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INVENTORY

The TPRC Data Series. Volume 6

DOCUMENT IDENTIFICATION

1970

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DIST	AVAIL AND/OR SPECIAL	
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DOCUMENT PROCESSING SHEET

THERMOPHYSICAL PROPERTIES OF MATTER
The TPRC Data Series
VOLUME 6

SPECIFIC HEAT
Nonmetallic Liquids and Gases

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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.

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Thermophysical Properties of Matter-The TPRC Data Series--Vol 6. Specific Heat-Nonmetallic Liquids and Gases		5. TYPE OF REPORT & PERIOD COVERED Data Book (see block 18)
		6. PERFORMING ORG. REPORT NUMBER TPRC Data Series/Vol. 6
7. AUTHOR(s) Touloukian, Y.S. and Makita, T.		8. CONTRACT OR GRANT NUMBER(s) F33615-68-C-1229
9. PERFORMING ORGANIZATION NAME AND ADDRESS CINDAS/Purdue University 2595 Yeager Road West Lafayette,IN 47906		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Logistics Agency DTIC-AI/Cameron Station Alexandria, VA 22314		12. REPORT DATE 1970
		13. NUMBER OF PAGES 383
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Army Materials & Mechanics Research Center Attn: DRXMR-P/Arsenal Street Watertown, MA 02172		15. SECURITY CLASS. (of this report) Unclasified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES TEPIAC Publication (DTIC Source Code 413571) Limited hard copies on Data Book available from publisher; Plenum Publishing Corp., 227 W. 17th St., New York, NY 10011

Price: $50/copy   Microfiche copy available from DTIC.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

*Specific heat--*thermophysical properties--*nonmetallics--*liquids--*fluids--*gases--air--acids--acetone--acetylene--alcohol--argon--benzene--benzyl compounds--

(continue on reverse side)

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

The TPRC Data Series published in 13 volumes plus a Master Index volume constitutes a permanent and valuable contribution to science and technology. This 17,000 page Data Series should form a necessary acquisition to all scientific and technological libraries and laboratories. These volumes contain an enormous amount of data and information for thermophysical properties on more than 5,000 different materials of interest to researchers in government laboratories and the defense industrial establishment.

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DD FORM 1 JAN 73 1473   EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

19. KEYWORDS (cont)

inorganic compounds--organic compounds--bromides--chlorides--nitrides--iodiodes--butanol--butylene--carbon oxides--carbon sulfides--deuterium--ethane--ethylene--ethylene compounds--ethyl compounds--fluorine--freon compounds--glycerin--glycol--hydrogen-helium--helium mixtures--hydrogen oxides--oxygen--pentanol--pentane--phenyl compounds--phosgene--propene--propanol--propyl compounds--propylene compounds--

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20. ABSTRACT (cont)

Volume 6. 'Specific Heat - Nonmetallic Liquids and Gases, 'Touloukian, Y. S. and Makita, T., 383 pp., 1970.

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 $50.00 ($60.00 outside US)

THERMOPHYSICAL PROPERTIES OF MATTER
VOLUME 6

SPECIFIC HEAT

Nonmetallic Liquids and Gases

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IFI/PLENUM • NEW YORK-WASHINGTON • 1970

Library of Congress Catalog Card Number 73-129616

SBN (13-Volume Set) 306-67020-8

SBN (Volume 6) 306-67026-7

IFI/Plenum Data Corporation is a subsidiary of
Plenum Publishing Corporation
227 West 17th Street, New York, N.Y. 10011

Distributed in Europe by Heyden & Son, Ltd.
Spectrum House, Alderton Crescent
London N.W. 4, England

Printed in the United States of America

"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

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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″ × 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 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

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*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.

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 — Y. S. Toulоukian
July 1969 — T. Makita

Contents

Theory, Estimation, and Measurement

Numerical Data

Material Index

GROUPING OF MATERIALS AND LIST OF FIGURES AND TABLES

1. ELEMENTS

2. INORGANIC COMPOUNDS

3. ORGANIC COMPOUNDS

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*L = liquid, G = gas.

3. ORGANIC COMPOUNDS (continued)

4. MIXTURES

Theory, Estimation, and Measurement

Notation

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

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

and

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

This is
<u>terrible</u>.
What are
U P V
E Q
Wk

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

$$dQ = dE + đ(\mathrm{Wk}) \tag{3}$$

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

$$dQ = dE + P\,dV$$

or

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

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

$$\begin{aligned} 0 &= dE + P\,dV - đ(\mathrm{Wk}) \\ đ(\mathrm{Wk}) &= dE + P\,dV \\ &= d(E + PV) \\ &= dH \end{aligned} \tag{5}$$

When the magnitude of the heat exchanged in the first process is made equal to the shaft work done in the second process $|dQ| = |đ(Wk)|$, 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 used C_p instead of C_s 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:

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

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

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

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

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

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

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

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

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

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:

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

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:

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

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

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

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

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

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

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

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:

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

Substituting this relation into equation (16), we obtain

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

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:

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

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

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

$$C_p = -\frac{C}{\mu_J} \tag{23}$$

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

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

or

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

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

$$\bar{\epsilon} = \tfrac{1}{2}RT, \text{ per degree of freedom} \tag{26}$$

and the specific heat

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

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 $\tfrac{1}{2}R$. Actually, C_v for diatomic* and polyatomic gases

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*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	$\frac{6}{2}R \approx 6$	>6
n_A-atomic	3	3	$3n_A - 6$	$\frac{6}{2}R \approx 6$	>6

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

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

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

$$\epsilon = \epsilon_{tr} + \epsilon_{ro} + \epsilon_{vib} + \epsilon_{el} + \epsilon_{nu} \tag{28}$$

or

$$C_v^0 = \frac{\partial \epsilon}{\partial T} \tag{29}$$

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

But

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

Hence

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

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

$$\phi = \frac{4}{3}\pi V(2m\epsilon)^{3/2} \tag{31}$$

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

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

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)

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

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 W 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:

$$\Sigma n_r = N = \text{const}, \qquad \Sigma\delta n_r = 0 \qquad (34)$$

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

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

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

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

where n_r = number of molecules in the rth phase cell of volume Δ, ϵ_r = the energy of a molecule in the rth 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[*]

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

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 $\epsilon_0, \epsilon_1, \ldots, \epsilon_r$ 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

$$Q = q_0\exp(-\epsilon_0/kT) + q_1\exp(-\epsilon_1/kT) + \cdots + q_r\exp(-\epsilon_r/kT) = \Sigma q_r\exp(-\epsilon_r/kT) \qquad (39)$$

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),

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

Hence,

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

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

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[*] 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).

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

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

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

where $Nk = R$.
From equation (43)

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

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

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

$$Q = Q_{\mathrm{tr}} \times Q_{\mathrm{rot}} \times Q_{\mathrm{vib}} \times Q_{\mathrm{el}} \times Q_{\mathrm{nu}} \tag{45}$$

Since, $\ln Q = \ln Q_{\mathrm{tr}} + \ln Q_{\mathrm{rot}} + \ldots$, 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),

$$\bar{\epsilon} = \tfrac{1}{2}RT, \text{ per degree of freedom} \tag{26}$$

Therefore for the three degrees of freedom of translation

$$E_{\mathrm{tr}} = \tfrac{3}{2}RT$$

and

$$(C_v)_{\mathrm{tr}} = \tfrac{3}{2}R \tag{46}$$

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

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

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

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

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

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

b. Electronic Energy (Excited States)

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

$$\begin{aligned} Q_{\mathrm{el}} &= g_0 \exp(-\epsilon_0/kT) + g_1 \exp(-\epsilon_1/kT) + \cdots \\ &= g_e \exp(-\epsilon_0/kT) \end{aligned} \tag{50}$$

where,

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

From equation (50),

$$\ln Q_{\mathrm{el}} = \ln g_e - \frac{\epsilon_0}{kT} \tag{51}$$

$$T \ln Q_{\mathrm{el}} = T \ln g_e - \frac{\epsilon_0}{k} \tag{52}$$

From equations (43) and (51)

$$\begin{aligned} E_{\mathrm{el}} &= RT^2\left[\frac{d \ln g_e}{dT} - \frac{d(\epsilon_0/kT)}{dT}\right] \\ &= RT^2\left(\frac{d \ln g_e}{dT}\right) + (E_0)_{\mathrm{el}} \end{aligned} \tag{53}$$

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

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

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

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

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 = constant] equations (53) and (54) reduce to

$$E_{\mathrm{el}} = (E_0)_{\mathrm{el}} \tag{56}$$

$$(C_v)_{\mathrm{el}} = 0 \tag{57}$$

In most calculations, except at very high temperatures, C_{el} 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

$$\epsilon_{\mathrm{vib}} = h\nu_i[\nu + \tfrac{1}{2}] \tag{58}$$

where,

$$h\nu = hc\omega_i \tag{59}$$

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

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

Letting

$$x_i = h\nu_i/kT$$

from equation (60) we can write

$$\ln Q_{\mathrm{vib}} = -\frac{x_i}{2} - \ln(1-e^{-x_i}) \tag{61}$$

From equations (43) and (61) we get

$$E_{\mathrm{vib}} = \frac{RTx_i}{e^{x_i}-1} + \frac{1}{2}RTx_i = \frac{RTx_i}{e^{x_i}-1} + (E_0)_{\mathrm{vib}} \tag{62}$$

and from equation (62)

$$(C_v)_{\mathrm{vib}} = \frac{Rx_i^2e^{x_i}}{(e^{x_i}-1)^2} \tag{63}$$

In equations (62) and (63) ν_i 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

$$\theta_{\mathrm{vib}} = \frac{h\nu_i}{k} = \frac{hc\omega}{k} \tag{64}$$

then x becomes

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

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

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

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

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

$$E_{\mathrm{vib}} = \tfrac{1}{3}(E)_{\mathrm{Einstein}} \tag{67}$$

$$(C_v)_{\mathrm{vib}} = \tfrac{1}{3}(C_v)_{\mathrm{Einstein}} \tag{68}$$

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

$$\epsilon_J/hC = J(J+1)B \tag{69}$$

where B is a constant, $B = h/8\pi^2CI$. 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

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

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

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

Therefore from equations (43) and (71)

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

and

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

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

$$E_{\text{rot}} = \tfrac{3}{2}RT \tag{74}$$

$$(C_v)_{\text{rot}} = \tfrac{3}{2}R \tag{75}$$

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 ν.

An approximate value of $Q_{\nu,J}$ 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

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

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:

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

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 ϵ_0, ϵ_1, ϵ_2, etc. The nuclear partition function can be expressed then

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

However, it is to be noted that the difference between ϵ_0, ϵ_1, ϵ_2, etc., are exceedingly small, so that, for any temperature even a few degrees above absolute zero equation (78) can be written as

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

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

From equation (79):

$$\ln Q_{\text{nu}} = \ln g_{\text{nu}} - \epsilon_0/kT \tag{80}$$

and

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

From equations (43) and (80)

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

and from equations (44) and (81)

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

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

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

or

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

Polyatomic Gases:

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

or

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

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]:

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

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 Nonreacting 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 microcalorimeter
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

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

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

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*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 coworkers [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 equilibriums 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^{α} = constant can be shown readily to be

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

where $Z = PV/RT$.

Using such an expression, or equivalent ones involving γ or C_v, 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:

$$\gamma = -(a^2/V^2)[\partial V/\partial P]_T \tag{90}$$

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

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:

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

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 temperature 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.

References to Text

1. Partington, J. R. and Shilling, W. G., *The Specific Heats of Gases*, Ernest Benn, London, England, 1924.
2. McCullough, J. P. and Scott, D. W. (Editors), *Experimental Thermodynamics, Vol. I. Calorimetry of Non-reacting Systems*, Plenum Press (New York)/Butterworths (London), 1968.
3. White, W. P., *The Modern Calorimeter*, Chemical Catalog Co., New York, 1928.
4. Swietoslawski, W., *Microcalorimetry*, Reinhold, New York, 1964.
5. Calvet, E. and Prat, H., *Microcalorimétrie*, Masson et Cie, Paris, 1956.
6. Roth, W. A. and Becker, F., *Kalorimetrische Methoden zur Bestimmung chemischer Reaktionswärmen*, F. Vieweg, Braunschweig, 1956,
7. Rossini, F. D. (Editor), *Experimental Thermochemistry, Vol. I*, Interscience, New York, 1956.
8. Weissberger, A. (Editor), *"Calorimetry" in Technique of Organic Chemistry—Vol. I, Physical Methods of Organic Chemistry, Chap. X*, Interscience, New York, 1959.
9. Skinner, H. A. (Editor), *Experimental Thermochemistry, Vol. II*, Interscience, London, 1962.
10. Stull, D. R. (Editor), Report from Conference on Low Temperature Calorimetry, *Chem. Eng. News* **27**, 2772, 1949.
11. Rossini, F. D. (Editor), *Thermodynamics and Physics of Matter, Vol. I, High Speed Aerodynamics and Jet Propulsion*, Princeton University Press, Princeton, N.J., 1955.
12. Partington, J. R., *An Advanced Treatise on Physical Chemistry, Vol. I, Fundamental Principles/The Properties of Gases*, Longmans, Green and Co., London, 1949.
13. Herzberg, G., *Infrared and Raman Spectra of Polyatomic Molecules, Vol. II, Molecular Spectra and Molecular Structure*, D. Van Nostrand Co., Inc., 1945.
14. Pitzer, K. S., "The Heat Capacity of Gaseous Paraffin Hydrocarbons, Including Experimental Values for Pentane and 2,2-Dimethylbutane," *J. Am. Chem. Soc.* **66**, 2413–8, 1941.
15. Waddington, G. and Douslin, D. R., "Experimental Vapor Heat Capacities and Heats of Vaporization of Hexane and 2,2-Dimethylbutane," *J. Am. Chem. Soc.* **69**, 2275–9, 1947.
16. Waddington, G., Todd, S. S., and Huffman, H. M., "An Improved Flow Calorimeter—Experimental Vapor Heat Capacities and Heats of Vaporization of Heptane and 2,2,3-Trimethylbutane," *J. Am. Chem. Soc.* **69**, 22–30, 1947.
17. McCullough, J. P., Scott, D. W., Pennington, R. E., Hossenlopp, I. A., and Waddington, G., "The Thermodynamic Properties of 2-Methyl-2-Propanethiol from 0 to 1000 K," *J. Am. Chem. Soc.* **75**, 1818–24, 1953; "Nitromethane: The Vapor Heat Capacity, Heat of Vaporization, Vapor Pressure and Gas Imperfection; The Chemical Thermodynamic Properties from 0 to 1500 K," *J. Am. Chem. Soc.* **76**, 4791–6, 1954.
18. Osborne, N. S., Stimson, H. F., and Sligh, T. S., Jr., "A Flow Calorimeter for Specific Heats of Gases," *Sci. Papers—NBS* **20**, 503, 119–51, 1925.
19. Masi, J. F., "Thermodynamic Properties of Gaseous Difluorodichloromethane (Freon-12)," *J. Am. Chem. Soc.* **74**, 4738–41, 1952.
20. Wacker, P. F., Cheney, R. K., and Scott, R. B., "Heat Capacities of Gaseous Oxygen, Isobutane, and 1-Butene from −20 to 90 C," *Sci. Papers—NBS* **38**, 651, 1947.
21. Reynolds, A. E. and De Vries, T., "The Heat Capacity of Organic Vapors. VII. A Flow Calorimeter Requiring only 25 ml. of Liquid Sample," *J. Am. Chem. Soc.* **72**, 5443–5, 1950.
22. Bennewitz, K. and Schluze, O., "A New Method for Determining the Specific Heats of Gases and Vapors," *Z. Phys. Chem.* **A186**, 299–313, 1940.
23. Dailey, B. P. and Felsing, W. A., "The Heat Capacities at Higher Temperatures of Ethane and Propane," *J. Am. Chem. Soc.* **65**, 42–4, 1943.
24. Krase, N. W. and Mackey, B. H., "Specific Heats of Gases at High Pressures. I. Method and Apparatus at Room Temperature," *J. Am. Chem. Soc.* **52**, 108–15, 1930.
25. McCullough, J. P., Scott, D. W., Finke, H. L., Hubbard, W. N., Gross, M. E., Katz, C., Pennington, R. E., Messerley, J. F., and Waddington, G., "The Thermodynamic Properties of 2-Methyl-2-Propanethiol from 0 to 1000 K," *J. Am. Chem. Soc.* **75**, 1818–24, 1953.
26. Montgomery, J. B. and De Vries, T., "Heat Capacity of Organic Vapors, III. A Comparison of Flow Calorimeters," *J. Am. Chem. Soc.* **64**, 2372–5, 1942.
27. Sinhe, G. C. and De Vries, T., "Heat Capacity of Organic Vapours, VIII. Data for Some Aliphatic Alcohols Using an Improved Flow Calorimeter Requiring only 25 ml. of Sample," *J. Am. Chem. Soc.* **75**, 1815–8, 1953.
28. Ginnings, D. C. and Corrucini, R. J., "An Improved Ice Calorimeter—The Determination of Its Calibration Factor and the Density of Ice," *J. Res. Nat. But. Std.* **38**, 583–91, 1947.
29. Douglas, T. B., Furukawa, G. T., McCoskey, R. E., and Ball, A. F., "Calorimetric Properties of Heptane from 0 to 520 K," *J. Res. Nat. Bur. Std.* **53**, 139–53, 1954.
30. Giguere, P. A., Morissette, B. G., and Olmos, A. W., "A 27 C Isothermal Calorimeter," *Can. J. Chem.* **33**, 657–64, 1955.
31. Gregg, S. J., "The Heat of Absorption of Gases by Charcoal," *J. Chem. Soc.* 1494–1512, 1927.

32. Beynon, J. H. and Humphries, A. R., "The Enthalpy Differences Between α- and β-Copper Phthalocyanine Measured with an Isothermal Calorimeter," *Trans. Faraday Soc.* **51**, 1065–70, 1955.
33. Andrews, D. H., Lynn, G., and Johnston, J., "The Heat Capacities and Heat of Crystallization of Some Isomeric Aromatic Compounds," *J. Am. Chem. Soc.* **48**, 1274–87, 1926.
34. Ziegler, W. T. and Messer, C. E., "A Modified Heat-Conduction Calorimeter," *J. Am. Chem. Soc.* **63**, 2694–2700, 1941.
35. Nitta, I., Seki, S., and Momotani, M., "The Phase Transition in Pentaerythritol," *Proc. Japan Academy* **26**, 9, 25–9, 1950.
36. Kurbatov, V. Ya., "Heat Capacities of Liquids. II. Temperature Dependence of the Heat Capacity of Halogen Derivatives of Acyclic Hydrocarbons," *Zh. Obshch. Khim.* **18**, 372–87, 1948.
37. Workman, E. J., "The Variation of the Specific Heats (C_p) of Oxygen, Nitrogen, and Hydrogen with Pressure," *Phys. Rev.* **37**, 1345–55, 1931.
38. Brinkworth, J. H., "The Measurement of the Ratio of the Specific Heats Using Small Volumes of Gas. The Ratios of the Specific Heats of Air and of Hydrogen at Atmospheric Pressure and at Temperatures Between 20 and −183 C," *Proc. Roy. Soc. London* **A107**, 510–43, 1925.
39. Brinkworth, J. H., "The Rates of the Specific Heats of Nitrogen at Atmospheric Pressure and at Temperatures Between 10 and −183 C," *Proc. Roy. Soc. London* **A111**, 124–33, 1926.
40. Eucken, A. and Lude, K. V., "The Specific Heats of Gases at Medium and High Temperatures. I. The Specific Heat of the Gases: Air, Nitrogen, Oxygen, Carbon Monoxide, Carbon Dioxide, Nitrous Oxide, and Methane," *Z. Phys. Chem.* **5B**, 413–41, 1929.
41. Kistiakowsky, G. B. and Rice, W. W., "Gaseous Heat Capacities. I. The Method and Heat Capacities of C_2H_6 and C_2D_6," *J. Chem. Phys.* **7**, 281–8, 1939.
42. Partington, J. R. and Shilling, W. G., "The Variation of the Specific Heat of Air with Temperature," *Trans. Faraday Soc.* **18**, 386–90, 1923.
43. Eucken, A. and Parts, A., "Molar Heat and Normal Vibrations of Ethane and Ethylene," *Z. Phys. Chem.* **20B**, 184–94, 1933.
44. Sage, B. H., Webster, D. C., and Lacey, W. N., "Phase Equilibria in Hydrocarbon Systems. XX. Isobaric Heat Capacity of Gaseous Propane, Butane, Isobutane and Pentane," *Ind. Eng. Chem.* **29**, 1309–14, 1937.
45. Alleman, R. S., "Dissipative Acoustic Reflection Coefficients in Gases by Ultrasonic Interferometry," *Phys. Rev.* **55**, 87–93, 1939.
46. Fox, E., "Ultrasonic Interferometry for Liquid Media," *Phys. Rev.* **52**, 973–81, 1937.
47. Herzfeld, K. F., "Reflection of Sound," *Phys. Rev.* **53**, 899–906, 1938.
48. Hubbard, J. C. and Loomis, A. L., "The Velocity of Sound in Liquids at High Frequencies by the Sonic Interferometer," *Phil. Mag.* **5**, 1177–90, 1928.
49. Van Itterbeek, A. and Vandoninck, W., "The Velocity of Propagation of Sound in Air and in Mixtures of H_2 and N_2 at Low Temperatures," *Ann. Phys.* **19**, 88–104, 1944.
50. Van Itterbeek, A. and Van Paemel, O., "Measurements of the Velocity of Sound as a Function of Pressure in Oxygen Gas at Liquid Oxygen Temperatures. Calculation of the Second Virial Coefficient and the Specific Heats," *Physica* **5**, 593–604, 1938.
51. Galt, J. K., "Sound Absorption and Velocity in Liquefied Argon, Oxygen, Nitrogen, and Hydrogen," *J. Chem. Phys.* **16**, 505–7, 1948.
52. Pinkerton, J. M. M., "A Pulse Method for the Measurement of Ultrasonic Absorption in Liquids: Results for Water," *Nature* **160**, 128–9, 1947; "The Absorption of Ultrasonic Waves in Liquids and Its Relation to Molecular Constitution," *Proc. Phys. Soc. London* **62B**, 129–41, 1949.
53. Lucas, R. and Biquard, P., "New Optical Properties of Liquids Undergoing Ultra Sound Waves," *Compt. Rend.* **194**, 2132–4, 1932.
54. Akhmetsyanov, K. G., Shirkevich, M. G., and Rozhdestvenskii, I. B., "Determination of Specific Heat of Methyl Alcohol Vapor Near the Critical State from Acoustic Measurements," *Primenenie Ultraakustkik, Issled. Veshchestva* **4**, 127–35, 1957.
55. Partington, J. R. and Carroll, J. F., "The Specific Heats of Carbon Monoxide and Hydrocyanic Acid Vapor," *Phil. Mag.* **49** (6), 1665–80, 1925.
56. Partington, J. R. and Howe, A. B., "The Ratio of the Specific Heats of Hydrogen," *Proc. Roy. Soc. London* **A109**, 286–91, 1925.
57. Shilling, W. G., "Velocity of Sound in Steam, Nitrous Oxide and Carbon Dioxide with Reference to the Temperature Coefficients of the Molecular Heats," *Phil. Mag.* **3** (7), 273–301, 1927.
58. Shilling, W. G. and Partington, J. R., "Measurements of the Velocity of Sound in Air, Nitrogen and Oxygen, with Special Reference to the Temperature Coefficients of the Molecular Heats," *Phil. Mag.* **6** (7), 920–9, 1928.
59. King, F. E. and Partington, J. R., "Measurement of Sound Velocity in Air, Oxygen, and Carbon Dioxide at Temperatures from 900 to 1200 C with Special Reference to the Temperature Coefficient of the Molecular Heats," *Phil. Mag.* **9** (7), 1020–6, 1930.
60. Sherratt, G. G. and Griffiths, E., "The Determination of the Specific Heats of Gases at High Temperatures by the Velocity of Sound Method, V. Carbon Monoxide," *Proc. Roy. Soc. London* **A147**, 292–308, 1934.
61. Sherratt, G. G. and Griffiths, E., "The Determination of the Specific Heat of Gases at High Temperatures by the Sound Velocity Method. II. Carbon Dioxide," *Proc. Roy. Soc. London* **A156**, 504–17, 1936.
62. Hubbard, J. C. and Hodge, A. H., "Ratio of Specific Heats of Air, N_2 and CO_2 as a Function of Pressure by the Ultrasonic Method," *J. Chem. Phys.*, **5**, 978–9, 1937.
63. Cornish, R. E. and Eastman, E. D., "The Specific Heat of Hydrogen Gas at Low Temperature from the Velocity of Sound, and Precision Method of Measuring the Frequency of an Oscillating Circuit," *J. Am. Chem. Soc.* 50, 627–52, 1928.
64. Clark, A. L. and Katz, L., "Resonance Method for Measuring the Ratio of the Specific Heats of a Gas, C_p/C_v," *Can. J. Res.* **18A**, 23–38, 1940; "The Resonance Method of Measuring the Ratio of the Specific Heats of the Gas, C_p/C_v," *ibid.* Part IV, **21A**, 1–17, 1943.

65. Koehler, W. F., "The Ratio of the Specific Heats of Gases, C_p/C_v by a Method of Self-Sustained Oscillations," *J. Chem. Phys.* **18**, 465–72, 1950.
66. Roebuck, J. R. and Osterberg, H., "The Joule–Thomson Effect in Nitrogen," *Phys. Rev.* **48**, 450–7, 1935.
67. Sage, B. H., Kennedy, E. R., and Lacey, W. N., "Phase Equilibria in Hydrocarbon Systems. XIII. Joule–Thomson Coefficients of Propane," *Ind. Eng. Chem.* **28**, 601–4, 1936.
68. Sage, B. H. and Lacey, W. W., "Phase Equilibrium in Hydrocarbon Systems. Thermodynamics Properties of Isobutane," *Ind. Eng. Chem.* **30**, 673–81, 1938.
69. Baehr, H. D., "The Joule–Thomson Effect in Hydrogen," *J. Elektrochem* **59**, 32–5, 1955.
70. Burlew, J. S., "Measurements of the Heat Capacity of a Small Volume of Liquid by the Piezothermometric Method. III. Heat Capacity of Benzene and of Toluene from 8° to the Boiling Point," *J. Am. Chem. Soc.* **62**, 696–700, 1940.

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 compatability 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 bibliographic 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_p (25 C), cal g^{-1}K^{-1}	C_v (25 C), cal g^{-1}K^{-1}	Dipole Moment, Debyes
Acetone	C_3H_6O	58.081	0.933 (ℓ)†	178	329	508	0.528 (ℓ)		2.88
Acetylene	C_2H_2	26.039	1.077 -3**	179	191	309	0.407	0.329	0
Air		28.966	1.184 -3	60	79b, 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_6H_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_4H_{10}	58.126		114	262	408	0.404		0.132
n-Butane	n-C_4H_{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	$C_4H_{11}N$	73.143	0.711 (ℓ)	233	329	496	0.516 (ℓ)	--	1.11
Ethane	C_2H_6	30.070	1.243 -3	95 ± 6	185	305	0.422	0.335	0
Ethyl Alcohol	C_2H_6O	46.070	0.789 (ℓ)	159 ± 3	351	516	0.580 (ℓ)	--	1.69
Ethyl Ether	$C_4H_{10}O$	74.125	0.716 (ℓ)	157(α), 150(β)	308	467	0.559 (ℓ)	--	1.15
Ethylene	C_2H_4	28.055	1.155 -3	104	170	283	0.374	0.297	0
Ethylene Glycol	$C_2H_6O_2$	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_3F	137.369	5.840 -3	162	297	471	0.136*	0.125	0.45
Freon 12	CCl_2F_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	$CHCl_2F$	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	$C_2Cl_3F_3$	187.377	1.564 (ℓ)	238	321	481	0.225 (ℓ)		
Freon 114	$C_2Cl_2F_4$	170.922	7.012 -3	179	276	419	0.170	0.157	0.5
Glycerol	$C_3H_8O_3$	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_7H_{16}	100.208	0.681 (ℓ)	183	371	540	0.536 (ℓ)	--	
n-Hexane	C_6H_{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	~~[illegible]~~ 127.912		223	237	423	0.054*		
Hydrogen Sulfide	H_2S	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_4O	32.043	0.789 (ℓ)	175	338	513	0.602 (ℓ)		1.70
Methyl Chloride	CH_3Cl	50.488		175	249	416	0.193		
Methyl Formate	$C_2H_4O_2$	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_2O	44.013		176 ± 7	184	310	0.209*	0.170	0.167
n-Nonane	C_9H_{20}	128.262	0.714 (ℓ)	220	424	594	0.529 (ℓ)	--	
n-Octane	C_8H_{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_5H_{12}	72.154	0.621 (ℓ)	144	309	470	0.561 (ℓ)		
Cyclopropane	~~[illegible]~~ C_3H_6	M.W. 42.080 ~~[illegible]~~	~~[illegible]~~ 0.61 (ℓ)	146	240			--	
Propane	C_3H_8	44.098	1.854 -3	86	231	369	0.400	0.350	0.084
Propylene	C_3H_6	42.082	0.514 (ℓ)	87	226	365	0.370	0.320	
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_7H_8	92.144	1.028 (ℓ)	178	384	594	0.410 (ℓ)	--	0.36
Tritium	T_2			21	26	44			0
Water	H_2O	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

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* 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→	cal_{th} g-mol^{-1} C^{-1}	cal_{th} g^{-1} C^{-1}	cal_{IT} g-mol^{-1} C^{-1}	cal_{IT} g^{-1} C^{-1}	J g-mol^{-1} K^{-1}	J g^{-1} K^{-1}	J kg-mol^{-1} K^{-1}	J kg^{-1} K^{-1}	Btu_{th} lb^{-1} F^{-1}	Btu_{IT} lb^{-1} F^{-1}
cal_{th} g-mol^{-1} C^{-1}	1	1/M	0.999331	0.999331/M	4.184	4.184/M	4.184 x 10^3	4.184/M x 10^3	1/M	0.999331/M
cal_{th} g^{-1} C^{-1}	M	1	0.999331M	0.999331	4.184M	4.184	4.184M x 10^3	4.184 x 10^3	1	0.999331
cal_{IT} g-mol^{-1} C^{-1}	1.00067	1.00067/M	1	1/M	4.1868	4.1868/M	4.1868 x 10^3	(4.1868/M) x 10^3	1.00067/M	1/M
cal_{IT} g^{-1} C^{-1}	1.00067M	1.00067	M	1	4.1868M	4.1868	4.1868M x 10^3	4.1868 x 10^3	1.00067	1
J g-mol^{-1} K^{-1}	0.239006	0.239006/M	0.238846	0.238846/M	1	1/M	1 x 10^3	1 x 10^3/M	0.239006/M	0.238846/M
J g^{-1} K^{-1}	0.239006M	0.239006	0.238846M	0.238846	M	1	M x 10^3	10^3	0.239006	0.238846
J kg-mol^{-1} K^{-1}	2.39006 x 10^{-4}	(2.39006/M) x 10^{-4}	2.38846 x 10^{-4}	(2.38846/M) x 10^{-4}	10^{-3}	10^{-3}/M	1	1/M	(2.39006/M) x 10^{-4}	(2.38846/M) x 10^{-4}
J kg^{-1} K^{-1}	2.39006M x 10^{-4}	2.39006 x 10^{-4}	2.38846M x 10^{-4}	2.38846 x 10^{-4}	M x 10^{-3}	10^{-3}	M	1	2.39006 x 10^{-4}	2.38846 x 10^{-}
Btu_{th} lb^{-1} F^{-1}	M	1	0.999331M	0.999331	4.184M	4.184	4.184M x 10^3	4.184 x 10^3	1	0.999331
Btu_{IT} lb^{-1} F^{-1}	1.00067M	1.00067	M	1	4.1868M	4.1868	4.1868M x 10^3	4.1868 x 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, Lide, 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:

$1\ \mathrm{lb} = 0.45359237\ \mathrm{kg}^*$

$1\ \mathrm{cal_{th}} = 4.184\ \text{(exactly)}\ \mathrm{J}^*$

$1\ \mathrm{cal_{IT}} = 4.1868\ \text{(exactly)}\ \mathrm{J}^*$

$1\ \mathrm{Btu_{th}\ lb^{-1}\ F^{-1}} = 1\ \mathrm{cal_{th}\ g^{-1}\ C^{-1}}^\dagger$

$1\ \mathrm{Btu_{IT}\ lb^{-1}\ F^{-1}} = 1\ \mathrm{cal_{IT}\ g^{-1}\ C^{-1}}^\dagger$

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

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

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*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

LIQUID

Six sources of information are available for the specific heat of liquid argon. Among them, a set of recent data of Van Itterbeek (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

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

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.

RECOMMENDED VALUES

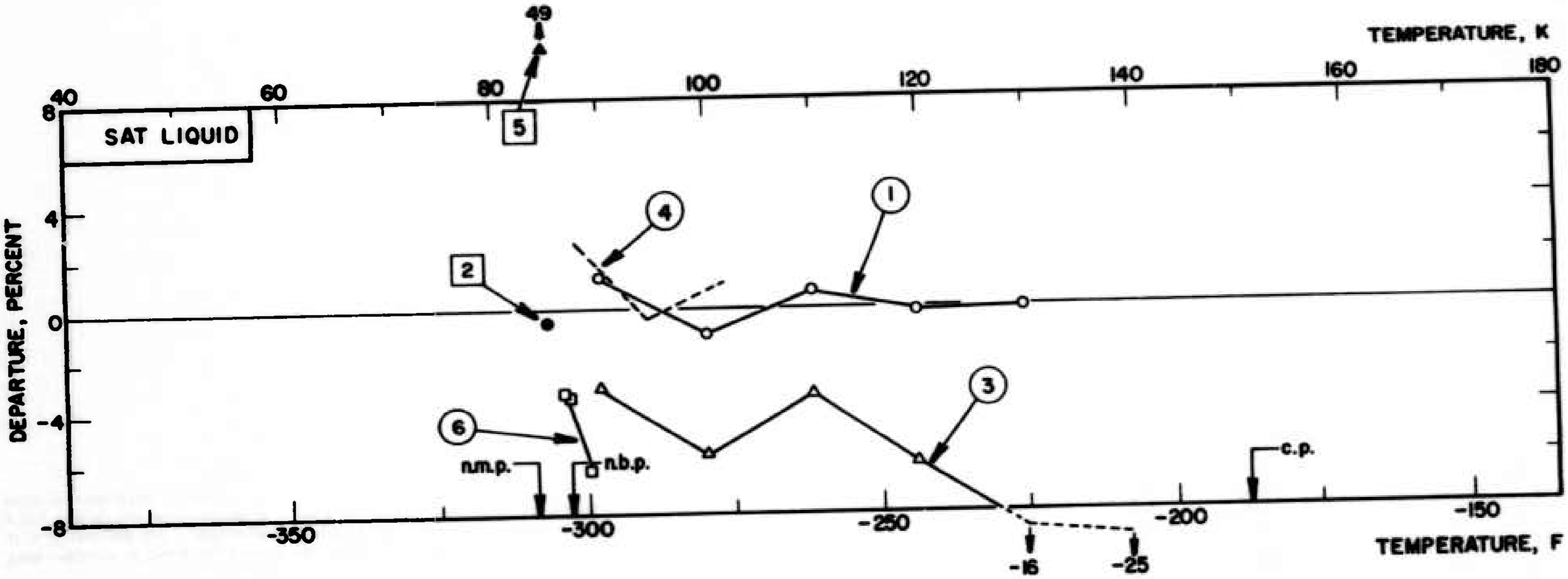
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

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

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 $C_p^0 = (5/2)R$, (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^0 remains constant up to 6000 K or more. Therefore the specific heat at the ideal gas state is given as follows:

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

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^0. 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^1, 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^0 with C_p^1.

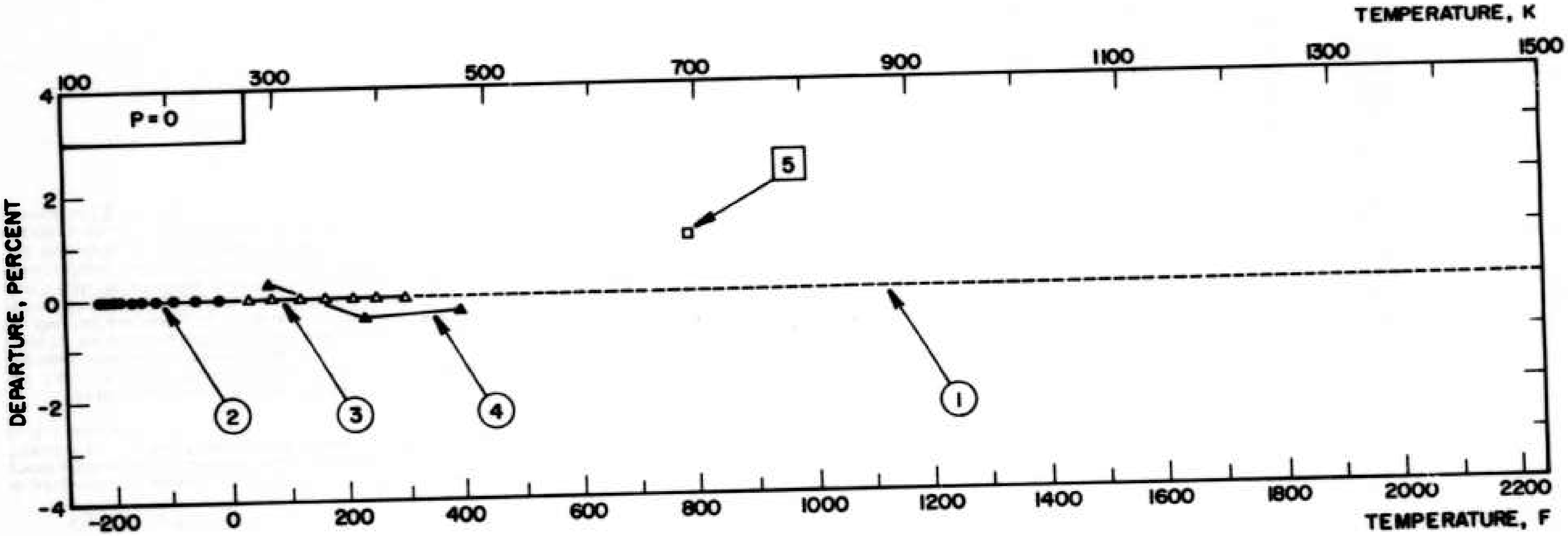
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p^1, B $\text{lb}^{-1}\text{F}^{-1}$]

GAS

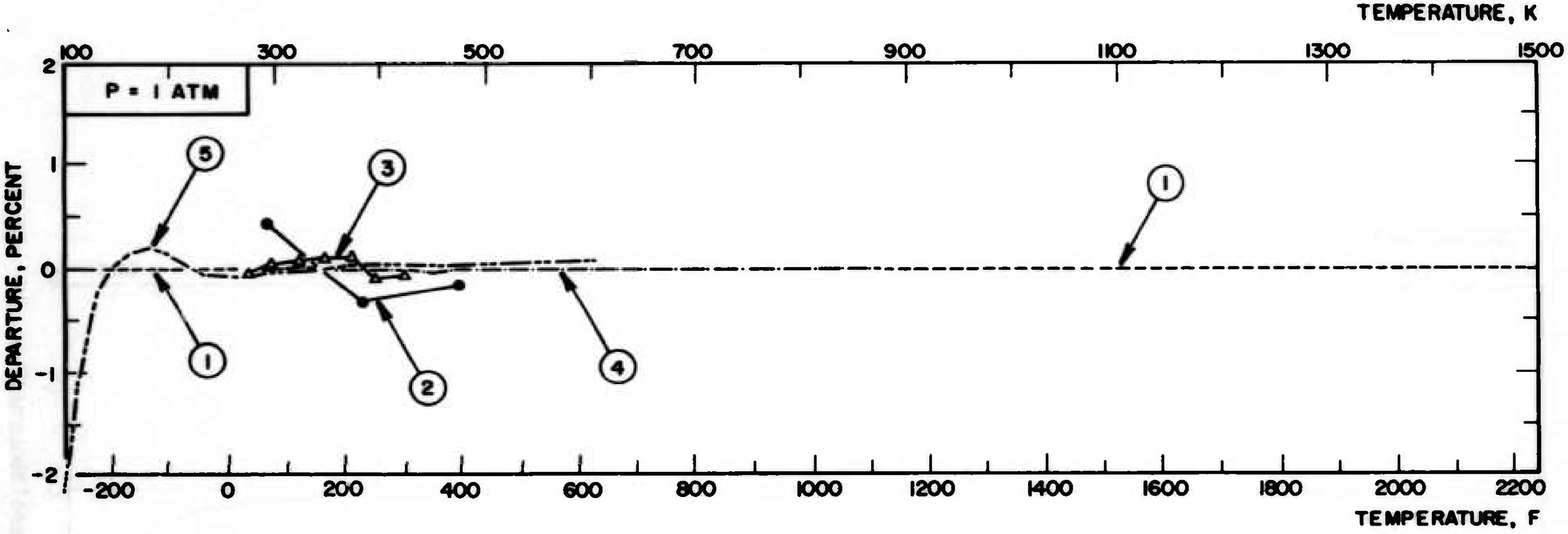
T	C_p^1	T	C_p^1
		500	0.12437
-280	0.12968	520	0.12437
-260	0.12814	540	0.12436
-240	0.12714	560	0.12436
-220	0.12653	580	0.12436
-200	0.12610	600	$0.1243\bar{5}$
-180	0.12577	620	$0.1243\bar{5}$
-160	0.12553	640	$0.1243\bar{5}$
-140	0.12534	660	$0.1243\bar{5}$
-120	0.12518	680	0.12434
-100	0.12506	700	0.12434
-80	0.12496	720	0.12434
-60	0.12488	740	0.12434
-40	0.12481	760	0.12434
-20	0.12474	780	0.12434
0	0.12470	800	0.12433
20	0.12466	820	0.12433
40	0.12463	840	0.12433
60	0.12460	860	0.12433
80	0.12457	880	0.12433
100	0.12454	900	0.12433
120	0.12453	920	0.12433
140	0.12452	940	0.12433
160	0.12450	960	0.12432
180	0.12448	980	0.12432
200	0.12447	1000	0.12432
220	0.12446	1100	0.12432
240	$0.1244\bar{5}$	1200	0.12432
260	0.12444	1300	0.12431
280	0.12443	1400	0.12431
300	0.12441	1500	0.12431
320	0.12441	1600	0.12431
340	0.12441	1700	0.12431
360	0.12440	1800	0.12430
380	0.12440	1900	0.12430
400	0.12439	2000	0.12430
420	0.12438		
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, 362, 389, 435
2	463
3	464, 465
4	56
5	319

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



Curve	Reference
1	265, 274, 454, 575
2	56
3	464, 465
4	556
5	251

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

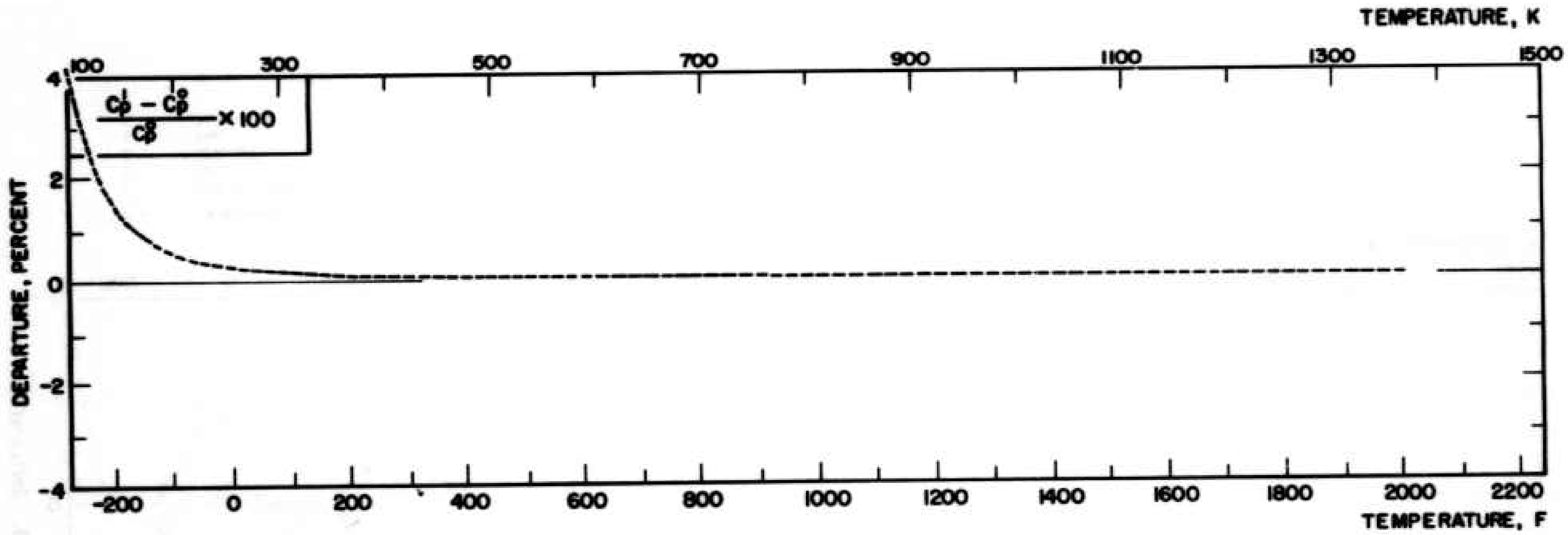


TABLE 2 SPECIFIC HEAT AT CONSTANT PRESSURE OF BROMINE

DISCUSSION

LIQUID

Only two sources of information are available for the specific heat at constant pressure of liquid bromine. The extensive calorimetric measurement of Hildenbrand 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

$$C_p\ (\mathrm{cal\ g^{-1}K^{-1}}) = 0.244162 - 7.47918 \times 10^{-4}T + 7.4341\overline{5} \times 10^{-7}T^2$$
$$+ 9.78071 \times 10^{-10}T^3 \qquad (T \text{ in K}).$$

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.

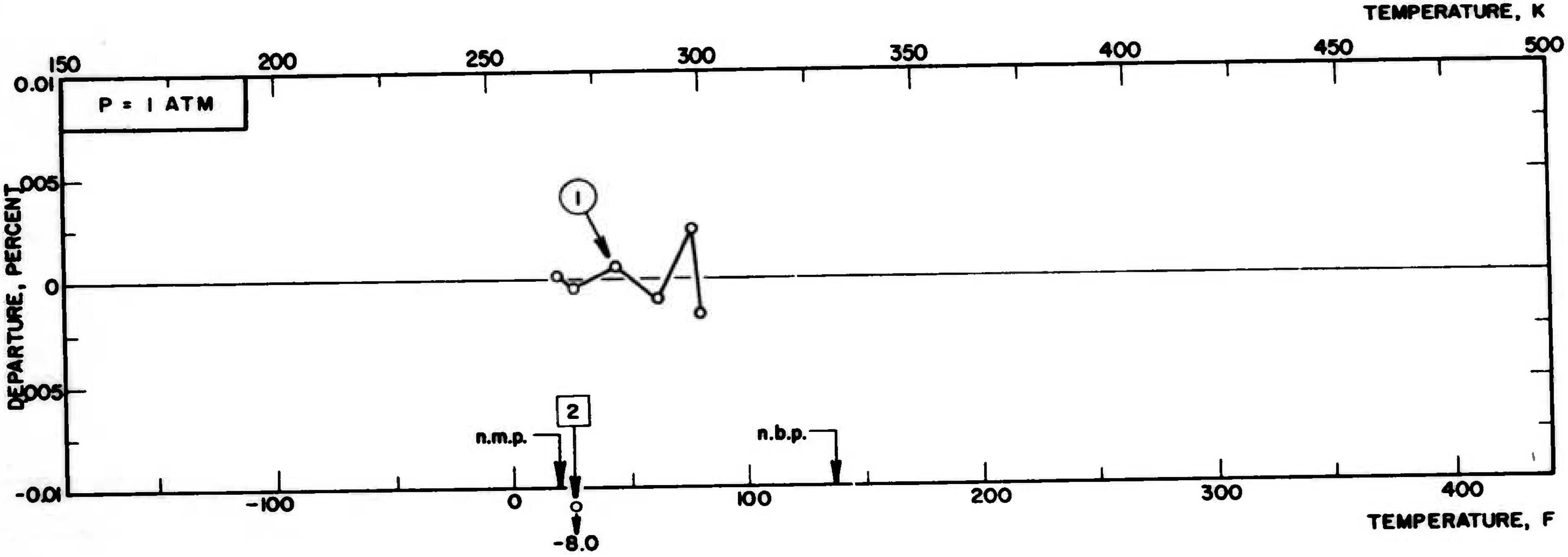
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B $\mathrm{lb^{-1}F^{-1}}$]

LIQUID

T	C_p^l
20	0.1161
30	0.1153
40	0.1147
50	0.1141
60	0.1137
70	0.1133
80	0.1130
90	0.1129

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

DISCUSSION

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:

$$C_p^0\ (\mathrm{cal\ g^{-1}K^{-1}}) = 0.0418420 + 7.34557 \times 10^{-5}T - 1.38188 \times 10^{-7}T^2 + 9.0441\overline{5} \times 10^{-11}T^3 \qquad (T \text{ in K}) \qquad (1)$$

For temperatures between 590 K and 1500 K:

$$C_p^0\ (\mathrm{cal\ g^{-1}K^{-1}}) = 0.0535106 + 5.16046 \times 10^{-6}T - 2.97904 \times 10^{-9}T^2 + 6.51581 \times 10^{-13}T^3 \qquad (T \text{ in K}) \qquad (2)$$

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.

RECOMMENDED VALUES

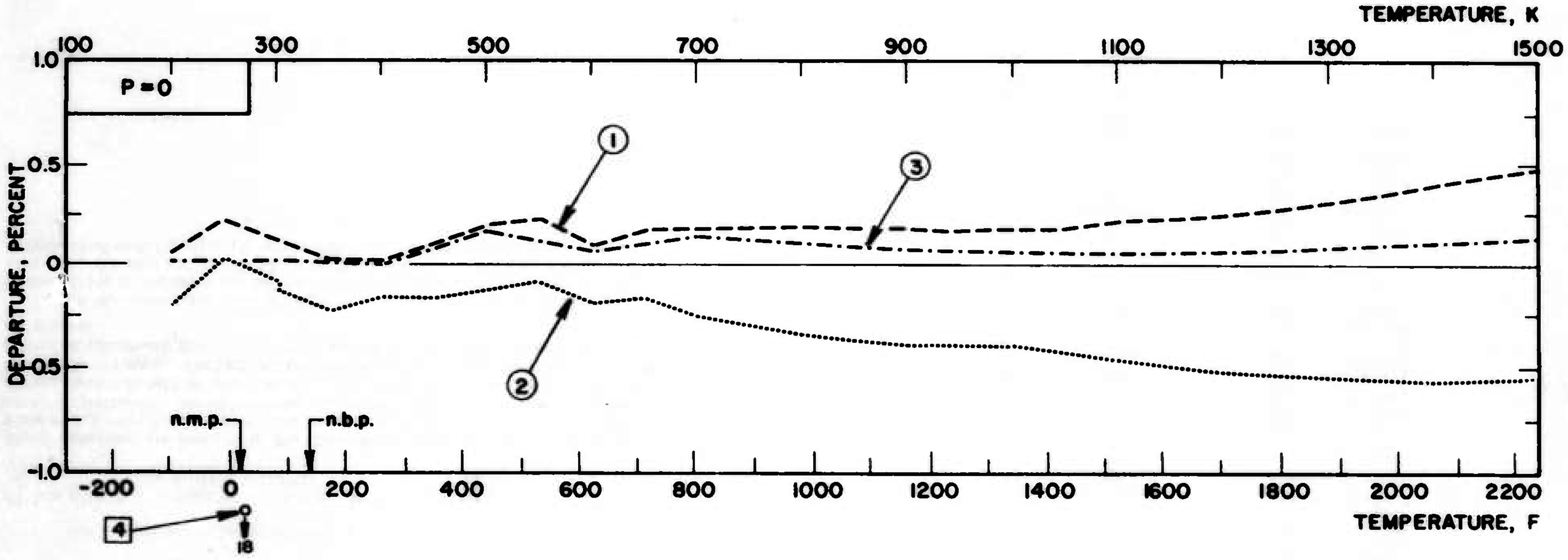
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

GAS

T	C_p^0	T	C_p^0
-100	0.05169	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	$0.0538\overline{5}$	780	0.05583
100	0.05401	800	$0.0558\overline{5}$
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	$0.0560\overline{5}$
320	$0.0550\overline{5}$	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	$0.0565\overline{5}$
480	0.05536	1900	0.05659
500	0.05539	2000	0.05663
520	0.05543		
540	0.05547		
560	0.05551		
580	0.05556		

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

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



Curve	Reference
1	355, 428
2	321, 508
3	254
4	216

TABLE 3 SPECIFIC HEAT AT CONSTANT PRESSURE OF CHLORINE

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 Giauque 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 Giauque and Powell, and are given no weight.

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

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

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.

RECOMMENDED VALUES

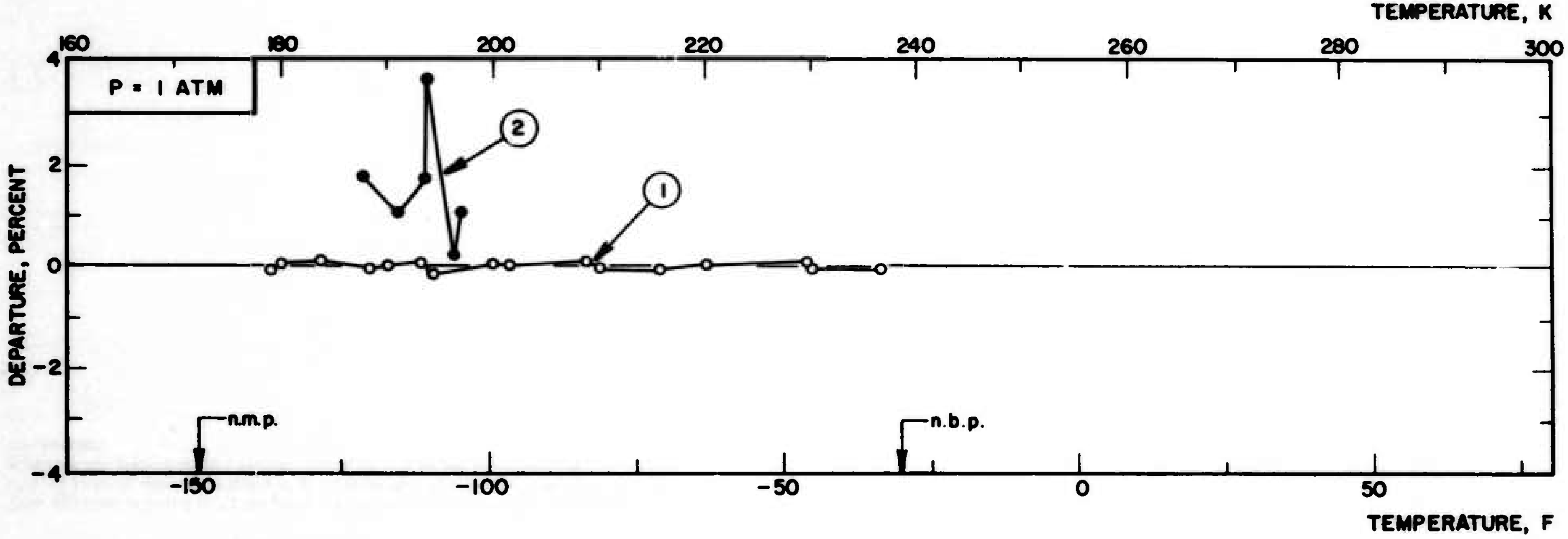
[Temperature, T, F; Specific Heat, C_p, B $lb^{-1}F^{-1}$

LIQUID

T	C_p^l
-145	0.2258
-140	0.2258
-135	0.2257
-130	0.2256
-125	0.2255
-120	0.2254
-115	0.2253
-110	0.2251
-105	0.2249
-100	0.2248
- 95	0.2246
- 90	0.2244
- 85	0.2241
- 80	0.2239
- 75	0.2237
- 70	0.2235
- 65	0.2232
- 60	0.2230
- 55	0.2228
- 50	0.2225
- 45	0.2223
- 40	0.2220
- 30	0.2216

n.b.p. = -30 F

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



Curve	Reference
1	343
2	317

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:

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

For temperatures between 640 K and 1500 K:

$$C_p^0\ (\text{cal g}^{-1}\text{K}^{-1}) = 0.111175 + 3.01054 \times 10^{-5}\,T - 1.94702 \times 10^{-8}\,T^2 + 4.54431 \times 10^{-12}\,T^3 \qquad (T \text{ in K}) \qquad (2)$$

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

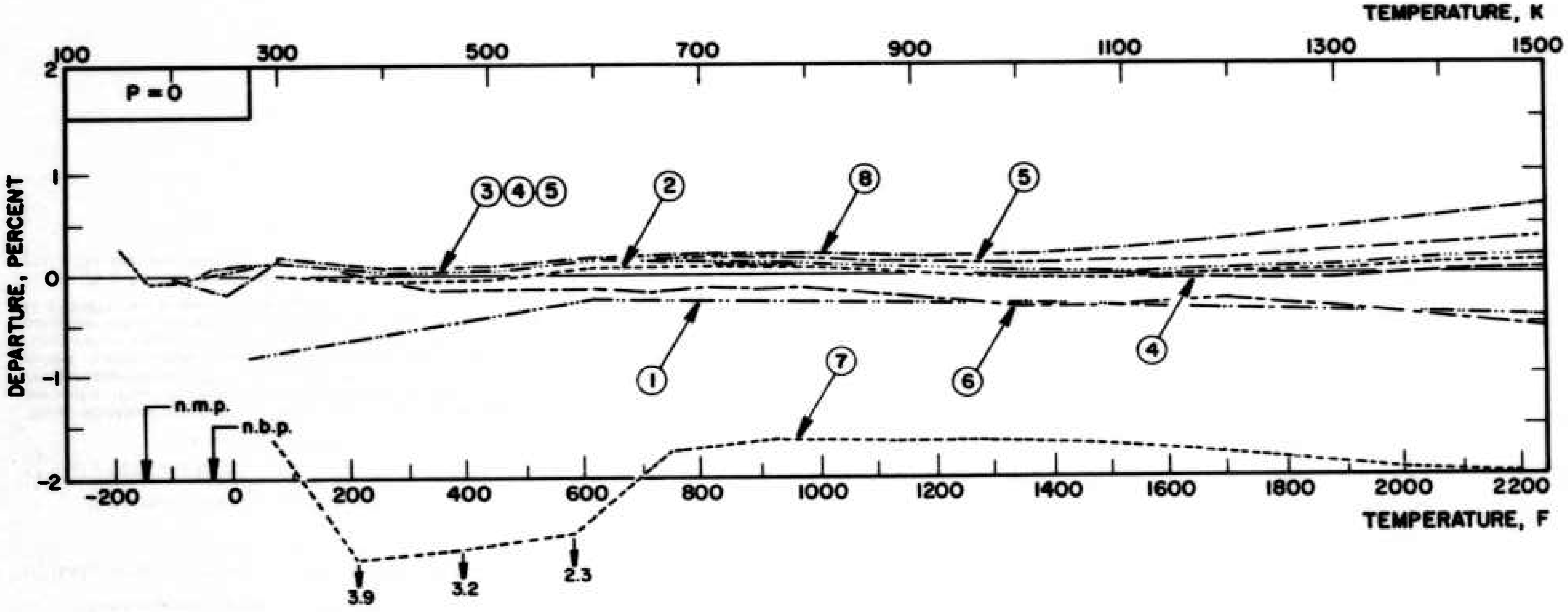
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

GAS

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	0.123$\underline{3}$
-20	0.1106	680	0.123$\overline{5}$
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	0.124$\overline{5}$
180	0.1171	880	0.1246
200	0.1176	900	0.1247
220	0.1181	920	0.1248
240	0.118$\overline{5}$	940	0.1249
260	0.1189	960	0.12$\overline{5}$0
280	0.1193	980	0.1250
300	0.1196	1000	0.1251
320	0.1199	1100	0.1255
340	0.1202	1200	0.1259
360	0.1205	1300	0.1262
380	0.1208	1400	0.1264
400	0.1211	1500	0.1267
420	0.1213	1600	0.1269
440	0.1215	1700	0.1270
460	0.1217	1800	0.1272
480	0.1219	1900	0.1273
500	0.1221	2000	0.127$\overline{5}$
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, 428, 479
4	254
5	335
6	508
7	278
8	532

TABLE 4 SPECIFIC HEAT AT CONSTANT PRESSURE OF n-DEUTERIUM

DISCUSSION

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 Clusius 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

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

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.

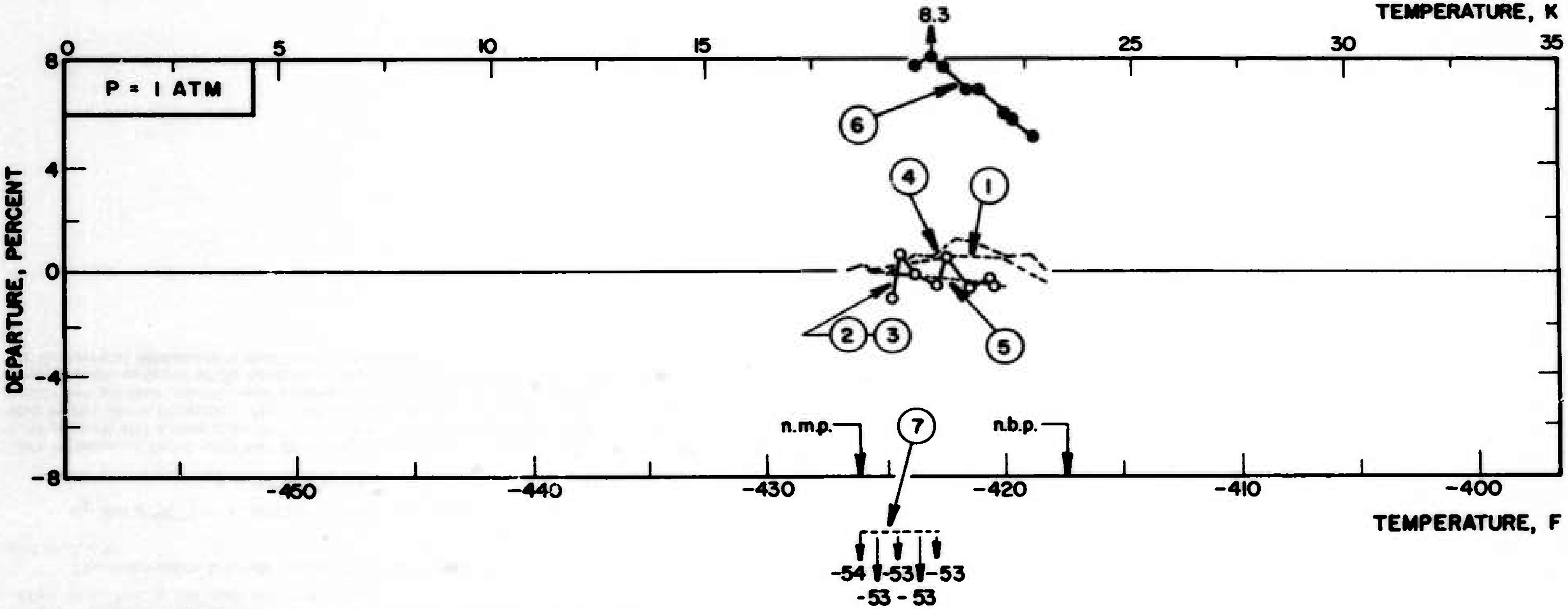
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B $lb^{-1} F^{-1}$]

LIQUID

T	C_p^1
-426	1.188
-424	1.253
-422	1.31$\bar{5}$
-420	1.382
-418	1.464

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



Curve	Reference
1	283
2	288
3	290
4	457
5	571
6	417
7	515

TABLE 4 SPECIFIC HEAT AT CONSTANT PRESSURE OF n-DEUTERIUM

DISCUSSION

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 (93). The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 200 K and 620 K

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

For temperatures between 620 K and 1500 K

$$C_p^0\,(\text{cal g}^{-1}\text{K}^{-1}) = 1.81328 - 4.84626 \times 10^{-4}T + 8.08487 \times 10^{-7}T^2 - 2.59126 \times 10^{-10}T^3 \qquad (T \text{ in K}). \quad (2)$$

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.

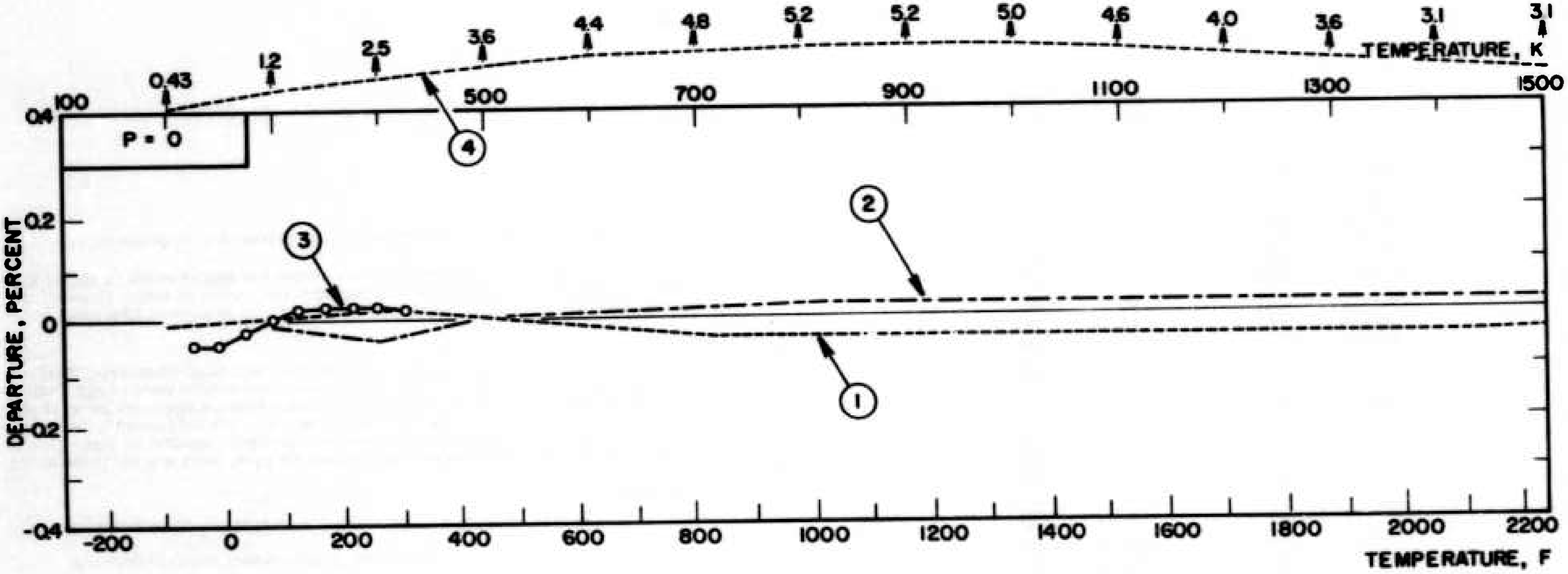
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B lb^{-1}F^{-1}]

GAS

T	C_p^0	T	C_p^0
-100	1.7318	600	1.7544
- 80	1.7316	620	1.7565
- 60	$1.731\bar{5}$	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	$1.731\bar{5}$	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	$1.750\bar{5}$		
580	1.7524		

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



Curve	Reference
1	571
2	396
3	461
4	93

TABLE 5 SPECIFIC HEAT AT CONSTANT PRESSURE OF FLUORINE

DISCUSSION

LIQUID

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

$$C_p\ (\text{cal g}^{-1}\text{K}^{-1}) = 0.360180 + 2.11636 \times 10^{-3}T - 6.3201\overline{5} \times 10^{-5}T^2 + 4.63308 \times 10^{-7}T^3 \qquad (T \text{ in K}).$$

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.

RECOMMENDED VALUES

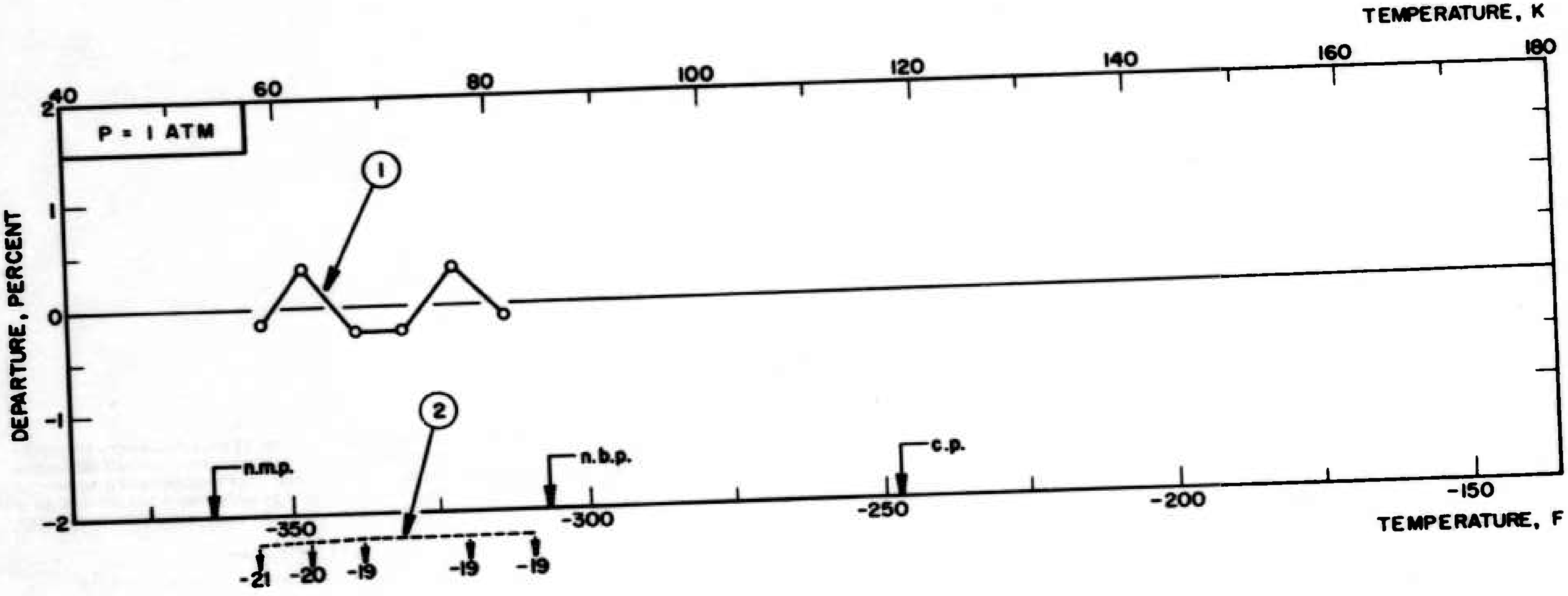
[Temperature, T, F; Specific Heat, C_p, B lb^{-1}F^{-1}]

LIQUID

T	C_p^1
-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

n.b.p. = -305 F

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



Curve	Reference
1	387, 388
2	280

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), Sinke (192), Cole et al. (298), Evans et al. (321), Furukawa et al. (335), Hildenbrand (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:

$$C_p^0\ (\mathrm{cal\ g^{-1}\ K^{-1}}) = 0.157376 + 1.60907 \times 10^{-4}\,T - 8.94787 \times 10^{-8}\,T^2 - 6.18535 \times 10^{-13}\,T^3 \qquad (1)$$

For temperatures between 770 K and 1500 K:

$$C_p^0\ (\mathrm{cal\ g^{-1} K^{-1}}) = 0.183543 + 9.52742 \times 10^{-5}\,T - 5.95103 \times 10^{-8}\,T^2 + 1.38398 \times 10^{-11}\,T^3 \qquad (2)$$

(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.

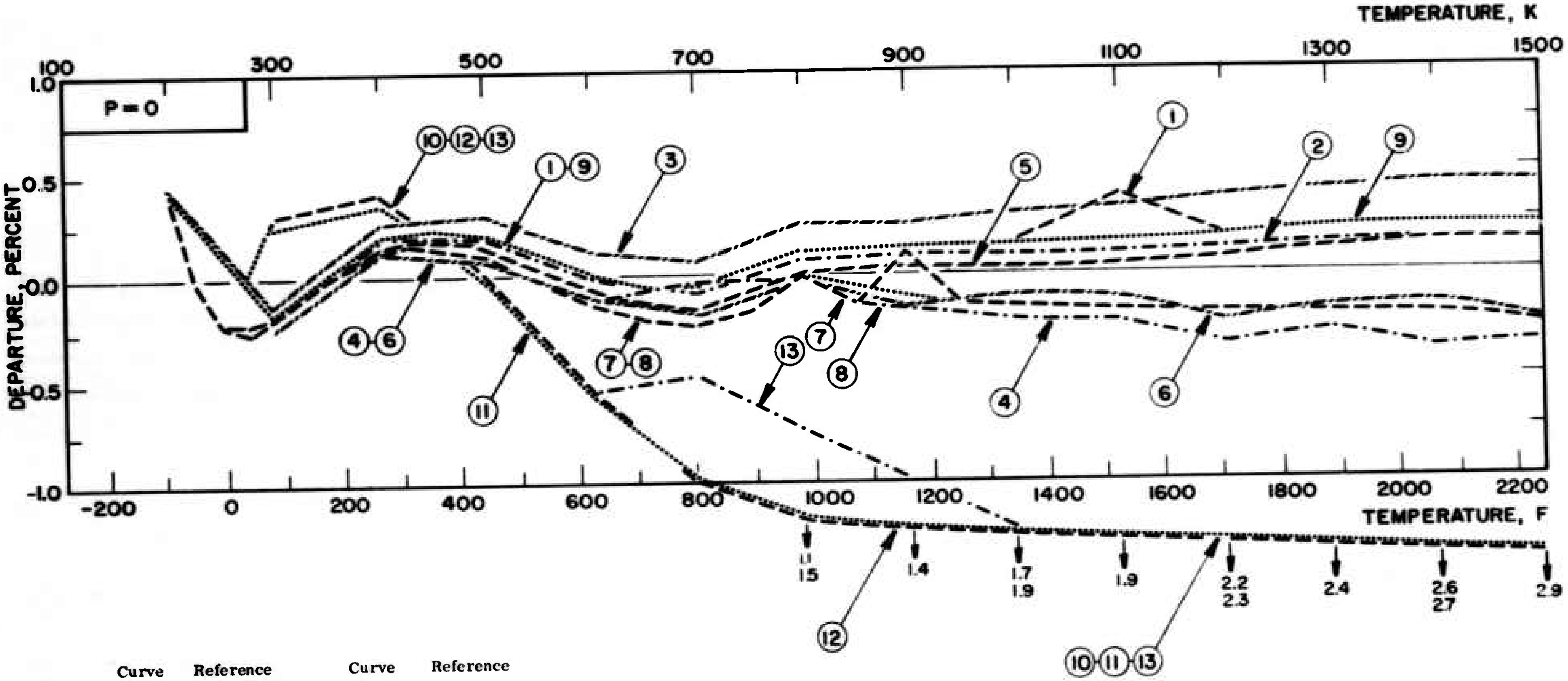
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-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	$0.192\bar{5}$	700	0.2236
20	0.1938	720	0.2241
40	0.1950	740	0.2245
60	0.1962	760	$0.22\bar{5}0$
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	$0.227\bar{5}$
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	$0.231\bar{5}$
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	$0.217\bar{5}$	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



Curve	Reference	Curve	Reference
1	72	8	493
2	137	9	298, 508
3	254	10	389
4	321	11	428
5	335	12	477
6	192, 380	13	476, 486
7	479		

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

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

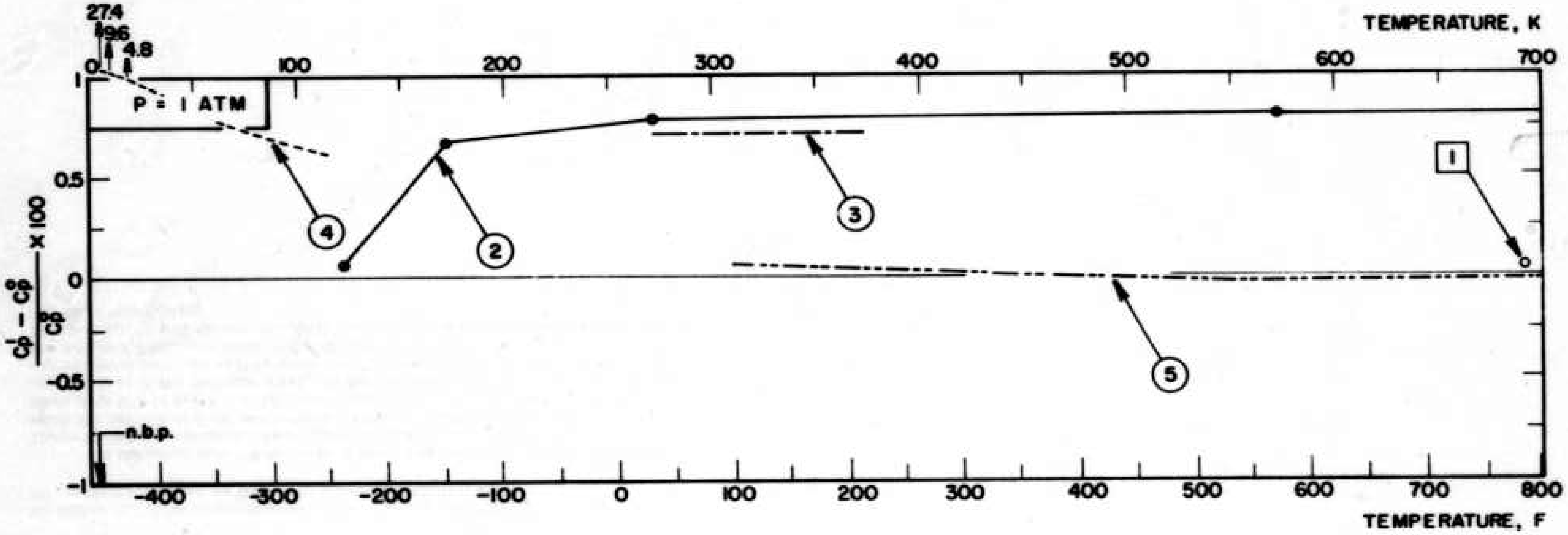
where M is molecular weight. The recommended value of C_p^0 is given by Equation (1) or

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

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).

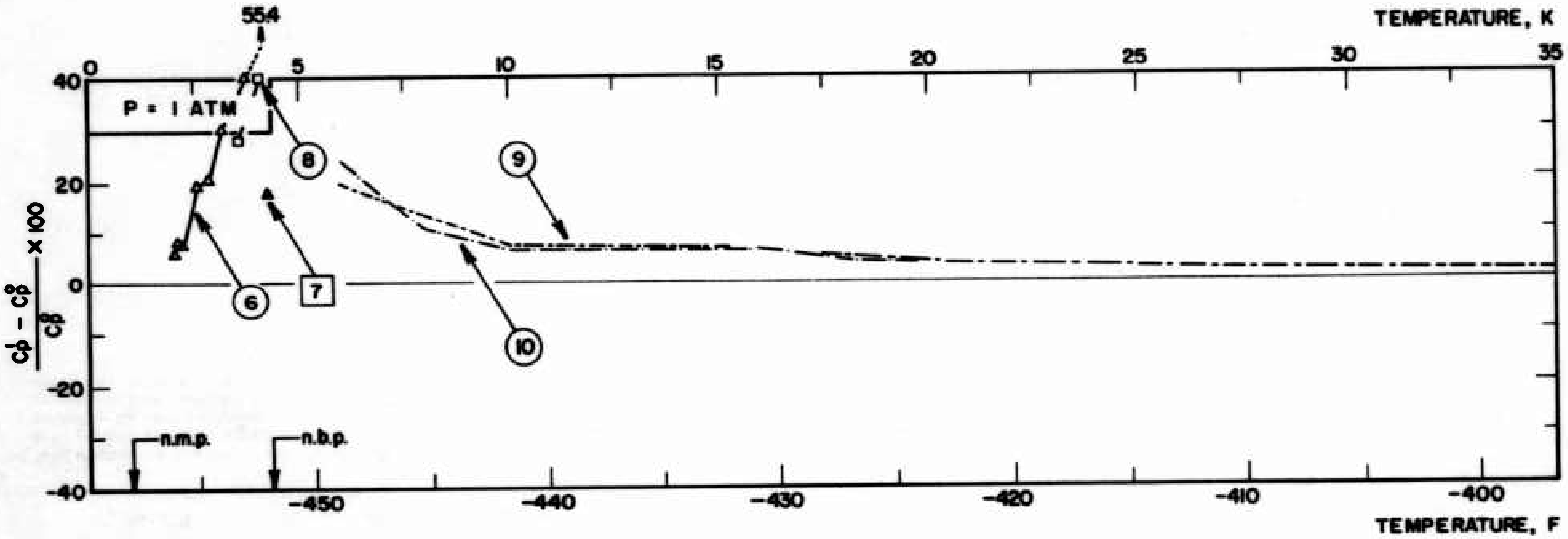
On the other hand, many sets of data at the real gas state are available. These include experimental data reported from P-V-T relations (391, 545), adiabatic expansion (319) and velocity of sound measurements (306, 547, 548). As these data fail to cover a wide temperature range, it is difficult to correlate 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



Curve	Reference
1	319
2	391
3	442
4	446
5	564

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



Curve	Reference
6	306, 547
7	545
8	548
9	283
10	452

TABLE 7 SPECIFIC HEAT AT CONSTANT PRESSURE OF HYDROGEN

DISCUSSION

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

$$C_p\ (\text{cal g}^{-1}\text{K}^{-1}) = 2.64317 - 0.230392\ T + 1.3435\bar{5} \times 10^{-2}T^2 - 1.45134 \times 10^{-4}T^3 \qquad (T \text{ in K}).$$

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.

RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B $lb^{-1}F^{-1}$]

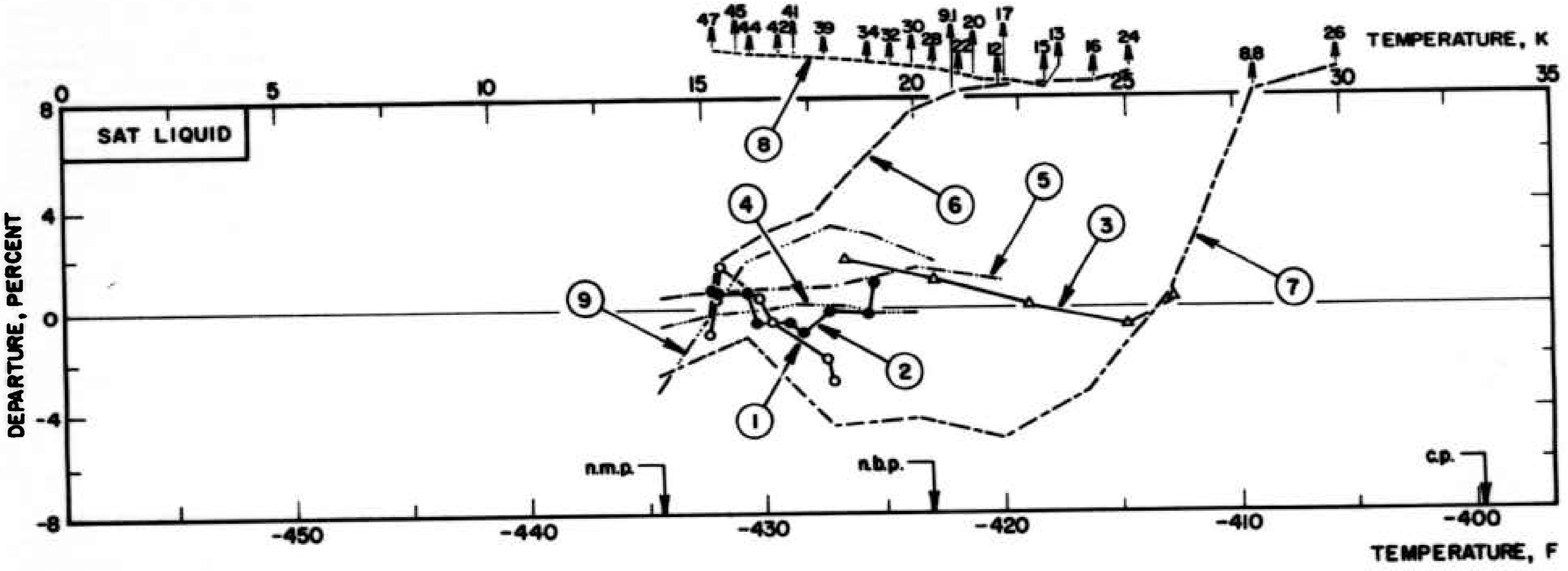
LIQUID

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

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	293
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), Sinke (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:

$$C_p^0\ (\mathrm{cal\ g^{-1}K^{-1}}) = 1.46910 + 1.60057 \times 10^{-2}T - 4.44048 \times 10^{-5}T^2 + 4.21220 \times 10^{-8}T^3 \quad (1)$$

For temperatures between 400 K and 1500 K:

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

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 (85) 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:

$$C_p\ (\mathrm{cal\ g^{-1}K^{-1}}) = 1.539\overline{5}0 + 1.50825 \times 10^{-2}T - 4.02449 \times 10^{-5}T^2 + 3.63544 \times 10^{-8}T^3 \quad (3)$$

For temperatures between 420 K and 1500 K:

$$C_p\ (\mathrm{cal\ g^{-1}K^{-1}}) = 3.58927 - 5.55096 \times 10^{-4}T + 6.9423\overline{5} \times 10^{-7}T^2 - 1.45155 \times 10^{-10}T^3 \quad (T\ \mathrm{in\ K}) \quad (4)$$

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

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

GAS

T	C_p^0	C_p
-280	2.664	2.678
-260	2.754	2.765
-240	2.836	$2.84\overline{5}$
-220	2.911	2.918
-200	2.978	$2.98\overline{5}$
-180	3.040	3.046
-160	3.095	3.101
-140	$3.14\overline{5}$	3.150
-120	3.189	$3.19\overline{5}$
-100	3.228	3.234
-80	3.263	3.269
-60	3.293	3.300
-40	3.319	3.327
-20	3.341	3.350
0	3.360	3.370
20	3.376	3.387
40	3.389	3.401
60	3.400	3.412
80	3.409	3.421
100	3.417	3.429
120	3.423	$3.43\overline{5}$
140	3.428	3.439
160	3.433	3.443
180	3.437	3.446
200	3.442	3.449
220	3.447	3.451
240	3.453	3.454
260	3.460	3.458
280	3.462	3.462

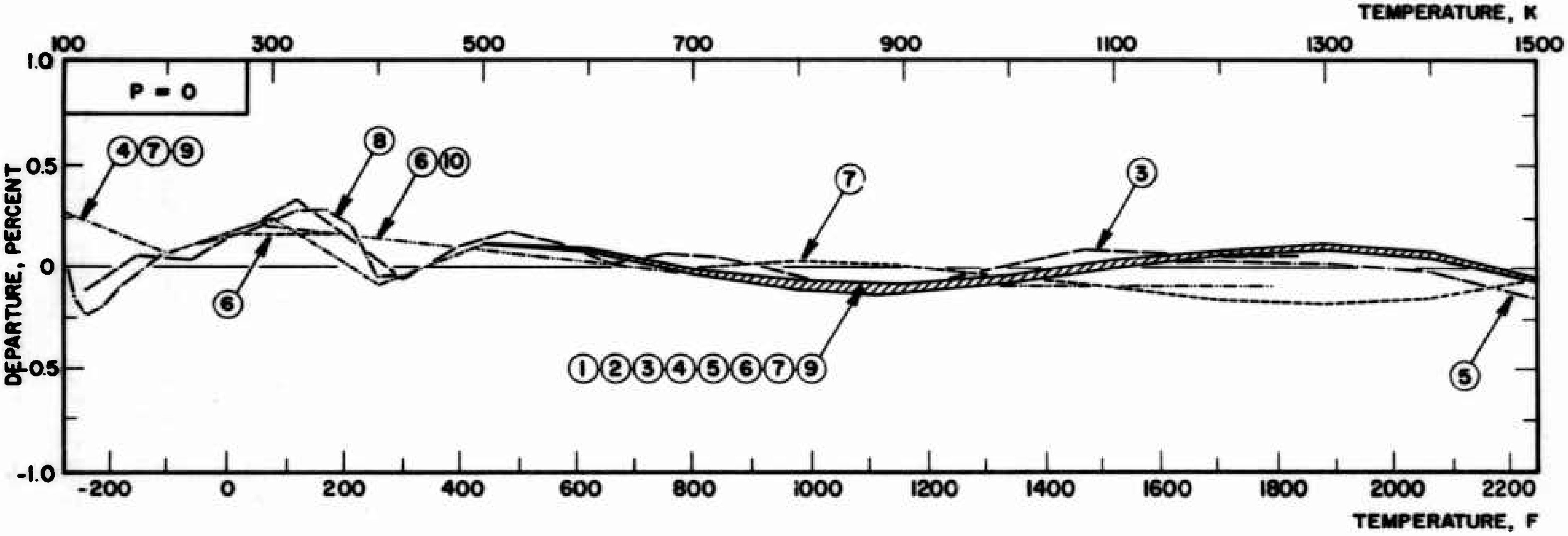
T	C_p^0	C_p
300	3.462	3.465
320	3.462	3.465
340	3.462	$3.46\overline{5}$
360	3.462	3.464
380	3.462	3.464
400	3.462	3.464
420	3.462	$3.46\overline{5}$
440	3.463	3.465
460	3.463	3.465
480	3.464	3.466
500	$3.46\overline{5}$	3.466
520	3.465	3.467
540	3.466	3.468
560	3.467	3.469
580	3.469	3.470
600	3.470	3.471
620	3.471	3.472
640	3.473	3.474
660	3.474	3.475
680	3.476	3.477
700	3.478	3.479
720	3.480	3.481
740	3.482	3.482
760	3.484	3.484
780	3.486	3.487
800	3.488	3.489
820	3.490	3.491
840	3.493	3.493
860	3.495	3.496
880	3.498	3.499

RECOMMENDED VALUES

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

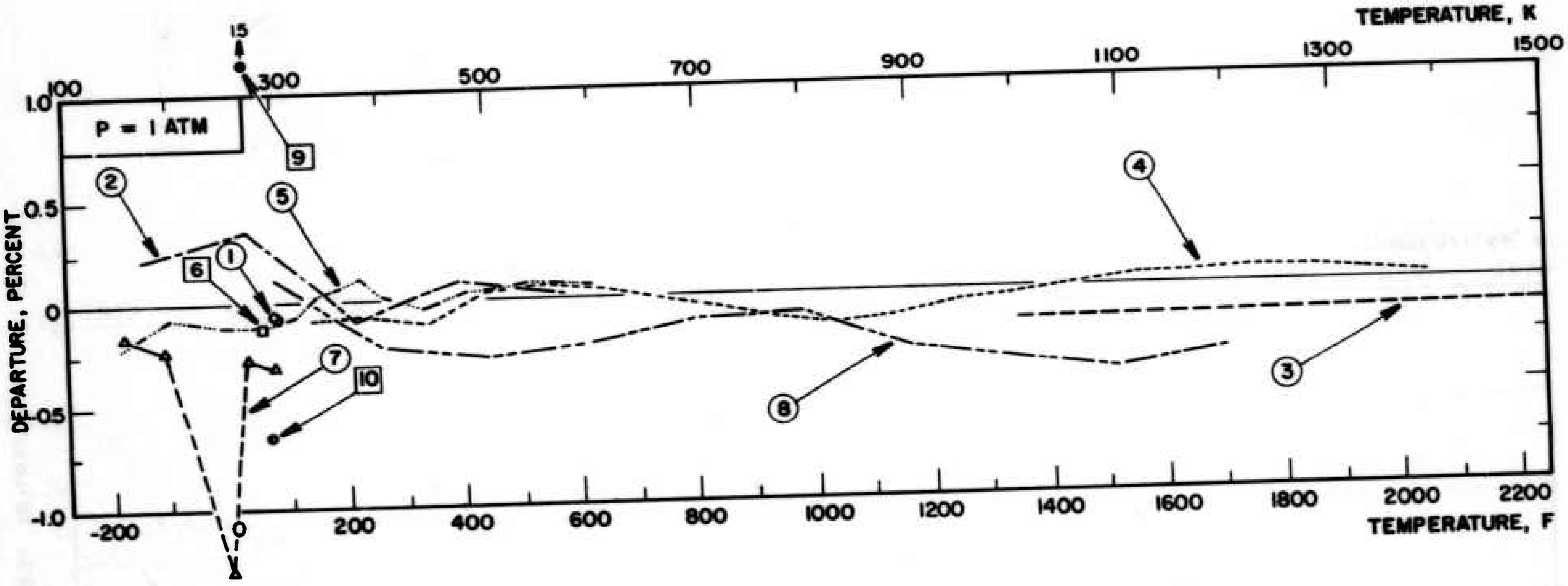
T	C_p^0	C_p
900	3.501	3.501
920	3.503	3.504
940	3.506	3.507
960	3.509	3.510
980	3.512	3.513
1000	3.515	3.516
1100	3.532	3.533
1200	3.551	3.552
1300	3.571	3.572
1400	3.593	3.594
1500	3.617	3.618
1600	3.642	3.643
1700	3.669	3.670
1800	3.696	
1900	3.725	
2000	$3.75\overline{5}$	

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



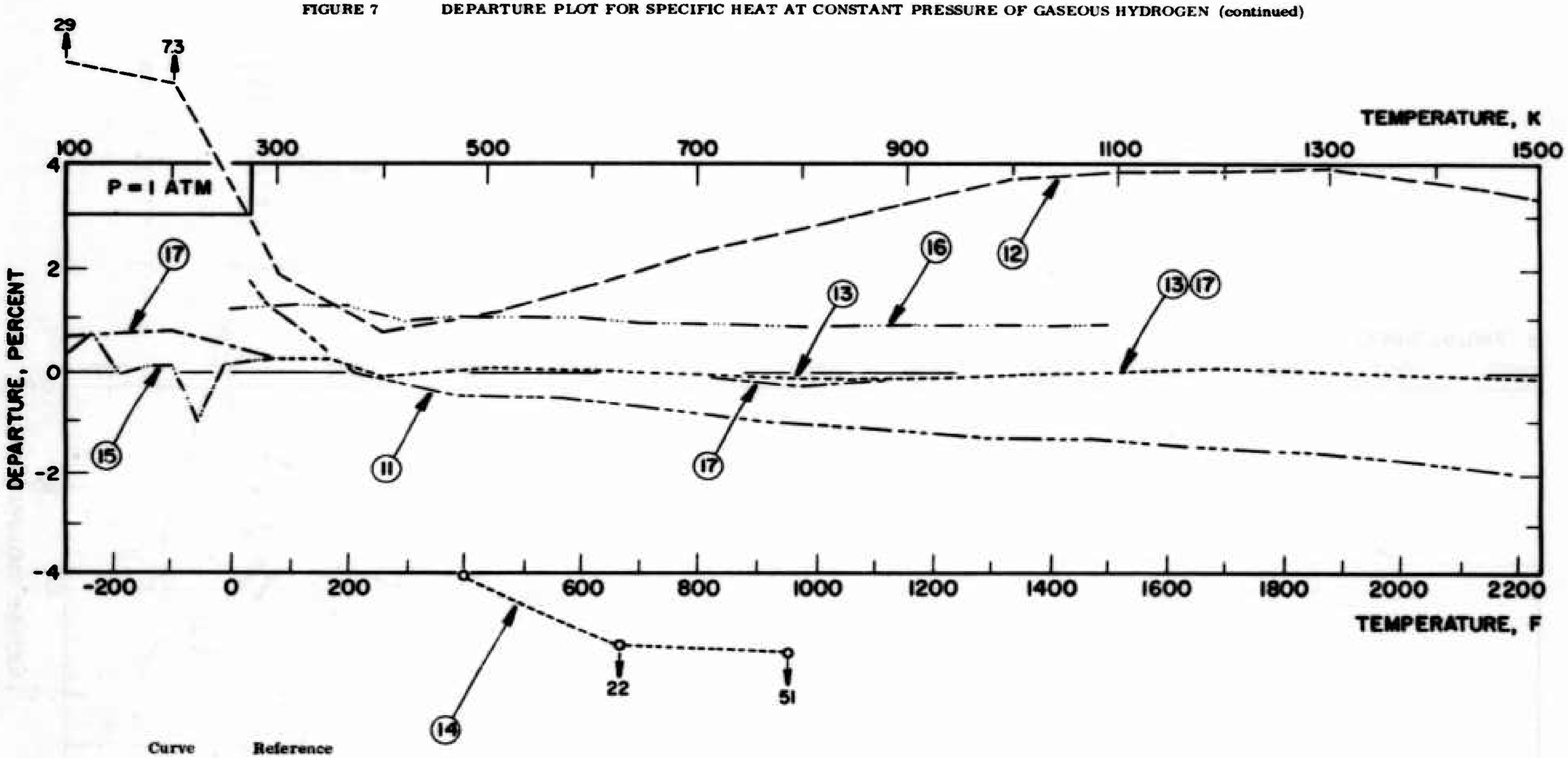
Curve	Reference
1	22, 285
2	72, 167, 192, 380 389, 426, 486
3	100
4	137, 571
5	226, 403
6	253
7	254
8	461
9	575
10	59

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



Curve	Reference
1	85
2	249
3	314
4	375, 376, 541
5	575, 132, 283, 446, 454, 457, 481
6	78
7	277
8	354
9	374
10	482

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



Curve	Reference
11	24, 278
12	93
13	304
14	319
15	339
16	357
17	501

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

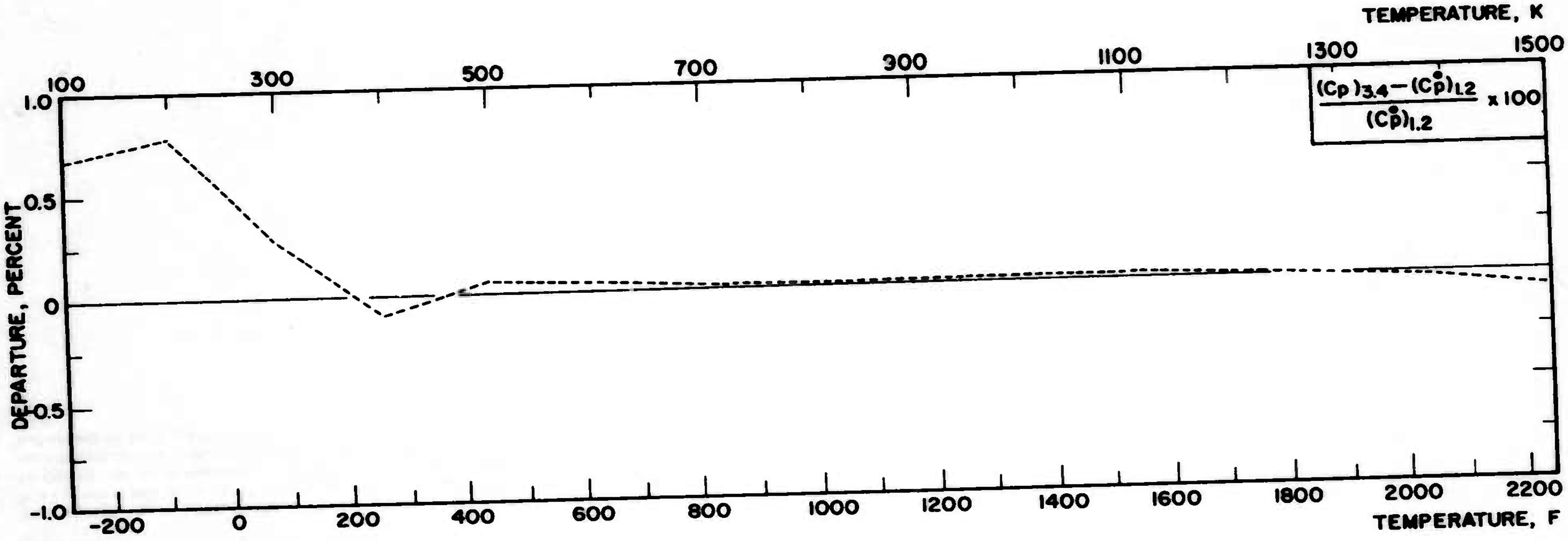


TABLE 8 SPECIFIC HEAT AT CONSTANT PRESSURE OF KRYPTON

DISCUSSION

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

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

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.

RECOMMENDED VALUES

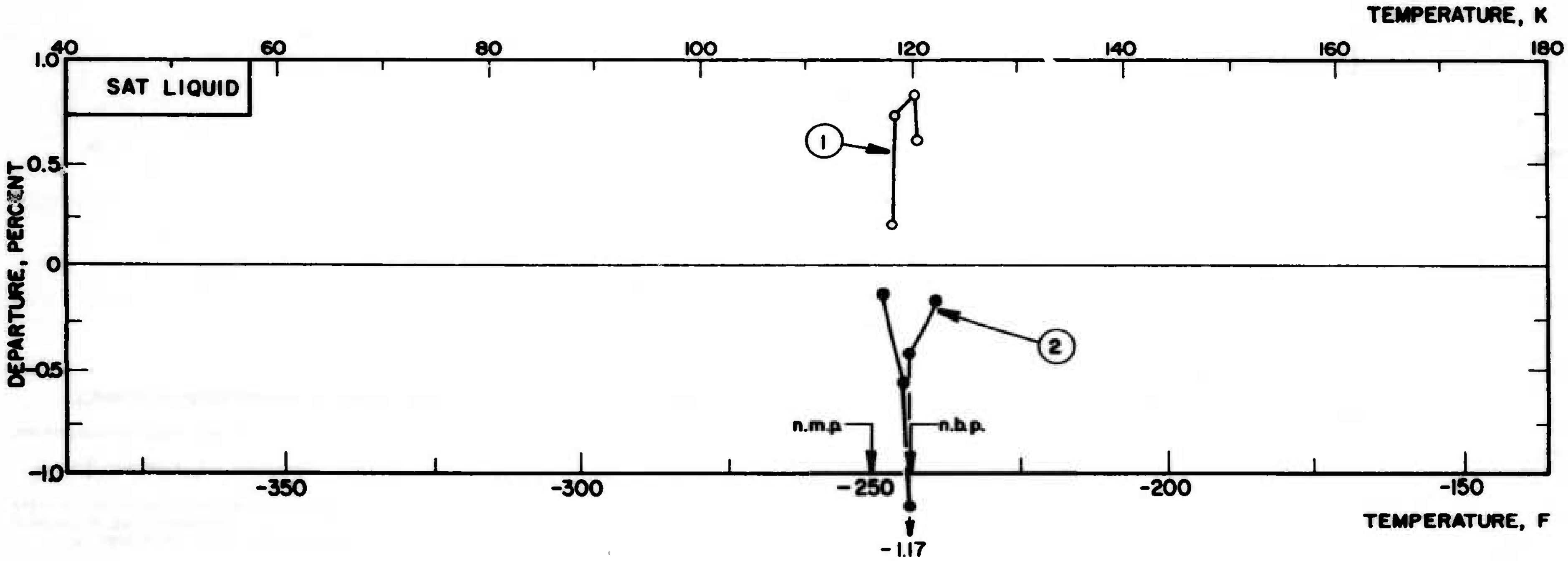
[Temperature, T, F; Specific Heat, C_p, B $lb^{-1}F^{-1}$]

LIQUID

T	C_p
-250	0.1259
-245	0.1276
-240	0.1278

n.b.p. = -244 F

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



Curve	Reference
1	289
2	294

TABLE 8 SPECIFIC HEAT AT CONSTANT PRESSURE OF KRYPTON

DISCUSSION

GAS

Information on the constant pressure specific heat of gaseous krypton is nearly nonexistant 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:

$$C_p^0\ (\mathrm{cal\ g^{-1}K^{-1}}) = \frac{5R}{2M} = \frac{5}{2}\,\frac{1.98719}{83.80} = 0.059284, \qquad (1)$$

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

$$C_p^0\ (\mathrm{Btu\ lb^{-1}F^{-1}}) = 0.05924\bar{5}\ ,$$

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 monatonic gas and the molecules do not possess any internal degrees of freedom, the molar heat capacity at the ideal gas state is given by $C_p^o = (5/2)R$, (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:

$$C_p^o\ (\mathrm{cal\ g^{-1}K^{-1}}) = \frac{5R}{2M} = \frac{5}{2}\,\frac{1.98719}{20.183} = 0.2461\overline{5}\ , \qquad (1)$$

where M is the molecular weight.

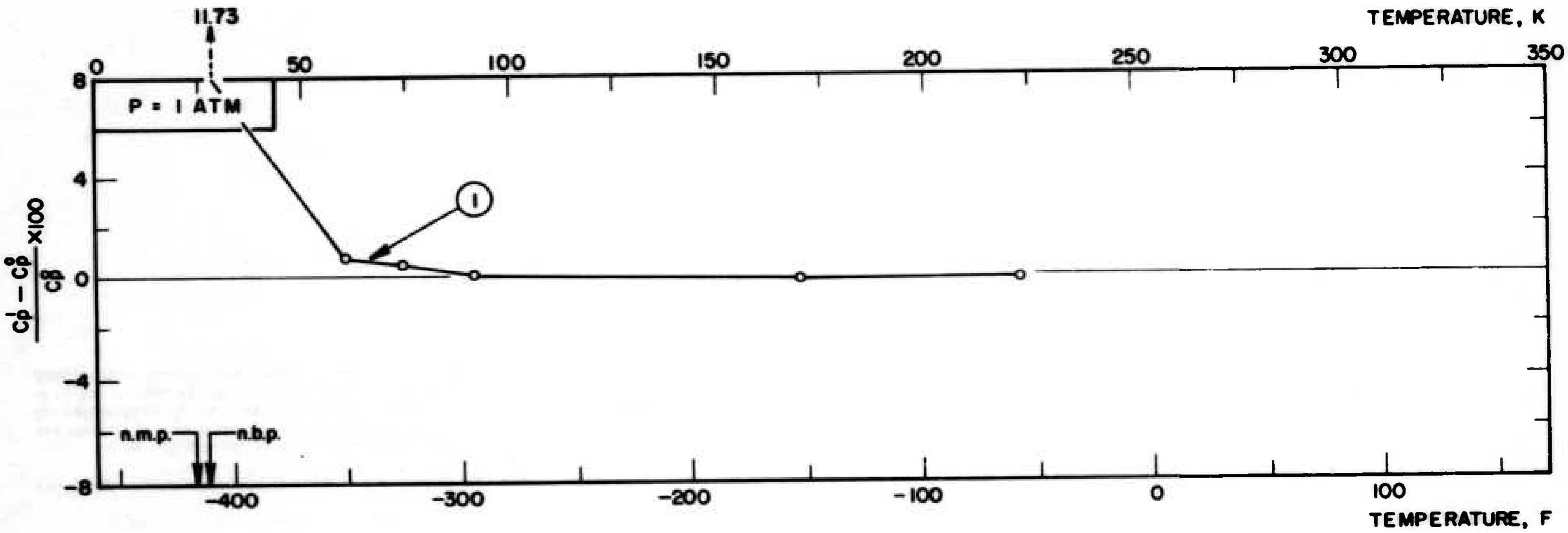
Statistical mechanical calculations (325, 435) showed that C_p^o should be constant in the temperature range from 10 K to 8000 K. The recommended value of the isobaric specific heat at the ideal gas state is given by Equation (1), or

$$C_p^o\ (\mathrm{Btu\ lb^{-1}F^{-1}}) = 0.24599$$

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

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 Giauque and Clayton (341) 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 (248) 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

$$C_p\ (\mathrm{cal\ g^{-1}K^{-1}}) = -0.530224 + 3.86307 \times 10^{-2}T - 4.97385 \times 10^{-4}T^2 + 2.17816 \times 10^{-6}T^3 \qquad (T \text{ in K}).$$

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.

RECOMMENDED VALUES

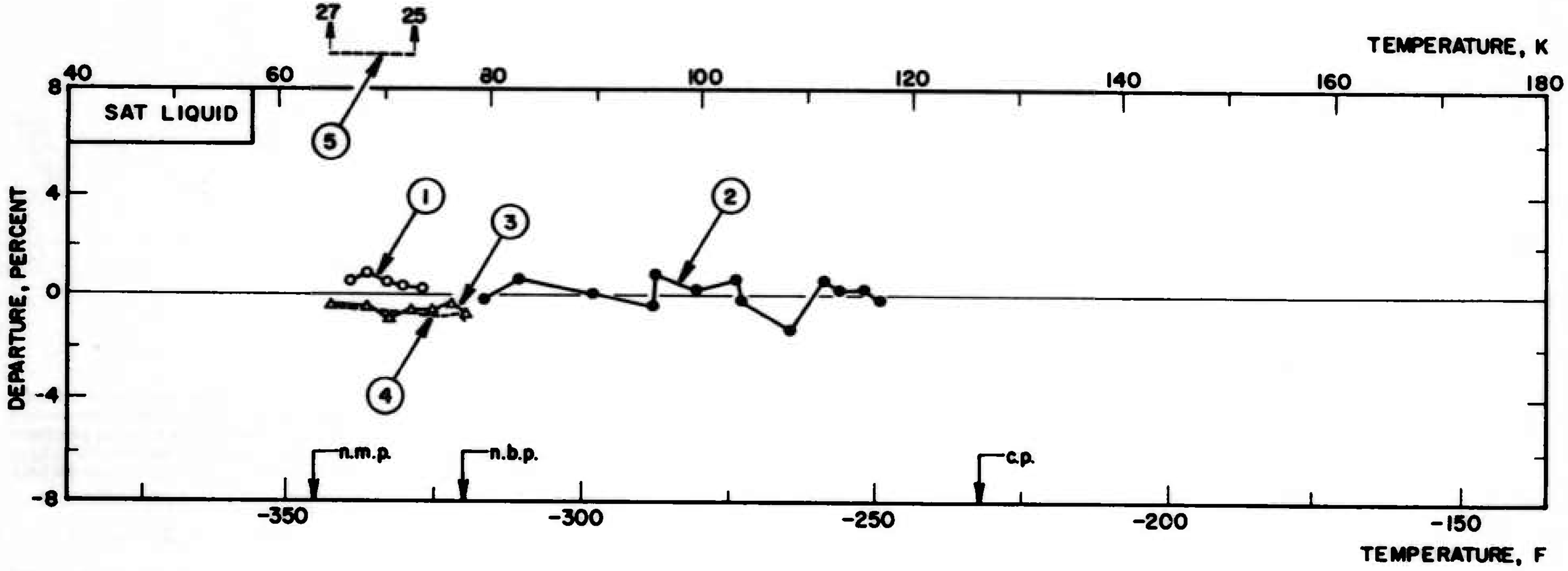
[Temperature, T, F; Specific Heat, C_p, B $\mathrm{lb^{-1}F^{-1}}$]

LIQUID

T	C_p
-340	0.4794
-335	0.4828
-330	$0.485\bar{5}$
-325	0.4877
-320	0.4899
-315	0.4922
-310	0.4949
-305	0.4984
-300	0.5028
-295	$0.508\bar{5}$
-290	0.5157
-285	0.5248
-280	0.5360
-275	0.5495
-270	0.5658
-265	$0.58\bar{5}0$
-260	0.6074
-255	0.6334
-250	0.6630
-245	0.6968
-240	0.7349

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

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 (167), 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:

$$C_p^0\ (\text{cal g}^{-1}\text{K}^{-1}) = 0.259934 - 8.42119 \times 10^{-5}T + 1.72117 \times 10^{-7}T^2 - 6.72914 \times 10^{-11}T^3 \qquad (1)$$

For temperatures between 775 K and 1500 K:

$$C_p^0\ (\text{cal g}^{-1}\text{K}^{-1}) = 0.201678 + 1.08013 \times 10^{-4}T - 3.32212 \times 10^{-8}T^2 + 2.45228 \times 10^{-12}T^3 \qquad (T \text{ in K}) \qquad (2)$$

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 too 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:

$$C_p\ (\text{Cal g}^{-1}\text{K}^{-1}) = 0.261365 - 9.01034 \times 10^{-5}T + 1.80323 \times 10^{-7}T^2 - 7.08987 \times 10^{-11}T^3 \qquad (3)$$

For temperatures between 780 K and 1500 K:

$$C_p\ (\text{cal g}^{-1}\text{K}^{-1}) = 0.200469 + 1.10194 \times 10^{-4}T - 3.37414 \times 10^{-8}T^2 + 2.21178 \times 10^{-12}T^3 \qquad (T \text{ in K}) \qquad (4)$$

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)

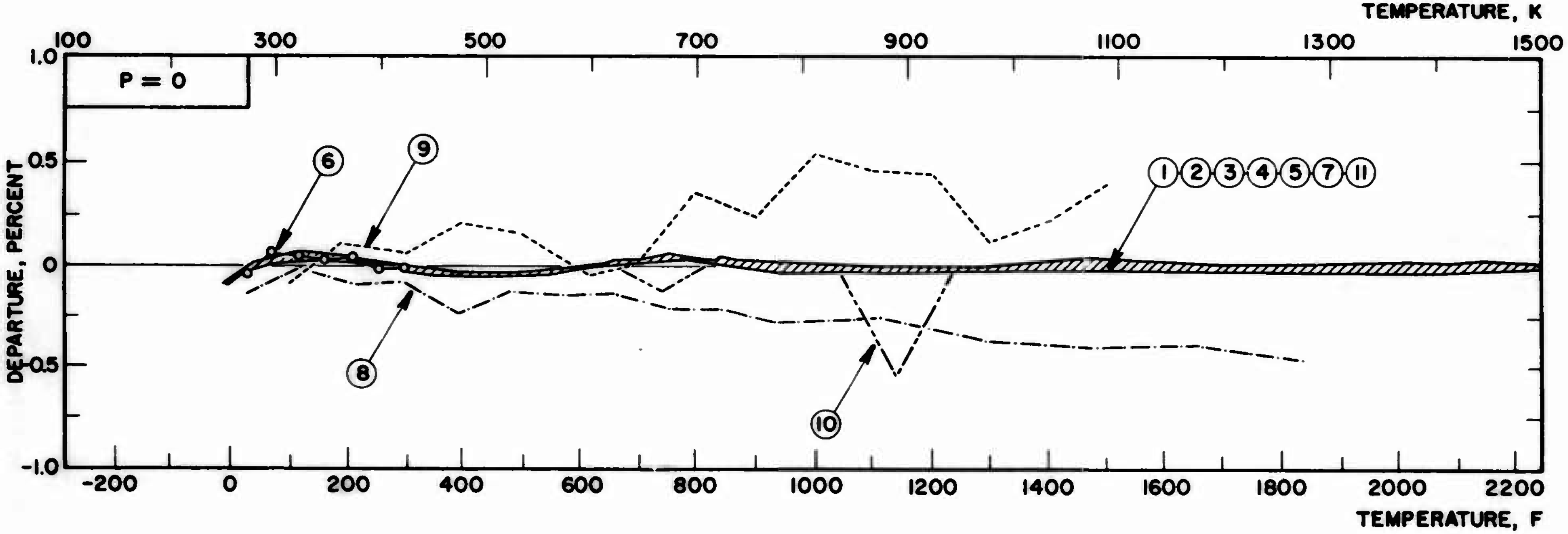
RECOMMENDED VALUES

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

GAS

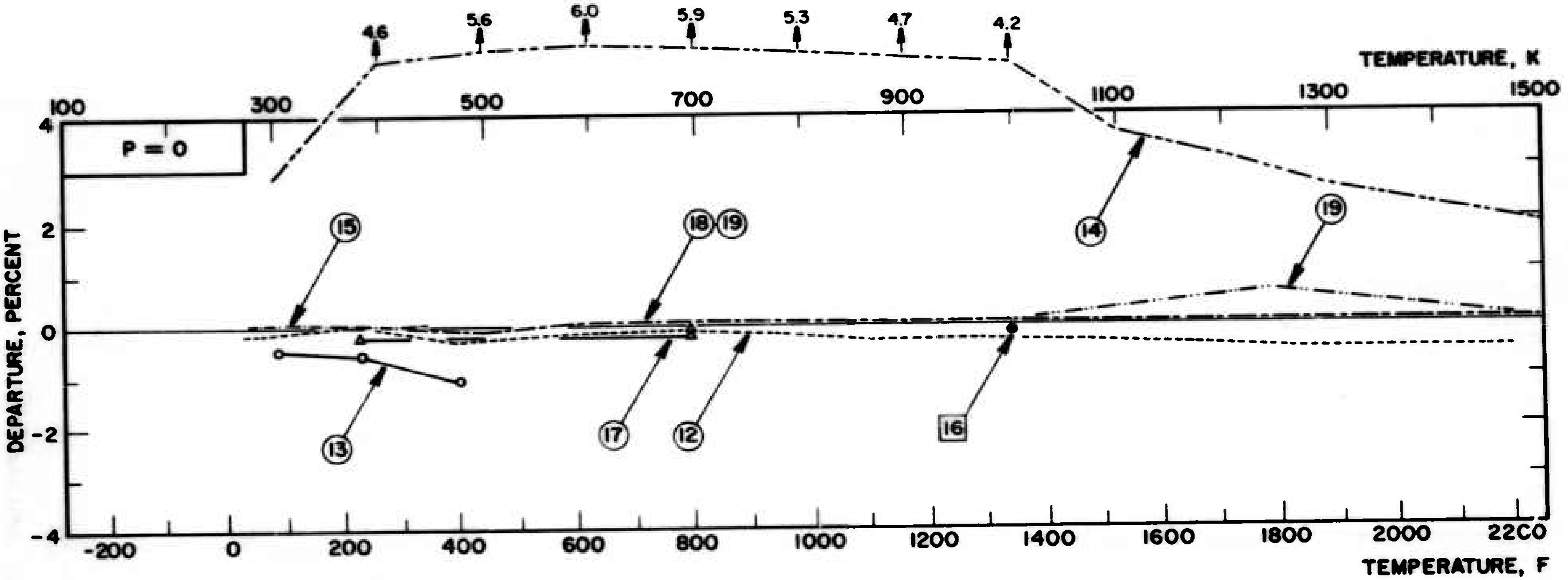
T	C_p^0	C_p	T	C_p^0	C_p
0	0.24837	0.2488	700	0.25896	0.2590
20	0.24828	0.2487	720	0.25956	0.2596
40	0.24822	0.2486	740	0.26017	0.2603
60	0.24819	0.2485	760	0.26079	0.2609
80	0.24818	$0.248\overline{5}$	780	0.26142	0.2615
100	0.24820	$0.248\overline{5}$	800	0.26206	0.2622
120	0.24825	0.2485	820	0.26271	0.2628
140	0.24833	0.2486	840	0.26336	$0.263\overline{5}$
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	$0.265\overline{5}$
220	0.24889	0.2491	920	0.26603	0.2661
240	0.24909	0.2493	940	0.26656	0.2668
260	0.24931	$0.249\overline{5}$	960	0.26723	0.2673
280	0.24956	0.2497	980	0.26790	0.2680
300	0.24983	$0.2\overline{5}00$	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	$0.287\overline{5}0$	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	$0.293\overline{5}$
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



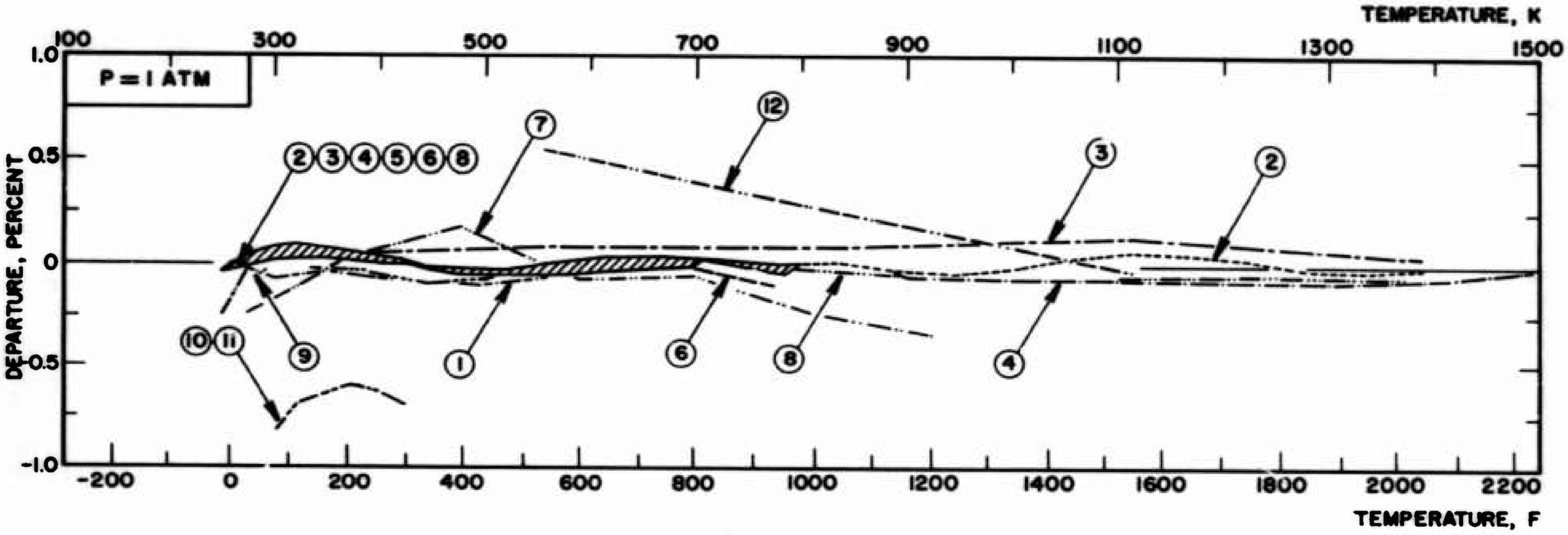
Curve	Reference
1	59, 167, 226, 426, 429
2	72, 254, 380, 389
3	253
4	351
5	362
6	466
7	568, 575
8	100
9	360
10	368
11	403

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



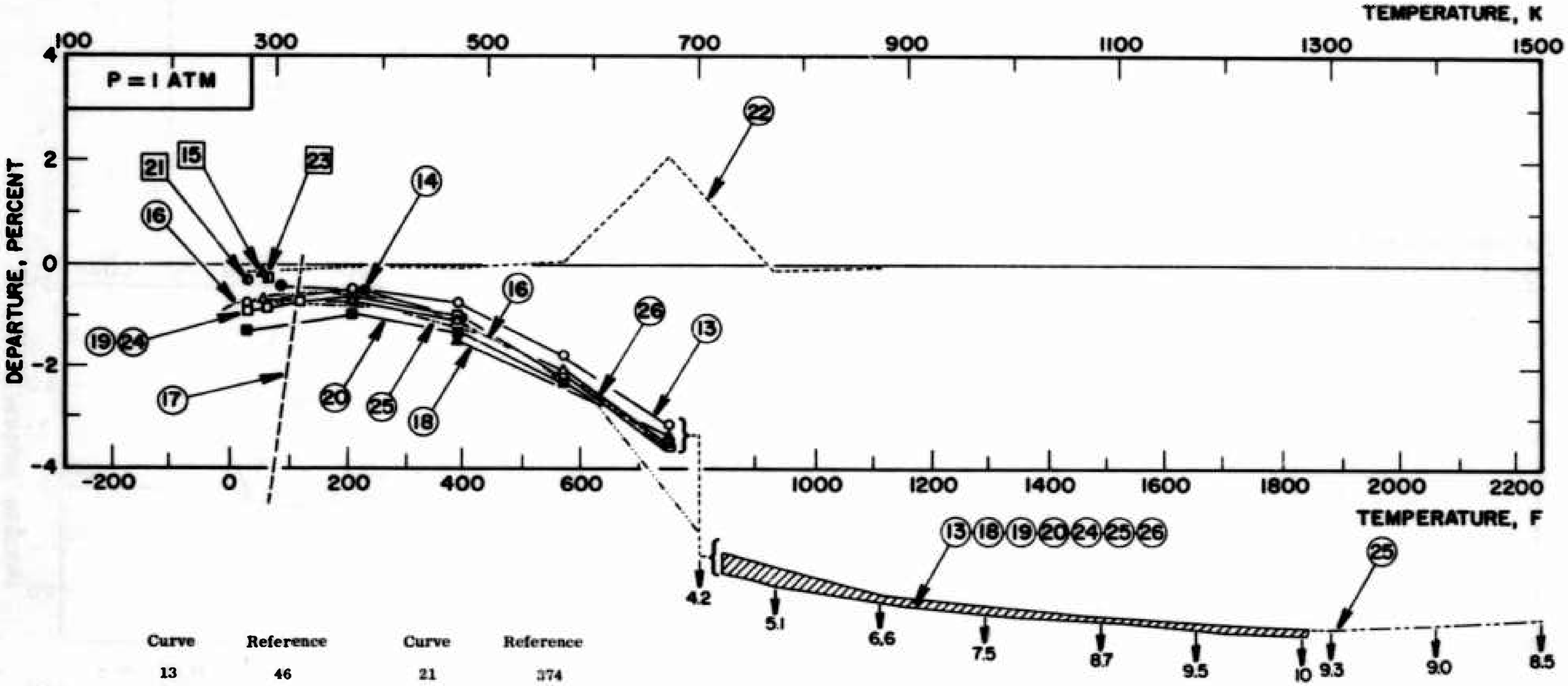
Curve	Reference
12	24, 278
13	56
14	93
15	178
16	266
17	319
18	395
19	501

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)



Curve	Reference	Curve	Reference
13	46	21	374
14	56	22	481
15	78	23	482
16	252	24	507
17	279	25	519
18	286	26	520
19	307		
20	309		

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

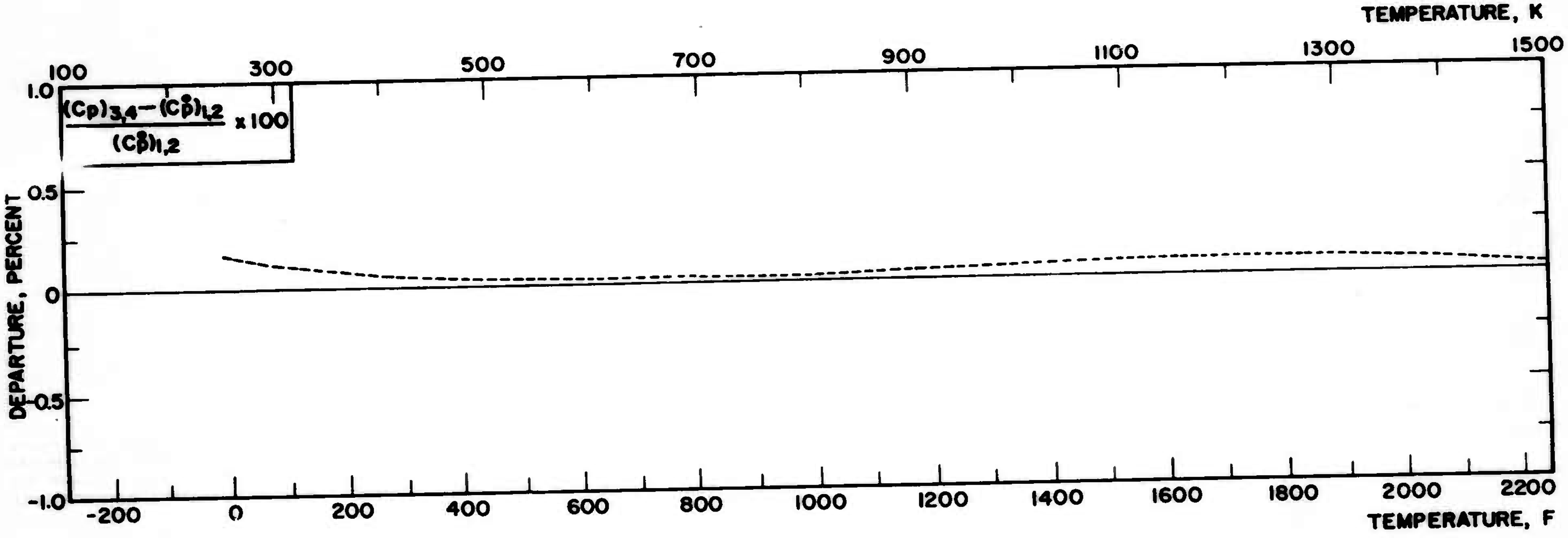


TABLE 11 SPECIFIC HEAT AT CONSTANT PRESSURE OF OXYGEN

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

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}) = 0.391168 + 4.98693 \times 10^{-5}T \qquad (T \text{ in K}).$$

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.

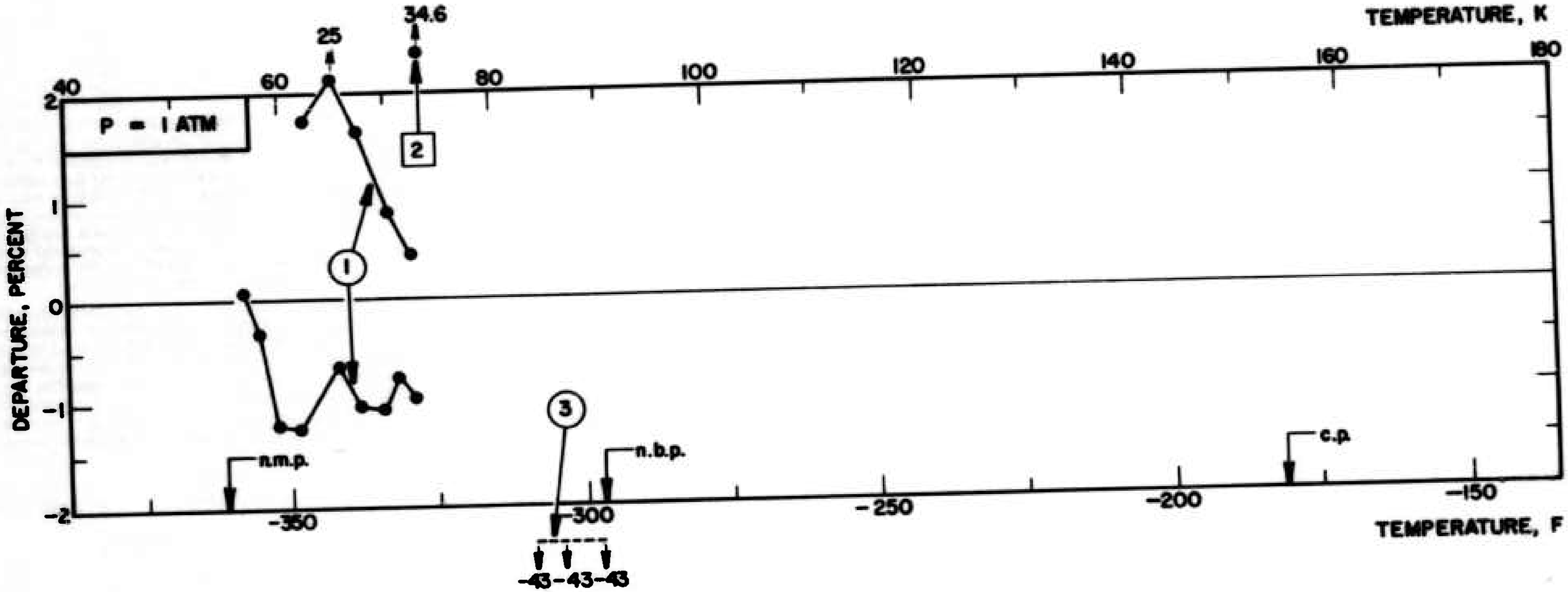
RECOMMENDED VALUES

(Temperature, T, F; Specific Heat, C_p, B $lb^{-1}F^{-1}$)

LIQUID

T	C_p^l
-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), Faltin (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:

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

For temperatures between 760 K and 1500 K:

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

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^0_p 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:

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

For temperatures between 790 K and 1500 K:

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

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 (184, 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)

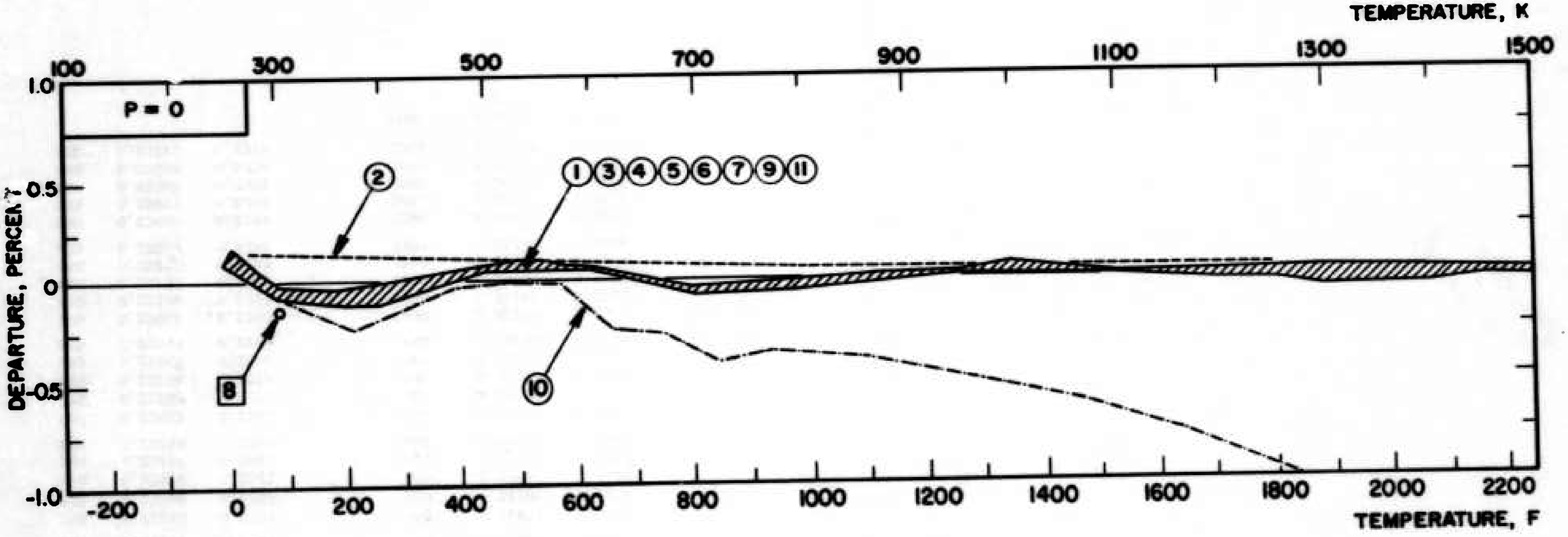
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p° and C_p, B lb^{-1} F^{-1}]

GAS

T	C_p°	C_p	T	C_p°	C_p
0	0.21764	0.2183	600	0.2385$\bar{5}$	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	0.2193$\bar{5}$	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	0.2286$\bar{5}$	0.2286	960	0.25128	0.2513
380	0.22944	0.2294	980	0.25184	0.2518
400	0.2302$\bar{5}$	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	0.26$\bar{5}$0
540	0.2360$\bar{5}$	0.2362	1700	0.26632	0.266$\bar{5}$
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

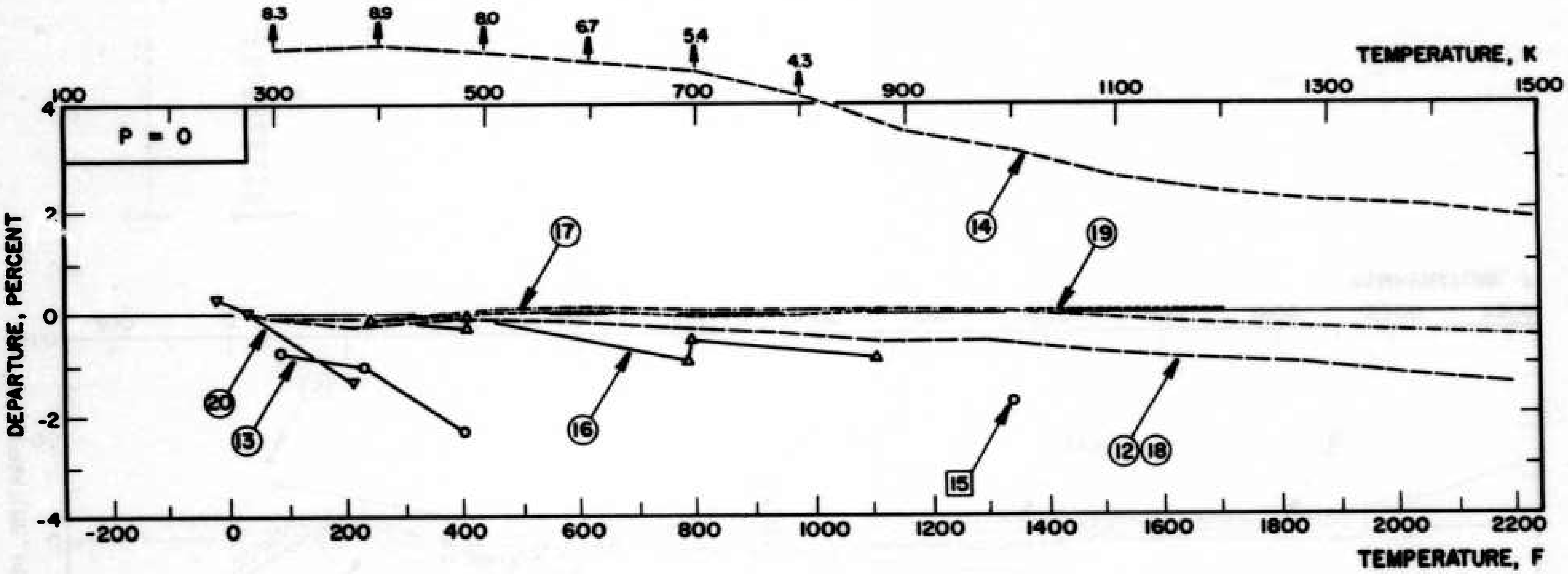
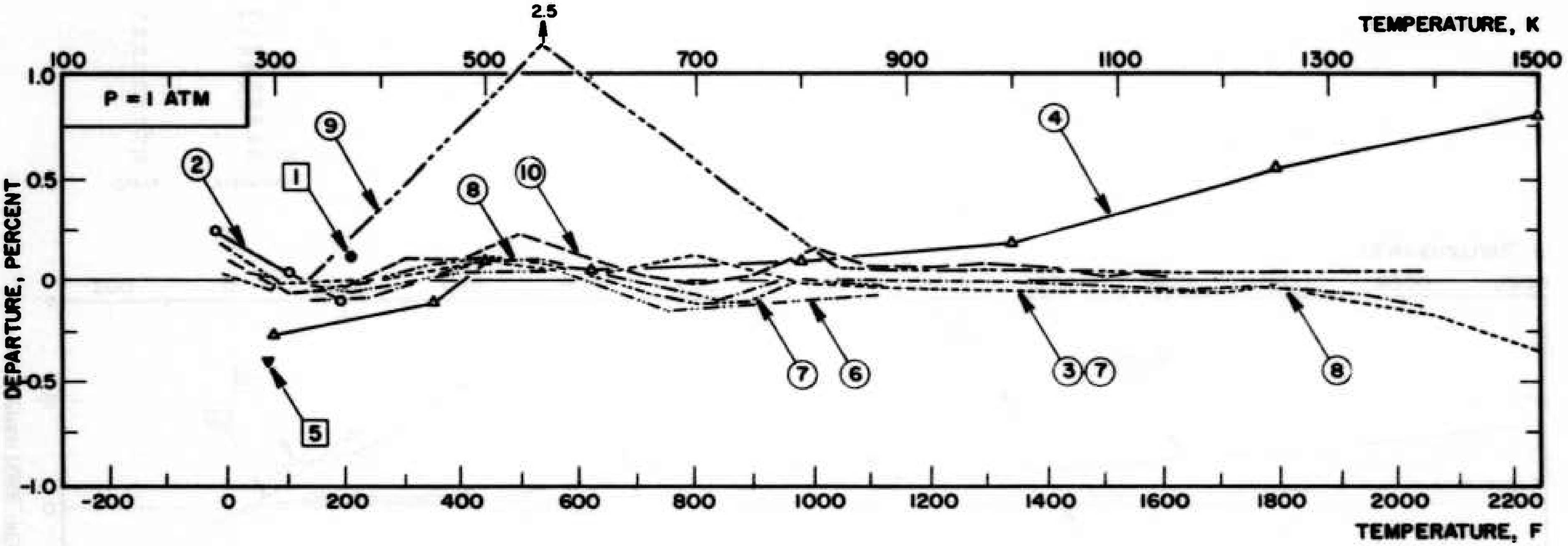


FIGURE 11 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS OXYGEN (continued)

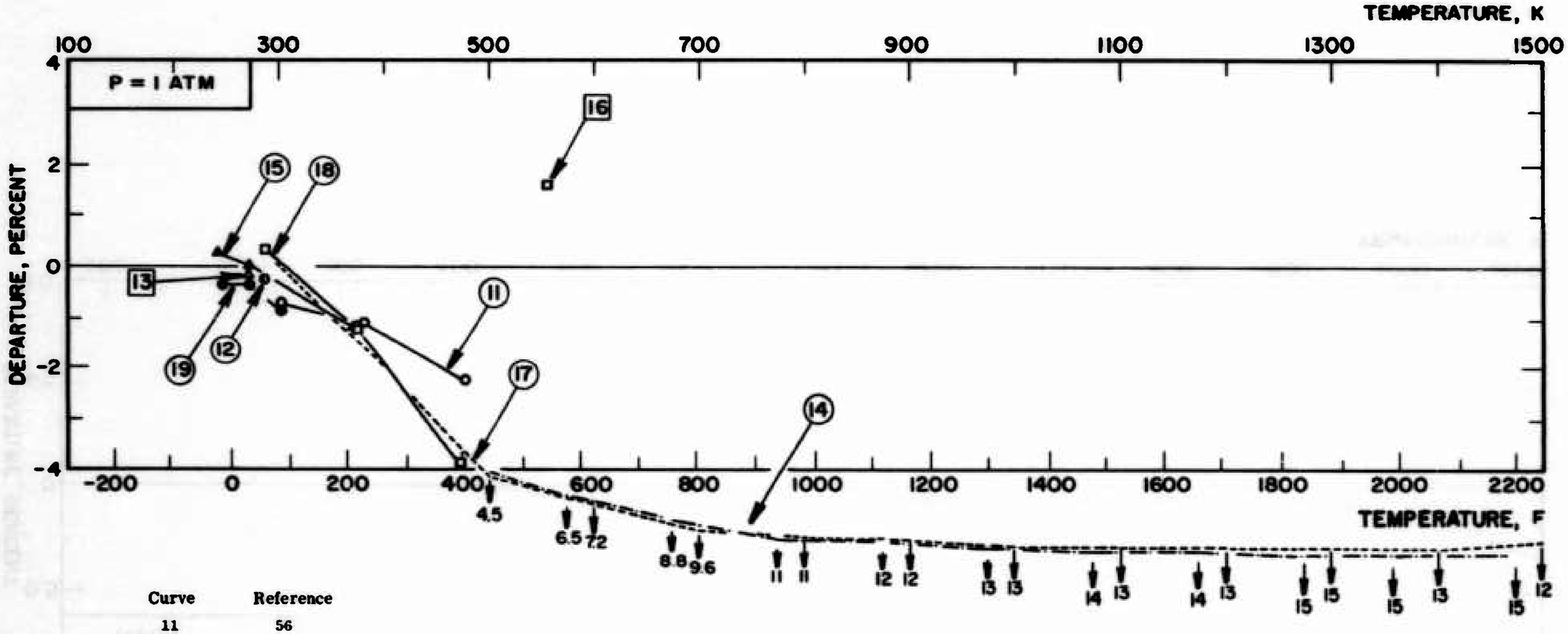
Curve	Reference
12	24, 278
13	56
14	93
15	266
16	319
17	397, 501
18	398
19	426
20	453

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



Curve	Reference
1	144
2	223
3	274
4	444
5	482
6	553
7	567, 575
8	375
9	376
10	541

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



Curve	Reference
11	56
12	78
13	374
14	422
15	453
16	512
17	519
18	520
19	551

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

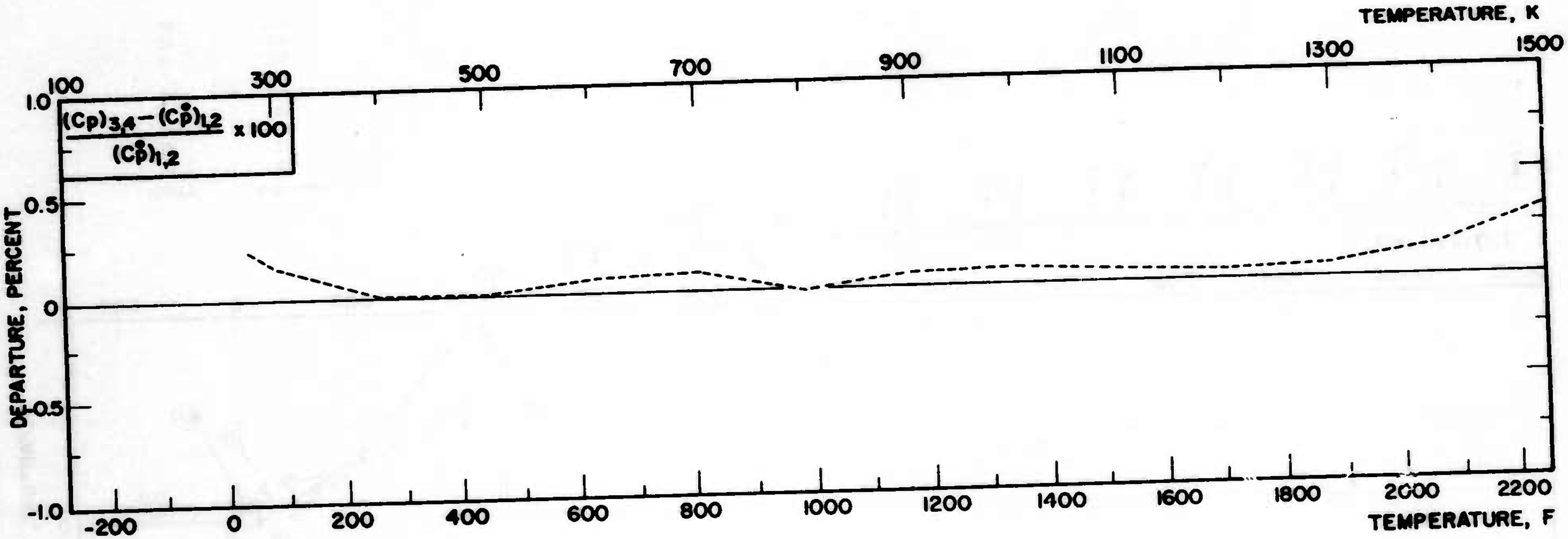


TABLE 12 SPECIFIC HEAT AT CONSTANT PRESSURE OF XENON

DISCUSSION

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:

$$C_p\ (\mathrm{cal\ g^{-1}K^{-1}}) = -0.120492 + 2.51711 \times 10^{-4}T + 1.91008 \times 10^{-5}T^2 - 8.04351 \times 10^{-8}T^3 \qquad (T \text{ in K}).$$

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.

RECOMMENDED VALUES

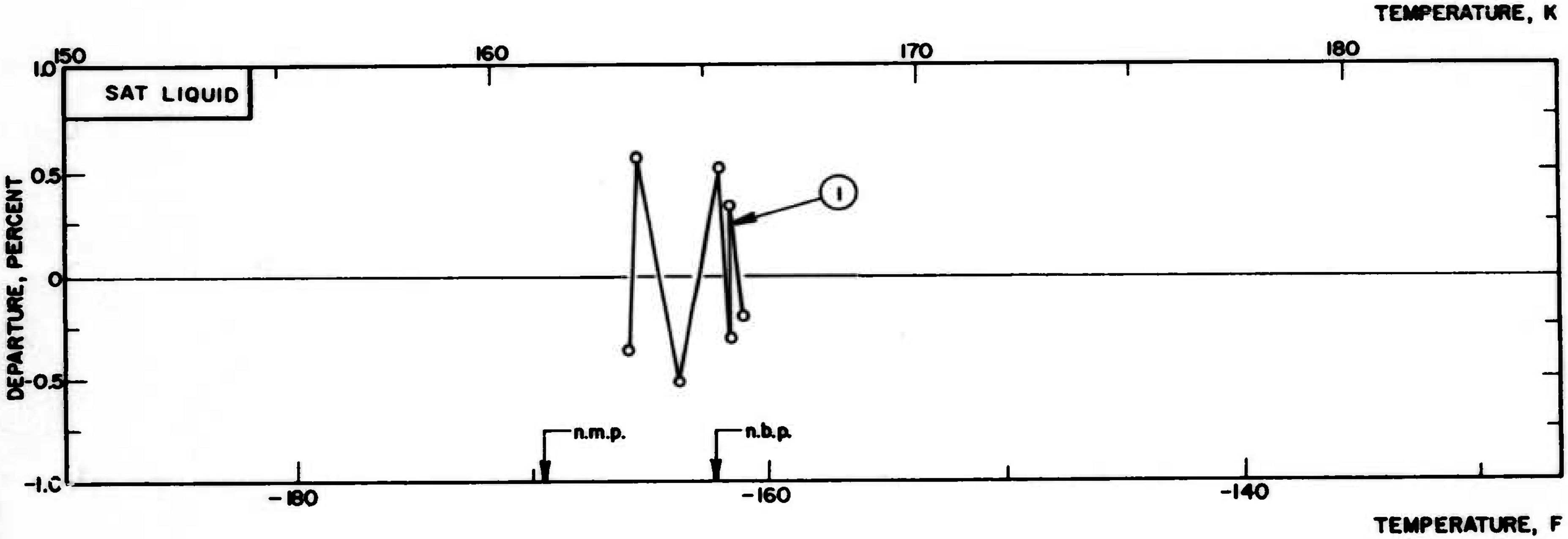
[Temperature, T, F; Specific Heat, C_p, B $lb^{-1}F^{-1}$]

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

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:

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

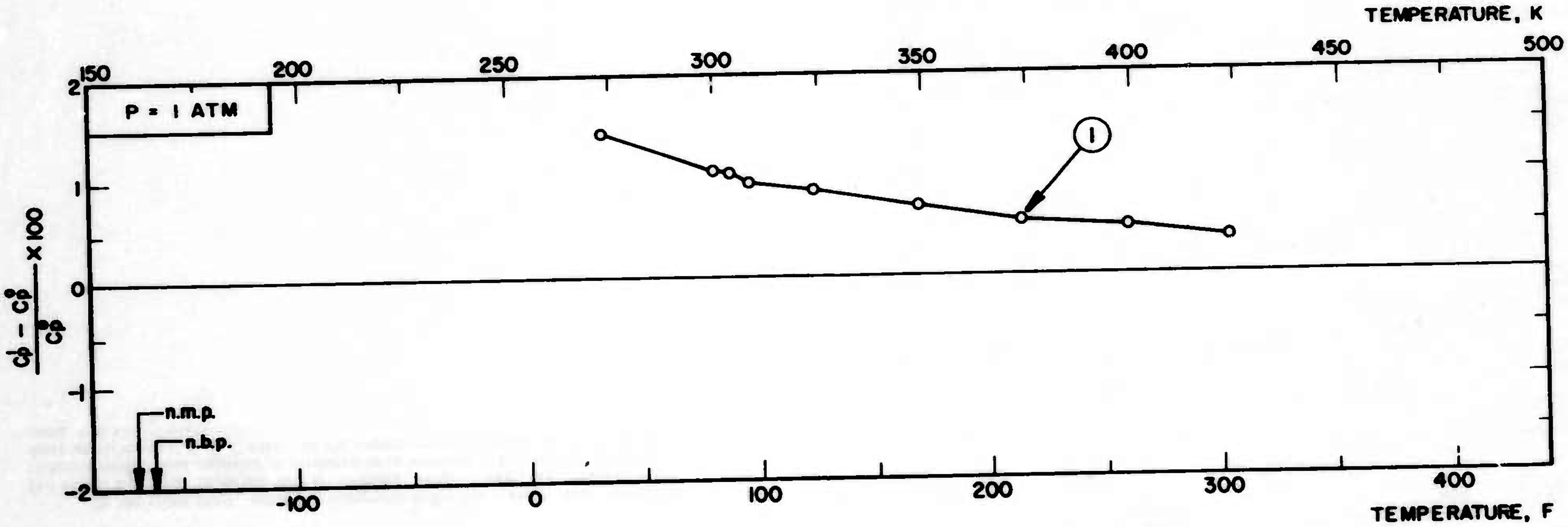
where M is the molecular weight.

Kolsky, et al. (435) showed that C_p^0 remains constant in the temperature range from 10 K to 5200 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 Giauque (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

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

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

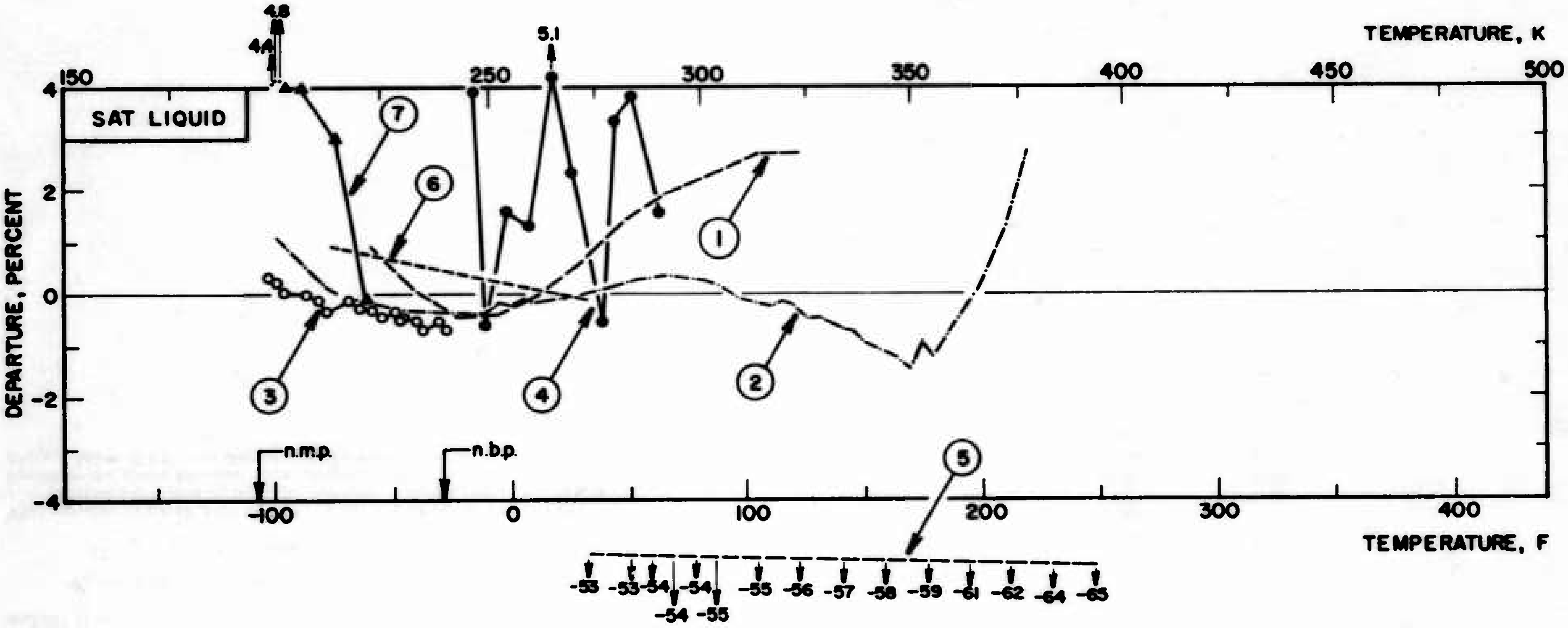
[Temperature, T, F; Specific Heat, C_p, B lb^{-1}F^{-1}]

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.b.p. = -28 F

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



Curve	Reference
1	249
2	478
3	484
4	43
5	198
6	216
7	317

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:

$$C_p^\circ\ (\text{cal g}^{-1}\text{K}^{-1}) = 0.46575\bar{0} - 1.96818 \times 10^{-4}T + 1.30052 \times 10^{-6}T^2 - 8.66281 \times 10^{-10}T^3 \qquad (1)$$

For temperatures between 630 K and 1500 K:

$$C_p^\circ\ (\text{cal g}^{-1}\text{K}^{-1}) = 0.32079\bar{5} + 5.72260 \times 10^{-4}T - 9.24803 \times 10^{-8}T^2 - 1.27816 \times 10^{-11}T^3 \quad (T \text{ in K}) \qquad (2)$$

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. Emperical 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:

$$C_p\ (\text{cal g}^{-1}\text{K}^{-1}) = 0.640706 - 1.24\bar{5}00 \times 10^{-3}T + 3.45991 \times 10^{-6}T^2 - 2.3485\bar{5} \times 10^{-9}T^3 \quad (T \text{ in K}) \qquad (3)$$

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

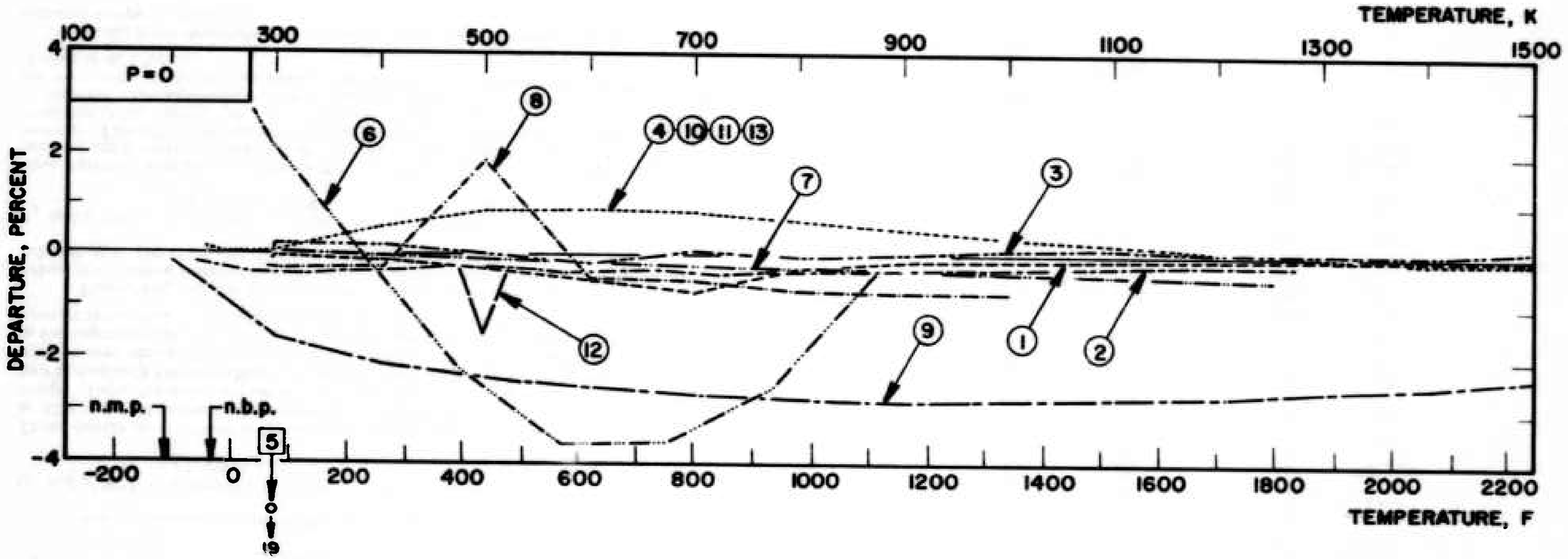
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

GAS

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

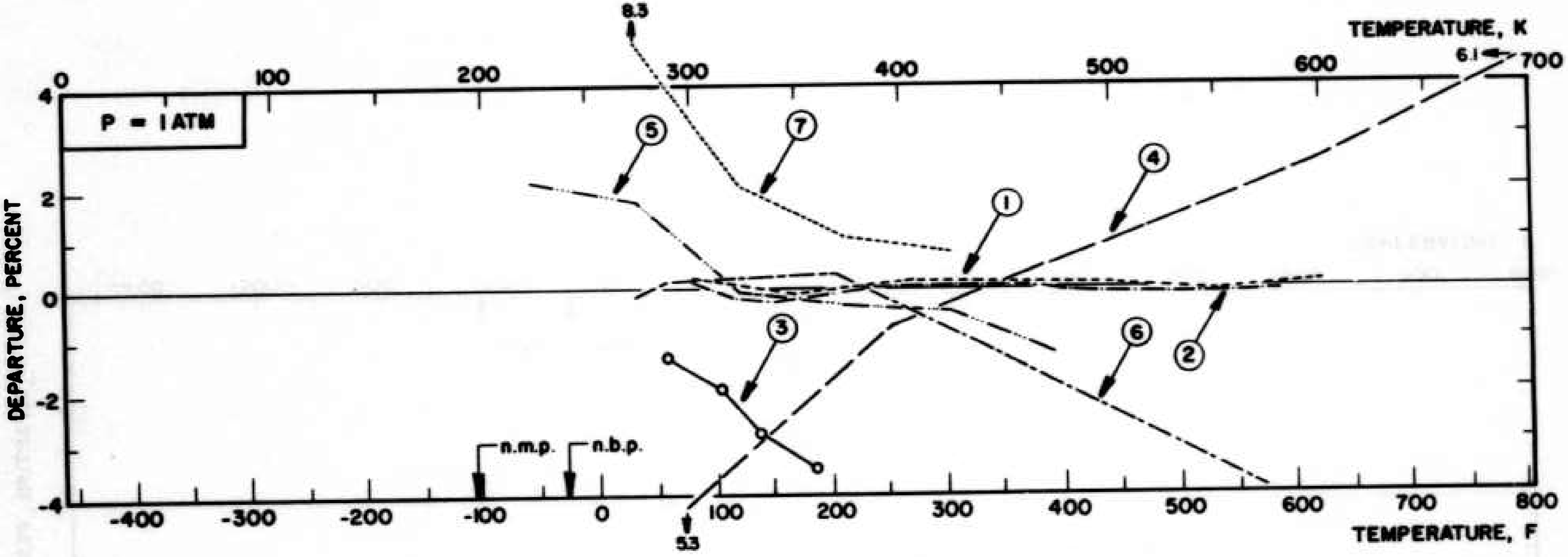
n.b.p. = -28 F

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



Curve	Reference	Curve	Reference
1	72	8	213
2	100	9	254
3	167	10	350
4	107, 371	11	372
5	18	12	407
6	24	13	535
7	59		

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

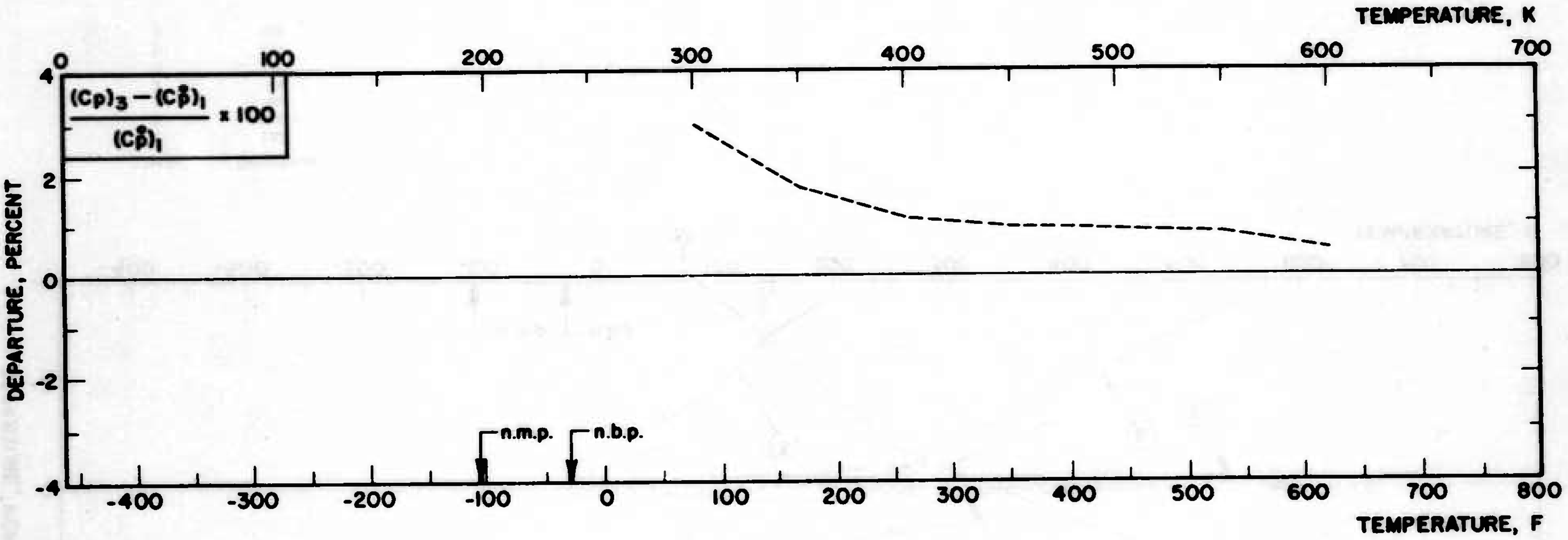


TABLE 14 SPECIFIC HEAT AT CONSTANT PRESSURE OF BORON TRIFLUORIDE

DISCUSSION

LIQUID

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:

$$C_p\ (\text{cal g}^{-1}\text{K}^{-1}) = 0.326803 + 5.5826\overline{5} \times 10^{-5}T + 2.05148 \times 10^{-6}T^2 - 5.35251 \times 10^{-9}T^3 \qquad (T \text{ in K}).$$

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.

RECOMMENDED VALUES

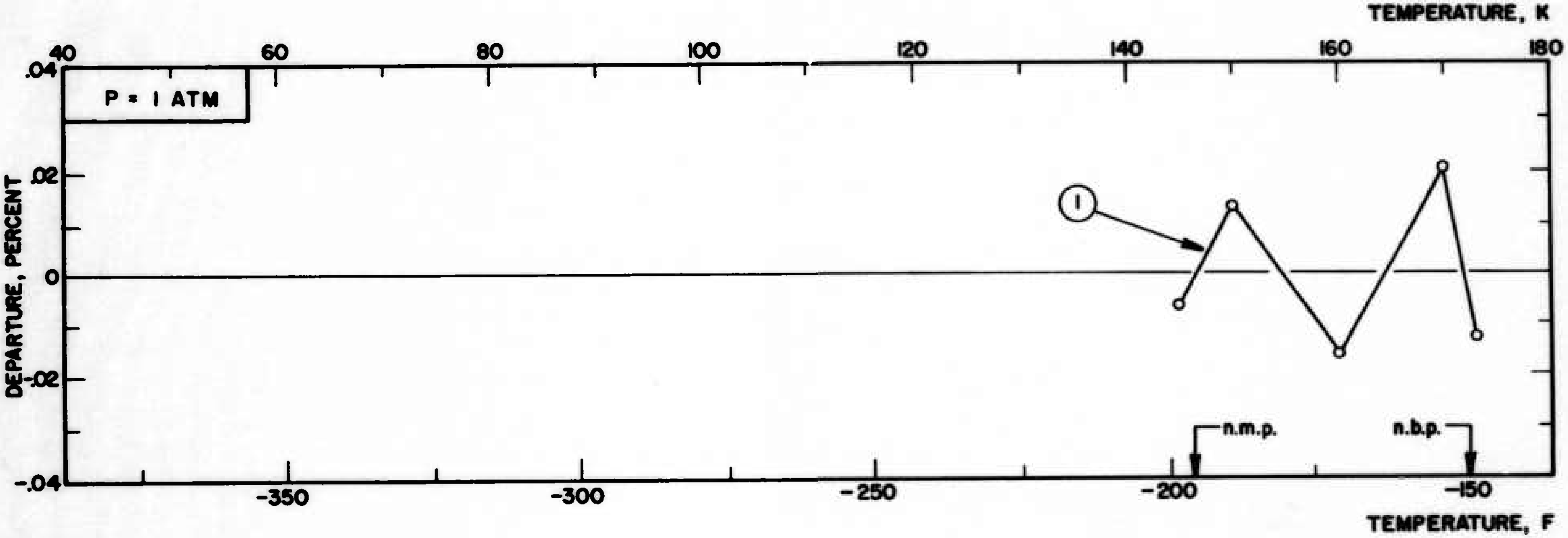
[Temperature, T, F; Specific Heat, C_p, B lb^{-1}F^{-1}]

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

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:

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

For temperatures between 600 K and 1500 K:

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

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 $0.1\overline{5}$ 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

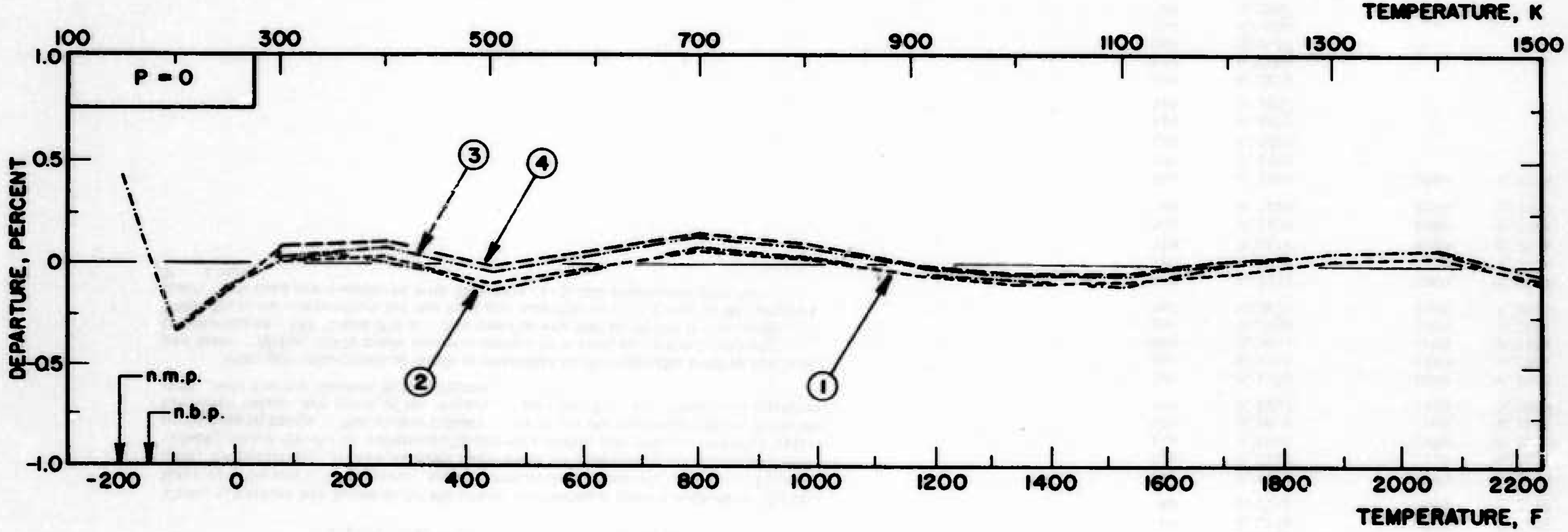
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

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	$0.241\overline{5}$
-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	$0.165\overline{5}$	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	$0.255\overline{5}$
200	$0.19\overline{5}0$	1000	0.2563
220	0.1976	1100	0.2601
240	0.2001	1200	0.2634
260	0.2026	1300	0.2662
280	$0.20\overline{5}0$	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	$0.225\overline{5}$		
500	0.2272		
520	0.2289		
540	$0.230\overline{5}$		
560	0.2320		
580	$0.233\overline{5}$		

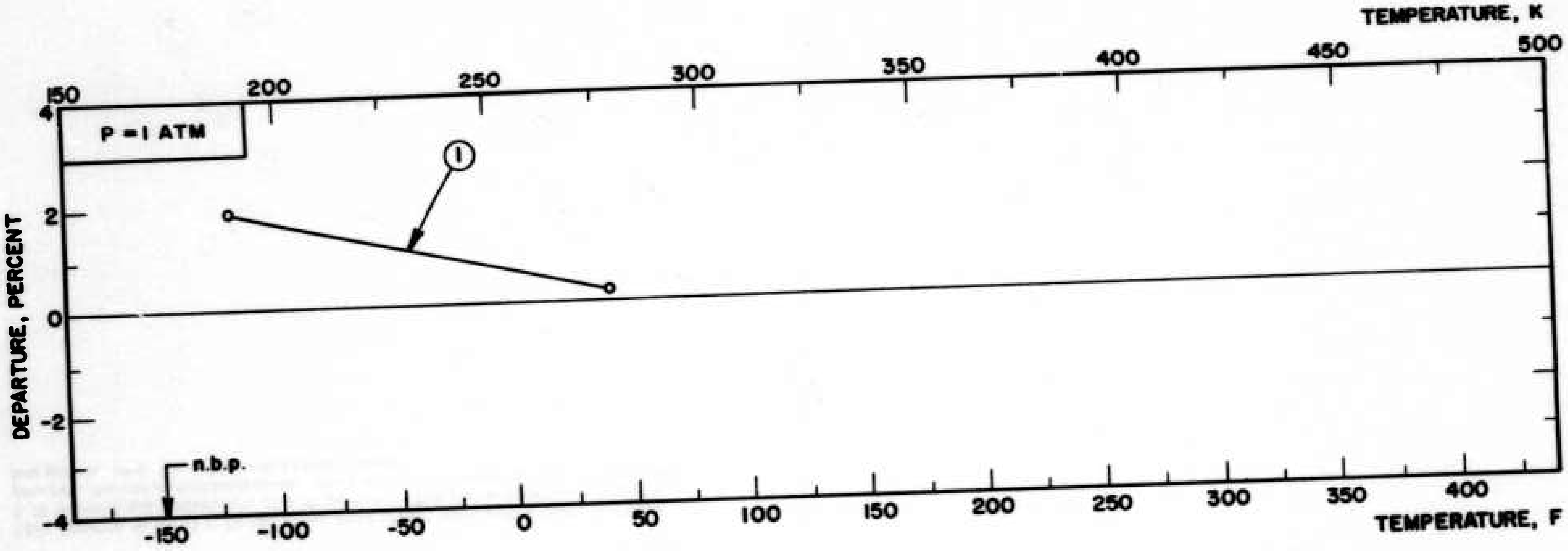
n.m.p. = -197 F
n.b.p. = -150 F

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



Curve	Reference
1	254
2	137, 323. 324, 327
3	380
4	72, 389, 486, 531

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

LIQUID

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

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}) = -1.33043 + 3.20880 \times 10^{-2}T - 1.99437 \times 10^{-4}T^2 + 4.14111 \times 10^{-7}T^3 \quad \text{(T in K)}.$$

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.

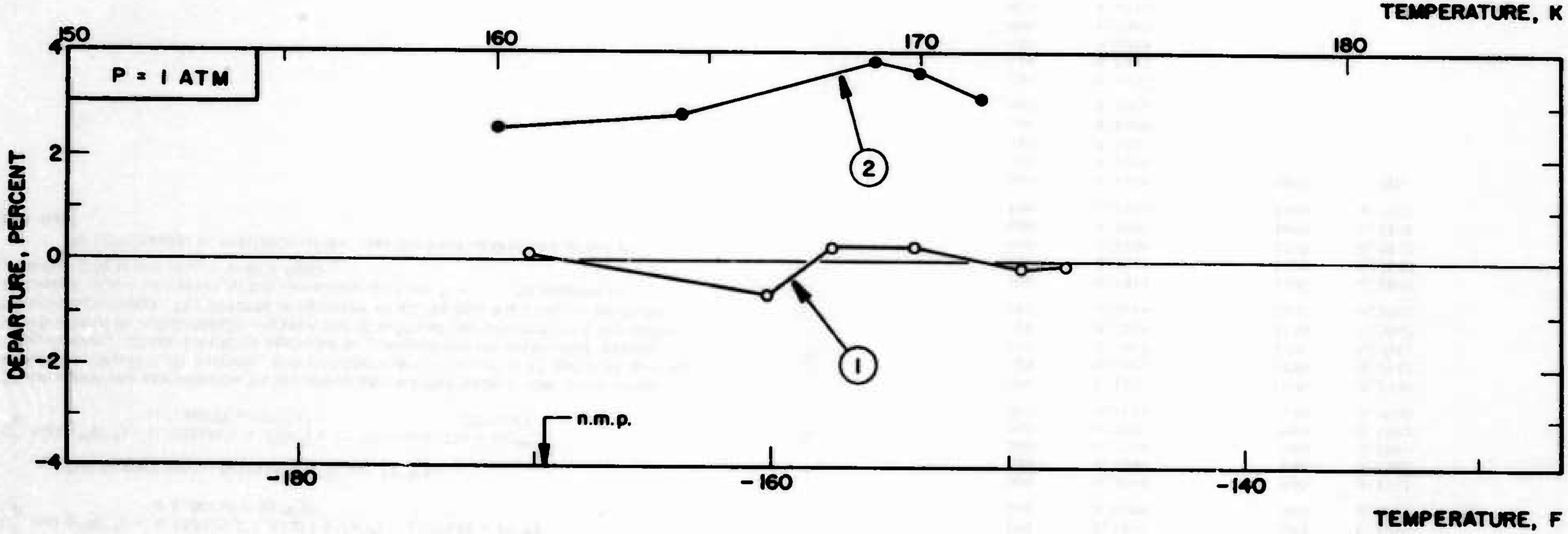
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B lb^{-1}F^{-1}]

LIQUID

T	C_p
-165	0.3943
-160	0.3946
-155	$0.39\bar{5}0$
-150	0.3955
-145	0.3963
-140	0.3973
-135	0.3987
-130	$0.400\bar{5}$

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

DISCUSSION

GAS

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 (380), 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 (59, 428) 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:

For temperatures between 250 K and 770 K:

$$C_p^\circ \text{ (cal g}^{-1}\text{K}^{-1}) = 0.193329 - 1.51244 \times 10^{-5}T + 1.89621 \times 10^{-8}T^2 + 1.26710 \times 10^{-11}T^3 \quad (1)$$

For temperatures between 770 K and 1500 K:

$$C_p^\circ \text{ (cal g}^{-1}\text{K}^{-1}) = 0.180499 + 3.4907\overline{5} \times 10^{-5}T + 3.61248 \times 10^{-9}T^2 - 1.30027 \times 10^{-11}T^3 \quad (T \text{ in K}) \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.05 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.

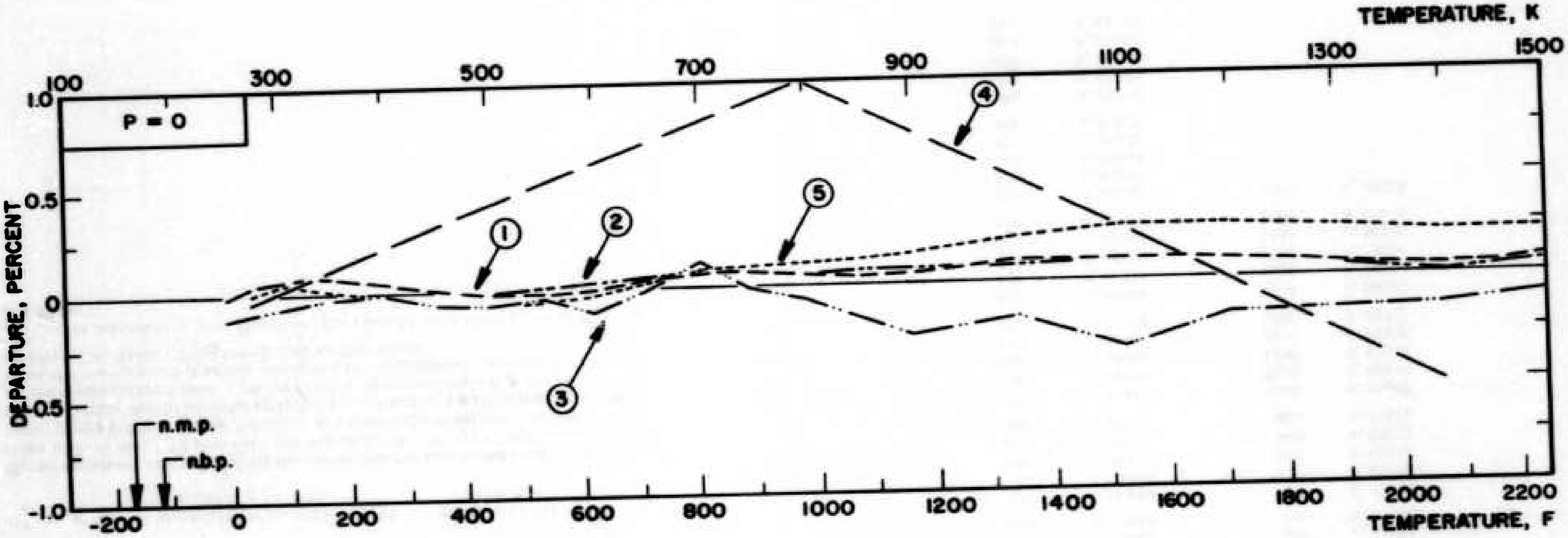
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

GAS

T	C_p°	T	C_p°
0	0.1906	700	0.1947
20	0.1906	720	0.1950
40	0.1907	740	0.1953
60	0.1907	760	0.1956
80	0.1907	780	0.1959
100	0.1907	800	0.1962
120	0.1907	820	0.1966
140	0.1907	840	0.1969
160	0.1907	860	0.1973
180	0.1908	880	0.1977
200	0.1908	900	0.1981
220	0.1909	920	0.198$\overline{5}$
240	0.1909	940	0.1988
260	0.1910	960	0.1992
280	0.1911	980	0.1996
300	0.1912	1000	0.2000
320	0.1912	1100	0.2021
340	0.1913	1200	0.2041
360	0.1914	1300	0.2062
380	0.1916	1400	0.2082
400	0.1917	1500	0.2102
420	0.1918	1600	0.2122
440	0.1920	1700	0.2141
460	0.1921	1800	0.2159
480	0.1923	1900	0.2177
500	0.1924	2000	0.2194
520	0.1926		
540	0.1928		
560	0.1930		
580	0.1932		
600	0.193$\overline{5}$		
620	0.1937		
640	0.1939		
660	0.1942		
680	0.1944		

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



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

TABLE 16 SPECIFIC HEAT AT CONSTANT PRESSURE OF HYDROGEN IODIDE

DISCUSSION

GAS

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:

$$C_p^\circ \text{ (cal g}^{-1}\text{K}^{-1}) = 0.0559084 - 1.11109 \times 10^{-5}T + 2.09174 \times 10^{-8}T^2 - 3.27269 \times 10^{-13}T^3 \quad (1)$$

For temperatures between 620 K and 1500 K:

$$C_p^\circ \text{ (cal g}^{-1}\text{K}^{-1}) = 0.0471113 + 1.66509 \times 10^{-5}T - 2.70113 \times 10^{-10}T^2 - 1.59501 \times 10^{-12}T^3 \quad \text{(T in K)} \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.04 and 0.0$\bar{5}$ 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.

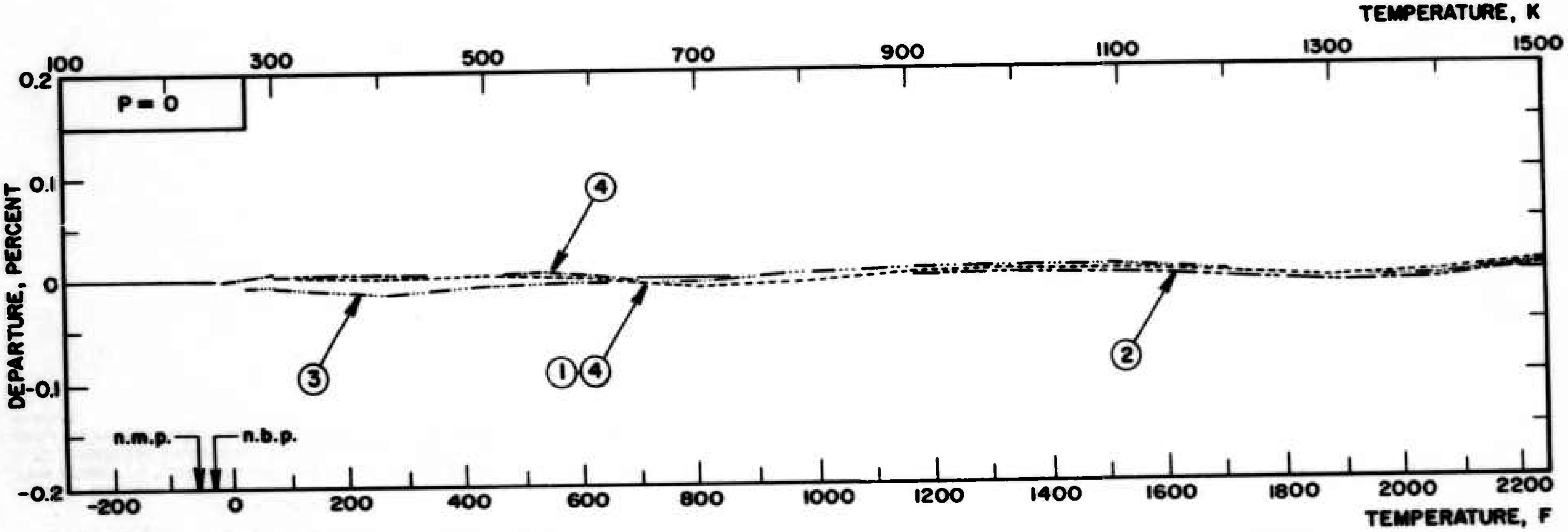
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

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	0.0580$\bar{5}$
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	0.0595$\bar{5}$
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	0.06338
440	0.05550	1700	0.06390
460	0.05561	1800	0.06439
480	0.05573	1900	0.06484
500	0.05584	2000	0.0652$\bar{5}$
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		

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

LIQUID

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 (340) reported data with an experimental error of 0.2 percent covering temperatures from 189.95 K to 210.99 K, and Clusius 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

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

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.

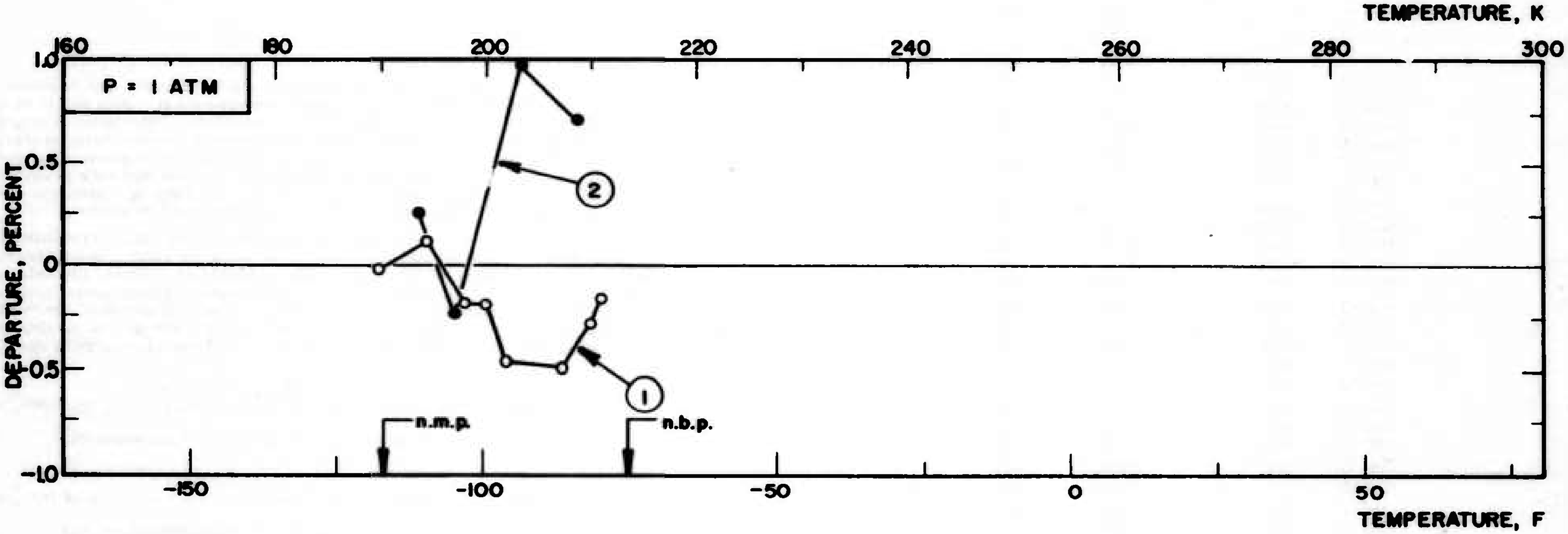
RECOMMENDED VALUES

[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

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



Curve	Reference
1	292
2	346

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:

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

For temperatures between 620 K and 1500 K:

$$C_p^0(\mathrm{cal\ g^{-1}K^{-1}}) = 0.184201 + 1.58423 \times 10^{-4}T - 9.60009 \times 10^{-9}T^2 - 1.12799 \times 10^{-11}T^3 \qquad (T \text{ in K}) \qquad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.07 and 0.1$\bar{5}$ 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 (142) 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

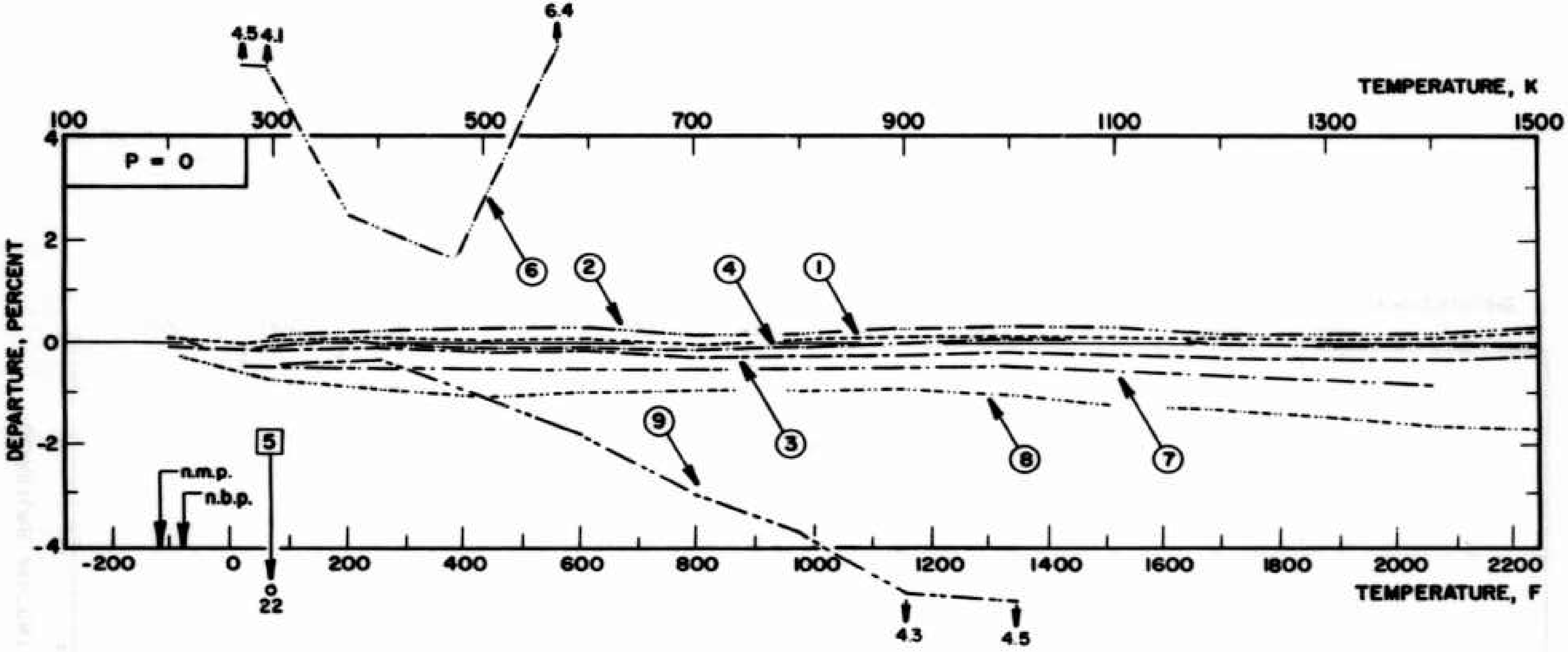
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

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	$0.24\bar{5}0$	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	$0.32\bar{5}0$
400	$0.258\bar{5}$	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		

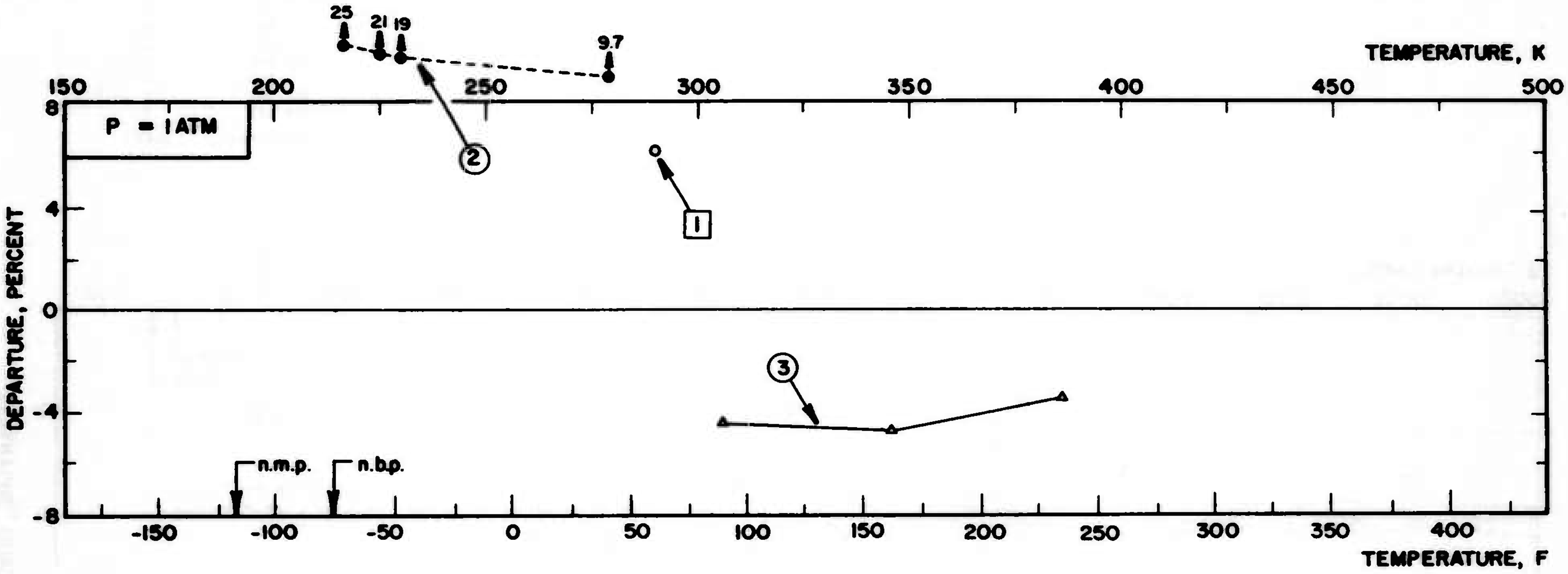
n.b.p. = -75 F

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



Curve	Reference
1	78
2	142
3	328

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 (317) 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

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

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

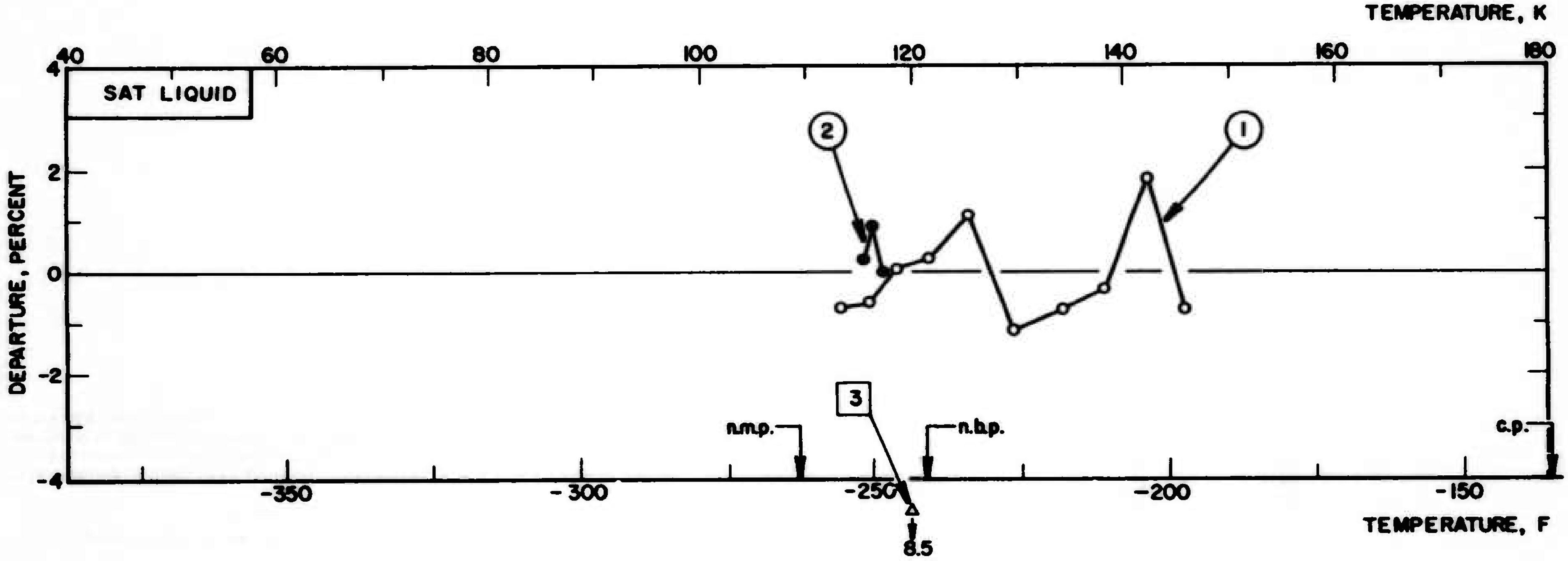
[Temperature, T, F; Specific Heat, C_p, B lb^{-1}F^{-1}]

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), Sinke (192), Beckett and Haar (266), Glatt et al. (348), Hildenbrand (380), Huff et al. (389) 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:

$$C_p^{o}\,(\mathrm{cal\ g^{-1}K^{-1}}) = 0.282183 - 3.16841 \times 10^{-4}\,T + 6.88734 \times 10^{-7}\,T^2 - 4.22833 \times 10^{-10}\,T^3 \qquad (1)$$

For temperatures between 590 K and 1500 K:

$$C_p^{o}\,(\mathrm{cal\ g^{-1}K^{-1}}) = 0.192074 + 1.22287 \times 10^{-4}\,T - 5.05602 \times 10^{-8}\,T^2 + 6.90346 \times 10^{-12}\,T^3 \qquad (T\ \mathrm{in\ K}) \qquad (2)$$

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, 185) 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 Mckowen (460), 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:

$$C_p\,(\mathrm{cal\ g^{-1}K^{-1}}) = 0.309760 - 5.23433 \times 10^{-4}\,T + 1.18484 \times 10^{-6}\,T^2 - 8.04772 \times 10^{-10}\,T^3 \qquad (3)$$

For temperatures between 580 K and 1500 K:

$$C_p\,(\mathrm{cal\ g^{-1}K^{-1}}) = 0.192096 + 1.23339 \times 10^{-4}\,T - 5.24720 \times 10^{-8}\,T^2 + 7.70996 \times 10^{-12}\,T^3 \qquad (T\ \mathrm{in\ K}) \qquad (4)$$

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 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

T	C_p°	C_p	T	C_p°	C_p
			300	0.2392	0.2392
			320	0.2396	0.2398
-260	0.2548		340	0.2401	0.2403
-240	0.2528		360	0.2406	0.2409
-220	0.2510		380	0.2412	0.2416
-200	0.2494		400	0.2417	0.2422
-180	0.2478		420	0.2423	0.2428
-160	0.2464	0.2516	440	0.2429	$0.243\bar{5}$
-140	0.2451	0.2495	460	0.2435	0.2441
-120	0.2439	0.2476	480	0.2442	0.2448
-100	0.2428	0.2459	500	0.2448	0.2454
-80	0.2419	0.2444	520	0.2454	0.2459
-60	0.2410	0.2430	540	0.2461	$0.246\bar{5}$
-40	0.2402	0.2418	560	0.2467	0.2470
-20	0.2396	0.2407	580	0.2473	$0.247\bar{5}$
0	0.2390	0.2398	600	0.2479	0.2479
20	0.2385	0.2390	620	0.2486	0.2487
40	0.2381	0.2384	640	0.2493	$0.249\bar{5}$
60	0.2378	0.2379	660	0.2501	0.2502
80	0.2375	$0.237\bar{5}$	680	0.2508	0.2509
100	0.2374	0.2372	700	0.2516	0.2517
120	0.2373	0.2370	720	0.2523	0.2524
140	0.2373	0.2370	740	0.2530	0.2531
160	0.2373	0.2370	760	0.2537	0.2538
180	0.2374	0.2371	780	0.2544	0.2545
200	0.2376	0.2373	800	0.2551	0.2552
220	0.2378	0.2376	820	0.2558	0.2559
240	0.2381	0.2379	840	0.2564	0.2565
260	0.2384	0.2383	860	0.2571	0.2572
280	0.2388	0.2387	880	0.2578	0.2578

n.m.p. =260 ± 2 F

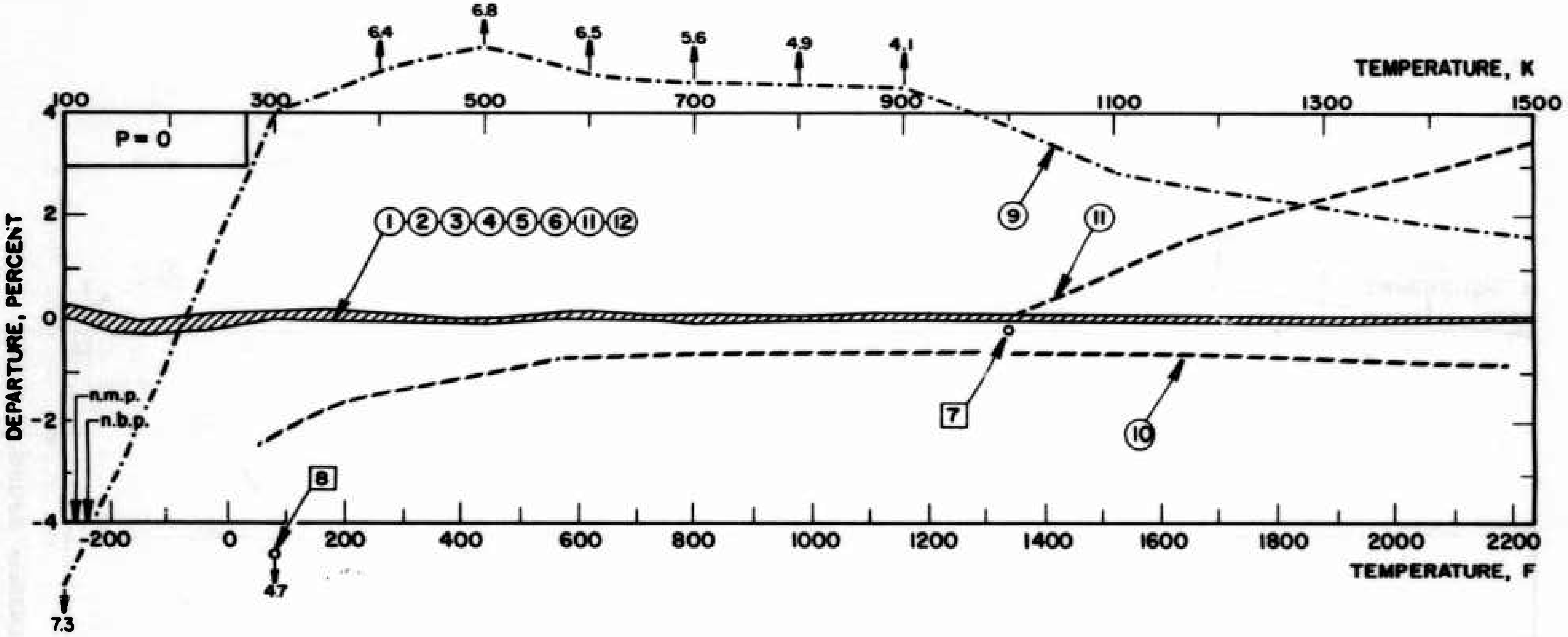
n.b.p. =-241 F

RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p° and C_p, B lb^{-1} F^{-1}]

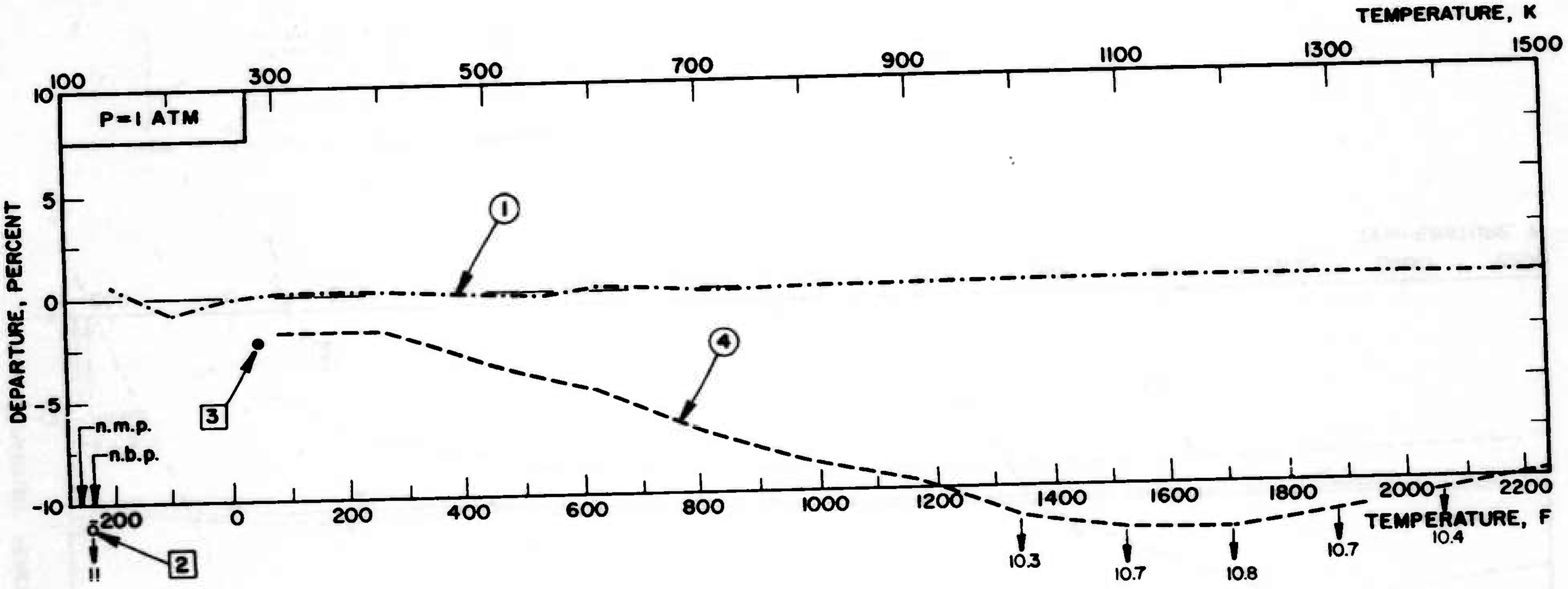
T	C_p°	C_p
900	0.2584	$0.258\bar{5}$
920	0.2590	0.2591
940	0.2597	0.2597
960	0.2603	0.2603
980	0.2609	0.2610
1000	0.2615	0.2615
1100	0.2644	0.2644
1200	0.2671	0.2671
1300	0.2696	0.2696
1400	0.2719	0.2718
1500	0.2740	0.2740
1600	0.2760	0.2759
1700	0.2778	0.2777
1800	0.2794	0.2793
1900	0.2809	0.2808
2000	0.2822	0.2821

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



Curve	Reference	Curve	Reference
1	59	7	266
2	100	8	18
3	253	9	93
4	254	10	278
5	72,348, 380	11	393
6	167, 192, 389, 403, 429	12	562

FIGURE 18 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

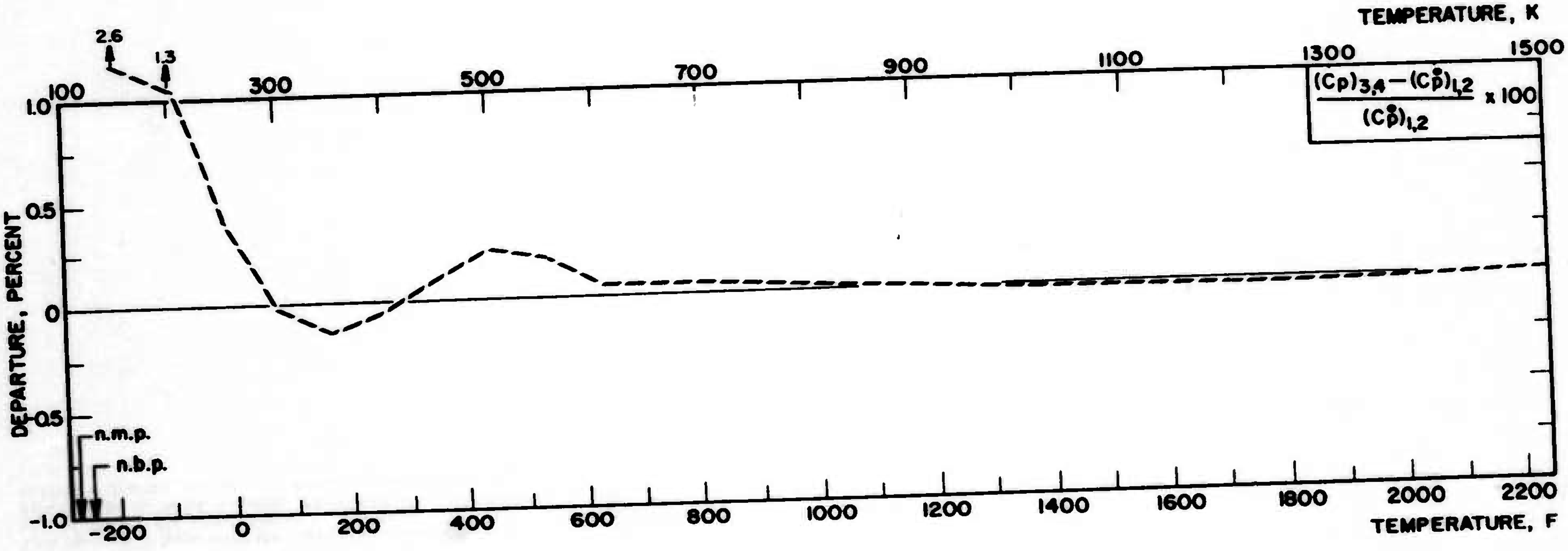


TABLE 19 SPECIFIC HEAT AT CONSTANT PRESSURE OF NITROGEN PEROXIDE

DISCUSSION

LIQUID

Only one experimental work on the constant pressure specific heat of liquid nitrogen peroxide was reported by Giauque 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

$$C_p\ (\mathrm{cal\ g^{-1}K^{-1}}) = 1.97538 - 1.76174 \times 10^{-2}T + 6.25487 \times 10^{-5}T^2 - 7.21761 \times 10^{-8}T^3 \qquad (T \text{ in K}).$$

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.

RECOMMENDED VALUES

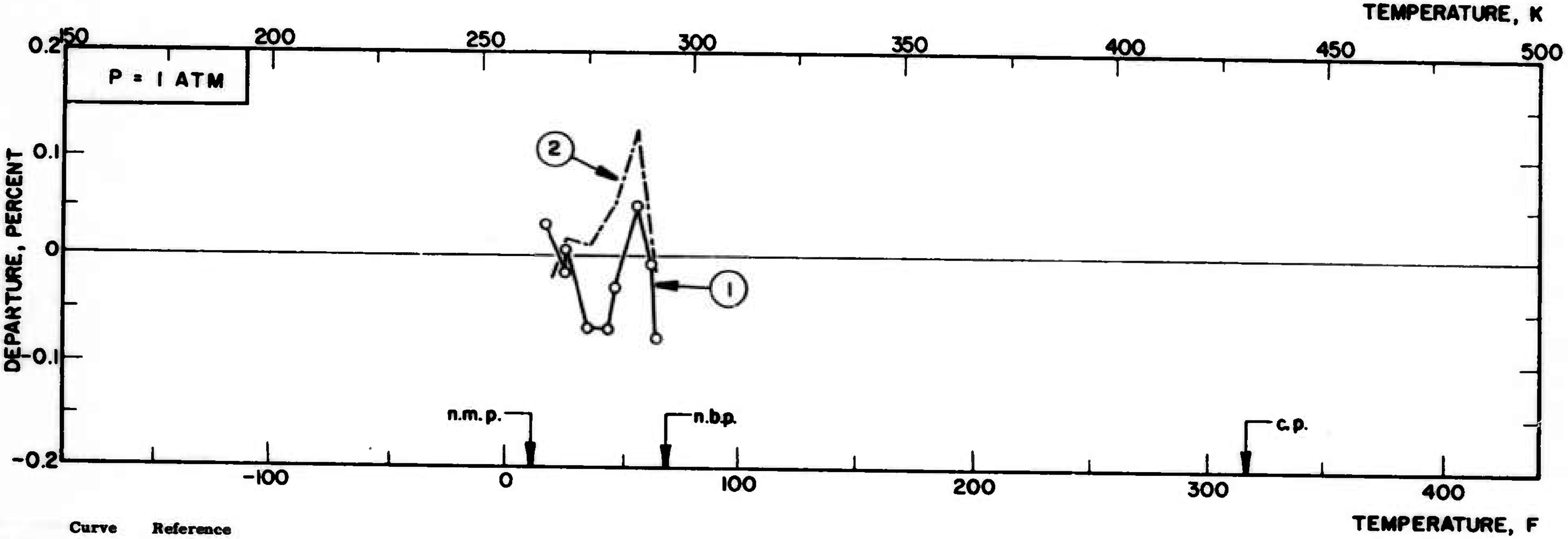
[Temperature, T, F; Specific Heat, C_p, B lb^{-1}F^{-1}]

LIQUID

T	C_p
20	0.3563
30	0.3584
40	0.3606
50	0.3631
60	0.3655
70	0.3680
80	0.370$\overline{5}$
90	0.3727

n.b.p. = 71 F

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



Curve	Reference
1	342
2	445

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:

$$C_p\ (\text{cal g}^{-1}\text{K}^{-1}) = 0.368113 + 2.89976 \times 10^{-4} T \qquad (T \text{ in K}).$$

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

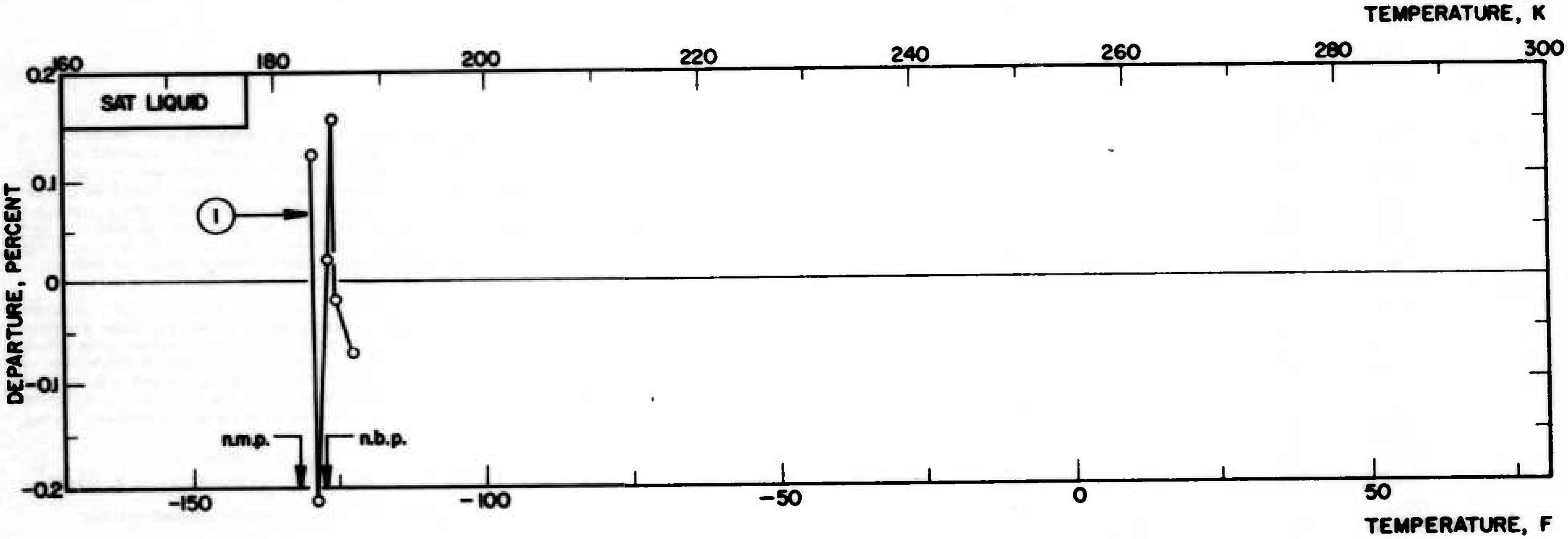
[Temperature, T, F; Specific Heat, C_p, B, $lb^{-1}F^{-1}$]

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

DISCUSSION

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 (458) 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, 405). The correlation formulas obtained for the ideal gas specific heat are as follows:

For temperatures between 200 K and 600 K:

$$C_p^0\ (\text{cal g}^{-1}\text{K}^{-1}) = 0.103451 + 4.89293 \times 10^{-4}T - 5.19278 \times 10^{-7}T^2 + 2.44839 \times 10^{-10}T^3 \quad (1)$$

For temperatures between 600 K and 1500 K:

$$C_p^0\ (\text{cal g}^{-1}\text{K}^{-1}) = 0.149343 + 2.57192 \times 10^{-4}T - 1.47619 \times 10^{-7}T^2 + 3.01604 \times 10^{-11}T^3 \quad (T \text{ in K}) \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.04 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.

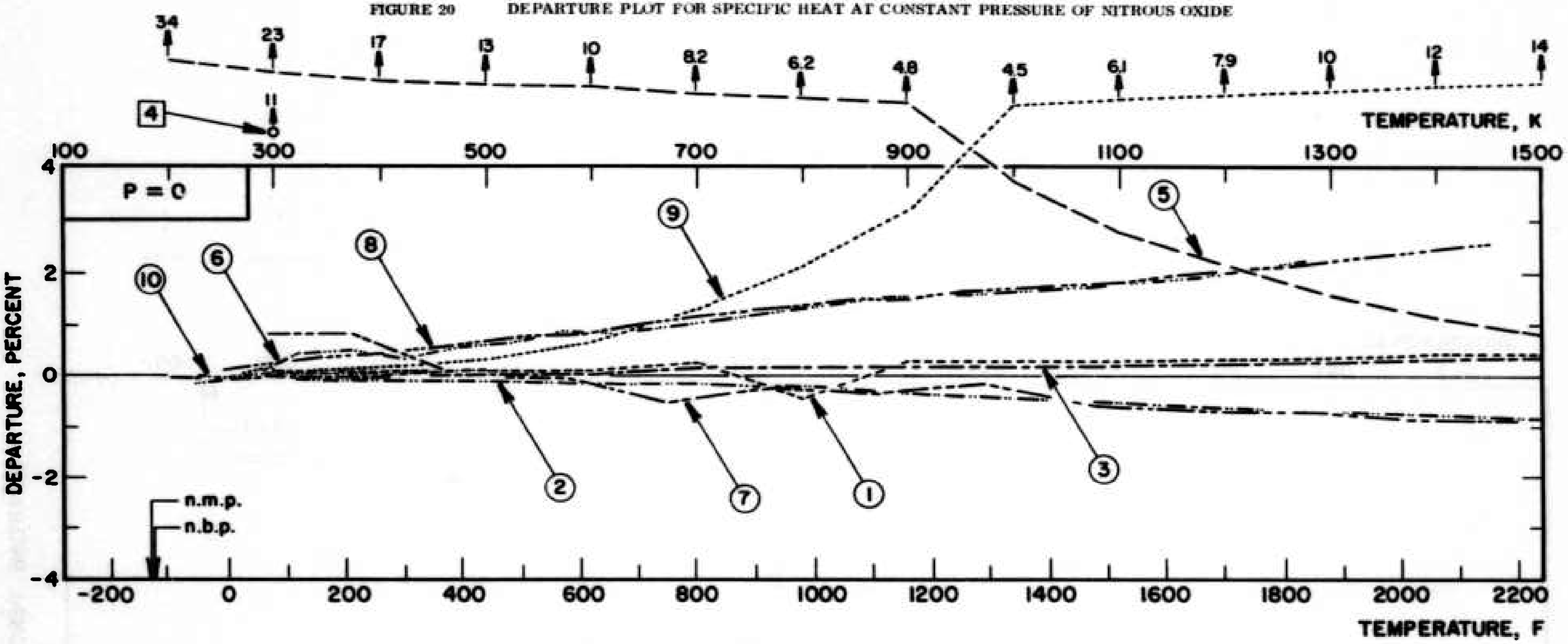
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

GAS

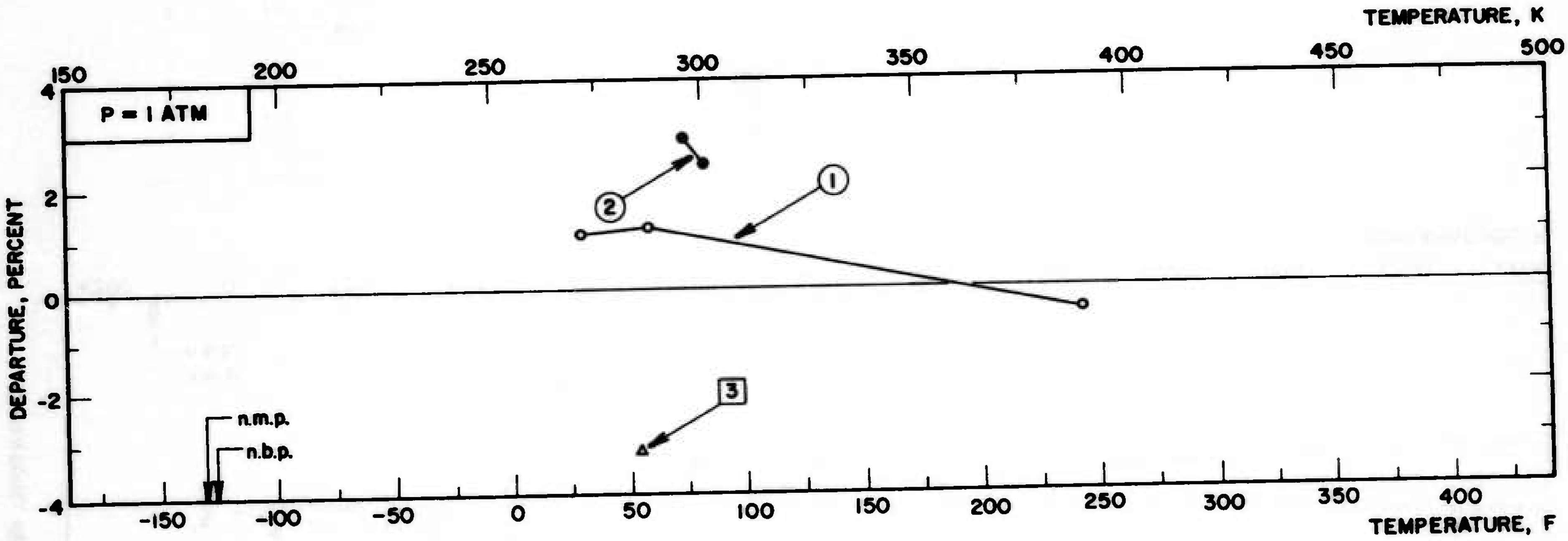
T	C_p^0	T	C_p^0
-100	0.1823	600	0.2613
-80	0.1857	620	0.2628
-60	0.1890	640	0.2642
-40	0.1923	660	0.2655
-20	0.1954	680	0.2668
0	$0.198\overline{5}$	700	0.2681
20	$0.201\overline{5}$	720	0.2694
40	0.2044	740	0.2706
60	0.2072	760	0.2718
80	0.2099	780	0.2730
100	0.2126	800	0.2742
120	0.2152	820	0.2753
140	0.2177	840	$0.276\overline{5}$
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	$0.289\overline{5}$
340	0.2396	1200	0.2937
360	0.2415	1300	$0.297\overline{5}$
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		

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



Curve	Reference
1	56
2	85
3	488

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 sample 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

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

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

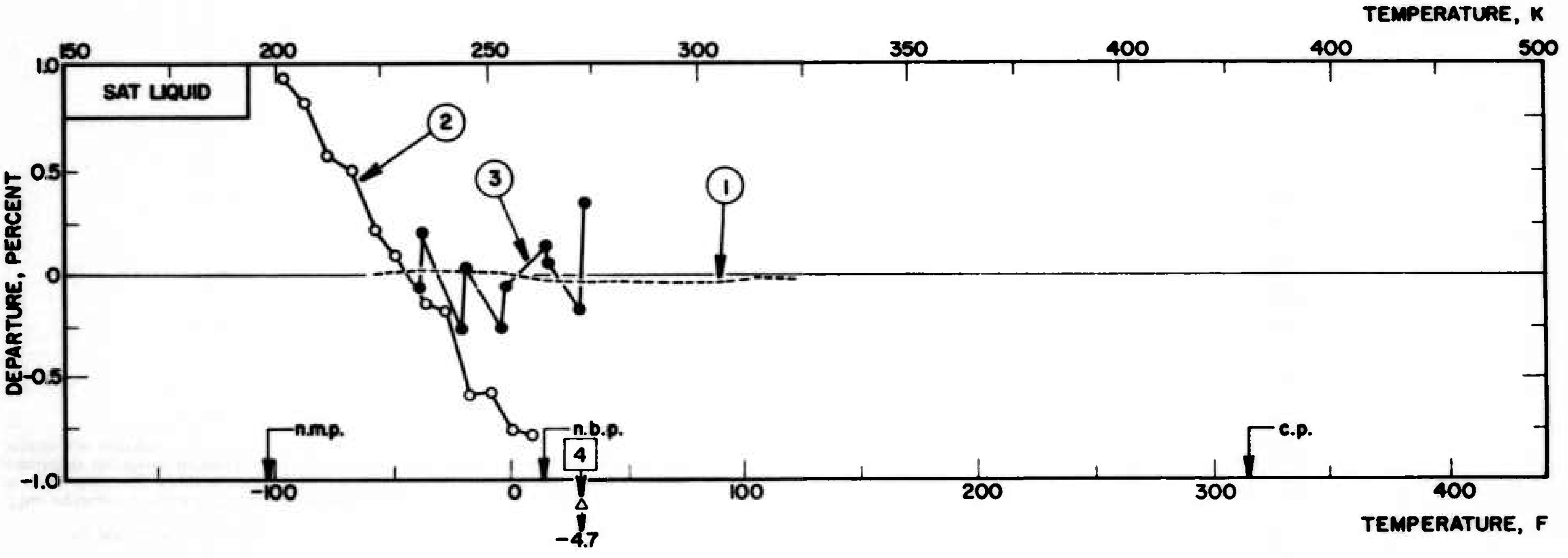
[Temperature, T, F; Specific Heat, C_p, B $lb^{-1}F^{-1}$]

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

DISCUSSION

GAS

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), Sinke (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:

$$C_p^0 \ (\mathrm{cal\ g^{-1}K^{-1}}) = 0.0961779 + 2.09023 \times 10^{-4}T - 1.13480 \times 10^{-7}T^2 + 8.07944 \times 10^{-12}T^3 \quad (1)$$

For temperatures between 770 K and 1500 K:

$$C_p^0 \ (\mathrm{cal\ g^{-1}K^{-1}}) = 0.116719 + 1.64753 \times 10^{-4}T - 1.01758 \times 10^{-7}T^2 + 2.26034 \times 10^{-11}T^3 \quad (T \text{ in K}) \quad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.16 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, 184, 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.

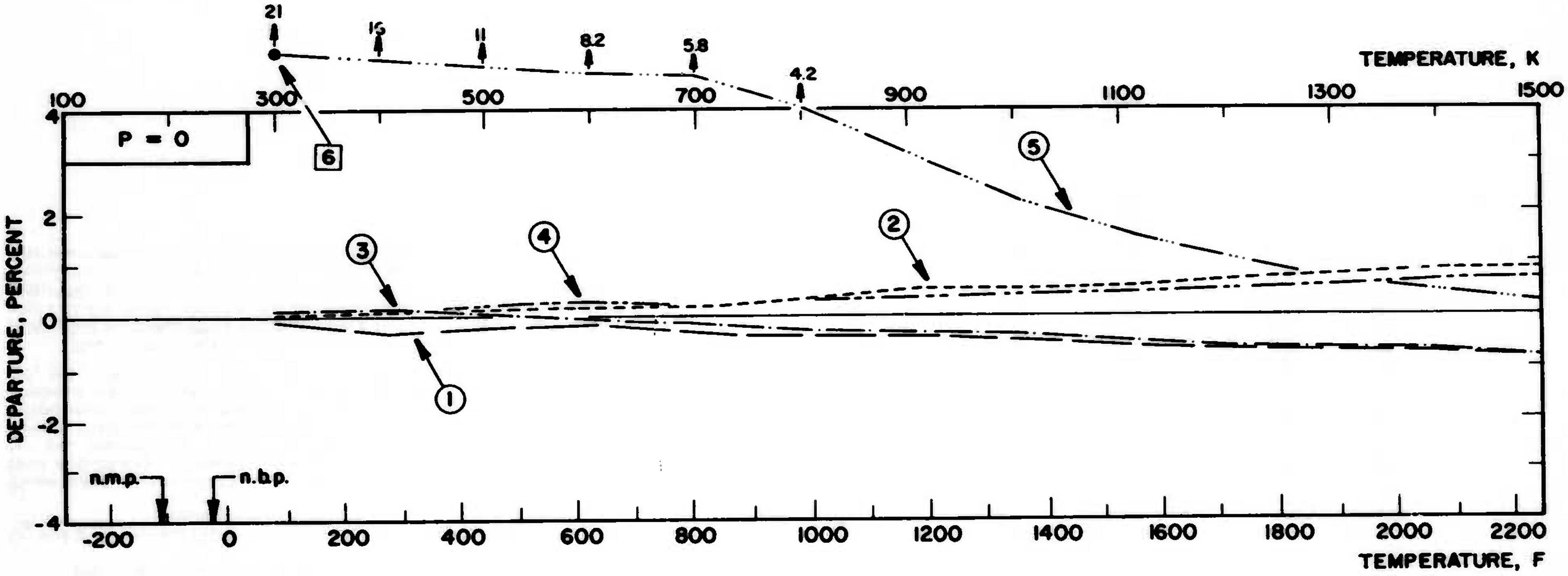
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

GAS

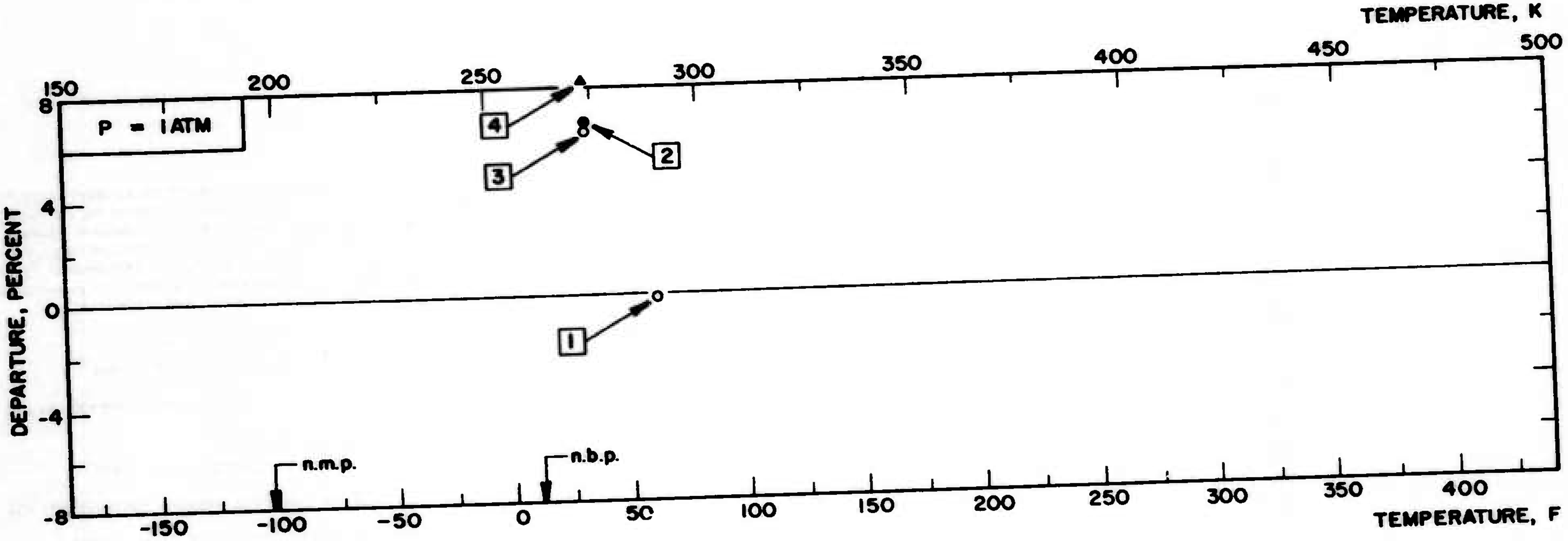
T	C_p^0	T	C_p^0
		700	0.1858
		720	0.1866
		740	0.1873
		760	0.1881
80	0.1488	780	0.1888
100	0.1503	800	0.1895
120	0.1519	820	0.1902
140	0.1534	840	0.1909
160	0.1549	860	$0.191\bar{5}$
180	0.1564	880	0.1921
200	0.1578	900	0.1927
220	0.1593	920	0.1932
240	0.1607	940	0.1938
260	0.1620	960	0.1943
280	0.1634	980	0.1948
300	0.1647	1000	0.1953
320	0.1660	1100	0.1977
340	0.1672	1200	0.1997
360	$0.168\bar{5}$	1300	0.2015
380	0.1697	1400	0.2031
400	0.1709	1500	0.2045
420	0.1721	1600	0.2057
440	0.1732	1700	0.2068
460	0.1743	1800	0.2078
480	0.1754	1900	0.2086
500	$0.176\bar{5}$	2000	0.2094
520	0.1775		
540	0.1785		
560	0.1795		
580	$0.180\bar{5}$		
600	0.1814		
620	0.1824		
640	0.1832		
660	0.1841		
680	$0.18\bar{5}0$		

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



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

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:

$$C_p\ (\text{cal g}^{-1}\text{K}^{-1}) = 2.13974 - 9.68137 \times 10^{-3}T + 2.68536 \times 10^{-5}T^2 - 2.42139 \times 10^{-8}T^3 \qquad (T \text{ in K}), (1)$$

For temperatures between 410 K and 590 K:

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

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.

RECOMMENDED VALUES

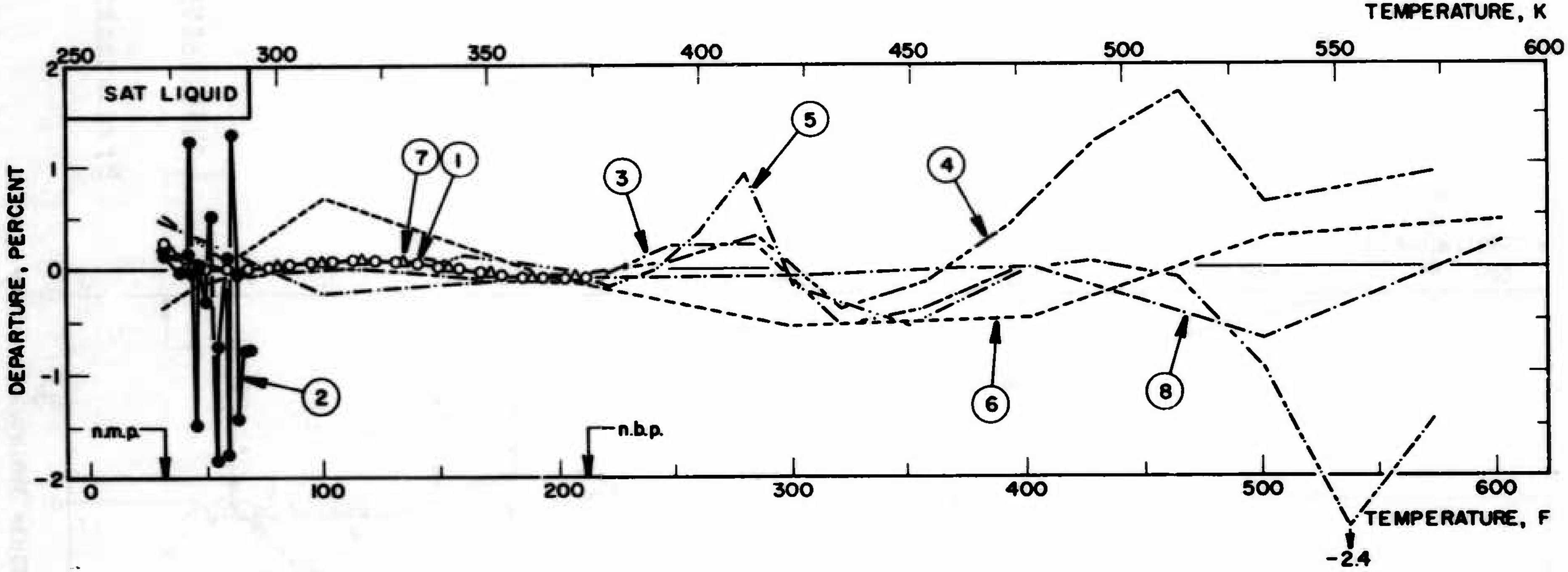
[Temperature, T, F; Specific Heat, C_p, B lb^{-1}F^{-1}]

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
390	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

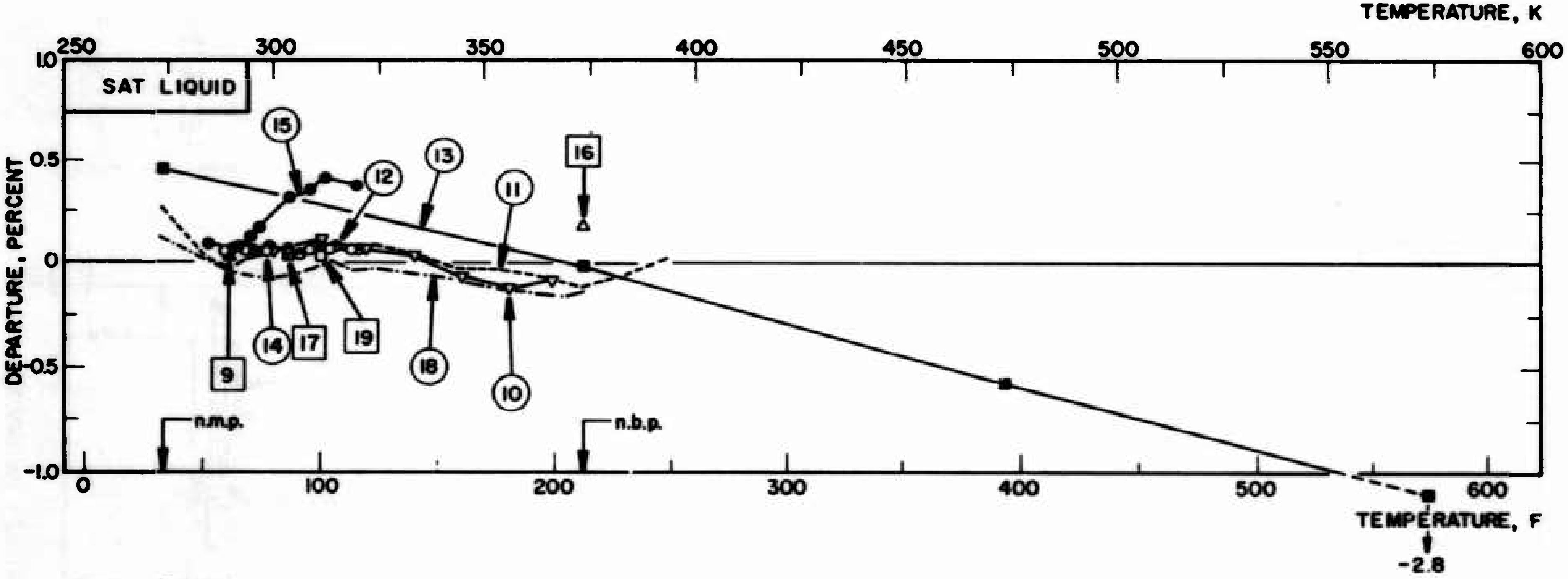
n.b.p. = 212 F

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



Curve	Reference
1	68
2	181
3	249
4	336
5	406
6	480
7	483
8	529

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



Curve	Reference
9	78
10	172
11	198
12	296
13	303
14	329
15	392
16	442
17	492
18	509
19	564

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	$0.4477\overline{5}$		840	0.50055	0.5008
160	0.44868		860	0.50232	$0.502\overline{5}$
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	$0.5110\overline{5}$	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	$0.588\overline{5}$
480	0.46959	0.4736	1900	0.59582	0.5970
500	0.47118	0.4742	2000	0.60394	0.6051
520	0.47280	$0.475\overline{5}$			
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

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), Hildenbrand (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, 573) 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:

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

For temperatures between 800 K and 1500 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}) = 0.378278 + 1.53443 \times 10^{-4}T + 3.31531 \times 10^{-8}T^2 - 1.7843\bar{5} \times 10^{-11}T^3 \quad \text{(T in K)} \quad (2)$$

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 (249) Two sets of These values are given equal weight in the present analysis. 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:

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}) = 1.94480 - 8.92530 \times 10^{-3}T + 1.78830 \times 10^{-5}T^2 - 1.18442 \times 10^{-9}T^3 \quad (3)$$

For temperatures between 535 K and 1500 K:

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}) = 0.443222 - 2.85391 \times 10^{-5}T + 1.98477 \times 10^{-7}T^2 - 6.63724 \times 10^{-11}T^3 \quad \text{(T in K)} \quad (4)$$

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

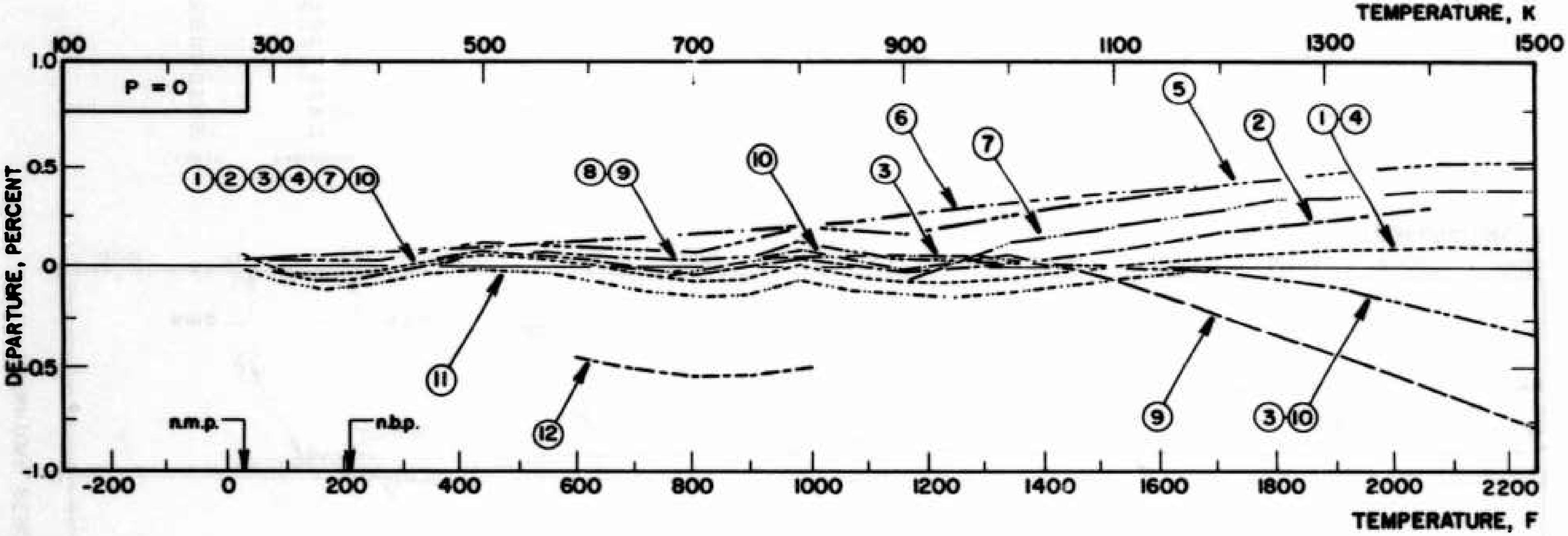
[Temperature, T, F; Specific Heat, C_p^0 and C_p, B lb^{-1} F^{-1}]

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	$0.4468\underline{7}$		820	0.49878	0.4991
140	$0.4477\overline{5}$		840	0.50055	$0.500\underline{8}$
160	0.44868		860	0.50232	$0.502\overline{5}$
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	$0.5093\underline{2}$	0.5095
260	0.45411	0.4777	960	$0.5110\overline{5}$	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.[illegible]5294	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	$0.579\underline{7}$
460	0.46802	0.4729	1800	0.58747	$0.588\overline{5}$
480	0.46959	0.4736	1900	0.59582	0.5970
500	0.47118	$0.474\underline{2}$	2000	0.60394	0.6051
520	0.47280	$0.475\overline{5}$			
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			

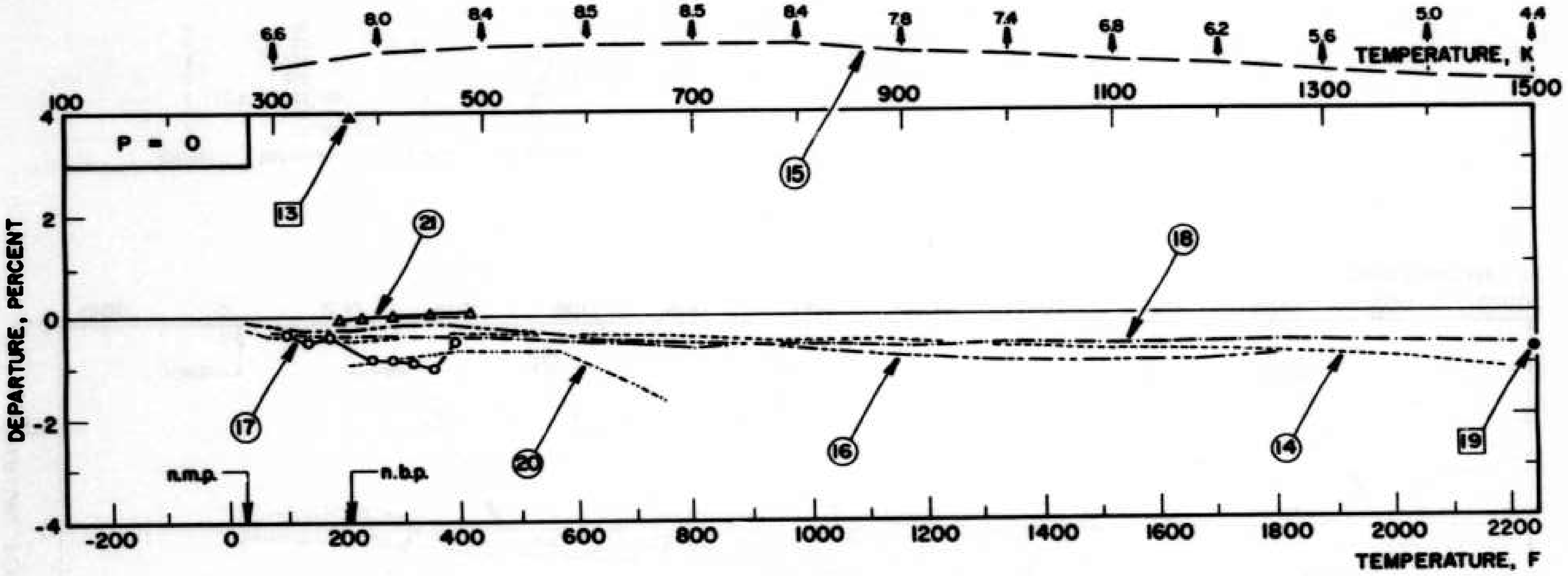
n.b.p. = 212 F

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



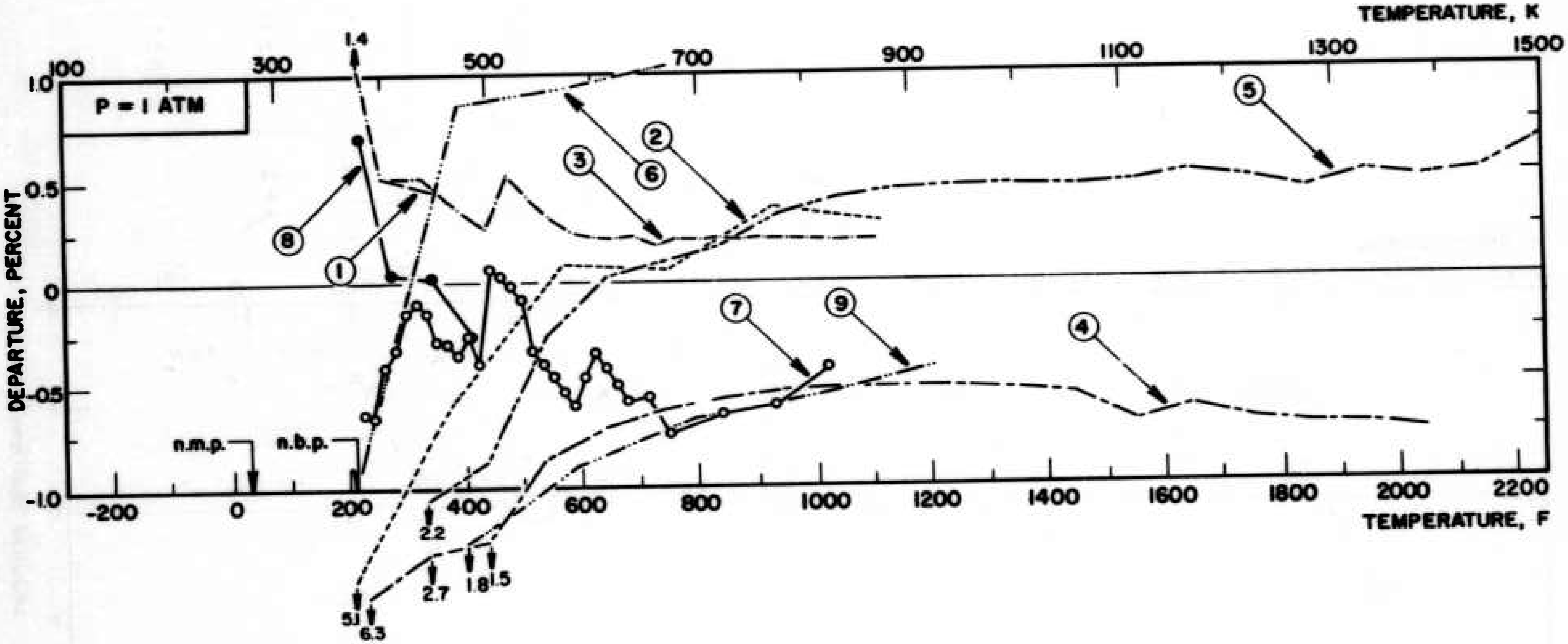
Curve	Reference	Curve	Reference
1	72, 326, 332, 333, 380, 575	7	167, 226
		8	325
2	137, 458	9	347
3	253	10	389, 403, 426
4	254	11	513
5	22	12	573
6	59		

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



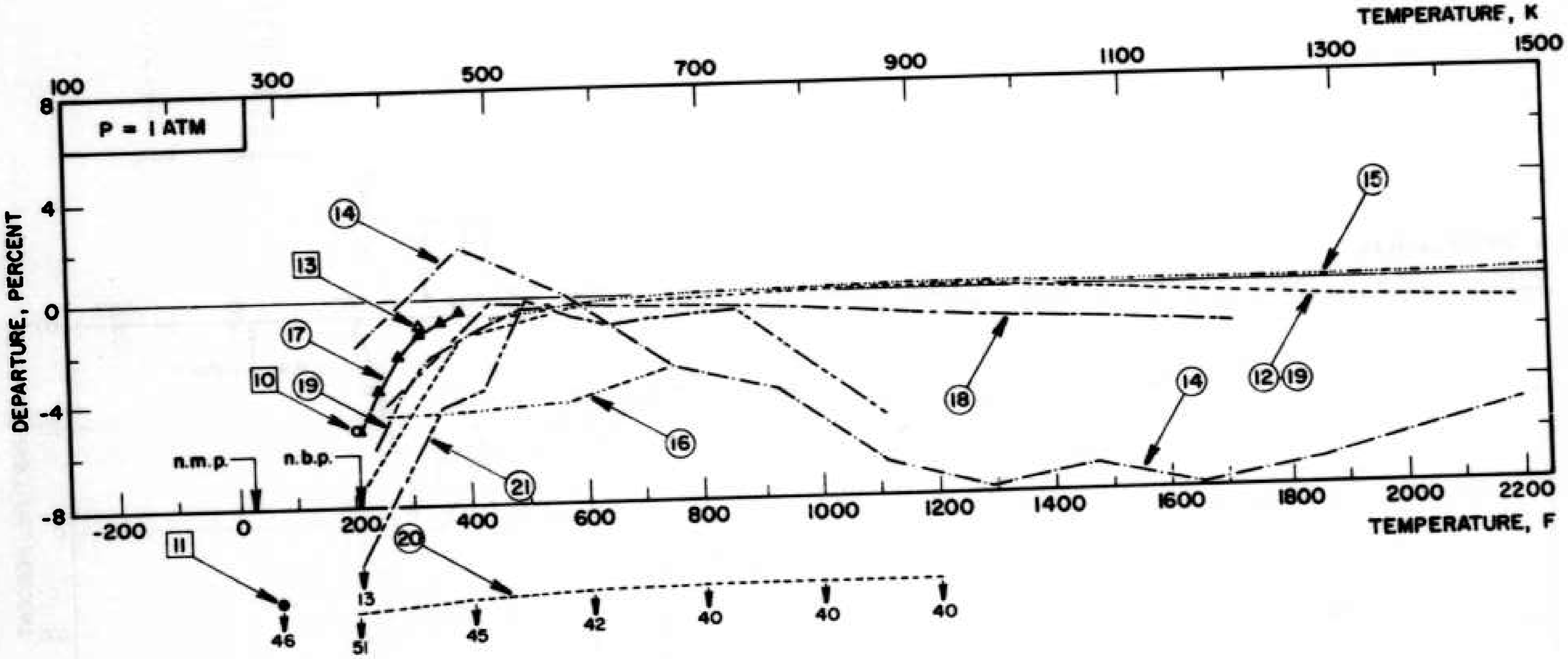
Curve	Reference
13	13
14	24, 278
15	93
16	100
17	334
18	352
19	353
20	419
21	459

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



Curve	Reference
1	132
2	249
3	325, 326, 575
4	375
5	376
6	419
7	425
8	459
9	127

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



Curve	Reference	Curve	Reference
10	13	16	303
11	18	17	334
12	71	18	354
13	162	19	366
14	269	20	529
15	274	21	555

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

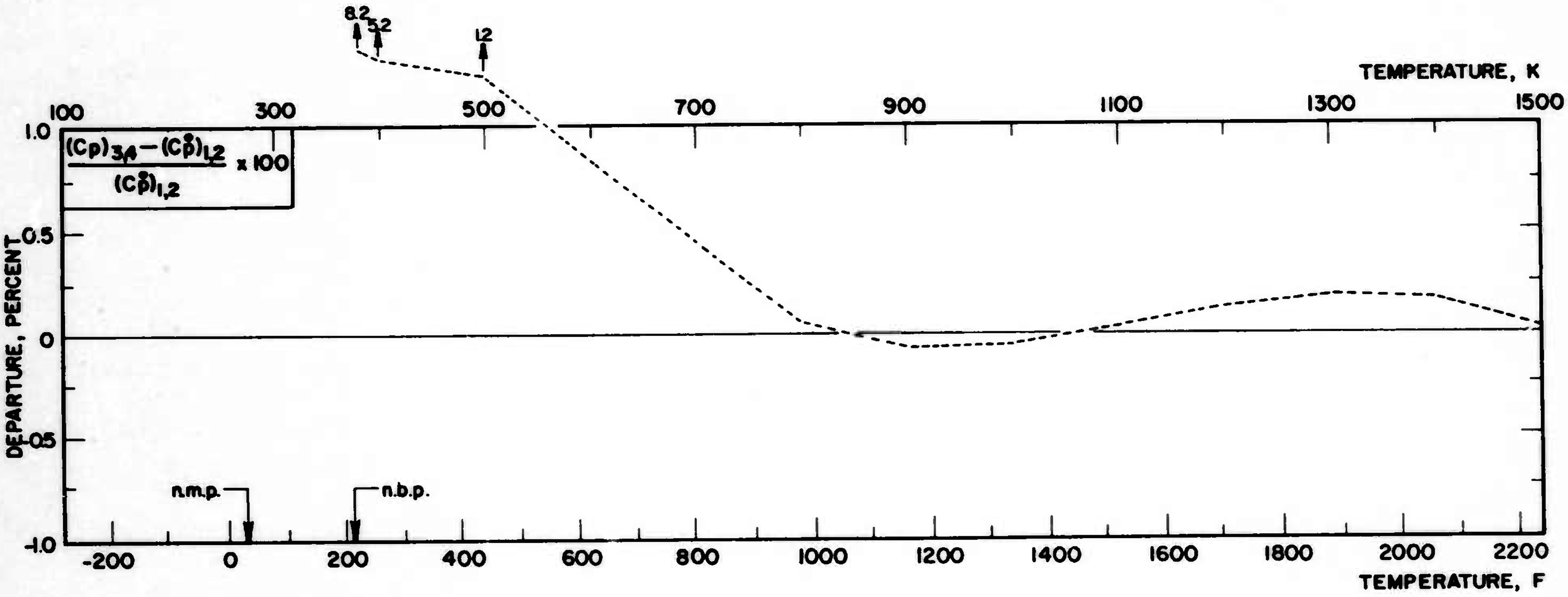


TABLE 23 SPECIFIC HEAT AT CONSTANT PRESSURE OF ACETONE

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 Mitsukuri 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

$$C_p(\mathrm{cal\ g^{-1}\ K^{-1}}) = 0.839890 - 4.60183 \times 10^{-3}T + 1.82400 \times 10^{-5}T^2 - 2.11716 \times 10^{-8}T^3 \quad (T \text{ in K}).$$

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, 188) are not shown.

RECOMMENDED VALUES

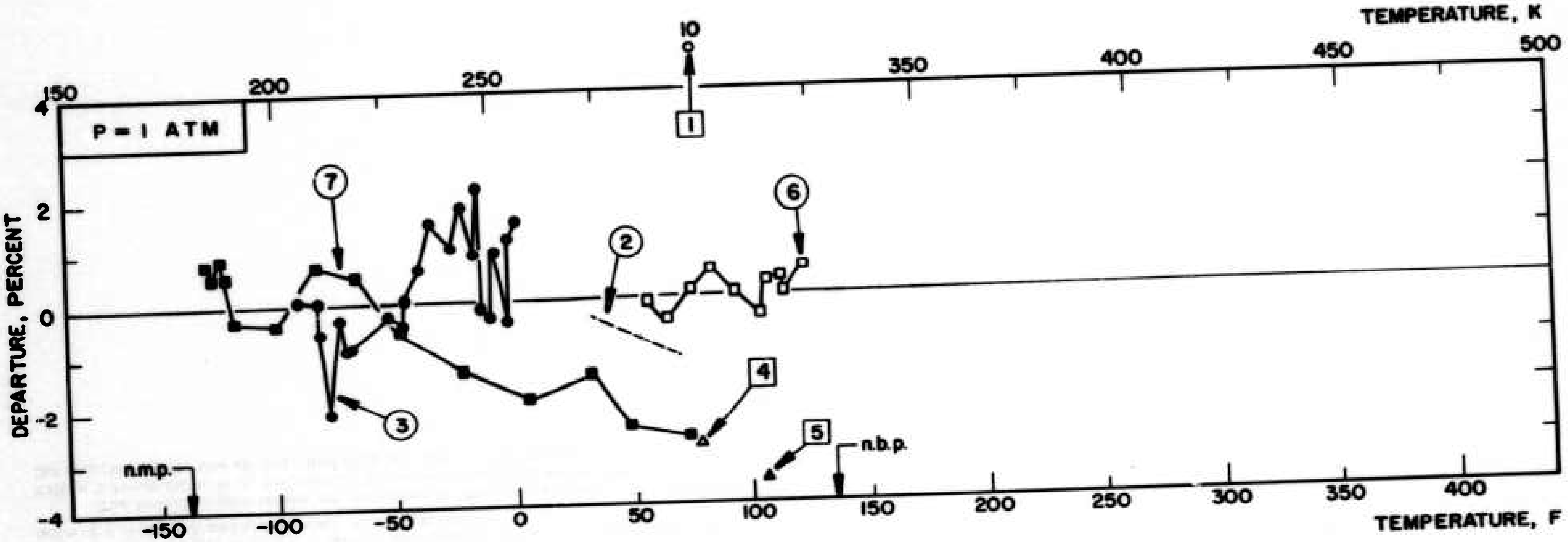
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

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



Curve	Reference
1	23
2	36
3	143
4	215
5	216
6	199
7	244

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

DISCUSSION

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:

For the temperature range between 270 K and 800 K:

$$C_p^0(\text{cal g}^{-1}\,\text{K}^{-1}) = 6.3352\bar{5} \times 10^{-2} + 9.05719 \times 10^{-4}T - 2.14992 \times 10^{-7}T^2 - 9.00590 \times 10^{-11}T^3 \text{ (T in K)},$$

and for the temperature range between 800 K and 1500 K:

$$C_p^0(\text{cal g}^{-1}\,\text{K}^{-1}) = 0.144995 + 7.79868 \times 10^{-4}T - 2.80143 \times 10^{-7}T^2 + 2.94348 \times 10^{-11}T^3 \text{ (T in K)}.$$

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 Bennewitz and Rossner (15) at 410 K with a reported error of 0.6 percent. Jatkar (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 correlation is made for the real gas specific heat.

RECOMMENDED VALUES

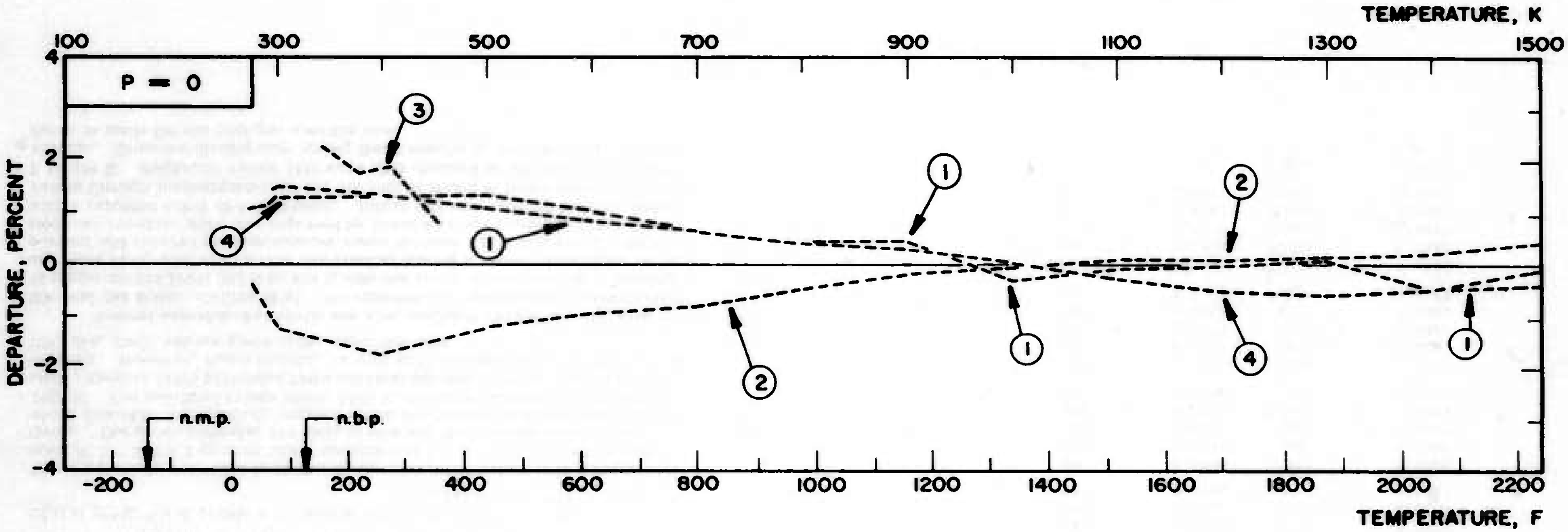
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

GAS

T	C_p^0	T	C_p^0
		600	0.5033
		620	0.5095
40	0.2961*	640	0.5156
60	0.3046*	660	0.5215
80	0.3129*	680	0.5274
100	0.3213*	700	0.5332
120	0.3295*	720	0.5389
140	0.3377	740	0.544$\bar{5}$
160	0.3458	760	0.5$\bar{5}$00
180	0.3538	780	0.5554
200	0.3617	800	0.5607
220	0.3696	820	0.5659
240	0.3774	840	0.5710
260	0.3851	860	0.5760
280	0.3927	880	0.5808
300	0.4003	900	0.5856
320	0.4077	920	0.5903
340	0.4151	940	0.5949
360	0.4224	960	0.5994
380	0.4296	980	0.6038
400	0.4368	1000	0.608$\bar{5}$
420	0.4438	1100	0.6291
440	0.4508	1200	0.6485
460	0.4577	1300	0.6667
480	0.464$\bar{5}$	1400	0.6837
500	0.4712	1500	0.6995
520	0.4778	1600	0.7142
540	0.4843	1700	0.7278
560	0.4907	1800	0.7403
580	0.4971	1900	0.7517
		2000	0.7622

*n.b.p. = 133 F

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



Curve	Reference
1	106
2	157, 158
3	48
4	105

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:

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

For temperatures between 750 K and 1500 K:

$$C_p^0\ (\text{cal g}^{-1}\text{K}^{-1}) = 0.312657 + 4.64654 \times 10^{-4}T - 1.98142 \times 10^{-7}T^2 + 3.62964 \times 10^{-11}T^3 \quad (T \text{ in K}) \qquad (2)$$

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.$\overline{5}$ and 2.$\overline{5}$ 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, 184, 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:

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

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.

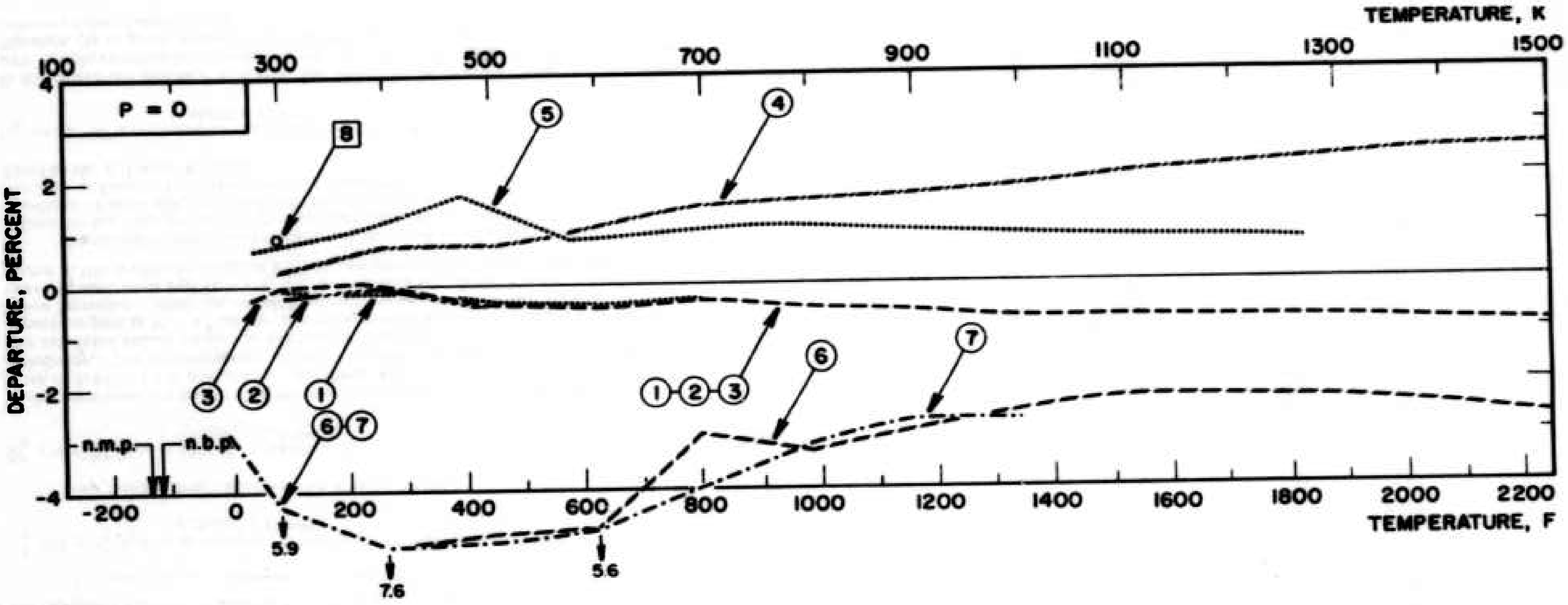
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

GAS

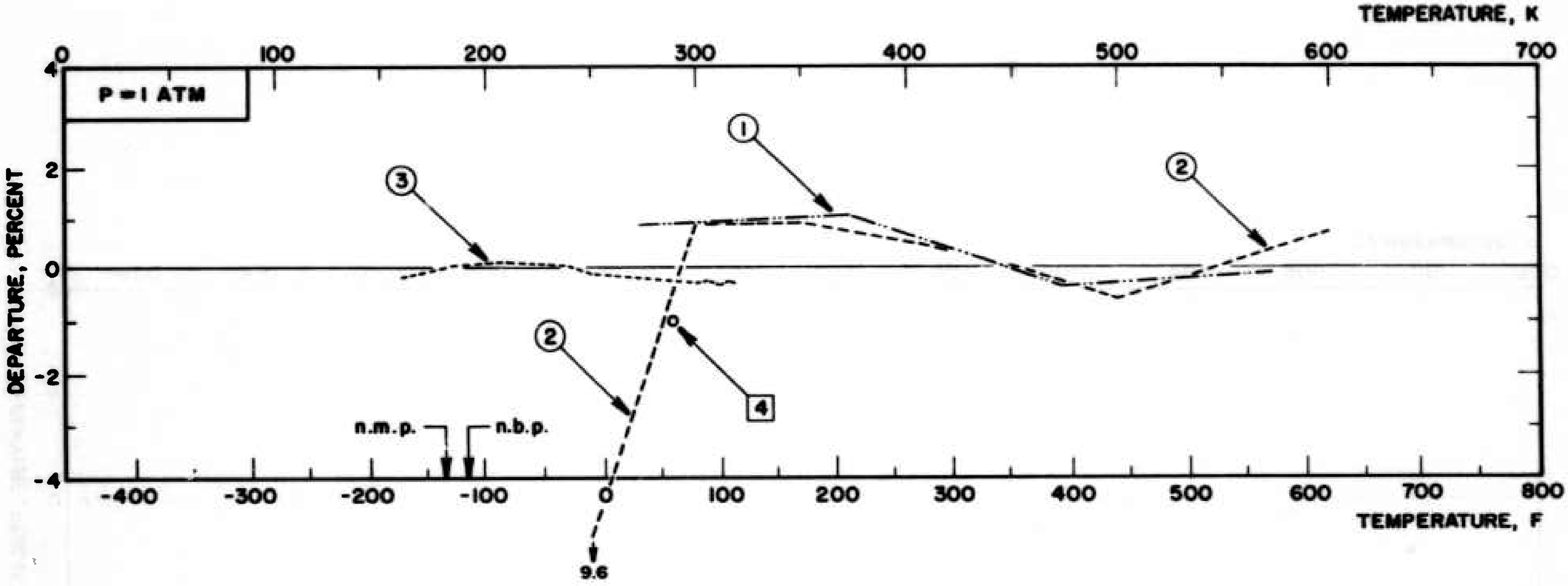
T	C_p^0	T	C_p^0
		700	0.5401
		720	0.5428
40	0.3894	740	0.5454
60	0.3970	760	0.5480
80	0.4043	780	0.5505
100	0.4114	800	0.5531
120	0.4182	820	0.5556
140	0.4248	840	0.5582
160	0.4312	860	0.5608
180	0.4373	880	0.5633
200	0.4432	900	0.5659
220	0.4489	920	0.5684
240	0.4544	940	0.5709
260	0.4597	960	0.5733
280	0.4648	980	0.5757
300	0.4697	1000	0.5781
320	0.474$\overline{5}$	1100	0.5897
340	0.479$\underline{1}$	1200	0.6007
360	0.483$\overline{5}$	1300	0.6110
380	0.4877	1400	0.6208
400	0.4918	1500	0.6301
420	0.4958	1600	0.6389
440	0.4996	1700	0.6472
460	0.5033	1800	0.6551
480	0.5069	1900	0.6626
500	0.5103	2000	0.6698
520	0.5137		
540	0.5169		
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



Curve	Reference
1	59, 72, 167, 227
2	111, 192, 255
3	171, 253
4	137
5	93
6	203
7	222
8	18

FIGURE 24 DEPARTURE [illegible] FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS ACETYLENE



Curve	Reference
1	14
2	202
3	251
4	78

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

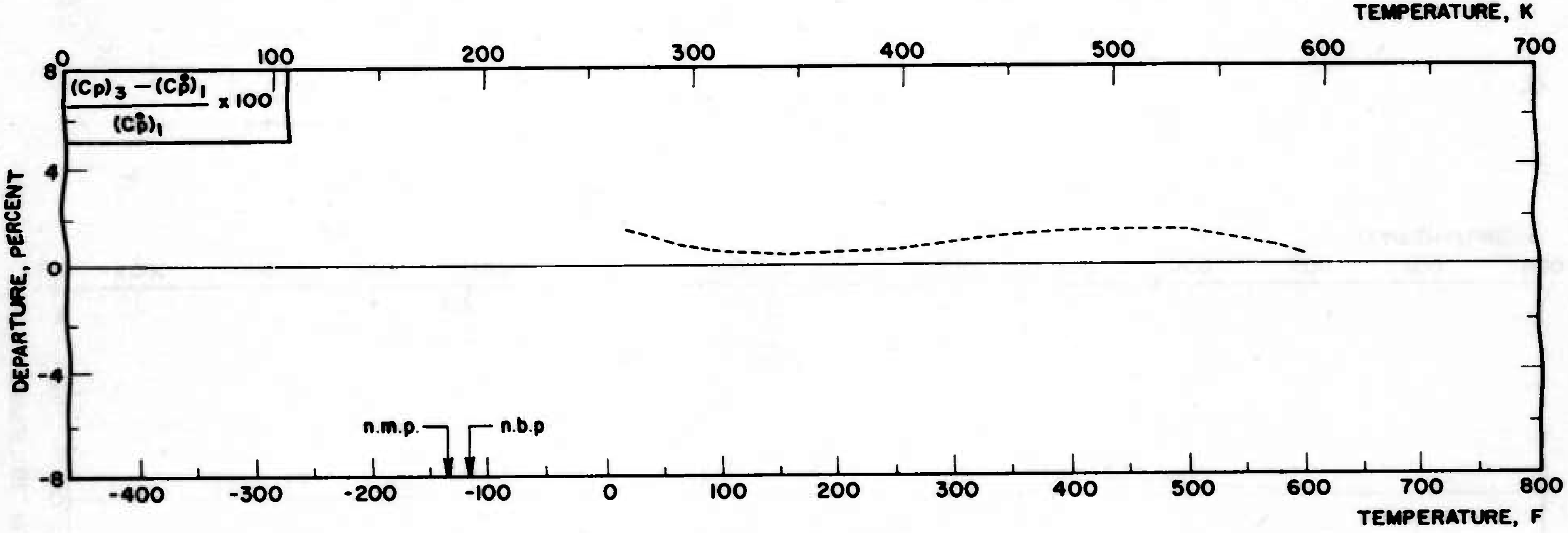


TABLE 25 SPECIFIC HEAT AT CONSTANT PRESSURE OF BENZENE

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 Atwood (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 Staveley 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 Fiock 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, 86, 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

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

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 ‡

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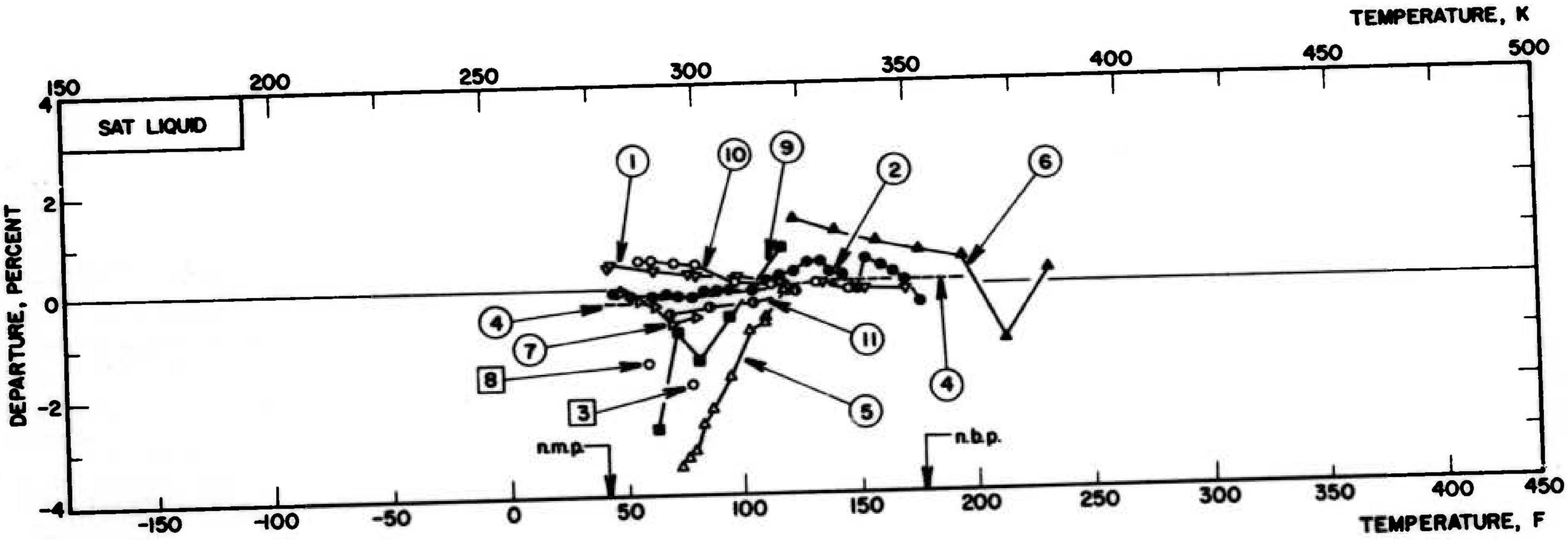
†Extrapolated for the liquid phase ignoring pressure dependence (n. m. p. = 42 F)

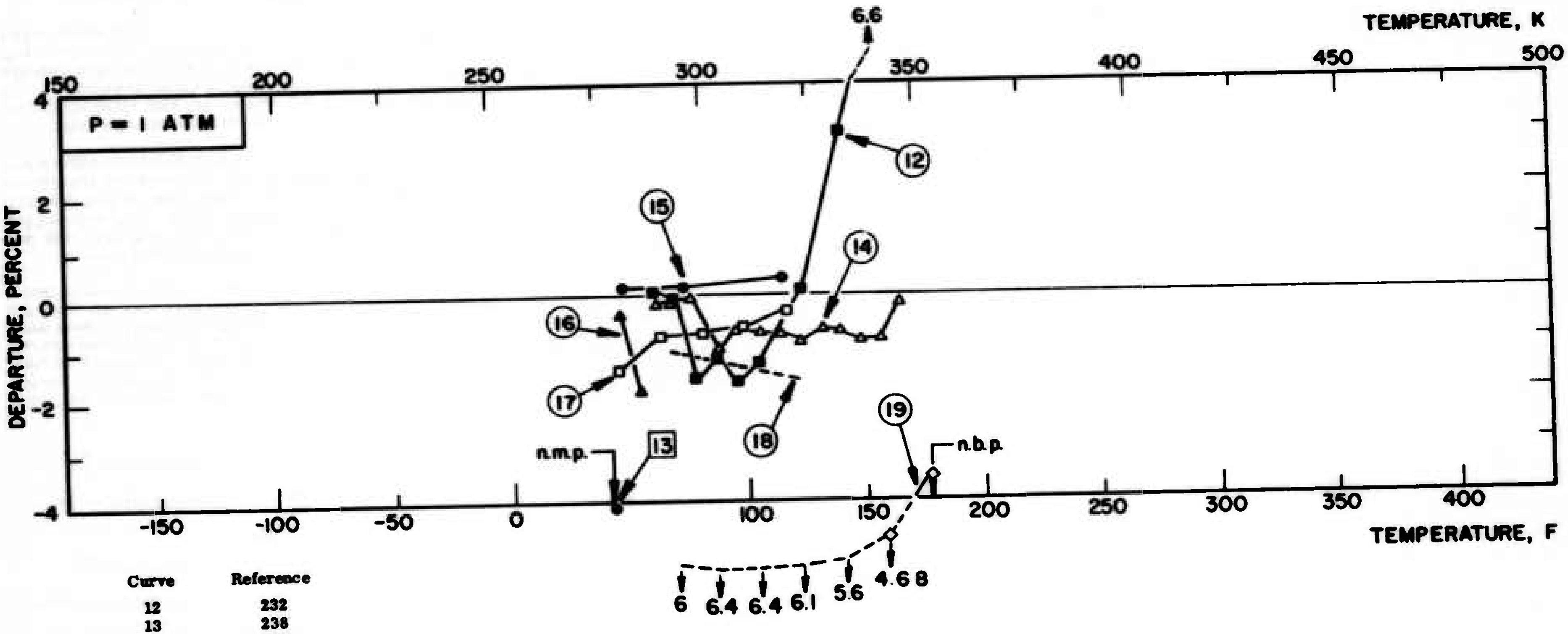
‡n. b. p. = 176 F

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



Curve	Reference
1	9
2	31
3	190
4	36
5	60
6	62
7	86
8	115
9	117
10	148
11	168

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



Curve	Reference
12	232
13	238
14	199
15	237
16	200
17	201
18	216
19	231

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:

$$C_p^g\,(\text{cal g}^{-1}\text{K}^{-1}) = -0.115011 + 1.48459 \times 10^{-3}T - 9.2679\bar{5} \times 10^{-7}T^2 + 1.89526 \times 10^{-10}T^3 \qquad (T \text{ in K}), (1)$$

For temperatures between 770 K and 1500 K:

$$C_p^g\,(\text{cal g}^{-1}\text{K}^{-1}) = 0.0510547 + 1.0001\bar{5} \times 10^{-3}T - 5.04836 \times 10^{-7}T^2 + 9.57398 \times 10^{-11}T^3 \qquad (T \text{ in K}). (2)$$

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 = O, 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 Weltner 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^1, is computed from the ideal gas values, C_p^g, using known thermodynamic relations together with the Berthelot's equation of state which corrects for gas imperfection. The resulting C_p^1 values for the temperatures range 300 K to 610 K are fitted to the following equation:

$$C_p^1\,(\text{cal g}^{-1}\text{K}^{-1}) = -0.051863\bar{5} + 1.15983 \times 10^{-3}T - 3.44023 \times 10^{-7}T^2 - 1.67132 \times 10^{-10}T^3 \qquad (T \text{ in K}). (3)$$

The recommended values of C_p^1 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^1 given by Equation (3) is compared with C_p^g given by Equation (1) over their common temperature range.

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

RECOMMENDED VALUES

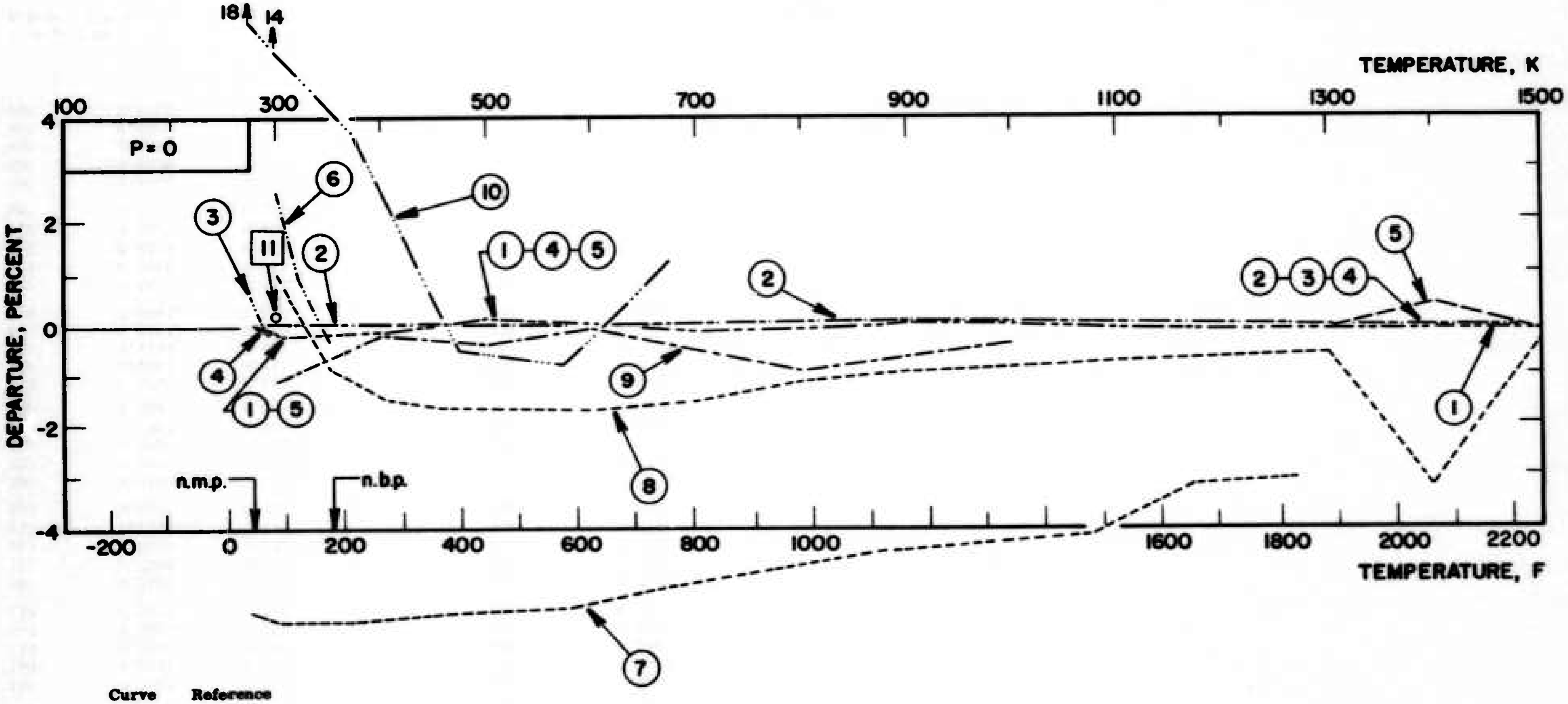
[Temperature, T, F; Specific Heat, C_p, B $lb^{-1}F^{-1}$]

GAS

T	C_p°	C_p^{1}	T	C_p°
			700	0.5071
			720	0.5129
40	0.2296		740	0.5185
60	0.2408		760	0.5240
80	0.2517	0.260	780	0.5294
100	0.2625	0.270	800	0.5347
120	0.2731	0.280	820	0.5398
140	0.2835	0.290	840	0.5447
160	0.2938	0.300	860	0.5496
180	0.3038	0.309	880	0.5543
200	0.3137	0.319	900	0.5589
220	0.3234	0.328	920	0.5634
240	0.3329	0.337	940	0.5682
260	0.3423	0.346	960	0.5724
280	$0.351\bar{5}$	0.355	980	0.5767
300	$0.360\bar{5}$	0.364	1000	0.5808
320	0.3693	0.372	1100	0.6005
340	0.3780	0.381	1200	0.6187
360	$0.386\bar{5}$	0.389	1300	0.6354
380	0.3948	0.397	1400	0.6506
400	0.4030	0.405	1500	0.6647
420	0.4110	0.413	1600	$0.677\bar{5}$
440	0.4189	0.421	1700	0.6892
460	0.4266	0.428	1800	0.7000
480	0.4341	0.436	1900	0.7098
500	0.4415	0.443	2000	0.7189
520	0.4487	0.450		
540	0.4558	0.457		
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			

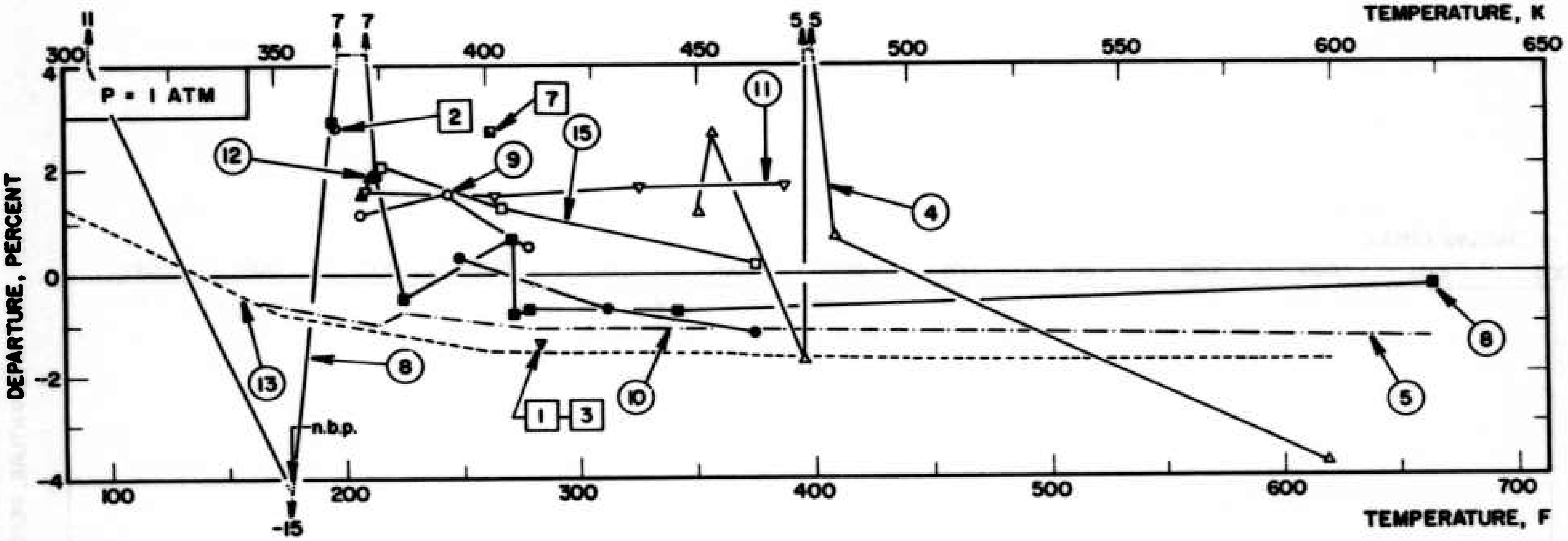
n.m.p. = 42 F
n.b.p. = 176 F

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



Curve	Reference
1	22
2	59
3	110, 167
4	171, 253
5	208
6	13
7	92
8	202
9	222
10	24
11	18

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



Curve	Reference	Curve	Reference
1	15	9	145
2	46	10	165
3	48	11	186
4	58	12	191
5	65	13	202
6	78	14	216
7	85	15	229
8	89		

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

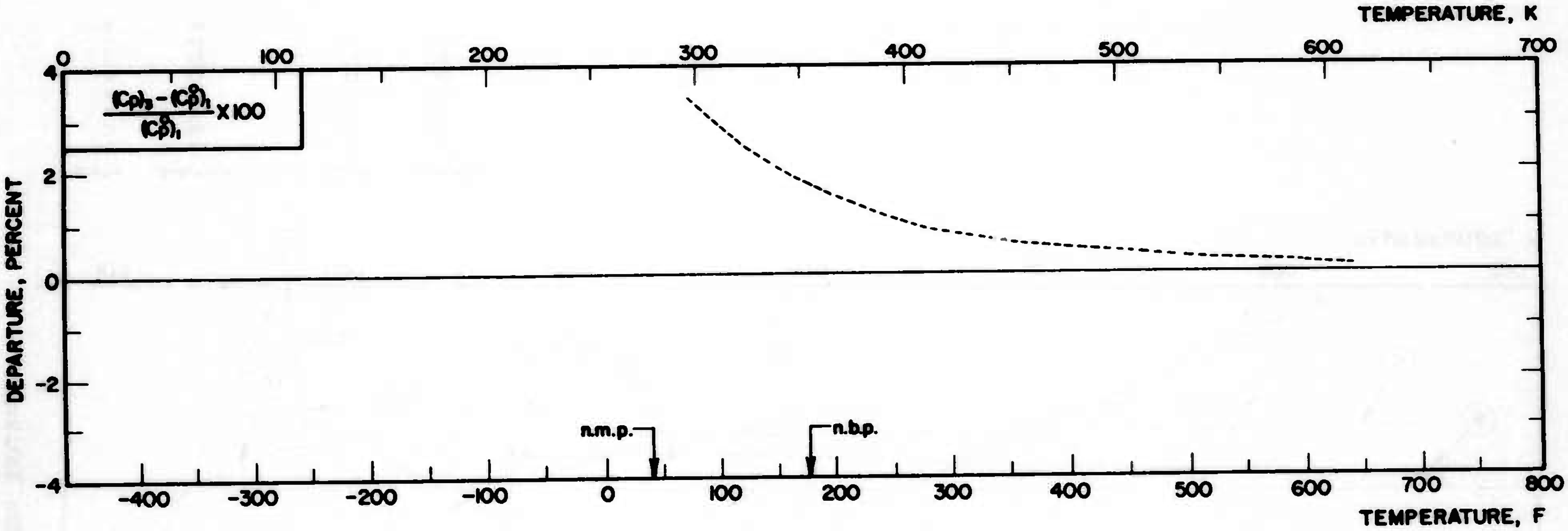


TABLE 26 SPECIFIC HEAT AT CONSTANT PRESSURE OF Iso-BUTANE

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

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

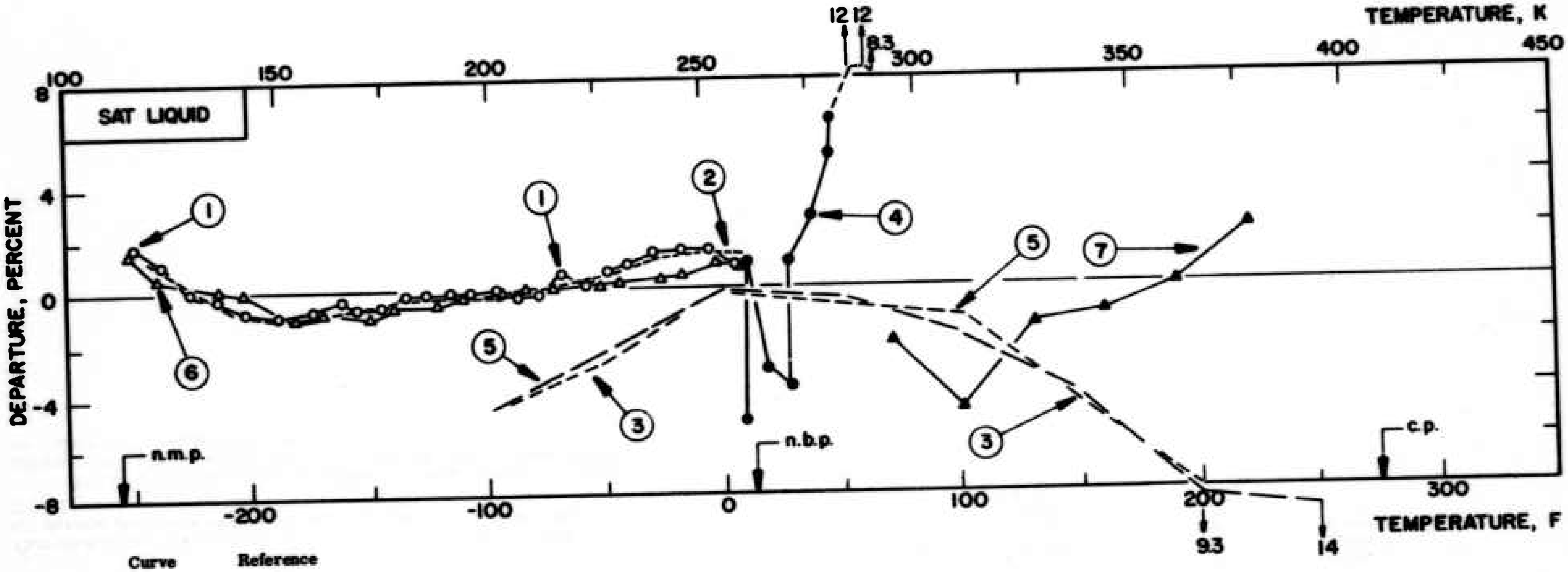
[Temperature, T, F; Specific Heat, C_p, Blb^{-1} F^{-1}

LIQUID

T	C_p	T	C_p
		0	0.5204
		20	0.5338
		40	0.549
-240	0.4091	60	0.566
-220	0.4202	80	0.585
-200	0.4301	100	0.607
-180	0.4392	120	0.631
-160	0.4476	140	0.659
-140	0.4556	160	0.689
-120	0.4635	180	0.723
-100	0.4714	200	0.761
-80	0.4796	220	0.803
-60	0.4884	240	0.848
-40	0.4980		
-20	0.5086		

n.b.p. = 12 F

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



Curve	Reference
1	7
2	7*
3	32
4	43
5	83
6	155
7	175

*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 Aston 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:

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

For temperatures from 785 K to 1500 K:

$$C_p^g \text{ (cal g}^{-1}\text{K}^{-1} = 0.127560 + 1.26105 \times 10^{-3}T - 5.36522 \times 10^{-7}T^2 + [illegible].39621 \times 10^{-11}T^3 \qquad (T \text{ in K}). \quad (2)$$

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 Felsing (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^g. Therefore, in the present analysis, the specific heat at the real gas state, C_p^1, is calculated from C_p^g and corrected for gas imperfection, using the Berthelot's equation of state. The resulting C_p^1 values for temperatures from 233 K to 710 K are represented by the following formula:

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

The recommended values of C_p^1 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)

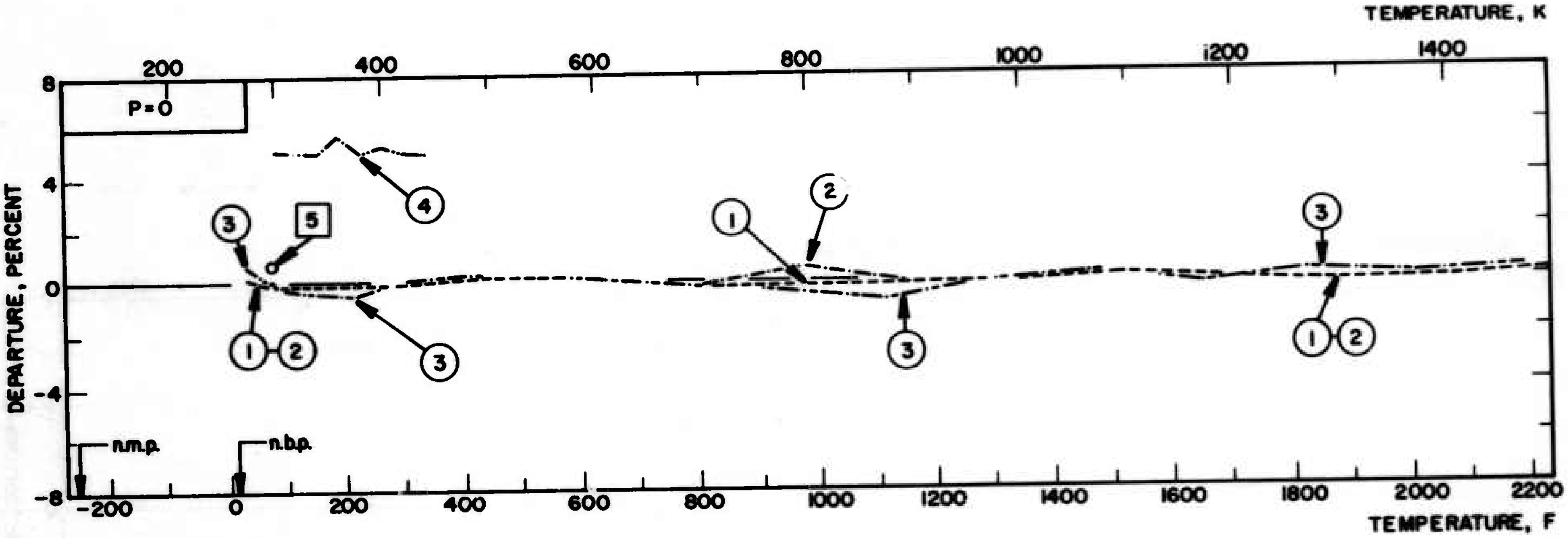
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

GAS

T	C_p^0	C_p^1
40	0.3732	0.381
60	0.3867	0.394
80	0.4000	0.406
100	0.4131	0.419
120	0.4260	0.431
140	0.4388	0.444
160	0.4514	0.456
180	0.4639	0.468
200	0.4762	0.480
220	0.4883	0.491
240	0.5003	0.503
260	0.5121	0.514
280	0.5237	0.526
300	0.5352	0.537
320	0.5465	0.548
340	0.5577	0.559
360	0.5687	0.570
380	0.5795	0.581
400	0.5902	0.591
420	0.6007	0.602
440	0.6111	0.612
460	0.6213	0.622
480	0.6314	0.632
500	0.6413	0.642
520	0.6511	0.652
540	0.6607	0.662
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
700	0.7323	0.733
720	0.7406	0.741
740	0.7488	0.749
760	0.7568	0.757
780	0.7646	0.765
800	0.7724	0.773
820	0.7800	0.780
840	0.7874	
860	0.7947	
880	0.8019	
900	0.8089	
920	0.8158	
940	0.8226	
960	0.8291	
980	0.8354	
1000	0.8416	
1100	$0.871\bar{5}$	
1200	0.8994	
1300	0.9254	
1400	0.9497	
1500	0.9723	
1600	0.9932	
1700	1.0126	
1800	1.0305	
1900	1.0471	
2000	$1.062\bar{5}$	

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



Curve	Reference
1	109
2	164
3	171
4	7
5	18

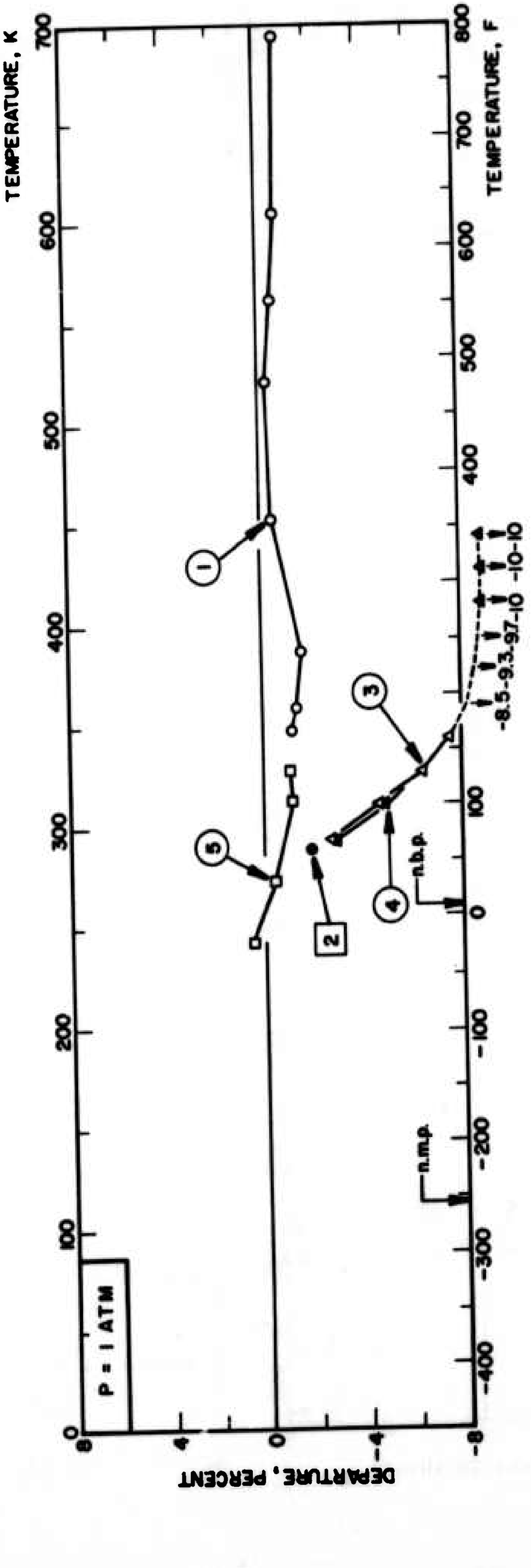


FIGURE 26 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS iso-BUTANE

Curve	Reference
1	41
2	78
3	175
4	178
5	223

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

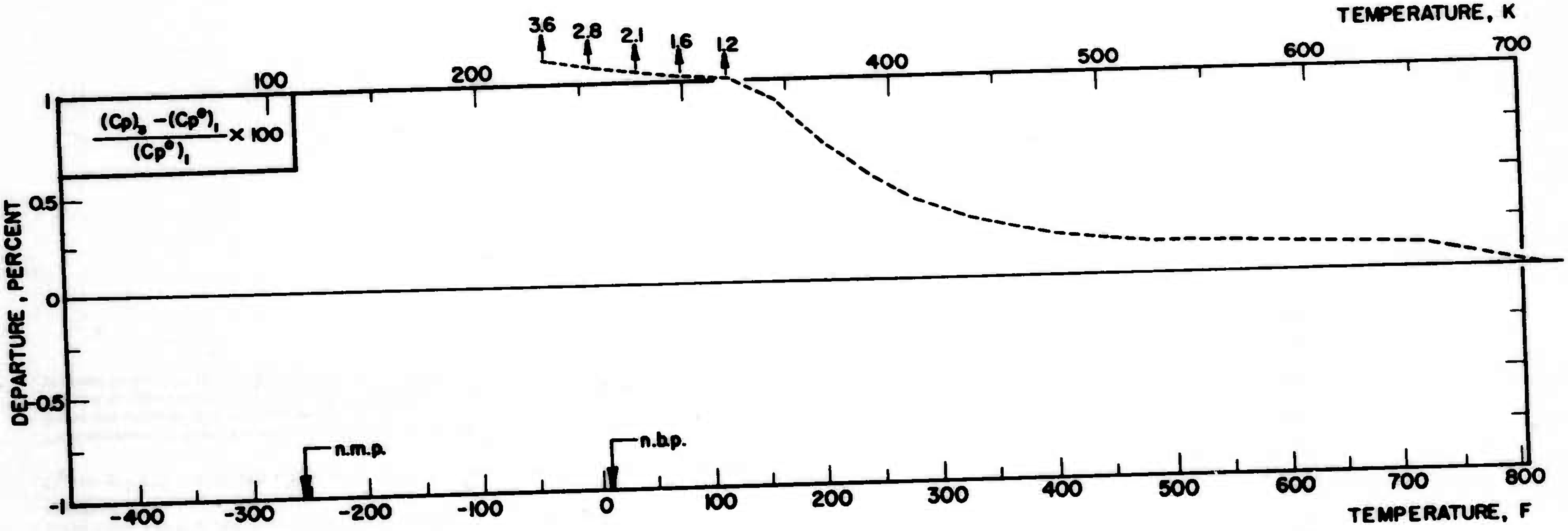


TABLE 27 SPECIFIC HEAT AT CONSTANT PRESSURE OF n-BUTANE

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 366 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:

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

(T 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}]

LIQUID

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	$0.496\bar{5}$
- 60	0.5030
- 40	0.5104
- 20	0.5189
0	$0.528\bar{5}$
20	$0.539\bar{5}$
40	0.5519
60	0.566
80	0.582
100	0.599
120	0.619
140	0.641
160	0.665
180	0.692

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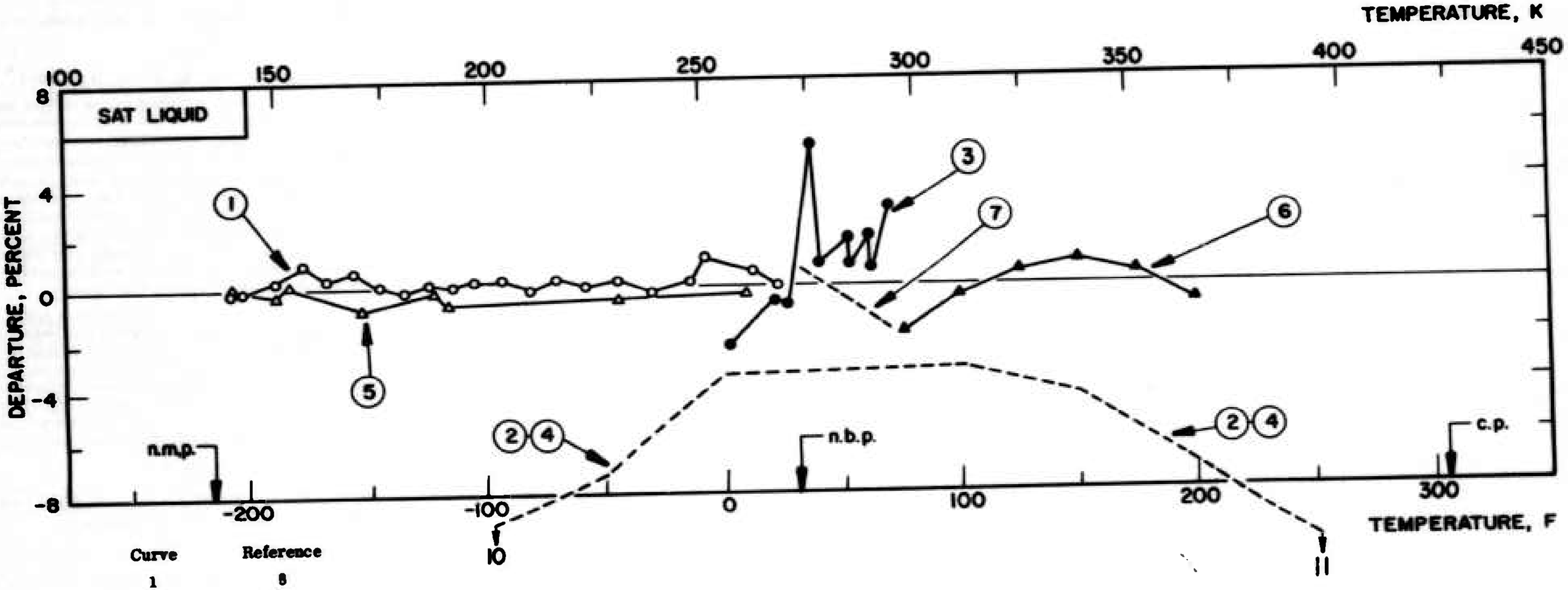
†Extrapolated for the liquid phase ignoring pressure dependence (n. m. p. = -213 ± 4 F).

n. b. p. = 32 F

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



Curve	Reference
1	8
2	32
3	43
4	83
5	87
6	172
7	36

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:

For temperatures between 270 K and 790 K:

$$C_p^0\,(\mathrm{cal\ g^{-1}\,K^{-1}}) = 0.0564796 + 1.22083 \times 10^{-3}\,T - 1.00571 \times 10^{-7}\,T^2 - 2.72977 \times 10^{-10}\,T^3. \qquad (T \text{ in K}) \tag{1}$$

For temperatures between 790 K and 1500 K:

$$C_p^0\,(\mathrm{cal\ g^{-1}\,K^{-1}}) = 0.0507543 + 1.43941 \times 10^{-3}\,T - 6.79897 \times 10^{-7}\,T^2 + 1.22485 \times 10^{-10}\,T^3 \qquad (T \text{ in K}). \tag{2}$$

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, 178) 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:

$$C_p\,(\mathrm{cal\ g^{-1}\,K^{-1}}) = 0.0703903 + 1.11291 \times 10^{-3}\,T + 2.44476 \times 10^{-7}\,T^2 - 5.82753 \times 10^{-10}\,T^3 \qquad (T \text{ in K}). \tag{3}$$

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 plot for P = 1 atm. The third plot is the comparison of Equation (3) for the temperature range where Equation (3) is valid. In this figure percent is calculated by

$$\frac{(C_p)_3 - (C_p^0)_1}{(C_p^0)_1} \times 100$$

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

RECOMMENDED VALUES

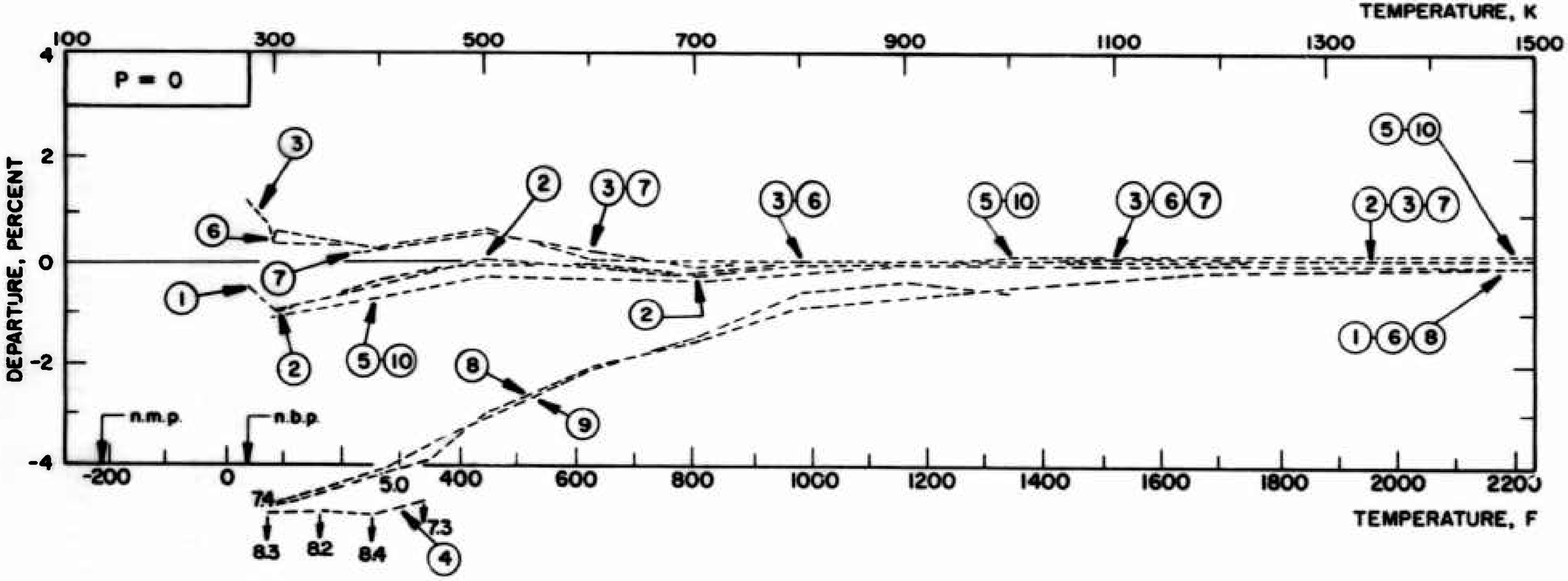
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

GAS

T	C_p^0	T	C_p^0
		600	0.6842
20	0.3693*	620	0.6932
40	0.3815	640	0.7021
60	0.3937	660	0.7108
80	0.4058	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	$0.77\bar{5}0$
240	$0.499\bar{5}$	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	$0.586\bar{5}$	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	$0.990\bar{5}$
540	0.6563	1700	1.0099
560	0.6657	1800	1.0279
580	0.6750	1900	1.0446
		2000	1.0600

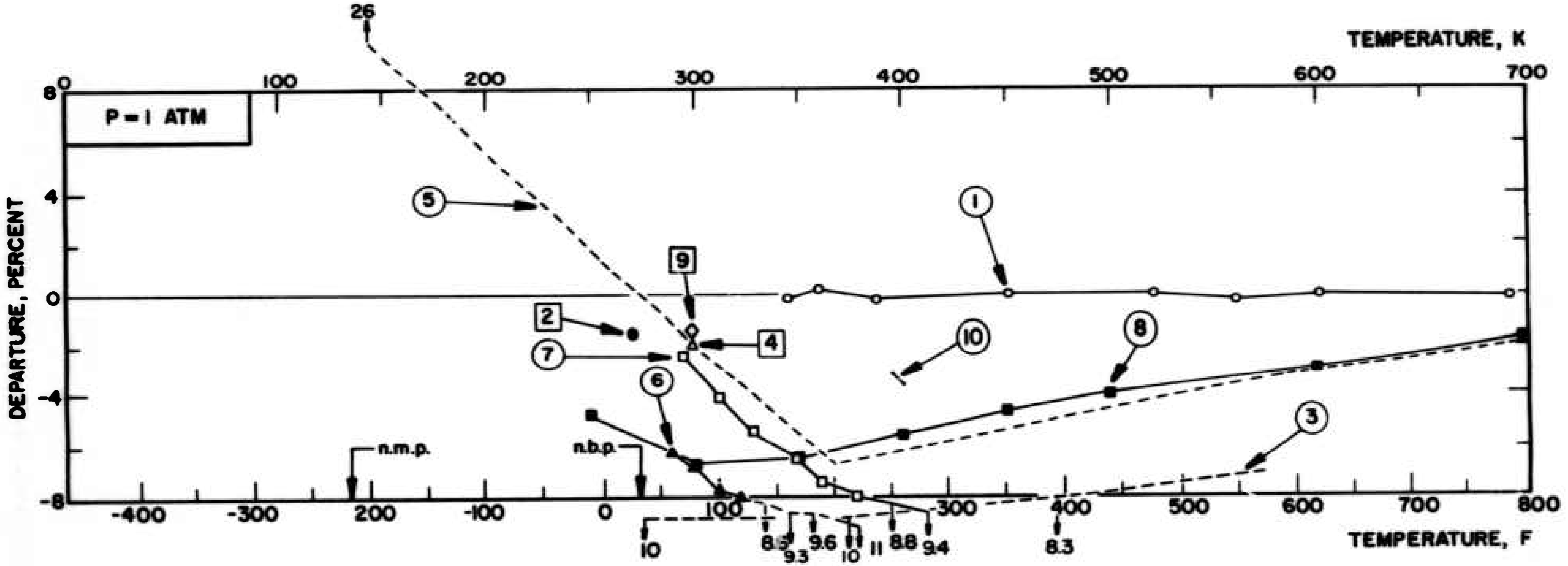
*n.b.p. = 32 F

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



Curve	Reference
1	253
2	159
3	59, 109, 164, 167
4	48
5	134
6	161
7	171
8	203
9	222
10	133

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



Curve	Reference
1	41
2	13
3	14
4	18
5	32, 83
6	172
7	178
8	202
9	209
10	85

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

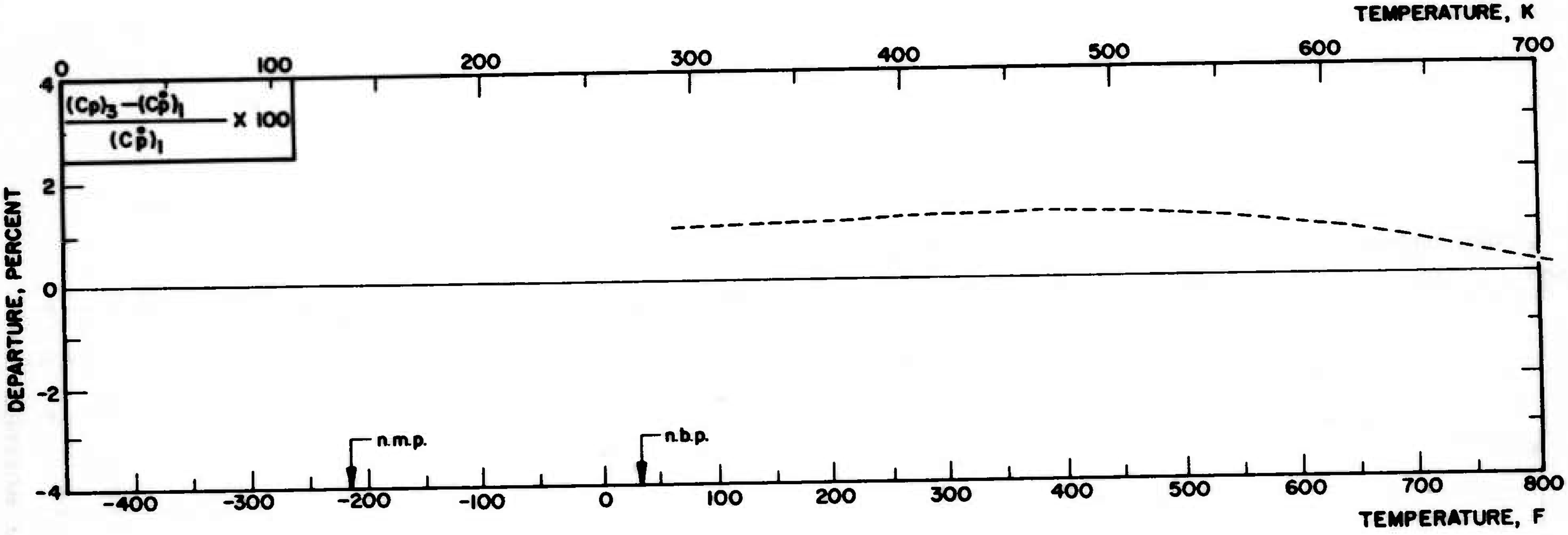


TABLE 28 SPECIFIC HEAT AT CONSTANT PRESSURE OF CARBON DIOXIDE

DISCUSSION

LIQUID

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:

$$C_p \text{ (cal g}^{-1}\text{K}^{-1}) = -46.6258 + 0.584679\,T - 2.42252 \times 10^{-3}T^2 + 3.34972 \times 10^{-6}T^3 \quad (T \text{ in K}).$$

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.

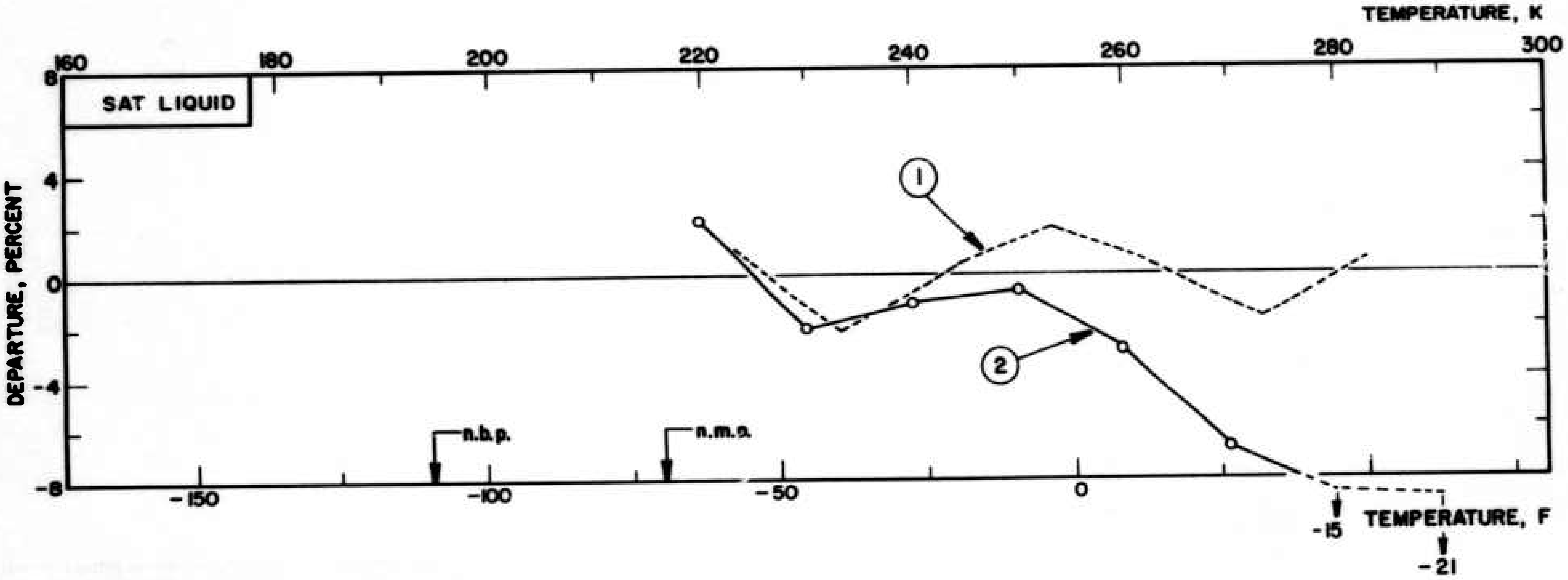
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B lb^{-1}F^{-1}]

LIQUID

T	C_p
-60	0.4308
-55	0.4414
-50	0.4494
-45	0.4554
-40	0.4598
-30	0.4652
-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:

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

For temperatures between 590 K and 1500 K:

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

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 MacCormack 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 (85) 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:

$$C_p \ (\mathrm{cal\ g^{-1}K^{-1}}) = 0.136812 + 2.15312 \times 10^{-4}T + 7.25177 \times 10^{-8}T^2 - 1.57146 \times 10^{-10}T^3 \qquad (3)$$

For temperatures between 540 K and 1500 K:

$$C_p \ (\mathrm{cal\ g^{-1}K^{-1}}) = 0.144592 + 2.5844\bar{5} \times 10^{-4}T - 1.31976 \times 10^{-7}T^2 + 2.42548 \times 10^{-11}T^3 \qquad (T \text{ in K}) \qquad (4)$$

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

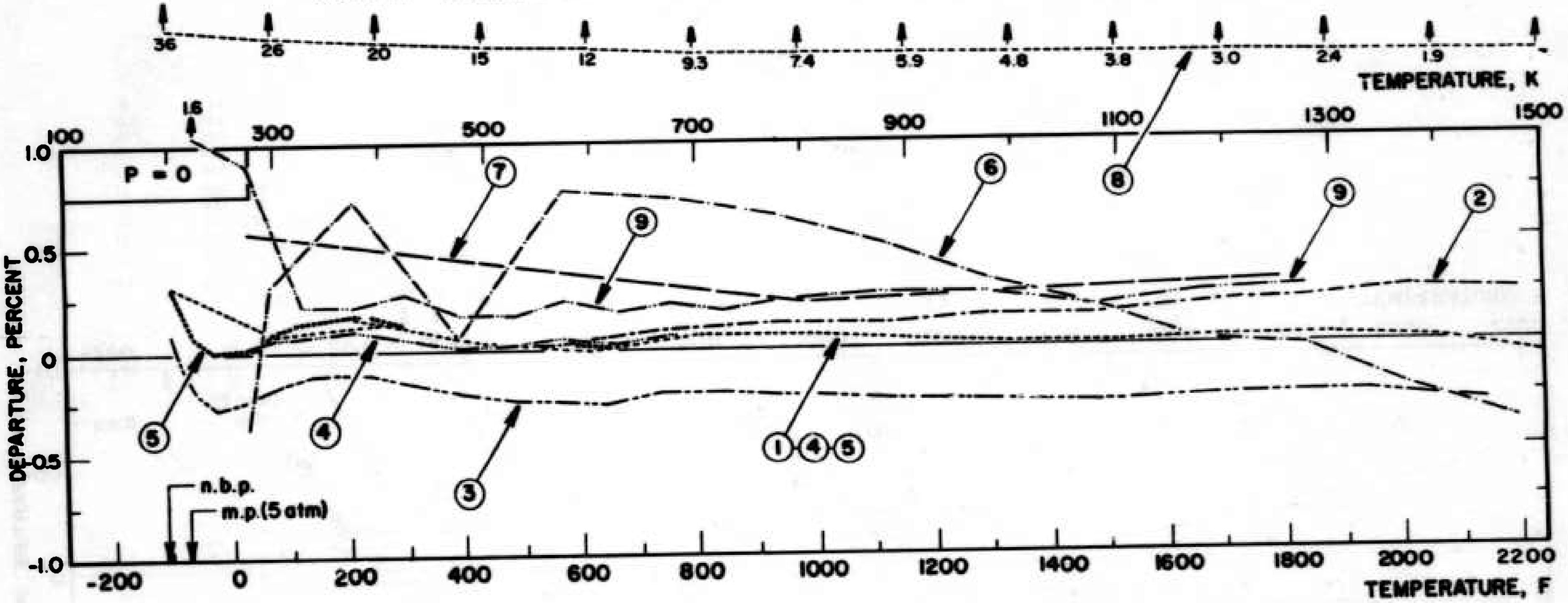
[Temperature, T, F; Specific Heat, C_p^0 and C_p, B lb^{-1} F^{-1}]

GAS

T	C_p^0	C_p	T	C_p^0	C_p
-100	0.17499	0.1814	600	$0.2551\bar{5}$	0.2558
-80	0.17821	0.1839	620	0.25680	0.2572
-60	0.18136	0.1864	640	0.25822	0.2586
-40	$0.1844\bar{5}$	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	$0.266\bar{5}$
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	$0.2121\bar{5}$	0.2130	360	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	$0.2261\bar{5}$	$0.226\bar{5}$	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	$0.246\bar{5}$	1900	0.31036	0.3110
500	0.24728	0.2482	2000	0.31245	0.3130
520	0.24894	0.2499			
540	$0.2505\bar{5}$	0.2514			
560	0.25212	0.2529			
580	0.25366	0.2543			

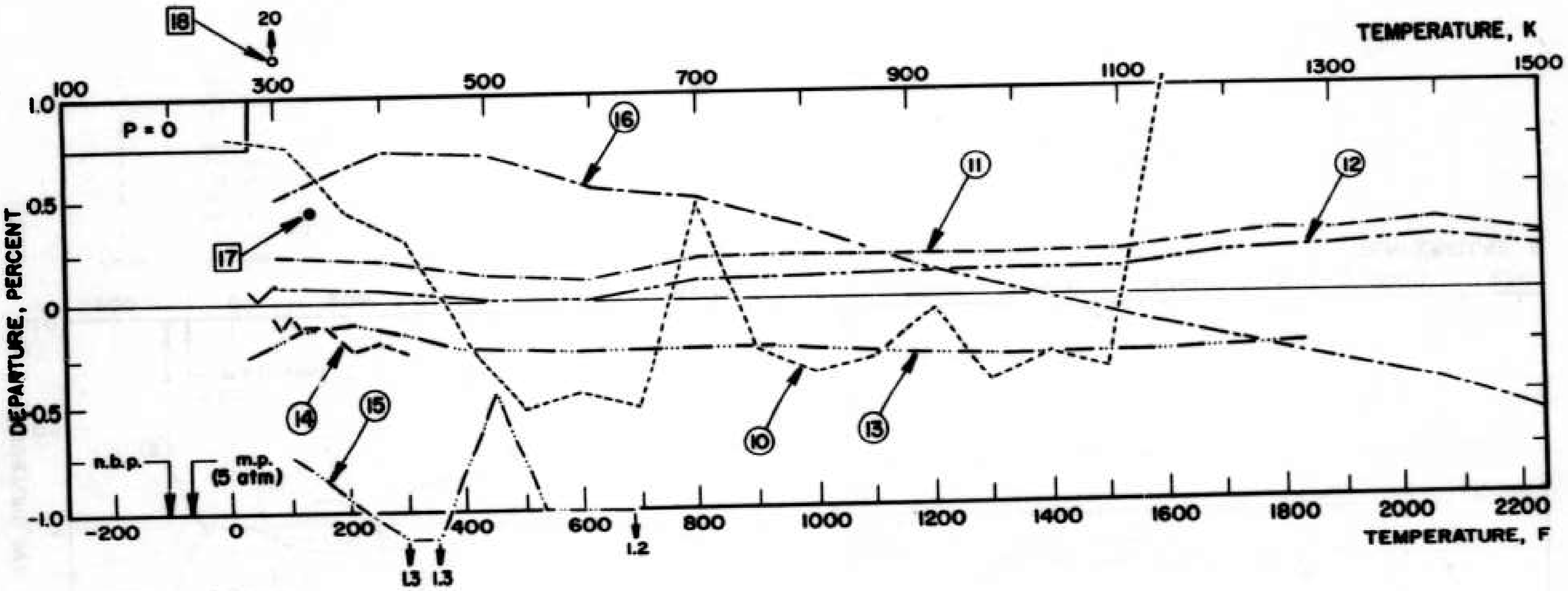
n.m.p. (5 atm) = -70 F
n.b.p. = -109 F

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



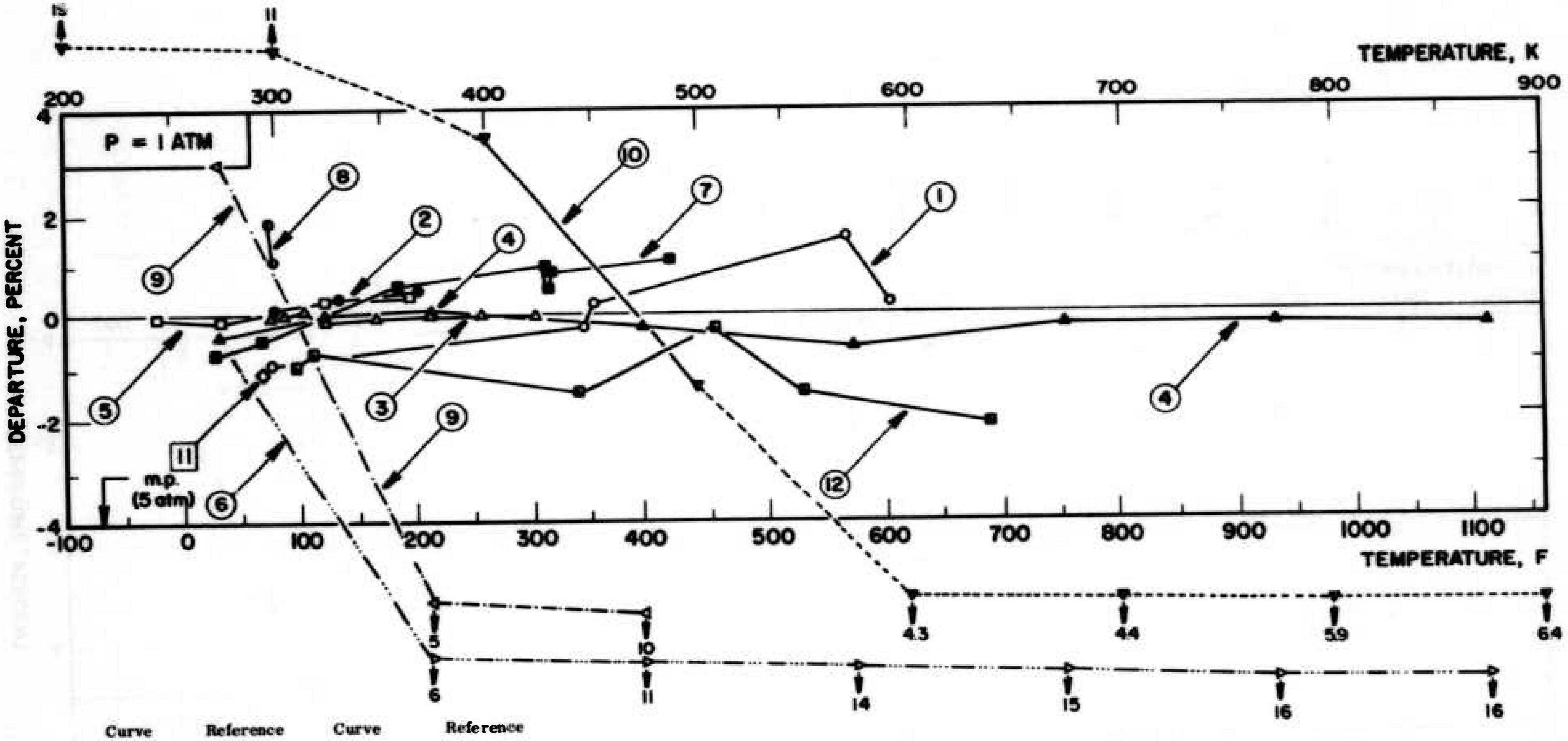
Curve	Reference
1	72, 137, 254, 380, 458
2	253
3	361, 362
4	495, 496
5	570, 575
6	24, 278
7	59
8	93
9	100

FIGURE 28 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS CARBON DIOXIDE (continued)



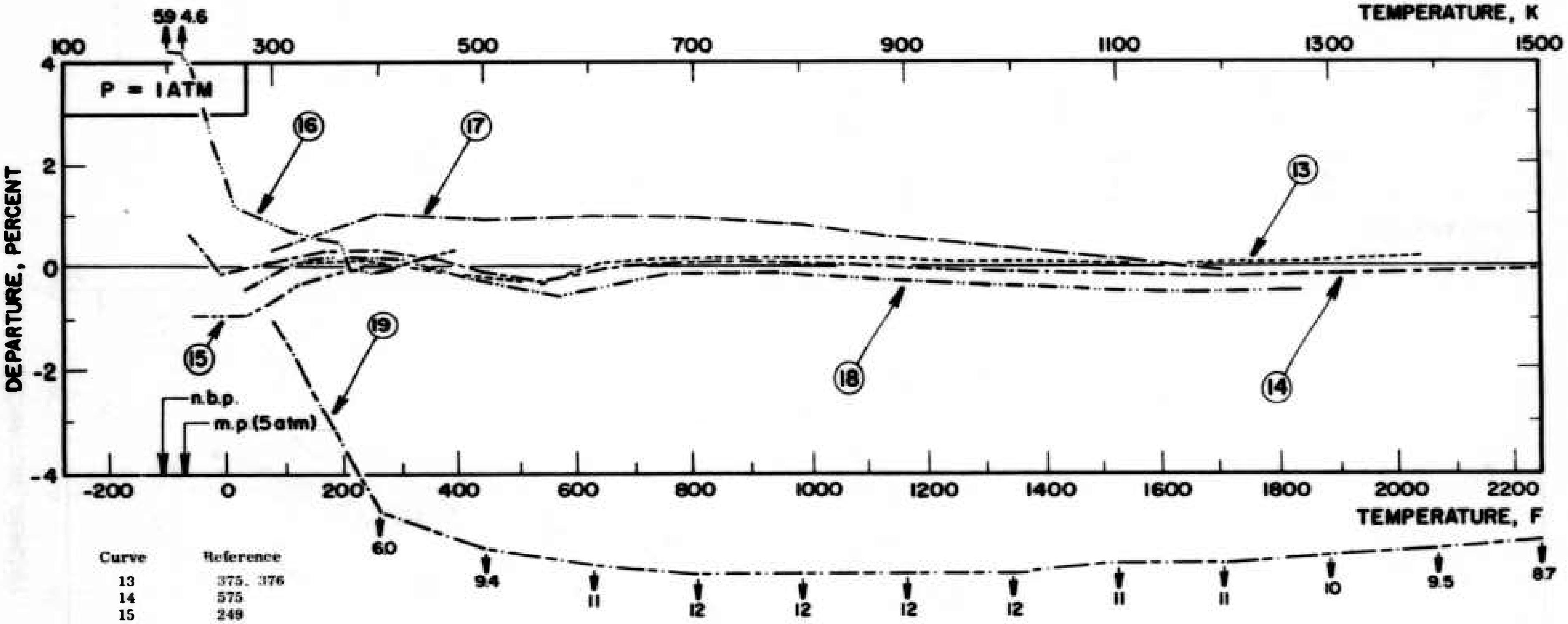
Curve	Reference
10	284, 359
11	285, 405
12	167, 226, 389, 403, 426
13	450, 494
14	462
15	514
16	532
17	561
18	18

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



Curve	Reference	Curve	Reference
1	58	7	56
2	103	8	85
3	305	9	241
4	450	10	422
5	453	11	482
6	46	12	514

FIGURE 28 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS CARBON DIOXIDE (continued)



Curve	Reference
13	375, 376
14	575
15	249
16	250
17	354
18	494
19	519

FIGURE 28 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS CARBON DIOXIDE

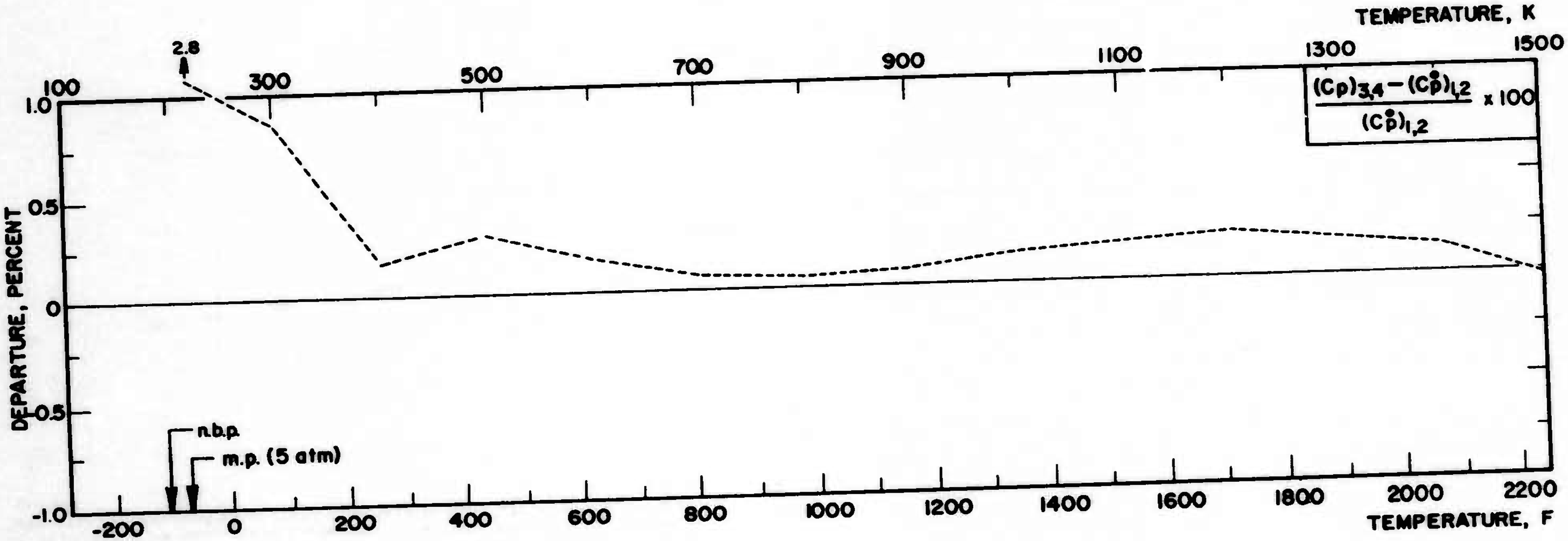


TABLE 29 SPECIFIC HEAT AT CONSTANT PRESSURE OF CARBON MONOXIDE

DISCUSSION

LIQUID

Two sets of calorimetric data and a single-point theoretical value are available for the specific heat of liquid carbon monoxide. Clusius (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

$$C_p \ (\mathrm{cal\ g^{-1} K^{-1}}) = 0.480696 + 4.74088 \times 10^{-4} T \qquad (T \text{ in K}).$$

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.

RECOMMENDED VALUES

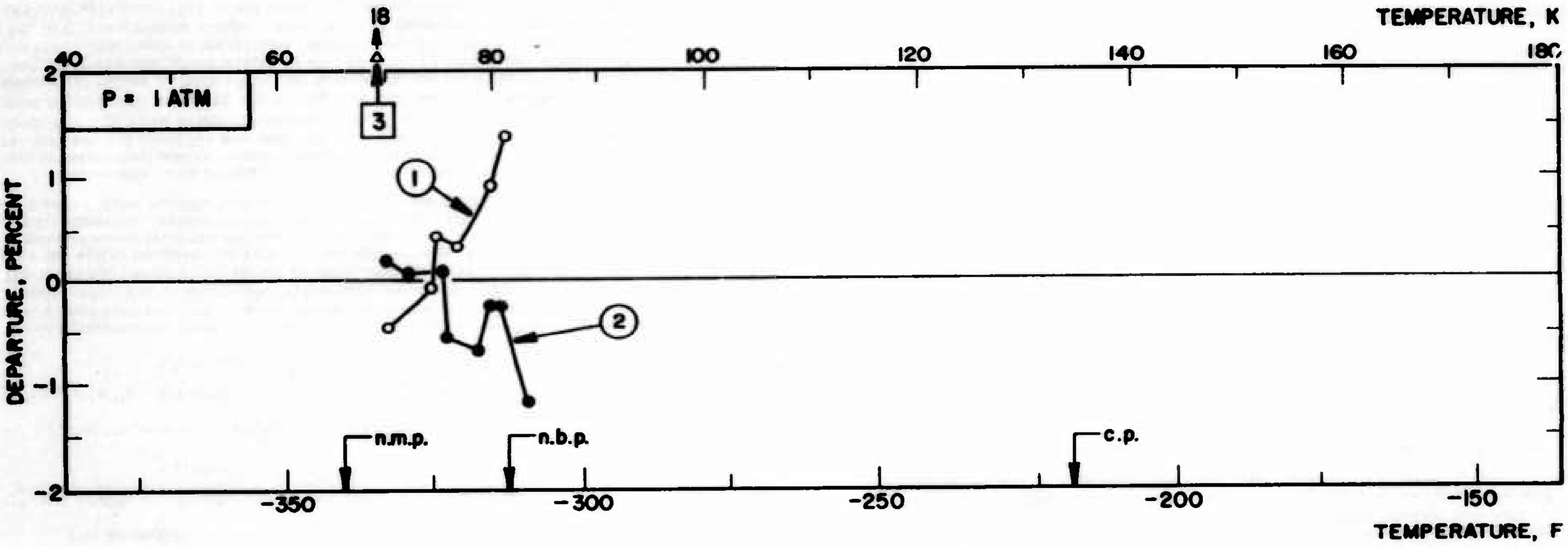
[Temperature, T, F; Specific Heat, C_p, B $lb^{-1}F^{-1}$]

LIQUID

T	C_p
-335	0.5132
-330	0.5145
-325	0.5158
-320	0.5171
-315	0.5185
-310	0.5198

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:

$$C_p^0\ (\mathrm{cal\ g^{-1}K^{-1}}) = 0.256859 - 6.46329 \times 10^{-5}\,T + 1.3186\bar{5} \times 10^{-7}\,T^2 - 2.65440 \times 10^{-11}\,T^3 \qquad (1)$$

For temperatures between 615 K and 1500 K:

$$C_p^0\ (\mathrm{cal\ g^{-1}K^{-1}}) = 0.21034\bar{5} + 9.44224 \times 10^{-5}\,T - 1.94071 \times 10^{-8}\,T^2 - 2.3538\bar{5} \times 10^{-12}\,T^3 \qquad (T \text{ in K}) \qquad (2)$$

These equations are found to fit the above cited values with mean deviations of 0.01 and 0.03 percent, and maximum deviations of $0.0\bar{5}$ 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:

$$C_p\ (\mathrm{cal\ g^{-1}K^{-1}}) = 0.261531 - 9.32244 \times 10^{-5}\,T + 1.93514 \times 10^{-7}\,T^2 - 7.14562 \times 10^{-11}\,T^3 \qquad (3)$$

For temperatures between 635 K and 1500 K:

$$C_p\ (\mathrm{cal\ g^{-1}K^{-1}}) = 0.212217 + 8.82394 \times 10^{-5}\,T - 1.26583 \times 10^{-8}\,T^2 - 4.68276 \times 10^{-12}\,T^3 \qquad (T \text{ in K}) \qquad (4)$$

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)

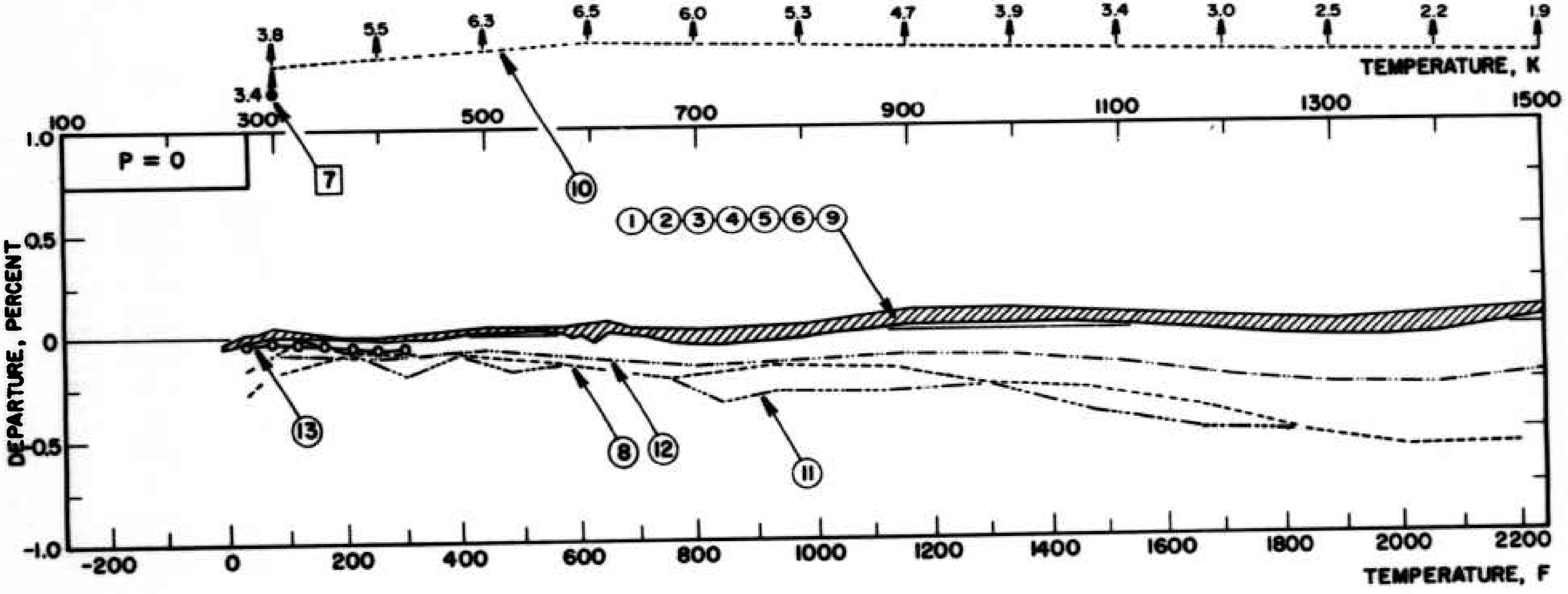
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p^0 and C_p, B $lb^{-1} F^{-1}$]

GAS

T	C_p^0	C_p	T	C_p^0	C_p
0	0.2483$\overline{5}$		600	0.25893	0.2590
20	0.24834		620	0.25964	0.2596
40	0.2483$\overline{5}$	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	0.249$\underline{3}$	760	0.26451	0.2646
180	0.24919	0.249$\overline{5}$	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	0.250$\underline{2}$	840	0.26734	0.2674
260	0.25024	0.250$\overline{5}$	860	0.26804	0.2681
280	0.25056	0.2508	880	0.26872	0.2688
300	0.25091	0.251$\underline{1}$	900	0.26940	0.269$\overline{5}$
320	0.25128	0.251$\overline{5}$	920	0.27008	0.2701
340	0.25168	0.2519	940	0.2707$\overline{5}$	0.270$\underline{8}$
360	0.25210	0.2523	960	0.27141	0.271$\overline{5}$
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	0.2914$\underline{4}$	0.2916
560	0.25757	0.2577	1800	0.2934$\overline{5}$	0.2936
580	0.25824	0.2583	1900	0.29528	0.2954
			2000	0.29693	0.2970

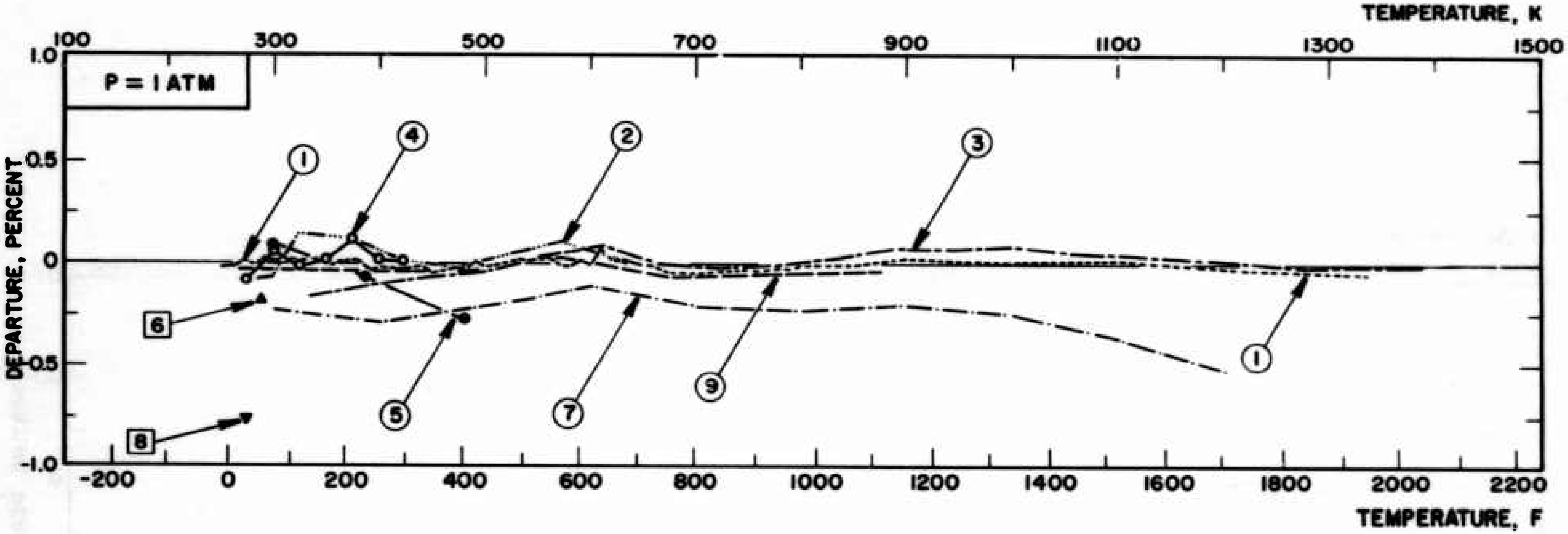
FIGURE 29 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS CARBON MONOXIDE



Curve	Reference
1	72, 167, 192, 254, 267, 380, 389, 403, 426
2	137, 575
3	226
4	253
5	351, 362
6	538
7	18

Curve	Reference
8	24, 278
9	59, 285, 395, 501
10	93
11	100
12	404
13	467, 468

FIGURE 29 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS CARBON MONOXIDE



Curve	Reference
1	132, 538, 575
2	250
3	375
4	467, 468
5	56
6	78
7	354
8	374
9	553

FIGURE 29 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS CARBON MONOXIDE

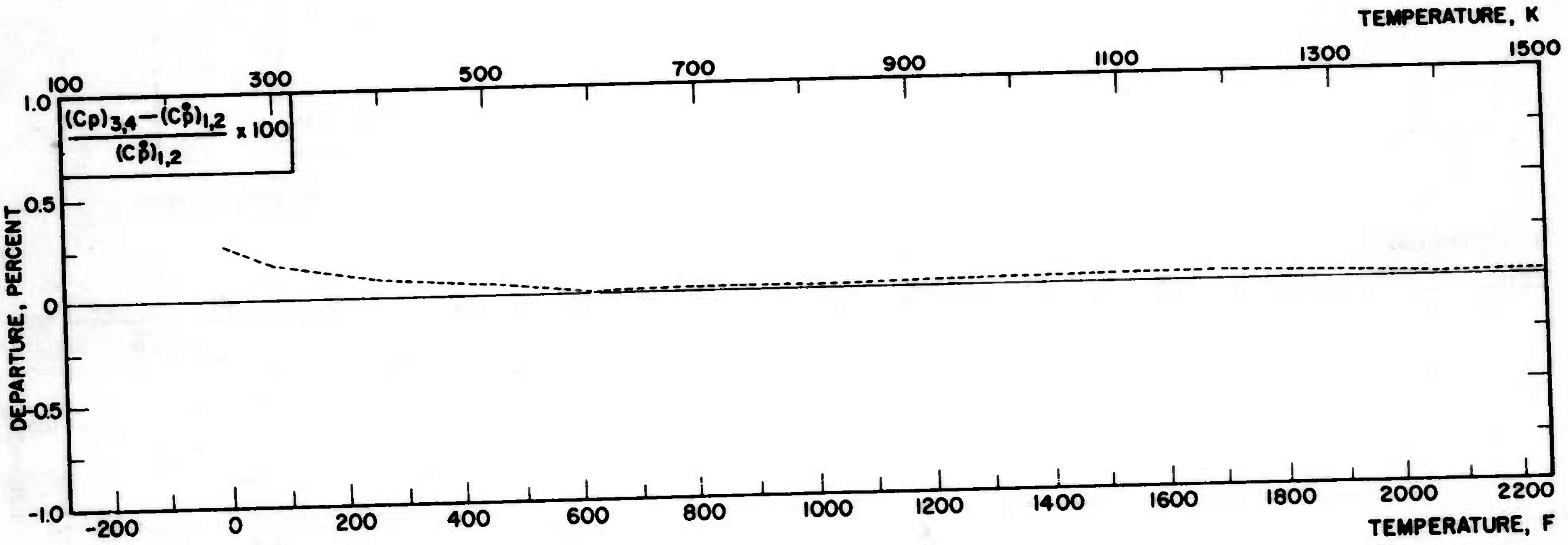


TABLE 30 SPECIFIC HEAT AT CONSTANT PRESSURE OF CARBON TETRACHLORIDE

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 Moelwyn-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

$$C_p\,(\mathrm{cal\ g^{-1}K^{-1}}) = -0.911601 + 1.15185 \times 10^{-2}T - 3.97844 \times 10^{-5}T^2 + 4.59652 \times 10^{-8}T^3 \quad (T \text{ in K}).$$

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.

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‡

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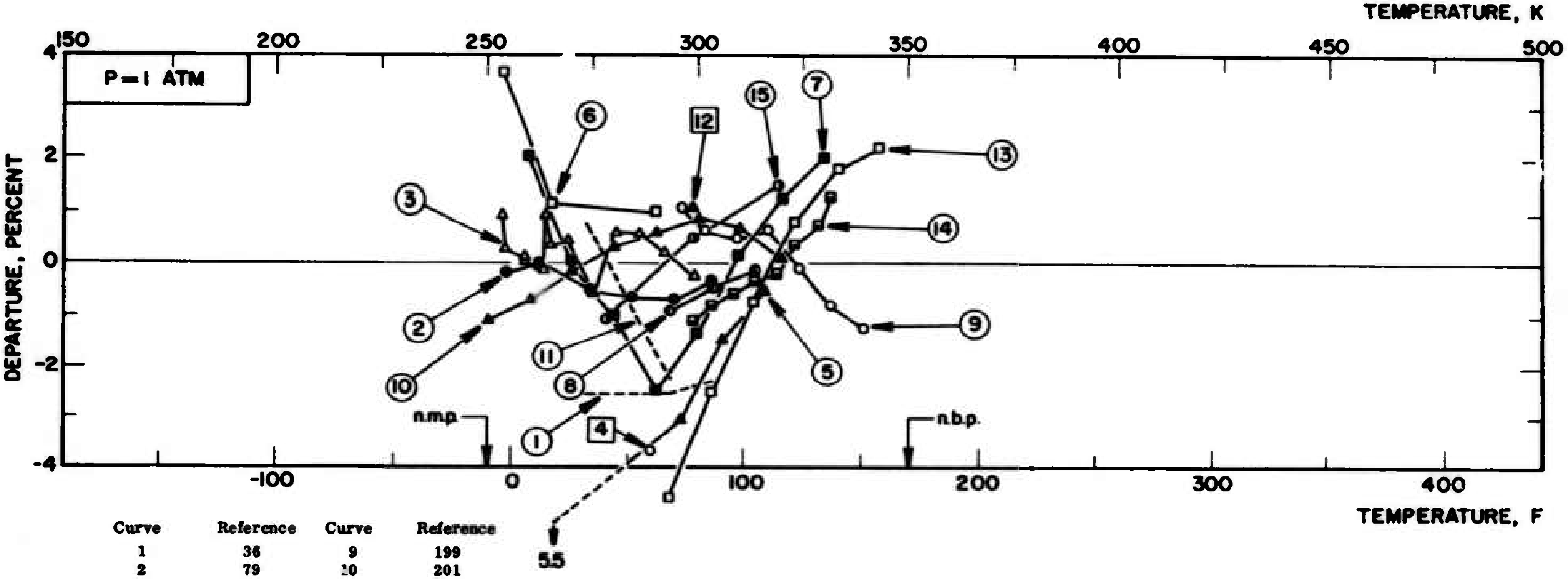
†Extrapolated for the liquid phase ignoring pressure dependence (n. m. p. = -9 F).

‡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



Curve	Reference	Curve	Reference
1	36	9	199
2	79	10	201
3	82	11	216
4	115	12	221
5	118	13	231
6	123	14	232
7	128	15	237
8	168		

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 Erdös (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

$$C_p^0 \,(\text{cal g}^{-1}\text{K}^{-1}) = 0.0223810 + 6.07856 \times 10^{-4}T - 1.0108\bar{5} \times 10^{-6}T^2 + 6.1215\bar{5} \times 10^{-10}T^3 \quad (T \text{ in K}), \quad (1)$$

For temperatures between 590 K and 1500 K

$$C_p^0 \,(\text{cal g}^{-1}\text{K}^{-1}) = 0.109265 + 1.26510 \times 10^{-4}T - 9.86439 \times 10^{-8}T^2 + 2.62643 \times 10^{-11}T^3 \quad (T \text{ in K}). \quad (2)$$

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^1, 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^1 values obtained over the temperature range from 344 K to 478 K are expressed by the following formula:

$$C_p^1 \,(\text{cal g}^{-1}\text{K}^{-1}) = 0.0548174 + 4.39770 \times 10^{-4}T - 7.047\bar{5}0 \times 10^{-7}T^2 + 4.21167 \times 10^{-10}T^3 \quad (T \text{ in K}). \quad (3)$$

The recommended values for C_p^1 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

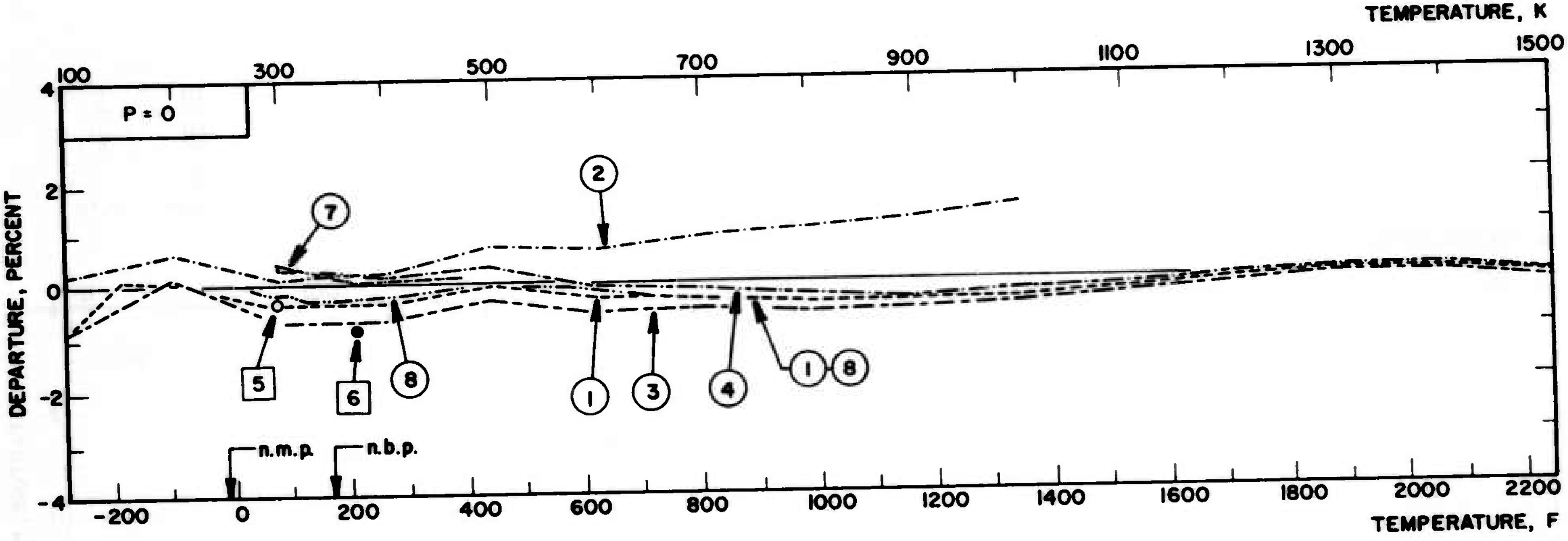
[Temperature, T, F; Specific Heat, C_p, B $lb^{-1}F^{-1}$]

GAS

T	C_p^0	C_p^1	T	C_p^0
			500	0.1518
-280	0.0735		520	0.1524
-260	0.0782		540	0.1529
-240	0.0826		560	0.1535
-220	0.0868		580	0.1541
-200	0.0908		600	0.1547
-180	0.0947		620	0.1552
-160	0.0983		640	0.1556
-140	0.1018		660	0.1560
-120	0.1051		680	0.1564
-100	0.1083		700	0.1567
-80	0.1113		720	0.1571
-60	0.1141		740	0.1574
-40	0.1168		760	0.1578
-20	0.1194		780	0.1581
0	0.1218		800	0.1584
20	0.1241		820	0.1587
40	0.1262		840	0.1590
60	0.1283		860	0.1592
80	0.1302		880	0.1595
100	0.1320		900	0.1598
120	0.1337		920	0.1600
140	0.1352		940	$0.160\underline{2}$
160	0.1367	0.140	960	$0.160\bar{5}$
180	0.1381	0.141	980	0.1607
200	0.1394	0.142	1000	0.1609
220	0.1406	0.143	1100	0.1618
240	0.1418	0.144	1200	0.1625
260	0.1429	0.145	1300	0.1631
280	0.1439	0.146	1400	0.1635
300	0.1448	0.146	1500	0.1639
320	0.1457	0.147	1600	0.1641
340	$0.146\bar{5}$	0.148	1700	0.1643
360	0.1473	0.149	1800	$0.164\bar{5}$
380	0.1480	0.149	1900	0.1647
400	0.1487	0.150	2000	0.1649
420	0.1494			
440	0.1500			
460	0.1506			
480	0.1512			

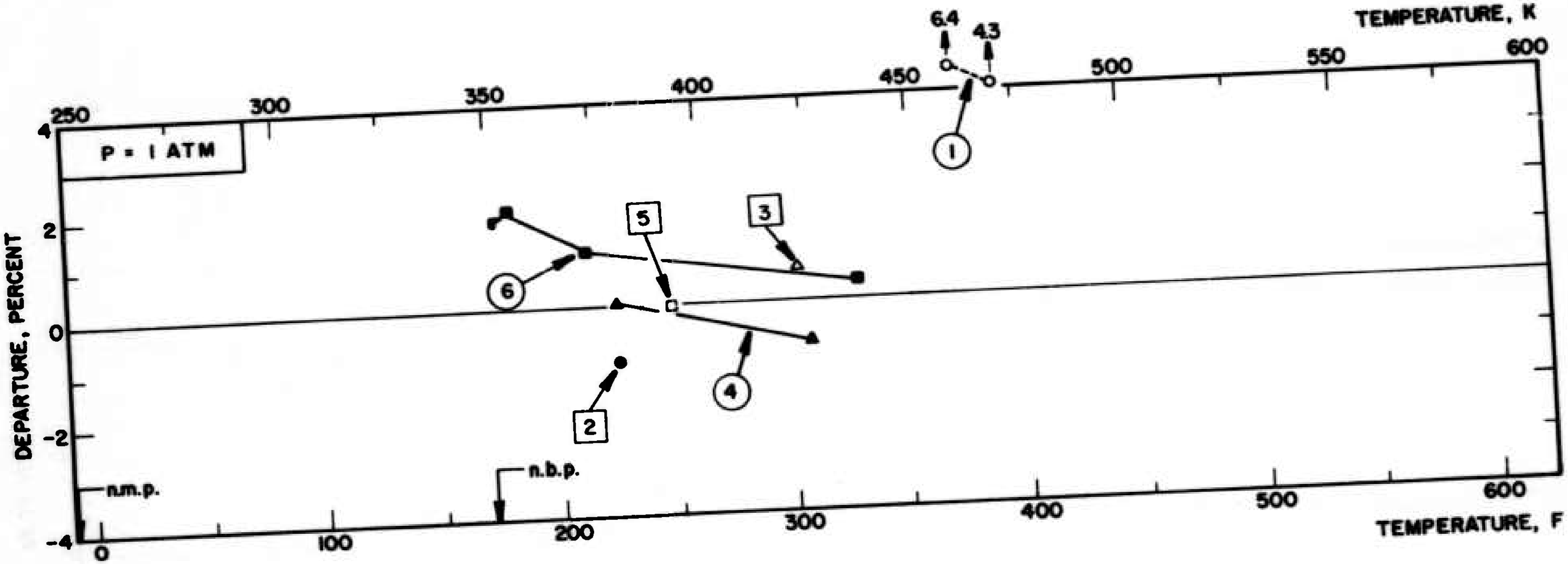
n.m.p. = -9 F
n.b.p. = 170 F

FIGURE 30 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS CARBON TETRACHLORIDE



Curve	References
1	19, 34, 35, 66, 113, 130
2	2, 108
3	137, 254
4	73, 242
5	20
6	48
7	69
8	220, 236

FIGURE 30 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS CARBON TETRACHLORIDE



Curve	Reference
1	58
2	144
3	162
4	163
5	165
6	191

FIGURE 30 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS CARBON TETRACHLORIDE

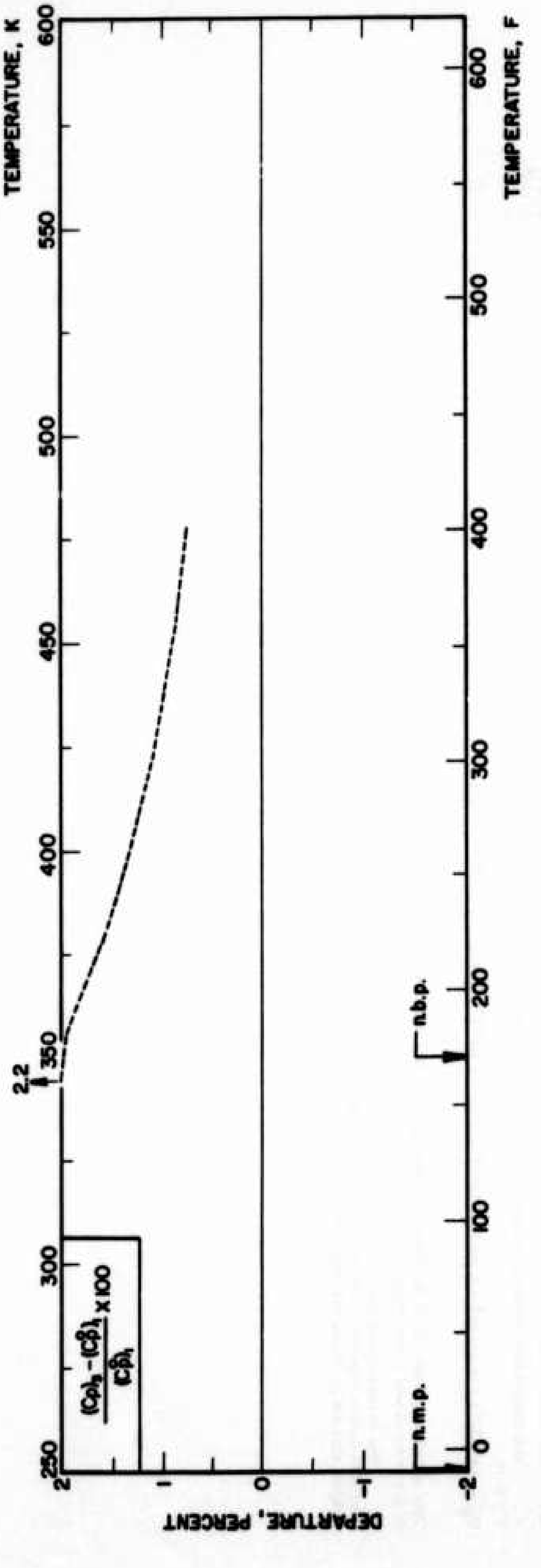


TABLE 31 SPECIFIC HEAT AT CONSTANT PRESSURE OF CHLOROFORM

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 Moelwyn-Hughes (79) and Staveley et al. (199) 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 (36) 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

$$C_p\ (\text{cal g}^{-1}\text{K}^{-1}) = 0.189615 + 2.66488 \times 10^{-4}T - 1.00653 \times 10^{-6}T^2 + 2.12180 \times 10^{-9}T^3$$

(T 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}]

LIQUID

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	0.238‡
180	0.241‡
200	0.244‡

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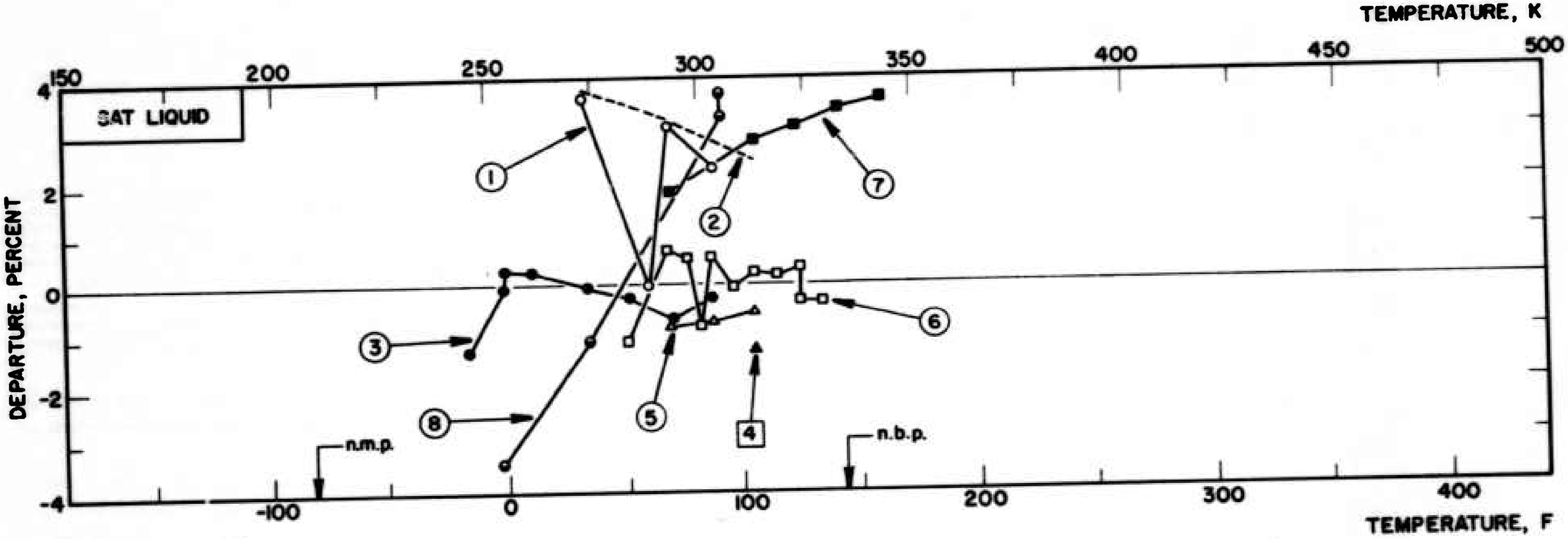
‡Extrapolated for the liquid phase ignoring pressure dependence (n.b.p. = 142 F).

FIGURE 31 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID CHLOROFORM



Curve	Reference
1	36
2	63
3	79
4	216
5	168
6	199
7	231
8	118

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:

$$C_p^0\ (\text{cal g}^{-1}\text{ K}^{-1}) = 9.74324 \times 10^{-2} + 1.82053 \times 10^{-4}T - 1.14526 \times 10^{-7}T^2 + 2.65931 \times 10^{-11}T^3 \quad (T \text{ in K})$$

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.

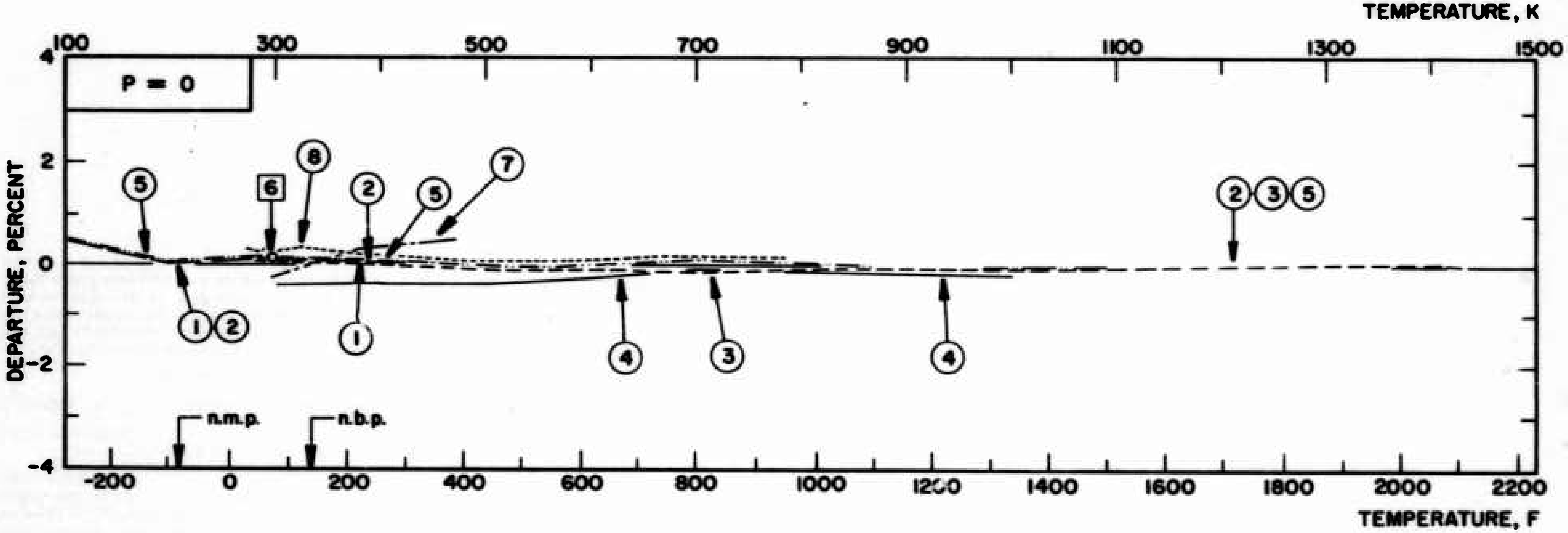
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]
GAS

T	C_p^0	T	C_p^0
		500	0.1653
-280	0.08007*	520	0.1663
-260	0.08359*	540	0.1673
-240	0.08703*	560	0.1683
-220	0.09039*	580	0.1692
-200	0.09366*	600	0.1700
-180	0.09686*	620	0.1711
-160	0.09998*	640	0.1719
-140	0.1030*	660	0.1727
-120	0.1060*	680	0.1734
-100	0.1089*	700	0.1742
-80	0.1117*	720	0.1749
-60	0.1144*	740	0.1757
-40	0.1171*	760	0.1764
-20	0.1197*	780	0.1771
0	0.1222*	800	0.1777
20	0.1247*	820	0.1784
40	0.1271*	840	0.1791
60	0.1294*	860	0.1797
80	0.1316*	880	0.1803
100	0.1338*	900	0.1809
120	0.1359	920	0.1815
140	0.1380*	940	0.1821
160	0.1400	960	0.1827
180	0.1419	980	0.1833
200	0.1438	1000	0.1838
220	0.1456	1100	0.1864
240	0.1474	1200	0.1886
260	0.1491	1300	0.1907
280	0.1507	1400	0.1925
300	0.1523	1500	0.1941
320	0.1538	1600	0.1955
340	0.1553	1700	0.1968
360	0.1567	1800	0.1980
380	0.1581	1900	0.1991
400	0.1594	2000	0.2001
420	0.1607		
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



Curve	Reference
1	34
2	66
3	113
4	130
5	254
6	20
7	69
8	220

TABLE 32 SPECIFIC HEAT AT CONSTANT PRESSURE OF n-DECANE

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

$$C_p\,(\mathrm{cal\ g^{-1}\,K^{-1}}) = 0.581718 - 8.44526 \times 10^{-4}\,T + 1.21946 \times 10^{-6}\,T^2 + 3.37247 \times 10^{-9}\,T^3 \qquad (T \text{ in K}).$$

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.

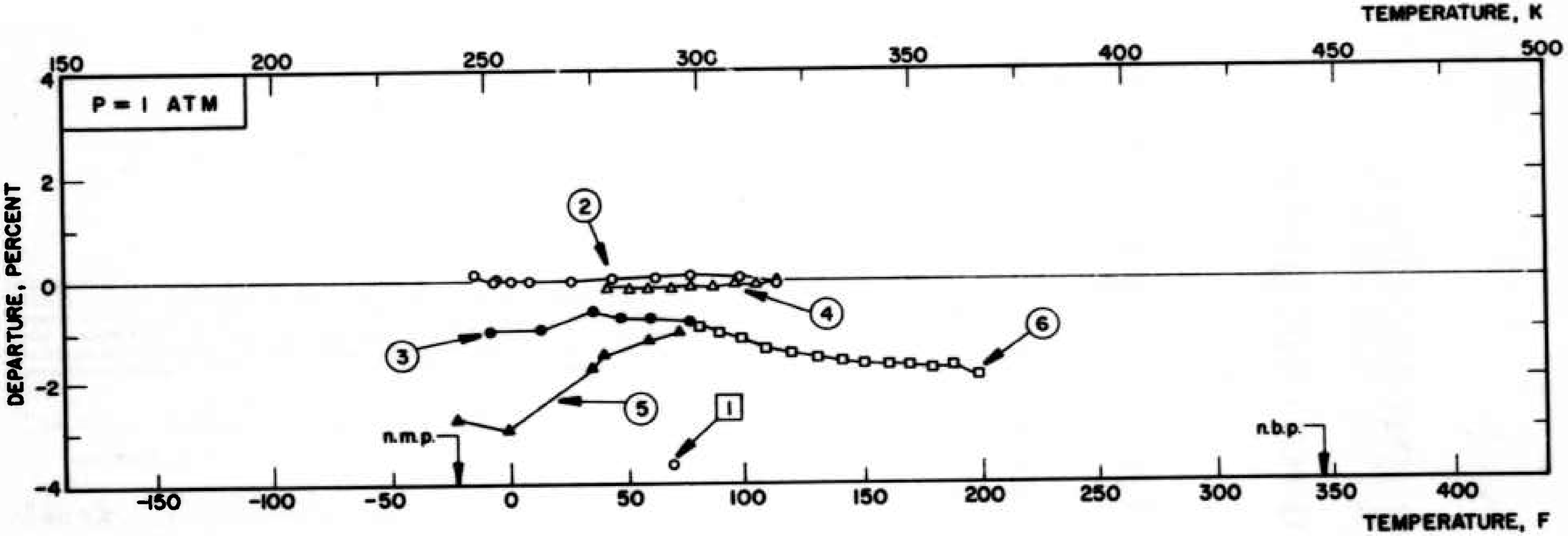
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

LIQUID

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

FIGURE 32 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID n-DECANE



Curve	Reference
1	36
2	61
3	87
4	149
5	153
6	179

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 (78) 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:

$$C_p^\circ\ (\text{cal g}^{-1}\text{K}^{-1}) = 0.0572925 + 1.22049 \times 10^{-3}T - 1.53983 \times 10^{-7}T^2 - 2.53576 \times 10^{-10}T^3 \quad (T \text{ in K}) \qquad (1)$$

For temperatures between 785 K and 1500 K:

$$C_p^\circ\ (\text{cal g}^{-1}\text{K}^{-1}) = 0.0560393 + 1.41072 \times 10^{-3}T - 6.96289 \times 10^{-7}T^2 + 1.31224 \times 10^{-10}T^3 \quad (T \text{ in K}) \qquad (2)$$

These equations are found to fit the above enumerated values with the mean deviations of 0.86 and 0.0$\bar{5}$ 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°	T	C_p°
		700	0.7114
		720	0.7192
		740	0.7268
		760	0.7342
80	0.4023	780	0.741$\bar{5}$
100	0.4140	800	0.7486
120	0.4256	820	0.7555
140	0.4371	840	0.7623
160	0.4486	860	0.7689
180	0.4599	880	0.7753
200	0.4711	900	0.7815
220	0.4822	920	0.7876
240	0.4932	940	0.793$\bar{5}$
260	0.5041	960	0.7994
280	0.5149	980	0.8056
300	0.5256	1000	0.8116
320	0.5361	1100	0.840$\bar{5}$
340	0.5465	1200	0.8671
360	0.5568	1300	0.8917
380	0.5670	1400	0.9144
400	0.5771	1500	0.9353
420	0.5870	1600	0.9546
440	0.5968	1700	0.9723
460	0.606$\bar{5}$	1800	0.9887
480	0.6160	1900	1.0038
500	0.6254	2000	1.0178
520	0.6346		
540	0.6438		
560	0.6527		
580	0.6616		
600	0.6703		
620	0.6788		
640	0.6872		
660	0.6954		
680	0.703$\bar{5}$		

n.b.p. = 344 F

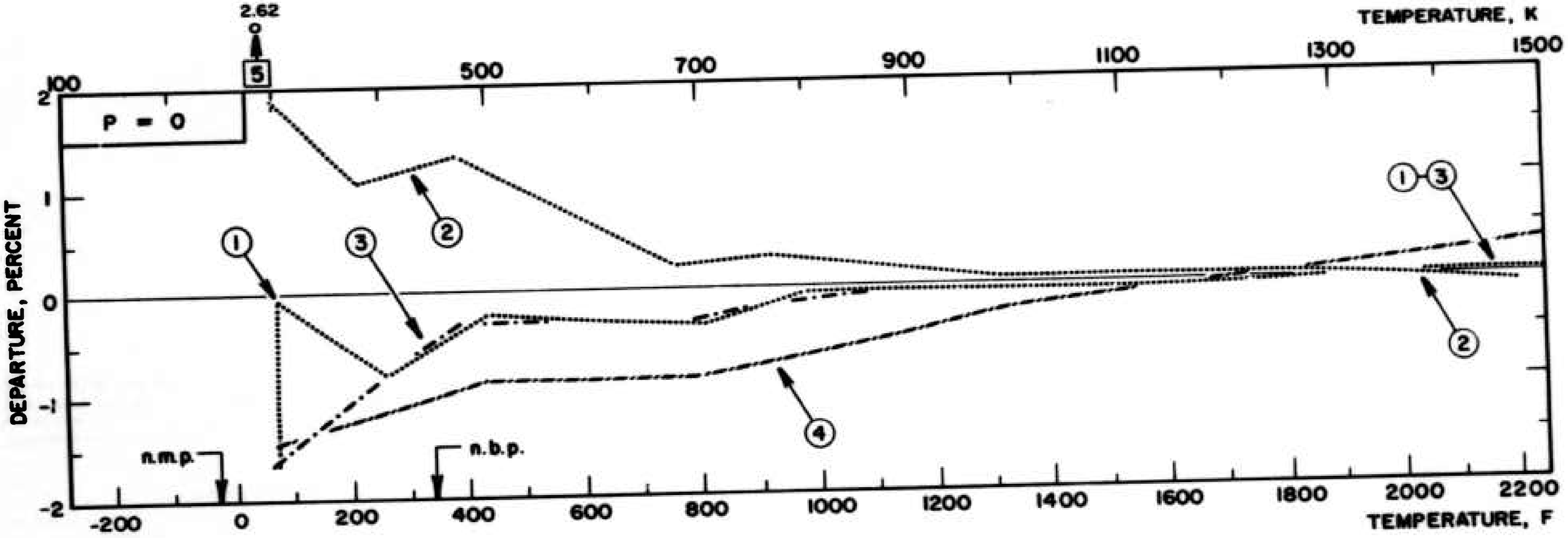


FIGURE 32 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS n-DECANE

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

$$C_p\ (\mathrm{cal\ g^{-1}\,K^{-1}}) = 0.471189 + 1.57503 \times 10^{-3}\,T - 1.20173 \times 10^{-5}\,T^2 + 3.60166 \times 10^{-8}\,T^3 \quad (T \text{ in K}).$$

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

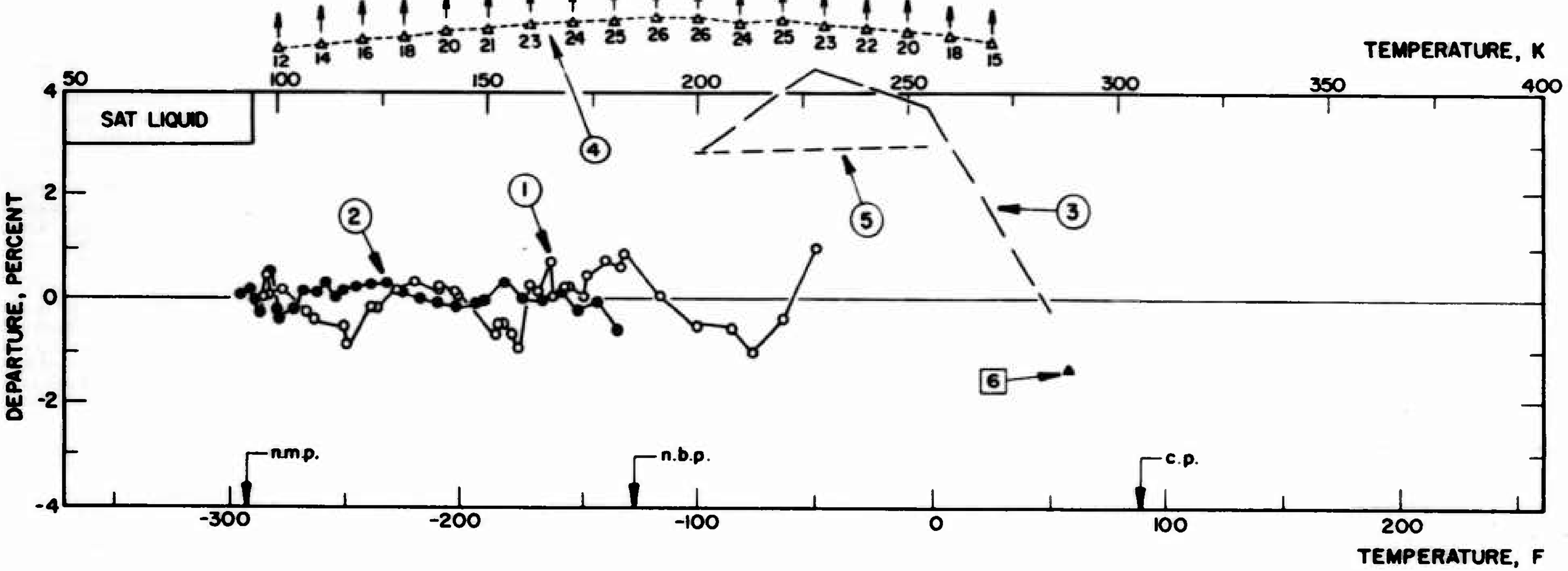
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

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



Curve	Reference
1	230
2	233
3	32
4	55
5	83
6	78

TABLE 33 SPECIFIC HEAT AT CONSTANT PRESSURE OF ETHANE

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:

$$C_p^0\ (\text{cal g}^{-1}\text{K}^{-1}) = 0.127300 + 8.96790 \times 10^{-4}T + 4.29320 \times 10^{-7}T^2 - 5.10678 \times 10^{-10}T^3 \quad (T \text{ in K}) \qquad (1)$$

For temperatures between 780 K and 1500 K:

$$C_p^0\ (\text{cal g}^{-1}\text{K}^{-1}) = 0.0188191 + 1.515\text{[illegible]} \times 10^{-3}T - 6.71170 \times 10^{-7}T^2 + 1.12362 \times 10^{-10}T^3 \quad (T \text{ in K}) \qquad (2)$$

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 e 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 (85, 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

$$C_p\ (\text{cal g}^{-1}\text{K}^{-1}) = 0.326541 - 4.89639 \times 10^{-4}T + 3.53571 \times 10^{-6}T^2 - 2.73616 \times 10^{-9}T^3 \quad (T \text{ in K}) \qquad (3)$$

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.

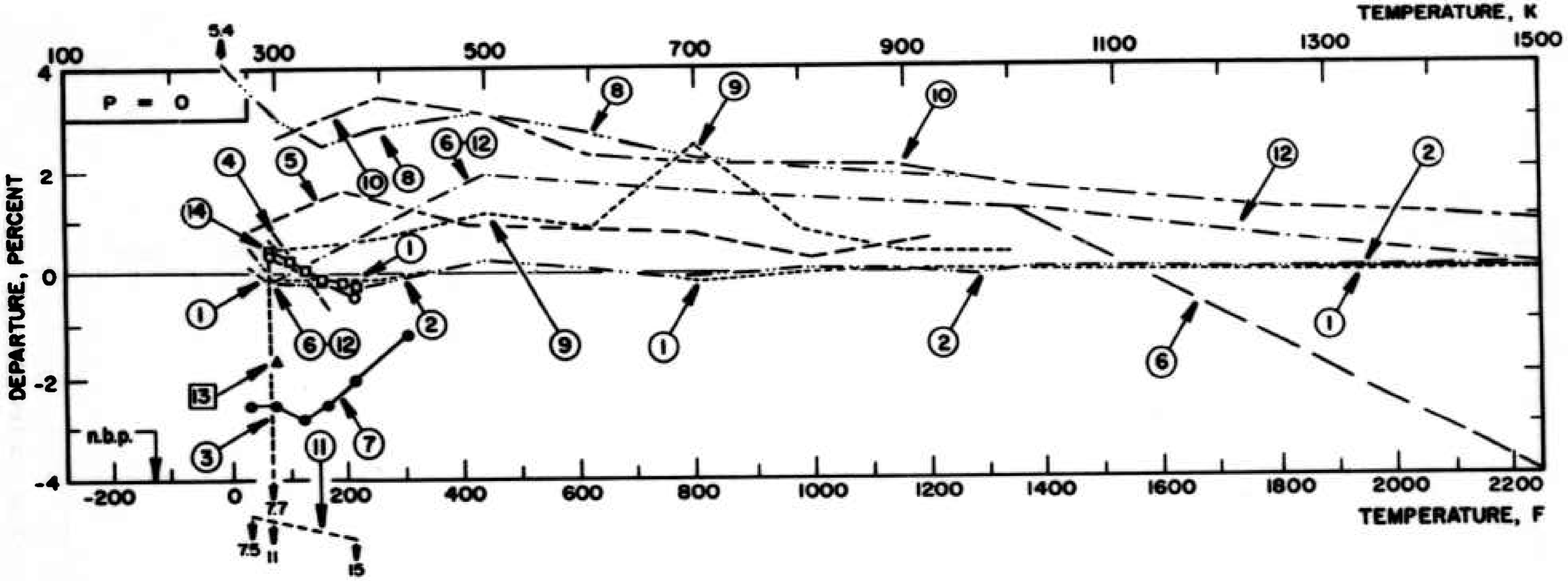
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

GAS

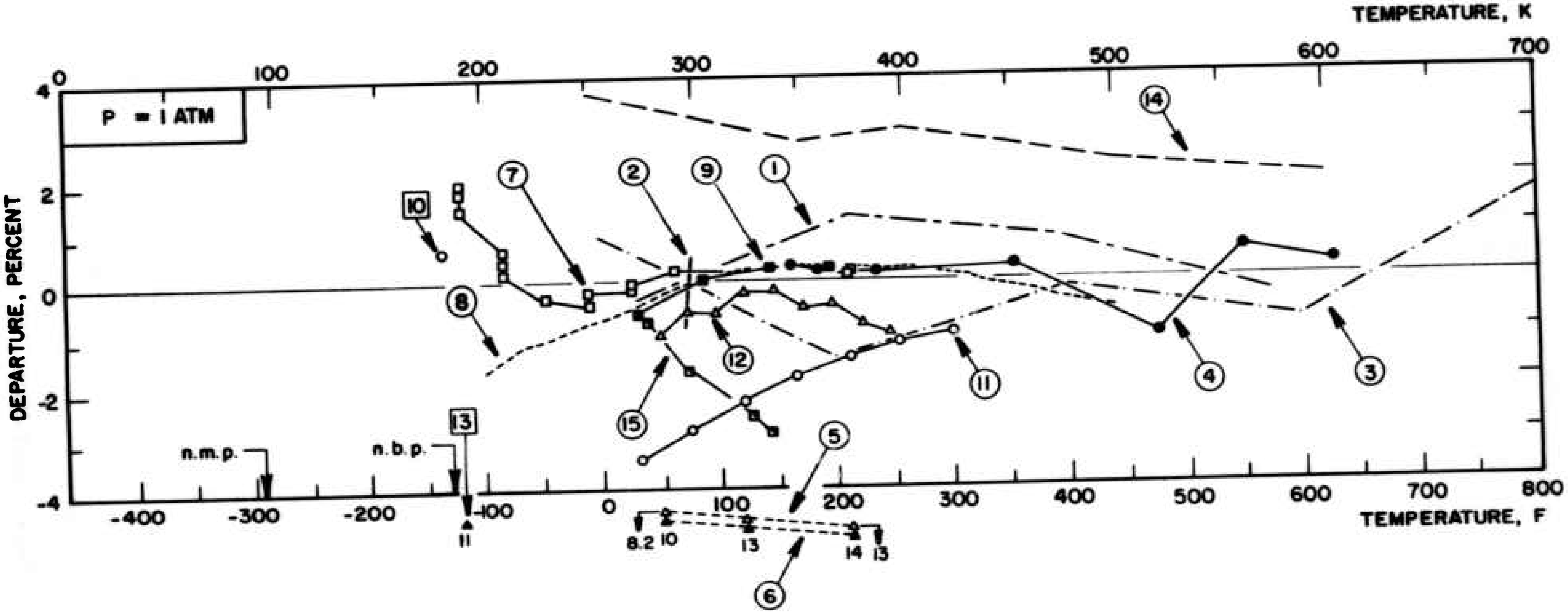
T	C_p^0	T	C_p^0
		700	0.7462
		720	0.7552
40	0.3981	740	0.7640
60	0.4094	760	0.7727
80	0.4207	780	0.7812
100	0.4320	800	0.7896
120	0.4433	820	0.7978
140	0.4545	840	0.8059
160	0.4658	860	0.8138
180	0.4770	880	0.8215
200	0.4882	900	0.8290
220	0.4993	920	0.8364
240	0.5104	940	0.8436
260	0.5215	960	0.8510
280	0.5325	980	0.8583
300	0.5435	1000	0.8656
320	0.5544	1100	0.9004
340	0.5653	1200	0.9328
360	0.5761	1300	0.9631
380	0.5868	1400	0.9912
400	0.5975	1500	1.0173
420	0.6081	1600	1.0416
440	0.6186	1700	1.0641
460	0.6290	1800	1.0849
480	0.6394	1900	1.1042
500	0.6496	2000	1.1221
520	0.6598		
540	0.6699		
560	0.6798		
580	0.6896		
600	0.6994		
620	0.7090		
640	0.7185		
660	0.7279		
680	0.7371		

FIGURE 33 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS ETHANE



Curve	Reference	Curve	Reference
1	22, 59, 109, 161, 167	8	203
2	171, 253	9	213
3	57	10	222
4	99	11	24
5	127	12	133
6	134	13	18
7	141	14	28

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

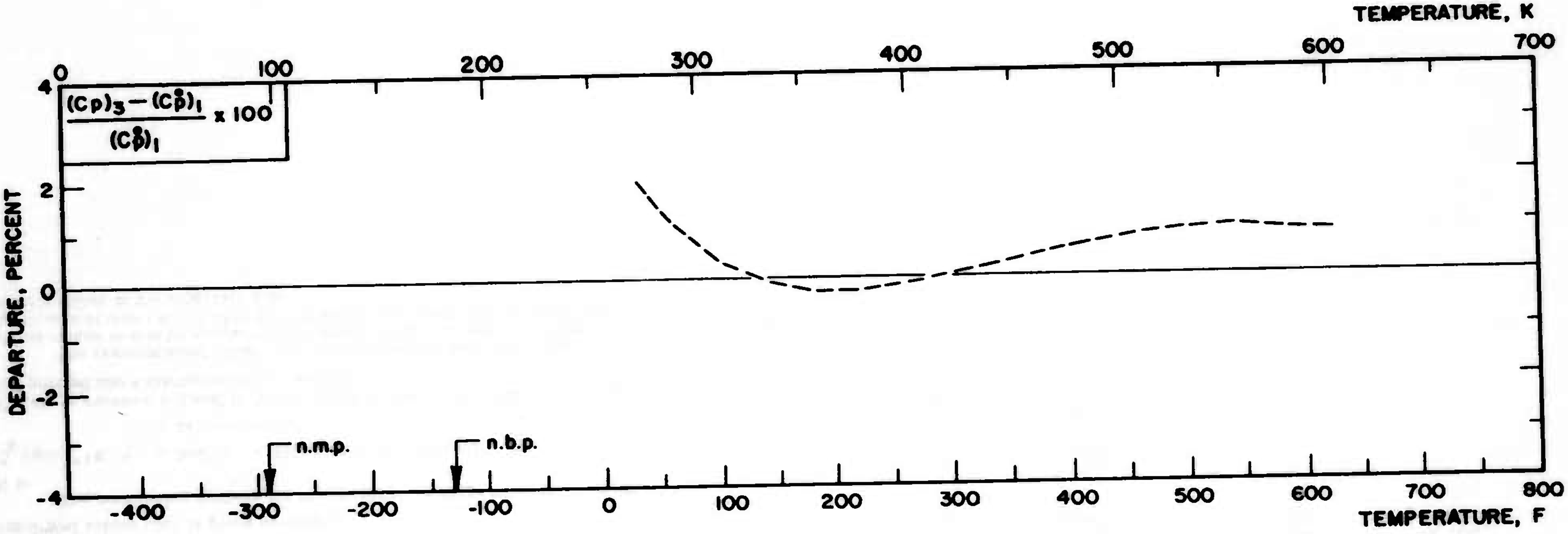


TABLE 34 SPECIFIC HEAT AT CONSTANT PRESSURE OF ETHYL ALCOHOL

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 Fiock, 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

$$C_p\,(\mathrm{cal\ g^{-1}\,K^{-1}}) = 0.504351 - 4.81584 \times 10^{-4}\,T - 9.21631 \times 10^{-7}\,T^2 + 1.14379 \times 10^{-8}\,T^3 \qquad (T \text{ in K}).$$

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

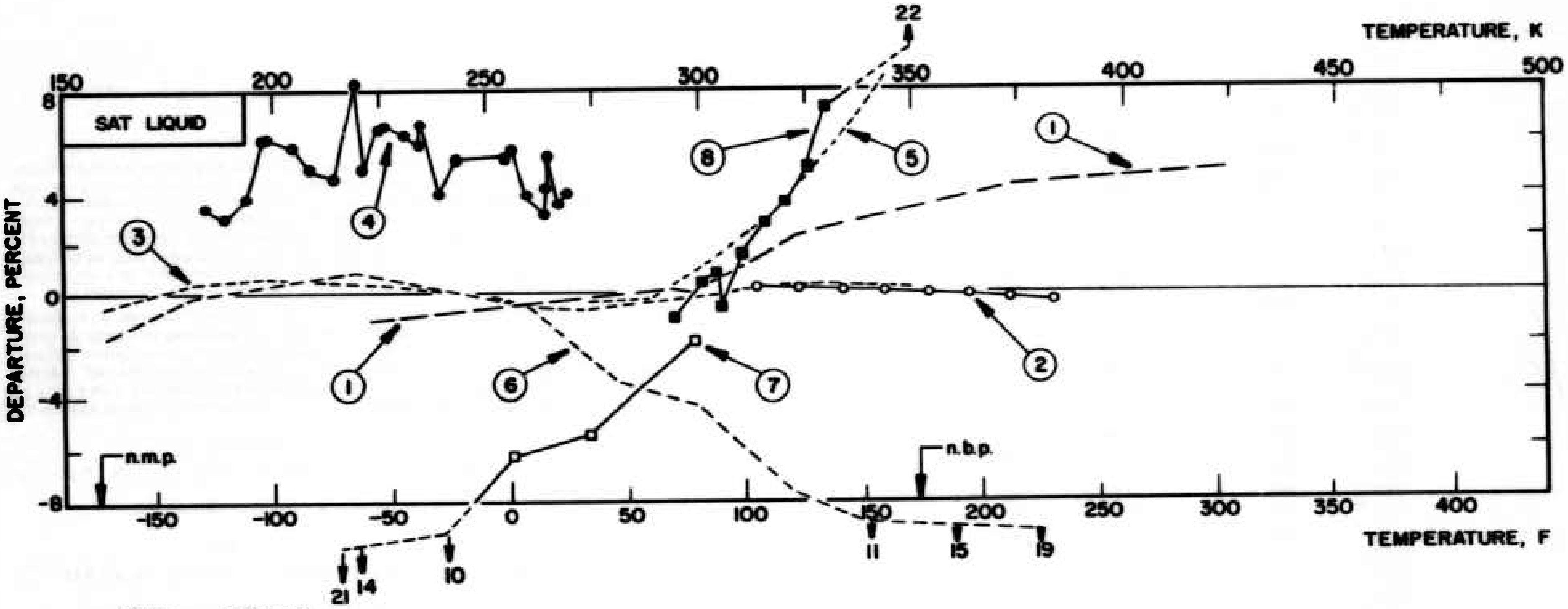
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

LIQUID

T	C_p	T	C_p
		100	0.6089
		120	0.6353
-160	0.4511	140	0.6641
-140	0.4535	160	0.6955
-120	0.4572	180	0.7297††
-100	0.4623	200	0.7666††
-80	0.4688	220	0.8063††
-60	0.4769	240	0.8491††
-40	0.4866	260	0.8949††
-20	0.4981		
0	0.5114		
20	0.5267		
40	0.5440		
60	0.5634		
80	0.5850		

††n.b.p. = 173 F

FIGURE 34 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID ETHYL ALCOHOL



Curve	Reference
1	36
2	62
3	74
4	143
5	198
6	151
7	187
8	231

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:

$$C_p^0\ (\mathrm{cal\ g^{-1}\ K^{-1}}) = 0.131122 + 9.18566 \times 10^{-4}\ T - 2.35957 \times 10^{-7}\ T^2 - 7.19165 \times 10^{-11}\ T^3, \qquad (T \text{ in K}) \qquad (1)$$

For temperatures between 785 K and 1500 K:

$$C_p^0\ (\mathrm{cal\ g^{-1}\ K^{-1}}) = 0.136067 + 9.84955 \times 10^{-4}\ T - 4.44996 \times 10^{-7}\ T^2 + 7.63654 \times 10^{-11}\ T^3 \qquad (T \text{ in K}) \qquad (2)$$

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

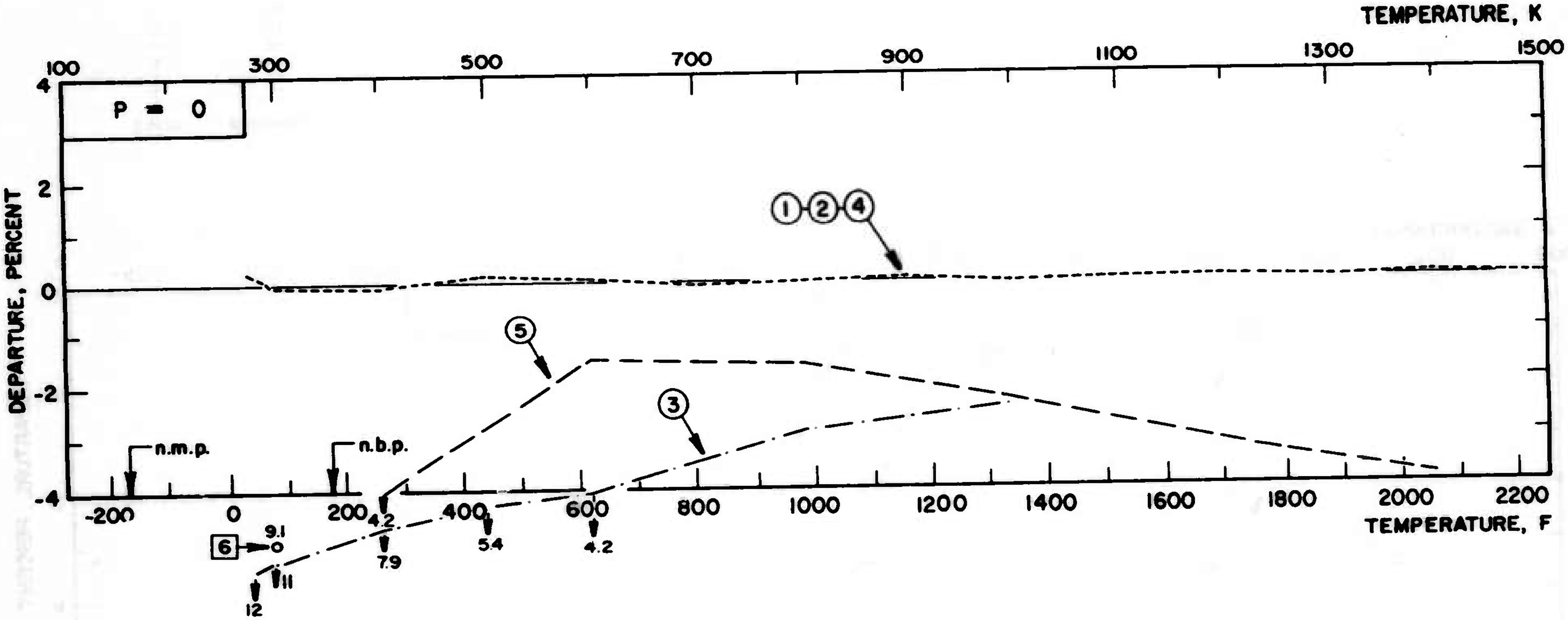
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

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

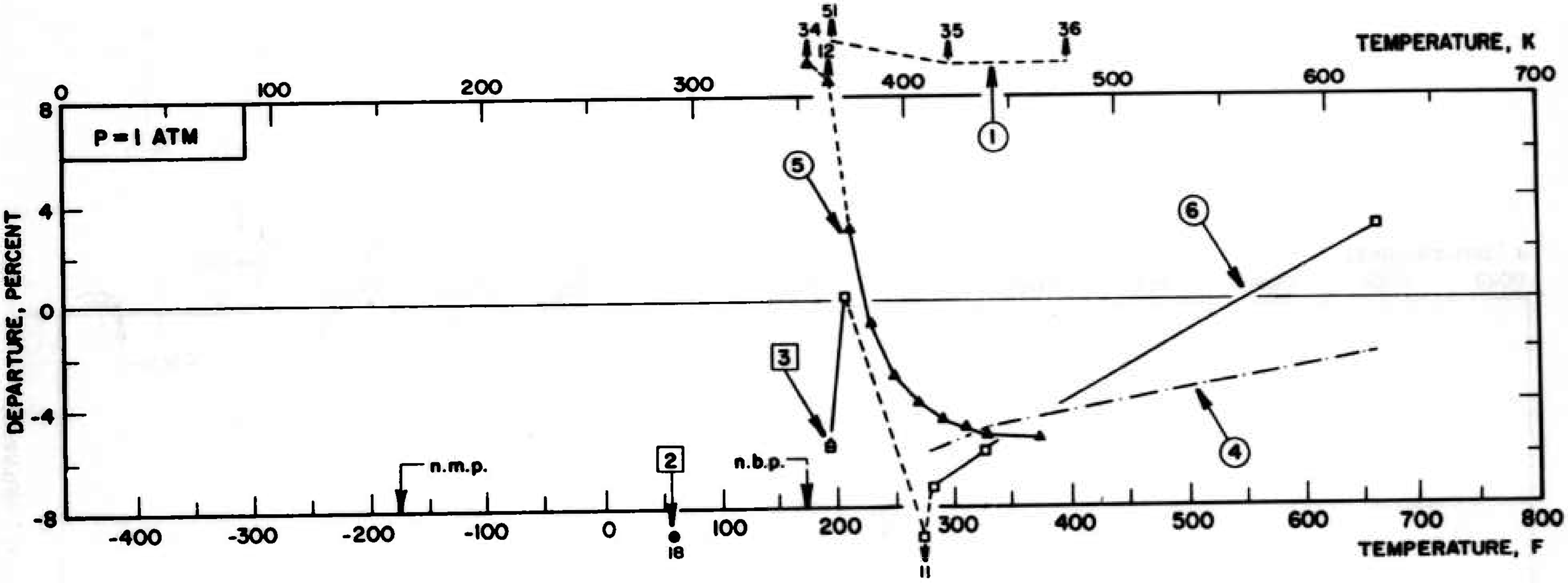
n.b.p. = 173 F

FIGURE 34 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS ETHYL ALCOHOL



Curve	Reference
1	22
2	114
3	74
4	167
5	235
6	18

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

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) is as follows:

$$C_p\ (\mathrm{cal\ g^{-1}\ K^{-1}}) = 0.562894 + 1.64465 \times 10^{-3}\ T - 1.96469 \times 10^{-5}\ T^2 + 6.07683 \times 10^{-8}\ T^3 \qquad (T \text{ in K}).$$

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.

RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

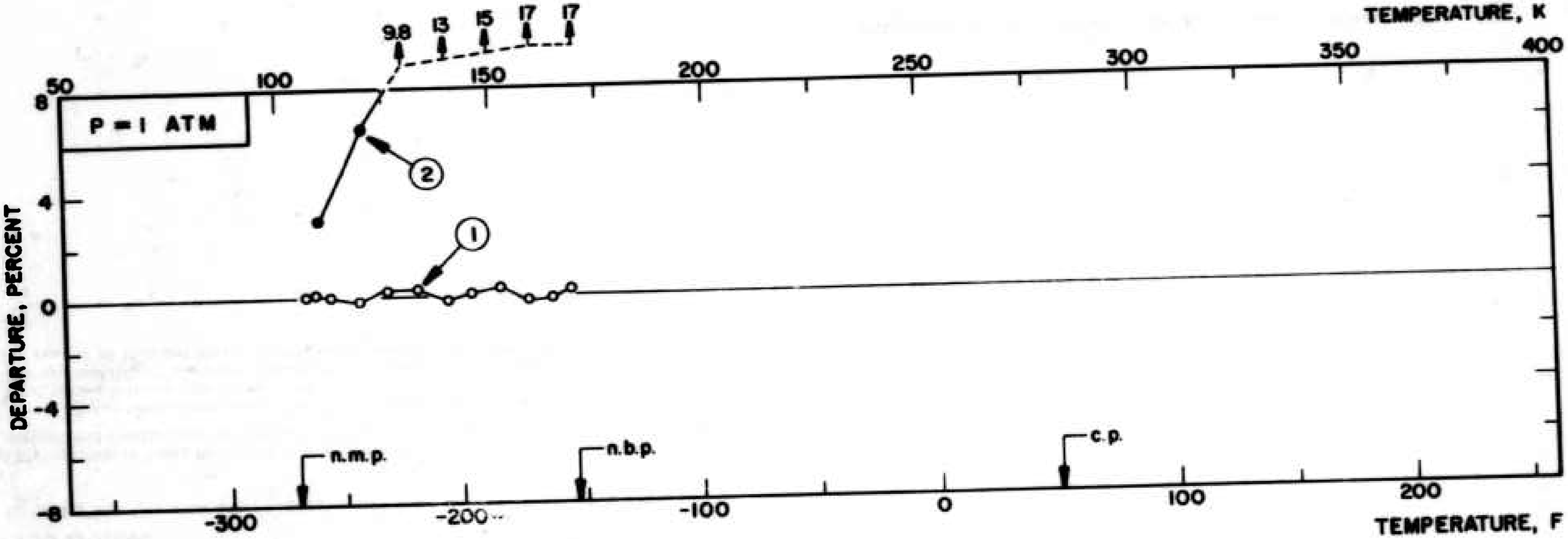
LIQUID

T	C_p
-280	0.5914[†]
-260	0.5861
-240	0.5811
-220	0.5766
-200	0.5733
-180	0.5717
-160	0.5722
-140	0.5753[‡]
-120	0.5816[‡]

[†] 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



Curve	Reference
1	53
2	55

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:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}) = 0.0594797 + 1.16218 \times 10^{-3}T - 3.74170 \times 10^{-7}T^2 - 5.78817 \times 10^{-11}T^3 \qquad (T \text{ in K}). \quad (1)$$

For temperatures from 785 K to 1500 K:

$$C_p^0 \text{ (cal g}^{-1}\text{K}^{-1}) = 0.103519 + 1.12042 \times 10^{-3}T - 5.06926 \times 10^{-7}T^2 + 8.79117 \times 10^{-11}T^3 \qquad (T \text{ in K}). \quad (2)$$

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^1, 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^1 values for temperatures from 178 K to 610 K are fitted to the following equation:

$$C_p^1 \text{ (cal g}^{-1}\text{K}^{-1}) = 0.111919 + 8.27703 \times 10^{-4}T + 3.44484 \times 10^{-7}T^2 - 5.69197 \times 10^{-10}T^3 \qquad (T \text{ in K}). \quad (3)$$

The recommended values of C_p^1 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^1 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)

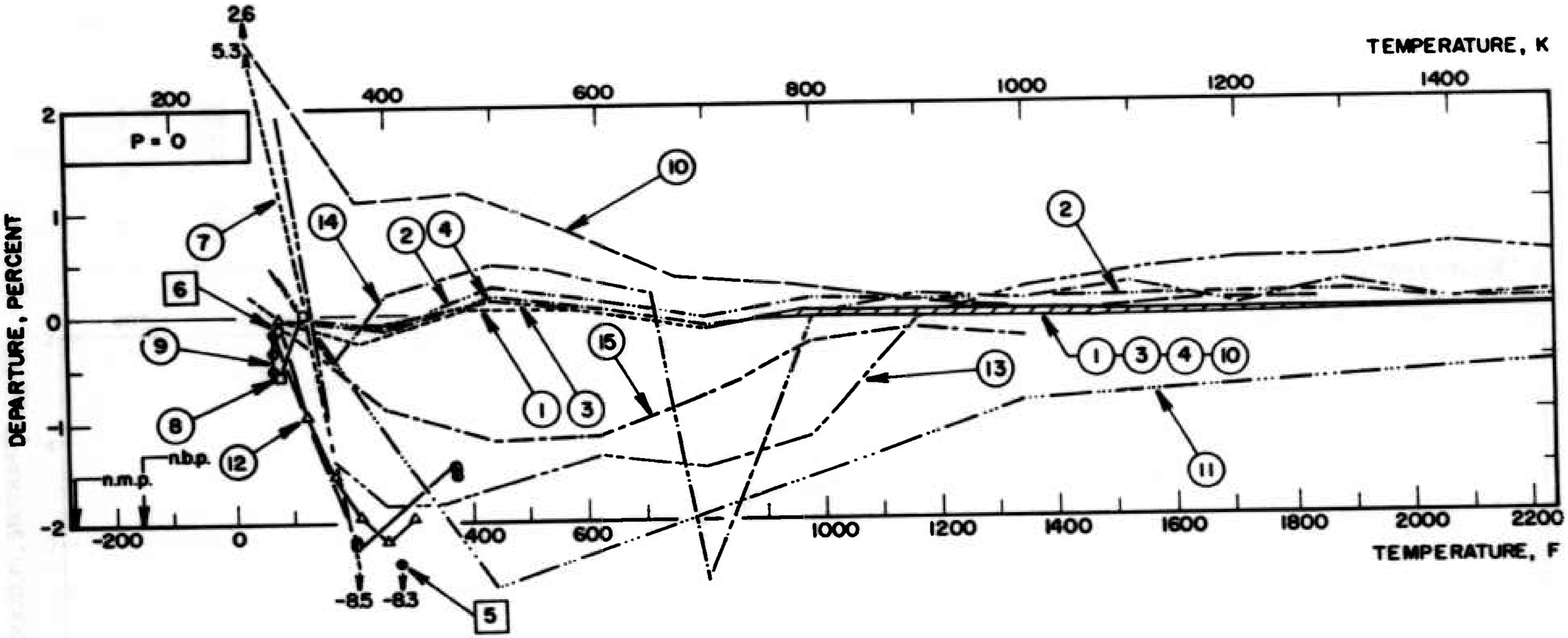
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B lb^{-1}F^{-1}]

GAS

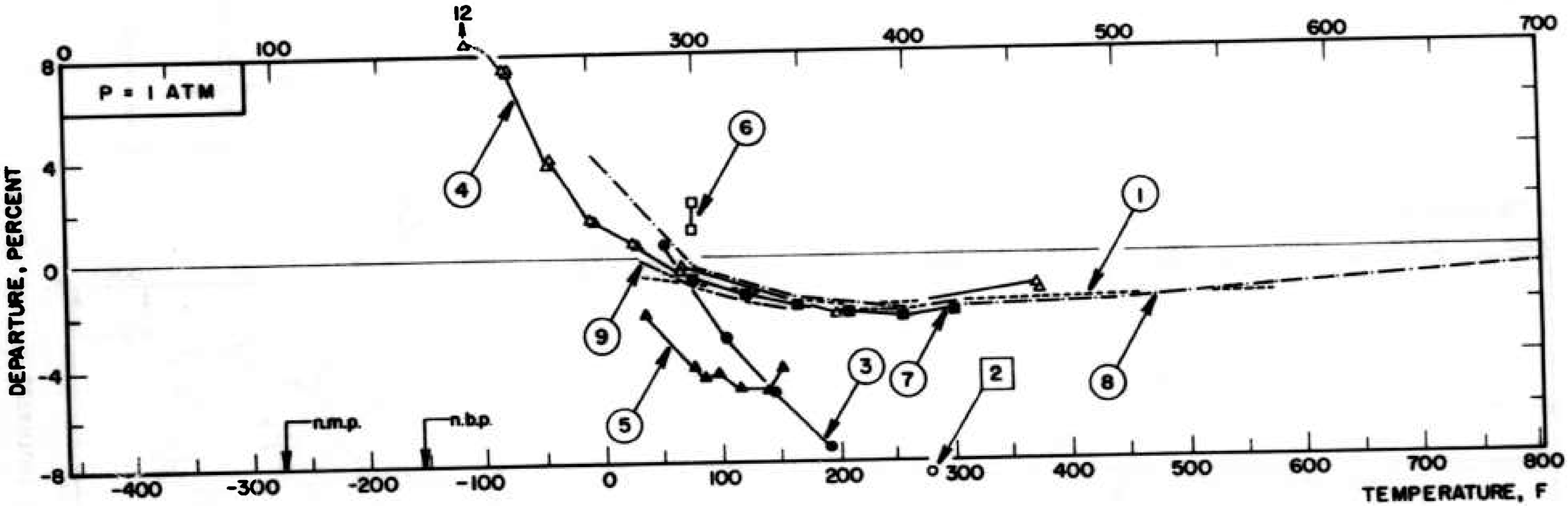
T	C_p^0	C_p^1	T	C_p^0
			700	0.6370
			720	0.6437
40	0.3518	0.356	740	0.6503
60	0.3622	0.366	760	0.6567
80	0.372$\bar{5}$	0.375	780	0.6631
100	0.3827	0.385	800	0.6693
120	0.3928	0.395	820	0.6754
140	0.4027	0.405	840	0.6813
160	0.4126	0.414	860	0.6872
180	0.4224	0.424	880	0.6929
200	0.4320	0.433	900	0.698$\bar{5}$
220	0.4416	0.443	920	0.7039
240	0.4510	0.452	940	0.7093
260	0.4603	0.461	960	0.7145
280	0.4695	0.470	980	0.7199
300	0.4787	0.479	1000	0.7252
320	0.4877	0.488	1100	0.7504
340	0.4965	0.497	1200	0.7740
360	0.5053	0.506	1300	0.7960
380	0.5140	0.515	1400	0.8164
400	0.5225	0.523	1500	0.8354
420	0.5310	0.532	1600	0.8530
440	0.5393	0.540	1700	0.8693
460	0.5475	0.548	1800	0.8845
480	0.5556	0.557	1900	0.8986
500	0.5636	0.564	2000	0.9117
520	0.571$\bar{5}$	0.572		
540	0.5792	0.580		
560	0.5869	0.587		
580	0.5944	0.595		
600	0.6018	0.602		
620	0.6091	0.609		
640	0.6162	0.616		
660	0.6233			
680	0.6302			

FIGURE 35 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS ETHYLENE



Curve	Reference	Curve	Reference
1	171, 253	9	57
2	22	10	93
3	59, 72, 101, 112, 167	11	133
4	137	12	140
5	15	13	203
6	18	14	213
7	24	15	222
8	30		

FIGURE 35 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS ETHYLENE



Curve	Reference
1	14
2	15
3	46
4	57
5	77
6	85
7	140
8	202
9	251

FIGURE 35 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS ETHYLENE

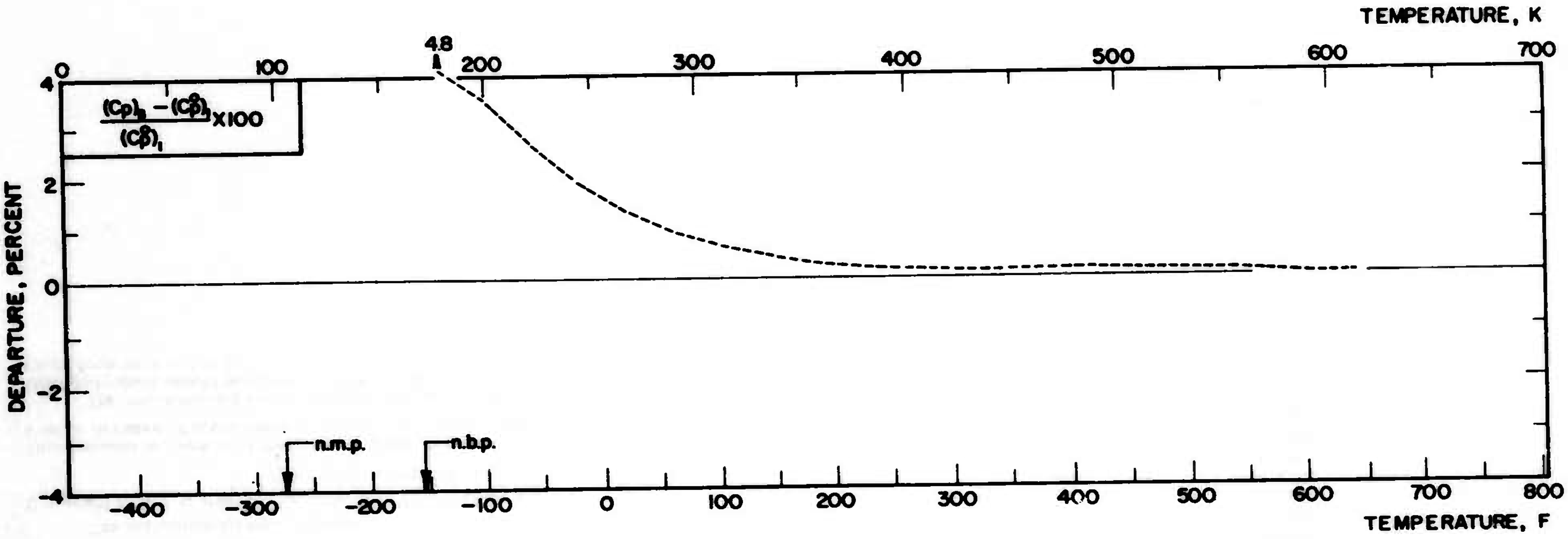


TABLE 36 SPECIFIC HEAT AT CONSTANT PRESSURE OF ETHYLENE GLYCOL

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 (154) 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 collelation formula obtained is

$$C_p(\mathrm{cal\ g^{-1}\ K^{-1}}) = 0.0168840 + 3.35083 \times 10^{-3}T - 7.22400 \times 10^{-6}T^2 + 7.61748 \times 10^{-9}T^3 \quad (T \text{ in K})$$

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

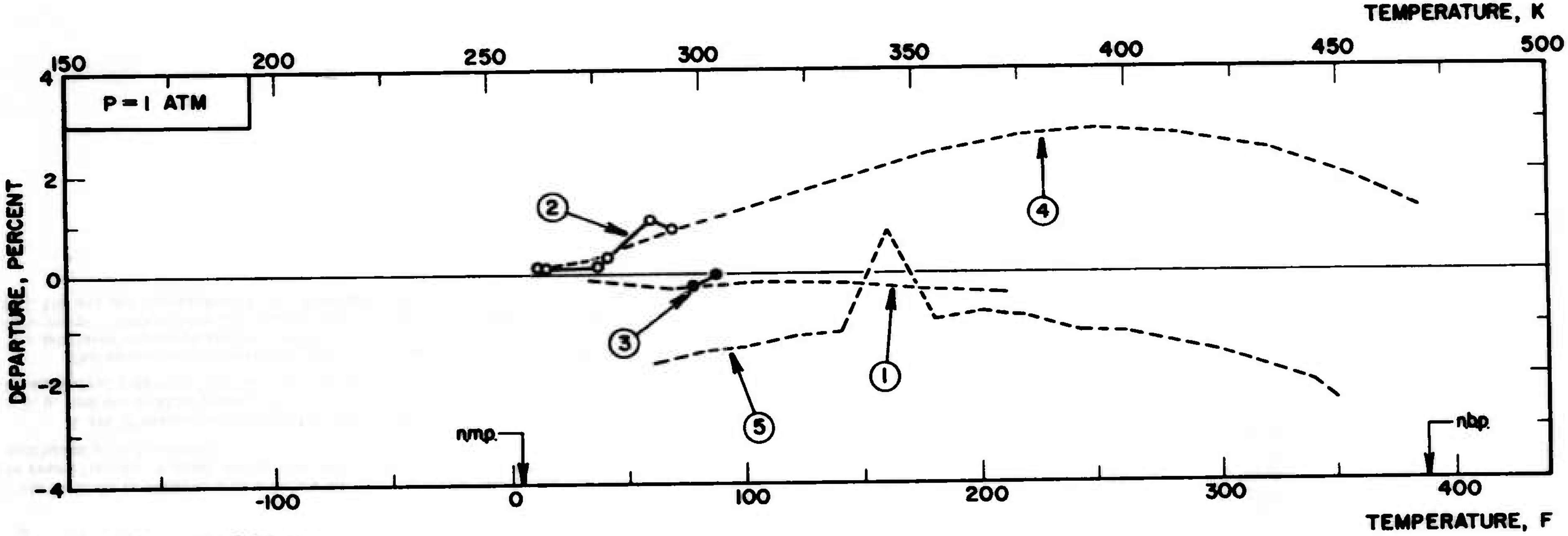
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

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



Curve	Reference
1	249
2	154
3	188
4	207
5	256

TABLE 37 SPECIFIC HEAT AT CONSTANT PRESSURE OF ETHYL-ETHER

DISCUSSION

LIQUID

Five experimental works published before 1940 fall within the temperature range from the n.m.p. to the n.b.p. Among them, two sets of extensive results were obtained by Mazur (135, 136) using an adiabatic calorimeter, who gave a linear equation

$$C_p\,(\mathrm{cal\ g^{-1}K^{-1}}) = 0.54239 + 0.00059563\ t \qquad (t \text{ in C}).$$

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

$$C_p\,(\mathrm{cal\ g^{-1}K^{-1}}) = 0.232794 + 2.59892 \times 10^{-3}T - 8.92565 \times 10^{-6}T^2 + 1.30136 \times 10^{-8}T^3 \qquad (T \text{ in K}).$$

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.

A set of extensive calorimetric data obtained at temperatures between the n.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.

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.

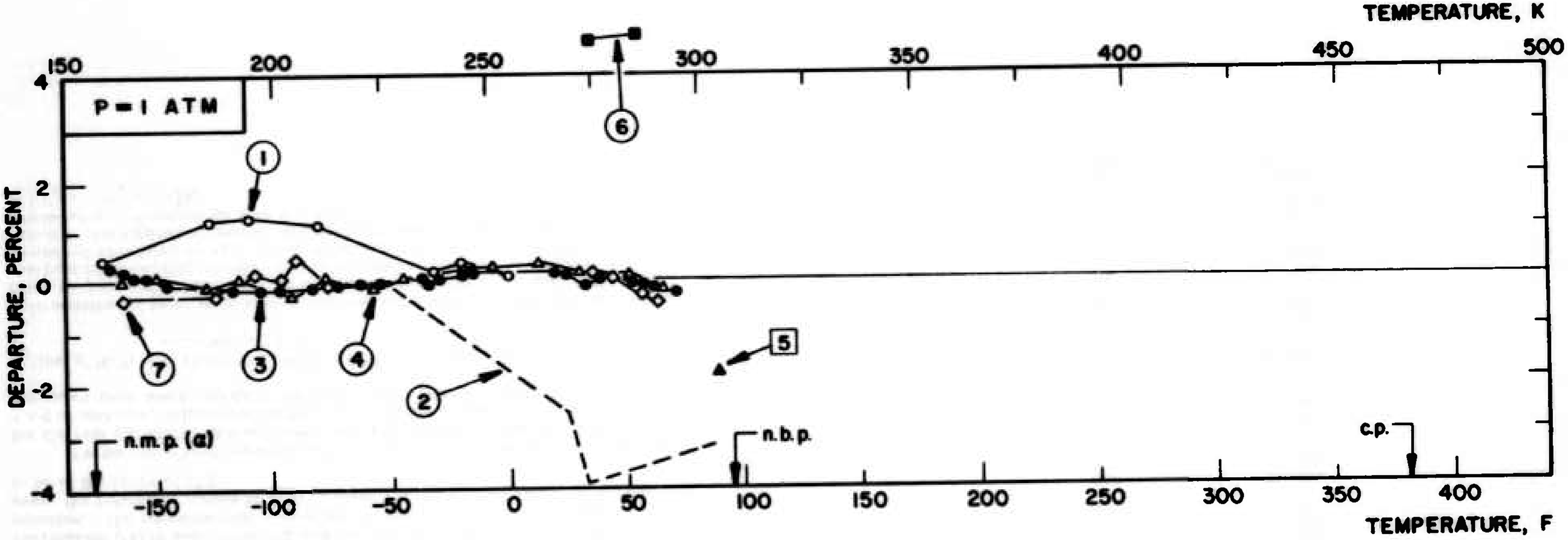
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B $\mathrm{lb^{-1}\,F^{-1}}$]

LIQUID

T	C_p
-160	0.4778
-140	0.4854
-120	0.4925
-100	0.4992
-80	0.5057
-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



Curve	Reference
1	5
2	36
3	135
4	136
5	216
6	245
7	247

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:

$$C_p^0\ (\mathrm{cal\ g^{-1}K^{-1}}) = -0.967148 + 7.98827 \times 10^{-3}T - 1.61408 \times 10^{-5}T^2 + 1.21565 \times 10^{-8}T^3 \quad (T \text{ in K}) \qquad (1)$$

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:

$$C_p\ (\mathrm{cal\ g^{-1}K^{-1}}) = 0.192557 + 3.2857\overline{5} \times 10^{-4}T + 1.70641 \times 10^{-6}T^2 - 1.89605 \times 10^{-9}T^3 \quad (T \text{ in K}) \qquad (2)$$

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 $[(C_p)_2 - (C_p^0)_1]/(C_p^0)_1$.

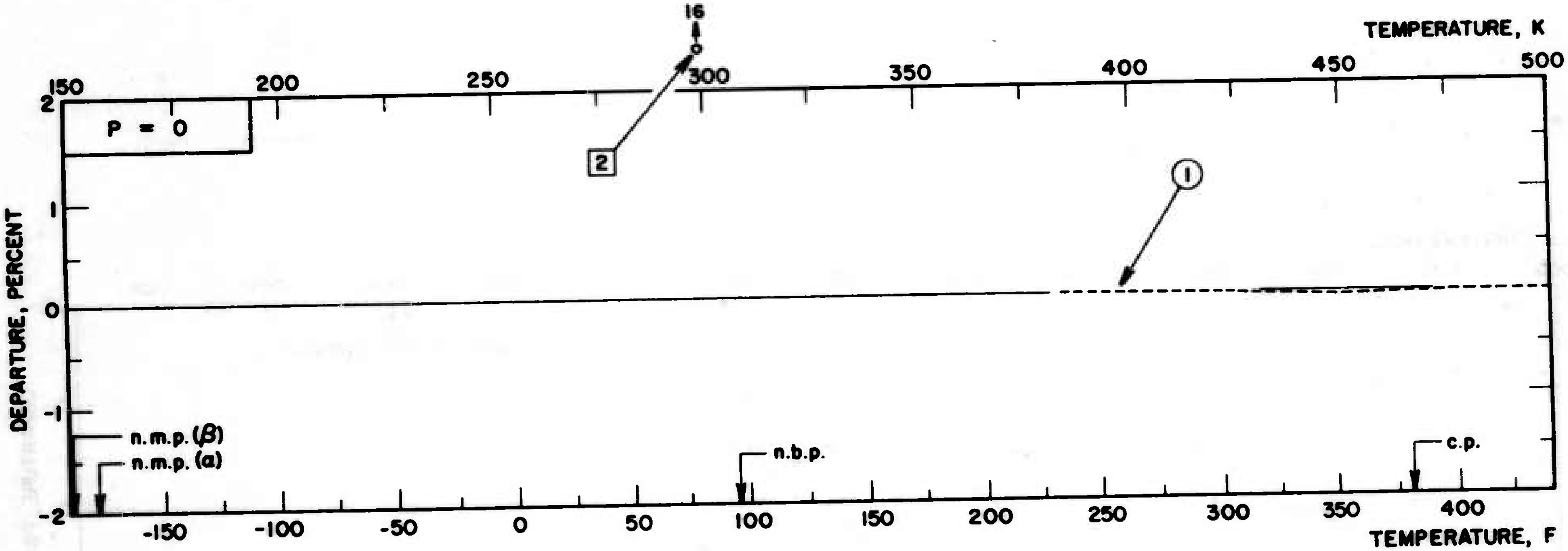
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B $\mathrm{lb^{-1}\ F^{-1}}$]

GAS

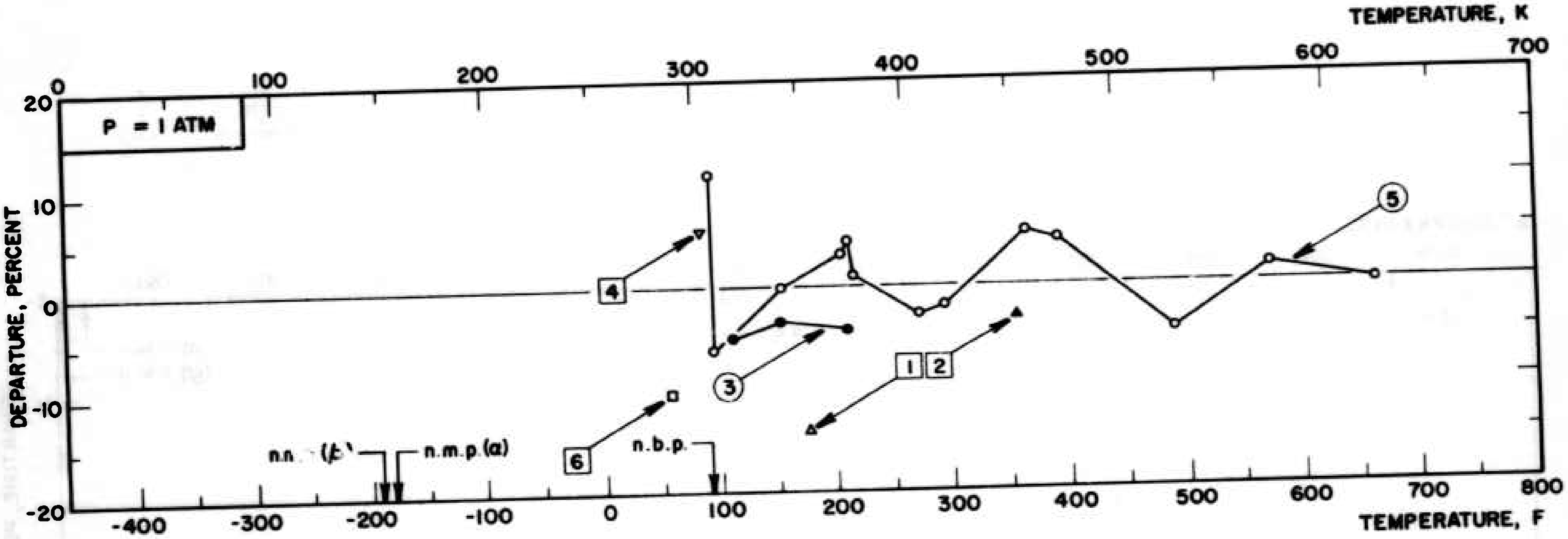
T	C_p^0
100	0.3214
120	0.3372
140	0.3520
160	0.3657
180	0.3786
200	0.3907
220	0.4021
240	0.4129
260	0.4232
280	0.4331
300	0.4428
320	0.4523
340	0.4617
360	0.4711
380	0.4806
400	0.4903
420	0.5004
440	0.5108
460	0.5218
480	0.5334
500	0.5457
520	0.5588
540	0.5729
560	0.5879
580	0.6041
600	0.6215
620	0.6402

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

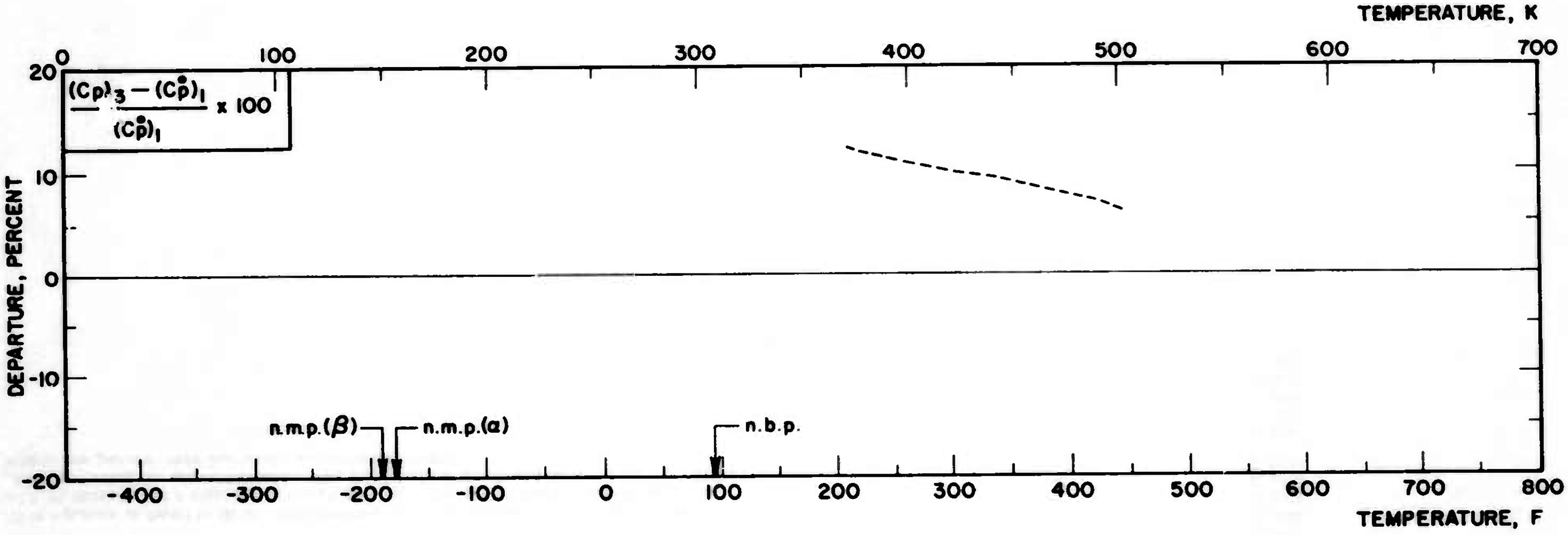


FIGURE 37 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS ETHYL ETHER

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

$$C_p(\text{cal g}^{-1}\text{ K}^{-1}) = 0.159171 + 2.68130 \times 10^{-4}T - 7.30278 \times 10^{-7}T^2 + 1.41282 \times 10^{-9}T^3$$

(T 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

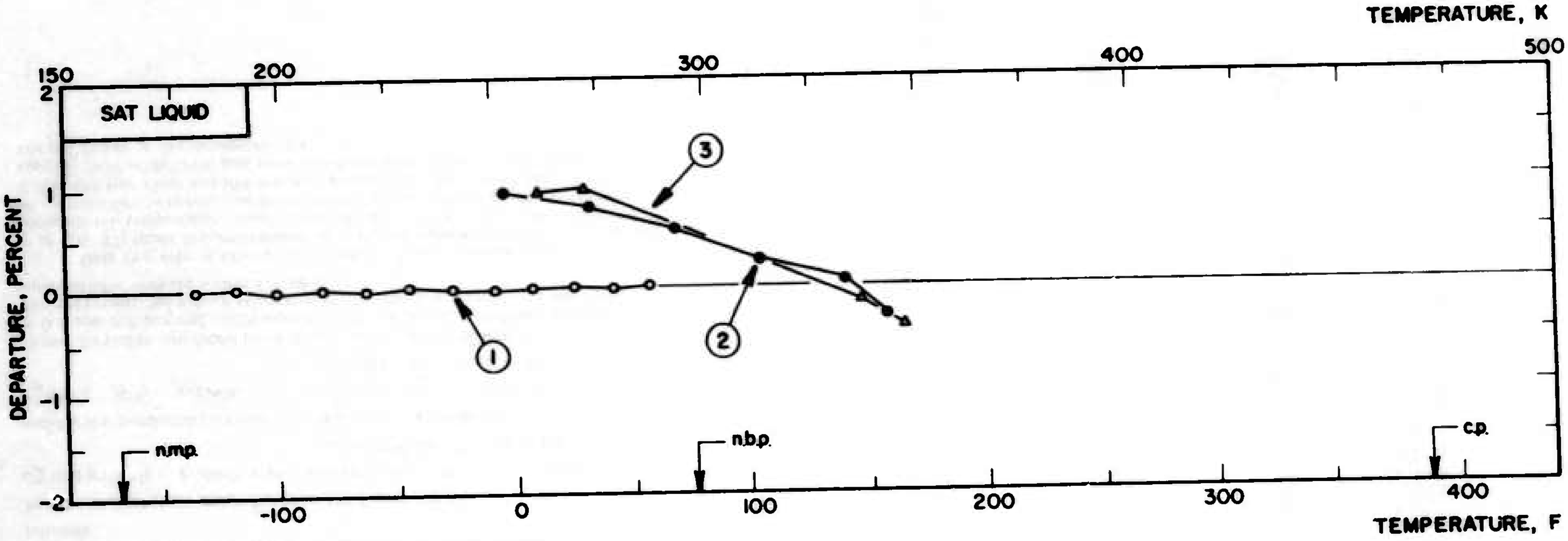
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

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



Curve	Reference
1	246
2	16
3	17

TABLE 38 SPECIFIC HEAT AT CONSTANT PRESSURE OF FREON-11 (continued)

DISCUSSION

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. Kobe 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 (20,48).

The correlation formulas obtained for the ideal gas specific heat are as follows:

For the temperature range between 100 K and 490 K:

$$C_p^0 \,(\mathrm{cal\ g^{-1}K^{-1}}) = 2.23277 \times 10^{-2} + 6.19827 \times 10^{-4}T - 9.74217 \times 10^{-7}T^2 + 5.89557 \times 10^{-10}T^3, \quad (T \text{ in K})$$

and for the temperature range between 490 K and 1500 K:

$$C_p^0 \,(\mathrm{cal\ g^{-1}K^{-1}}) = 9.61600 \times 10^{-2} + 2.01180 \times 10^{-4}T - 1.58863 \times 10^{-7}T^2 + 4.26581 \times 10^{-11}T^3 \quad (T \text{ in K})$$

These formulas are found to fit to 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.

RECOMMENDED VALUES

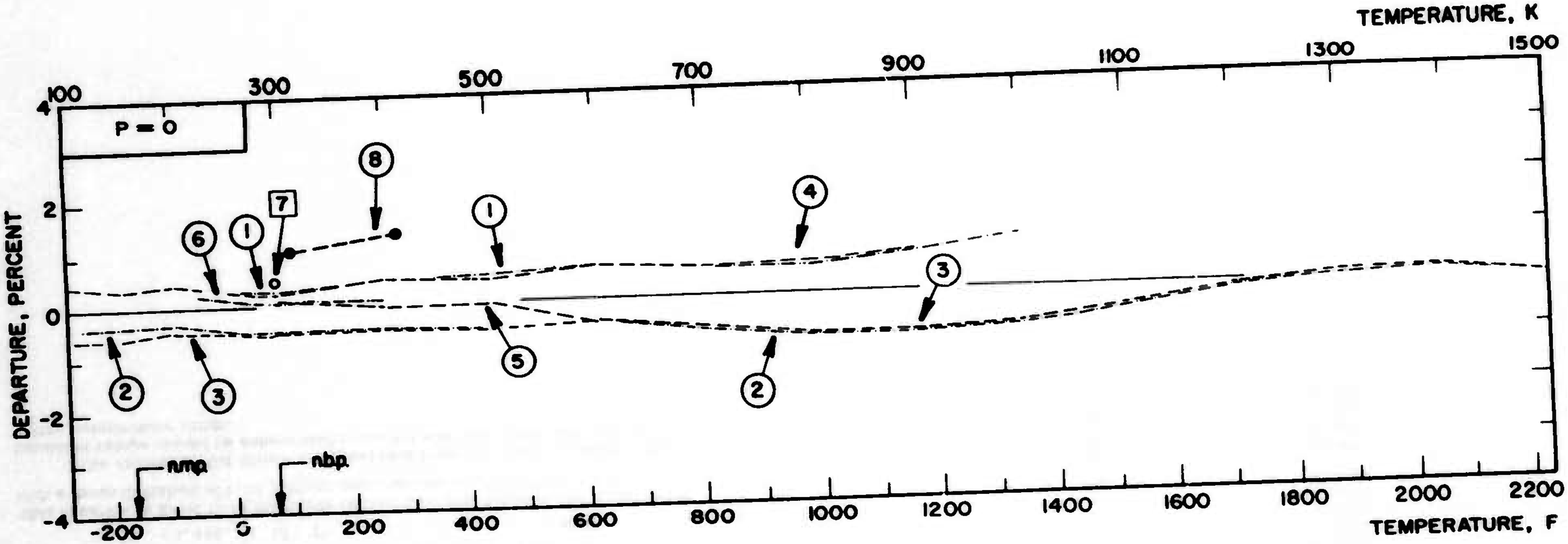
[Temperature, T, F; Specific Heat, C_p, B lb^{-1}F^{-1}]

GAS

T	C_p^0	T	C_p^0
-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

FIGURE 38 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

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).

$$C_p(\text{cal g}^{-1}\text{K}^{-1}) = 0.00963113 + 2.32124 \times 10^{-3}T - 9.72940 \times 10^{-6}T^2 + 1.49532 \times 10^{-8}T^3 \qquad (T \text{ in K}).$$

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.

RECOMMENDED VALUES

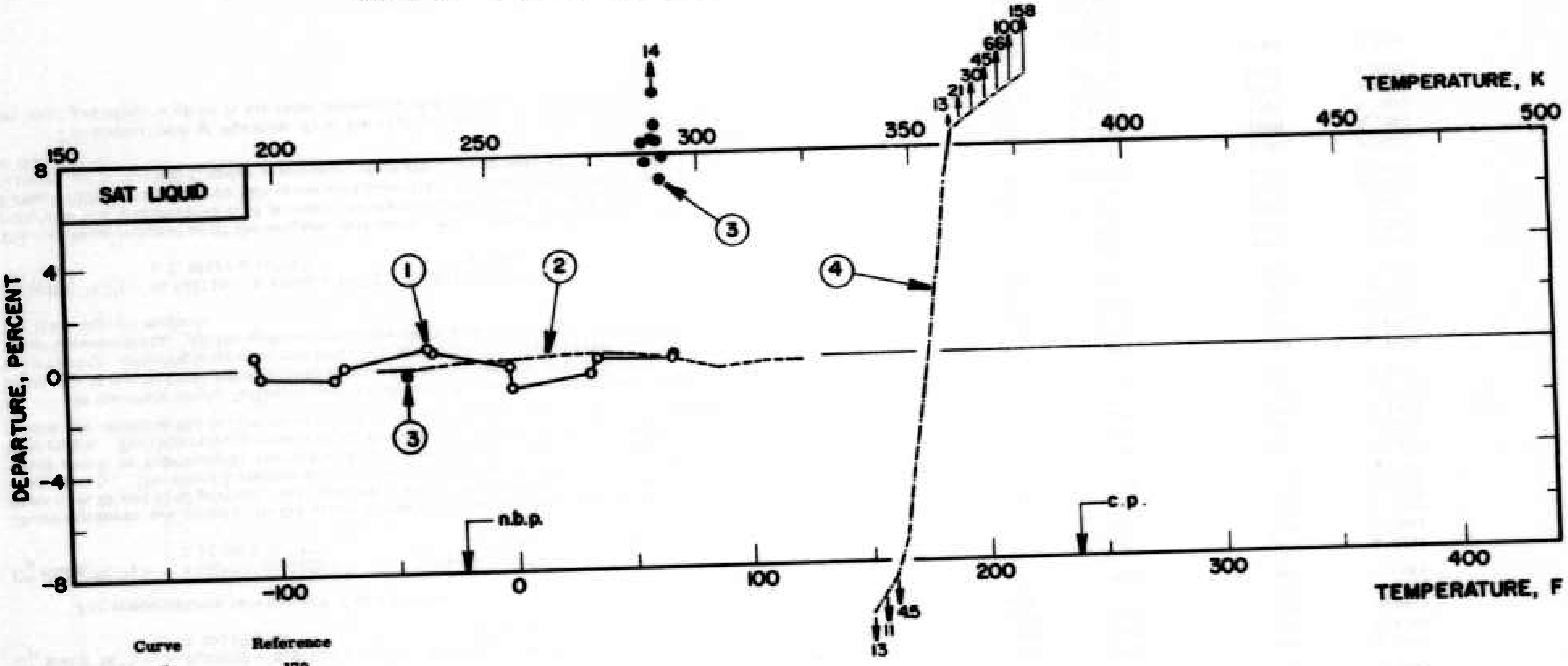
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

LIQUID

T	C_p
-140	0.1986
-120	0.2016
-100	0.2042
-80	0.2066
-60	0.2089
-40	0.2113
-20	0.2139
0	0.2168
20	0.2201
40	0.2240
60	0.2285
80	0.2338
100	0.2401
120	0.2474
140	0.2558
160	0.2656
180	0.2767

n.b.p. = -22 F

FIGURE 39 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID FREON-12



Curve	Reference
1	170
2	249
3	29
4	33

TABLE 39 SPECIFIC HEAT AT CONSTANT PRESSURE OF FREON-12

DISCUSSION

GAS

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 (59), 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:

$$C_p^0\ (\text{cal g}^{-1}\text{K}^{-1}) = 0.0278828 + 5.68820 \times 10^{-4}T - 7.04559 \times 10^{-7}T^2 + 3.28112 \times 10^{-10}T^3 \quad (T \text{ in K}) \qquad (1)$$

For temperatures between 600 K and 1500 K:

$$C_p^0\ (\text{cal g}^{-1}\text{K}^{-1}) = 0.102099 + 2.24224 \times 10^{-4}T - 1.64846 \times 10^{-7}T^2 + 4.25588 \times 10^{-11}T^3 \quad (T \text{ in K}) \qquad (2)$$

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 Fleischer (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:

$$C_p\ (\text{cal g}^{-1}\text{K}^{-1}) = 0.133136 - 3.87835 \times 10^{-4}T + 2.31512 \times 10^{-6}T^2 - 2.90113 \times 10^{-9}T^3 \quad (T \text{ in K}) \qquad (3)$$

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 388 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 $[(C_p)_1 - (C_p^0)_1]/(C_p^0)_1$.

RECOMMENDED VALUES

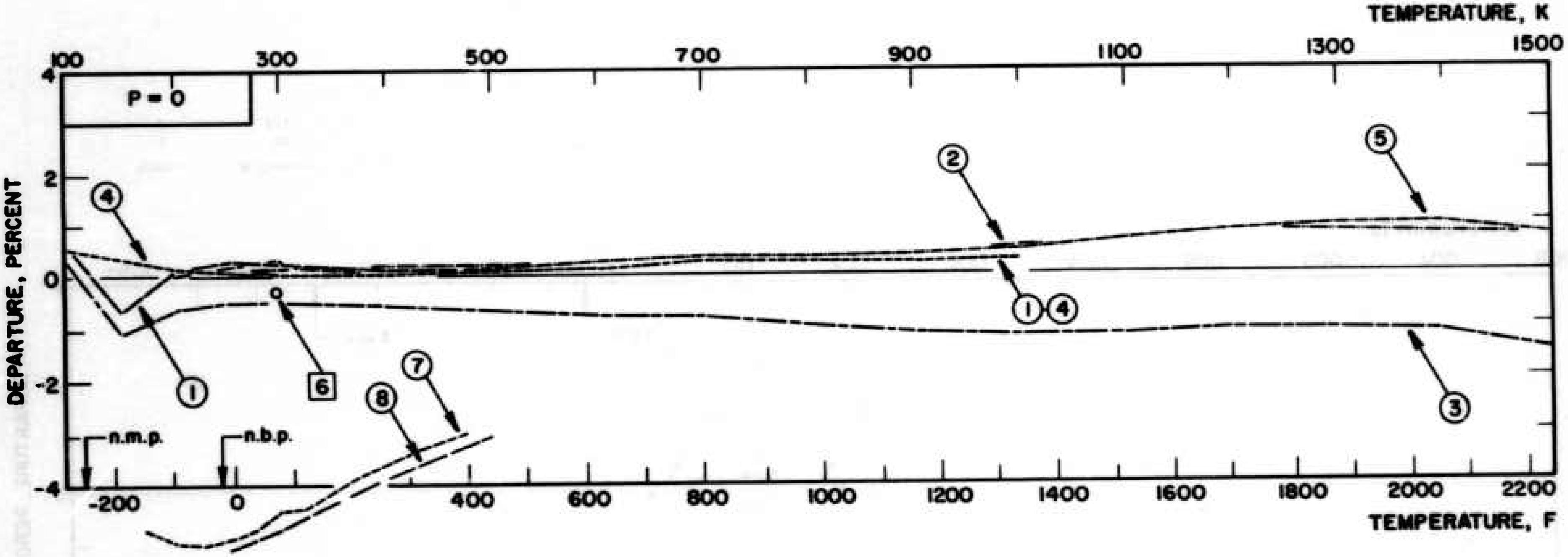
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

GAS

T	C_p^0	T	C_p^0
		500	0.180$\bar{5}$
-280	0.0779	520	0.1815
-260	0.0827	540	0.1826
-240	0.0873	560	0.1835
-220	0.0918	580	0.184$\bar{5}$
-200	0.0962	600	0.1854
-180	0.1004	620	0.1863
-160	0.104$\bar{5}$	640	0.1871
-140	0.1084	660	0.1879
-120	0.1123	680	0.1887
-100	0.1160	700	0.1894
-80	0.1195	720	0.1901
-60	0.1230	740	0.1908
-40	0.1263	760	0.191$\bar{5}$
-20	0.129$\bar{5}$	780	0.1921
0	0.1326	800	0.1927
20	0.1356	820	0.1934
40	0.1384	840	0.1939
60	0.1412	860	0.1945
80	0.1438	880	0.1951
100	0.1464	900	0.1956
120	0.1489	920	0.1962
140	0.1512	940	0.1967
160	0.153$\bar{5}$	960	0.1972
180	0.1557	980	0.1976
200	0.1578	1000	0.1981
220	0.1598	1100	0.2002
240	0.1617	1200	0.2019
260	0.1635	1300	0.2034
280	0.1653	1400	0.2046
300	0.1670	1500	0.2056
320	0.1686	1600	0.206$\bar{5}$
340	0.1702	1700	0.2072
360	0.1717	1800	0.2079
380	0.1731	1900	0.208$\bar{5}$
400	0.174$\bar{5}$	2000	0.2091
420	0.1758		
440	0.1770		
460	0.1782		
480	0.1794		

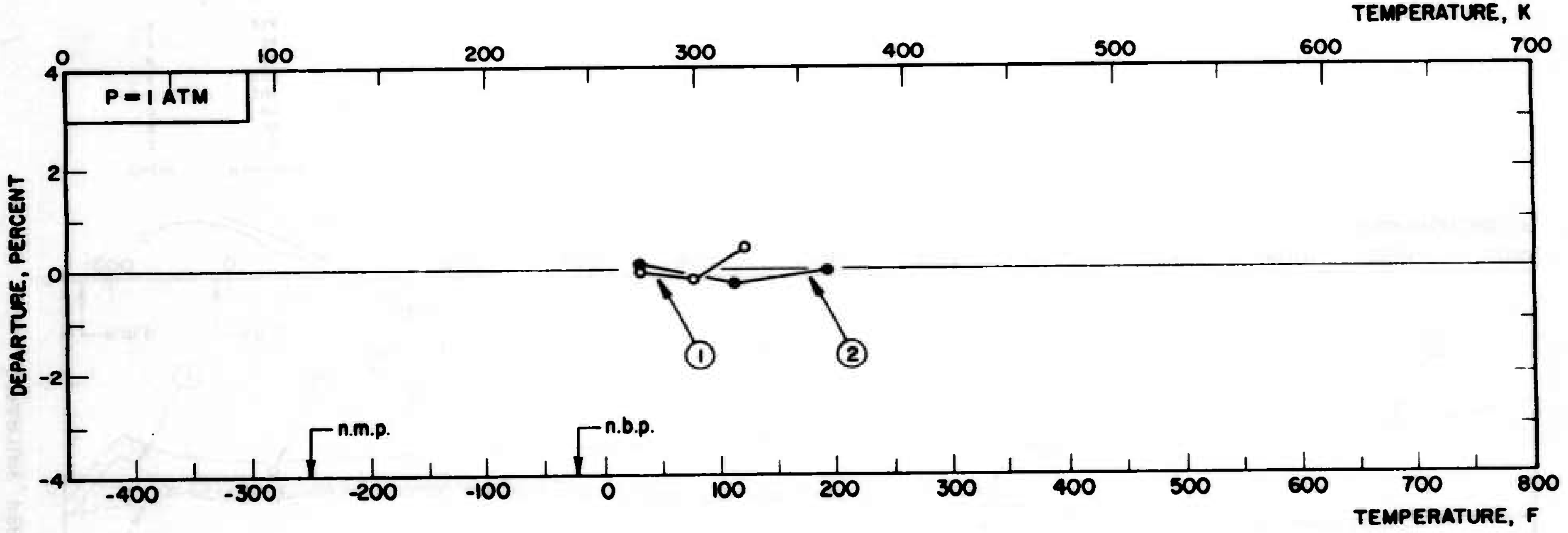
n.m.p. = -252 F
n.b.p. = -22 F

FIGURE 39 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS FREON-12



Curve	Reference
1	2
2	59
3	66
4	108
5	131
6	20
7	94
8	214

FIGURE 39 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS FREON-12



Curve	Reference
1	29
2	131

FIGURE 39 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS FREON-12

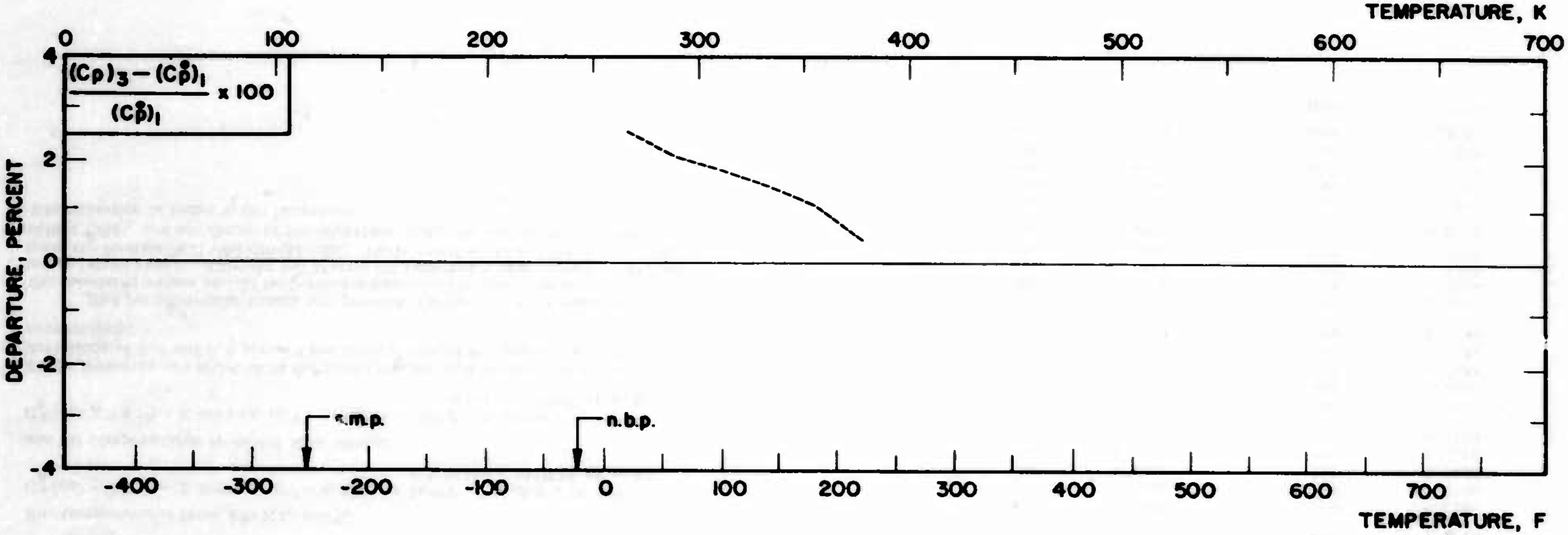


TABLE 40 SPECIFIC HEAT AT CONSTANT PRESSURE OF FREON-13

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:

$$C_p^0\,(\text{cal g}^{-1}\,\text{K}^{-1}) = 2.26848 \times 10^{-2} + 6.22016 \times 10^{-4}T - 7.05220 \times 10^{-7}T^2 + 3.04164 \times 10^{-10}T^3 \quad (T \text{ in K}).$$

and for temperatures from 600 K to 1000 K:

$$C_p^0\,(\text{cal g}^{-1}\,\text{K}^{-1}) = 8.46943 \times 10^{-2} + 3.32099 \times 10^{-4}T - 2.50258 \times 10^{-7}T^2 + 6.50464 \times 10^{-11}T^3 \quad (T \text{ in K}).$$

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.

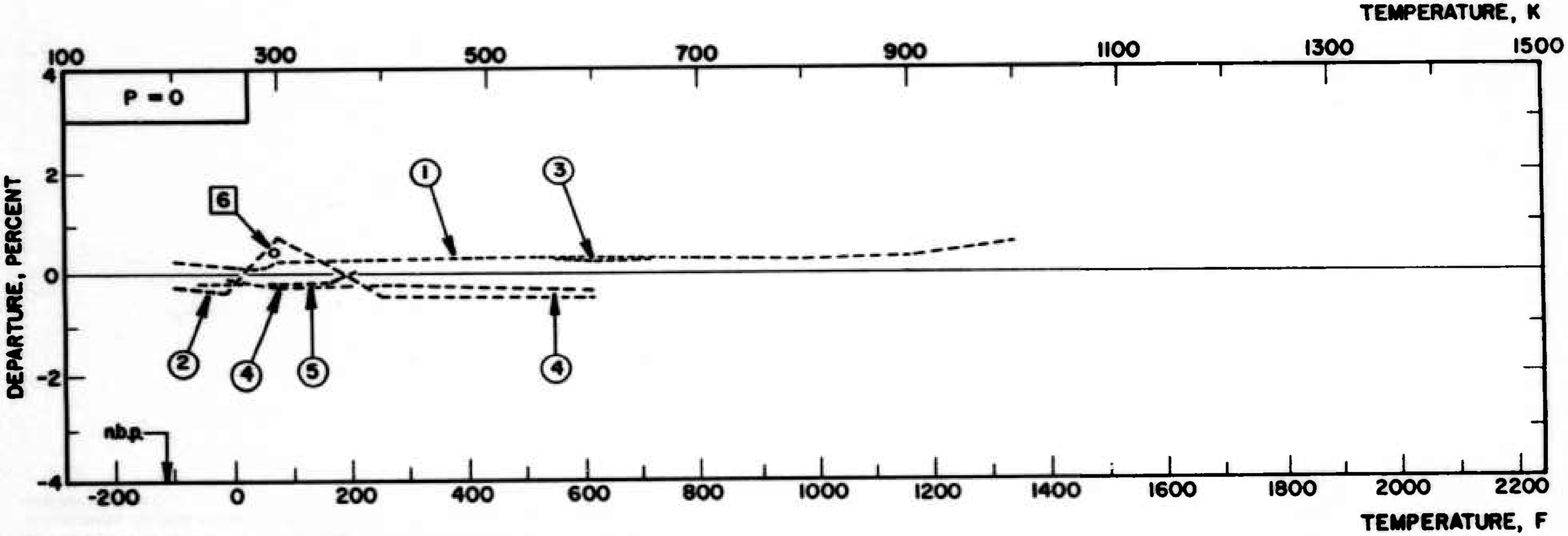
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

GAS

T	C_p^0	T	C_p^0
-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



Curve	Reference
1	2
2	66
3	108
4	214
5	95
6	20

TABLE 41 SPECIFIC HEAT AT CONSTANT PRESSURE OF FREON-21

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

$$C_p\,(\mathrm{cal\ g^{-1}\,K^{-1}}) = 0.19531 + 1.8896 \times 10^{-4}\,T \qquad (T \text{ in K}).$$

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.

RECOMMENDED VALUES

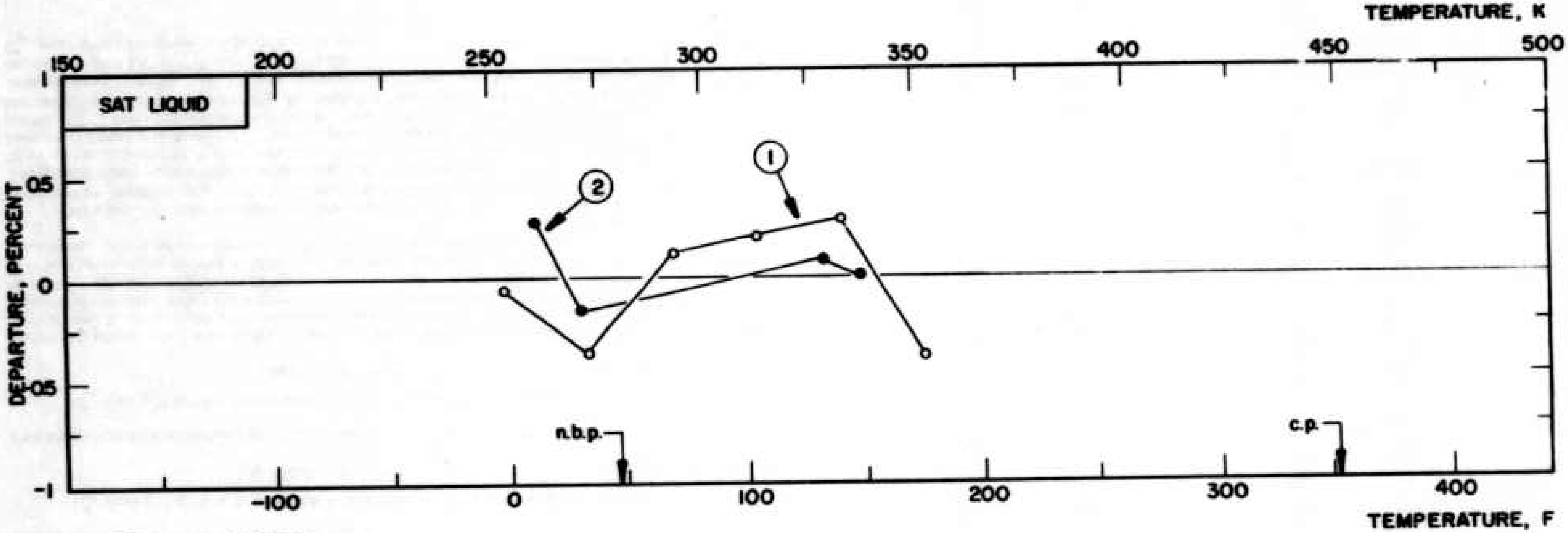
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

LIQUID

T	C_p
-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

n.b.p. = 48 F

FIGURE 41 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID FREON-21



Curve	Reference
1	16
2	17

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 Gelles 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:

$$C_p^0\ (\mathrm{cal\ g^{-1}\ K^{-1}}) = 0.0537464 + 3.47156 \times 10^{-4}\ T - 1.58035 \times 10^{-7}\ T^2 - 6.39583 \times 10^{-11}\ T^3 \qquad (T \text{ in K}). \quad (1)$$

For temperatures between 590 K and 1500 K:

$$C_p^0\ (\mathrm{cal\ g^{-1}\ K^{-1}}) = 0.0919903 + 2.47070 \times 10^{-4}\ T - 1.56916 \times 10^{-7}\ T^2 + 3.66968 \times 10^{-11}\ T^3 \qquad (T \text{ in K}). \quad (2)$$

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, B lb^{-1} F^{-1}]

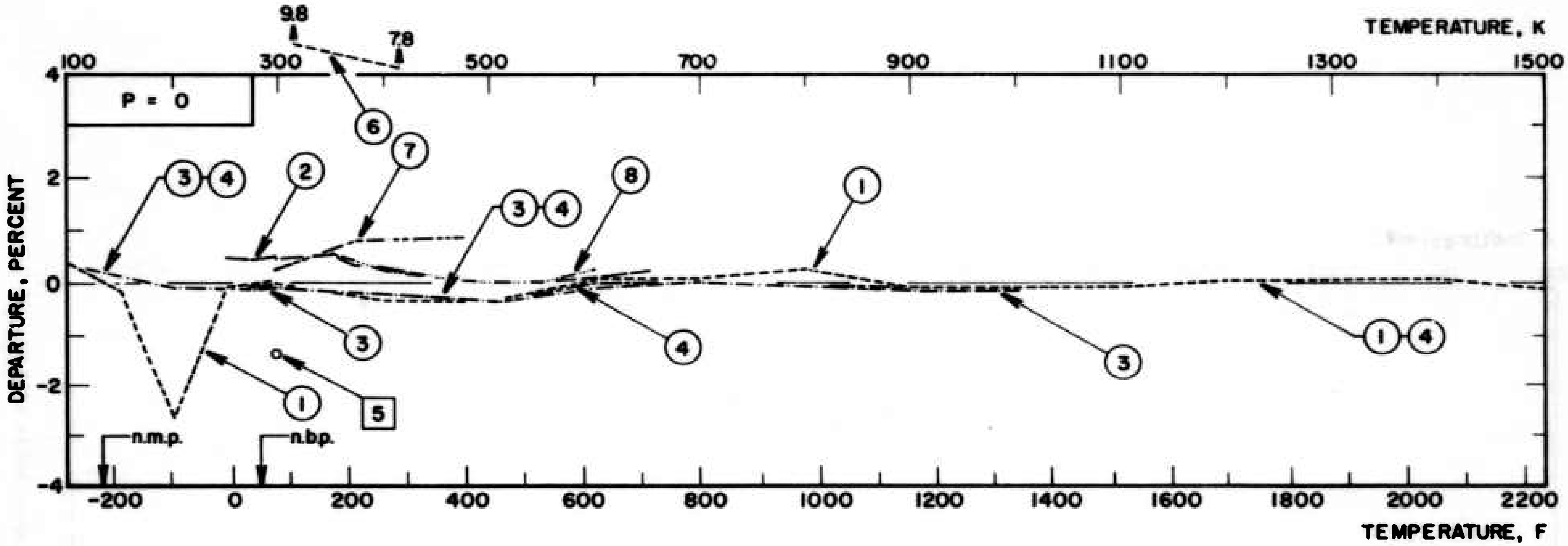
GAS

T	C_p^0	C_p^1
-280	0.0867	
-260	0.0902	
-240	0.0936	
-220	0.0970	
-200	0.1003	
-180	0.1036	
-160	0.1068	
-140	0.1100	
-120	0.1131	
-100	0.1162	
- 80	0.1193	
- 60	0.1223	
- 40	0.1252	
- 20	0.1281	
0	0.1309	
20	$0.133\underline{7}$	
40	$0.136\bar{5}$	
60	0.1392	
80	0.1418	
100	0.1444	$0.14\underline{7}$
120	0.1469	$0.1\bar{5}0$
140	0.1494	0.152
160	0.1518	0.154
180	0.1542	0.156
200	$0.156\bar{5}$	0.158
220	0.1588	0.160
240	0.1609	0.162
260	0.1631	0.164
280	0.1652	0.166
300	0.1672	
320	0.1692	
340	0.1711	
360	0.1729	
380	0.1747	
400	0.1764	
420	0.1781	
440	0.1797	
460	0.1812	
480	0.1827	

T	C_p^0
500	0.1841
520	0.1854
540	0.1867
560	0.1879
580	0.1891
600	0.1902
620	0.1915
640	0.1926
660	0.1937
680	0.1947
700	0.1957
720	0.1967
740	0.1977
760	0.1986
780	0.1996
800	$0.200\bar{5}$
820	0.2014
840	0.2023
860	0.2031
880	0.2040
900	0.2048
920	0.2056
940	0.2063
960	0.2071
980	0.2079
1000	0.2086
1100	0.2120
1200	0.2150
1300	0.2177
1400	0.2201
1500	0.2222
1600	0.2241
1700	0.2258
1800	0.2273
1900	0.2287
2000	0.2301

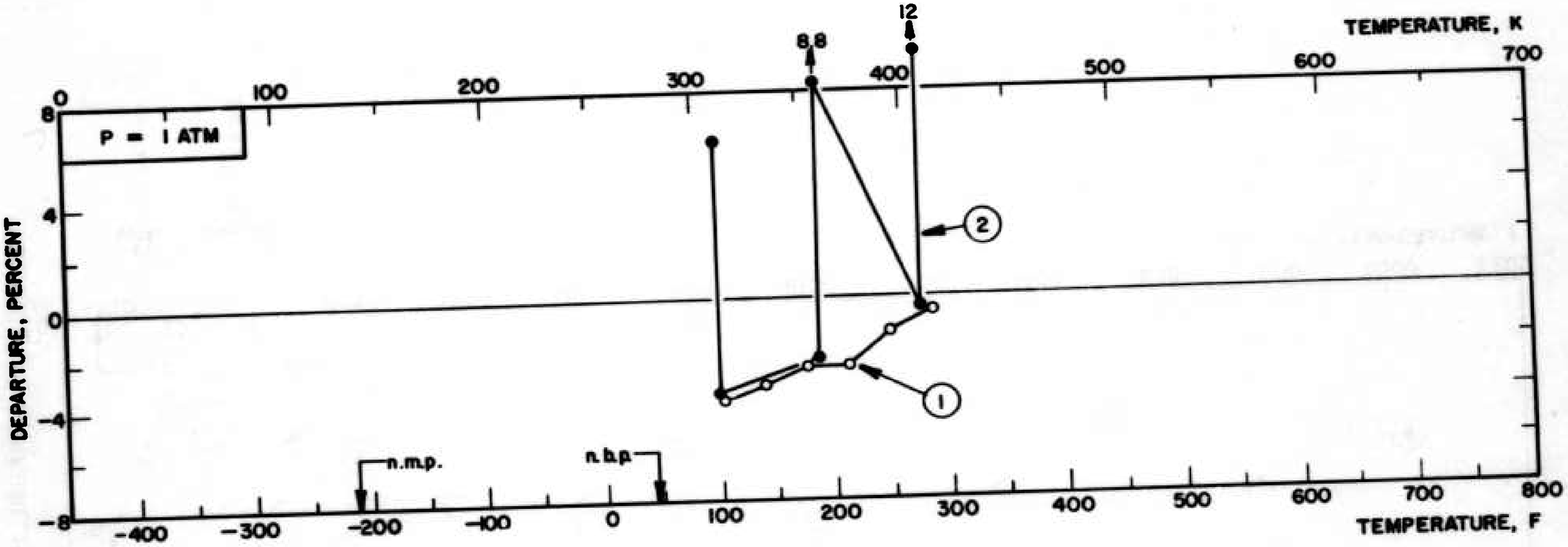
n.m.p. = -221 F
n.b.p. = 48 F

FIGURE 41 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS FREON-21



Curve	Reference
1	66
2	70
3	228
4	254
5	20
6	48
7	69

FIGURE 41 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS FREON-21



Curve	Reference
1	16
2	17

FIGURE 41 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS FREON-21

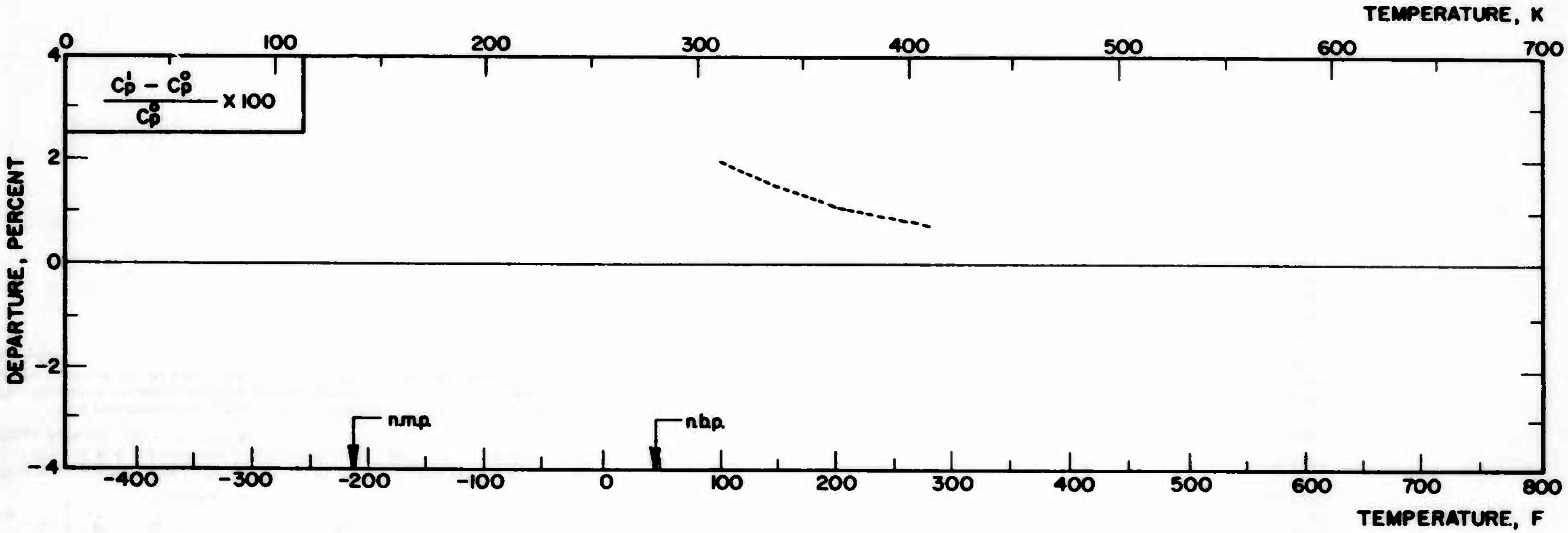


TABLE 42 SPECIFIC HEAT AT CONSTANT PRESSURE OF FREON-22

DISCUSSION

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

$$C_p\ (\mathrm{cal\ g^{-1}\ K^{-1}}) = 0.267165 + 3.22637 \times 10^{-5}T - 1.93112 \times 10^{-6}T^2$$
$$+ 7.26552 \times 10^{-9}T^3 \qquad (T \text{ in K}).$$

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.

RECOMMENDED VALUES

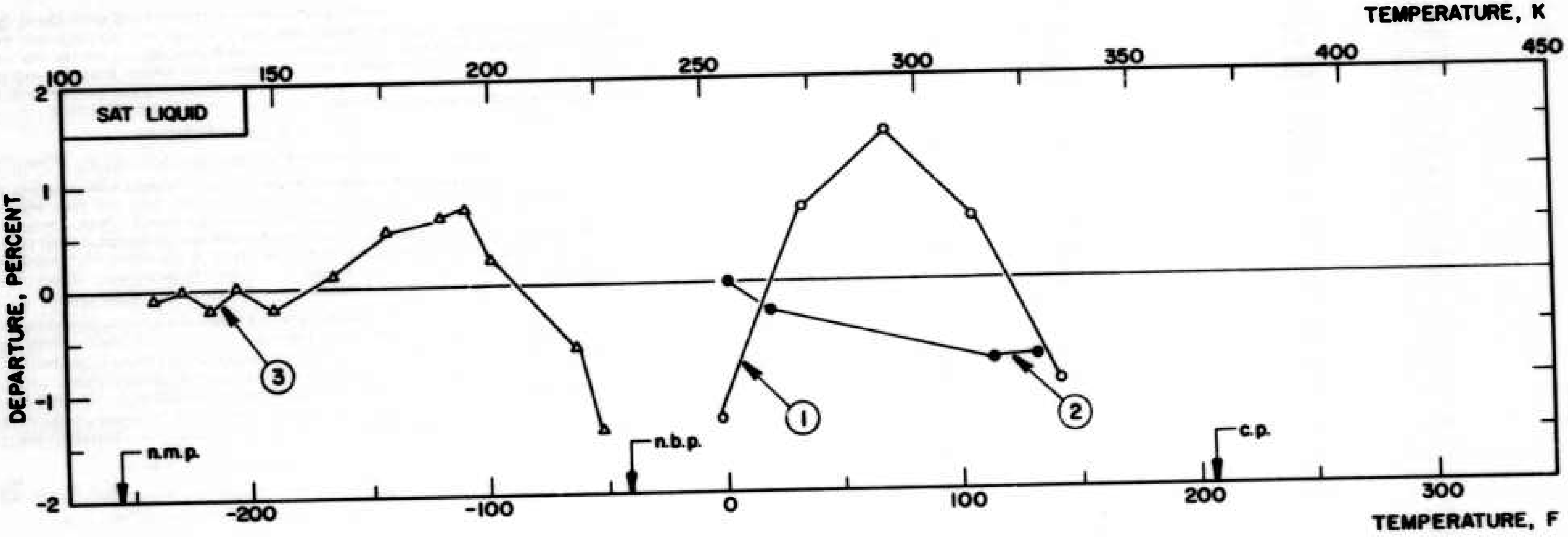
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

LIQUID

T	C_p
-240	0.2554
-220	0.2542
-200	0.2533
-180	0.2526
-160	0.2524
-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
100	0.3087
120	0.3197
140	0.3320
160	0.346
180	0.361

n.b.p. = -41 F

FIGURE 42 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID FREON-22



Curve	Reference
1	16
2	17
3	146

TABLE 42 SPECIFIC HEAT AT CONSTANT PRESSURE OF FREON-22 (continued)

DISCUSSION

GAS

There exist 10 sources of information for the specific heat at constant pressure of gaseous Freon-22. Extensive theoretical values for the ideal gas state derived from spectroscopic data were reported by Gelles and Pitzer (66), Weissman, et al (228) and JANAF Thermochemical Tables (254). Excellent agreement is found among them. These sets of values are given equal weight in this analysis. The early statistical values of Glockler and Edgell (70), which were cited in (236), are thought to be less reliable based on the molecular data used, and are given no weight as well as empirically derived values (20, 69). The correlation formulas obtained for the ideal gas specific heat are:

For temperatures between 100 K and 590 K

$$C_p^0\ (\text{cal g}^{-1}\text{K}^{-1}) = 0.0712690 + 2.41204 \times 10^{-4}\,T - 2.42847 \times 10^{-7}\,T^2 + 3.99893 \times 10^{-10}\,T^3. \quad (T \text{ in K}) \qquad (1)$$

For temperatures between 590 K and 1500 K

$$C_p^0\ (\text{cal g}^{-1}\text{K}^{-1}) = 0.0668378 + 3.80033 \times 10^{-4}\,T - 2.51645 \times 10^{-7}\,T^2 + 6.07102 \times 10^{-11}\,T^3 \quad (T \text{ in K}). \qquad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.3 and 0.2 percent and maximum deviations of 1.1 and 1.2 percent, respectively. The above formulas are used to generate the recommended values, which should be correct within 1.5 percent. The departures of all the original values mentioned above from the recommended values are plotted in the departure plot for P = 0. In this figure, a set of derived values (120) extrapolated to zero pressure are also given.

Meanwhile, two sets of experimental data at one atmosphere were obtained by Benning, et al (16, 17) by means of a flow calorimeter, covering temperatures from 313 K to 413 K. Landsberg and Seibald (120) also derived heat capacity at one atmosphere from a virial equation of state between 253 K to 393 K. Using all these reported data points, a correlation formula for the real gas state between 253 K and 413 K is determined, independently of the ideal gas values. The resulting equation is as follows:

$$C_p\ (\text{cal g}^{-1}\text{K}^{-1}) = -0.0761230 + 1.65032 \times 10^{-3}\,T - 4.26184 \times 10^{-6}\,T^2 + 4.30551 \times 10^{-9}\,T^3 \quad (T \text{ in K}). \qquad (3)$$

This equation is found to fit the above data points with a mean deviation of 0.8 percent and a maximum of 3 percent. In the departure plot at P = 1 atm, all the reported values are compared with Equation (3). It should be noted that the values for the real gas are considerably lower than those for the ideal gas specific heat, as shown in the third departure plot, therefore, Equation (3) is not used to calculate recommended values.

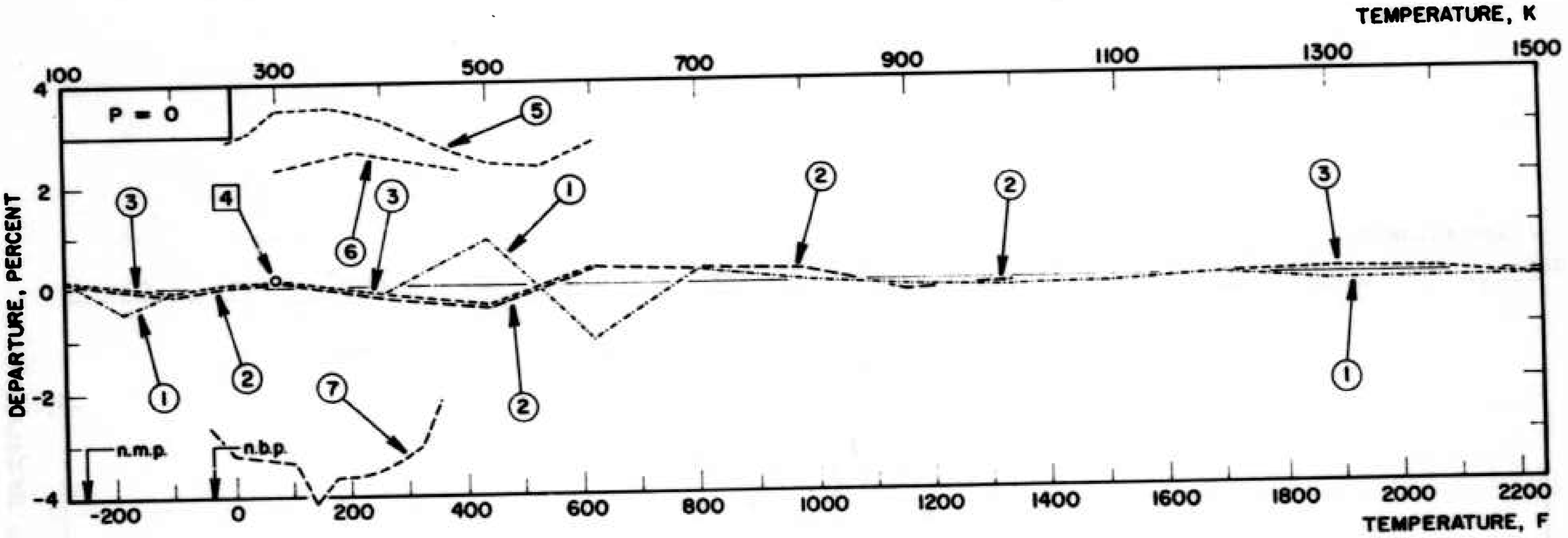
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

GAS

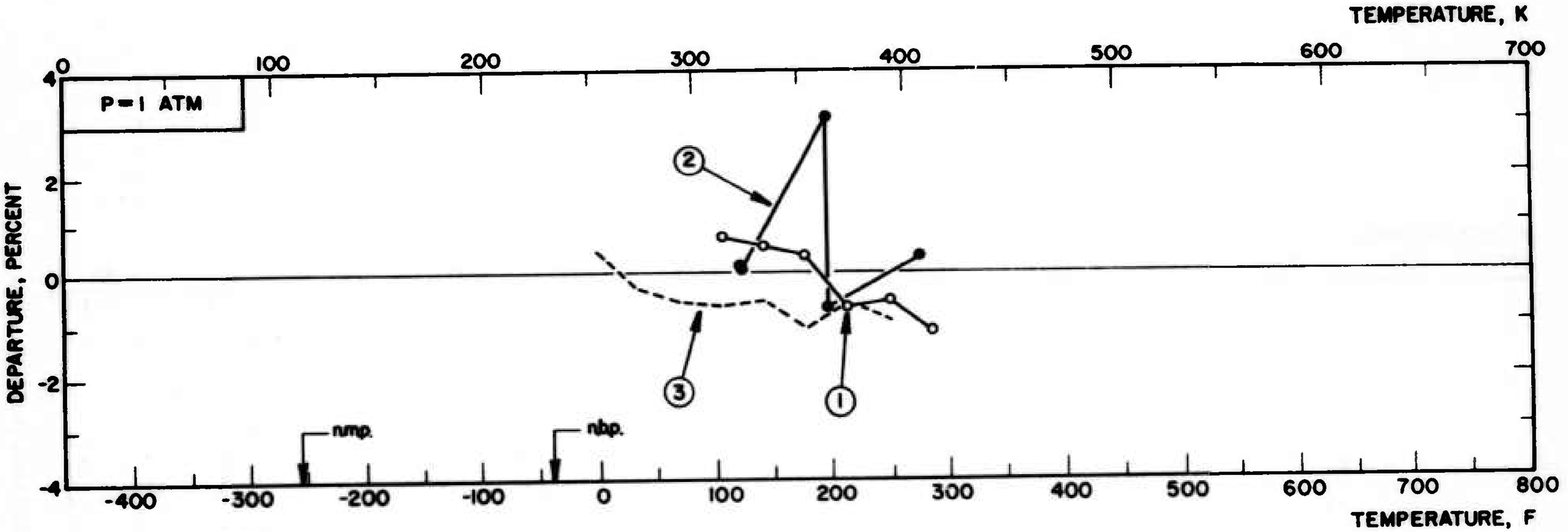
T	C_p^0	T	C_p^0
-300	0.09424	500	0.2082
-280	0.09730	520	0.2099
-260	0.1004	540	0.2115
-240	0.1035	560	0.2130
-220	0.1067	580	0.2144
-200	0.1098	600	0.2157
-180	0.1130	620	0.2172
-160	0.1162	640	0.2188
-140	0.1194	660	0.2203
-120	0.1227	680	0.2218
-100	0.1259	700	0.2233
-80	0.1291	720	0.2248
-60	0.1323	740	0.2262
-40	0.1355	760	0.2275
-20	0.1388	780	0.2289
0	0.1419	800	0.2302
20	0.1451	820	0.2315
40	0.1483	840	0.2327
60	0.1514	860	0.2340
80	0.1545	880	0.2352
100	0.1576	900	0.2363
120	0.1607	920	0.2375
140	0.1637	940	0.2386
160	0.1667	960	0.2397
180	0.1696	980	0.2407
200	0.1725	1000	0.2418
220	0.1753	1100	0.2465
240	0.1781	1200	0.2507
260	0.1809	1300	0.2544
280	0.1835	1400	0.2576
300	0.1861	1500	0.2605
320	0.1887	1600	0.2630
340	0.1912	1700	0.2652
360	0.1936	1800	0.2673
380	0.1959	1900	0.2692
400	0.1982	2000	0.2710
420	0.2003		
440	0.2024		
460	0.2044		
480	0.2063		

FIGURE 42 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS FREON-22



Curve	Reference
1	66
2	228
3	254
4	20
5	70, 236
6	69
7	120

FIGURE 42 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS FREON-22



Curve	Reference
1	16
2	17
3	120

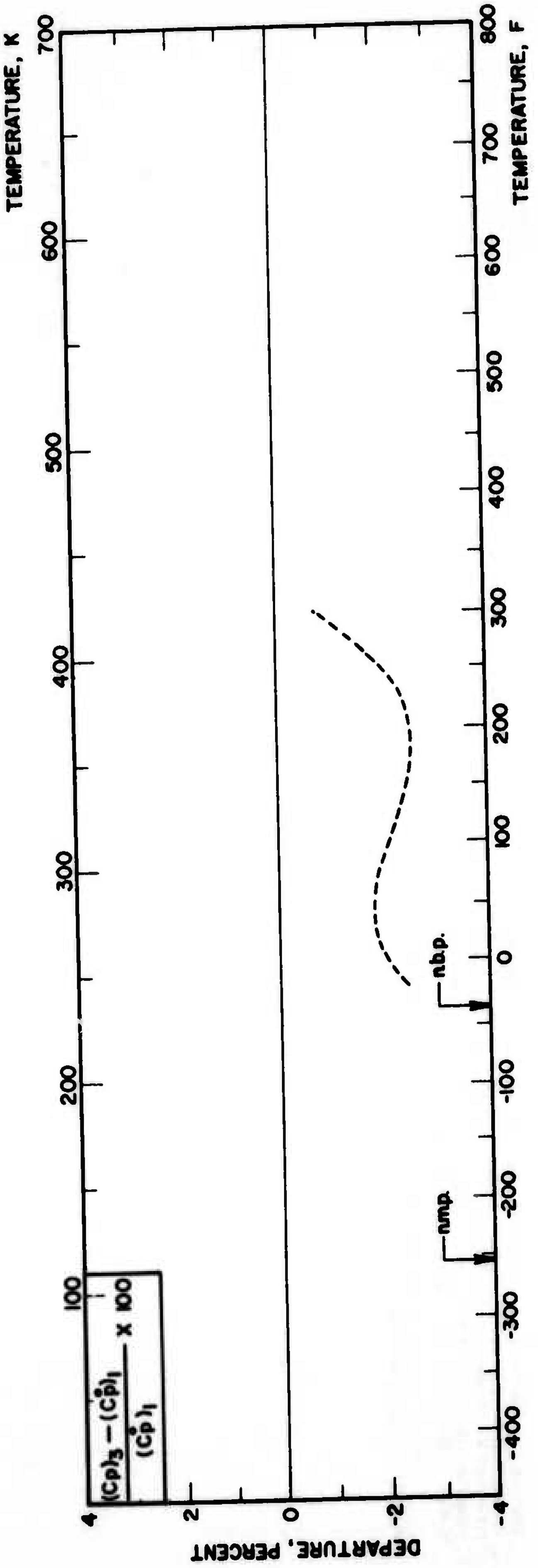


FIGURE 42 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS FREON 22

TABLE 43 SPECIFIC HEAT AT CONSTANT PRESSURE OF FREON-113

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

$$C_p(\text{cal g}^{-1}\text{K}^{-1}) = 0.299591 - 1.33126 \times 10^{-3}T + 5.21678 \times 10^{-6}T^2 - 5.34447 \times 10^{-9}T^3 \quad (T \text{ in K}).$$

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 tabulated 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.

RECOMMENDED VALUES

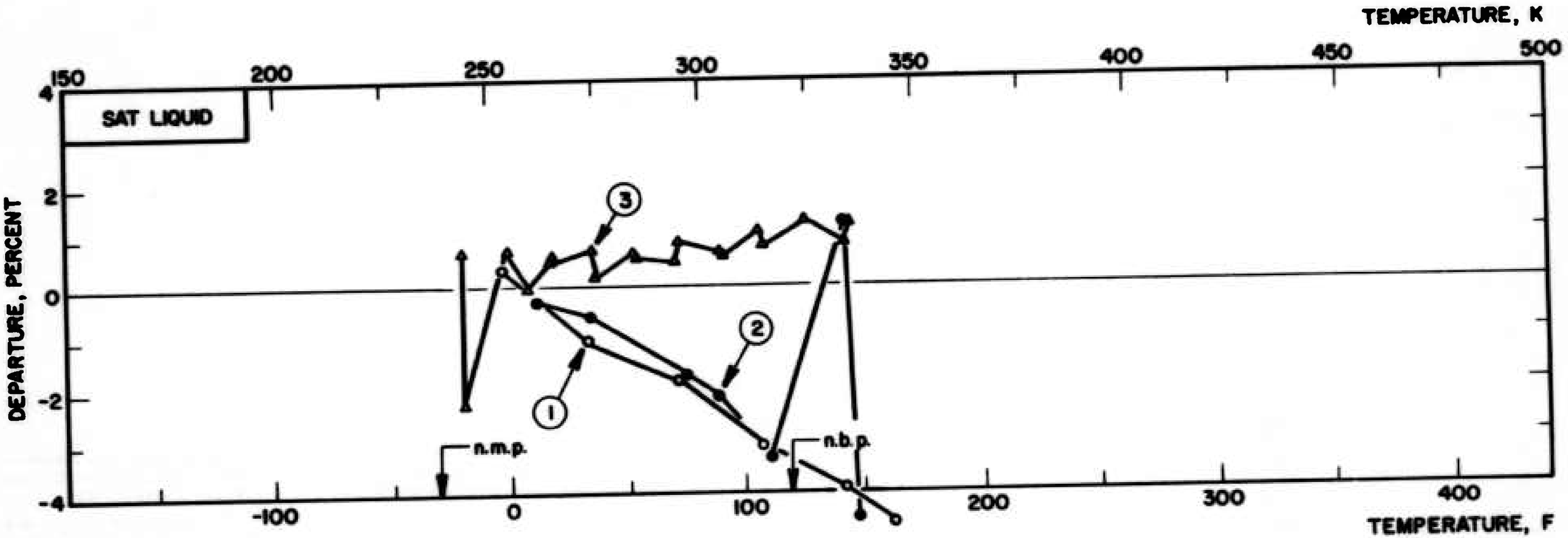
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

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

n.b.p. = 118 F

FIGURE 43 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID FREON-113



Curve	Reference
1	16
2	17
3	169

TABLE 43 SPECIFIC HEAT AT CONSTANT PRESSURE OF FREON-113 (continued)

DISCUSSION

GAS

Only two sets of calorimetric measurements are available on the isobaric specific heat of gaseous Freon-113, both being those of Benning, 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

$$C_p\,(\text{cal g}^{-1}\,\text{K}^{-1}) = 0.234595 - 1.05032 \times 10^{-3}\,T + 3.68350 \times 10^{-6}\,T^2 - 3.58501 \times 10^{-9}\,T^3 \qquad (T \text{ in K}).$$

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.

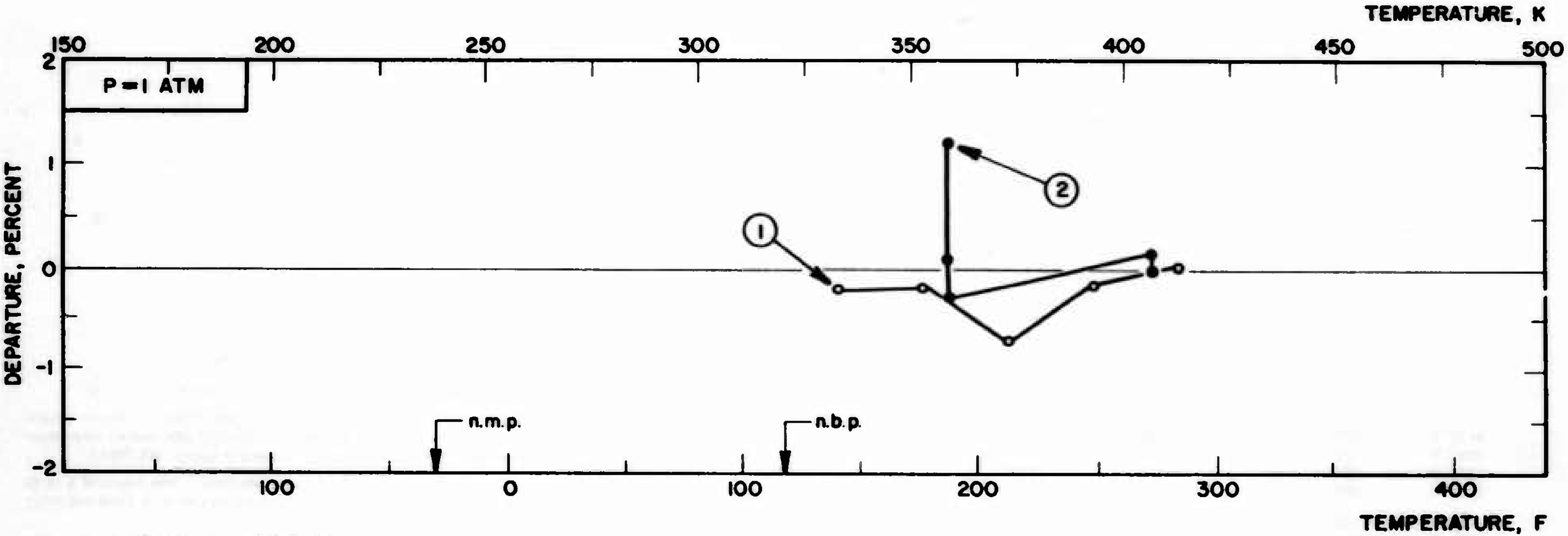
RECOMMENDED VALUES

[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

FIGURE 43 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS FREON-113



Curve	Reference
1	16
2	17

TABLE 44 SPECIFIC HEAT AT CONSTANT PRESSURE OF FREON-114

DISCUSSION

GAS

Only two sets of derived values are available in the literature for the isobaric specific heat of gaseous Freon-114 in the real gas state. Van Wie and Ebel (218, 219) presented derived results by use of an empirical equation, covering temperatures from 233 K to 478 K and pressures up to 1600 psi. In this analysis, the reported values under saturation vapor pressures at temperatures below the n. b. p. are given equal weight, as well as the values at one atm. above the n. b. p., which are extrapolated from those under higher pressures.

The correlation formula obtained is

$$C_p(\mathrm{cal\ g^{-1}\ K^{-1}}) = -0.0222438 + 1.08849 \times 10^{-3}T - 1.82865 \times 10^{-6}T^2 + 1.15928 \times 10^{-9}T^3 \text{ (T in K).}$$

This formula is found to fit the above enumerated values with a mean deviation of 0. 1 percent and a maximum of 0. 5 percent.

Using the above equation, the recommended values are generated. The tabulated values should be substantially correct within [illegible] percent over the entire temperature range.

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

RECOMMENDED VALUES

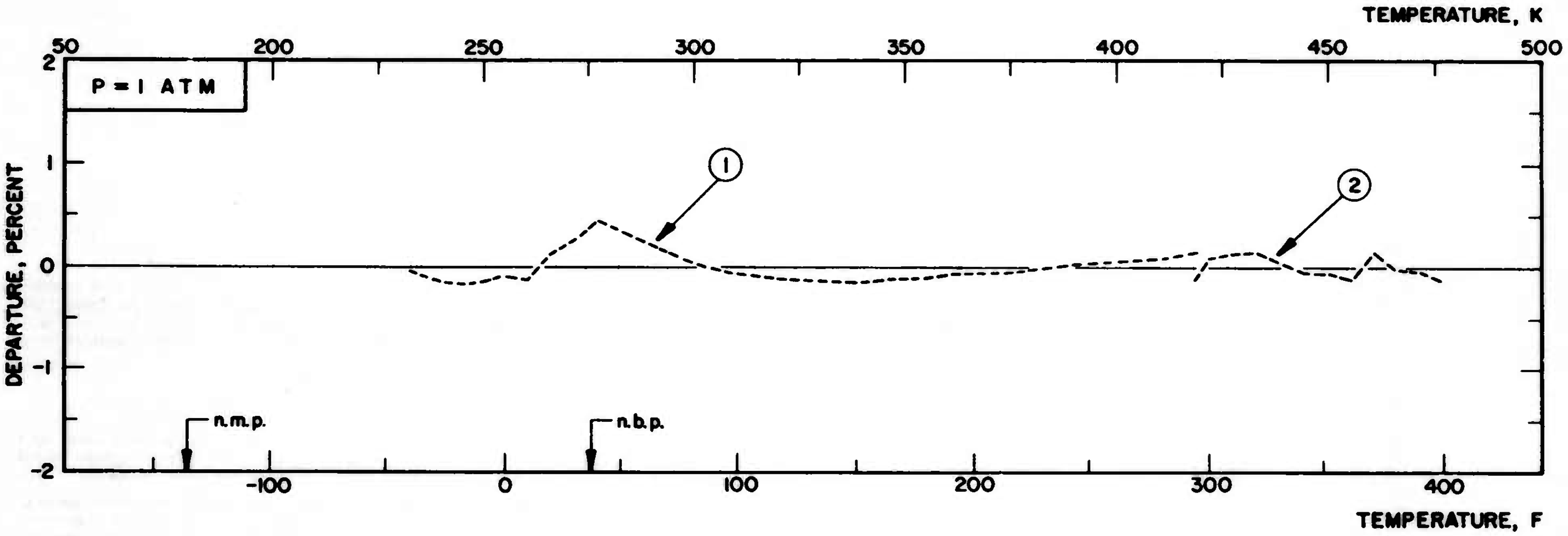
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

GAS

T	C_p	T	C_p
		200	0. 1880
		220	0. 1903
-60	0. 1419	240	0. 1925
-40	0. 1467	260	0. 1946
-20	0. 1513	280	0. 1966
0	0. 1557	300	0. 1984
20	0. 1598	320	0. 2002
40	0. 1637	340	0. 2019
60	0. 1674	360	0. 2035
80	0. 1709	380	0. 2051
100	0. 1741	400	0. 2067
120	0. 1772	420	0. 2081
140	0. 1802	440	0. 2096
160	0. 1829	460	0. 2110
180	0. 1855		

n. b. p. = 38 F

FIGURE 44 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS FREON-114



Curve	Reference
1	218
2	219

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:

$$C_p(\text{cal g}^{-1}\text{K}^{-1}) = 0.098645 + 1.88655 \times 10^{-3}T - 1.36428 \times 10^{-6}T^2 + 1.03166 \times 10^{-9}T^3 \qquad (T \text{ in K}).$$

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

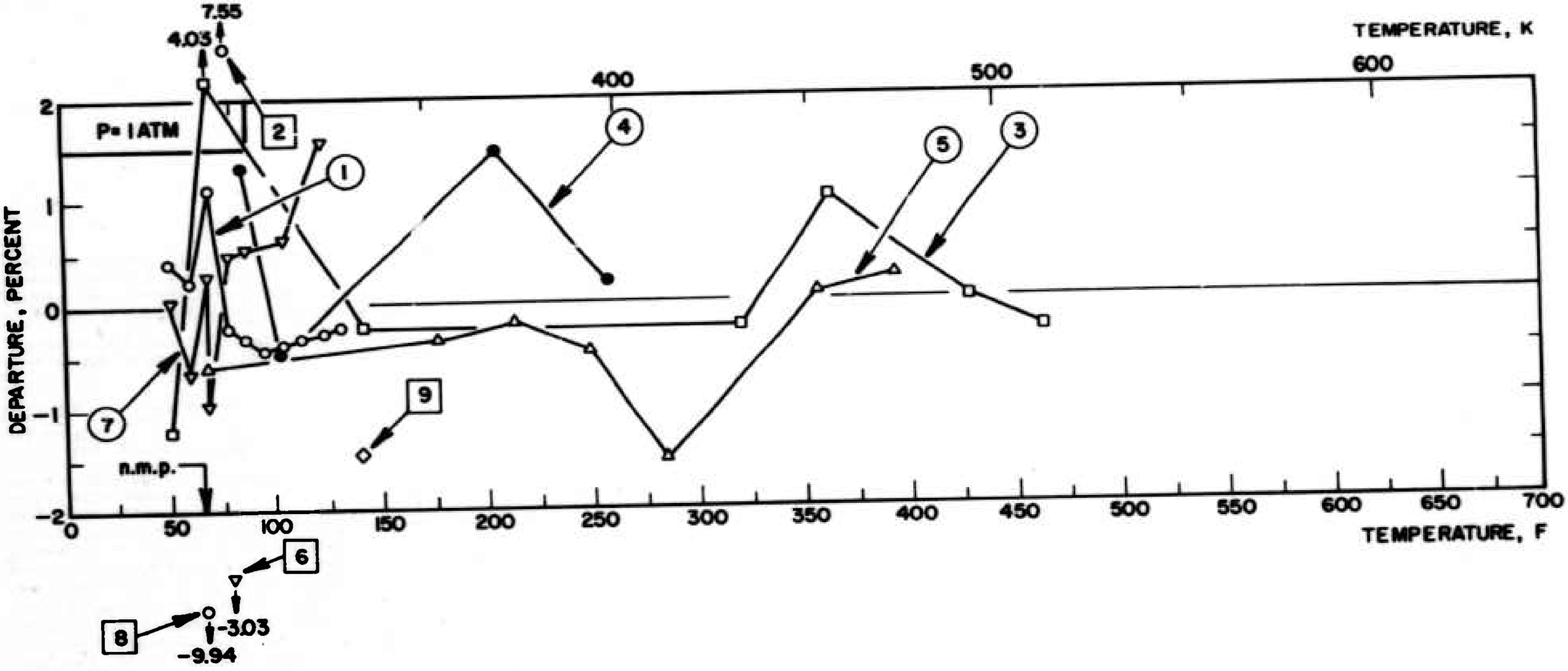
[Temperature, T, F; Specific Heat, C_p, B $lb^{-1}F^{-1}$]

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



Curve	Reference
1	593
2	594
3	595
4	595
5	595
6	590
7	198
8	591
9	592

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 Ginning 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 Ginnings (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

$$C_p(\text{cal g}^{-1}\text{K}^{-1}) = 0.454958 - 3.46073 \times 10^{-4}\,T + 2.14820 \times 10^{-6}\,T^2 - 2.48653 \times 10^{-10}\,T^3 \quad (T \text{ in K}).$$

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

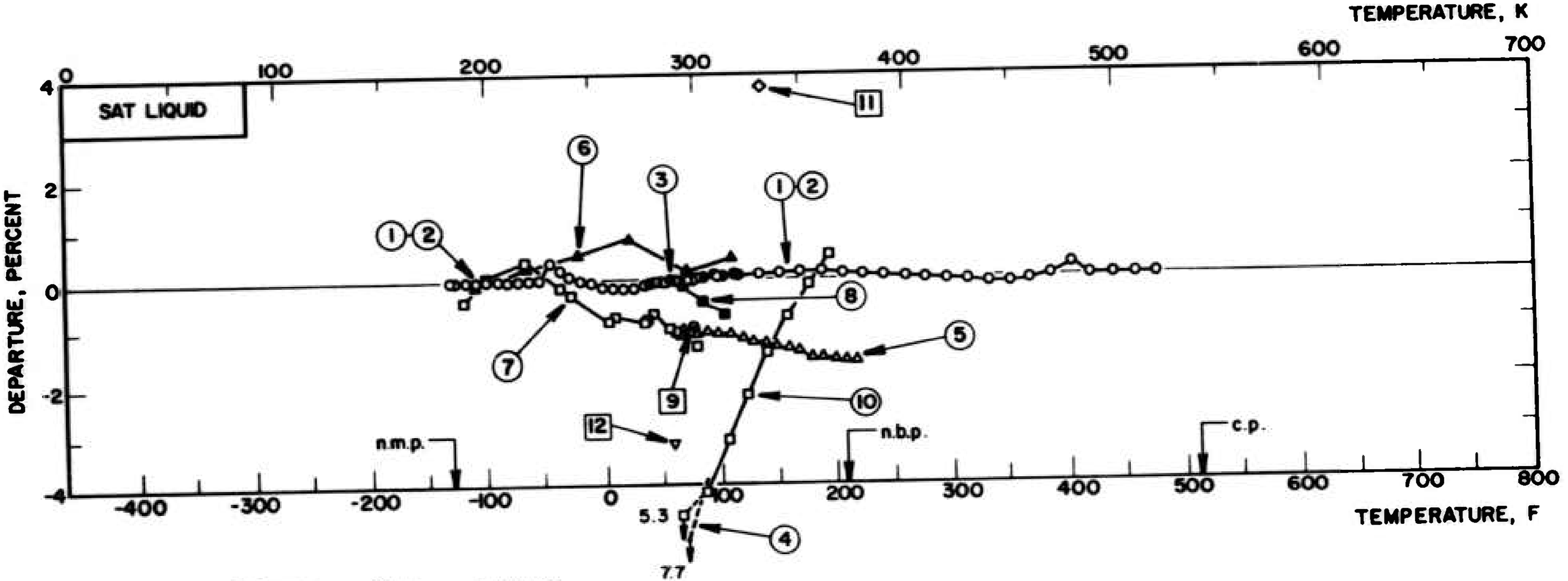
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

LIQUID

T	C_p	T	C_p
-120	0.482		
-100	0.480	200	0.6040
-80	0.482	220	0.6168
-60	0.484	240	0.6300
-40	0.4876	260	0.6437
-20	0.4946	280	0.6578
0	0.5022	300	0.6724
20	0.5102	320	0.6874
40	0.5188	340	0.7029
60	0.5278	360	0.7189
80	0.5373	380	0.7353
100	0.5472	400	0.7521
120	0.5576	420	0.773
140	0.5685	440	0.799
160	0.5799	460	0.838
180	0.5917	480	0.939

n.b.p. = 209 F

FIGURE 46 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID n-HEPTANE



Curve	Reference	Curve	Reference
1	49	9	221
2	68	10	231
3	149	11	257
4	36	12	78
5	80		
6	162		
7	153		
8	168		

TABLE 46 SPECIFIC HEAT AT CONSTANT PRESSURE OF n-HEPTANE

DISCUSSION

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 (159), 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:

$$C_p^0\ (\text{cal g}^{-1}\text{K}^{-1}) = 0.0254671 + 1.37666 \times 10^{-3}\,T - 4.00040 \times 10^{-7}\,T^2 - 1.13314 \times 10^{-10}\,T^3. \qquad (1)$$

For temperature range from 800 K and 1500 K:

$$C_p^0\ (\text{cal g}^{-1}\text{K}^{-1}) = 0.0982018 + 1.30398 \times 10^{-3}\,T - 5.92804 \times 10^{-7}\,T^2 + 1.01054 \times 10^{-10}\,T^3 \qquad (T \text{ in K}) \qquad (2)$$

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 500K 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:

$$C_p\ (\text{cal g}^{-1}\text{K}^{-1}) = 4.62354 - 3.27676 \times 10^{-2}\,T + 8.38934 \times 10^{-5}\,T^2 - 6.91452 \times 10^{-8}\,T \qquad (T \text{ in K}) \qquad (3)$$

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 $[(C_p)_3 - (C_p^0)_1]/(C_p^0)_1$.

RECOMMENDED VALUES

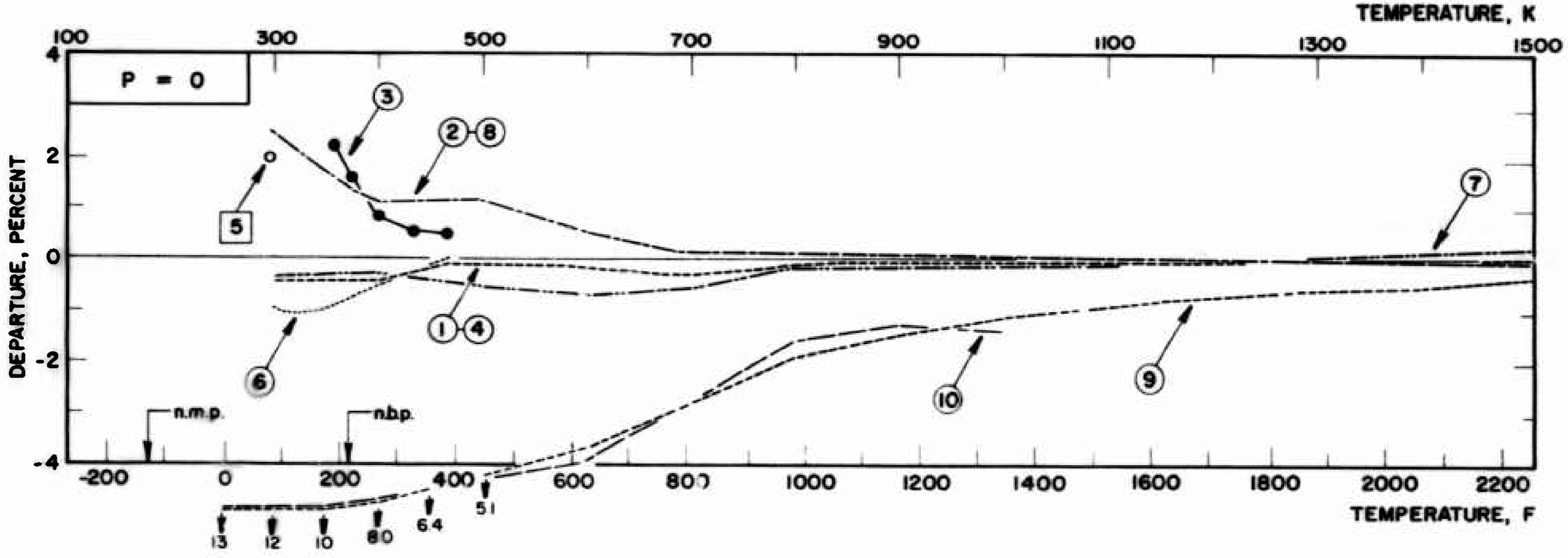
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

GAS

T	C_p^0	T	C_p^0
		600	0.6737
		620	0.6824
		640	0.6909
		660	0.6993
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

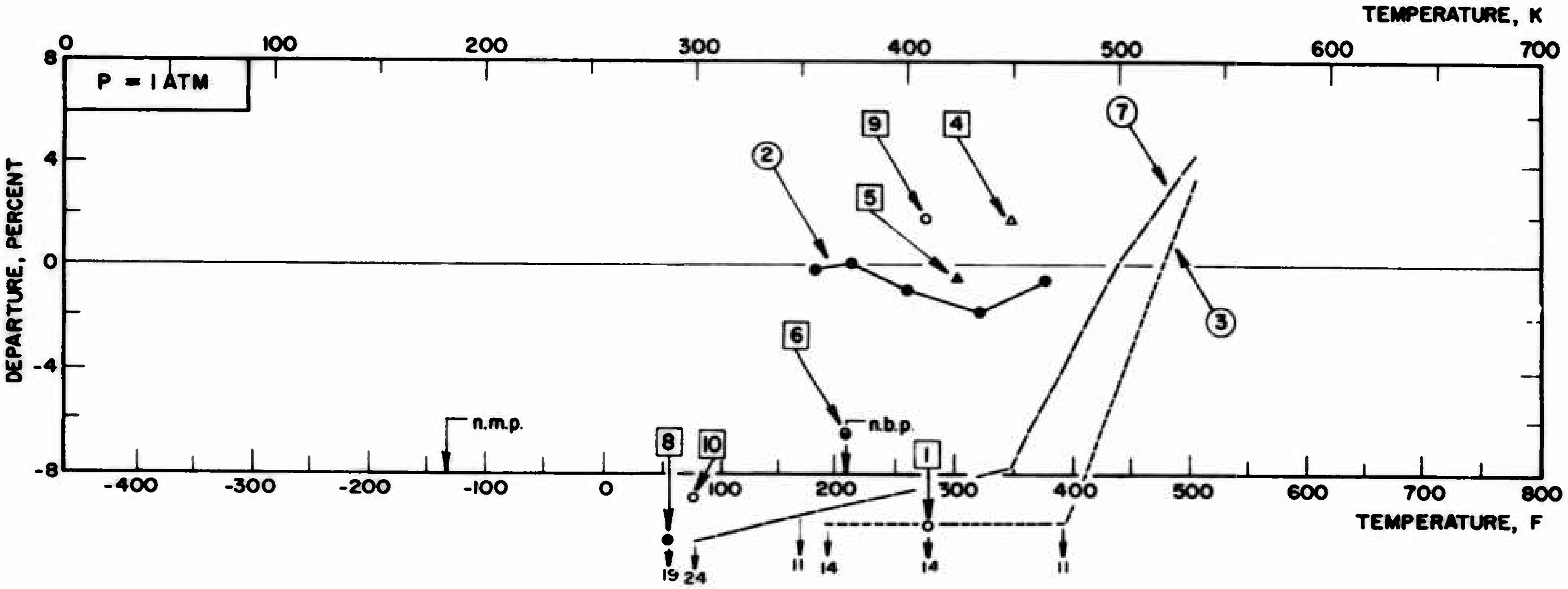
n.b.p. = 209 F

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

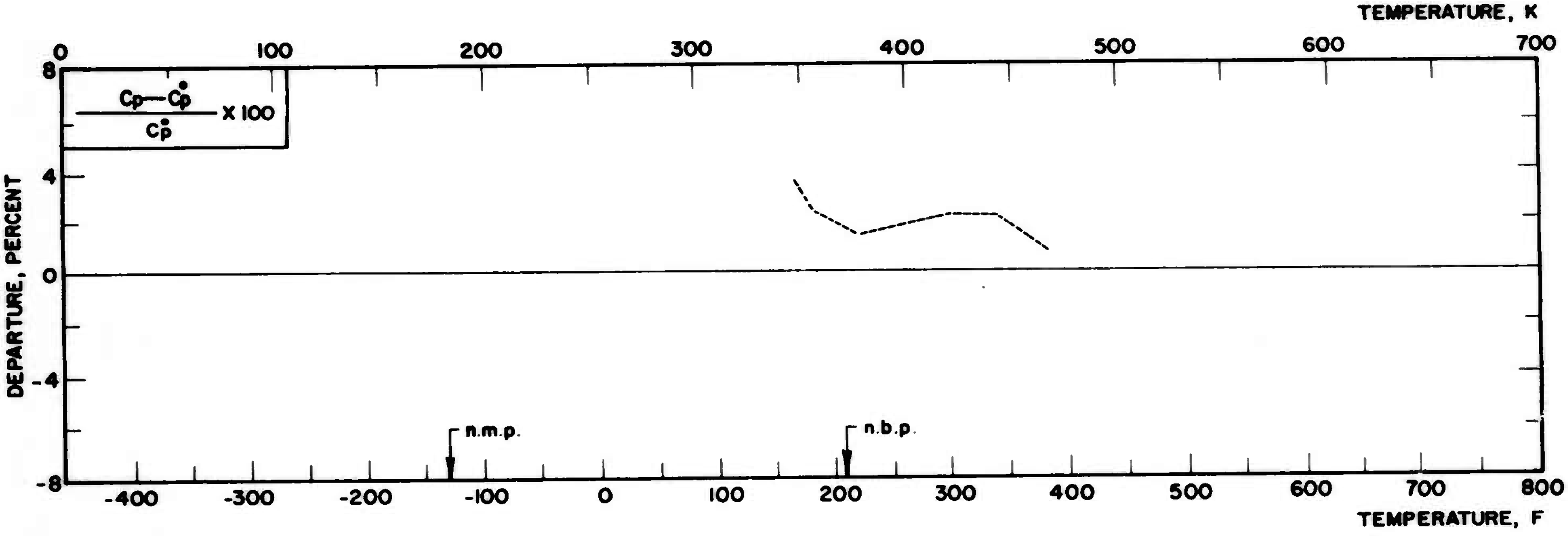


TABLE 47 SPECIFIC HEAT AT CONSTANT PRESSURE OF n-HEXANE

DISCUSSION

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 neat 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

$$C_p\ (\mathrm{cal\ g^{-1}K^{-1}}) = 0.577652 - 1.43082 \times 10^{-3}\,T + 5.00921 \times 10^{-6}T^2 - 2.01933 \times 10^{-9}T^3 \quad (T \text{ in K}).$$

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.

RECOMMENDED VALUES

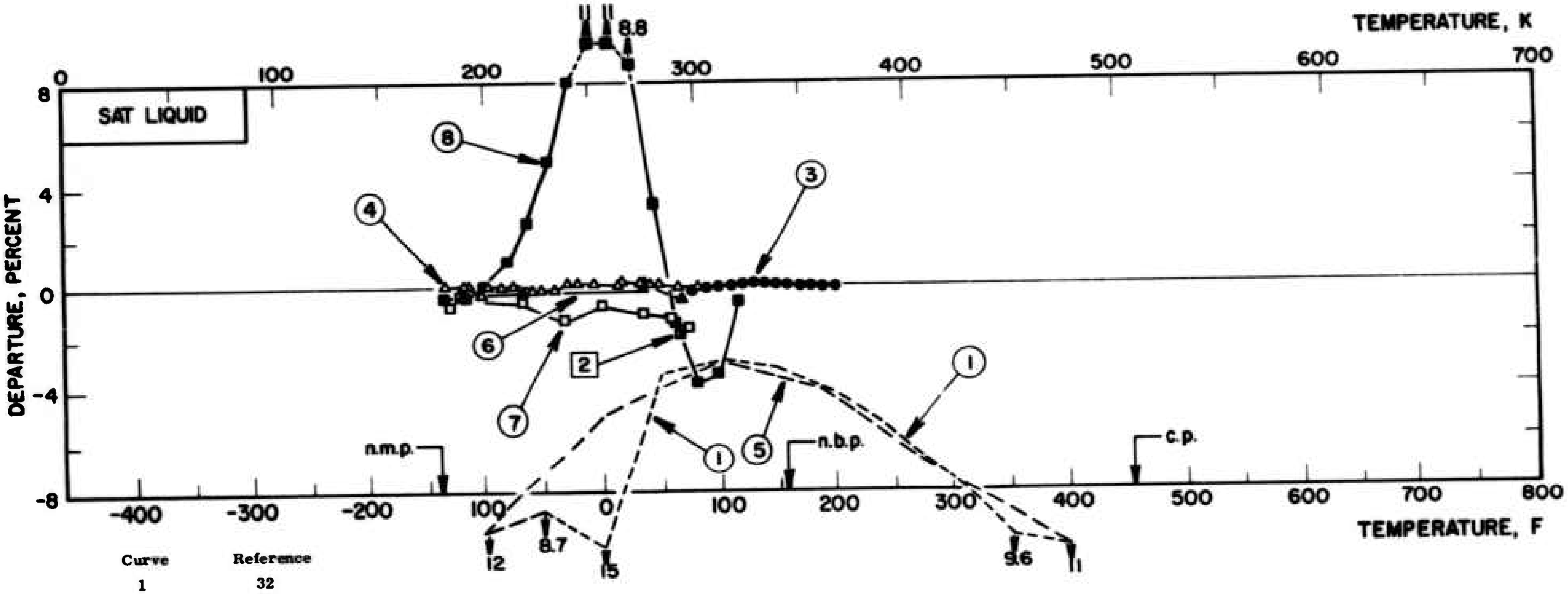
[Temperature, T, F; Specific Heat, C_p, B $\mathrm{lb^{-1}\,F^{-1}}$

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

FIGURE 47 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID n-HEXANE



Curve	Reference
1	32
2	36
3	39
4	50
5	83
6	87
7	153
8	201

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 extensive 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:

$$C^0_p\,(\mathrm{cal\ g^{-1}K^{-1}}) = 0.0586880 + 1.21316 \times 10^{-3}\,T - 1.21609 \times 10^{-7}\,T^2 - 2.6381\bar{5} \times 10^{-10}\,T^3, \qquad (1)$$

For temperatures between 790 K and 1500 K:

$$C^0_p\,(\mathrm{cal\ g^{-1}K^{-1}}) = 0.0650063 + 1.39341 \times 10^{-3}\,T - 6.62474 \times 10^{-7}\,T^2 + 1.19713 \times 10^{-10}\,T^3 \qquad (T \text{ in K}) \qquad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.7$\bar{5}$ and 0.03 percent and maximum ones of 2.2 and 0.1$\bar{5}$ 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 Douslin(224) and Eucken and Sarstedt (58) were obtained by means of flow calorimeters covering the temperature range from 333K to 574K. 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:

$$C_p\,(\mathrm{cal\ g^{-1}K^{-1}}) = 0.649840 - 2.81865 \times 10^{-3}\,T + 8.92647 \times 10^{-6}\,T^2 - 6.88679 \times 10^{-9}\,T^3 \qquad (T \text{ in K}) \qquad (3)$$

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 $[(C_p)_3 - (C^0_p)_1]/(C^0_p)_1$.

RECOMMENDED VALUES

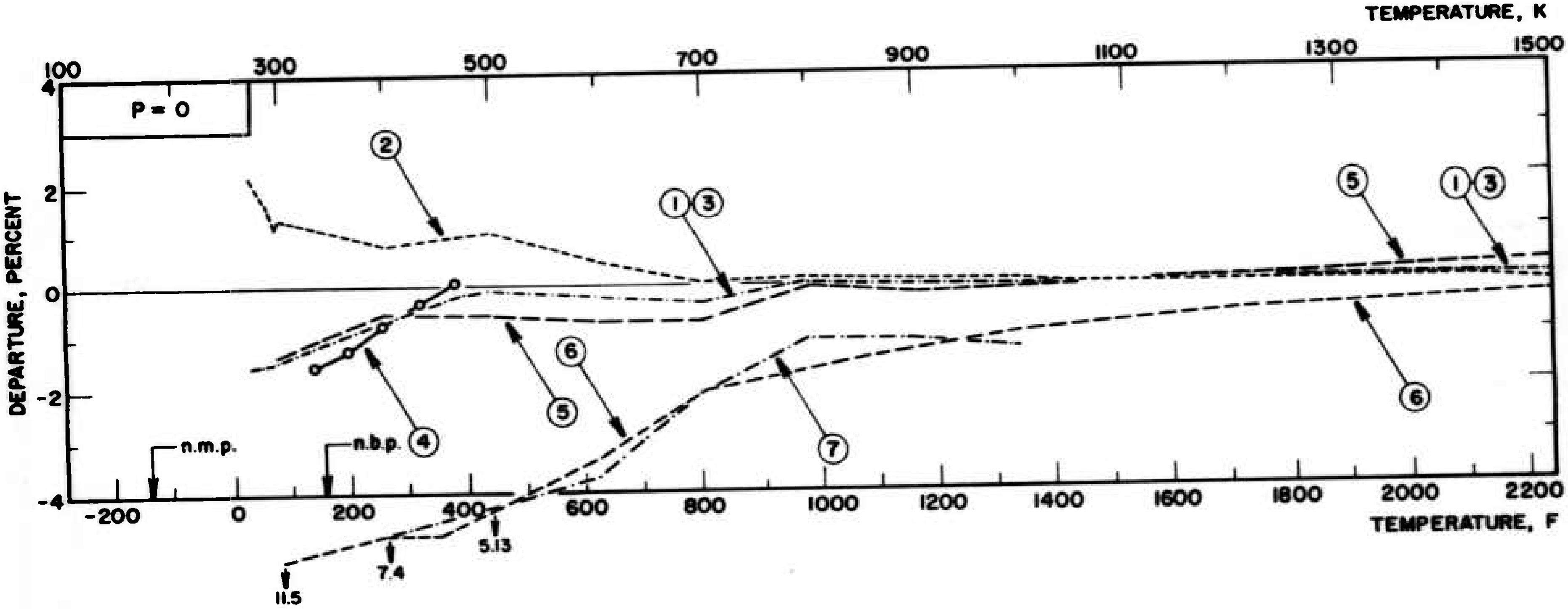
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

GAS

T	C^0_p	T	C^0_p
		600	0.676$\bar{5}$
		620	0.6852
40	0.3802	640	0.6938
60	0.3922	660	0.7023
80	0.4041	680	0.7106
100	0.4159	700	0.7188
120	0.4277	720	0.7268
140	0.4393	740	0.7346
160	0.4509	760	0.7423
180	0.4623	780	0.7499
200	0.4737	800	0.7572
220	0.4849	820	0.7644
240	0.4961	840	0.7714
260	0.5071	860	0.7783
280	0.5180	880	0.78$\bar{5}$0
300	0.5289	900	0.791$\bar{5}$
320	0.5396	920	0.7978
340	0.5502	940	0.8039
360	0.5606	960	0.8099
380	0.5710	980	0.8164
400	0.5812	1000	0.8226
420	0.5913	1100	0.8523
440	0.6013	1200	0.8798
460	0.6112	1300	0.9053
480	0.6209	1400	0.9289
500	0.6305	1500	0.9507
520	0.6400	1600	0.9708
540	0.6493	1700	0.9883
560	0.6585	1800	1.0064
580	0.6676	1900	1.0222
		2000	1.0368

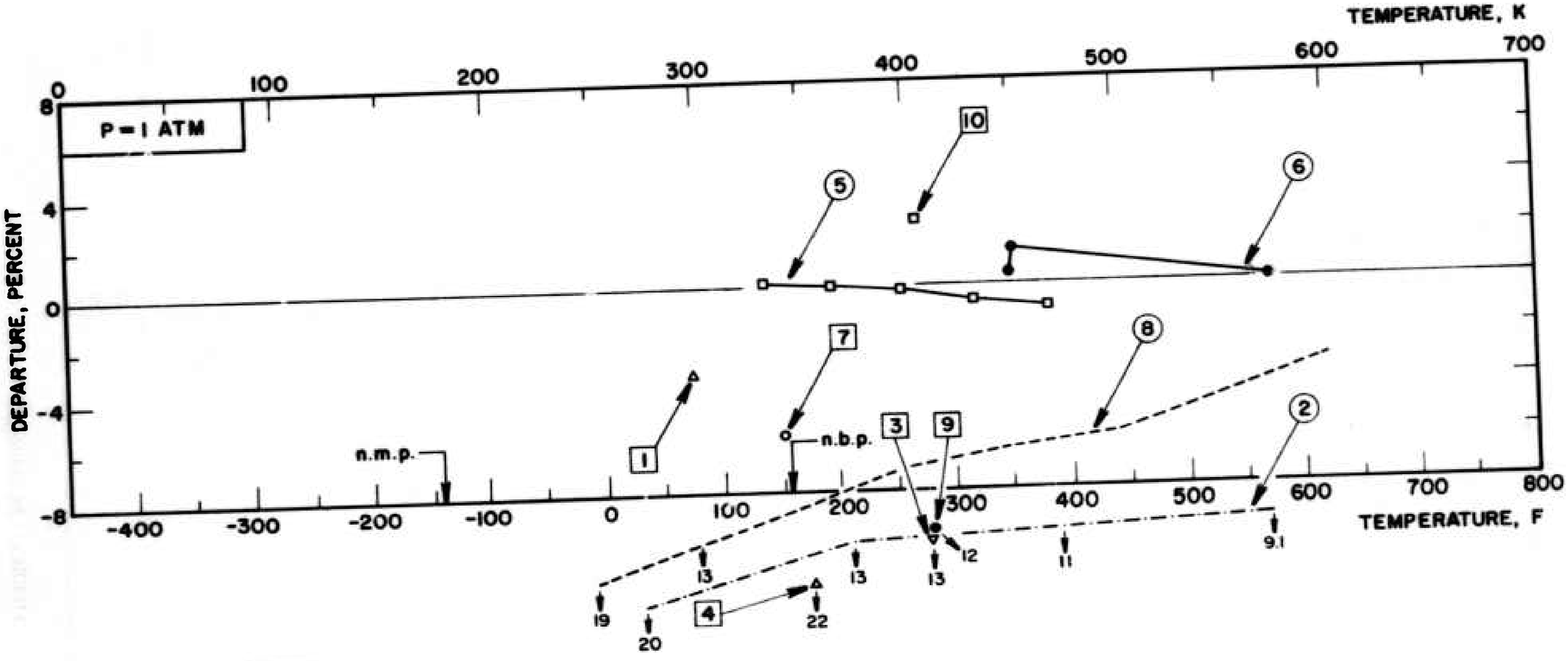
n.b.p. = 156 F

FIGURE 47 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS n-HEXANE



Curve	Reference
1	253
2	109, 161, 164, 167, 171
3	159
4	224
5	133, 134
6	203
7	222

FIGURE 47 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS n-HEXANE



Curve	Reference
1	13
2	14
3	15
4	46
5	224
6	58
7	182
8	202
9	89
10	85

FIGURE 47 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS n-HEXANE

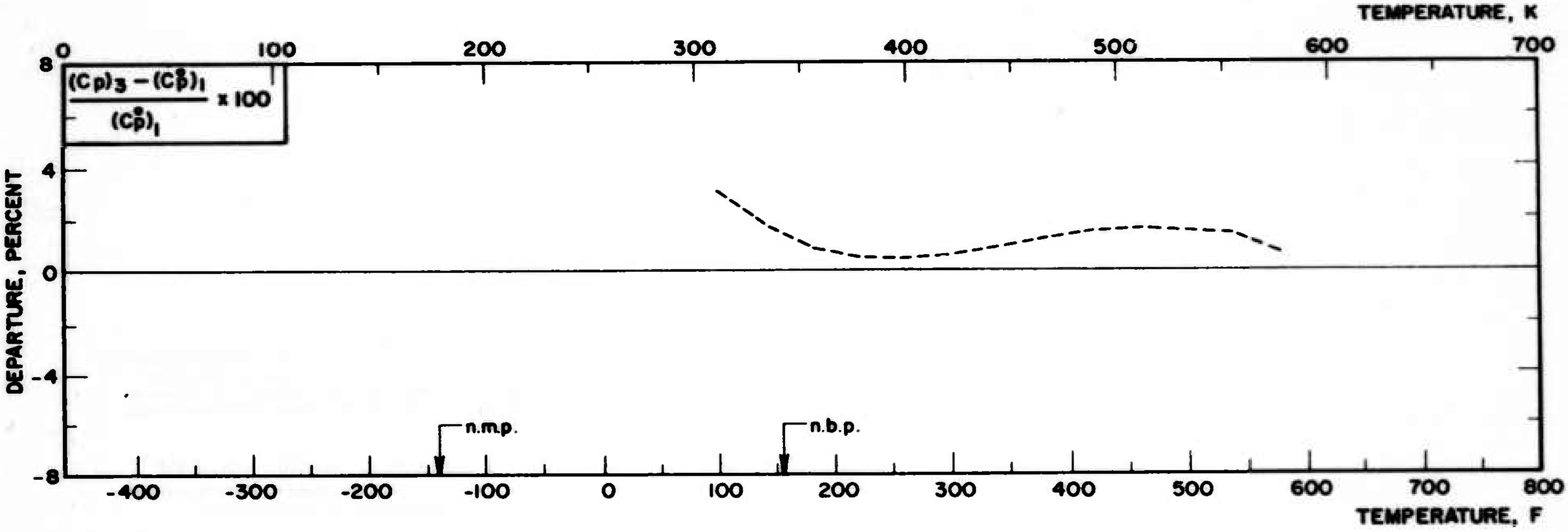


TABLE 48 SPECIFIC HEAT AT CONSTANT PRESSURE OF METHANE

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 Itterbeek 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

$$C_p\,(\text{cal g}^{-1}\,\text{K}^{-1}) = 1.51754 - 1.71493 \times 10^{-2}T + 1.23794 \times 10^{-4}T^2 - 2.34165 \times 10^{-7}T^3 \quad (T \text{ in K}).$$

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 140K are generated using the above formula, and those above 140 K are obtained graphically. The tabulated values should be correct within four percent.

RECOMMENDED VALUES

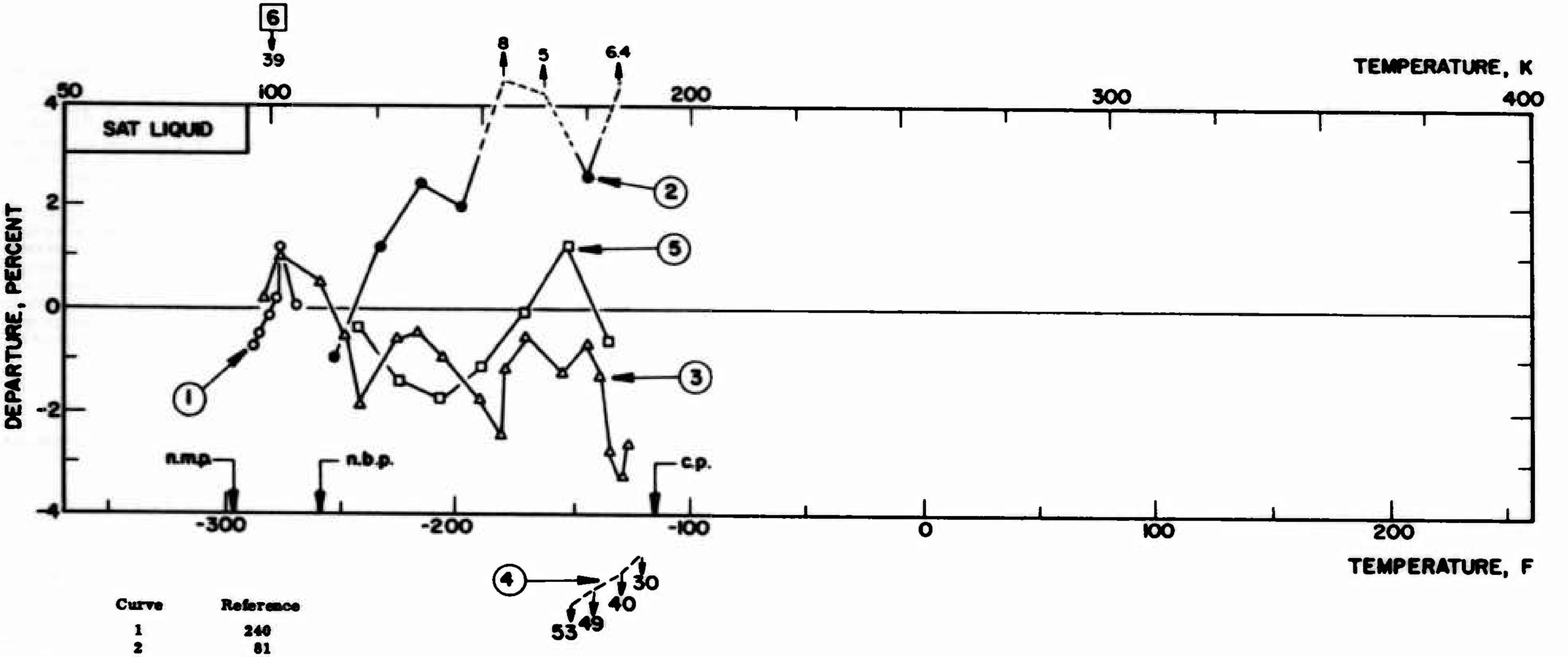
[Temperature, T, F; Specific Heat, C_p, B lb^{-1}F^{-1}]

LIQUID

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

n.m.p. = -297 F
n.b.p. = -258 F

FIGURE 48 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID METHANE



Curve	Reference
1	240
2	81
3	248
4	52
5	259
6	216

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

$$C_p^0\,(\text{cal g}^{-1}\,\text{K}^{-1}) = 0.458066 - 2.61341 \times 10^{-4}\,T + 2.07904 \times 10^{-6}\,T^2 - 1.25017 \times 10^{-9}\,T^3 \qquad (T \text{ in K}). \qquad (1)$$

For temperatures between 790 K and 1500 K

$$C_p^0\,(\text{cal g}^{-1}\,\text{K}^{-1}) = 0.0258866 + 1.60802 \times 10^{-3}\,T - 6.67069 \times 10^{-7}\,T^2 + 1.06432 \times 10^{-10}\,T^3 \qquad (T \text{ in K}). \qquad (2)$$

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:

$$C_p^1\,(\text{cal g}^{-1}\,\text{K}^{-1}) = 0.495585 - 5.25602 \times 10^{-4}\,T + 2.71563 \times 10^{-6}\,T^2 - 1.76417 \times 10^{-9}\,T^3 \qquad (T \text{ in K}). \qquad (3)$$

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.

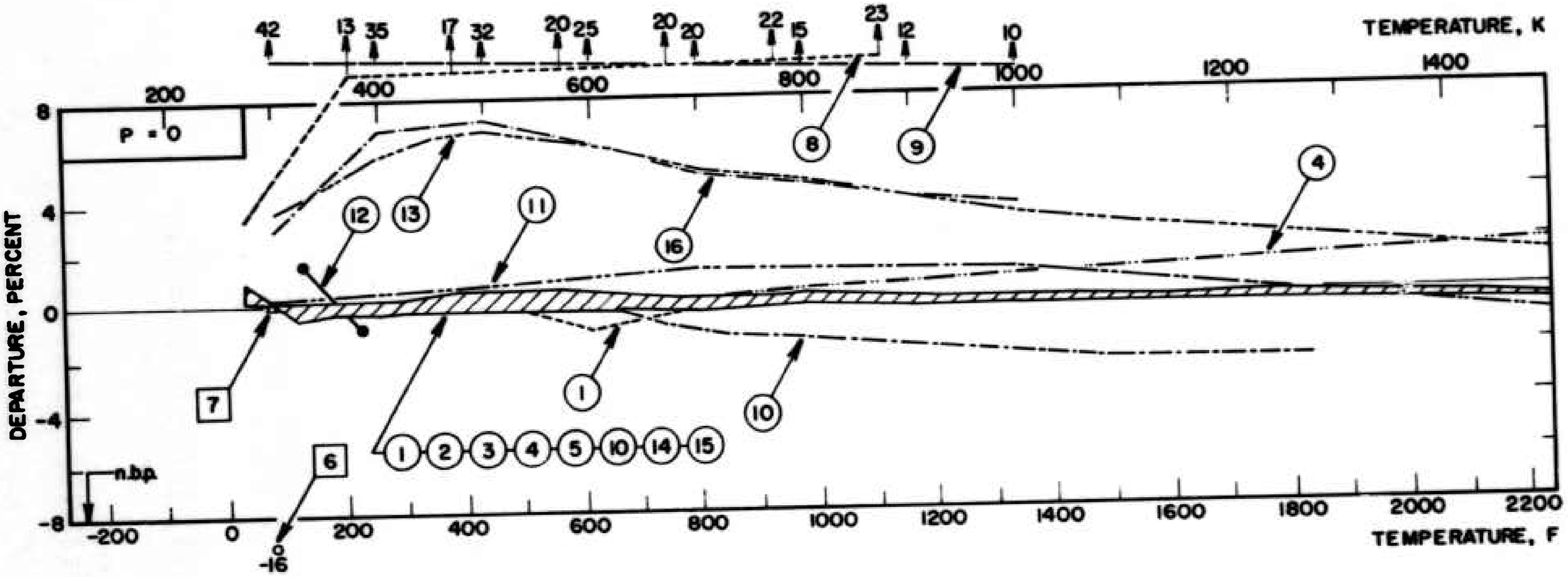
TABLE 48 SPECIFIC HEAT AT CONSTANT PRESSURE OF METHANE (continued)

RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

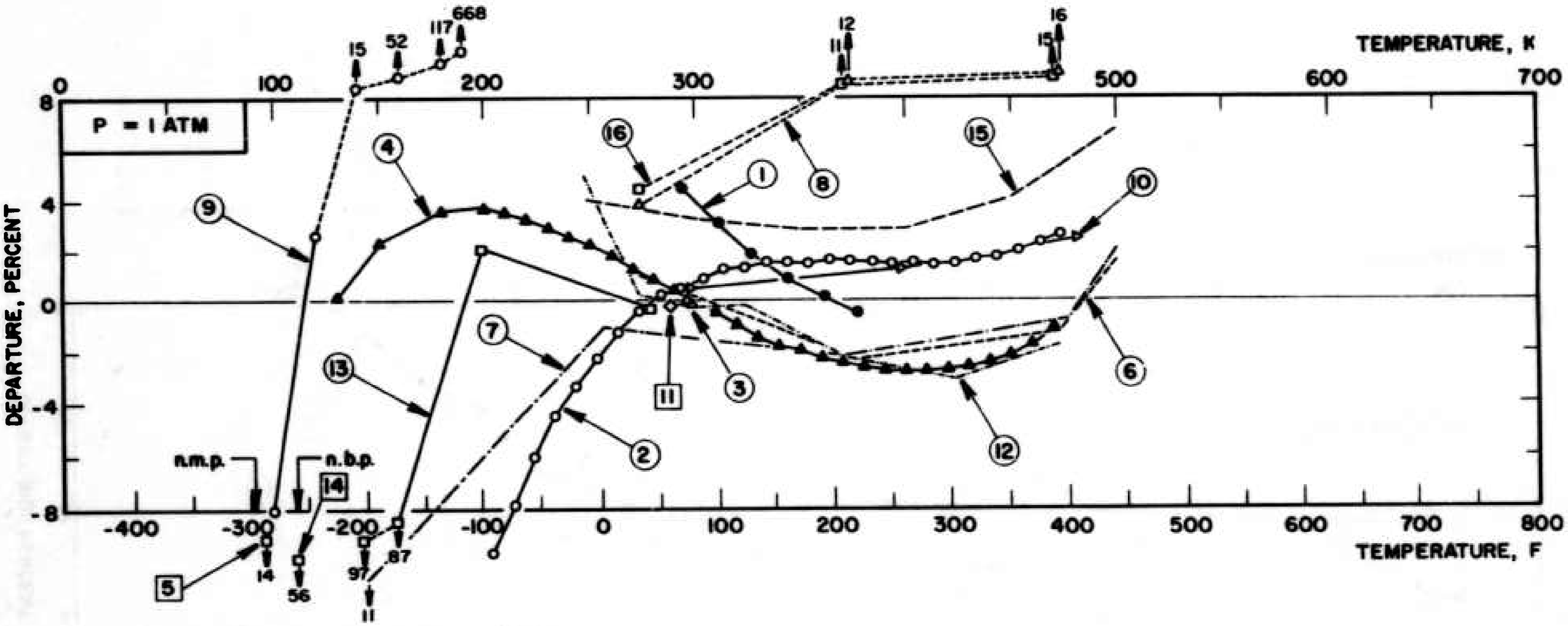
T	C_p^0	C_p^1	T	C_p^0
			600	0.7692
			620	0.7790
40	0.518$\underline{6}$	0.521	640	0.7888
60	0.525$\overline{5}$	0.527	660	0.7985
80	0.5326	0.534	680	0.8082
100	0.5399	0.541	700	0.8178
120	0.5474	0.549	720	0.8273
140	0.5552	0.556	740	0.8367
160	0.5631	0.564	760	0.8460
180	0.5713	0.572	780	0.8553
200	0.5796	0.580	800	0.8643
220	0.5881	0.589	820	0.8733
240	0.5968	0.598	840	0.8821
260	0.6056	0.606	860	0.8907
280	0.6146	0.615	880	0.8992
300	0.6237	0.624	900	0.9075
320	0.6329	0.634	920	0.9156
340	0.6423	0.643	940	0.9235
360	0.6517	0.652	960	0.9313
380	0.6612	0.662	980	0.9391
400	0.6708	0.671	1000	0.9473
420	0.6805	0.681	1100	0.9870
440	0.6903	0.691	1200	1.0242
460	0.7001	0.700	1300	1.0591
480	0.7099		1400	1.0918
500	0.7198		1500	1.122$\overline{5}$
520	0.7297		1600	1.1512
540	0.7395		1700	1.1780
560	0.7494		1800	1.203$\underline{1}$
580	0.7593		1900	1.226$\overline{5}$
			2000	1.2484

FIGURE 48 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, 161, 167, 226	12	178
3	72, 171, 254	13	202
4	137	14	213
5	253	15	220
6	18	16	222
7	20		
8	24		
9	93		
10	100		

FIGURE 48 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUSMETHANE



Curve	Reference	Curve	Reference
1	27	11	78
2	51, 52	12	125
3	85	13	142
4	252	14	182
5	13	15	203
6	14	16	241
7	32, 83		
8	46		
9	54		
10	56		

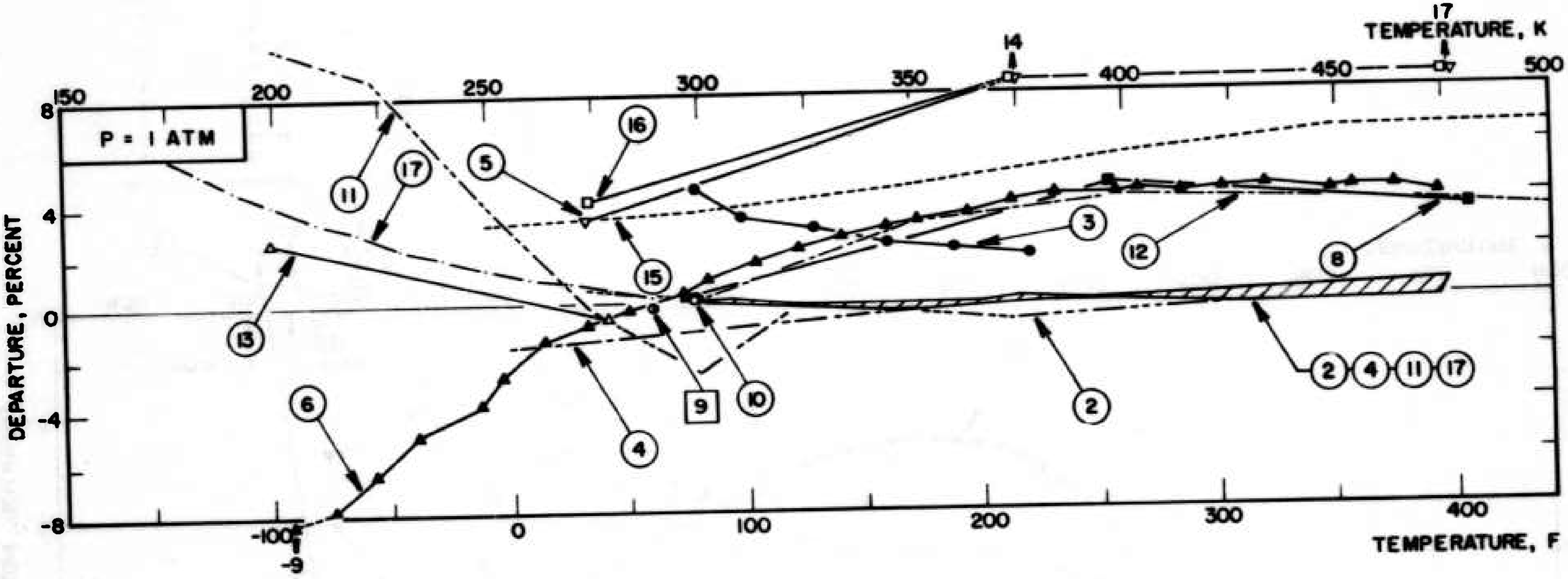


FIGURE 48 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS METHANE (continued)

Curve	Reference	Curve	Reference
1	13	10	85
2	14	11	125
3	27	12	132
4	32	13	142
5	46	14	182
6	51	15	203
7	54	16	241
8	56	17	252
9	78		

FIGURE 48 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS METHANE

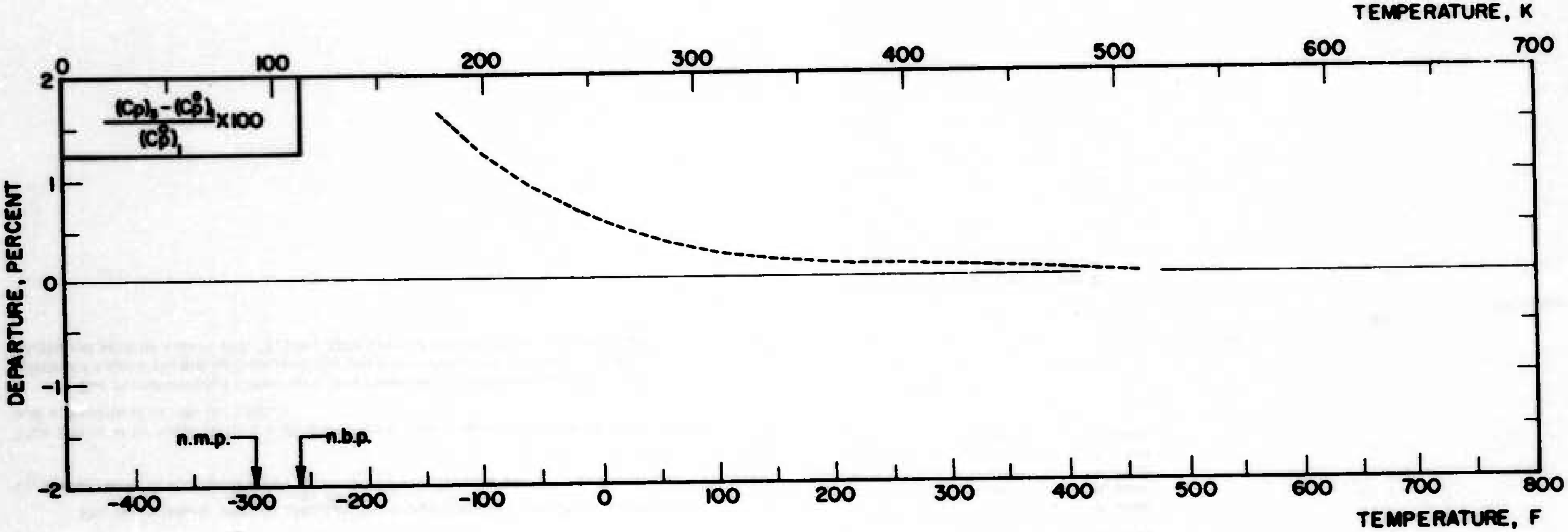


TABLE 49 SPECIFIC HEAT AT CONSTANT PRESSURE OF METHYL ALCOHOL

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 Fiock 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

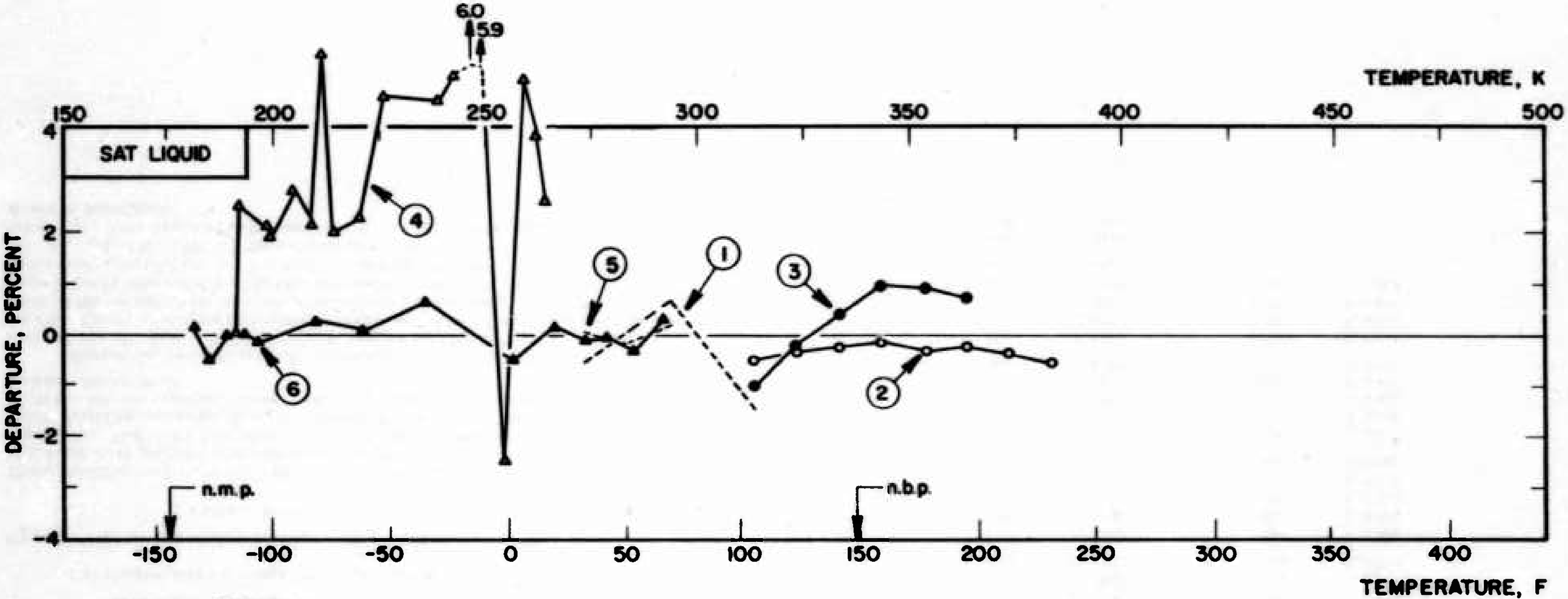
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

LIQUID

T	C_p	T	C_p
		100	0.6223
		120	0.6418
		140	0.6634
-140	0.5220	160	0.6871††
-120	0.5229	180	0.7132††
-100	0.5248	200	0.7417††
-80	0.5279	220	0.7726††
-60	0.5323	240	0.8062††
-40	0.5379		
-20	0.5450		
0	0.5536		
20	0.5638		
40	0.5757		
60	0.5893		
80	0.6048		

$\dagger\dagger$: n.b.p. = 148 F

FIGURE 49 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID METHYL ALCOHOL



Curve	Reference
1	36
2	62
3	84
4	143
5	198
6	243

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:

$$C_p^{\circ}\,(\text{cal g}^{-1}\text{K}^{-1}) = 0.189431 + 3.61729 \times 10^{-4}\,T + 5.4082\bar{5} \times 10^{-7}\,T^2 - 4.43004 \times 10^{-10}\,T^3 \qquad (1)$$

For temperatures between 785 K and 1000 K

$$C_p^{\circ}\,(\text{cal g}^{-1}\text{K}^{-1}) = 0.376893 - 9.77068 \times 10^{6}\,T + 5.70656 \times 10^{-7}\,T^2 - 2.65182 \times 10^{-10}\,T^3 \qquad (T \text{ in K}) \qquad (2)$$

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

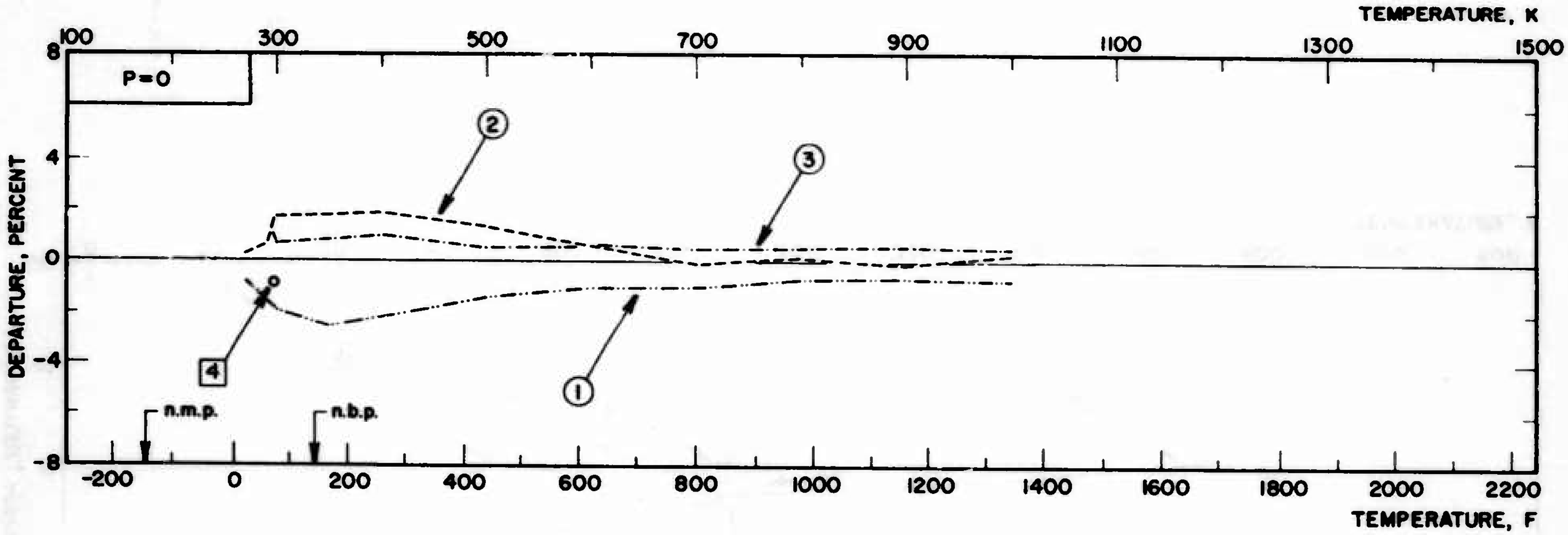
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

GAS

T	C_p°	T	C_p°
		600	0.4991
		620	0.5051
40	0.3218	640	0.5109
60	0.3281	660	0.5167
80	0.3343	680	0.522$\bar{5}$
100	0.3406	700	0.5281
120	0.3470	720	0.5337
140	0.3534	740	0.5392
160	0.3597	760	0.5447
180	0.3662	780	0.5500
200	0.3726	800	0.5552
220	0.3790	820	0.5604
240	0.385$\bar{5}$	840	0.5654
260	0.3919	860	0.5704
280	0.3984	880	0.5752
300	0.4049	900	0.5799
320	0.4113	920	0.5846
340	0.4178	940	0.5890
360	0.4242	960	0.5937
380	0.4306	980	0.5981
400	0.4370	1000	0.6024
420	0.4434	1100	0.6239
440	0.4497	1200	0.6447
460	0.4560	1300	0.6645
480	0.4623		
500	0.4686		
520	0.4748		
540	0.4809		
560	0.4870		
580	0.4931		

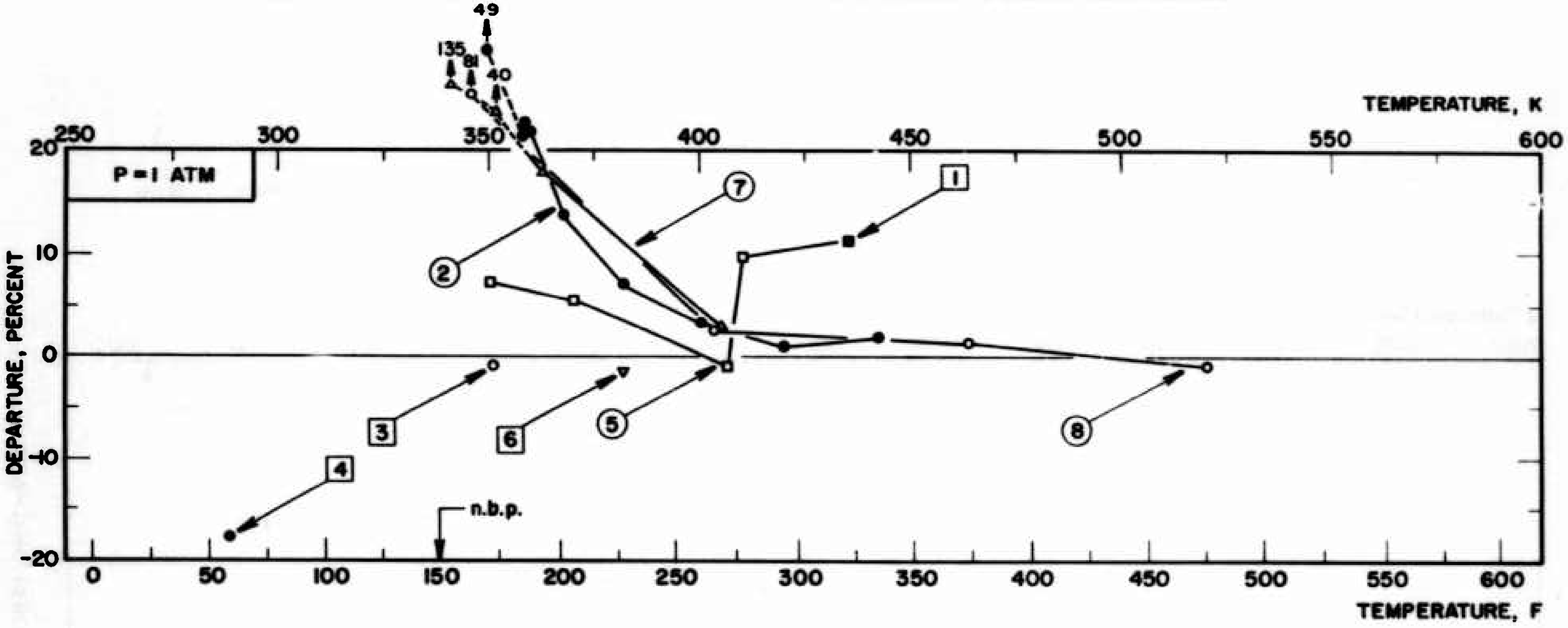
n.b.p. = 148 F

FIGURE 49 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS METHYL ALCOHOL



Curve	Reference
1	88
2	114
3	193
4	18

FIGURE 49 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS METHYL ALCOHOL



Curve	Reference
1	15
2	45
3	46
4	78
5	90
6	144
7	191
8	229

TABLE 50 SPECIFIC HEAT AT CONSTANT PRESSURE OF METHYL CHLORIDE

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.

RECOMMENDED VALUES

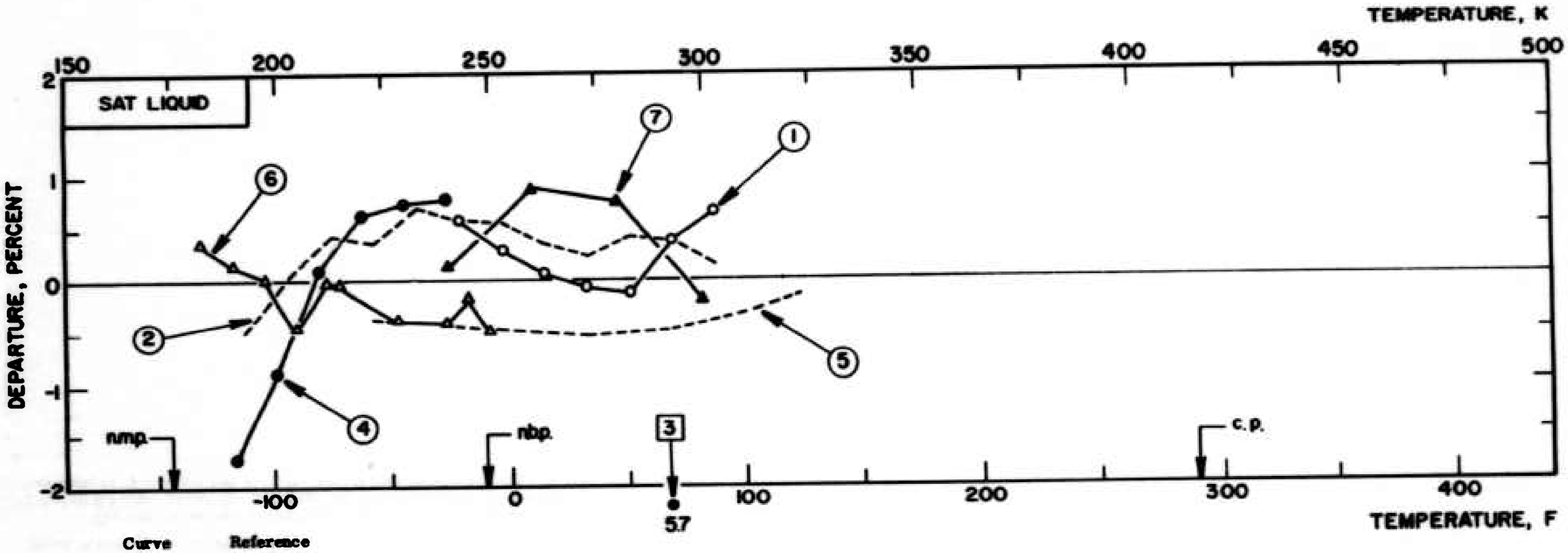
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

LIQUID

T	C_p
-140	0.352
-120	0.3515
-100	$0.351\bar{5}$
-80	0.3521
-60	0.3533
-40	0.3553
-20	0.3580
0	$0.361\bar{5}$
20	0.3659
40	0.3712
60	$0.377\bar{5}$
80	0.3848
100	0.3931
120	0.4026
140	0.413

n.b.p. = -11 F

FIGURE 50 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID METHYL CHLORIDE



Curve	Reference
1	10
2	10*
3	36
4	52
5	249
6	138
7	206

* Smoothed values

TABLE 50 SPECIFIC HEAT AT CONSTANT PRESSURE OF METHYL CHLORIDE (continued)

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:

$$C_p^0\ (\mathrm{cal\ g^{-1}\ K^{-1}}) = 7.95197 \times 10^{-2} + 3.91691 \times 10^{-4}T - 1.07495 \times 10^{-8}T^2 - 9.51899 \times 10^{-11}T^3 \quad (T \text{ in K}).$$

and for temperatures between 782 K and 1500 K:

$$C_p^0\ (\mathrm{cal\ g^{-1}\ K^{-1}}) = 7.14539 \times 10^{-2} + 4.84503 \times 10^{-4}T - 2.2068\bar{5} \times 10^{-7}T^2 + 3.82628 \times 10^{-11}T^3 \quad (T \text{ in K}).$$

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.

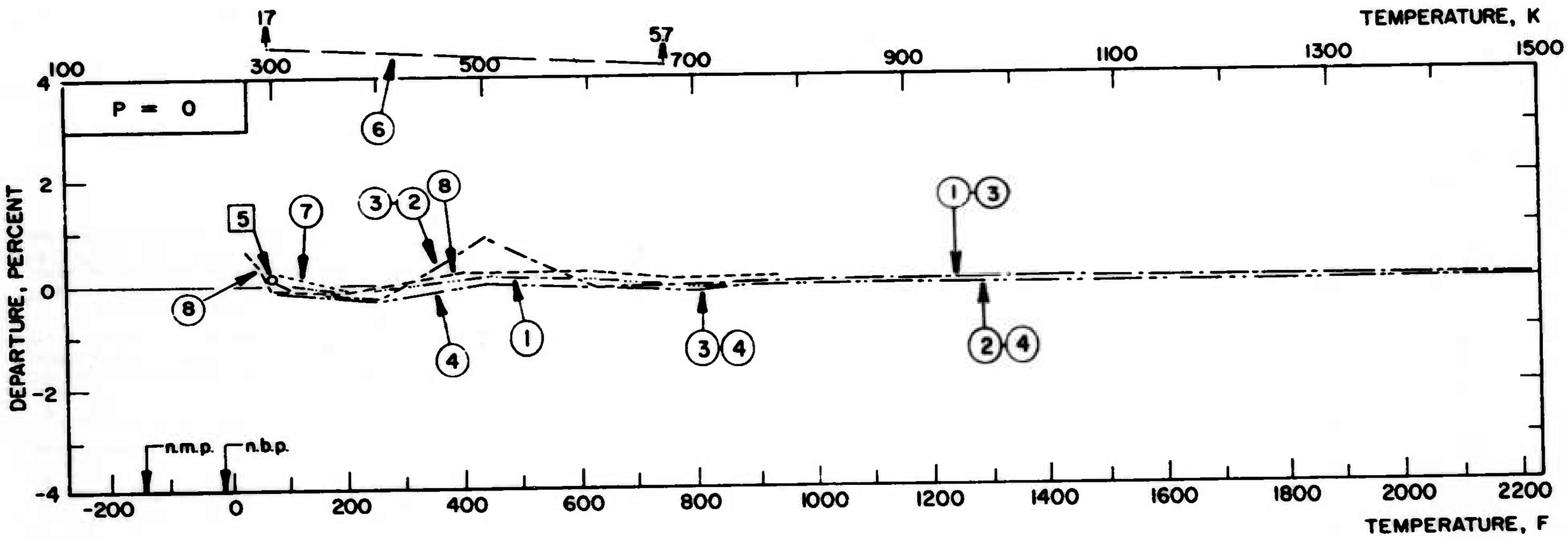
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

GAS

T	C_p^0	T	C_p^0
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	$0.386\bar{5}$
520	0.2740	1600	0.3940
540	0.2773	1700	0.4009
560	$0.280\bar{5}$	1800	0.4073
580	0.2836	1900	0.4133
		2000	0.4188

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 Ginnings (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:

$$C_p(\text{cal g}^{-1}\text{K}^{-1}) = 0.970146 - 5.32528 \times 10^{-3}T + 1.80857 \times 10^{-5}T^2 - 1.7375\bar{5} \times 10^{-8}T^3 \quad (T \text{ in K}).$$

This equation is found to fit the above enumerated data points with a mean deviation of 0.05 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.

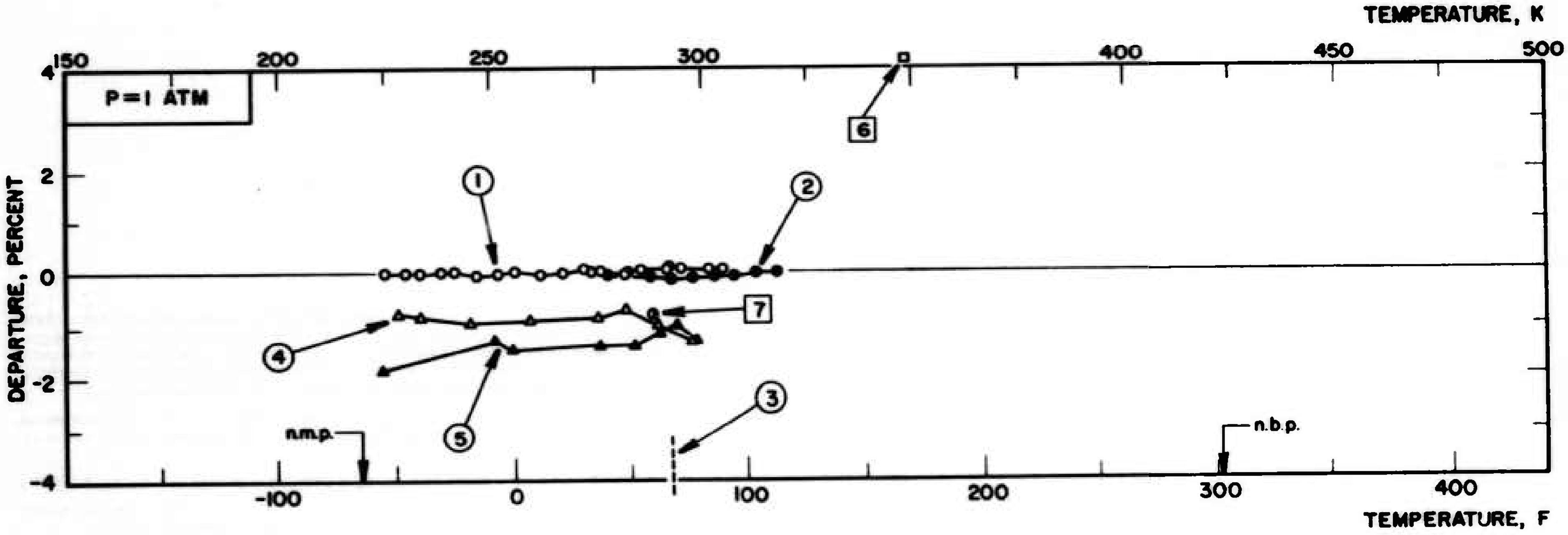
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

LIQUID

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	0.560$\bar{5}$
160	0.5710
180	0.5815
200	0.5920

FIGURE 51 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID n-NONANE



Curve	Reference
1	61
2	149
3	36
4	87
5	153
6	257
7	78

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:

$$C_p^\circ\ (\text{cal g}^{-1}\text{K}^{-1}) = \overset{0.0558798}{\cancel{\text{[illegible]}}} + 1.22834 \times 10^{-3}\,T - 1.64406 \times 10^{-7}\,T^2 - 2.46534 \times 10^{-10}\,T^3 \qquad (1)$$

For temperatures between 780 K and 1500 K:

$$C_p^\circ\ (\text{cal g}^{-1}\text{K}^{-1}) = 0.0721002 + 1.36989 \times 10^{-3}\,T - 6.58734 \times 10^{-7}\,T^2 + 1.20639 \times 10^{-10}\,T^3 \qquad (T\ \text{in K}) \qquad (2)$$

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 atm.

RECOMMENDED VALUES

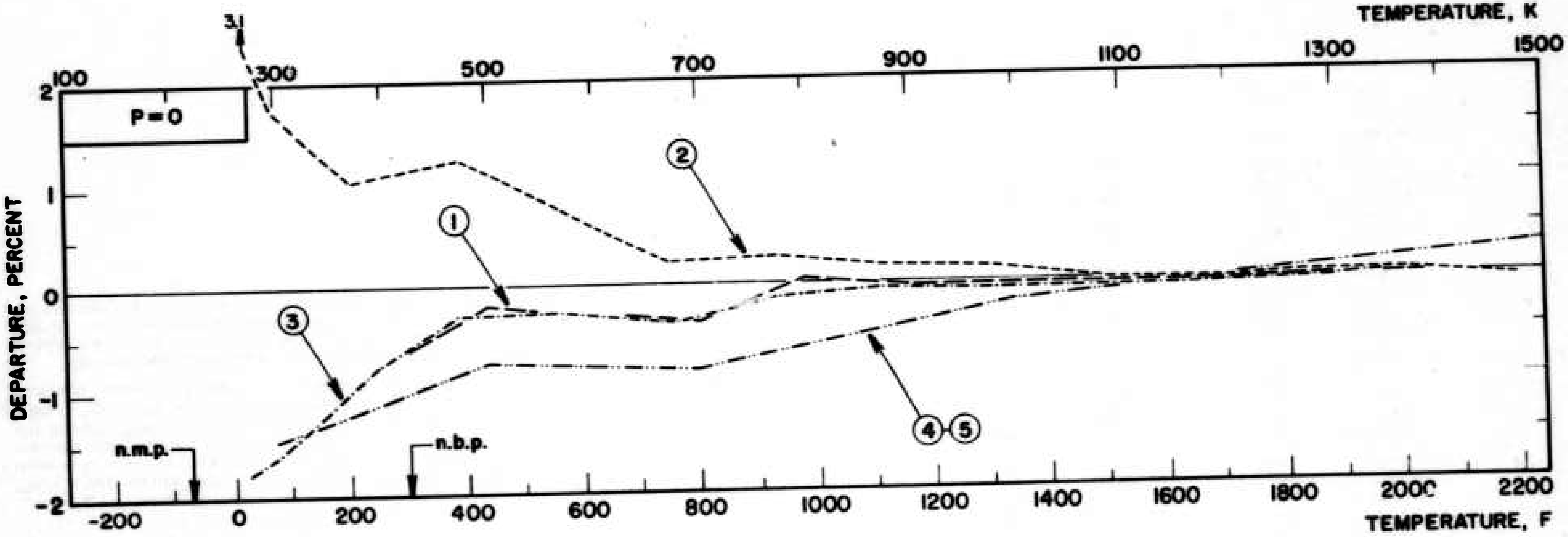
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

GAS

T	C_p°	T	C_p°
		600	0.6713
		620	0.6799
40	0.3787	640	0.6883
60	0.3906	660	0.6966
80	0.4025	680	0.7047
100	0.4142	700	0.7126
120	0.4259	720	0.7204
140	0.4375	740	0.7281
160	0.4489	760	0.7355
180	0.4603	780	0.7429
200	0.4715	800	0.7500
220	0.4827	820	0.7570
240	0.4937	840	0.7638
260	0.5046	860	0.7704
280	0.5154	880	0.7769
300	0.5261	900	0.7832
320	0.5367	920	0.7893
340	0.5472	940	0.7952
360	0.5575	960	0.8014
380	0.5677	980	0.8076
400	0.5778	1000	0.8136
420	0.5878	1100	0.8424
440	0.5976	1200	0.8692
460	0.6073	1300	0.8939
480	0.6168	1400	0.9167
500	0.6263	1500	0.9378
520	0.6356	1600	0.9572
540	0.6447	1700	0.9752
560	0.6537	1800	0.9917
580	0.6626	1900	1.0070
		2000	1.0211

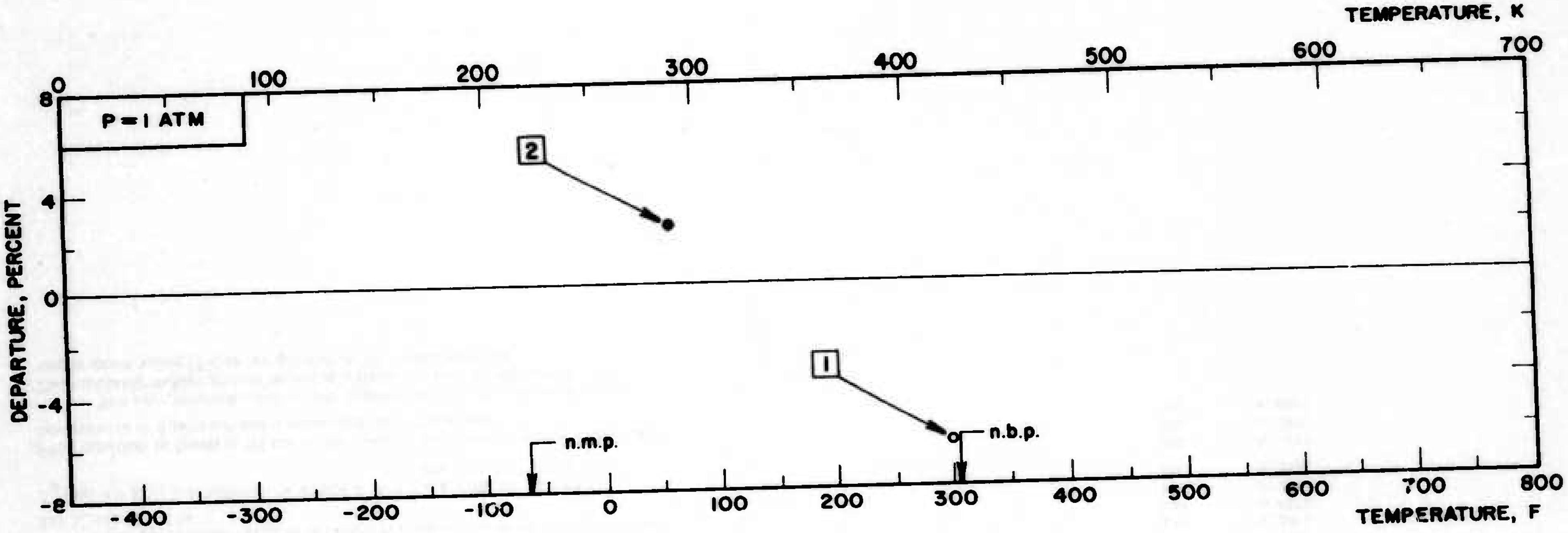
n.b.p. = 303 F

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



Curve	Reference
1	182
2	78

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 Finke 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

$$C_p\,(\text{cal g}^{-1}\,\text{K}^{-1}) = 0.526048 - 9.57018 \times 10^{-4}T + 4.07363 \times 10^{-6}T^2 - 2.74978 \times 10^{-9}T^3 \quad (T \text{ in K}).$$

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.

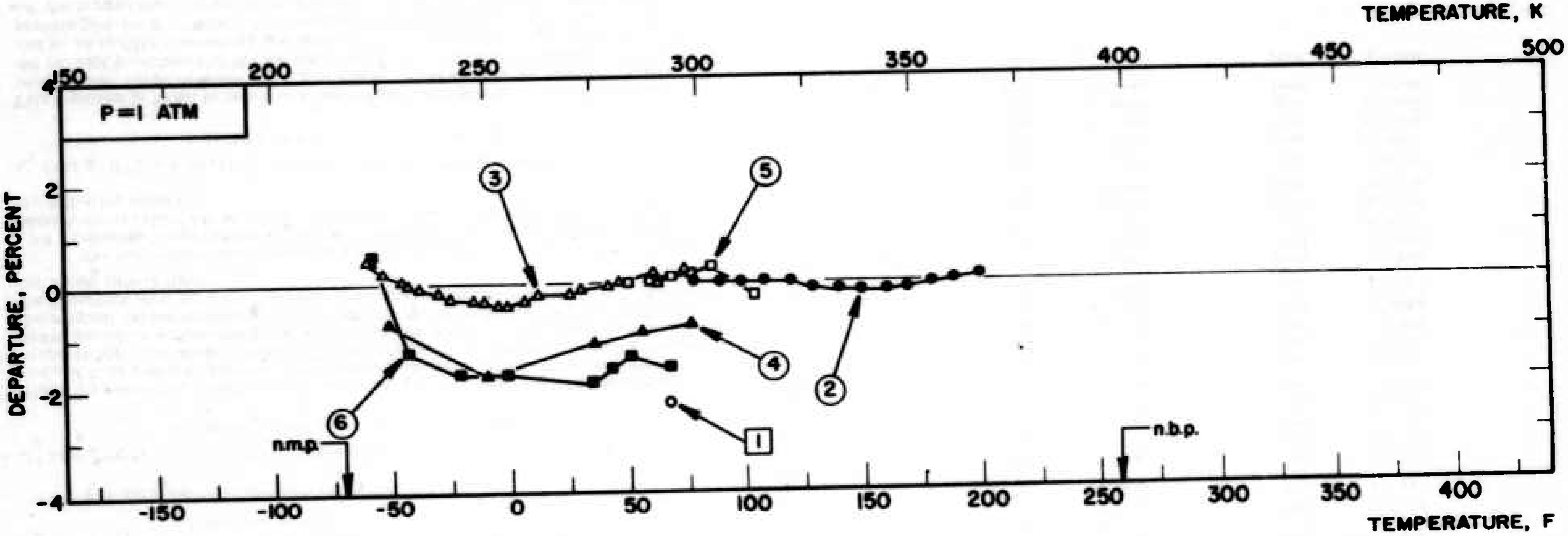
RECOMMENDED VALUES

[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



Curve	Reference
1	36
2	39
3	61
4	87
5	149
6	153

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:

$$C_p^{\circ}\,(\mathrm{cal\ g^{-1}K^{-1}}) = 0.05110\bar{5}0 + 1.28099 \times 10^{-3}\,T - 2.81774 \times 10^{-7}\,T^2 - 1.66703 \times 10^{-10}\,T^3 \qquad (1)$$

For temperatures between 780 K and 1500 K:

$$C_p^{\circ}\,(\mathrm{cal\ g^{-1}K^{-1}}) = 0.0873567 + 1.33119 \times 10^{-3}\,T - 6.20477 \times 10^{-7}\,T^2 + 1.08914 \times 10^{-10}\,T^3 \qquad (T\ \mathrm{in\ K}) \qquad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.88 and 0.0$\bar{5}$ 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:

$$C_p\,(\mathrm{cal\ g^{-1}K^{-1}}) = 0.361819 - 1.10474 \times 10^{-3}\,T + 5.77902 \times 10^{-6}\,T^2 - 5.21314 \times 10^{-9}\,T^3 \qquad (T\ \mathrm{in\ K}) \qquad (3)$$

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

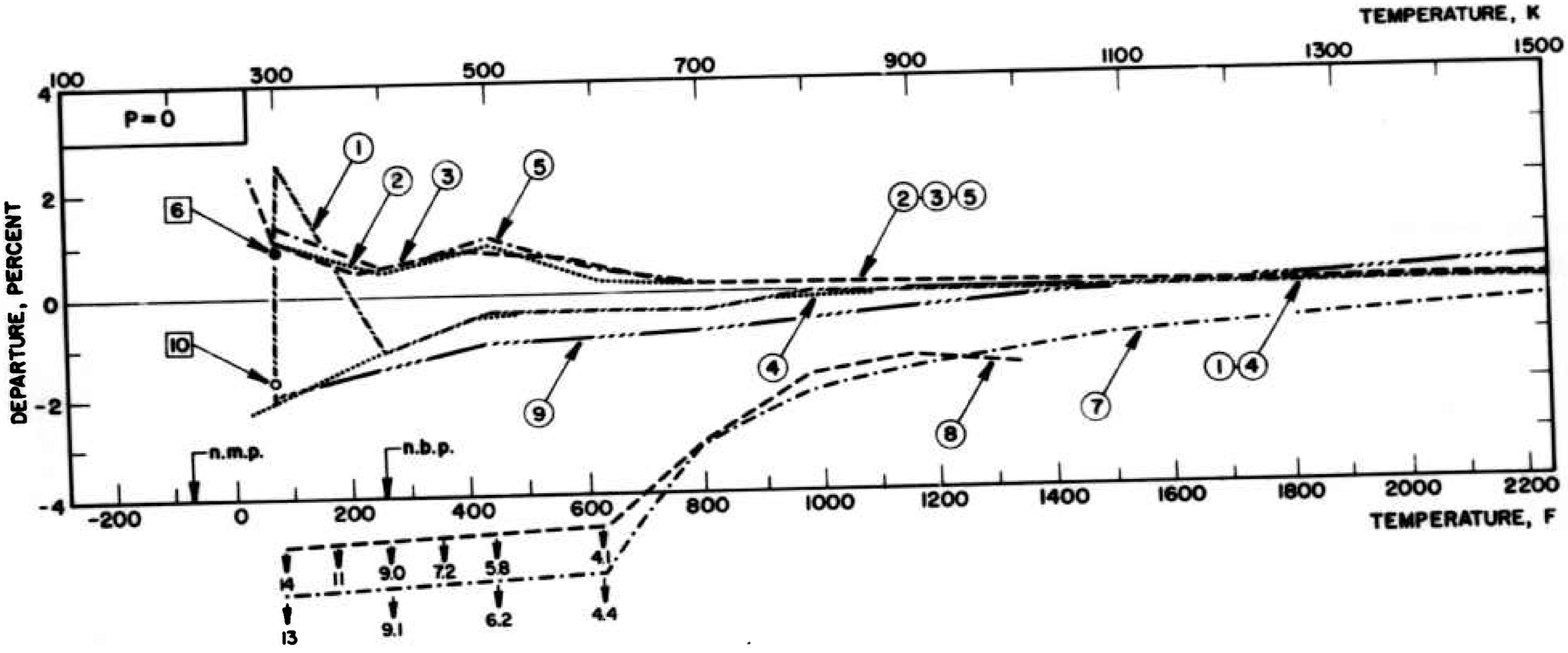
[Temperature, T, F; Specific Heat, C_p, B lb^{-1}F^{-1}]

GAS

T	C_p°	T	C_p°
		600	0.6731
		620	0.6817
40	0.3812	640	0.6901
60	0.3932	660	0.6983
80	0.4051	680	0.7064
100	0.4169	700	0.7144
120	0.4286	720	0.7222
140	0.4401	740	0.7299
160	0.4516	760	0.7374
180	0.4630	780	0.7447
200	0.4742	800	0.7519
220	0.4853	820	0.7590
240	0.4963	840	0.7659
260	0.5072	860	0.7726
280	0.5180	880	0.7792
300	0.5287	900	0.7856
320	0.5392	920	0.7918
340	0.5496	940	0.7979
360	0.5599	960	0.8042
380	0.5701	980	0.8103
400	0.5801	1000	0.8164
420	0.5900	1100	0.8453
440	0.5998	1200	0.8721
460	0.6094	1300	0.8969
480	0.6189	1400	0.9199
500	0.6283	1500	0.9411
520	0.6375	1600	0.9607
540	0.6466	1700	0.9788
560	0.6556	1800	0.995$\bar{5}$
580	0.6644	1900	1.0109
		2000	1.0250

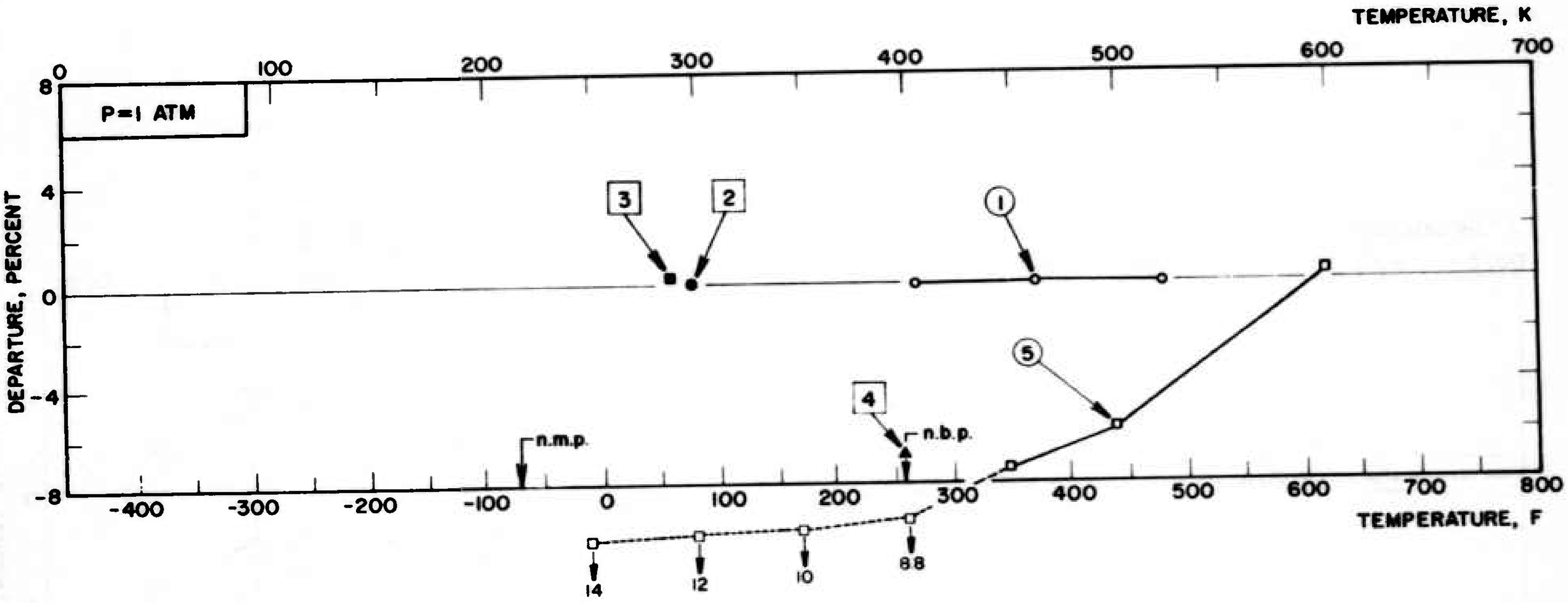
n.b.p. = 258 F

FIGURE 52 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS n-OCTANE



Curve	Reference	Curve	Reference
1	159	6	13
2	161	7	202
3	171	8	222
4	253	9	133, 134
5	167	10	18

FIGURE 52 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS n-OCTANE



Curve	Reference
1	12
2	13
3	78
4	182
5	203

FIGURE 52 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS n-OCTANE

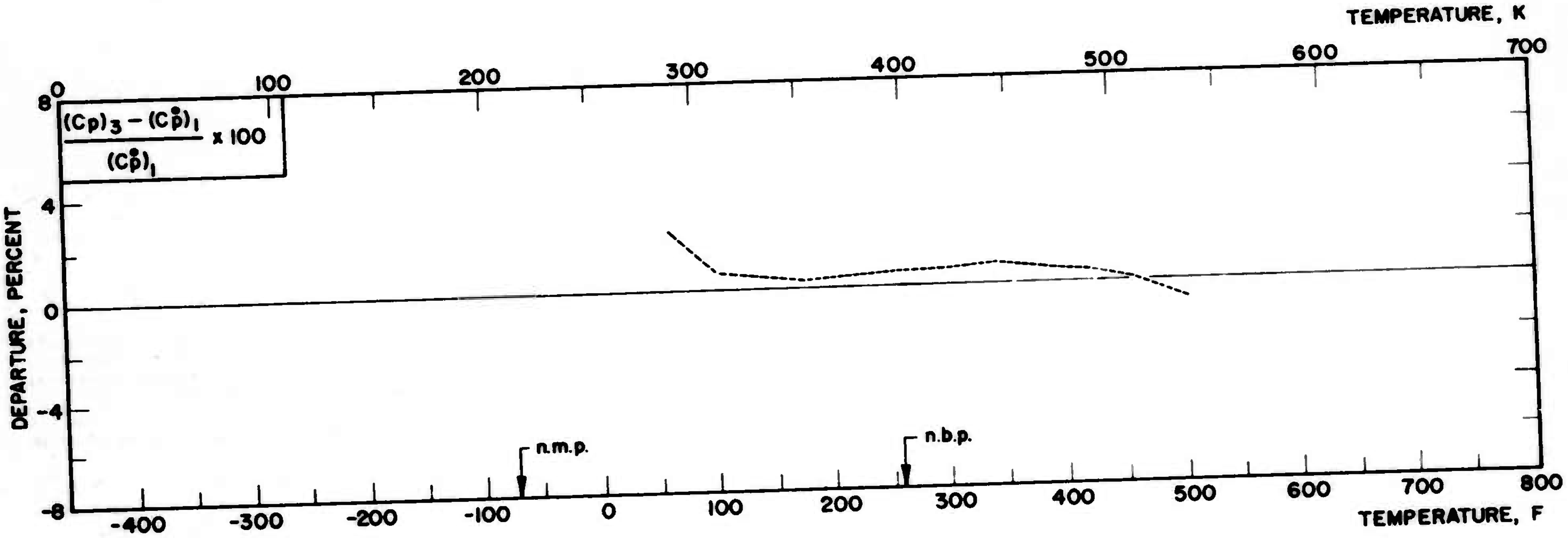


TABLE 53 SPECIFIC HEAT AT CONSTANT PRESSURE OF n-PENTANE

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

$$C_p(\text{cal g}^{-1}\text{ K}^{-1}) = 0.463639 + 1.23858 \times 10^{-4}T - 2.17509 \times 10^{-6}T^2 + 9.5702\bar{5} \times 10^{-9}T^3 \quad (T \text{ in K}).$$

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}]

LIQUID

T	C_p
-200	0.4647
-180	0.4660
-160	0.4678
-140	0.4703
-120	0.4736
-100	0.4776
- 80	$0.482\bar{5}$
- 60	0.4884
- 40	0.4952
- 20	0.5033
0	$0.512\bar{5}$
20	0.5229
40	$0.53\bar{5}$
60	0.548
80	0.563
100	0.579‡
120	0.597‡
140	0.617‡
160	0.639‡
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

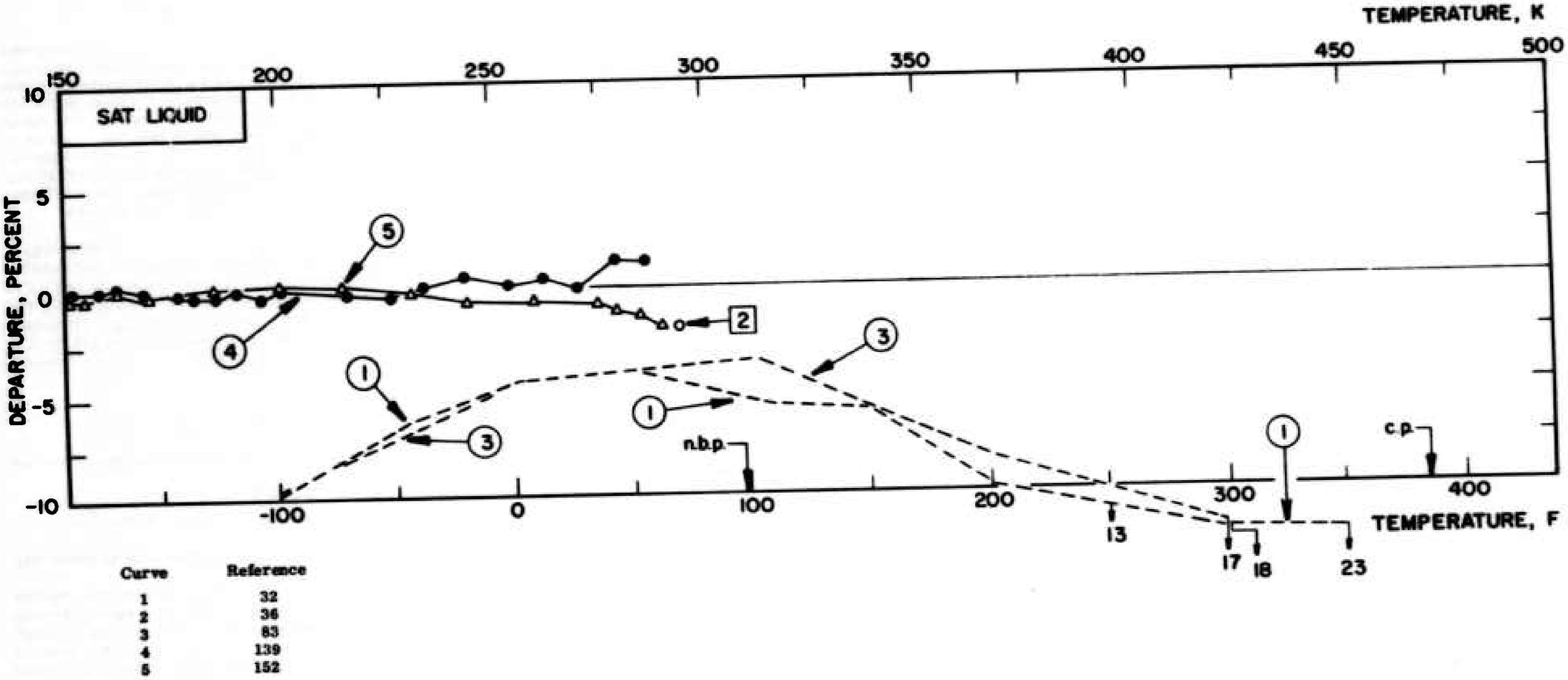


TABLE 53 SPECIFIC HEAT AT CONSTANT PRESSURE OF n-PENTANE

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), Maslov (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

$$C_p^{\,0}\,(\mathrm{cal\ g^{-1}\ K^{-1}}) = 0.0651968 + 1.16432 \times 10^{-3}\,T - 1.53714 \times 10^{-6}\,T^2 - 3.22752 \times 10^{-10}\,T^3 \qquad (T \text{ in K}), \qquad (1)$$

For temperatures between 780 K and 1500 K

$$C_p^{\,0}\,(\mathrm{cal\ g^{-1}\ K^{-1}}) = 0.0635648 + 1.40263 \times 10^{-3}\,T - 6.63570 \times 10^{-7}\,T^2 + 1.19788 \times 10^{-10}\,T^3 \qquad (T \text{ in K}). \qquad (2)$$

These equations are found to fit the above enumerated values with mean deviations of 0.63 and 0.03 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 substanitally 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:

$$C_p^{\,1}\,(\mathrm{cal\ g^{-1}\ K^{-1}}) = 0.147363 + 7.02528 \times 10^{-4}\,T + 8.79322 \times 10^{-7}\,T^2 - 9.07666 \times 10^{-10}\,T^3 \qquad (T \text{ in K}). \qquad (3)$$

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)

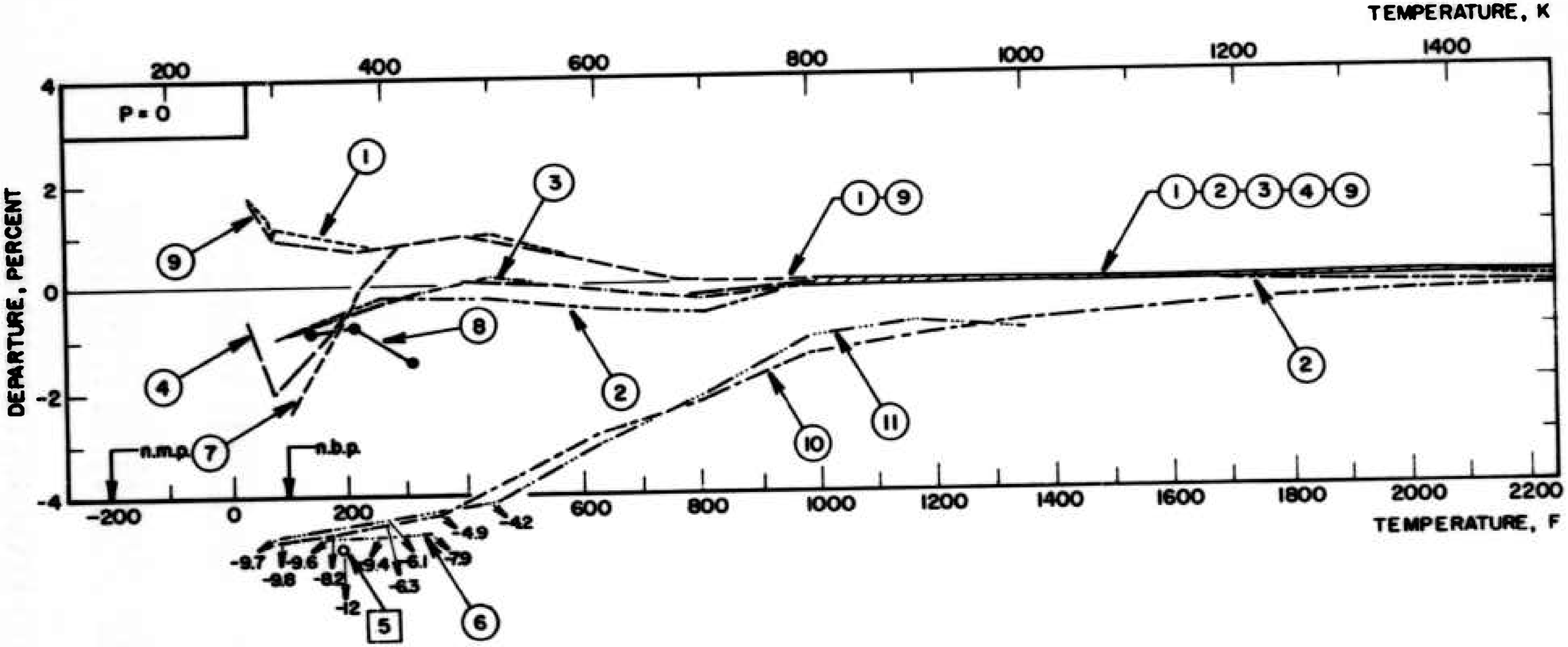
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

T	C_p^0	C_p^l	T	C_p^0	C_p^l
			600	0.6790	0.680
			620	0.6879	0.689
40	0.3801	0.390	640	0.6967	0.697
60	0.3920	0.401	660	0.7054	
80	0.4039	0.412	680	0.7138	
100	0.4158	0.423	700	0.7222	
120	0.4275	0.434	720	0.7303	
140	0.4392	0.445	740	0.7383	
160	0.4507	0.456	760	0.7462	
180	0.4622	0.467	780	0.7539	
200	0.4736	0.478	800	0.7614	
220	0.4849	0.489	820	0.7687	
240	0.4962	0.500	840	0.7759	
260	0.5073	0.510	860	0.7829	
280	0.5183	0.521	880	0.7897	
300	0.5292	0.532	900	0.7963	
320	0.5401	0.543	920	0.8027	
340	0.5508	0.553	940	0.8090	
360	0.5614	0.564	960	0.8153	
380	0.5718	0.574	980	0.8217	
400	$0.582\underline{2}$	0.584	1000	0.8280	
420	$0.592\overline{5}$	0.594	1100	0.8581	
440	0.6026	0.604	1200	0.8860	
460	0.6126	0.614	1300	0.9119	
480	0.6225	0.624	1400	0.9359	
500	0.6323	0.634	1500	0.9580	
520	0.6419	0.643	1600	$0.978\underline{5}$	
540	0.6514	0.653	1700	$0.997\overline{5}$	
560	0.6607	0.662	1800	$1.01\overline{5}0$	
580	0.6699	0.671	1900	1.0311	
			2000	1.0461	

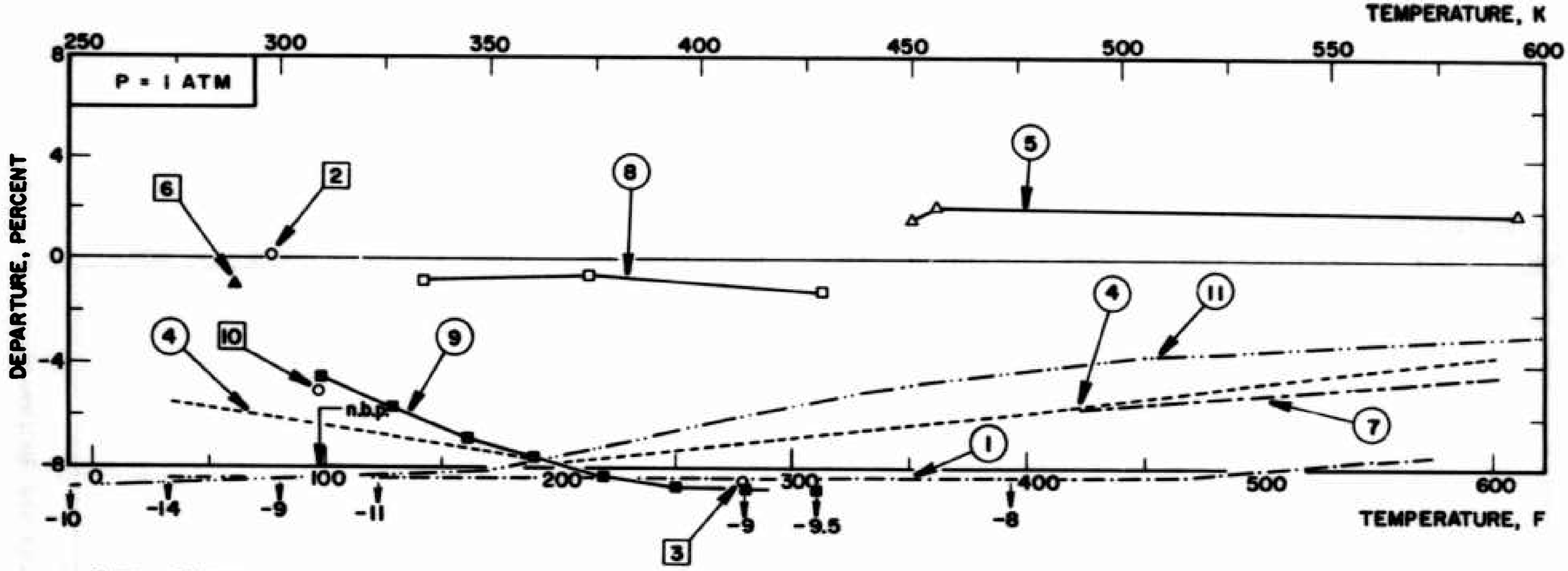
n.b.p. = 97 F

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



Curve	Reference
1	6
2	13
3	15
4	32
5	58
6	78
7	83
8	163
9	178
10	182
11	203

FIGURE 53 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS n-PENTANE

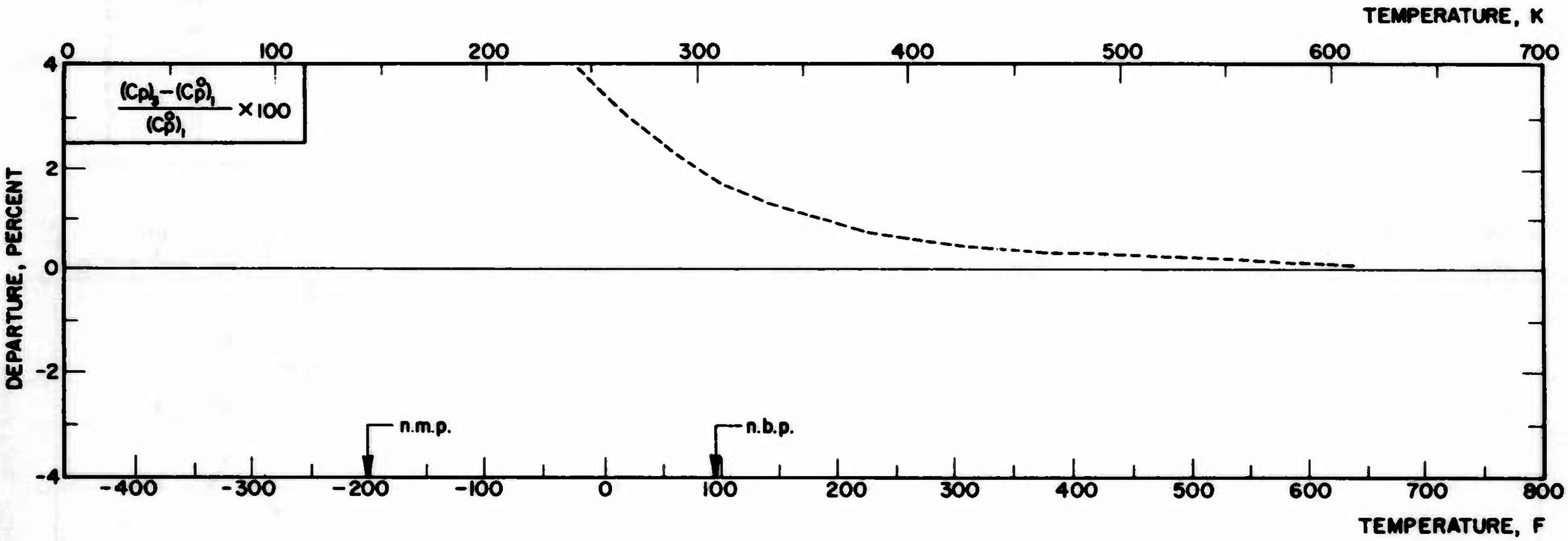


TABLE 54 SPECIFIC HEAT AT CONSTANT PRESSURE OF PROPANE

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, 78, 83).

The correlation formula obtained in the temperature range from 89 K to 230 K is

$$C_p(\text{cal g}^{-1}\text{ K}^{-1}) = 0.433027 + 3.9163\bar{5} \times 10^{-4}T - 2.18185 \times 10^{-6}T^2 + 1.02882 \times 10^{-8}T^3 \quad (T \text{ in K}).$$

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

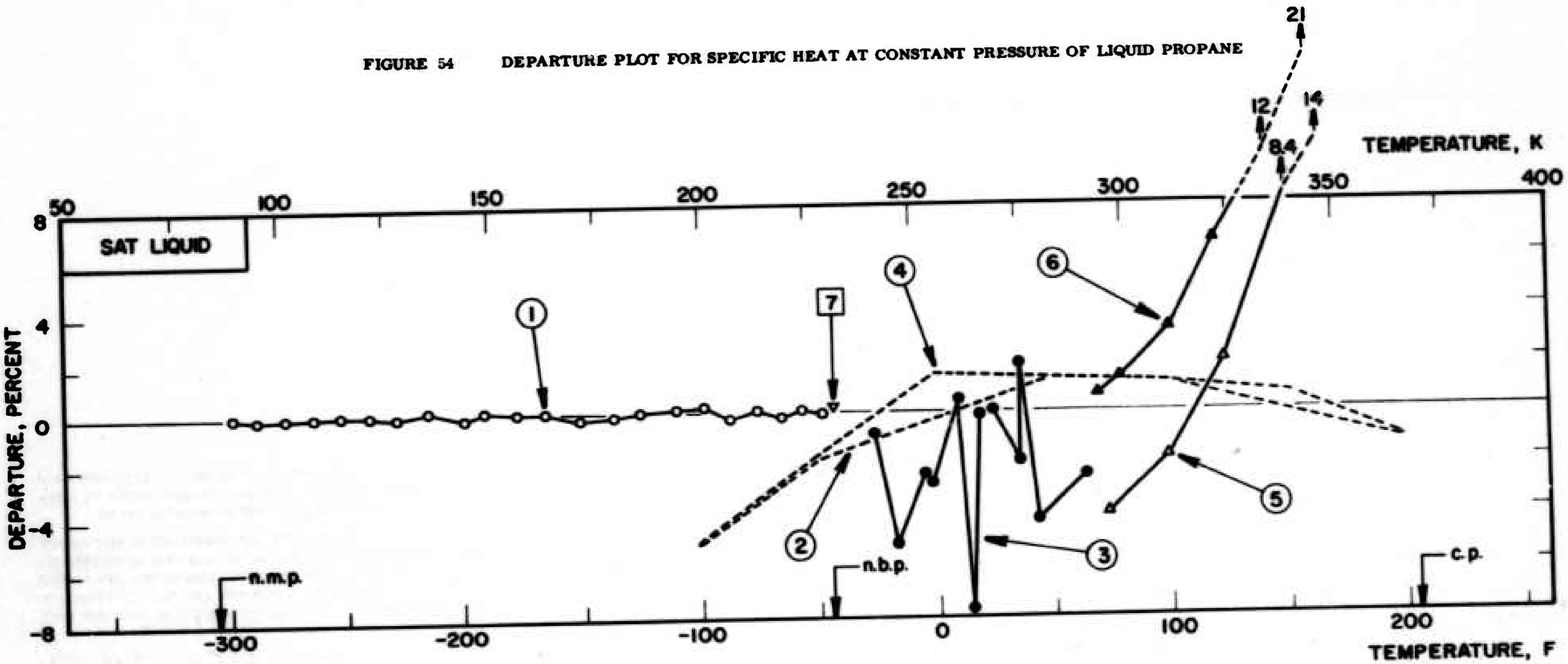
[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

LIQUID

T	C_p	T	C_p
-300	$0.457\bar{5}$	0	0.5617‡
-280	0.4603	20	0.5768‡
-260	0.4634	40	0.5933‡
-240	0.4667	60	0.6114‡
-220	$0.470\bar{5}$	80	0.6312‡
-200	0.4747	100	0.6527‡
-180	$0.479\bar{5}$	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)

FIGURE 54 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF LIQUID PROPANE



Curve	Reference
1	98
2	32
3	43
4	83
5	172
6	173
7	78

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), Ribaud (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:

$$C_p^0\ (\mathrm{cal\ g^{-1}K^{-1}}) = 0.0198573 + 1.38072 \times 10^{-3}T - 3.12097 \times 10^{-7}T^2 - 1.65153 \times 10^{-10}T^3 \qquad (1)$$

For temperatures between 780 K and 1500 K:

$$C_p^0\ (\mathrm{cal\ g^{-1}K^{-1}}) = 0.0391462 + 1.46886 \times 10^{-3}T - 6.78173 \times 10^{-7}T^2 + 1.18767 \times 10^{-10}T^3 \qquad (T \text{ in K}) \qquad (2)$$

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 693 K is:

$$C_p\ (\mathrm{cal\ g^{-1}K^{-1}}) = 0.147658 + 4.62079 \times 10^{-4}T + 1.80565 \times 10^{-6}T^2 - 1.73337 \times 10^{-9}T^3 \qquad (T \text{ in K}) \qquad (3)$$

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.

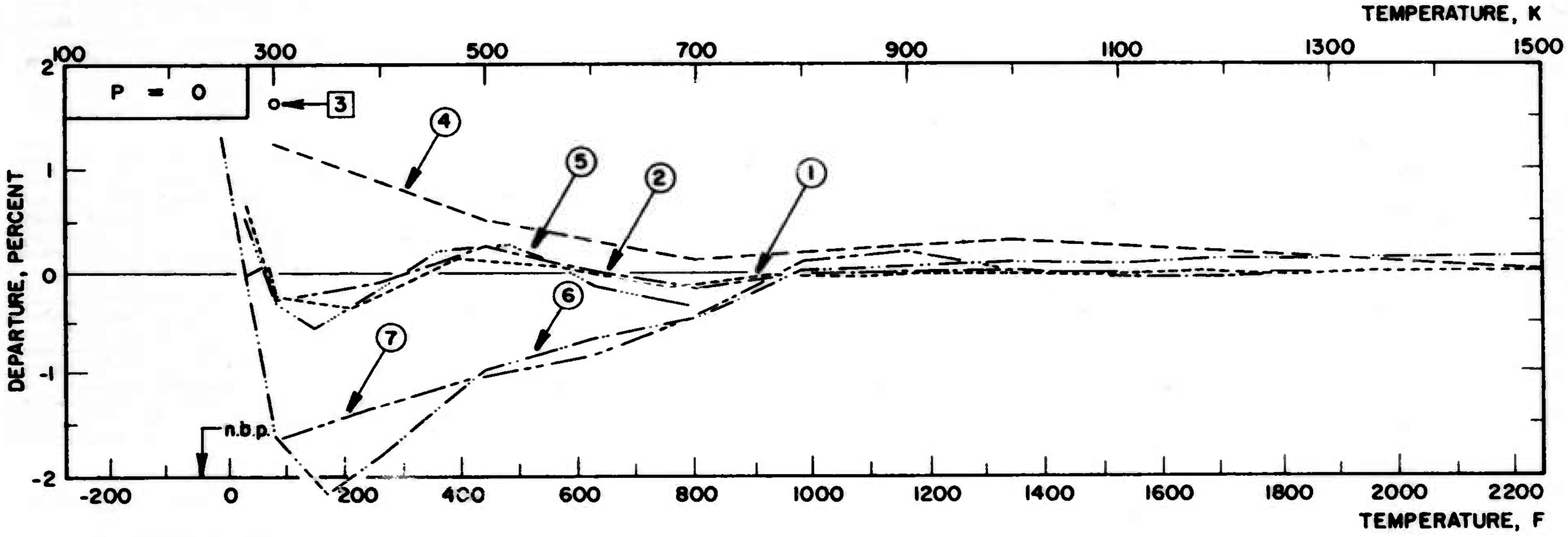
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

GAS

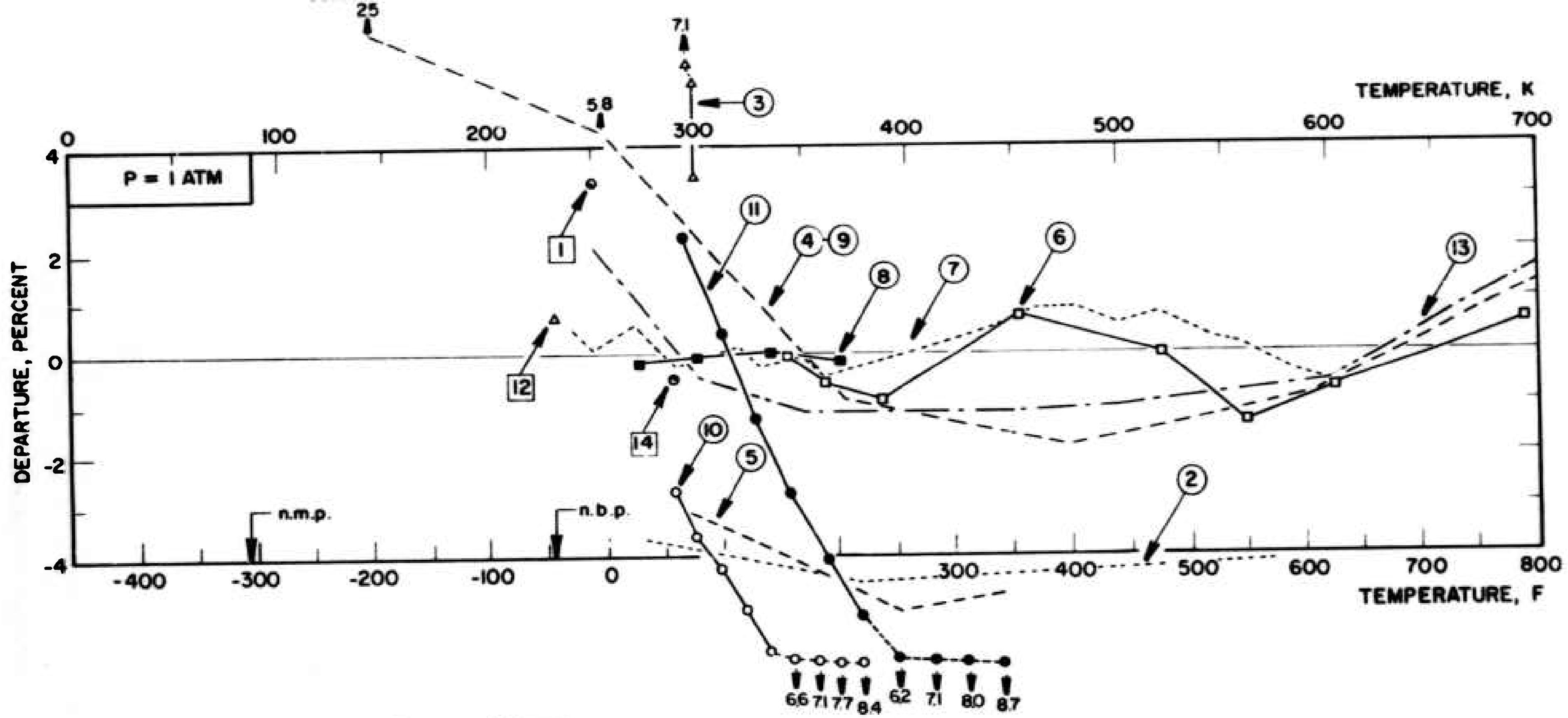
T	C_p^0	T	C_p^0
		600	0.6904
		620	0.6997
40	0.3753	640	0.7088
60	0.3882	660	0.7177
80	0.4011	680	0.7266
100	0.4138	700	0.7352
120	0.4263	720	0.7437
140	0.4388	740	0.7521
160	0.4512	760	0.7603
180	0.4634	780	0.7683
200	0.4755	800	0.7762
220	0.4875	820	0.7839
240	0.4994	840	0.7914
260	0.5111	860	0.7988
280	0.5227	880	0.8060
300	0.5342	900	0.8130
320	0.5456	920	0.8199
340	0.5568	940	0.8266
360	0.5679	960	0.8335
380	0.5789	980	0.8404
400	0.5897	1000	0.8471
420	0.6004	1100	0.8794
440	0.6110	1200	0.9094
460	0.6214	1300	0.9373
480	0.6317	1400	0.9632
500	0.6418	1500	0.9871
520	0.6518	1600	1.0092
540	0.6617	1700	1.0297
560	0.6714	1800	1.0486
580	0.6810	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	59, 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



Curve	Reference	Curve	Reference
1	13	9	83
2	14	10	172
3	85	11	178
4	32	12	182
5	48	13	202
6	40	14	78
7	251		
8	104		

FIGURE 54 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS PROPANE

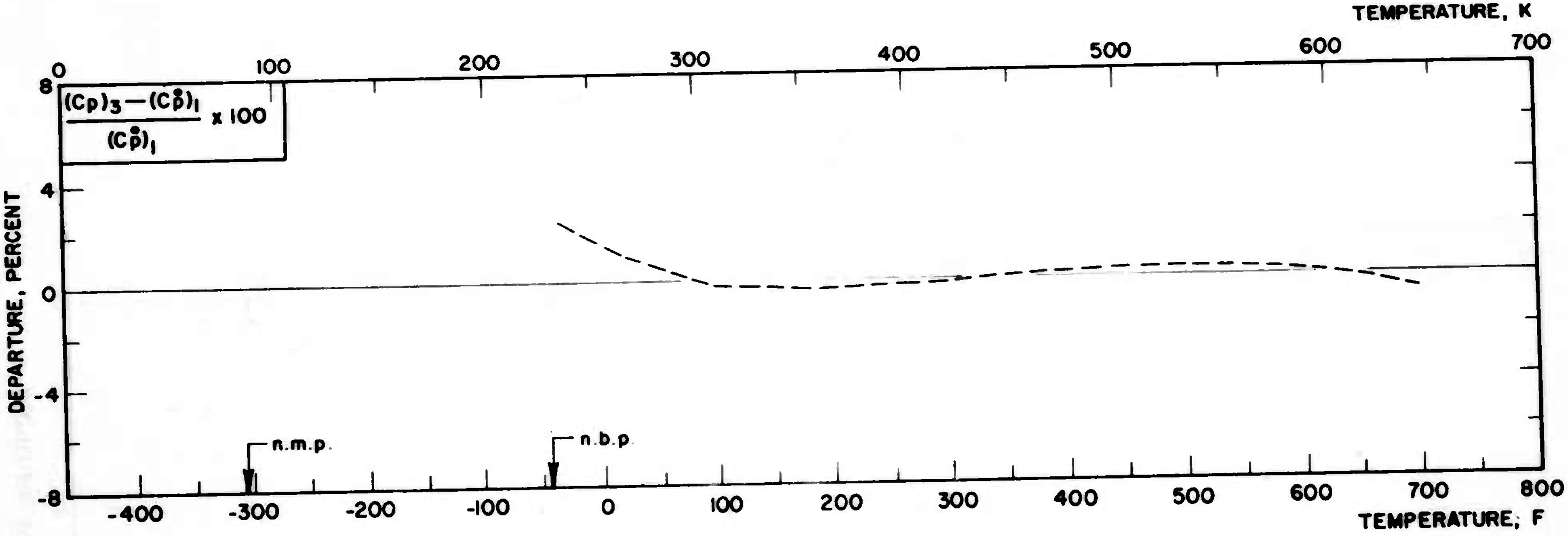


TABLE 55 SPECIFIC HEAT AT CONSTANT PRESSURE OF TOLUENE

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 Burlew (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 temperatures 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 383 K is

$$C_p(\text{cal g}^{-1}\,\text{K}^{-1}) = 0.451584 - 1.65686 \times 10^{-3}\,T + 7.12868 \times 10^{-6}\,T^2 - 6.82620 \times 10^{-9}\,T^3$$

(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}]

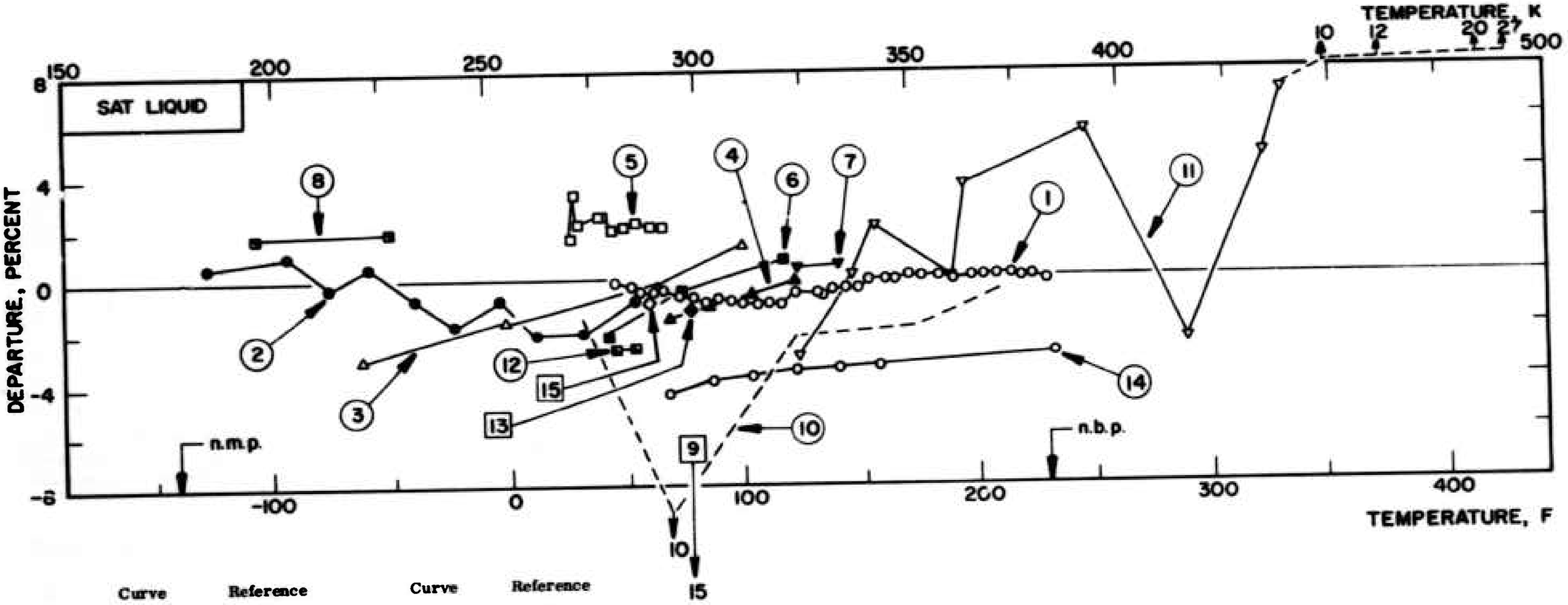
LIQUID

T	C_p	T	C_p
		100	0.4201
		120	0.4291
		140	0.4381
-140	0.3437†	160	0.4472
-120	0.3467	180	0.4564
-100	$0.350\bar{5}$	200	0.4655
-80	$0.35\bar{5}0$	220	0.4745
-60	0.3602	240	~~[illegible]~~‡ 0.4834
-40	$0.366\underline{0}$	260	0.492‡
-20	$0.372\bar{5}$	280	0.500‡
0	0.3794	300	0.509‡
20	0.3869	320	0.516‡
40	0.3947		
60	0.4029		
80	0.4114		

†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



Curve	Reference	Curve	Reference
1	31	9	23
2	97	10	36
3	117	11	147
4	168	12	200
5	181	13	221
6	237	14	231
7	258	15	78
8	5		

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

$$C_p^0\,(\mathrm{cal\ g^{-1}\ K^{-1}}) = -0.0744426 + 1.34989 \times 10^{-3}\,T - 6.75927 \times 10^{-7}\,T^2 + 6.15416 \times 10^{-11}\,T^3 \qquad (T \text{ in K}), \qquad (1)$$

For temperatures between 760 K and 1500 K

$$C_p^0\,(\mathrm{cal\ g^{-1}\ K^{-1}}) = 0.0286835 + 1.10456 \times 10^{-3}\,T - 5.69020 \times 10^{-7}\,T^2 + 1.10798 \times 10^{-10}\,T^3 \qquad (T \text{ in K}). \qquad (2)$$

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:

$$C_p^1\,(\mathrm{cal\ g^{-1}\ K^{-1}}) = -1.41207 \times 10^{-4} + 9.66922 \times 10^{-4}\,T + 1.27754 \times 10^{-8}\,T^2 - 3.60844 \times 10^{-10}\,T^3 \qquad (T \text{ in K}). \qquad (3)$$

The recommended values for C_p^1 are generated using the above equation. In the departure plot for P = 1 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)

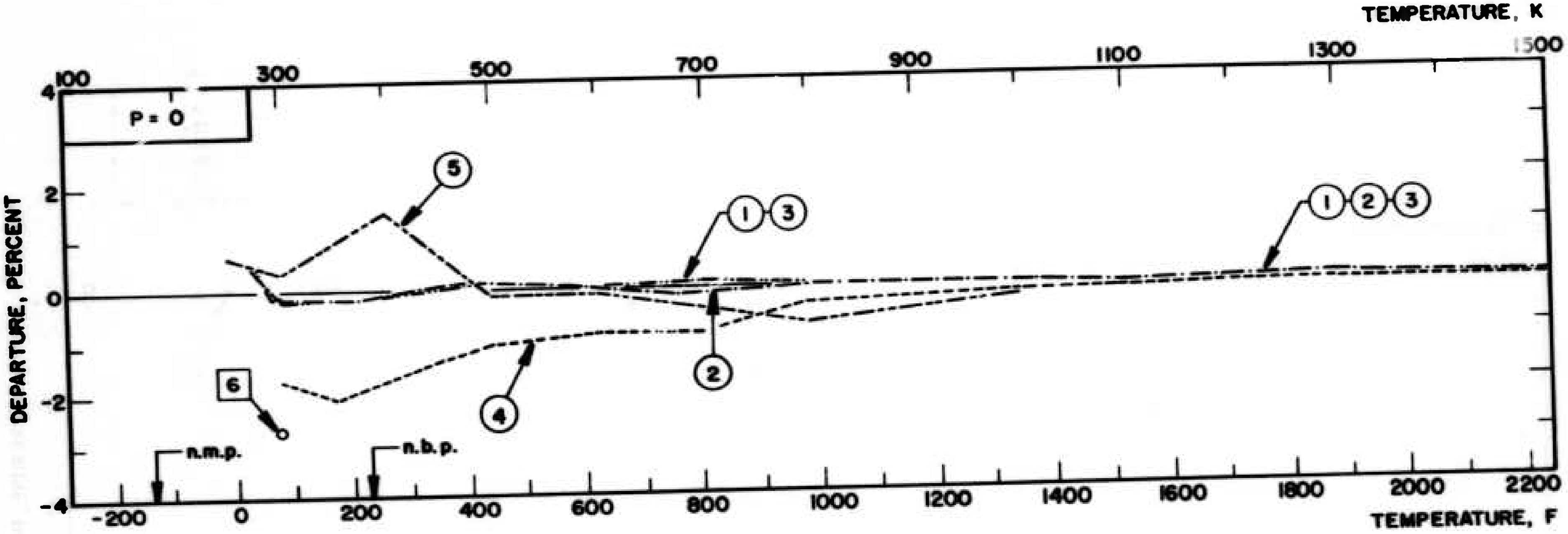
RECOMMENDED VALUES

[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
			600	0.4982	0.500
			620	0.5050	0.506
40	0.2493		640	0.5117	0.513
60	0.2603		660	0.5182	
80	0.2710	0.281	680	0.5246	
100	0.2816	0.291	700	0.5308	
120	0.2920	0.300	720	0.5369	
140	0.3023	0.310	740	0.5429	
160	0.312$\bar{5}$	0.319	760	0.5487	
180	0.322$\bar{5}$	0.329	780	0.5544	
200	0.3323	0.338	800	0.5599	
220	0.3420	0.347	820	0.5654	
240	0.3515	0.356	840	0.5706	
260	0.3609	0.365	860	0.5758	
280	0.3702	0.374	880	0.5808	
300	0.3792	0.383	900	0.5857	
320	0.3882	0.391	920	0.5905	
340	0.3970	0.400	940	0.5952	
360	0.4056	0.408	960	0.5999	
380	0.4141	0.417	980	0.6044	
400	0.4225	0.425	1000	0.6089	
420	0.4307	0.433	1100	0.6302	
440	0.4388	0.441	1200	0.6498	
460	0.4467	0.449	1300	0.6678	
480	0.4545	0.456	1400	0.6842	
500	0.4621	0.464	1500	0.6993	
520	0.4696	0.471	1600	0.7131	
540	0.4770	0.479	1700	0.7257	
560	0.4842	0.486	1800	0.7373	
580	0.4913	0.493	1900	0.7479	
			2000	0.7577	

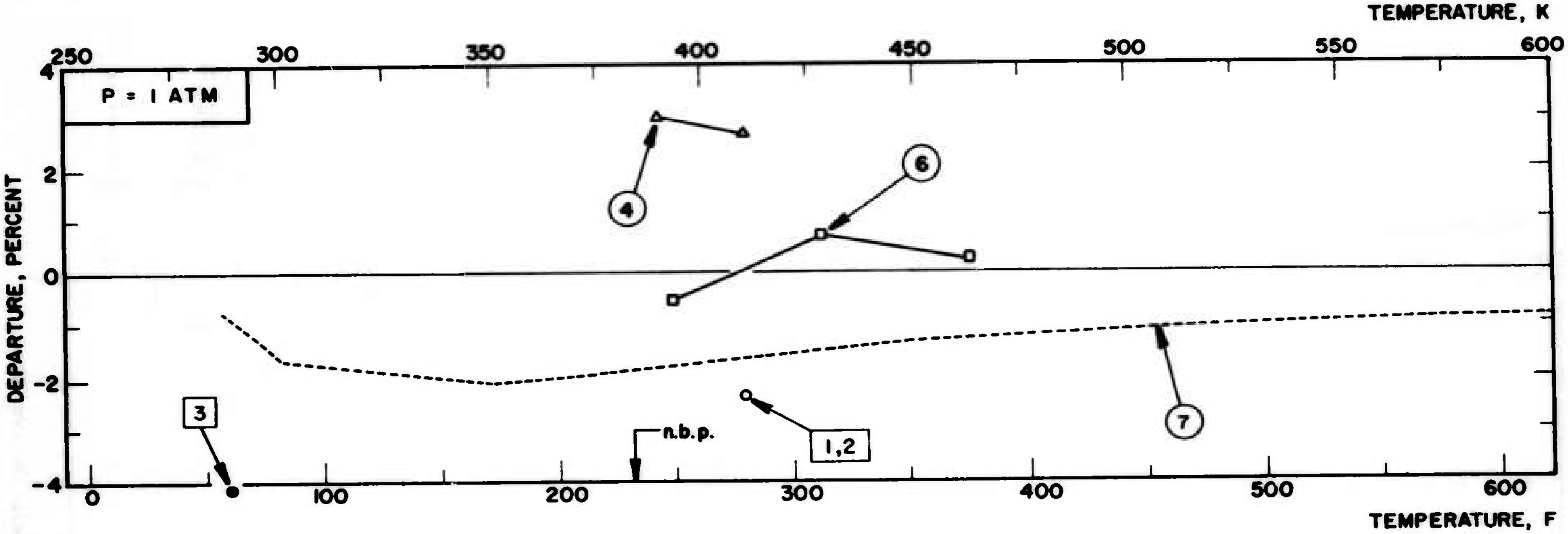
n.b.p. = 231 F

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



Curve	Reference
1	15
2	48
3	78
4	145
5	147
6	165
7	203

FIGURE 55 COMPARISON OF IDEAL GAS AND ONE ATMOSPHERE SPECIFIC HEAT OF GASEOUS TOLUENE

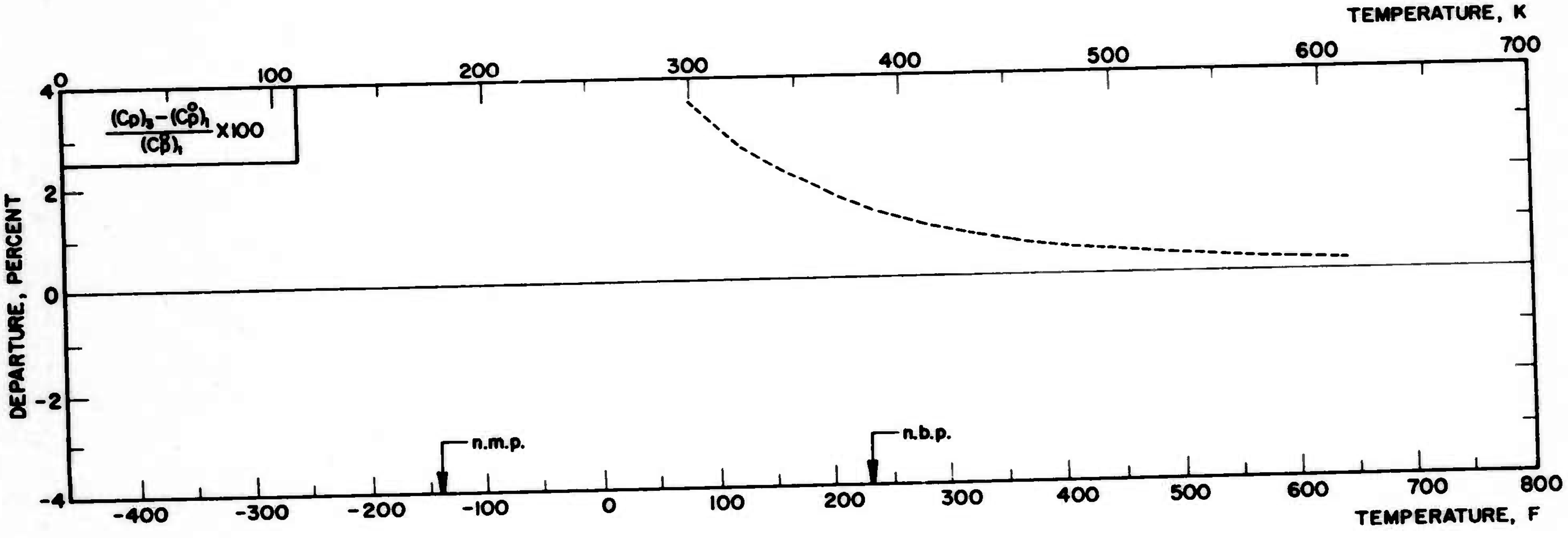


TABLE 56 SPECIFIC HEAT AT CONSTANT PRESSURE OF AIR

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

$$C_p^0 \ (\text{cal g}^{-1}\text{ K}^{-1}) = 0.244388 - 4.20419 \times 10^{-5}\ T + 9.61128 \times 10^{-8} T^2 - 1.16383 \times 10^{-11}\ T^3 \qquad (T \text{ in K}), \qquad (1)$$

For temperatures between 600 K and 1500 K

$$C_p^0 \ (\text{cal g}^{-1}\text{ K}^{-1}) = 0.208831 + 7.71027 \times 10^{-5}\ T - 8.56726 \times 10^{-9} T^2 - 4.75772 \times 10^{-12}\ T^3 \qquad (T \text{ in K}). \qquad (2)$$

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:

$$C_p \ (\text{cal g}^{-1}\text{ K}^{-1}) = 0.249679 - 7.55179 \times 10^{-5}\ T + 1.69194 \times 10^{-7}\ T^2 - 6.46128 \times 10^{-11}\ T^3 \qquad (T \text{ in K}), \qquad (3)$$

For temperatures between 610 K and 900 K

$$C_p \ (\text{cal g}^{-1}\text{ K}^{-1}) = 0.239496 - 3.89538 \times 10^{-5}\ T + 1.36120 \times 10^{-7}\ T^2 - 6.40730 \times 10^{-11}\ T^3 \qquad (T \text{ in K}). \qquad (4)$$

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^1 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

[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

GAS

T	C_p^0	C_p^1
-280	0. 24098	
-260	0. 24073	
-240	0. 24051	
-220	0. 24031	
-200	0. 24013	
-180	0. 23998	
-160	0. 23984	
-140	0. 23973	
-120	0. 23964	
-100	0. 23958	
- 80	0. 23953	
- 60	0. 23951	
- 40	0. 23951	
- 20	0. 23953	
0	0. 23957	0. 2402
20	0. 23963	0. 2402
40	0. 23972	0. 2402
60	0. 23982	0. 2403
80	0. 23995	0. 2403
100	0. 24010	$0.240\overline{5}$
120	0. 24027	0. 2406
140	0. 24046	0. 2408
160	0. 24067	0. 2409
180	0. 24091	0. 2412
200	0. 24116	0. 2414
220	0. 24143	0. 2417
240	0. 24173	0. 2419
260	0. 24204	0. 2422
280	0. 24238	0. 2426
300	0. 24273	0. 2429
320	0. 24311	0. 2433
340	0. 24350	0. 2437
360	$0.2439\underline{2}$	0. 2441
380	$0.2443\overline{5}$	0. 2445
400	0. 24480	$0.245\underline{0}$
420	0. 24528	$0.245\overline{5}$
440	0. 24577	$0.246\underline{0}$
460	0. 24628	$0.246\overline{5}$
480	0. 24682	0. 2470
500	0. 24737	0. 2476
520	0. 24794	0. 2481
540	0. 24853	0. 2487
560	0. 24914	0. 2493
580	0. 24976	0. 2499
600	0. 25041	0. 2505
620	0. 25107	0. 2511
640	0. 25149	0. 2517
660	0. 25217	0. 2523
680	0. 25284	0. 2530
700	0. 25351	0. 2536
720	0. 25418	0. 2542
740	0. 25484	0. 2549
760	$0.2554\underline{9}$	0. 2555
780	$0.2561\overline{5}$	0. 2561
800	0. 25679	0. 2568
820	0. 25744	0. 2574
840	0. 25808	0. 2580
860	0. 25871	0. 2587
880	0. 25934	0. 2593

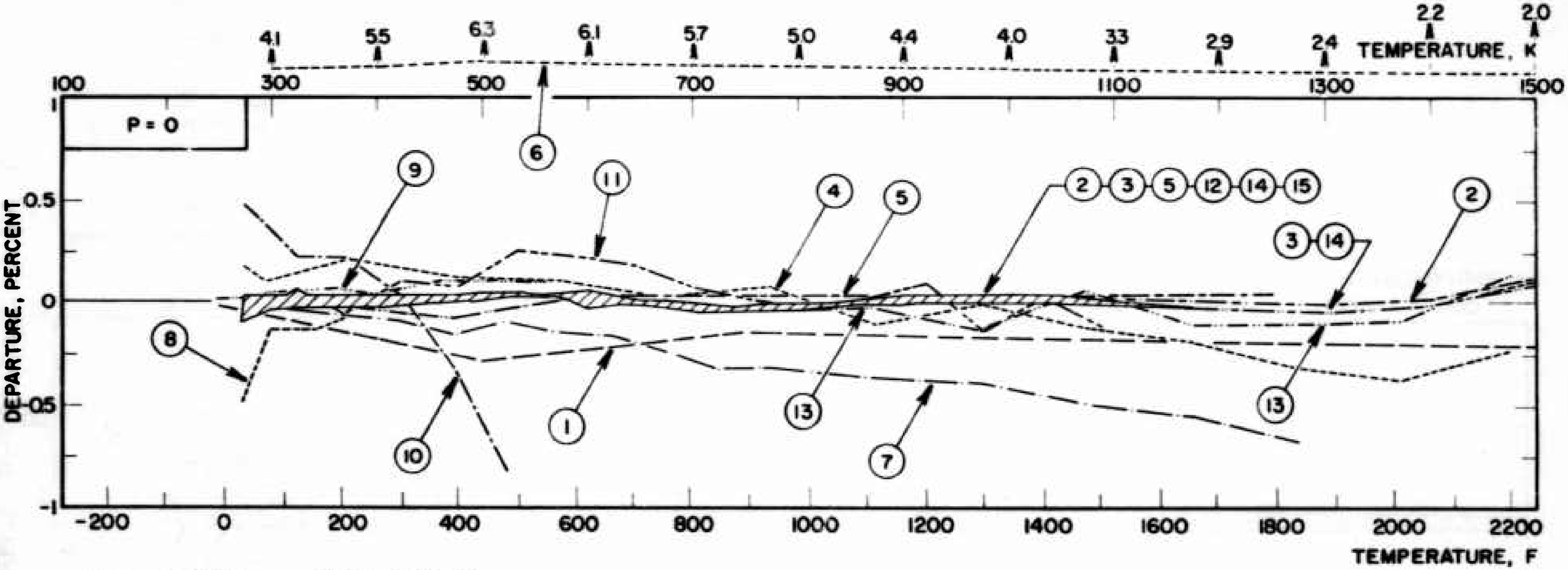
RECOMMENDED VALUES

[Temperature, T, F; Specific Heat, C_p, B lb^{-1} F^{-1}]

GAS

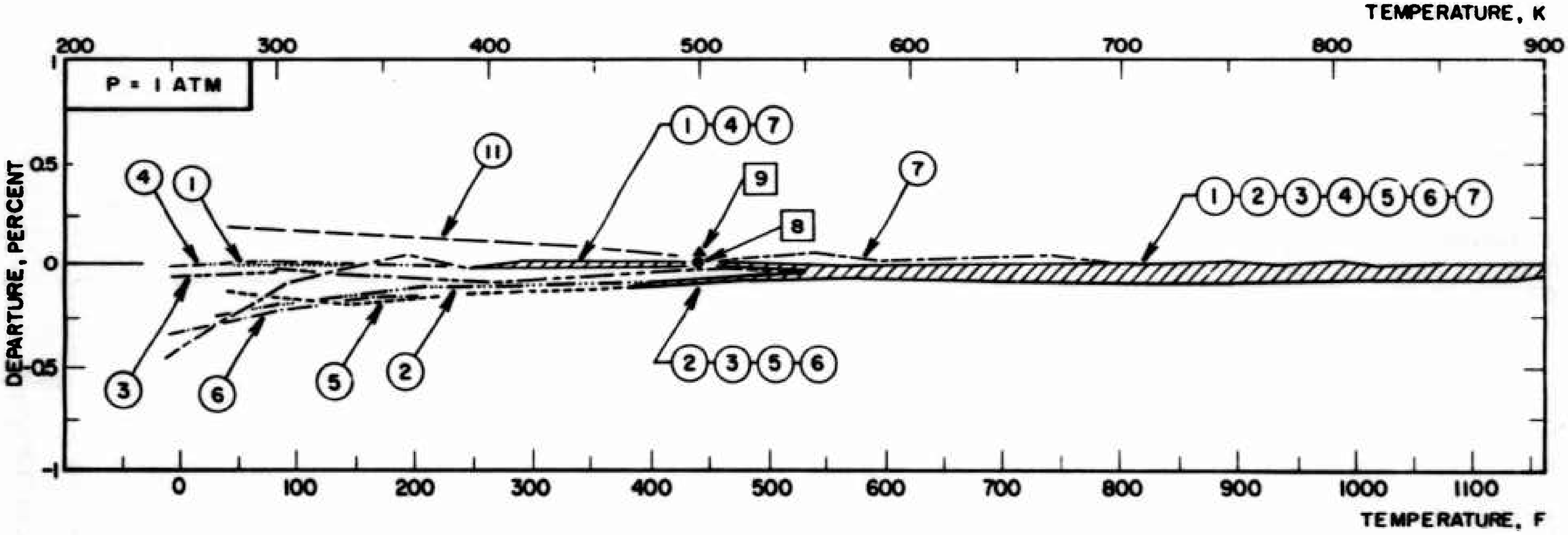
T	C_p^0	C_p^1
900	0. 25996	0. 2600
920	0. 26058	0. 2606
940	0. 26120	0. 2612
960	0. 26181	$0.261\underline{8}$
980	0. 26241	$0.262\overline{5}$
1000	0. 26301	0. 2631
1100	0. 26594	0. 2660
1200	0. 26873	
1300	0. 27140	
1400	0. 27392	
1500	0. 27630	
1600	0. 27853	
1700	0. 28061	
1800	0. 28252	
1900	0. 28428	
2000	0. 28587	

FIGURE 56 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS AIR



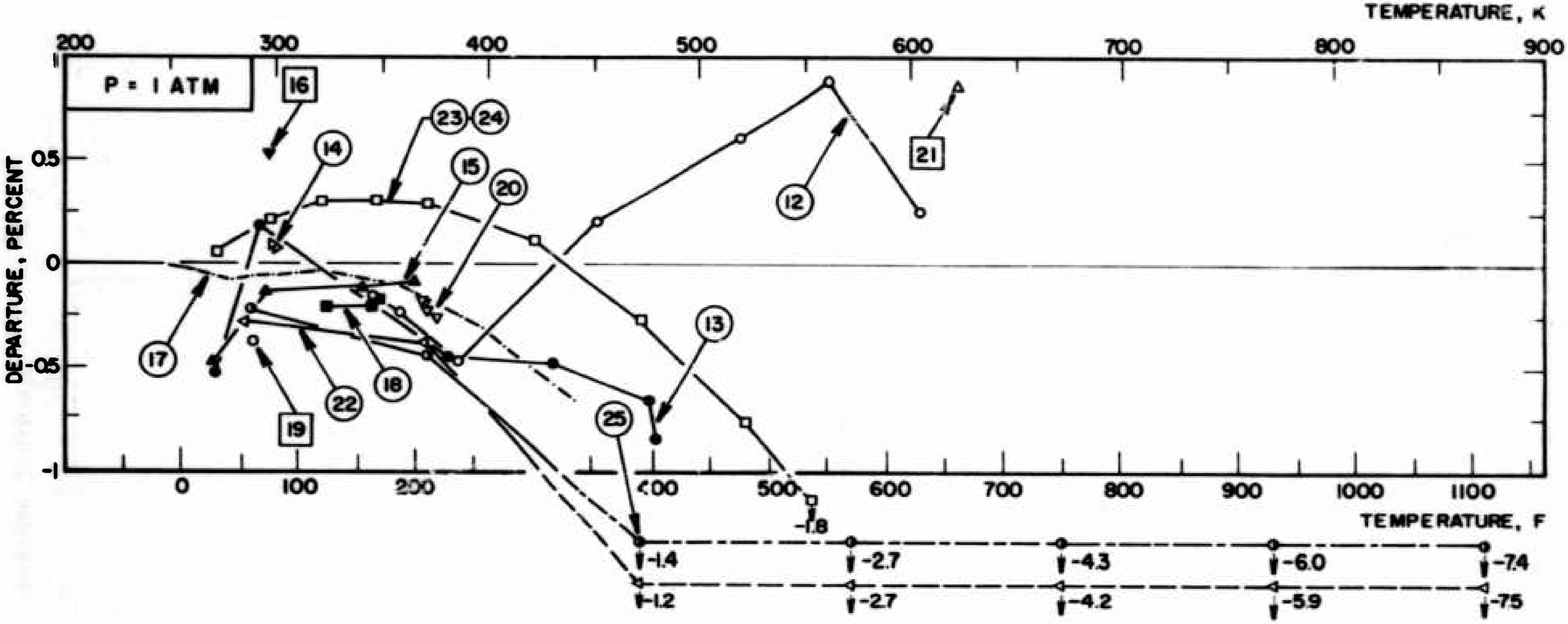
Curve	Reference	Curve	Reference
1	311	9	338
2	403	10	350
3	575	11	358
4	24	12	368
5	59	13	402
6	93	14	426
7	100	15	470
8	103		

FIGURE 56 DEPARTURE PLOT FOR SPECIFIC HEAT AT CONSTANT PRESSURE OF GASEOUS AIR



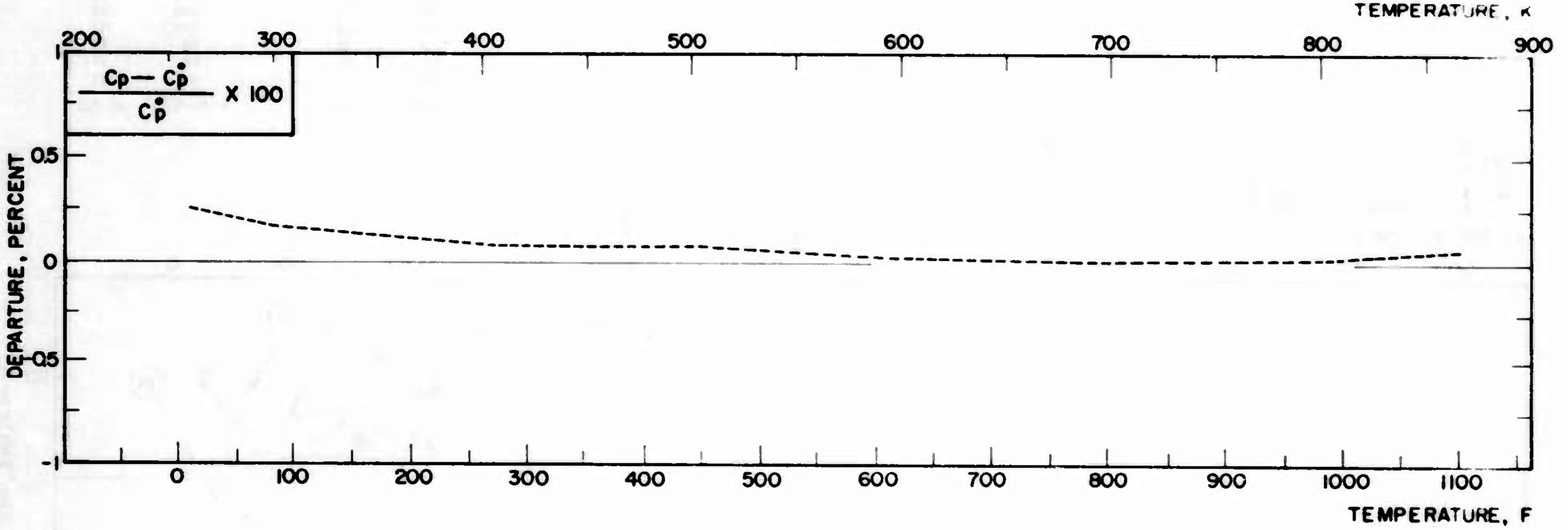
Curve	Reference
1	132 [illegible]60, 313, 454, 481, 575
2	71, 249, 553
3	274, 403
4	302
5	315, 367, 376, 406, 512, 541
6	330
7	366
8	368
9	369, 370
10	490
11	497

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



REFERENCES TO DATA SOURCES

Ref. No.	TPRC No.	
1	19335	Akhmetsyanov, K.G., Shirkevich, M.G., and Rozhdestvenskii, I.B., Primeneniye Ultraakustiki K. Issledovaniyu Veshchestva, 4, 127-35, 1957.
2	9562	Albright, L.F., Galegar, W.C., and Innes, K.K., J. Am. Chem. Soc., 76, 6017-19, 1954.
3	6332	Albright, L.F. and Martin, J.J., Ind. Eng. Chem., 44, 188-98, 1952.
4	676	Andrianova, T.N., Zhur. Tekh. Fiz., 23, 1014-25, 1953.
5	14116	Aoyama, S. and Kanda, E., Science Repts. Tohoku Imp. Univ., 24, 116-21, 1935.
6	31762	Aston, J.G., Ind. Eng. Chem., 34, 514-21, 1942.
7	28363	Aston, J.G., Kennedy, R.M., and Schumann, S.C., J. Am. Chem. Soc., 62, 2059-63, 1940.
8	7828	Aston, J.G. and Messerly, G.H., J. Am. Chem. Soc., 62, 1917-23, 1940.
9	9823	Atwood, G.R., Univ. Microfilms Publ. 2014, 1-76, 1958.
10	12330	Awbery, J.H. and Griffiths, E., Proc. Phys. Soc., (London), 52, 770-6, 1940.
11	583	Barrow, G.M., J. Chem. Phys., 20, 1739-44, 1952.
12	980	Barrow, G.M., J. Am. Chem. Soc., 73, 1824-6, 1951.
13	1046	Barrow, G.M., J. Chem. Phys., 21, 1912-13, 1953.
14	31763	Beeck, O., J. Chem. Phys., 4, 680-89, 1936.
15	31764	Bennewitz, K. and Rossner, W., Z. Physik. Chem. (Leipzig)., B39, 126-44, 1938.
16	11717	Benning, A.F. and McHarness, R.C., Ind. Eng. Chem., 31, 912-16, 1939.
17	28270	Benning, A.F., McHarness, R.C., Markwood, W.H., Jr., and Smith, W.J., Ind. Eng. Chem., 32, 976-80, 1940.
18	18269	Benson, S.W. and Buss, J.H., J. Chem. Phys., 29, 546-72, 1958.
19	275	Bernstein, H.J., J. Chem. Phys., 24, 911-2, 1956.
20	292	Bernstein, H.J., J. Chem. Phys., 24, 911, 1956.
21	13790	Bhagavantam, S., Proc. Indian Acad. Sci., 7A, 245-50, 1938.
22	20570	Brickwedde, F.G., Moskow, M., and Aston, J.G., J. Research Natl. Bur. Standards, 37, 263-97, 1946.
23	17062	Brock, F.H., ARS. J., 31(2), 265-8, 1961.
24	10861	Bruckner, H., Gas-u. Wasserfach, 78, 637-9, 1935.
25	13938	Bryant, W.M.D., Ind. Eng. Chem., 25, 820-3, 1933.
26	3799	Bubushyan, M.B., Teploenergetika, 3,39-51, 1954.
27	11720	Budenholzer, R.A., Sage, B.H., and Lacey, W.N., Ind. Eng. Chem. 31, 369-74, 1939.
28	33578	Budenholzer, R.A., Sage, B.H., and Lacey, W.N., Ind. Eng. Chem., 31, 1288-92, 1939.
29	21734	Buffington, R.M. and Fleischer, J.M., Ind. Eng. Chem., 23, 1290-2, 1931.
30	3430	Burcik, E.J., Eyster, E.H., and Yost, D.M., J. Chem. Phys., 9, 118-19, 1941.
31	13169	Burlew, J.S., J. Am. Chem. Soc., 62, 696-700, 1940.
32	19092	Buthod, A.P., Oil Gas. J., 58(3), 67-82, 1960.
33	17006	Calcaterra, P.C., MIT-ONR TR-3, 21 pp., 1960. [AD 242 361]
34	12098	Cerny, C. and Erdos, E., Collection of Czechoslov. Chem. Commun., 19, 646-52, 1954.
35	591	Cerny, C. and Erdos, E., Chem. Listy., 47, 1742-9, 1953.
36	465	Chow, W.M. and Bright, J.A., Jr., Chem. Eng. Progr., 49, 175-80, 1953.
37	10006	Cleveland, F.F., Bernstein, R.B., and Zietlow, J.P., Illinois Inst. of Tech., Chicago Tech. Rept. No. 11 (Rev.), 1-8, 1954 [AD 3131 (Rev.)]
38	1538	Collins, B.T., Coleman, C.F., and DeVries, T., J. Am. Chem. Soc., 71, 2929-30, 1949.
39	974	Connolly, T.J., Sage, B.H., and Lacey, W.N., Ind. Eng. Chem., 43, 946-50, 1951.
40	1168	Dailey, B.P. and Felsing, W.A., J. Am. Chem. Soc., 65, 42-4, 1943.
41	1165	Dailey, B.P. and Felsing, W.A., J. Am. Chem. Soc., 65, 44-6, 1943.

Ref. No.	TPRC No.	
42	11897	Damkohler, G., Z. Physik. Chem. (Leipzig), 31B, 439-53, 1936.
43	10430	Dana, L.I., Jenkins, A.C., Burdick, J.N., and Timm, R.C., Refrig. Eng., 12(12), 387-405, 1926.
44	17098	Danilova, A.I., Nauch. Zapiski L'Vov. Politekh. Inst., 22, 127-34, 1956.
45	4641	DeVries, T. and Collins, B.T., J. Am. Chem. Soc., 63, 1343-6, 1941.
46	22417	Dixon, H.B. and Greenwood, G., Proc. Roy. Soc. (London), 105A, 199-220, 1924.
47	10928	Dobbins, T.O., WADC-TR-59-757, 1-711, 1959. [AD 232 465]
48	28272	Dobratz, C.J., Ind. Eng. Chem., 33, 759-62, 1941.
49	373	Douglas, T.B., Furukawa, G.T., McCoskey, R.E., and Ball, A.F., J. Research Natl. Bur. Standards, 53, 139-53, 1954.
50	8669	Douslin, D.R., and Huffman, H.M., J. Am. Chem. Soc., 68, 1704-8, 1946.
51	11698	Edmister, W.C., Ind. Eng. Chem., 28, 1112-16, 1936.
52	8599	Edmister, W.C., Petrol. Refiner, 27(11), 609-15, 1948.
53	13337	Egan, C.J. and Kemp, J.D., J. Am. Chem. Soc., 59, 1264-8, 1937.
54	16461	Eucken, A. and Berger, W., Z. Ges. Kalte-Ind., 41, 145-52, 1934.
55	22868	Eucken, A. and Hauck, F., Z. Physik. Chem. (Leipzig), 134, 161-77, 1928.
56	31766	Eucken, A. and Lude, K.V., Z. Physik. Chem. (Leipzig), 5B, 413-41, 1929.
57	16491	Eucken, A. and Parts, A., Z. Physik. Chem. (Leipzig), 20B, 184-94, 1933.
58	1384	Eucken, A. and Sarstedt, B., Z. Physik. Chem. (Leipzig), 50B, 143-70, 1941.
59	14546	Faltin, H., Technik, 15, 592-6, 1960.
60	15949	Ferguson, A. and Miller, J.T., Proc. Phys. Soc. (London), 45, 194-207, 1933.
61	550	Finke, H.L., Gross, M.E., Waddington, G., and Huffman, H.M., J. Am. Chem. Soc., 76, 333-41, 1954.
62	21515	Fiock, E.F., Ginnings, D.C., and Holton, W.B., J. Research Natl. Bur. Standards, 6, 881-900, 1931.
63	9537	Freyer, E.B., Hubbard, J.C., and Andrews, D.H., J. Am. Chem. Soc., 51, 759-770, 1929.
64	14792	Frost, A.V., Trans. Exptl. Research Lab. "Khemgas" (Leningrad), 3, 27-32, 1936.
65	11708	Fugassi, P. and Rudy, C.E., Jr., Ind. Eng. Chem., 30, 1029-30, 1938.
66	7784	Gelles, E. and Pitzer, K.S., J. Am. Chem. Soc., 75, 5259-67, 1953.
67	13304	Giacalone, A., Gass. Chim. Ital., 77, 88-92, 1947.
68	1699	Ginnings, D.C., and Furukawa, G.T., J. Am. Chem. Soc., 75, 522-7, 1953.
69	28274	Glockler, G. and Edgell, W.F., Ind. Eng. Chem., 34, 532-4, 1942.
70	33764	Glockler, G. and Edgell, W.F., J. Chem. Phys., 9, 224-30, 1941.
71	1667	Godridge, A.M., Bull. Brit. Coal Util. Res. Assoc., 18, 1-21, 1954.
72	10530	Gordon, J.S., WADC-TR-57-33, 1-172, 1957. [AD 110 735]
73	10832	Gordon, J.S., RMD-210-E3, 1-222, 1960. [AD 231 995]
74	26383	Green, J.H.S., Trans. Faraday Soc., 57, 2132-7, 1961.
75	15166	Gumz, W., Feuerungstechnik, 23, 85-6, 1935, Correction, 23, 137, 1935.
76	10702	Haas, M.E., Univ. Pittsburgh Bull., 29, 116-20, 1933.
77	21897	Haas, M.E. and Stegeman, G., J. Phys. Chem., 36, 2127-32, 1932.
78	19088	Hanna, W.S. and Matteson, R., Oil Gas. J., 45, 61-4, 67, 1947.
79	1353	Harrison, D. and Moelwyn-Hughes, E.A., Proc. Roy. Soc. (London), 239A, 230-46, 1957.
80	1278	Helfrey, P.F., Heiser, D.A., and Sage, B.H., Ind. Eng. Chem., 47, 2385-8, 1955.
81	23186	Hestermans, P. and White, D., J. Phys. Chem., 65, 362-65, 1961.
82	28386	Hicks, J.F.G., Hooley, J.G., and Stephenson, C.C., J. Am. Chem. Soc., 66, 1064-67, 1944.
83	28276	Holcomb, D.E. and Brown, G.G., Ind. Eng. Chem., 34, 590-602, 1942.
84	1500	Hough, E.W., Mason, D.M., and Sage, B.H., J. Am. Chem. Soc., 72, 5775-7, 1950.
85	3525	Huetz-Aubert, M., Publs. Sci. et Tech. Ministerel'air (France) Notes Tech., 68, 1-182, 1957.
86	21826	Huffman, H.M., Parks, G.S., and Daniels, A.C., J. Am. Chem. Soc., 52, 1547-58, 1930.
87	33584	Huffman, H.M., Parks, G.S., and Barmore, M., J. Am. Chem. Soc., 53, 3876-88, 1931.

Ref. No.	TPRC No.	
88	33763	Ivash, E.V., Li, J.C.M., and Pitzer, K.S., J. Chem. Phys., 23, 1814-8, 1955.
89	14727	Jatkar, S.K.K., J. Indian Inst. Sci., 22A, (2), 19-37, 1939.
90	14170	Jatkar, S.K.K., J. Indian Inst. Sci., 22A, 39-58, 1939.
91	15376	Jennings, W.H. and Bixler, M.E., J. Phys. Chem., 38, 747-51, 1934.
92	4739	Justi, E., Feuerungstechnik, 26, 313-22, 1938.
93	15168	Justi, E. and Luder, H., Forsch. Gebiete Ingenieurw. 6B, 209-16, 1935.
94	1578	Justi, E. and Langer, F., Z. Tech. Physik, 21, 189-94, 1940.
95	1229	Justi, E. and Langer, F., Z. Tech. Physik, 22, 124-9, 1941.
96	1254	Kazavchinskii, Ya.Z. and Katkhe, O.I., Zhur. Fiz. Khim., 29, 2230-5, 1955.
97	21821	Kelley, K.K., J. Am. Chem. Soc., 51, 2738-41, 1929.
98	11846	Kemp, J.D. and Egan, C.J., J. Am. Chem. Soc., 60, 1521-5, 1938.
99	33586	Kemp, J.D. and Pitzer, K.S., J. Am. Chem. Soc., 59, 276-79, 1937.
100	10637	Keyes, F.G., Project Squid Technical Rept., No. 37, 1-33, 1952. [ATI-167173]
101	198	Kilpatrick, J.E. and Pitzer, K.S., J. Research N.B.S., 37, 163-71, 1946.
102	11104	Kistiakowsky, G.B., Lacher, J.R., and Ransom, W.W., J. Chem. Phys., 8, 970-7, 1940.
103	11641	Kistiakowsky, G.B. and Rice, W.W., J. Chem. Phys., 7, 281-88, 1939.
104	13244	Kistiakowsky, G.B. and Rice, W.W., J. Chem. Phys., 8, 610-18, 1940.
105	1288	Kobe, K.A., Harrison, R.H., and Pennington, R.E., Petrol. Refiner, 30(8), 119-22, 1951.
106	1220	Kobe, K.A., Harrison, R.H., Petrol. Refiner, 33(8), 109-10, 1954.
107	1231	Kobe, K.A. and Harrison, R.H., Petrol. Refiner, 33(11), 161-4, 1954.
108	19162	Kobe, K.A. and Kobe, D.H., Petrol. Refiner, 38(12), 117-20, 1959.
109	28504	Kobe, K.A. and Long, E.G., Petrol. Refiner, 28(2), 113-16, 1949.
110	28506	Kobe, K.A. and Long, E.G., Petrol. Refiner, 28(7), 145-8, 1949.
111	1283	Kobe, K.A. and Long, E.G., Petrol. Refiner, 28(10), 133-6, 1949.
112	28505	Kobe, K.A. and Long, E.G., Petrol. Refiner, 28(11), 125-8, 1949.
113	1360	Kobe, K.A. and Long, E.G., Petrol. Refiner, 29(3), 157-60, 1950.
114	1514	Kobe, K.A. and Pennington, R.E., Petrol. Refiner, 29(9), 135-8, 1950.
115	13883	Kolosovskii, N.A. and Udovenko, V.V., Compt. rend., 197, 519-20, 1933.
116	15314	Kolosovskii, N.A. and Udovenko, V.V., J. Gen. Chem. USSR (Eng. Transl.), 4, 1027-33, 1934.
117	1562	Kurbatov, V.Ya., J. Gen. Chem. USSR (Eng. Transl.), 17, 1999-2009, 1947.
118	731	Kurbatov, V.Ya., Zhur. Obshchei Khim., 18, 372-87, 1948.
119	11381	Kuznetsov, V.T., J. Gen. Chem. USSR (Eng. Transl.), 9, 2009-11, 1939.
120	668	Landsberg, R. and Seibald, S., Bull. Research Council Israel, 3, 414-16, 1954.
121	1528	Lapshina, M.I. and Khomyakov, K.G., Vestnik Moskov Univ., 6(3), Ser. Fiz-Mat. I Estestven. Nauk, 2, 35-48, 1951.
122	1872	Lashakov, L.M., J. Chem. Ind. (USSR), 18(19), 17-19, 1941.
123	33583	Latimer, W.M., J. Am. Chem. Soc., 44, 90-97, 1922.
124	19880	Lependin, L.F., Uchenye, Zapiski Moskov, Oblast. Pedagog. Inst., 43, 129-44, 1956.
125	2069	Levchenko, G.T., J. Phys. Chem. (USSR), 18, 453-65, 1944.
126	15053	Litovitz, T.A., J. Acoust. Soc. Amer., 30(3), 210-14, 1958.
127	6833	Lohrisch, F.W., J. Appl. Chem. (London), 2, 464-9, 1952.
128	33581	Lord, R.C. and Blanchard, E.R., J. Chem. Phys., 4, 707-10, 1936.
129	3933	Luft, N.W., J. Chem. Phys., 22, 155-6, 1954.
130	11127	Madigan, J.R. and Cleveland, F.F., J. Chem. Phys., 19, 119-23, 1951.
131	564	Masi, J.F., J. Am. Chem. Soc., 74, 4738-41, 1952.
132	1696	Masi, J.F., Trans. Am. Soc. Mech. Engrs., 76, 1067-74, 1954.
133	18172	Maslov, P.G., Zhur. Priklad. Khim., 30, 777-85, 1957.
134	1348	Maslov, P.G., Zhur. Priklad. Khim., 30, 736-44, 1957.

Ref. No.	TPRC No.	
135	14095	Mazur, J., Acta Phys. Polon., 7, 318-26, 1938.
136	4306	Mazur, J., Z. Physik, 113, 710-20, 1939.
137	24959	McBride, B.J., Heimel, S., Ehlers, J.G., and Gordon, S., NASA SP-3001, 328, 1963.
138	7824	Messerly, G.H. and Aston, J.G., J. Am. Chem. Soc., 62, 886-90, 1940.
139	28364	Messerly, G.H. and Kennedy, R.M., J. Am. Chem. Soc., 62, 2988-91, 1940.
140	1767	Michels, A., DeGroot, S.R., and Geldermans, M., Appl. Sci. Research, 1A, 55-65, 1947.
141	604	Michels, A., Van Straaten, W., and Dawson, J., Physica, 20, 17-23, 1954.
142	21773	Millar, R.W., J. Am. Chem. Soc., 45, 874-81, 1923.
143	18985	Mitsukuri, S. and Hara, K., Bull. Chem. Soc. (Japan), 4, 77-81, 1929.
144	8980	Montgomery, J.B. and DeVries, T., J. Am. Chem. Soc., 64, 2372-5, 1942.
145	33588	Montgomery, J.B. and DeVries, T., J. Am. Chem. Soc., 64, 2375-7, 1942.
146	7097	Neilson, E.F. and White, D., J. Am. Chem. Soc., 79, 5618-21, 1957.
147	19645	Nesselmann, K. and Dardin, F., Wiss. Veroffentl. Siemens-Konzern, 10(2), 129-54, 1931.
148	2021	Oliver, G.D., Eaton, M., and Huffman, H.M., J. Am. Chem. Soc., 70, 1502-5, 1948.
149	1781	Osborne, N.S. and Ginnings, D.C., J. Research Natl. Bur. Standards, 39, 453-77, 1947.
150	13462	Pall, D.B. and Maass, O., Can. J. Research, 16B, 449-52, 1938.
151	5059	Papini, G. and Cuomo, S., Antincendio (Rome), 8, 338-44, 1956.
152	31768	Parks, G.S. and Huffman, H.M., J. Am. Chem. Soc., 52, 4381-91, 1930.
153	31769	Parks, G.S., Huffman, H.M., and Thomas, S.B., J. Am. Chem. Soc., 52, 1032-41, 1930.
154	21788	Parks, G.S. and Kelley, K.K., J. Am. Chem. Soc., 47, 2089-97, 1925.
155	11615	Parks, G.S., Shomate, C.H., Kennedy, W.D., and Crawford, B.L., Jr., J. Chem. Phys., 5, 359-63, 1937.
156	1572	Pavlova, I.A., Kholodilnaya Tekh., 42-58, 1955.
157	289	Pennington, R.E. and Kobe, K.A., J. Am. Chem. Soc., 79, 300-5, 1957.
158	6555	Pennington, R.E. and Kobe, K.A., Univ. Texas, 1-30, 1956. [AD100 228]
159	1228	Person, W.B. and Pimentel, G.C., J. Am. Chem. Soc., 75, 532-8, 1953.
160	28294	Pitzer, K.S., J. Chem. Phys., 12, 310-14, 1944.
161	1875	Pitzer, K.S., Ind. Eng. Chem., 36, 829-31, 1944
162	7833	Pitzer, K.S., J. Am. Chem. Soc., 62, 1224-7, 1940.
163	2542	Pitzer, K.S., J. Am. Chem. Soc., 63, 2413-18, 1941.
164	20085	Pitzer, K.S. and Kilpatrick, J.E., Chem. Rev., 39, 435-447, 1946.
165	33589	Pitzer, K.S. and Scott, D.W., J. Am. Chem. Soc., 65, 803-29, 1943.
166	16582	Rykov, V.I., Uchenye Zapiski Kishinev. Gosudarst. Univ., 17, 127-39, 1955.
167	1702	Ribaud, G., Publs. Sci. et Tech. Ministere Air (France), 266, 1-169, 1952.
168	21848	Richards, W.T. and Wallace, J.H., Jr., J. Am. Chem. Soc., 54, 2705-13, 1932.
169	12254	Riedel, L., Z. Ges. Kalte-Ind., 45, 221-5, 1938.
170	12798	Riedel, L., Z. Ges. Kalte-Ind., 46, 105-6, 1939.
171	794	Rossini, F.D., Pitzer, K.S., Taylor, W.J., Ebert, J.P., Kilpatrick, J.E., Beckett, C.W., Williams, M.G., and Werner, H.G., NBS-C 461, 1-483, 1947.
172	11694	Sage, B.H. and Lacey, W.N., Ind. Eng. Chem., 27, 1484-8, 1935.
173	33575	Sage, B.H., Kennedy, E.R., and Lacey, W.N., Ind. Eng. Chem., 28, 601-4, 1936.
174	33574	Sage, B.H., Lacey, W.N., and Schaafsma, J.G., Ind. Eng. Chem., 27, 48-50, 1935.
175	33577	Sage, B.H. and Lacey, W.N. Ind. Eng. Chem., 30, 673-81, 1938.
176	33573	Sage, B.H., Schaafsma, J.G., and Lacey, W.N., Ind. Eng. Chem., 26, 1218-24, 1934.
177	33576	Sage, B.H., Webster, D.C., and Lacey, W.N., Ind. Eng. Chem., 29, 658-66, 1937.
178	11706	Sage, B.H., Webster, D.C., and Lacey, W.N., Ind. Eng. Chem., 29, 1309-14, 1937.
179	616	Schlinger, W.G. and Sage, B.H., Ind. Eng. Chem., 44, 2454-6, 1952.
180	325	Schnaible, H.W. and Smith, J.M., Chem. Eng. Progr., Symposium Ser., 49(7), 159-65, 1953.

Ref. No.	TPRC No.	
181	6539	Schrock, V.E., Gott, R.E., and Starkman, E.S., WADC, TR-56-104, 1-144, 1956. [AD 103 097]
182	33765	Schultz, J.W., Ind. Eng. Chem., 22, 785-88, 1930.
183	16565	Schuster, F., Warme, 58, 39-40, 1935.
184	13923	Schwarz, C., Arch. Eisenhuttenw, 7, 281-92, 1933.
185	14114	Schwarz, C., Arch. Eisenhuttenw, 9, 389-96, 1935.
186	1747	Scott, D.W., Waddington, G., Smith, J.C., and Huffman, H.M., J. Chem. Phys., 15, 565-8, 1947.
187	699	Sheindlin, A.E. and Shleifer, S.G., Zhur. Tekh. Fiz., 23, 1411-26, 1953.
188	9335	Shiba, H., Inst. Phys. Chem. Research (Tokyo), 16, 205-41, 1931.
189	19881	Shirkevich, M.G., Uchenye Zapiski Moskov Oblast, Pedagog, Inst., 43, 119-27, 1956.
190	1831	Sieg, L., Crutzen, J.L., and Jost, W., Z. Physik. Chem. (Leipzig), 198A, 263-9, 1951.
191	525	Sinke, G.C. and DeVries, T., J. Am. Chem. Soc., 75, 1815-18, 1953.
192	8282	Sinke, G.C., AR-15-59, 1959. [AD 214 587]
193	2004	Smith, J.M., Chem. Eng. Progr., 44(7), 521-8, 1948.
194	18082	Sokolov, S.N., Izvest. Vysshikh Ucheb. Zavedenii Neft i Gaz, 2(4), 79-84, 1959.
195	6339	Spencer, H.M., Ind. Eng. Chem., 40, 2152-4, 1948.
196	2445	Spencer, H.M., J. Am. Chem. Soc., 67, 1859-60, 1945.
197	5178	Spencer, H.M. and Flannagan, G.N., J. Am. Chem. Soc., 64, 2511-13, 1942.
198	12862	Stage, H., Faldix, P., Kurth, W., and Muller, E., Chem. Tech. (Berlin), 6, 132-8, 1954.
199	567	Staveley, L.A.K., Tupman, W.I., and Hart, K.R., Trans. Faraday Soc., 51, 323-43, 1955.
200	12455	Stephens, R.W.B., Phil. Mag., 17, 297-312, 1934.
201	12139	Stull, D.R., J. Am. Chem. Soc., 59, 2726-33, 1937.
202	1008	Stull, D.R. and Mayfield, F.D., Ind. Eng. Chem., 35, 639-45, 1943.
203	1008	Stull, D.R. and Mayfield, F.D., Ind. Eng. Chem., 35, 1303-4, 1943.
204	1365	Sun, C. and Liu, J., J. Chinese Chem. Soc., 17, 1-8, 1950.
205	14175	Sweigert, R.L. and Beardsley, M.W. Georgia School Tech. Eng. Expt. Sta.Bulletin, 2, 1-11, 1938.
206	11718	Tanner, H.G., Benning, A.F., and Mathewson, W.F., Ind. Eng. Chem., 31, 878-83, 1939.
207	33572	Taylor, C.A. and Rinkenbach, W.H., Ind. Eng. Chem., 18, 676-8, 1926.
208	5162	Taylor, M.J., Wagman, D.D., Williams, M.G., Pitzer, K.S., and Rossini, F.D., J. Research Natl. Bur. Standards, 37, 95-122, 1946.
209	33590	Templeton, D.H., Davies, D.D., and Felsing, W.A., J. Am. Chem. Soc., 66, 2033-5, 1944.
210	368	Teranishi, H., Rev. Phys. Chem. Japan, 25, 25-33, 1955.
211	302	Tetzlaff, W., Ciencia Y Cult, (Maracaibo), 2(5), 77-105, 1957.
212	21889	Thayer, V.R. and Stegeman, G., J. Phys. Chem., 35, 1505-11, 1931.
213	8059	Thompson, H.W., Trans. Faraday Soc., 37, 344, 1941.
214	33582	Thompson, H.W. and Temple, R.B., J. Chem. Soc., 1948, 1422-8, 1948.
215	11120	Trew. V.C.G., Watkins, M.C., Trans. Faraday. Soc., 29, 1310-18, 1933.
216	9340	Tsien, H.S., J. Am. Rocket Soc., 23, 17-24, 35, 1953.
217	1361	Valentin, F.H.H., J. Chem. Soc., 498-500, 1950.
218	9358	Van Wie, N.H. and Ebel, R.A., AEC and OTS, K-1430, 1, 1-242, 1959.
219	9359	Van Wie, N.H. and Ebel, R.A., AEC and OTS, K-1430, 2, 1-27, 1959.
220	15361	Vold, R.D., J. Am. Chem. Soc., 57, 1192-5, 1935.
221	33587	Vold, R.D., J. Am. Chem. Soc., 59, 1515-21, 1937.
222	2500	Vvedenskii, A.A., Neftyanoe Khoz., 25(2), 47-50, 1947.
223	5608	Wacker, P.F., Cheney, R.K., and Scott, R.B., J. Research Natl. Bur. Standards, 38, 651-9, 1947.
224	1815	Waddington, G. and Douslin, D.R., J. Am. Chem. Soc., 69, 2275-9, 1947.
225	3901	Waddington, G., Todd, S.S., and Huffman, H.M., J. Am. Chem. Soc., 69, 22-30, 1947.

Ref. No.	TPRC No.	
226	4265	Wagman, D.D., Kilpatrick, J.E., Taylor, W.J., Pitzer, K.S., and Rossini, F.D., J. Research Natl. Bur. Standards, 34, 143-61, 1945.
227	4525	Wagman, D.D., Kilpatrick, J.E., Pitzer, K.S., and Rossini, F.D., J. Research Natl. Bur . Standards, 35, 467-96, 1946.
228	33762	Weissman, H.B., Meister, A.G., and Cleveland, F.F., J. Chem. Phys., 29, 72-7, 1958.
229	1248	Weltner, W., Jr. and Pitzer, K.S., J. Am. Chem. Soc., 73, 2606-10, 1951.
230	21828	Wiebe, R., Hubbard, K.H., and Brevoort, M.J., J. Am. Chem. Soc., 52, 611-22, 1930.
231	21778	Williams, J.W. and Daniels, F., J. Am. Chem. Soc., 46, 903-17, 1924.
232	21776	Williams, J.W. and Daniels, F., J. Am. Chem. Soc., 46, 1569-77, 1924.
233	12337	Witt, R.K. and Kemp, J.D., J. Am. Chem. Soc., 59, 273-6, 1937.
234	494	Yusufova, V.D., Trudy Energet. Inst. Akad. Nauk, Azerbaidzhan. SSR, 1, 127-41, 1953.
235	13541	Zeise, H., Z. Elektrochem., 45, 456-63, 1939.
236	3771	Zeise, H., Z. Elektrochem., 48, 425, 1942.
237	4671	Zhdanov, A.K., J. Gen. Chem. USSR (Engl. Transl.), 11, 471-81, 1941.
238	21796	Andrews, D.H., Lynn, G., and Johnston, J., J. Am. Chem. Soc., 48, 1274-87, 1926.
239	22862	Bennewitz, K. and Wendroth, H., Z. Physik. Chem. (Leipzig), 125, 111-34. 1927.
240	22874	Clusius, K., Z. Physik. Chem. (Leipzig), B3, 41-79, 1929.
241	33769	Dixon, H.B., Campbell, C., and Parker, A., Proc. Roy. Soc. (London), A100, 1-26, 1921.
242	33770	Gordon, J.S., J. Chem. Phys., 29, 899-90, 1958.
243	21805	Kelley, K.K., J. Am. Chem. Soc., 51, 180-87, 1929.
244	21816	Kelley, K.K., J. Am. Chem. Soc., 51, 1145-50, 1929.
245	21781	Keyes, F.G. and Beattie, J.A., J. Am. Chem. Soc., 46, 1753-60, 1924.
246	28372	Osborne, D.W., Garner, C.S., Doescher, R.N., and Yost, D.M., J. Am. Chem. Soc., 63, 3496-9, 1941.
247	21798	Parks, G.S. and Huffman, H.M., J. Am. Chem. Soc., 48, 2788-93, 1926.
248	21827	Wiebe, R. and Brevoort, M.J., J. Am. Chem. Soc., 52, 622-33, 1930.
249	28791	Koch, B., "Grundlagen des Warmeaustausches", Verlagsaustalt H. Beucke and Sohne, 1950.
250	28079	Din, F. (Ed.), "Thermodynamic Functions of Gases", Vol. 1, Butterworths Sci. Publ., London, 1956.
251	28079	Din, F. (Ed.), "Thermodynamic Functions of Gases", Vol. 2, Butterworths Sci. Publ., London, 1956.
252	28079	Din, F. (Ed.), "Thermodynamic Functions of Gases", Vol. 3, Butterworths Sci. Publ., London, 1961.
253	33799	"Selected Values of Properties of Hydrocarbons and Related Compounds", American Petroleum Institute Research Project 44, Chem. Thermo. Properties Center, A and M College of Texas, College Station, Texas.
254	29402	"JANAF Thermochemical Tables", Thermal Research Laboratory, The Dow Chemical Co., Midland, Michigan.
255	28832	"Matheson Gas Data Book", The Matheson Co., Inc., E. Rutherford, New Jersey, 1961.
256		Natl. Bur. of Standards, Cooperative Fuel Research Committee, Aviation Fuels Division, Cooling Liquids Project, Physical Properties Group, "Physical Properties of Aqueous Ethylene Glycol Solutions", 1943.
257	17523	Swietoslawski, W. and Zielenkiewicz, A., Bull. Acad.-Polon. Sci., Ser. sci., chim. geol. et geograph, 6, 365-6, 1958.
258	17524	Swietoslawski, W. and Zielenkiewicz, A., Bull. Acad.-Polon. Sci., Ser. sci., chim. geol. et geograph, 6, 367-9, 1958.
259	30824	Van Itterbeek, A., Verbeke, O., and Staes, K., Physica, 29(6), 742-54, 1963.
260	6950	Staff Appl. Phys. Lab., John Hopkins Univ., "Handbook of Supersonic Aerodynamics, "USGPO NAVORD Rpt. 1488 (Vol. 5), 239 pp., 1953.
261	726	Aston, J.G. and Mastrangelo, S.V.R., Supt. of Docs. USGPO NBS Circ. 519, 191-2, 1952.
262	1033	Aston, J.G., Szasz, G.J., and Kington, G.L., J. Am. Chem. Soc., 73, 1937-8, 1951.
263	705	Baehr, H.D., Z. Elektrochem. 59, 32-5, 1955.

Ref. No.	TPRC No.	
264	948	Barrow, G.M. and Pitzer, K.S., Ind. Eng. Chem., 41, 2737-40, 1949.
265	7073	Beckett, C.W. and Fano, L., NBS Rept. 2562, 1-51, 1953. [AD 20002]
266	19350	Beckett, C.W. and Haar, L., Proc. Conf. Thermodynamic and Transport Properties Fluids, London, 1957, 27-33, (Pub. 1958).
267	10025	Belzer, J., Savedoff, L.G., and Johnston, H.L., TR-316-6, 1-9, 1953. [AD 11325]
268	3421	Bennewitz, K. and Schulze, O., Z. Physik Chem., 186A, 299-313, 1940.
269	9954	Bentley, R., Brown, G., and Schlegel, R., Metall Lab., Univ. of Chicago, AEC and OTS, CP-3061, 1-48, 1945.
270	12558	Bestehorn, R., Motortech. Z., 7, 42-5, 1946.
271	15348	Blue, R.W. and Giauque, W.F., J. Am. Chem. Soc., 57, 991-7, 1935.
272	9066	Boekemeier, D.W., J. Aero/Space Sci., 25(10), 658-9, 1958.
273	1890	Bolshakov, P.E., J. Phys. Chem. (USSR), 18, 121-30, 1944.
274	10508	Bonilla, C.F., Bowen, J.S., Jr., Brooks, R.D., Glassman, I., Heine, M.A., Hoffman, H.W., and Walker, L., Jr., ASTIA, 1-57, 1948. [AD 97581].
275	1698	Borger, H.E.A., J. Sci. Ind. Research (India), 13B, 595-7, 1954.
276	9769	Brewer, D.F., Sreedhar, A.K., Kramers, H.C., and Daunt, J.G., Phys. Rev., 110, 282-4, 1958.
277	35169	Brinkworth, J.H., Proc. Roy. Soc. (London), 107, 510-43, 1925.
278	16482	Bruckner, H., Z. Anal. Chem., 100, 281-4, 1935.
279	5465	Brunot, A.W., Trans. Am. Soc. Mech. Engrs., 62, 613-9, 1940.
280	14668	Burger, L.L., Fluorine Chemistry, 1, 315-8, 1950.
281	16079	Burhorn, F. and Wienecke, R., Z. Physik. Chem., 213, 37-43, 1960.
282	10786	Cann, G.L. and Ducati, A.C., Giannini Research Lab., AFOSR, TN-59-633, 1-76, 1959. [AD 228710]
283	16895	Chelton, D.B. and Mann, D.B., OTS, UCRL-3421, 1-116, 1956.
284	16745	Chen, L.H., OTS, GA-1038, 1-157, 1959.
285	15351	Chipman, J. and Fontana, M.G., J. Am. Chem. Soc., 57, 78-51, 1935.
286	18865	Chopin, M., Compt. Rend., 188, 1660-2, 1929.
287	21854	Clayton, J.O. and Giauque, W.F., J. Am. Chem. Soc., 54,2610-26, 1932.
288	11468	Clusius, K. and Bartholome, E., Z. Physik. Chem., B30, 237-57, 1935.
289	35180	Clusius, K., Z.Phys. Chem., B31, 459-74, 1936.
290	10270	Clusius, K. and Bartholome, E., Nachr ges wiss gottingen math-physik klasse, 1, 29-39, 1934.
291	15822	Clusius, K. and Bartholome, E., Naturwissenschaften, 22, 297, 1934.
292	11473	Clusius, K. and Frank, A., Z. Physik. Chem. B34,420-31, 1936.
293	22876	Clusius, K. and Hiller, K., Z. Phys. Chem., B4, 158-68, 1929.
294	13563	Clusius, K., Kruis, A., and Konnertz, F., Ann. Physik, (5)33, 642-50, 1938.
295	11481	Clusius, K. and Riccoboni, L., Z. Physik. Chem., B38, 81-95, 1937.
296	8796	Cockett, A.H. and Ferguson, A., Phil. Mag., 29, 185-99, 1940.
297	10332	Colburn, A.P., Drew, T.B. and Worthington, H., Ind. Eng. Chem., 39, 958-64, 1947.
298	33867	Cole, L.G., Farber, M., and Elverum, G.W., J. Chem. Phys., 20(4), 586-90, 1952.
299	436	Cramer, F., Chem-Ing. Tech., 27, 484-97, 1955.
300	33579	Cross, P.C., J. Chem. Phys., 3, 168-69, 1935.
301	33580	Cross, P.C., J. Chem. Phys., 3, 825-7, 1935.
302	16501	Curtiss, C.F. and Hirschfelder, J.O., CM-472, 1-12, 1948. [ATI 35673]
303	11199	Daugherty, F.L., Trans. Am. Soc. Mech. Engrs. 57, 193-6, 1935.
304	15335	Davis, C.O. and Johnston, H.L., J. Am. Chem. Soc., 56, 1045-7, 1934.
305	1855	DeGroot, S.R. and Michels, A., Physica, 14, 218-22, 1948.
306	14501	DeLaet, J., Verhandl K. Vlaamse Acad. Wetensch. (Belgium), (66), 1-52, 1960.
307	22324	Deming, W.E. and Shupe, L.E., Phys. Rev., 37, 638-54, 1931.

Ref. No.	TPRC No.	
308	22328	Deming, W.E. and Shupe, L.E., Phys. Rev., 40, 848-59, 1932.
309	14119	Collins, S.C. and Keyes, F.G., Proc. Am. Acad. Arts Sci., 72, 283-99, 1938.
310	449	Dokoupil, Z., Van Soest, G., Wansink, D.H.N., and Kapadnis, D.G., Physica, 20, 1181-8, 1954.
311	6464	Dommett, R.L., RAE-TN-GW 429, 1-39, 1956. [AD 115386]
312	3782	Drain, L.E. and Morrison, J.A., Trans. Faraday Soc., 48, 840-7, 1952.
313	16058	Eckert, E.R.G., Ibele, W.E., and Irvine, T.F., Jr., NASA, TN D-533, 1-39, 1960. [AD 241 819]
314	10575	Edse, R., WADC TR-57-485, 1-37, 1956. [AD 151 184]
315	8263	English, R.E. and Hauser, C.H., NACA, RM E56G03, 1-85, 1956.
316	1237	Eucken, A. and Eigen, M., Z. Elektrochem., 55, 343-54, 1951.
317	35181	Eucken, A. and Karwat, E., Z. Phys. Chem., 112, 467-85, 1924.
318	12901	Eucken, A. and Krome, H., Z. Phys. Chem., B45, 175-92, 1940.
319	35179	Eucken, A. and Mucke, O., Z. Phys. Chem., B18, 167-88, 1932.
320	35182	Eucken, A. and Schroder, E., Z. Phys. Chem., B41, 307-19, 1938.
321	401	Evans, W.H., Munson, T.R., and Wagman, D.D., J. Research Natl. Bur. Standards, 55, 147-64, 1955.
322	450	Evans, W.H. and Wagman, D.D., J. Research Natl. Bur. Standards, 49, 141-8, 1952.
323	10563	Evans, W.H., Wagman, D.D., and Prosen, E.J., NBS 4943, 1-73, 1956. [AD 129 837]
324	15932	Evans, W.H., Wagman, D.D., and Prosen, E.J., NBS Rpt. 6252, 1-23, 1958.
325	7072	Fano, L., Hubbell, J.H., and Beckett, C.W., NBS Rpt. 2535, 1-57, 1953. [AD 19 904]
326	750	Fano, L., Hubbell, J.H., and Beckett, C.W., NACA TN 3273, 1-61, 1956. [AD 103 415]
327	17031	Farber, M., Davis, J.W., Brown, D., Fisher, C.E., and Schmus, W.R., 1-24, 1960. [AD 250 175]
328	12675	Felsing, W.A. and Drake, G.W., J. Am. Chem. Soc., 58, 1714-7, 1936.
329	11671	Ferguson, A. and Cockett, A.H., Nature, 138, 842-3, 1936.
330	10467	Fielding, D. and Topps, J.E.C., R and M 3099, NASA N-80770, 1-115, 1959.
331	960	Frederikse, H.P.R., Physica, 15(10), 860-2, 1949.
332	702	Friedman, A.S. and Haar, L., J. Chem. Phys., 22(12), 205-8, 1954.
333	10503	Friedman, A.S. and Haar, L., NBS Rpt. 3101, 1-15, 1954. [AD 29 942]
334	3936	Fritz, W. and Koch, B., Warme-u Kalte-Tech., 42, 65-9, 1940.
335	17036	Furukawa, G.T., Reilly, M.L., Henning, J.M., Douglas, T.B., Victor, A.C., and Beaudoin, A.R., NBS Rpt. 6484, 17-35, 1959. [AD 235 429]
336	17635	Gambill, W.R., Chem. Eng., 66(7), 139-40, 1959. (Correction, 66(10), 241, 1959)
337	15705	Gelperin, I.I. and Rips, S.M., Khimstroi, 6, 599-602, 1934.
	32654	Gelperin, I.I. and Rips, S.M., SLA, TT64-10759, 10 pp., 1963.
338	35172	Gerhardt, R.V., Brunner, F.D., Mickley, H.S., Sage, B.H., and Lacey, W.N., Mech. Eng., 64, 270-2, 1942.
339	35166	Giauque, W.F., J. Am. Chem. Soc., 52, 4816-31, 1930.
340	12352	Giauque, W.F. and Blue, R.W., J. Am. Chem. Soc., 58, 831-7, 1936.
341	15332	Giauque, W.F. and Clayton, J.O., J. Am. Chem. Soc., 55, 4875-89, 1933.
342	11617	Giauque, W.F. and Kemp, J.D., J. Chem. Phys., 6, 40-52, 1938.
343	11872	Giauque, W.F. and Powell, T.M., J. Am. Chem. Soc., 61, 1970-4, 1939.
344	11847	Giauque, W.F. and Stephenson, C.C., J. Am. Chem. Soc., 60, 1389-94, 1938.
345	6733	Glassman, I. and Bonilla, C.F., Chem. Eng. Progr. Symp. Ser., 49(5), 153-62, 1953.
346	7006	Glassner, A., USGPO, ANL 5750, 1-70, 1957.
347	10072	Glatt, L., Adams, J.H., and Johnston, H.L., TR 316-8, 1-26, 1953. [AD 13 782]
348	10166	Glatt, L., Belzer, J., and Johnston, H.L., TR 316-10, 1-12, 1953. [AD 16 678]
349	506	Godnev, I.N., Zhur. Fiz. Khim., 27, 1702-9, 1953.
350	15706	Godnev, I.N. and Sverdlin, A.S., Khimstroi, 6, 8-14, 1934.
	32666	Godnev, I.N. and Sverdlin, A.S., SLA-TT-64-10760, 1-20, 1963.

Ref. No.	TPRC No.	
351	8480	Goff, J. A. and Gratch, S., Trans. A.S.M.E., 72, 741-9, 1950.
352	10360	Gordon, A.R., J. Chem. Phys., 2, 65-72, 1934.
353	35178	Gordon, A.R., J. Chem. Phys., 2, 549, 1934.
354	35184	Gordon, A.R. and Barnes, C., J. Phys. Chem., 36, 1143-51, 1932.
355	12399	Gordon, A.R. and Barnes, C., J. Chem. Phys., 1, 692-5, 1933.
356	12005	Gorter, C.J., Kasteleijn, P.W., and Mellink, J.H., Physica, 16(2), 113-21, 1950.
357	134	Granet, I., Petroleum Refiner, 33(5), 205-6, 1954.
358	1665	Granet, I. and Kass, P., Petroleum Refiner, 31(10), 113-4, 1952.
359	1662	Granet, I. and Kass, P., Petroleum Refiner, 31(11), 137-8, 1952.
360	1664	Granet, I. and Kass, P., Petroleum Refiner, 32(3), 149-50, 1953.
361	24287	Gratch, S., Trans. ASME, 71, 897-902, 1949.
362	6625	Gratch, S., 1-84, 1950. [ATI 79488]
363	11494	Gutsche, H., Z. Phys. Chem. A184, 45-58, 1939.
364	3973	Haar, L., Bradley, J.C., and Friedman, A.S., J. Research Natl. Bur. Standards, 55, 285-90, 1955.
365	10116	Haar, L., Bradley, J. C., and Friedman, A.S., NBS Rpt. 4067, 1-22, 1955. [AD 68056]
366	7698	Hall, E.W. and Weber, R.J., NACA RM E56B27, 1-82, 1956. [AD 117785 and AD 160115]
367	1830	Hall, N.A., S.A.E. Quart Trans., 1, 490-7, 1947.
368	7119	Hall, N.A. and Ibele, W.E., 1-157, 1951. [AD 42301]
369	6961	Hansen, C.F., NACA TN4150, 67, 1958. [AD 156266]
370	15665	Hansen, C.F., NASA TR-R-50, 1-35, 1959.
371	914	Harrison, R.H. and Kobe, K.A., Chem. Eng. Prog., 49, 349-53, 1953.
372	11652	Haupt, R.F. and Teller, E., J. Chem. Phys., 7, 925-7, 1939.
373	15200	Havlicek, J. and Miskovsky, L., Helv. Phys. Acta, 9, 161-207, 1936.
374	19913	Haywood, R.W., "Thermodynamic Tables and Other Data" 2nd Ed. Cambridge Univ. Press, 23 pp., 1960.
375	3603	Heck, R.C.H., Mech. Eng., 62, 9-12, 1940.
376	1139	Heck, R.C.H., Mech. Eng., 63, 126-35, 1941.
377	14861	Hellman, Die Warme, 59, 495-7, 1936.
378	22440	Henry, P.S.H., Proc. Roy. Soc. (London), A133, 492-506, 1931.
379	464	Hercus, G.R. and Wilks, J., Phil. Mag., 45, 1163-72, 1954.
380	19460	Hildenbrand, D.L., C-623, 1-157, 1959. [AD 233467]
381	11522	Hildenbrand, D.L., Kramer, W.R., McDonald, R.A., and Stull, D.R., J. Am. Chem.Soc., 80, 4129-32, 1958.
382	462	Hill, R.W. and Lounasmaa, O.V., Phil. Mag. (8)2, 143-8, 1957.
383	17228	Hill, R.W. and Lounasmaa, O.V., Phil. Trans. Roy. Soc. (London), A252, 357-95, 1960.
384	6561	Hilsenrath, J., Green, M.S., and Beckett, C.W., AFSWC TR 56-35, 1-22, 1957. [AD 96303]
385	10696	Hochstim, A.R., ZPH-004, /REV/ 1-193, 1958. [AD 207515]
386	10607	Hochstim, A.R. and Arave, R.J., ZPH-004, 1-135, 1957. [AD 152728]
387	915	Hu, Jih-Heng, White, D., and Johnston. H.L., J. Am. Chem. Soc., 75, 5642-5, 1953.
388	7040	Hu, Jih-Heng, White, D., and Johnston, H.L., TR-283-23, 1-11, 1953. [AD 10067]
389	8274	Huff, V.N., Gordon, S., and Morrell, V.E., NACA Rept. 1037, 1-57, 1951.
390	1246	Hull, R.A., Wilkinson, K.R., and Wilks, J., Proc. Phys. Soc. (London), A64, 379-88, 1951.
391	16391	Jacyna, V., Z. Phys., 92, 661-74, 1934.
392	15953	Jessel, R., Proc. Phys. Soc. (London), 46, 747-63, 1934.
393	15852	Johnston, H.L. and Chapman, A.T., J. Am. Chem. Soc., 55, 153-72, 1933.
394	379	Johnston, H.L., Clarke, J.T., Rifkin, E.B., and Keer, E.C., J. Am. Chem. Soc., 72, 3933-8, 1950.
395	15859	Johnston, H.L. and Davis, C.O., J. Am. Chem. Soc., 56, 271-6, 1934.

Ref. No.	TPRC No.	
396	15400	Johnston, H.L. and Long, E.A., J. Chem. Phys., 2, 389-95, 1934.
397	10347	Johnston, H.L. and Walker, M.K., J. Am. Chem. Soc., 55, 172-86, 1933.
398	15346	Johnston, H.L. and Walker, M.K., J. Am. Chem. Soc., 57, 682-4, 1935.
399	14254	Jones, H., Proc. Cambridge Phil. Soc., 34, 253-61, 1938.
400	301	Jones, G.O. and Walker, P.A., Proc. Phys. Soc. (London), B69, 1348-9, 1956.
401	15157	Justi, E., Forsch. Gebiete Ingenieurw., A2 117-24, 1931.
402	13560	Justi, E., Ann. Phys., (5)29, 302-5, 1937.
403	6377	Kallman, H.K., RM 442, 1-44, 1950. [AD 103216]
404	35185	Kassel, L.S., J. Chem. Phys., 1, 576-85, 1933.
405	33585	Kassel, L.S., J. Am. Chem. Soc., 56, 1838-42, 1934.
406	10510	Kays, W.M. and London, A.L., Stanford Univ., Tech. Rept. No. 23, 1954. [AD 49051]
407	1814	Kazarnovskii, Y.S., and Karapetyants, M.K., J. Phys. Chem. (USSR), 17, 172-86, 1943.
408	35170	Keenan, J.H., Mech. Eng., 48(2), 144-51, 1926.
409	13143	Keesom, W.H., Z. Ges, Kalte-Ind., 40, 49-54, 1933.
410	14594	Keesom, W.H. and Keesom, A.P., Proc. Acad. Sci. Amsterdam, 35, 736-42, 1932.
411	11010	Keesom, W.H. and Keesom, A.P., Physica, 2, 557-69, 1935.
412	11911	Keesom, W.H. and Keesom, A.P., Physica, 3, 105-17, 1936.
413	12583	Keesom, W.H. and Van Lammeren, J.A., Physica, 1, 1161-70, 1934.
414	1205	Keesom, W.H. and Westmijze, W.K., Physica, 8(9), 1044, 1941.
415	21812	Kelley, K.K., J. Am. Chem. Soc., 51, 779-86, 1929.
416	300	Kerr, E.C., Univ. Microfilms Publ., 21480, 1-80, 1957.
417	479	Kerr, E.C., Rifkin, E.B., Johnston, H.L., and Clarke, J.T.,J. Am. Chem. Soc., 73, 282-4, 1951.
418	1812	Keyes, F.G., J. Chem. Phys., 17, 923-34, 1949.
419	35171	Keyes, F.G., Smith, L.B., and Gerry, H.T., Mech. Eng., 56, 87-92, 1934.
420	35186	Keyes, F.G., Smith, L.B., and Gerry, H.T., Proc. Am. Acad. Arts and Sci., 70, 319-64, 1936.
421	10463	King, C.R., NASA TN-D-275, 1-71, 1960. [AD 235647]
422	22305	King, F.E. and Partington, J.R., Phil. Mag., (7)9, 1020-6, 1930.
423	6987	Kirillin, V.A., Sheindlin, A.E., and Shpilrain, E.E., Teploenergetika, 3(1), 16-21, 1956.
424	22937	Knoblauch, O. and Koch, W., VDI Z., 72, 1733-9, 1928.
425	20506	Knoblauch, O. and Raisch, E., VDI Z., 66, (17), 418-23, 1922.
426	962	Kobe, K.A. and Long, E.G., Petroleum Refiner, 28(11), 127-32, 1949.
427	1344	Kobe, K.A. and Long, E.G., Petroleum Refiner, 29(1), 126-30, 1950.
428	1370	Kobe, K.A. and Long, E.G., Petroleum Refiner, 29(2), 124-8, 1950.
429	1210	Kobe, K.A. and Pennington, R.E., Petroleum Refiner, 29(7), 129-33, 1950.
430	35177	Koch, W., Forsch. Gebiete Ingenieurw., 3, 189-92, 1932.
431	35176	Koch, W., Z. Tech. Physik, 13, 263-6, 1932.
432	10263	Koch, W., Forsch. Gebiete Ingenieurw., B5, 138-45, 1934.
433	993	Koeppe, W., Kaltetechnik, 9, 30-1, 1957.
434	15979	Koeppe, W., Forsch. Gebiete Ingenieurw., 24, 161-4. 1958.
435	6996	Kolsky, H.G., OTS, LA 2110, 1-138, 1957.
436	18101	Konecny, V., Jaderna Energie, 5, 336-9, 1959.
437	654	Kramers, H.C., Koninkl. Ned. Akad. Wetenschap., Proc., B58, 366-400, 1955.
438	9231	Kramers, H.C., Koninkl. Ned. Akad. Wetenschap., Proc., B58, 386-400, 1955.
439	1787	Kramers, H.C., Wasscher, J.D., and Gorter, C.J., Physica, 18, 329-38, 1952.
440	11482	Kruis, A. and Clusius, K., Z. Phys. Chem., B38, 156-76, 1937.
441	6383	Kubaschewski, O., Trans. Faraday Soc., 45(10), 931-40, 1949.
442	12989	Lachner, H., Metall, 12, 387-95, 1958.

Ref. No.	TPRC No.	
443	7061	Lemmon, A.W., Jr., Daniels, D.J., Sparrow, D.E., Geankoplis, C.J., Ward, J.J., and Clegg, J.W., BMI 858, 1-64, 1953. [AD 18337]
444	14381	Lewis, B. and Von Elbe, G., J. Am. Chem. Soc., 55, 511-9, 1933.
445	16595	Liberto, R.R., AFFTC, TR 60-62, 1-70, 1960. [AD 249542]
446	17005	Little, A.D., AFFTC, TR 60-19, 1-246, 1960. [AD 242285]
447	6406	Logan, J.G., Jr. and Turner, C.E., 1-307, 1957. [AD 143759]
448	10009	Lounasmaa, O.V. and Kojo, E., Ann. Acad. Sci. Fennicae, A6(36), 1-25, 1959.
449	1795	Lunbeck, R.J., Michels, A., and Wolkers, G.J., Applied Sci. Research, A3, 197-210, 1952.
450	1506	MacCormack, K.E. and Schneider, W.G., J. Chem. Phys., 18, 1273-5, 1950.
451	21726	Mackey, B.H. and Krase, N.W., Ind. Eng. Chem., 22, 1060-2, 1930.
452	16877	Mann, D.B. and Stewart, R.B., NBS Tech. Note-8, 1-39, 1959. [PB 151367]
453	557	Masi, J.F. and Petkof, B., J. Research Natl. Bur. Standards, 48, 179-87, 1952.
454	10976	Massey, G.V., DEG. Rept. 14 (D), 1-19, 1960.
455	35193	Mastrangelos, V.R. and Aston, J.G., J. Chem. Phys., 19(11), 1370-5, 1951.
456	15203	Maxwell, G.B. and Wheeler, R.V., J. Chem. Soc., 882-5, 1933.
457	16875	Chelton, D.B. and Mann, D.B., WADC TR-59-8, 1-144, 1959. [AD 208155]
458	27459	McBride, B.J. and Gordon, S., J. Chem. Phys., 35, 2198-2206, 1961.
459	530	McCullough, J.P., Pennington, R.E., and Waddington, G., J. Am. Chem. Soc., 74, 4439-42, 1952.
460	10577	McKowen, P., Tech. Data Rept. 02-984-040, 1-428, 1957. [AD 142607]
461	15723	Michels, A., DeGraaff, W., and Wolkers, G.J., Physica, 25, 1097-1124, 1959.
462	4491	Michels, A., and DeGroot, S.R., Applied Sci. Research, A1, 94-102, 1948.
463	8180	Michels, A., Levelt, J.M., and Wolkers, G.J., Physica, 24, 769-94, 1958.
464	959	Michels, A., Lunbeck, R.J., and Wolkers, G.J., Physica, 15, 689-95, 1949.
465	985	Michels, A., Lunbeck, R.J., and Wolkers, G.J., Applied Sci. Research, A2, 345-50, 1951.
466	1808	Michels, A., Lunbeck, R.J., and Wolkers, G.J., Physica, 17, 801-16, 1951.
467	1054	Michels, A., Lunbeck, R.J., and Wolkers, G.J., Appl. Sci. Research, A3, 253-60, 1952.
468	1832	Michels, A., Lunbeck, R.J., and Wolkers, G.J., Physica, 18, 128-34, 1952.
469	419	Michels, A., Wassenaar, T., Wolkers, G.J., and Dawson, J., Physica, 22, 17-28, 1956.
470	618	Michels, A., Wassenaar, T., and Wolkers, G.J., Appl. Sci. Research, A5, 121-36, 1955.
471	4182	Michels, A. and Wouters, H., Physica, 8, 923-32, 1941.
472	6380	Misra, S.C., Indian J. Phys., 30, 626-7, 1956.
473	383	Morrison, J.A., Drain, L.E., and Dugdale, J.S., Can. J. Chem., 30, 890-903, 1952.
474	1386	Morrison, J.A., Los, J.M., and Drain, L.E., Trans. Faraday Soc., 47, 1023-30, 1951.
475	1773	Morrison, J.A. and Szasz, G.J., J. Chem. Phys., 16, 280-6, 1948.
476	1208	Murphy, G.M. and Vance, J.E., J. Chem. Phys., 18, 1514-5, 1950.
477	11656	Murphy, G.M. and Vance, J.E., J. Chem. Phys., 7, 806-10, 1939.
478	16813	NBS CIRC. 142, 1-48, 1923.
479	10718	NBS, Rept. 6297, 1-136, 1959. [AD 213384]
480	6663	Newman, B.O., Gen. Elect. Rept. GI-401, 1-29, 1947. [AD 64951]
481	434	Nicklin, A.W., UKAEA Ind. Group Tech. Note, No. 36, 1-20, 1956.
482	14896	Okamura, T., Science Repts. Tohoku Imp. Univ., 22, 519-36, 1933.
483	11670	Osborne, N.S., Stimson, H.F., and Ginnings, D.C., J. Res. Natl. Bur. Standards, 23, 197-260, 1939.
484	12344	Overstreet, R. and Giauque, W.F., J. Am. Chem. Soc., 59, 254-9, 1937.
485	1583	Pace, E.L., Berg, W.T., and Siebert, A.R., J. Am. Chem. Soc., 78, 1531-3, 1956.
486	6538	Pack, D.H. and Hill, G.R., MCC 1023-TR-169, 1-67, 1955. [AD 103146]
487	21783	Parks, G.S., J. Am. Chem. Soc., 47, 338-45, 1925.

Ref. No.	TPRC No.	
488	22288	Partington, J.R. and Shilling, W.G., Phil. Mag., 45, 416-30, 1923.
489	35187	Partington, J.R. and Shilling, W.G., Trans. Faraday Soc., 18, 386-90, 1923.
490	10624	Patterson, G.N., AGARD Rept. 134, 1-58, 1957. [AD 157 313]
491	35192	Pennington, R.E. and Kobe, K.A., J. Chem. Phys., 22(8), 1442-7, 1954.
492	13550	Phansalkar, G.R., J. Sci. Research Banaras Hindu Univ., 9(1), 29-35, 1958.
493	11051	Potter, R.L., J. Chem. Phys., 26(2), 394-7, 1957.
494	10099	Price, D., NAVORD Rept. 2876, 1-39, 1953. [AD 52 596]
495	10556	Price, D., NAVORD Rept. 3846, 1-59, 1954. [AD 123 073]
496	357	Price, D., Ind. Eng. Chem., 47, (8), 1649-52, 1955.
497	10544	Randall, R.E., AEDC-TR-57-8, 1-16, 1957. [AD 135 331]
498	10545	Randall, R.E., AEDC-TR-57-10, 1-33, 1957. [AD 135 332]
499	17781	Rasskazov, D.S. and Sheindlin, A.E., Doklady Akad. Nauk. SSSR, 120(4), 771-3, 1958.
500	17350	Rasskazov, D.S. and Sheindlin, A.E., Soviet Phys-Doklady, 3(3), 652-4, 1959.
501	15418	Ribaud, G., J. Phys. Radium, 6, 55-64, 1935.
502	16759	Rice, M.H. and Walsh, J.M., J. Chem. Phys., 26(4), 824-30, 1957.
503	2040	Rice, O.K., J. Chem. Phys., 14, 324-38, 1946.
504	12632	Riedel, L., Bull. Intern. Inst. Refrig., 20(4), (ANNEX No. 5), B1-10, 1939.
505	35173	Roebuck, J.R., Proc. Am. Acad. Arts and Sci., 60(13), 537-96, 1925.
506	35188	Roebuck, J.R., Proc. Am. Acad. Arts and Sci., 64(9), 287-334, 1930.
507	10404	Roebuck, J.R. and Osterberg, H., Phys. Rev., 48, 450-7, 1935.
508	7001	Rossini, F.D., Cowie, P.A., Ellison, F.O., and Browne, C.C., ONR Rept. ACR-17, 1-448, 1956. [AD 135 271]
509	11484	Roth, W.A., Z. Phys. Chem., A183, 38-42, 1938.
510	9504	Saurel, J.R., Genie Chim., 79, 12-22, 44-51, 1958.
511	15748	Saurel, J. and Lecocq, A., Compt. Rend., 248, 653-5, 1959.
512	15654	Scala, S.M. and Boneknight, C.W., 58SD232, 1-48, 1958.
513	15737	Schmidt, E., "VDI Steam Tables", 4th Ed., Springer-verlag, Berlin, 1-109, 1956. (6th Ed., 1-151, 1963.)
514	520	Schrock, V.E., NACA, TN 2838, 1-46, 1952.
515	15407	Scott, R.B., Brickwedde, F.G., Urey, H.C., and Wahl, M.H., J. Chem. Phys., 2, 454-64, 1934.
516	866	Sheindlin, A.E., Teploenergetika, (1), 11-9, 1954.
517	29740	Sheindlin, A.E., SLA 62-10739, 1-16, 1961.
518	19684	Sheindlin, A.E., Shpilrain, E.E., and Sychev, V.V., Teploenergetika, 5(7), 13-7, 1958.
	17362	Sheindlin, A.E., Shpilrain, E.E., and Sychev, V.V., RTS 1540, SLA 61-15396, 1-16, 1961.
519	35189	Shilling, W.G., Trans. Faraday Soc., 22, 377-400, 1926.
520	35168	Shilling, W.G. and Partington, J.R., Phil. Mag., 6, 920-9, 1928.
521	11805	Simon, F. and Swain, R.C., Z. Phys. Chem. B28, 189-98, 1935.
522	6954	Sirota, A.M., Teploenergetika, 5(7), 10-2, 1958.
523	20960	Sirota, A.M., RTS-1539 SLA 61-15409, 1-7, 1961.
524	17361	Sirota, A.M. and Maltsev, B.K., MDF-S-137, 1-15, 1959.
525	21018	Sirota, A.M. and Maltsev, B.K., Teploenergetika, 6(9), 7-15, 1959.
526	16955	Sirota, A.M., Maltsev, B.K., and Belyakova, P.E., Teploenergetika, 7(7), 16-23, 1960.
527	16950	Sirota, A.M., Maltsev, B.K., and Belyakova, P.E., SLA 61-14569, 1-20, 1961.
528	5202	Smallwood, J.C., Ind. Eng. Chem., 34, 863-4, 1942.
529	16866	Smith, A.K., WIAP-M-38, 1-49, 1954.
530	1038	Smith, A.L., Hallett, N.C., and Johnston, H.L., J. Am. Chem. Soc., 76, 1486-8, 1954.
531	28297	Spencer, H.M., J. Chem. Phys., 14, 729-32, 1946.
532	15343	Spencer, H.M. and Justice, J.L., J. Am. Chem. Soc., 56, 2311-2, 1934.

Ref. No.	TPRC No.	
533	9740	Stern, S.A., Univ. Microfilms Publ., 698, 1-190, 1958.
534	16227	Stupochenko, E.V., Stakhanov, I.P., Samuilov, E.V., Pleshanov, A.S., and Rozhdestvenskii, I.B., ARS. J., 30, 98-112, 1960.
535	12877	Su, Kou-Cheng and Huang, Tzu-Ching, J. Chinese Chem. Soc., 1, 1-9, 1933.
536	35190	Sweigert, R.S., Weber, P., and Allen, R.L., Ind. Eng. Chem., 38(2), 185-200, 1946.
537	1028	Tanishita, I., Rept. Inst. Sci. Technol. (Univ. Tokyo), 3, 122-5, 1949.
538	7070	Touloukian, Y.S., ~~NVS~~ NBS Rept. 2568, 1-23, 1953. [AD 19902]
539	6724	Traustel, S., Brennstoff-Warme-Kraft, 3(4), 120-2, 1951.
540	13130	Trautz, M. and Ader, H., Z. Physik, 89, 15-23, 1934.
541	8779	Tribus, M. and Boelter, L.M., NACA, Rept. W-9, 1-14, 1946.
542	1262	Tykodi, R.J., Aston, J.G., and Schreiner, G.D.L., J. Am. Chem. Soc., 77, 2168-71, 1955.
543	6557	Univ. Texas, 1-218, 1956. [AD 98581]
544	15847	Van Itterbeek, A., Wiss. Natuurk. Tijdschr., 5, 192, 1931.
545	10728	Van Itterbeek, A., Communs. Kamerlingh Onnes Lab. Univ. Leiden, Suppl, C70, 13-8, 1932.
546	13847	Van Itterbeek, A., J. Phys. Radium, 9, 313-8, 1938.
547	7748	Van Itterbeek, A. and DeLaet, W., Physica, 24, 59-67, 1958.
548	719	Van Itterbeek, A. and Forrez, G., Physica, 20, 767-72, 1954.
549	3522	Van Itterbeek, A. and Vandoninck, W., Ann. Phys., (11)19, 88-104, 1944.
550	11920	Van Itterbeek, A. and Van Paemel, O., Physica, 5, 593-604, 1938.
551	14079	Van Itterbeek, A. and Zink, J., Appl. Sci. Research, A7, 375-85, 1958.
552	11908	Van Lammeren, J.A., Physica, 2, 833-9, 1935.
553	19351	Vukalovich, M.P., Novikov, III., Lebed, D.V., Siletskii, V.S., Dzampov, B.V., Zubarev, V.N., and Rasskazov, D.S., Proc. Conf. Thermodynamic and Transport Properties of Fluids, London, 1957, 91-110, 1958.
554	18387	Siletz, V.S. and Fridkin, L.M. (Editors), "Vsesoyuznyc Ordena Trudovogo Krasnogo Zrameni Teplotechniicheskii Nauchno-Issledovatelskii Institut imeni F.E. Dsrjinskogo", Gosudarstvennoye Energeticheshoe Isdatelstvo Moscow Leningrad, 1952.
555	16862	Siletz, V.S. and Fridkin, L.M. (Editors), "Tables of Thermodynamic Properties of Water and Water Vapor Based on Experimental Data", Westinghouse Electric Corp., Westinghouse Electric Corp. Transl., 1-104, 1952.
556	1574	Whalley, E., Can. J. Technol., 33, 111-6, 1955.
557	3384	Wheeler, H.P., Jr., USBM Circ. 7344, 1-66, 1946.
558	643	Wiebes, J., Niels-Hakkenberg, C.G., and Kramers, H.C., Physica, 23, 625-32, 1957.
559	10145	Williams, M.M. and McEwan, W.S., NAVORD Rept. 3421, 1-99, 1955. [AD 64171]
560	15876	Wilson, M.P., Jr., U.S. At. Energy Comm., GA1355, 1-146, 1960.
561	19022	Wintle, H.J., Nature, 184(26), 2007-8, 1959.
562	15344	Witmer, E.E., J. Am. Chem. Soc., 56, 2229-33, 1934.
563	14879	Wohl, H. and Maget, M., Z. Phys. Chem., B19, 117-38, 1932.
564	10384	Woodruff, O.J., Jr., McShane, W.J., and Purcell, W.J., Nucleonics, 11(6), 27-34, 1953.
565	1771	Woolley, H.W., J. Research Natl. Bur. Stds., 40, 163-8, 1948.
566	6409	Woolley, H.W., 1-4, 1949. [AD 72777]
567	7069	Woolley, H.W., Natl. Bur. Stds. Rept. 2611, 1-25, 1953. [AD 19900]
568	7071	Woolley, H.W., Natl. Bur. Stds, Rept. 2287, 1-39, 1953. [AD 19903]
569	6562	Woolley, AFSWC TR-56-34, 1-108, 1957. [AD 96302]
570	319	Woolley, H.W., J. Research Natl. Bur. Stds., 52, 289-92, 1954.
571	15661	Woolley, H.W., Scott, R.B., and Brickwedde, F.G., J. Research Natl. Bur. Stds., 41, 379-475, 1948.
572	22321	Workman, E.J., Phys. Rev., 37, 1345-55, 1931.
573	470	Yang, Kwang-Tzu, Ind. Eng. Chem., 45, 786-8, 1953.
574	35191	Zeise, H., Z. Elektrochem., 47, 595-617, 1941.

Ref. No.	TPRC No.	
575	1558	Hilsenrath, J., Beckett, C.W., Benedict, W.S., Fano. L., Hoge, H.J., Masi, J.F., Nuttal, R.L., Touloukian, Y.S., and Woolley, H.W., Natl. Bur. Stds. Circ. 564, 1-488, 1955.
576	16714	Armstrong, R.H., ANL-6255, 1-53, 1960.
577	1551	Butkov, K.V. and Rozenbaum, R.B., Zhur, Fiz. Khim., 24, 706-13, 1950.
578	8364	Chen, L.H., ASME Symp. on Thermal Properties, 358-69, 1959.
579	16739	Hirschfelder, J.O. and Curtiss, C.F., CM-518, 1-120, 1948.
580	21644	Osborne, N.S., Stimson, H.F., Sligh, T.S., Jr., and Cragoe, C.S., Natl. Bur. Stds. Sci. Paper No. 501, 20, 65-110, 1925.
581	17353	Shiffman, C.A., USAEC Publ. NP 4945, 1-70, 1952.
582	149	Vvedenskii, A.A. and Takhtareva, N.K., Zhur. Obshchei Khim., 19, 1083-8, 1949.
	31501	Vvedenskii, A.A. and Takhtareva, N.K., J. Gen. Chem. (USSR), 19, 1075-9, 1949.
583	8328	Westrum E.F., Jr., ASME Symp. on Thermal Properties, 275-81, 1959.
~~[illegible]~~ 584	21786	Williams, J.W. and Daniels, F., J. Am. Chem. Soc., 47, 1490-1503, 1925.
585	31767	Arnold, C.W. and Kobe, K.A., Chem. Eng. Progr., 48(6), 293-6, 1952.
586	31777	Edmister, W.C., Ind. Eng. Chem., 30, 352-8, 1938.
587	31994	Fink, C.G. and Bonilla, C.F., J. Phys. Chem., 37, 1135-67, 1933.
588	32039	Gordon, A.R. and Barnes, C., J. Phys. Chem., 36, 2292-8, 1932.
589	39817	Roebuck, J.R. and Osterberg, H., Phys. Rev., 45, 332-40, 1934.
590	1714	Wilke, W., Automobiltech. Z., 56, 21-4, 1954.
591	14897	Winter-Klein, A., Compt. Rend., 250, 3000-2, 1960.
592	25152	Schumann, T.E.W. and Voss, V., Fuel in Science and Practice, 13(8), 249-56, 1934.
593	26918	Rabinovich, I.B. and Nikolaev, P.N., Proc. Akad. Sci. USSR, Phys. Chem. Sect., 142(6), 195-8, 1962.
594	40184	Weber, H.F., Exner's Repertorium, 22, 116-22, 1886.
595	27766	Blaha, O., Cesk. Casopis Fys., 12, 216-25, 1962.

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Freon 13 ($ClCF_3$)	6	210
Freon 20 (see Chloroform)		
Freon 21 (Cl_2CHF)	6	212
Freon 22 ($ClCHF_2$)	6	218
Freon 113 (CCl_2FCClF_2)	6	224
Freon 114 ($CClF_2CClF_2$)	6	228
Gadolinia (see Gadolinium oxide)		
Gadolinium	4	72
Gadolinium trichloride hexahydrate ($GdCl_3 \cdot 6H_2O$)	5	826
Gadolinium trinitrate hexahydrate ($Gd(NO_3)_3 \cdot 6H_2O$)	5	1142
Gadolinium oxide (Gd_2O_3)	5	92
Gadolinium sesquioxide (see Gadolinium oxide)		
Digadolinium trioxide (see Gadolinium oxide)		
Gallium	4	75
Gallium antimonide (GaSb)	5	300

Material Name	Vol.	Page
Magnesium aluminate (see Magnesium dialuminum tetraoxide)		
Magnesium metaaluminate (see Magnesium dialuminum tetraoxide)		
Magnesium dialuminum tetraoxide ($MgAl_2O_4$)	5	1479
Magnesium aluminum silicate (see Dimagnesium tetraaluminum pentasilicon 18-oxide)		
Dimagnesium tetraaluminum pentasilicon 18-oxide ($Mg_2Al_4Si_5O_{18}$)	5	1503
Magnesium borides:		
MgB_2	5	345
MgB_4	5	348
Magnesium diboride (MgB_2)	5	345
Magnesium tetraboride (MgB_4)	5	348
Magnesium cadmium alloys:		
MgCd	4	294
$MgCd_3$	4	300
Mg_3Cd	4	297
Magnesium chlorides:		
$MgCl_2$	5	838
$MgCl_2 \cdot H_2O$	5	841
$MgCl_2 \cdot 2H_2O$	5	844
$MgCl_2 \cdot 4H_2O$	5	847
$MgCl_2 \cdot 6H_2O$	5	850
Magnesium dichloride ($MgCl_2$)	5	838
Magnesium dichloride monohydrate ($MgCl_2 \cdot H_2O$)	5	841
Magnesium dichloride dihydrate ($MgCl_2 \cdot 2H_2O$)	5	844
Magnesium dichloride tetrahydrate ($MgCl_2 \cdot 4H_2O$)	5	847
Magnesium dichloride hexahydrate ($MgCl_2 \cdot 6H_2O$)	5	850
Magnesium chromite (see Magnesium dichromium tetraoxide)		
Magnesium dichromium tetraoxide ($MgCr_2O_4$)	5	1482
Magnesium ferrites:		
$MgFe_2O_4$	5	1485
$Mg_xFe_yO_4$	5	1488
Magnesium difluoride (MgF_2)	5	956
Magnesium germanide (see Dimagnesium germanide)		
Dimagnesium germanide (Mg_2Ge)	5	481
Magnesium diiron tetraoxide ($MgFe_2O_4$)	5	1485
Magnesium iron tetraoxide, nonstoichiometric ($Mg_xFe_yO_4$)	5	1488
Magnesium molybdate (see Magnesium molybdenum tetraoxide)		
Magnesium molybdenum tetraoxide ($MgMoO_4$)	5	1491
Magnesium nitride (see Trimagnesium dinitride)		
Trimagnesium dinitride (Mg_3N_2)	5	1084
Magnesium oxide (MgO)	5	140
Magnesium silicates:		
$MgSiO_3$	5	1494
Mg_2SiO_4	5	1497
$Mg_3Si_4O_{11} \cdot H_2O$	5	1500
Magnesium silicon trioxide ($MgSiO_3$)	5	1497
Dimagnesium silicon tetraoxide (Mg_2SiO_4)	5	1497
Trimagnesium tetrasilicon undecaoxide monohydrate ($Mg_3Si_4O_{11} \cdot H_2O$)	5	1500
Magnesium titanates:		
$MgTiO_3$	5	1506
$MgTi_2O_5$	5	1509
Mg_2TiO_4	5	1512
Magnesium dititanate (see Magnesium dititanium pentaoxide)		
Magnesium metatitanate (see Magnesium titanium trioxide)		
Dimagnesium titanate (see Dimagnesium titanium tetraoxide)		
Magnesium titanium trioxide ($MgTiO_3$)	5	1506
Magnesium dititanium pentaoxide ($MgTi_2O_5$)	5	1509
Dimagnesium titanium tetraoxide (Mg_2TiO_4)	5	1512
Magnesium tungstate (see Magnesium tungsten tetraoxide)		
Magnesium tungsten tetraoxide ($MgWO_4$)	5	1515
Magnesium vanadates:		
MgV_2O_6	5	1518
$Mg_2V_2O_7$	5	1521

Material Name	Vol.	Page
Samarium	4	193
Samarium oxide (Sm_2O_3)	5	193
Samarium sesquioxide (see Samarium oxide)		
Disamarium trioxide (see Samarium oxide)		
Scandia (see Scandium oxide)		
Scandium	4	198
Scandium oxide (Sc_2O_3)	5	196
Scandium sesquioxide (see Scandium oxide)		
Discandium trioxide (see Scandium oxide)		
Selenium	4	201
Silica (see Silicon dioxide)		
Silica glass	5	202
Silicon	4	204
Silicon carbide (SiC)	5	448
Silicon carbide + Carbon + ΣX_i, cermet ($SiC + C + \Sigma X_i$)	5	1279
Silicon tetrachloride ($SiCl_4$)	5	881
Silicon tetrafluoride (SiF_4)	5	991
Silicon nitride ~~(SiN)~~ Si_3N_4	5	1087
Silicon dioxide [SiO_2 (cristobalite)]	5	210
Silicon dioxide [SiO_2 (Quartz crystal)]	5	207
Silicon dioxide [SiO_2 (Quartz glass)]	5	202
Silicon dioxide [SiO_2 (Tridymite)]	5	213
Silicon dioxide + Dialuminum trioxide + ΣX_i ($SiO_2 + Al_2O_3 + \Sigma X_i$)	5	1546
Sillimanite (see Dialuminum silicon pentaoxide)		
Silver	4	208
Silver, electrolytic	4	208
Silver, inquartation	4	208
Disilver carbonate (Ag_2CO_3)	5	1127
Silver chloride ($AgCl$)	5	884
Silver nitrite ($AgNO_2$)	5	1148
Silver oxide (Ag_2O)	5	199
Disilver oxide (see Silver oxide)		
Silver selenides:		
Ag_2Se	5	553
Ag_xSe (nonstoichiometric)	5	556
Disilver selenide (Ag_2Se)	5	553
Silver selenide, nonstoichiometric (Ag_xSe)	5	556
Silver sulfide, nonstoichiometric (Ag_xS)	5	705
Silver tellurides:		
Ag_2Te	5	753
Ag_xTe (nonstoichiometric)	5	756
Disilver telluride (Ag_2Te)	5	753
Silver telluride, nonstoichiometric (Ag_xTe)	5	756
Soda lime glass ($SiO_2 + Na_2O + \Sigma X_i$)	5	1240
Soda-lime silica plate glass (see Soda lime glass)		
Sodium	4	213
Sodium, electrolytic	4	213
Sodium + Potassium (Na_2K)	4	431
Trisodium aluminum hexafluoride (Na_3AlF_6)	5	997
Sodium aluminate (see Sodium aluminum dioxide)		
Sodium metaaluminate (see Sodium aluminum dioxide)		
Sodium aluminum dioxide ($NaAlO_2$)	5	1549
Sodium aluminum silicate (see Sodium aluminum trisilicon octaoxide)		
Sodium aluminum trisilicon octaoxide ($NaAlSi_3O_8$)	5	1602
Sodium tetraborate (see Disodium tetraboron heptaoxide)		
Sodium borates:		
$NaBO_2$	5	1552
$Na_2B_4O_7$	5	1556
Sodium boron dioxide ($NaBO_2$)	5	1552
Disodium tetraboron heptaoxide ($Na_2B_4O_7$)	5	1556
Sodium bromide ($NaBr$)	5	772
Disodium carbonate (Na_2CO_3)	5	1130
Sodium bicarbonate ($NaHCO_3$)	5	1133
Sodium chloride ($NaCl$)	5	887

Material Name	Vol.	Page
Sodium ferrite (see Sodium iron dioxide)		
Sodium fluoride (NaF)	5	994
Sodium hydrogen carbonate (see Sodium bicarbonate)		
Sodium hexafluoroaluminate (see Trisodium aluminum hexafluoride)		
Sodium monohydrogen difluoride ($NaHF_2$)	5	1000
Sodium iodide (NaI)	5	506
Sodium iron dioxide (N_2FeO_2)	5	1560
Sodium molybdates:		
Na_2MoO_4	5	1563
$Na_2Mo_2O_7$	5	1566
Disodium molybdenum tetraoxide (Na_2MoO_4)	5	1563
Disodium dimolybdenum heptaoxide ($Na_2Mo_2O_7$)	5	1566
Sodium nitrate ($NaNO_3$)	5	1151
Sodium oxides:		
Na_2O	5	216
NaO_2	5	222
Na_2O_2	5	219
Sodium oxide (Na_2O)	5	216
Sodium superoxide (NaO_2)	5	222
Sodium peroxide (Na_2O_2)	5	219
Sodium dioxide (see Sodium superoxide)		
Disodium oxide (see Sodium oxide)		
Disodium monoxide (see Sodium oxide)		
Sodium silicates:		
Na_2SiO_3	5	1569
$Na_2Si_2O_5$	5	1572
Sodium disilicate (see Disodium disilicon pentaoxide)		
Sodium metasilicate (see Disodium silicon trioxide)		
Sodium silicate glass No. 23	5	1240
Disodium silicon trioxide (Na_2SiO_3)	5	1569
Disodium disilicon pentaoxide ($Na_2Si_2O_5$)	5	1572

Material Name	Vol.	Page
Sodium sulfates:		
Na_2SO_4	5	1218
$Na_2SO_4 \cdot 10H_2O$	5	1221
Disodium sulfate (Na_2SO_4)	5	1218
Disodium sulfate decahydrate ($Na_2SO_4 \cdot 10H_2O$)	5	1221
Sodium tellurate (see Disodium tellurium tetraoxide)		
Disodium tellurium tetraoxide (Na_2TeO_4)	5	1575
Sodium titanates:		
Na_2TiO_3	5	1578
$Na_2Ti_2O_5$	5	1581
$Na_2Ti_3O_7$	5	1584
Sodium dititanate (see Disodium dititanium pentaoxide)		
Sodium metatitanate (see Disodium titanium trioxide)		
Sodium trititanate (see Disodium trititanium heptaoxide)		
Disodium titanium trioxide (Na_2TiO_3)	5	1578
Disodium dititanium pentaoxide ($Na_2Ti_2O_5$)	5	1581
Disodium trititanium heptaoxide ($Na_2Ti_3O_7$)	5	1584
Sodium tungstates:		
Na_2WO_4	5	1587
$Na_2W_2O_7$	5	1590
Disodium tungsten tetraoxide (Na_2WO_4)	5	1587
Disodium ditungsten heptaoxide ($Na_2W_2O_7$)	5	1590
Sodium vanadates:		
$NaVO_3$	5	1593
Na_3VO_4	5	1596
$Na_4V_2O_7$	5	1599
Sodium metavanadate (see Sodium vanadium trioxide)		
Sodium orthovanadate (see Trisodium vanadium tetraoxide)		
Sodium pyrovanadate (see Tetrasodium divanadium heptaoxide)		
Sodium vanadium trioxide ($NaVO_3$)	5	1593
Trisodium vanadium tetraoxide (Na_3VO_4)	5	1596

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