_4	5	1497
MgC	4	300	$\text{Mg}_3\text{Si}_4\text{O}_{11} \cdot \text{H}_2\text{O}$	5	1500
Mg_3Cd	4	297	Magnesium silicon trioxide (MgSiO_3)	5	1497
Magnesium chlorides:			Dimagnesium silicon tetraoxide (Mg_2SiO_4)	5	1497
MgCl_2	5	838	Trimagnesium tetrasilicon undecaoxide monohydrate ($\text{Mg}_3\text{Si}_4\text{O}_{11} \cdot \text{H}_2\text{O}$)	5	1500
$\text{MgCl}_2 \cdot \text{H}_2\text{O}$	5	841	Magnesium titanates:		
$\text{MgCl}_2 \cdot 2\text{H}_2\text{O}$	5	844	MgTiO_3	5	1506
$\text{MgCl}_2 \cdot 4\text{H}_2\text{O}$	5	847	MgTi_2O_5	5	1509
$\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$	5	850	Mg_2TiO_4	5	1512
Magnesium dichloride (MgCl_2)	5	838	Magnesium dititanate (see Magnesium dititanium pentaoxide)		
Magnesium dichloride monohydrate ($\text{MgCl}_2 \cdot \text{H}_2\text{O}$)	5	841	Magnesium metatitanate (see Magnesium titanium trioxide)		
Magnesium dichloride dihydrate ($\text{MgCl}_2 \cdot 2\text{H}_2\text{O}$)	5	844	Dimagnesium titanate (see Dimagnesium titanium tetraoxide)		
Magnesium dichloride tetrahydrate ($\text{MgCl}_2 \cdot 4\text{H}_2\text{O}$)	5	847	Magnesium titanium trioxide (MgTiO_3)	5	1506
Magnesium dichloride hexahydrate ($\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$)	5	850	Magnesium dititanium pentaoxide (MgTi_2O_5)	5	1509
Magnesium chromite (see Magnesium dichromium tetraoxide)			Dimagnesium titanium tetraoxide (Mg_2TiO_4)	5	1512
Magnesium dichromium tetraoxide (MgCr_2O_4)	5	1482	Magnesium tungstate (see Magnesium tungsten tetraoxide)		
Magnesium ferrites:			Magnesium tungsten tetraoxide (MgWO_4)	5	1515
MgFe_2O_4	5	1485	Magnesium vanadates:		
$\text{Mg}_x\text{Fe}_y\text{O}_4$	5	1488	MgV_2O_6	5	1518
Magnesium difluoride (MgF_2)	5	956	$\text{Mg}_2\text{V}_2\text{O}_7$	5	1521

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Magnesium metavanadate (see Magnesium divanadium hexaoxide)			Manganese sesquioxide (Mn_2O_3)	5	151
Magnesium pyrovanadate (see Magnesium divanadium hexaoxide)			Dimanganese trioxide (see Manganese sesquioxide)		
Magnesium divanadium hexaoxide (MgV_2O_6)	5	1518	Trimanganese tetraoxide (Mn_3O_4)	5	154
Dimagnesium divanadium heptaoxide ($Mg_2V_2O_7$)	5	1521	Manganese (Ic) oxide (see Manganese sesquioxide)		
Magnesium wolframate (see Magnesium tungsten tetraoxide)			Manganese (ous) chloride (see Manganese dichloride)		
Manganese	4	127	Manganese (ous) fluoride (see Manganese difluoride)		
Manganese, electrolytic	4	127	Manganese (ous) oxide (see Manganese monoxide)		
Manganese + Aluminum	4	372	Manganese (ous) sulfide (see Manganese sulfide)		
Manganese + Copper	4	377	Manganese selenide (see Manganous selenide)		
Manganese + Nickel	4	380	Manganese silicate (see Manganese silicon trioxide)		
Manganese aluminum carbide (see Trimanganese aluminum carbide)			Manganese silicides:		
Trimanganese aluminum carbide (Mn_3AlC)	5	427	Mn_3Si	5	586
Manganese carbide (see Trimanganese carbide)			$MnSi_x$ (nonstoichiometric)	5	589
Trimanganese carbide (Mn_3C)	5	433	Trimanganese silicide (Mn_3Si)	5	586
Manganese carbonate ($MnCO_3$)	5	1121	Manganese silicide, nonstoichiometric ($MnSi_x$)	5	589
Manganese chlorides:			Manganese silicon trioxide ($MnSiO_3$)	5	1524
$MnCl_2$	5	853	Manganese sulfide (MnS)	5	684
$MnCl_2 \cdot 4H_2O$	5	856	Manganese monosulfide (see Manganese sulfide)		
Manganese dichloride ($MnCl_2$)	5	853	Manganese telluride (see Manganous telluride)		
Manganese dichloride tetrahydrate (see Manganous dichloride tetrahydrate)			Manganese zinc carbide (see Trimanganese zinc carbide)		
Manganese difluoride (MnF_2)	5	959	Trimanganese zinc carbide (Mn_3ZnC)	5	430
Manganese oxides:			Manganin	4	338
MnO	5	145	Manganomanganic oxide (see Trimanganese tetraoxide)		
MnO_2	5	148	Manganous dichloride tetrahydrate ($MnCl_2 \cdot 4H_2O$)	5	856
Mn_2O_3	5	151	Manganous selenide ($MnSe$)	5	539
Mn_3O_4	5	154	Manganous telluride ($MnTe$)	5	732
Manganese binoxide (see Manganese dioxide)			Marsh gas (see Methane)		
Manganese dioxide (MnO_2)	5	148	Mercuric oxide [see Mercury (Ic) oxide]		
Manganese monoxide (MnO)	5	145			
Manganese peroxide (see Manganese dioxide)					
Manganese protoxide (see Manganese monoxide)					

Material Name	Vol.	Page	Material Name	Vol.	Page
Mercuric selenide (see Mercury selenide)			Molybdenum silicides:		
Mercury	4	131	MoSi ₂	5	592
Mercury selenide (HgSe)	5	542	Mo ₃ Si	5	595
Dimercury sulfate (Hg ₂ SO ₄)	5	1503	Molybdenum disilicide (MoSi ₂)	5	592
Mercury sulfide (HgS)	5	687	Trimolybdenum silicide (Mo ₃ Si)	5	595
Mercury (ic) oxide (HgO)	5	157	Molybdenum sulfide (see Molybdenum di-sulfide)		
Methane (CH ₄)	6	244	Molybdenum disulfide (MoS ₂)	5	690
Methanol (see Methyl alcohol)			Mond nickel	4	146
Methyl alcohol (CH ₃ OH)	6	252	Monel alloy	4	562
Methyl chloride (CH ₃ Cl)	6	257	Monel alloy 400 (see Monel alloy)		
Methylbenzene (see Toluene)			Monel alloy K-500 (see Monel K alloy)		
Methylmethane (see Ethane)			Monel K alloy	4	562
Molybdenum	4	135	MSM-70 (see Titanium, Ti-75 A)		
Molybdenum + Titanium	4	383	MSM-2.5 Al-16V (see Titanium alloy Ti-2.5Al-16V)		
Molybdenum + Titanium + ΣX_1	4	544	MSM-6Al-4V (see Titanium alloy Ti-6Al-4V)		
Molybdenum + Tungsten	4	386	MSM-8Mn (see Titanium alloy C-110 M)		
Molybdenum beryllide (see Molybdenum dodecaberyllide)			MST-2.5 Al-16V (see Titanium alloy Ti-2.5Al-16V)		
Molybdenum dodecaberyllide (MoBe ₁₂)	5	316	MST-6Al-4V (see Titanium alloy Ti-6Al-4V)		
Molybdenum borides:			MST-8Mn (see Titanium alloy C-110M)		
MoB	5	358	Natrium (see Sodium)		
MoB ₂	5	352	Neodymia (see Neodymium oxide)		
Mo ₂ B	5	355	Neodymium	4	146
Molybdenum boride (MoB)	5	358	Neodymium trichloride hexahydrate (NdCl ₃ ·6H ₂ O)	5	859
Molybdenum diboride (MoB ₂)	5	352	Neodymium gallate (see Trineodymium pentagallium dodecaoxide)		
Dimolybdenum boride (Mo ₂ B)	5	355	Trineodymium pentagallium dodecaoxide [Nd ₃ Ga ₅ O ₁₂ (Garnet)]	5	1527
Molybdenum carbide (see Dimolybdenum carbide)			Neodymium oxide (Nd ₂ O ₃)	5	166
Dimolybdenum carbide (Mo ₂ C)	5	436	Neodymium sesquioxide (see Neodymium oxide)		
Molybdenum hexafluoride (MoF ₆)	5	962	Neon	6	37
Molybdenum oxides:			Neptunium	4	143
MoO ₂	5	160	Neptunium + Calcium + ΣX_1	4	547
MoO ₃	5	163	Neptunium dioxide (NpO ₂)	5	169
Molybdenum dioxide (MoO ₂)	5	160			
Molybdenum trioxide (MoO ₃)	5	163			

Material Name	Vol.	Page	Material Name	Vol.	Page
Nichrome V	4	556	Nickel alloys (specific types) continued		
Nickel	4	146	OKh 20 N60 B	4	559
Nickel, electrolytic	4	146	Rene 41	4	556
Nickel, mond	4	146	Nickel chlorides:		
Nickel + Aluminum	4	389	NiCl ₂	5	863
Nickel + Chromium	4	392	NiCl ₂ ·6H ₂ O	5	866
Nickel + Chromium + ΣX_i ($9 \leq Cr \leq 11$)	4	550	Nickel dichloride (NiCl ₂)	5	863
Nickel + Chromium + ΣX_i ($15 \leq Cr \leq 16$)	4	553	Nickel dichloride hexahydrate (NiCl ₂ ·6H ₂ O)	5	866
Nickel + Chromium + ΣX_i ($18 \leq Cr \leq 20$)	4	556	Nickel ferrites:		
Nickel + Chromium + ΣX_i ($Cr > 20$)	4	559	NiFe ₂ O ₄	5	1530
Nickel + Copper	4	398	Ni _x Fe _y O ₄ (nonstoichiometric)	5	1533
Nickel + Copper + ΣX_i	4	562	Nickel difluoride (NiF ₂)	5	973
Nickel + Iron	4	403	Nickel fluosilicate hexahydrate (A) (NiSiF ₆ ·6H ₂ O)	5	966
Nickel + Iron + ΣX_i	4	565	Nickel fluosilicate hexahydrate (B) (NiSiF ₆ ·6H ₂ O)	5	970
Nickel + Magnesium (MgNi ₂)	4	407	Nickel diiron tetraoxide (NiFe ₂ O ₄)	5	1530
Nickel + Manganese	4	410	Nickel iron tetraoxide, nonstoichiometric (Ni _x Fe _y O ₄)	5	1533
Nickel + Manganese + ΣX_i	4	568	Nickel oxide (NiO)	5	172
Nickel + Molybdenum + ΣX_i	4	571	Nickel monoxide (see Nickel oxide)		
Nickel + Silicon	4	413	Nickel protoxide (see Nickel oxide)		
Nickel + Tungsten (Ni ₄ W)	4	416	Nickel selenides:		
Nickel + Zinc	4	419	NiSe ₂	5	549
Nickel alloys (specific types):			Ni _x Se (nonstoichiometric)	5	545
60Ni 15Cr (ASTM B83-46)	4	565	Nickel diselenide (NiSe ₂)	5	549
80 Ni 20Cr	4	556	Nickel selenide, nonstoichiometric (Ni _x Se)	5	545
90 Ni 10Cr	4	550	Nickel sulfate hexahydrate (NiSO ₄ ·6H ₂ O)	5	1206
Alumel	4	568	Nickel sulfides:		
Chromel A (see Nickel alloy Nichrome V)			NiS	5	693
Chromel-P	4	392	Ni ₃ S ₂	5	696
EI-435	4	559	Nickel sulfide (NiS)	5	693
GE J 1500 (same as M252)			Trinickel disulfide (Ni ₃ S ₂)	5	696
GEJ 1610 (same as Rene 41)			Nickel tellurides:		
M252	4	556	NiTe ₂	5	738
Monel	4	562	NiTe _x (nonstoichiometric)	5	735
Nichrome V	4	556	Nickel ditelluride (NiTe ₂)	5	738
OKh 21 N78 T	4	559			

Material Name	Vol.	Page	Material Name	Vol.	Page
Nickel telluride, nonstoichiometric (NiTe_x)	5	735	Niobium pentafluoride (NbF_5)	5	976
Nickel zinc ferrite [see Nickel zinc diiron tetraoxide (nonstoichiometric)]			Niobium oxides:		
Nickel zinc diiron tetraoxide [$\text{Ni}_x\text{Zn}_y\text{Fe}_2\text{O}_4$ (nonstoichiometric)]	5	1536	NbO	5	175
Nickel (ous)oxide (see Nickel oxide)			NbO_2	5	178
Niobium	4	153	Nb_2O_5	5	181
Niobium + Iron + ΣX_i	4	574	Niobium monoxide (NbO)	5	175
Niobium + Molybdenum + ΣX_i	4	577	Niobium dioxide (NbO_2)	5	178
Niobium + Tantalum + ΣX_i	4	580	Diniobium pentaoxide (Nb_2O_5)	5	181
Niobium + Titanium + ΣX_i	4	583	Nitric oxide (NO)	6	83
Niobium + Tungsten + ΣX_i	4	586	Nitrogen	6	39
Niobium + Zirconium	4	422	Nitrogen peroxide (NO_2)	6	90
Niobium alloys (specific types)			Nitrous oxide (N_2O)	6	92
5 Mo-5 V-1 Zr	4	577	n-Nonane (C_9H_{20})	6	261
27 Ta-12 W-0.5 Zr	4	580	n-Octane (C_8H_{18})	6	266
10 Ti-5 Zr	4	583	OFHC copper	4	51
15 W-5 Mo-1 Zr-0.05 C	4	586	Olefiant gas (see Ethylene)		
10 W-5 Zr	4	586	Osmium	4	157
10 W-1 Zr-0.1 C	4	586	Oxygen	6	48
CB-752	4	586	Palladium	4	160
D-36 (see Niobium alloy 10 W-5 Zr)			Palladium + Silver	4	425
F-48	4	586	Palladium tellurides:		
Ferroniobium	4	574	PdTe	5	741
FS-82 B	4	580	PdTe_2	5	744
Niobium dodecaberyllide (NbBe_{12})	5	319	Palladium telluride (PdTe)	5	741
Niobium borides:			Palladium ditelluride (PdTe_2)	5	744
NbB_2	5	365	Pearlite	4	655
NbB_x (nonstoichiometric)	5	361	n-Pentane (C_5H_{12})	6	272
Niobium diboride (NbB_2)	5	365	Perchloromethane (see Carbon tetrachloride)		
Niobium boride, nonstoichiometric (NbB_x)	5	361	Phenylmethane (see Toluene)		18
Niobium carbides:			Phosphorus	5	18
NbC	5	442	Phosphorus, black	5	18
NbC_x (nonstoichiometric)	5	439	Phosphorus trichloride (PCl_3)	5	869
Niobium carbide (NbC)	5	442	Phosphorus (ous) chloride (see Phosphorus trichloride)		
Niobium carbide, nonstoichiometric (NbC_x)	5	439	Pittsburgh No. 3235 glass	5	1236

Material Name	Vol.	Page	Material Name	Vol.	Page
Plate glass No. 9330	5	1240	Potassium nitrate (KNO_3)	5	1145
Platinum	4	163	Potassium dioxide (see Potassium superoxide)		
Platinum sulfides:			Potassium superoxide (KO_2)	5	184
PtS	5	699	Dipotassium sulfate (K_2SO_4)	5	1209
PtS ₂	5	702	Praseodymium	4	177
Platinum sulfide (PtS)	5	699	Praseodymium oxide (see Hexapraseodymium undecaoxide)		
Platinum disulfide (PtS ₂)	5	702	Hexapraseodymium undecaoxide (Pr_6O_{11})	5	187
Platinum tellurides:			Propane (C_3H_8)	6	279
PtTe	5	747	2-Propanone (see Acetone)		
PtTe ₂	5	750	Pyrex 774	5	1230
Platinum telluride (PtTe)	5	747	Pyrex glasses	5	1230
Platinum ditelluride (PtTe ₂)	5	750	Pyroacetic ether (see Acetone)		
Plutonium	4	167	Pyroceram	5	1237
Plutonium + Cerium + ΣX_1	4	589	Pyroceram 9606	5	1237
Plutonium carbide (PuC)	5	445	Pyroceram 9608	5	1237
Plutonium dioxide (PuO ₂)	5	190	Quartz	5	207
Potassium	4	171	Quartz crystal	5	207
Potassium + Sodium	4	428	Quartz glass	5	202
Potassium aluminum silicates:			Quick silver (see Mercury)		
$\text{KAl}_3\text{Si}_3\text{O}_{11}$	5	1540	RC-70 (see Titanium, Ti-75 A)		
$\text{KAl}_3\text{Si}_3\text{O}_{11} \cdot \text{H}_2\text{O}$	5	1543	Rene 41	4	556
Potassium trialuminum trisilicon undecaoxide ($\text{KAl}_3\text{Si}_3\text{O}_{11}$)	5	1540	Rhenium	4	181
Potassium trialuminum trisilicon undecaoxide monohydrate ($\text{KAl}_3\text{Si}_3\text{O}_{11} \cdot \text{H}_2\text{O}$)	5	1543	Rhenium trichloride (ReCl_3)	5	878
Potassium aluminum sulfates:			Rhodium	4	184
$\text{KAl}(\text{SO}_4)_2$	5	1212	RS-70 (see Titanium, Ti-75 A)		
$\text{KAl}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$	5	1215	Rubidium	4	187
Potassium aluminum disulfate [$\text{KAl}(\text{SO}_4)_2$]	5	1212	Rubidium bromide (RbBr)	5	769
Potassium aluminum disulfate dodecahydrate [$\text{KAl}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$]	5	1215	Rubidium fluoride (RbF)	5	985
Potassium bromide (KBr)	5	765	Rubidium monohydrogen difluoride (RbHF_2)	5	988
Dipotassium carbonate (K_2CO_3)	5	1124	Rubidium iodide (RbI)	5	503
Potassium chloride (KCl)	5	872	Ruthenium	4	190
Potassium fluoride (KF)	5	979	Rutile (see Titanium dioxide)		
Potassium hydrogen difluoride (KHF_2)	5	982	SAE 1010	4	647
Potassium iodide (KI)	5	500	Samaria (see Samarium oxide)		

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Samarium	4	193	Silver selenides:		
Samarium oxide (Sm_2O_3)	5	193	Ag_2Se	5	553
Samarium sesquioxide (see Samarium oxide)			Ag_xSe (nonstoichiometric)	5	556
Disamarium trioxide (see Samarium oxide)			Disilver selenide (Ag_2Se)	5	553
Scandia (see Scandium oxide)			Silver selenide, nonstoichiometric (Ag_xSe)	5	556
Scandium	4	198	Silver sulfide, nonstoichiometric (Ag_xS)	5	705
Scandium oxide (Sc_2O_3)	5	196	Silver tellurides:		
Scandium sesquioxide (see Scandium oxide)			Ag_2Te	5	753
Discandium trioxide (see Scandium oxide)			Ag_xTe (nonstoichiometric)	5	756
Selenium	4	201	Disilver telluride (Ag_2Te)	5	753
Silica (see Silicon dioxide)			Silver telluride, nonstoichiometric (Ag_xTe)	5	756
Silica glass	5	202	Soda lime glass ($\text{SiO}_2 + \text{Na}_2\text{O} + \Sigma\text{X}_i$)	5	1240
Silicon	4	204	Soda-lime silica plate glass (see Soda lime glass)		
Silicon carbide (SiC)	5	448	Sodium	4	213
Silicon carbide + Carbon + ΣX_i , cermet ($\text{SiC} + \text{C} + \Sigma\text{X}_i$)	5	1279	Sodium, electrolytic	4	213
Silicon tetrachloride (SiCl_4)	5	881	Sodium + Potassium (Na_2K)	4	431
Silicon tetrafluoride (SiF_4)	5	991	Trisodium aluminum hexafluoride (Na_3AlF_6)	5	997
Silicon nitride from Si_3N_4	5	1087	Sodium aluminate (see Sodium aluminum dioxide)		
Silicon dioxide [SiO_2 (cristobalite)]	5	210	Sodium metaaluminate (see Sodium aluminum dioxide)		
Silicon dioxide [SiO_2 (Quartz crystal)]	5	207	Sodium aluminum dioxide (NaAlO_2)	5	1549
Silicon dioxide [SiO_2 (Quartz glass)]	5	202	Sodium aluminum silicate (see Sodium aluminum trisilicon octaoxide)		
Silicon dioxide [SiO_2 (Tridymite)]	5	213	Sodium aluminum trisilicon octaoxide ($\text{NaAlSi}_3\text{O}_8$)	5	1602
Silicon dioxide + Dialuminum trioxide + ΣX_i ($\text{SiO}_2 + \text{Al}_2\text{O}_3 + \Sigma\text{X}_i$)	5	1546	Sodium tetraborate (see Disodium tetra-boron heptaoxide)		
Sillimanite (see Dialuminum silicon penta-oxide)			Sodium borates:		
Silver	4	208	NaBO_2	5	1552
Silver, electrolytic	4	208	$\text{Na}_2\text{B}_4\text{O}_7$	5	1556
Silver, inquantation	4	208	Sodium boron dioxide (NaBO_2)	5	1552
Disilver carbonate (Ag_2CO_3)	5	1127	Disodium tetraboron heptaoxide ($\text{Na}_2\text{B}_4\text{O}_7$)	5	1556
Silver chloride (AgCl)	5	884	Sodium bromide (NaBr)	5	772
Silver nitrite (AgNO_2)	5	1148	Disodium carbonate (Na_2CO_3)	5	1130
Silver oxide (Ag_2O)	5	199	Sodium bicarbonate (NaHCO_3)	5	1133
Disilver oxide (see Silver oxide)			Sodium chloride (NaCl)	5	887

Material Name	Vol.	Page	Material Name	Vol.	Page
Sodium ferrite (see Sodium iron dioxide)			Sodium sulfates:		
Sodium fluoride (NaF)	5	994	Na_2SO_4	5	1218
Sodium hydrogen carbonate (see Sodium bicarbonate)			$\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$	5	1221
Sodium hexafluoroaluminate (see Trisodium aluminum hexafluoride)			Disodium sulfate (Na_2SO_4)	5	1218
Sodium monohydrogen difluoride (NaHF_2)	5	1000	Disodium sulfate decahydrate ($\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$)	5	1221
Sodium iodide (NaI)	5	506	Sodium tellurate (see Disodium tellurium tetraoxide)		
Sodium iron dioxide (N_2FeO_2)	5	1560	Disodium tellurium tetraoxide (Na_2TeO_4)	5	1575
Sodium molybdates:			Sodium titanates:		
Na_2MoO_4	5	1563	Na_2TiO_3	5	1578
$\text{Na}_2\text{Mo}_2\text{O}_7$	5	1566	$\text{Na}_2\text{Ti}_2\text{O}_5$	5	1581
Disodium molybdenum tetraoxide (Na_2MoO_4)	5	1563	$\text{Na}_2\text{Ti}_3\text{O}_7$	5	1584
Disodium dimolybdenum heptaoxide ($\text{Na}_2\text{Mo}_2\text{O}_7$)	5	1566	Sodium dititanate (see Disodium dititanium pentaoxide)		
Sodium nitrate (NaNO_3)	5	1151	Sodium metatitanate (see Disodium titanium trioxide)		
Sodium oxides:			Sodium trititanate (see Disodium trititanium heptaoxide)		
Na_2O	5	216	Disodium titanium trioxide (Na_2TiO_3)	5	1578
NaO_2	5	222	Disodium dititanium pentaoxide ($\text{Na}_2\text{Ti}_2\text{O}_5$)	5	1581
Na_2O_2	5	219	Disodium trititanium heptaoxide ($\text{Na}_2\text{Ti}_3\text{O}_7$)	5	1584
Sodium oxide (Na_2O)	5	216	Sodium tungstates:		
Sodium superoxide (NaO_2)	5	222	Na_2WO_4	5	1587
Sodium peroxide (Na_2O_2)	5	219	$\text{Na}_2\text{W}_2\text{O}_7$	5	1590
Sodium dioxide (see Sodium superoxide)			Disodium tungsten tetraoxide (Na_2WO_4)	5	1587
Disodium oxide (see Sodium oxide)			Disodium ditungsten heptaoxide ($\text{Na}_2\text{W}_2\text{O}_7$)	5	1590
Disodium monoxide (see Sodium oxide)			Sodium vanadates:		
Sodium silicates:			NaVO_3	5	1593
Na_2SiO_3	5	1569	Na_3VO_4	5	1596
$\text{Na}_2\text{Si}_2\text{O}_5$	5	1572	$\text{Na}_4\text{V}_2\text{O}_7$	5	1599
Sodium disilicate (see Disodium disilicon pentaoxide)			Sodium metavanadate (see Sodium vanadium trioxide)		
Sodium metasilicate (see Disodium silicon trioxide)			Sodium orthovanadate (see Trisodium vanadium tetraoxide)		
Sodium silicate glass No. 23	5	1240	Sodium pyrovanadate (see Tetrasodium divanadium heptaoxide)		
Disodium silicon trioxide (Na_2SiO_3)	5	1569	Sodium vanadium trioxide (NaVO_3)	5	1593
Disodium disilicon pentaoxide ($\text{Na}_2\text{Si}_2\text{O}_5$)	5	1572	Trisodium vanadium tetraoxide (Na_3VO_4)	5	1596

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Tetrasodium divanadium heptaoxide ($\text{Na}_4\text{V}_2\text{O}_7$)	5	1599	Steels (specific types) continued		
Solex 2808 plate glass	5	1240	Steel 19	4	687
Solex S plate glass	5	1240	Stellite HE 1049	4	526
Stainless steels (specific types)			T-261	4	655
1 KH 18 N9T	4	699	T-262	4	655
17-4 PH	4	717	T-270	4	655
17-7 PH	4	696	T-278	4	655
AISI 301	4	693	T-279	4	655
AISI 304	4	699	T-310	4	655
AISI 305	4	702	T-311	4	655
AISI 310	4	705	Stibium (see Antimony)		
AISI 316	4	708	Strontia (see Strontium oxide)		
AISI 347	4	711	Strontium	4	218
AISI 420	4	678	Strontium bromide (SrBr)	5	775
AISI 430	4	681	Strontium carbonate (SrCO_3)	5	1136
AISI 446	4	684	Strontium chloride (see Strontium dichloride)		
AM 355	4	717	Strontium dichloride (SrCl_2)	5	890
Austenite	4	655	Strontium difluoride (SrF_2)	5	1003
EI 257	4	720	Strontium nitrate ($\text{Sr}(\text{NO}_3)_2$)	5	1154
EI 855	4	726	Strontium oxide (SrO)	5	225
HMN Crucible	4	714	Strontium silicates:		
Stannia (see Tin dioxide)			SrSiO_3	5	1605
Stannic oxide (see Tin dioxide)			Sr_2SiO_4	5	1608
Stannous oxide (see Tin monoxide)			Strontium silicon trioxide (SrSiO_3)	5	1605
Steel, austenite	4	655	Distrontium silicon tetraoxide (Sr_2SiO_4)	5	1608
Steel, eutectoid	4	655	Strontium sulfides:		
Steel, pearlite	4	655	SrS	5	708
Steels (specific types)			SrS_2	5	711
4 Kh 13	4	690	Strontium sulfide (SrS)	5	708
Mark 1 X 18 N9T	4	699	Strontium disulfide (SrS_2)	5	711
Mark 12 MX	4	723	Strontium titanates:		
Mild steel	4	647	SrTiO_3	5	1611
OKh 16N 36V 3T	4	726	Sr_2TiO_4	5	1614
Stainless steels (see separate entries under stainless steels)			Strontium metatitanate (see Strontium titanium trioxide)		

Material Name	Vol.	Page	Material Name	Vol.	Page
Strontium orthotitanate (see Distrontium titanium tetraoxide)			Tellurium dioxide (TeO_2)	5	231
Strontium titanium trioxide (SrTiO_3)	5	1611	Terbium	4	232
Distrontium titanium tetraoxide (Sr_2TiO_4)	5	1614	Tetrachloromethane (see Carbon tetrachloride)		
Strontium zirconate (see Strontium zirconium trioxide)			Thallium	4	237
Strontium zirconium trioxide (SrZrO_3)	5	1617	Thallium + Lead (PbTl_2)	4	437
Sulfur	5	21	Thallium monohydrogen difluoride (TlHF_2)	5	1006
Sulfur dioxide (SO_2)	6	97	Thallium nitrate (TlNO_3)	5	1157
Sulfuretted hydrogen (see Hydrogen sulfide)			Thoria (see Thorium dioxide)		
Sulfuric ether (see Ethyl ether)			Thorium	4	242
Tantalum	4	221	Thorium tetraboride (ThB_4)	5	375
Tantalum + Niobium + ΣX_1	4	592	Thorium carbide, nonstoichiometric (ThC_x)	5	454
Tantalum + Tungsten	4	434	Thorium tetrafluoride (ThF_4)	5	1009
Tantalum + Tungsten + ΣX_1	4	595	Thorium dioxide (ThO_2)	5	234
Tantalum alloys (specific types)			Thulium	4	245
30 Nb - 7.5 V	4	592	Tin	4	249
8 W - 2 Hf	4	595	Tin, grey	4	249
Tantalum beryllides:			Tin, white	4	249
TaBe_{12}	5	322	Tin + Bismuth	4	440
$\text{Ta}_2\text{Be}_{17}$	5	325	Tin + Indium	4	443
Tantalum dodecaberyllide (TaBe_{12})	5	322	Tin + Lead	4	446
Ditantalum 17-beryllide ($\text{Ta}_2\text{Be}_{17}$)	5	325	Tin + Magnesium (Mg_2Sn)	4	449
Tantalum borides:			Tin oxides:		
TaB	5	372	SnO	5	237
TaB_2	5	368	SnO_2	5	240
Tantalum boride (TaB)	5	372	Tin monoxide (SnO)	5	237
Tantalum diboride (TaB_2)	5	368	Tin dioxide (SnO_2)	5	240
Tantalum carbide (TaC)	5	451	Titania (see Titanium dioxide)		
Ditantalum hydride (Ta_2H)	5	1040	Titanium	4	257
Tantalum nitride (TaN)	5	1090	Titanium, Ti-75 A	4	257
Ditantalum pentaoxide (Ta_2O_5)	5	228	Titanium + Aluminum + ΣX_1	4	598
Tantalum disilicide (TaSi_2)	5	598	Titanium + Chromium + ΣX_1	4	601
Telluric acid anhydride (see Tellurium dioxide)			Titanium + Iron + Cobalt	4	604
Tellurite (see Tellurium dioxide)			Titanium + Manganese	4	453
Tellurium	4	229	Titanium + Molybdenum	4	456
			Titanium + Vanadium + ΣX_1	4	607

Material Name	Vol.	Page	Material Name	Vol.	Page
Titanium alloys (specific types)			Titanium hydrides - continued		
AMS 4928 (same as Ti-6Al-4V)	4	598	TiH _x (nonstoichiometric)	5	1044
C-110 M	4	543	Titanium dihydride (TiH ₂)	5	1047
C-120 AV (same as Ti-6Al-4V)	4	598	Titanium hydride, nonstoichiometric (TiH _x)	5	1044
M-6	4	456	Titanium tetraiodide (TiI ₄)	5	510
M-8	4	456	Titanium nitride (TiN)	5	1093
M-9	4	456	Titanium oxides:		
M-10	4	456	TiO	5	243
MSM-2.5Al-16V (same as Ti-2.5Al-16V)	4	607	TiO ₂	5	246
MSM-6Al-4V (same as Ti-6Al-4V)	4	598	Ti ₂ O ₃	5	250
MSM-8Mn (same as C-110M)	4	543	Ti ₃ O ₅	5	256
MST-2.5Al-16V (same as Ti-2.5Al-16V)	4	607	Titanium monoxide (TiO)	5	243
MST-6Al-4V (same as Ti-6Al-4V)	4	598	Titanium dioxide (TiO ₂)	5	246
MST-8Mn (same as C-110M)	4	543	Titanium sesquioxide (Ti ₂ O ₃)	5	250
RC-130 A (same as C-110M)	4	543	Trititanium pentaoxide (Ti ₃ O ₅)	5	253
RS-110 A (same as C-110M)	4	543	Titanium silicides:		
Ti-4Al-3Mo-1V	4	598	TiSi	5	601
Ti-2.5Al-16V	4	607	TiSi ₂	5	604
Ti-6Al-4V	4	598	Ti ₅ Si ₃	5	607
Ti-8Mn (same as C-110M)	4	543	Titanium silicide (TiSi)	5	601
Ti-13V-11Cr-3Al	4	607	Titanium disilicide (TiSi ₂)	5	604
Titanium beryllide (see Titanium dodecaber- beryllide)			Pentatitanium trisilicide (Ti ₅ Si ₃)	5	607
Titanium dodecaber-beryllide (TiBe ₁₂)	5	328	Toluene (C ₆ H ₅ CH ₃)	6	285
Titanium diboride (TiB ₂)	5	378	Trichlorofluoromethane (see Freon 11)		
Titanium bromides:			Trichloromethane (see Chloroform)		
TiBr ₃	5	778	Trichlorotrifluoroethane (see Freon 113)		
TiBr ₄	5	781	Tridymite [see Silicon dioxide (tridymite)]		
Titanium tribromide (TiBr ₃)	5	778	Tungsten	4	263
Titanium tetrabromide (TiBr ₄)	5	781	Tungsten + Cobalt (Co ₇ W ₆)	4	459
Titanium carbide (TiC)	5	457	Tungsten + Iron (Fe ₇ W ₆)	4	462
Titanium trichloride (TiCl ₃)	5	893	Tungsten borides:		
Titanium tetrafluoride (TiF ₄)	5	1012	WB	5	382
Titanium hydrides:			W ₂ B	5	385
TiH ₂	5	1047	W ₂ B ₅	5	388
			Tungsten boride (WB)	5	382

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Ditungsten boride (W_2B)	5	385	Uranium nitride (UN)	5	1096
Ditungsten pentaboride (W_2B_5)	5	388	Uranium nitride, nonstoichiometric (UN_x)	5	1099
Tungsten carbide (WC)	5	460	Uranium oxides:		
Tungsten carbide + Cobalt, cermet (WC + Co)	5	1282	UO_2	5	259
Tungsten trioxide (WO_3)	5	256	UO_3	5	262
Tungsten disilicide (WSi_2)	5	610	U_3O_8	5	265
Tungstic acid anhydride (see Tungsten trioxide)			U_4O_9	5	269
Uranic chloride (see Uranium tetrachloride)			Uranium dioxide (UO_2)	5	259
Uranic iodide (see Uranium tetraiodide)			Uranium trioxide (UO_3)	5	262
Uranic oxide (see Uranium dioxide)			Triuranium octaoxide (U_3O_8)	5	265
Uranium	4	268	Tetrauranium enneaoxide (see Tetrauranium nonaoxide)		
Uranium carbides:			Tetrauranium nonaoxide (U_4O_9)	5	269
UC	5	463	Uranium silicides:		
UC_2	5	466	USi_2	5	619
U_2C_3	5	472	USi_3	5	616
UC_x (nonstoichiometric)	5	469	U_3Si	5	613
Uranium carbide (UC)	5	463	$U_3Si_2 + U_3Si$	5	622
Uranium dicarbide (UC_2)	5	466	Uranium disilicide (USi_2)	5	619
Diuranium tricarbide (U_2C_3)	5	472	Uranium trisilicide (USi_3)	5	616
Uranium carbide, nonstoichiometric (UC_x)	5	469	Triuranium silicide (U_3Si)	5	613
Uranium chlorides:			Triuranium disilicide + Triuranium monosilicide ($U_3Si_2 + U_3Si$)	5	622
UCl_3	5	896	Uranous uranic oxide (see Triuranium octaoxide)		
UCl_4	5	899	Uranyl oxide (see Uranium trioxide)		
Uranium trichloride (UCl_3)	5	896	Uranyl uranate (see Triuranium octaoxide)		
Uranium tetrachloride (UCl_4)	5	899	Vanadic anhydride (see Divanadium pentaoxide)		
Uranium fluorides:			Vanadium	4	271
UF_4	5	1015	Vanadium + Aluminum	4	465
UF_6	5	1018	Vanadium + Antimony	4	468
Uranium tetrafluoride (UF_4)	5	1015	Vanadium + Iron	4	471
Uranium hexafluoride (UF_6)	5	1018	Vanadium + Tin	4	474
Uranium trihydride (UH_3)	5	1050	Vanadium + Titanium	4	477
Uranium tetraiodide (UI_4)	5	513	Vanadium carbide (VC)	5	475
Uranium nitrides:					
UN	5	1096			
UN_x (nonstoichiometric)	5	1099			

Material Name	Vol.	Page	Material Name	Vol.	Page
Vanadium chlorides:			Triytterbium pentagallium dodecaoxide [Yb ₃ Ga ₅ O ₁₂ (Garnet)]	5	1620
VCl ₂	5	902	Ytterbium oxide (Yb ₂ O ₃)	5	284
VCl ₃	5	905	Ytterbium sesquioxide (see Ytterbium oxide)		
Vanadium dichloride (VCl ₂)	5	902	Diytterbium trioxide (see Ytterbium oxide)		
Vanadium trichloride (VCl ₃)	5	905	Yttria (see Yttrium oxide)		
Vanadium trifluoride (VF ₃)	5	1021	Yttrium	4	278
Vanadium hydride, nonstoichiometric (VH _x)	5	1053	Yttrium deuterides:		
Vanadium nitride (VN)	5	1103	YD ₂	5	1062
Vanadium oxides:			YD ₃	5	1066
VO	5	272	Yttrium dideuteride (YD ₂)	5	1062
V ₂ O ₃	5	275	Yttrium trideuteride (YD ₃)	5	1066
V ₂ O ₄	5	278	Yttrium gallate (see Triyttrium pentagallium dodecaoxide)		
V ₂ O ₅	5	281	Triyttrium pentagallium dodecaoxide [Y ₃ Ga ₅ O ₁₂ (Garnet)]	5	1623
Vanadium monoxide (VO)	5	272	Yttrium hydrides:		
Vanadium sesquioxide (V ₂ O ₃)	5	275	YH ₂	5	1056
Divanadium tetraoxide (V ₂ O ₄)	5	278	YH ₃	5	1059
Divanadium pentaoxide (V ₂ O ₅)	5	281	Yttrium dihydride (YH ₂)	5	1056
Vanadium silicides:			Yttrium trihydride (YH ₃)	5	1059
VSi ₂	5	628	Yttrium oxide (Y ₂ O ₃)	5	287
V ₃ Si	5	625	Yttrium sesquioxide (see Yttrium oxide)		
V ₅ Si ₃	5	631	Diyttrium trioxide (see Yttrium oxide)		
Vanadium disilicide (VSi ₂)	5	628	Zinc	4	281
Trivanadium silicide (V ₃ Si)	5	625	Zinc + Copper	4	480
Pentavanadium trisilicide (V ₅ Si ₃)	5	631	Zinc + Magnesium (MgZn ₂)	4	483
Vycor 7900	5	1324	Zinc + Zirconium (ZrZn ₂)	4	486
Vycor glasses	5	1234	Zinc dichloride (ZnCl ₂)	5	908
Water (H ₂ O)	6	102	Zinc ferrite (see Zinc diiron tetraoxide)		
Wolfram (see Tungsten)			Zinc difluoride (ZnF ₂)	5	1027
X-metal (see Uranium)			Zinc diiron tetraoxide (ZnFe ₂ O ₄)	5	1626
Xenon	6	57	Zinc oxide (ZnO)	5	290
Xenon tetrafluoride (XeF ₄)	5	1024	Zinc orthosilicate (see Dizinc silicon tetra- oxide)		
Ytterbia (see Ytterbium oxide)			Dizinc silicon tetraoxide (Zn ₂ SiO ₄)	5	1629
Ytterbium	4	274	Zinc sulfate heptahydrate (ZnSO ₄ ·7H ₂ O)	5	1224
Ytterbium gallate (see Triytterbium penta- gallium dodecaoxide)					

Material Name	Vol.	Page	Material Name	Vol.	Page
Zinc sulfide (ZnS)	5	714	Zirconium silicon tetraoxide (ZrSiO ₄)	5	16:5
Zinc orthotitanate (see Dizinc titanium tetraoxide)			ZT-15-M	5	1285
Dizinc titanium tetraoxide (Zn ₂ TiO ₄)	5	1632			
Zircaloy 2	4	501			
Zircon (see Zirconium silicon tetraoxide)					
Zirconia (see Zirconium dioxide)					
Zirconium	4	287			
Zirconium + Hafnium + ΣX_i	4	613			
Zirconium + Indium	4	489			
Zirconium + Iron (ZrFe ₂)	4	492			
Zirconium + Iron + ΣX_i	4	610			
Zirconium + Niobium	4	495			
Zirconium + Silver	4	498			
Zirconium + Tin	4	501			
Zirconium + Titanium	4	504			
Zirconium + Uranium	4	507			
Zirconium + Uranium + ΣX_i	4	616			
Zirconium beryllide (see Zirconium 13-beryllide)					
Zirconium 13-beryllide (ZrBe ₁₃)	5	331			
Zirconium diboride (ZrB ₂)	5	391			
Zirconium carbide (ZrC)	5	478			
Zirconium tetrachloride (ZrCl ₄)	5	911			
Zirconium tetrafluoride (ZrF ₄)	5	1030			
Zirconium hydrides:					
ZrH ₂	5	1072			
ZrH _x (nonstoichiometric)	5	1069			
Zirconium dihydride (ZrH ₂)	5	1072			
Zirconium hydride, nonstoichiometric (ZrH _x)	5	1069			
Zirconium nitride (ZrN)	5	1106			
Zirconium dioxide (ZrO ₂)	5	293			
Zirconium dioxide + Titanium, cermet (ZrO ₂ + Ti)	5	1285			
Zirconium orthosilicate (see Zirconium silicon tetraoxide)					

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