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WADD TECHNICAL REPORT 60-66
PART I

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A COMPENDIUM OF THE PROPERTIES OF MATERIALS AT LOW TEMPERATURE (PHASE I)

PART I. PROPERTIES OF FLUIDS

Victor J. Johnson, General Editor

National Bureau of Standards
Cryogenic Engineering Laboratory

JULY 1960

WRIGHT AIR DEVELOPMENT DIVISION

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WADD TECHNICAL REPORT 60-56
PART I

A COMPENDIUM OF THE PROPERTIES OF MATERIALS AT LOW TEMPERATURE (PHASE I)

PART I. PROPERTIES OF FLUIDS

Victor J. Johnson, General Editor

National Bureau of Standards
Cryogenic Engineering Laboratory

OCTOBER 1960

Materials Central
Contract No. AF 33(616)-58-4
Project No. 7360

WRIGHT AIR DEVELOPMENT DIVISION
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

2,300 – January 1961 – 18-704C

FOREWORD

This report was prepared by the National Bureau of Standards Cryogenic Engineering Laboratory under U. S. Air Force Contract No. 33(616)58-4. This contract was initiated under Project No. 8-(8-7360), "Thermophysical Properties of Cryogenic Materials", Task No. 73603. The work was administered under the direction of the Physics Laboratory, Directorate of Laboratories, Wright Air Development Division, with Mr. Paul W. Dimiduk acting as project engineer.

This report covers work conducted from January 1958 to March 1959.

The following members of the Cryogenic Engineering Laboratory Staff contributed to this phase of the compendium: D. B. Mann (task author for helium), Dr. F. E. E. Germann (task author for hydrogen), Dr. K. D. Timmerhaus* (task author for neon, nitrogen and carbon monoxide), John Macinko (task author for oxygen), D. A. Van Gundy, and W. J. Veigle (task authors for air), Dr. P. L. Barrick* (task author for argon), R. F. Robbins (task author for fluorine and methane), R. L. Powell (task author for thermal conductivity of solids), and Dr. R. J. Corruccini (task author for expansivity, specific heat and enthalpy of solids); R. B. Scott and E. H. Brown reviewed most of the data sheets, noted many inconsistencies and offered many suggestions for improving the validity and usefulness of the data; Dr. R. D. Goodwin planned the program for compiling the compendium and initiated work on it. (He also along with Dr. Corruccini, conferred with the sponsor (WADC) and Armour Research Foundation regarding the scope and arrangement of the compendium. The proposal and contract were evolved from this planning.) D. B. Chelton (literature searches for nitrogen and carbon monoxide); R. V. Smith** and R. B. Stewart*** (hydrogen literature searching); Dr. V. D. Arp and J. J. Gniewek compiled data on specific heat and enthalpy of solids; R. J. Rasmussen and B. D. Troyer, graduate students, assembled much of the data for typing and drafting of the data sheets; J. A. Brennan and J. R. Cahoon monitored completion of the data sheets and prepared check prints; W. W. Bulla and G. A. Reynolds drew most of the graphs; Genevieve Michels and Signe Hartley typed most of the data sheets; and D. E. Jordan assisted in final review and completion of the compendium. Many other staff members contributed to the compendium in numerous ways but it is difficult to name them all and identify their aid. The task was a huge one and all contributions were valuable.

Many others who were sent preliminary copies of this compilation contributed helpful suggestions and criticisms of the material which has materially improved the final presentation and its accuracy. The following is a partial list of such contributions: I. Simon and I. A. Black of A. D. Little Co., F. Din of British Oxygen Co., L. C. Matsch and staff of Linde Co., W. B. Mitchell of Convair Astronautics, T. I. Bell of British Royal Aircraft Establishment, Paul Hernandez of the University of California Radiation Laboratory, W. T. Ziegler of Georgia Institute of Technology, P. E. Liley of Purdue University, E. J. Dethke of National Cylinder Gas, W. E. Schaefer of Air Reduction Sales Co., and H. Ziebland of British Ministry of Aviation. Their help and the help of many others is gratefully acknowledged.

The efforts of Genevieve Michels in carefully supervising the many changes and corrections made throughout the compendium and preparing it for final publication are sincerely appreciated.

---

*Professor of Chemical Engineering, University of Colorado, employed part-time by the Cryogenic Engineering Laboratory.

**Assoc. Professor of Mechanical Engineering, Colorado State University, Fort Collins.

***Assoc. Professor of Mechanical Engineering, University of Colorado

ABSTRACT

This first phase of the Compendium covers ten properties of ten fluids (Part I), three properties of solids (Part II), and an extensive bibliography of references (Part III). Density, expansivity, thermal conductivity, specific heat and enthalpy, transition heats, phase equilibria, dielectric constants, adsorption, surface tension and viscosity for the solid, liquid and gas phases of helium, hydrogen, neon, nitrogen, oxygen, air, carbon monoxide, fluorine, argon and methane are given wherever adequate data could be collected. Thermal expansion, thermal conductivity and specific heat and enthalpy are given for a number of solids of interest in cryogenic engineering. Data sheets, primarily in graphic form, are presented from "best values" of data collected. The source of the material used, other references and tables of selected values with appropriate comments are furnished with each data sheet to document the data presented. Conversion tables and other helpful information are also included.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Jules I. Wittebort
JULES I. WITTEBORT
Chief, Thermophysics Branch
Physics Laboratory
Materials Central

TABLE OF CONTENTS*

APPENDIXES

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* General Contents only; detailed contents given at the beginning of each chapter.

** Code designation sequence used in lieu of page numbers to permit internal expansion.

NOTE TO USER

This volume is intended basically as a loose-leaf report for continuous expansion and revision as new and revised data sheets are produced. It has been bound as an economical means of assembly and distribution. It is also punched for standard three hole binders that are available from many commercial sources. A simple method of removing the bound cover and loosening the sheets is to shear off approximately 1/16" of the bound edge in an ordinary printers shear.

Manuscript released for publication August 1960 as a WADD Technical Report.

INTRODUCTION

A. General Introduction to Phase I of the Compilation Program

In the past ten years there has been a greatly accelerated growth of interest and activity in cryogenic engineering. From a few industrial applications such as the liquefaction of oxygen and from laboratory scale research at low temperatures, the activity has spread to nuclear reactors, controlled thermonuclear reactions, high altitude flight, missiles and rockets, the use of cryogenic fuels and oxidants, nuclear powered rockets, and transportation of liquefied gases; to name a few areas of application in this ever widening field.

As a result of the increased cryogenic activity, and the rigorous technical demands that often occur in new applications, it soon became apparent that a great deal more information and data on the properties of materials at low temperatures is needed by design engineers and physicists than is now readily available to them. The Wright Air Development Division of the U. S. Air Force, which is conducting and sponsoring a large amount of engineering development involving cryogenics, arranged with the National Bureau of Standards to undertake a program of collecting and compiling data on the thermophysical properties of materials used in low temperature applications. The program was started early in 1958 by the Cryogenic Engineering Laboratory Staff and this compendium presents the first phase of the work.

The scope of this first phase includes as extensive a literature search as was deemed practical and the correlation and presentation of data on ten specified properties of ten of the most common cryogenic fluids. It also includes three of the more pertinent properties of a number of solids used at low temperatures. The specified temperature range of primary interest was from near absolute zero to 110°K. Where desirable and practicable, however, data are included for temperatures up to near room temperature (300°K). Upon the selection and presentation of the "best values" found in the literature graphical presentation of the data is also made where practicable. It was stipulated that the metric system of units be used for the primary coordinates of graphs and that "English" or engineering units also be shown as alternate coordinates to aid design engineers not accustomed to metric units.

The plan adopted for organizing the compendium embodied two basic features. One was a "loose-leaf" design allowing more data to be added as it became available. The other concerned the numbering scheme for arranging the data sheets. Considering that there are a limited number of properties of materials and almost an unlimited number of materials that might eventually be of interest, the primary arrangement was made by properties and a secondary order established for materials. Each data sheet then is made complete and somewhat independent of any of the other data sheets. Each is assigned a code number by property and material classification and placed in the compendium in a corresponding order.

The data sheets are designed in such a manner as to serve both the design engineer who needs preselected values suitable for direct use and the researcher who is interested in the nature of the data and how it was derived. The "best values", or what are considered to be the most probable values, have been plotted as a full page graph whenever practicable with no encumbering deviations or alternate values. This is intended primarily for the design engineer. As complete a documentation as feasible is given to support each graph and to aid those interested or in need of a more thorough evaluation of the data. This includes the source of the data, other references of merit, brief comments concerning the data and a tabulation of values selected from the source. Occasionally, alternate values from other references are tabulated also for comparison purposes. In most cases the values are given just as they appeared in the source and accordingly the units are not necessarily the same as used on the graph. By doing this, possible conversion errors were eliminated and the full significance of the values retained.

This first phase of the program was divided into a number of tasks for assignment to qualified senior staff members. The task break-down for the fluids was by material and so there were ten such tasks. The break-down for solids was made by property resulting in three additional tasks.

The person assigned a task is referred to as a "task author". It was the task author's responsibility to make as complete a literature search as practicable and record the scope of his search. He also selected "best values" from the references he found and made pertinent comments regarding the data. He then presented it to the "general editor" for preparation of the data sheets. Student aides from the University of Colorado (both graduates and undergraduates in engineering) were used extensively in preparing the detailed data sheets. They also assisted the senior staff members in identifying references in the literature search. The Cryogenic Data Center played an important role in actually obtaining documents for task authors. It also profited as a result of this assistance since the literature searches turned up nearly two thousand new references of interest in cryogenics.

Division of the work in the manner just described has both advantages and disadvantages over other arrangements. A major advantage is that use can be made of a great diversity of talent by seeking help from persons most familiar with the subject matter. On the other hand, these people are usually the ones that already have the greatest demands made on their time and so it is very difficult to achieve orderly progress of the work on a reasonable time schedule. A somewhat better arrangement from a scheduling standpoint might be to have about two experienced persons working full time instead of ten or more on a hit-and-miss basis. Two difficulties immediately become apparent. One is finding persons with broad enough experience to handle a wide cross section of subject matter as is represented in this work who would accept the tediousness of such a task for a year or more. The other is that no one or two persons can possess the general knowledge that is usually represented by a large number of persons each working in a somewhat specialized area. Present planning for the future phases of this work is to reach some kind of a compromise between the two plans, i.e. have at least one full time experienced person carrying the bulk of the search and correlation load but utilize numerous other staff members to review and criticize the data derived.

The next phase of the program (Phase II) is already well underway.

It covers the following additional properties for essentially the same materials as included in Phase I:

Compressibility Factor ($Z = PV/RT$)	11.000*
Compressibility $\left[-\frac{1}{V}\left(\frac{dV}{dP}\right)_T\right]$ and Compressibility Coefficient $\left[-\frac{P}{V}\left(\frac{dV}{dP}\right)_T\right]$	12.000
Thermal Conductivity Integrals $\left[\int_{T_0}^{T_1} \lambda \, dT\right]$	13.000
Entropy (S)	14.000
Velocity of Sound	15.000
Solubility (2 component mixtures of liquids and gases)	16.000
Electrical Resistivities	17.000
Ferromagnetic Properties	18.000

* This number represents the coding sequence.

It will be issued as a supplement to this first phase of the Compendium and will be arranged for uniform continuity. There also will, undoubtedly, be revisions and additions to the material issued here as inconsistencies and better data are discovered. Revised data sheets will be prepared and issued to supplant or supplement the current ones.

Comments on this compendium will be greatly appreciated. They should be sent to the Cryogenic Engineering Laboratory, attention of the general editor for the WADD Compendium. We would also appreciate being informed of any errors (typographical, or otherwise) that may be discovered and any new information that users may have that would enhance the value of this compilation.

B. Introduction to Part I

This Compendium is divided into three parts for convenience; Part I, Properties of Fluids; Part II, Properties of Solids; and Part III, Bibliography of References, Cross-Indexed.

The following are the Properties and the Fluids included in this phase of the work.

1.*- Density
2. - Expansivity
3. - Thermal Conductivity
4. - Specific Heat and Enthalpy
5. - Transition Heats
6. - Phase Equilibria
7. - Dielectric Constants
8. - Adsorption
9. - Surface Tension
10. - Viscosity

Helium - - - - - .001*
Hydrogen - - - - .002
Neon - - - - - - .003
Nitrogen - - - - .004
Oxygen - - - - - .005
Air - - - - - - - - .006
Carbon Monoxide - .007
Fluorine - - - - .008
Argon - - - - - - .009
Methane - - - - - .010

(*These are the code numbers assigned for sequence of presentation.)

Data sheets are presented individually for each property and material combination that was found in the literature search. Separate data sheets are included for each phase or state unless a clearer interpretation could be made by showing more than one phase or state together. For instance, separate data sheets are given for the specific heats of solid, liquid, and gaseous hydrogen, but a single data sheet presents the thermal conductivity of liquid and gaseous nitrogen. Numerous combinations of property and material on some phases or states of a material or temperature ranges of interest are missing in the compilation. Such omission indicates that no information was found in the search and perhaps may be that no measurements have been made in those areas for those cases. Where information does exist but was not found in the search, it is planned that data sheets will be prepared as the information is received and added to this compilation. Likewise, where better information than now presented is developed or found, a revised data sheet will be prepared to replace the current one.

The graphical presentation of "best values" selected from data given in the literature is made on full-page graphs as far as practicable. Metric units are used for the primary coordinates, but "English" or engineering units are also given as alternate coordinates except in a few instances where the metric units are regularly used by engineers. (It might be noted that alternate use of calories and joules exists among some of the graphs. The joule is now the accepted metric unit of energy, but unfortunately some of the first graphs were prepared using calories and have not yet been redrawn.) Careful note should be made of the units used when picking values from a graph. Not only should the exact dimensions of the units be noted but also the magnitude of the unit. For instance, some units are given in watts, others in milliwatts or microwatts, etc. Also, occasionally there is a note to "multiply by 10^{-3}" or "multiply value by 10^{-5}", etc. For all instances, this means to multiply the numerical value taken from the graph by the number given. It has no direct reference to the size of the unit. For example, a value of 317 may be read from a graph that has a note to "multiply by 10^{-4}". The actual value is .0317 of the units given. The curves on the graphs are often plotted for a limited temperature range because of the limitation of available data. It is dangerous to extrapolate such curves beyond the extent plotted because of transitions and other anomalies that frequently are present but not indicated.

Conversion tables of dimensional units pertinent to a particular property are given at the beginning of each property chapter. Other conversion tables of more general application have been included for users' convenience as appendixes.

C. Scope of Literature Searches

Specific literature searches were made by the task authors in an effort to survey as much of the published literature as possible on the thermophysical properties of materials of interest in cryogenic engineering. The principal indexes and bibliography services used for searching out the desired literature were: Chemical Abstracts, Physics Abstracts, Engineering Index, Industrial Arts Index, ASME Seventy-Seven Year Index, Dissertation Abstracts, Bureau of Mines Bibliographies, and other published bibliographies. The usual procedure was to search the indexes of the various abstracts and note all items that might possibly pertain to the desired subject matter. A review of the actual abstracts of the referenced literature then indicated more conclusively whether the article was pertinent. Articles selected were then ordered from various library services and reviewed in full text. All articles that contained pertinent information were then listed in the applicable bibliography of references and considered in the selection of data. There is listed below the extent of the specific searches made for each task:

Properties of Helium

a. Chemical Abstracts: Volumes 46 thru 49 (1952 - 1955)

b. ASME Seventy-Seven Year Index, Technical Papers 1880-1956
Subjects Searched - Gases, Heat Transmission, Liquids, Thermodynamics, and Viscosity

c. Engineering Index: (1950 - 1956)
Subjects Searched - Gas Analysis, Density, Gases, Heat Transmission, Helium Liquids, Low Temperature Engineering, Thermodynamics, and Viscosity

d. Industrial Arts Index: (1943 - 1957)
Subjects Searched - Helium (this sole listing was deemed sufficient)

e. Bureau of Mines Bulletin 484; Helium: Bibliography of Technical and Scientific Literature from its Discovery (1868) to January 1, 1947.

f. Bureau of Mines Information Circular 7344. A Comprehensive Bibliography from 1933 to 1945.

Properties of Hydrogen

a.	Chemical Abstracts	1948 thru 1955
b.	Physics Abstracts	1949 thru 1957
c.	Industrial Arts Index	1948 thru 1956; Feb., May, Aug., Nov. 1957; Jan.-Mar., May, Aug. 1958
d.	Engineering Index	1948 thru 1956
e.	ASME Transactions	1948 thru 1956

The NBS Research Paper RP 1932 on Properties of Hydrogen by Woolley, Scott and Brickwedde covered an extensive search of the literature prior to 1948. Also NBS Circular 564. edited by J. Hilsenrath covers an extensive search of the literature prior to 1952 on "Properties of Gases" including hydrogen.

Properties of Neon

a. Chemical Abstracts: Volumes 1 thru 52 (1907 - 1958)
b. Physics Abstracts: 1892 thru 1912
c. Engineering Index: 1945 thru 1957
Subjects Searched: Rare gases, thermodynamics, density, viscosity and low temperature engineering.

Properties of Nitrogen

a. Chemical Abstracts: Volumes 1 thru 53 (1907 - 1959)

Properties of Oxygen

a. Chemical Abstracts: Volumes 31 thru 50 (1937 - 1956)

Properties of Air (including mixtures of oxygen and nitrogen)

a. Chemical Abstracts: Volumes 43 thru 52, No. 9 (1949 - Sept. 25, 1958)
b. Physics Abstracts: Volumes 46, 52 thru 61, No. 3 (1943, 1949 - August, 1958)
c. Industrial Arts Index: 1949 - 1957 and May - July, 1958
Subjects Searched - Air (this sole listing was deemed sufficient)
d. The Engineering Index: 1949 - 1957
Subjects Searched - Gases, Thermodynamics, and Liquids
e. Dissertation Abstracts 1954 - Aug. 1958

Properties of Carbon Monoxide

a. Chemical Abstracts: Volumes 44 thru 50 (1950 - 1956)

Properties of Fluorine

a. Chemical Abstracts: Volumes 1 thru 50 (1907 - 1956)
b. Industrial Arts Index: 1945 thru 1955

Properties of Argon

a. Chemical Abstracts: Volumes 42 thru 44 (1948 - 1950)

Properties of Methane

a. Chemical Abstracts: Volumes 1 thru 50 (1907 - 1956)

In addition to the specific searches listed above, a considerable number of references were found from listings on file in the Data Center that had been acquired somewhat at random. Also, inasmuch as most of the searches were for all properties of a particular material, many of the articles covered several materials. These additional references were added to the bibliographies of the other materials covered and were used by task authors in their evaluation and selection of data. A third additional source of references was from the documents themselves. Selected documents frequently listed references of a broader coverage than the material presented in it, and thus provided a more extensive range of properties. As a result, the actual scope of the literature searching was much greater than indicated by the specific searches as listed.

PART I

PROPERTIES OF CRYOGENIC FLUIDS

Code No.	Property	Fluid	Code No.
1.	Density	Helium	.001
2.	Expansivity	Hydrogen	.002
3.	Thermal Conductivity	Neon	.003
4.	Specific Heat and Enthalpy	Nitrogen	.004
5.	Transition Heats	Oxygen	.005
6.	Phase Equilibria	Air	.006
7.	Dielectric Constants	Carbon Monoxide	.007
8.	Adsorption	Fluorine	.008
9.	Surface Tension	Argon	.009
10.	Viscosity	Methane	.010

DENSITY of CRYOGENIC FLUIDS

CONTENTS

(continued)

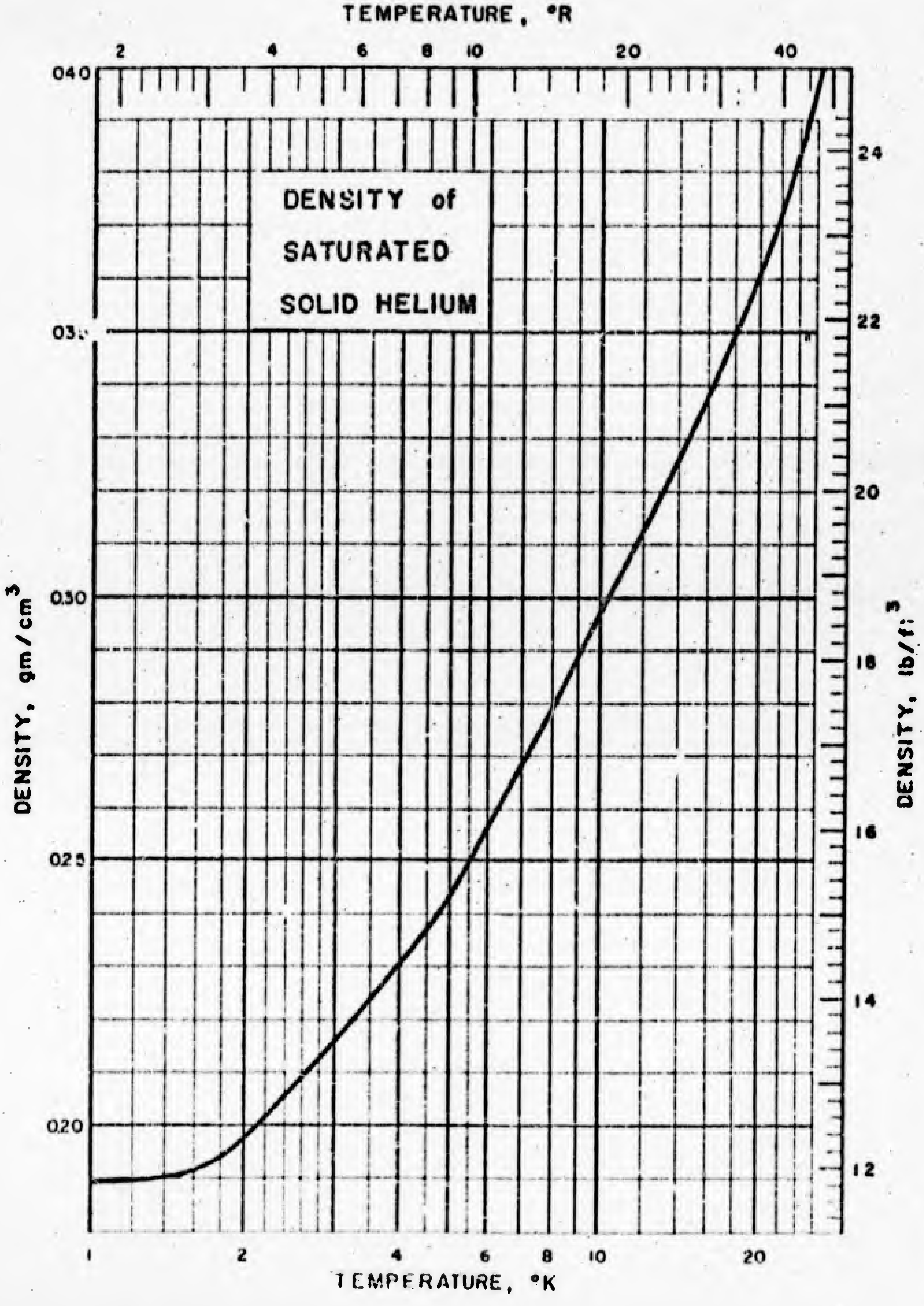
DENSITY of CRYOGENIC FLUIDS

CONTENTS (continued)

CONVERSION FACTORS for DENSITY

	gm/cm3	gm/in3	Kg/gal	Kg/ft3	lb/gal	lb/ft3
1 gm/cm3 =	1.000	16.3872	3.78543	28.3170	8.34545	62.4283
1 gm/in3 =	0.0610232	1.000	0.231000	1.72800	0.509268	3.80959
1 Kg/gal =	0.264171	4.32900	1.000	7.48052	2.20462	16.4917
1 Kg/ft3 =	0.0353145	0.578704	0.133681	1.000	0.294715	2.20462
1 lb/gal =	0.119826	1.96360	0.453592	3.39311	1.000	7.48052
1 lb/ft3 =	0.0160184	0.262496	0.0606365	0.453592	0.133681	1.000

1.001


TEMPERATURE, °R
2
4
6
8
10
20
40
DENSITY of
SATURATED
SOLID HELIUM
040
03.
0.30
0.25
0.20
DENSITY, gm/cm^3
24
22
20
18
16
14
12
DENSITY, lb/ft^3
1
2
4
6
8
10
20
TEMPERATURE, °K

1.001

DENSITY of SOLID HELIUM
(At Saturation)

Source of Data:

Domb, C. and Dugdale, J. S., Progress in Low Temperature Physics, Vol. II, North Holland Publishing Co., Amsterdam, The Netherlands, (1957) 460.

Other References:

Stewart, J. W., Bull. Am. Phys. Soc. (2) 1, 218 (1956)

Swenson, C. A., Phys. Rev. 79, No. 4, 626-31 (Aug. 1950)

Swenson, C. A., Phys. Rev. 89, No. 3, 538-44 (Feb. 1953)

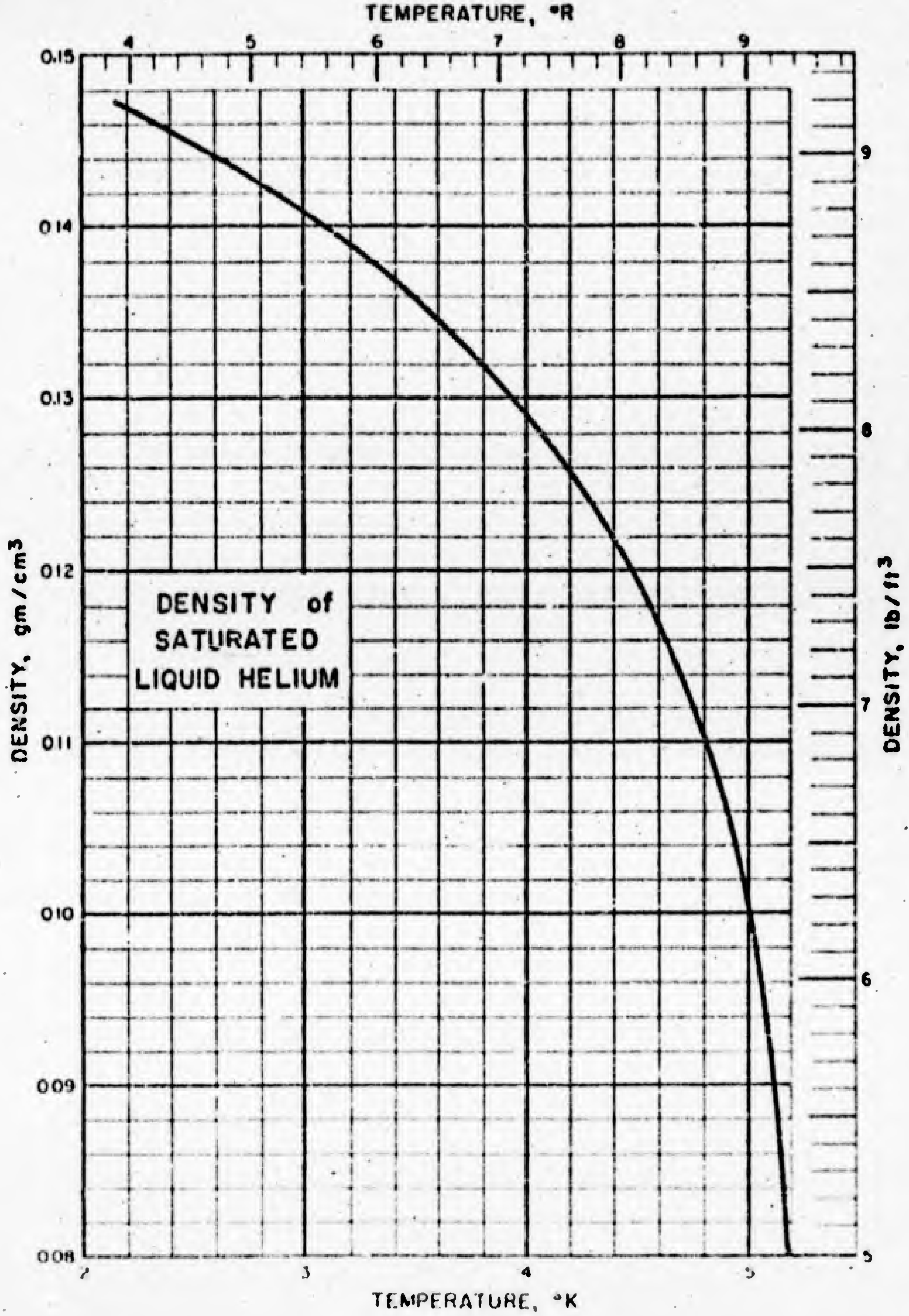
Simon, F. E., Swenson, C. A., Nature 165, 829 (May 1950)

Keesom, W. H., Helium, Elsevier, Amsterdam (1942) 494pp.

Temperature		Density at Saturation	
°K	°R	gm/cc	lb/ft^3
0	0	0.1890	11.80
1.0	1.8	0.1891	11.81
1.2	2.16	0.1893	11.82
1.4	2.52	0.1902	11.87
1.6	2.88	0.1911	11.93
2.0	3.60	0.1976	12.34
2.5	4.50	0.2072	12.94
3.0	5.4	0.2162	13.50
4.0	7.2	0.2305	14.39
6.0	10.8	0.2678	16.72
10.0	18.0	0.2976	18.58
14.0	25.2	0.3255	20.32
18.0	32.4	0.3505	21.88
22.0	39.6	0.3724	23.25
26.0	46.8	0.3963	24.74

DHM/GAH/JHC Issued: 7-15-59

1.001



DENSITY of SATURATED LIQUID HELIUM

1.001

DENSITY of LIQUID HELIUM

(At Saturation)

Source of Data:

Berman, R. and Mate, C. F., Phil. Mag. (8) 3, 461-69 (May 1958)

Other References:

Kerr, E. C., J. Chem. Phys. 26, 511-14 (Mar. 1957)

Ham, N. S., Roy. Australian Chem. Inst. J. & Proc. 17, 273-83 (July 1950)

Keller, W. E., Phys. Rev. 97, No. 1, 1-8 (Jan. 1955)

Dash, J. G. and Taylor, R. D., Phys. Rev. 107, No. 5, 1228-1237 (Sept. 1957)

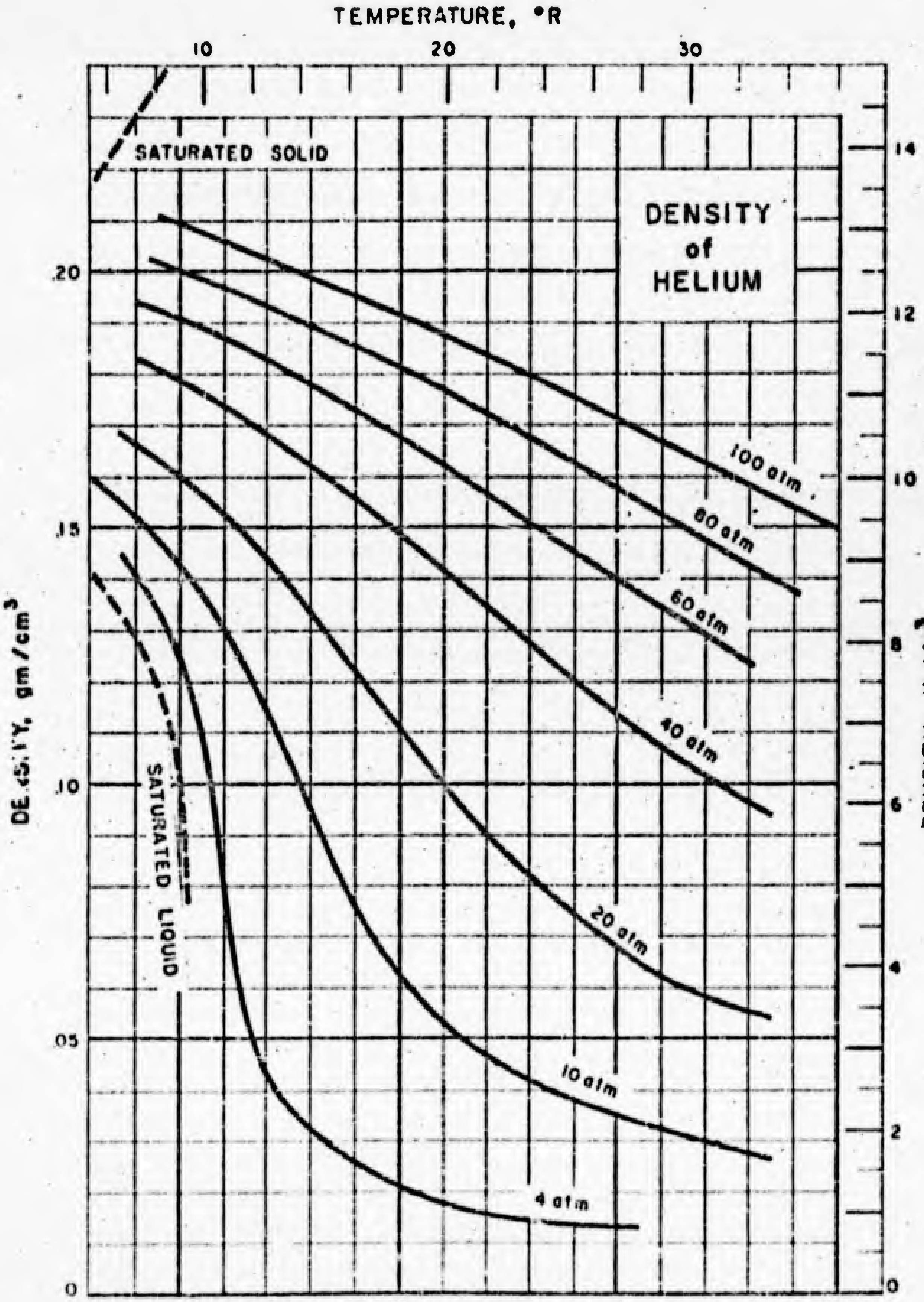
Borelius, G., Arkiv. Fysik, Band 13, No. 29, 369-378 (Jan. 1958)

Keesom, W. H., Helium, Elsevier, Amsterdam, (1942) p. 494

Temp. °K	Density $\frac{gm}{cm^3}$
2.2	0.147
2.3	0.146
2.4	0.146
2.6	0.144
2.8	0.143
3.00	0.141
3.2	0.139
3.4	0.137
3.6	0.134
3.8	0.132
4.00	0.129
4.2	0.125
4.4	0.122
4.6	0.117
4.8	0.111
5.0	0.101
5.15	0.087
5.18	0.079

DBM/GAR/JHC Issued: 7-14-59

1.001


TEMPERATURE, °R
10
20
30
SATURATED SOLID
DENSITY of HELIUM
100 atm
80 atm
60 atm
40 atm
20 atm
10 atm
4 atm
SATURATED LIQUID
DENSITY, gm/cm³
.20
.15
.10
.05
0
DENSITY, lb/ft³
14
12
10
8
6
4
2
0
5
10
15
20
TEMPERATURE, °K

1.001

DENSITY of HELIUM

(3° - 20°K)

Source of Data:

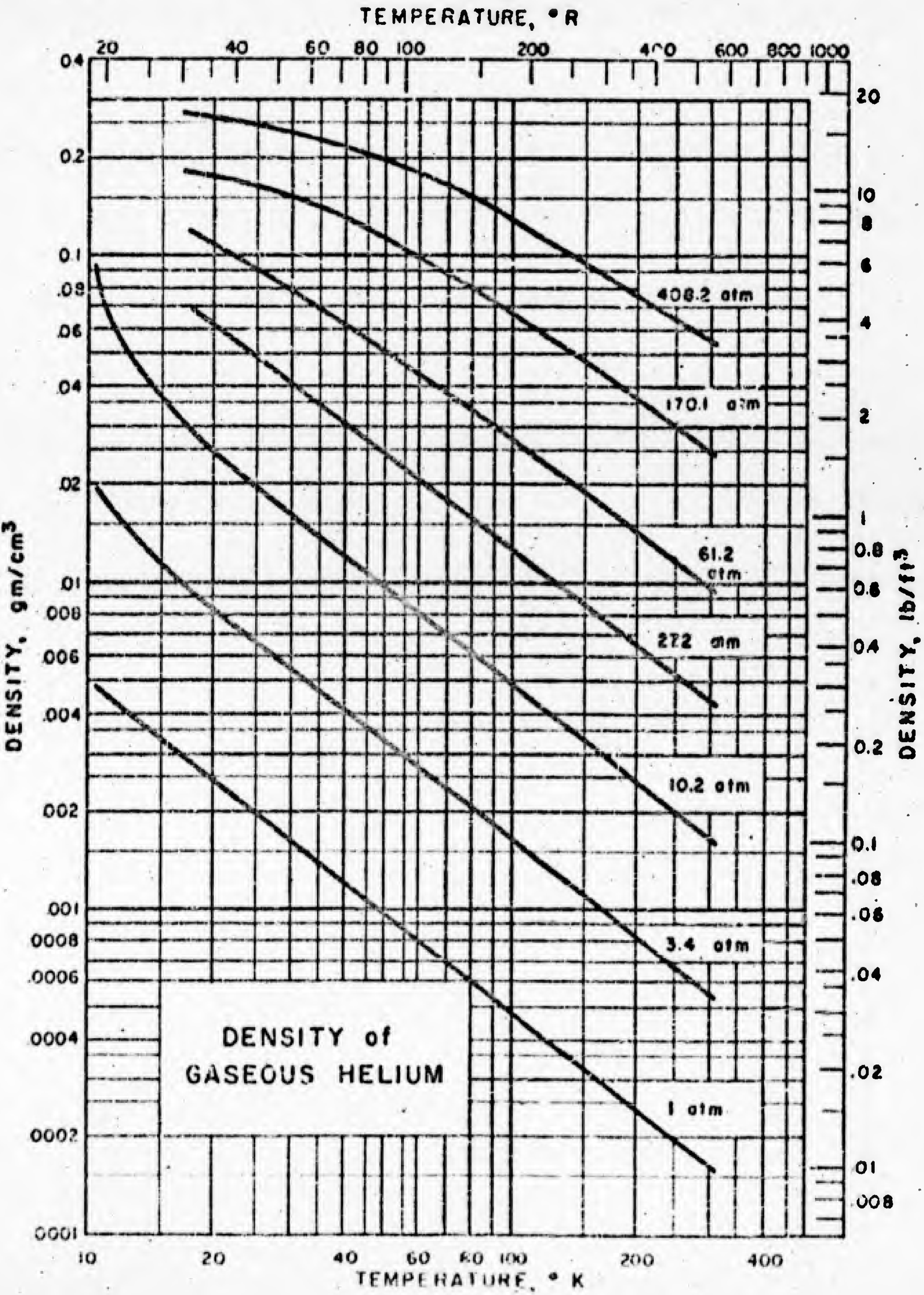
Lounasmaa, O. V., Thesis submitted for the Degree of Doctor of Philosophy, University of Oxford (1958).

Comments:

The lines for the saturated liquid and solid indicated on the gr[illegible] were plotted from data sheets for density of saturated liquid and solid Helium.

Pressure atm.	Temp. °K	Density gm/cm^3
4	14.67	0.013 86
	8.58	.027 72
	7.04	.041 58
	6.46	.055 44
	6.18	.069 30
	5.99	.083 16
	5.79	.097 02
	5.49	.110 88
	5.00	.124 74
	4.20	.138 60
10	18.11	0.027 7_
	13.05	.041 58
	10.75	.055 44
	9.46	.069 30
	8.58	.083 16
	7.90	.097 02
	7.21	.110 88
	6.44	.124 74
	5.51	.138 60
	4.11	.152 46
	3.04	.159 39
20	17.82	0.055 44
	14.74	.069 30
	12.74	.083 16
	11.24	.097 02
	9.97	.110 86
	8.76	.124 72
	7.51	.138 60
	6.05	.152 46
	5.12	.159 39
	3.93	.166 32
40	20.98	0.083 16
	17.83	.097 02
	15.38	.110 88
40	13.30	0.124 74
	11.35	.138 60
	9.43	.152 46
	8.43	.159 39
	7.33	.166 32
	6.09	.173 25
	4.60	.180 18
60	17.81	0.124 74
	15.17	.138 60
	12.70	.152 46
	11.48	.159 39
	10.25	.166 32
	8.96	.173 25
	7.55	.180 18
	5.97	.187 11
	3.99	.194 04
80	18.99	0.138 60
	15.95	.152 46
	14.52	.159 39
	13.09	.166 32
	11.66	.173 25
	10.18	.180 18
	8.59	.187 11
	6.83	.194 04
	4.71	.200 97
100	19.20	0.152 46
	17.54	.159 39
	15.91	.166 32
	14.26	.173 25
	12.68	.180 18
	11.02	.187 11
	9.27	.194 04
	7.40	.200 97
	4.86	.207 90

DLM/CAR/EHB/VJJ Issued: [illegible]


TEMPERATURE, °R
20
40
60
80
100
200
400
600
800
1000
DENSITY, gm/cm³
04
0.2
0.1
.08
.06
.04
.02
.01
.008
.006
.004
.002
.001
.0008
.0006
.0004
.0002
.0001
DENSITY, lb/ft³
20
10
8
6
4
2
1
0.8
0.6
0.4
0.2
0.1
.08
.06
.04
.02
.01
.008
408.2 atm
170.1 atm
61.2 atm
27.2 atm
10.2 atm
3.4 atm
1 atm
DENSITY of
GASEOUS HELIUM
10
20
40
60
80
100
200
400
TEMPERATURE, ° K

DENSITY of GASEOUS HELIUM
(10 - 300°K)

Source of Data:

Akin, W. S., Trans. ASME 72, 751-57 (Aug. 1950)

Other References:

Keesom, W. H., Helium, Elsevier, Amsterdam (1942)

Keller, W. E., Phys. Rev. 97, No. 1, 1-8 (Jan. 1955)

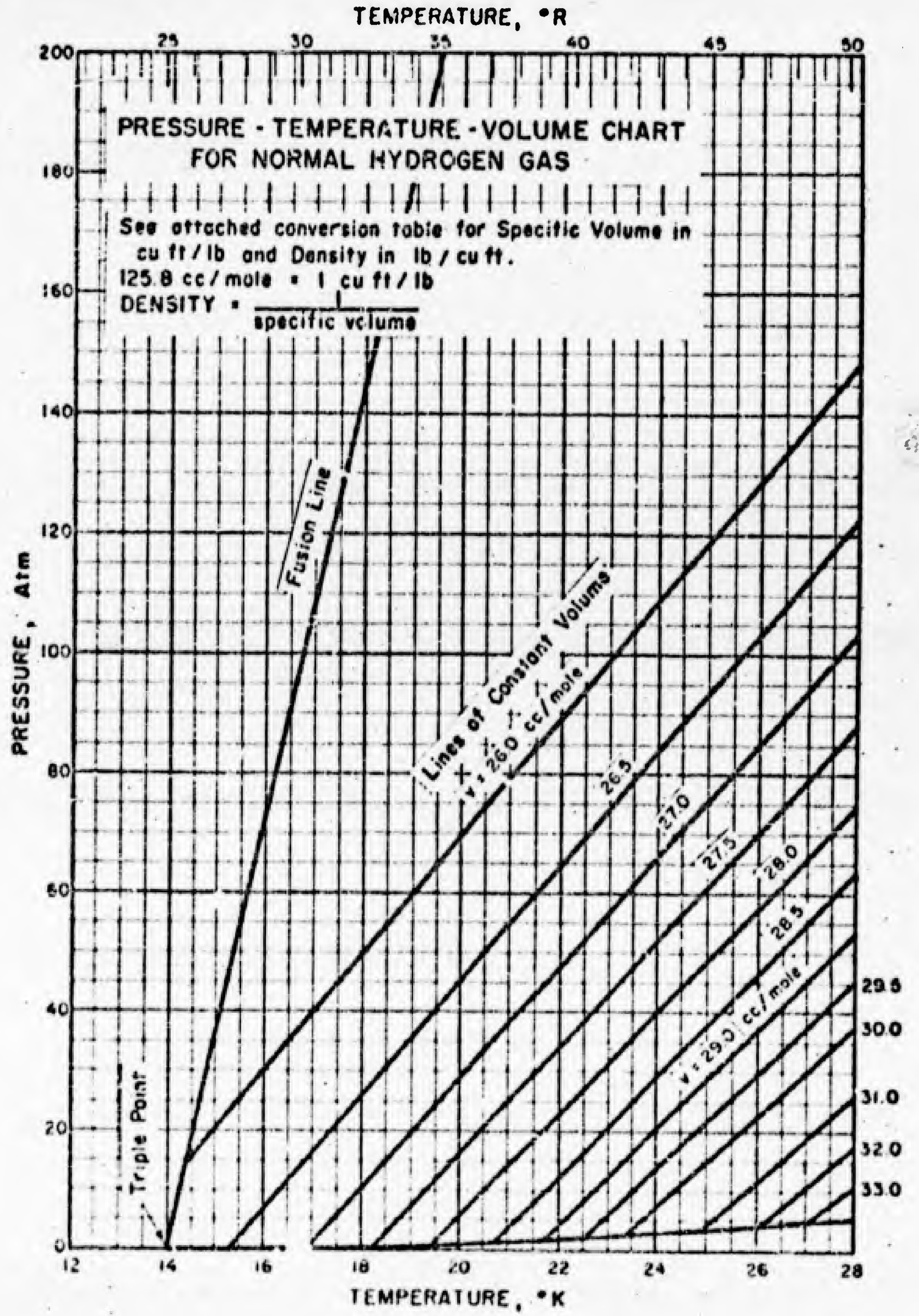
Moslan, F. D. and Littman, T. M., Ind. Eng. Chem. 45, 1566-8 (1953)

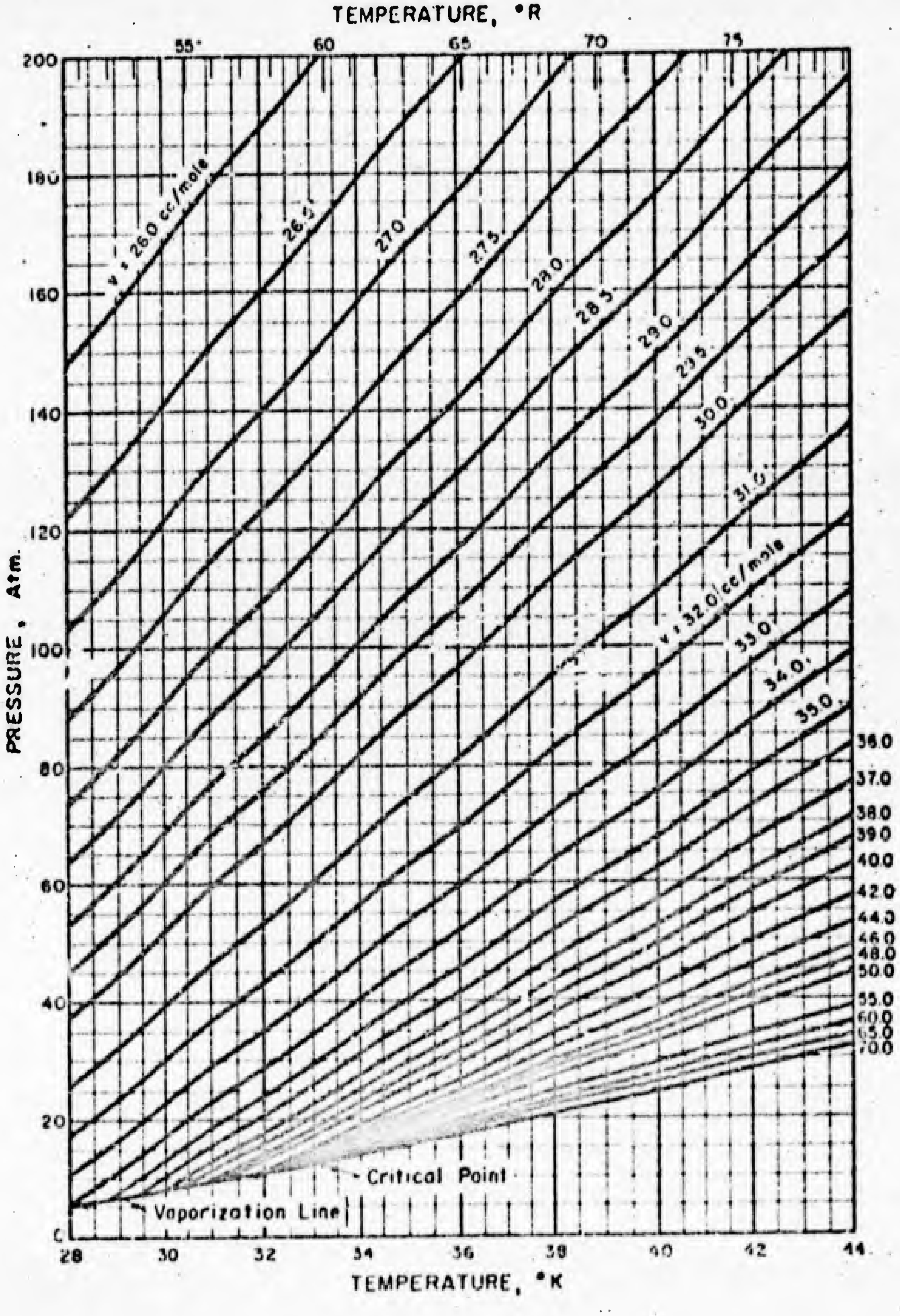
Comments:

Density is given in gm/cm^3 in Table of Selected Values below.

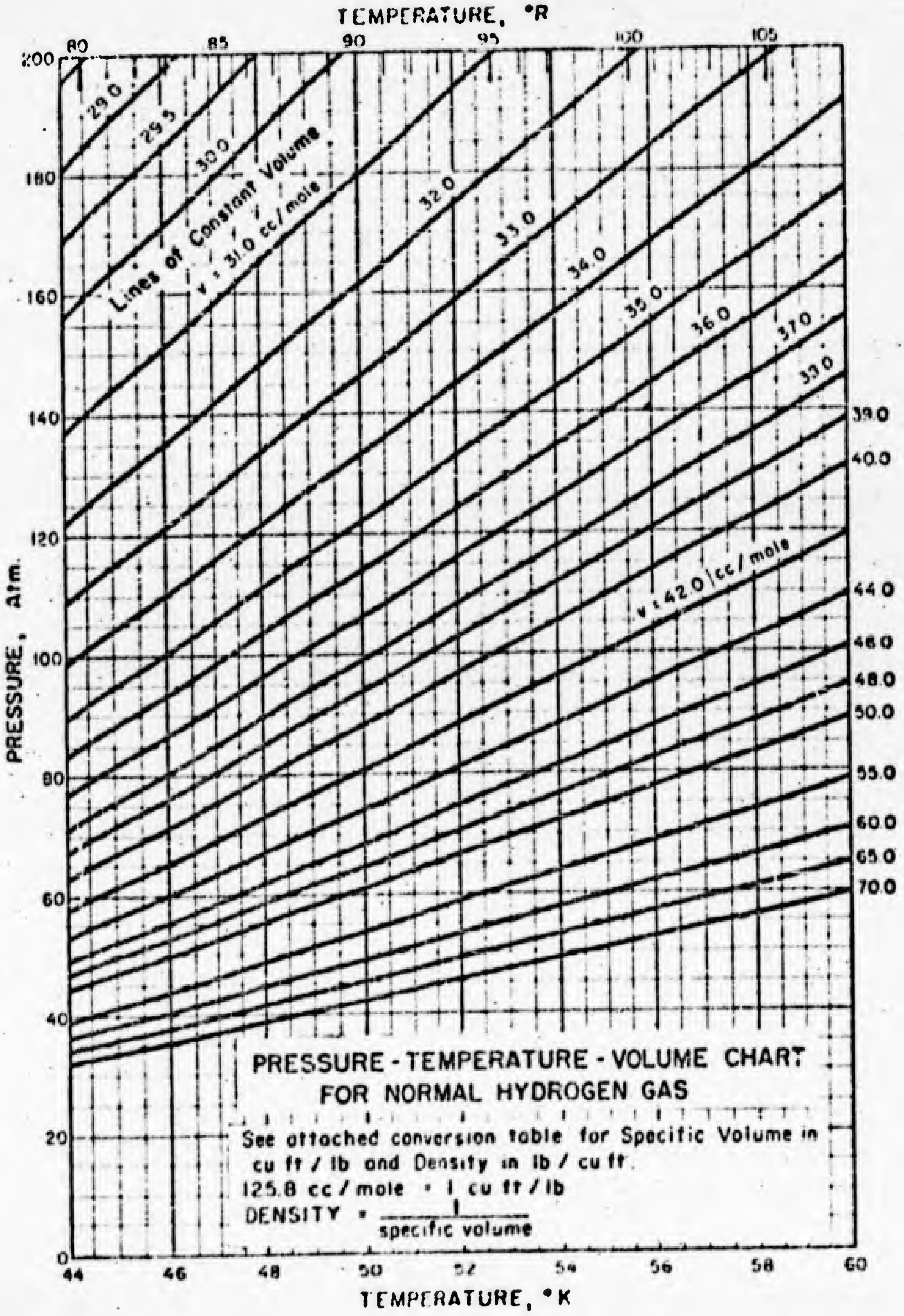
Press. psia / T °K	14.7	50	150	400	900	2500	6000
	1 atm	3.4 atm	10.2 atm	27.2 atm	61.2 atm	170.1 atm	408.2 atm
10.94	0.004 602	0.018 10	0.078 1				
19.27	.002 350	.008 672	.025 9	0.0626	0.110	0.178	0.267
33.15	.001 467	.004 967	.014 6	.0368	.0724	.1455	.229
61.00	.000 798	.002 704	.008 0	.0213	.0432	.098	.178
88.7	.000 549	.001 860	.007 66	.0144	.0307	.0740	.141
116.50	.000 418	.001 418	.004 21	.0110	.0238	.0591	.117
144.2	.000 338	.001 145	.003 41	.0089	.0198	.0504	.100
172.0	.000 283	.000 9611	.002 91	.0075	.0165	.0422	.0875
199.7	.000 244	.000 828	.002 47	.0065	.0143	.0369	.0782
255.3	.000 192	.000 648	.001 94	.0052	.0113	.0295	.0637
311.0	.000 156	.000 532	.001 59	.0042	.0093	.0251	.0540

DBM/GAR/VJJ Issued: 9-24-59


TEMPERATURE, °R
25
30
35
40
45
50
PRESSURE - TEMPERATURE - VOLUME CHART
FOR NORMAL HYDROGEN GAS
See attached conversion table for Specific Volume in cu ft/lb and Density in lb/cu ft.
125.8 cc/mole = 1 cu ft/lb
DENSITY = 1/specific volume
PRESSURE, Atm
200
180
160
140
120
100
80
60
40
20
0
Fusion Line
Lines of Constant Volume
V = 26.0 cc/mole
26.5
27.0
27.5
28.0
28.5
V = 29.0 cc/mole
29.5
30.0
31.0
32.0
33.0
Triple Point
12
14
16
18
20
22
24
26
28
TEMPERATURE, °K


TEMPERATURE, °R
55°
60
65
70
75
200
180
160
140
120
100
80
60
40
20
0
PRESSURE, Atm.
v = 26.0 cc/mole
26.5
27.0
27.5
28.0
28.5
29.0
29.5
30.0
31.0
v = 32.0 cc/mole
33.0
34.0
35.0
36.0
37.0
38.0
39.0
40.0
42.0
44.0
46.0
48.0
50.0
55.0
60.0
65.0
70.0
Critical Point
Vaporization Line
28
30
32
34
36
38
40
42
44
TEMPERATURE, °K

1.002

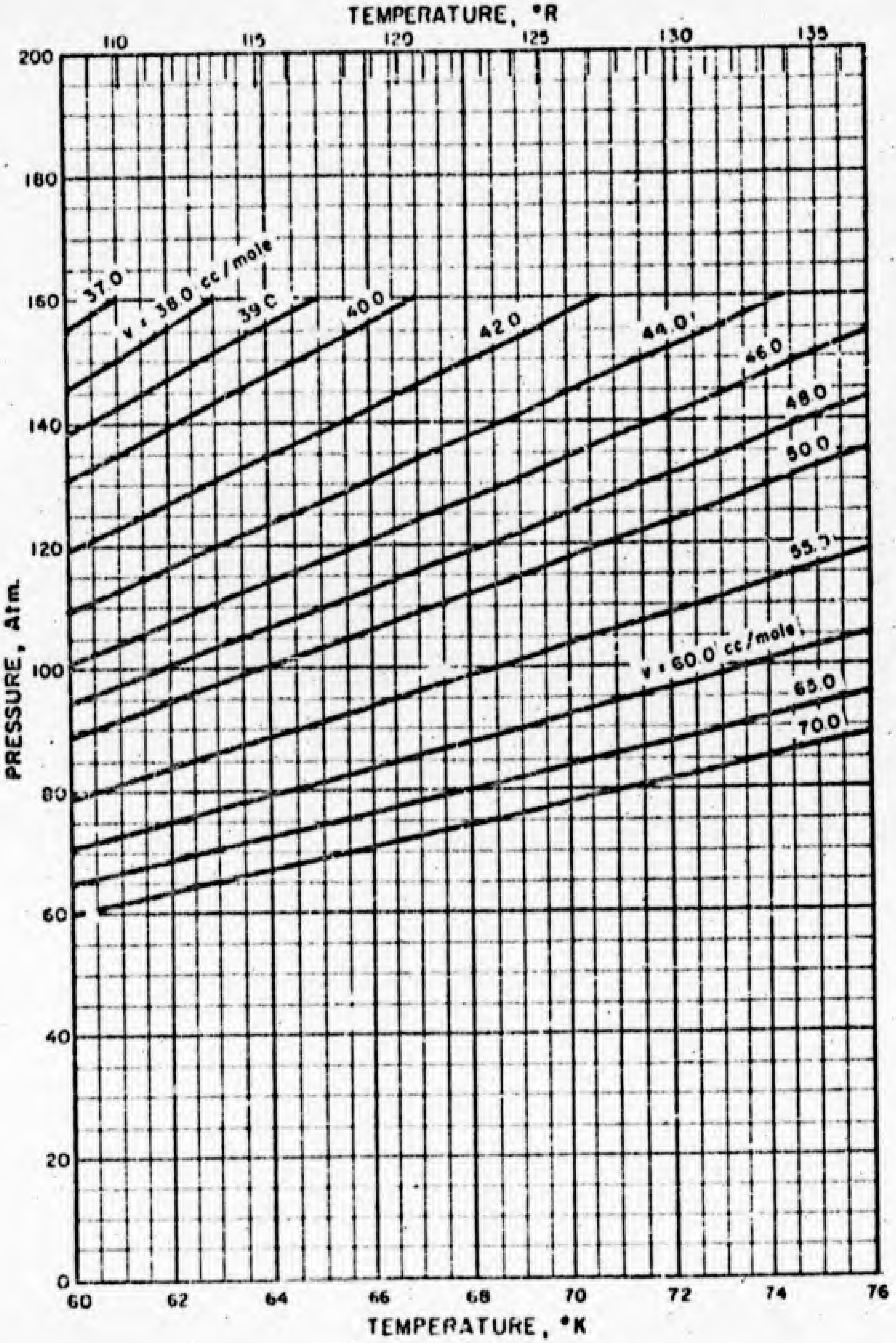


PRESSURE - TEMPERATURE - VOLUME CHART FOR NORMAL HYDROGEN GAS

See attached conversion table for Specific Volume in cu ft / lb and Density in lb / cu ft.

125.8 cc / mole = 1 cu ft / lb

DENSITY = $\frac{1}{\text{specific volume}}$


TEMPERATURE, °R
110
115
120
125
130
135
PRESSURE, Atm.
200
180
160
140
120
100
80
60
40
20
0
37.0
v = 38.0 cc/mole
39.0
40.0
42.0
44.0
46.0
48.0
50.0
55.0
v = 60.0 cc/mole
65.0
70.0
60
62
64
66
68
70
72
74
76
TEMPERATURE, °K

DENSITY of NORMAL HYDROGEN GAS

I. Pressure-Volume-Temperature Correlations.

Source of Data:	Woolley, Scott and Brickwedde, RP1932 (1948); Johnston, White, Wirth, Swanson, Jensen and Friedman, Ohio State Univ. Tech. Report TR264-25 (1953); White, Friedman and Johnston, J. Amer. Chem. Soc. 72, 3927-32 (1950); Johnston, Keller and Friedman, J. Amer. Chem. Soc. 76, 1482-6 (1954); E. Bartholome, Z. physik. Chem. B 33, 387 (1936).
Other References:	Friedman and Hilsenrath, NBS Report 3163 (1954); White and Johnston, Ohio State Univ. Tech. Report TR264-23 (1953); also TR264-26 (1953); White, Friedman and Johnston, Ohio State Univ. Tech. Report TR264-12 (1951).

Discussion: A correlation of P-V-T data given in the above listed sources was made for the compressed liquid and gas ranging from the triple point to 80°K in temperature and to 200 atmospheres in pressure for specific volumes from 26 to 70 cc/mole. Lines of constant volume (isometrics) were plotted on a large graph for all the data given in the selected range. These isometric lines, plotted on Pressure-Temperature coordinates, were found to be straight for all but limited areas, i.e. at pressures over 160 to 180 atmospheres and near the critical point. (Differences in the data in overlapping areas covered by RP1932 and by Johnston, et al., are all very small with only a few approaching 2% on the pressure scale). The correlation was accomplished by plotting the slopes of the straight isometrics as a function of the molar volume. The intercepts of these same lines with the 0°K temperature line were also plotted as a function of molar volume. The slopes and the intercepts are the constants B_V and A_V respectively of the equation:

$$P = A_V + B_V T,$$

that was used to represent the isometric lines. By smoothing the curves representing the slopes and the intercepts, smoothed values for B_V and A_V were obtained. By replotting the isometrics, using the above equation, a smooth representation of all the data was achieved. These are shown in the four plates accompanying this section.

Densities can be obtained by taking the reciprocal of the specific volume indicated for the desired conditions. A conversion table is included to facilitate determining density values on the isometric lines.

At high pressures, in the neighborhood of 200 atmospheres, a definite curvature of the isometric lines plotted on the P-T coordinates was indicated. The data were not extensive enough, however, to establish any definite trend for the curvature. It is therefore not prudent to extrapolate the data to pressures above 200 atmospheres.

1.002

HYDROGEN

CONVERSION TABLE FOR SPECIFIC VOLUMES AND DENSITY

Specific Volume		Density
cc/mole	cu. ft./lb.	lb./cu. ft.
26	0.207	4.84
26.5	0.211	4.75
27	0.215	4.66
27.5	0.219	4.58
28	0.222	4.49
28.5	0.226	4.42
29	0.230	4.34
29.5	0.234	4.27
30	0.238	4.20
31	0.246	4.06
32	0.254	3.93
33	0.262	3.81
34	0.270	3.70
35	0.278	3.60
36	0.286	3.50
37	0.294	3.40
38	0.302	3.31
39	0.310	3.23
40	0.318	3.15
42	0.334	3.00
44	0.350	2.86
46	0.365	2.74
48	0.381	2.62
50	0.397	2.52
55	0.437	2.29
60	0.477	2.10
65	0.516	1.94
70	0.556	1.80

1.003

DENSITY of SOLID NEON

Sources of Data:

Clusius, K., Z. physik. Chem. B31, 459-74 (1936).

de Smedt, J., Keesom, W. H. and Mooy, H. H., Proc. Akad. Wetenschappen 33, 255 (1930).

Commun. Kamerlingh Onnes Lab. Univ. Leiden, Commun. No. 203e.

Comments:

The Leiden temperature scale (0°C = 273.09°K) is used.

Table of Selected Values

Temperature		Density		Molal Volume*	Specific Volume
°K	°R	gm/cm^3	lb/ft^3	cm^3/gm-mole	ft^3/lb
4.3	7.7	1.443	90.04	13.95	0.01111
24.57	44.23	1.444**	90.09	13.98	0.01110

* Molecular Weight of Neon is 20.18_3

** Normal Melting Point Value

XDT/BDT Issued: 6-17-59

DENSITY of LIQUID NEON

Sources of Data:

Benson, S. W., J. Phys. and Colloid Chem. 52, 1060-74 (1948)

Clusius, K., Z. physik. Chem. B31, 459-74 (1936)

Onnes, H. K., and Crommelin, C. A., Proc. Akad. Wetenschappen 18, 515-20 (1915).

Table of Selected Values

Temperature		Density		Molal Volume*	Specific Volume
°K	°R	gm/cm^3	lb/ft^3	cm^3/gm-mole	ft^3/lb
27.2	49.0	59.6 $\frac{\text{gm-mole}}{\text{liter}}$	75.11	16.77	0.01331
27.21	48.98	1.204+	75.17	16.76	0.01330
24.58	44.24	1.248 ++	77.91	16.17	0.01284
24.57	44.23	1.248	77.91	16.17++	0.01284

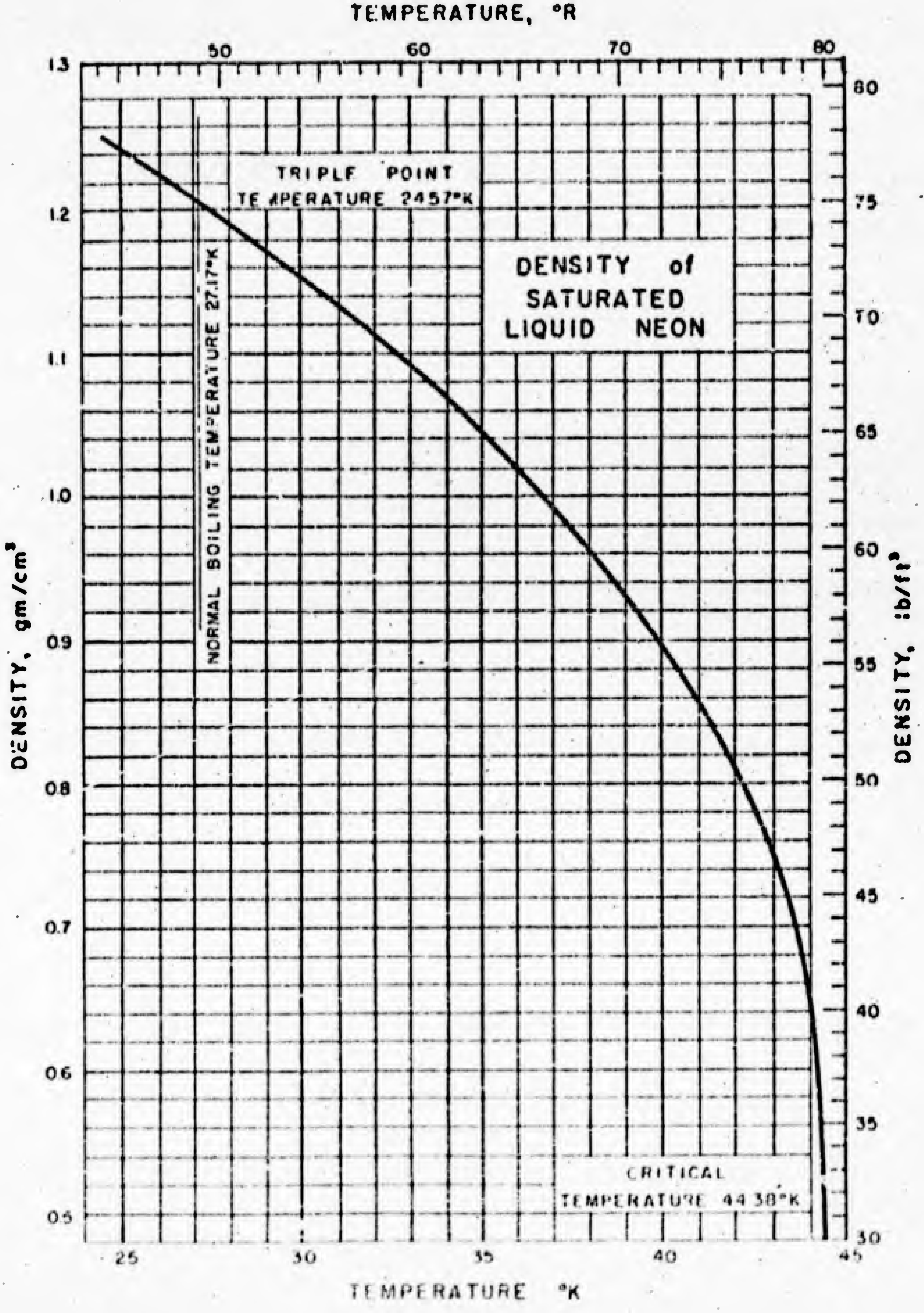
\+ Normal boiling point value

++ Normal melting point value

* Molecular weight of Neon is 20.183.

KDT/BDT/VJJ Issued: 6-18-59

1 008


TEMPERATURE, °R
50
60
70
80
TRIPLE POINT TEMPERATURE 24.57°K
NORMAL BOILING TEMPERATURE 27.17°K
DENSITY of SATURATED LIQUID NEON
CRITICAL TEMPERATURE 44.38°K
DENSITY, gm/cm^3
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
DENSITY, lb/ft^3
80
75
70
65
60
55
50
45
40
35
30
25
30
35
40
45
TEMPERATURE °K

DENSITY of LIQUID NEON

(Saturated)

Sources of Data:

Crommelin, C. A., Rec. trav. chim. 42, 814-7 (1923)

Mathias, E., Crommelin, C. A. and Onnes, H. K., Ann. Physik 19, 231-9 (1923)

Onnes, H. K. and Crommelin, C. A., Proc. Akad. Wetenschappen 18 515-20 (1915)

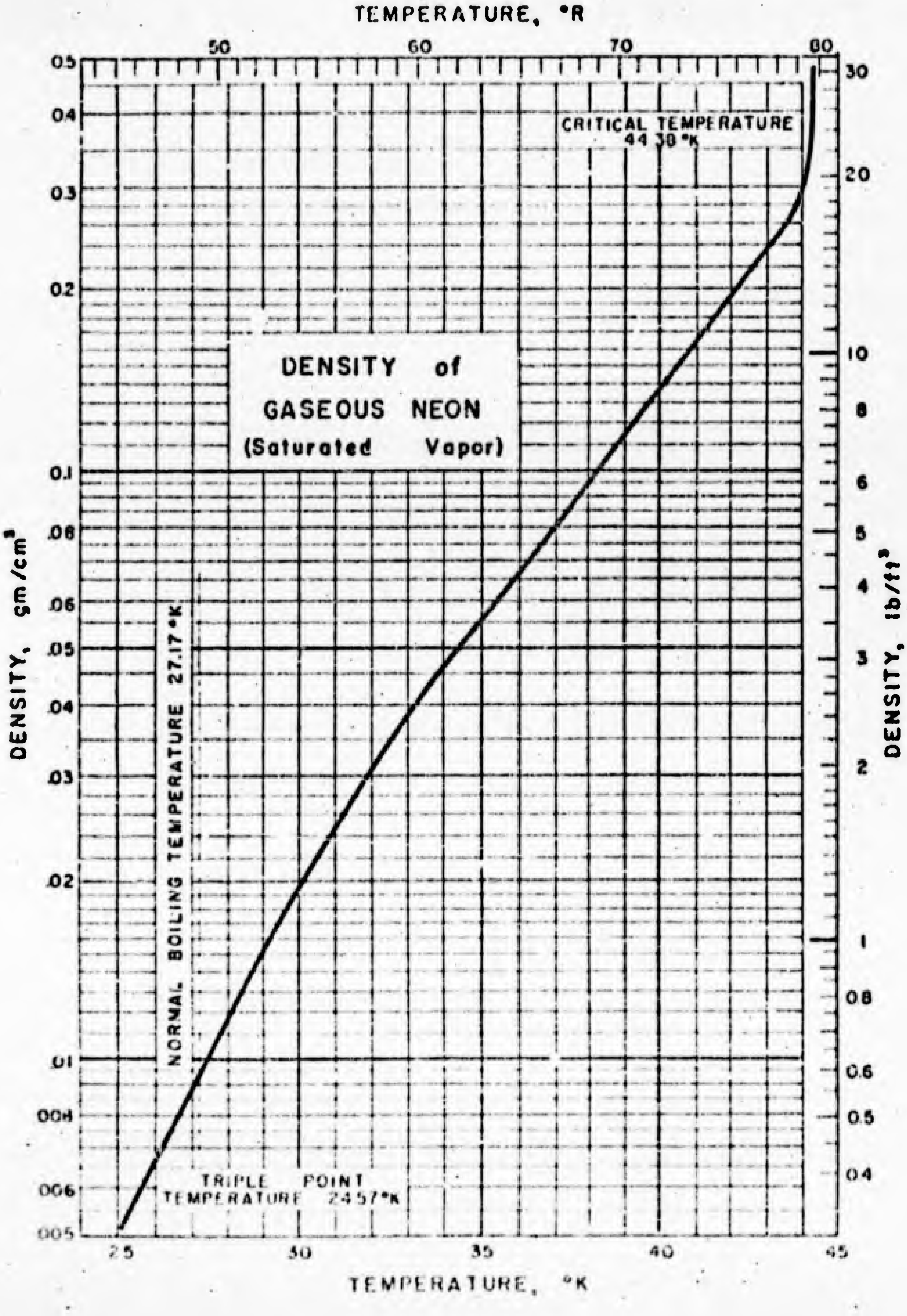
Onnes, H. K., Crommelin, C. A. and Cath, P. G., Proc. Acad. Sci. Amsterdam 19, 1058-62 (1917)

Comments:

The Leiden Temperature scale (0°C = 273.09°K) was used for the data given below.

Temp. °K	Density gm/cm³
24.57†	
25.17	1.238 24
27.17‡	
30.13	1.149 60
36.05	1.017 50
39.08	0.928 03
43.02	0.748 66
44.38*	0.483 5

* Critical Temperature
† Triple Point Temperature
‡ Normal Boiling Temperature


TEMPERATURE, °R
50
60
70
80
DENSITY of
GASEOUS NEON
(Saturated Vapor)
CRITICAL TEMPERATURE
44.38 °K
NORMAL BOILING TEMPERATURE 27.17 °K
TRIPLE POINT
TEMPERATURE 24.57 °K
DENSITY, gm/cm³
0.5
.04
.03
.02
0.1
.08
.06
.05
.04
.03
.02
.01
.008
.006
.005
DENSITY, lb/ft³
30
20
10
8
6
5
4
3
2
1
0.8
0.6
0.5
0.4
25
30
35
40
45
TEMPERATURE, °K

1.003

DENSITY of GASEOUS NEON

(Saturated Vapor)

Sources of Data:

Crommelin, C. A., Rec. trav. chim. 42, 814-7 (1923)

Mathias, E., Crommelin, C. A. and Onnes, H. K., Ann. Physik 19, 231-9 (1923)

Onnes, H. K. and Crommelin, C. A., Proc. Akad. Wetenschappen 18, 515-20 (1915)

Onnes, H. K., Crommelin, C. A. and Cath, P. G., Proc. Acad. Sci. Amsterdam 19, 1058-62 (1917)

Comments:

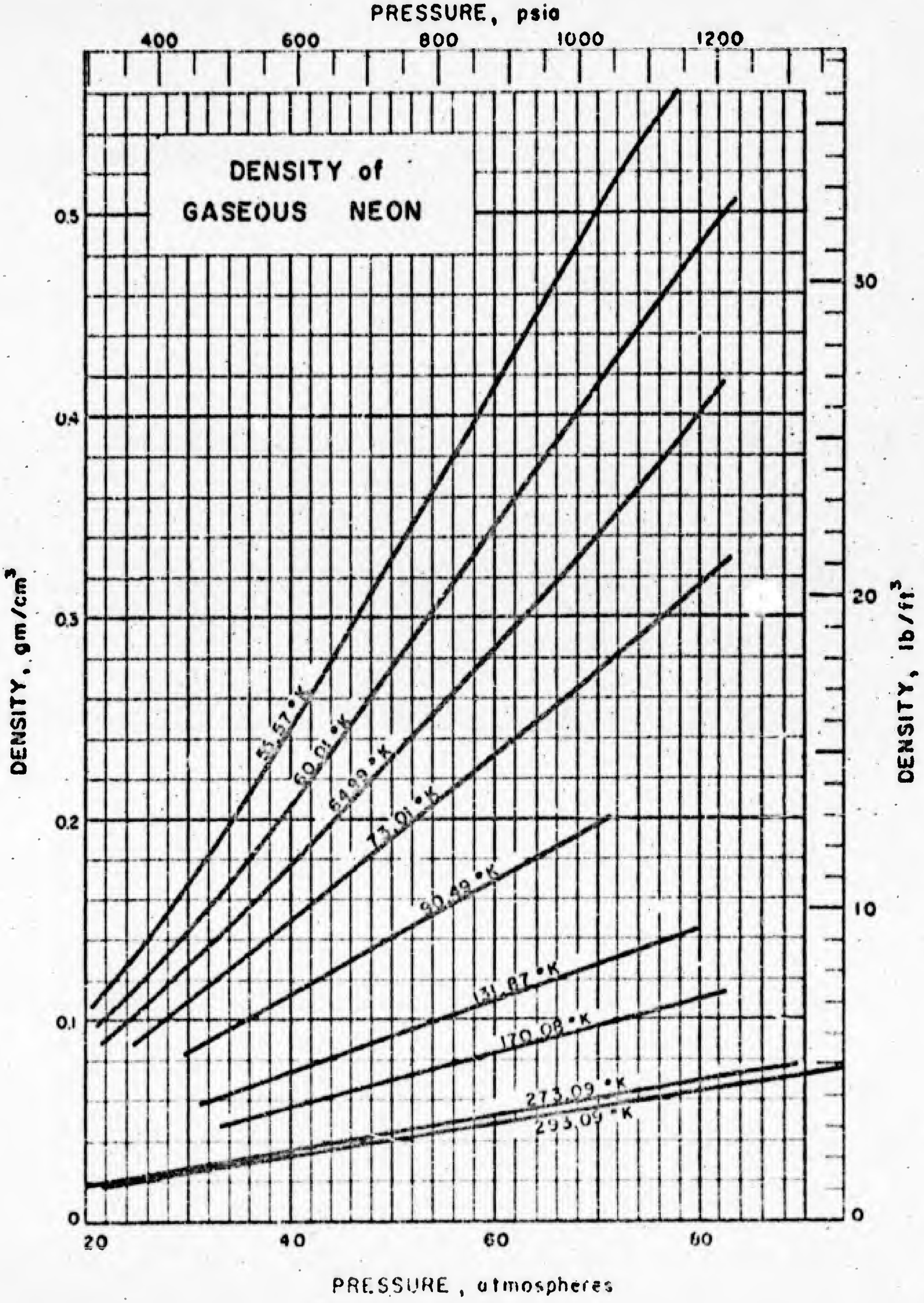
The Leiden Temperature scale (0°C = 273.09°K) was used for the data given below.

Temp. °K	Density gm/cm³
24.57†	
25.17	0.005 34
27.17‡	
30.13	0.020 13
36.05	0.067 42
39.08	0.115 92
43.02	0.239 35
44.38*	0.483 5

* Critical Temperature
† Triple Point Temperature
‡ Normal Boiling Temperature

KDT/BDT/VJJ Issued: 7-8-59

1.003


PRESSURE, psia
400
600
800
1000
1200
DENSITY of GASEOUS NEON
0.5
0.4
0.3
0.2
0.1
0
DENSITY, gm/cm³
30
20
10
0
DENSITY, lb/ft³
53.67 °K
60.01 °K
64.99 °K
73.01 °K
90.49 °K
131.87 °K
170.08 °K
273.09 °K
293.09 °K
20
40
60
80
PRESSURE, atmospheres

DENSITY of GASEOUS NEON

(P-V-T Relations)

Sources of Data:

Crommelin, C. A., Martinez, J. P. and Onnes, K. H., Verslag. Akad. Wetenschappen Amsterdam 27, 1316-26 (1919)

Onnes, K. H. and Crommelin, C. A., Proc. Akad. Wetenschappen 18, 515-20 (1915)

Comments:

In the tables below, V = 1.0000 at 0°C and 1 atm. The density, d, is expressed as a ratio to normal density at 0°C and 1 atm. (0.9002 grams per liter). The Leiden temperature scale (0°C = 273.09°K) is used. Pressure, P, is given in atmospheres (76 cm Hg).

For the graph, the density in gm/cm^3 = d x .9002/1000.028. A tabulation of density values for selected temperatures and pressures is given on the next page.

+20.00°C

P	PV	d
22.804	1.0835	21.064
25.015	1.0852	23.052
26.575	1.0863	24.464
29.090	1.0872	26.757
32.572	1.0877	29.891
34.887	1.0902	32.002
35.423	1.0917	32.447
37.812	1.0928	34.601
39.168	1.0928	35.843
44.762	1.0955	40.862
54.149	1.1003	49.213
59.717	1.1026	54.161
65.021	1.1059	58.797
77.360	1.1131	69.338
82.545	1.1160	73.967
88.239	1.1186	78.886
93.298	1.1229	83.154

0.00°C

P	PV	d
22.064	1.0089	21.869
23.555	1.0103	23.316
25.867	1.0121	25.558
28.468	1.0135	28.089
30.790	1.0147	30.345
39.753	1.0168	39.098
44.862	1.0190	44.030
59.777	1.0265	58.234
66.104	1.0307	64.135
74.059	1.0359	71.493
79.100	1.0392	76.117
84.662	1.0408	81.347

-103.01°C

P	PV	d
35.558	0.6304	56.40
36.677	0.6300	58.21
40.610	0.6324	64.21
42.107	0.6329	66.53
55.136	0.6369	86.57
58.533	0.6384	91.70
78.110	0.6481	120.52

-141.22°C

P	PV	d
33.840	0.4846	69.83
37.707	0.4852	77.71
38.581	0.4853	79.50
43.319	0.4869	88.97
49.881	0.4875	102.32
51.916	0.4878	106.42
66.471	0.4927	134.91
78.558	0.4970	158.06

-182.60°C

P	PV	d
32.057	0.3210	99.89
32.988	0.3208	102.84
36.438	0.3205	113.69
36.880	0.3205	115.07
41.371	0.3196	129.44
42.533	0.3194	133.15
49.943	0.3189	156.61
50.514	0.3186	158.55
63.320	0.3179	199.21

-200.06°C

P	PV	d
26.214	0.2494	105.10
28.402	0.2483	114.38
31.417	0.2469	127.24
34.268	0.2451	139.81
34.285	0.2451	139.88
39.843	0.2425	164.30
39.891	0.2423	164.63
46.517	0.2394	194.30
46.529	0.2392	194.51
47.951	0.2389	200.79
61.657	0.2339	263.77
67.456	0.2317	291.10
73.699	0.2302	320.15
79.823	0.2283	349.59

-208.10°C

P	PV	d
24.071	0.2151	111.90
28.844	0.2114	136.44
31.948	0.2088	153.00
37.856	0.2041	185.47
41.798	0.2010	207.95
58.472	0.1897	308.32
64.451	0.1867	345.22
69.692	0.1844	377.89
74.532	0.1822	409.18
79.228	0.1804	439.18

-213.08°C

P	PV	d
23.086	0.1925	119.92
24.810	0.1911	129.82
26.673	0.1893	140.90
29.365	0.1862	157.70
32.441	0.1829	177.37
37.418	0.1776	210.68
53.896	0.1611	334.59
59.769	0.1565	382.03
66.271	0.1522	435.46
72.858	0.1503	484.75
79.698	0.1491	534.62

-217.52°C

P	PV	d
21.349	0.1730	123.40
22.997	0.1707	134.72
24.686	0.1683	146.67
26.848	0.1652	162.51
30.042	0.1607	186.94
32.795	0.1564	209.66
49.230	0.1373	358.51
53.528	0.1353	395.62
59.618	0.1301	458.40
64.975	0.1271	511.05
71.649	0.1253	571.69
79.417	0.1236	642.51

1.003

DENSITY of GASEOUS NEON (Cont.)

Tabulation of Density for Selected Temperatures and Pressures

+20.00°C (293.09°K)

Pressure atm.	Density gm/cm^3
22.8	.0190
25.0	.0207
26.6	.0220
29.1	.0241
32.6	.0269
34.9	.0288
35.4	.0292
37.8	.0311
39.2	.0322
44.8	.0368
54.15	.0442
59.7	.0488
65.0	.0529
77.4	.0624
82.5	.0666
88.2	.0710
93.3	.0748

0.00°C (273.09°K)

Pressure atm.	Density gm/cm^3
22.1	.0197
23.55	.0210
25.9	.0230
28.5	.0253
30.8	.0273
39.8	.0352
44.9	.0396
59.8	.0524
66.1	.0576
74.1	.0644
79.1	.0685
84.7	.0731

-103.01°C (170.08°K)

Pressure atm.	Density gm/cm^3
35.6	.0508
36.7	.0524
40.6	.0577
42.1	.0599
55.1	.0780
58.6	.0826
78.1	.1085

-141.22°C (131.87°K)

Pressure atm.	Density gm/cm^3
33.8	.0623
37.1	.0700
38.6	.0715
43.3	.0801
49.9	.0920
51.9	.0957
66.5	.1213
78.6	.1425

-182.60°C (90.49°K)

Pressure atm.	Density gm/cm^3
32.1	.0900
33.0	.0925
36.4	.1022
36.9	.1038
41.4	.1165
42.5	.1200
49.9	.1410
50.5	.1428
63.3	.1795

-200.08°C (73.01°K)

Pressure atm.	Density gm/cm^3
26.2	.0945
28.4	.1030
31.4	.1146
34.3	.1259
34.3	.1260
39.8	.1480
39.9	.1482
46.5	.1750
46.5	.1751
48.0	.1808
61.7	.2373
67.5	.2620
73.85	.2910
79.9	.3140

-208.10°C (64.99°K)

Pressure atm.	Density gm/cm^3
24.1	.1008
28.8	.1229
31.95	.1378
37.9	.1670
41.8	.1872
58.5	.2778
64.45	.3106
69.7	.3400
74.5	.3688
79.2	.3960

-213.08°C (60.01°K)

Pressure atm.	Density gm/cm^3
23.1	.1080
24.8	.1169
26.7	.1269
29.4	.1420
32.4	.1598
37.4	.1899
53.9	.3012
59.8	.3440
66.3	.3920
72.9	.4360
79.7	.4810

-217.52°C (55.57°K)

Pressure atm.	Density gm/cm^3
21.35	.1111
23.0	.1212
24.7	.1320
26.85	.1463
30.0	.1682
32.8	.1838
49.9	.3230
53.5	.3240
59.6	.4130
65.0	.4610
71.65	.5150
79.4	.5685

1.003

DENSITY of GASEOUS NEON

(At Selected Points)

Sources of Data: Baxter, G. and Starkweather, Proc. Nat. Acad. Sci. 14 50-7 (1928); Mathias, E., and Crommelin, C. A., Proc. Fourth Intern. Congress of Refrigeration 1, 89-106a (1924); Onnes, H. K. and Crommelin, C. A., Proc. Akad. Wettenschappen 18, 515-20 (1915); Ramsay, W. and Travers, M. W., Trans. Roy. Soc. (London) 197, 47 (1901); Watson, H., J. Chem. Soc. 97, 810-33 (1910).

Comments: Other values of saturated density available are 0.9016 grams per liter [Aston, Proc. Roy. Soc. (London) A89, 439 (1914); Phil. Mag. 37, 523 (1919)], 0.89990 grams per liter [Baxter, G. and Starkweather, Proc. Nat. Acad. Sci. 14, 50-7 (1928)], 0.8935 grams per liter [Leduc, A., Ann. Physik 9, 24 (1918); Compt. rend. 158, 864-6 (1914)], and 0.891 grams per liter [Ramsay, W. and Travers, M. W., Trans. Roy. Soc. (London) 197, 47 (1901)]. Other values of the density of neon at the critical temp. available are 23.9 gram-moles per liter [Benson, S. W., J. Phys. and Colloid Chem. 52, 1060-74 (1948)], 0.483 grams per cubic centimeter [Crommelin, C. A., Onnes-Festschrift, 197 (1922); Phys. Ber. 4, 702 (1923)], 0.456 grams per cubic centimeter [Van Laar, J. J., Chem. Weekblad. 16, 1557-64 (1919)], and 0.528 grams per cubic centimeter [Mathias, E., Onnes-Festschrift, 169-96 (1922); Phys. Ber. 4, 701-2 (1923)]. Holborn, L. and Otto, J., Z. Physik 23, 77-94 (1924); Z. Physik 33, 1-12 (1925) also give 22.430 liters per gram-mole as the value of the molal volume under standard conditions.

The Leiden Temperature Scale (0°C = 273.09°K) is used.

Table of Selected Values

State	Pressure		Temperature		Density	
	atm	psia	°K	°R	gm/cm^3	lb/ft^3
Standard	1	14.696	273.09	491.56	0.9002 x 10^{-3}	0.056 20
Normal B.P.	1	14.696	27.17	48.91	9.46 "	0.591
Critical	26.86	394.7	44.38	79.88	483.5 "	30.18
	1	14.696	289.09	520.36	0.9004 "	0.056 21
	1	14.696	291.09	523.96	0.9004 "	0.056 21
	0.6667	9.797	273.09	491.56	0.60004 "	0.037 459
	0.3333	4.899	273.09	491.56	0.30009 "	0.018 734
Molal Volume	1	14.696	273.09	491.56	22.430 liters/mole	17.802 ft^3/lb

FDT/BDT Issued: 5-30-59

1.004

ATOMIC WEIGHT of NITROGEN

Source of Data:

Moles, E., Gazz. chim. itali. 56, 915-47 (1926).

Moles, E. and Sancho, J., Anales soc. espan. fis. y quim. 32, 931-53 (1934).

Other References:

Batuecas, T. and Casado, F. L., Anales real soc. espan. fis. y quim. (Madrid) 48B, 295-304 (1952).

Baxter, G. P. and Starkweather, H. W., Proc. Nat. Acad. Sci. U.S. 12, 703-7 (1926)

Moles, E. and Salazar, M. T., Anales soc. espan. fis. y quim. 32, 954-78 (1934).

Comments:

Some values given for the atomic weight of Nitrogen are:

14.0095 ± 0.0018 (Batuecas, T. and Casado, F. L.)
14.007 and 14.005 (Baxter, G. P. and Starkweather, H. W.)
14.0083 (Moles, E. and Salazar, M. T.)

Most probable value is 14.008

KDT/RJR/VJJ Issued: 6-10-59

DENSITY of NITROGEN in VARIOUS STATES

Sources of Data:

Baxter, G. P. and Starkweather, H. W., Proc. Nat. Acad. Sci. 12, 703-7 (1926).

Dewar, J., Proc. Roy. Soc. (London) A73, No. 492, 251-61 (1904).

Gray, J. Chem. Soc. (London) 87, 1601 (1905).

International Critical Tables

Keesom, W. H., Onnes-Festschrift 1922, 89-163 (1922).

Keesom, W. H., Physik Ber. 4, 613 (1923).

Mathias, E. and Crommelin, C. A., Proc. Fourth Intern. Congress of Refrig. 1, 89-106a (1924).

Moles, E., J. chim. phys. 19, 283 (1922).

Moles, E. and Clavera, J. M., Anales soc. espana. fis. y quim. 20, 550 (1922).

Moles, E. and Clavera, J. M., J. chim. phys. 21, 10-14 (1924).

Other References:

International Critical Tables

Paya and Moles, E., Anales soc. españa. fis. y quim. 20, 247 (1922).

Moles, E., Gazz. chim. ital. 56, 915-47 (1926).

Pickering, S. F., Nat. Bur. Standards Sci. Paper No. 541, 597-629 (1926).

Comments:

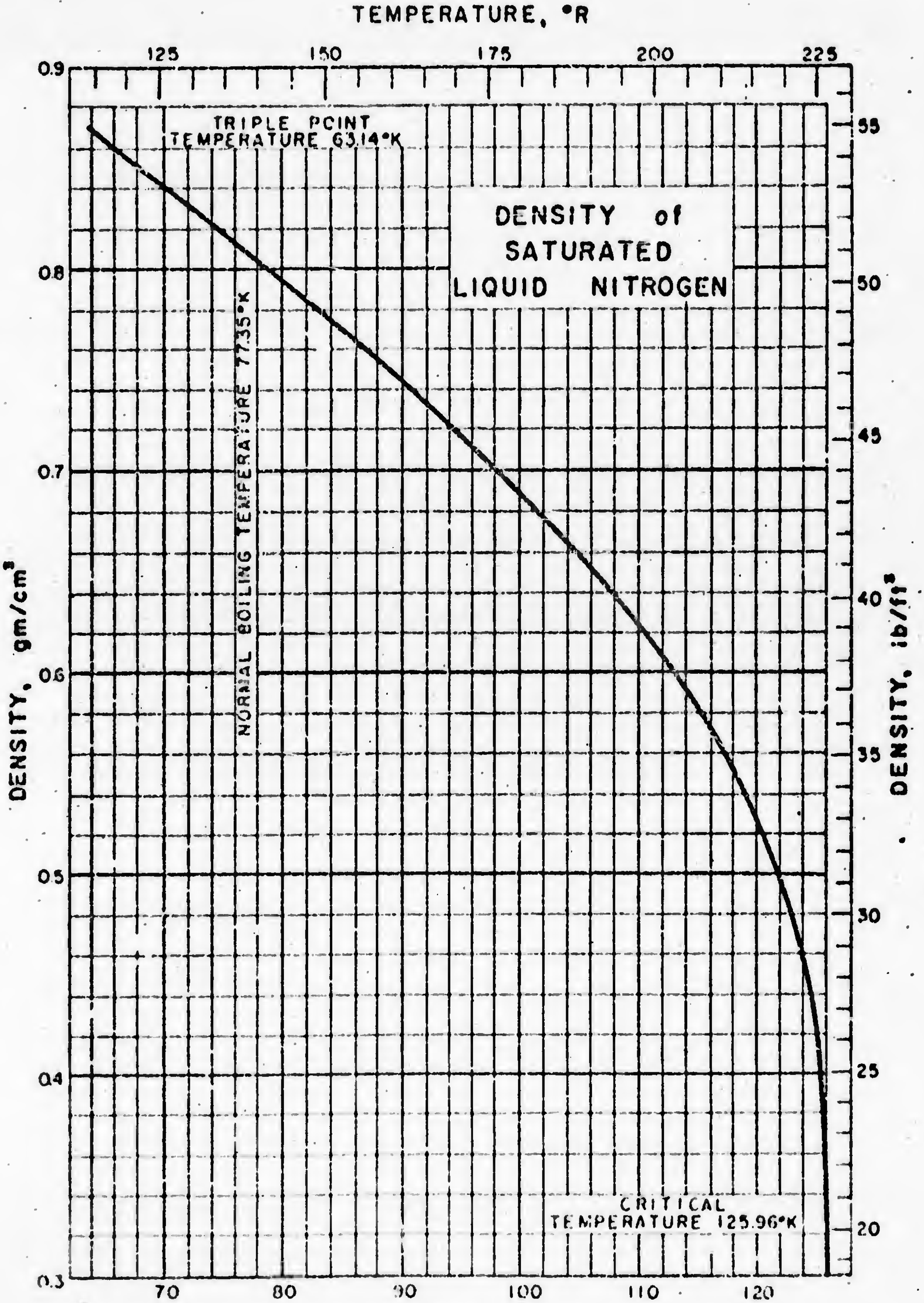
The International Critical Tables and Paya and Moles give a value of 0.0012568 gm/cm3 for the density of nitrogen at standard conditions (0°C, 1 atm.), however, the nitrogen used in their determinations was impure and this value should not be used. International Critical Tables, Moles, and Pickering all give a value of 0.311 gm/cm3 for the critical density of nitrogen. The temperature scale used is one which sets 0°C equal to 273.10°K.

Table of Selected Values

State	Temperature		Pressure		Density	
	°K	°R	atm.	psia	gm/cm3	lb/ft3
Standard	273.10	491.58	1	14.696	0.001 2505$_7$	0.078 073
Critical	126.26	227.27	33.54	492.9	.310 96	19.413
Boiling Liquid	77.32	139.18	1	14.696	.8084	50.4
Solid	20.7	37.3			1.026$_5$	64.08

KDT/RJR/VJJ Issued: 6-11-59

1.004


TEMPERATURE, °R
125
150
175
200
225
TRIPLE POINT TEMPERATURE 63.14°K
DENSITY of SATURATED LIQUID NITROGEN
NORMAL BOILING TEMPERATURE 77.35°K
CRITICAL TEMPERATURE 125.96°K
DENSITY, gm/cm³
0.9
0.8
0.7
0.6
0.5
0.4
0.3
DENSITY, lb/ft³
55
50
45
40
35
30
25
20
70
80
90
100
110
120
TEMPERATURE, °K

DENSITY of LIQUID NITROGEN
(Saturated)

Sources of Data:

Gerold, E., Ann. Physik 65, 82-96 (1921)

International Critical Tables

Mathias, E. and Crommelin, C. A., Proc. Fourth Intern. Congress of Refrig. 1, 89-106a (1924)

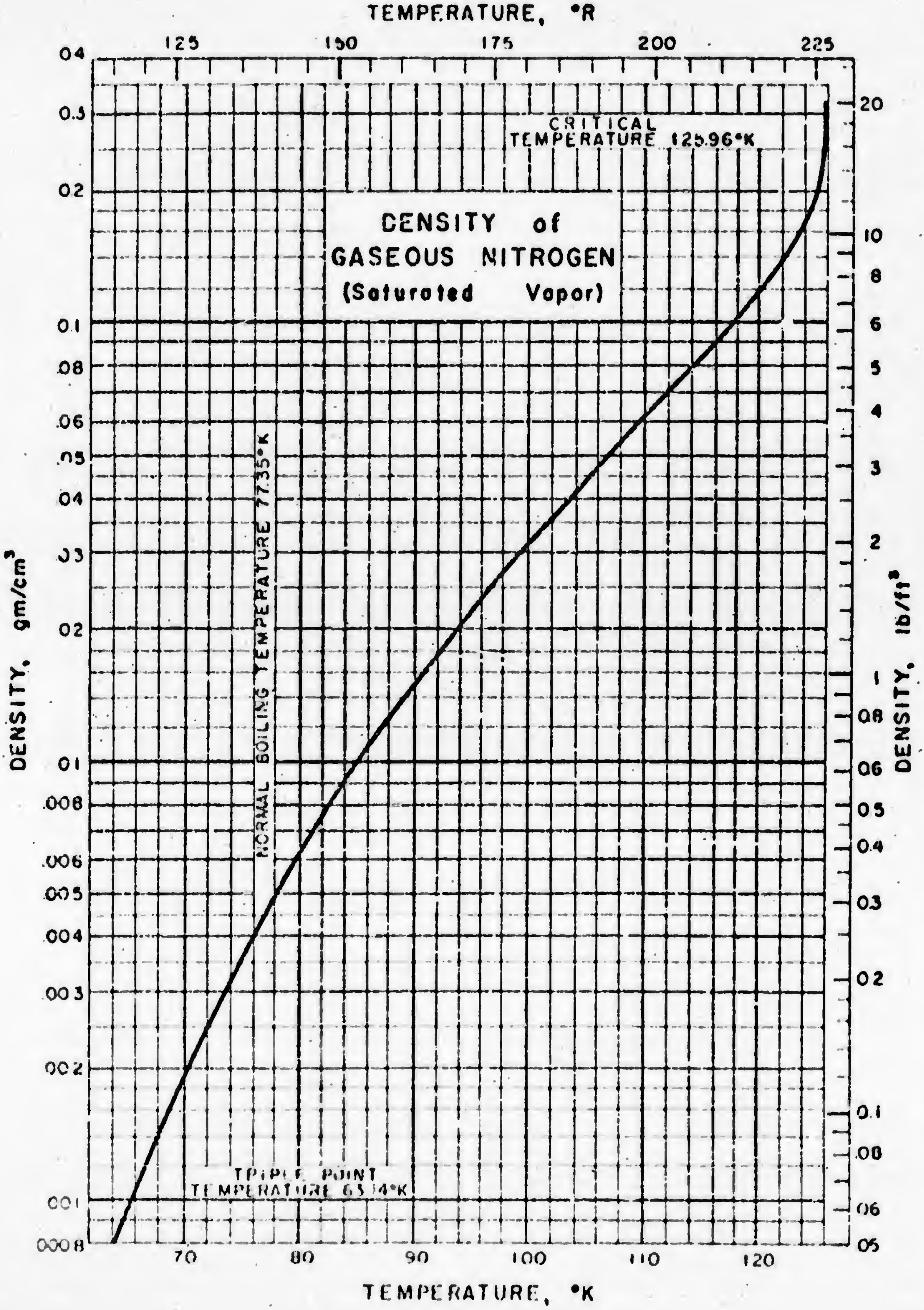
Comments:

The Leiden Temperature scale (0°C = 273.09°K) was used for the data given below.

Temp. °K	Density gm/cm^3
63.14+	
64.73	0.8622
77.31	.8084
77.32‡	
77.5	
78.00	.8043
90.58	.7433
99.36	.6922
111.89	.6071
119.44	.5332
125.01	.4314
125.96*	.31096

* Critical Temperature
\+ Triple Point Temperature
‡ Normal Boiling Temperature

KDT/RJR/VJJ Issued: 7-9-59


TEMPERATURE, °R
125
150
175
200
225
CRITICAL TEMPERATURE 125.96°K
DENSITY of GASEOUS NITROGEN (Saturated Vapor)
NORMAL BOILING TEMPERATURE 77.35°K
TRIPLE POINT TEMPERATURE 63.14°K
DENSITY, gm/cm³
0.4
0.3
0.2
0.1
.08
.06
.05
.04
.03
.02
.01
.008
.006
.005
.004
.003
.002
.001
.0008
DENSITY, lb/ft³
20
10
8
6
5
4
3
2
1
0.8
0.6
0.5
0.4
0.3
0.2
0.1
.08
.06
.05
70
80
90
100
110
120
TEMPERATURE, °K

1.004

DENSITY of GASEOUS NITROGEN

(Saturated Vapor)

Sources of Data:

Gerold, E., Ann. Physik 65, 82-96 (1921)

International Critical Tables

Mathias, E. and Crommelin, C. A., Proc. Fourth Intern. Congress of Refrig. 1, 89-106a (1924)

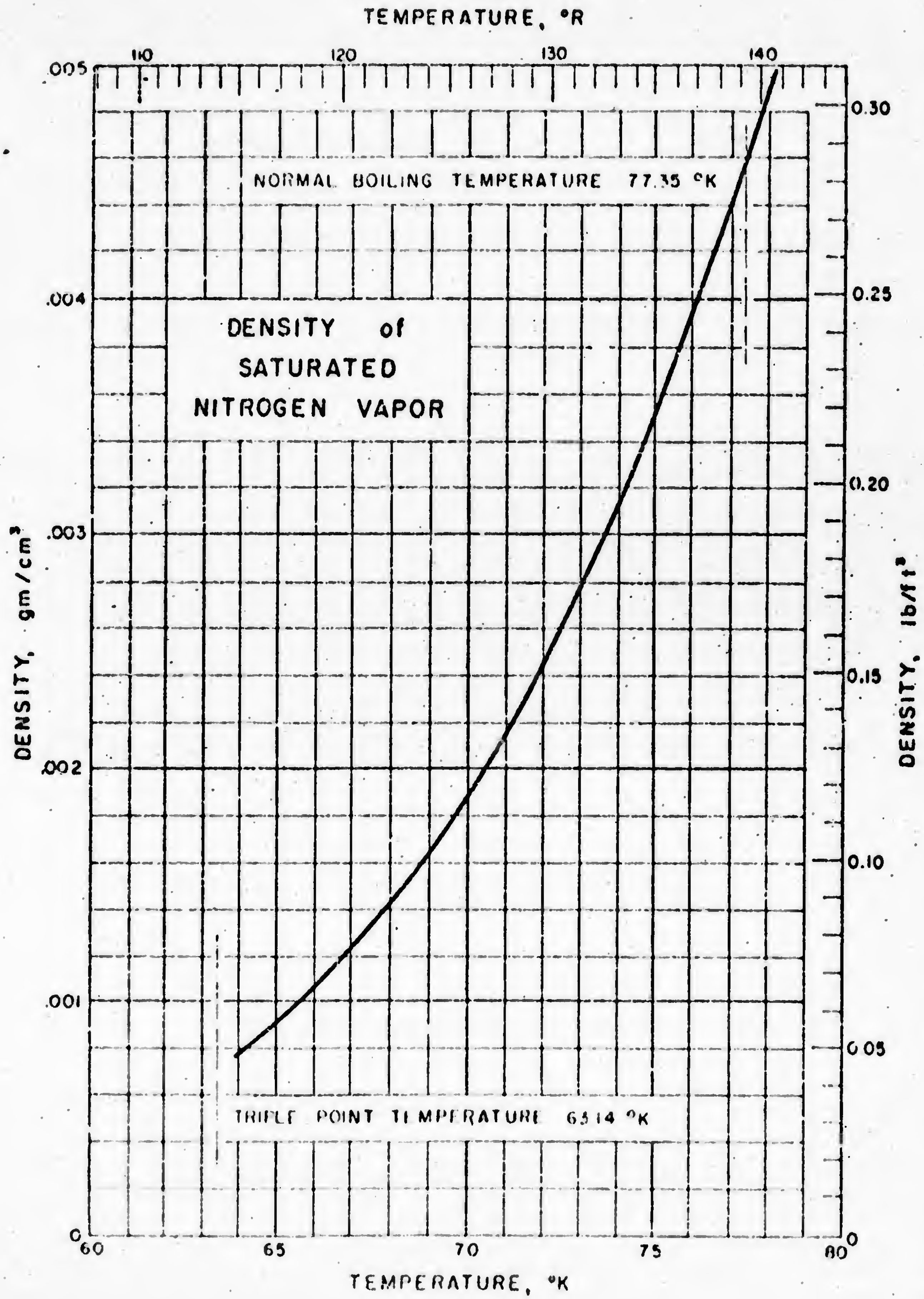
Comments:

The Leiden Temperature scale (0°C = 273.09°K) was used for the data given below.

Temp. °K	Density gm/cm3
63.14‡	
64.73	0.000 868$^+$
77.31	
77.32*	
77.5	.004 4973
78.00	.004 98
90.58	.015 76
99.36	.029 62
111.89	.069 87
119.44	.117 7
125.01	.200 0
125.96**	.310 96

$^+$ Calculated from Equation of State
‡ Triple Point Temperature
* Normal Boiling Temperature
** Critical Temperature

KDT/RJR/VJJ Issued: 7-9-59


TEMPERATURE, °R
110
120
130
140
DENSITY of SATURATED NITROGEN VAPOR
NORMAL BOILING TEMPERATURE 77.35 °K
TRIPLE POINT TEMPERATURE 63.14 °K
DENSITY, gm/cm^3
.005
.004
.003
.002
.001
0
DENSITY, lb/ft^3
0.30
0.25
0.20
0.15
0.10
0.05
0
60
65
70
75
80
TEMPERATURE, °K

1.004

DENSITY of GASEOUS NITROGEN

(Saturated Vapor Below 1 Atmosphere)

Source of Data:

Armstrong, G. T., J. Research Natl. Bur. Standards 53, 263-6 (1954)

Comments:

There are two values of density for each temperature due to duplicated determinations. An equation which fits this experimental data is:

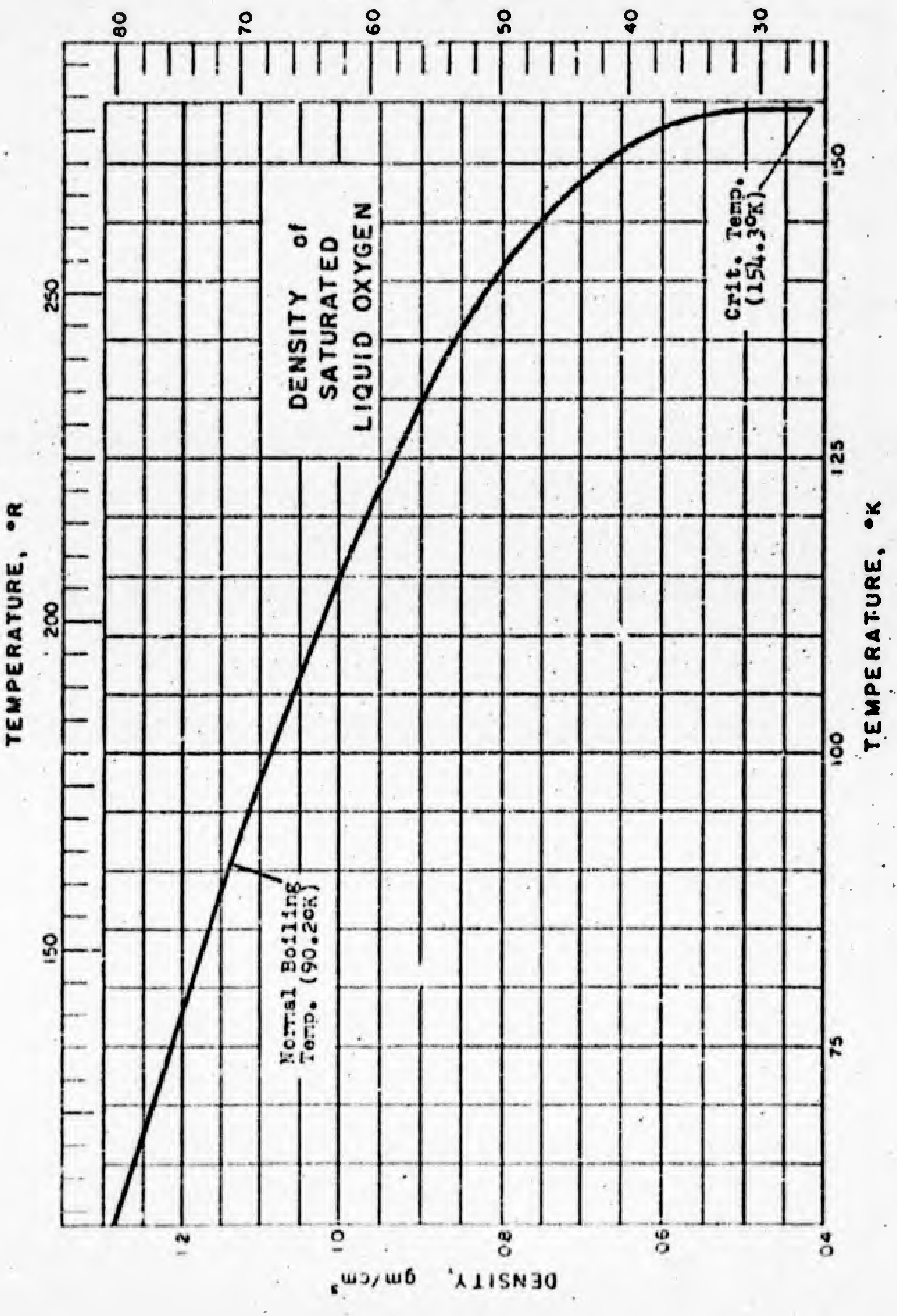
$$\text{Log}\ \rho T = 3.39858 - \frac{282.953}{T - 3.83}$$

where ρ = density in gm/cm^3
and T = temperature in °K

The Absolute temperature scale (0°C = 273.16°K) was used in the table of selected values below.

Temp. °K	Density, gm/cm^3	
	Determ. 1	Determ. 2
64.80	0.883 x 10^{-3}	0.89 x 10^{-3}
67.71	1.376 "	1.36 "
68.00	1.434 "	1.434 "
73.10	2.818 "	2.818 "
73.13	2.828 "	2.78 "
77.364	4.593 "	4.593 "
78.00	4.915 "	4.916 "
78.07	4.952 "	4.98 "

KDT/RJR ISSUED: 7/13/59



DENSITY of SATURATED LIQUID OXYGEN

Normal Boiling Temp. (90.2°K)

Crit. Temp. (154.3°K)

1.005

DENSITY of LIQUID OXYGEN

(Saturated)

Sources of Data:

Van Itterbeek, A., Progress in Low Temperature Physics Vol. I, North Holland Publishing Company, Amsterdam, The Netherlands, (1955) 366

Mathias, E. and Onnes, H. K., Commun. Phys. Lab. Univ. Leiden, No. 117 (1911)

Other References:

Chelton, D. B. and Mann, C. B., Univ. of Calif. Rad. Lab. Cryogenic Data Book, UCRL-3421, 37 (1956) refers to Handbook of Chemistry and Physics (Chemical Rubber Publ. Co.) which gives the following:

Temp. °C	Density gm/cm³	Reference
-123	.89	Cailletet & Hautefeuille, 1881
-182.7*	1.14	Kamerlingh Onnes & Perrier, 1910
-205	1.25	Baly and Donnan

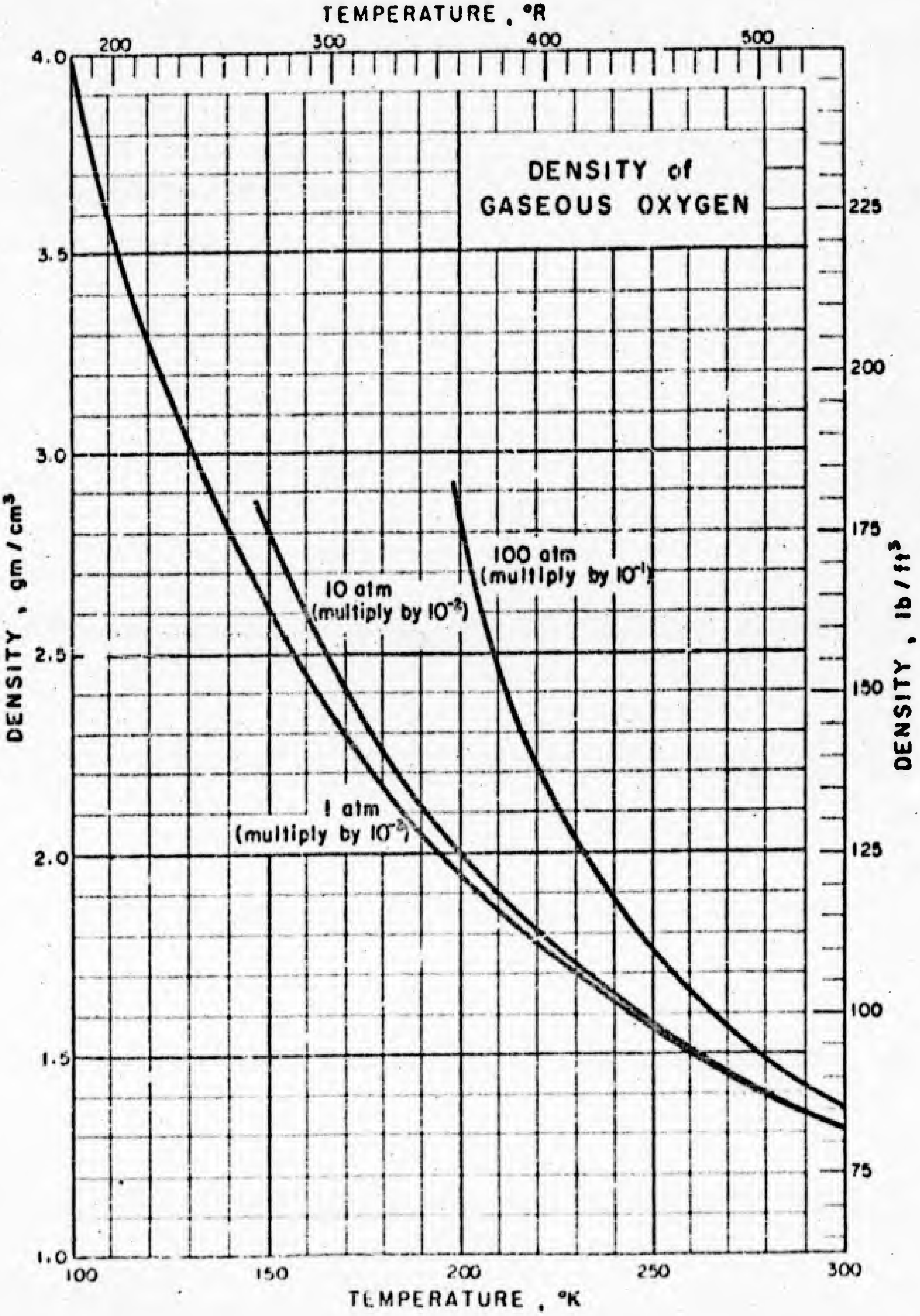
* Normal Boiling Temperature (current accepted value is -182.97°C)

Table of Selected Values

A. Van Itterbeek		Mathias & Onnes	
Temp. °K	Density gm/cm³	Temp. °K	Density gm/cm³
61	1.282	62.7	1.2746
65	1.263	91.1	1.1415
70	1.239	118.6	.9758
75	1.215	132.9	.8742
80	1.191	143.2	.7781
85	1.167	149.8	.6779
90	1.142	152.7	.6032
		154.3*	.4299

* Critical Point (current accepted value is 154.[illegible]°K [illegible] on present International Scale of 0°C = 273.[illegible]°K instead of the Leiden Temperature Scale of 0°C = 273.09°K)

SS/LJR/VJ Issued: [illegible]/10/57


TEMPERATURE, °R
200
300
400
500
DENSITY of GASEOUS OXYGEN
4.0
3.5
3.0
2.5
2.0
1.5
1.0
DENSITY, gm/cm³
225
200
175
150
125
100
75
DENSITY, lb/ft³
100 atm
(multiply by 10^{-1})
10 atm
(multiply by 10^{-2})
1 atm
(multiply by 10^{-3})
100
150
200
250
300
TEMPERATURE, °K

1.005

DENSITY of GASEOUS OXYGEN

Source of Data:

Hilsenrath, J., et al., Nat. Bur. Standards Cir. 564, 396-8 (1955)

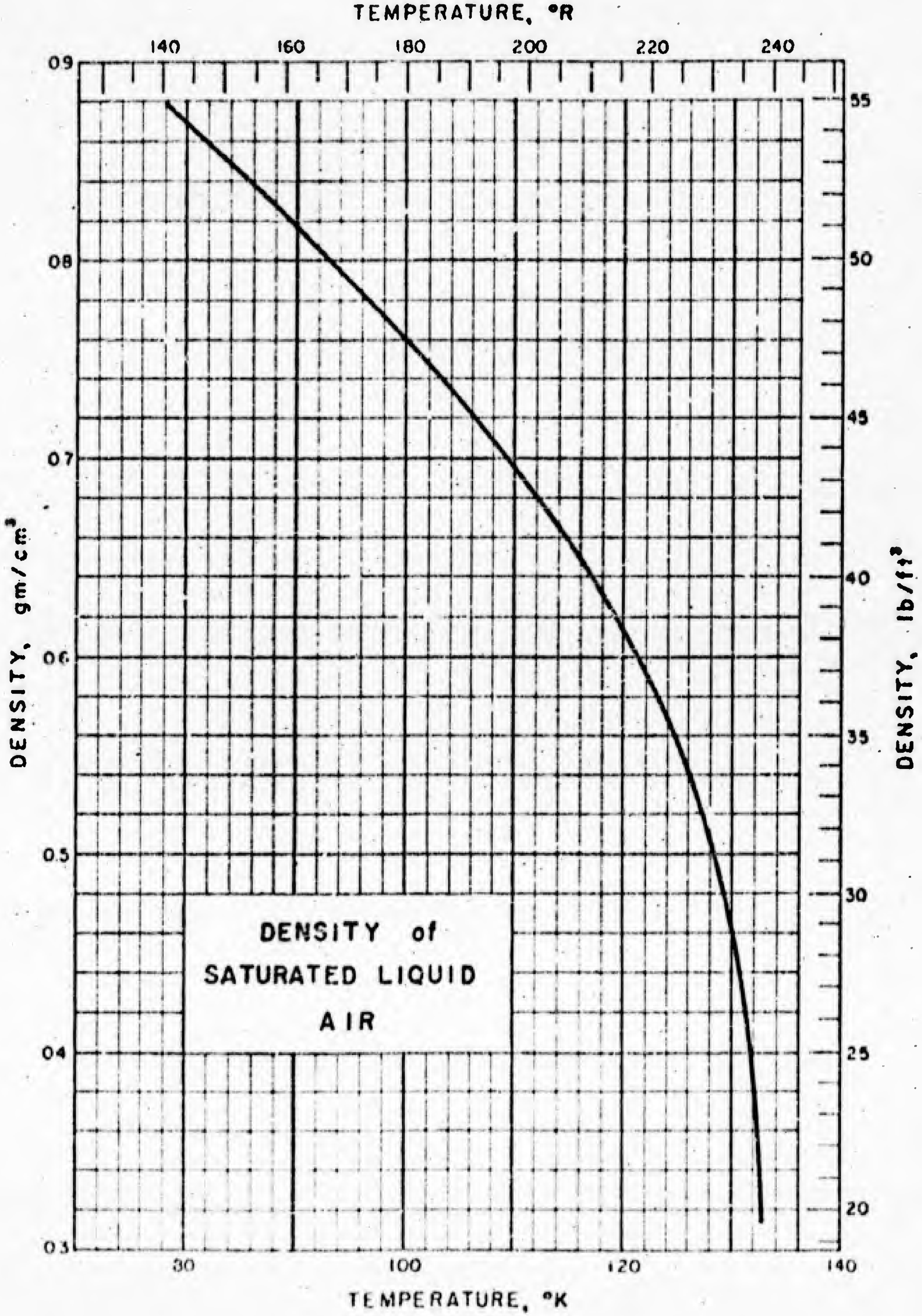
Comments:

The data were given in the form of ρ/ρ_0 the ratio of actual density to density at standard conditions (1 atm, 0°C) which is 1.42900×10^{-3} gm/cm^3.

The absolute temperature scale (0°C = 273.16°K) was used in the table of selected values below.

Temp. °K	Density, gm/cm^3 1 atm	10 atm	100 atm
100	3.9906×10^{-3}		
110	3.6074 "		
120	3.2942 "		
130	3.0324 "		
140	2.8100 "		
150	2.6186 "	2.8137×10^{-2}	
160	2.4519 "	2.5980 "	
170	2.3054 "	2.4180 "	
180	2.1756 "	2.2635 "	
190	2.0597 "	2.1292 "	
200	1.9557 "	2.0110 "	2.8366×10^{-1}
210	1.8618 "	1.9061 "	2.4707 "
220	1.7765 "	1.8124 "	2.2207 "
230	1.6987 "	1.7278 "	2.0335 "
240	1.6275 "	1.6512 "	1.8949 "
250	1.5620 "	1.5815 "	1.76393 "
260	1.5017 "	1.5176 "	1.66036 "
270	1.4458 "	1.4587 "	1.57147 "
280	1.3940 "	1.4046 "	1.49330 "
290	1.3457 "	1.3543 "	1.42430 "
300	1.3007 "	1.3077 "	1.36241 "

JN/RJR [illegible] [illegible]-22-59


TEMPERATURE, °R
140
160
180
200
220
240
0.9
0.8
0.7
0.6
0.5
0.4
0.3
DENSITY, gm/cm³
55
50
45
40
35
30
25
20
DENSITY, lb/ft³
DENSITY of
SATURATED LIQUID
AIR
80
100
120
140
TEMPERATURE, °K

1.006

DENSITY of LIQUID AIR

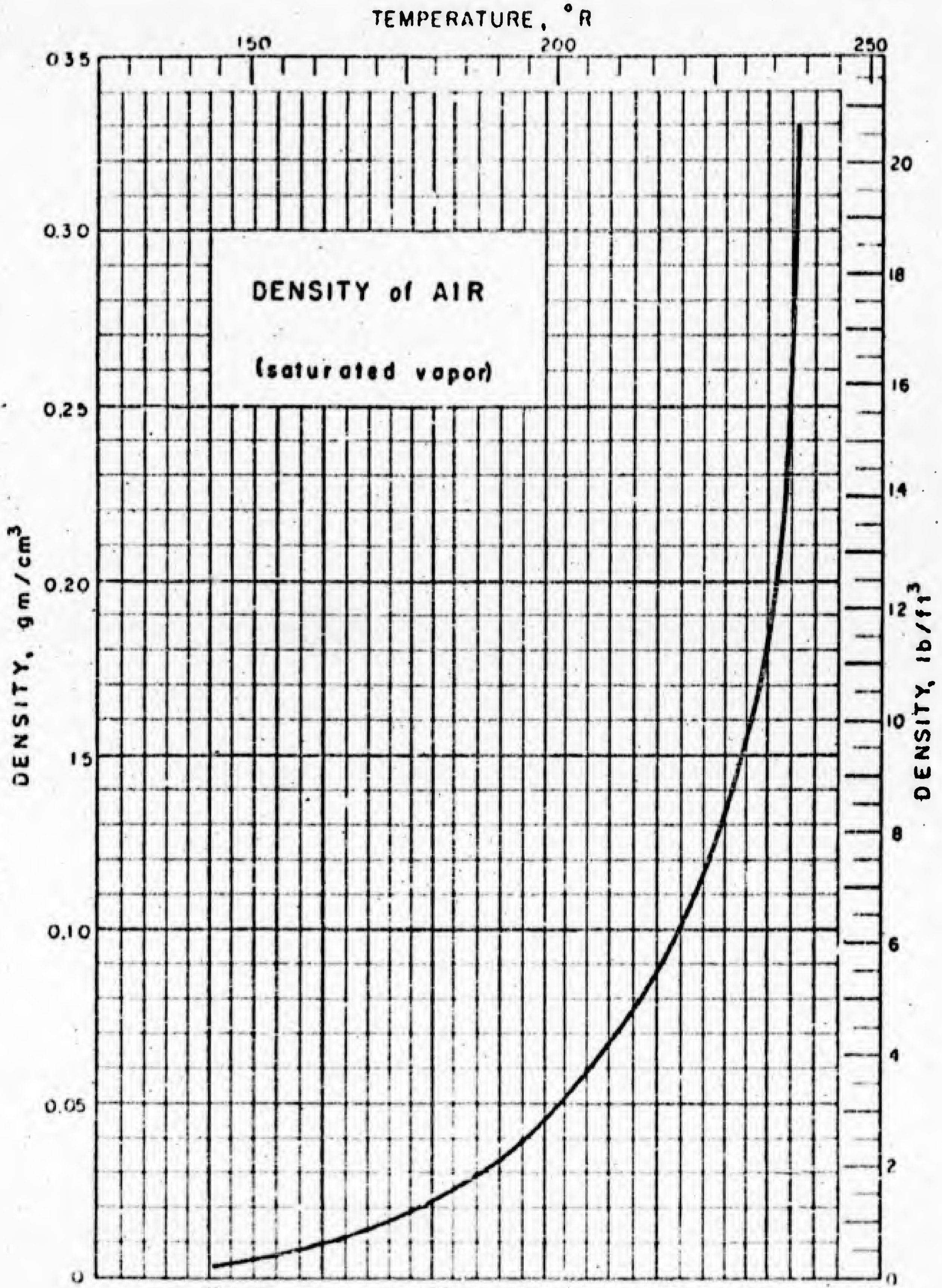
(Saturated)

Source of Data: Din, F., Thermodynamic Functions of Gases, Vol. 2, Butterworth's Scientific Publications, London (1956).

Density of Saturated Liquid

Pressure atm.	Temp. °K	Volume cm^3/mole	Density gm/cm^3	 lb/ft^3
1	78.8	33.14	0.8739	54.56
2	85.55	34.39	.8421	52.57
3	90.94	35.40	.8181	51.07
5	96.38	36.94	.7840	48.94
7	101.04	38.21	.7579	47.31
10	106.47	40.00	.7240	45.20
15	113.35	43.21	.6702	41.84
20	118.77	46.63	.6211	38.77
25	123.30	50.37	.5749	35.89
30	127.26	55.69	.5200	32.46
35	130.91	64.90	.4462	27.86
37.17	132.52	90.52	.3199	19.97
37.25	132.42	88.28	.3280	20.48

WJV/DAV/JAB Issued: 7-9-59


TEMPERATURE, °R
150
200
250
DENSITY of AIR
(saturated vapor)
DENSITY, gm/cm³
0.35
0.30
0.25
0.20
15
0.10
0.05
0
DENSITY, lb/ft³
20
18
16
14
12
10
8
6
4
2
0
80
100
120
140
TEMPERATURE, °K

DENSITY of AIR
(at Saturation)

Source of Data:

Din, F., Thermodynamic Functions of Gases, Vol. 2, Butterworth's Scientific Publications, London (1956).

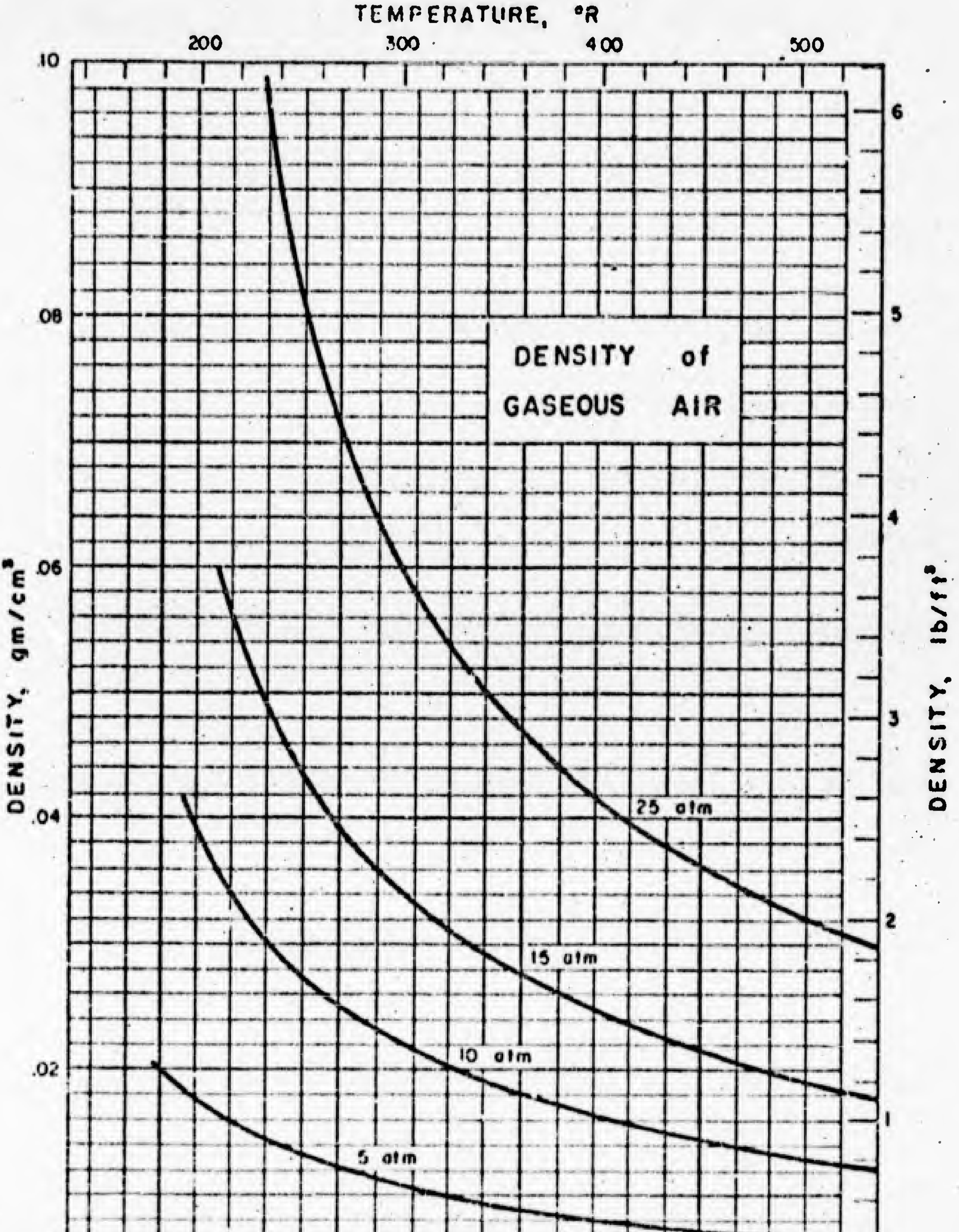
Comments:

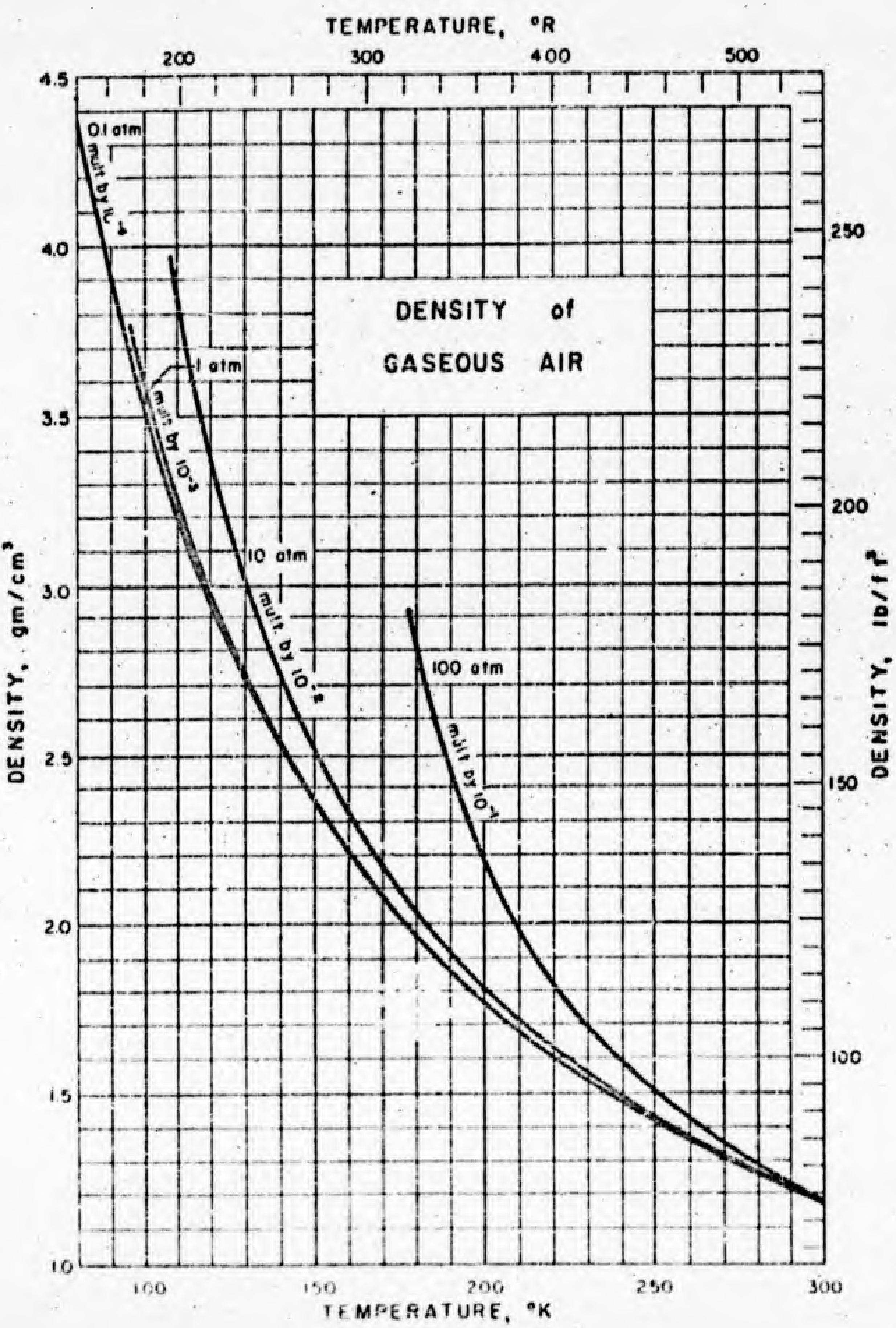
In the table of selected values below, the density of air at saturation is given over a narrow range of temperature and pressure where,

T = °K (0°C = 273.15°K)
P = atmosphere

Pressure atm.	Temp. °K	Volume cm^3/mole	Density gm/cm^3	Density lb/ft^3
1	81.8	6456.7	0.004 485	0.2800
2	88.31	3389.1	.008 545	.5334
3	92.63	2319.0	.012 49	.7797
5	98.71	1427.6	.020 29	1.266
7	103.16	1029.1	.028 14	1.757
10	108.35	718.4	.040 31	2.516
15	114.91	464.8	.062 31	3.890
20	120.07	330.4	.087 65	5.472
25	124.41	246.6	.117 4	7.329
30	128.12	186.6	.155 2	9.689
35	131.42	134.2	.215 8	13.47
37.17	132.52	90.52	.319 9	19.97
37.25	132.42	88.28	.328 0	20.48

WJV/DAV/JAB Issued: 7-14-59


TEMPERATURE, °R
200
300
400
500
.10
.08
.06
.04
.02
0
DENSITY, gm/cm^3
6
5
4
3
2
1
0
DENSITY, lb/ft^3
DENSITY of GASEOUS AIR
25 atm
15 atm
10 atm
5 atm
75
100
150
200
250
300
TEMPERATURE, °K


TEMPERATURE, °R
200
300
400
500
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
DENSITY, gm/cm^3
0.1 atm
mult by 10^{-4}
1 atm
mult by 10^{-3}
10 atm
mult. by 10^{-2}
100 atm
mult by 10^{-1}
DENSITY of GASEOUS AIR
250
200
150
100
DENSITY, lb/ft^3
100
150
200
250
300
TEMPERATURE, °K

1.006

DENSITY of AIR (Gaseous State)

Source of Data: NBS Circular 564 (1955); Din, F., *Thermodynamic Functions of Gases*, 2, Butterworths Scientific Publications, London (1956).

Other References: Ishkin, I. P., and Kaganer, M. G., Sov. Phys. Tech. Phys., 1, 2255-2262, 2263-2271 (1956); Michels, A., Wassenaar, T., and Wolker, G., Appl. Sci. Res. Sect. A, 5 (1955).

Density of Air, gm/cm^3

Temp.	Data from NBS Circular 564			
°K	.1 ATM	1 ATM	10 ATM	100 ATM
80	4.4274 x 10^{-4}			
90	3.9317 " "			
100	3.5365 " "	3.5984 x 10^{-3}		
110	3.2135 " "	3.2563 " "	3.8970 x 10^{-2}	
120	2.9448 " "	2.9753 " "	3.3796 " "	
130	2.7176 " "	2.7400 " "	3.0136 " "	
140	2.5230 " "	2.5397 " "	2.7342 " "	
150	2.3546 " "	2.3672 " "	2.5092 " "	
180	1.9616 " "	1.9672 " "	2.0299 " "	2.8230 x 10^{-1}
210	1.6812 " "	1.6841 " "	1.7141 " "	1.9790 " "
240	1.4709 " "	1.4727 " "	1.4873 " "	1.5900 " "
270	1.3074 " "	1.3081 " "	1.3152 " "	1.3514 " "
300	1.1766 " "	1.177 " "	1.180 " "	1.1850 " "
	Data from F. Din			
	1 ATM	5 ATM	15 ATM	25 ATM
90	4.038 x 10^{-3}			
100	3.606 " "	1.989 x 10^{-2}		
110	3.260 " "	1.750 " "		
120	2.978 " "	1.570 " "	5.666 x 10^{-2}	
130	2.741 " "	1.428 " "	4.860 " "	9.837 x 10^{-2}
140	2.540 " "		4.318 " "	8.114 " "
150	2.367 " "	1.214 " "	3.912 " "	7.089 " "
180	1.967 " "	0.9972 " "	3.102 " "	5.370 " "
210	1.684 " "	0.8485 " "	2.5966 " "	4.413 " "
240	1.472 " "	0.7393 " "	2.2429 " "	3.778 " "
270	1.308 " "	0.6555 " "	1.9785 " "	3.315 " "
300	1.177 " "	0.5891 " "	1.7719 " "	2.959 " "

WJV/DAV/JAB Issued: 9-9-59

1.007

DENSITY of SOLID CARBON MONOXIDE

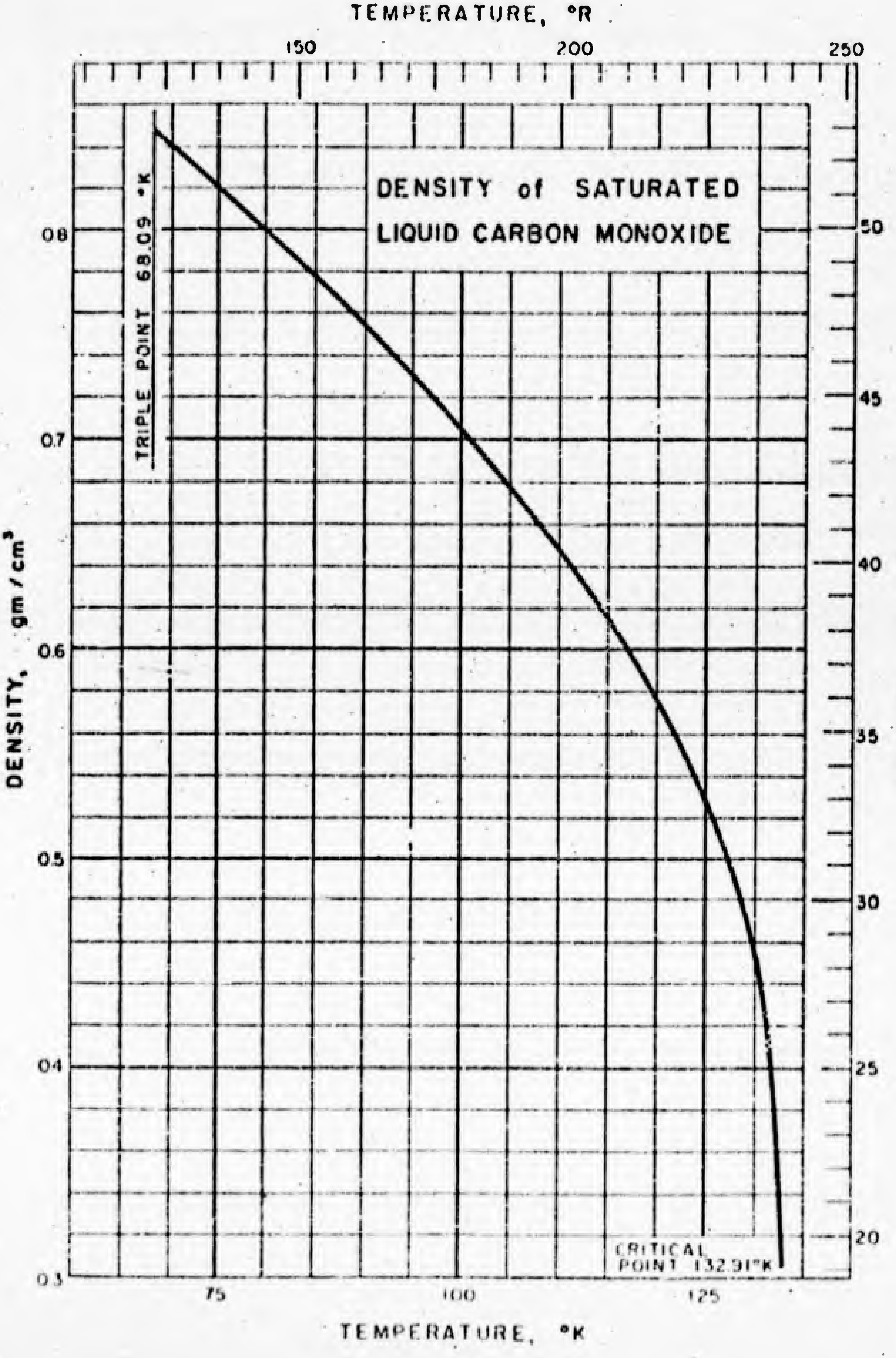
Source of Data: Vegard, L., Z. Physik 88, 235-41 (1934).

Comments: Solid carbon monoxide exists in two forms, α and β. The transition temperature from α to β is 61.5°K.

Table of Values

Form	Temp. °K	Density gm/cm³
α	20	1.0288
β	65	0.929

KDT/HDP Issued: 6-19-59


TEMPERATURE, °R
150
200
250
DENSITY of SATURATED
LIQUID CARBON MONOXIDE
TRIPLE POINT 68.09 °K
CRITICAL
POINT 132.91°K
DENSITY, gm/cm³
0.8
0.7
0.6
0.5
0.4
0.3
DENSITY, lb/ft³
50
45
40
35
30
25
20
75
100
125
TEMPERATURE, °K

1.007

DENSITY OF LIQUID CARBON MONOXIDE
(at Saturation)

Sources of Data:

Fales, H. A. and Shapiro, C. S., J. Am. Chem. Soc. 62, 393-406 (1940)

Mathias, E. and Crommelin, C. A., Ann. phys. 5, 137-66 (1936)

Comments:

Other values of the critical density available are 0.3110 gm/cc [Cardoso, E., J. chim. phys. 13, 312 (1915); and Pickering, S. F., N.B.S. Sci. Paper No. 541, (1926)] and 0.301 gm/cc [Guggenheim, E. A., J. Chem. Phys. 13, 253-61 (1945); and Mathias, E., Crommelin, C. A., Bijleveld, W. J. and Grigg, P. P., Commun. Kamerlingh Onnes Lab. Univ. Leiden, Commun. No. 221b.

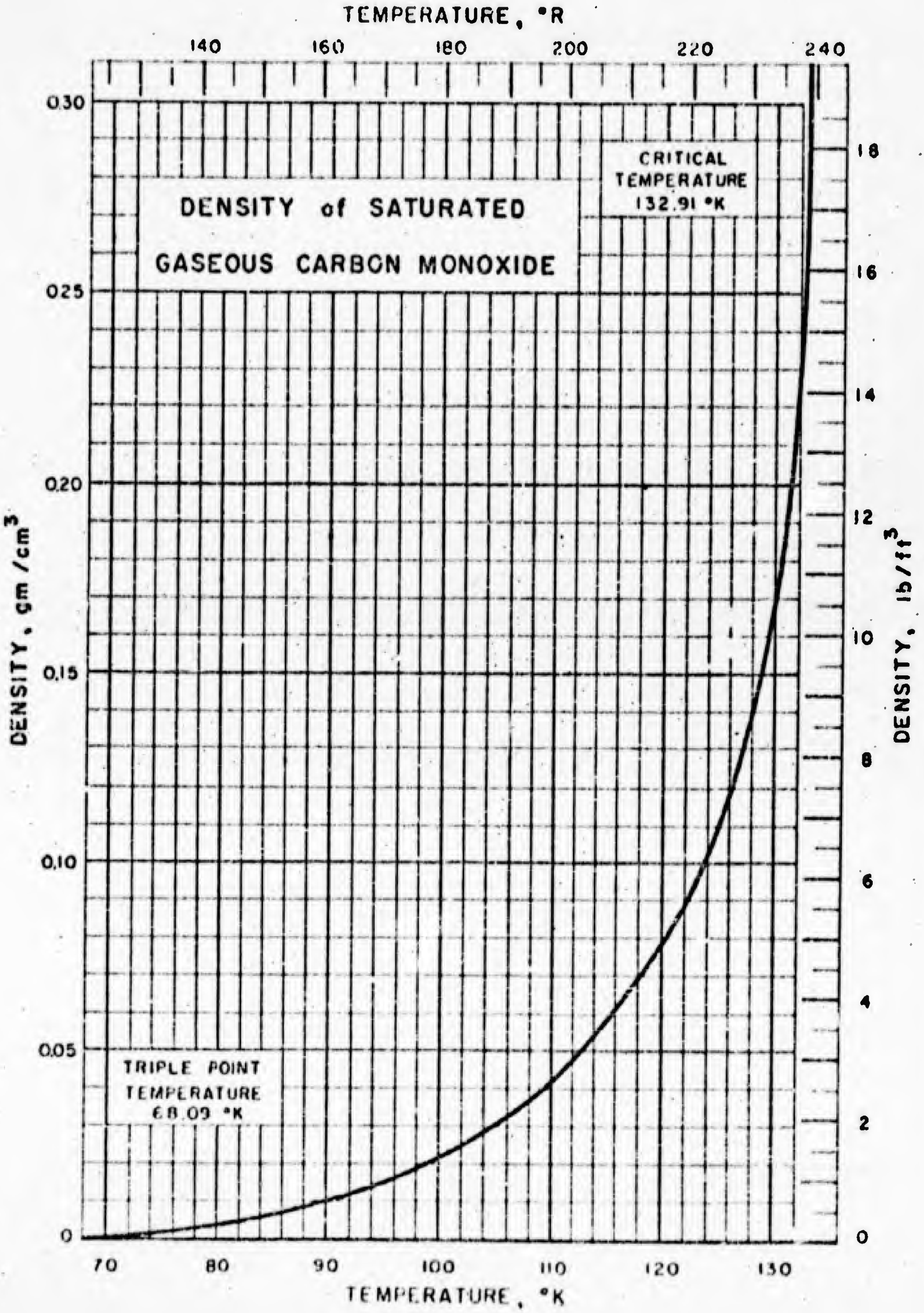
Table of Selected Values

Temp. °K	Density gm/cm^3	Temp. °K	Density gm/cm^3
68.13	0.84714	109.05	0.65262
73.56	.82554	120.90	.56582
78.03*	.80640	125.60	.52083
82.25	.79086	127.82	.49190
87.15	.76904	129.81	.45640
90.28	.75446	130.56	.44026
94.16	.73408	130.86	.43365
100.23	.69953	131.39*	.4220
103.50	.68560	132.91+	.305
107.61	.66168		

\+ Critical Point

* Authors believe to be inaccurate

KDT/BDT Issued: 6-19-59


TEMPERATURE, °R
140
160
180
200
220
240
DENSITY of SATURATED
GASEOUS CARBON MONOXIDE
CRITICAL
TEMPERATURE
132.91 °K
TRIPLE POINT
TEMPERATURE
68.09 °K
DENSITY, gm /cm^3
0.30
0.25
0.20
0.15
0.10
0.05
0
DENSITY, lb/ft^3
18
16
14
12
10
8
6
4
2
0
70
80
90
100
110
120
130
TEMPERATURE, °K

1.007

DENSITY of GASEOUS CARBON MONOXIDE
(Saturated)

Sources of Data:

Fales, H. A. and Shapiro, C. S., J. Am. Chem. Soc. 62, 393-406 (1940)

Mathias, E. and Crommelin, C. A., Ann. phys. 5, 137-66 (1936)

Comments:

Other values of the critical density available are:

0.3110 gm/cc [Cardoso, E., J. chim. phys. 13, 312 (1915); and Pickering, S. F., Natl. Bur. Standards Sci. Paper No. 541 (1926)]

0.301 gm/cc [Guggenheim, E. A., J. Chem. Phys. 13, 253-61 (1945); and Mathias, E., Crommelin, C. A., Bijleveld, W. J. and Grigg, P. P., Communs. Kamerlingh Onnes lab. Univ. Leiden, Commun. No. 221b.]

The Leiden temperature scale (0°C = 273.09°K) was used in the table of selected values below.

Temp. °K	Density gm/cm3	Temp. °K	Density gm/cm3
68.13	0.00080**	109.05	0.04014
73.56	.00171**	120.90	.08202
78.03*	.00296**	125.60	.11607
82.25	.00477**	127.82	.13601
87.15	.00774**	129.81	.16357
90.28	.01019**	130.56	.17767
94.16	.01422**	130.76	.18462
100.93	.02359	131.39*	.19392
103.50	.02624	132.91+	.305
107.61	.03281		

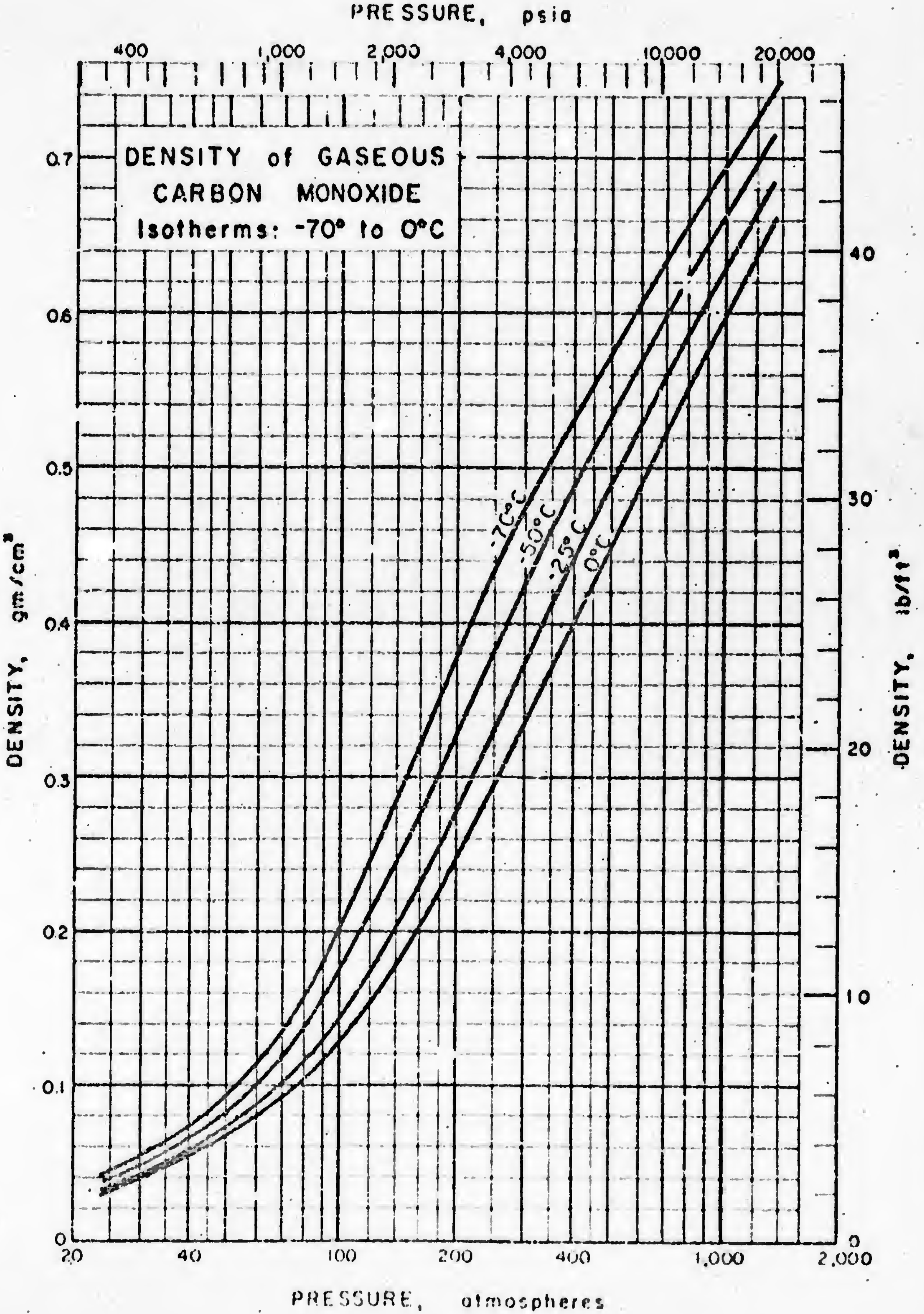
+ Critical Point

* Authors believe to be inaccurate

** Calculated from equation of state

[illegible]/BDT Issued: 7-31-59

1.007


PRESSURE, psia
400
1,000
2,000
4,000
10,000
20,000
DENSITY of GASEOUS
CARBON MONOXIDE
Isotherms: -70° to 0°C
-70°C
-50°C
-25°C
0°C
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
DENSITY, gm/cm³
40
30
20
10
0
DENSITY, lb/ft³
20
40
100
200
400
1,000
2,000
PRESSURE, atmospheres

DENSITY of GASEOUS CARBON MONOXIDE

Source of Data:

Deming, W. E. and Shupe, L. E., Phys. Rev. [2] 38, 2245-64 (1931).

Table of Selected Values

Pressure atm.	Density, gm/cm^3			
	-70°C	-50°C	-25°C	0°C
25	0.04453	0.03980	0.03524	0.03168
50	.09395	.08239	.07186	.06400
75	.1475	.1269	.1092	.09649
100	.2025	.1719	.1464	.1286
150	.3031	.2561	.2173	.1900
200	.3787	.3256	.2791	.2453
300	.4721	.4231	.3747	.3346
400	.5307	.4876	.4403	.4003
500	.5726	.5325	.4883	.4504
600	.6058	.5674	.5258	.4902
800	.6561	.6224	.5852	.5521
1000	.6941	.6643	.6301	.5995
1100	.7103	.6819	.6494	.6199
1200	.7252	.6979	.6666	.6380

EDT/RJR Issued: 6-19-59

1.007

DENSITY of GASEOUS CARBON MONOXIDE

(at Standard Conditions)

Sources of Data:

Moissan, H., Compt. rend. 102, 1245-48 (1886);
Moles, E., and Salazar, Y. M. T., Anales soc. espan. fis. y quim. 30, 182 (1932);
Pire, L. R. and Moles, E., Anales soc. espan. fis. y quim. 27, 267-72 (1929);
Rayleigh, L., Proc. Roy. Soc. (London) A62, 204-09 (1897);
Salazar, M. T. and Moles, E., Rev. acad. cienc. Madrid 28, 534-72 (1932);
Woodhead, M. and Whytlaw-Gray, R., J. Chem. Soc. 1933, 846-54 (1933).

Comments:

Standard Conditions (STP) are 1 Atmosphere and 0°C.

Selected Values

Reference	Density, gm/liter
Moissan	1.250
Moles	1.25010
Pire	1.25011 ±0.0005
Rayleigh	1.250
Salazar	1.25004 ±0.00007
Woodhead	1.25024

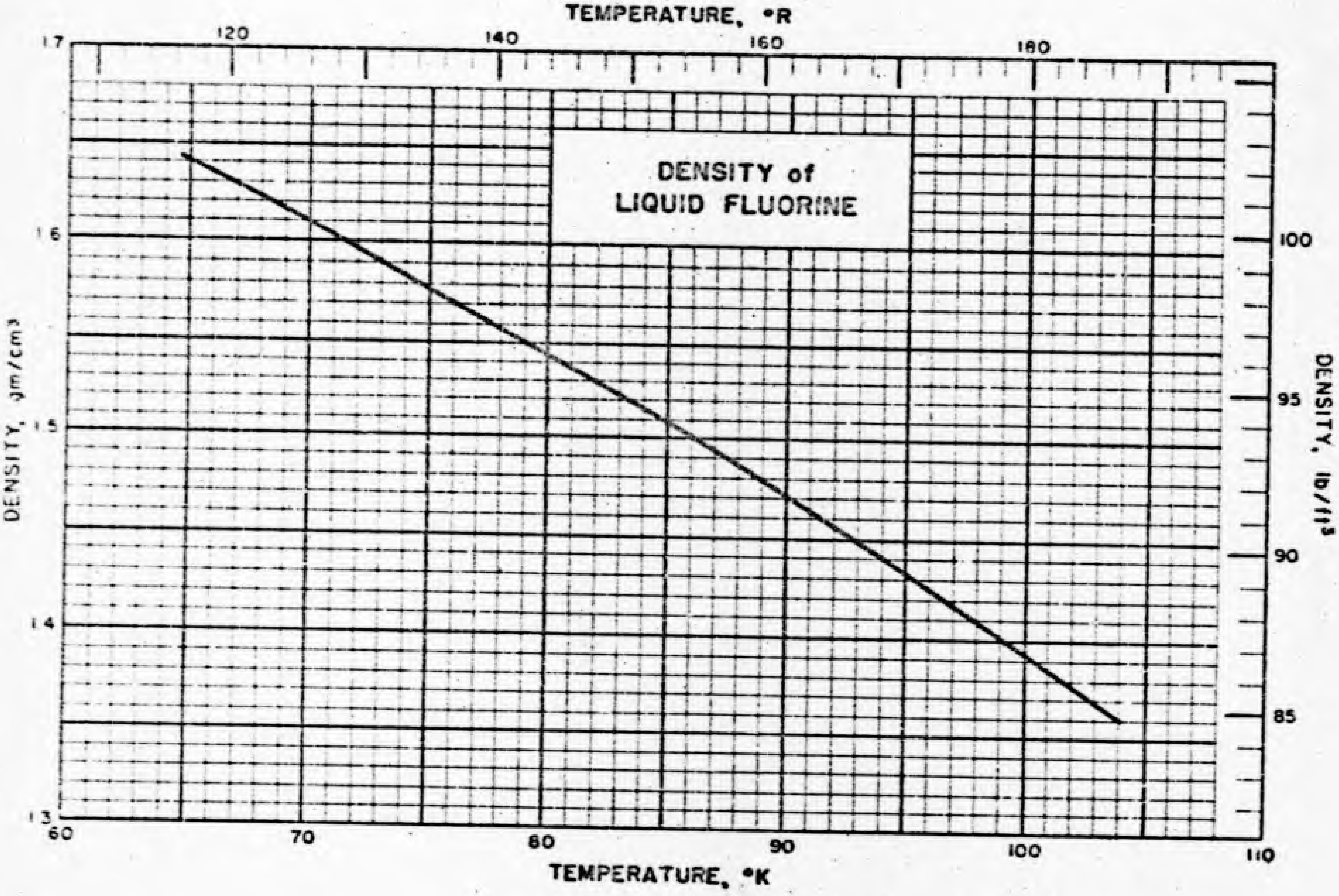
KDT/RJR Issued: 6-22-59

1.008

DENSITY of SOLID FLUORINE

Source of Data: Washburn, E. W. (Editor), *Critical Tables of Numerical Data, Physics, Chemistry, and Technology*, Vol. I McGraw-Hill Book Co. Inc. N. Y. 104 (1926).

Comments: Washburn gives a value of 1.3 gm/cm^3 for the density of solid Fluorine at 68.9°K.


DENSITY of
LIQUID FLUORINE
TEMPERATURE, °R
120
140
160
180
TEMPERATURE, °K
60
70
80
90
100
110
DENSITY, gm/cm³
1.7
1.6
1.5
1.4
1.3
DENSITY, lb/ft³
100
95
90
85

1.008

1.00[illegible]

DENSITY OF LIQUID FLUORINE

(at Saturation)

Source of Data:

Jarry, R. L. and Miller, H. C., J. Am. Chem. Soc. 78, 1552-3 (1956)

Other References:

Dunn, L. G. and Millikan, C. B., Combined Bimonthly Summary, No. 29, Calif. Inst. Tech., Jet Propulsion Lab., 4 (May 20, 1952) (Confidential L. P. H. 412)

Elverum, G. W. and Doescher, R. N., J. Chem. Phys. 20, 1834-6 (1952)

Kilner, S. B., Randolph, C. L. and Gillespie, R. W., J. Am. Chem. Soc. 74, 1086-7 (1952)

White, D., Hu, J.-H. and Johnston, H. L., J. Am. Chem. Soc. 76, 2584-6 (1954)

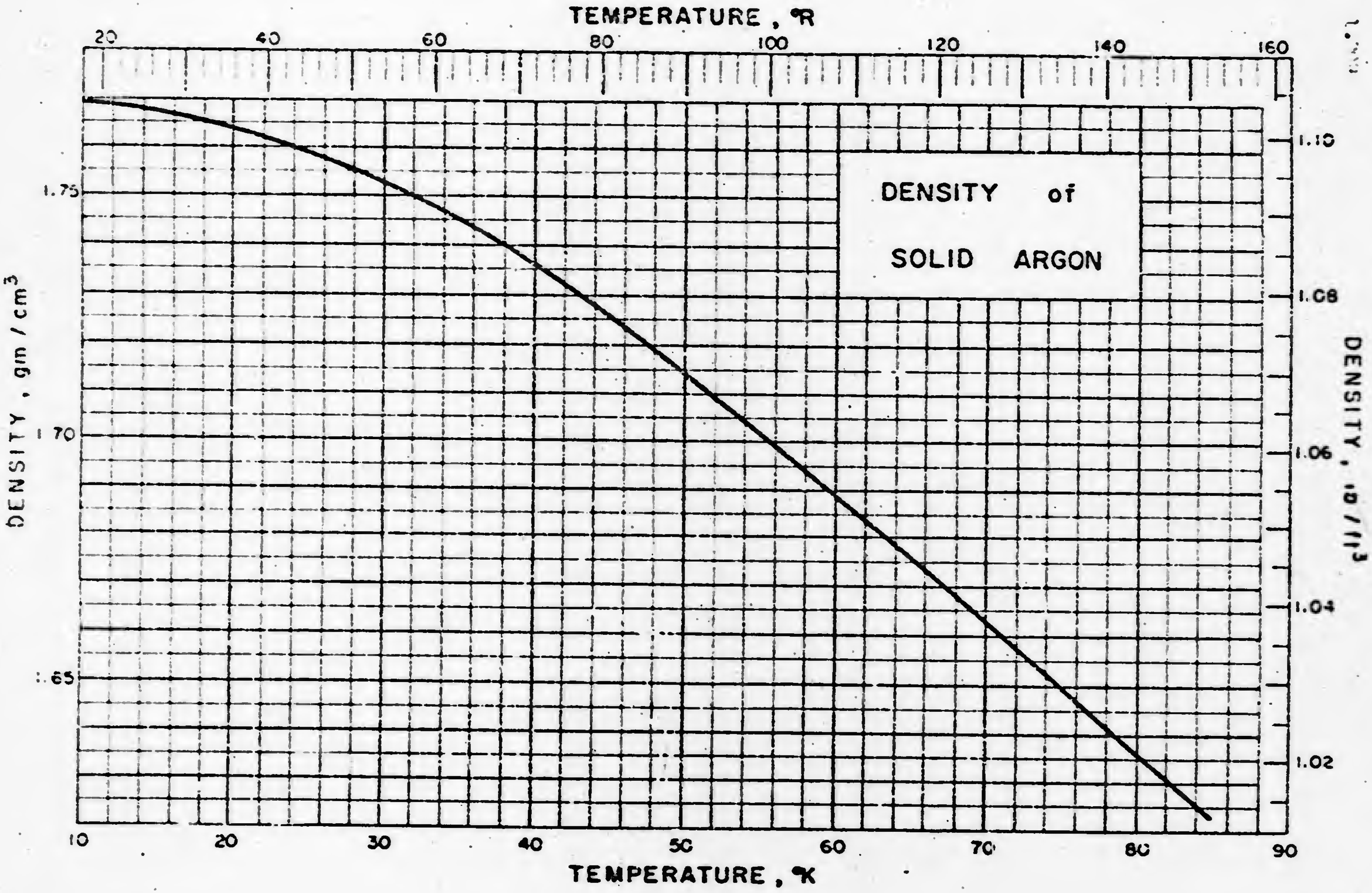
Comments:

The data from all the references are in good agreement. The Jarry and Miller data covered a wider temperature range and, therefore, are presented in the tabulation below and in the graph. Their data may by represented by the equation:

$$\rho = 1.907 - 2.201 \times 10^{-3} T - 2.948 \times 10^{-5} T^2 \ \mathrm{gm/cm^3}$$

Table of Selected Values

Temp. °K	ρ g/cm^3	Deviation from equation obsv'd-calc'd	Temp. °K	ρ g/cm^3	Deviation from equation obsv'd-calc'd
65.78	1.598	0.004	85.91	1.496	0.003
71.76	1.594	.003	88.26	1.481	.002
74.95	1.573	.002	88.50	1.484	.002
78.59	1.560	.002	90.08	1.472	.002
79.62	1.553	.001	91.55	1.458	.001
81.72	1.542	.002	91.75	1.450	.003
81.73	1.523	.002	94.73	1.434	.000
84.34	1.514	.003	97.56	1.412	.000
85.05	1.505	.002	100.21	1.391	.000
85.67	[illegible]	.003	102.7[illegible]	1.370	.000


TEMPERATURE, °R
20
40
60
80
100
120
140
160
DENSITY of
SOLID ARGON
DENSITY, gm/cm³
1.75
1.70
1.65
DENSITY, lb/ft³
1.10
1.08
1.06
1.04
1.02
10
20
30
40
50
60
70
80
90
TEMPERATURE, °K

1.009

DENSITY of SOLID ARGON

Sources of Data: Dobbs, E. R. and Jones G. O., Reports on Progress in Physics 20 516 (1957); Dobbs, E. R., Figgins, B. F., Jones, G. O, Piercey, D. C., and Riley, D. P. Nature, (London) 178, 483 (1956).

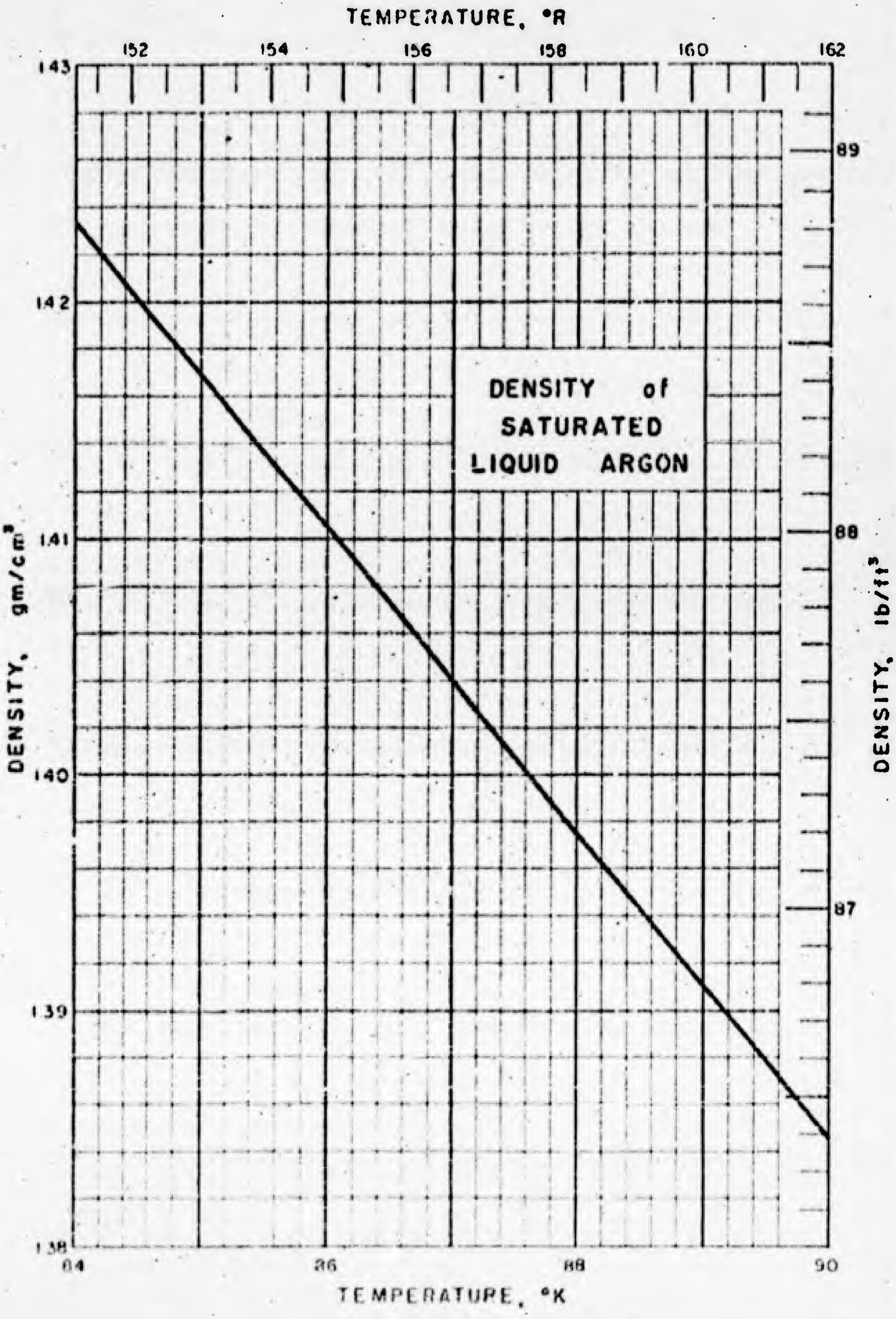
Comments: The density of solid argon has been measured by two independent methods. A low temperature x-ray camera was adapted in one method (Figgins), and the bulk density was used in the other method (Dobbs). The two methods agree within experimental error.

Table of Selected Values

Temperature °K	Density gm/cm^3
10	1.769*
20	1.764
30	1.753
40	1.736
50	1.714
60	1.689
70	1.664
80	1.636
84	1.623*

* extrapolated values

FLB/RJE Issued: 5-25-59


TEMPERATURE, °R
152
154
156
158
160
162
DENSITY of SATURATED LIQUID ARGON
1.43
1.42
1.41
1.40
1.39
1.38
DENSITY, gm/cm³
89
88
87
DENSITY, lb/ft³
84
86
88
90
TEMPERATURE, °K

1.009

DENSITY of SATURATED LIQUID ARGON

Sources of Data:

Clusius, K. and Weigand, K., Z. physik, Chem. B46, 1 (1940)

Rudenko, N. S., Zhur. Tekh. Fiz. 18, 1123-6 (1948)

Baly, E. C. C. and Donnan, F. G., J. Chem. Soc. 81, 907 (1902)

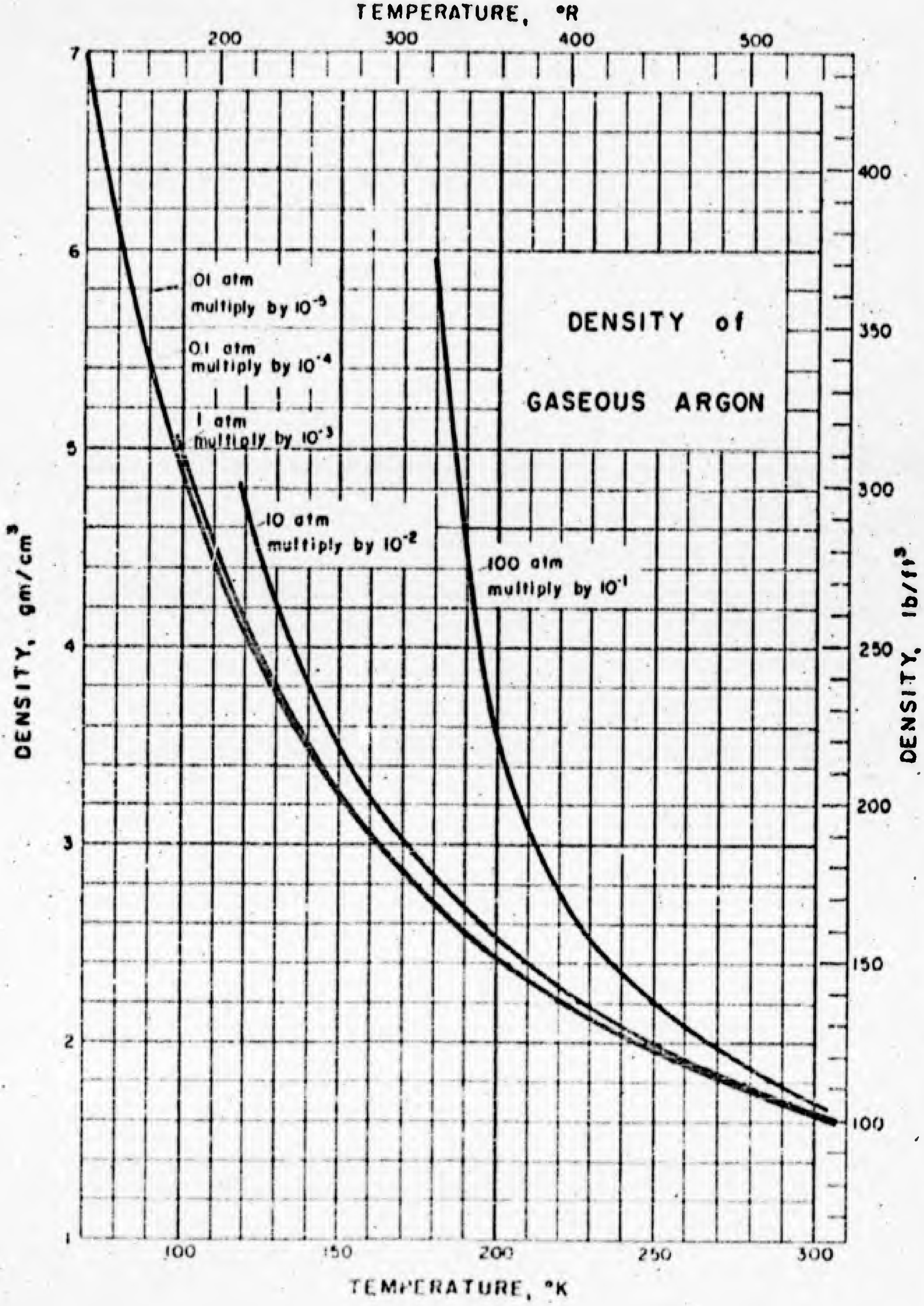
Comments:

The data tabulated below are from the work of Baly and Donnan. These results may be expressed by the formula:

$$d = 1.42333 - 0.006467 (T - 84)$$

where d is the density in gm/cm^3 and T is the absolute temperature in °K.

Temperature °K	Density gm/cm^3
84.0	1.4233
84.5	1.4201
85.0	1.4169
85.5	1.4136
86.0	1.4104
86.5	1.4072
87.0	1.4039
87.5	1.4007
88.0	1.3975
88.5	1.3942
89.0	1.3910
89.5	1.3878
90.0	1.3845

TEMPERATURE, °R
200
300
400
500
DENSITY of
GASEOUS ARGON
.01 atm
multiply by 10⁻⁵
0.1 atm
multiply by 10⁻⁴
1 atm
multiply by 10⁻³
10 atm
multiply by 10⁻²
100 atm
multiply by 10⁻¹
DENSITY, gm/cm³
7
6
5
4
3
2
1
DENSITY, lb/ft³
400
350
300
250
200
150
100
100
150
200
250
300
TEMPERATURE, °K

DENSITY of GASEOUS ARGON

Source of Data: NBS Circular 564 (1955).

Other References: Beattie, J. A. and Julien, H. P., Ind. Eng. Chem. 46, 1668-9 (1954); Holborn, L., Schultze, H. and Otto, J., Handbuch der Experimentalphysik, VIII, part 2, 152 (1929); Michels, A., Wijker, H., Wijker, Hk., Physica 15, 627 (1949); Onnes, H. K. and Crommelin, C. A., Leiden Comm. No. 118b (1910).

Comments: No experimental data on the density of Argon have been published since NBS Circular 564.

Table of Selected Values

Temp. °K	Density, gm/cm^3 .01 Atm	.1 Atm	1 Atm	10 Atm	100 Atm
70	6.959×10^{-5}				
80	6.098 "	6.101×10^{-4}			
90	5.410 "	5.424 "			
100	4.870 "	4.879 "	4.977×10^{-3}		
110	4.426 "	4.433 "	4.500 "		
120	4.056 "	4.062 "	4.110 "	4.74×10^{-2}	
130	3.744 "	3.748 "	3.783 "	4.21 "	
140	3.477 "	3.480 "	3.507 "	3.82 "	
150	3.245 "	3.248 "	3.268 "	3.50 "	
160	3.043 "	3.045 "	3.061 "	3.23 "	
170	2.863 "	2.865 "	2.877 "	3.01 "	
180	2.704 "	2.706 "	2.715 "	2.820 "	5.834×10^{-1}
210	2.319 "	2.319 "	2.324 "	2.378 "	3.068 "
240	2.03 "	2.028 "	2.034 "	2.060 "	2.339 "
270	1.8028 "	1.8030 "	1.8048 "	1.8210 "	1.958 "
300	1.6226 "	1.6227 "	1.6236 "	1.6327 "	1.698 "

FLB/RJR Issued: 5-25-59

DENSITY of SOLID METHANE

Sources of Data:

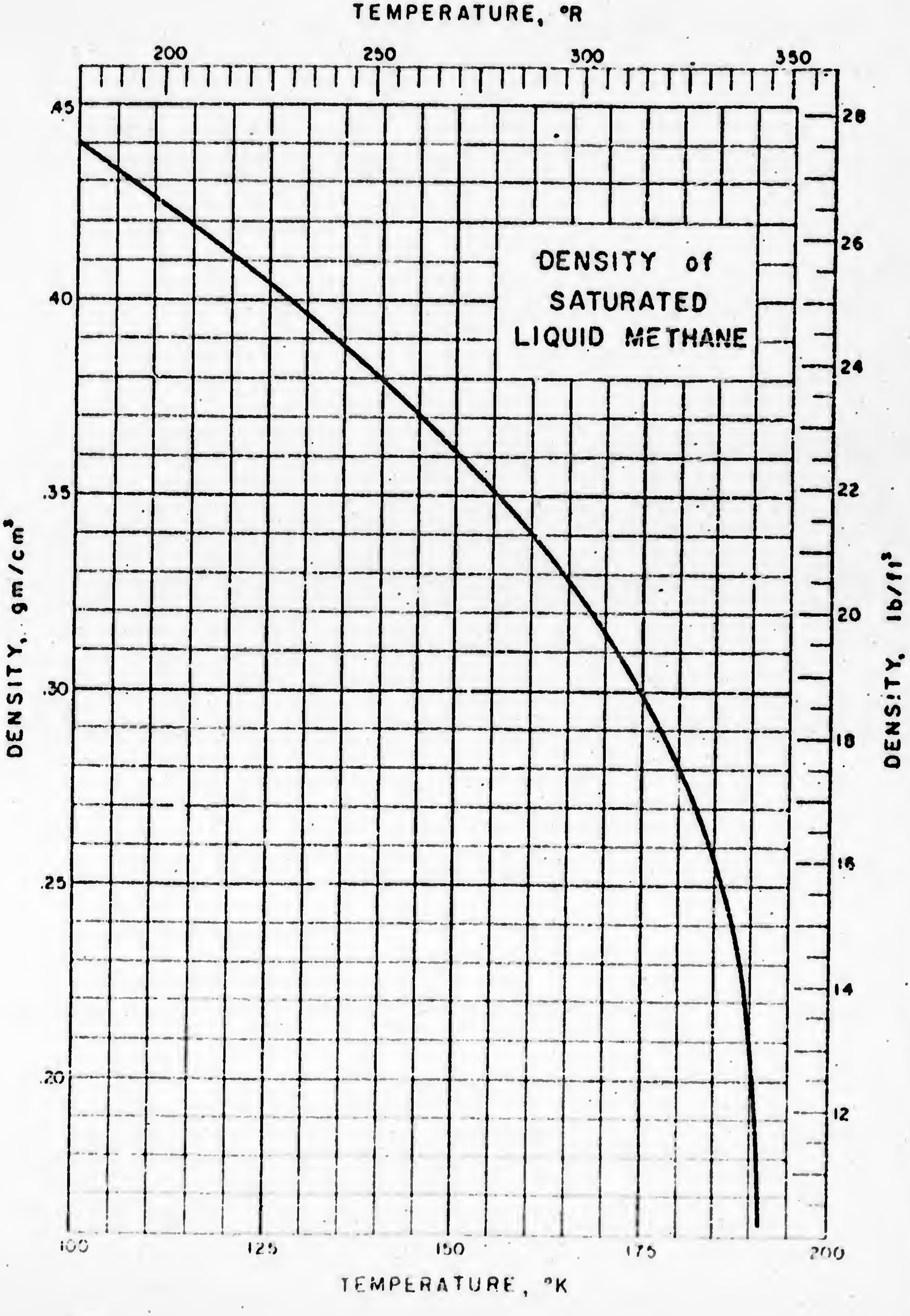
Heuse, W., Z. phys. Chem. A147, 266-74 (1930)

Mooy, H. H., Comm. Kamerlingh Onnes Lab., Univ. Leiden, Comm. No. 213d.

Table of Values

Reference	Temp. °K	Density gm/cc
Heuse		0.522 ± 0.001
Mooy	20.4	0.517 ± 0.006

RFR Issued: 7-13-59


TEMPERATURE, °R
200
250
300
350
DENSITY of
SATURATED
LIQUID METHANE
.45
.40
.35
.30
.25
.20
DENSITY, gm/cm³
28
26
24
22
20
18
16
14
12
DENSITY, lb/ft³
100
125
150
175
200
TEMPERATURE, °K

DENSITY of LIQUID METHANE
(Saturated)

Source of Data:

Matthews, C. S., and Hurd, C. O., Trans. Am. Inst. Chem. Eng. 42 55-78 (1946)

Other References:

Rossini, F. E., et al., Selected Values of Physical and Thermodynamic Properties of Hydrocarbons and Related Compounds, Carnegie Press, Pittsburgh (1953) pp. 287, 299

McLennan, W. C., et al., Trans. Roy. Soc. Can., Sec. III, 37-46 (1930)

Comments:

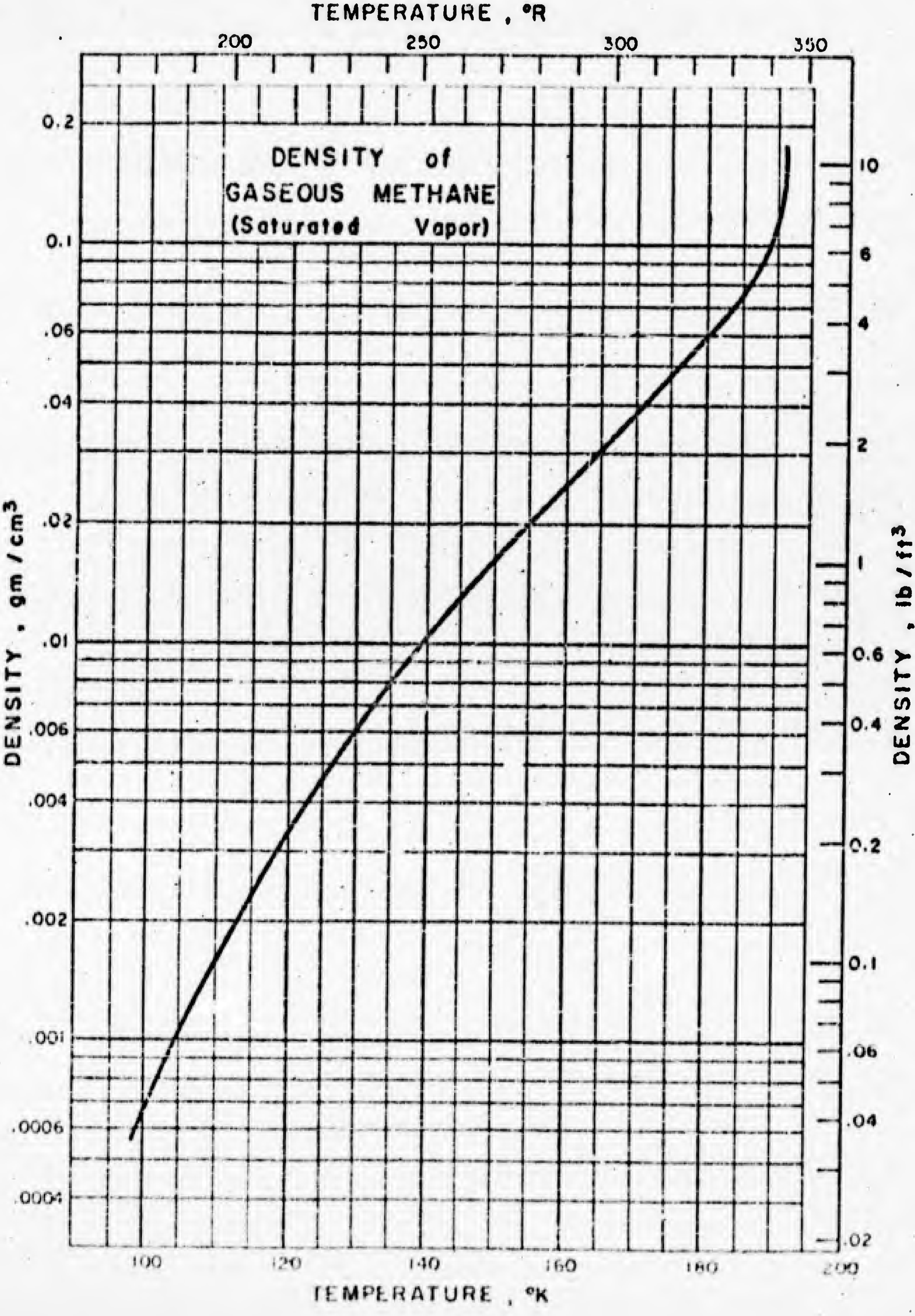
The graph on the preceding page was made from data selected from the above listed source.

Table of Selected Values

Temperature		Pressure	Specific Vol.	Density	
°K	°R	psia	ft^3/lb	gm/cm^3	lb/ft^3
99.8	179.7	4.90	0.03635	0.4407	27.51
105.4	189.7	8.44	0.03698	0.4331	27.04
110.9	199.7	13.80	0.03766	0.4253	26.55
116.5	209.7	21.71	0.03839	0.4173	26.05
122.1	219.7	32.4	0.03915	0.4091	25.54
127.6	229.7	46.4	0.03999	0.4006	25.01
133.2	239.7	64.5	0.04092	0.3915	24.44
138.7	249.7	87.6	0.04193	0.3820	23.85
144.3	259.7	115.7	0.04306	0.3719	23.22
149.8	269.7	150.0	0.04431	0.3615	22.57
155.4	279.7	191.5	0.04575	0.3502	21.86
160.9	289.7	240.0	0.04745	0.3375	21.07
166.5	299.7	297.0	0.04944	0.3241	20.23
172.1	309.7	364	0.05197	0.3082	19.24
177.6	319.7	440	0.05524	0.2899	18.10
183.2	329.7	527	0.05999	0.2670	16.67
188.7	339.7	627	0.06961	0.2302	14.37
*191.1	343.9	673	0.0983	0.163	10.2

* Critical Temp. (Normal Boil. Temp. = 111.7°K T.P. Temp. = 90.7°K)

[illegible]/VJJ Issued: 7-15-59


TEMPERATURE , °R
200
250
300
350
DENSITY of
GASEOUS METHANE
(Saturated Vapor)
0.2
0.1
.06
.04
.02
.01
.006
.004
.002
.001
.0006
.0004
DENSITY , gm / cm³
10
6
4
2
1
0.6
0.4
0.2
0.1
.06
.04
.02
DENSITY , lb / ft³
100
120
140
160
180
200
TEMPERATURE , °K

1.010

DENSITY of GASEOUS METHANE

(At Saturation)

Source of Data:

Matthews, C. S. and Hurd, C. O., Trans. Am. Inst. Chem. Eng. 42, 55-78 (1946)

Table of Selected Values

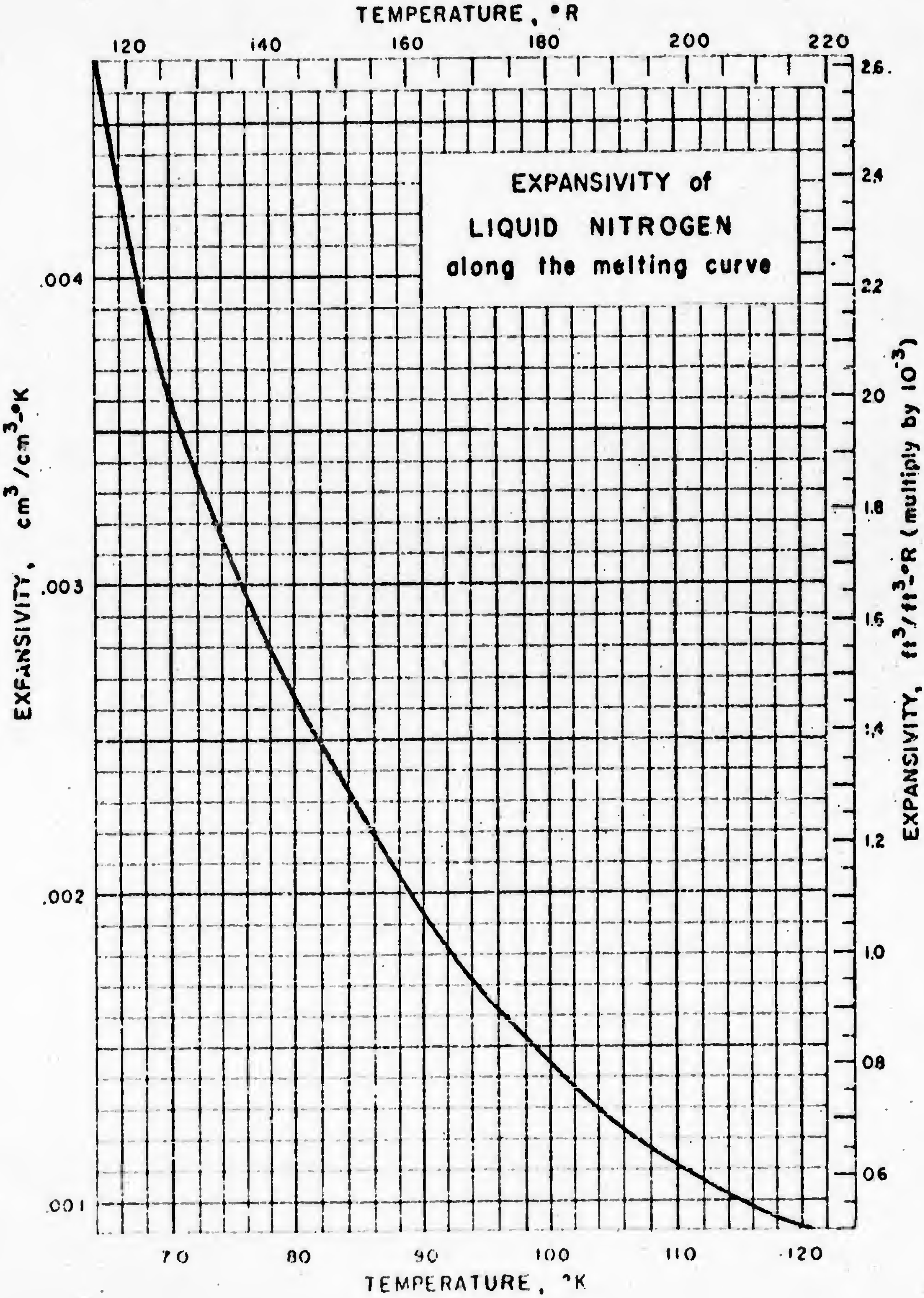
Temperature		Pressure	Specific Vol.	Density	
°K	°R	psia	ft^3/lb	gm/cm^3	lb/ft^3
99.8	179.7	4.90	24.04	0.0006664	0.04160
105.4	189.7	8.44	14.01	0.001096	0.06845
110.9	199.7	13.80	9.31	0.00171	0.107
116.5	209.7	21.71	6.13	0.00261	0.163
122.1	219.7	32.4	4.24	0.00378	0.236
127.6	229.7	46.4	3.04	0.00527	0.329
133.2	239.7	64.5	2.23	0.00718	0.448
138.7	249.7	87.6	1.67	0.00960	0.599
144.3	259.7	115.7	1.281	0.01250	0.7806
149.8	269.7	150.0	0.990	0.0162	1.01
155.4	279.7	191.5	0.773	0.0207	1.29
160.9	289.7	240.0	0.610	0.0263	1.64
166.5	299.7	297.0	0.483	0.0332	2.07
172.1	309.7	364	0.381	0.0420	2.62
177.6	319.7	440	0.3008	0.05325	3.324
183.2	329.7	527	0.2318	0.06910	4.314
188.7	339.7	627	0.1613	0.09931	6.200
191.1*	343.9	673	0.0983	0.163	10.2

* Critical Temp. (Normal Boil. Temp. = 111.7°K T.P. Temp. = 88.7°K)

RFR Issued: 7-13-59

EXPANSIVITY of CRYOGENIC FLUIDS

CONTENTS


TEMPERATURE, °R
120
140
160
180
200
220
EXPANSIVITY of
LIQUID NITROGEN
along the melting curve
EXPANSIVITY, cm³/cm³-°K
.004
.003
.002
.001
EXPANSIVITY, ft³/ft³-°R (multiply by 10⁻³)
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
70
80
90
100
110
120
TEMPERATURE, °K

EXPANSIVITY OF LIQUID NITROGEN
along the melting curve

Source of Data:

Grilly, E. R. and Mills, R. L., Phys. Rev. 105, No. 4, 1140-45 (1957)

Comments:

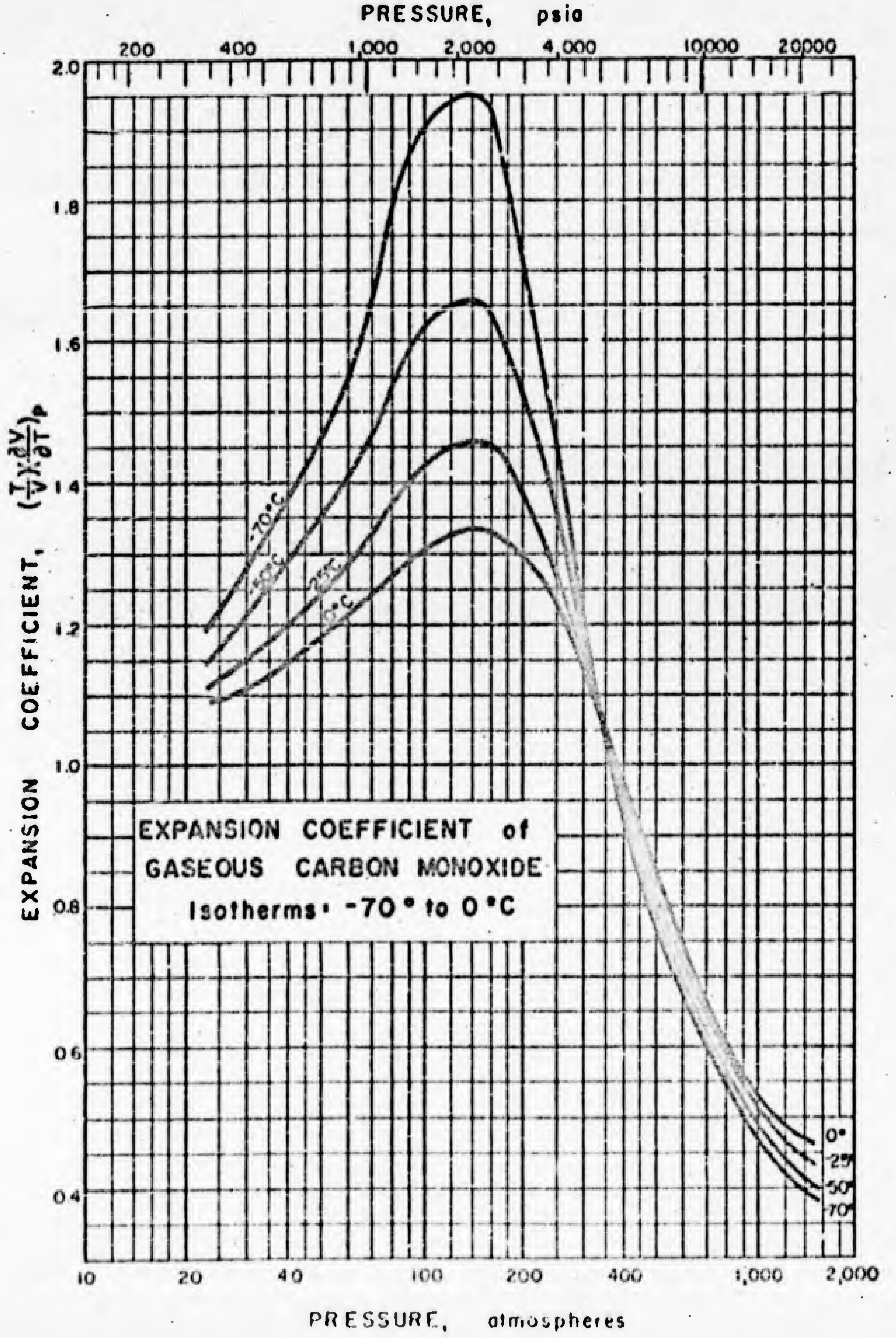
The values of expansivity (β_L) tabulated below were evaluated along the melting curve from the relation

$$\beta_L = \frac{1}{V_L}\left[\frac{\partial V_L}{\partial T}\right]_p$$

where: β_L is in reciprocal °K
V_L is in cm^3/gm

Table of Selected Values

Pressure		Temp.	β_L
kg/cm^2	atm.	°K	1/°K
1	0.968	63.14	
79.0	76.459	64.84	0.004 56
202.0	195.50	67.40	.004 14
354.7	343.29	70.46	.003 49
504.1	487.89	73.36	.03 17
710.9	688.04	77.24	.002 92
1066.8	1032.5	83.57	.002 39
1422.7	1376.9	89.54	.002 03
1920.7	1858.9	97.40	.001 68
2631.9	2547.3	107.83	.001 07
3555.6	3441.3	120.29	.000 94


EXPANSION COEFFICIENT of GASEOUS CARBON MONOXIDE
Isotherms: -70° to 0°C

2.007

EXPANSION COEFFICIENTS of GASEOUS CARBON MONOXIDE

Source of Data: Deming, W. E. and Shupe, L. E., Phys. Rev. [2] 38, 2245-64 (1931).

Comments: The constant pressure expansion coefficient is defined by

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

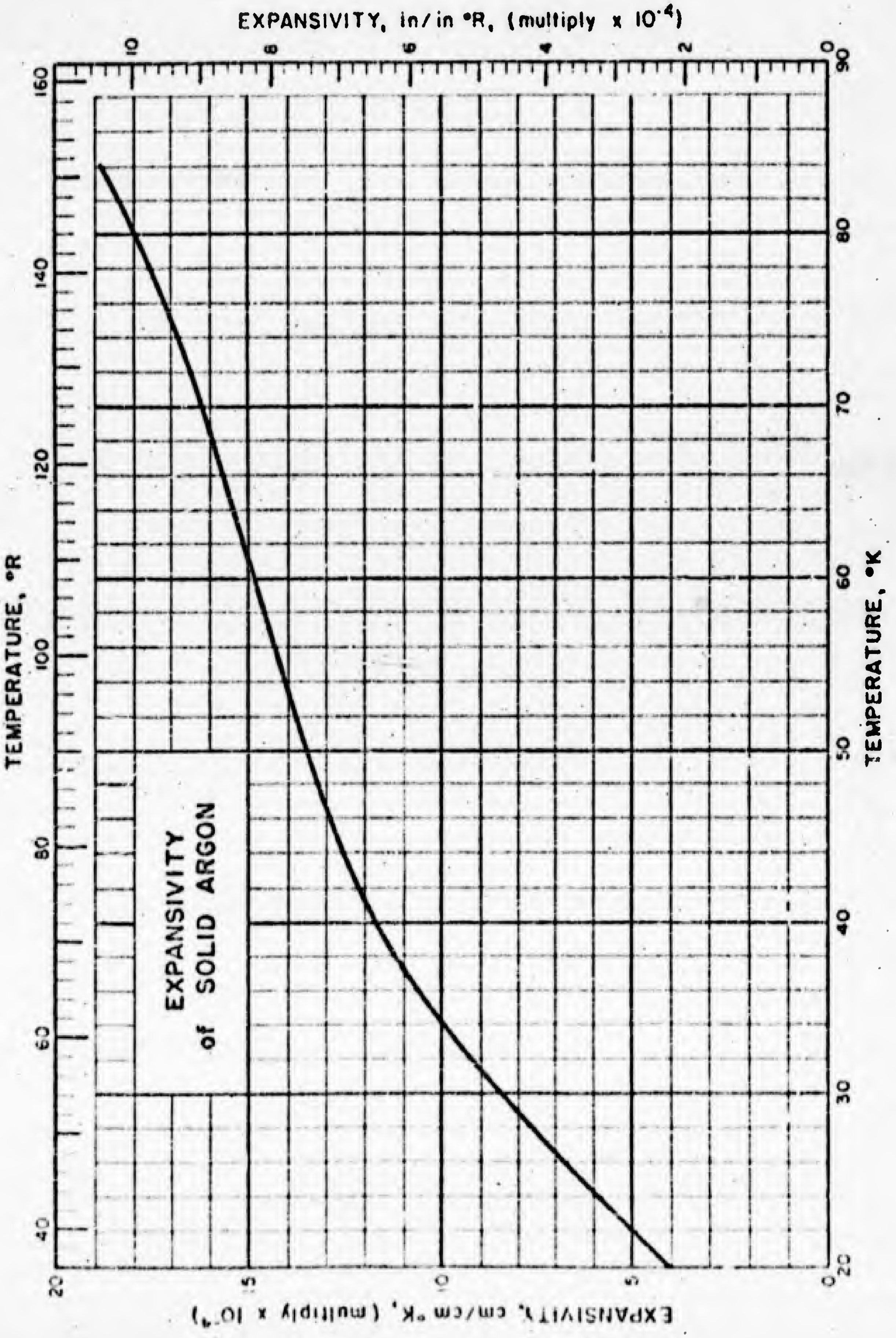
The values tabulated below were calculated by Deming and Shupe from PVT data given in Bartlett, E. P., Hetherington, H. C.; Kvalnes, H. M., and Tremearne, T. H., J. Am. Chem. Soc. 52, 1374-82 (1930). The Joule-Thomson coefficient, μ, may be calculated from

$$\mu = \frac{\left[\frac{T}{V}\right] \cdot \left[\frac{\partial V}{\partial T}\right]_p - 1}{\rho\, C_p}$$

Table of Selected Values

Pressure atm.	Expansion Coefficient			
	-70°C	-50°C	-25°C	0°C
25	1.220	1.168	1.124	1.094
50	1.455	1.352	1.245	1.183
75	1.710	1.500	1.348	1.255
100	1.899	1.619	1.421	1.305
150	1.943	1.655	1.454	1.334
200	1.706	1.528	1.392	1.299
300	1.188	1.172	1.152	1.135
400	0.888	0.942	0.969	0.980
500	0.780	0.810	0.833	0.851
600	0.708	0.710	0.724	0.748
800	0.552	0.569	0.591	0.616
1000	0.467	0.484	0.504	0.531
1100	0.426	0.447	0.469	0.496
1200	0.396	0.417	0.441	0.467

EDT/RJR Issued: [illegible]/59


EXPANSIVITY, in/in °R, (multiply x 10^-4)
10
8
6
4
2
0
TEMPERATURE, °R
160
140
120
100
80
60
40
TEMPERATURE, °K
90
80
70
60
50
40
30
20
EXPANSIVITY of SOLID ARGON
EXPANSIVITY, cm/cm °K, (multiply x 10^-4)
20
15
10
5
0

2.009

EXPANSIVITY of SOLID ARGON

Sources of Data:

Dobbs, E. R., Figgins, B. F., Jones, G. O., Piercey, D. C. and Riley, D. P., Nature 178, 483 (1956)

Dobbs, E. R. and Jones, G. O., Repts. Progr. in Phys. 20, 516 (1957)

Zucker, I. J., J. Chem. Phys. 25, 915 (1956)

Comments:

At temperatures below 30°K the expansivity will be frequency-sensitive and the Einstein model used by Zucker is probably inadequate. Further expansivity measurements below 30°K are necessary before this can be established with certainty.

Table of Experimental Values

Temperature °K	Expansivity $\frac{cm}{cm\ °K}$
10	0
20	4.0×10^{-4}
30	8.2 "
40	11.7 "
50	13.5 "
60	14.9 "
70	16.2 "
80	18.0 "
84	*18.91 $\times 10^{-4}$

* extrapolated value

PIB/BDT Issued: 7/15/59

EXPANSIVITY of LIQUID ARGON

Source of Data:

Mathias, E., Onnes, K. and Crommelin, C. A., Proc. Roy. Acad. Sci. Amsterdam 15, 667 (1912).

Comments:

Mathias, Onnes, and Crommelin found the thermal expansion of liquid argon to be related to the following expression:

$$\frac{1}{V}\frac{dV}{dT} = A \times 10^{-6}$$

at T = 90°K, A = 4500

Where:

T = absolute temperature (0°C = 273.16°K)

PLB/BDT Issued: 5/25/59

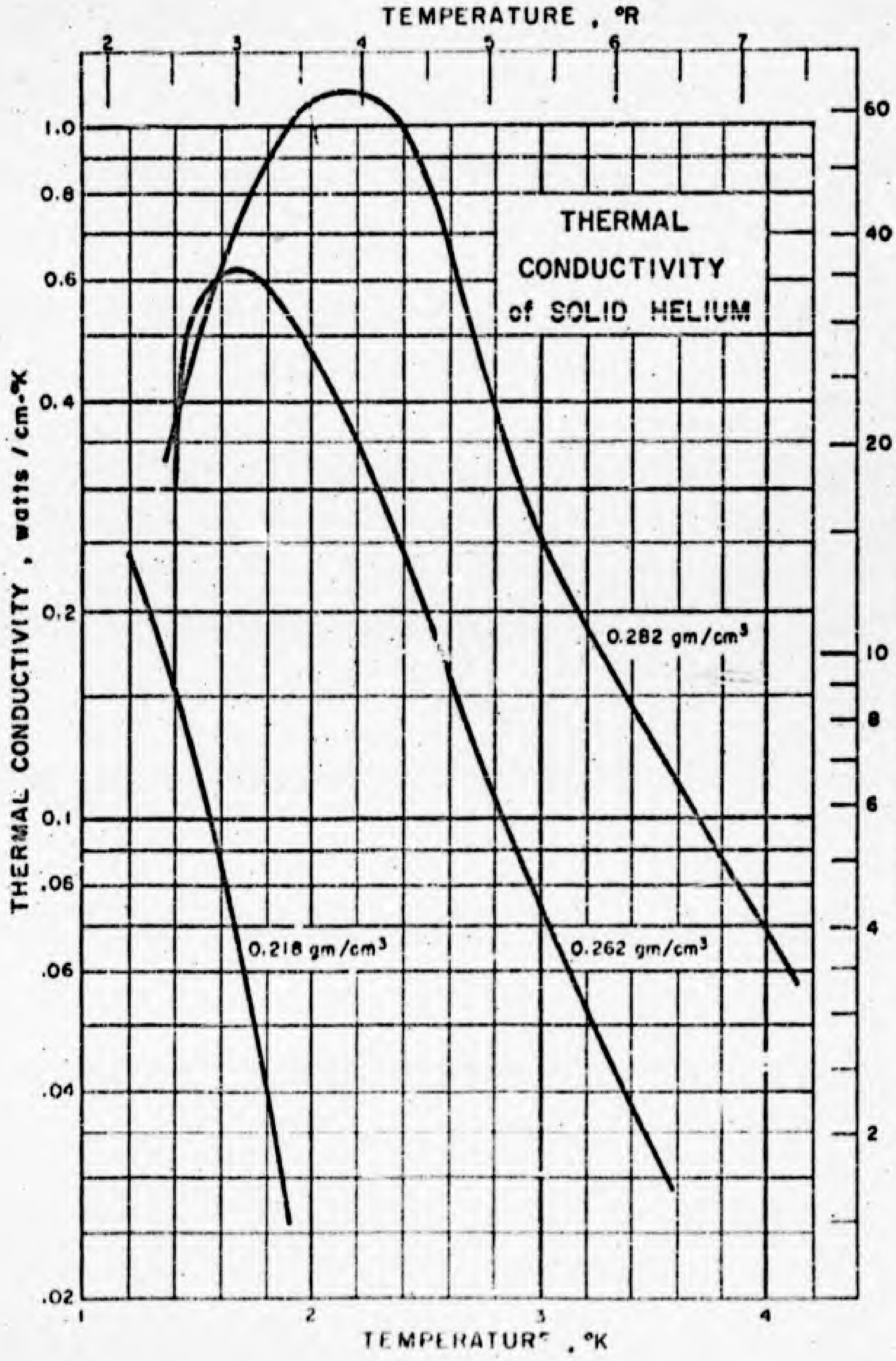
THERMAL CONDUCTIVITY of CRYOGENIC FLUIDS

CONTENTS

CONVERSION FACTORS for THERMAL CONDUCTIVITY

	$\frac{\text{Watts cm}}{\text{cm}^2\ ^\circ\text{K}}$	$\frac{\text{Watts in}}{\text{in}^2\ ^\circ\text{F}}$	$\frac{\text{Cal cm}}{\text{sec cm}^2\ ^\circ\text{K}}$	$\frac{\text{BTU in}}{\text{hr ft}^2\ ^\circ\text{F}}$	$\frac{\text{BTU ft}}{\text{hr ft}^2\ ^\circ\text{F}}$	$\frac{\text{BTU in}}{\text{sec in}^2\ ^\circ\text{F}}$	$\frac{\text{BTU in}}{\text{hr in}^2\ ^\circ\text{F}}$
1 $\frac{\text{Watts cm}}{\text{cm}^2\ ^\circ\text{K}}$ =	1.000	1.411	0.2389	6.9340×10^{2}	57.79	1.338×10^{-3}	4.816
1 $\frac{\text{Watts in}}{\text{in}^2\ ^\circ\text{F}}$ =	0.7087	1.000	0.1693	4.914×10^{2}	40.95	9.480×10^{-4}	3.413
1 $\frac{\text{Cal. cm}}{\text{sec cm}^2\ ^\circ\text{K}}$ =	4.1858	5.907	1.000	2.9027×10^{3}	2.419×10^{2}	5.602×10^{-3}	20.16
1 $\frac{\text{BTU in}}{\text{hr ft}^2\ ^\circ\text{F}}$ =	1.442×10^{-3}	2.035×10^{-3}	3.445×10^{-4}	1.000	8.33×10^{-2}	1.929×10^{-6}	6.944×10^{-3}
1 $\frac{\text{BTU ft}}{\text{hr ft}^2\ ^\circ\text{F}}$ =	1.730×10^{-2}	2.442×10^{-2}	4.135×10^{-3}	12.000	1.000	2.315×10^{-5}	8.333×10^{-2}
1 $\frac{\text{BTU in}}{\text{sec in}^2\ ^\circ\text{F}}$ =	7.4738×10^{2}	1.0548×10^{3}	1.785×10^{2}	5.184×10^{5}	4.3191×10^{4}	1.000	3.600×10^{3}
1 $\frac{\text{BTU in}}{\text{hr in}^2\ ^\circ\text{F}}$ =	0.2076	0.2930	4.960×10^{-2}	1.44×10^{2}	12.000	2.778×10^{-4}	1.000

JEC/VJJ Issued: 10/7/59


TEMPERATURE, °R
2
3
4
5
6
7
THERMAL CONDUCTIVITY of SOLID HELIUM
1.0
0.8
0.6
0.4
0.2
0.1
.08
.06
.04
.02
THERMAL CONDUCTIVITY, watts / cm-°K
60
40
20
10
8
6
4
2
THERMAL CONDUCTIVITY, BTU / hr ft-°R
0.282 gm/cm³
0.218 gm/cm³
0.262 gm/cm³
1
2
3
4
TEMPERATURE, °K

3.001

THERMAL CONDUCTIVITY of SOLID HELIUM

Source of Data:

Webb, F. S. and Wilks, J., Phil. Mag. 44, 644 (1953)

Other References:

Webb, F. S., Wilkins, K. R. and Wilks, J., Proc. Roy. Soc. (London) A214, 546-63 (1952)

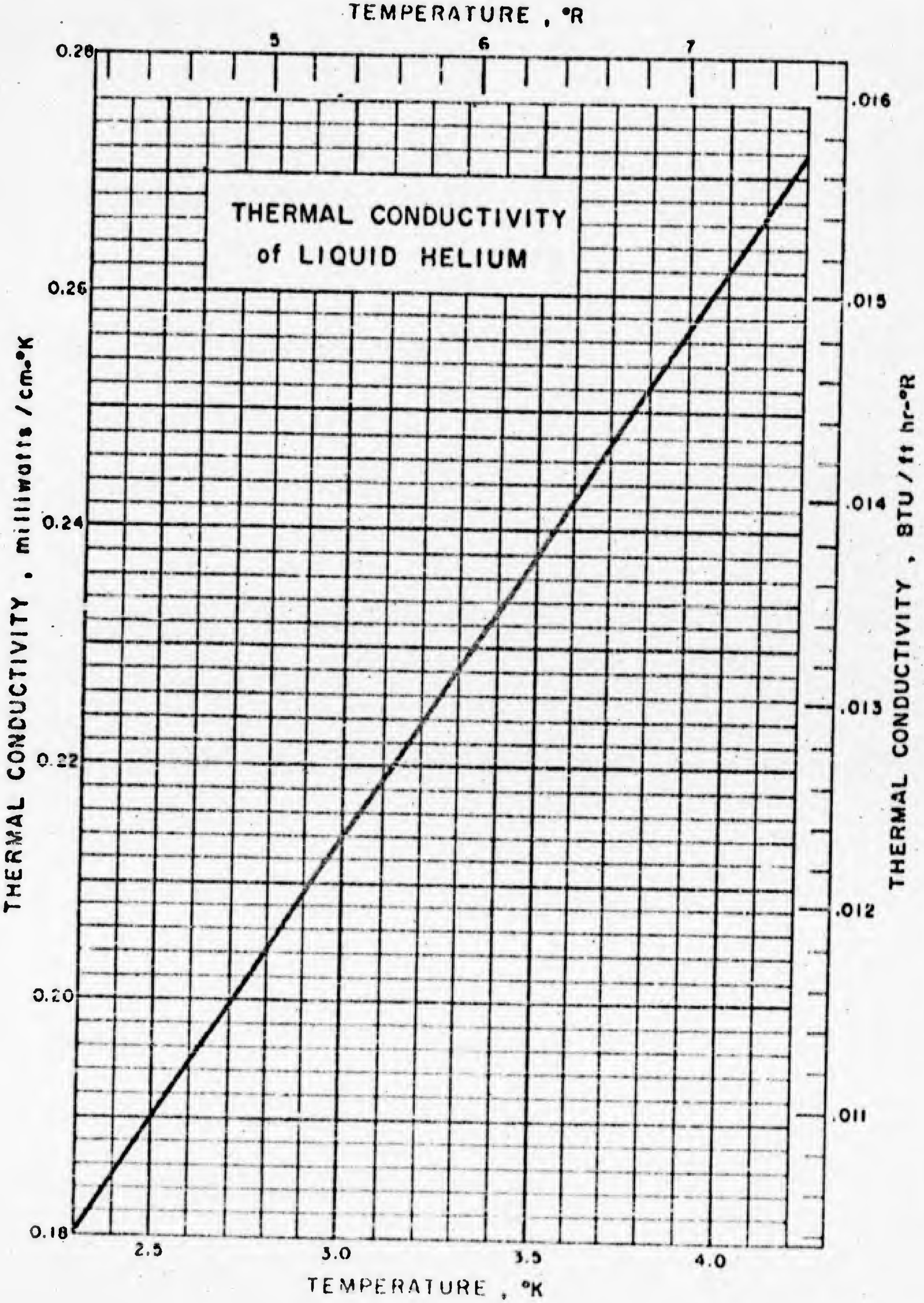
Wilkinson, K. R. and Wilks, J., Proc. Phys. Soc. (London) A64, 89-91 (1951)

Comments:

The Absolute temperature scale (0°C = 273.16°K = 491.56°R) and selected values for three different densities are given in the table below.

At 0.218 gm/cm^3		At 0.262 gm/cm^3		At 0.282 gm/cm^3	
Temp. °K	K watts/cm°K	Temp. °K	K watts/cm°K	Temp. °K	K watts/cm°K
1.25	0.22	1.39	.32	1.4	.38
1.34	0.18	1.45	.50	1.68	.74
1.37	0.170	1.70	.63	1.95	1.05
1.64	0.075	1.81	.60	2.2	1.07
1.87	0.03	2.00	.465	2.35	1.04
		2.12	.40	2.4	.91
		2.42	.24	2.6	.70
		2.95	.075	2.7	.46
		3.08	.065	3.25	.165
		3.55	.03	4.09	.06
		4.05	.01		

DEM/GAR Issued: 7/13/59


TEMPERATURE , °R
5
6
7
THERMAL CONDUCTIVITY
of LIQUID HELIUM
0.28
0.26
0.24
0.22
0.20
0.18
THERMAL CONDUCTIVITY , milliwatts /cm-°K
.016
.015
.014
.013
.012
.011
THERMAL CONDUCTIVITY , BTU / ft hr-°R
2.5
3.0
3.5
4.0
TEMPERATURE , °K

3.001

THERMAL CONDUCTIVITY of LIQUID HELIUM
(at Saturation)

Source of Data:

Grenier, C., Phys. Rev. 83, No. 3, 589-603 (1951)

Other References:

Bowers, I. R., Proc. Phys. Soc. (London) A65, 511-18 (1952)

Brewer, D. F. and Edwards, D. O., Proc. Phys. Soc. (London) 71, 117-125 (1958)

Fairbank, H. A. and Wilks, J., Phys. Rev. 95, 277-8 (July 1954)

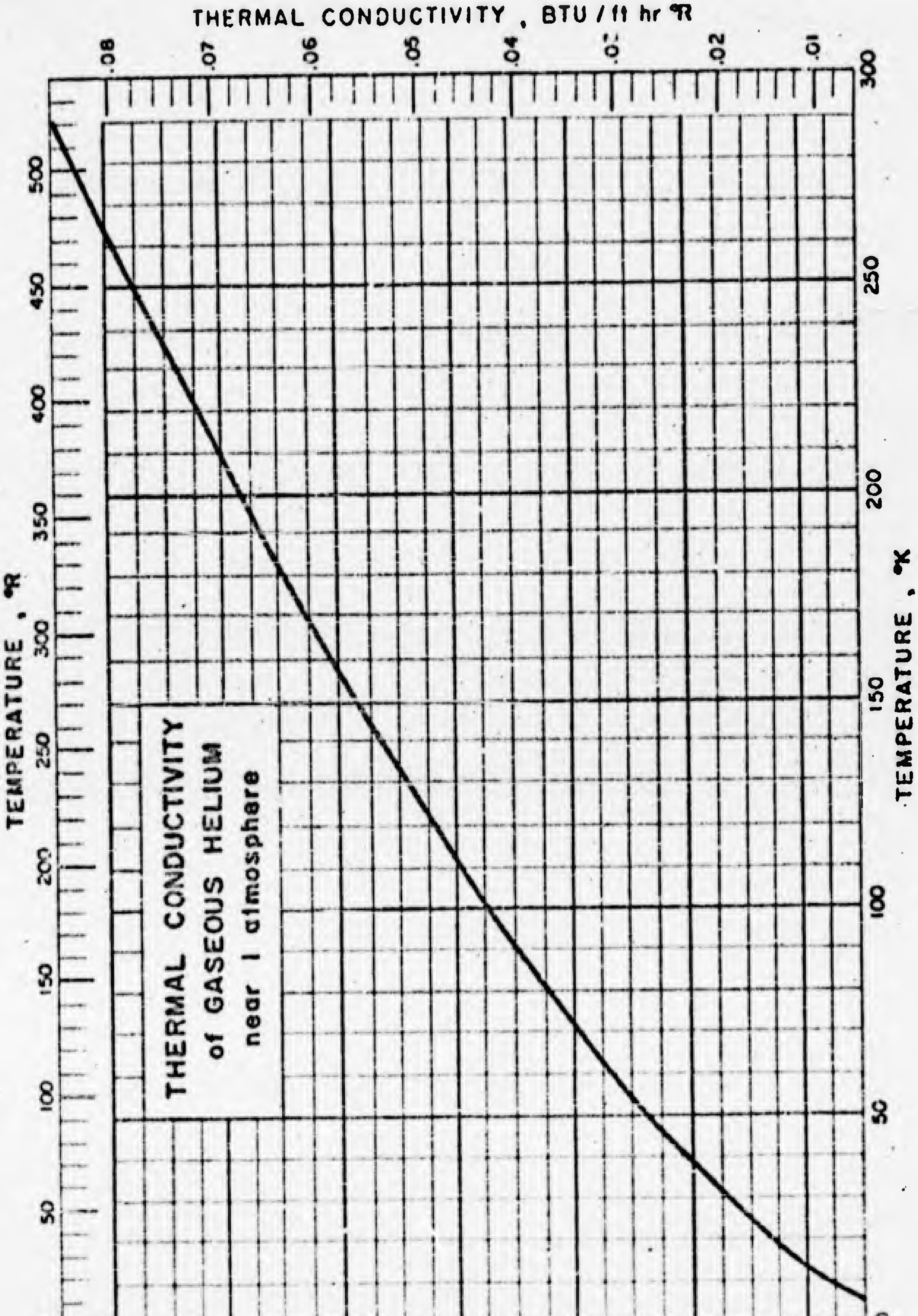
Comments:

The thermal conductivity is a linear function of temperature between 2.5° and 4.5°K.

The Absolute Temperature Scale (0°C = 273.16°K = 491.56°R) was used in the table of selected values below.

Temperature		Thermal Conductivity	
°K	°R	$\frac{\text{milliwatts}}{\text{cm-°K}}$	$\frac{\text{BTU}}{\text{ft hr °R}}$
2.3	4.14	0.181	0.010 45
2.4	4.32	.185	.010 65
2.6	4.68	.195	.011 25
2.8	5.04	.205	.011 81
3.0	5.4	.214	.012 35
3.5	6.3	.238	.013 71
4.0	7.2	.262	.015 1
4.2	7.56	.271	.015 65

DBM/GAR Issued: 7-11-59



THERMAL CONDUCTIVITY of GASEOUS HELIUM near 1 atmosphere

THERMAL CONDUCTIVITY OF GASEOUS HELIUM

(Near One Atmosphere)

Source of Data:

Akin, S. W., Trans. ASME 72, 751-57 (Aug. 1950)

Other References:

Amdur, I., J. Chem. Phys. 15, No. 7, 482-85 (July 1947)

Hawkins, G. A., Trans. ASME 70, 655 (1948)

Hilsenrath, J. and Touloukian, Y. S., Trans. ASME 76, No. 6 (Aug. 1954)

Kannuluik, W. G. and Carman, E. H., Proc. Phys. Soc. (London) B65, No. 393, 701-9 (Sept. 1952)

Keyes, F. G., Trans. ASME 73, 589 (July 1951)

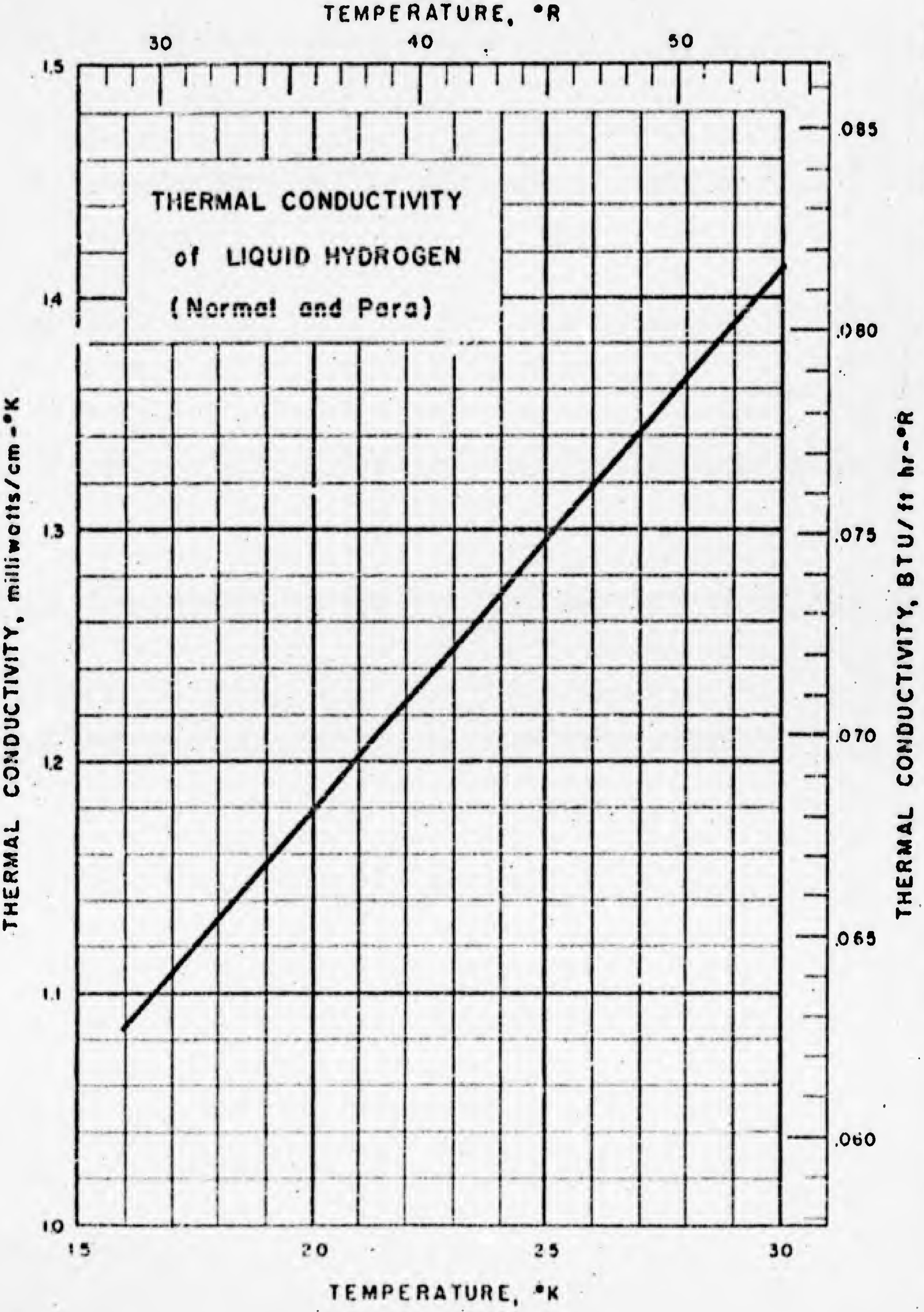
Keyes, F. G., Trans. ASME 76, No. 5, 809-16 (July 1954)

Waelbrock, P. Zuckerbrodt, J. Chem. Phys. 28, 523 (1958)

Comments:

The Absolute temperature scale (0°C = 273.16°K = 491.56°R) was used in the table below.

Temperature			Thermal Conductivity	
°K	°R	°F	$\frac{\text{milliwatts}}{\text{cm}\ {}^\circ\text{K}}$	$\frac{\text{BTU}}{\text{ft hr}\ {}^\circ\text{R}}$
5.38	9.69	-450	0.109	0.0063
10.94	19.69	-440	0.183	0.0106
16.49	29.69	-430	0.230	0.0133
22.05	39.69	-420	0.277	0.0160
27.61	49.69	-410	0.322	0.0186
33.16	59.69	-400	0.363	0.0210
88.72	159.69	-300	0.692	0.0400
144.27	259.69	-200	0.95	0.0550
199.83	359.69	-100	1.16	0.0673
255.38	459.69	0	1.37	0.0792
366.49	659.69	200	1.73	0.1000


TEMPERATURE, °R
30
40
50
THERMAL CONDUCTIVITY
of LIQUID HYDROGEN
(Normal and Para)
1.5
1.4
1.3
1.2
1.1
1.0
THERMAL CONDUCTIVITY, milliwatts/cm-°K
.085
.080
.075
.070
.065
.060
THERMAL CONDUCTIVITY, BTU/ft hr-°R
15
20
25
30
TEMPERATURE, °K

3.002

THERMAL CONDUCTIVITY of LIQUID NORMAL and PARA HYDROGEN

Source of Data: Powers, R. W., Mattox, R. W., and Johnston, H. L., J. Am. Chem. Soc. 76, 5968 and 5972 (1954).

Other References: Borovik, E., Matveev, A. and Panina, E., J. Tech. Phys. (U.S.S.R.) 10, 998 (1940); Schaefer, C. A., and Thodos, G., Ind. Eng. Chem. 50, 1585 (1958).

Comments: The only available information on the thermal conductivity of liquid hydrogen is that of Powers, Mattox and Johnston, who find that there is no significant difference between the conductivity of normal and of para hydrogen. They reduced their data to a straight line curve having the equation

$$k = (1.702 + 0.05573\ T) \times 10^{-4}\ \text{cal cm}^{-1}\ \text{sec}^{-1}\ \text{deg}^{-1}.$$

Data for both normal and para hydrogen are shown on this curve of experimental points, and the probable error of 2% is greater than the differences in the conductivities of the normal and para forms. In the measurements, corrections were made in the case of normal hydrogen, for the heat liberated in the spontaneous conversion of the normal to the para form. The curve has a positive slope showing that the thermal conductivity increases with temperature. This contrasts with the change of thermal conductivities of other low boiling liquids N_2, CO, CH_4 and and C_2H_4 previously investigated, which show a decreasing conductivity with rising temperature as shown by the work of Powers, Mattox and Johnston, and by Borovik, Matveev and Panina.

Schaefer and Thodos have developed curves showing a Reduced Thermal Conductivity Correlation for gaseous and liquid hydrogen, using data of other investigators.

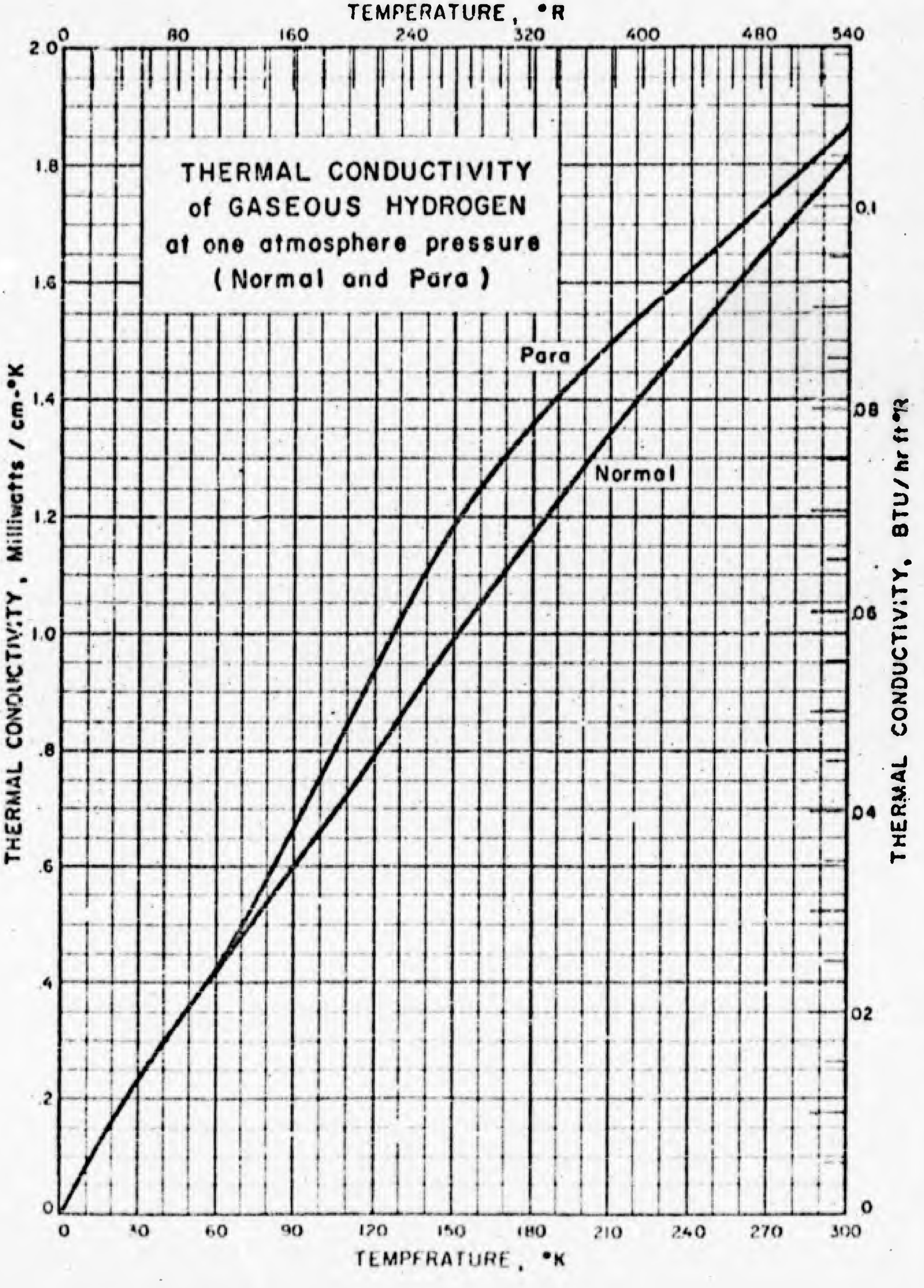
No data on thermal conductivity of solid hydrogen has been found.

Thermal conductivity values computed from the equation:

$$k = (1.702 + .05573\ T)\ 10^{-4}\ \text{cal/cm sec °K}$$

Temp. °K	K watts/cm °K	k cal/cm sec °K	Temp. °K	K watts/cm °K	k cal/cm sec °K
16	10.85 x 10^{-4}	2.593 x 10^{-4}	24	12.72 x 10^{-4}	3.040 x 10^{-4}
17	11.08 "	2.649 "	25	12.95 "	3.095 "
18	11.32 "	2.705 "	26	13.18 "	3.151 "
19	11.55 "	2.761 "	27	13.42 "	3.207 "
20	11.79 "	2.817 "	28	13.65 "	3.262 "
21	12.02 "	2.872 "	29	13.89 "	3.318 "
22	12.25 "	2.928 "	30	14.12 "	3.374 "
23	12.48 "	2.984 "			

3.002


TEMPERATURE, °R
0
80
160
240
320
400
480
540
THERMAL CONDUCTIVITY
of GASEOUS HYDROGEN
at one atmosphere pressure
(Normal and Para)
Para
Normal
THERMAL CONDUCTIVITY, Milliwatts / cm-°K
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
THERMAL CONDUCTIVITY, BTU/hr ft °R
0.1
.08
.06
.04
.02
0
0
30
60
90
120
150
180
210
240
270
300
TEMPERATURE, °K

3.002

THERMAL CONDUCTIVITY of GASEOUS HYDROGEN

(Normal and Para)

Sources of Data:

Farkas, A., Ortho-Para Hydrogen and Heavy Hydrogen, Cambridge University Press (1935)

Hilsenrath, J., et al., Nat. Bur. Standards Cir. 564, 285 (1955)

Other References:

Andrussow, L., J. Chim. Phys. 52, 295 (1955)

Godridge, A. M., Bull. Brit. Coal Utilisation Research Assoc. 18, 1 (1954)

Johnston, H. L. and Grilly, E. R., J. Chem. Phys. 14, 233 (1946)

Schaefer, C. A. and Thodos, G., Ind. Eng. Chem. 50, 1585 (1958)

Weitzel, D. H. and Hershey, R. L., Cryogenic Eng. Conf. Proc., Paper 2.02 (1954)

Comments:

The lower curve, being that for normal hydrogen, represents the data given in the Nat. Bur. Standards Cir. 564.

(Cont. on next page.)

Table 1. Selected Values of Thermal Conductivity from Circular 564 for Gaseous Normal Hydrogen and Corresponding Values Computed for Gaseous Para Hydrogen

Temp. °K	k_n $\frac{\text{milliwatt}}{\text{cm °K}}$	$\frac{k_p}{k_n}$	k_p $\frac{\text{milliwatt}}{\text{cm °K}}$
10	0.074	1.000	0.074
20	0.155	1.000	0.155
30	0.229	1.000	0.229
40	0.293	1.001	0.293
50	0.362	1.004	0.363
60	0.422	1.017	0.429
80	0.542	1.066	0.578
100	0.664	1.136	0.754
120	0.790₅	1.190	0.941
140	0.918	1.204	1.105
160	1.043	1.195	1.246
180	1.166	1.167	1.361
200	1.282	1.135	1.455
220	1.398	1.103	1.542
240	1.507	1.076	1.621₅
260	1.613	1.055	1.702
270	1.665	1.046	1.741₅
280	1.717	1.039	1.784
300	1.816₅	1.027	1.865₅

Table 2. k_p/k_n Values computed by Farkas

Temp. °K	$\frac{k_p}{k_n}$
30	1.000
40	1.001
50	1.004
75	1.051
100	1.136
125	1.196
150	1.203
175	1.175
200	1.135
225	1.096
250	1.065
273	1.044
298	1.028

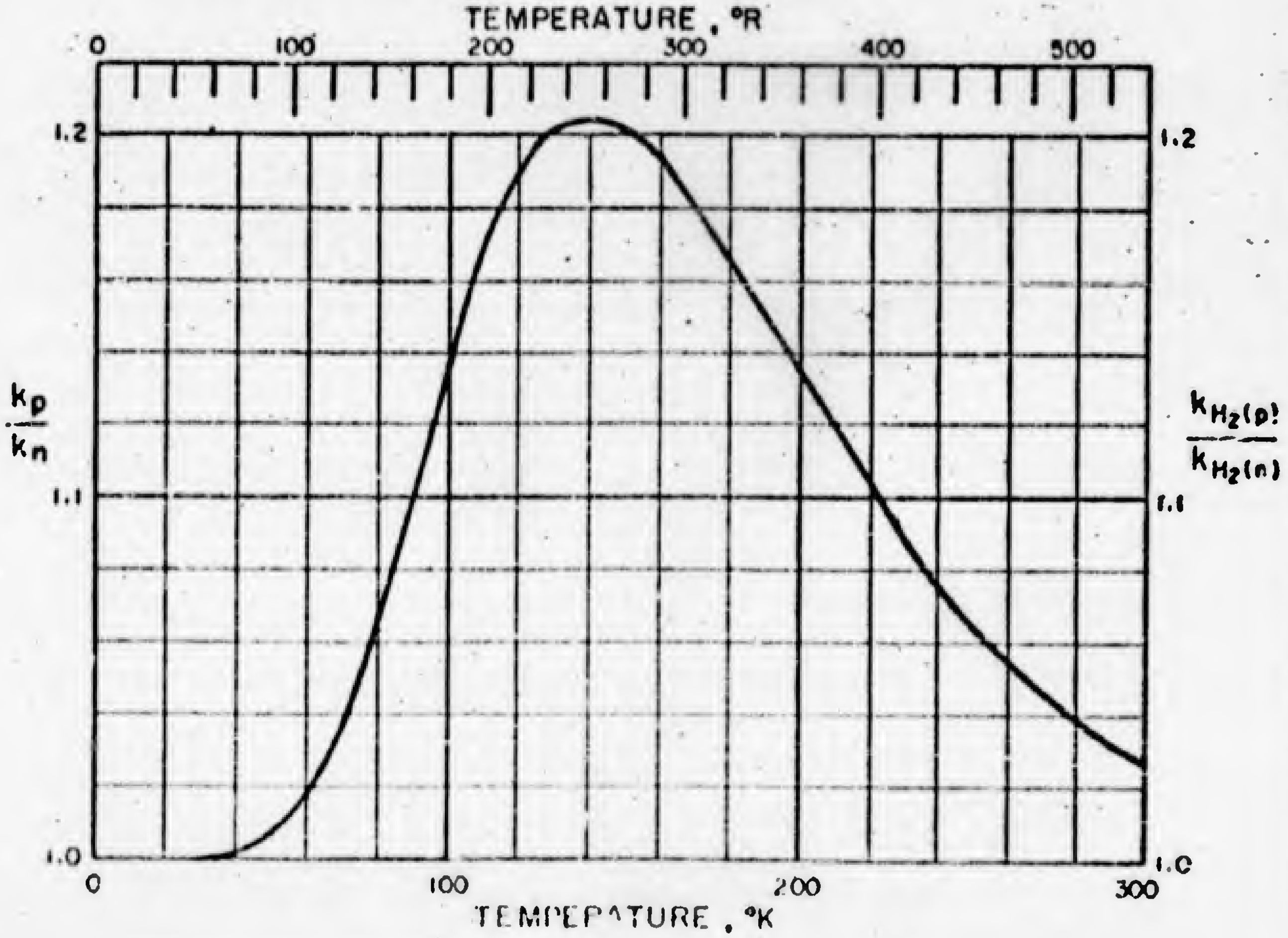
THERMAL CONDUCTIVITY of GASEOUS HYDROGEN (Cont.)

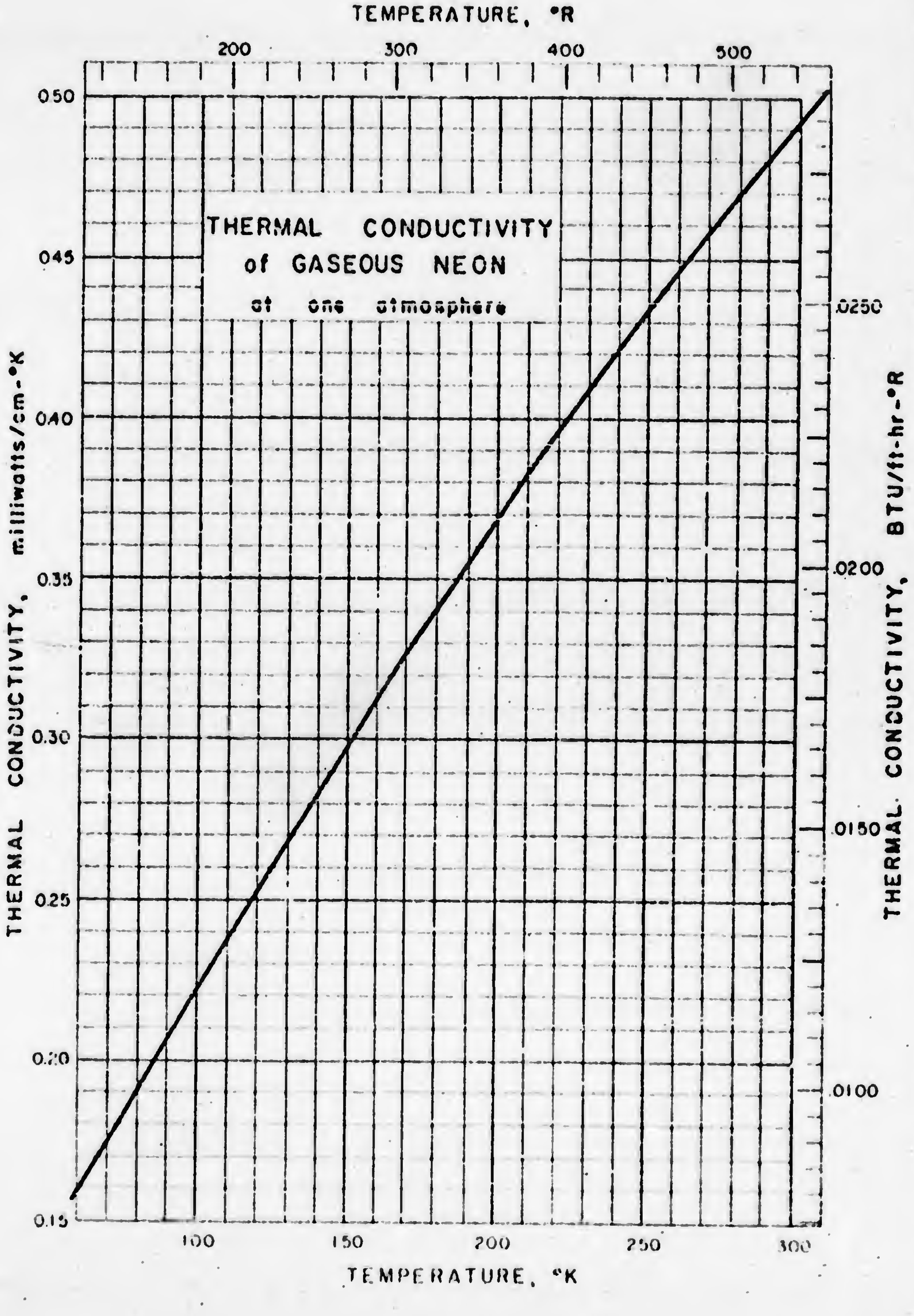
(normal and para)

Existing values near room temperature show a considerable scattering. Johnston and Grilly's value at 280.4°K of 4.039 x 10^{-4} cal/cm sec °K falls about 1.6% below the curve. A slightly smaller deviation in the same direction is shown in the same temperature region by Goldridge and by Andrussow. It is therefore possible that the curve should be lowered slightly at temperatures above 200°K. The upper curve, which is for para hydrogen, was calculated from the values of the heat capacities at constant volume of n- and p-hydrogen and the thermal conductivity of n-hydrogen, using the equation

$$\frac{k_{H_2(p)}}{k_{H_2(n)}} = \frac{C_v^{H_2(p)} + 2.25\ R}{C_v^{H_2(n)} + 2.25\ R}$$

which is given on page 21 of the book by Farkas cited above. (See Table 2). The curve below is from Weitzel and Hershey and shows the ratio of thermal conductivity of para hydrogen to normal hydrogen at temperatures from 0°K to 300°K.





THERMAL CONDUCTIVITY of GASEOUS NEON at one atmosphere

3.003

THERMAL CONDUCTIVITY of GASEOUS NEON
(at One Atmosphere)

Sources of Data:

Amdur, I., J. Chem. Phys. 16, 190-4 (1948)

Kannuluik, W. G. and Carman, E. H., Proc. Phys. Soc. (London) 65B, 701-9 (1952)

Srivastava, B. N. and Saxena, S. C., Proc. Phys. Soc. (London) 70B 369-78 (1957)

Thomas, L. B. and Golike, R. C., J. Chem. Phys. 22, 300-5 (1954)

Weber, S., Ann. Physik. 54, 325, 437, 481 (1917)

Weber, S., Proc. Roy. Acad. Sci. Amsterdam 21, 342 (1919(

Weber, S., Verslag Akad. Wetenschappen Amsterdam 26, 1338-53 (1918)

Comments:

Conversions from 0°C to °K in the table below are based on a value of the ice point of 273.09°K used by the Leiden Laboratory in 1917 and 1918. The disagreement with the currently accepted value, 273.15°K is of no consequence because of the small temperature dependence of thermal conductivity and the relative uncertainty of the conductivity measurements.

Temperature		Thermal Cond.	Temperature		Thermal Cond.
°C	°K	cal/cm-sec-°K	°C	°K	cal/cm-sec-°K
-213.09	60	*3.79 x 10^{-5}	-100	173.09	+ 8.13 x 10^{-5}
-203.09	70	*4.17 "	- 93.09	180	* 7.32 "
-193.09	80	*4.53 "	- 78.5	194.59	8.76 "
-183.09	90	*4.86 "	- 78.5	194.59	* 8.85 "
-183.09	90	4.93 "	- 74.37	198.72	8.79 "
-182.97	90.12	4.89 "	- 73.09	200	8.82 "
-182.97	90.12	*5.00 "	- 73.09	200	7.78 "
-181.43	91.66	4.99 "	- 50	223.09	+ 9.67 "
-181.4	91.69	+4.99 "	0	273.09	+11.04 "
-173.09	100	*5.19 "	0	273.09	10.87 "
-153.09	120	*5.78 "	0	273.09	11.10 "
-150	123.09	5.31 "	0	273.09	*11.13 "
-133.09	140	*6.33 "	35.61	308.7	**11.99 "
-113.09	160	*6.84 "	36.91	310	‡12.016 "

* Calculated Values ‡ Interpolated Values ** ± .20%

+ Presented as K_T/K_0 where K_0 = 11.04 cal/cm-sec-°K at 0°C

EDT/BDF Issued: 7/15/59

3.003

THERMAL CONDUCTIVITY of GASEOUS NEON
(at 274.79°K and 373.09°K)

Sources of Data:

Kannuluik, W. G. and Carman, E. H., Proc. Phys. Soc. (London) 65B, 701-9 (1952)

Kannuluik, W. G. and Martin, L. H., Proc. Roy. Soc. (London) A144, 496-513 (1934)

Weber, S., Ann. Physik. 82, 479-503 (1927)

Comments:

Values of the thermal conductivity at 273.09°K and 1 atmosphere are 10.91 x 10^{-5} g-cal/cm sec °K [Bannawitz, E., Ann. Physik. 48, 577-92 (1915)], 10.92 x 10^{-5} g-cal/cm sec °K [Curie, M. and Lepape, M., Compt. rend. 193, 842-3 (1931)], 11.10 x 10^{-5} g-cal/cm sec °K [Kannuluik, W. G. and Carman, E. G., Proc. Phys. Soc. (London) 65B, 701-9 (1952)], 11.12 x 10^{-5} g-cal/cm sec °K [Kannuluik, W. G. and Martin, L. H., Proc. Roy. Soc. (London) A144, 496-513 (1934)], and 10.87 x 10^{-5} g-cal/cm sec °K [Weber, S., Verslag Akad. Wetenschappen Amsterdam 26, 1338-53 (1918)].

A value of 11.04 x 10^{-5} g-cal/cm sec °K given by Weber is considered to be the best value at 273.09°K and 1 atmosphere.

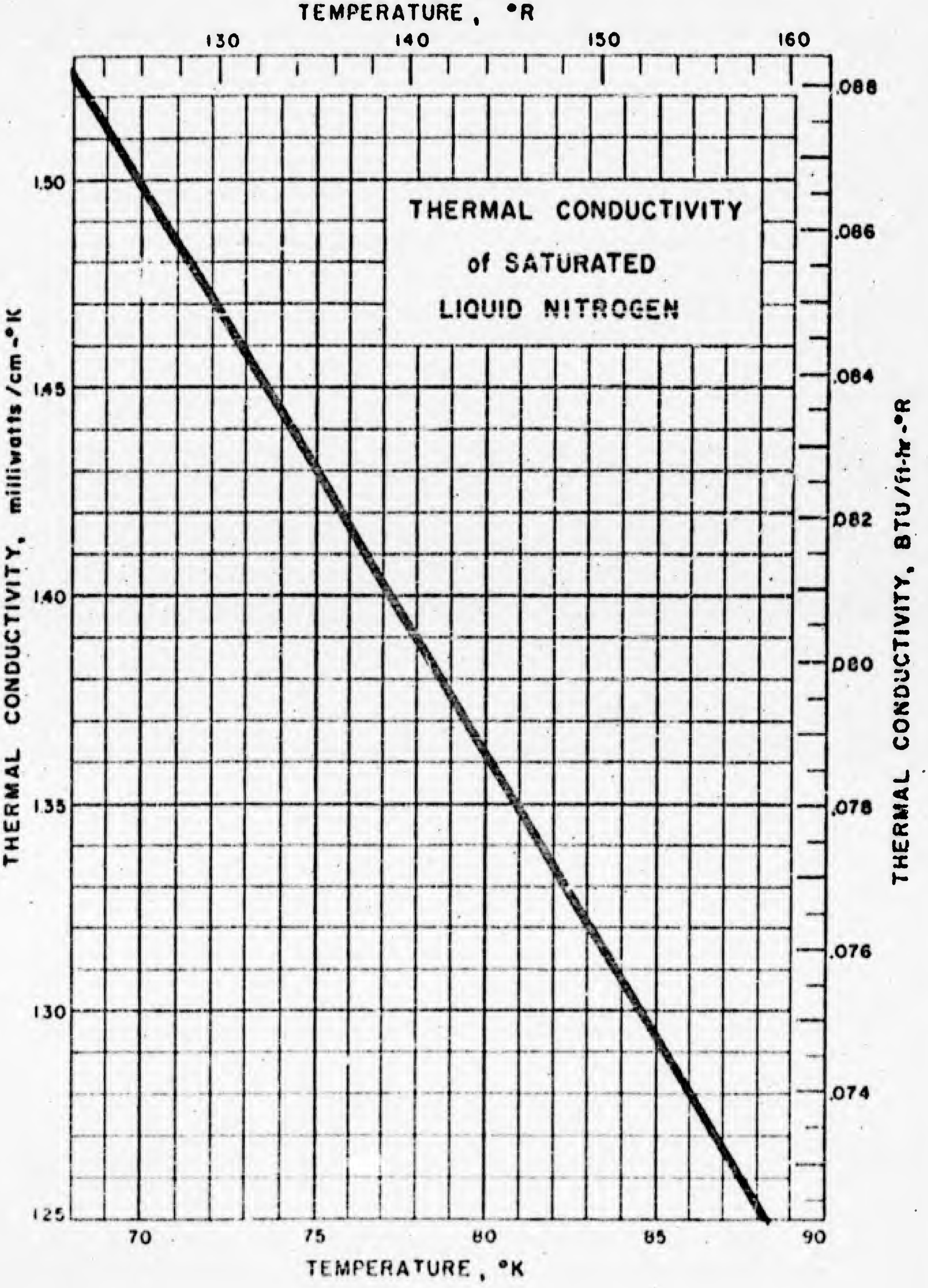
Table of Selected Values

T = 274.79°K	
Press. cm/Hg	Thermal Cond. cal/cm-sec-°K
67.0	11.28 x 10^{-5}
67.0	11.28 "
55.6	11.29 "
42.4	11.29 "
30.6	11.30 "
19.4	11.30 "
19.4	**11.31 "

T = 373.09°K *	
Press. cm/Hg	Thermal Cond. cal/cm-sec-°K
75.07	13.58 x 10^{-5}
66.43	13.59 "
57.42	13.59 "
50.15	13.57 "
41.89	13.47 "
33.82	13.56 "
25.56	13.58 "
17.40	13.60 "

* mean gas temperature = 374.49°K
** mean gas temperature = 274.19°K

KLT/LDT Issued: 11-19-59



THERMAL CONDUCTIVITY
of SATURATED
LIQUID NITROGEN

3.004

THERMAL CONDUCTIVITY of LIQUID NITROGEN
(at saturation)

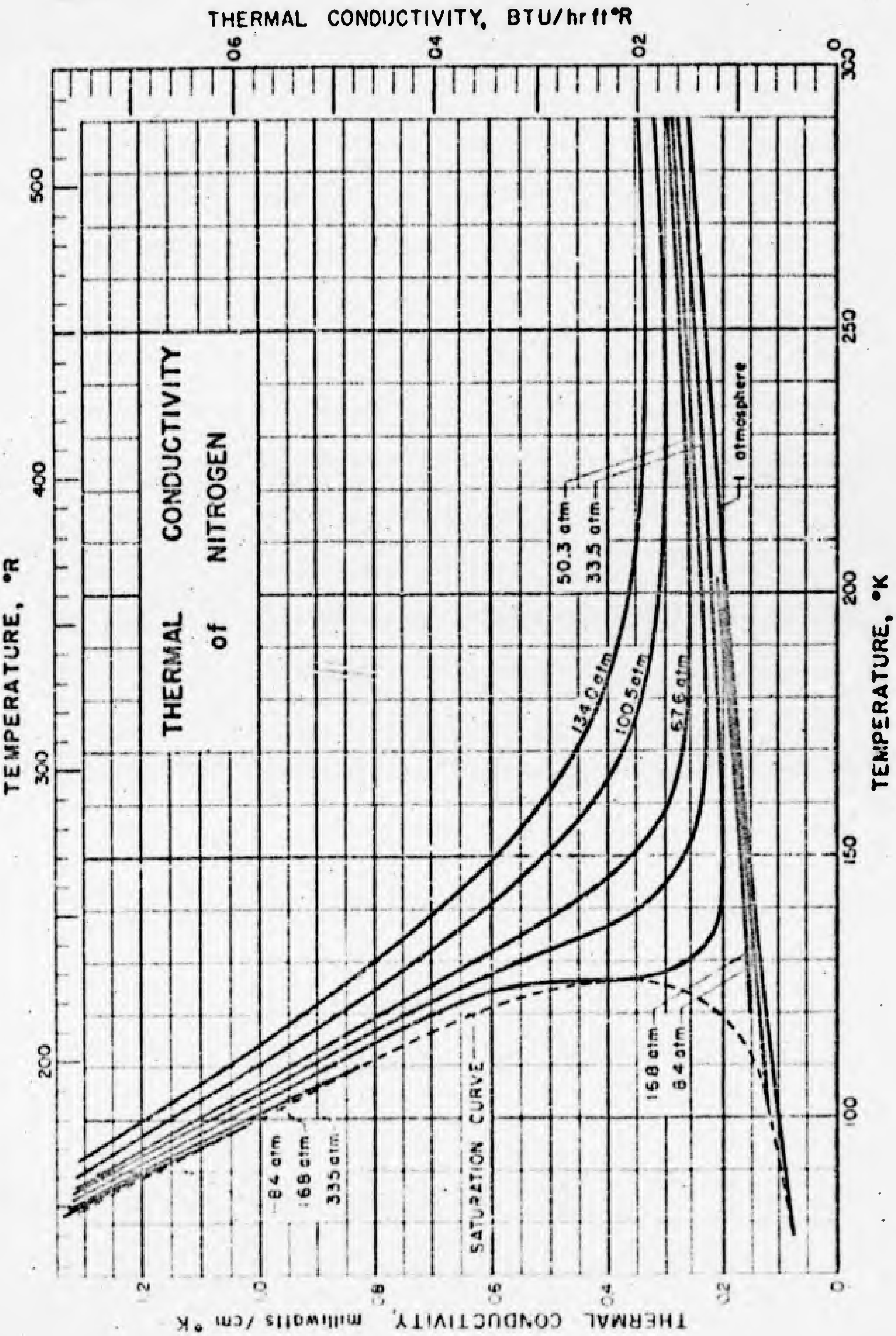
Source of Data:

Powers, R. W., Mattox, R. W. and Johnston, H. L., J. Am. Chem. Soc. 76, 5968-73 (1954).

Table of Selected Values

Temperature °K	Thermal Conductivity cal/cm·sec-°K
68.68	3.64×10^{-4}
69.92	3.53 "
70.94	3.59 "
73.66	3.44 "
76.26	3.39 "
77.66	3.33 "
78.73	3.31 "
81.11	3.18 "
81.77	3.15 "
83.77	3.12 "
86.44	3.07 "
88.12	3.00 "

KDT/RJR Issued: 8/28/59


THERMAL CONDUCTIVITY, BTU/hr ft °R
06
04
02
0
THERMAL CONDUCTIVITY of NITROGEN
TEMPERATURE, °R
500
400
300
200
TEMPERATURE, °K
300
250
200
150
100
50.3 atm
33.5 atm
1 atmosphere
134.0 atm
100.5 atm
67.6 atm
16.8 atm
8.4 atm
SATURATION CURVE
84 atm
168 atm
335 atm
1.2
1.0
.8
.6
.4
.2
0
THERMAL CONDUCTIVITY, milliwatts/cm °K

THERMAL CONDUCTIVITY of NITROGEN
(Liquid and Gas)

Source of Data:

Borovik, E., Matveev, A. and Panina, E., J. Tech. Phys. (U.S.S.R.) 10, 988-98 (1940).

Franck, E. U., Z. Elektrochem. 55, 636-43 (1951).

Keyes, F. G., Trans. ASME 77, 1395-6 (1955).

Lenoir, J. M. and Comings, E. W., Chem. Eng. Progr. 47, 223-31 (1951).

Uhlir, A. Jr., J. Chem. Phys. 20, 463-72 (1952).

Ziebland, H. and Burton, J. T. A., Brit. J. Appl. Phys. 9, 52-9 (1958).

Comments:

At low pressures and temperatures between 90 and 823°K, the following equation may be used to calculate the thermal conductivity of gaseous nitrogen, where k is in cal/cm·sec·°K and T is in °K.

$$k = \frac{6.15 \times 10^{-6} \sqrt{T}}{1 + (235.5/T)\,(10^{-12/T})}$$

Table of Selected Values

Temp. °K	Thermal Cond. cal/cm·sec·°K
1 atm	
92	0.208 x10⁻⁴
100	0.223 "
125.9	0.300 "
134.1	0.315 "
150.0	0.329 "
158.6	0.370 "
172.3	0.400 "
187.9	0.430 "
200.0	0.437 "
202.0	0.460 "
250.0	0.528 "
273.0	0.571 "
300.0	0.616 "
314.3	0.647 "
8.4 atm	
*88.2	2.79×10^{-4}
158.5	0.385 "
172.2	0.410 "
187.9	0.440 "
201.9	0.470 "
16.8 atm	
*87.7	2.84×10^{-4}
124.7	0.365 "
133.4	0.360 "
158.3	0.400 "
172.0	0.425 "
187.4	0.455 "
201.8	0.480 "
31.3 atm	
164.2	0.460×10^{-4}
188.8	0.490 "
202.5	0.510 "
33.5 atm (Pc)	
76.6	3.32×10^{-4}
85.0	3.00 "
87.7	2.90 "
88.7	2.92 "
97.3	2.56 "
105.8	2.17 "
111.0	2.01 "
114.6	1.810 "
116.1	1.750×10^{-4}
120.6	1.555 "
121.6	1.56 "
124.1	1.410 "
124.1	1.415 "
124.2	1.390 "
126.0	0.85 "
128.4	0.660 "
129.9	0.600 "
131.2	0.565 "
132.0	0.56 "
132.6	0.506 "
138.3	0.475 "
143.4	0.454 "
145.0	0.47
147.0	0.470 "
147.0	0.50 "
154.2	0.438 "
157.6	0.460 "
170.0	0.465 "
171.6	0.475 "
187.3	0.495 "
201.5	0.515 "

*Liquid

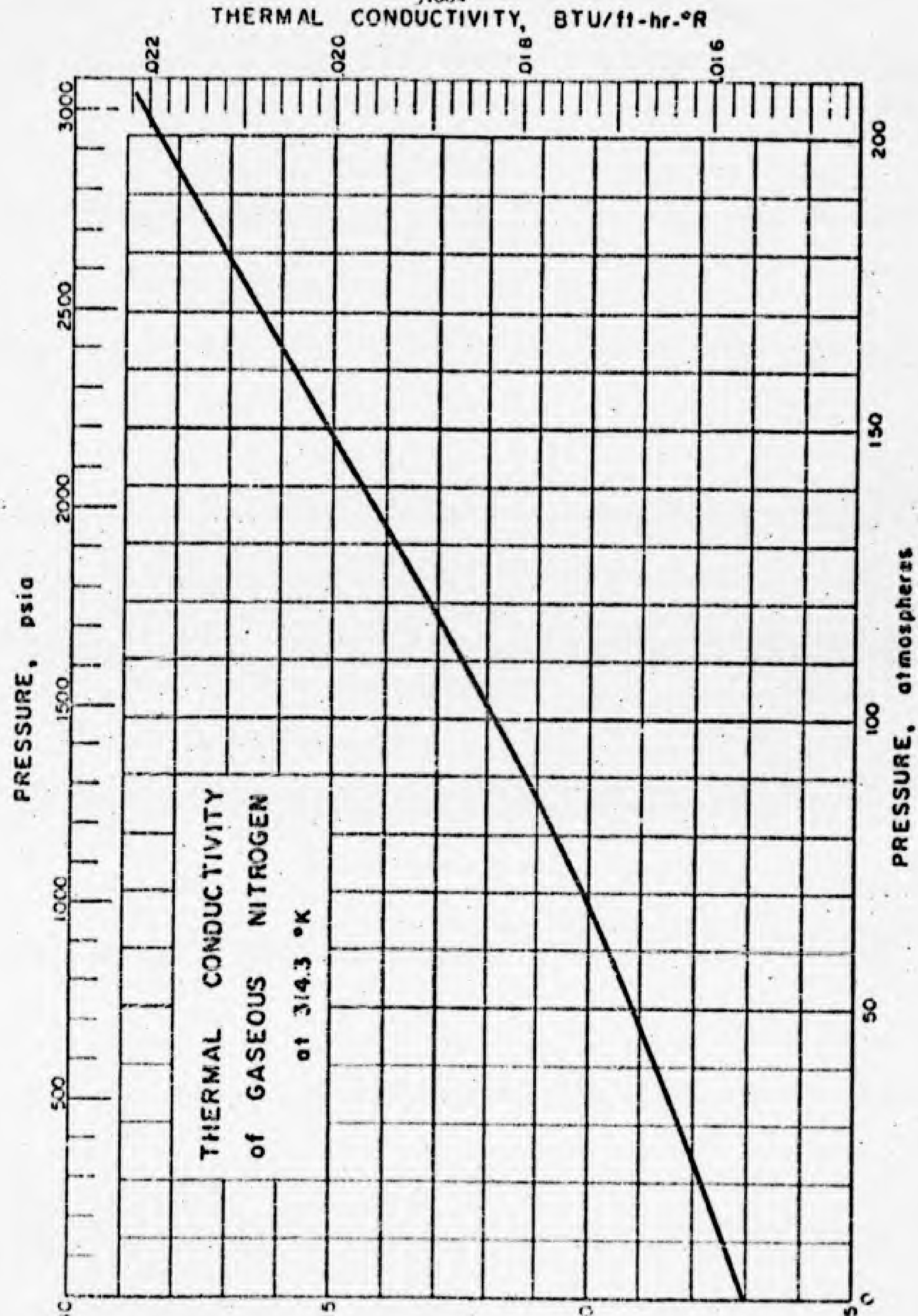
THERMAL CONDUCTIVITY of NITROGEN (cont.)

Temp. °K	Thermal Cond. cal/cm·sec·°K
50.3 atm	
105.9	2.25×10^{-4}
116.4	1.830 "
125.9	1.440 "
127.0	1.380 "
128.4	1.330 "
128.9	1.355 "
129.5	1.335 "
136.2	1.085 "
136.9	0.890 "
139.0	0.835 "
139.0	0.885 "
139.3	0.805 "
139.4	0.810 "
147.3	0.645 "
156.9	0.555 "
67.0 atm	
76.9	3.40×10^{-4}
83.3	3.18 "
85.0	3.12 "
87.3	2.98×10^{-4}
89.8	2.96 "
98.3	2.60 "
100.7	2.57 "
105.6	2.32 "
114.5	2.03 "
116.4	1.935 "
125.0	1.57 "
126.8	1.555 "
127.2	1.63 "
132.0	1.22 "
142.1	1.10 "
145.0	0.88 "
145.1	0.940 "
155.3	0.730 "
169.0	0.641 "
171.0	0.60 "
171.1	0.620 "
184.3	0.597 "
186.5	0.595 "
201.0	0.600 "
100.5 atm	
87.2	3.08×10^{-4}
98.2	2.70 "
105.6	2.46 "
116.1	2.11 "
126.6	1.755 "
145.1	1.257 "
155.2	1.065 "
170.9	0.845 "
185.8	0.755 "
200.5	0.710 "
134.0 atm	
87.3	3.16×10^{-4}
97.9	2.82 "
105.4	2.57 "
114.5	2.24 "
126.3	1.935 "
144.8	1.530 "
154.9	1.260 "
170.5	1.040 "
185.5	0.915 "
200.8	0.840 "

Press. atm.	Temp. °K	Thermal Cond. cal/cm·sec·°K
3.9	92.0	0.223×10^{-4}
5.8	77.2	3.23 "
7.6	273.1	0.582 "
8.2	76.4	3.31 "
10.6	273.1	0.586 "
10.9	91.8	2.70 "
27.6	80.9	3.18 "
28.1	80.7	3.19 "
38.4	107.2	2.23 "
38.7	121.3	1.65 "
47.6	314.3	0.691 "
56.5	314.3	$0.70, \times 10^{-4}$
73.9	314.3	0.725 "
82.7	314.3	0.737 "
96.3	314.3	0.758 "
121.7	314.3	0.786 "
136.0	314.3	0.824 "
144.7	314.3	0.828 "
167.6	314.3	0.861 "
170.3	314.3	0.865 "
196.1	314.3	0.915 "
205.7	314.3	0.918 "

T_c = 126.135 °K

P_c = 33.49 atm



THERMAL CONDUCTIVITY of GASEOUS NITROGEN at 314.3 °K

3.004

THERMAL CONDUCTIVITY of GASEOUS NITROGEN

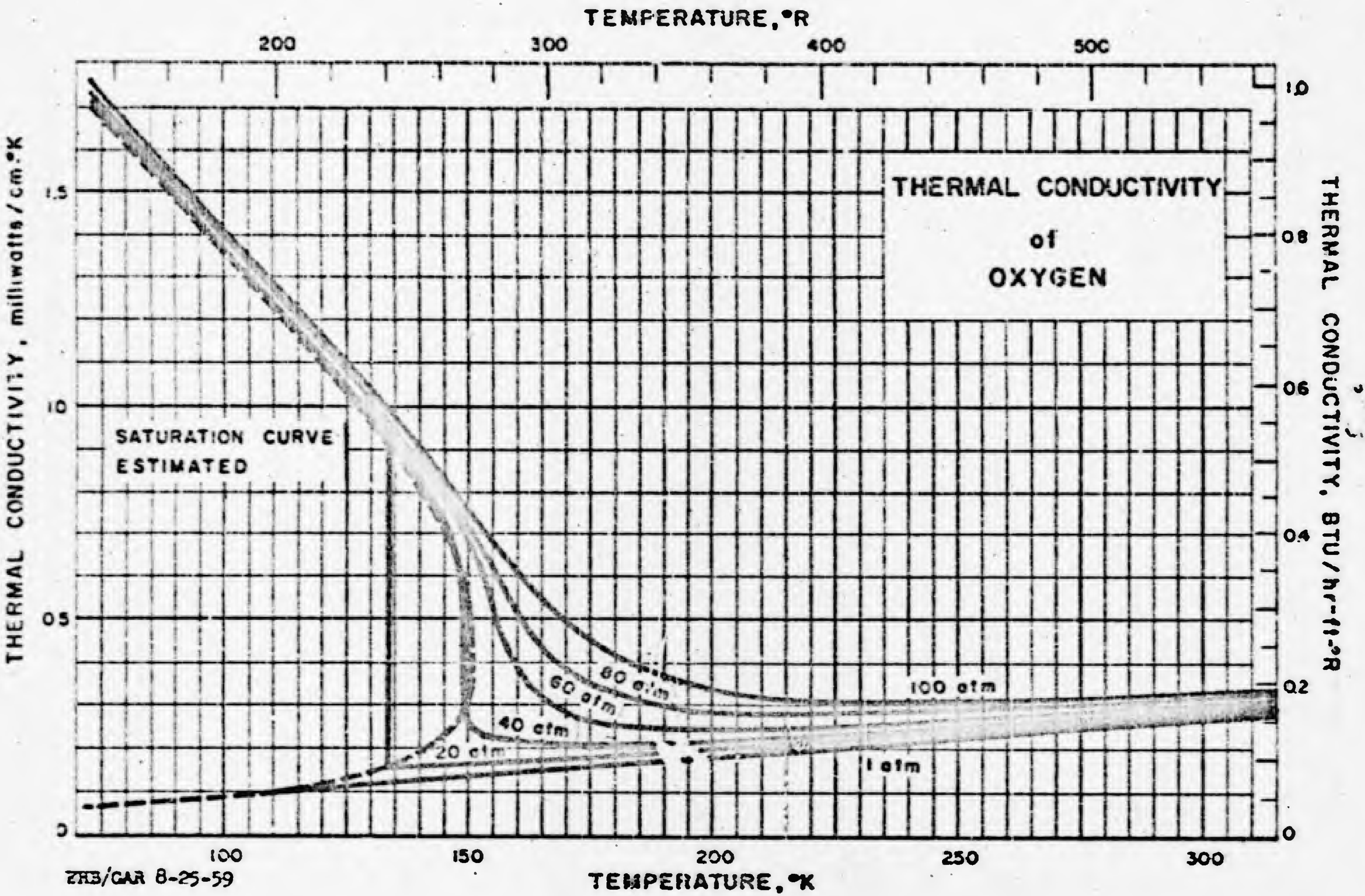
(at 314.3°K.)

Source of Data: Lenoir, J. M. and Comings, E. W., Chem. Eng. Prog. 47, 223-31 (1951).

Table of Selected Values

Press. atm.	Thermal Cond. cal/cm-sec-°K
1.0	0.647×10^{-4}
47.6	0.691 "
56.5	0.705 "
73.9	0.725 "
82.7	0.737 "
95.3	0.758 "
121.7	0.786 "
136.0	0.824 "
144.7	0.828 "
167.6	0.861 "
170.3	0.865 "
196.1	0.915 "
205.7	0.918 "

EDT/RJR Issued: 5/30/59


TEMPERATURE, °R
200
300
400
500
THERMAL CONDUCTIVITY
of
OXYGEN
THERMAL CONDUCTIVITY, milliwatts/cm-°K
1.5
1.0
0.5
0
THERMAL CONDUCTIVITY, BTU/hr-ft-°R
1.0
0.8
0.6
0.4
0.2
0
SATURATION CURVE
ESTIMATED
80 atm
60 atm
40 atm
20 atm
100 atm
1 atm
100
150
200
250
300
TEMPERATURE, °K
ZHB/GAR 8-25-59

THERMAL CONDUCTIVITY of OXYGEN

(Liquid and Gas)

Sources of Data:

Hilsenrath, J., et al., Natl. Bur. Standards Cir. 564, 425 (1955)
Tsederberg, N. V. and Timrot, D. L., Soviet Phys. Tech. Phys. 1, 1791-7 (1956); also in J. Tech. Phys. (USSR) 26, 1849-56 (1956)
Zeibland, H. and Burton, J. T. A., Brit. J. Appl. Phys. 6, 416-20 (1955); also ASTIA No. AD-90759

Other References:

Borovik, Ye., Zhur. Eksptl. i Teoret. Fiz. 17, 328-35 (1947)

Comments:

The values for gaseous oxygen at one atmosphere listed in NBS Circular 564 are in good agreement with data of Tsederberg and Timrot. Zeibland and Burton's values are consistently higher. They were not used for the graph except to indicate trend and are tabulated on the next page for purpose of comparison only. An approximate plotting of Zeibland and Burton's data is also shown to facilitate comparison with selected values tabulated on this page.

Temp. °K	Thermal Conductivity, milliwatts/cm°K					
	1 atm	20 atm	40 atm	60 atm	80 atm	100 atm
73.16*	0.0651	1.721	1.721	1.721	1.733	1.744
80	0.07193					
93.16*	0.0837	1.465	1.465	1.477	1.488	1.489
100	0.09034					
113.16*	0.1023	1.198	1.209	1.2328	1.244	1.256
120	0.10900					
133.16*	0.1209	0.1535	0.953	0.9769	1.000	1.0118
140	0.12766					
153.16*	0.1396	0.1640	0.2233	0.6164	0.663	0.709
160	0.14607					
173.16*	0.1582	0.1756	0.2082	0.2698	0.3558	0.4617
180	0.16424					
193.16*	0.1768	0.1907	0.2140	0.2466	0.2896	0.3489
200	0.18241					
213.16*	0.1942	0.2070	0.2256	0.2489	0.2791	0.3163
220	0.20008					
233.16*	0.2117	0.2245	0.2384	0.2570	0.2826	0.3070
240	0.21727					
253.16*	0.2233	0.2384	0.2512	0.2663	0.2884	0.3094
260	0.23421					
273.16*	0.2442	0.2535	0.2652	0.2791	0.2966	0.3140
280	0.25041					
293.16*	0.2605	0.2698	0.2803	0.2931	0.3082	0.3245
300	0.26760					
313.16*	0.2768	0.2861	0.2966	0.3092	0.3210	0.3349

* Data from Tsederberg and Timrot; other data from NBS Circular 564.

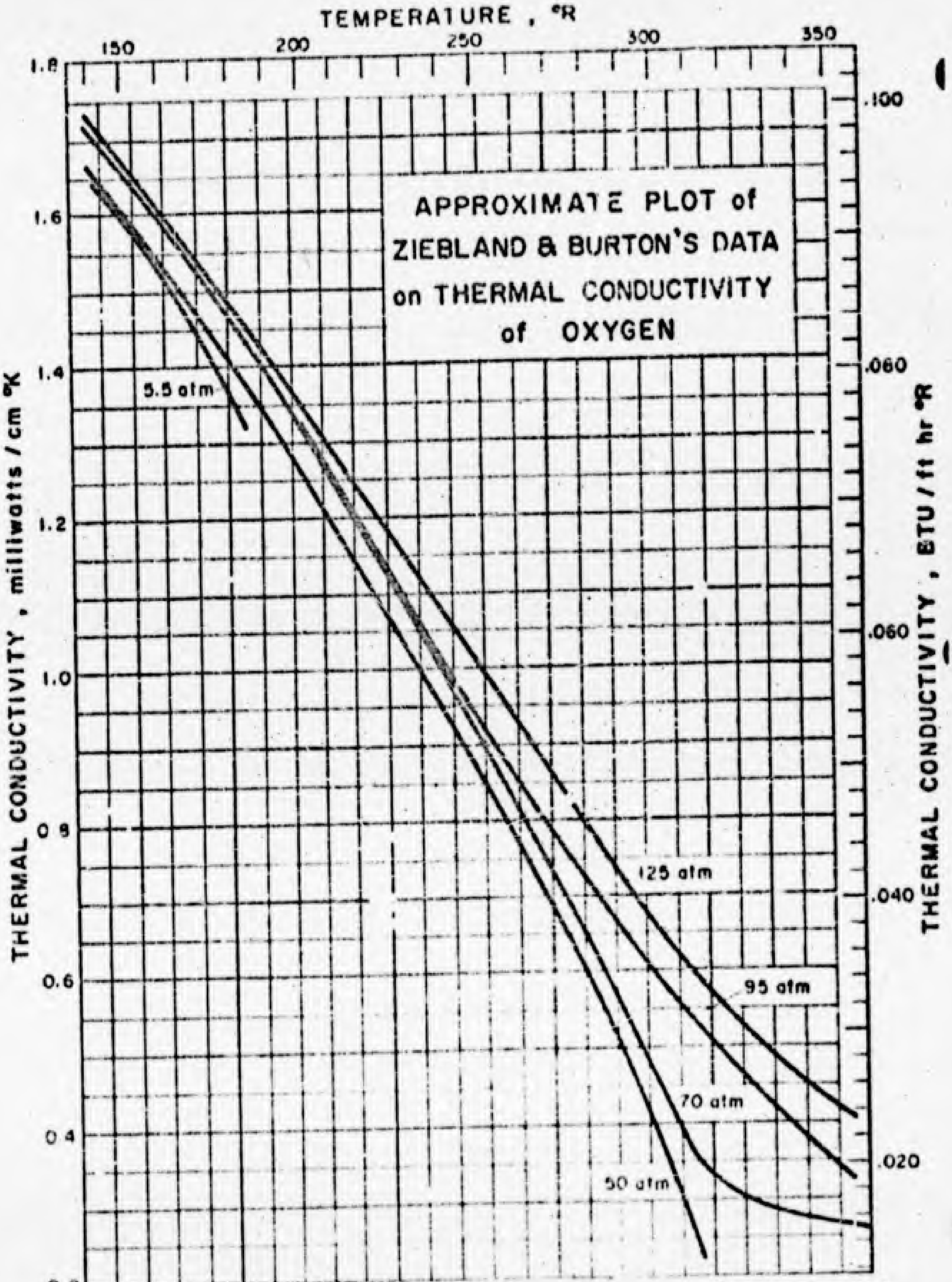
JM/JRC/VJJ Issued: 8-26-59

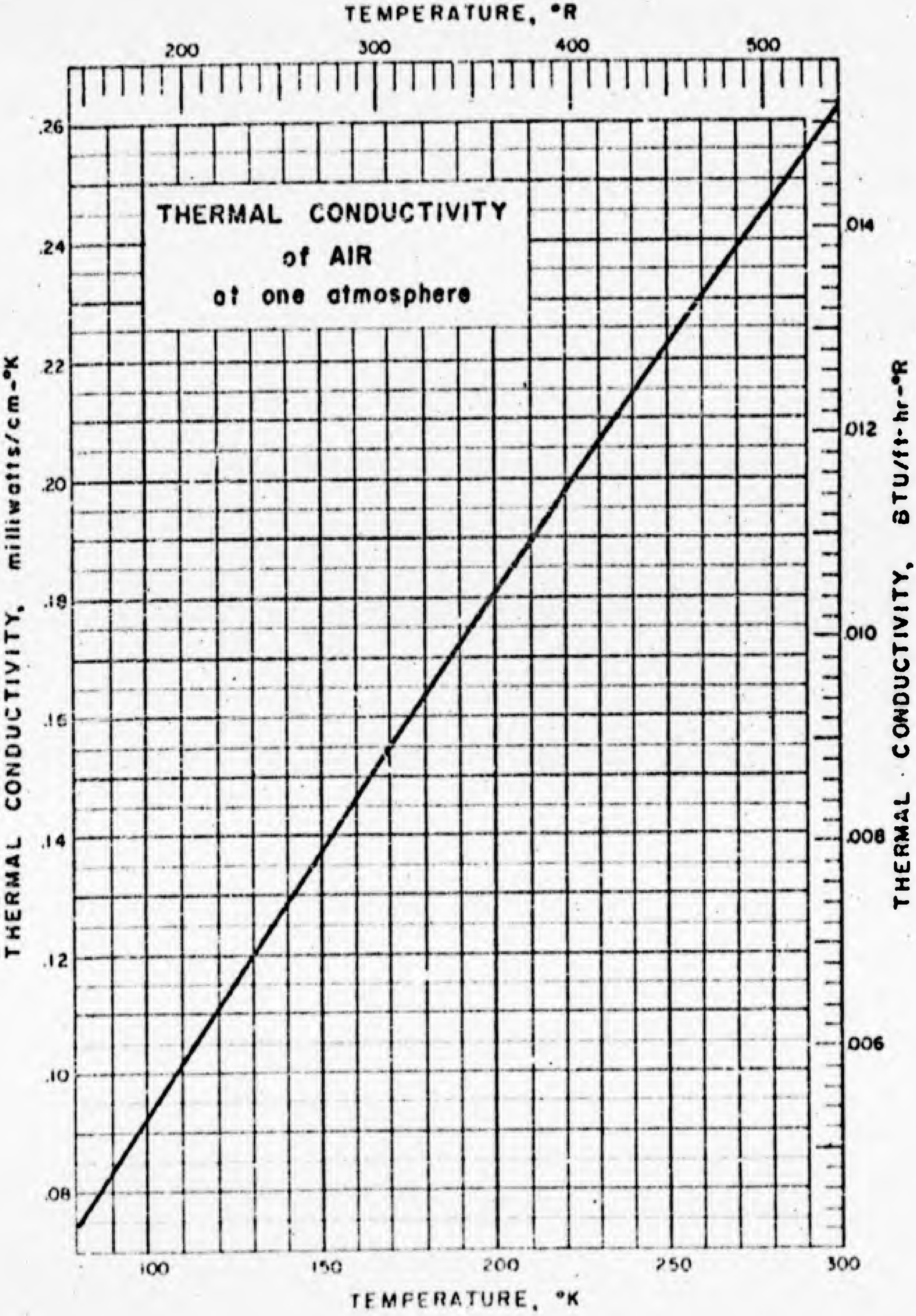
THERMAL CONDUCTIVITY of OXYGEN (Cont.)

(Liquid and Gas)

Data from Zeibland and Burton tabulated below for purpose of comparison only. (See graphical presentation on other side of this sheet.)

Pressure atm	Temp. °K	Thermal Conductivity milliwatt/cm-°K	Pressure atm	Temp. °K	Thermal Conductivity milliwatt/cm-°K
1	199	0.1882	49.9	147.1	0.757
1.7	170.2	0.1644	50.2	151	0.6838
1.7	196.1	0.1849	52.1	172.5	0.2415
5.5	79.7	1.632	52.1	173.1	0.240
5.5	93.5	1.464	56.9	164.9	0.301
5.5	94.1	1.460	61.4	165.1	0.3429
5.5	102.7	1.343	61.4	168.5	0.3008
15.4	79.7	1.627	61.4	170.1	0.2919
15.4	102.4	1.347	65.9	169.5	0.3345
15.4	118	1.113	70.5	79.8	1.697
23.8	199.8	0.1874	70.5	103.1	1.405
24.9	169.9	0.1866	70.5	148.8	0.752
28.2	79.8	1.657	70.5	159.3	0.599
29.7	92.3	1.510	70.5	173.3	0.350
29.7	104	1.334	70.5	199.2	0.2628
29.9	79.8	1.656	70.53	197.9	0.2655
31.8	118.2	1.125	87.4	158.7	0.658
32.3	141.1	0.7835	94.5	102.3	1.430
37.8	153.8	0.228	94.5	136.2	0.970
46.7	109.2	1.297	94.5	148.6	0.804
47.2	197.3	0.2288	94.5	197.4	0.3225
47.2	198.4	0.2309	114.0	194.8	0.3873
48.3	81	1.6775	122.0	197	0.4053
48.3	104.8	1.355	124.2	80.8	1.702
48.7	158.9	0.2938	124.2	101.7	1.464
48.7	159.9	0.2749	124.2	124.4	1.184
48.9	175	0.2259	124.2	149.3	0.881
49.2	80.7	1.661	124.2	158	0.752
49.3	83.6	1.615	124.2	167.1	0.641
49.3	134.3	0.950	124.2	173.7	0.591
49.5	79.2	1.643	129.7	82.9	1.6645
49.5	124	1.071	135.8	196.9	0.4423
49.7	144.9	0.755			


TEMPERATURE , °R
150
200
250
300
350
APPROXIMATE PLOT of
ZIEBLAND & BURTON'S DATA
on THERMAL CONDUCTIVITY
of OXYGEN
5.5 atm
125 atm
95 atm
70 atm
50 atm
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
THERMAL CONDUCTIVITY , milliwatts / cm °K
.100
.080
.060
.040
.020
THERMAL CONDUCTIVITY , BTU / ft hr °R
75
100
125
150
175
200
TEMPERATURE , °K


TEMPERATURE, °R
200
300
400
500
THERMAL CONDUCTIVITY
of AIR
at one atmosphere
.26
.24
.22
.20
.18
.16
.14
.12
.10
.08
THERMAL CONDUCTIVITY, milliwatts/cm-°K
.014
.012
.010
.008
.006
THERMAL CONDUCTIVITY, BTU/ft-hr-°R
100
150
200
250
300
TEMPERATURE, °K

3.006

THERMAL CONDUCTIVITY of AIR
(Gaseous State)

Source of Data:

Hilsenrath, J., et al., Nat. Bur. Standards Cir. 564, 70 (1955)

Other References:

Gambill, W. R., Chem. Eng. 64, No. 2-10 (Feb. - Oct. 1957)

Kannuluik, W. G. and Carman, E. H., Australian J. Sci. Research Ser. A 4, 305-314 (Sept. 1951)

Comments:

The data in the tabulation below and in the graph are presented as of 1 atm of pressure because to first order the thermal conductivity does not vary with pressure (except at extremes). Kannuluik and Carman show a variation of 1 part in 1500 over a pressure range of 0.08 atm to 1 atm.

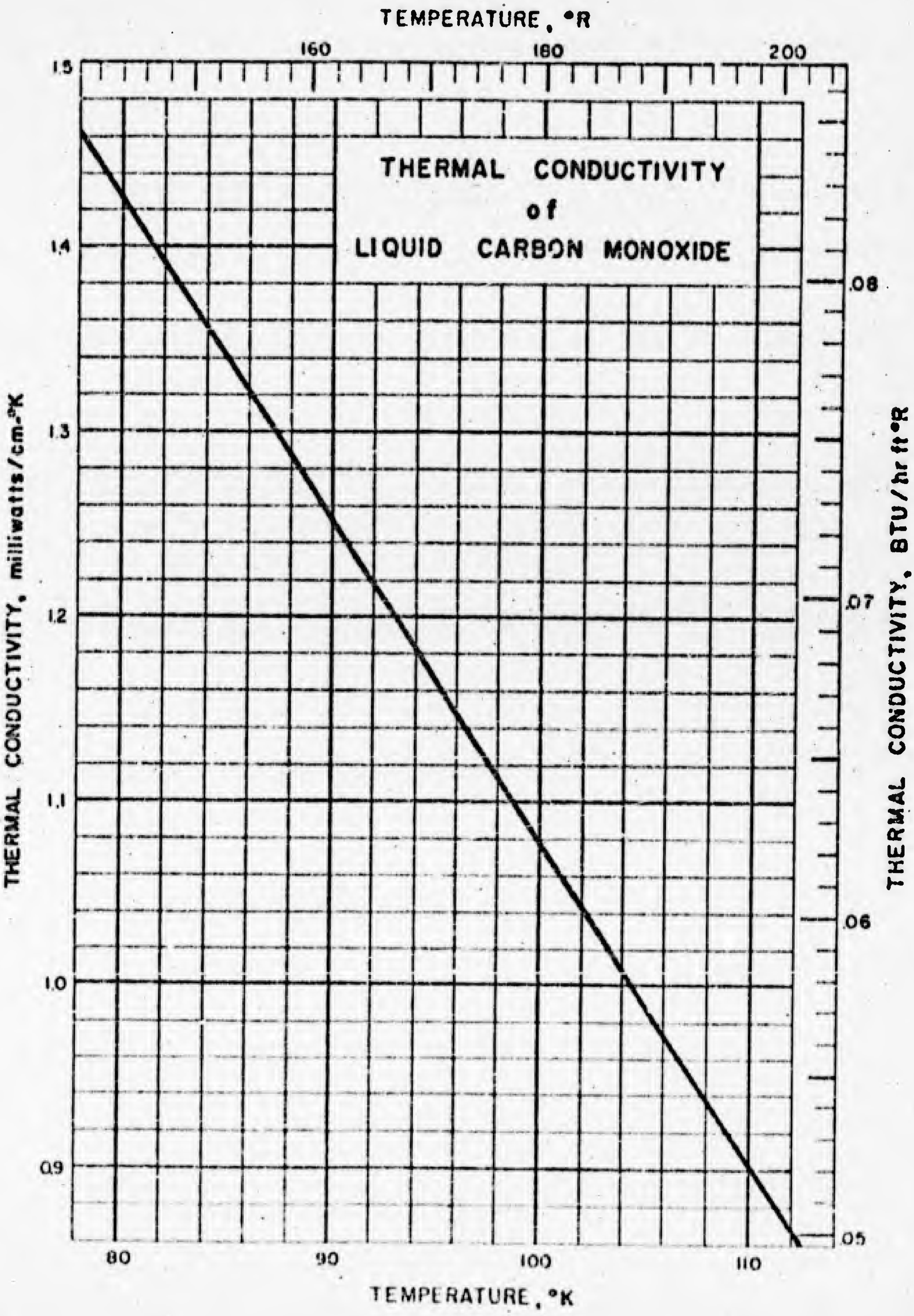
The data of Kannuluik and Carman agree with that in Circular 564 to within 3% over the temperature range 90°K - 300°K but were not used.

Gambill presents methods of estimating thermal conductivities.

Temperature		Thermal Conductivity	
°K	°R	milliwatt/cm-°K	BTU/ft-hr-°R
80	144	.07464	4.313 x 10^{-3}
90	162	.08350	4.825 "
100	180	.09248	5.344 "
110	198	.1015	5.863 "
120	216	.1105	6.383 "
130	234	.1194	6.902 "
140	252	.1284	7.419 "
150	270	.1373	7.933 "
160	288	.1461	8.442 "
170	306	.1549	8.953 "
180	324	.1637	9.458 "
190	342	.1723	9.957 "
200	360	.1809	10.45 "
210	378	.1894	10.94 "
220	396	.1978	11.43 "
230	414	.2062	11.92 "
240	432	.2145	12.39 "
250	450	.2227	12.87 "
260	468	.2308	13.34 "
270	486	.2388	13.80 "
280	504	.2467	14.25 "
290	522	.2547	14.72 "
300	540	.2624	15.16 "

DAV/WJV Issued: 7/14/59

3.007


TEMPERATURE, °R
160
180
200
THERMAL CONDUCTIVITY
of
LIQUID CARBON MONOXIDE
1.5
1.4
1.3
1.2
1.1
1.0
0.9
THERMAL CONDUCTIVITY, milliwatts/cm-°K
.08
.07
.06
.05
THERMAL CONDUCTIVITY, BTU/hr ft °R
80
90
100
110
TEMPERATURE, °K

THERMAL CONDUCTIVITY of LIQUID CARBON MONOXIDE

Source of Data:

Borovik, Ye., Matveyev, A., and Panina, Ye., Zhur. Tekh. Fiz. 10, 988-98 (1940)

Comments:

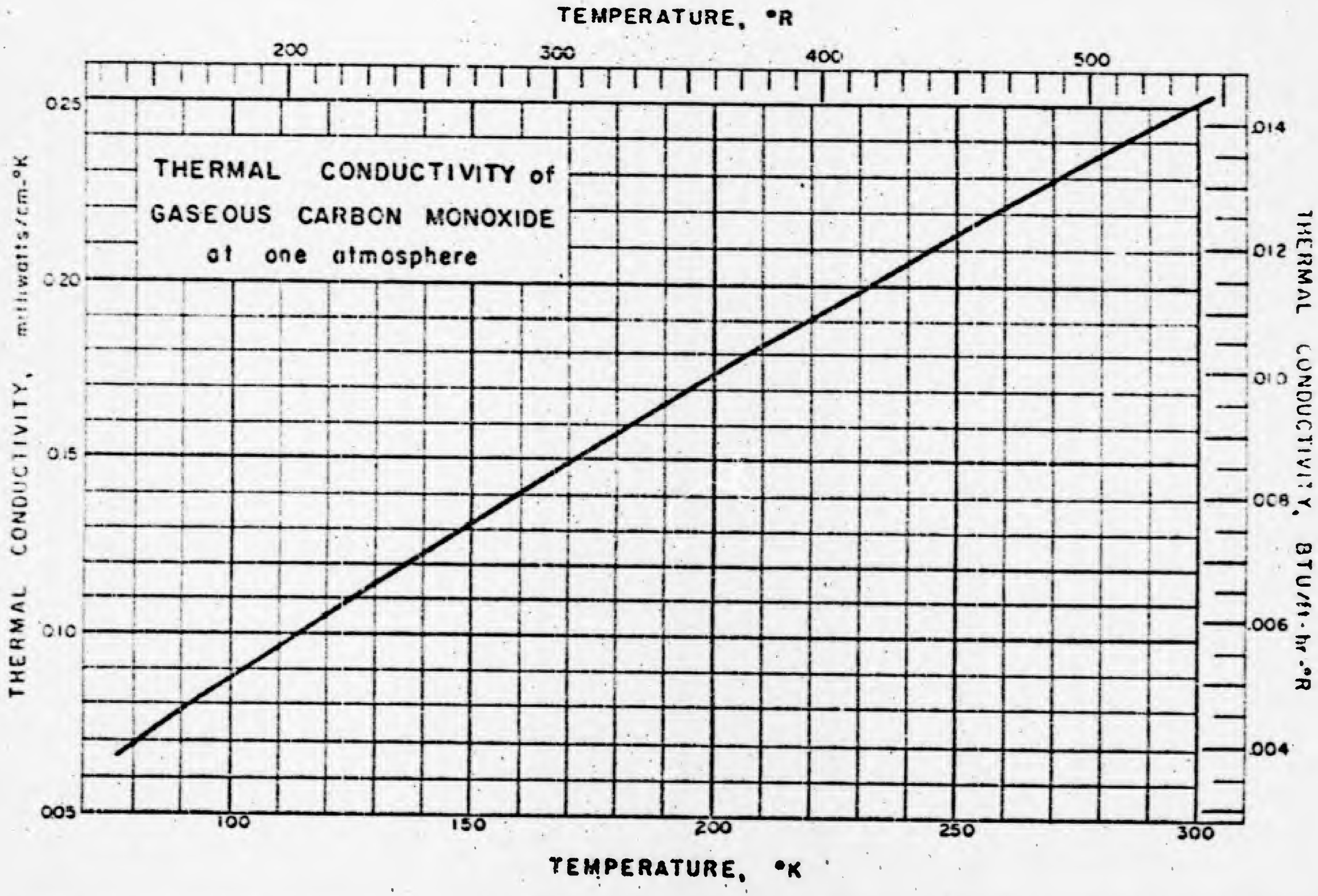
The authors maintained a pressure somewhat in excess of the vapor pressure for obtaining thermal conductivity of the liquid. The values vary rapidly with temperature but only slightly with pressure.

The absolute temperature scale (0°C = 273.16°K) was used in the table of experimental values below.

Temp. °K	Thermal Conductivity cal/cm·sec-°K
78.46	3.55×10^{-4}
90.46	2.88 "
102.86	2.38 "
112.46	2.1 "

KDT/RJR/VJJ Issued: 7/31/59

3.007



THERMAL CONDUCTIVITY of GASEOUS CARBON MONOXIDE at one atmosphere

3.007

THERMAL CONDUCTIVITY of GASEOUS CARBON MONOXIDE
(at one atmosphere)

Sources of Data:

Johnston, H. L. and Grilly, E. R., J. Chem. Phys. 14, 233-38 (1946).

Eucken, A., Physik Z. 14, 324-32 (1913).

Table of Experimental Values

Temp. °K	Thermal Cond. cal/cm-sec-°K	Temp. °K	Thermal Cond. cal/cm-sec-°K
82.1	1.650×10^{-5}	207.36	4.308×10^{-5}
87.41	1.802 "	222.62	4.604 "
97.87	2.039 "	237.21	4.876 "
130.06	2.717 "	253.12	5.162 "
145.31	3.054 "	267.08	5.412 "
155.07	3.261 "	282.15	5.683 "
176.06	3.682 "	296.90	5.950 "
192.28	4.013 "	312.00	6.210 "
198.4	4.020 "		

Table of Smoothed Values

Temp. °K	Thermal Cond. cal/cm-sec-°K	Temp. °K	Thermal Cond. cal/cm-sec-°K
80	1.652×10^{-5}	200	4.166×10^{-5}
90	1.870 "	210	4.361 "
100	2.086 "	220	4.553 "
110	2.302 "	230	4.741 "
120	2.516 "	240	4.926 "
130	2.730 "	250	5.107 "
140	2.942 "	260	5.286 "
150	3.153 "	270	5.465 "
160	3.361 "	280	5.644 "
170	3.565 "	290	5.821 "
180	3.768 "	300	5.998 "
190	3.968 "		

THERMAL CONDUCTIVITY of GASEOUS CARBON MONOXIDE

Sources of Data:

Dickins, B. G., Proc. Roy. Soc. (London) A143, 517-40 (1934)

Eucken, A., Physik. Z., 14, 324-32 (1913)

Gregory, H. and Archer, C. T., Proc. Roy. Soc. (London) A110, 91-122 (1926)

Gregory, H. and Archer, C. T., Proc. Roy. Soc. (London) A121, 285-93 (1928)

Johnston, H. L. and Grilly, E. R., J. Chem. Phys. 14, 233-38 (1946)

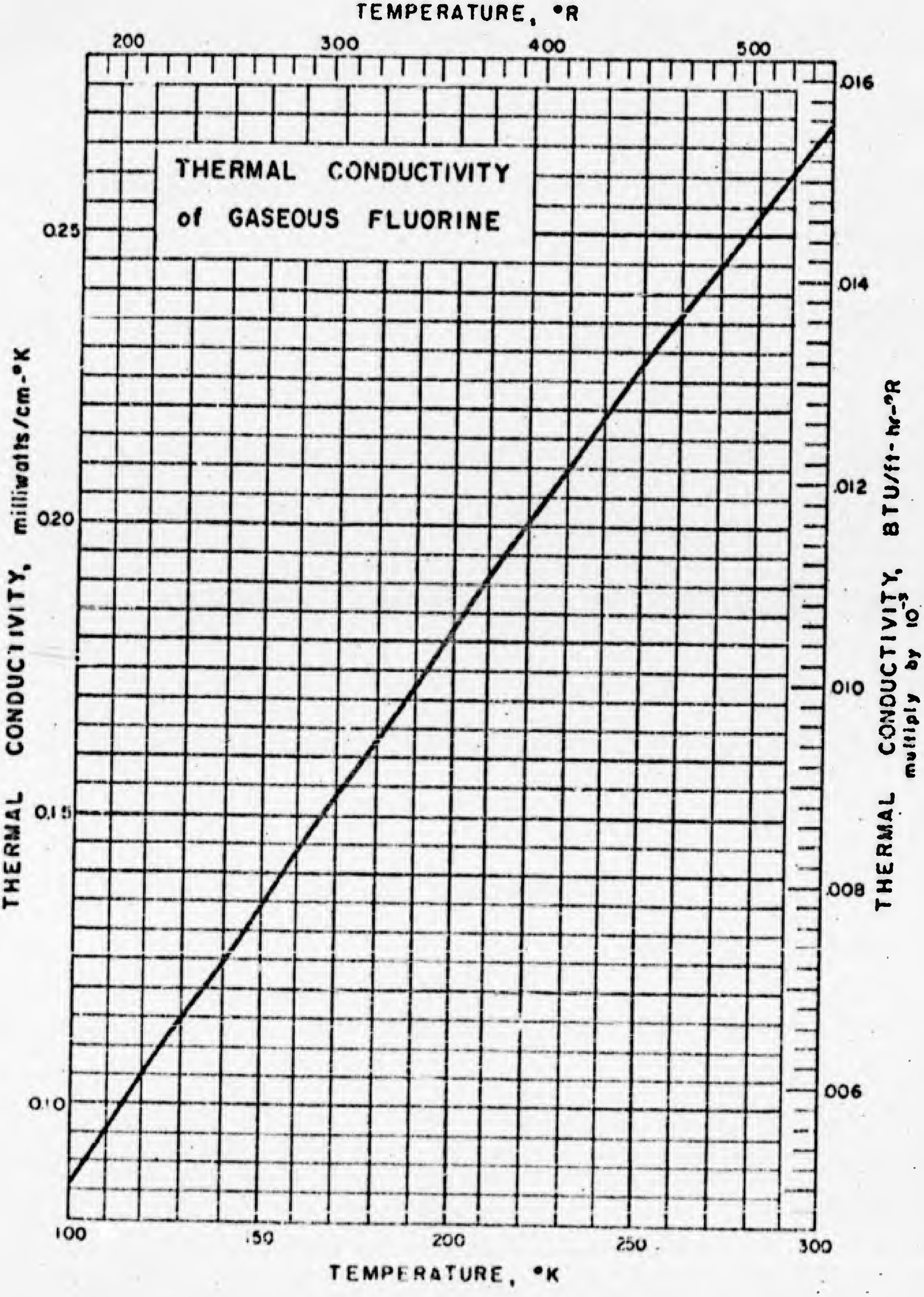
Kannuluik, W. . and Martin, H. L., Proc. Roy. Soc. (London) A144, 496-513 (1934)

Winkelmann, A., Ann. Physik. 156, 497-531 (1875)

Thermal Conductivity of Carbon Monoxide Gas
at 0°C and 1 atm.

Reference	Thermal Conductivity cal/cm·sec·°K
Winkelmann	4.992×10^{-5}
Johnston	*5.521 "
Dickins	5.58 "
Kannuluik	5.37 "
Gregory	5.633 "
Eucken	5.425 "

* Best Value


TEMPERATURE, °R
200
300
400
500
THERMAL CONDUCTIVITY of GASEOUS FLUORINE
THERMAL CONDUCTIVITY, milliwatts/cm-°K
0.25
0.20
0.15
0.10
THERMAL CONDUCTIVITY, BTU/ft-hr-°R multiply by 10^{-3}
.016
.014
.012
.010
.008
.006
100
150
200
250
300
TEMPERATURE, °K

3.008

THERMAL CONDUCTIVITY of GASEOUS FLUORINE

Source of Data:

Franck, E. U. and Wicke, E., Z. Elektrochem. 55, 636-643 (1951)

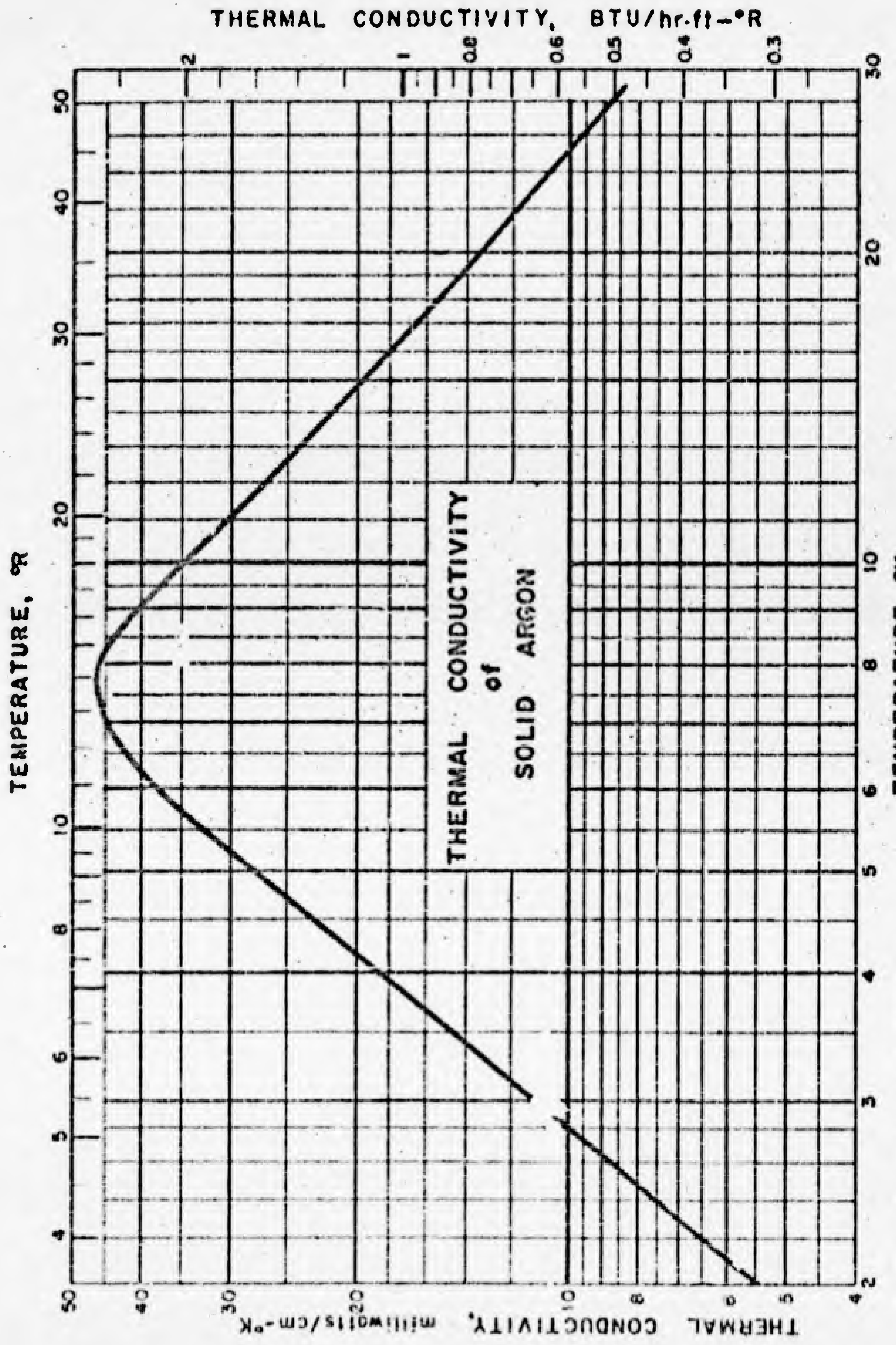
Comments:

Measurements by Franck and Wicke were made by the common method of heating a wire in a nickel tube filled with fluorine gas. No other measurements have been published.

Table of Selected Values

Temperature		Thermal Conductivity		
°K	°R	$\frac{\text{cal}}{\text{cm sec °K}}$	$\frac{\text{milliwatts}}{\text{cm °K}}$	$\frac{\text{BTU}}{\text{ft hr °R}}$
100	180	2.06×10^{-5}	.0862	4.98×10^{-3}
150	270	3.21 "	.134	7.75 "
200	360	4.36 "	.183	10.5 "
250	450	5.44 "	.228	13.2 "
273	491	5.92 "	.247	14.3 "
300	540	6.43 "	.269	15.5 "
350	630	7.36 "	.308	17.8 "

RFR/VJJ/JKC Issued: 6/15/59
Revised: 5/20/60


THERMAL CONDUCTIVITY of SOLID ARGON

JHE/JAR/MB Issued: 7-20-59

3.009

THERMAL CONDUCTIVITY of SOLID ARGON
(From 2 to 25°K)

Sources of Data:

Dobbs, E. R. and Jones, G. O. Repts. Progr. in Phys. 20, 556 (1957)

White, G. K. and Woods, S. B., Nature 177, 851-2 (1956)

Comments:

The thermal conductivity of solid argon in the range 2°K to 7°K rises approximately as the square of the temperature to a maximum value of 45 milliwatts/cm-°K at 7°K. At temperatures above 7°K the thermal conductivity decreases and between 15°K and 25°K may be expressed by

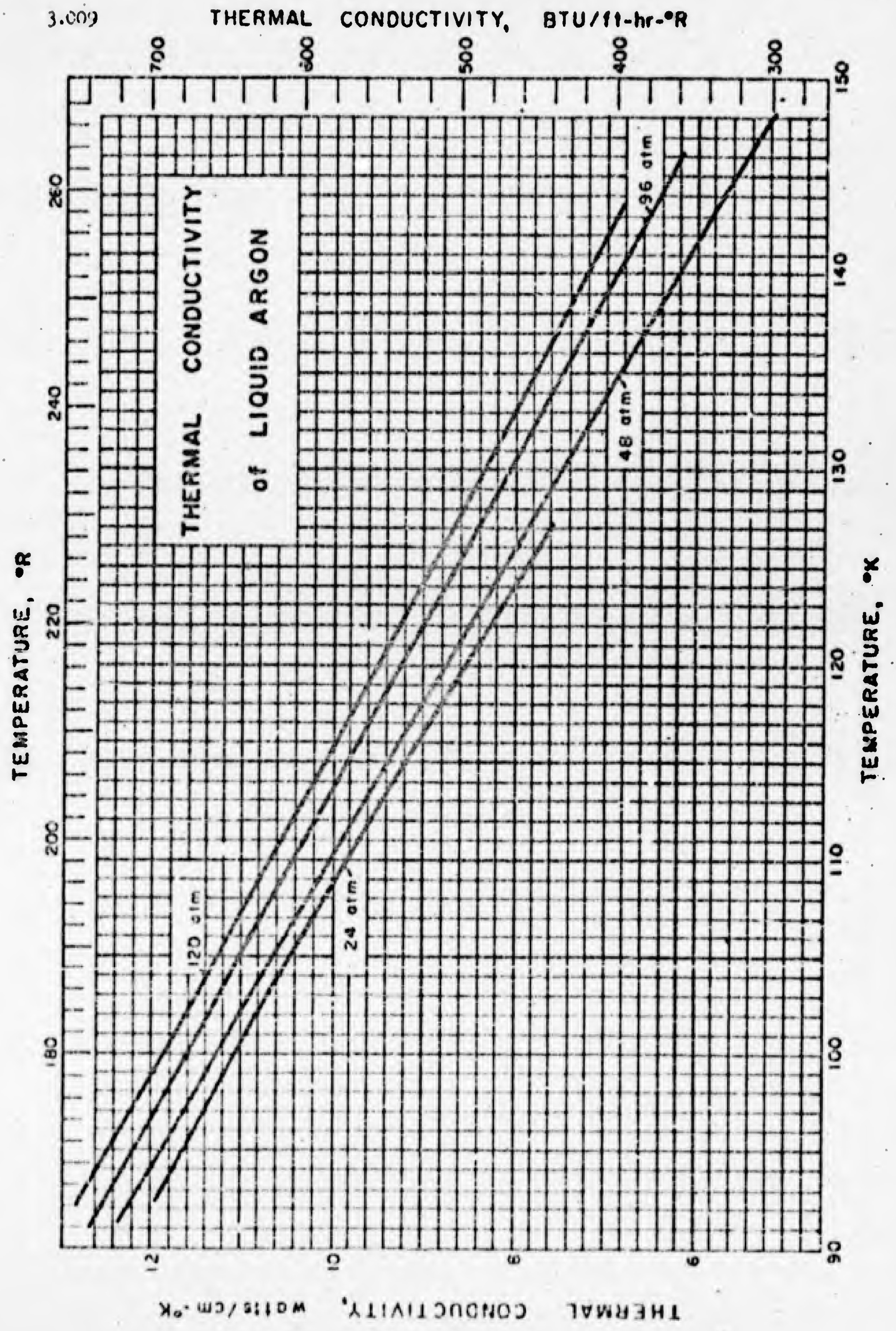
$$k \approx \frac{0.3}{T} \text{ watts/cm-°K}$$

The curve on the preceding page was reproduced as accurately as possible from the original curve. Only the following data were given in tabular form.

Table of Selected Values

Temp. °K	Thermal Conductivity milliwatts/cm-°K
10	35
15	18
20	15
25	10

PTB/RJR Issued: 7/20/59


THERMAL CONDUCTIVITY of LIQUID ARGON
THERMAL CONDUCTIVITY, BTU/ft-hr-°R
700
600
500
400
300
TEMPERATURE, °R
180
200
220
240
260
TEMPERATURE, °K
90
100
110
120
130
140
150
THERMAL CONDUCTIVITY, watts/cm-°K
12
10
8
6
120 atm
96 atm
48 atm
24 atm

3.009

THERMAL CONDUCTIVITY of LIQUID ARGON

Sources of Data: Uhlir, A., J. Chem. Phys. 20, 463-72 (1952); Keyes, F. G., ASME Trans. 77, 1395-6 (1955); Andrade, E. N. da C, Nature 170, 794 (1952); Ziebland, H. and Burton, J. T. A., Brit. J. Appl. Phys. 9, 52-59 (1958).

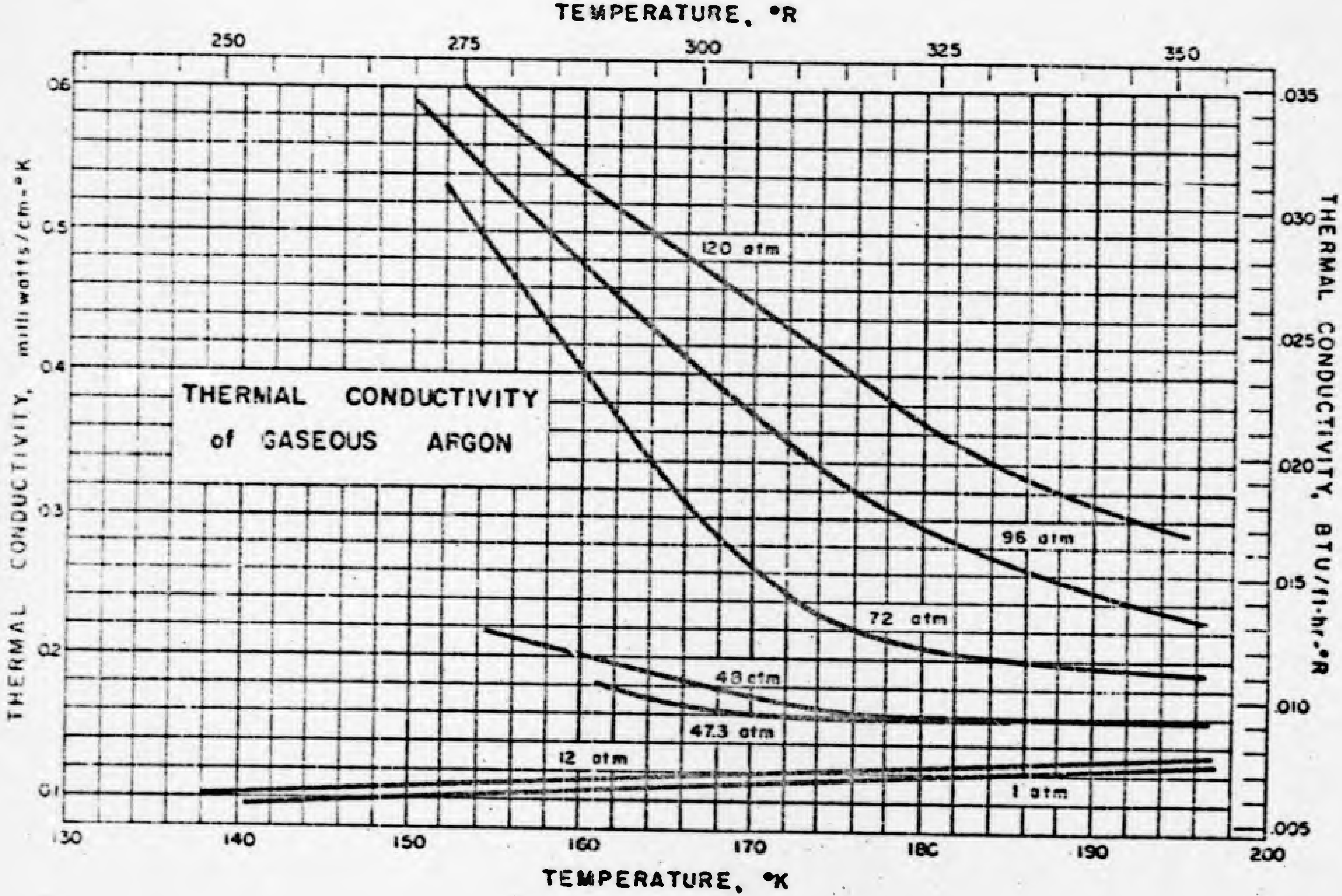
Comments: Recent determinations on liquid argon lead to a value of 0.8 for the ratio of the thermal conductivity to the coefficient of viscosity which is in approximate agreement with Andrade's theory. The tabulated data are those of Ziebland and Burton; these agree well with those obtained by most other authors.

The values plotted on the graph are for averaged pressures.

Table of Selected Values

Pressure atm.	Temp. °K	Thermal Cond. cal/cm-sec-°K
12.0	93.6	2.81
	98.0	2.68
	106.1	2.44
19.3	111.1	2.31
	117.2	2.15
	125.7	1.880
24.0	93.6	2.84
	98.0	2.71
	106.1	2.47
	116.1	2.16
	126.3	1.840
47.3	105.5	2.52
	111.6	2.33
	122.6	1.995
	136.5	1.628
	139.2	1.485
47.9	93.4	2.90
48.0	97.9	2.75
	104.5	2.58
	106.2	2.52
	115.9	2.25
	126.1	1.925
	133.8	1.665
	138.6	1.540
	142.5	1.385
	147.5	1.280
	147.6	1.220
	149.2	1.195
	149.2	1.365

Pressure atm.	Temp. °K	Thermal Cond. cal/cm-sec-°K
72.0	93.4	2.93
	97.8	2.80
	105.9	2.58
	115.8	2.30
	126.2	1.985
	133.8	1.765
	138.3	1.650
	142.3	1.470
	148.9	1.300
	149.3	1.280
95.5	115.8	2.33
	117.7	2.25
	129.1	1.995
	133.4	1.805
96.0	93.3	2.97
	97.7	2.84
	107.6	2.57
	115.7	2.36
	133.7	1.850
	138.2	1.720
	142.3	1.560
120	93.3	3.04
	97.6	2.89
	105.6	2.69
	107.5	2.63
	118.8	2.28
	125.7	2.11
	133.7	1.915
	136.1	1.835
	138.2	1.775
	138.2	1.765
	142.7	1.655


THERMAL CONDUCTIVITY
of GASEOUS ARGON
TEMPERATURE, °R
250
275
300
325
350
TEMPERATURE, °K
130
140
150
160
170
180
190
200
THERMAL CONDUCTIVITY, milliwatts/cm-°K
.06
.05
.04
.03
.02
.01
THERMAL CONDUCTIVITY, BTU/ft-hr-°R
.035
.030
.025
.020
.015
.010
.005
120 atm
96 atm
72 atm
48 atm
47.3 atm
12 atm
1 atm

THERMAL CONDUCTIVITY of GASEOUS ARGON

Source of Data: Ziebland, H. and Burton, J. T. A., Brit. J. Appl. Phys., 9, 52-59 (1958).

Other References: Keyes, F. G., Trans. ASME 77, 1395-6 (1955); Bateman, J. S., Proc. Conf. Thermodynamic and Transport Properties of Fluids, 169-31 (1958).

Comments: Keyes proposes the equation:

$$10^5 k = \frac{(0.384 \sqrt{T})\,(10^{8\tau})}{1 + 178.8\tau}\,;$$

where k is the thermal conductivity in cal/cm sec °K, T is the temperature in °K, and $\tau = 1/T$.

Table of Selected Values

Press. atm.	Temp. °K	Thermal Cond. cal/cm sec °K	Press. atm.	Temp. °K	Thermal Cond. cal/cm sec °K
1.0	93.4	0.000 0160	72	164.7	0.000 0845
	142.1	.000 0230		167.5	.000 0685
	175.1	.000 0275		173.0	.000 0576
	181.0	.000 0275		176.1	.000 0525
	182.4	.000 0280		186.4	.000 0480
	191.5	.000 0295		195.7	.000 0450
	194.3	.000 0300	95.5	150.7	0.000 1395
	196.1	.000 0300		152.2	.000 1375
12.0	138.9	0.000 0245		165.8	.000 1000
	182.4	.000 0295		173.3	.000 0810
	196.0	.000 0320		195.4	.000 0555
19.3	141.1	0.000 0285	96.0	152.9	0.000 1335
				159.5	.000 1155
24	182.6	0.000 0315		164.5	.000 1040
	191.6	.000 0330		172.6	.000 0825
47.3	161.6	0.000 0425		173.9	.000 0845
	161.7	.000 0430		185.5	.000 0635
	174.9	.000 0380		193.8	.000 0570
	184.5	.000 0380		195.6	.000 0535
			118.1	178.1	0.000 0925
40.0	155.4	0.000 0515		183.9	.000 0825
	176.0	.000 0390			
	181.8	.000 0380	120	153.8	0.000 1440
	195.7	.000 0380		154.8	.000 1400
				159.3	.000 1300
70.7	165.3	0.000 0884		164.1	.000 1200
				173.6	.000 1005
72	152.0	0.000 1220		175.2	.000 0980
	158.2	.000 1075		183.5	.000 0825
	159.2	.000 1075		193.8	.000 0705
	164.5	.000 0775		194.5	.000 0700

3.010

THERMAL CONDUCTIVITY of SOLID METHANE

(15° to 21°K)

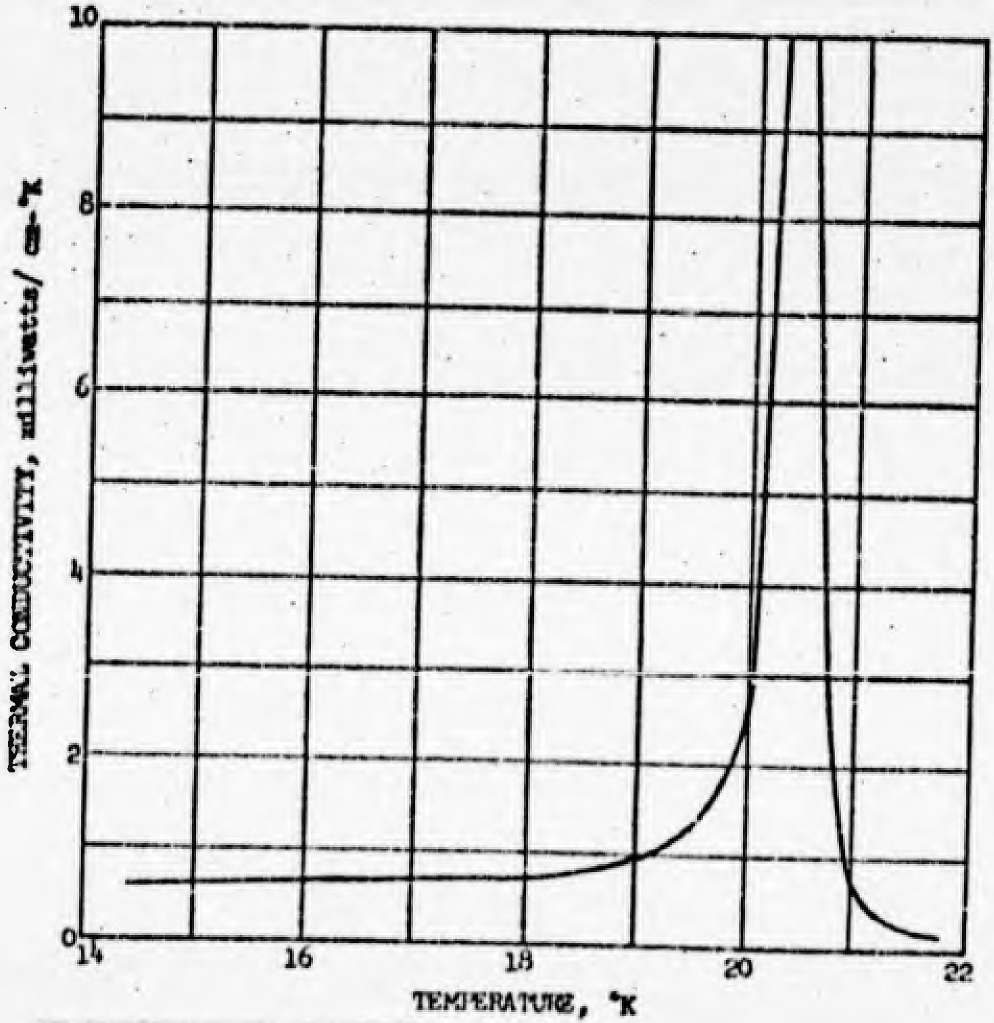
Sources of Data:

Gerritsen, A.N. and van der Star, P., Physica, 9, 503-12 (1942).

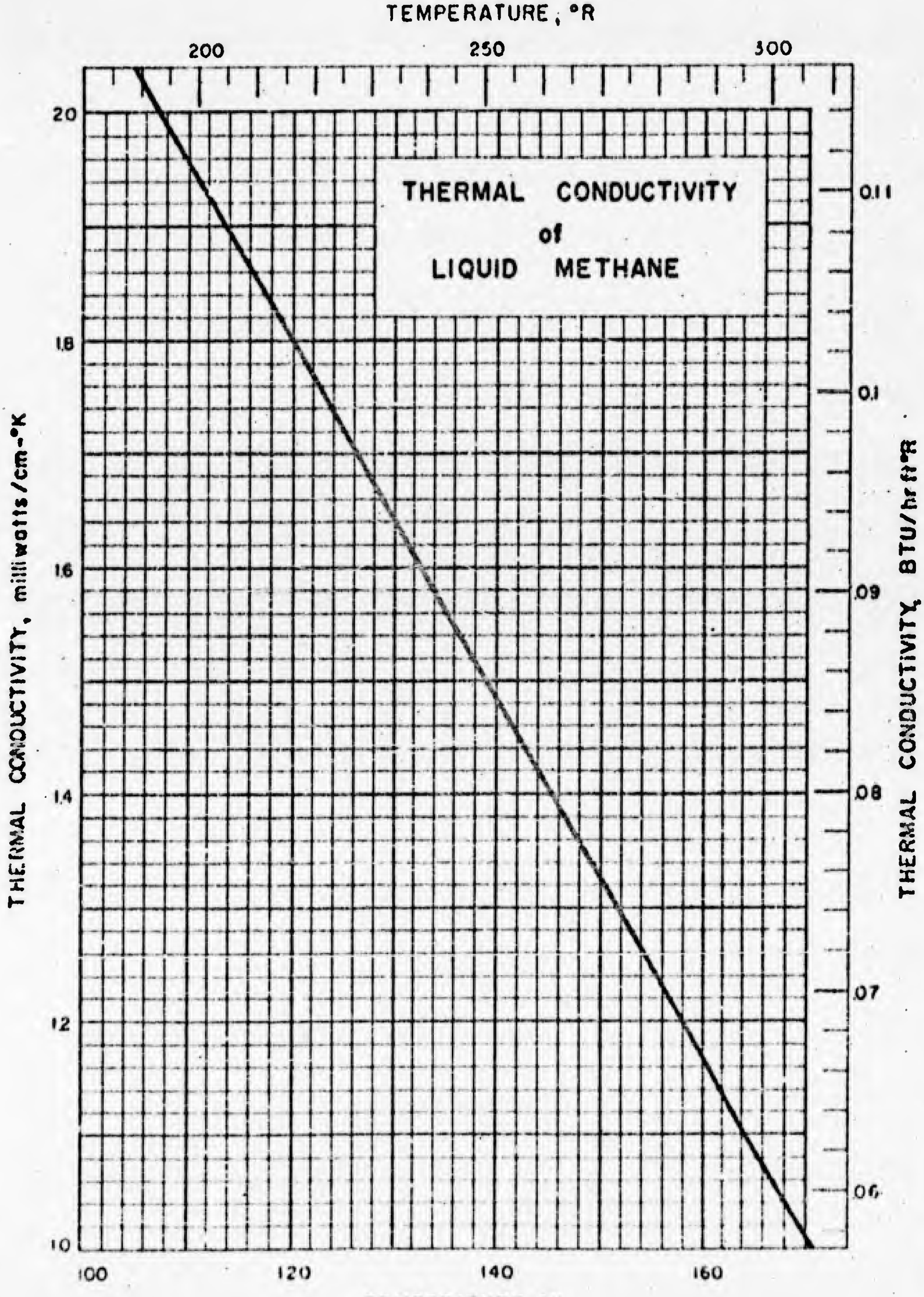
Commun. Kamerlingh Onnes Lab. Univ. Leiden, Commun. No. 265c.

Comments:

In the graph below the discontinuity that occurs at the transition temperature (20.4°K) is similar to that found for the specific heat.



KDT/VJJ Issued: 8/28/59


TEMPERATURE, °R
200
250
300
THERMAL CONDUCTIVITY of LIQUID METHANE
THERMAL CONDUCTIVITY, milliwatts/cm-°K
2.0
1.8
1.6
1.4
1.2
1.0
THERMAL CONDUCTIVITY, BTU/hr ft °R
0.11
0.1
.09
.08
.07
.06
100
120
140
160
TEMPERATURE, °K

THERMAL CONDUCTIVITY of LIQUID METHANE

Source of Data:

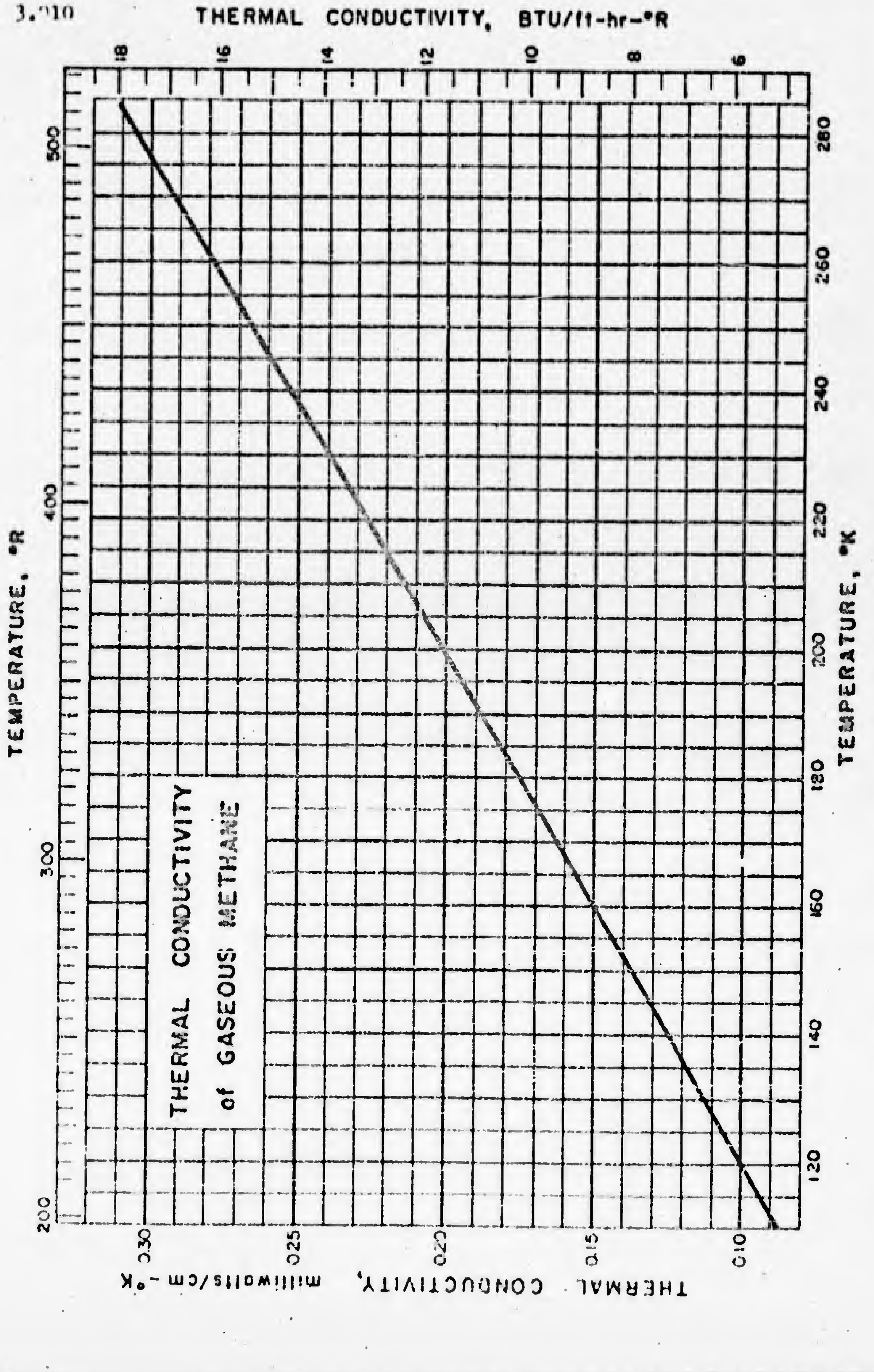
Borovik, Ye., Matvayev, A. and Panina, Ye., Zhur. Tekh. Fiz. 10, 988-98 (1940)

Comments:

The authors maintained a pressure somewhat in excess of the vapor pressure for obtaining thermal conductivity of the liquid. The values vary rapidly with temperature but only slightly with pressure.

The absolute temperature scale (0°C = 273.16°K) was used in the table of experimental values below.

Temp. °K	Thermal Conductivity cal/cm-sec-°K
103.26	4.85×10^{-4}
112.56	4.64 "
145.36	3.1 "
172.86	2.5 "


THERMAL CONDUCTIVITY of GASEOUS METHANE
THERMAL CONDUCTIVITY, BTU/ft-hr-°R
18
16
14
12
10
8
6
TEMPERATURE, °R
500
400
300
200
TEMPERATURE, °K
280
260
240
220
200
180
160
140
120
THERMAL CONDUCTIVITY, milliwatts/cm-°K
0.30
0.25
0.20
0.15
0.10

THERMAL CONDUCTIVITY of GASEOUS METHANE

Source of Data:

Davis, D. S., Ind. Eng. Chem. 33, 675-8 (1941)

Other References:

Washburn, E. W., International Critical Tables of Numerical Data, Physics, Chemistry and Technology, Vol. V, McGraw-Hill Book Co., Inc., New York (1929) pp. 214, 215.

Comments:

The selected thermal conductivity values in the table below were taken from a nomograph based on the International Critical Tables. The pressure was not specified but presumed to be one atmosphere.

Temp. °K	Thermal Conductivity cal/sec-cm-°K
110.9	21 x10^{-6}
144.3	31 "
172.1	41 "
199.8	48 "
227.6	57 "
255.4	65 "
283.2	74 "

4.000

SPECIFIC HEAT and ENTHALPY of CRYOGENIC FLUIDS

CONTENTS

(continued)

4.000

SPECIFIC HEAT and ENTHALPY of CRYOGENIC FLUIDS

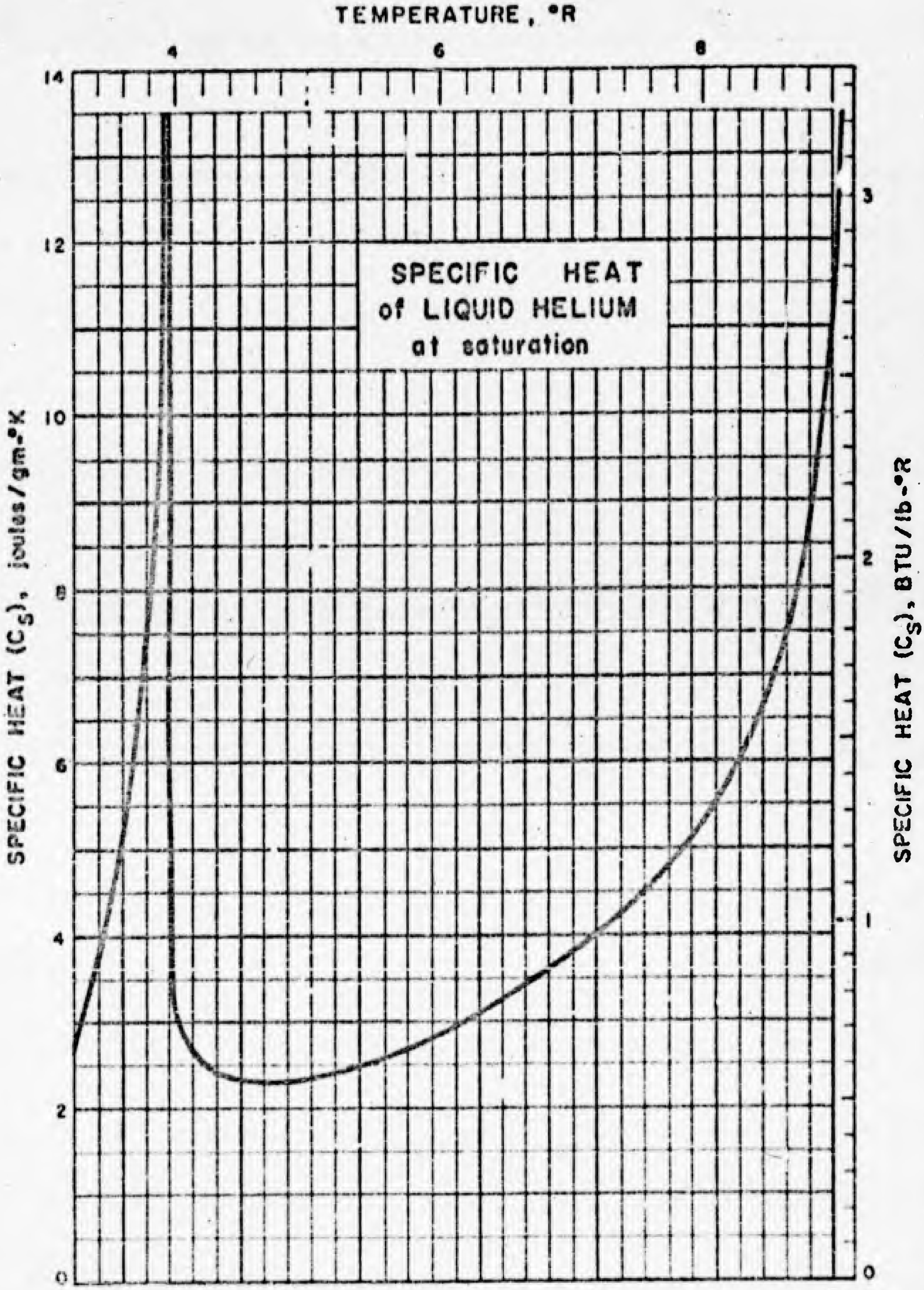
CONTENTS (continued)

CONVERSION FACTORS for SPECIFIC HEAT

	cal/gm °K	joules/gm °K	watt sec/gm °K	BTU/lb °R
1 cal/gm °K =	1.000	4.1840	4.1840	0.999346
1 joules/gm °K =	0.239006	1.000	1.000	0.238849
1 watt sec/gm °K =	0.239006	1.000	1.000	0.238849
1 BTU/lb °R =	1.000654	4.18674	4.18674	1.000

CONVERSION FACTORS for ENTHALPY

	cal/gm	joules/gm	watt sec/gm	BTU/lb
1 cal/gm =	1.000	4.1840	4.1840	1.798823
1 joules/gm =	0.239006	1.000	1.000	0.429929
1 watt sec/gm =	0.239006	1.000	1.000	0.429929
1 BTU/lb =	0.555919	2.32597	2.32597	1.000


TEMPERATURE, °R
4
6
8
14
12
10
8
6
4
2
0
SPECIFIC HEAT of LIQUID HELIUM at saturation
SPECIFIC HEAT (C_S), joules/gm-°K
SPECIFIC HEAT (C_S), BTU/lb-°R
3
2
1
0
2
3
4
5
TEMPERATURE, °K

4.001

SPECIFIC HEAT of LIQUID HELIUM
(At Saturation)

Source of Data:

Hill, R. W. and Lounasmaa, O. V., Phil. Mag. (8) 2, 143-48 (Feb. 1957)

Other References:

Wiebes, C. O., Niels-Hakkenberg, C. G. and Kramers, H. C., Physica 23, 625-32 (1957)

Markham, A. H., Thesis submitted for Degree of Doctor of Philisophy, Univ. Wisconsin (1958)

Kramers, H. J., Wasscher, J. D. and Gorter, C., Physica 18, No. 5, 329-38 (1952)

Keesom, W. H., Helium, Elsevier, Amsterdam (1942)

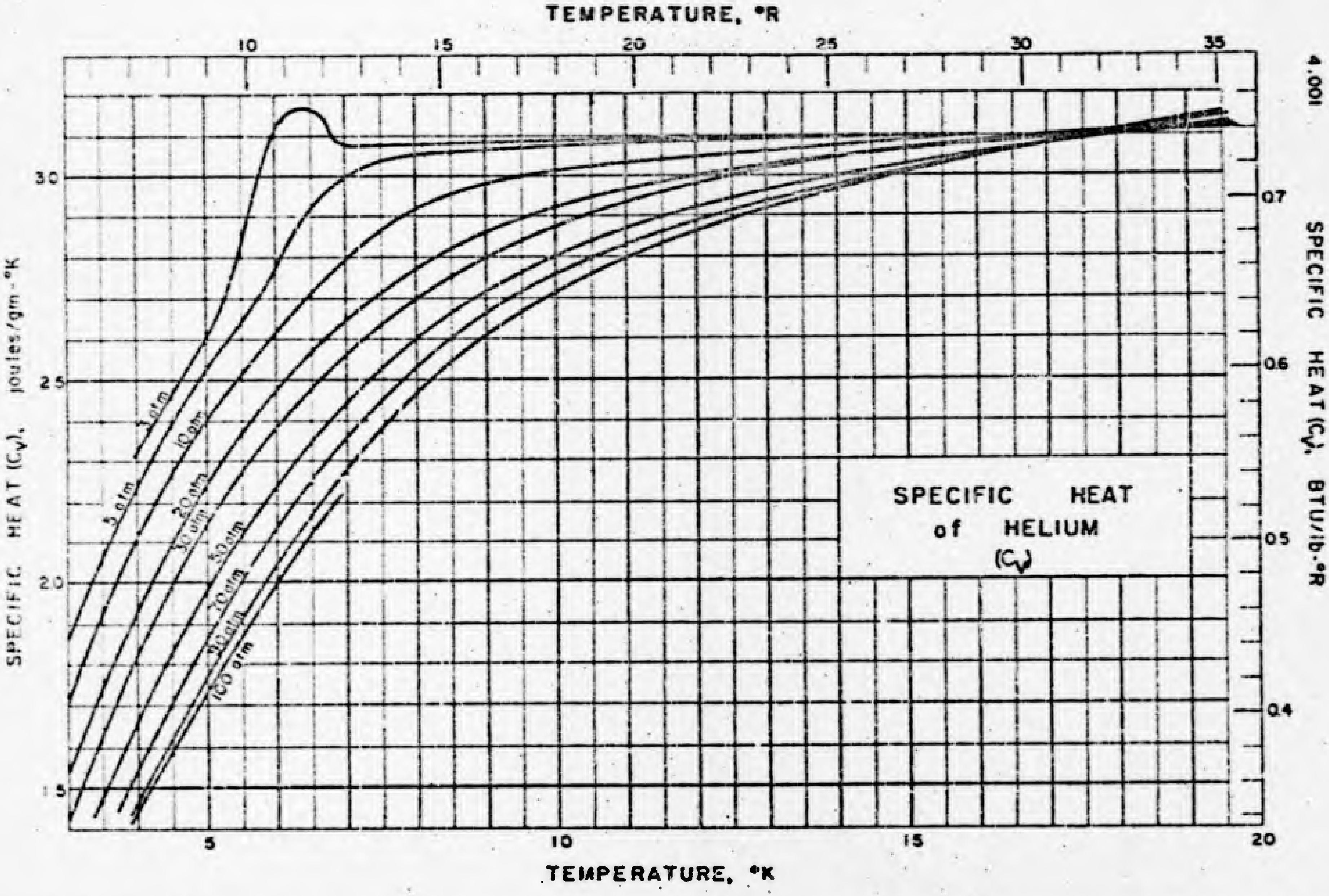
Comments:

The absolute temperature scale (0°C = 273.16°K = 491.69°R) was used in the Table of Selected Values below.

Temperature		Specific Heat (C_s)		Temperature		Specific Heat (C_s)	
°K	°R	Joules / gm °K	BTU / lb °R	°K	°R	Joules / gm °K	BTU / lb °R
1.8	3.24	2.81	0.672	3.0	5.40	2.49	0.595
1.85	3.33	3.26	0.779	3.2	5.76	2.69	0.643
1.9	3.42	3.79	0.906	3.4	6.12	2.97	0.710
2.0	3.60	5.18	1.24	3.6	6.48	3.26	0.779
2.05	3.69	6.16	1.47	3.8	6.84	3.60	0.860
2.10	3.78	7.51	1.80	4.0	7.2	3.99	0.953
2.15	3.87	9.35	[illegible]	4.2	7.56	4.48	1.07
2.1735	3.91	12.6	[illegible]	4.4	7.92	5.11	1.22
2.2	3.96	3.98	0.951	4.6	8.28	5.94	1.42
2.3	4.14	2.64	0.631	4.8	8.64	7.53	1.80
2.4	4.32	2.38	0.569	5.0	9.00	11.5	2.75
2.6	4.68	2.27	0.542	5.05	9.09	13.5	3.23
2.8	5.04	2.34	0.559				

DSM/GAR Issued: 7/14/59

4.001


TEMPERATURE, °R
10
15
20
25
30
35
SPECIFIC HEAT
of HELIUM
(C_v)
1 atm
3 atm
10 atm
20 atm
30 atm
50 atm
70 atm
80 atm
100 atm
SPECIFIC HEAT (C_v), joules/gm-°K
30
25
20
15
SPECIFIC HEAT (C_v), BTU/lb-°R
0.7
0.6
0.5
0.4
5
10
15
20
TEMPERATURE, °K

4.001

SPECIFIC HEAT (C_v) of HELIUM

Source of Data

Lounasmaa, O. V., Thesis submitted for the Degree of Doctor of Philosophy, University of Oxford 1958.

Other References

Itterbeek, A. Van, Bull. Inst. Intern. Froid, Annexe, 1955-2, 99-106 (1955);

Masi, J. F., Trans. ASME 76, No. 7, 1067-74 (Oct. 1954);

Akin, S. W., Trans. ASME 72, 751-57 (Aug. 1950);

Zelmanov, J., Journal of Phys. (USSR) 3, No. 1, 43-52 (1940);

Zelmanov, J., Journal of Phys. (USSR) 8, No. 3, 129-34 (1944).

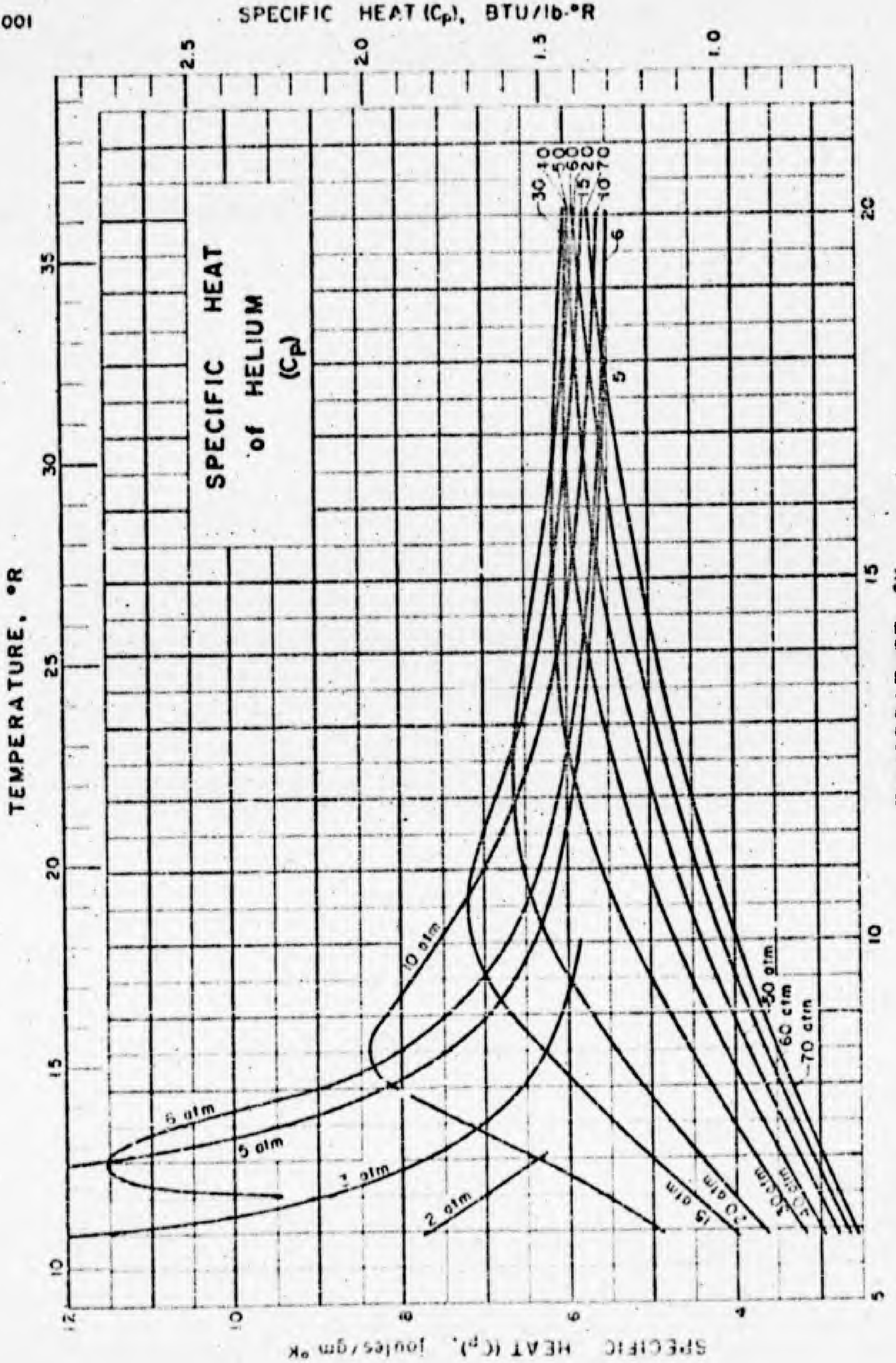
Keesom, W.H., Helium, Elsevier, Amsterdam (1942) pp 494

Specific Heat at constant volume, cal/gm-°K

Temp. °K	3 atm	5 atm	10 atm	20 atm	40 atm	60 atm	80 atm	100 atm
3		0.444	0.408	0.365	0.318			
4	0.555	0.534	0.504	0.464	0.415	0.382	0.358	0.345
5	0.621	0.604	0.575	0.538	0.492	0.459	0.434	0.414
6	0.746	0.664	0.626	0.593	0.552	0.523	0.501*	0.480*
6.5	0.751							
7	0.737	0.719	0.669	0.633	0.600	0.574	0.555	
8	0.738	0.730	0.699	0.664	0.634	0.613	0.596	
10	0.739	0.736	0.722	0.701	0.680	0.687	0.654	
12	0.740	0.740	0.732	0.721	0.717	0.700	0.796	
16	0.741		0.742	0.740	0.736	0.730	0.730	
20			0.750	0.752	0.755	0.758	0.760	

* Extrapolated Values

DRM/GAR Issued: [illegible]


SPECIFIC HEAT (Cp), BTU/lb-°R
2.5
2.0
1.5
1.0
SPECIFIC HEAT of HELIUM (Cp)
TEMPERATURE, °R
10
15
20
25
30
35
TEMPERATURE, °K
5
10
15
20
SPECIFIC HEAT (Cp), joules/gm °K
12
10
8
6
4
30
40
50
60
15
20
10
70
6
5
2 atm
3 atm
5 atm
6 atm
10 atm
15 atm
20 atm
30 atm
40 atm
50 atm
60 atm
70 atm

SPECIFIC HEAT (C_p) of HELIUM

Source of Data:

Lounasmaa, O. V., Thesis submitted for the Degree of Doctor of Philosophy, University of Oxford 1958.

Other References:

Itterbeck, A. Van, Bull. Inst. Intern. Froid, Annexe, 1955-2, 99-106 (1955);

Masi, J. F., Trans. ASME 76, No. 7, 1067-74 (Oct. 1954);

Akin, S. W., Trans. ASME 72, 751-57 (Aug. 1950);

Zelmanov, J., Journal of Phys. (USSR) 3, No. 1, 43-52 (1940);

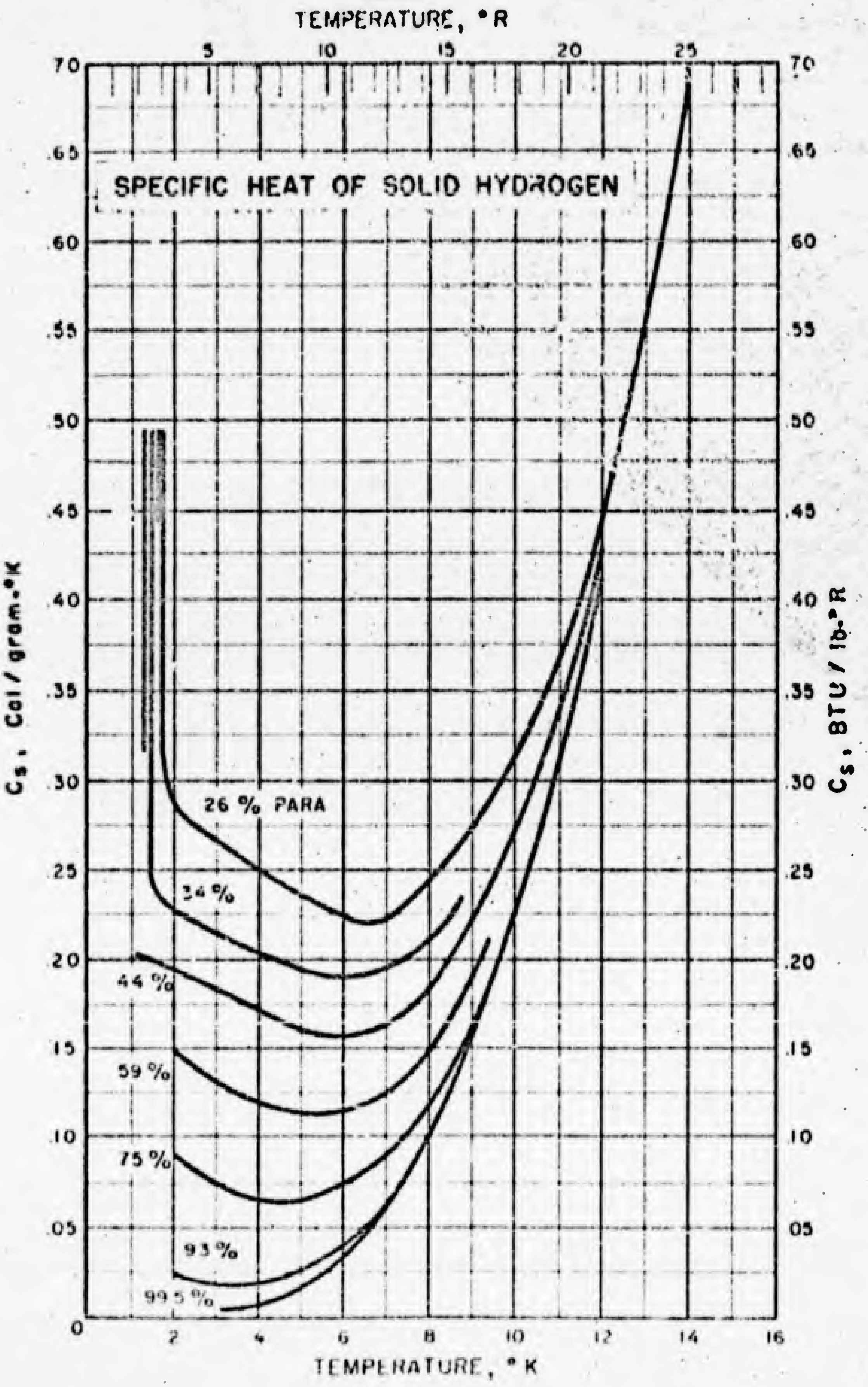
Zelmanov, J., Journal of Phys. (USSR) 8, No. 3, 129-134 (1944).
Keesom, W. H., Helium, Elsevier, Amsterdam (1942) pp494

Specific Heat at Constant Pressure, cal/gm-°K

Temp. °K	3 atm	5 atm	6 atm	10 atm	15 atm	30 atm	50 atm	70 atm
6	2.91			1.18	0.97	0.77	0.67	0.615
6.5	2.14	3.40	2.25	1.35	1.09			
7	1.84	2.93	2.84	1.53	1.20	0.90	0.74	0.71
8	1.55	1.96	2.17	1.93	1.41	1.02	0.87	0.79
9	1.46	1.67	1.78	1.96	1.60	1.14	0.91	0.87
10	1.40	1.53	1.61	1.81	1.71	1.25	1.05	0.95
12		1.42	1.46	1.59	1.64	1.40	1.18	1.08
14		1.37	1.39	1.47	1.52	1.47	1.28	1.18
16		1.34	1.35	1.40	1.45	1.48	1.37	1.22
18		1.32	1.33	1.36	1.41	1.46	1.41	1.32
20			1.31	1.34	1.38	1.44	1.43	1.37

DEM/GAR Issued: [illegible]

4.002


TEMPERATURE, °R
5
10
15
20
25
SPECIFIC HEAT OF SOLID HYDROGEN
26 % PARA
34 %
44 %
59 %
75 %
93 %
99.5 %
Cs, Cal / gram-°K
Cs, BTU / lb-°R
0
.05
.10
.15
.20
.25
.30
.35
.40
.45
.50
.55
.60
.65
.70
2
4
6
8
10
12
14
16
TEMPERATURE, °K

4.002

SPECIFIC HEAT (C_s) of SATURATED SOLID HYDROGEN

(Normal, Para and Various Mixtures of Ortho and Para)

Sources of Data:

Clusius, K. and Hiller, K., Z. physik. Chem. B4, 158 (1929)

Hill, R. W., J. Sci. Instr. 30, 331 (1953)

Hill, R. W., Report of the International Conference of Low Temperature Physics (Oxford) (1951)

Hill, R. W. and Ricketson, B. W. A., Phil. Mag. 45, 277 (1954)

Mendelssohn, K., Ruhemann, M. and Simon, F., Z. physik. Chem. B15, 121 (1931)

Simon, F., Z. Physik. 15, 307 (1923)

Simon, F., Mendelssonn, K. and Ruhemann, M., Naturwiss. 18, 34 (1930)

Simon, F. and Wohl, Ergebn. exakt. Naturw. 9, 264 (1930)

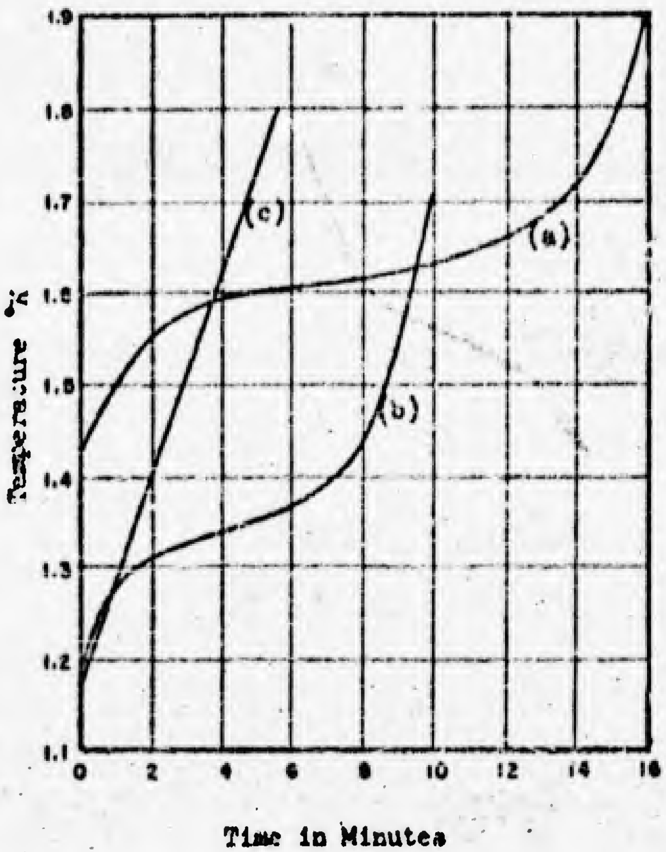
Comments:

The T-C_s chart for various concentrations of ortho-and para-hydrogen is a composite made up of data from the various sources quoted above. It can be seen that the saturation specific heat of the various concentrations is essentially the same at temperatures above 12°K. Below this temperature equilibrium hydrogen (0.21% ortho, 99.79% para) has a specific heat which approaches the temperature axis asymptotically as 0°K is approached. On the other hand hydrogen having higher concentrations of the ortho variety have heat capacities which start increasing at temperatures from 3 to 6 1/2°K as the temperature is lowered.

Recent work of Hill, Ricketson, Simon, Wohl and others has turned up a rather anomalous behavior of the specific heat when studies are carried out below 2°K. Because of the shape of the heat capacity curve in this region, the phenomenon has been called a lambda (λ) anomaly. Fig. 1 shows time-temperature or heating curves for (a) 26%, (b) 34%, and (c) 44% para hydrogen. Curve (a) for 26% para hydrogen shows that the temperature rises very slowly between 1.6 and 1.7°K. Figure 2 shows that in the neighborhood of this temperature the heat capacity rises abruptly from 0.3 calories per gram to over 7.0 calories per gram. In the case of 34% para, curve (b) of Fig. 1 shows that between 1.3 and 1.4°K the temperature rises slowly and Fig. 2 shows that near this temperature the heat capacity rises abruptly from 0.2 to about 3.0 calories per gram. When 44% para hydrogen was studied at temperatures down to 1.15°K, no such anomaly could be found. The peaks shown in Fig. 2 are sketched in on the heat capacity chart at temperatures below 2°K. The question as to what happens to the lambda anomaly for lower concentrations of ortho hydrogen will not be known until studies can be carried on below 1°K, and these studies have been promised by Hill and Ricketson.

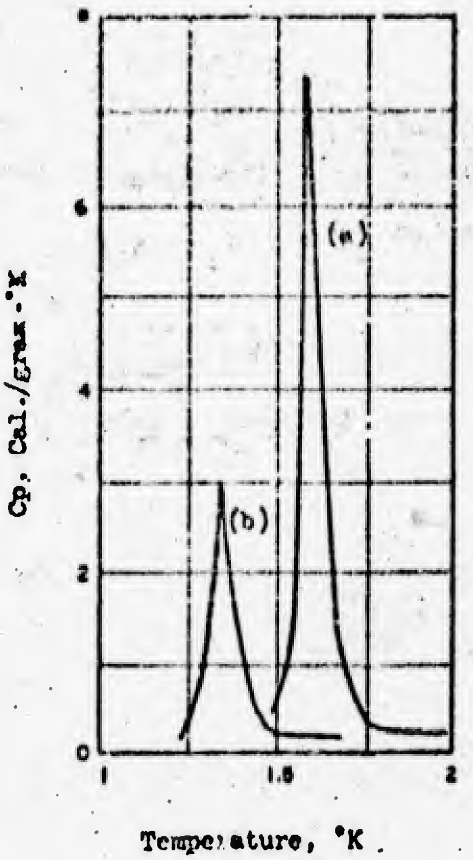
Some of the above work has been carried out at saturation pressures and others at constant pressure. Since any volume change is small, these values should not differ materially.

Figure 1



Heating curves for three hydrogen specimens (a) 26%, (b) 34%, (c) 44% para hydrogen.

Figure 2



The λ-anomalies in solid hydrogen. (a) 26%, (b) 34% para hydrogen.

TABLE 1

Specific Heat (C_s) of Solid Normal Hydrogen
(The 3:1 mixture ortho and para hydrogen)

Temp. °K	C_s cal/mole	C_s cal/gm
4.57	.455	.2257
5.67	.404	.2004
6.60	.474	.2351
6.20	.439	.2178
6.61	.441	.2188
6.96	.447	.2217
8.31	.514	.2550

Data of Mendelssohn, Ruhemann and Simon
Z. phys. Chem. B15, 121 (1931)

TABLE 2

Specific Heat (C_s) of 1:1 Mixture of Solid ortho and para Hydrogen

Temp. °K	C_s cal/ mole	C_s cal/gm
2.74	.41	.2034
4.47	.351	.1741
6.22	.351	.1741
7.86	.430	.2133
9.08	.521	.2584
9.72	.585	.2902
9.99	.620	.3075

Selected points from same authors reference in Table 1.

TABLE 3

Specific Heat (C_s) of 3:1 Mixture of Solid ortho and para Hydrogen

Temp. °K	C_s cal/mole	C_s cal/gm
10.96	.752	.3730
11.71	.888	.4405
12.70	1.080	.5357
13.35	1.270	.6300
13.50	1.270	.6300
13.96	1.370	.6795

Data of Simon and Lange, Z. Physik 15, 391 (1922)

TABLE 4

Specific Heat (C_s) of Solid Equilibrium Hydrogen
(0.21% ortho and 99.79% para hydrogen)

Temp. °K	Cs cal/mole	C_s cal/gm
3.04	.0521	.02584
4.98	.0869	.04311
5.11	.0730	.03621
5.48	.0929	.04608
5.68	.1025	.05084
5.95	.128	.06349
7.53	.252	.1250
7.93	.272	.1349
7.98	.302	.1498
8.07	.328	.1627
8.08	.312	.1548
8.39	.352	.1746
8.57	.405	.2009
9.09	.435	.2158
9.15	.511	.2535
9.87	.557	.2763

Data from NBS RP-1932 and Mendelssohn, Ruhemann and Simon, Z. physik. Chem. B15, 121 (1931); Clusius and Hiller, Z. physik. Chem. B4, 158 (1929).

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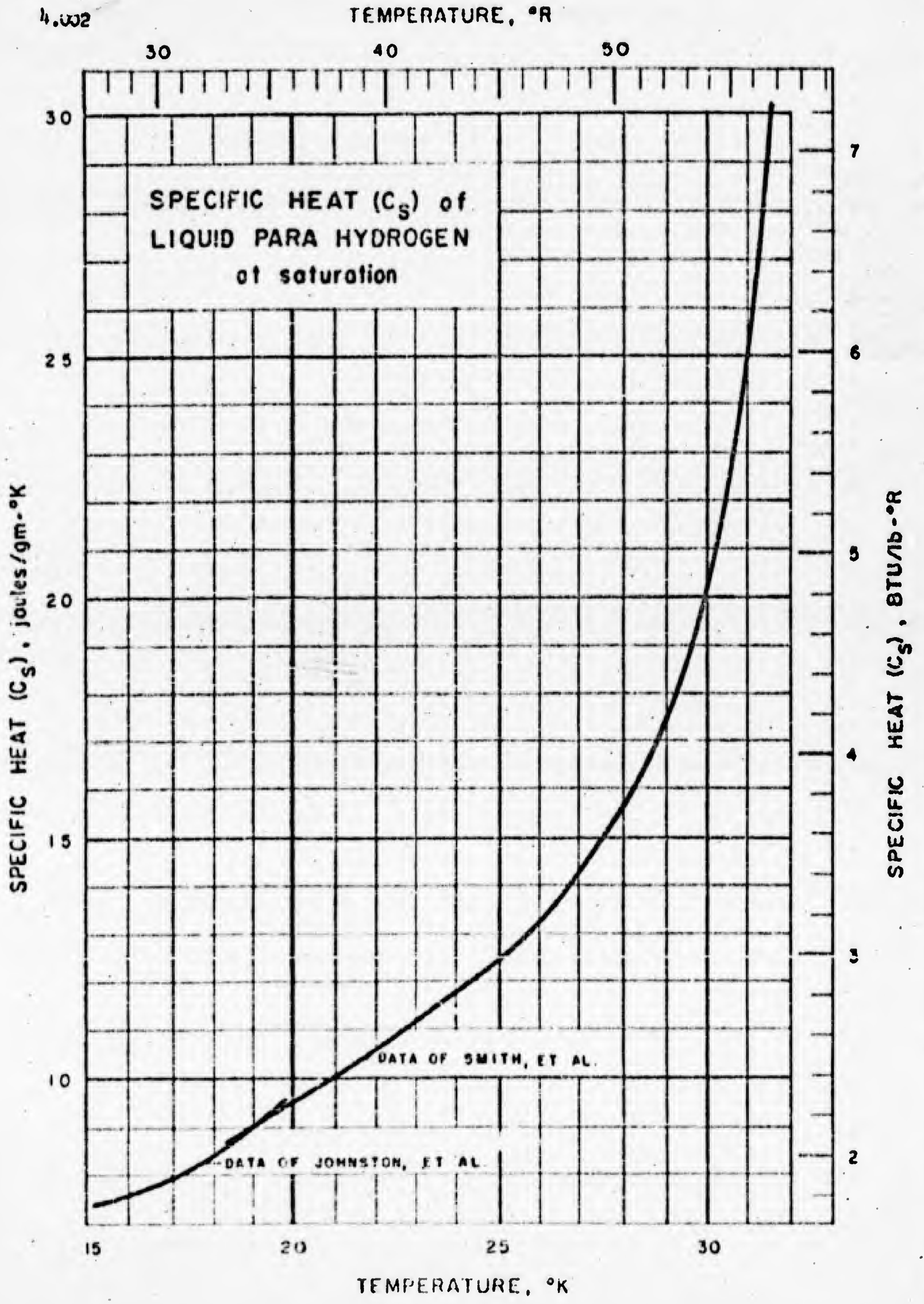
4.002



SPECIFIC HEAT (C_S) of LIQUID PARA HYDROGEN at saturation

4.002

SPECIFIC HEAT (C_s) of LIQUID HYDROGEN

(At Saturation)

Sources of Data:

Johnston, H. L., Clarke, J. T., Rifkin, E. B. and Kerr, E. C., J. Am. Chem. Soc. 72, 3933 (1950)

Smith, A. L., Hallett, N. C. and Johnston, H. L., J. Am. Chem. Soc. 76, 1486 (1954)

Other References:

Bonnhoefer, K. F. and Harteck, P., Naturwiss. 17, 182 (1929)

Clusius, K. and Hiller, K., Z. physik. Chem. B4, 158 (1929)

Dewar, J., Proc. Roy. Soc. (London) A76, 325 (1905)

Eucken, A., Verhandl. deut. physik. Ges. 18, 4-17 (1916)

Keesom, W. H., Comm. Phys. Lab. Univ. Leiden 137e (1911)

Simon, F. and Lange, R., Z. Physik. 15, 312 (1923)

Comments:

Heisenberg, Z. Physik. 38, 411 (1926); Hund, Z. Physik. 42, 93 (1927); and Dennison, Proc. Roy. Soc. (London) A115, 483 (1927) predicted the existence of two forms of molecular hydrogen on the basis of quantum theory. Shortly thereafter methods were developed for catalyzing the conversion. Since then heat capacity measurements have been carried out on known concentrations of the two varieties. Prior to 1929 all work was based on normal hydrogen (75% ortho and 25% para). Data for the curves were derived under conditions of saturation vapor pressure (C_s).

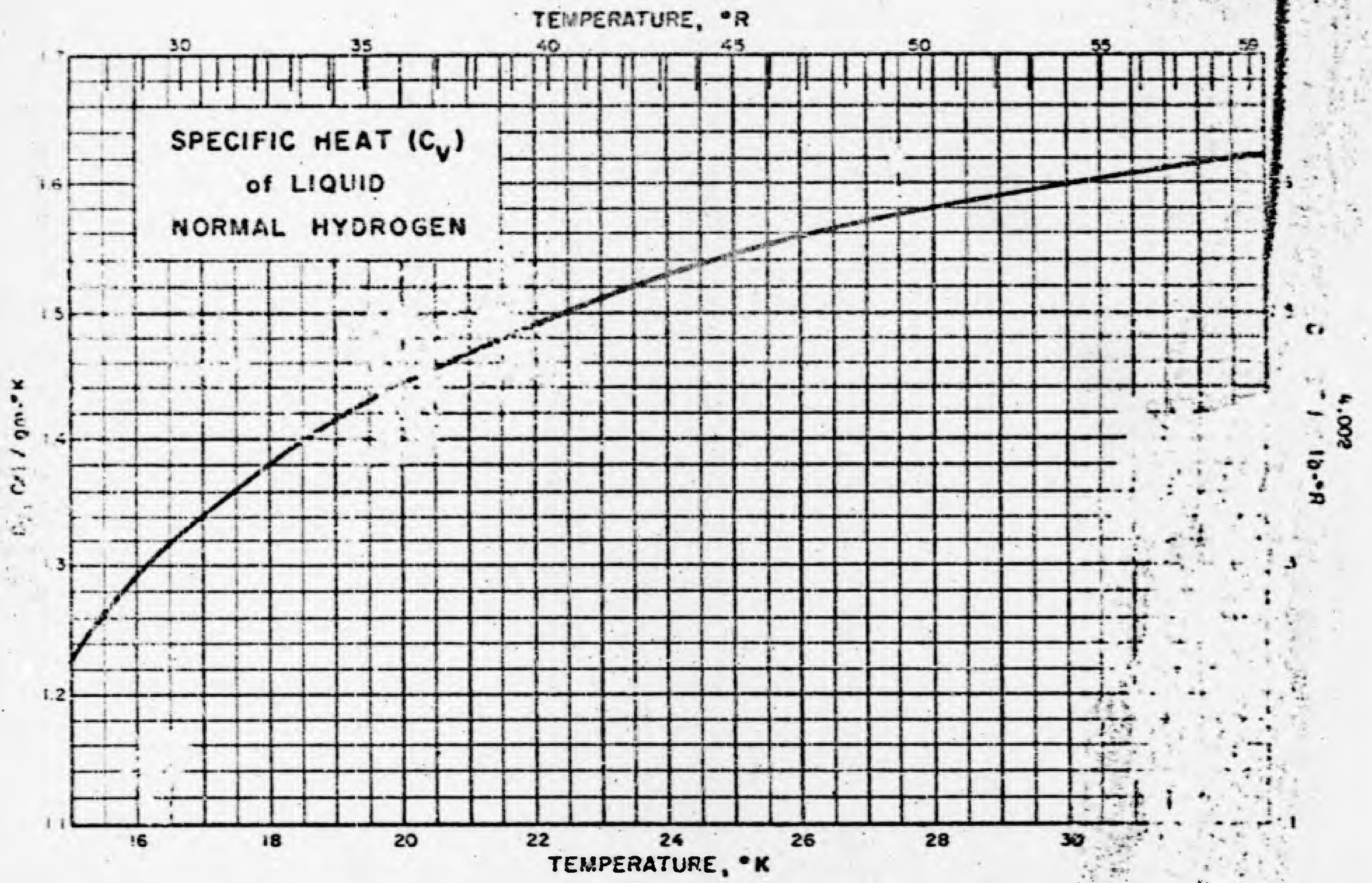
Data of Johnston, Clarke
Rifkin and Kerr.
J. Am. Chem. Soc. 72,
3933 (1950).

Temp. °K	C_s $\frac{\text{cal}}{\text{mole °K}}$	C_s $\frac{\text{cal}}{\text{gm °K}}$
15.15	3.52	1.746
15.30	3.54	1.756
16.09	3.67	1.820
16.26	3.66	1.815
17.03	3.81	1.890
17.31	3.85	1.910
17.98	4.03	[illegible]
18.27	4.10	[illegible]
18.89	4.24	2.103
18.99	4.32	2.143

Data of Smith, Hallett
and Johnston.
J. Am. Chem. Soc. 76,
1486 (1954).

Temp. °K	C_s $\frac{\text{cal}}{\text{mole °K}}$	C_s $\frac{\text{cal}}{\text{gm °K}}$
18.20	4.18	2.073
20.45	4.71	2.336
22.71	5.33	2.644
25.00	6.03	2.991
26.04	6.46	3.204
28.20	7.85	3.894
30.10	9.94	4.931
31.49	14.56	7.222

FEG/VJJ Issued: 7-14-59



SPECIFIC HEAT (C_V) of LIQUID NORMAL HYDROGEN

SPECIFIC HEAT (C_v) of LIQUID NORMAL HYDROGEN

[illegible]

[illegible] (B) 33, 387 [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

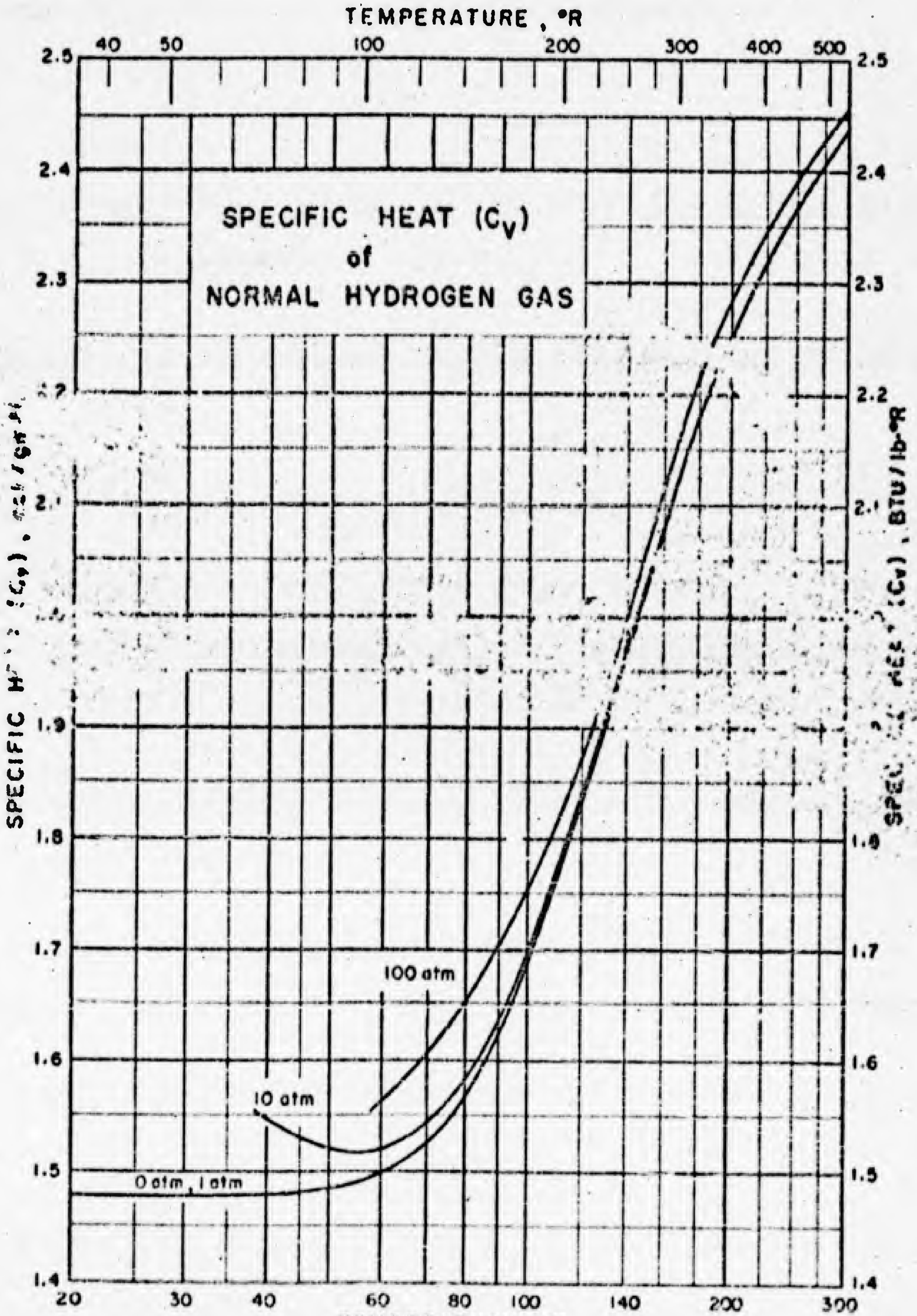
Comments:

The [illegible] Eucken in [illegible] are from the 1916 [illegible] of Eucken. [illegible] data form a good continuous curve. [illegible] it is assumed that all the work refers to normal [illegible] though the work of Bartholome and Eucken was published [illegible] discovery of the ortho and para forms. Future studies should take into account the existence of these varieties.

Table of Selected Values

Temp. °K	C_v $\frac{\text{Cal}}{\text{Mole-°K}}$	C_v $\frac{\text{Cal}}{\text{Gram-°K}}$
15.33	2.54	1.260
15.86	2.56	1.270
16.23	2.63	1.305
16.87	2.70	1.339
17.22	2.70	1.339
17.88	2.78	1.379
18.92	2.84	1.409

Temp. °K	C_v $\frac{\text{Cal}}{\text{Mole-°K}}$	C_v $\frac{\text{Cal}}{\text{Gram-°K}}$
19.50	2.89	1.434
20.00	2.92	1.448
20.50	2.98	1.478
21.09	2.93	1.453
21.46	2.94	1.458
22.16	3.00	1.488
23.13	2.99	1.483


SPECIFIC HEAT (C_V)
of
NORMAL HYDROGEN GAS
TEMPERATURE , °R
40
50
100
200
300
400
500
2.5
2.4
2.3
2.2
2.1
1.9
1.8
1.7
1.6
1.5
1.4
SPECIFIC HEAT (C_V) , cal/gm-°K
SPECIFIC HEAT (C_V) , BTU/lb-°R
100 atm
10 atm
0 atm , 1 atm
20
30
40
60
80
100
140
200
300
TEMPERATURE , °K

..002

SPECIFIC HEAT (C_v) of NORMAL HYDROGEN GAS

Sources of Data:

Eucken, A., Sitzber. kgl. preuss. Akad. Wiss. 141 (1912)

Hilsenrath, J., et al., Nat. Bur. Standards Cir. 564, 282 (1954)

Scheel, K. and Heuse, H., Ann. Physik. (4) 40, 473 (1913)

Workman, E. J., Phys. Rev. (2) 37, 1345 (1931)

Comments:

The curves have been constructed using the data as listed in NBS Circular 564, based on the above references. No more recent data have been located. Future studies should take into account the existence of the ortho and para forms of hydrogen.

$$\text{Specific Heat, } C_v = \frac{\text{Specific Heat, } C_p}{k}$$

Table of Selected Values

Temp. °K	0 Atm.			1 Atm.		
	k	C_p $\frac{\text{cal}}{\text{gm °K}}$	C_v $\frac{\text{cal}}{\text{gm °K}}$	k	C_p $\frac{\text{cal}}{\text{gm °K}}$	C_v $\frac{\text{cal}}{\text{gm °K}}$
20	1.667	2.4643	1.478			
30	1.667	2.4643	1.478	1.736	2.5904	1.492
40	1.666	2.4653	1.480	1.700	2.5274	1.487
50	1.664	2.4692	1.484	1.684	2.5067	1.489
60	1.658	2.4830	1.498	1.672	2.5076	1.500
70	1.646	2.5106	1.525	1.655	2.5283	1.528
80	1.628	2.5540	1.569	1.634	2.5673	1.571
100	1.583	2.6752	1.690	1.587	2.6831	1.691
120	1.539	2.8162	1.830	1.541	2.8211	1.831
140	1.502	2.9502	1.964	1.503	2.9532	1.965
160	1.474	3.0636	2.078	1.475	3.0665	2.079
180	1.454	3.1582	2.172	1.455	3.1602	2.172
200	1.439	3.2331	2.248	1.439	3.2351	2.248
220	1.427	3.2923	2.307	1.428	3.2933	2.306
240	1.419	3.3386	2.353	1.419	3.3396	2.353
260	1.413	3.3751	2.389	1.413	3.3761	2.389
270	1.410	3.3889	2.403	1.410	3.3899	2.404
280	1.408	3.4007	2.415	1.408	3.4017	2.416
300	1.405	3.4194	2.434	1.405	3.4204	2.434

(continued on next page)

SPECIFIC HEAT (C_v) of NORMAL HYDROGEN GAS

(Continued)

Table of Selected Values

	10 Atm.			100 Atm.		
Temp °K	k	C_p cal/gm °K	C_v cal/gm °K	k	C_p cal/gm °K	C_v cal/gm °K
30						
40	2.205	3.4135	1.548			
50	1.913	2.9049	1.519			
60	1.804	2.7403	1.519	2.497	3.9005	1.562
70	1.738	2.6930	1.549	2.256	3.7319	1.654
80	1.694	2.6841	1.584	2.066	3.5131	1.700
90	1.655	2.7077	1.636	1.945	3.3179	1.706
100	1.617	2.7501	1.701	1.844	3.2479	1.761
120	1.558	2.8635	1.838	1.704	3.1957	1.875
140	1.517	2.9828	1.966	1.613	3.2174	1.995
160	1.484	3.0902	2.082	1.549	3.2785	2.117
180	1.461	3.1800	2.177	1.507	3.3287	2.209
200	1.444	3.2489	2.250	1.479	3.3642	2.275
220	1.431	3.3071	2.311	1.459	3.4046	2.334
240	1.422	3.3504	2.356	1.442	3.4362	2.383
260	1.416	3.3839	2.390	1.431	3.4539	2.414
270	1.413	3.3968	2.404	1.427	3.4598	2.425
280	1.410	3.4086	2.417	1.423	3.4658	2.436
300	1.406	3.4263	2.437	1.417	3.4756	2.453

4.002

SPECIFIC HEAT (C_p) of NORMAL HYDROGEN GAS

Sources of Data:

Eucken, A., Sitzber. kgl. preuss. Akad. Wiss. 141 (1912)
Hilsenrath, J., et al., Nat. Bur. Standards Cir. 564, 282 (1955)
Scheel, K. and Heuse, W., Ann. Physik. (4) 40, 473 (1913)
Workman, E. J., Phys. Rev. (2) 37, 1345 (1931)

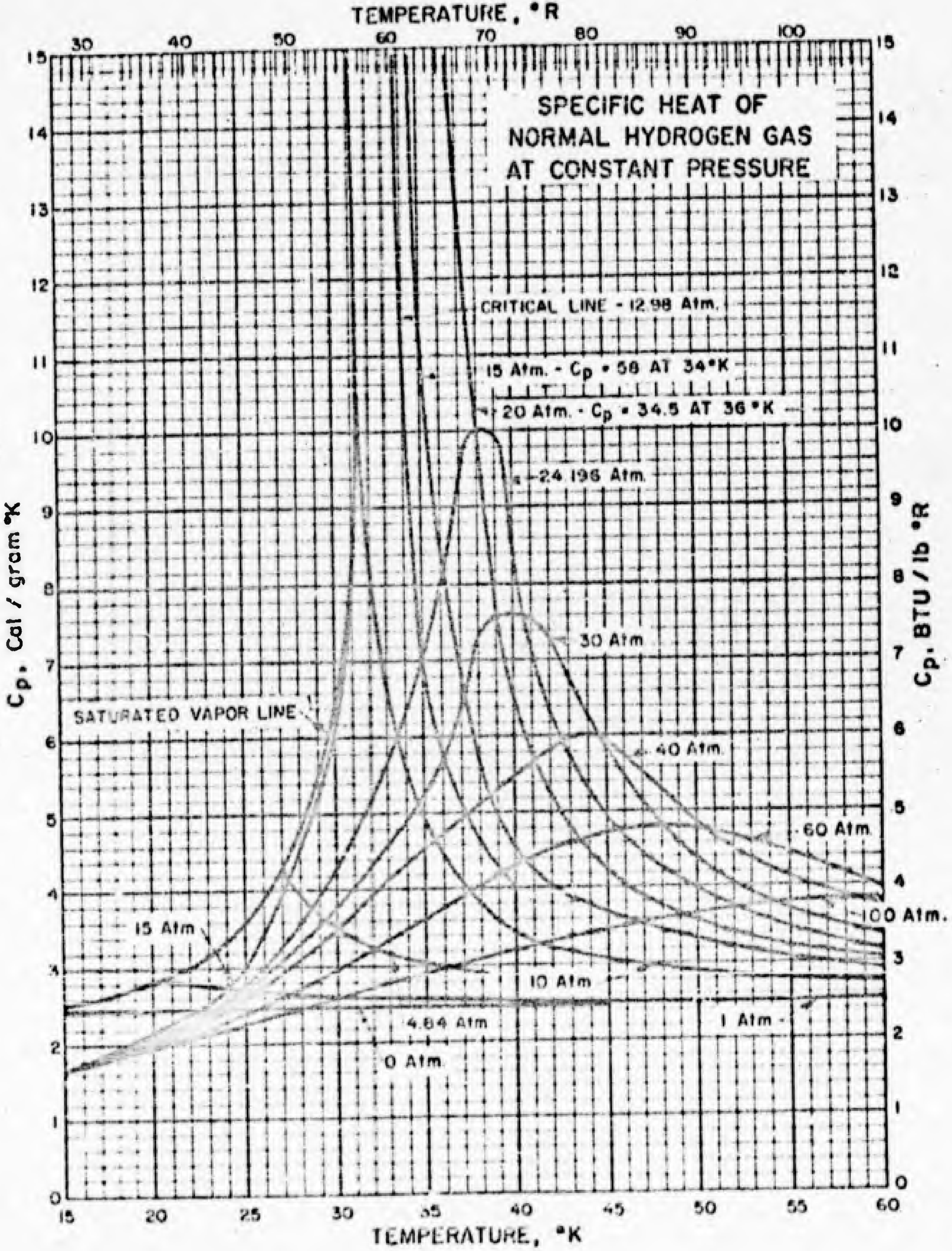
Comments:

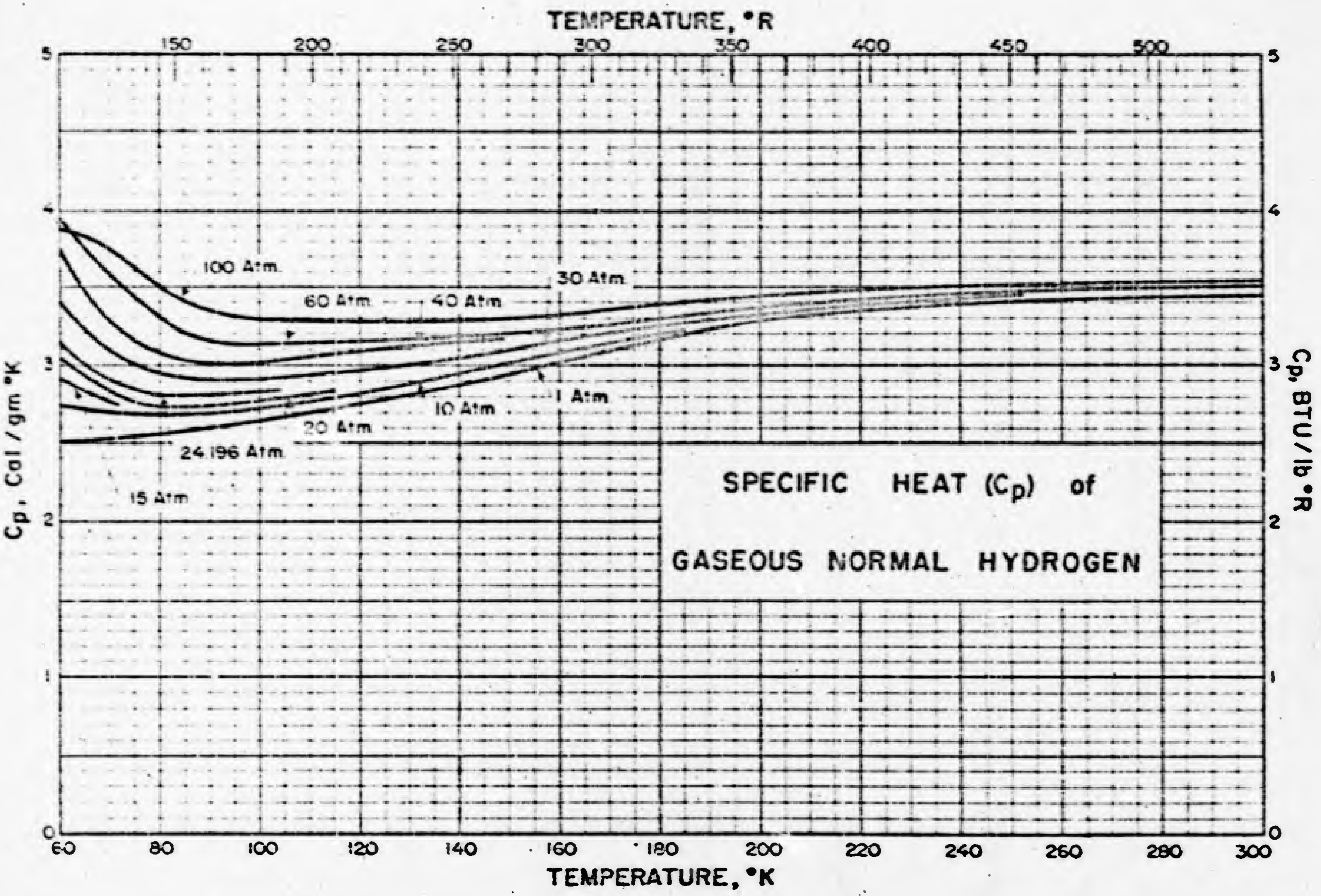
The above articles were all used by the NBS staff in compiling the data for Circular 564. Accordingly the present curves have been constructed using these same data. We have been unable to discover anything more recent. When more does appear, it should take into account the existence of ortho and para-hydrogen.

Table of Selected Values

Temp. °K	$\frac{C_p}{R}$	C_p $\frac{cal}{gm\,°K}$	$\frac{C_p}{R}$	C_p $\frac{cal}{gm\,°K}$	$\frac{C_p}{R}$	C_p $\frac{cal}{gm\,°K}$	$\frac{C_p}{R}$	C_p $\frac{cal}{gm\,°K}$
	0 Atm		1 Atm		10 Atm		100 Atm	
20	2.50	2.4643						
30	2.50	2.4643	2.628	2.5904				
40	2.501	2.4653	2.564	2.5274	3.463	3.4135		
50	2.505	2.4692	2.543	2.5067	2.947	2.9049		
60	2.519	2.4830	2.544	2.5076	2.780	2.7403	3.957	3.9005
70	2.547	2.5106	2.565	2.5283	2.732	2.6930	3.786	3.7319
80	2.591	2.5540	2.605	2.5678	2.723	2.6841	3.564	3.5131
90	2.648	2.610	2.658	2.6200	2.747	2.7077	3.365	3.3179
100	2.714	2.6752	2.722	2.6831	2.790	2.7501	3.295	3.2479
120	2.857	2.8162	2.862	2.8211	2.905	2.8635	3.242	3.1957
140	2.993	2.9502	2.996	2.9532	3.026	2.9828	3.264	3.2174
160	3.108	3.0636	3.111	3.0665	3.135	3.0902	3.326	3.2785
180	3.204	3.1582	3.206	3.1602	3.226	3.1800	3.377	3.3287
200	3.280	3.2331	3.282	3.2351	3.296	3.2489	3.413	3.3642
220	3.340	3.2923	3.341	3.2933	3.355	3.3071	3.454	3.4046
240	3.387	3.3386	3.388	3.3396	3.399	3.3504	3.486	3.4362
260	3.424	3.3751	3.425	3.3761	3.433	3.3839	3.504	3.4539
270	3.438	3.3889	3.439	3.3899	3.446	3.3968	3.510	3.4598
280	3.450	3.4007	3.451	3.4017	3.458	3.4086	3.516	3.4658
300	3.469	3.4194	3.470	3.4204	3.476	3.4263	3.526	3.3756

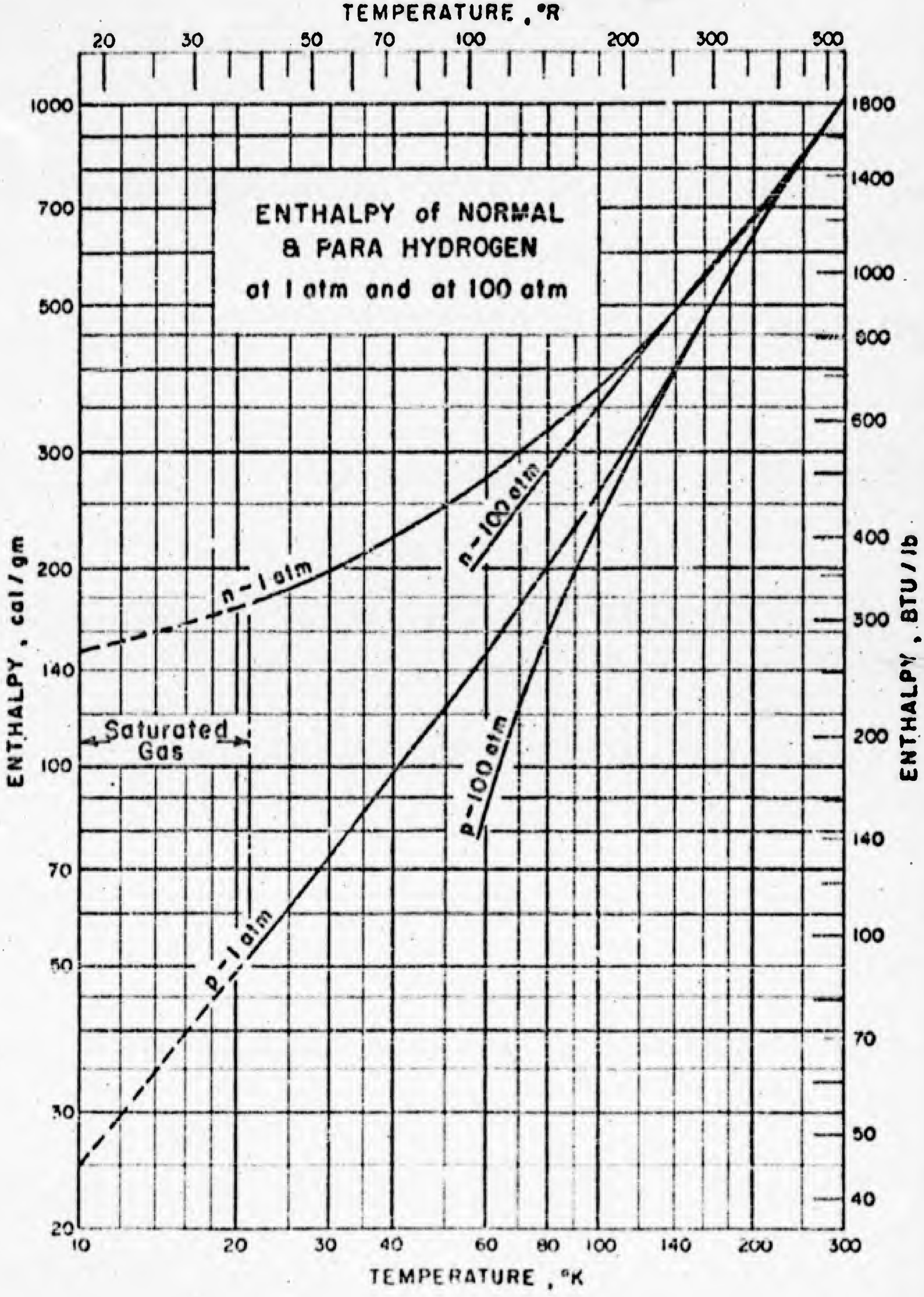
See next two pages for graphical presentation of the data.


TEMPERATURE, °R
30
40
50
60
70
80
90
100
SPECIFIC HEAT OF
NORMAL HYDROGEN GAS
AT CONSTANT PRESSURE
CRITICAL LINE - 12.98 Atm.
15 Atm. - C_p = 58 AT 34°K
20 Atm. - C_p = 34.5 AT 36°K
24.196 Atm.
30 Atm
40 Atm.
60 Atm.
100 Atm.
SATURATED VAPOR LINE
15 Atm
10 Atm
4.84 Atm
1 Atm
0 Atm.
C_p, Cal / gram °K
C_p, BTU / lb °R
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
15
20
25
30
35
40
45
50
55
60
TEMPERATURE, °K



SPECIFIC HEAT (C_p) of GASEOUS NORMAL HYDROGEN

4.002


TEMPERATURE , °R
20
30
50
70
100
200
300
500
ENTHALPY of NORMAL
& PARA HYDROGEN
at 1 atm and at 100 atm
1000
700
500
300
200
140
100
70
50
30
20
ENTHALPY , cal / gm
1800
1400
1000
800
600
400
300
200
140
100
70
50
40
ENTHALPY , BTU / lb
n - 1 atm
n - 100 atm
p - 100 atm
p - 1 atm
Saturated
Gas
10
20
30
40
60
80
100
140
200
300
TEMPERATURE , °K

4.002

ENTHALPY of NORMAL and PARA HYDROGEN GAS

Sources of Data: Hilsenrath, J., et al., Nat. Bur. Standards Cir. 564, 279 (1955); Woolley, H. W., Scott, R. B. and Brickwedde, R. G. NBS Research Paper RP 1932 (1948).

Comments: Enthalpy of normal hydrogen was obtained from Circular 564 for both 1 and 100 atmospheres for temperatures at 60°K and above. Enthalpy of para hydrogen was calculated from data on page 387 of RP 1932 for one atmosphere pressure. Enthalpy of para hydrogen at 100 atmospheres pressure was calculated by assuming that the difference in enthalpy of para hydrogen between one and 100 atmospheres was the same as the difference in the case of normal hydrogen.

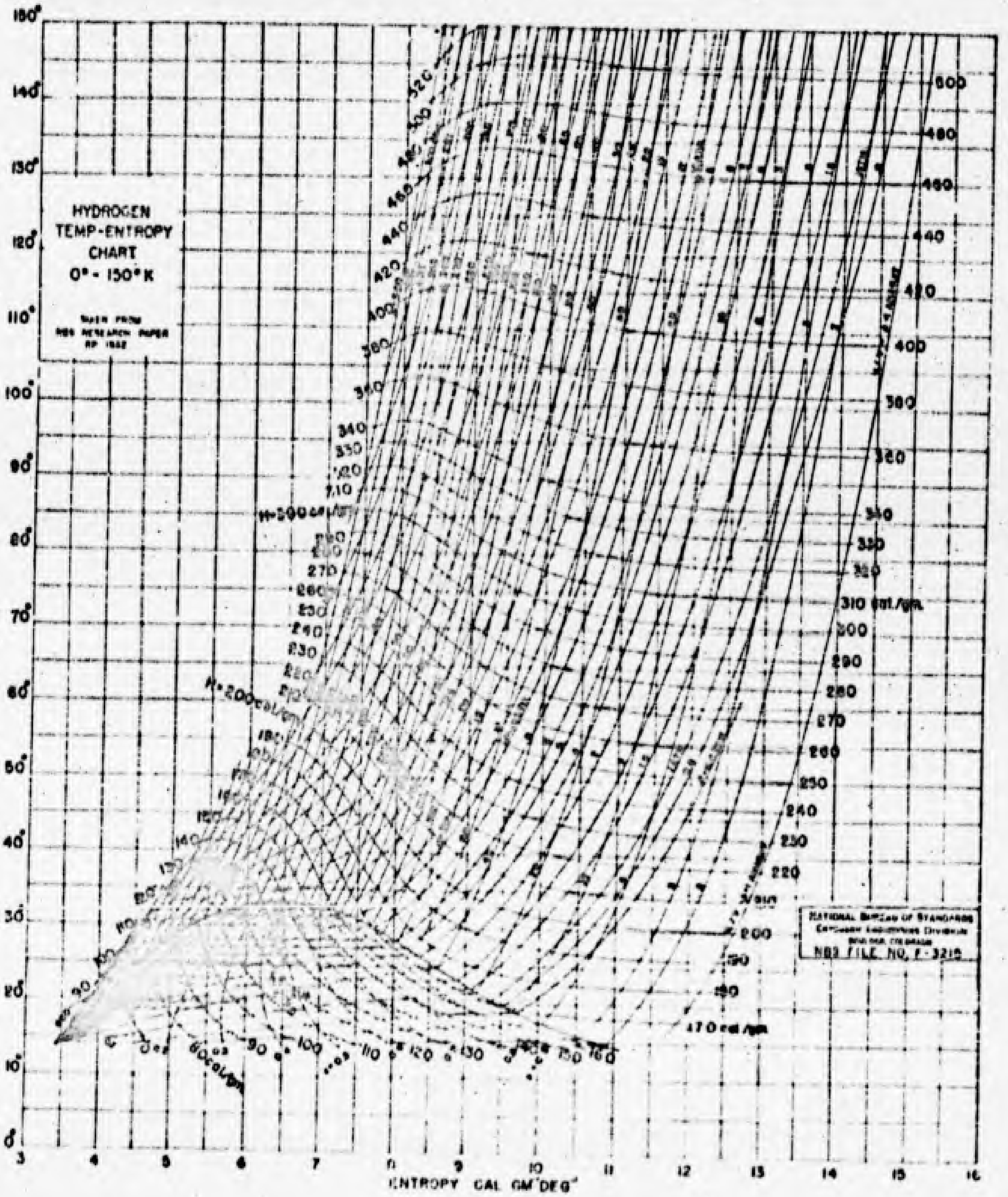
No data were found in the literature for the enthalpy of hydrogen gas at pressures above one atmosphere for temperatures below 60°K. For values in this region a temperature-entropy chart, Figures 31 and 32, from RP-1932 has been reproduced and included with this data sheet.

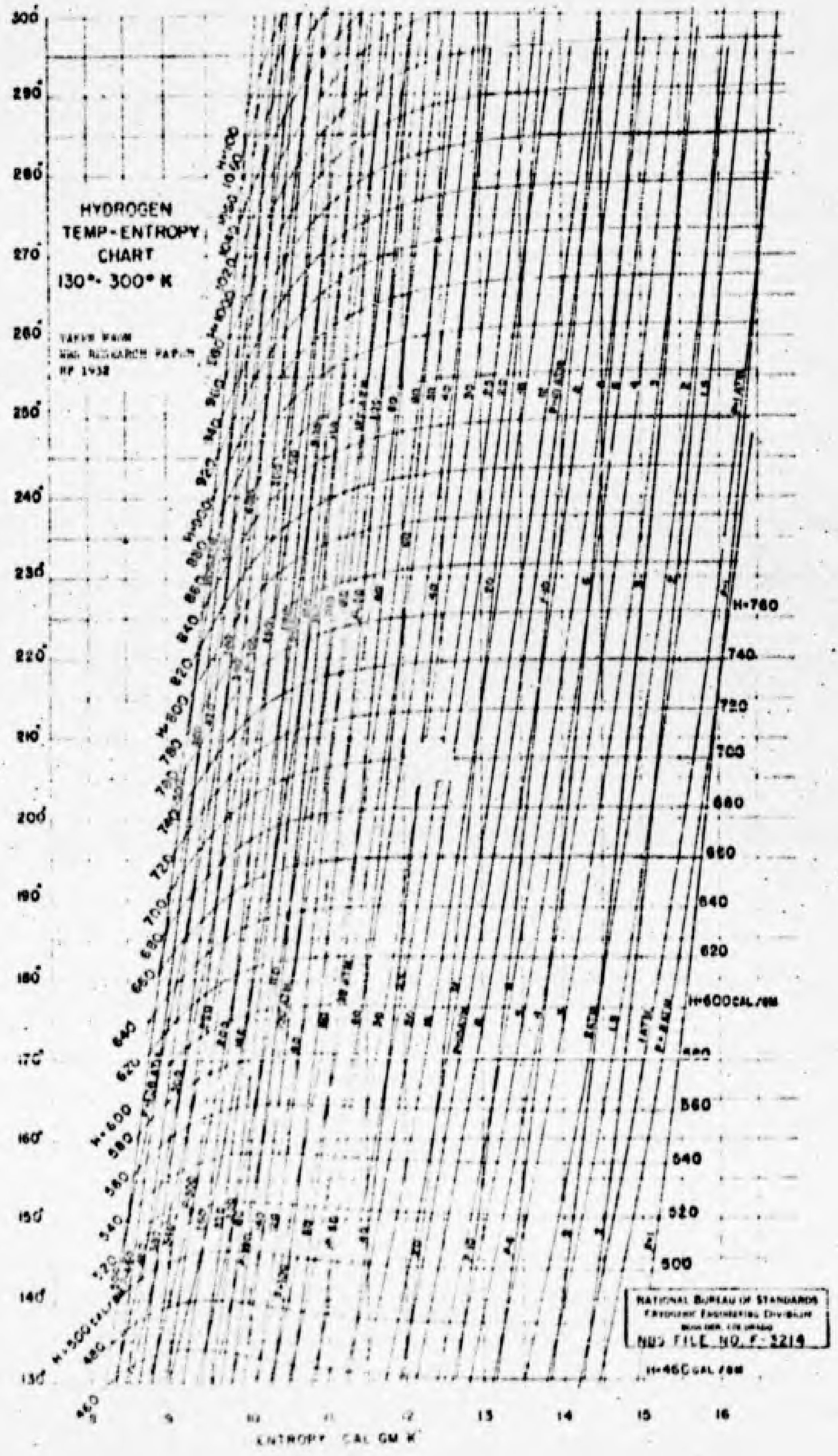
Temp. °K	Normal Hydrogen			Para Hydrogen			Heat of Convers. H_c
	1 Atm.		100 Atm.	1 Atm.		100 Atm.	
	cal/mole	cal/gm	cal/gm	cal/mole	cal/gm	cal/gm	
	Data from RP 1932						
10	303.665*	150.627*		49.678*	24.642*		125.985
20	353.344	175.270		99.357	49.284		125.985
30	403.022	199.912		149.036	73.927		125.985
40	452.705	224.556		198.729	98.576		125.980
50	502.426	249.219		248.581	123.304		125.915
	Data from Circular 564					RP 1932	
60	550.529	273.079	210.504	297.316	147.478	84.903	125.601
70	601.228	298.228	248.631	349.828	173.526	123.928	124.702
80	652.525	323.673	284.792	490.150	200.844	161.963	122.829
90	704.799	349.602	318.799	463.523	229.922	199.119	119.680
100	758.212	376.097	351.621	526.132	260.978	236.503	115.119
120	869.165	431.133	415.974	663.306	329.021	313.862	102.112
150	1045.799	518.749	512.340	890.413	441.673	435.264	77.076
200	1361.612	675.402	677.933	1282.700	636.260	638.791	39.142
250	1694.633	840.590	848.506	1660.650	823.735	831.651	16.855
300	2036.719	1010.275	1021.584	2023.435	1003.688	1014.997	6.587

* Saturated Gas

FEEG/VJJ Issued: 7-21-59

ENTHALPY of NORMAL HYDROGEN




HYDROGEN
TEMP-ENTROPY
CHART
130°- 300° K
TAKEN FROM
NBS RESEARCH PAPER
RP 1932
NATIONAL BUREAU OF STANDARDS
CRYOGENIC ENGINEERING DIVISION
BOULDER, COLORADO
NBS FILE NO. F-3214
300°
290°
280°
270°
260°
250°
240°
230°
220°
210°
200°
190°
180°
170°
160°
150°
140°
130°
H=460
H=500 CAL/GM
H=600
H=800
H=1000
H=1100
H=760
740
720
700
680
660
640
620
H=600 CAL/GM
580
560
540
520
500
H=460 CAL/GM
9
10
11
12
13
14
15
16
ENTROPY CAL/GM °K

4.002

ENTHALPY of SATURATED VAPOR and CONDENSED PHASES of NORMAL and PARA HYDROGEN FROM 0°K to 15°K

References: Simon, Z. Physik 15, 307 (1923); Simon and Lange, Z. Physik 15, 312 (1923); Clusius and Hiller, Z. physik. Chem. [B] 4, 158 (1929); Mendelssohn, Ruhemann and Simon, Z. physik. Chem. [B] 15, 121 (1931); Eucken, Verh. deut. phys. Ges. 18, 4 (1916); Bartholomé and Eucken, Z. Elektrochem. 42, 547 (1936); Woolley, Scott and Brickwedde, RP1932, 41 (1948); Hill and Ricketson, Phil. Mag. 45, 277 (1954).

Discussion: Simon calculated the heat of sublimation of normal solid hydrogen at 0°K and zero pressure to be 183.4 cal/mole. Under these conditions the entropy of the gas is infinite. By arbitrarily fixing the enthalpy of para hydrogen gas at this point to be 0 and assuming the heat of sublimation of para hydrogen at 0°K to be the same as for normal hydrogen, the enthalpy of solid para hydrogen at 0°K, zero pressure is -183.4 cal/mole. By graphically integrating the saturation specific heat (C_s) curve for para hydrogen from 0 to 14°K, as plotted by Mendelssohn, Ruhemann and Simon, 5.55 cal/mole are obtained for the gain in enthalpy. (Graphical integration of the corresponding saturation specific heat curve for normal hydrogen indicates an enthalpy gain of approximately 8 cal/mole, as close as can be ascertained in view of the λ anomaly). The heat of fusion of both forms of hydrogen is 28.0 cal/mole. The saturation specific heat for both para and normal liquid hydrogen between 14 and 15°K is 1.27 cal/mole. The heat of vaporization of 15°K can be obtained from the equation:

$$H_L = 219.7 - 0.27 (T - 16.6)^2$$

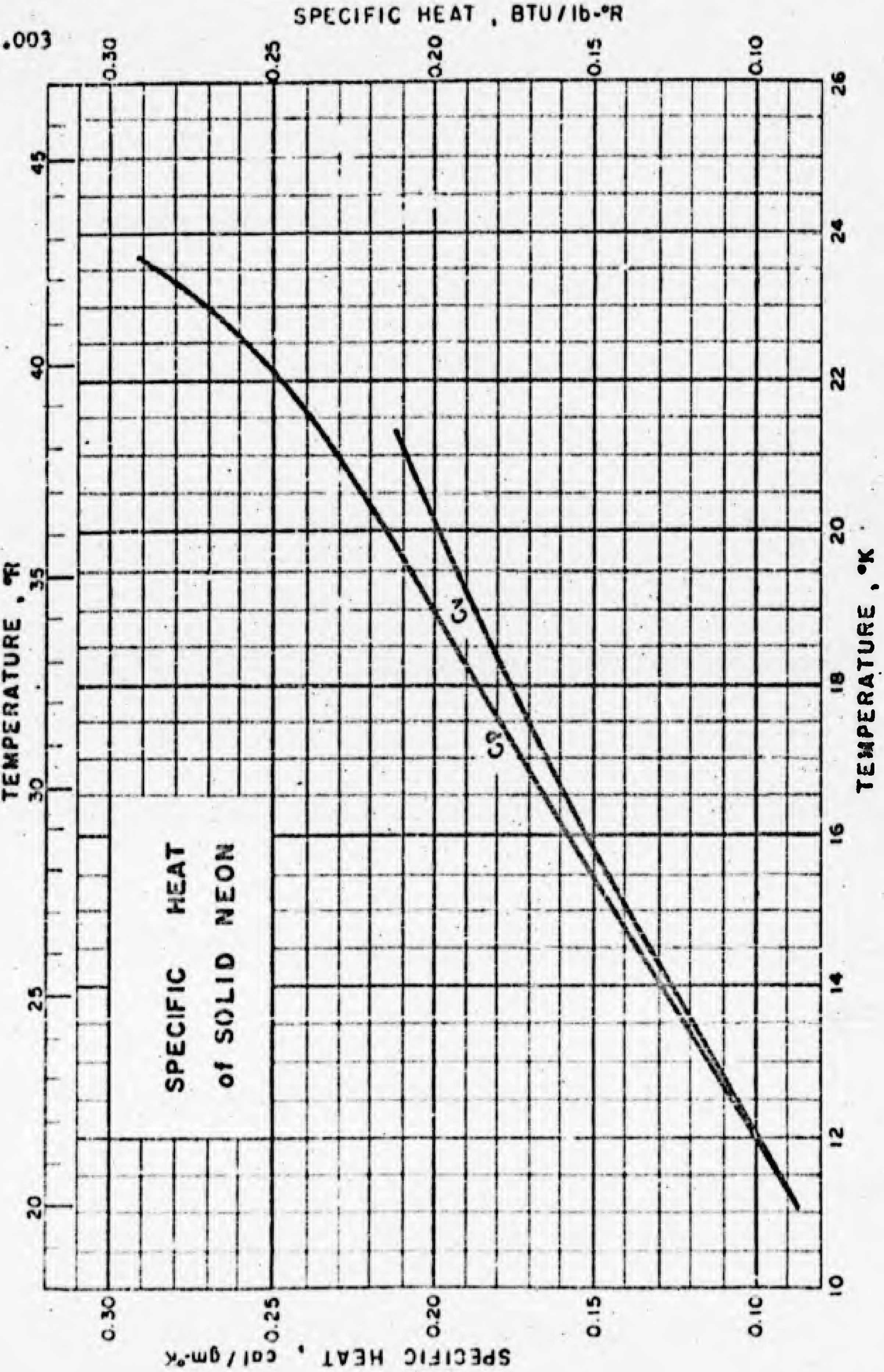
of Simon and Lange from which H_L = 219.0 cal/mole with an error of ± 1.1 cal/mole. The heat of conversion of para to normal hydrogen at 15°K is 254.0 cal/mole as shown in RP1932 of Woolley, Scott and Brickwedde.

On the basis of the enthalpy values discussed above, numerical values can be assigned for various temperatures and conditions as shown in the following tabulation:

Temperature; Phase	Para		Normal	
	Cal/mole	Cal/gm	Cal/mole	Cal/gm
0° K; Gas; S = ∞	0	0	251.6	124.8
0° K; Solid: S=0	-183.4	-91.0	68.2	33.8
14° K; Sat. Solid	-177.85	-88.2	76.15±~0.3	37.8±~0.2
14° K; Sat. Liquid	-149.85	-74.3	104.15±~0.3	51.7±~0.2
15° K; Sat. Liquid	-148.58	-73.7	105.42±~0.3	52.3±~0.2
15° K; Sat. Vapor	70.42±~1.1	34.9±~0.5	324.42±~1.4	160.9±~0.6

The value of 160.9 cal/gm agrees very well with that read from the temperature entropy diagram given on page 470 of RP1932.

FEEC/VJJ Issued: 5-26-59



SPECIFIC HEAT of SOLID NEON

4.003

SPECIFIC HEAT of SOLID NEON

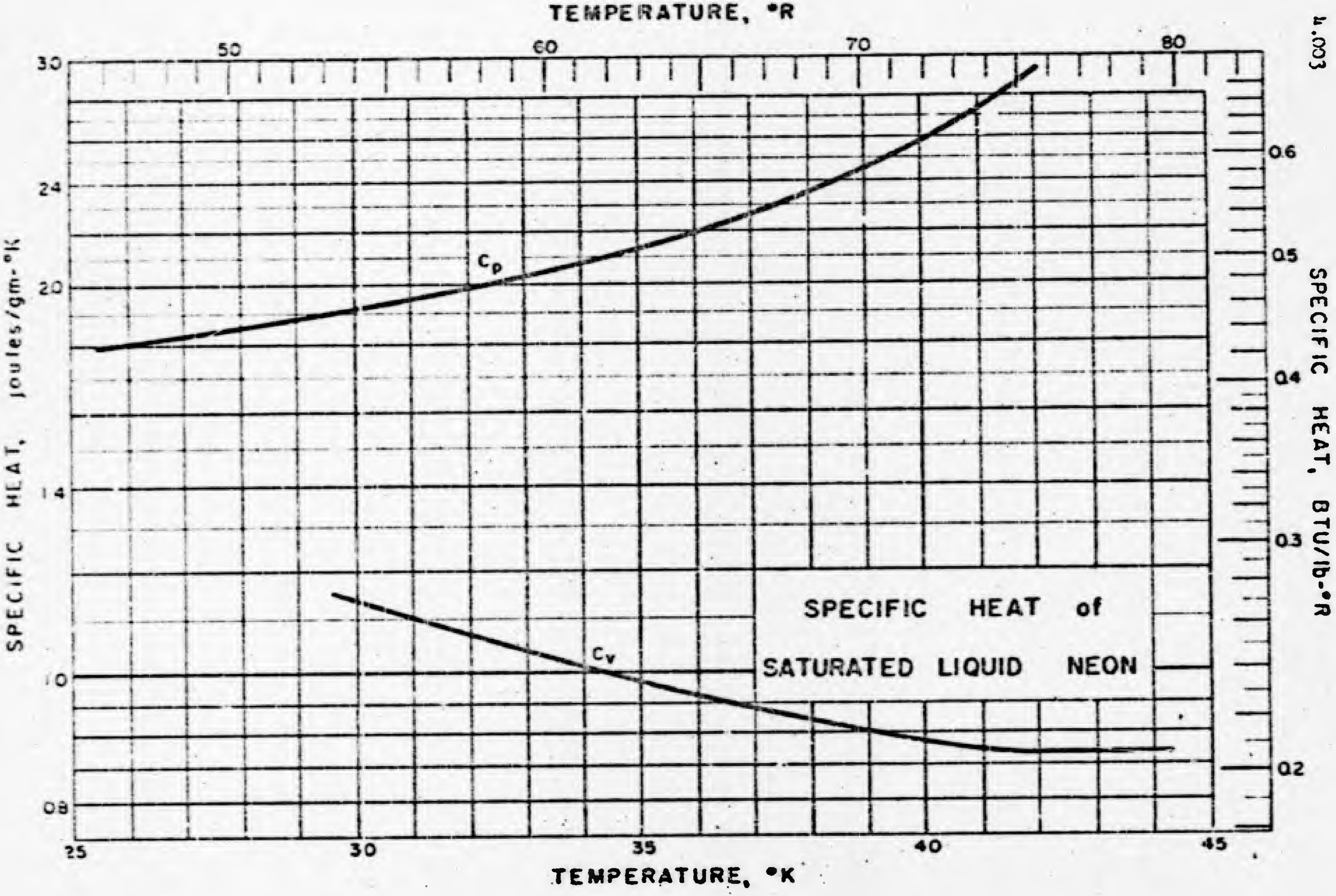
Sources of Data: Clusius, K., Z. physik. Chem. B4, 1-13 (1929); Clusius, K., Z. physik. Chem. B31, 459-74 (1936).

Comment: The value of the melting point given in Z. physik. Chem B4 was 24.59°K and that given in Z. physik. Chem. B31 was 24.55°K.

Table of Selected Values

Temp. °K	C_p		C_v	
	cal / g-mole °K	cal / gm °K	cal / g-mole °K	cal / gm °K
11.24	1.84_2	0.0912_7	1.80_9	0.0896_3
12.3	2.07	0.103	2.03	0.101
13.07	2.38_2	0.118_0	2.31_7	0.114_8
13.1	2.32	0.115	2.26	0.112
14.7	2.78	0.138	2.68	0.133
15.28	3.02_2	0.149_7	2.90_1	0.143_7
15.64	3.154	0.156_3	3.01_9	0.1496
16.6	3.35	0.166	3.19	0.158
18.4	3.91_0	0.193_7	3.66_5	0.1816
18.5	3.83	0.190	3.60	0.178
18.8	3.97	0.197		
19.77	4.28_0	0.212_1	3.96_5	0.196_5
20.0	4.58	0.227		
20.9	4.59	0.227		
21.15	4.66_0	0.230_9	4.26_1	0.211_1
21.25	4.83_5	0.239_6		
22.1	5.03	0.249		
22.57	5.23_5	0.259_1		
22.7	5.29	0.262		
22.8	5.41	0.268		
23.5	5.81	0.288		
23.65	5.82_5	0.288_6		

KDT/BDT Issued: 5/25/59


SPECIFIC HEAT of
SATURATED LIQUID NEON
TEMPERATURE, °R
50
60
70
80
TEMPERATURE, °K
25
30
35
40
45
SPECIFIC HEAT, joules/gm-°K
30
24
20
1.4
1.0
0.8
SPECIFIC HEAT, BTU/lb-°R
0.6
0.5
0.4
0.3
0.2
C_p
C_v

SPECIFIC HEAT of SATURATED LIQUID NEON

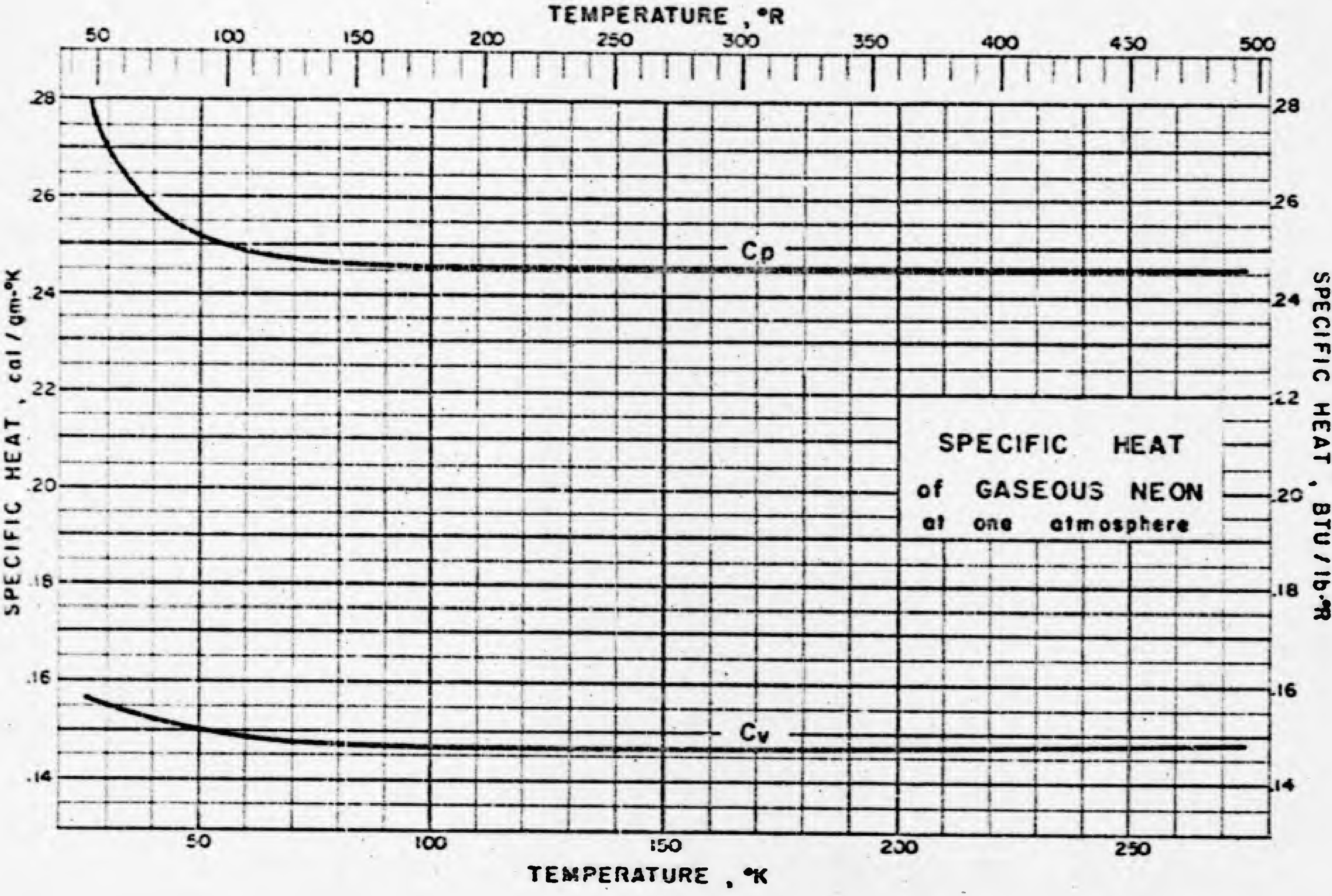
Sources of Data: Clusius, K., Z. physik. Chem. B4, 1-13 (1929); Clusius, K., Z. physik. Chem. B31, 459-74 (1936).

Table of Selected Values

Temp. °K	C_p		C_v	
	$\frac{\text{cal}}{\text{g-mole °K}}$	$\frac{\text{cal}}{\text{gm °K}}$	$\frac{\text{cal}}{\text{g-mole °K}}$	$\frac{\text{cal}}{\text{gm °K}}$
25.7	8.64	0.428		
25.85	8.64	0.428		
25.86	8.68	0.430		
26.8	8.88	0.440		
27.8	9.06	0.449		
28.5	9.13	0.452		
30.1			5.46	0.271
32.25			5.15	0.255
34.65			4.86	0.241
35.0			4.71	0.233
37.5			4.48	0.222
37.9	11.17	0.553		
39.1	11.47	0.568		
39.3			4.36	0.216
39.95			4.26	0.211
40.25	12.93	0.641		
41.5			3.99	0.198
41.85	13.78	0.683		
43.8			4.18	0.207
49.9*			4.20	0.208
52.5*			4.04	0.200

* Above the critical temperature (44.38°K)

KDT/BDT Issued: 5/25/59


SPECIFIC HEAT
of GASEOUS NEON
at one atmosphere
TEMPERATURE, °R
50
100
150
200
250
300
350
400
450
500
SPECIFIC HEAT, cal/gm-°K
.28
.26
.24
.22
.20
.18
.16
.14
SPECIFIC HEAT, BTU/lb·°R
.28
.26
.24
.22
.20
.18
.16
.14
Cp
Cv
TEMPERATURE, °K
50
100
150
200
250

SPECIFIC HEAT of GASEOUS NEON

Source of Data: Keesom, W. H. and van Lammeren, J. A., Physica 1, 1161-70 (1934).

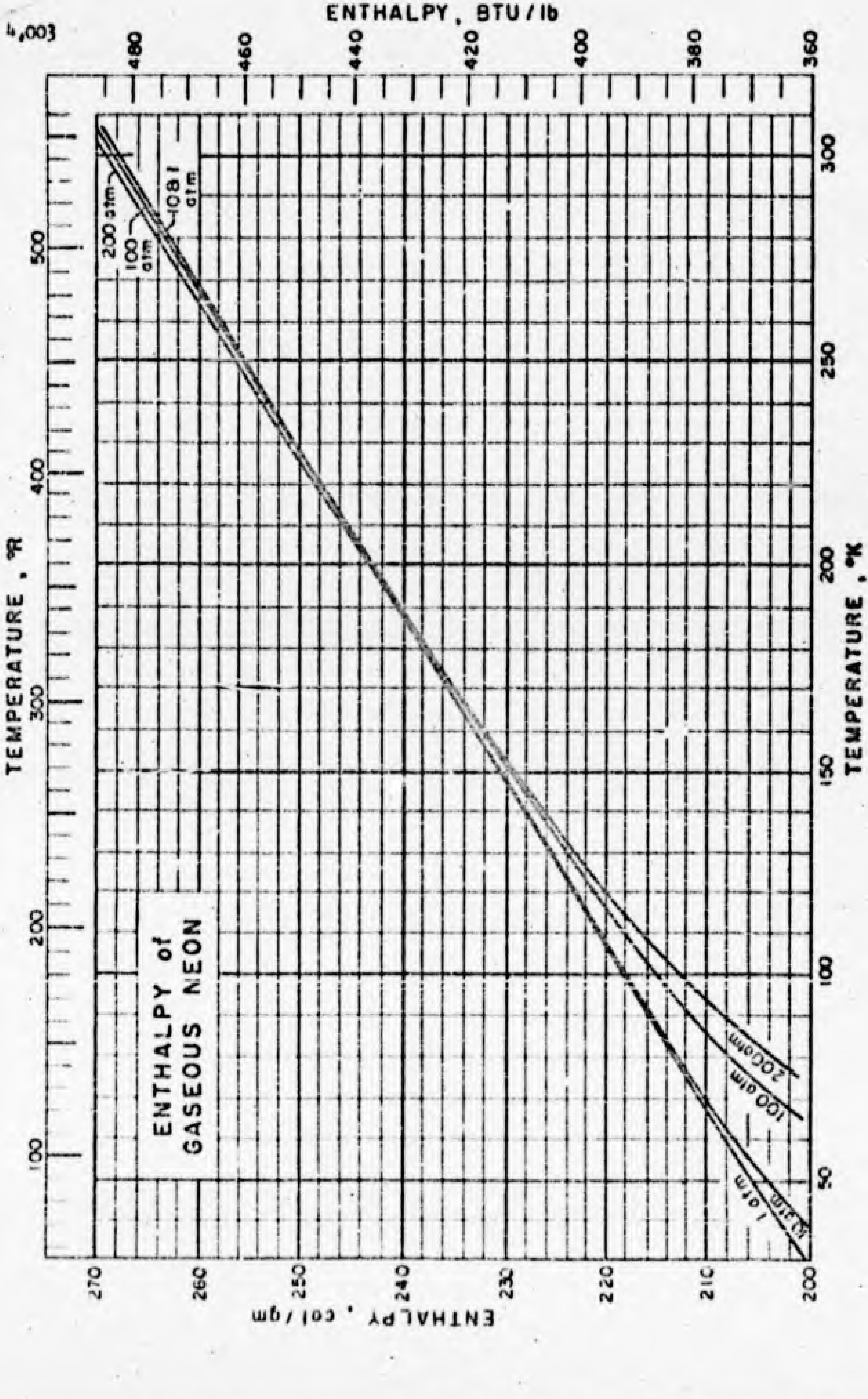
Comments: Holborn, L. and Otto, J., Z. Physik 33, 1-12 (1925) give a value of C_p/C_v at 0°C and 1 atm of 1.66. Michels, A. and Gibson, R. O., Ann. Physik (4), 87, 850-76 (1928) give a value of C_p/C_v at 0°C and 1 atm of 1.65. Ramsay, W., Proc. Roy. Soc. (London) 86, 100 (1912) gives a value of C_p/C_v at 19°C and 1 atm of 1.64.

Table of Selected Values

Temp. °K	Pressure Atm.	C_p		C_v		$\frac{C_p}{C_v}$
		$\frac{\text{cal}}{\text{g-mole °K}}$	$\frac{\text{cal}}{\text{gm °K}}$	$\frac{\text{cal}}{\text{g-mole °K}}$	$\frac{\text{cal}}{\text{gm °K}}$	
26.25	0.6	5.36	0.266	3.07	0.152	1.744
26.25	0.4	5.22	0.259	3.04	0.151	1.717
26.25	0.2	5.08	0.252	3.00	0.149	1.692
26.25	0.0	4.95	0.248	2.97	0.147	1.669
27.80	1.0	5.55	0.275	3.14	0.156	1.771
27.80	0.8	5.43	0.269	3.11	0.154	1.748
27.80	0.6	5.31	0.263	3.07	0.152	1.726
27.80	0.4	5.19	0.257	3.04	0.151	1.706
27.80	0.2	5.07	0.251	3.01	0.149	1.687
27.80	0.0	4.95	0.245	2.97	0.147	1.669
62.54	0.9784	5.01	0.248	2.99	0.148	1.677
74.11	0.8152	4.99	0.247	2.98	0.148	1.673
90.24	0.9581	4.97	0.246	2.97	0.147	1.674
170.0	0.9822	4.96	0.246	2.97	0.147	1.670
273.1	0.8797	4.96	0.246	2.98	0.148	1.668

KDT/BHP Issued: 5/25/59

4,003



ENTHALPY, BTU/lb
480
460
440
420
400
380
360
TEMPERATURE, °R
100
200
300
400
500
TEMPERATURE, °K
50
100
150
200
250
300
ENTHALPY, cal/gm
270
260
250
240
230
220
210
200
ENTHALPY of GASEOUS NEON
200 atm
100 atm
1.081 atm
200 atm
100 atm
1 atm
1.081 atm

4.003

ENTHALPY of GASEOUS NEON

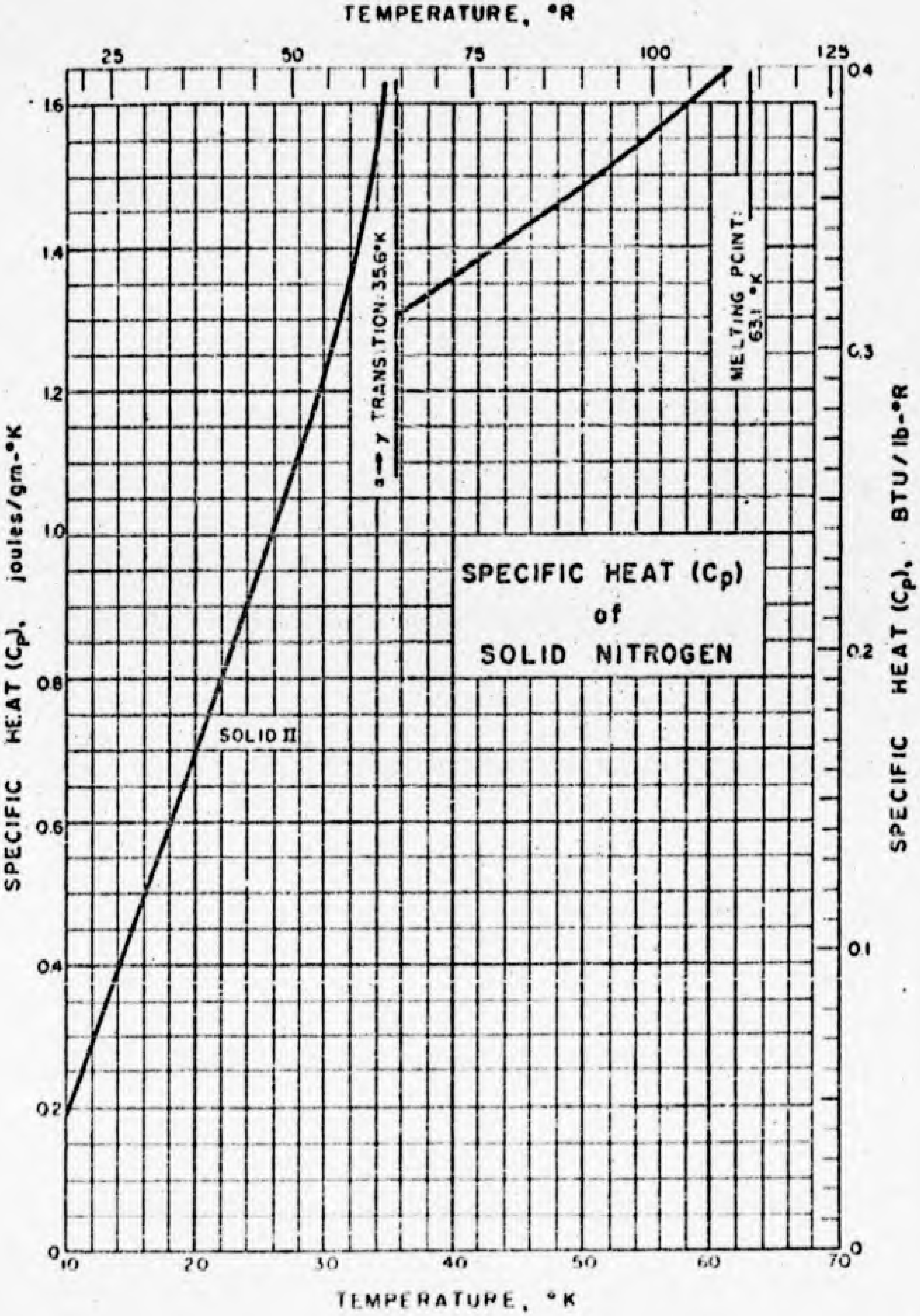
Sources of Data: Yendall, E. F., Proceedings of the 1958 Cryogenic Eng. Conf., 47-64 (1959).

Comments: The values presented by Yendall were calculated from the PVT observations made at Leiden University and at the Physikalisch-Technische Reichsanstalt.

Enthalpy of Gaseous Neon, cal/gm

Temp. °K	Pressure, atm. 1	10	100	200
30	200.56			
35	201.94			
40	203.26	200.68		
45	204.55	202.68		
50	205.81	204.38	198.27	
55	207.07	205.92	198.00	
60	208.31	207.38	198.88	
65	209.56	208.75	201.07	
70	210.80	210.11	203.48	
75	212.04	211.44	205.76	200.93
80	213.27	212.75	207.85	203.57
85	214.52	214.04	209.77	206.23
90	215.75	215.33	211.57	208.55
95	216.99	216.60	213.28	210.68
100	218.22	217.88	214.93	212.68
105	219.44	219.15	216.52	214.56
110	220.68	220.40	218.06	216.37
115	221.91	221.66	219.56	218.10
120	223.15	222.91	221.03	219.77
125	224.38	224.17	222.48	221.40
130	225.61	225.41	223.90	223.00
135	226.84	226.67	225.31	224.55
140	228.07	227.92	226.70	226.07
145	229.30	229.16	228.07	227.56
150	230.53	230.41	229.44	229.04
155	231.77	231.64	230.79	230.50
160	233.00	232.88	232.13	231.94
165	234.23	234.13	233.47	233.36
170	235.46	235.36	234.80	234.77

Temp. °K	Pressure, atm. 1	10	100	200
175	236.68	236.61	236.12	236.16
180	237.92	237.84	237.43	237.56
185	239.15	239.08	238.74	238.93
190	240.38	240.32	240.05	240.29
195	241.61	241.56	241.34	241.65
200	242.85	242.79	242.64	243.00
205	244.07	244.03	243.93	244.35
210	245.30	245.26	245.22	245.68
215	246.53	246.50	246.51	247.02
220	247.76	247.74	247.78	248.34
225	249.00	248.97	249.06	249.66
230	250.22	250.21	250.34	250.98
235	251.45	251.44	251.62	252.28
240	252.68	252.68	252.89	253.59
245	253.91	253.91	254.16	254.90
250	255.15	255.15	255.42	256.20
255	256.37	256.38	256.69	257.50
260	257.60	257.60	257.96	258.80
265	258.83	258.84	259.22	260.08
270	260.06	260.07	260.49	261.37
275	261.30	261.31	261.74	262.66
280	262.52	262.54	263.00	263.95
285	263.76	263.78	264.27	265.22
290	264.99	265.01	265.52	266.51
295	266.21	266.25	266.78	267.79
300	267.44	267.47	268.03	269.07
305	268.67	268.70	269.29	270.33
310	269.91	269.94	270.54	271.61
315	271.13	271.17	271.79	272.87
320	272.36	272.41	273.05	274.15


TEMPERATURE, °R
25
50
75
100
125
SPECIFIC HEAT (Cp) of SOLID NITROGEN
α → γ TRANSITION: 35.6°K
MELTING POINT: 63.1 °K
SOLID II
SPECIFIC HEAT (Cp), joules/gm-°K
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
SPECIFIC HEAT (Cp), BTU/lb-°R
0
0.1
0.2
0.3
0.4
10
20
30
40
50
60
70
TEMPERATURE, °K

SPECIFIC HEAT (C_p) of SOLID NITROGEN

Sources of Data: Clusius, K., Z. physik Chem. B3, 41-79 (1929); Giauque, W. F. and Clayton, J. O., J. Am. Chem. Soc. 55, 4875-89 (1933); International Critical Tables (1930); Keesom, W. H. and Onnes, H. K., Comm. Phys. Lab. Univ. Leiden, Comm. No. 149a (1916).

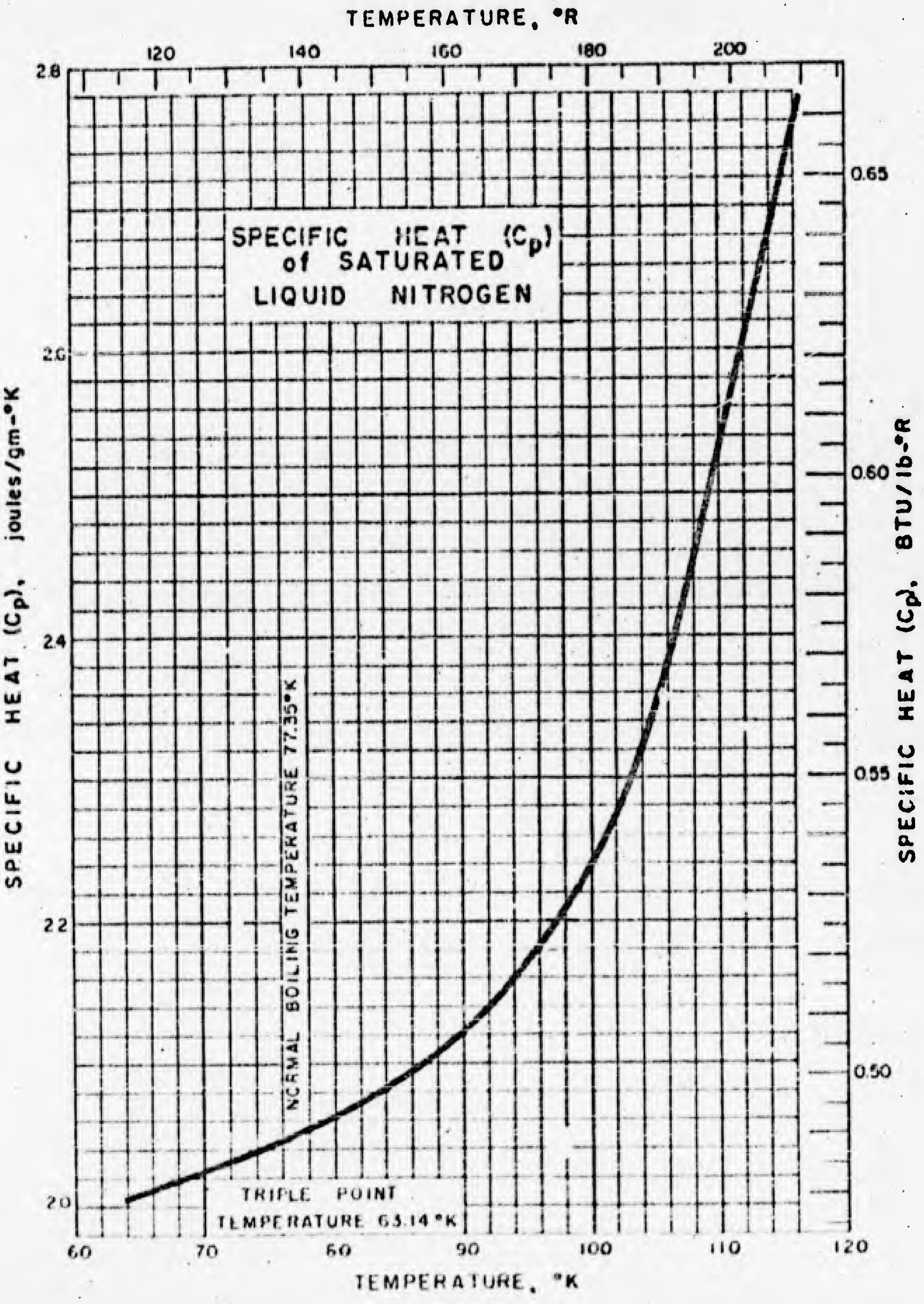
Comments: The data from the above references are not in complete agreement. The graph on the previous page is an average of all the data tabulated below.

Table of Selected Values

Temp. °K	C_p cal/gm-mole °K	Temp. °K	C_p cal/gm-mole °K	Temp. °K	C_p cal/gm-mole °K
10.42	1.362	20.75	4.860	39.13	8.948
10.71	1.447	20.75	4.98	39.16	8.82
11.08	1.544	20.78	4.86*	39.40	9.00
11.33	1.600	20.93	5.02	40.8	9.176
11.67	1.714	21.40	4.995	43.1	9.380
12.18	1.875	21.71	4.94	43.27	9.325
12.60	2.073	21.8	5.305	45.88	9.48
13.31	2.328	21.94	5.447	45.9	9.610
13.59	2.462	23.8	5.920	48.07	9.752
13.77	2.506	24.49	6.331	48.7	9.850
14.39	2.692	24.85	6.380	51.88	10.09
15.07	2.871	25.8	6.623	51.9	10.17
15.27	3.20	27.14	7.170	53.55	10.26
15.72	3.196	27.5	7.308	55.26	10.32
15.82	3.124	28.32	7.540	55.4	10.52
15.82	3.124	29.4	7.813	55.88	10.44
16.00	3.322	29.89	8.137	56.04	10.30
16.50	3.55	31.0	8.440	56.12	10.10
16.72	3.528	31.29	8.643	56.85	10.39
17.03	3.624	32.8	9.079	57.99	10.65
17.49	3.742	32.84	9.397	58.5	10.82
17.66	3.840	34.3	10.26	60.0	11.02
18.40	4.084	34.42	[illegible]	61.32	10.54
18.44	4.065	34.68	10.49	61.40	11.09
19.12	4.229	35.05	10.84	61.41	11.07
19.51	4.577	35.33	10.97	61.41	11.07
19.95	4.492	α-β transition: 35.6°K		61.68	10.95
20.15	4.542	35.8	[illegible]	Melting pt: 63.1°K	

* considered in error by authors

EDP/BDP Issued: 7/15/59


TEMPERATURE, °R
120
140
160
180
200
SPECIFIC HEAT (C_p) of SATURATED LIQUID NITROGEN
2.8
2.6
2.4
2.2
2.0
SPECIFIC HEAT (C_p), joules/gm-°K
0.65
0.60
0.55
0.50
SPECIFIC HEAT (C_p), BTU/lb-°R
NORMAL BOILING TEMPERATURE 77.35°K
TRIPLE POINT TEMPERATURE 63.14°K
60
70
80
90
100
110
120
TEMPERATURE, °K

4.004

SPECIFIC HEAT (C_p) of Liquid Nitrogen

(at saturation)

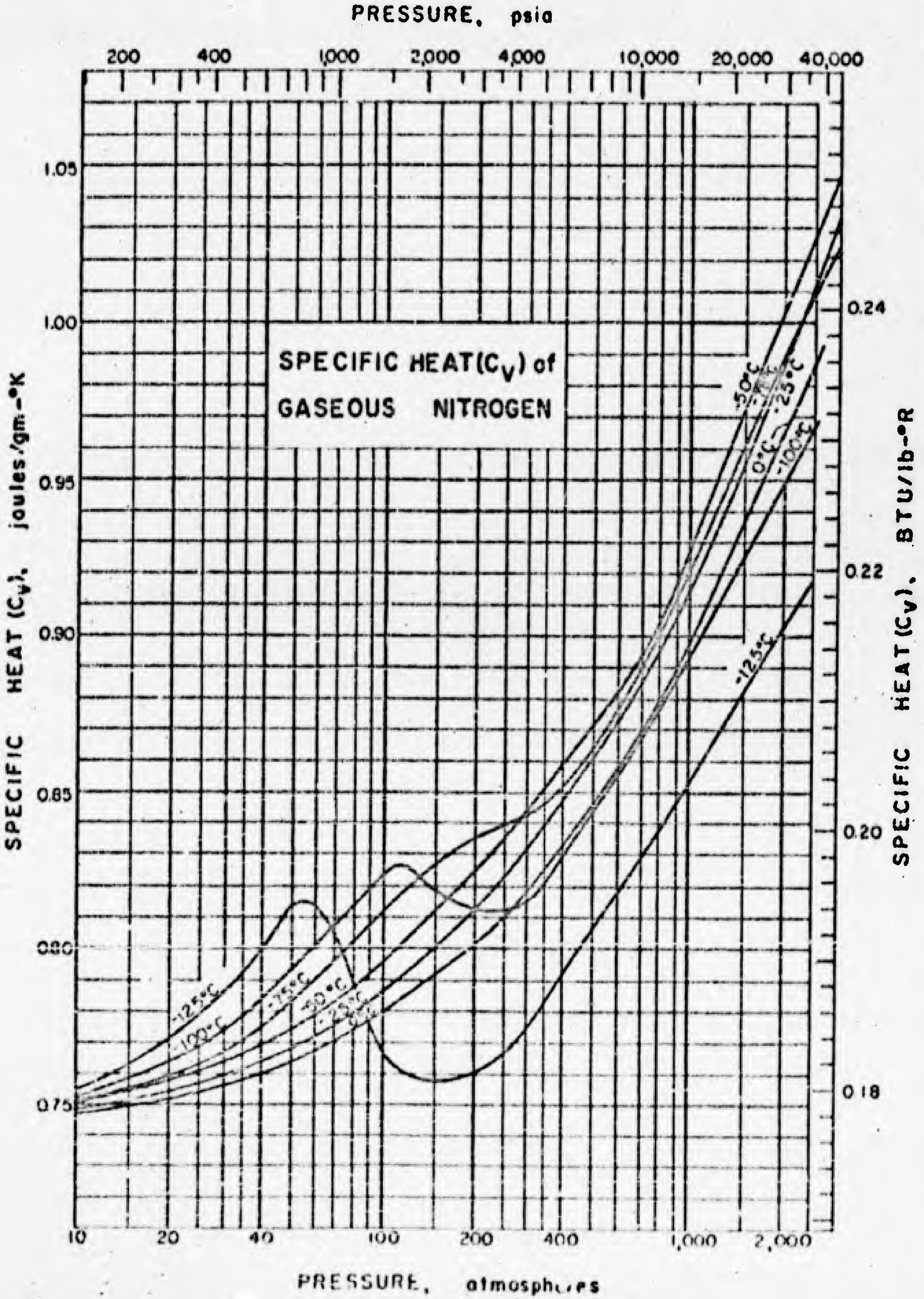
Sources of Data: Clusius, K., Z. physik Chem. Abt. B3, 41-79 (1929); Giauque, W. F. and Clayton, J. O., J. Am. Chem. Soc. 55, 4875-89 (1933); Keesom, W. H. and Onnes, H. K., Comm. Phys. Lab. Univ. Leiden, Comm. No. 149a (1916); Wiebe, R. and Brevoort, M. J., J. Am. Chem. Soc. 52, 622-33 (1930).

Comments: The above references are not in complete agreement as can be seen by the table below. The graph on the previous page is an average of all the tabulated data.

Table of Selected Values

Temp. °K	C_p cal/gm-mole -°K	Temp. °K	C_p cal/gm-mole -°K
63.95	13.34	79.17	13.76
65.02	13.33	82.64	13.95
66.9	13.54	89.50	14.16
68.4	13.64	95.39	14.50
68.41	13.45	95.46	14.71
69.15	13.40	99.55	15.04
70.2	13.63	103.31	15.63
70.28	13.45	103.72	15.56
71.8	13.66	107.72	15.99
72.69	13.56	107.48	16.10
73.5	13.69	111.57	17.30
74.57	13.59	112.97	17.60
75.46	13.74	115.25	18.27
76.58	13.68	116.99	18.72
77.74	13.64		

4.004


PRESSURE, psia
200
400
1,000
2,000
4,000
10,000
20,000
40,000
SPECIFIC HEAT(C$_V$) of GASEOUS NITROGEN
SPECIFIC HEAT (C$_V$), joules/gm-°K
1.05
1.00
0.95
0.90
0.85
0.80
0.75
SPECIFIC HEAT (C$_V$), BTU/lb-°R
0.24
0.22
0.20
0.18
-125°C
-100°C
-75°C
-50°C
-25°C
0°C
-50°C
-75°C
0°C
-25°C
-100°C
-125°C
10
20
40
100
200
400
1,000
2,000
PRESSURE, atmospheres

4.004

SPECIFIC HEAT (C_v) of GASEOUS NITROGEN

Source of Data:

Lunbeck, R. J., Michels, A., and Wolkers, G. J., Appl. Sci. Research A3, 197-210 (1952).

Comments:

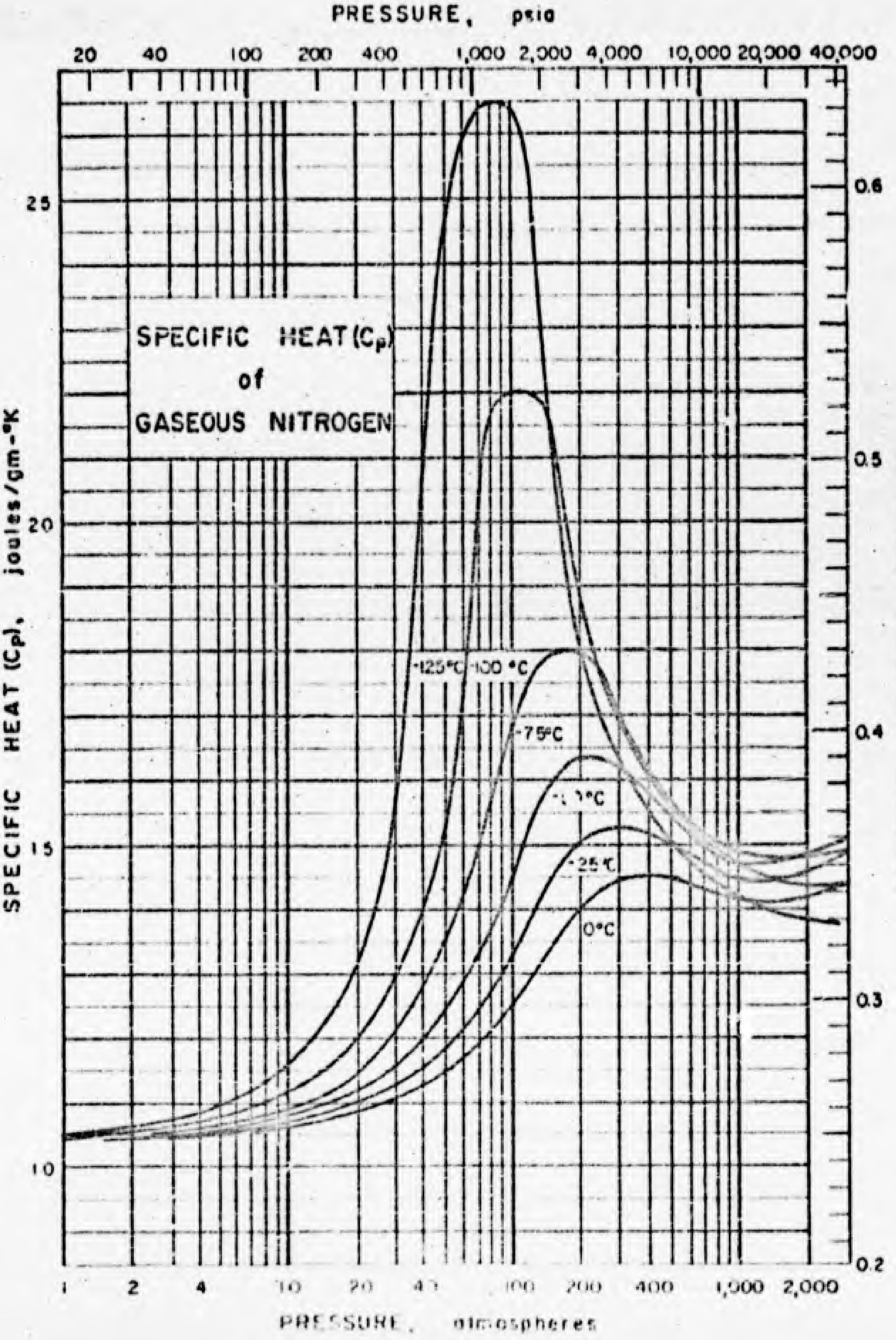
The peaks of the curves are only estimates since the original data are insufficient at these points.

The temperature conversion used for the graph was 0°C = 273.15°K.

Table of Selected Values

Pressure	Specific Heat (C_v), cal/gm-mole-°K					
atm	-125°C	-100°C	-75°C	-50°C	-25°C	0°C
0	4.967	4.968	4.968	4.968	4.969	4.970
10	5.055	5.03	5.02	5.01	5.00	4.995
30	5.255	5.165	5.125	5.09	5.065	5.045
50	5.45	5.305	5.225	5.17	5.125	5.095
100	5.135	5.51	5.425	5.34	5.265	5.20
200	5.095	5.425	5.58	5.53	5.44	5.35
300	5.17	5.455	5.64	5.65	5.565	5.46
400	5.27	5.54	5.70	5.74	5.665	5.56
600	5.465	5.71	5.87	5.91	5.34	5.735
800	5.60	5.86	6.03	6.06	5.99	5.88
1000	5.71	5.98	6.17	6.20	6.125	6.00
1200	5.795	6.075	6.29	6.33	6.245	6.11
1500	5.90	6.195	6.435	6.50	6.40	6.25
2000	6.03	6.345	6.62	6.71	6.62	6.44
2500	6.13	6.465	6.76	6.875	6.79	6.60
3000	6.22	6.565	6.875	7.01	6.93	6.735

KDT/RDT Issued: 6/22/59


SPECIFIC HEAT (C$_p$) of GASEOUS NITROGEN
PRESSURE, psia
20
40
100
200
400
1,000
2,000
4,000
10,000
20,000
40,000
SPECIFIC HEAT (C$_p$), joules/gm-°K
25
20
15
10
SPECIFIC HEAT (C$_p$), BTU/lb-°R
0.6
0.5
0.4
0.3
0.2
-125°C
-100°C
-75°C
-50°C
-25°C
0°C
1
2
4
10
20
40
100
200
400
1,000
2,000
PRESSURE, atmospheres

4.004

SPECIFIC HEAT (C_p) OF GASEOUS NITROGEN

Source of Data:

Lunbeck, R. J., Michels, A., and Wolkers, G. J.; Appl. Sci. Research A3, 197-210 (1952).

Comments:

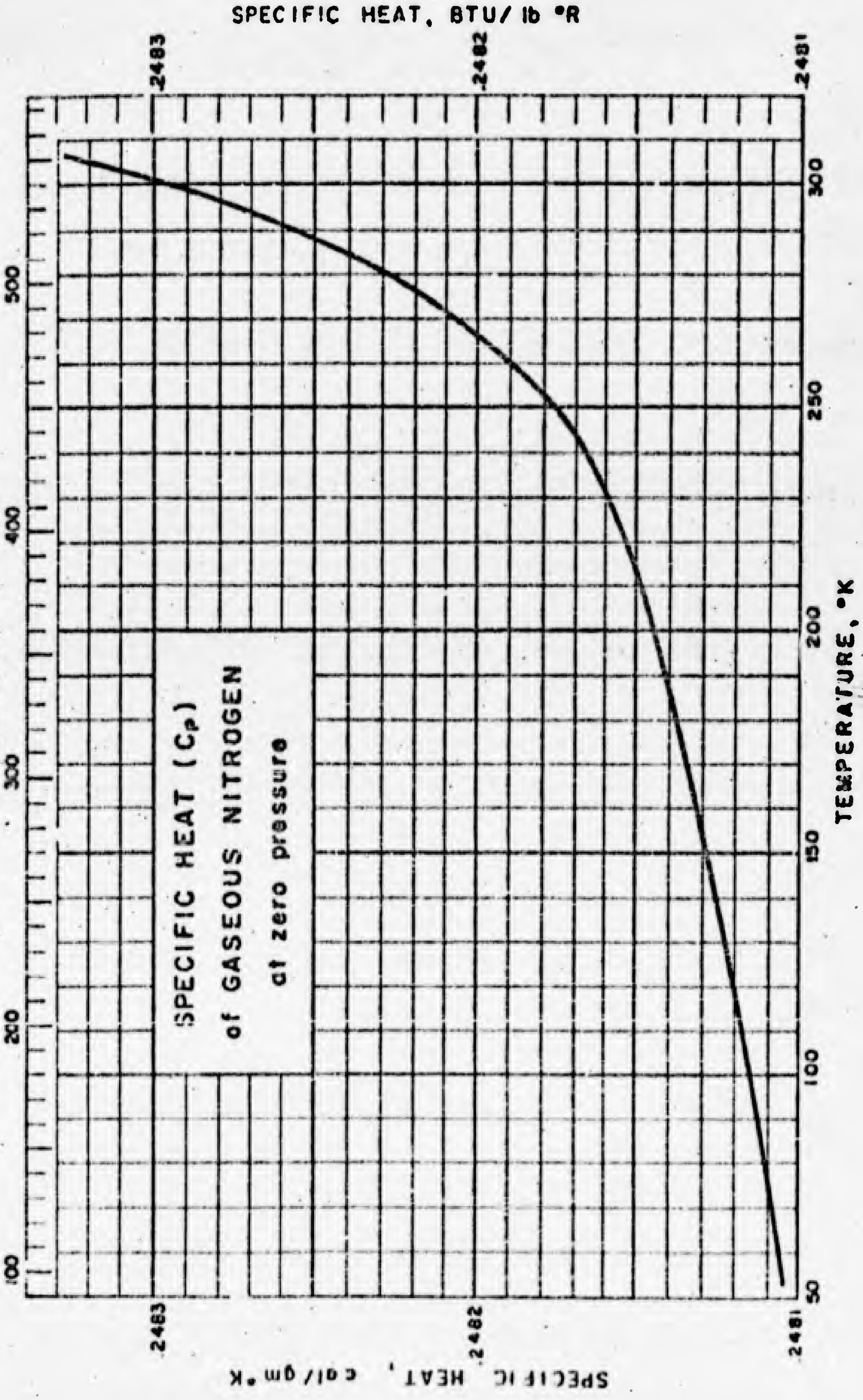
The peaks of the curves are only estimates since the original data are insufficient at these points.

The temperature conversion used for the graph was 0°C = 273.15°K.

Table of Selected Values

Pressure Atm.	Specific Heat C_p, cal/gm mole °K					
	-125°C	-100°C	-75°C	-50°C	-25°C	0°C
0	6.954	6.954	6.954	6.955	6.955	6.956
1	7.018	6.989	6.983	6.977	6.975	6.971
3	7.171	7.103	7.060	7.030	7.015	7.001
5	7.314	7.204	7.133	7.089	7.057	7.034
10	7.72	7.465	7.310	7.213	7.153	7.107
30	10.30	8.70	8.09	7.73	7.53	7.39
50	16.52	10.22	8.90	8.28	7.91	7.69
100	17.66	14.73	11.11	9.60	8.82	8.37
200	12.30	12.74	12.05	10.93	9.96	9.27
300	11.03	11.45	11.35	10.85	10.20	9.60
400	10.45	10.83	10.85	10.60	10.12	9.68
600	9.92	10.21	10.29	10.18	9.90	9.59
800	9.66	9.96	10.03	9.93	9.76	9.49
1000	9.51	9.83	9.94	9.82	9.67	9.43
1200	9.40	9.75	9.90	9.80	9.62	9.41
1500	9.30	9.68	9.87	9.83	9.61	9.40
2000	9.23	9.62	9.87	9.91	9.70	9.44
2500	9.20	9.60	9.92	9.98	9.80	9.50
3000	9.26	9.65	9.93	10.05	9.39	9.58

[illegible] Issued: 6-18-59



SPECIFIC HEAT (C$_p$) of GASEOUS NITROGEN at zero pressure

4.004

SPECIFIC HEAT (C_p) OF GASEOUS NITROGEN
at Zero Pressure

Source of Data:

Goff, J. A. and Gratch, S., Trans. ASME 72, 741-9 (1950)

Comments:

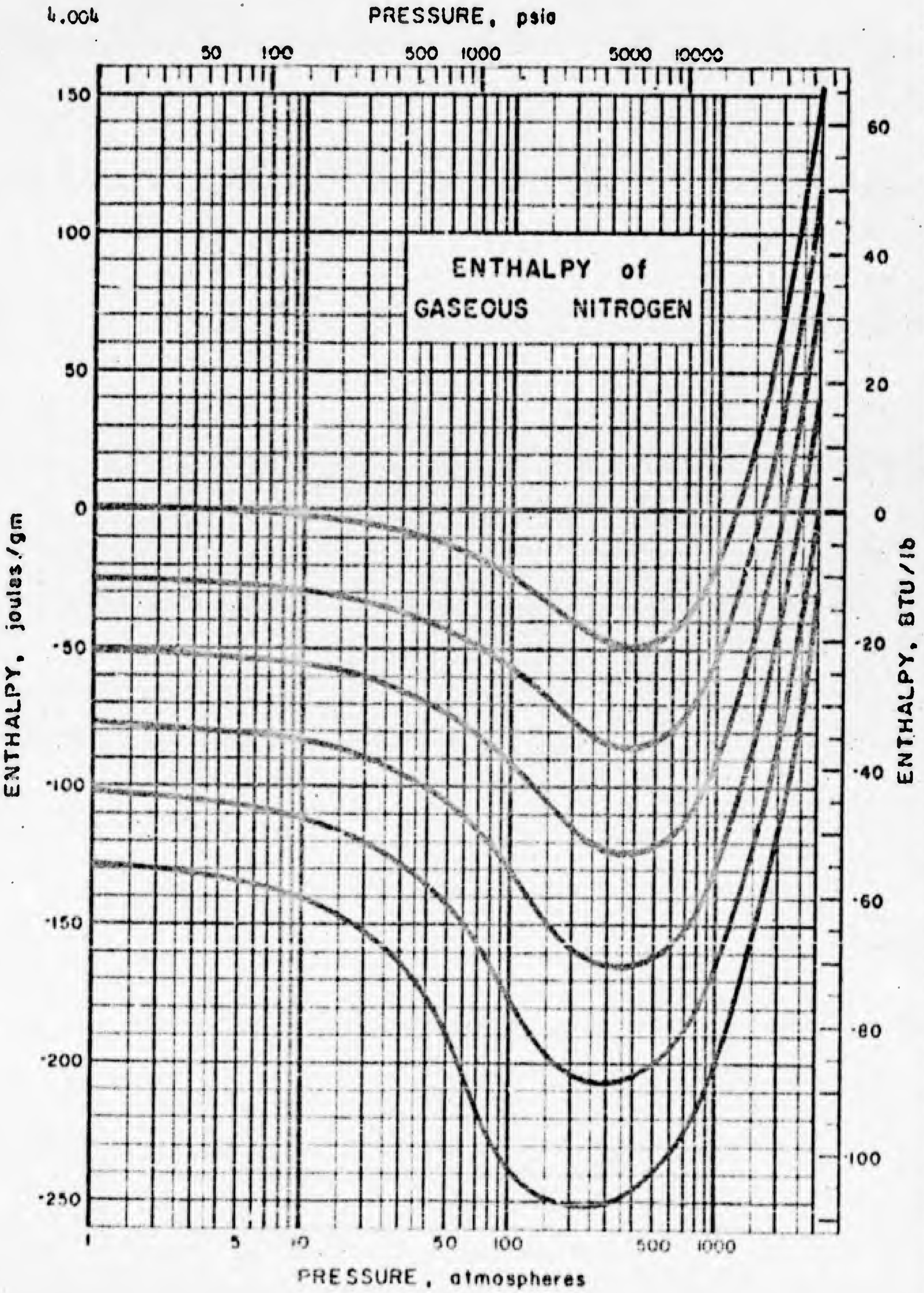
The data given below are the most accurate values of C_p at zero pressure available.

Table of Selected Values

Temperature		Specific Heat at Zero Pressure cal/gm-mole °K	Temperature		Specific Heat at Zero Pressure cal/gm-mole °K
°R	°K		°R	°K	
100	55.56	6.950 91	230	127.78	6.951 39
105	58.34	6.950 92	240	133.33	6.951 43
110	61.11	6.950 93	260	144.44	6.951 52
115	63.89	6.950 95	280	155.56	6.951 61
120	66.67	6.950 96	300	166.67	6.951 70
125	69.45	6.950 97	320	177.78	6.951 79
130	72.22	6.950 99	340	188.89	6.951 88
140	77.78	6.951 03	360	200.00	6.951 99
150	83.33	6.951 06	380	211.11	6.952 11
160	88.89	6.951 10	400	222.22	6.952 27
170	94.44	6.951 14	420	233.33	6.952 47
180	100.00	6.951 18	440	244.44	6.952 73
190	105.56	6.951 22	460	255.56	6.953 10
200	111.11	6.951 26	480	266.67	6.953 59
210	116.67	6.951 31	500	277.78	6.954 25
220	122.22	6.951 35	550	305.56	6.956 95

KDT/BDT Issued: 5/25/59

4.004


PRESSURE, psia
50
100
500
1000
5000
10000
ENTHALPY of GASEOUS NITROGEN
ENTHALPY, joules/gm
150
100
50
0
-50
-100
-150
-200
-250
ENTHALPY, BTU/lb
60
40
20
0
-20
-40
-60
-80
-100
1
5
10
50
100
500
1000
PRESSURE, atmospheres

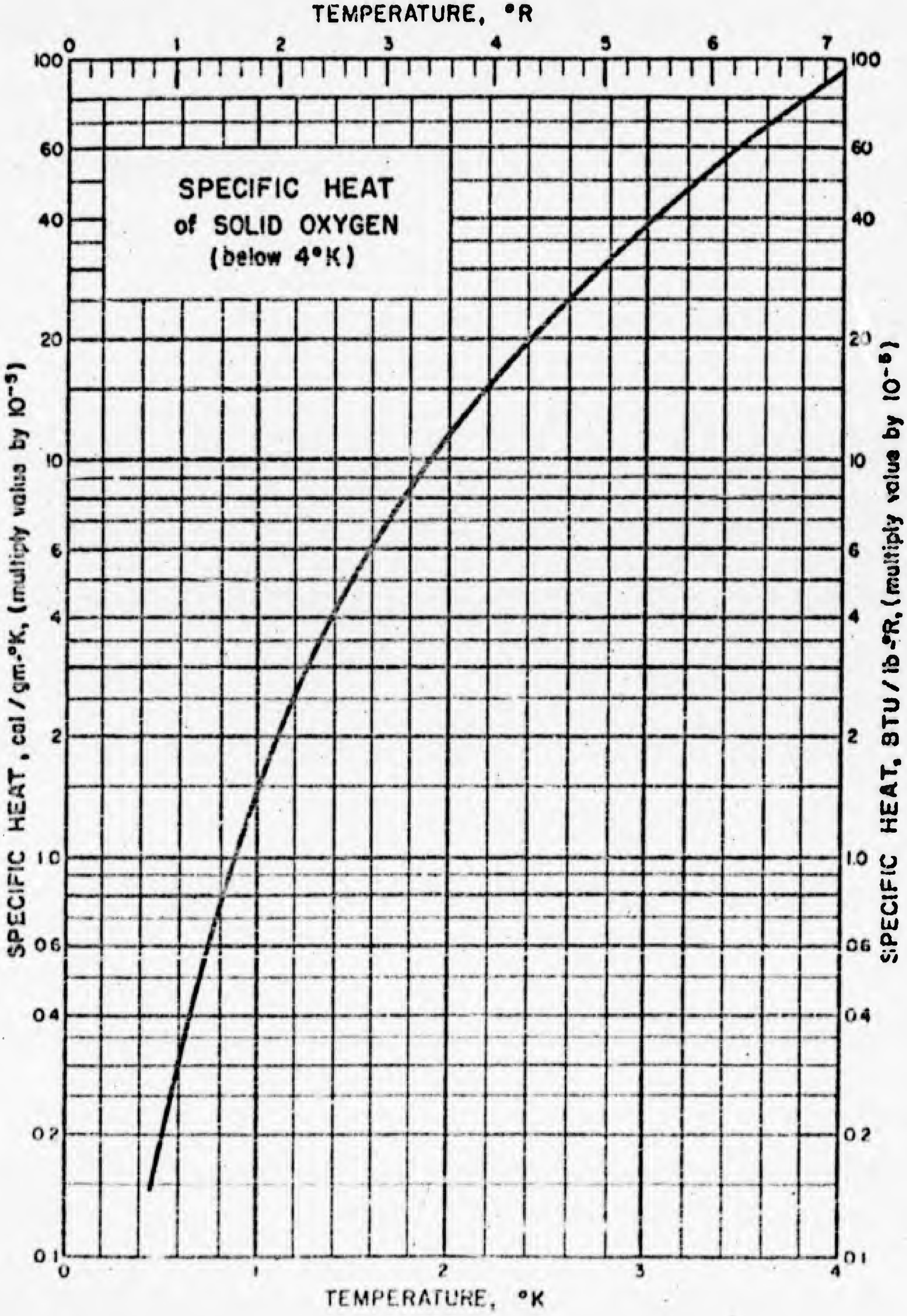
ENTHALPY of GASEOUS NITROGEN

Source of Data: Lunbeck, R. J., Michels, A., and Wolkers, G. J., Appl. Sci. Research A3, 197-210 (1952)

Comments: The basis for the enthalpy values given below is H = 0 at 1 atm and 0°C. The temperature conversion used was 0°C = 273.15°K.

Table of Selected Values

Pressure atm.	Enthalpy, cal/gm mole					
	-125°C	-100°C	-75°C	-50°C	-25°C	0°C
0	- 867.5	- 693.6	- 519.8	-345.9	-172.0	+ 1.8
1	- 873.6	- 698.4	- 523.5	-348.7	-174.4	0.0
3	- 885.5	- 707.8	- 530.9	-354.5	-179.1	- 3.8
5	- 898.2	- 717.4	- 538.3	-360.2	-183.8	- 7.5
10	- 929.3	- 740.9	- 556.8	-374.6	-195.3	- 16.8
30	-1070.2	- 838.3	- 629.9	-431.2	-240.0	- 52.9
50	-1250.6	- 937.5	- 701.8	-486.5	-283.0	- 86.9
100	-1604.1	-1181.7	- 864.9	-609.1	-378.2	-164.7
200	-1686.8	-1372.1	-1060.7	-772.1	-510.5	-272.3
300	-1680.0	-1396.0	-1111.2	-832.0	-568.7	-323.1
400	-1647.5	-1379.5	-1109.1	-839.2	-579.7	-334.7
600	-1557.2	-1304.4	-1048.6	-790.0	-536.8	-296.0
800	-1453.2	-1207.1	- 957.9	-704.7	-455.2	-217.7
1000	-1343.1	-1100.8	- 854.8	-604.5	-357.2	-121.6
1200	-1230.2	- 990.2	- 746.0	-497.1	-250.6	- 16.2
1500	-1057.9	- 820.4	- 577.5	-329.2	- 82.8	+151.0
2000	- 769.2	- 533.8	- 291.5	- 42.3	+205.2	440.3
2500	- 481.0	- 246.7	- 4.4	+246.0	495.4	733.2
3000	- 195.3	+ 39.7	+ 281.4	532.9	784.6	1025.8


TEMPERATURE, °R
0
1
2
3
4
5
6
7
SPECIFIC HEAT
of SOLID OXYGEN
(below 4°K)
100
60
40
20
10
6
4
2
1.0
0.6
0.4
0.2
0.1
SPECIFIC HEAT, cal/gm-°K, (multiply value by 10⁻⁵)
SPECIFIC HEAT, BTU/lb-°R, (multiply value by 10⁻⁵)
0
1
2
3
4
TEMPERATURE, °K

4.005

SPECIFIC HEAT of SOLID OXYGEN
(Below 4°K)

Source of Data: Kostryukova, M. O. and Strelkov, P. G., Doklady Acad. Nauk., U.S.S.R., 90, 525-8 (1953).

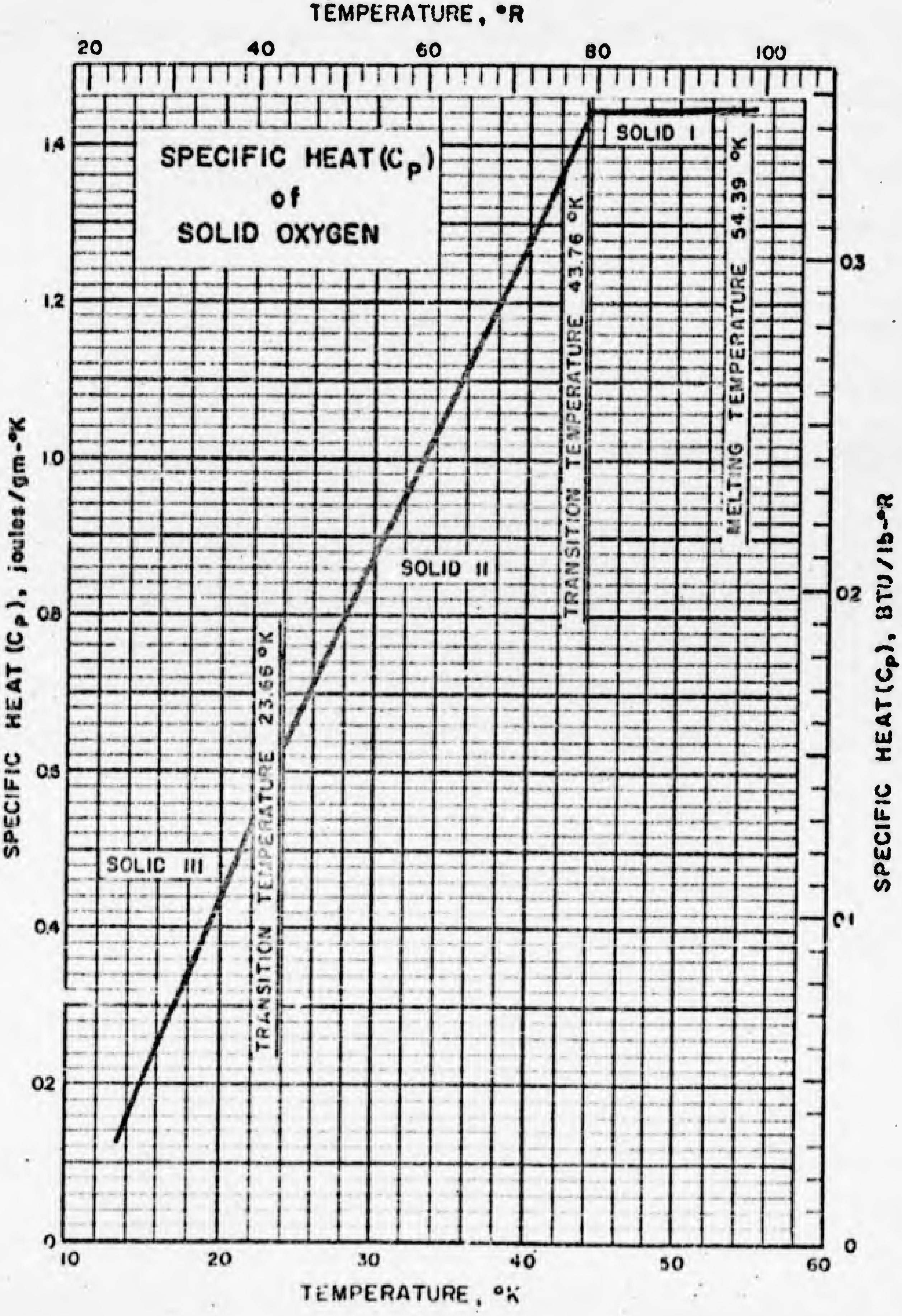
Comments: The above reference gave no tabular data. The original data was a graph of the ratio of specific heat to temperature versus temperature squared. The resulting curve was a straight line of the equation

$$\frac{C}{T} = 0.0000146\ T^2$$

where T is in °K and C is in cal/gm-°K. C may be taken as either C_p or C_v since there is no significant difference between these two specific heats in this temperature range. The following table was calculated from the above equation:

Temp. °K	Heat Capacity cal/gm-°K
0	0
0.5	0.182×10^{-5}
1	1.46 "
1.5	4.93 "
2	11.7 "
2.5	22.8 "
3	39.4 "
3.5	62.6 "
4	93.4 "

JM/RJR Issued: 7/20/59


TEMPERATURE, °R
20
40
60
80
100
SPECIFIC HEAT (Cp) of SOLID OXYGEN
SOLID I
SOLID II
SOLIC III
TRANSITION TEMPERATURE 43.76 °K
MELTING TEMPERATURE 54.39 °K
TRANSITION TEMPERATURE 23.66 °K
SPECIFIC HEAT (Cp), joules/gm-°K
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
SPECIFIC HEAT (Cp), BTU/lb-°R
0.3
0.2
0.1
0
10
20
30
40
50
60
TEMPERATURE, °K

4.005

SPECIFIC HEAT (C_p) of SOLID OXYGEN

Source of Data:

Giauque, W. R. and Johnston, H. L., J. Am. Chem. Soc. 51, 2300 (1929)

Other References:

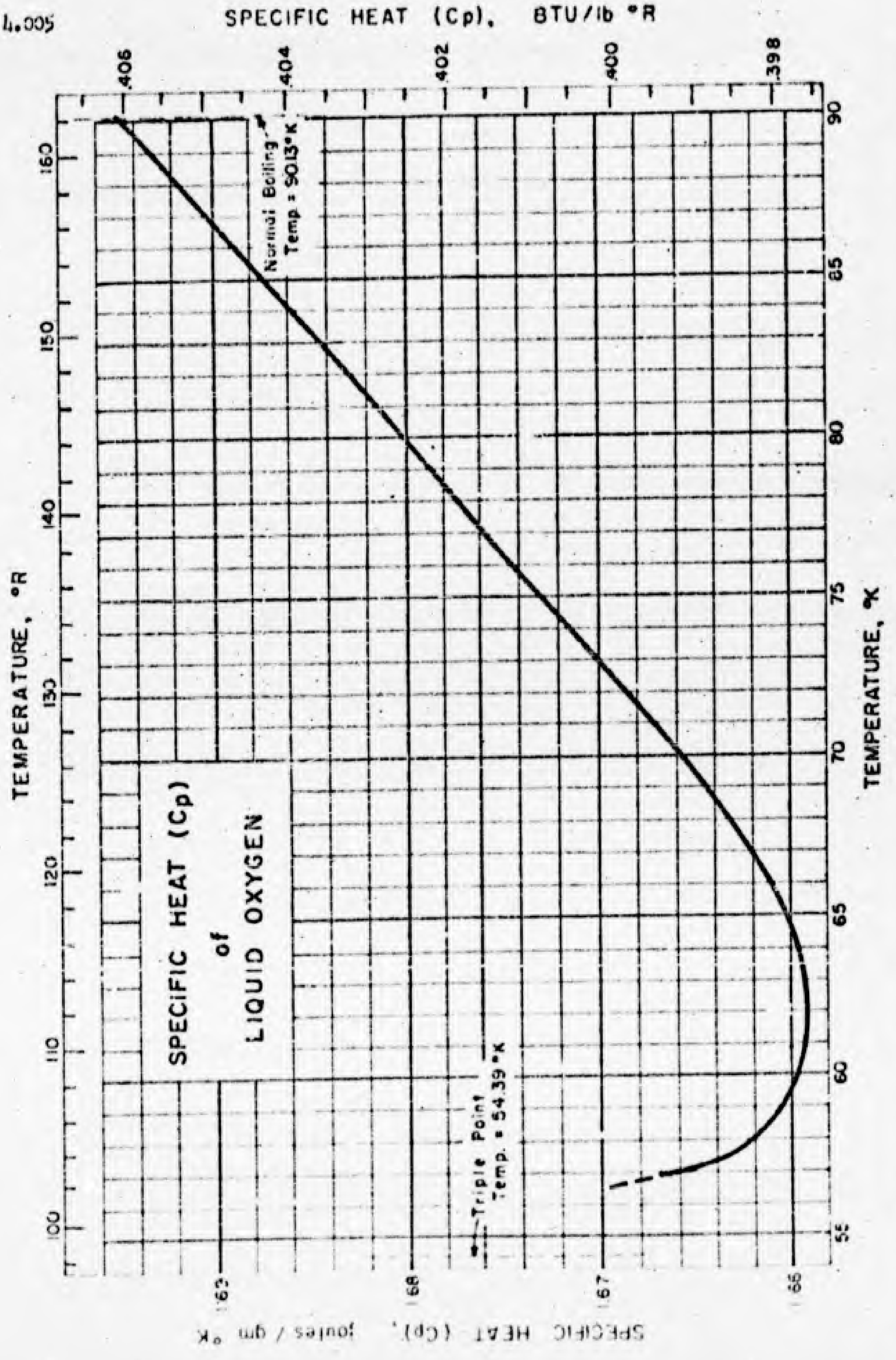
Borovik-Romanov, A. S., Orlova, M. P. and Strelkov, P. G., Doklady Akad. Nauk S.S.S.R. 99, 699-704 (1954)

Table of Selected Values

Temp. °K	C_p cal/mole deg
Solid III	
12.97	1.10
14.14	1.52
15.12	1.60
15.57	1.79
16.66	2.33
16.80	2.18
16.94	2.25
18.13	2.67
18.32	2.71
18.45	2.79
19.34	3.07
20.26	3.50
20.33	3.52
20.85	3.60
21.84	4.20
22.24	4.27
22.24	4.40
23.66*	
Solid II	
25.02	5.42
25.61	5.57
25.61	5.47
26.75	5.75
28.00	6.05
28.08	6.42
29.88	6.61
30.63	6.94
31.08	6.93
33.05	7.52
33.33	7.73
34.41	8.08
35.57	8.26
35.77	8.49
37.59	9.08
37.85	9.12
38.47	9.80
39.99	9.80
40.18	9.92
40.67	10.16
42.21	10.73
43.76*	
Solid I	
45.90	11.02
47.76	11.07
48.11	11.01
48.97	10.99
50.55	11.01
51.68	11.03
52.12	11.06
54.39**	

* Transition Temperature ** Melting Temperature

JM/RIR Issued: 7/28/59


SPECIFIC HEAT (Cp), BTU/lb °R
.406
.404
.402
.400
.398
TEMPERATURE, °R
100
110
120
130
140
150
160
TEMPERATURE, °K
55
60
65
70
75
80
85
90
SPECIFIC HEAT (Cp) of LIQUID OXYGEN
Normal Boiling Temp = 90.13°K
Triple Point Temp. = 54.39°K
1.69
1.68
1.67
1.66
SPECIFIC HEAT (Cp), joules / gm °K

SPECIFIC HEAT (C_p) of LIQUID OXYGEN

Source of Data:

Giauque, W. R. and Johnston, H. L., J. Am. Chem. Soc. 51, 2300 (1929).

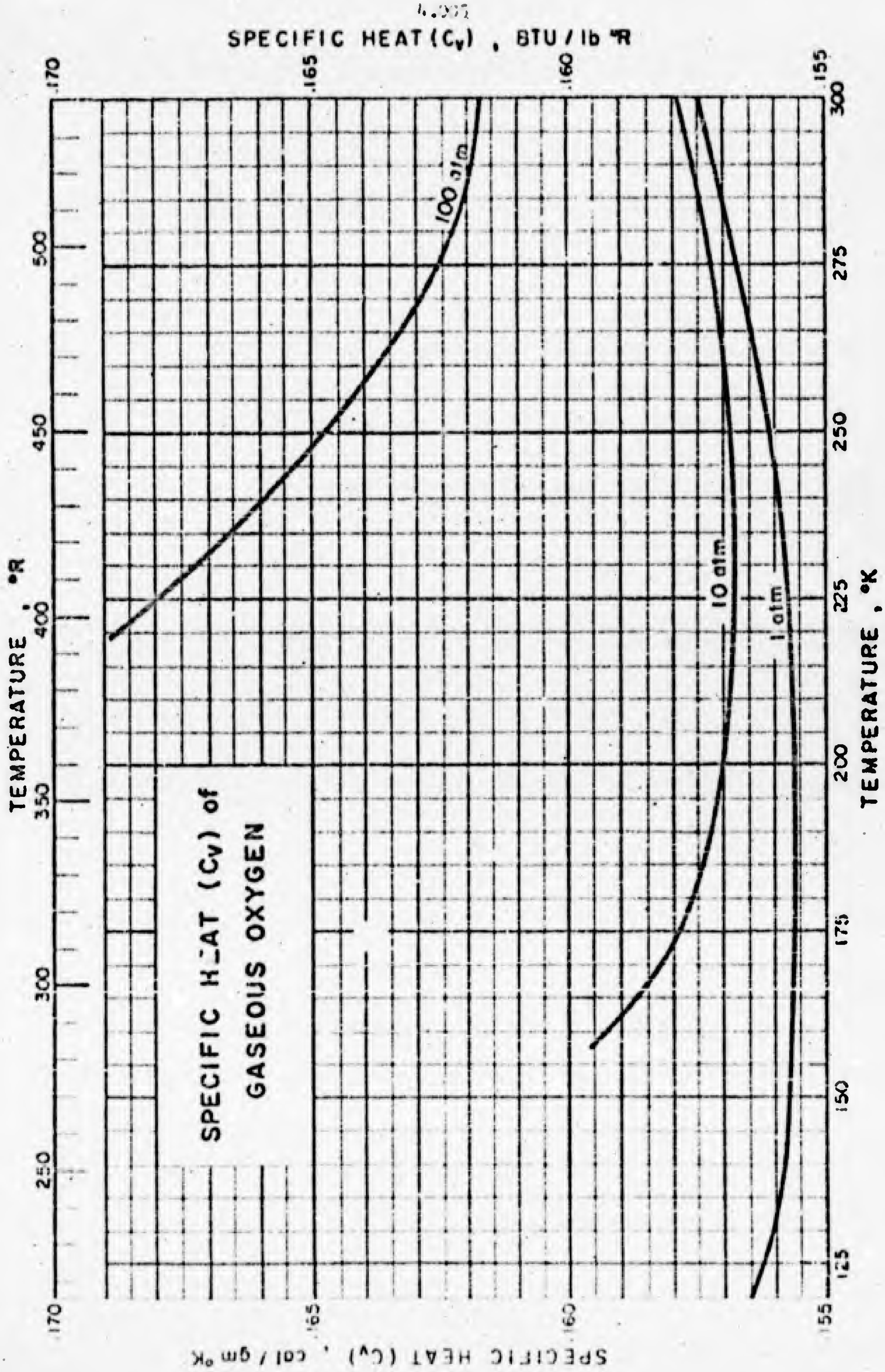
Other References:

Borovik-Romanov, A. S., Orlova, M. P. and Strelkov, P. G., Doklady Akad. Nauk. S.S.S.R. 99, 699-704 (1954).

Table of Selected Values

Temp. °K	C_p cal/mole-°K	Temp. °K	C_p cal/mole-°K
56.95	12.76	75.86	12.80
57.95	12.72	77.58	12.84
60.97	12.71	78.68	12.83
61.48	12.71	81.13	12.88
65.57	12.71	82.31	12.86
65.92	12.71	82.96	12.88
68.77	12.73	84.79	12.93
69.12	12.75	86.43	12.91
70.67	12.77	86.61	12.95
71.38	12.78	86.97	12.92
73.31	12.81	87.32	12.91
74.95	12.85	90.33	12.99

Triple Point Temp. = 54.39°K Normal Boiling Temp. = 90.13°K



SPECIFIC HEAT (Cv) of GASEOUS OXYGEN

SPECIFIC HEAT (C_v) of GASEOUS OXYGEN

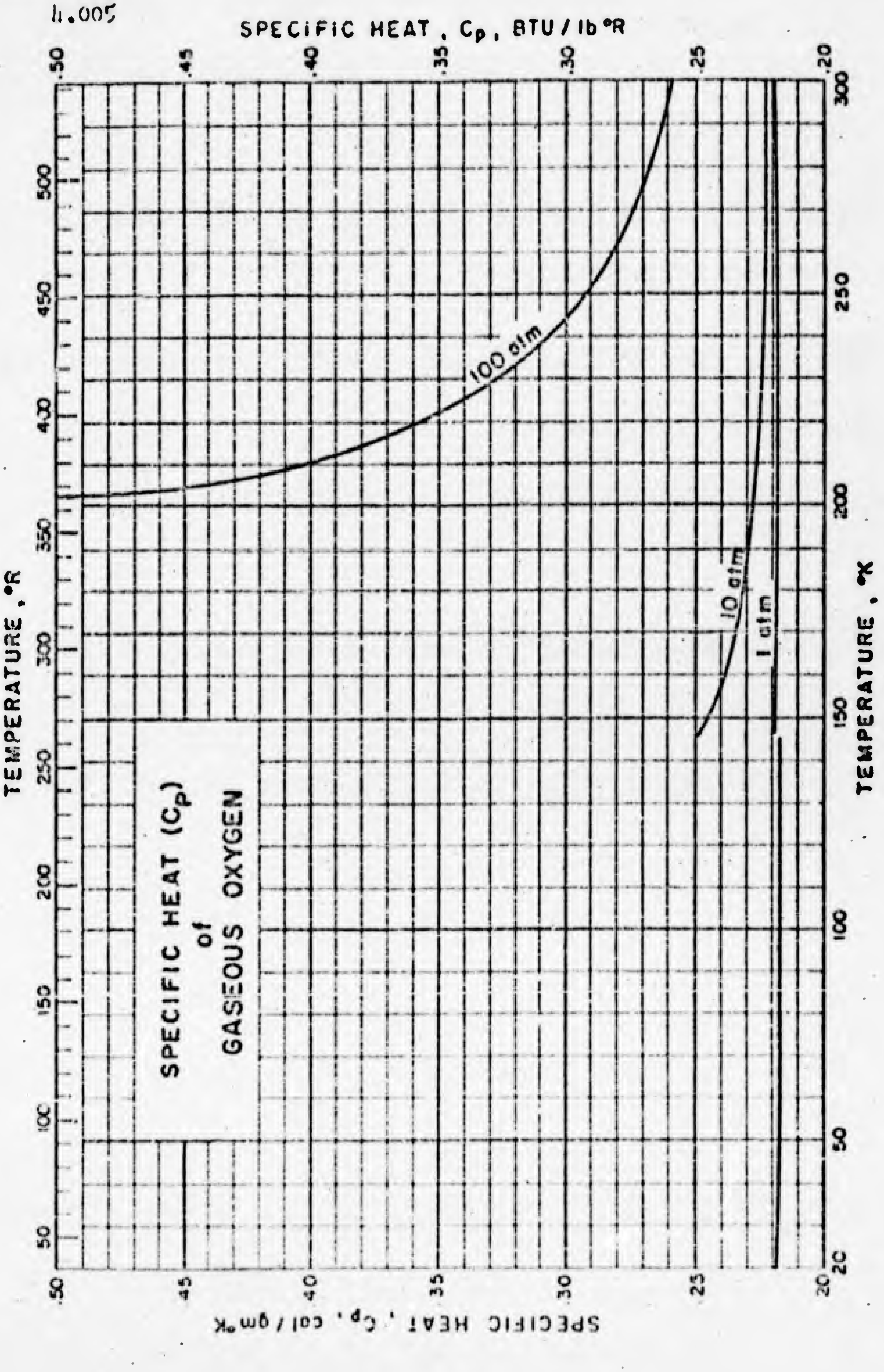
Source of Data: Hilsenrath, J., et al., Nat. Bur. Standards Circ. 564, 400-5 (1955).

Comments: The original data were given as C_p/R and C_p/C_v. C_p/R was divided by C_p/C_v to give C_v/R which was then multiplied by 0.0620997 to give C_v in cal/gm-°K.

Table of Selected Values

Temperature		C_v, cal/gm-°K		
°K	°R	1 atm	10 atm	100 atm
120	216	0.1565		
140	252	0.1558		
160	288	0.1557	0.1593	
180	324	0.1556	0.1576	
200	360	0.1556	0.1570	
220	396	0.1557	0.1568	0.1687
240	432	0.1559	0.1568	0.1662
260	468	0.1563	0.1570	0.1637
280	504	0.1569	0.1573	0.1623
300	540	0.1575	0.1579	0.1617

JM/BDF Issued: 8/25/59


SPECIFIC HEAT (Cp) of GASEOUS OXYGEN
SPECIFIC HEAT, Cp, BTU/lb°R
.50
.45
.40
.35
.30
.25
.20
SPECIFIC HEAT, Cp, cal/gm°K
.50
.45
.40
.35
.30
.25
.20
TEMPERATURE, °R
50
100
150
200
250
300
350
400
450
500
TEMPERATURE, °K
20
50
100
150
200
250
300
100 atm
10 atm
1 atm

SPECIFIC HEAT (C_p) of GASEOUS OXYGEN

Source of Data:

Hilsenrath, J., et al., Nat Bur. Standards Cir. 564, 402-4 (1955)

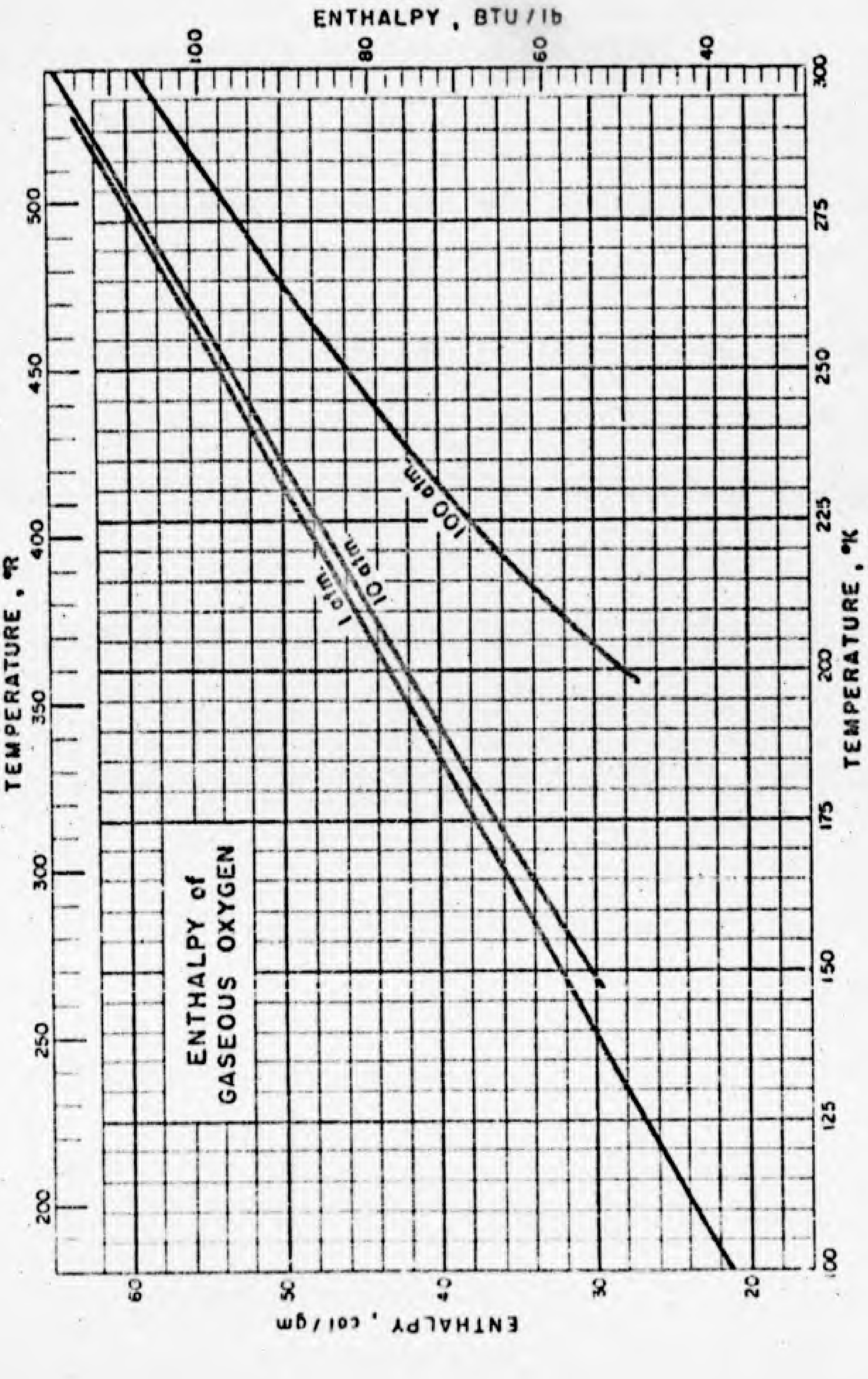
Woolley, H. W., J. Research Nat. Bur. Standards RP 1864, 40 (1948)

Comments:

Specific heat data below 140°K plotted on the graph and shown in the table below were taken from NBS RP 1864. The other data were selected from NBS Circular 564.

Table of Selected Values

Temp. °K	Cp, cal/gm-°K		
	1 ATM.	10 ATM.	100 ATM.
	Data from NBS RP 1864		
20	0.2185		
40	0.2179		
60	0.2177		
80	0.2175		
100	0.2175		
120	0.2175		
140	0.2175		
	Data from NBS Circular 564		
120	0.2214		
130	0.2205		
140	0.2199		
150	0.2195	0.2454	
160	0.2192	0.2389	
170	0.2189	0.2347	
180	0.2188	0.2319	
190	0.2186	0.2298	
200	0.2185	0.2281	0.9720
210	0.2185	0.2269	0.4024
220	0.2185	0.2259	0.3577
230	0.2185	0.2251	0.3273
240	0.2186	0.2245	0.3074
250	0.2187	0.2240	0.2925
260	0.2188	0.2237	0.2817
270	0.2190	0.2234	0.2737
280	0.2193	0.2233	0.2675
290	0.2195	0.2233	0.2626
300	0.2199	0.2233	0.2586


ENTHALPY, BTU/lb
100
80
60
40
TEMPERATURE, °R
200
250
300
350
400
450
500
TEMPERATURE, °K
100
125
150
175
200
225
250
275
300
ENTHALPY, cal/gm
60
50
40
30
20
ENTHALPY of GASEOUS OXYGEN
1 atm.
10 atm.
100 atm.

4.005

ENTHALPY of GASEOUS OXYGEN

Source of Data:

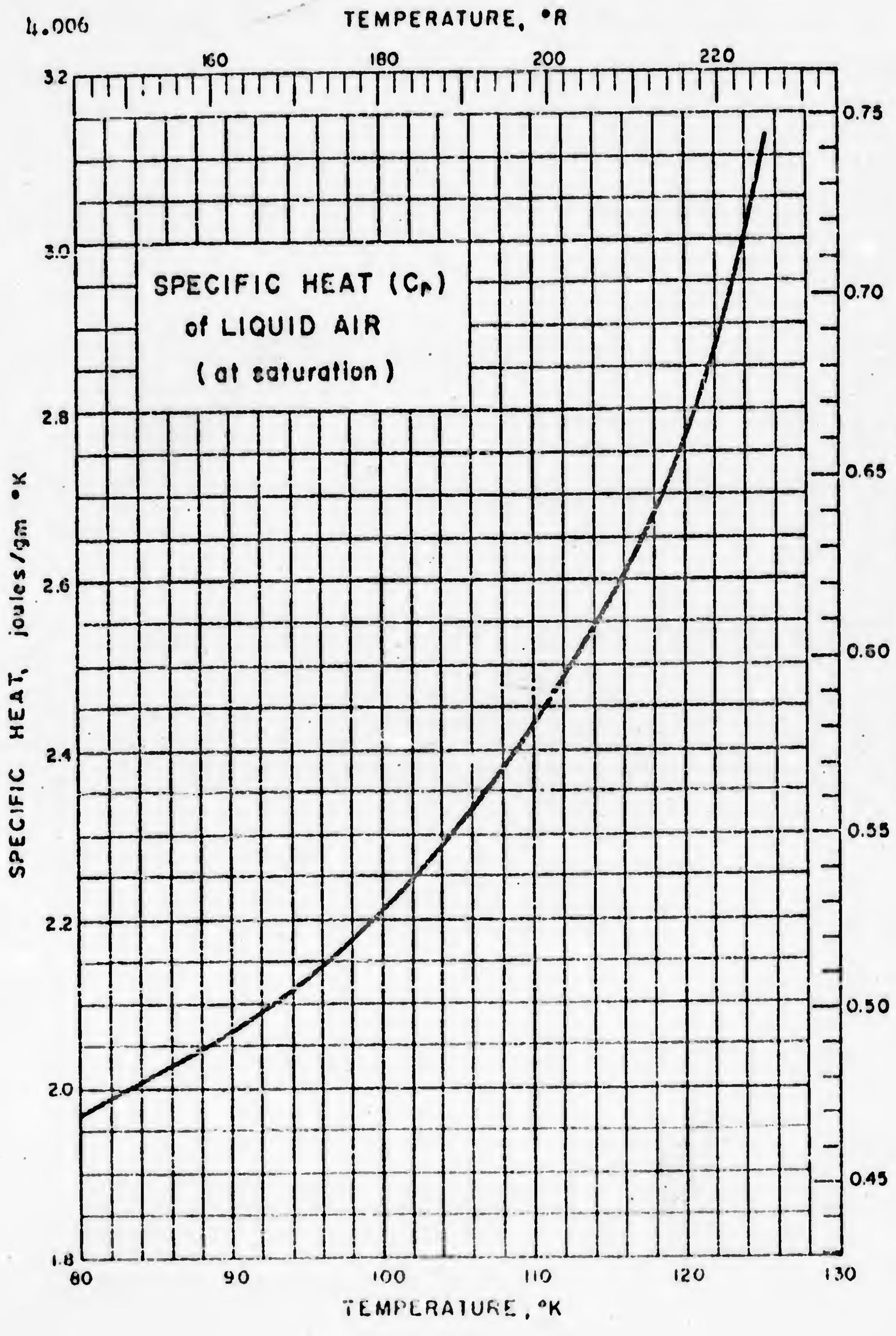
Hilsenrath, J., et al., Nat. Bur. Standards Cir. 564, 406-17 (1955)

Comments:

The data were presented in the form of $(H - E_0°)/RT_0$. This was converted to $(H - E_0°)$ in BTU/lb by multiplying by 30.5137 and to $(H - E_0°)$ in cal/gm by multiplying by 16.9632. $E_0°$ is the internal energy of oxygen at 0°K.

Temperature		Enthalpy $(H - E_0°)$					
		cal/gm			BTU/lb		
°K	°R	1 atm	10 atm	100 atm	1 atm	10 atm	100 atm
100	180	21.27			38.26		
110	198	23.52			42.31		
120	216	25.74			46.30		
130	234	27.95			50.28		
140	252	30.15			54.24		
150	270	32.35	30.47		58.19	54.81	
160	288	34.54	32.89		62.13	59.17	
170	306	36.73	35.26		66.07	63.82	
180	324	38.92	37.59		70.01	67.62	
190	342	41.11	39.90		73.94	71.77	
200	360	43.30	42.19	28.14	77.88	75.89	50.62
210	378	45.48	44.46	32.50	81.81	79.98	58.46
220	396	47.66	46.73	36.27	85.74	84.05	65.24
230	414	49.85	48.98	39.69	89.67	88.11	71.40
240	432	52.03	51.23	42.85	93.60	92.15	77.08
250	450	54.22	53.47	45.85	97.53	96.19	82.48
260	468	56.41	55.71	48.72	101.47	100.21	87.64
270	486	58.60	57.94	51.48	105.41	104.23	92.61
280	504	60.79	60.18	54.20	109.35	108.24	97.49
290	522	62.98	62.41	56.84	113.29	112.26	102.25
300	540	65.18	64.64	59.46	117.25	116.28	106.95

~~JH/RHR Issued: 7/30/59~~
Revised: 8/1/60


TEMPERATURE, °R
160
180
200
220
SPECIFIC HEAT (Cp)
of LIQUID AIR
(at saturation)
SPECIFIC HEAT, joules/gm °K
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
SPECIFIC HEAT, BTU/lb °R
0.75
0.70
0.65
0.60
0.55
0.50
0.45
80
90
100
110
120
130
TEMPERATURE, °K

4.006

SPECIFIC HEAT (C_p) of LIQUID AIR

at saturation

Source of Data: Ishkin, I. P. and Kaganer, M. G., Soviet Phys. Tech. Phys., 1, 2263-2271 (1956)

Other References: Din. F., Thermodynamic Functions of Gases, Vol 2, Butterworths Scientific Publications, London (1956).

Euckon and Hauck, Zeits. Physikal Chem. 134, 161-177 (1928)

Comments: The data of Ishkin and Kaganer were based on the work of Eucken and Hauck and are the specific heats at constant pressure along the saturated liquid line.

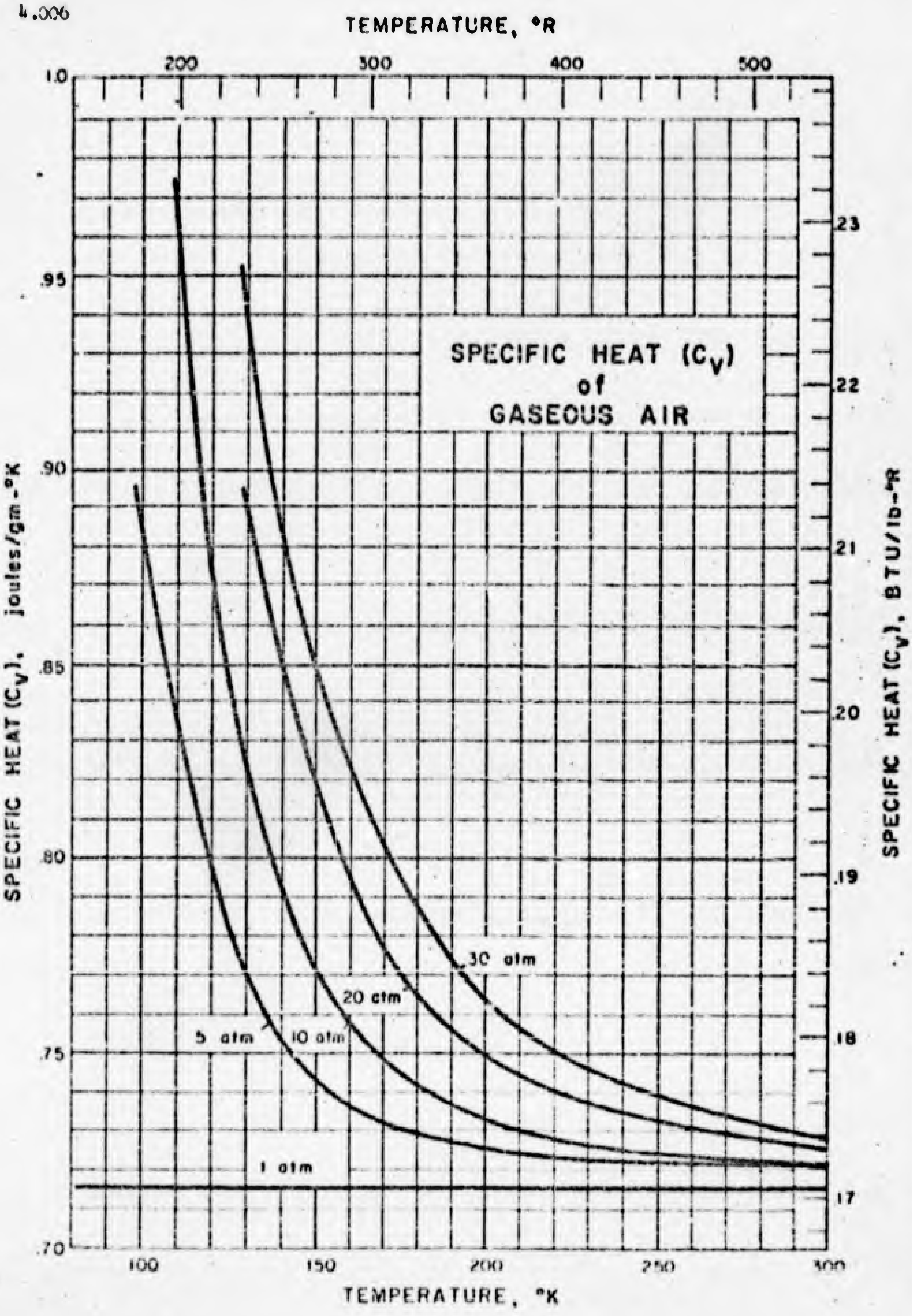
Din's data are for specific heats at constant pressure for liquid air at higher temperatures and pressures not on the saturated liquid line.

Table of Selected Values for Saturated Liquid

Temperature		Pressure	Specific Heat at Constant Pressure	
°K	°R	atm.	Joules/gm °K	BTU/lb °R
80	144	1.175	1.97	0.471
85	153	1.982	2.02	.482
90	162	3.138	2.07	.494
95	171	4.736	2.13	.509
100	180	6.858	2.21	.528
105	189	9.589	2.31	.552
110	198	13.00	2.44	.583
115	207	17.17	2.58	.616
120	216	22.17	2.77	.662
125	225	28.31	3.10	.740

DAV/WJV Issued: [illegible]

4.006


TEMPERATURE, °R
200
300
400
500
SPECIFIC HEAT (C_V)
of
GASEOUS AIR
1.0
.95
.90
.85
.80
.75
.70
SPECIFIC HEAT (C_V), joules/gm-°K
.23
.22
.21
.20
.19
.18
.17
SPECIFIC HEAT (C_V), BTU/lb-°R
30 atm
20 atm
10 atm
5 atm
1 atm
100
150
200
250
300
TEMPERATURE, °K

SPECIFIC HEAT (C_v) of GASEOUS AIR

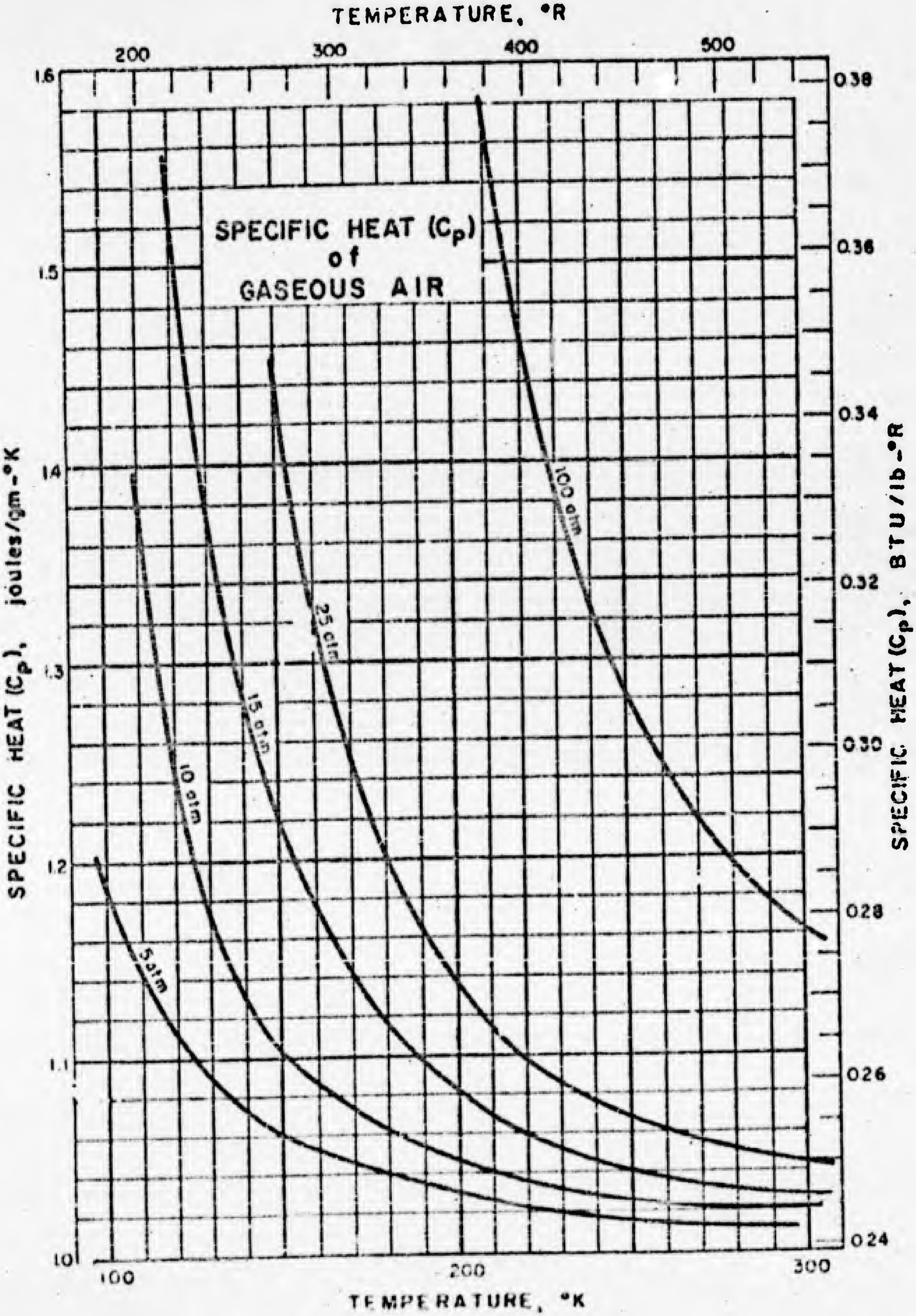
Source of Data: Din, F., Thermodynamic Functions of Gases, Vol. 2, Butterworths Scientific Publications, London (1956).

Other References: NBS Circular 564 (1955).

Comments: The data in NBS Circular 564 are not in close agreement with the data of Din. Din does not claim an accuracy of better than 5% in general and less accuracy in the critical region.

Specific Heat at Constant Volume, Joules/gm-°K

Temp. °K	Data from F. Din				
	1 ATM	5 ATM	10 ATM	20 ATM	30 ATM
90	0.715				
100	0.715	0.884			
110	0.715	0.835	0.970		
120	0.715	0.797	0.873		
130	0.715	0.770	0.822	0.891	0.942
140	0.715	0.753	0.791	0.849	0.884
150	0.715	0.742	0.770	0.818	0.846
180	0.715	0.728	0.742	0.780	0.787
200	0.715	0.725	0.732	0.749	0.763
240	0.715	0.722	0.725	0.735	0.742
280	0.718	0.722	0.722	0.728	0.732
300	0.718	0.722	0.722	0.725	0.728


SPECIFIC HEAT (C_p) of GASEOUS AIR
TEMPERATURE, °R
200
300
400
500
SPECIFIC HEAT (C_p), joules/gm-°K
1.6
1.5
1.4
1.3
1.2
1.1
1.0
SPECIFIC HEAT (C_p), BTU/lb-°R
0.38
0.36
0.34
0.32
0.30
0.28
0.26
0.24
100 atm
25 atm
15 atm
10 atm
5 atm
100
200
300
TEMPERATURE, °K

SPECIFIC HEAT (C_p) of GASEOUS AIR

Sources of Data: NBS Circular 564 (1955); Din, F., Thermodynamic Functions of Gases, Vol. 2, Butterworths Scientific Publications, London, (1956).

Other References: Michels, et. al., Appl. Sci. Res. A, 4, 52 (1953).

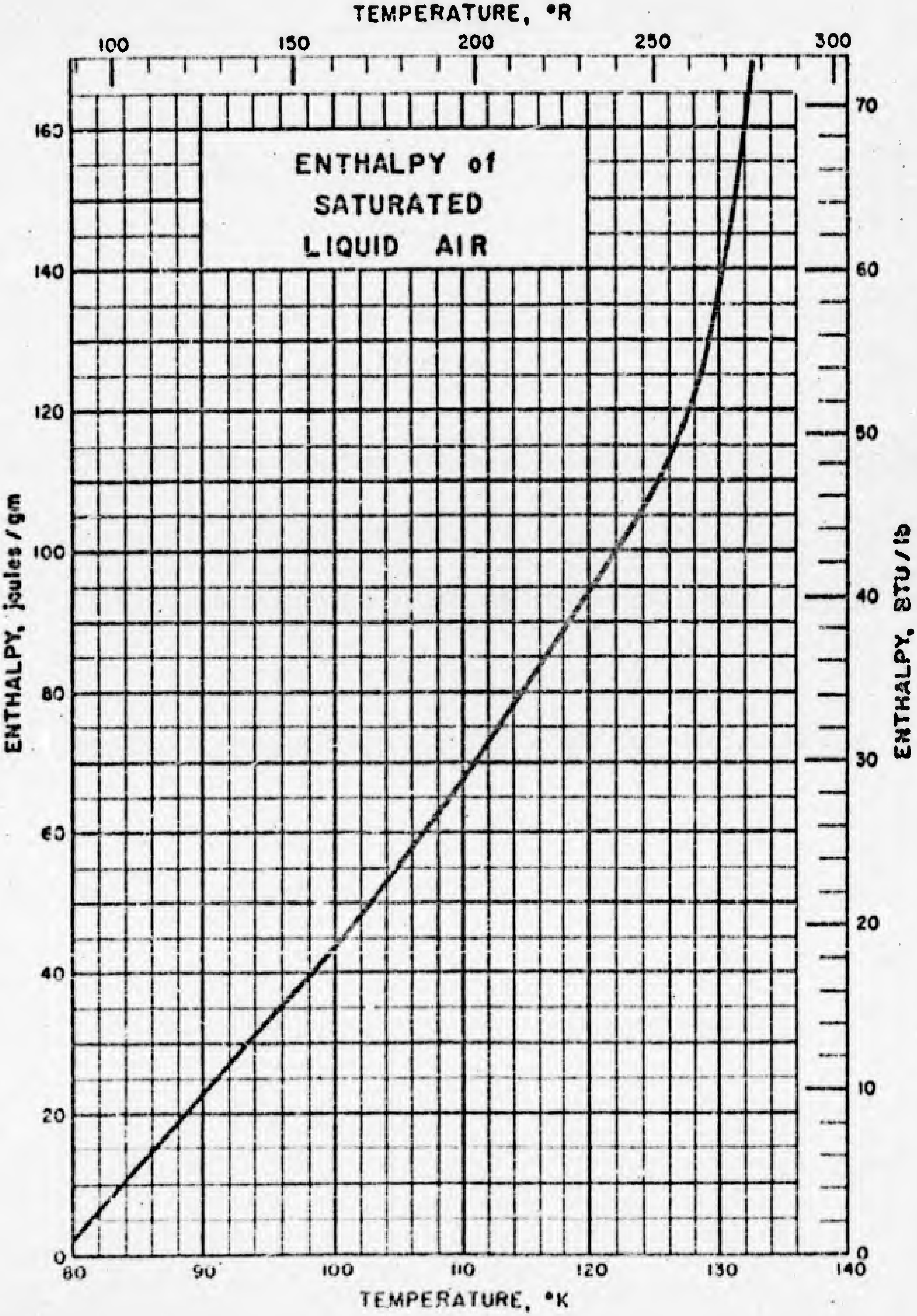
Comments: At temperatures above 200°K the data of Din and NBS Circular 564 agree within about 1%. At temperatures near and above 300°K they converge. At the lower temperatures the variation increases with pressure up to about 3.5% at 110°K and 10 atmospheres.

Din's data are based on the work of Michels et. al.

Specific Heat at Constant Pressure, Joules/gm.°K

Temp. °K	Data from NBS Circular 564			
	.1 ATM	1 ATM	10 ATM	100 ATM
90	1.0055			
100	1.0046	1.0283		
110	1.0040	1.0218	1.380	
120	1.0036	1.0175	1.241	
130	1.0034	1.0144	1.171	
140	1.0032	1.0122	1.131	
150	1.0030	1.0105	1.1034	
180	1.0028	1.0075	1.0601	2.43
210	1.0028	1.0060	1.0404	1.572
240	1.0031	1.0054	1.0296	1.326
270	1.0038	1.0055	1.0237	1.219
300	1.0049	1.0063	1.0203	1.161
	Data from F. Din			
	1 ATM	5 ATM	15 ATM	25 ATM
90	1.052			
100	1.044	1.187		
110	1.040	1.142		
120	1.036	1.112	1.537	
130	1.033	1.089	1.372	2.13
140	1.030	1.074	1.275	1.67
150	1.027	1.065	1.218	1.443
180	1.019	1.043	1.116	1.201
210	1.012	1.026	1.069	
240	1.007	1.017	1.046	1.076
270	1.005	1.014	1.035	1.057
300	1.006	1.012	1.028	1.045

DAV/WJV Issued: 7/31/59


TEMPERATURE, °R
100
150
200
250
300
ENTHALPY of SATURATED LIQUID AIR
ENTHALPY, joules/gm
0
20
40
60
80
100
120
140
160
ENTHALPY, BTU/lb
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
TEMPERATURE, °K

4.006

ENTHALPY of LIQUID AIR

(Saturated)

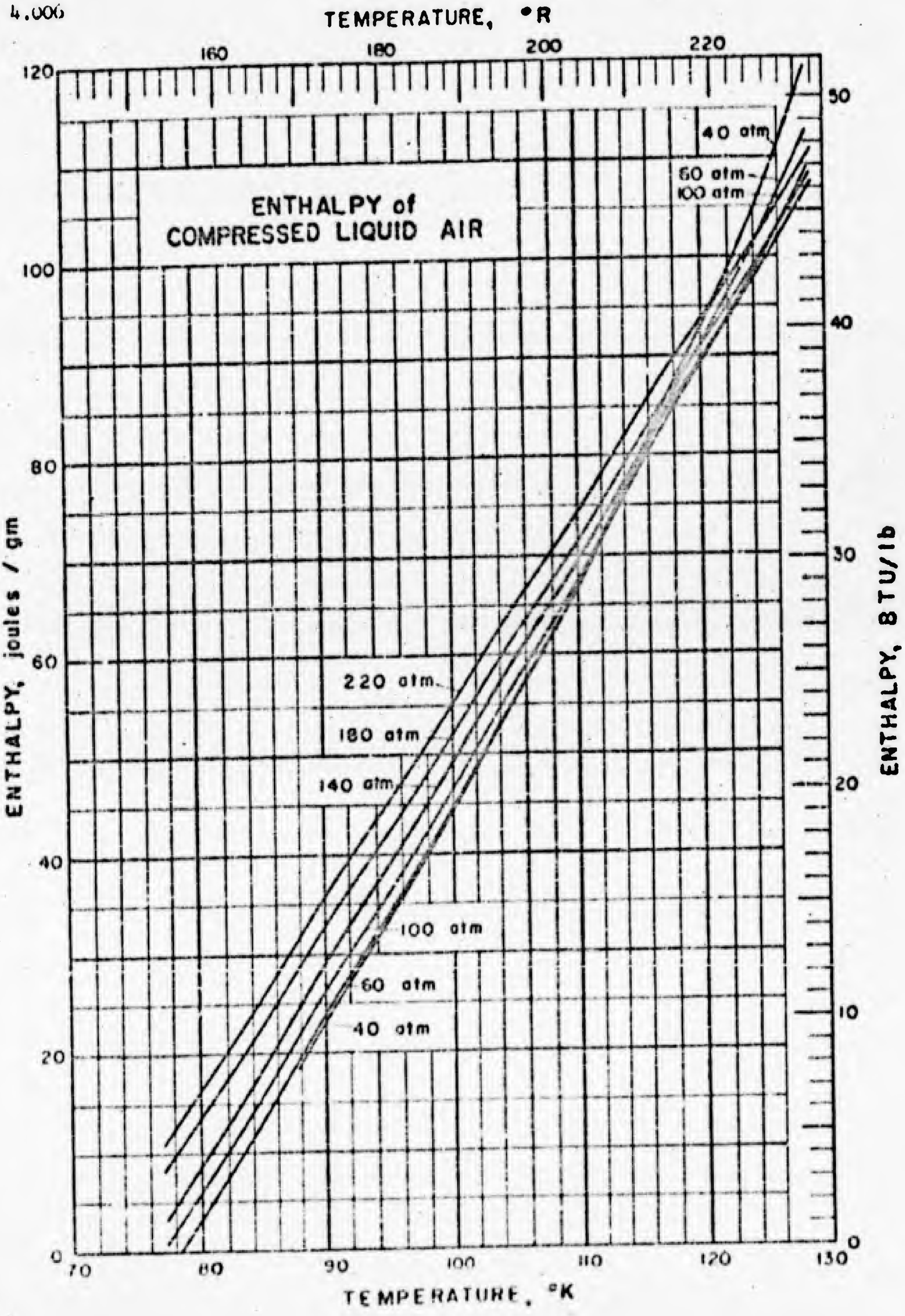
Source of Data: Williams, V.C., Trans. Am. Inst. Chem Engrs. 39, 93-111 (1943).

Comments: The original data presents the enthalpy of saturated liquid at 1 atm as 46.33 BTU per pound. The data presented here have been found by subtracting 46.33 from the original data in order to be in agreement, by definition, with the data of Din for gaseous air. The data of Din present enthalpy as zero at 1 atm and 78.8°K (bubble point).

Table of Selected Values

Temp. (Bubble)		Pressure	Enthalpy	
°K	°R	Atm.	Joules/gm	BTU/lb
78.72	141.70	1	0	0
85.34	153.61	2	13.19	5.67
93.18	167.72	4	29.47	12.67
96.02	172.84	5	35.24	15.15
98.47	177.25	6	40.52	17.42
102.60	184.68	8	49.82	21.42
106.05	190.89	10	57.68	24.80
112.96	203.33	15	74.73	32.13
118.43	213.17	20	89.25	38.37
127.11	228.80	30	117.74	50.62
132.66	238.84	37.25	168.45	72.42

DAV/WJV Issued: 7/31/59


TEMPERATURE, °R
160
180
200
220
ENTHALPY of
COMPRESSED LIQUID AIR
40 atm
60 atm
100 atm
220 atm
180 atm
140 atm
100 atm
60 atm
40 atm
120
100
80
60
40
20
0
50
40
30
20
10
0
ENTHALPY, joules / gm
ENTHALPY, BTU/lb
70
80
90
100
110
120
130
TEMPERATURE, °K

ENTHALPY of COMPRESSED LIQUID AIR

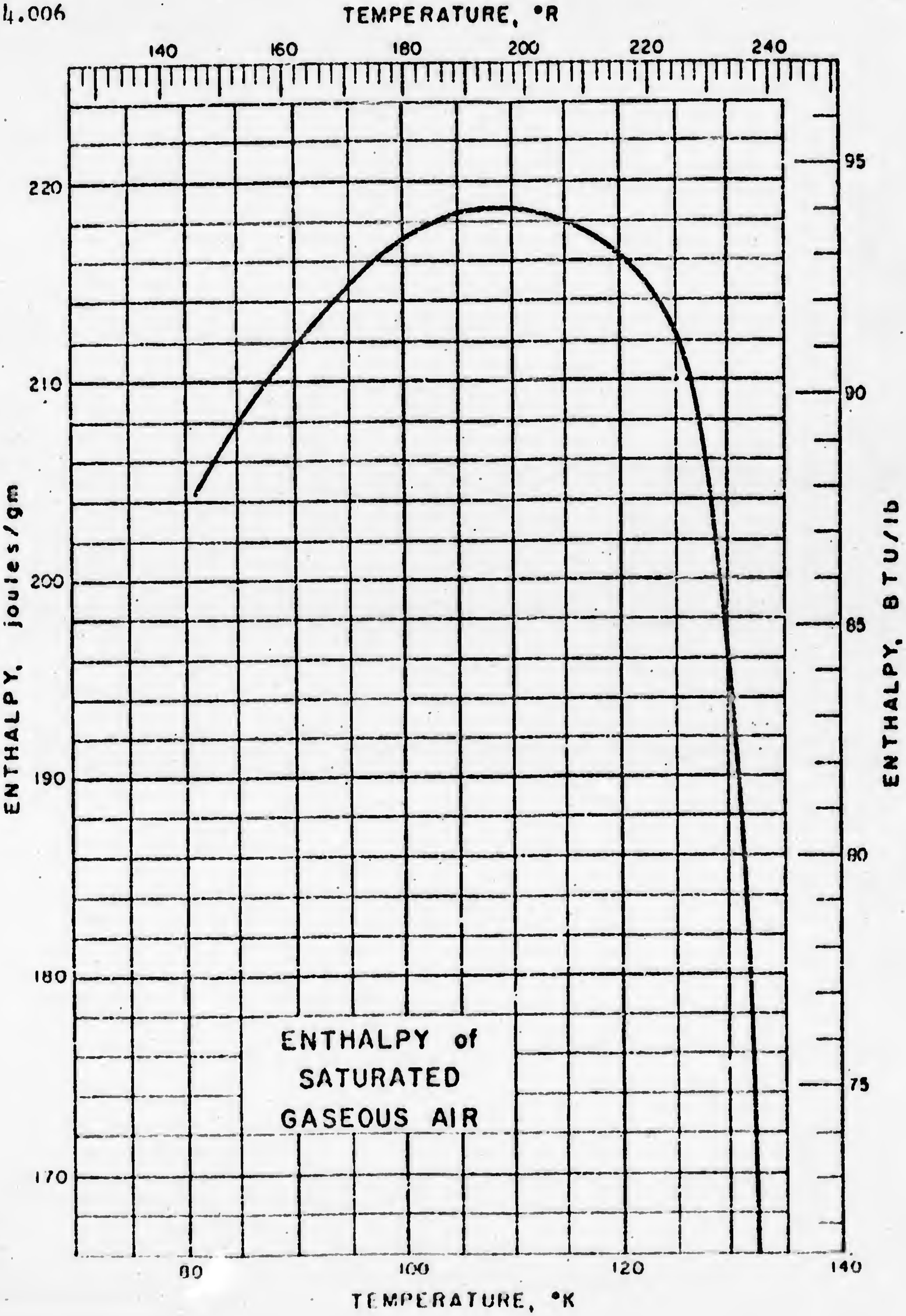
Source of Data: Williams, V. C., Trans. Am. Inst. Chem. Engr. 39, 93-111 (1943).

Comments: The original data presents the enthalpy of saturated liquid at 1 atm as 46.33 BTU per pound. The data presented here have been found by subtracting this 46.33 from the original data in order to be in agreement, by definition, with the data of Din for gaseous air. The data of Din presents enthalpy as zero at 1 atm and 78.8°K (bubble point).

Table of Selected Values, Joules/gm

Temp. °K	40 atm	60 atm	100 atm	140 atm	180 atm	220 atm
77.8		-0.95	0.86	4.42	9.47	12.02
88.89	20.98	21.44	23.77	26.91	30.63	33.54
100	44.12	44.59	46.57	49.24	52.10	55.06
111.11	69.99	69.99	69.99	71.80	73.66	76.90
122.22	99.37	96.46	94.25	94.13	95.53	98.27
127.78	117.97	111.23	107.51	105.76	106.69	109.04

DAV/WJV Issued: 5/25/59


TEMPERATURE, °R
140
160
180
200
220
240
220
210
200
190
180
170
ENTHALPY, joules/gm
95
90
85
80
75
ENTHALPY, BTU/lb
ENTHALPY of
SATURATED
GASEOUS AIR
80
100
120
140
TEMPERATURE, °K

4.006

ENTHALPY of AIR

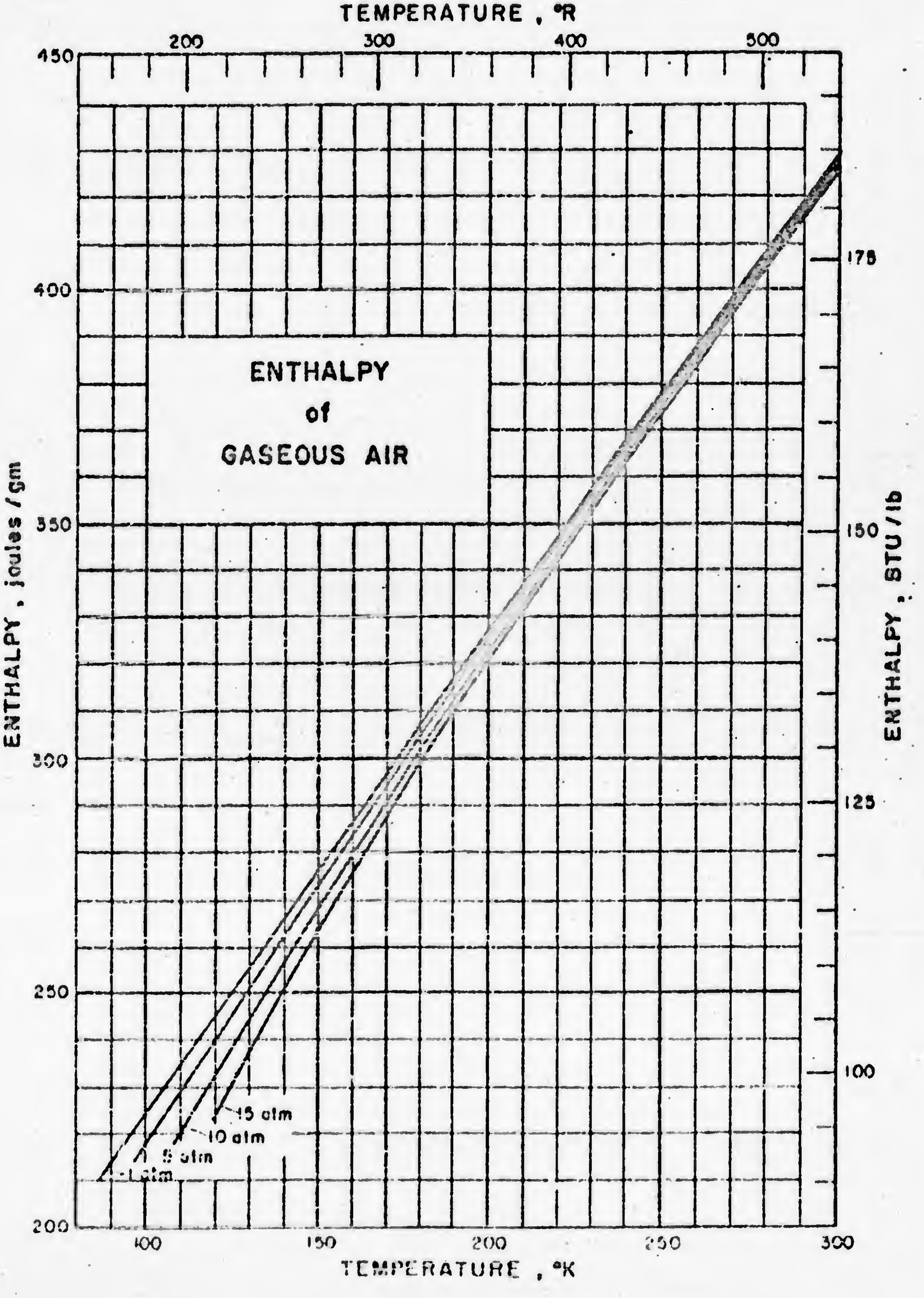
(Gaseous State - Saturated)

Source of Data: Williams, V.C., Trans. Am. Inst. Chem. Engrs. 39, 93-111 (1943).

Comments: The original data presents the enthalpy of saturated liquid at 1 atm as 46.33 BTU per pound. The data presented here have been found by subtracting 46.33 from the original data in order to be in agreement, by definition, with the data of Din for gaseous air. The data of Din present enthalpy as zero at 1 atm and 78.8°K (bubble point).

Table of Selected Values

Temp. (Dew)		Pressure	Enthalpy	
°K	°R	Atm.	Joules/gm	BTU/lb
81.76	147.17	1	205.20	88.22
88.21	158.78	2	210.43	90.47
95.77	172.39	4	215.16	92.50
98.49	177.28	5	216.43	93.05
100.83	181.49	6	217.41	93.47
104.75	188.55	8	218.34	93.87
108.01	194.42	10	218.62	93.99
114.49	206.09	15	218.06	93.75
119.57	215.23	20	216.25	92.97
127.56	229.61	30	207.06	89.02
132.41	238.34	37.25	168.45	72.42


TEMPERATURE , °R
200
300
400
500
450
400
350
300
250
200
ENTHALPY , joules /gm
ENTHALPY
of
GASEOUS AIR
175
150
125
100
ENTHALPY , BTU/lb
15 atm
10 atm
5 atm
1 atm
100
150
200
250
300
TEMPERATURE , °K

4.006

ENTHALPY of GASEOUS AIR

Source of Data:

Din, F., Thermodynamic Functions of Gases, Vol. 2, Butterworth's Scientific Publications, London (1956)

Other References:

Hilsenrath, J., et al., Nat. Bur. Standards Cir. 564, 45-50 (1955)

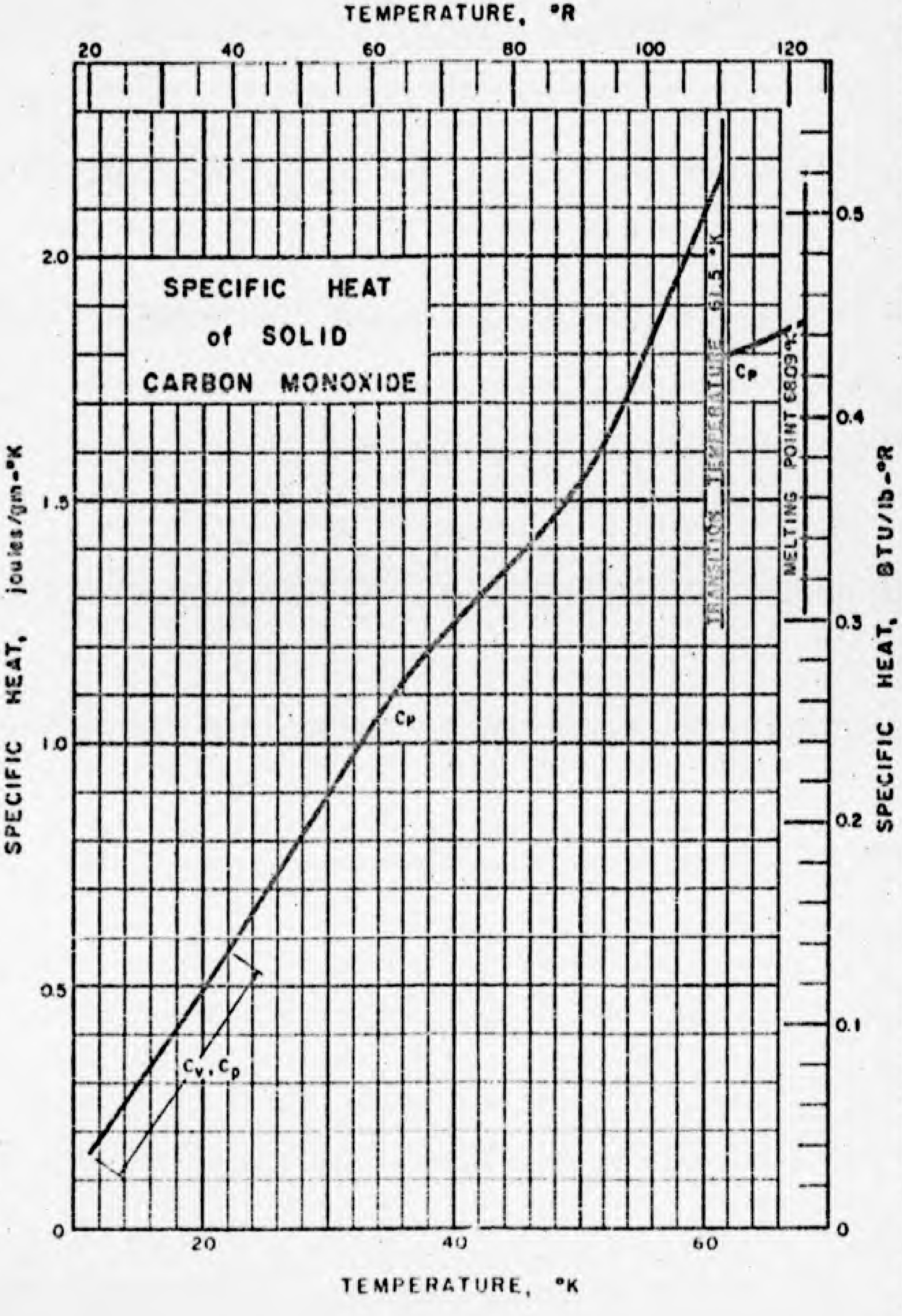
Comments:

Enthalpy is taken as zero at the bubble point (1 atm., 78.8°K). The data in Nat. Bur. Standards Cir. 564 are presented as the enthalpy minus the enthalpy of the ideal gas at absolute zero.

Table of Selected Values, Joules/gm

Temp. °K	1 Atm	5 Atm	10 Atm	15 Atm
90	213.7			
100	224.2	217.4		
110	234.6	229.0	219.4	
120	245.0	240.3	232.7	223.4
125	250.2	245.8	239.0	230.8
130	255.3	251.3	245.1	237.8
140	265.7	262.1	256.9	251.1
150	276.0	272.8	268.3	263.5
180	306.7	304.4	301.4	298.3
210	337.2	335.5	333.3	331.1
240	367.4	366.1	364.5	362.8
270	397.6	396.6	395.3	394.0
300	427.8	427.0	425.9	424.9

DAV/WJV Issued: 7/31/59


TEMPERATURE, °R
20
40
60
80
100
120
SPECIFIC HEAT
of SOLID
CARBON MONOXIDE
TRANSITION TEMPERATURE 61.5 °K
MELTING POINT 68.09 °K
Cp
Cp
Cv, Cp
SPECIFIC HEAT, joules/gm-°K
2.0
1.5
1.0
0.5
0
SPECIFIC HEAT, BTU/lb-°R
0.5
0.4
0.3
0.2
0.1
0
20
40
60
TEMPERATURE, °K

4.007

SPECIFIC HEAT of SOLID CARBON MONOXIDE

Sources of Data: Clayton, J. O. and Giauque, W. F., J. Am. Chem. Soc. 54, 2610-26 (1932); Clayton, J. O. and Giauque, W. F., J. Am. Chem. Soc. 55, 5071-73 (1933); Clusius, K., Z. physik. Chem. B3, 41-79 (1929).

Comments: Clayton and Giauque state that the specific heat of solid carbon monoxide may be represented by the following equation:

$$C_p = -1.25 + 0.24\ T$$

where:

C_p is in cal/gm-mole °K
T is in °K

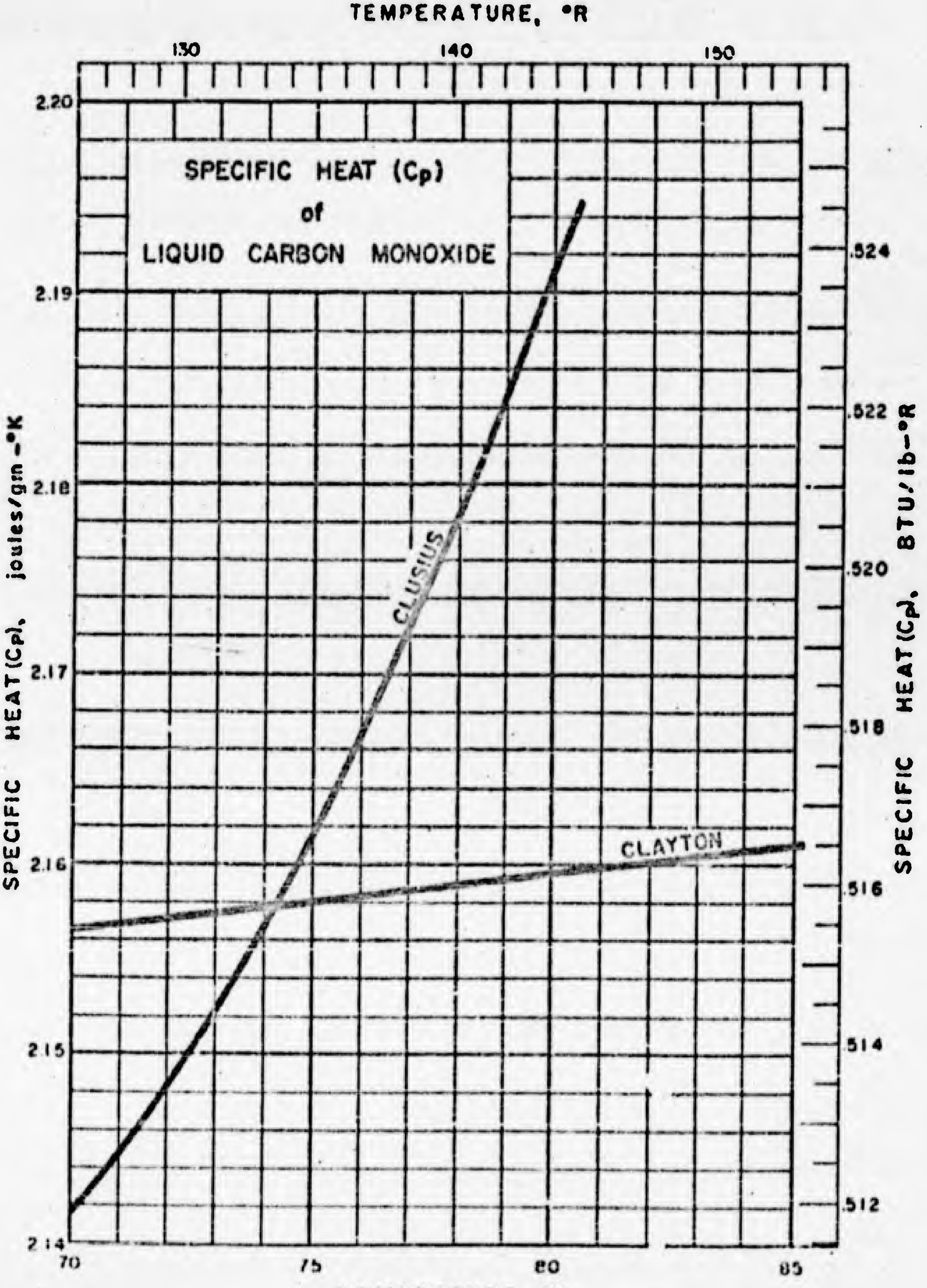
Range: 20 – 61.55°K

Data from Clayton and Giauque

Temp. °K	C_p cal/gm-mole °K	Temp. °K	C_p cal/gm-mole °K
14.36	1.637	47.90	9.883
16.94	2.458	48.34	9.937
19.37	3.268	52.34	11.01
21.93	3.976	55.07	11.73
24.31	4.573	56.82	12.71
26.64	5.114	59.04	13.61
29.01	5.681	61.55	Transition Temp.
31.56	6.272	63.47	12.02
39.85	8.111	64.55	12.16
44.21	9.055	66.02	12.30
44.71	9.089	68.09	Melting Point

Data from Clusius

Temp. °K	C_p cal/gm-mole °K	C_v cal/gm-mole °K	Temp. °K	C_p cal/gm-mole °K
11.89	1.214	1.209	41.6	8.640
13.43	1.716	1.704	44.7	9.160
15.35	2.082	2.061	47.6	9.840
16.19	2.306	2.279	50.5	10.48
18.08	2.667	2.627	52.8	11.15
19.53	3.037	2.980	55.2	11.90
20.0	3.198	3.134	57.0	12.81
21.9	3.733	3.636	61.5	Transition Temp.
22.0	3.749		63.2	12.12
23.9	4.305		63.5	12.24
25.8	5.108		63.9	12.07
28.7	5.808		65.2	12.29
30.9	6.247		66.2	12.35
33.1	6.750		66.3	12.29
35.7	7.352		68.22	Melting Point
38.5	7.940			


TEMPERATURE, °R
130
140
150
SPECIFIC HEAT (Cp)
of
LIQUID CARBON MONOXIDE
CLUSIUS
CLAYTON
2.20
2.19
2.18
2.17
2.16
2.15
2.14
SPECIFIC HEAT (Cp), joules/gm -°K
.524
.522
.520
.518
.516
.514
.512
SPECIFIC HEAT (Cp), BTU/lb-°R
70
75
80
85
TEMPERATURE, °K

SPECIFIC HEAT (C_p) of LIQUID CARBON MONOXIDE

Sources of Data:

Clusius, K., Z. physik. Chem. B3. 41-79 (1929);
Clayton, J. O. and Giauque, W. F., J. Am. Chem. Soc. 54, 2610-26 (1932);
Clayton, J. O. and Giauque, W. F., J. Am. Chem. Soc. 55, 5071-73 (1933).

Comments:

Comparison of these two references shows that the agreement for the specific heat of liquid carbon monoxide is not good. A relative magnitude seems to be the best that can be realized here.

Table of Values

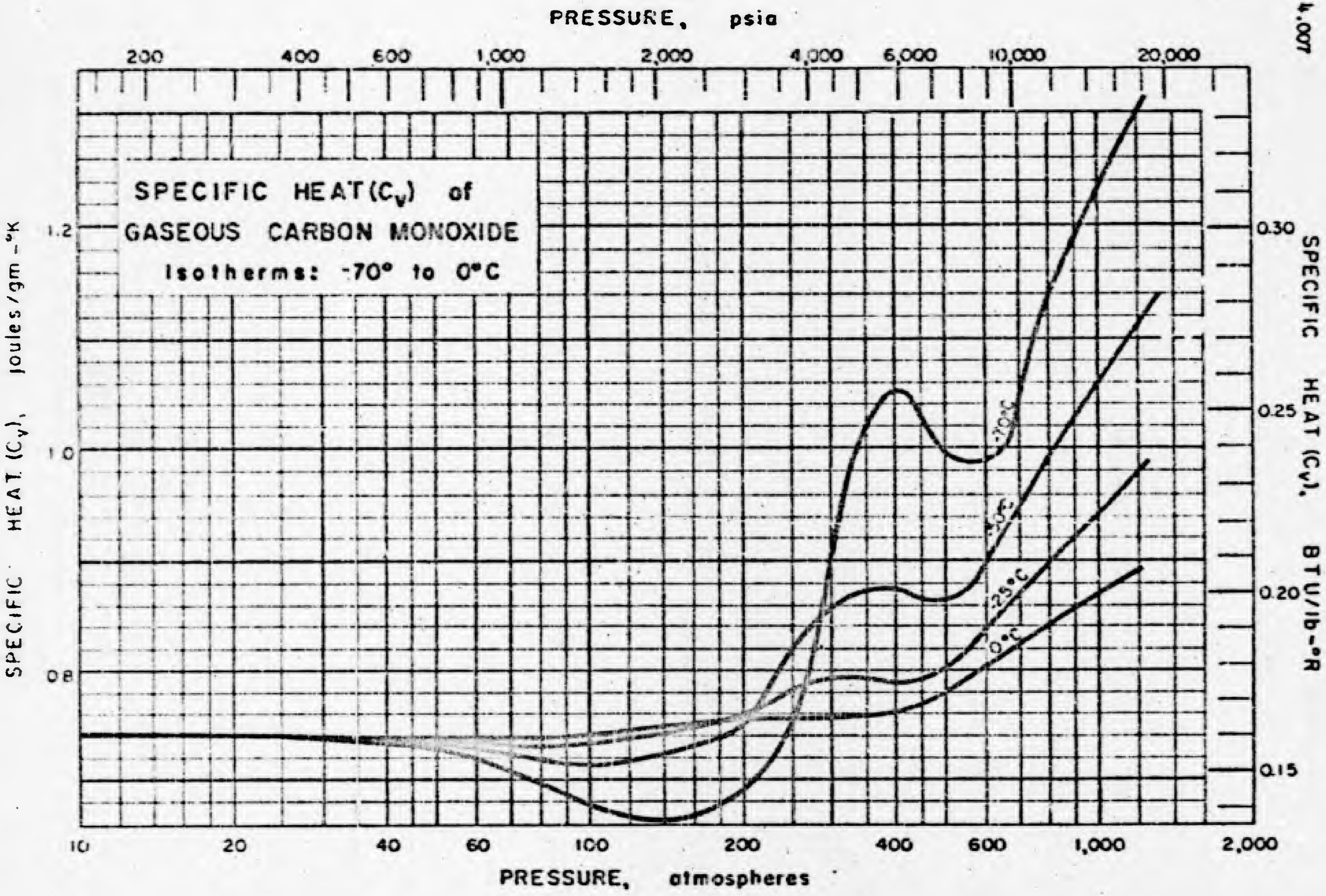
From Clusius

Temp. °K	Cp cal/gm-mole °C
70.1	14.33
74.2	14.44
74.7	14.52
76.9	14.53
80.0	14.66
81.3	14.75

From Clayton and Giauque

Temp. °K	Cp cal/gm-mole °C
70.02	14.42
72.17	14.43
75.47	14.48
75.80	14.39
78.78	14.41
79.06	14.48
80.61	14.50
83.39	14.40
84.66	14.45

4.007


PRESSURE, psia
200
400
600
1,000
2,000
4,000
6,000
10,000
20,000
SPECIFIC HEAT(C$_v$) of
GASEOUS CARBON MONOXIDE
Isotherms: -70° to 0°C
-70°C
-50°C
-25°C
0°C
SPECIFIC HEAT (C$_v$), joules/gm -°K
1.2
1.0
0.8
SPECIFIC HEAT (C$_v$), BTU/lb-°R
0.30
0.25
0.20
0.15
10
20
40
60
100
200
400
600
1,000
2,000
PRESSURE, atmospheres

SPECIFIC HEAT (C_V) of GASEOUS CARBON MONOXIDE

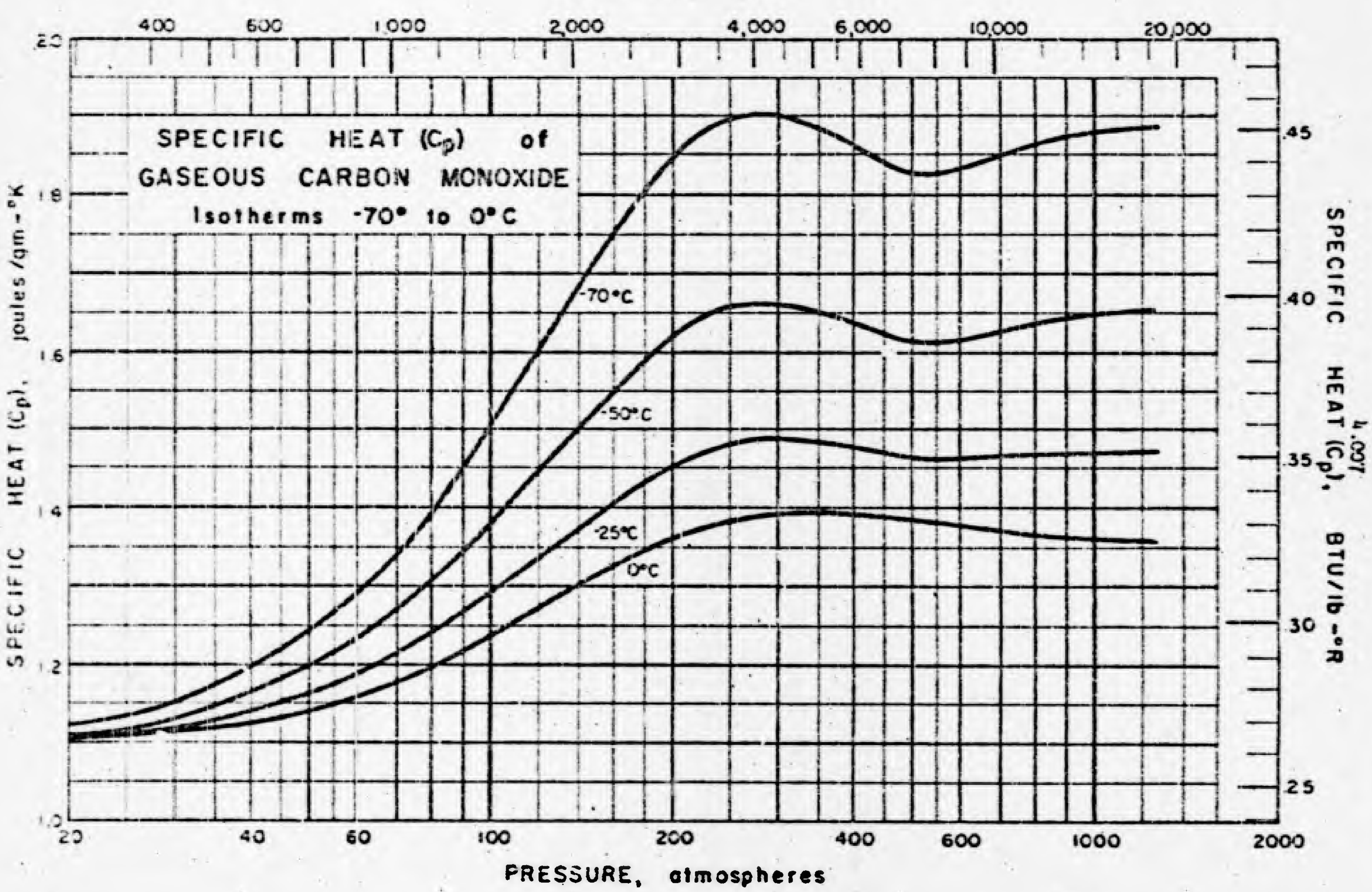
Source of Data: Deming, W. E. and Shupe, L. E., Phys. Rev. [2] 38, 2245-64 (1931).

Comments: These values of Cv were calculated from p-V-T data obtained from: Bartlett, E. P., Hetherington, H. C., Kvalnes, H. M., and Tremearne, T. H., J. Am. Chem. Soc. 52, 1374-81 (1930).

Table of Values

Pressure atm.	Specific Heat (Cv), cal/gm-mole-°K			
	-70°C	-50°C	-25°C	0°C
0	4.967	4.967	4.968	4.970
25	4.94	4.95	4.96	4.96
50	4.86	4.85	4.93	4.94
75	4.71	4.83	4.90	4.94
100	4.54	4.77	4.90	4.95
150	4.45	4.87	5.00	5.02
200	4.64	5.02	5.02	5.05
300	6.01	5.74	5.31	5.07
400	7.05	5.86	5.30	5.10
500	6.67	5.80	5.36	5.22
600	6.62	6.02	5.61	5.39
800	7.63	6.63	5.99	5.57
1000	8.17	7.08	6.31	5.81
1100	8.54	7.31	6.48	5.93
1200	8.75	7.44	6.48	5.92

4.007



SPECIFIC HEAT (C_p) of GASEOUS CARBON MONOXIDE
Isotherms -70° to 0°C

4.007

SPECIFIC HEAT (C_p) of GASEOUS CARBON MONOXIDE

Source of Data: Deming, W. E. and Shupe, L. E., Phys. Rev., [2] 38, 2245-64 (1931).

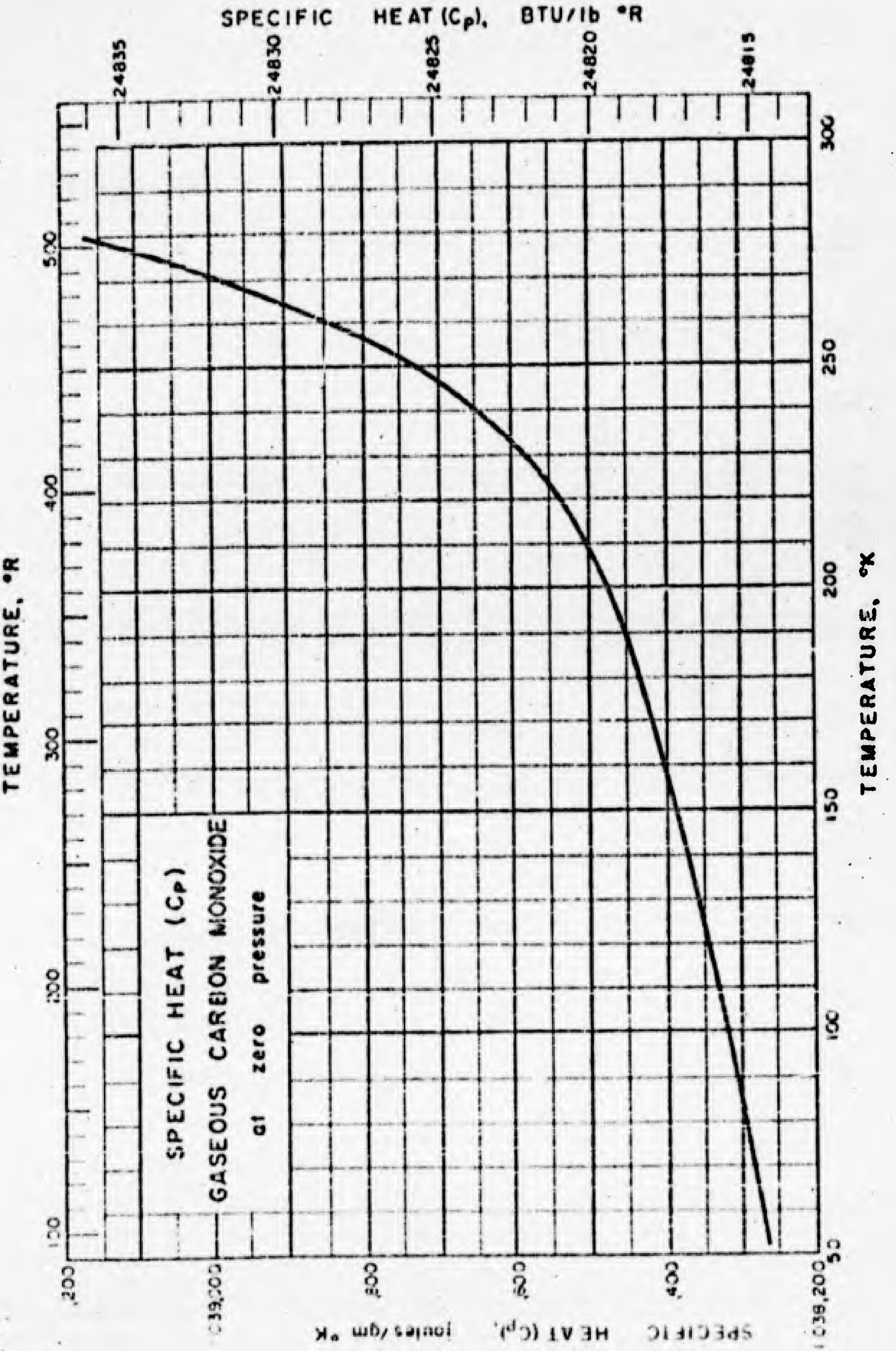
Comments: These values of Cp were calculated from p-V-T data obtained from: Bartlett, E. P., Hetherington, H. C., Kvalnes, H. M., and Tremearne, T. H., J. Am. Chem. Soc. 52, 1374-81 (1930).

Table of Values

Pressure	Specific Heat (Cp), cal/gm-mole-°K			
atm.	-70°C	-50°C	-25°C	0°C
0	6.953	6.953	6.954	6.956
25	7.58	7.46	7.36	7.28
50	8.32	8.02	7.78	7.62
75	9.16	8.63	8.22	7.95
100	10.06	9.23	8.64	8.27
150	11.53	10.23	9.31	8.79
200	12.34	10.82	9.71	9.10
300	12.72	11.11	9.95	9.32
400	12.47	10.96	9.88	9.31
500	12.21	10.81	9.80	9.27
600	12.26	10.83	9.78	9.23
800	12.47	10.97	9.81	9.16
1000	12.57	11.03	9.82	9.12
1100	12.60	11.05	9.83	9.11
1200	12.62	11.06	9.84	9.10

KIM/RJR Issued: 6/22/59

4.007


SPECIFIC HEAT (Cp) GASEOUS CARBON MONOXIDE at zero pressure
SPECIFIC HEAT (Cp), BTU/lb °R
24835
24830
24825
24820
24815
TEMPERATURE, °R
100
200
300
400
500
TEMPERATURE, °K
50
100
150
200
250
300
SPECIFIC HEAT (Cp), joules/gm °K
.200
1.039,000
.800
.600
.400
1.038,200

SPECIFIC HEAT (C_p) of GASEOUS CARBON MONOXIDE
(at Zero Pressure)

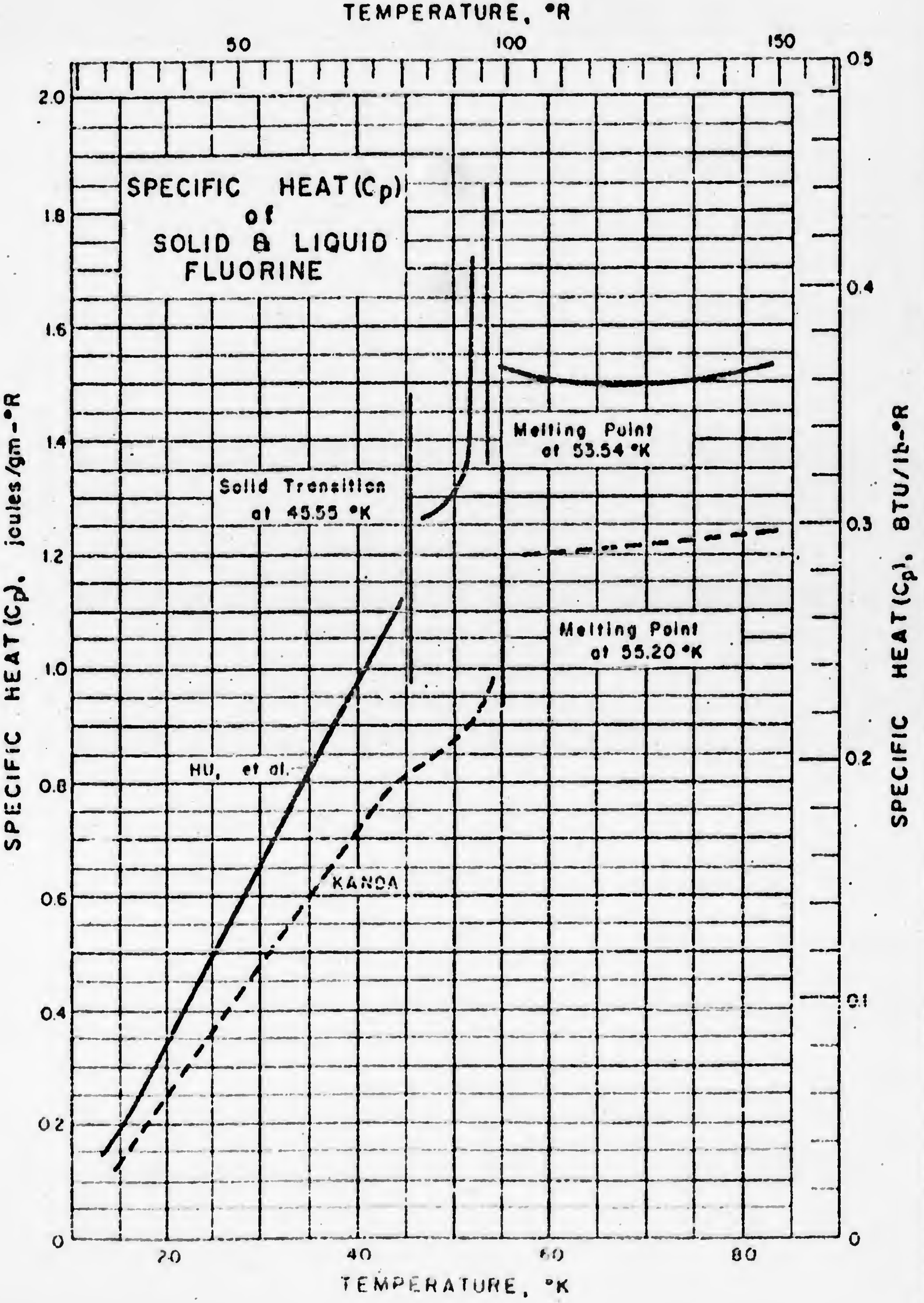
Source of Data:

Goff, J. A. and Gratch, S., Trans. ASME 72, 741-749 (1950).

Table of Selected Values

Temperature		Specific Heat
°K	°R	cal/gm-mole °C
55.56	100	6.95099
58.34	105	6.95100
61.11	110	6.95102
63.89	115	6.95104
66.67	120	6.95106
69.45	125	6.95108
72.22	130	6.95110
77.78	140	6.95114
83.33	150	6.95119
88.89	160	6.95123
94.44	170	6.95128
100.00	180	6.95133
105.56	190	6.95138
111.11	200	6.95143
116.67	210	6.95148
122.22	220	6.95153
127.78	230	6.95159
133.33	240	6.95164
144.44	260	6.95174
155.56	280	6.95185
166.67	300	6.95196
177.78	320	6.95207
188.89	340	6.95220
200.00	360	6.95236
211.11	380	6.95257
222.22	400	6.95284
233.33	420	6.95322
244.44	440	6.95375
255.56	460	6.95448
266.67	480	6.95545
277.78	500	6.95674
305.56	550	6.96174

EDT/RJR Issued: 6/18/59


TEMPERATURE, °R
50
100
150
SPECIFIC HEAT (Cp) of SOLID & LIQUID FLUORINE
Melting Point at 53.54 °K
Solid Transition at 45.55 °K
Melting Point at 55.20 °K
HU, et al.
KANDA
SPECIFIC HEAT (Cp), joules/gm-°R
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
SPECIFIC HEAT (Cp), BTU/lb-°R
0.5
0.4
0.3
0.2
0.1
0
20
40
60
80
TEMPERATURE, °K

4.008

SPECIFIC HEAT (C_p) of SOLID and LIQUID FLUORINE

Sources of Data:

Hu, J. H., White, D. and Johnston, H. L., J. Am. Chem. Soc. 75, 5642-5 (1953)

Kanda, E., Bull. Chem. Soc. Japan 12, 473-9 (1937)

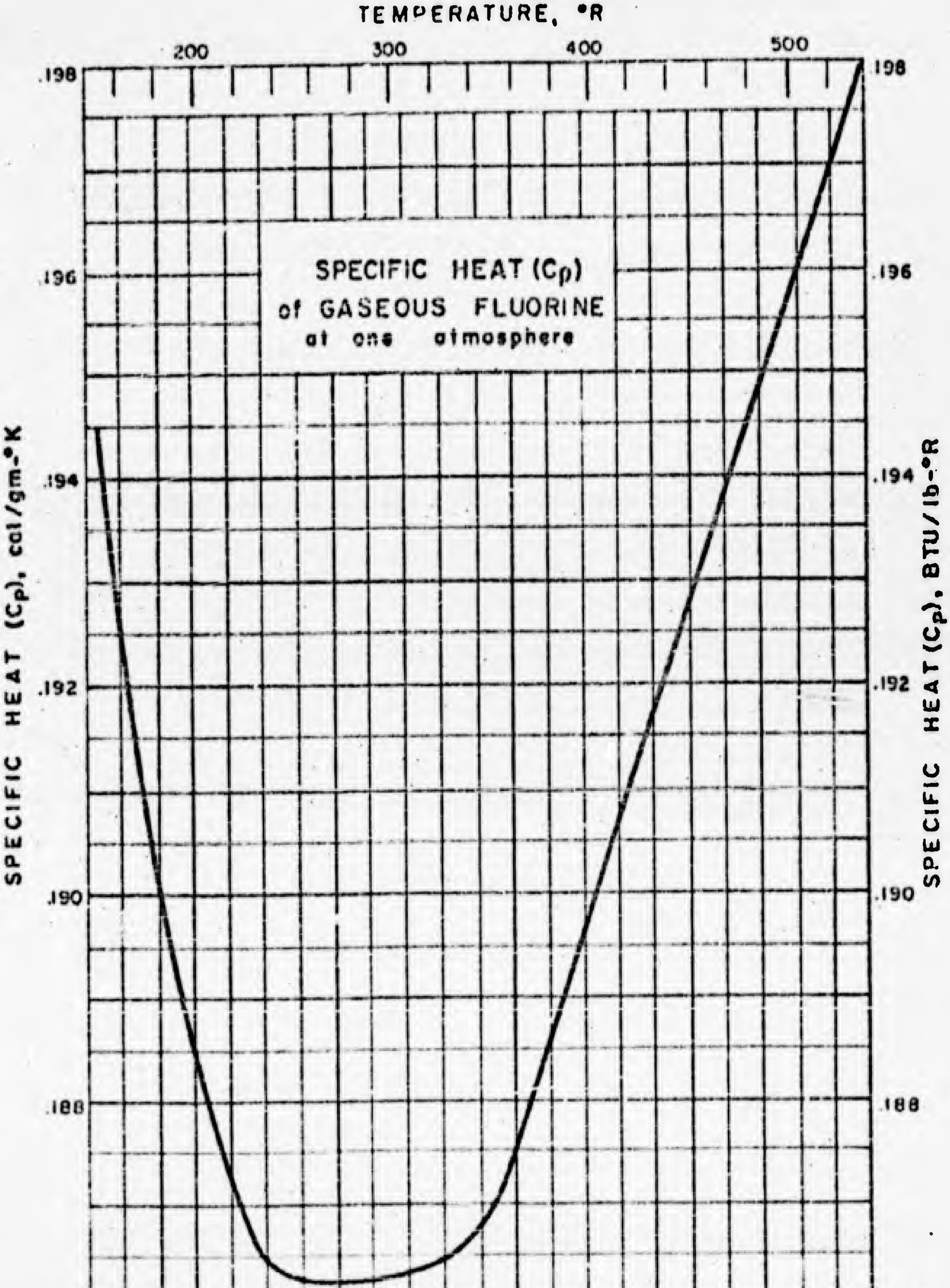
Comments:

The data from the two sources are not in agreement. Since the more recent measurements of Hu, et al. used improved instruments and techniques their values are probably more reliable. However, since the results have not been verified, Kanda's work is presented by the dotted line on the graph. Noteworthy is the lack of a solid state transition in Kanda's data.

The absolute temperature scale (0°C = 273.16°K) was used in the table of selected values below.

Temp. °K	C_p $\frac{cal}{gm\ °K}$	Temp. °K	C_p $\frac{cal}{gm\ °K}$	Temp. °K	C_p $\frac{cal}{gm\ °K}$
Data from Hu et. al.		51.49	0.3350	25.42	0.0905
		52.09	0.4562	29.50	0.1134
13.89	0.0396			32.00	0.1262
15.49	0.0492	53.54	Melting point	35.40	0.1464
17.08	0.0611			39.11	0.1653
18.86	0.0730	58.14	0.3601	43.10	0.1874
21.37	0.0939	62.27	0.3601	47.95	0.2037
24.16	0.1161	67.05	0.3568	52.98	0.2161
27.60	0.1413	71.86	0.3571	53.98	0.2306
31.60	0.1705	76.60	0.3610		
36.99	0.2085	81.32	0.3631	55.20	Melting point
41.48	0.2430				
		Data from Kanda		57.50	0.2853
45.55	transition pt.			62.51	0.2872
		14.91	0.0307	67.49	0.2890
48.51	0.3046	17.75	0.0476	77.10	0.2927
49.42	0.3090	20.01	0.0590	83.41	0.2948
50.39	0.3116	23.10	0.0748		

IFR/JAB Issued: 7/13/59


TEMPERATURE, °R
200
300
400
500
SPECIFIC HEAT (Cp)
of GASEOUS FLUORINE
at one atmosphere
.198
.196
.194
.192
.190
.188
.186
SPECIFIC HEAT (Cp), cal/gm-°K
SPECIFIC HEAT (Cp), BTU/lb-°R
100
150
200
250
300
TEMPERATURE, °K

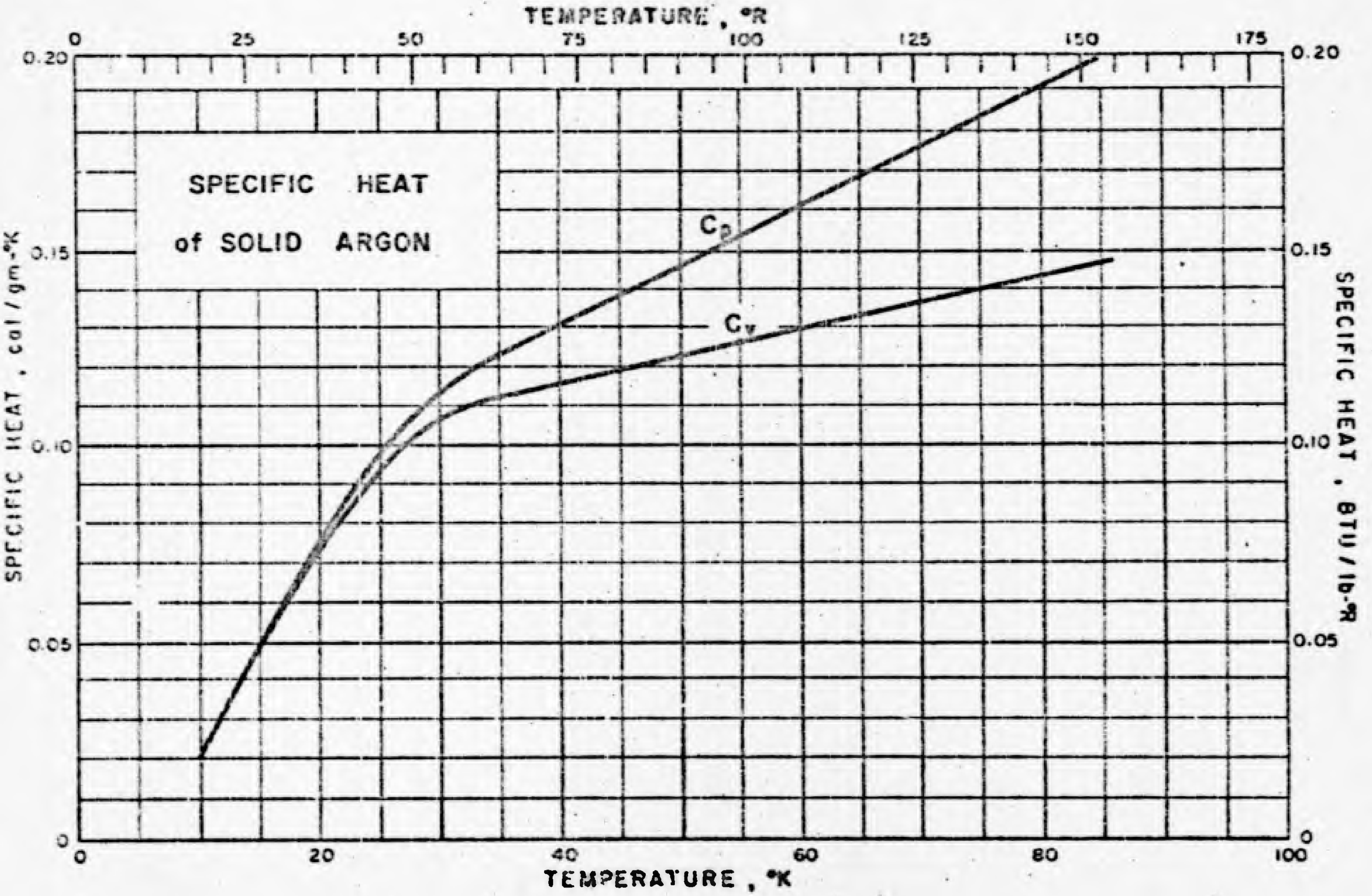
SPECIFIC HEAT (C_p) of GASEOUS FLUORINE
at one atmosphere

Source of Data: Fricke, E. F., Report No. F-5028-101, ATI 121 150, Republic Aviation Corporation, Farmingdale, L. I., New York.

Table of Selected Values

Temp. °K	C_p cal/gm.-°K	Temp. °K	C_p cal/gm.-°K
85.24	0.1942	140	0.1863
90	.1926	160	.1863
95	.1913	180	.1865
100	.1902	200	.1876
105	.1892	220	.1897
110	.1886	240	.1918
115	.1879	260	.1939
120	.1873	280	.1960
125	.1868	298.16	.1979
130	.1865		

4.009


TEMPERATURE, °R
0
25
50
75
100
125
150
175
SPECIFIC HEAT
of SOLID ARGON
C_p
C_v
SPECIFIC HEAT, cal / gm-°K
0.20
0.15
0.10
0.05
0
SPECIFIC HEAT, BTU / lb-°R
0.20
0.15
0.10
0.05
0
0
20
40
60
80
100
TEMPERATURE, °K

SPECIFIC HEAT (C_p, C_v) of SOLID ARGON

Sources of Data:

Barker, J. R. and Dobbs, E. R., Phil. Mag. 46, 1069 (1955)

Clusius, K., Z. phys. Chem. B31, 459 (1936)

Dobbs, E. R. and Jones, G. O., Repts. Progr. in Phys. 20, 561 (1957)

Figgins, B. F. (Private Communication)(1955)

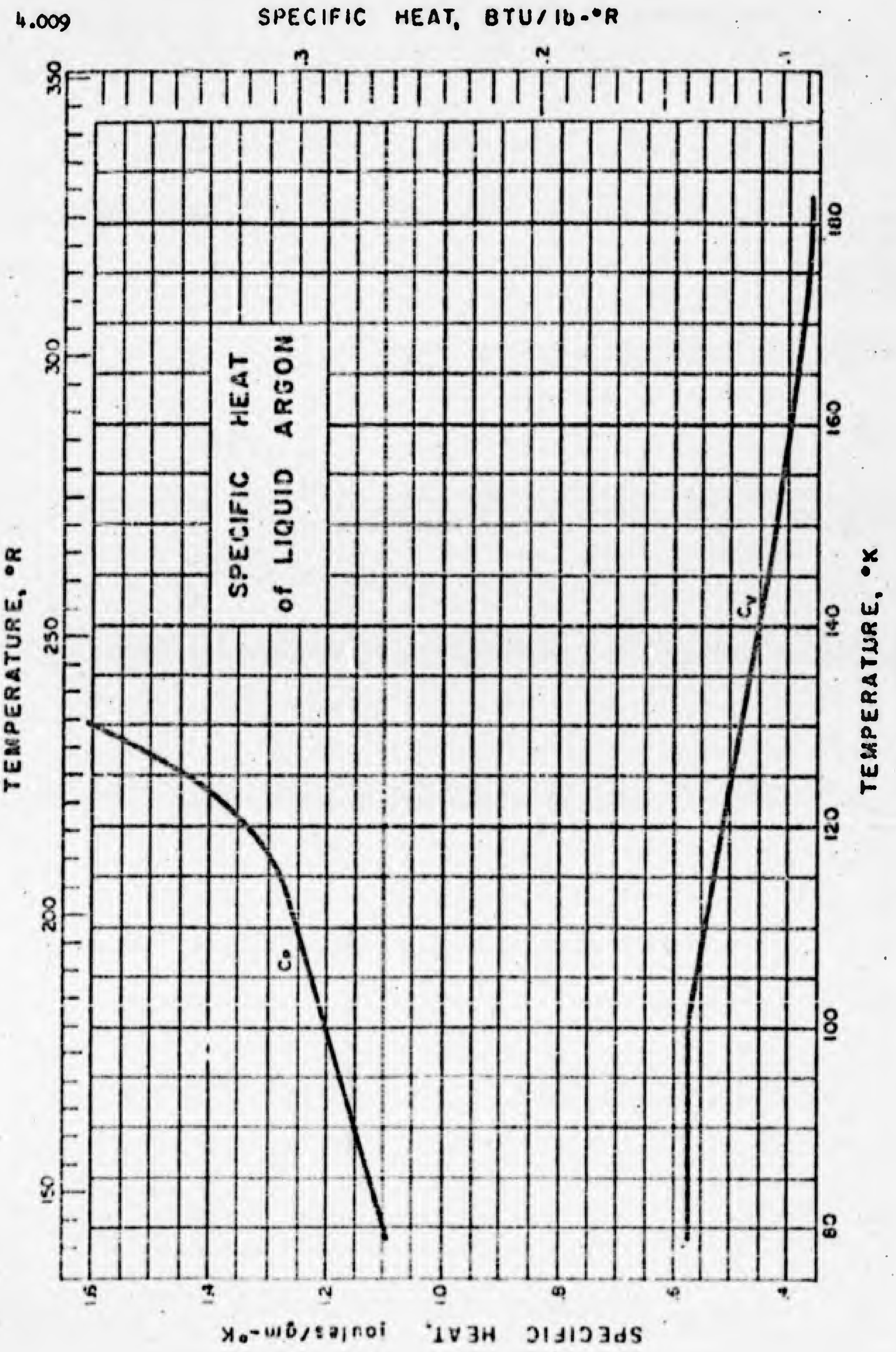
Hill, R. W., (Private Communication) (1954)

Comments:

Hill and Figgins agree within 0.25% of one another, but differ from Clusius by as much as 5%. Only these recent measurements below 35°K can be used in detailed comparison with lattice theory, but a mean curve through the results of Hill and Figgins up to 35°K and of Clusius between 35°K and 85°K is helpful in calculating other quantities.

Table of Selected Values

Temp. °K	C_p cal/gm-°K	C_v cal/gm-°K
10	0.0200	0.0200
20	0.0750	0.0735
30	0.1130	0.106
40	0.131	0.115
50	0.147	0.123
60	0.160	0.128
70	0.176	0.136
80	0.192	0.144
84	0.197	0.145


SPECIFIC HEAT, BTU/lb-°R
.3
.2
.1
350
300
250
200
150
TEMPERATURE, °R
SPECIFIC HEAT of LIQUID ARGON
Cp
Cv
180
160
140
120
100
80
TEMPERATURE, °K
1.6
1.4
1.2
1.0
.8
.6
.4
SPECIFIC HEAT, joules/gm-°K

SPECIFIC HEAT of LIQUID ARGON

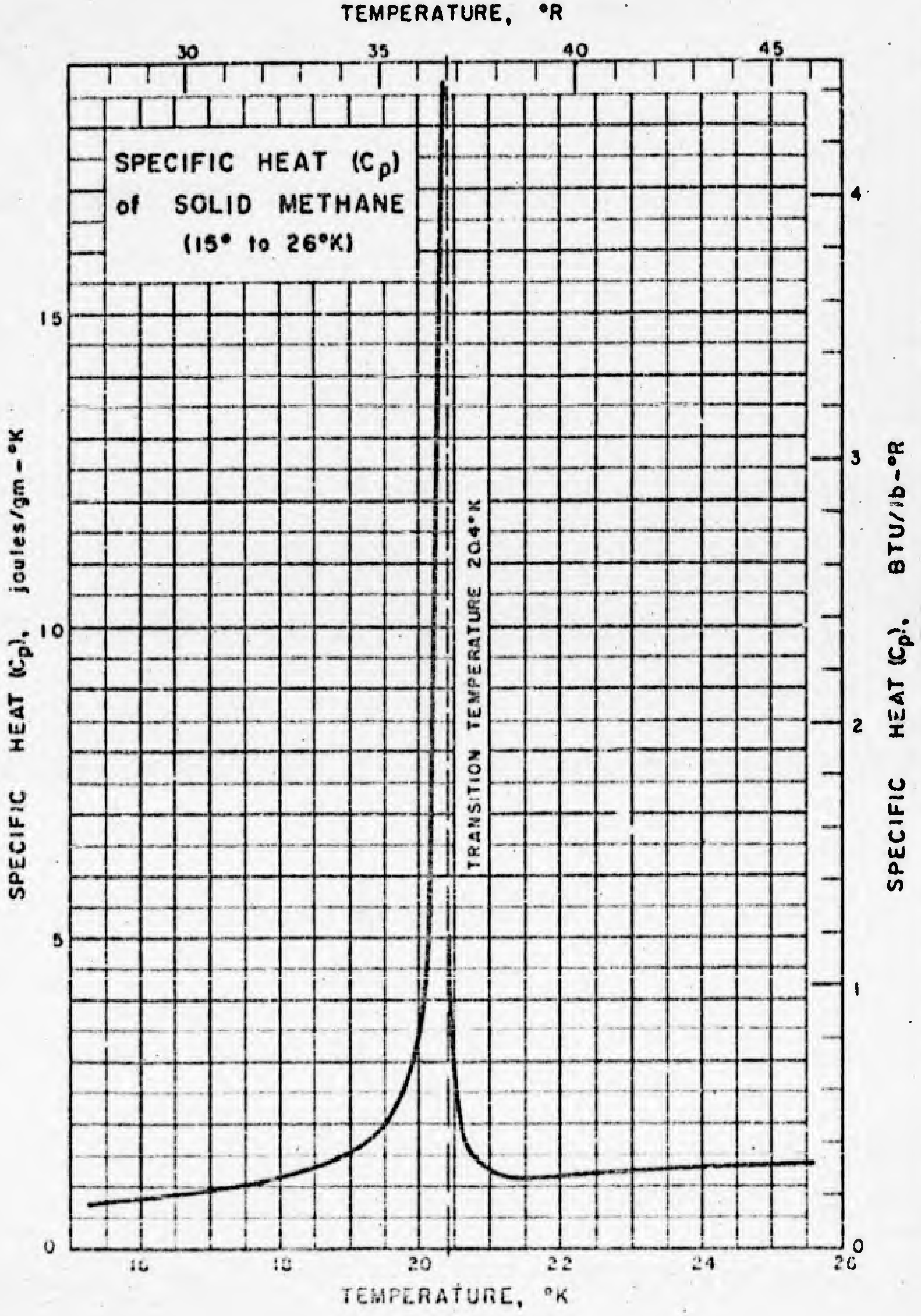
Sources of Data: Eucken, A. and Hauck, F., Z. physik Chem., 134, 161-77 (1928).

Other References: Jones, G. O. and Walker, P. A., Proc. Phys. Soc. (London), 69B, 1348-9 (1956); Prigogine, I. and Raulier S., Physica, 9, 396-404 (1942).

Table of Selected Values

Temp. °K	C_p cal/gm·°K	C_v cal/gm·°K
80	0.2641	0.1377
90	0.2742	0.1377
100	0.2879	0.1377
110	0.3004	0.1302
120	0.3205	0.1227
130	0.3831	0.1164
140		0.1089
150		0.1002
160		0.0939
170		0.0901
180		0.0876

FLB/RJR Issued: 5/29/59


TEMPERATURE, °R
30
35
40
45
SPECIFIC HEAT (C_p)
of SOLID METHANE
(15° to 26°K)
TRANSITION TEMPERATURE 20.4°K
SPECIFIC HEAT (C_p), joules/gm-°K
0
5
10
15
SPECIFIC HEAT (C_p), BTU/lb-°R
0
1
2
3
4
16
18
20
22
24
26
TEMPERATURE, °K

SPECIFIC HEAT (C_p) of SOLID METHANE
(15 to 26°K)

Source of Data:

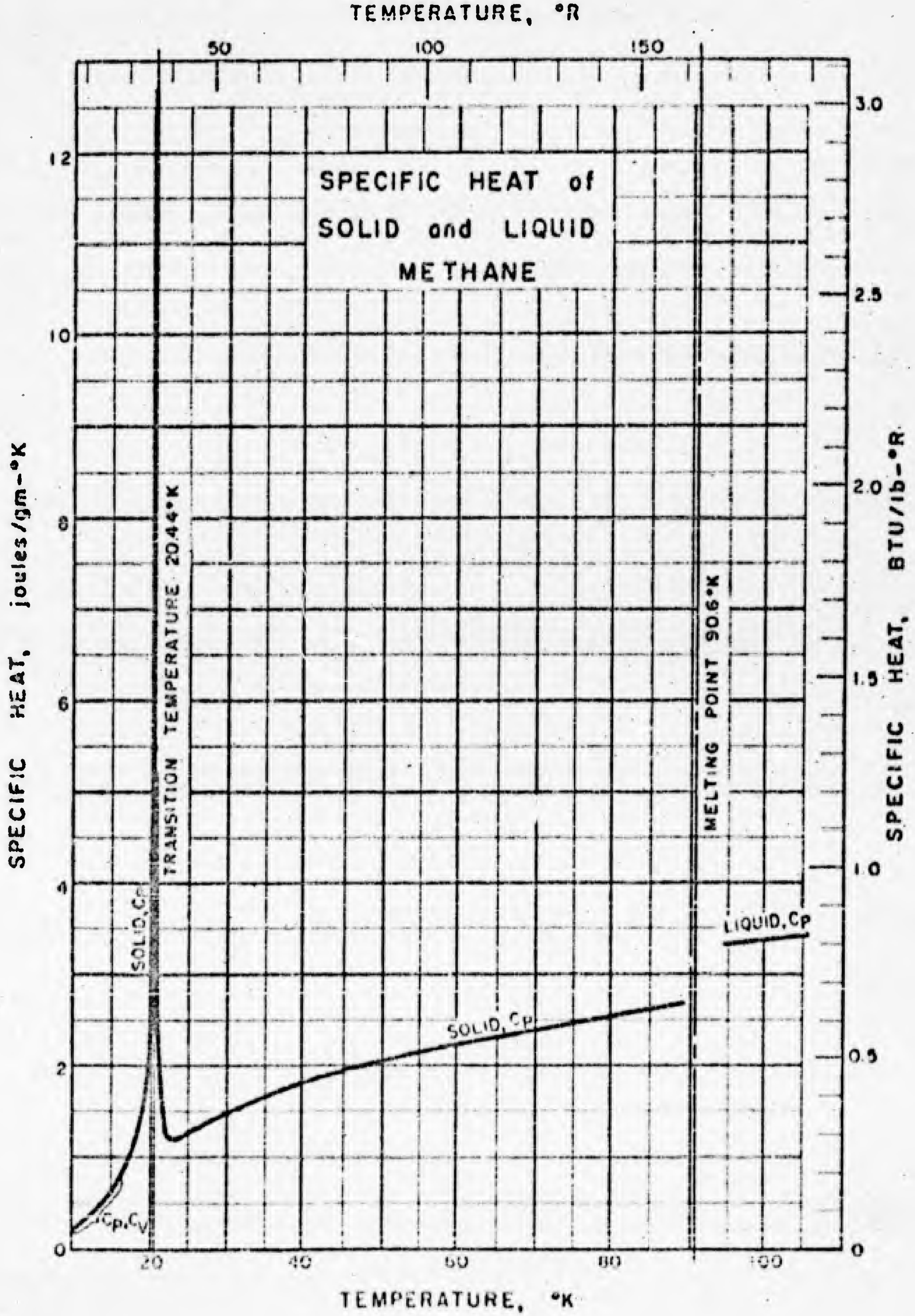
Frank, A. and Clusius, K., Z. physik. Chem. B36, 291-300 (1937).

Comments:

The transition in solid methane occurs at 20.4°K.

Table of Selected Values

Temp. °K	Specific Heat, C_p cal/gm-mole °K	Temp. °K	Specific Heat, C_p cal/gm-mole °K
15.48	2.774	20.27	45.3
16.55	3.300	20.32	47.6
16.61	3.362	20.34	71.6
17.74	4.207	20.37	69.3
17.78	4.240	20.4	Transition Temp.
18.56	5.154	20.40	42.5
18.73	5.262	20.44	27.4
19.17	6.152	20.53	10.31
19.47	7.324	21.06	4.504
19.78	10.65	21.35	4.325
19.94	10.91	22.48	4.641
20.12	17.20	23.13	4.782
20.18	20.7	24.65	4.912
20.27	35.7	25.52	5.193


TEMPERATURE, °R
50
100
150
SPECIFIC HEAT of
SOLID and LIQUID
METHANE
12
10
8
6
4
2
0
3.0
2.5
2.0
1.5
1.0
0.5
0
SPECIFIC HEAT, joules/gm-°K
SPECIFIC HEAT, BTU/lb-°R
TRANSITION TEMPERATURE 20.44°K
MELTING POINT 90.6°K
SOLID, Cp
SOLID, Cp
LIQUID, Cp
Cp, Cv
20
40
60
80
100
TEMPERATURE, °K

4.010

SPECIFIC HEAT of SOLID and LIQUID METHANE

Source of Data: Clusius, K., Z. physik. Chem. B3, 41-79 (1929).

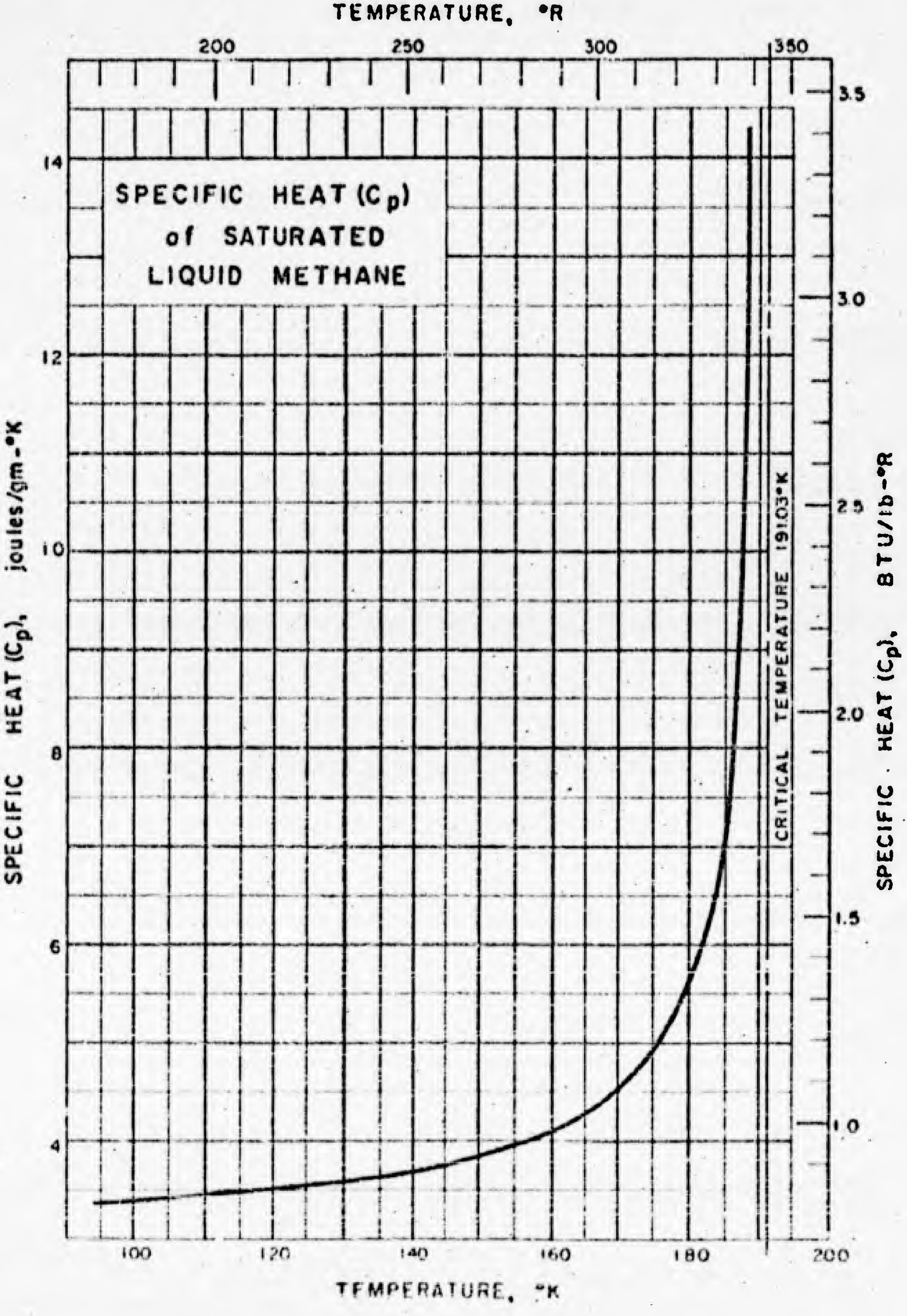
Table of Selected Values

Temp. °K	Specific Heat, C_p cal/gm-mole °K	Specific Heat, C_v cal/gm-mole °K
10.33	0.954	0.952
10.68	1.059	1.056
10.98	1.118	1.115
11.35	1.164	1.160
11.98	1.283	1.279
12.06	1.380	1.375
12.33	1.414	1.408
13.08	1.718	1.709
13.19	1.854	1.843
13.48	1.892	1.881
14.18	2.044	2.030
14.45	2.212	
15.04	2.340	2.321
15.41	2.530	
15.88	2.910	2.878

Temp. °K	Specific Heat, C_p cal/gm-mole °K
15.94	2.842
16.91	3.212
17.23	3.590
17.27	3.590
17.87	4.035
18.74	5.105
18.82	5.123
19.15	5.792
19.67	7.173
19.93	8.615
20.21	13.31
20.38	40.50
20.38	48.74
20.44	Transition Temp.
20.86	12.07

Temp. °K	Specific Heat, C_p cal/gm-mole °K
20.94	9.978
22.80	4.618
24.9	4.932
26.7	5.273
28.5	5.535
30.7	5.831
35.2	6.392
37.6	6.695
40.0	6.932
42.3	7.238
44.4	7.363
46.7	7.553
49.7	7.830
52.5	8.058
55.7	8.254
58.3	8.471
61.4	8.673
65.1	8.814
67.2	8.951

Temp. °K	Specific Heat, C_p cal/gm-mole °K
68.6	9.032
70.7	9.176
71.9	9.252
75.0	9.382
75.6	9.500
79.4	9.660
79.5	9.715
83.0	9.957
83.7	10.02
87.0	10.12
87.2	10.19
90.6	Normal Melting Pt.
95.4	12.81
97.7	12.85
98.9	12.90
102.0	12.97
102.1	13.12
105.3	13.01


TEMPERATURE, °R
200
250
300
350
SPECIFIC HEAT (C$_p$) of SATURATED LIQUID METHANE
SPECIFIC HEAT (C$_p$), joules/gm-°K
14
12
10
8
6
4
SPECIFIC HEAT (C$_p$), BTU/lb-°R
3.5
3.0
2.5
2.0
1.5
1.0
CRITICAL TEMPERATURE 191.03°K
100
120
140
160
180
200
TEMPERATURE, °K

4.010

SPECIFIC HEAT (C_p) of LIQUID METHANE
(Saturated)

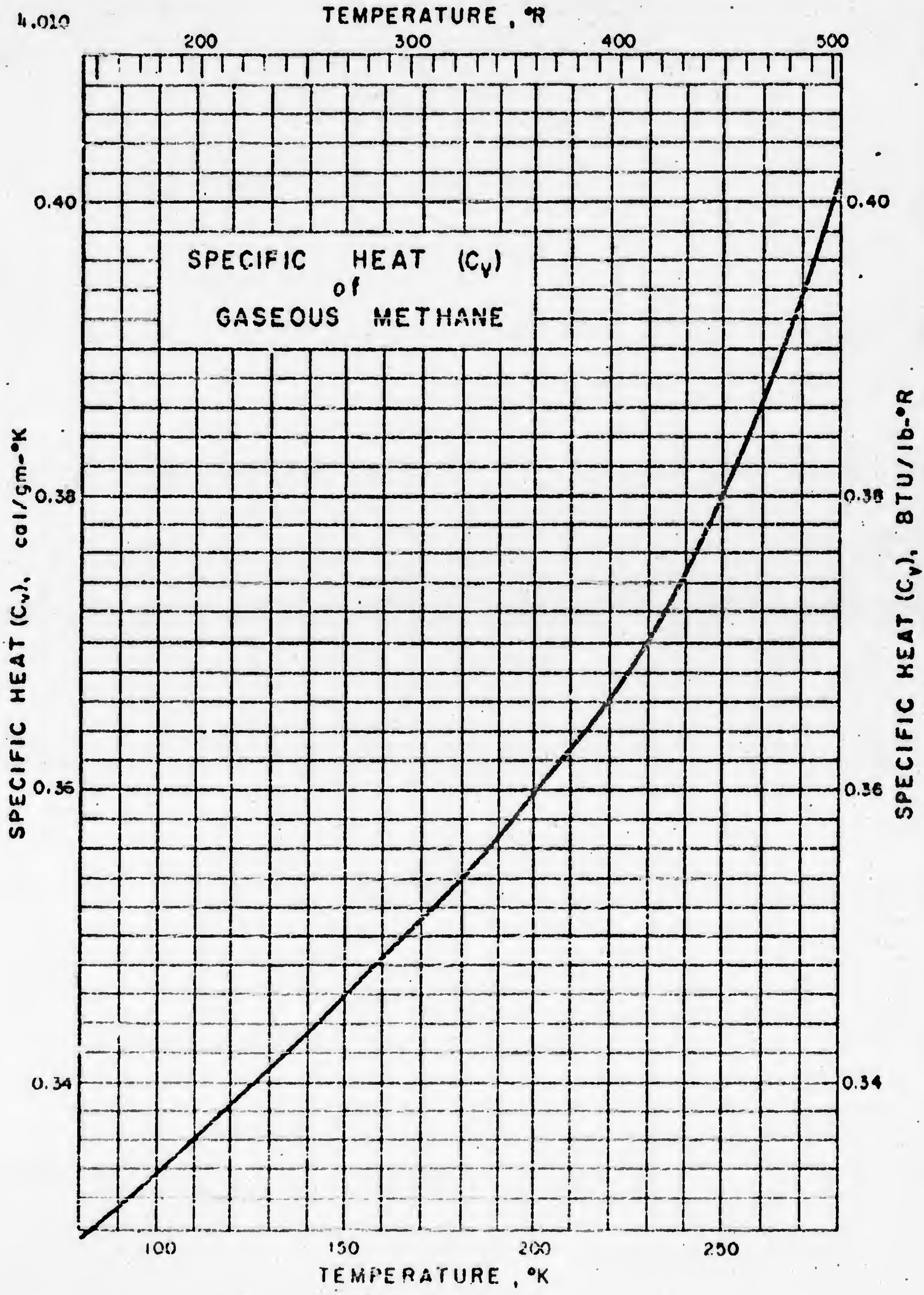
Source of Data:

Wiebe, R. and Brevoort, M. J., J. Am. Chem. Soc. 52, 622-33 (1930).

Table of Selected Values

Temp. °K	Specific Heat, C_p cal/gm-mole -°K	Temp. °K	Specific Heat, C_p cal/gm-mole -°K
97.73	12.94	160.96	16.01
102.27	13.09	169.02	17.30
110.94	13.20	174.75	19.48
117.53	13.27	178.00	20.90
121.82	13.26	180.86	22.18
129.32	13.77	182.82	23.92
134.28	14.05	182.95	24.18
140.49	14.34	184.43	26.01
149.51	14.78	188.24	52.34
153.70	14.97	191.03	Critical Temp.
154.75	15.27		

RFR Issued: 7/31/59


TEMPERATURE, °R
200
300
400
500
SPECIFIC HEAT (C_v) of GASEOUS METHANE
0.40
0.38
0.36
0.34
SPECIFIC HEAT (C_v), cal/gm-°K
SPECIFIC HEAT (C_v), BTU/lb-°R
100
150
200
250
TEMPERATURE, °K

4.010

SPECIFIC HEAT (C_v) of GASEOUS METHANE

Source of Data: Giacomini, F. A., Phil. Mag. 50, 146-56 (1925).

Other References: Millar, R. W., J. Am. Chem. Soc. 45, 874-81 (1923).

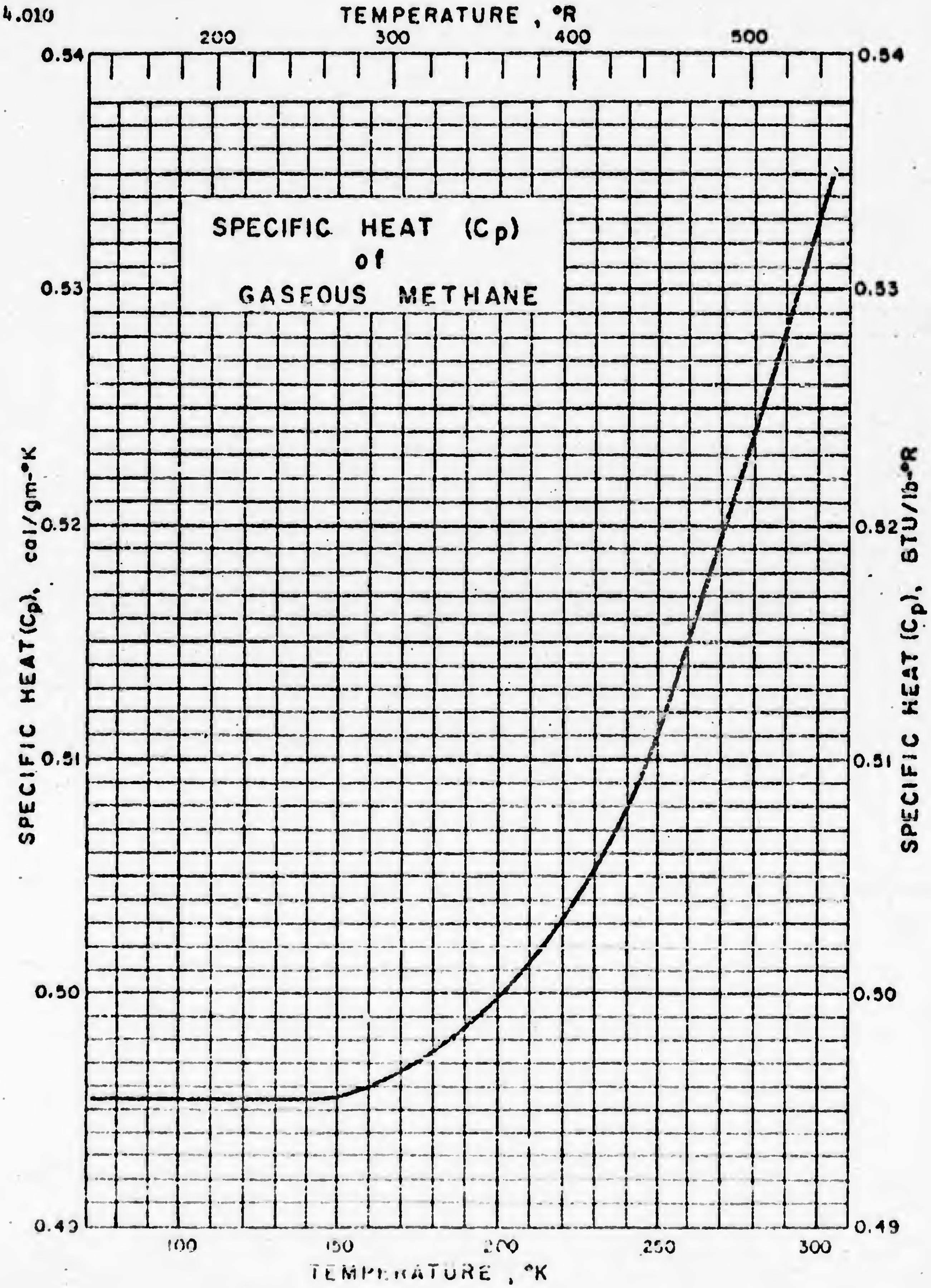
Comments: The values were obtained by measuring Cv directly instead of relying on a relationship between Cv and Cp.

Table of Selected Values

Temperature °K	Pressure mm Hg	Cv cal/gm-°K
83	60	0.330
180	507	0.354
222	570	0.367
278	760	0.400

RFR Issued 6-16-59

4.010


SPECIFIC HEAT (C_p) of GASEOUS METHANE

SPECIFIC HEAT (C_p) of GASEOUS METHANE

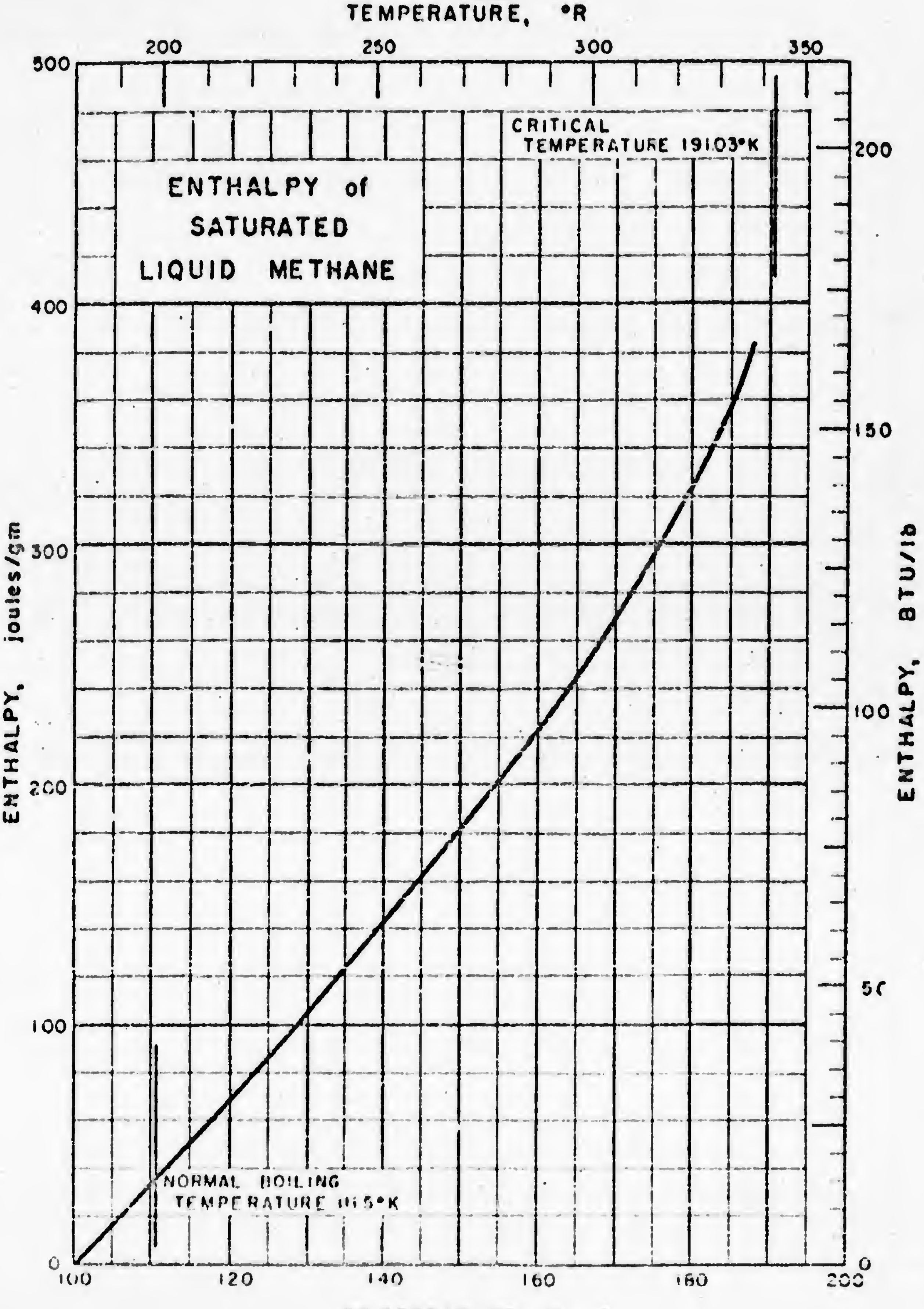
Source of Data: Rossini, F. D., et al., Selected Values of Physical and Thermodynamic Properties of Hydrocarbons and Related Compounds, Carnegie Press, Pittsburgh (1953), pp. 633, 655, 685.

Other References: Edmister, W. C., Oil and Gas J., 50-2 (Nov. 5, 1936); Eucken and Fried, Physik 29, 41 (1924); Eucken and Lude, Z. Physik. Chem. B5, 413 (1929); Heuse, Ann. Phys. 59, 86 (1919); Millar, R. W. J. Am. Chem. Soc. 45, 874-81 (1923); Pitzer, Ind. Eng. Chem. 36, 829 (1944).

Table of Selected Values

Temperature		Cp
°K	°R	cal/gm-°K
73.2	131.7	0.4955
88.7	159.7	0.4955
100.0	180.0	0.4955
116.5	209.7	0.4955
123.2	221.7	0.4955
144.3	259.7	0.4955
150.0	270.0	0.4958
172.1	309.7	0.4964
173.2	311.7	0.4965
199.8	359.7	0.4987
200.0	360.0	0.4988
223.2	401.7	0.5037
227.6	409.7	0.5048
250.0	450.0	0.5102
255.4	459.7	0.5135
273.2	491.7	0.5204
283.2	509.7	0.5248
288.7	519.7	0.5274
293.2	527.7	0.5296
298.2	536.7	0.5321
300.0	540.0	0.5331

4.010


TEMPERATURE, °R
200
250
300
350
ENTHALPY of SATURATED LIQUID METHANE
CRITICAL TEMPERATURE 191.03°K
NORMAL BOILING TEMPERATURE 111.5°K
ENTHALPY, joules/gm
0
100
200
300
400
500
ENTHALPY, BTU/lb
0
50
100
150
200
100
120
140
160
180
200
TEMPERATURE, °K

4.010

ENTHALPY of LIQUID METHANE
(Saturated)

Source of Data:

Wiebe, R. and Brevoort, M. J., J. Am. Chem. Soc. 52, 622-33 (1930).

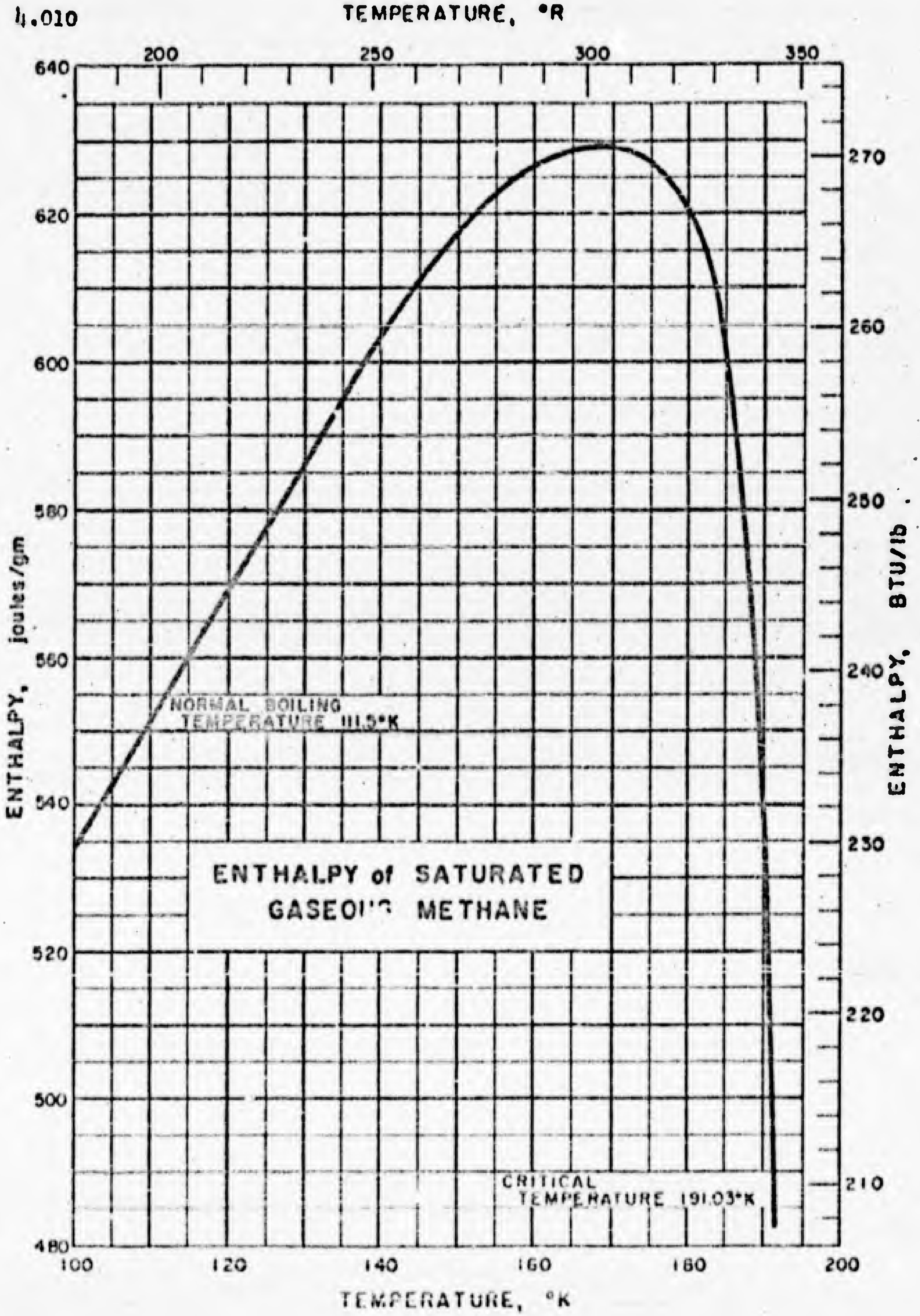
Comments:

The enthalpy values tabulated below have as their basis H = 0 for saturated liquid methane at 100°K.

Table of Selected Values

Temp. °K	Enthalpy, H, sat. liq. cal/g-mole
100	0.0
105	65.7
110	131.8
111.5*	152.2
115	198.7
120	266.3
125	334.7
130	404.6
135	475.2
140	547.1
145	620.2
150	696.0
155	774.0
160	855.1
165	940.2
170	1030.7
175	1128.7
180	1238.6
185	1366.3
191.03**	1850

* Normal Boiling Point
** Critical Point, H value found by extrapolation



ENTHALPY of SATURATED GASEOUS METHANE

4.010

ENTHALPY of GASEOUS METHANE
(Saturated)

Source of Data:

Wiebe, R. and Brevoort, M. J., J. Am. Chem. Soc. 52, 622-33 (1930).

Comments:

The enthalpy values tabulated below have as their basis H = 0 for saturated liquid methane at 100°K.

Table of Selected Values

Temp. °K	Enthalpy, H, sat. vap. cal/g-mole
100	2048
105	2081
110	2115
111.5*	2124
115	2149
120	2183
125	2218
130	2251
135	2283
140	2314
145	2341
150	2366
155	2386
160	2401
165	2410
170	2413
175	2405
180	2380
185	2306
191.03**	1850

* Normal Boiling Point

** Critical Point; H value found by extrapolation

5.000

PHASE TRANSITION HEATS

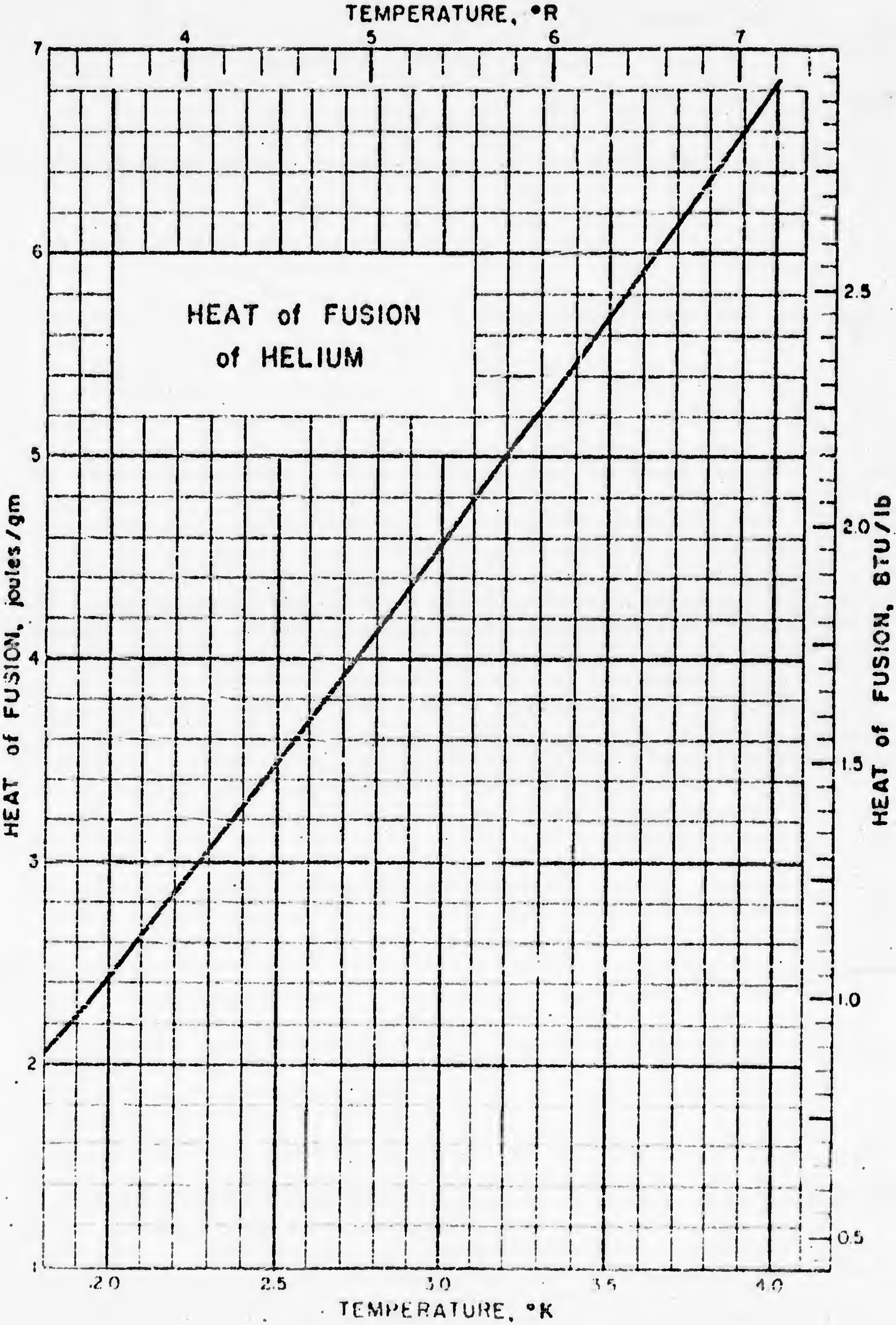
CONTENTS

CONVERSION FACTORS for TRANSITION HEATS and HEATS of CONVERSION

	$\frac{\text{cal}}{\text{gm}}$	$\frac{\text{joules}}{\text{gm}}$	$\frac{\text{watt sec}}{\text{gm}}$	$\frac{\text{BTU}}{\text{lb}}$
1 $\frac{\text{cal}}{\text{gm}}$ =	1.000	4.1840	4.1840	1.798823
1 $\frac{\text{joules}}{\text{gm}}$ =	0.239006	1.000	1.000	0.429929
1 $\frac{\text{watt sec}}{\text{gm}}$ =	0.239006	1.000	1.000	0.429929
1 $\frac{\text{BTU}}{\text{lb}}$ =	0.555919	2.32597	2.32597	1.000

92B

VJJ/JRC Issued: 10-7-59


TEMPERATURE, °R
4
5
6
7
HEAT of FUSION
of HELIUM
HEAT of FUSION, joules/gm
7
6
5
4
3
2
1
HEAT of FUSION, BTU/lb
2.5
2.0
1.5
1.0
0.5
2.0
2.5
3.0
3.5
4.0
TEMPERATURE, °K

5.001

HEAT of FUSION of HELIUM

Source of Data:

Swenson, C. A., Phys. Rev. 79, No. 4, 626-631 (Aug. 1950)

Other References:

Swenson, C. A., Phys. Rev. 86, No. 6, 870-6 (June 1952)

Holland, F. A., Huggill, J.A.W. and Jones, G. O., Proc. Roy. Soc. (London) A207, 268-77 (1951)

Swenson, C. A., Phys. Rev. 89, No. 3, 538-544 (Feb. 1953)

Domb, C. and Dugdale, J. S., Progress in Low Temperature Physics, Vol. II, Amsterdam, The Netherlands, North Holland Publishing Co. (1957) 480

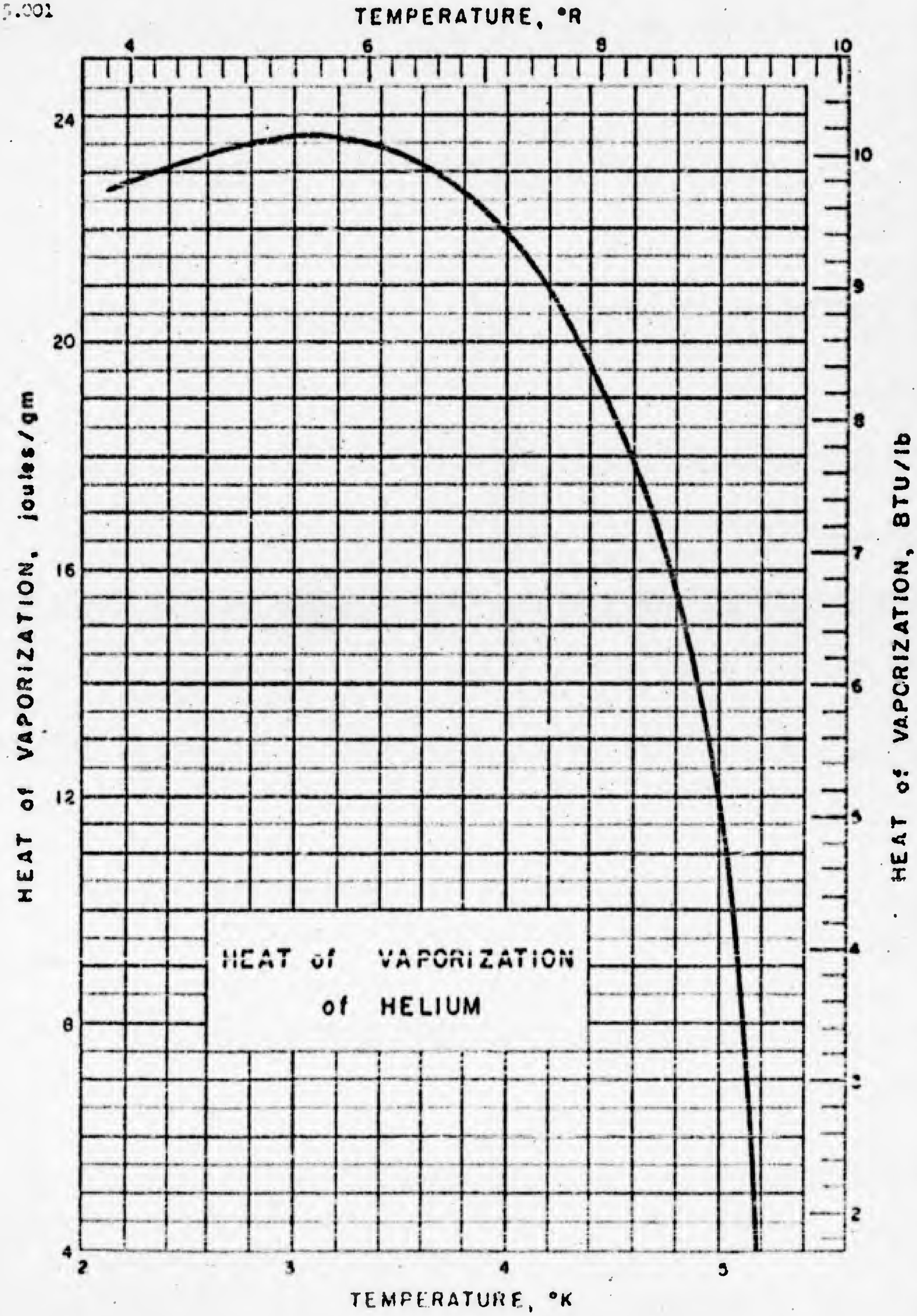
Keesom, W. H., Helium, Elsevier, Amsterdam (1942) p. 494

Table of Selected Values

Temperature		Heat of Fusion	
°K	°R	Joules/gm	BTU/lb
1.77	3.19	1.98	0.852
1.80	3.24	2.07	0.890
1.83	2.29	2.16	0.929
2.00	3.60	2.44	1.05
2.50	4.5	3.49	1.50
3.00	5.4	4.55	1.96
3.50	6.3	5.70	2.45
4.00	7.2	6.80	2.93

DBM/GAR Issued: 7/13/59
Revised: 5/20/60

5.001


TEMPERATURE, °R
4
6
8
10
24
20
16
12
8
4
HEAT of VAPORIZATION, joules/gm
10
9
8
7
6
5
4
3
2
HEAT of VAPORIZATION, BTU/lb
HEAT of VAPORIZATION
of HELIUM
2
3
4
5
TEMPERATURE, °K

5.001

HEAT of VAPORIZATION of HELIUM

Source of Data:

Berman, R. and Mate, C. R., Phil. Mag. (8) 3, 461-69 (May 1958)

Other References:

Dranen, J. Van, J. Chem. Phys. 23, 213 (Jan. 1955)

Keesom, W. H., Helium, Elsevier, Amsterdam (1942)

Rosenbaum, B. and Atkins, R., Bull. Am. Phys. Soc. 1, 218 (1956)

Van Dijk, H. and Durieux, M., Progress in Low Temperature Physics, Vol. II, North Holland Publishing Co., Amsterdam, The Netherlands (1957) 480 pp.

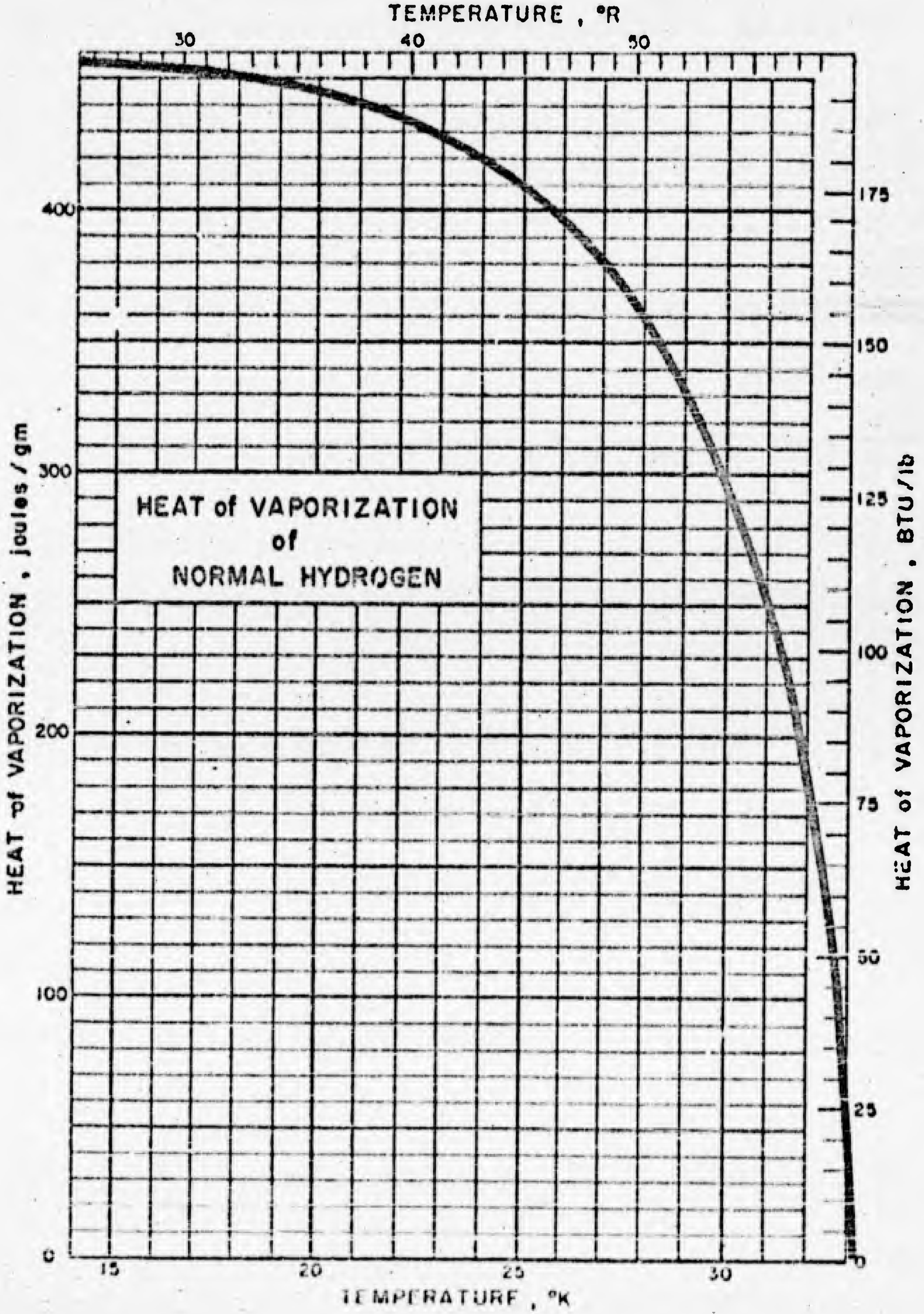
Comments:

The Absolute temperature scale (0°C = 273.16°K) was used in the table of selected values below.

Temp. °K	H_v $\frac{\text{Joules}}{\text{gm}}$	Temp. °K	H_v $\frac{\text{Joules}}{\text{gm}}$
2.20	22.8	4.00	21.9
2.40	23.1	4.20	20.9
2.60	23.3	4.40	19.7
2.80	23.5	4.60	18.0
3.00	23.7	4.80	15.6
3.20	23.6	5.00	12.0
3.40	23.5	5.10	8.99
3.60	23.2	5.15	6.70
3.80	22.7	5.18	4.00

DBM/GAR Issued: 7/13/59

5.002


TEMPERATURE , °R
30
40
50
HEAT of VAPORIZATION
of
NORMAL HYDROGEN
HEAT of VAPORIZATION , joules / gm
400
300
200
100
0
HEAT of VAPORIZATION , BTU/lb
175
150
125
100
75
50
25
0
15
20
25
30
TEMPERATURE , °K

HEAT of VAPORIZATION of NORMAL HYDROGEN

Sources of Data:

Woolley, H. W., Scott, R. B. and Brickwedde, F. G., J. Research Natl. Bur. Standards 41, 379-475 (1948); Research Report RP 1932

Simon, F. and Lange, F., Z. Physik. 15, 312 (1923)

Other References:

Koeppe, W., The Determination of Unknown Thermal Data by the Modified Theorem of Corresponding States, Kaltetechnik 8, No. 9 (1957)

Comments:

The data tabulated below were obtained from a T-S diagram included in RP 1932. Simon and Lange made direct measurements of the heat of vaporization at several temperatures between the triple point and the normal boiling point. They fitted their data with the equation:

$$L_v \text{ (in cal/mole)} = 219.7 - 0.27\,(T - 16.6)^2$$

It is quite likely that this equation will give somewhat more accurate values of the heat of vaporization between 14° and 20.4°K than will the table. In constructing the T-S diagram, it was found that the experimental values of L_v differed from those obtained from the Clausius-Clapeyron equation; accordingly, the values shown on the diagram represent a compromise.

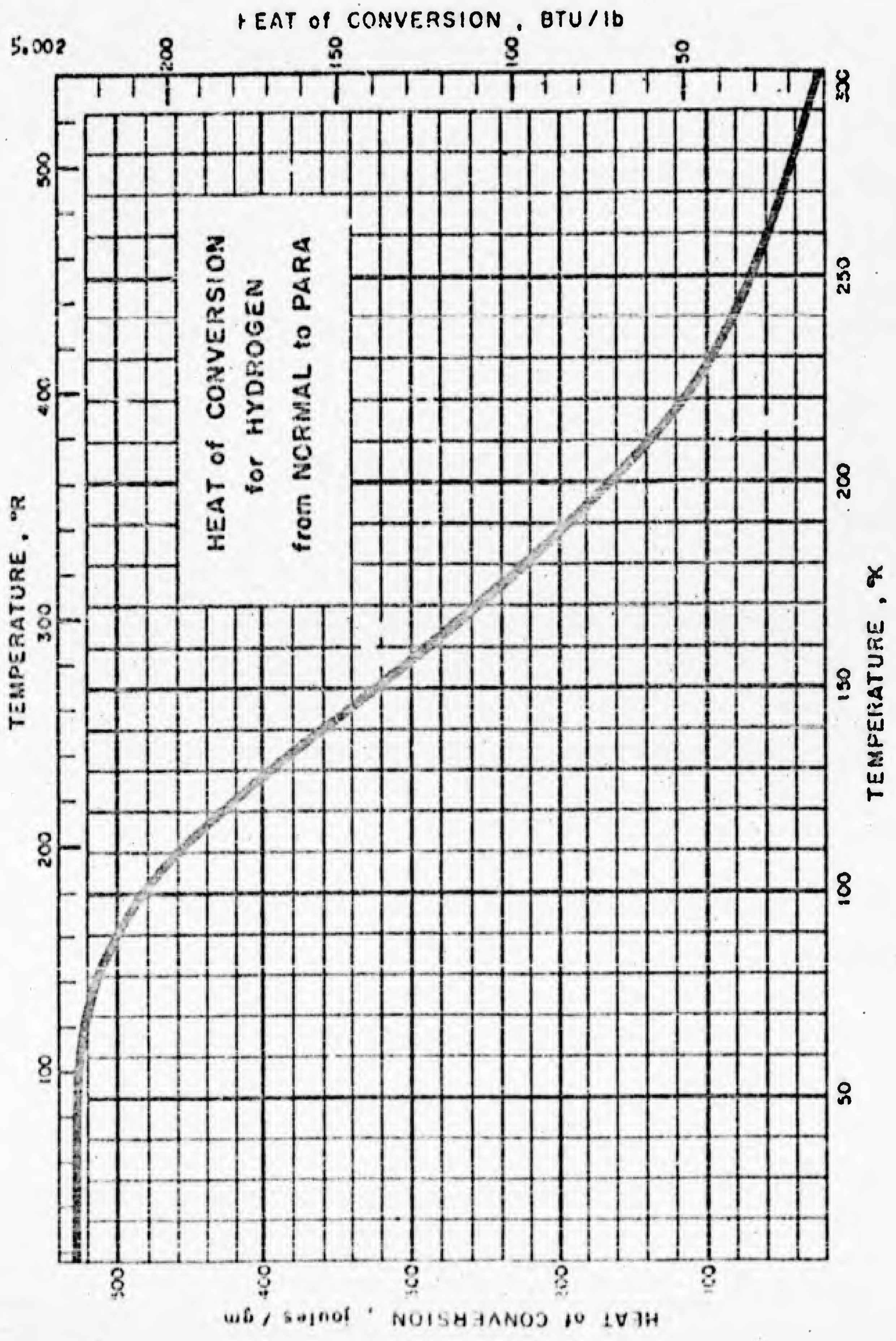
Pressure atm.	Temperature °K	cal/gm $\Delta H_{vap.}$
0.12	15.0	108.6*
0.6	17.8	106.7
0.8	19.7	106.0
1.0	20.5	105.5
1.5	22.0	103.3
2.0	23.0	102.0
3.0	24.75	98.0
4.0	26.2	94.3
5.0	27.3	89.0
6.0	28.3	84.0
8.0	30.0	71.2
10.0	31.3	57.1
12.0	32.6	33.0
12.98	33.19	0

* From Simon and Lange; all the other values determined graphically from RP 1932.

Melting Temperature = 13.95°K
Normal Boiling Temp. = 20.39°K
Critical Temperature = 33.19°K

DEJ/VJJ Issued: 12/10/59

5.002



HEAT of CONVERSION for HYDROGEN from NORMAL to PARA
HEAT of CONVERSION , BTU/lb
200
150
100
50
TEMPERATURE , °R
100
200
300
400
500
TEMPERATURE , °K
50
100
150
200
250
300
HEAT of CONVERSION , joules / gm
500
400
300
200
100

5.002

HEAT of CONVERSION of NORMAL HYDROGEN to PARA HYDROGEN
(10° to 300°K)

Source of Data:

Woolley, H. W., Scott, R. B. and Brickwedde, F. G., J. Research Natl. Bur. Standards 41, 379-475 (1948)

Other References:

Epstein, P. S., Textbook on Thermodynamics, John Wiley and Sons, Inc., New York, N.Y. (1937)

Giauque, W. F., J. Am. Chem. Soc. 52, 4808 (1930)

Glasstone, S., Textbook of Physical Chemistry, D. Van Nostrand Co., Inc., New York, N.Y. (1940)

MacDougall, F. H., Thermodynamics and Chemistry, John Wiley and Sons, Inc., New York, N.Y. (1939)

Comments:

The values for heat of conversion from para to normal hydrogen for the ideal gas state at one atmosphere pressure were obtained by direct summation. Assuming only the ground state energy makes an appreciable contribution to the state energy sum; then,

$$H^\circ - E^\circ_0 = 5/2RT$$

The heat of conversion from para to normal hydrogen in the table of values below is obtained by

$$\sum \left[H^\circ - E^\circ\right]_{nH_2} - \left[H^\circ - E^\circ\right]_{pH_2}$$

Where:

H° = molar heat content for a substance in ideal gaseous state.
E°_0 = E° at absolute zero when energy associated with internal degrees of freedom for each molecule is at its lowest quantized state.
R = molar gas constant
T = absolute temperature (0°C = 273.16°K)
E° = E for a substance in the ideal gaseous state

Temp. °K	Heat of Conversion l/mole	Temp. °K	Heat of Conversion cal/mole
10	253.9865	80	247.023
20	253.987	90	241.275
20.39	253.986	100	232.079
30	253.986	120	205.857
33.1	253.986	150	155.385
40	253.976	200	78.91
50	253.845	250	33.96
60	253.212	298.16	13.76
70	251.406	300	13.28

DEJ Issued: 12/10/59

HEAT of FUSION of NEON

Source of Data: Clusius, K., Z. physik. Chem., B31, 459-74 (1936).

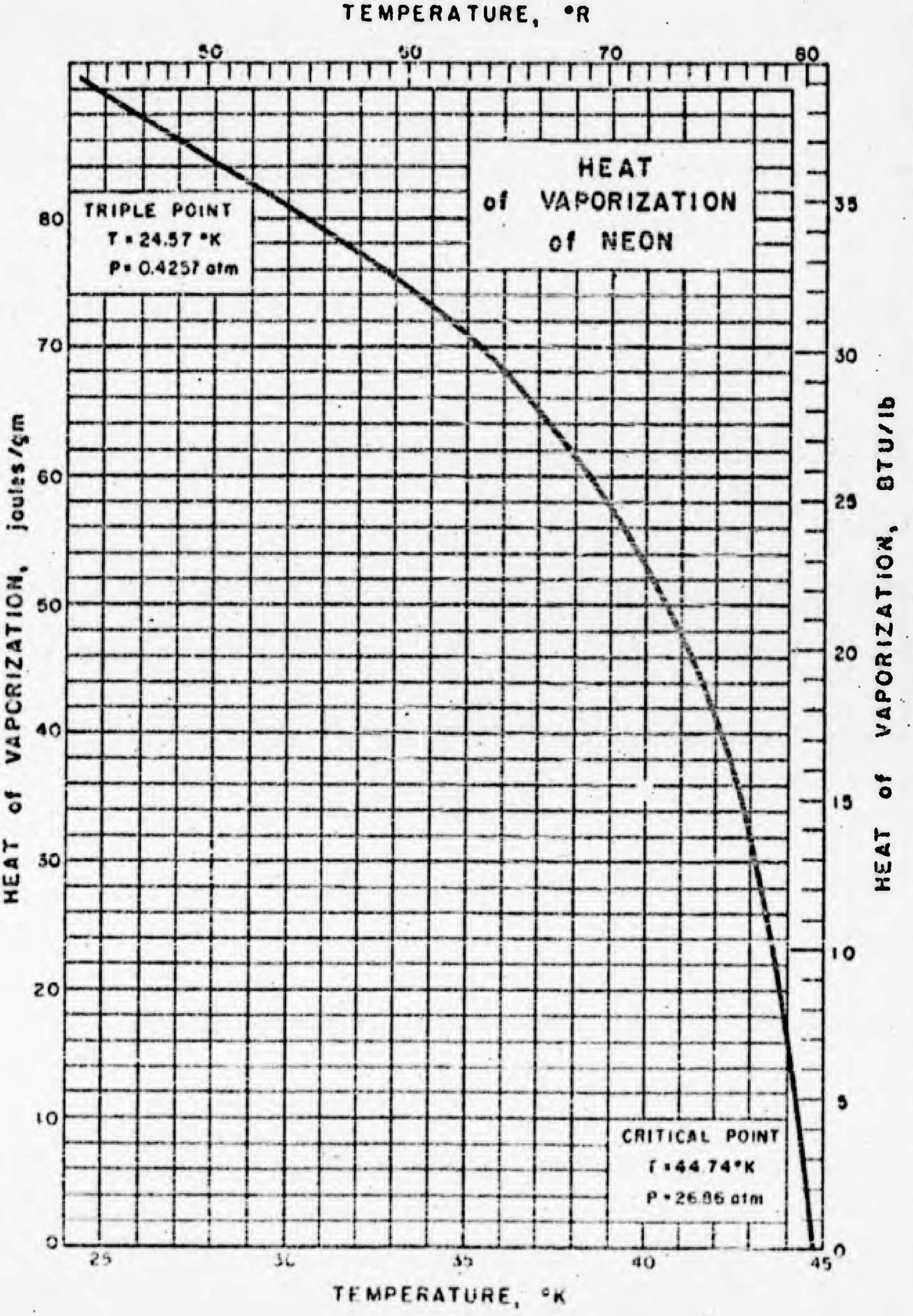
Comments: Other values of the heat of fusion at the melting point temperature available are 80.07 cal/mole = 3.967 cal/gm. (Guggenheim, E. A., J. Chem. Phys., 13, 253-6 [1945]) and 57.3 cal/mole = 2.839 cal/gm (Int. Crit. Tables [1926]).

The heat of fusion of neon at the melting point temperature is 80.1 cal/mole = 3.969 cal/gm.

The ratio of the heat of fusion to the heat of vaporization given by K. Clusius is 0.191 and is recommended.

J. K. Mackenzie and N. F. Mott, Proc. Phys. Soc. (London) 63A, 411-12 (1950) give a value of 0.136 for H_f/H_v.

KDT/EDT Issued: 5/25/59


TEMPERATURE, °R
50
60
70
80
HEAT
of VAPORIZATION
of NEON
TRIPLE POINT
T = 24.57 °K
P = 0.4257 atm
CRITICAL POINT
T = 44.74 °K
P = 26.86 atm
HEAT of VAPORIZATION, joules/gm
0
10
20
30
40
50
60
70
80
HEAT of VAPORIZATION, BTU/lb
0
5
10
15
20
25
30
35
25
30
35
40
45
TEMPERATURE, °K

HEAT of VAPORIZATION of NEON

Sources of Data: Clusius, K., Z. physik. Chem., B4, 1-13 (1929); Clusius, K., Z. physik. Chem., B31, 459-74 (1936); Kane, G., J. Chem. Phys., 7, 603-13 (1939); Kassel, L. S. and Muskat, M., Phys. Rev., 40, 627-32 (1932); Mathias, E., Crommelin, C. A., and Onnes, H. K., Compt. rend., 176, 939-40 (1923); Mathias, E., Crommelin, C. A., and Onnes, H. K., Leiden Comm., 162B (1922).

Comments: Values at 0°K are calculated for heat of vaporization from liquid at 0°K even though the latter does not exist. Other values of the heat of vaporization at the normal boiling point available are 20.58 cal per gram [Hood, C. B. and Grilly, E. R., Rev. Sci. Instr., 23, 357 (1952)], 20.6 cal per gram [Int. Crit. Tables (1928)], and 20.63 cal per gram [Mathias, E., Crommelin, C. A., and Onnes, H. K., Leiden Comm., 162B, (1922)].

The Leiden Temperature scale (0°C = 273.09°K) is used.

Equation for calculating the heat of vaporization:

$$L^2 = 43.56922\ (T_c-T) - 1.744347\ (T_c-T)^2 + 0.0371203\ (T_c-T)^3$$

where: L is the heat of vaporization, cal/gram
T_c is the critical temperature, °K (44.74°K)
T is the temperature, °K.

Table of Selected Values

Temperature		Heat of vaporization
°K	°R	cal/gram
0	0	22.20*
0	0	22.20*
0	0	22.17*
25.17	45.31	21.36
26.15	47.07	20.96
27.15	48.87	20.56
27.17	48.91	20.6
30.13	54.23	19.34
33.09	59.56	17.97
34.00	61.20	18.83**
36.05	64.89	16.23
37.83	68.09	14.87
39.08	70.34	13.69
41.065	73.92	11.26
43.02	77.44	7.491

* calculated ** doubtful

HEAT of TRANSITION in SOLID NITROGEN

Sources of Data:

Clusius, K., Z. physik Chem. Abt. B3, 41-79 (1929)

Eucken, A., Verh. deut. physik Ges. 18, 4-17 (1916)

Giauque, W. F. and Clayton, J. O., J. Am. Chem. Soc. 55, 4875-89 (1933)

Comments:

The table below lists all the available data of the heat of α → γ transition in solid nitrogen. The best value is not known. The α form is probably cubic close packed and the γ form is hexagonal close packed.

Table of Selected Values

Temp. °K	Heat of α → γ Transition cal/g-mole
35.4	51.4
35.5	53.8
35.61	54.71 ± 0.1

HEAT of FUSION of NITROGEN at the NORMAL MELTING POINT

Sources of Data:

Clusius, K., Z. physik Chem. Abt. B3, 41-79 (1929)

Eucken, A., Verh. deut. physik. Ges. 18, 4-17 (1916)

Giauque, W. F. and Clayton, J. O., J. Am. Chem. Soc. 55, 4785-89 (1933)

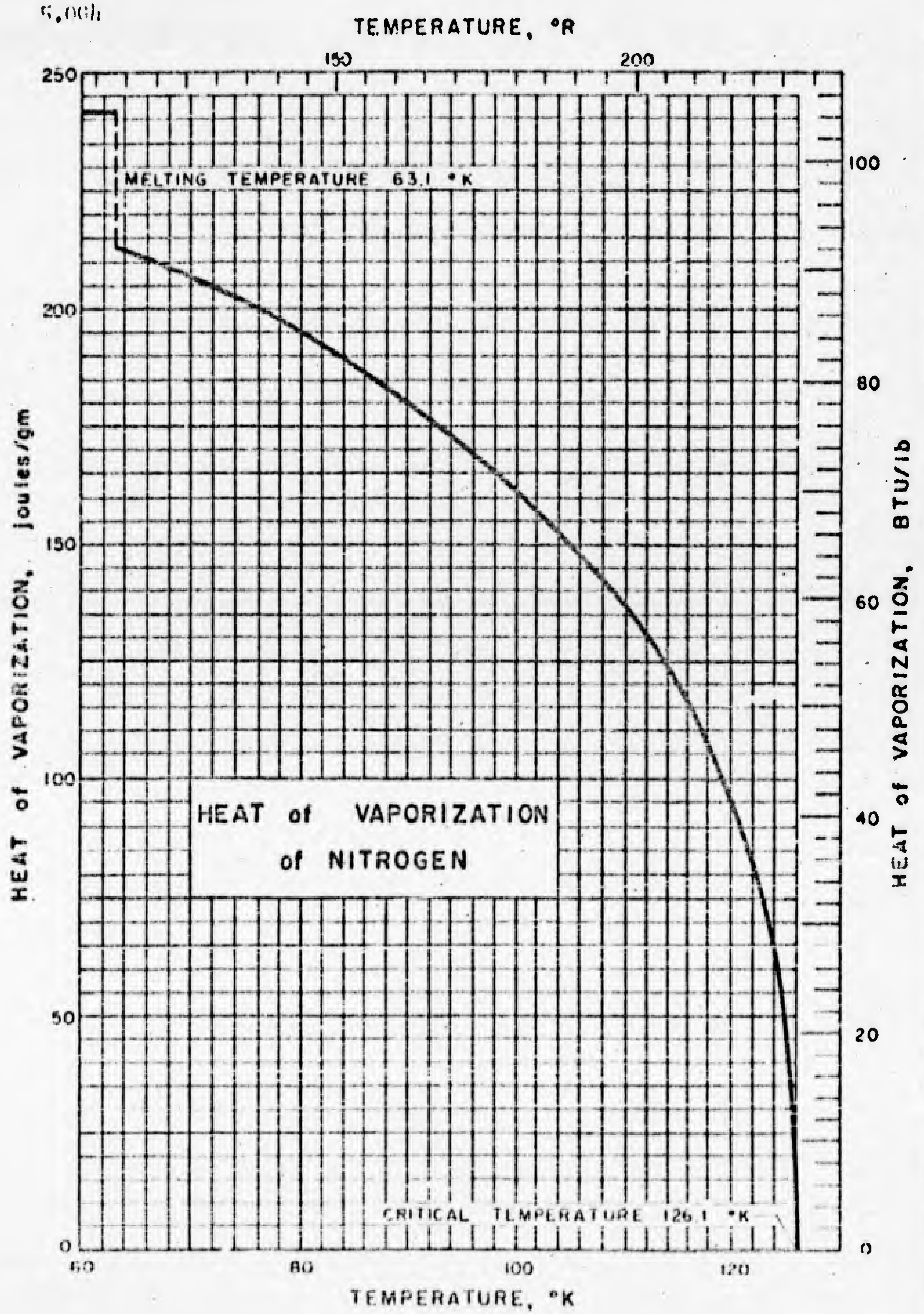
Comments:

The table below lists all the values from the above references. An average value of 171 ± 1 cal/gm-mole at 63.1 ± .05°K is probably the best value.

Table of Selected Values

Temp. °K	Heat of Fusion, ΔH_f cal/g-mole
63.08	170.95
63.1	168.7
63.14 ± 0.05	172.3

5.006


TEMPERATURE, °R
150
200
250
200
150
100
50
0
100
80
60
40
20
0
MELTING TEMPERATURE 63.1 °K
HEAT of VAPORIZATION
of NITROGEN
CRITICAL TEMPERATURE 126.1 °K
60
80
100
120
TEMPERATURE, °K
HEAT of VAPORIZATION, Joules/gm
HEAT of VAPORIZATION, BTU/lb

HEAT of VAPORIZATION of NITROGEN

Sources of Data:

Furukawa, G. T. and McCoskey, R. E., NACA Tech. Note No. 2969, 30 pp. (1953).

Millar, R. W. and Sullivan, J. D., Bureau of Mines Tech. Paper No. 424 (1928).

Table of Selected Values

	Temp. °K	Heat of Vaporization, ΔH_v	
		joules/mole	cal/mol
Solid	62.00	6775.0	
	62.0018	6787.4	
	62.0172	6762.4	
Liquid	67.9588	5901.6	
	67.9620	5899.0	
	68.00	5899.0	
	73.0913	5739.1	
	73.0887	5732.1	
	73.10	5735.2	
	77.395	5592.2	
	78.00	5579.4	
	78.0147	5563.1	
	78.0153	5571.8	
	80		1313
	85		1266
	90		1213
	95		1155
	100		1086
	105		1010
	110		918
	115		803
	120		643
	125		328
	126.1*		0

* Critical point

5.004

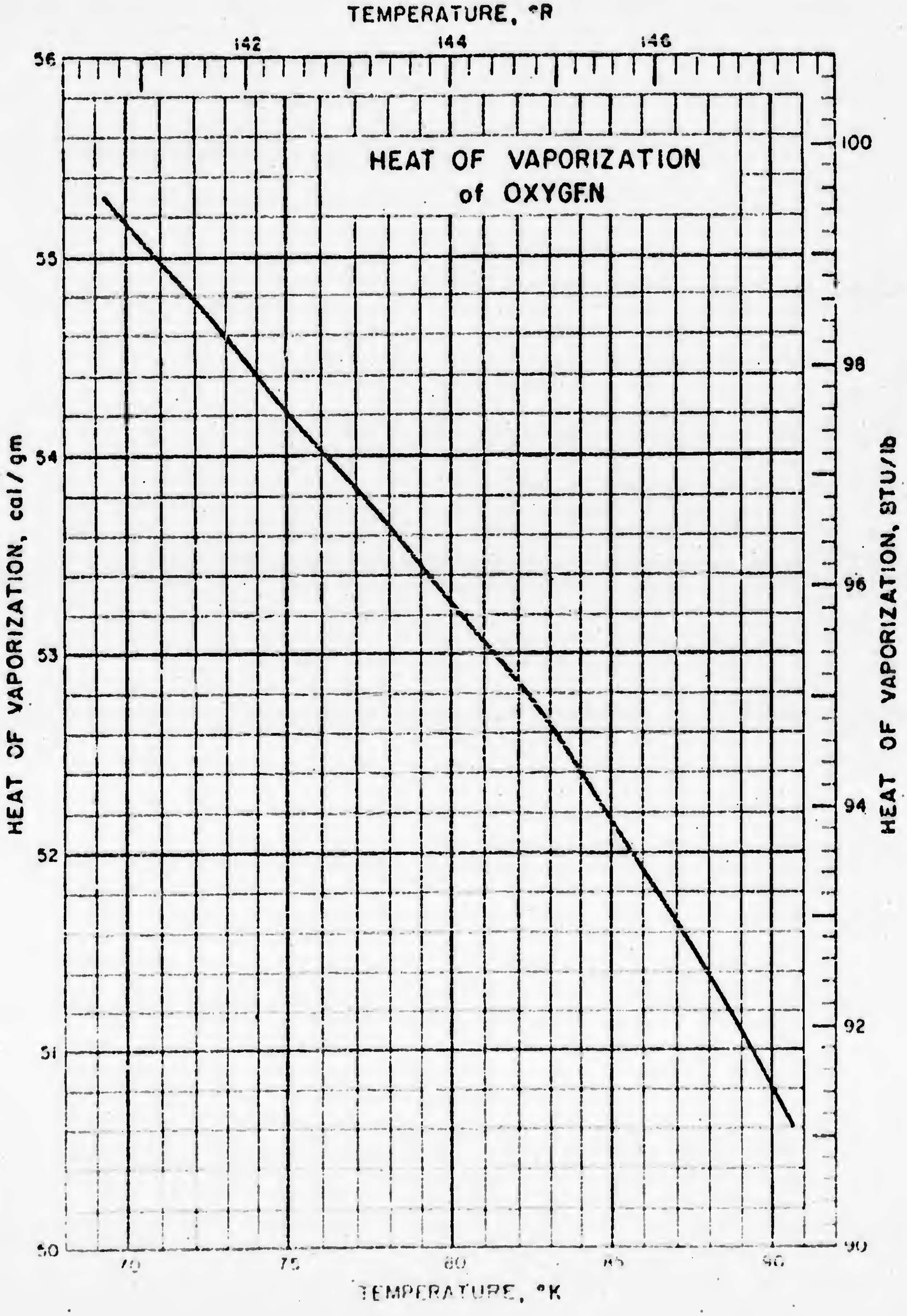
HEAT of VAPORIZATION of NITROGEN at the NORMAL BOILING POINT

Source of Data: Furukawa, G. T. and McCoskey, R. E., N.A.C.A. Tech. Note No. 2969, 30 pp. (1953).

Comments: Other values of the heat of vaporization of nitrogen at the normal boiling point (77.35 ± 0.05°K, 1 atm) available are 5582 joules/mole [Alt, H., Ann. Phys. 19, 739-82 (1906)]; 5593.0 joules/mole [Armstrong, G. T., J. Res. Nat. Bur. Standards 53, 263-6 (1954); and Dana, L. I., Proc. Am. Acad. Arts & Sci. 60, No. 4, 241-67 (1925)]; 5900 joules/mole [Dewar, J., Proc. Roy. Soc. (London) A76, 325-40 (1905)]; 5703 joules/mole [Eucken, A., Verh. deut. physik. Ges. 18, 4-17 (1916)]; 5578 joules/mole [Giauque, W. F. and Clayton, J. O., J. Am. Chem. Soc. 55, 4875-89 (1933)]; 5590 joules/mole [Millar, R. W. and Sullivan, J. D., Bureau of Mines Tech. Paper No. 424 (1928)]; and 5810 joules/mole [Witt, G., Arkiv. Mat., Astron. och Fysik 7, No. 32, 1-13 (1912)].

The best value of the heat of vaporization of nitrogen at the normal boiling point (77.35 ± 0.05°K, 1 atm) available is 5592.2 joules/mole. This is equal to 47.707 cal/gm.

KDT/BWF Issued: 7/31/59

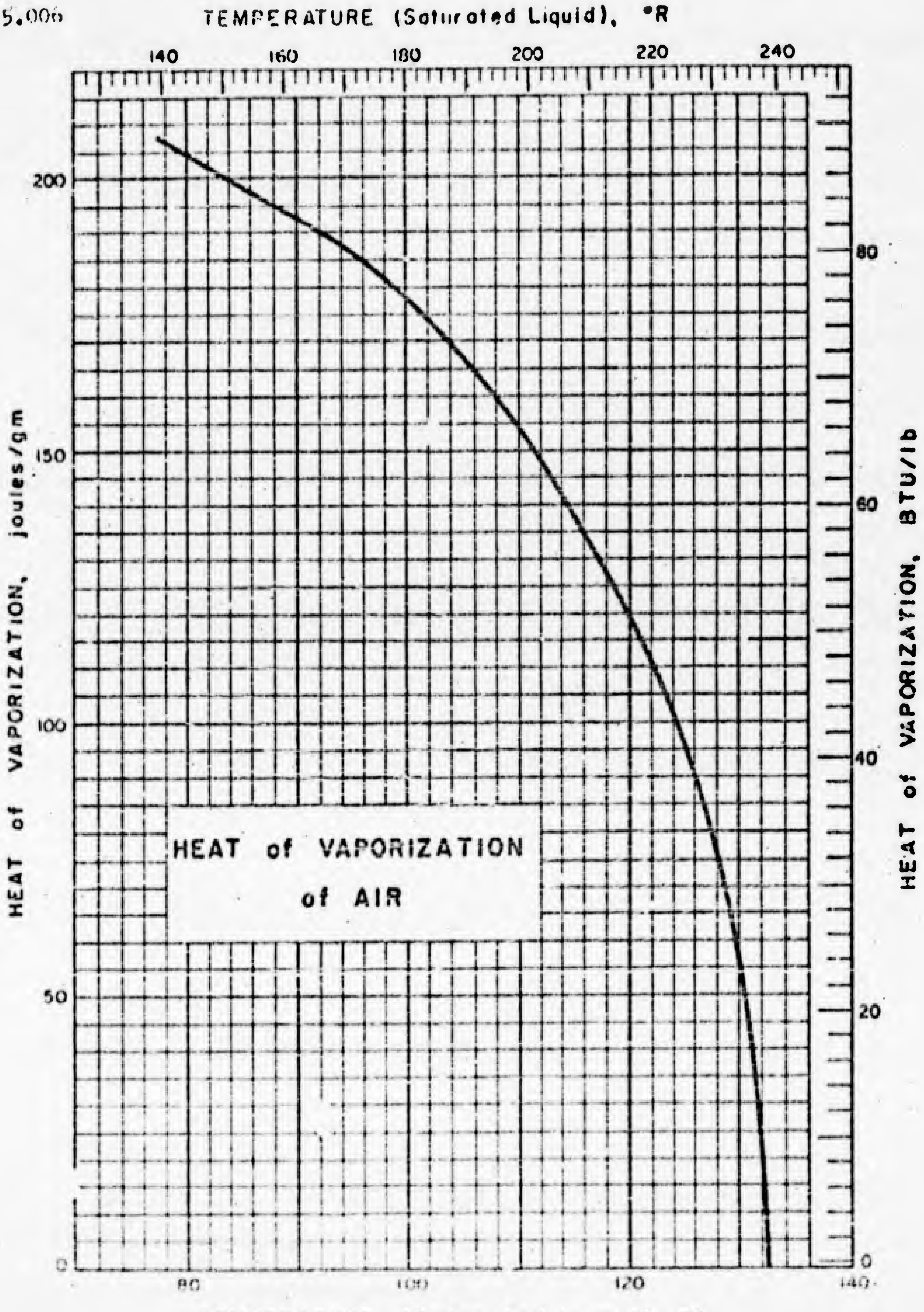


TEMPERATURE, °R
142
144
146
HEAT OF VAPORIZATION of OXYGEN
56
55
54
53
52
51
50
HEAT OF VAPORIZATION, cal / gm
100
98
96
94
92
90
HEAT OF VAPORIZATION, BTU/lb
70
75
80
85
90
TEMPERATURE, °K

HEAT of VAPORIZATION of LIQUID OXYGEN

Source of Data: Furukawa, G. T. and M.Coskey, R. E., NACA Tech. Note 2969, (June-1953).

Comments: There was no tabular data in the above reference.


TEMPERATURE (Saturated Liquid), °R
140
160
180
200
220
240
HEAT of VAPORIZATION, joules/gm
200
150
100
50
0
HEAT of VAPORIZATION, BTU/lb
80
60
40
20
0
HEAT of VAPORIZATION
of AIR
80
100
120
140
TEMPERATURE (Saturated Liquid), °K

HEAT of VAPORIZATION of AIR

Source of Data:

Din, F., Thermodynamic Functions of Gases, Vol. 2, Butterworth's Scientific Publications, London (1956)

Other References:

Claitor, L. C. and Crawford, D. B., Trans. ASME 71, 885-895 (Nov. 1949)

Dana, L. J., Proc. Am. Acad. Arts Sci. 60, 241 (1925)

Williams, V. C., Trans. Am. Inst. Chem. Eng. 39, 93 (1943)

Comments:

The latent heat of vaporization is usually defined for a single component and is the heat required to completely change a given quantity of liquid at its bubble point (boiling point) to vapor at its dew point at constant temperature and pressure. However, for the multicomponent system tabulated below only the pressure remains constant while the temperature rises throughout the process.

The data of Din is based on the work of Dana. The data are given at the temperature and pressure of the saturated liquid (bubble point).

Heat of Vaporization

Pressure	Temp. (Sat. Liq.)		Heat of Vaporization	
Atm.	°K	°R	Joules/gm	BTU/lb.
1	78.8	142.	205.2	88.22
2	85.55	154.0	197.4	84.87
3	90.94	163.7	191.4	80.86
5	96.38	173.5	183.9	79.06
7	101.04	181.87	175.0	75.24
10	106.47	191.65	163.5	70.29
15	113.35	204.03	143.5	61.69
20	118.77	213.79	124.1	53.35
25	123.30	221.94	103.2	44.37
30	127.26	229.07	80.39	34.56
35	130.91	235.64	48.45	20.83
37.17	132.52	238.49	0	0

5.007

HEAT of TRANSITION of SOLID CARBON MONOXIDE

(α to β Form)

Sources of Data:

Clusius, K. and Teske, W., Z. physik. Chem. B6, 135-151 (1929)

Clusius, K., Z. physik. Chem. B3, 41-79 (1929)

Eucken, A., Ber. deut. physik. Ges. 18, 4-17 (1916)

Clayton, J. O. and Giauque, W. F., J. Am. Chem. Soc. 54, 2610-26 (1932)

Kaishev, P., Z. physik. Chem. B40, 273-80 (1938)

Comments:

Best value is considered to be that of Clayton and Giauque.

Table of Values

Reference	Temperature °K	Heat of Transition cal/gm-mole
Clusius & Teske; Clusius	61.5_1	151.2
Eucken	60.4	144.1
Clayton and Giauque	61.55 ± .05	151.3 ± 1.0
Kaishev	61.49	150.9

KDF/SDF Issued: 7/31/59

5.007

HEAT of FUSION of CARBON MONOXIDE

Sources of Data:

Clusius, K. and Teske, W., Z. physik. Chem. B6, 135-151 (1929)

Clusius, K., Z. physik. Chem. B3, 41-79 (1929)

Eucken, A., Ber. deut. physik. Ges. 18, 4-17 (1916)

Clayton, J. O. and Giauque, W. F., J. Am. Chem. Soc. 54, 2610-26 (1932)

Kaishev, P., Z. physik. Chem. B40. 273-80 (1938)

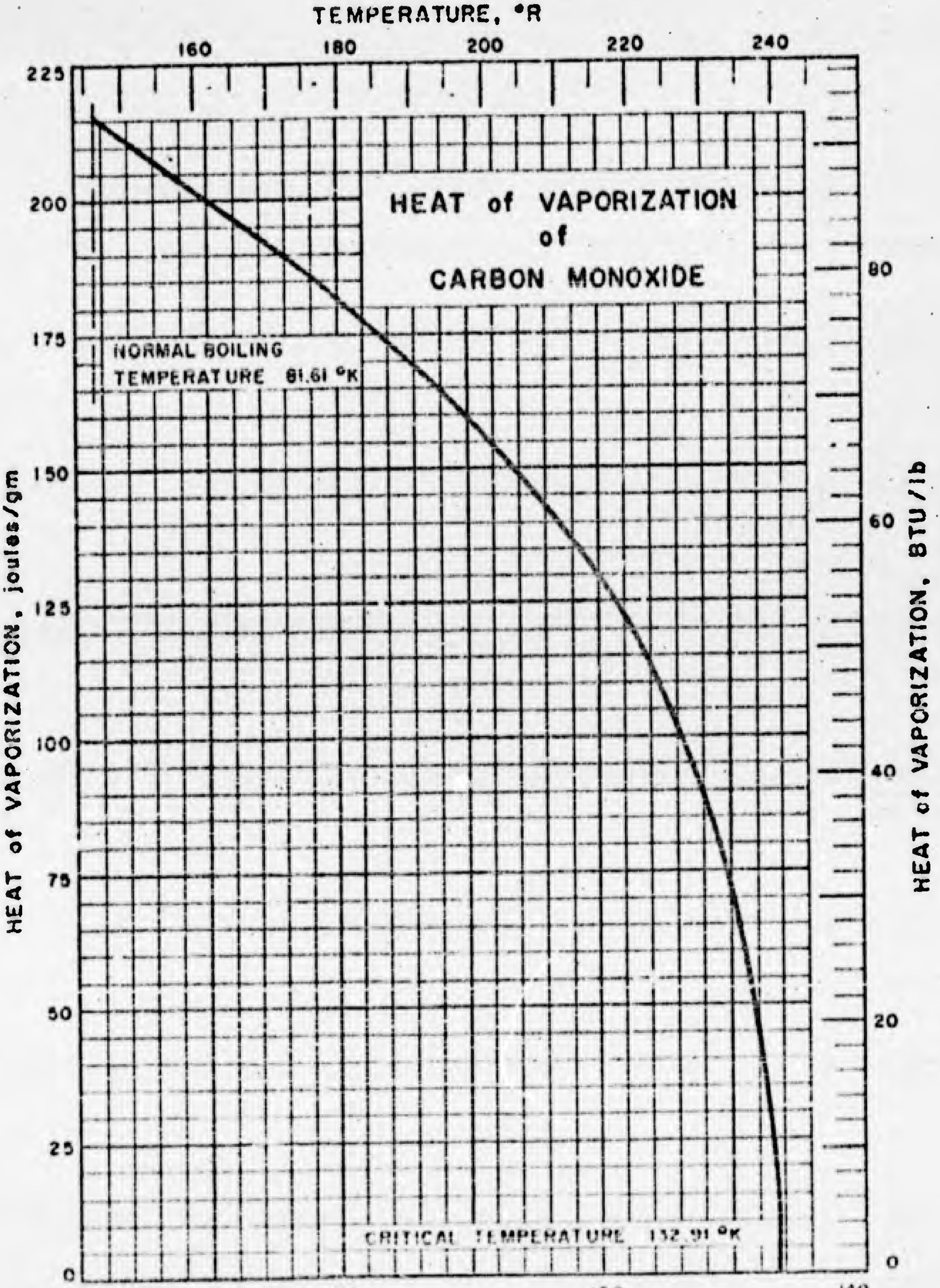
Comments:

Best value is considered to be that of Clayton and Giauque.

Table of Values

Reference	Temperature °K	Heat of Fusion cal/gm-mole
Clusius & Teske; Clusius	68.2$_2$	201.5
Eucken	67.3	198.2
Clayton and Giauque	68.09 ± .05	199.7 ± 0.2
Kaishev	68.10	200.9

KDT/BDF Issued: 7/31/59


TEMPERATURE, °R
160
180
200
220
240
HEAT of VAPORIZATION of CARBON MONOXIDE
NORMAL BOILING TEMPERATURE 81.61 °K
CRITICAL TEMPERATURE 132.91 °K
HEAT of VAPORIZATION, joules/gm
225
200
175
150
125
100
75
50
25
0
HEAT of VAPORIZATION, BTU/lb
80
60
40
20
0
80
100
120
140
TEMPERATURE, °K

5.007

HEAT of VAPORIZATION of CARBON MONOXIDE

Sources of Data:

Clayton, J. O. and Giauque, W. F., J. Am. Chem. Soc. 54, 2610-26 (1932)

Clusius, K. and Teske, W., Z. physik. Chem. B6, 135-151 (1929)

Crommelin, C. A., Bijleveld, W. J., and Brown, E. G., Communs. Kamerlingh Onnes Lab., Univ. Leiden, Communs. No. 217b (1931)

Eucken, A., Ber. deut. physik. Ges. 18, 4-17 (1916)

Kordes, E., Z. Elektrochem. 58, 424-31 (1954)

Comments:

Kordes used the following equation to calculate the heat of vaporization:

$$\Delta H_v = (\Delta H_v)_0 \left[\frac{T_c - T}{T_c}\right]^{0.375}$$

Where:

ΔH_v = heat of vaporization at temperature T

$(\Delta H_v)_0$ = heat of vaporization at 0°K = 72.9 cal/gm

T_c = critical temperature = 134°K

T = temperature in question, °K

The molecular weight was taken as 28.01.

Table of Values

Reference	Temperature °K	Observed ΔH_v	Calculated ΔH_v
Clayton	81.61±0.05	1443.6±1.0 cal/gm-mole	
Clusius	0		1904.6 cal/gm-mole
Crommelin	81.61	1444 cal/gm-mole	
Eucken		1414 cal/gm-mole	
Kordes	81.5	51.5 cal/gm	51.5 cal/gm
"	93	46.7 "	46.8 "
"	103	42.0 "	40.8 "
"	113	36.3 "	32.1 "
"	123	28.5 "	29.6 "
"	134*	0	0

* Note that the accepted critical temperature is 132.91°K

5.007

HEAT of SUBLIMATION of CARBON MONOXIDE

Source of Data: Clayton, J. O. and Giauque, W. F., J. Am. Chem. Soc., 54, 2610-2626 (1932).

Comments: At 61.55°K the heat of sublimation is 1963 cal/gm-mole.

KDT/BDT Issued: 6/18/59

5.008

PHASE TRANSITION HEATS of FLUORINE

Sources of Data:

Hu, J. H., White, D. and Johnston, H. L., J. Am. Chem. Soc. 75, 5642-5645 (1953)

Rossini, F. D. et. al., Nat. Bur. Standards Cir. 500 (Feb. 1952)

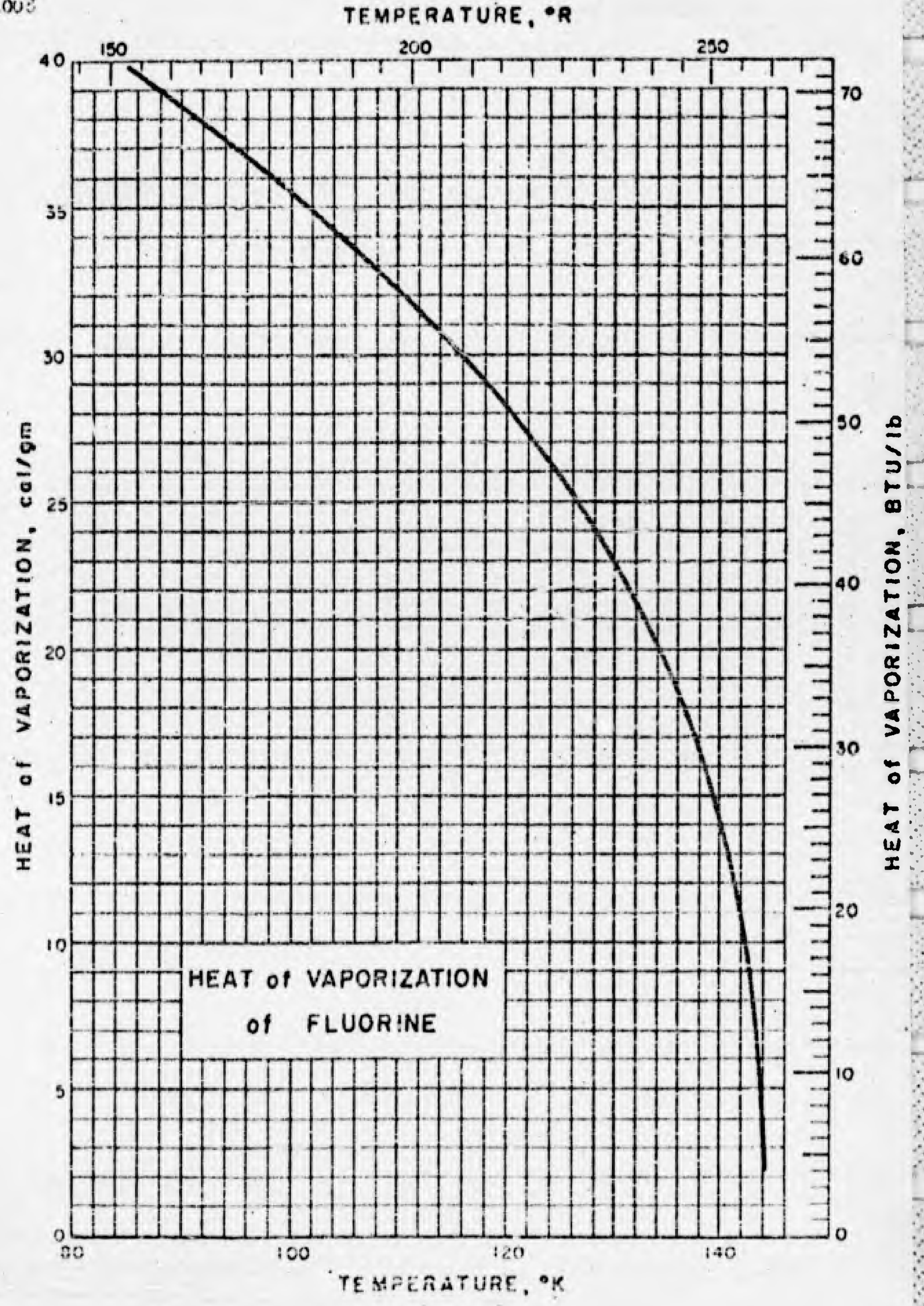
Comments:

The absolute temperature scale (0°C = 273.16°K) was used in the table of selected values below.

Transition	Temp. °K	Transition Heats cal/gm
Solid Transition	45.55	4.575
Fusion	53.51	3.209
Vaporization	85.21	39.728

RFR/JRC Issued: 7/13/59

5.003


TEMPERATURE, °R
150
200
250
40
35
30
25
20
15
10
5
0
HEAT of VAPORIZATION, cal/gm
70
60
50
40
30
20
10
0
HEAT of VAPORIZATION, BTU/lb
HEAT of VAPORIZATION
of FLUORINE
80
100
120
140
TEMPERATURE, °K

HEAT of VAPORIZATION of FLUORINE

Source of Data: Fricke, E. F., Report No. F-5028 101
ATI 121 150, Republic Aviation Corp.
Farmingdale, L. I., New York.

Table of Selected Values

Temp. °K	Heat of Vaporization cal/gm
85.25	39.73
90	38.47
95	37.04
100	35.52
105	33.94
110	32.18
115	30.26
120	28.13
125	25.73
130	22.86
135	19.29
140	14.13
144	3.55

RFR/JHC Issued: 1/22/59

PHASE TRANSITION HEATS of ARGON

Sources of Data:

Eucken, A. and Hauck, F., Z. physik Chem. 134, 161-77 (1938)

Harashima, A., Proc. Phys. Math. Soc. Japan 23, 977-83 (1941)

Staveley, L. A. K. and Tupman, W. I., J. Chem. Soc. (London) 3597-3606 (1950)

Whalley, E. and Schneider, W. G., J. Chem. Phys. 23, 1644-50 (1955)

Comments:

Eucken and Hauck determined the heat of fusion as 6.640 cal/gm at a melting point of 83.55°K.

Whalley and Schneider calculated the heat of vaporization at 0°K, including zero-point energy as 50.02 cal/gm.

5.010

PHASE TRANSITION HEATS of METHANE

Sources of Data:

Rossini, F. D., et al., Selected Values of Physical and Thermodynamic Properties of Hydrocarbons and Related Compounds, Carnegie Press, Pittsburgh (1953) pp. 435, 436, 469, 470

Wheeler, J. A., and Cannon, C. V., Phys. Rev. 52, 684-5 (1937)

Other References:

Natural Gasoline Supply Men's Assoc. Engineering Data Book, 7th Ed., Tulsa (1957) pp. 135, 138

Pacific Coast Gas Assoc., Gas Engineer's Handbook, McGraw Hill Book Co., Inc., New York (1934) p. 370

Table of Selected Values

Transition	Transition Heats		Source
	cal/gm	BTU.lb	
Vaporization	121.87	219.22	Rossini
Fusion	14.03	25.24	Rossini
Solid Transition	0.979	1.76	Wheeler

6.000

PHASE EQUILIBRIA and TRANSITION TEMPERATURES of CRYOGENIC FLUIDS

CONTENTS

6.000

CONVERSION FACTORS for VAPOR PRESSURE

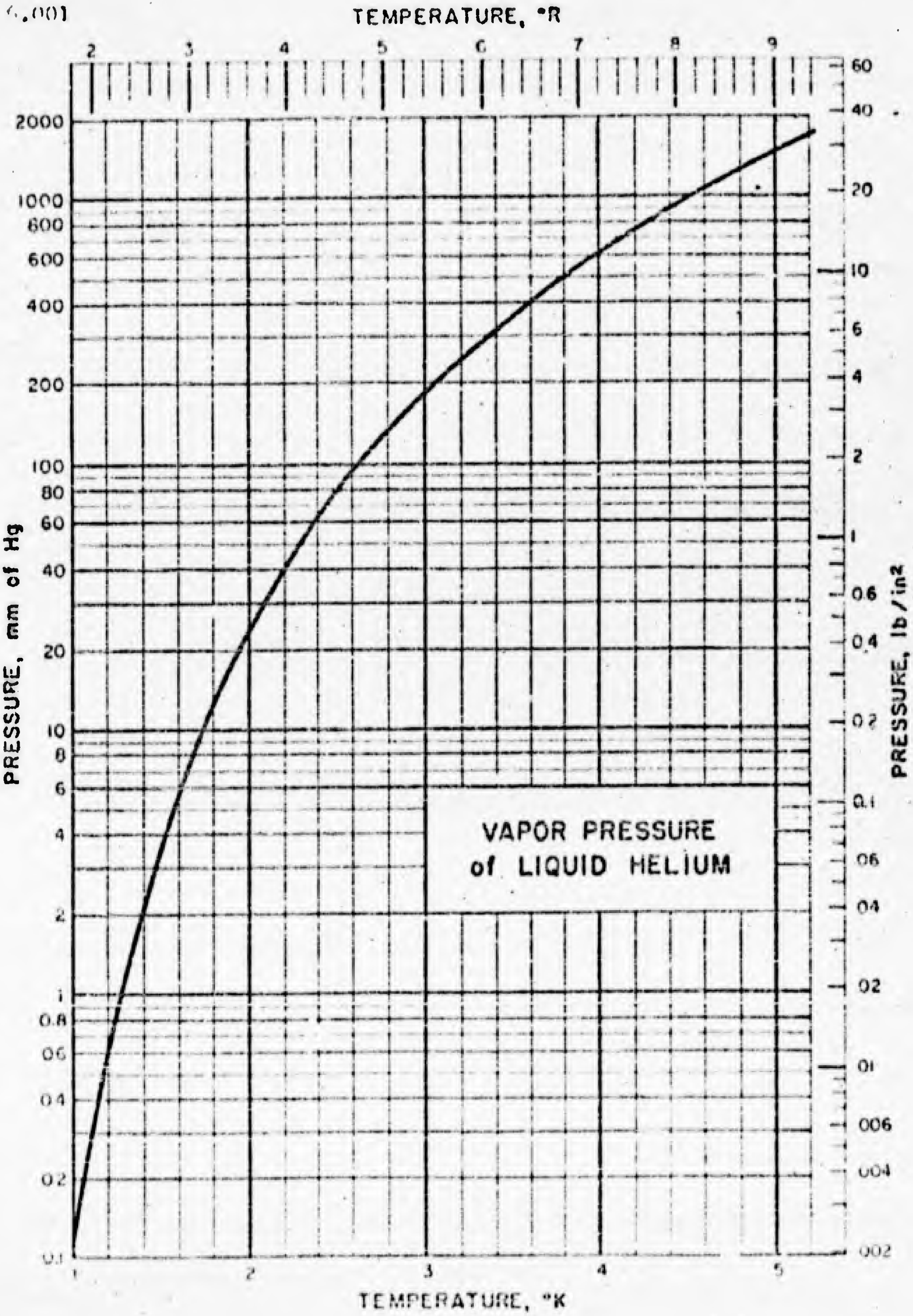
	$\frac{\text{dyne}}{\text{cm}^2}$	standard atmosphere	$\frac{\text{kg}}{\text{cm}^2}$	mm Hg	in Hg	$\frac{\text{lb}}{\text{in}^2}$
1 $\frac{\text{dyne}}{\text{cm}^2}$ =	1.000	9.869 233 x 10^{-7}	1.019 7162 x 10^{-6}	7.500 617 x 10^{-4}	2.952 993 x 10^{-5}	1.450 3830 x 10^{-5}
1 standard atmosphere =	1.013 250 x 10^{6}	1.000	1.033 2275	7.60 x 10^{2}	29.921 20	14.696 006
1 $\frac{\text{kg}}{\text{cm}^2}$ =	9.806 65 x 10^{5}	0.967 8411	1.000	7.355 592 x 10^{2}	28.958 97	14.223 398
1 mm Hg =	13.332 237 x 10^{3}	1.315 7895 x 10^{-2}	1.359 5098 x 10^{-2}	1.000	0.393 7	19.336 850 x 10^{-2}
1 in Hg =	3.386 395 x 10^{4}	3.342 112 x 10^{-2}	3.453 162 x 10^{-2}	25.400 05	1.000	49.115 70 x 10^{-2}
1 $\frac{\text{lb}}{\text{in}^2}$ =	6.894 713 x 10^{4}	6.804 570 x 10^{-2}	7.030 669 x 10^{-2}	51.714 73	2.036.009	1.000

VJJ/JRC Issued: 10-7-59
Revised: 5-20-60

6.000

CONVERSION FACTORS for VAPOR PRESSURE

6.001


TEMPERATURE, °R
2
3
4
5
6
7
8
9
60
40
20
10
6
4
2
1
0.6
0.4
0.2
0.1
.06
.04
.02
.01
.006
.004
.002
PRESSURE, lb/in2
2000
1000
800
600
400
200
100
80
60
40
20
10
8
6
4
2
1
0.8
0.6
0.4
0.2
0.1
PRESSURE, mm of Hg
1
2
3
4
5
TEMPERATURE, °K
VAPOR PRESSURE
of LIQUID HELIUM

6.001

VAPOR PRESSURE OF LIQUID HELIUM

Source of Data:

Clement, J. R., et al., Phys. Rev. 100, 743-4 (Oct. 1955)

Other References:

Berman, R. and Swenson, C. A., Phys. Rev. 95, No. 2, 311-14 (July 1954)

Erickson, R. A. and Roberts, L. D., Phys. Rev. 93, 957-62 (Mar. 1954)

Gratch, S., Trans. ASME 70, 631-40 (Aug. 1948)

Van Dijk, H. and Durieux, M., Progress in Low Temperature Physics, Vol. II, North Holland Publishing Co., Amsterdam, The Netherlands, (1957) 480 pp.

Van Dijk, H. and Shoenberg, D., Nature, 164, 151 (July 1949)

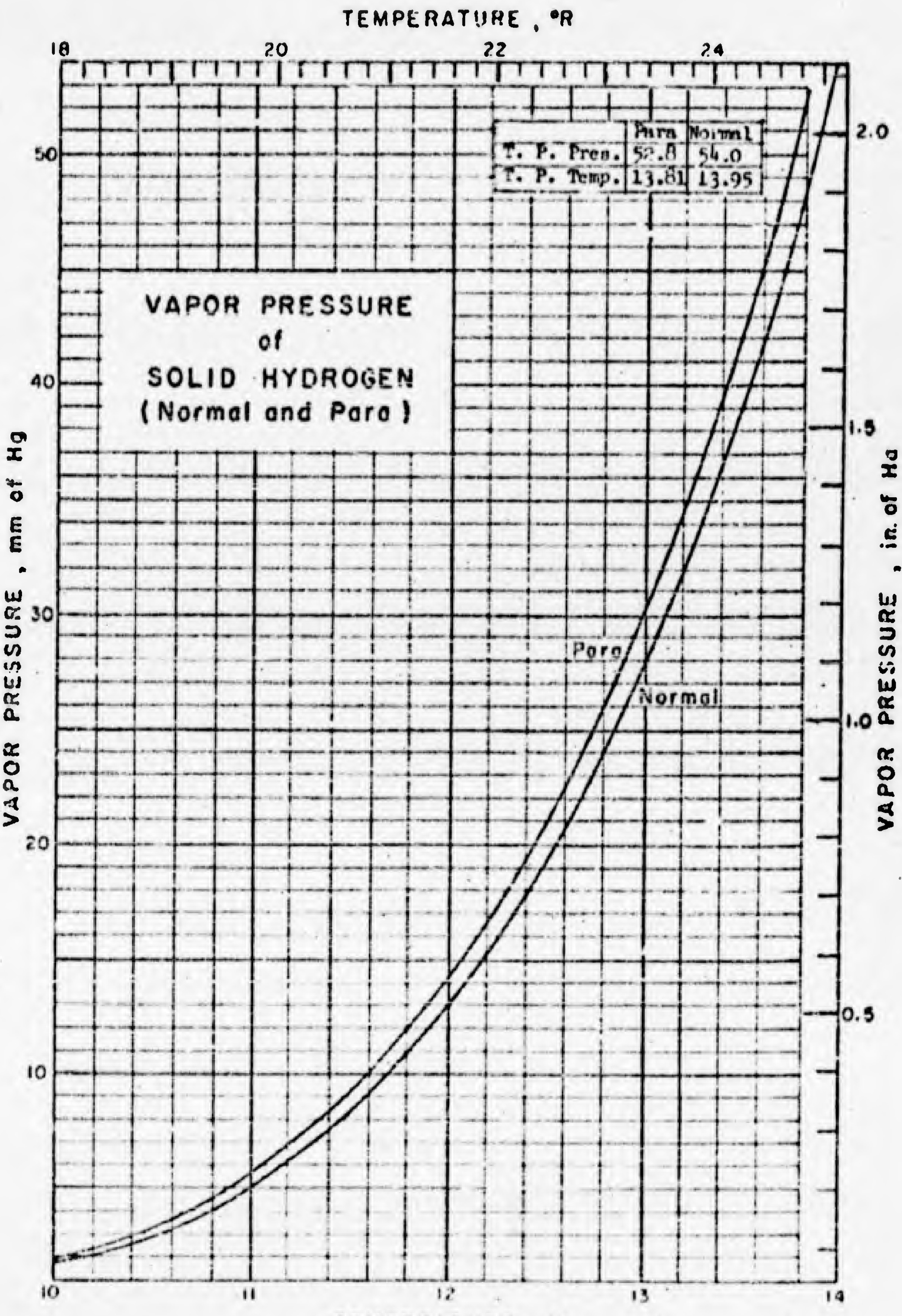
Worley, R. D., Zemansky, M. W. and Boorse, H. A., Phys. Rev. 93, No. 1, (Jan. 1954)

Comments:

The Absolute temperature scale (0°C = 273.16°K) was used in the table of selected values below.

Temp.		Pressure		Temp.		Pressure	
°K	°R	mm Hg	lb/in^2	°K	°R	mm Hg	lb/in^2
1	1.8	0.12	0.002 31	3.2	5.76	243	4.69
1.2	2.16	0.62	0.011 9	3.4	6.12	316	6.09
1.4	2.52	2.1	0.040 4	3.6	6.48	402	7.74
1.6	2.88	5.7	0.101	3.8	6.74	505	9.68
1.8	3.24	12.5	0.241	4.0	7.2	619	11.9
2.0	3.6	23.8	0.458	4.2	7.56	753	14.5
2.2	3.96	41.	0.790	4.4	7.92	900	17.3
2.4	4.32	64.	1.23	4.6	8.28	1080	20.8
2.6	4.68	94.	1.81	4.8	8.64	1270	24.5
2.8	5.04	134	2.58	5.0	9.00	1490	28.7
3.0	5.40	183	3.53	5.2	9.36	1710	33.1

DBM/GAR Issued: 7/13/59


TEMPERATURE , °R
18
20
22
24
| | Para | Normal |
T. P. Pres. 52.8 54.0
T. P. Temp. 13.81 13.95
VAPOR PRESSURE
of
SOLID HYDROGEN
(Normal and Para)
Para
Normal
VAPOR PRESSURE , mm of Hg
10
20
30
40
50
VAPOR PRESSURE , in. of Hg
0.5
1.0
1.5
2.0
10
11
12
13
14
TEMPERATURE , °K

VAPOR PRESSURE of SOLID HYDROGEN
(Normal and Para)

Source of Data:

Woolley, H. W., Scott, R. B. and Brickwedde, F. G., J. Research Natl. Bur. Standards RP 1932 41, 379 (1948)

Other References:

Henning, F., Z. Physik 40, 775 (1926)

Keesom, W. H., Bijl, A. and Van der Horst, H., Communs. Phys. Lab. Univ. Leiden 217a (1931)

Martinez, J. P. and Onnes, H. K., Communs. Phys. Lab. Univ. Leiden 156b (1922)

Scott, R. B., Brickwedde, F. G., Urey, H. C. and Wahl, M. H., J. Chem. Phys. 2, 454 (1934)

Comments:

The differences between the hydrogen vapor pressure data reported through 1934, and the more recent work of the NBS stem principally from the temperature scales used and the uncertainty of the ortho-para composition. The NBS work is based on the low temperature scale established at the National Bureau Standards and on known ortho-para compositions.

The curve for normal hydrogen is represented by the equation:

Normal hydrogen (75% o-H_2, 25% p-H_2):

$$\log_{10} P\ (\text{mm Hg}) = 4.56488 - \frac{47.2059}{T} + 0.03939\ T$$

and for 20.4°K equilibrium (Para) hydrogen (99.79% p-H_2; 0.21% o-H_2):

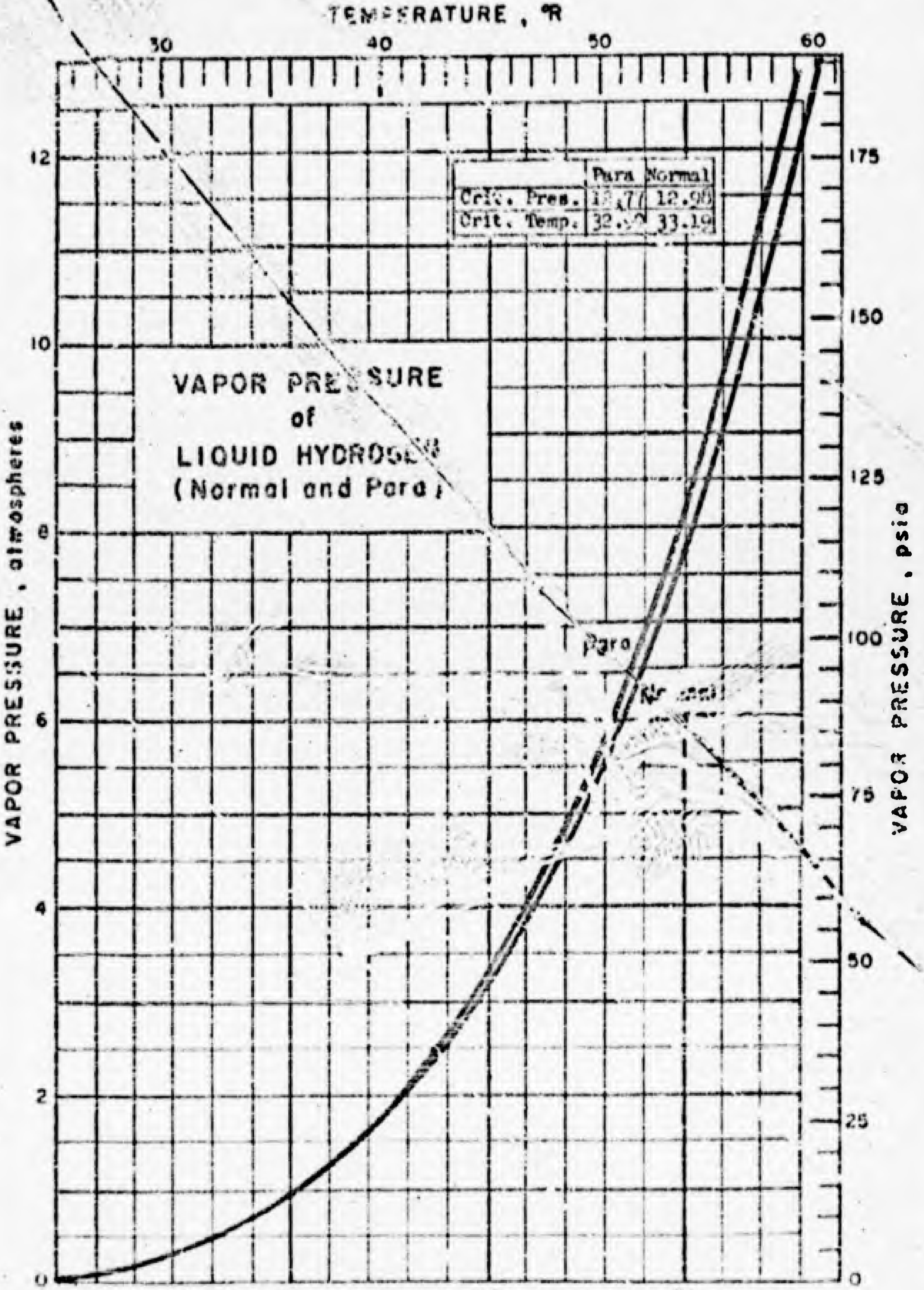
$$\log_{10} P\ (\text{mm Hg}) = 4.62438 - \frac{47.0172}{T} + 0.03635\ T$$

Tables of Selected Values

Normal Hydrogen	
Temp. °K	Vap. Press. mm Hg
10	1.73
10.5	3.04
11.0	5.09
11.5	8.19
12.0	12.7
12.25	15.6
12.50	19.1
12.75	23.2
13.00	27.9
13.95	54.0*

Para Hydrogen	
Temp. °K	Vap. Press. mm Hg
10	1.93
10.5	3.38
11	5.62
11.5	8.99
12.0	13.9
12.25	17.04
12.50	20.8
12.75	25.1
13.00	30.2
13.81	52.8*

* Triple Point


TEMPERATURE , °R
30
40
50
60
VAPOR PRESSURE
of
LIQUID HYDROGEN
(Normal and Para)
Para Normal
Crit. Pres. 12.77 12.98
Crit. Temp. 32.97 33.19
Para
Normal
VAPOR PRESSURE , atmospheres
0
2
4
6
8
10
12
VAPOR PRESSURE , psia
0
25
50
75
100
125
150
175
15
20
25
30
TEMPERATURE , °K

6.002

VAPOR PRESSURE of LIQUID HYDROGEN

(Normal and Para)

Sources of Data: White, Friedman and Johnston, J. Am. Chem. Soc. 72, 3927 (1950); Nat. Bur. Standards Circ. 564, 237 (1955); Nat. Bur. Standards Research Paper RP 1932 41, (1948); Kelley, K. K., U.S. Bur. Mines Bull. 383, 50 (1935).

Other References: Bonhoeffer and Harteck, Naturwiss. 17, 321 (1929).

Comments: Vapor pressure data on liquid hydrogen dates back to 1903. The first studies on the vapor pressure of liquid para hydrogen were arrived at by Bonhoeffer and Harteck. Rather wide variations appear in the data of various authors both before and after the discovery of the two forms of hydrogen. In order to emphasize these discrepancies, tables are given showing values for the two forms from the several sources. Kelley's values were calculated from the following equations:

$$\text{Normal Hydrogen} \quad \log_{10} P_{atm} = -\frac{51.15}{T} + 2.505$$

$$\text{Para Hydrogen} \quad \log_{10} P_{atm} = -\frac{50.54}{T} + 2.496$$

White, Friedman and Johnston, for the vapor pressure of liquid normal hydrogen, used the equation:

$$\log_{10} P_{atm} = 3.058201 - \frac{22.25642}{T} - 3.1282 \times 10^{-2}\,T + 6.6989 \times 10^{-4}\,T^2$$

The NBS Report RP 1932 gives the following equations:

$$\text{Normal Hydrogen} \quad \log_{10} P_{mm\,Hg} = 4.66687 - \frac{44.9562}{T} + .020537\,T$$

$$\text{Para Hydrogen} \quad \log_{10} P_{mm\,Hg} = 4.64392 - \frac{44.3450}{T} + .02093\,T$$

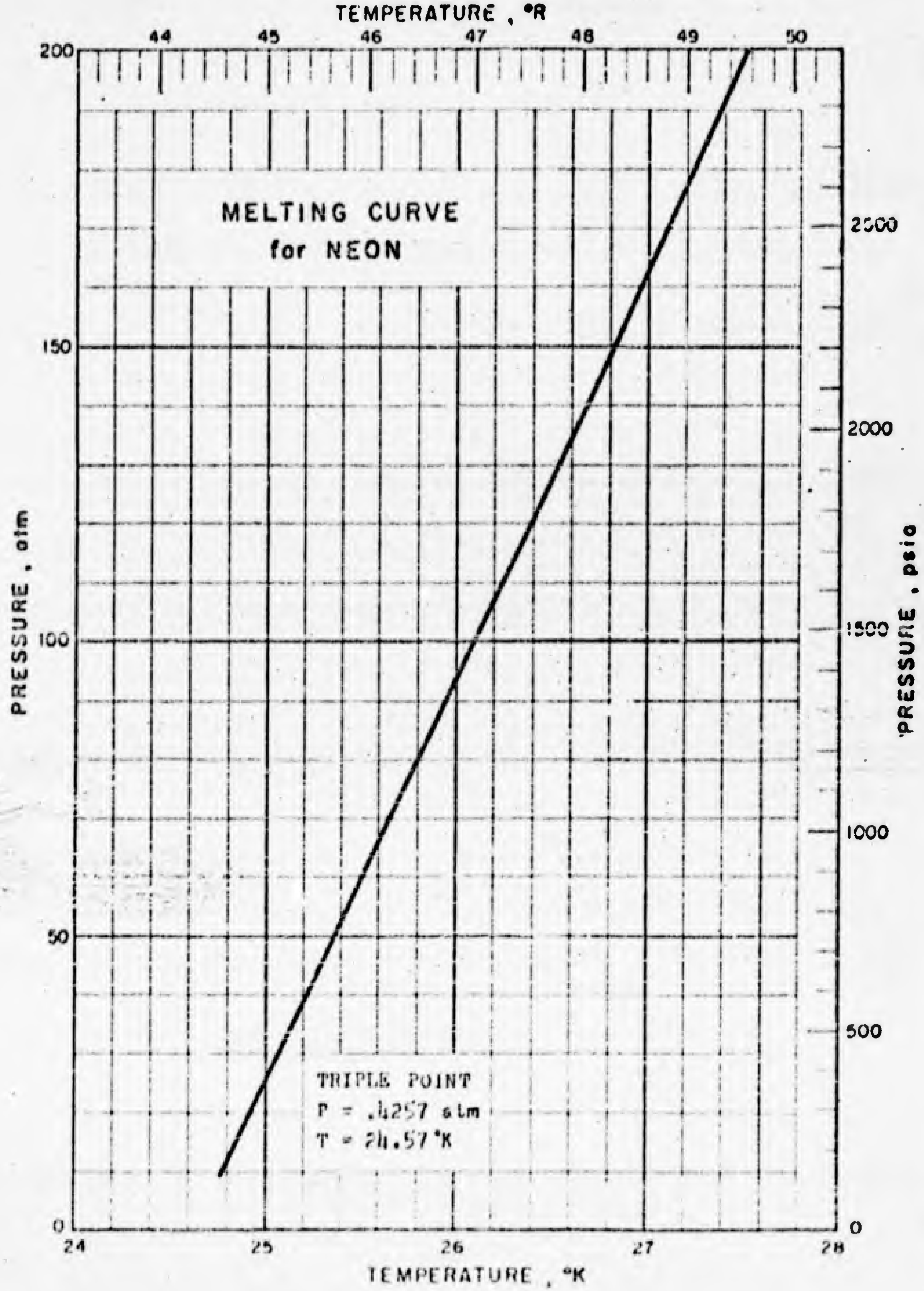
Para hydrogen refers to equilibrium hydrogen which at 20.4°K is .21% ortho and 99.79% para and at 30°K is 2.98% ortho and 97.02% para.

Comparison of Selected Values of Vapor Pressure

Temp. °K	Normal Hydrogen (Atm) W. F. & J.	Normal Hydrogen (Atm) Kelley*	Normal Hydrogen (Atm) RP 1932	Para Hydrogen (Atm) Cir. 564	Para Hydrogen (Atm) Kelley*	Para Hydrogen (Atm) RP 1932
14	.0653*	.0710	.0723	.0774	.0760	.0774
16	.1931*	.2032	.2018	.2121	.2174	.2120
18	.4492*	.4606	.4551	.4741	.4878	.4745
20	.8867	.8862	.8901	.9200	.931	.9215
22	1.556	1.514	1.5645	1.6101	1.580	1.6141
24	2.513	2.364	2.5450	2.6076	2.456	2.6164
26	3.744	3.413	3.9000	3.9775	3.564	3.9967
28	5.548	4.707	5.6047	5.778	4.91	5.8093
30	7.778	6.310	8.0092	8.103	6.476	8.1316
32	10.626	8.066	10.9029	11.031	8.253	11.1404

* Tabulated for comparison purposes only. Not recommended for use.

It is clear from the above that the vapor pressure of para hydrogen is higher than that of normal hydrogen in both the earlier and the more recent data.


TEMPERATURE , °R
44
45
46
47
48
49
50
MELTING CURVE
for NEON
TRIPLE POINT
P = .4257 atm
T = 24.57°K
PRESSURE , atm
200
150
100
50
0
PRESSURE , psia
2500
2000
1500
1000
500
0
24
25
26
27
28
TEMPERATURE , °K

MELTING POINT TEMPERATURE of NEON

Source of Data:

Mills, R. L. and Grilly, E. R., Phys. Rev. 99, 480-86 (1955)

Other References:

Keesom, W. H. and Lisman, J. H. C., Proc. Acad. Sci. Amsterdam 36, 378-80 (1933)

Simon, F., Ruheman, M. and Edwards, W. A. M., Z. physik. Chem. Abt. B6, 331-42 (1930)

Comments:

The following equation was derived with 37 experimental points covering a pressure range of 0 - 3500 kg/cm^2.

$$p = a + bT^c$$

where:

p is the pressure in kg/cm^2
T is the temperature in °K
a, b and c are constants

For Neon:

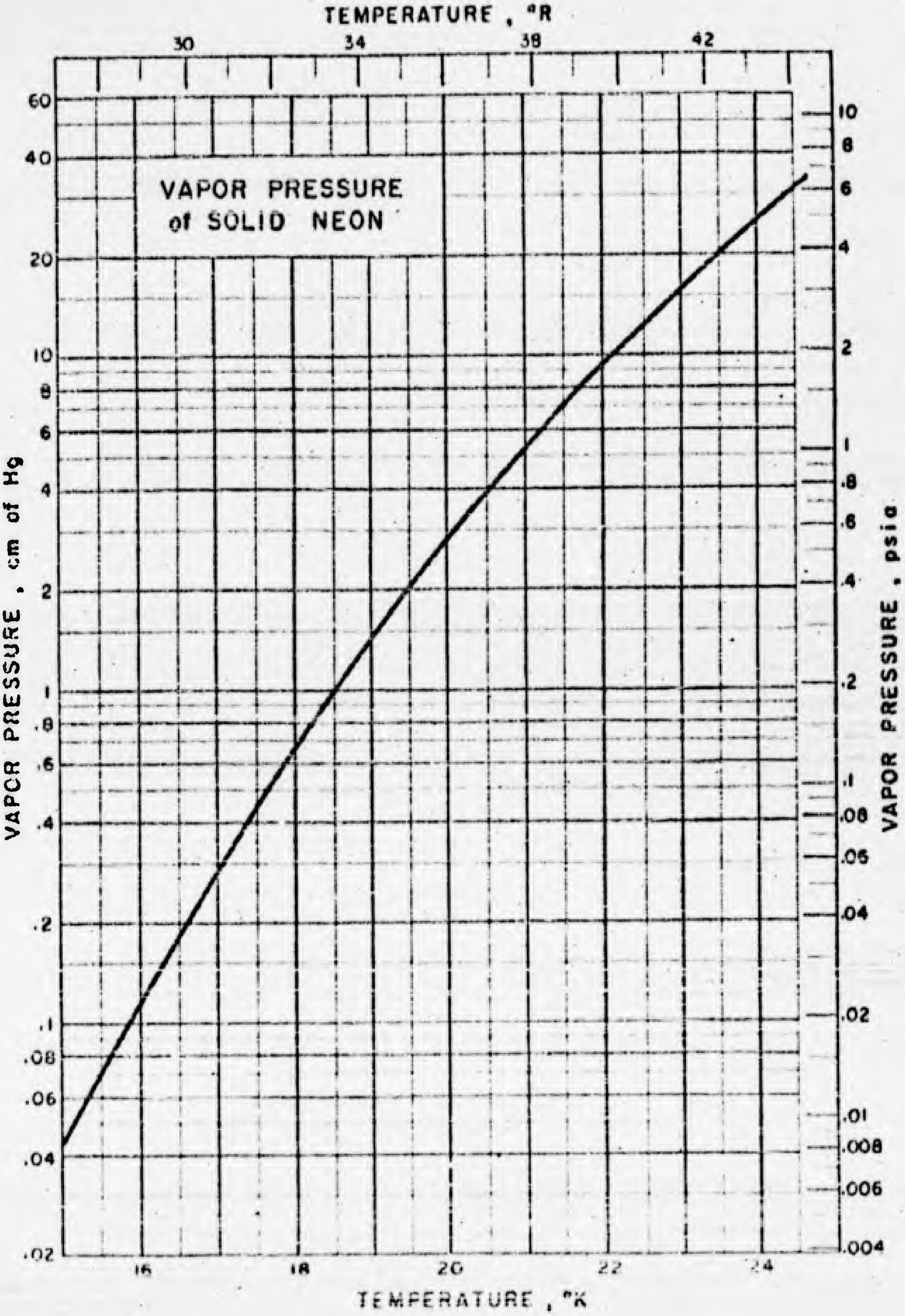
$a = -1057.99$
$b = 6.289415$
$c = 1.599916$

The graph on the preceding page and the following table were prepared by using the above equation and converting the pressures to standard atmospheres.

The data of Mills and Grilly are more reliable than that of Simon, et. al. since the neon in the latter case was not pure. There is good agreement between the data of Mills and Grilly and that of Keesom and Lisman.

Table of Calculated Values

Pressure		Melting Point Temp. °K	Pressure		Melting Point Temp. °K
atm	psia		atm	psia	
0	0	24.27	110	1617	26.24
10	147	24.77	120	1764	26.38
20	294	24.92	130	1911	26.53
30	441	25.07	140	2058	26.67
40	588	25.21	150	2205	26.81
50	735	25.36	160	2352	26.96
60	882	25.51	170	2499	27.10
70	1029	25.65	180	2646	27.24
80	1176	25.78	190	2793	27.38
90	1323	25.95	200	2940	27.52
100	1470	26.09			


TEMPERATURE , °R
30
34
38
42
VAPOR PRESSURE
of SOLID NEON
VAPOR PRESSURE , cm of Hg
60
40
20
10
8
6
4
2
1
.8
.6
.4
.2
.1
.08
.06
.04
.02
VAPOR PRESSURE , psia
10
8
6
4
2
1
.8
.6
.4
.2
.1
.08
.06
.04
.02
.01
.008
.006
.004
16
18
20
22
24
TEMPERATURE , °K

6.003

VAPOR PRESSURE of SOLID NEON

Sources of Data:

Crommelin, C. A. and Gibson, R. D., Verslag Akad. Wetenschap. Amsterdam 36, 173-6 (1927)

Keesom, W. H. and Haantjes, J., Physica 2, 460-2 (1935)

Comments:

The calculated values in the tabulation below were computed from the following equation:

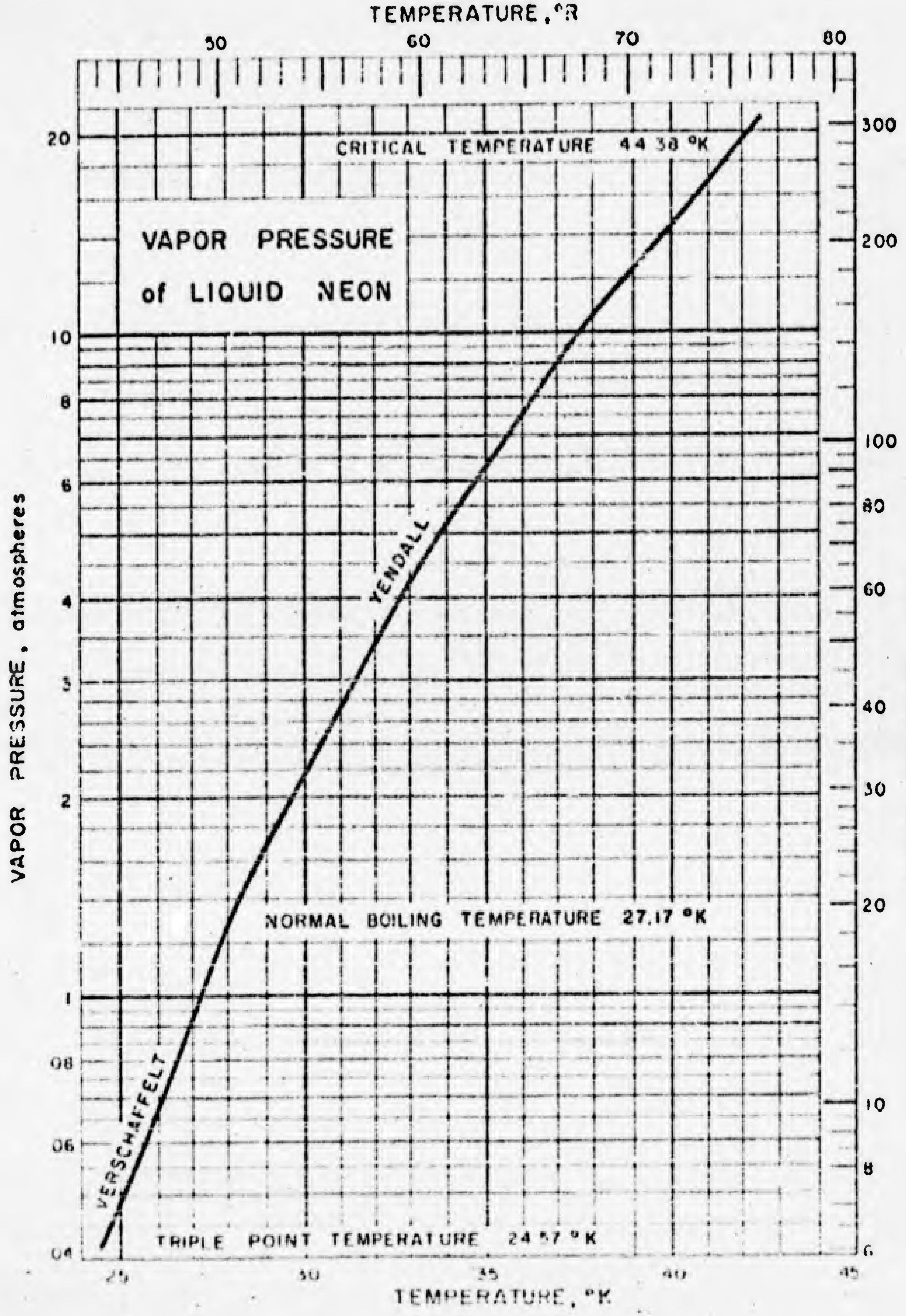
$$\log_{10} p = -\frac{111.76}{T} + 6.0424$$

where p is in cm Hg and T is in °K, valid between 15° and 20.5°K.

Temp. °K	Pressure cm Hg	Temp. °K	Pressure cm Hg
15.00	0.039*	19.455	1.964
15.038	0.046	19.792	2.408
15.119	0.0485	20.00	2.84*
15.928	0.107	20.315	3.4[illegible]
16.00	0.114*	20.40	3.67*
16.165	0.130	20.456	3.795
16.933	0.267	21.85	9.1
17.00	0.292*	22.25	11.1
17.262	0.379	22.87	14.8
17.971	0.670	23.47	19.5
18.00	0.678*	24.00	25.0
18.158	0.758	24.25	27.9
18.586	1.071	24.51	31.5
19.00	1.44*	24.53	31.7
19.153	1.585		

* calculated

KDT/BDT Issued: 5/28/59


TEMPERATURE, °R
50
60
70
80
VAPOR PRESSURE of LIQUID NEON
CRITICAL TEMPERATURE 44.38 °K
NORMAL BOILING TEMPERATURE 27.17 °K
TRIPLE POINT TEMPERATURE 24.57 °K
YENDALL
VERSCHAFFELT
VAPOR PRESSURE, atmospheres
20
10
8
6
4
3
2
1
.08
.06
.04
VAPOR PRESSURE, psia
300
200
100
80
60
40
30
20
10
8
6
25
30
35
40
45
TEMPERATURE, °K

6.003

VAPOR PRESSURE of LIQUID NEON

Sources of Data:

Mathias, E., Crommelin, C. A. and Onnes, H. K., 7th Congr. Intern. Froid. 1st Comm. Intern., Repparts et Commun. 1936, 96- [illegible] (1936)

Verschaffelt, J. E., Communs. Kamerlingh Onnes Lab. Un. Leiden, Supple. No. 64d (1929)

Yendall, E. F., Proc. 1958 Cryogenic Eng. Conf. 47-64 (1959)

Other References:

Cath, P. G. and Onnes, H. K., Proc. Acad. Sci. Amsterdam 20, 1160-2 (1918)

Crommelin, C. A., Rec. trave. chim. 42, 814 (1923)

Mathias, E., Crommelin, C. A. and Onnes, H. K., Compt. rend. 175, 933 (1922)

Mathias, E., Crommelin, C. A. and Onnes, H. K., Compt. rend. 176, 939 40 (1923)

Onnes, H. K. and Crommelin, C. A., Proc. Akad. Wetenschappen 18, 515-20 (1915)

Onnes, H. K., Crommelin, C. A. and Cath, P. G., Proc. Acad. Sci. Amsterdam 19, 1058 (1917)

Comments:

Verschaffelt's values were experimental. Yendall's values were calculated from an equation of state.

Verschaffelt presents the following vapor pressure equation:

$$T \log_{10} p = 28.100 + 36.00\,(T-35) + 0.003333\,(T-35)^2 + 0.000400\,(T-35)^3 + 0.00002667\,(T-35)^4$$

where T is in °K (Leiden scale) and between 25° and 35°K, and p is in atm.

Mathias, et. al., give a critical point of 44.38°K and 26.84 atm.

The Leiden temperature scale (0°C = 273.09°K) is used in the following table.

Verschaffelt

Temp. °K	Press. atm.
24.58	0.427
24.58	0.4273
24.80	0.461
24.99	0.491
25.27	0.540
25.60	0.5938
25.76	0.640
26.43	0.7958

Yendall

Temp. °K	Press. atm.
27.17*	1.00
29.69	2.00
32.69	4.00
34.70	6.00
36.26	8.00
37.61	10.00
40.18	15.00
42.16	20.00

* Normal Boiling Point

[illegible]

6.003

VAPOR PRESSURE of NEON ISOTOPES

Sources of Data: Keesom, W. H. and Haantjes, J., Proc. Acad. Sci. Amsterdam <u>38</u>, 810 (1933); Physica <u>2</u>, 986-99 (1935).

Comments: The above reference gives tables of vapor pressure as a function of temperature.

The vapor pressure of mixtures may be calculated from the relation:

$$P_{\text{mixture}} = P_{20} + 2.731\ X$$

where P_{20} is the vapor pressure of pure Ne^{20} and X is the molar content of Ne^{22}. All values of vapor pressure are in cm Hg.

KDT/BDT Issued: 6/5/59

PHASE TRANSITION TEMPERATURES of NEON
(Also Includes Critical Contants)

Sources of Data:

Critical Point

Mathias, E. and Crommelin, C. A., 7th Congr. Intern. Froid. 1st Comm. Intern., Rapports et Commun. 1936, 96-102 (1936).

Normal Boiling Point

Mathias, E. and Crommelin, C. A., Proc. 4th Intern. Congr. of Refrig. 1, 89-106a (1924); Mathias, E., Crommelin, C. A. and Onnes, H. K., Commun. Phys. Lab. Univ. Leiden Commun. No. 162b (1922).

Normal Melting Point

Crommelin, C. A. and Gibson, R. D., Comm. Phys. Lab. Univ. Leiden 185b.

Triple Point

Crommelin, C. A. and Gibson, R. D., Comm. Phys. Lab. Univ. Leiden 185b.

Table of Selected Values

Property	Pressure		Temperature	
	atm	psia	°K	°R
Critical Point*	26.84	394.5	44.38	79.88
Boiling Point	1	14.696	27.17	48.91
Melting Point	1	14.696	24.57	44.23
Triple Point	0.4257	6.256	24.57	44.23

* Critical Volume = 42 cm^3/mole

Other References:

Critical Point

Benson, S. W., J. Phys. and Colloid Chem. 52, 1060-74 (1948); Keesom, W. H., Onnes-Festschrift 1922, 89-163 (1922); Onnes, H. K., Crommelin, C. A. and Cath, P. G., Proc. Acad. Sci. Amsterdam 19, 1058-62 (1917); Crommelin, C. A., Physik. Ber. 5, 1376 (1924); Mathias, E. and Crommelin, C. A., Proc. 4th Intern. Congr. Refrig. 1, 89-106a (1924); Herz, R., Z. Elektrochem. 29, 527-30 (1923); Lennard-Jones, J. E., Proc. Roy. Soc. (London) 112, 214-29 (1926).

PHASE TRANSITION TEMPERATURES of NEON

(Continued)

Normal Boiling Point

Benson, S. W., J. Phys. & Colloid Chem. 52, 1060-74 (1948); Keesom, W. H., Onnes-Festschrift 1922, 89-163 (1922); Keesom, W. H., Physik. Ber. 4, 613 (1923); Billig, K., Ber. 70B, 157-62 (1937); Burton, E. F., et. al. "Phenomena at the Temperature of Liquid Helium", A.C.S. Monograph Series, No. 83, Reinhold Publ. Corp., New York (1940); Onnes, H. K., Proc. Akad. Wetenschappen 18, 507-15 (1915); Guggenheim, E. A., J. Chem. Phys. 13, 253-6 (1945); Clusius, K., Z. ges Kalteind 39, 94-7 (1932); Hood, C. B. and Orilly, E. R., Rev. Sci. Instr. 23, 397 (1952).

Normal Melting Point

Clusius, K., Z. physik. Chem B31, 459-74 (1936); Clusius, K., Z. physik. Chem. B4, 1-13 (1929).

Triple Point

Mathias, E. and Crommelin, C. A., Proc. 4th Intern. Congr. Refrig. 1, 89-106a (1924); Keesom, W. H., Onnes-Festschrift 1922, 89-163 (1922); Keesom, W. H., Physik. Ber. 4, 613 (1923); Guggenheim, E. A., J. Chem. Phys. 13, 253-6 (1945).

Comments:

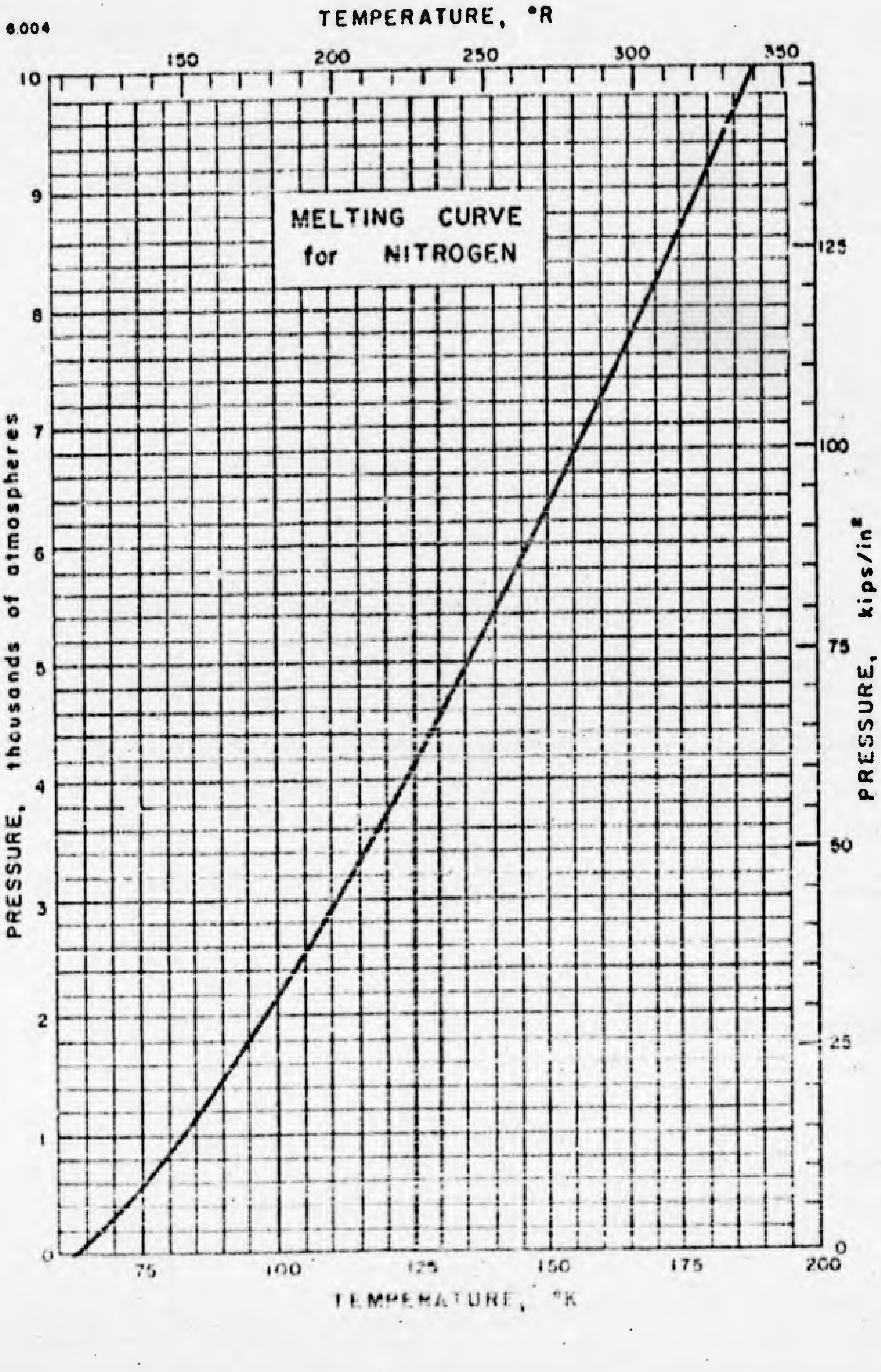
Benson gives a value of 26.9 atmospheres (760 mm Hg) for the critical pressure and 44.4°K for the critical temperature.
Keesom gives a value of 26.86 international atmospheres (75.9529 mm Hg) for the critical pressure and -228.35°C (44.74°K) for the critical temperature.
Onnes, Crommelin and Cath give the same values.
Mathias and Crommelin as well as Herz also agree on the critical pressure but give values of 44.38 and 44.39°K respectively for the critical temperature.

The critical volume of 42 cm³/gm-mole was taken from a paper by V. W. Heuse and J. Otto, Ann. Physik (5) 2, 1012 (1929). A value of 41.4 cm³/gm-mole was quoted by L. Schames, Physik Z 32, 16-20 (1931) and a value of 41.7 cm³/gm-mole was given by E. A. Guggenheim, J. Chem. Phys. 13, 253-6 (1945).

A dimensionless value of 3.28 was given by L. Schames (ibid.) for the term $\frac{R\,T_c}{P_cV_c}$. K. Wohl, Z. physik Chem. Abt B, 2, 77-114 (1929) and C. A. Crommelin, Onnes-Festschrift, 197 (1922); Phys. Ber. 4, 702 (1923) give corresponding values of 3.2733 and 3.248 respectively.

Baxter, G. and Starkweather, Proc. Nat. Acad. Sci. 14, 50-57 (1928) give a value of 20.182 for the molecular weight of Neon. Other values found in the literature range from 20.1[illegible] to 20.2.
See: E. Mathias, Onnes-Festschrift [illegible]-96 (1922); Phys. Ber. 4, 701-2 (1923)
S. W. Benson, J. Phys. & Colloid Chem. 52, 1060-74 (1948)
E. [illegible], Physik Z. 11, 7[illegible] ([illegible])

6.004



TEMPERATURE, °R
150
200
250
300
350
MELTING CURVE
for NITROGEN
PRESSURE, thousands of atmospheres
10
9
8
7
6
5
4
3
2
1
0
PRESSURE, kips/in²
125
100
75
50
25
0
75
100
125
150
175
200
TEMPERATURE, °K

MELTING CURVE for NITROGEN

Sources of Data:

Mills, R. L. and Grilly, E. R., Phys. Rev. 99, No. 2, 480-6 (1955)

Robinson, D. W., Proc. Roy. Soc. (London) A225, 393-405 (1954)

Comments:

Mills and Grilly devised the following equation from 26 experimental points:

$$p = -1638.30 + 0.976780\ T^{1.791000}$$

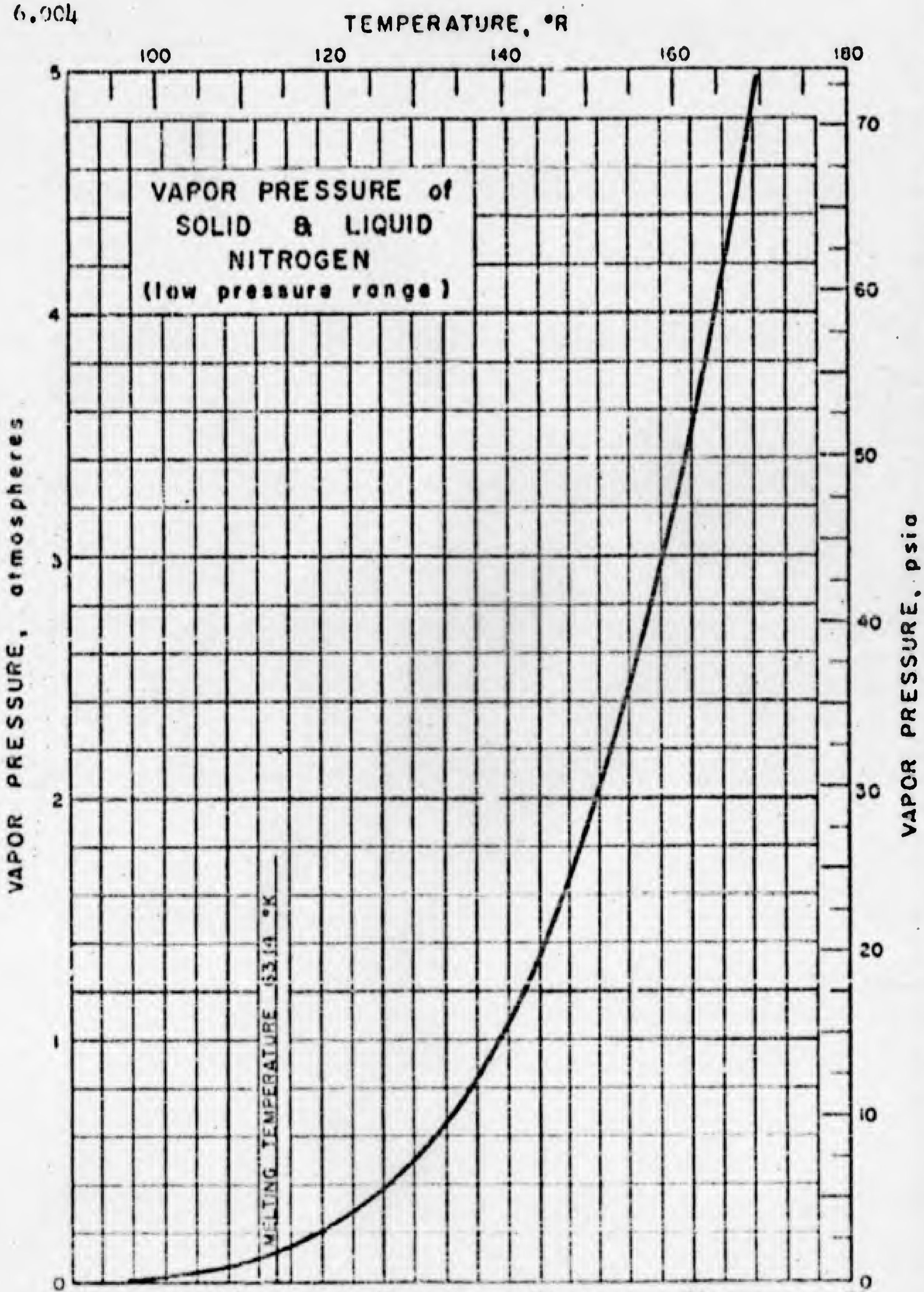
where p is in kg/cm^2 and T is in °K. The range is from 0 to 3600 kg/cm^2.

The following tabulated data is from Robinson.

Table of Selected Values

Pressure atm	Melting Temperature °K
1	63.1
1000	82.5
2000	97.5
3000	111.0
4000	123.5
5000	135.0
6000	146.5
7000	157.5
8000	169.0
9000	178.5
9100	179.5
10000*	190.0

* extrapolated value


TEMPERATURE, °R
100
120
140
160
180
VAPOR PRESSURE of SOLID & LIQUID NITROGEN (low pressure range)
5
4
3
2
1
0
VAPOR PRESSURE, atmospheres
70
60
50
40
30
20
10
0
VAPOR PRESSURE, psia
MELTING TEMPERATURE 63.14 °K
50
60
70
80
90
100
TEMPERATURE, °K

VAPOR PRESSURE of SOLID and LIQUID NITROGEN

Sources of Data:

Hoge, H. J., J. Research Natl. Bur. Standards 44, 321-45 (1950)

Hoge, H. J. and King, G. K., NBS - NACA Table of Thermal Properties of Gases, Table 11.50 (July 1950)

Keesom, W. H., Onnes-Festschrift 1922, 89-163 (1922)

Keesom, W. H., Physik. Ber. 4, 613 (1923)

Mathias, E. and Crommelin, C. A., Proc. Fourth Intern. Congress of Regrigeration 1, 89-106a (1924)

Comments:

The data from the above references are in quite good agreement. The deviation is generally 0.4% or less.

Table of Selected Values

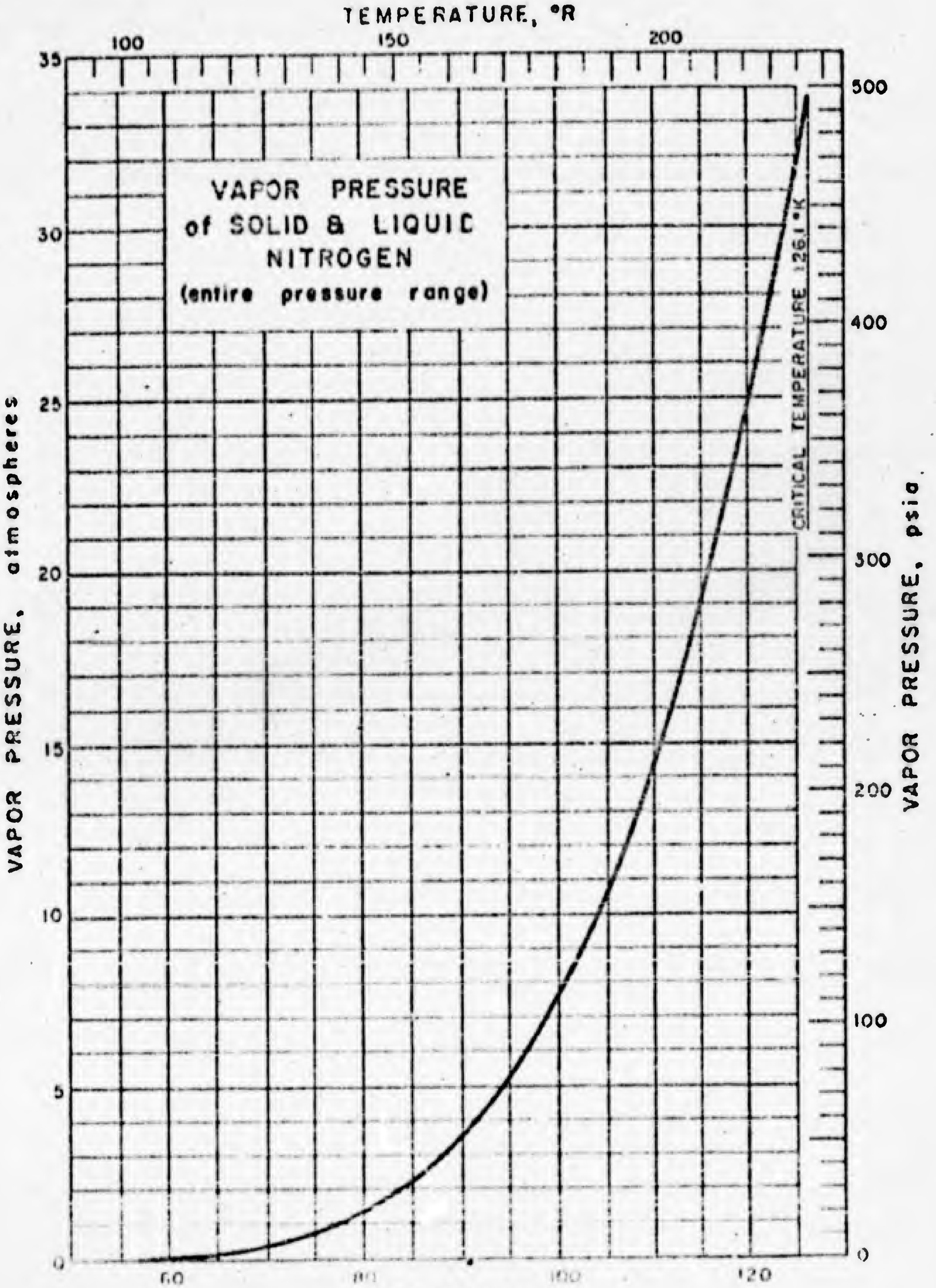
Temp. °K	Vap. Press. atm	Temp. °K	Vap. Press. atm	Temp. °K	Vap. Press. atm
52	0.0072	76	0.9461	104	10.07
54	.0134	77.34±.02[b]	1.000	105.0	10.71
56	.0232	78	1.073	106	11.47
57.9	.0379	80.0	1.36	108	12.91
58	.0387	80	1.341	110.0	14.54
59.0	.0496	82	1.657	110	14.52
60	.0621	84	2.026	112	16.26
61.0	.0787	85.0	2.25	114	18.15
62	.0969	86	2.460	115.0	19.28
63.14[a]	.1268	88	2.967	116	20.20
63.156	.1237	90.0	3.54	118	22.41
64	.1439	90	3.548	120.0	25.04
64.55	.1591	92	4.203	120	24.81
66	.2028	94	4.937	122	27.40
68	.2797	95.0	5.31	124	30.21
69.4	.3005	96	5.76	125.0	31.94
70	.3784	98	6.68	126	33.27
72	.5033	100.0	7.67	126.1[c]	33.49
74	.6579	100	7.70	126.1±.1[c]	33.5
74.9	.7386	102	8.83		

[a] Melting Point

[b] Normal Boiling Point

[c] Critical Point

[illegible] Issued: 7/31/59


TEMPERATURE, °R
100
150
200
VAPOR PRESSURE
of SOLID & LIQUID
NITROGEN
(entire pressure range)
CRITICAL TEMPERATURE 126.1°K
VAPOR PRESSURE, atmospheres
35
30
25
20
15
10
5
0
VAPOR PRESSURE, psia
500
400
300
200
100
0
60
80
100
120
TEMPERATURE, °K

VAPOR PRESSURE EQUATIONS for SOLID NITROGEN

Sources of Data:

Cath, P. G., Proc. Acad. Sci. Amsterdam 21, 656-63 (1919)

Henning, F., Z. Physik 40, 775-85 (1927)

Hoge, H. J., J. Research Natl. Bur. Standards 44, 321-45 (1950)

Hoge, H. J. and King, G. K., NBS - NACA Tables of Thermal Properties of Gases, Table 11.50 (July, 1950)

Keesom, W. H., Onnes-Festschrift 1922, 89-163 (1922)

Keesom, W. H., Physik Ber. 4, 613 (1923)

Mathias, E. and Crommelin, C. A., Proc. Fourth Intern. Congress of Refrigeration 1, 89-106a (1924)

Comments:

All logarithms are to the base 10.

I. $\log p = -\frac{360.500}{T} + 7.679324$

where:

p is in mm Hg
T is in °K

II. $\log p = -\frac{358.73}{T} + 4.7769$

where:

p is in atm
T is in °K

III. $\log p = a - \frac{359.093}{T}$

where:

T is in °K
a = 7.65894 for p in mm Hg
a = 4.77813 for p in atm
a = 5.94532 for p in psia

This is considered the best equation.

IV. $\log p = -\frac{334.64}{T} + 7.577 - 0.00476\,T$

where:

p is in mm Hg
T is in °K

Range: p below 760 mm Hg

(This equation is also valid for liquid nitrogen from 63.14°K to 77.35°K; 96.4 mm Hg to 760 mm Hg.)

VAPOR PRESSURE EQUATIONS for LIQUID NITROGEN

Sources of Data:

Armstrong, G. T., J. Research Natl. Bur. Standards 53, 263-6 (1954)

Cath, P. G., Proc. Acad. Sci. Amsterdam 21, 656-63 (1919)

Dodge, B. F. and Davis, H. N., J. Am. Chem. Soc. 49, 610-20 (1927)

Henning, F., Z. Physik 40, 775-85 (1927)

Keesom, W. H., Onnes-Festschrift 1922, 89-163 (1922)

Keesom, W. H., Physik. Ber. 4, 613 (1923)

Mathias, E. and Crommelin, C. A., Proc. Fourth Intern. Congress of Refrigeration 1, 89-106a (1924)

Porter, F. and Perry, J. H., J. Am. Chem. Soc. 48, 2059-60 (1926)

White, D., Friedman, S. A. and Johnston, H. L., J. Am. Chem. Soc. 73 5713-15 (1951)

	Equations for $\log_{10} P$	Range
	(p is in mm Hg; T is in °K)	
I	$= 6.49594 - \frac{255.821}{T - 6.600}$	64 - 78°K
II	$= -\frac{313.694}{T} + 1.75 \log T - 0.011096\, T + 4.487879$	
*III	$= -\frac{334.64}{T} + 7.5777 - 0.00476\, T$	p below 760 mm Hg
	(p is in atmosphere; T is in °K)	
IV	$= -\frac{316.824}{T} + 4.47582 - 0.0071701\, T + 2.940 \times 10^{-5}\, T^2$	1 - 32 atm
V	$= -\frac{334.64}{T} + 4.6969 - 0.00476\, T$	57.89°K - 84.21°K
VI	$= -\frac{302.34}{T} + 3.94127 - 0.00274\, T + 1.16 \times 10^{-6} (T - 100.5)^3$	90.12°K (3.631 atm)- 121.47°K (26.75 atm)
VII	$= 3.730697 - \frac{294.51750}{T} + 9.9433 \times 10^{-4}\, T - 1.234 \times 10^{-6}\, T^2$	**
VIII	$= 5.76381 - \frac{953.522}{T} + \frac{54372.3}{T^2} - \frac{1783500}{T^3}$	p above 1 atm

** Equation VII gives very good values above the normal boiling point (77.3°K) but deviates in the critical region.

* Equation III also valid for solid Nitrogen.

6.004

PHASE TRANSITION TEMPERATURES of NITROGEN

(Aso Includes Critical Constants)

Sources of Data:

Critical Point

Onnes, H. K., Dorsman, C. and Holst, G., Commun. Phys. Lab. Univ. Leiden, No. 145b (1915)
Pickering, S. F., Nat. Bur. Standards Sci. Paper No. 541, 597-629 (1926)
International Critical Tables (1928)

Normal Boiling Point

Heuse, W. and Otto, J., Ann. Physik. 14, 185-92 (1932)
Aoyama, S. and Kanda, E., Bull. Chem. Soc. Japan 10, 472-81 (1935)
Henning, F. and Heuse, W., Z. Physik 23, 105-16 (1924)
Mathias, E. and Crommelin, C. A., Proc. 4th Intern. Congr. Refrig. 1, 89-106a (1924)
Keesom, W. H., Onnes-Festschrift 1922, 89-163 (1922)
Keesom, W. H., Physik. Ber. 4, 613 (1923)
Giauque, W. F. and Clayton, J. O., J. Am. Chem. Soc. 55, 4875-89 (1933)
Dodge, B. F. and Davis, H. N., J. Am. Chem. Soc. 49, 610-20 (1927)
Cath, P. G., Commun. Phys. Lab. Univ. Leiden Commun. No. 152d (1918)
Henning, F., Z. Physik. 40, 775-85 (1926)
Keesom, W. H. and Bijl, A., Physica 4, 305-10 (1937)
Armstrong, G. T., J. Research Nat. Bur. Standards 53, 263-6 (1954)
Friedman, A. S. and White, D., J. Am. Chem. Soc. 72, 3931-32 (1950)

Normal Melting Point

Guertler, W. and Pirani, M., Z. Metallkunde 11, 1-7 (1919)
International Critical Tables (1928)
Giauque, W. F. and Clayton, J. O., J. Am. Chem. Soc. 55, 4875-89 (1933)
Verschoyle, T. T. H., Trans. Roy. Soc. (London) A230, 189-220 (1931)
Eucken, A., Verh. deut. physik. Ges. 18, 4-17 (1916)
Clusius, K., Z. physik. Chem. Abt B, 3, 41-79 (1929)
Henning, F., Z. Physik. 40, 775-85 (1927)

Triple Point

Mathias, E. and Crommelin, C. A., Proc. 4th Intern. Congr. Refrig. 1, 89-106a (1924)

Solid Transition

Eucken, A., Verh. deut. physik. Ges. 18, 4-17 (1916)
Swenson, C. A., J. Chem. Phys. 23, 1963-4 (1955)

- over -

PHASE TRANSITION TEMPERATURES of NITROGEN (cont.)

Table of Selected Values

Property	Pressure		Temperature	
	atm	psia	°K	°R
Critical Point**	33.5±.02	492.9±.3	126.26±.04	227.27±.07
Boiling Point*	1	14.696	77.35±.05	139.23±.09
Melting Point*	1	14.696	63.1 ±.05	113.6 ±.09
Triple Point	0.1268	1.863	63.14	113.65
α → γ transition	1	14.696	35.5	63.9
β → γ transition	1	14.696	53	95
Triple Point in Solid	4650	68,340	44.5	80.1

** Critical Density = 0.311 gm/cm^3
* An average of the values presented in the Sources of Data

Comments:

Swenson reported an α → γ transition at 39.5°K and at 4°K. Wyckoff [Wyckoff, R. W. G., Crystal Structures, Interscience Publishers, Inc. New York, (1951)] reports that the α form of solid nitrogen is probably cubic close packed and the γ form is hexagonal close packed. Wyckoff makes no mention of the β form.

Other References:

Critical Point

Mathias, E. and Crommelin, C. A., Proc. 4th Intern. Cong. Refrig. 1, 89-106a (1924)

Pickering, S. F., J. Phys. Chem. 28, 97-124 (1924)

Keesom, W. H., Onnes-Festschrift 1922, 89-163 (1922)

Keesom, W. H., Physik. Ber. 4, 613 (1923)

Triple Point

Keesom, W. H., Onnes-Festschrift 1922, 89-163 (1922)

Keesom, W. H., Physik. Ber. 4, 613 (1923)

Henning, F., Z. Physik 40, 775-85 (1927)

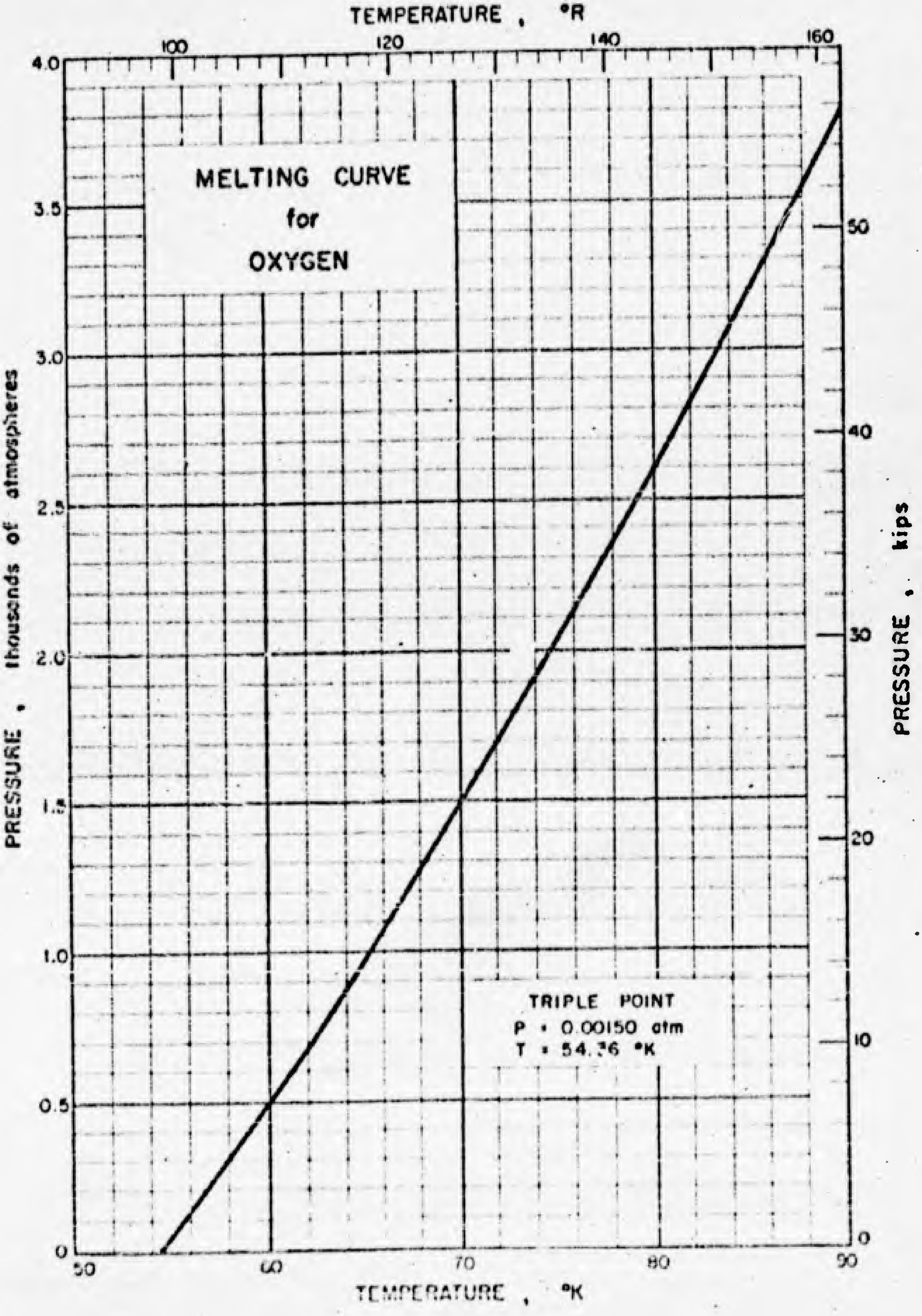
Cath, P. G., Proc. Acad. Sci. Amsterdam 21, 656-63 (1919)

Solid Transition

Swenson, C. A., J. Chem. Phys. 23, 1963-4 (1955)

Clusius, K., Z. physik. Chem. Abt B, 3, 41-79 (1929)

Giauque, W. F. and Clayton, J. O., J. Am. Chem. Soc. 55, 4875-89 (1933)


TEMPERATURE , °R
100
120
140
160
MELTING CURVE
for
OXYGEN
TRIPLE POINT
P = 0.00150 atm
T = 54.36 °K
PRESSURE , thousands of atmospheres
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
PRESSURE , kips
50
40
30
20
10
0
50
60
70
80
90
TEMPERATURE , °K

6.005

MELTING POINT TEMPERATURE of OXYGEN

Source of Data:

Mills, R. L. and Grilly, E. R., Phys. Rev. 99, 480-6 (1955)

Comments:

The values in the table below were computed from the Simon melting equation, $P_{eq} = a + bT^c$,

where: P is in kgm/cm^2
T is in °K

and for Oxygen: a = -2786.83
b = 2.635754
c = 1.742594

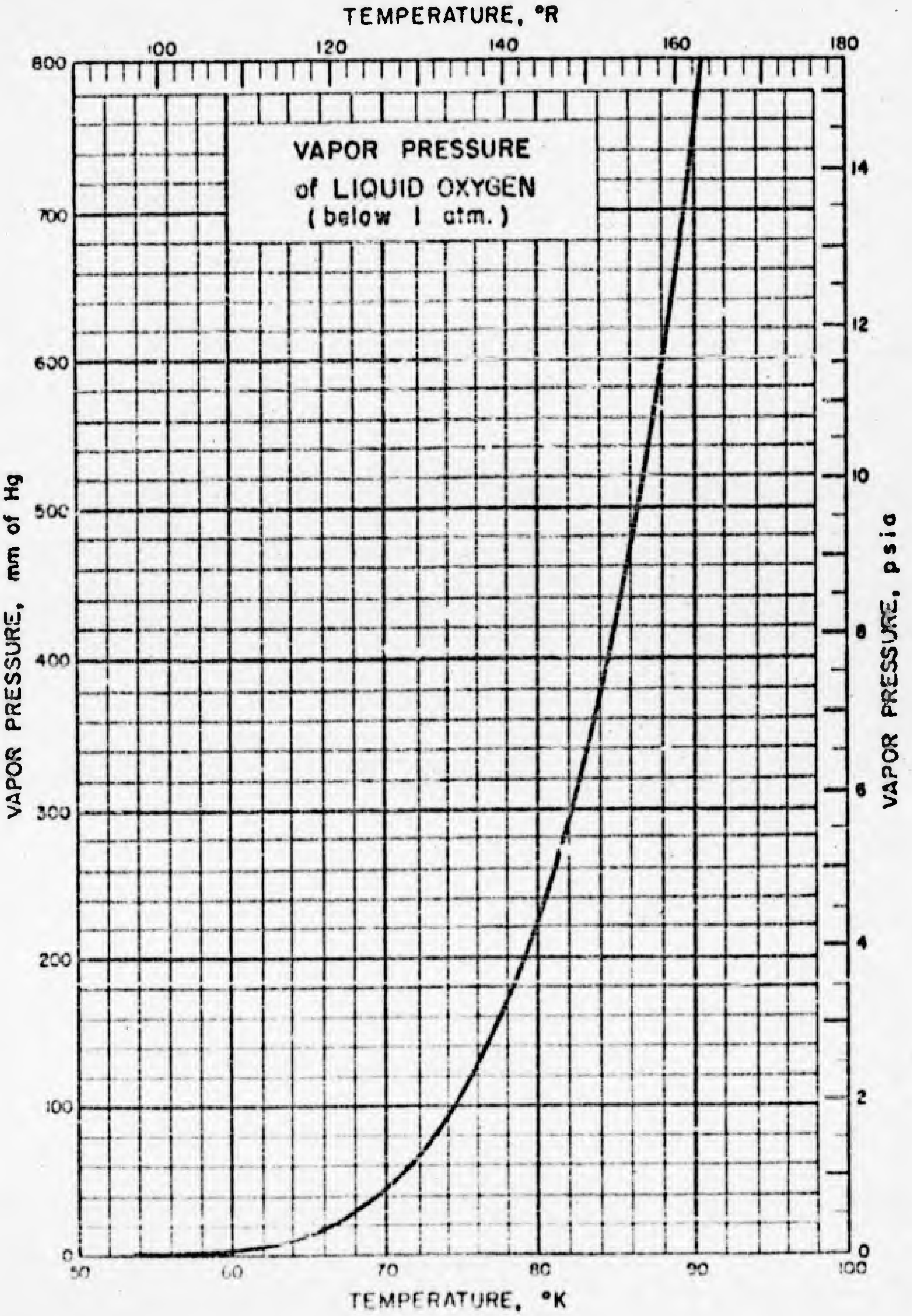
Table of Selected Values

Temp. °K	Pressure	
	kgm/cm^2	Atm.
54.36+	0.00155	0.00150
55	54.51	52.76
60	521.04	504.28
65	1016.56	983.87
70	1541.08	1491.52
75	2091.95	2024.67
80	2674.45	2588.44
85	3280.68	3175.17
90*	3918.53	3792.51

+ Triple Point Temperature

* Beyond range of applicability of the Simon equation.

JM/RJR Issued: 10/13/59


TEMPERATURE, °R
100
120
140
160
180
VAPOR PRESSURE
of LIQUID OXYGEN
(below 1 atm.)
VAPOR PRESSURE, mm of Hg
0
100
200
300
400
500
600
700
800
VAPOR PRESSURE, psia
0
2
4
6
8
10
12
14
50
60
70
80
90
100
TEMPERATURE, °K

6.005

VAPOR PRESSURE of LIQUID OXYGEN

(Below 1 Atmosphere)

Source of Data:

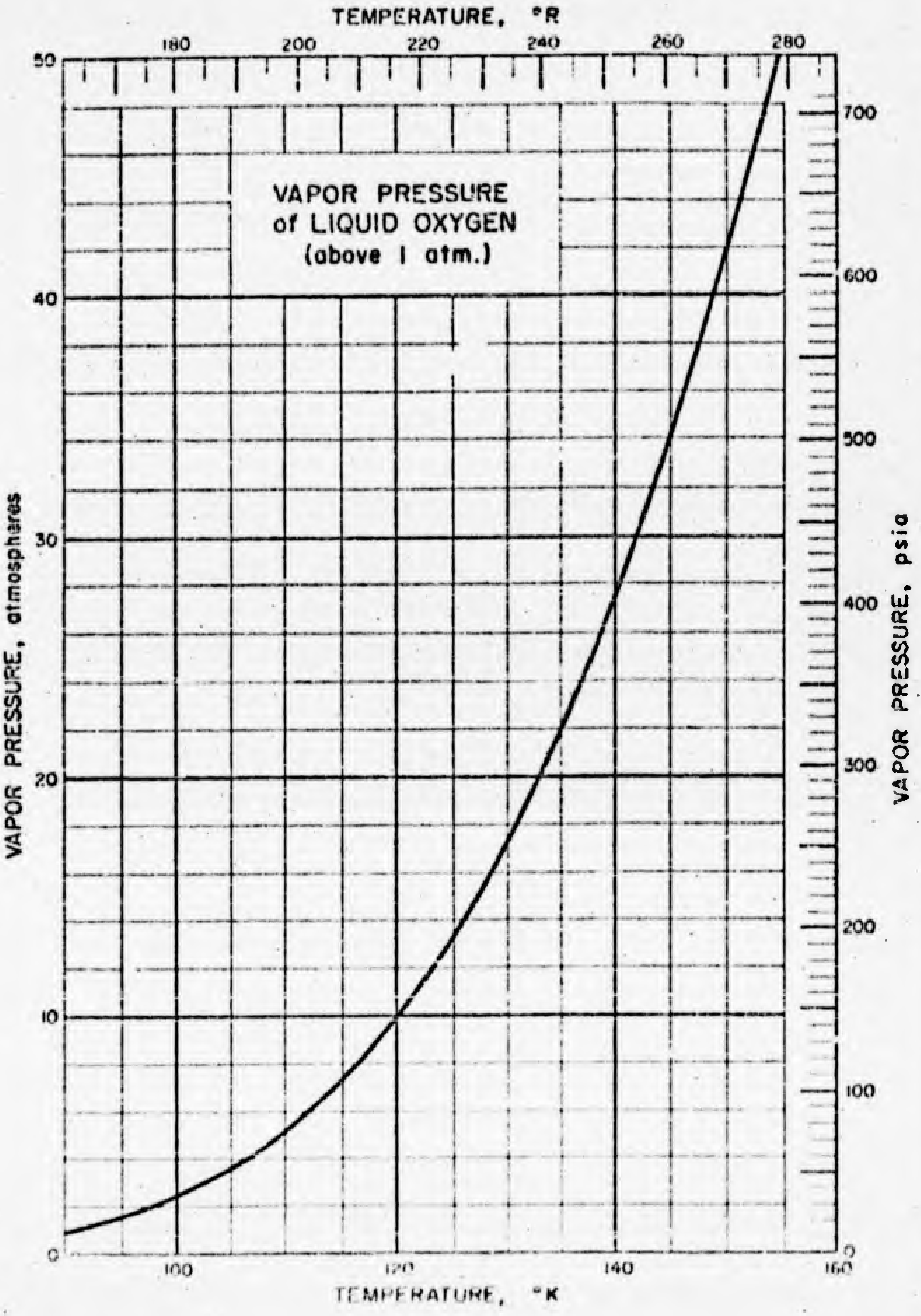
Hilsenrath, J., et al., Nat. Bur. Standards Cir. 564, 427-9 (1955)

Table of Selected Values

Temperature		Vapor Pressure		
°K	°R	atm	psia	cm.Hg
54.393*	97.853	0.00150	0.022	0.114
55	99	0.00182	0.027	0.138
60	108	0.00716	0.105	0.544
65	117	0.0229	0.34	1.74
70	126	0.0616	0.90	4.68
75	135	0.1430	2.10	10.87
80	144	0.2964	4.36	22.53
85	153	0.5597	8.23	42.54
90	162	0.9803	14.41	74.50
90.19 **	162.34	1.000	14.696	76.000

* Triple Point
** Normal Boiling Point

JM/BH/T Issued: [illegible]
Revised: 5/20/60


TEMPERATURE, °R
180
200
220
240
260
280
VAPOR PRESSURE
of LIQUID OXYGEN
(above 1 atm.)
VAPOR PRESSURE, atmospheres
50
40
30
20
10
0
VAPOR PRESSURE, psia
700
600
500
400
300
200
100
0
100
120
140
160
TEMPERATURE, °K

VAPOR PRESSURE of LIQUID OXYGEN
(Above 1 Atmosphere)

Source of Data:

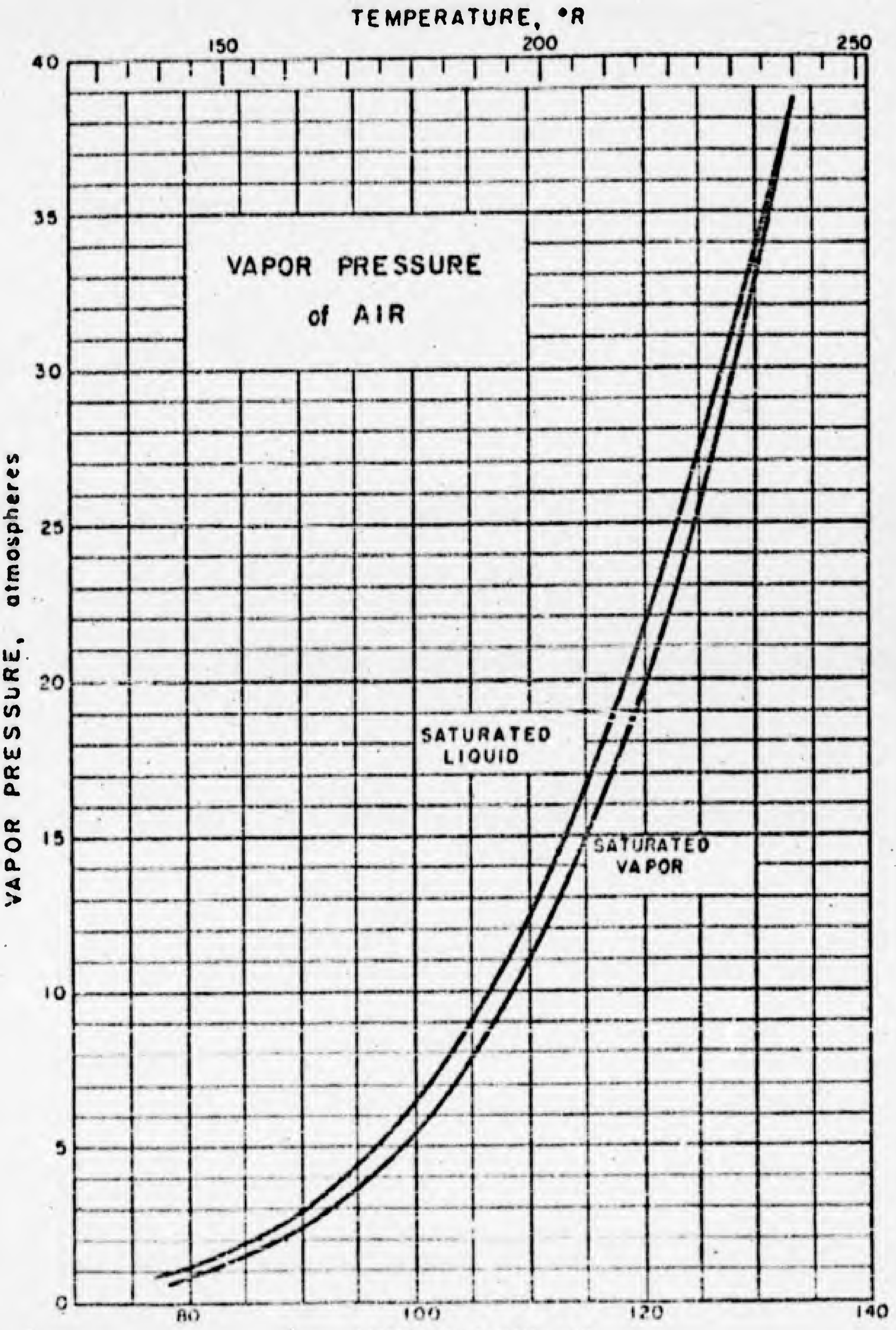
Hilsenrath, J., et al., Nat. Bur. Standards Cir. 564, 427-9 (1955).

Table of Selected Values

Temperature		Vapor Pressure		
°K	°R	atm	psia	cm Hg
90.190*	162.342	1.000	14.696	76.000
95	171	1.6096	23.65	122.30
100	180	2.5066	36.84	190.50
105	189	3.7345	54.88	283.82
110	198	5.3591	78.76	407.29
115	207	7.4495	109.48	566.16
120	216	10.077	198.09	765.86
125	225	13.316	195.7	1012.00
130	234	17.239	253.4	1310.2
135	243	21.934	322.3	1667.0
140	252	27.489	404.0	2089.2
145	261	34.004	499.7	2584.3
150	270	41.620	611.6	3163.1
154.7**	278.6	50.1	736	3810

* Normal Boiling Point
** Critical Point

JH/BDT Issued: 7/21/59


TEMPERATURE, °R
150
200
250
VAPOR PRESSURE of AIR
SATURATED LIQUID
SATURATED VAPOR
VAPOR PRESSURE, atmospheres
0
5
10
15
20
25
30
35
40
80
100
120
140
TEMPERATURE, °K

VAPOR PRESSURE OF AIR

(Liquid and Vapor)

Source of Data:

Din, F., Thermodynamic Functions of Gases, Vol. 2, Butterworths Scientific Publications, London (1956)

Other References:

Dodge, B. F. and Dunbar, A. K.; J. Am. Chem. Soc. 49, 591-610 (1927)

Ishkin, I. P. and Kaganer, M. G., Soviet Phys. Tech. Phys. 1, 2263-2271 (1956)

Kuenen, J. P. and Clark, A. L., Communs. Phys. Lab. Univ. Leiden No. 150b (1917)

Michels, A., Wassenaar, T., Levelt, J. M. and deGraaff, W., Appl. Sci. Research A4, No. 5-6, 381-392 (1954)

Comments:

The data reported by Din are based on the work by Kuenen and Clark, Dodge and Dunbar, and Michels, et al. The data of Ishkin et al. are based on the work of Dodge and Dunbar also.

It should be noted that there are separate curves for the vapor pressure of saturated liquid (bubble) and saturated vapor (dew). Air is a multicomponent mixture and at the same pressure the saturated liquid is at a different temperature than the saturated vapor.

Table of Selected Values

Pressure		Sat. Liquid (Bubble) Temperature		Sat. Vapor (Dew) Temperature	
atm.	lb/in²	°K	°R	°K	°R
1	14.70	78.8	141.84	81.8	147.24
2	29.40	85.55	153.99	88.31	158.96
3	44.10	90.94	163.69	92.63	166.73
5	73.50	96.38	173.48	98.71	177.68
7	102.90	101.04	181.87	103.16	185.69
10	147.00	106.47	191.65	108.35	195.03
15	220.50	113.35	204.03	116.08	208.94
20	294.00	118.77	213.79	120.07	216.13
25	367.50	123.30	221.94	124.41	223.94
30	441.00	127.26	229.07	128.12	230.62
35	514.50	130.91	235.64	131.42	236.56
37.17	546.40	132.52	238.54	132.52	238.54
37.25	547.58	132.42	238.36	132.42	238.36

DAV/WJV Issued: [illegible]

6.007

VAPOR PRESSURE OF CARBON MONOXIDE

Sources of Data.

Clayton, J. O. and Giauque, W. F., J. Am. Chem. Soc. 54, 2610-26 (1932)

Clusius, K. and Teske, W., Z. physik. Chem. B6, 135-151 (1929)

Crommelin, C. A., Bijleveld, W. J. and Brown, E. G., Communs. Kamerlingh Onnes Lab., Univ. Leiden, No. 217b (1931)

Mathias, E. and Crommelin, C. A., Ann. phys. 5, 137-66 (1936)

Michels, A., Wassenaar, T. and Zwietering, T. N., Physica 18, 160-2 (1952)

Comments:

The vapor pressure data given in Clusius and Teske was presented in mm Hg. These were converted to atmospheres to correspond with the data presented in the other four references.

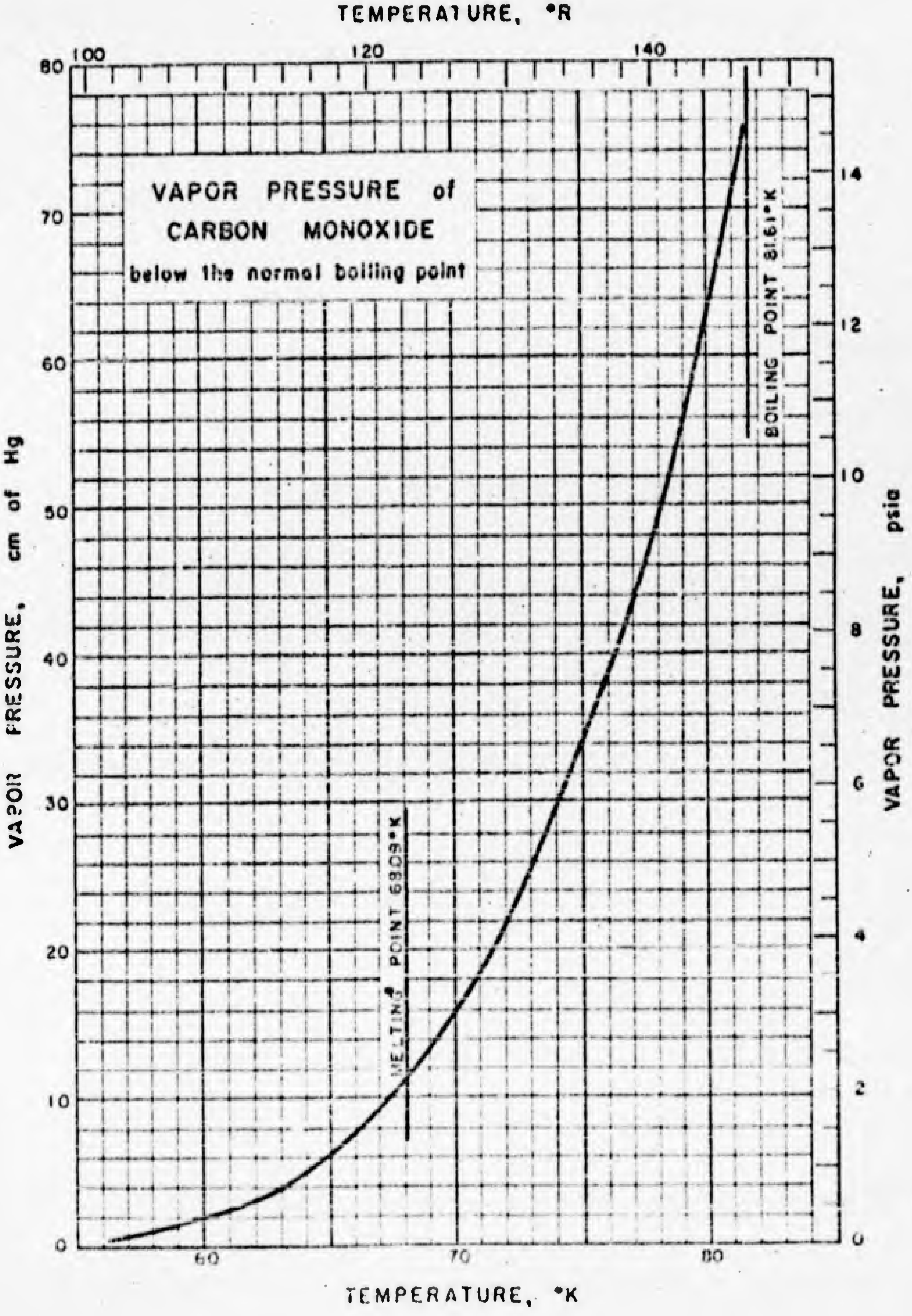
Table of Selected Values

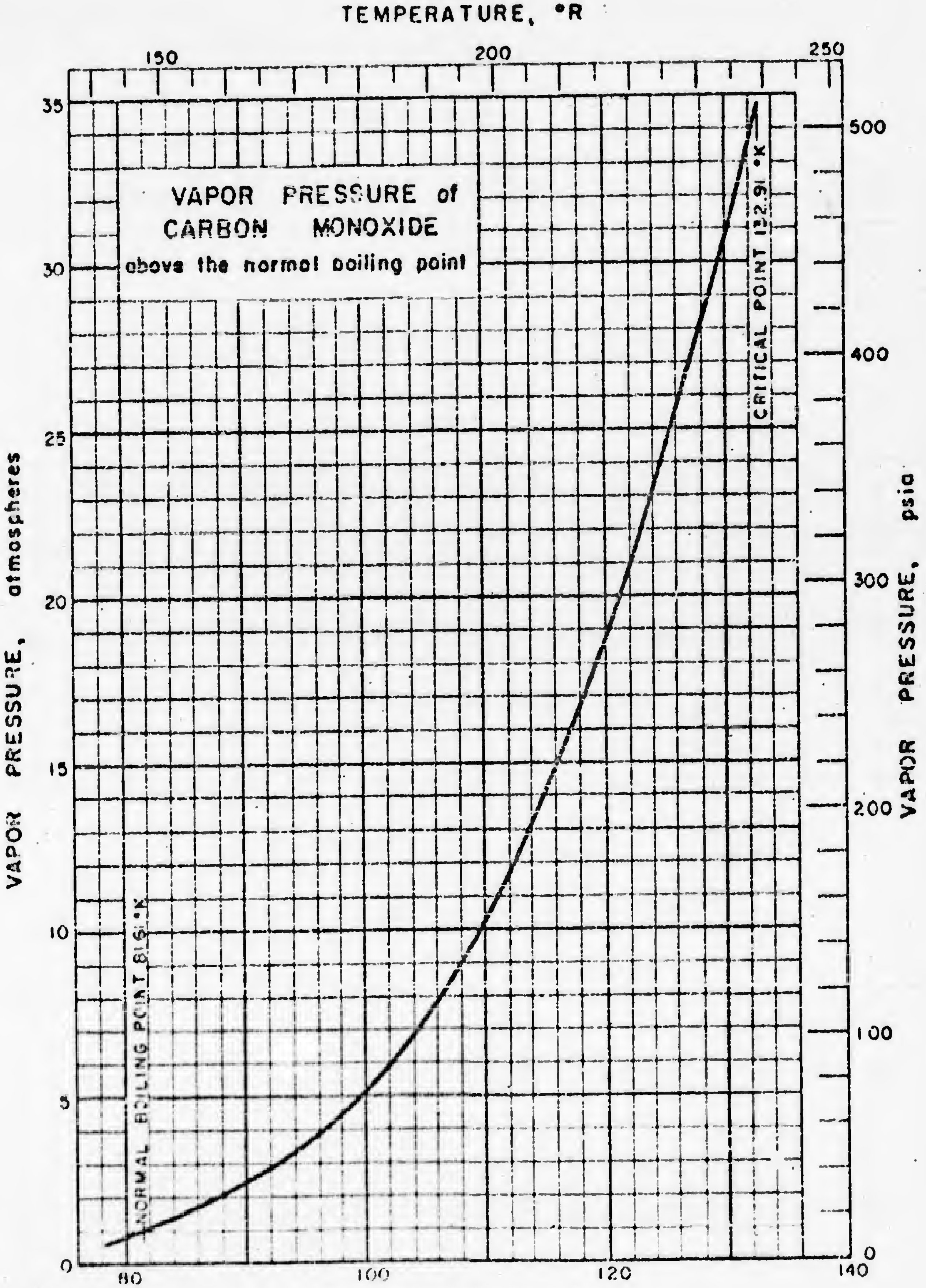
Temp. °K	Press. atm	Temp. °K	Press. atm	Temp. °K	Press. atm	Temp. °K	Press. atm
56.86	0.009493	68.18	0.15307	77.50	0.61196	108.318	9.7789
60.34	.02686	68.21*	.15417	77.50	.61209	112.22	12.072
60.62	.027385	69.73	.19986	77.99	.64466	112.464	12.2094
61.46	.03230	70.80	.23449	78.77	.67226	116.385	15.1299
61.99	.04095	71.46	.26069	78.83	.71913	116.387	15.1909
62.69	.043003	72.34	.30058	79.76	.75877	119.334	17.9113
63.97	.05985	73.35	.34798	79.97	.821825	122.709	21.2562
64.39	.07269	73.41	.34916	81.47	.98131	123.48	22.152
64.90	.08031	73.86	.37197	81.61	[normal boil. pt.]	124.990	23.7927
64.96	.079931	73.86	.37198			125.98	25.014
65.67	.092847	73.87	.37237	87.63	1.8833	127.531	26.0594
65.97	.10217	73.99	.37992	93.291	3.1461	129.25	29.160
66.29	.10493	74.69	.41509	94.36	3.473	129.25	29.104
66.33	.10663	74.72	.42006	94.730	3.5223	129.975	30.0316
67.14	.10855	74.72	.42216	96.236	4.0237	131.141	31.0405
67.17	.13021	75.56	.46637	101.274	5.9273	131.75	32.911
67.37	.13113	75.63	.47635	103.021	6.7016	131.993	33.9704
67.90	.14566	76.00	.50018	103.40	6.922	132.50	33.999
68.07	.14119	76.33	.52256	105.135	7.7092	132.595	34.0209
68.09	[melting point]	76.45	.53691	107.68	9.092	132.91**	34.529
68.15	.15292	76.57	.53823	108.515	9.7762		

* Clusius and Teske report the melting point to be 68.09°K.

** Critical point

[illegible] Issued: 7/1/59


TEMPERATURE, °R
100
120
140
VAPOR PRESSURE of CARBON MONOXIDE below the normal boiling point
BOILING POINT 81.61°K
MELTING POINT 68.09°K
VAPOR PRESSURE, cm of Hg
0
10
20
30
40
50
60
70
80
VAPOR PRESSURE, psia
0
2
4
6
8
10
12
14
60
70
80
TEMPERATURE, °K


TEMPERATURE, °R
150
200
250
VAPOR PRESSURE of CARBON MONOXIDE
above the normal boiling point
CRITICAL POINT 132.91 °K
NORMAL BOILING POINT 81.61 °K
VAPOR PRESSURE, atmospheres
0
5
10
15
20
25
30
35
VAPOR PRESSURE, psia
0
100
200
300
400
500
80
100
120
140
TEMPERATURE, °K

VAPOR PRESSURE EQUATIONS for CARBON MONOXIDE

Source of Data:

Clayton, J. O. and Giauque, W. F., J. Am. Chem. Soc. 54, 2610-26 (1932).

Comments:

In the following equations p is in cm Hg and T is in °K.

Range	$\log_{10} p =$
solid below $\alpha - \beta$ transition temp. (61.55°K)	$-\frac{418.2}{T} + 4.127 \log_{10} T + 1.47365 - 0.02623\,T$
solid between $\alpha - \beta$ transition temp. (61.55°K) and melting point (68.09°K)	$-\frac{425.1}{T} + 7.82259 - 0.0075960\,T$
liquid above 68.09°K	$-\frac{477.3}{T} + 11.23721 - 0.064129\,T + 0.00025911\,T^2$

6.007

PHASE TRANSITION TEMPERATURES of CARBON MONOXIDE

(Also Includes Critical Constants)

Source of Data:

Clayton, J. O. and Giauque, W. F., J. Am. Chem. Soc. 54, 2610-26 (1932).

Mathias, E. and Crommelin, C. A., Ann. Physik 5, 137-66 (1936).

Table of Selected Values

Transition	Reference	Temperature	Pressure
Normal Melting	Clayton	68.09±0.05°K	1 atm
Normal Boiling	Clayton	81.61±0.05°K	1 atm
$\alpha \rightarrow \beta$	Clayton	61.55±0.05°K	1 atm
Triple Point	Clayton	68.09±0.05°K	11.531 cm Hg
Critical Point*	Mathias	132.91°K	34.529 atm

* Critical Volume = 3.322 cm^3/gm

Comments:

I. Normal Melting Point – Other values available follow:

68.2_2°K: Clusius, K., Z. physik. Chem. B3, 41-47 (1929); and Clusius, K. and Teske, W., Z. physik Chem. B6, 135-151 (1929).

67.3 °K: Eucken, A., Ber. deut. physik. Ges. 18, 4-17 (1916).

68.10°K: Crommelin, C. A., Bijleveld, W. J. and Brown, E. G., Commun. Kamerlingh Onnes Lab. Univ. Leiden, Commun. No. 217b (1931); and Kaishev, R., Z. physik. Chem. B40, 273-80 (1938).

68.06°K: Verschoyle, T., Trans. Roy. Soc. (London) A230, 189 (1931).

II. Normal Boiling Point – Other values available follow:

81.8 °K: Baly, E. C. C. and Donnan, F. G., J. Chem. Soc. (London) 81, 907 (1902).

81.62°K: Clusius, K., Z. physik. Chem. B3, 41-47 (1929) and Clusius, K. and Teske, W., Z. physik. Chem. B6, 135-151 (1929).

81.63°K: Crommelin, C. A., Bijleveld, W. J. and Brown, E. G., Commun. Kamerlingh Onnes Lab. Univ. Leiden, Commun. No. 217b (1931).

-191.484°C: Heuse, W. and Otto, J., Ann. Physik 14, 185-92 (1932).

81.66°K: van Winning, E., Ph. D. dissertation, Berlin (1919).

PHASE TRANSITION TEMPERATURES of CARBON MONOXIDE
(cont.)

III. $\alpha \rightarrow \beta$ Transition Temperature – Other values available follow:

61.51°K: Clusius, K., Z. physik. Chem. B3, 41-47 (1929); and Clusius, K. and Teske, W., Z. physik. Chem. B6, 135-151 (1929).

60.4 °K: Eucken, A., Ber. deut. physik. Ges. 18, 4-17 (1916).

61.49°K: Kaishev, R., Z. physik. Chem. B40, 273-80 (1938).

IV. Triple Point – Other values available follow:

68.10°K and 0.15146 atm: Crommelin, C. A., Bijleveld, W. J. and Brown, E. G., Commun. Kamerlingh Onnes Lab. Univ. Leiden, Commun. No. 217b (1931).

68.06°K and 11.486 cm Hg: Verschoyle, T., Trans. Roy. Soc. (London) A230, 189 (1931).

V. Critical Point – Other values available follow:

-139°C and 35 atm: Baly, E. C. C. and Donnan, F. G., J. Chem. Soc. (London) 81, 907 (1902); and Pickering, S. F., Nat. Bur. Standards Sci. Paper No. 541, 597-629 (1926).

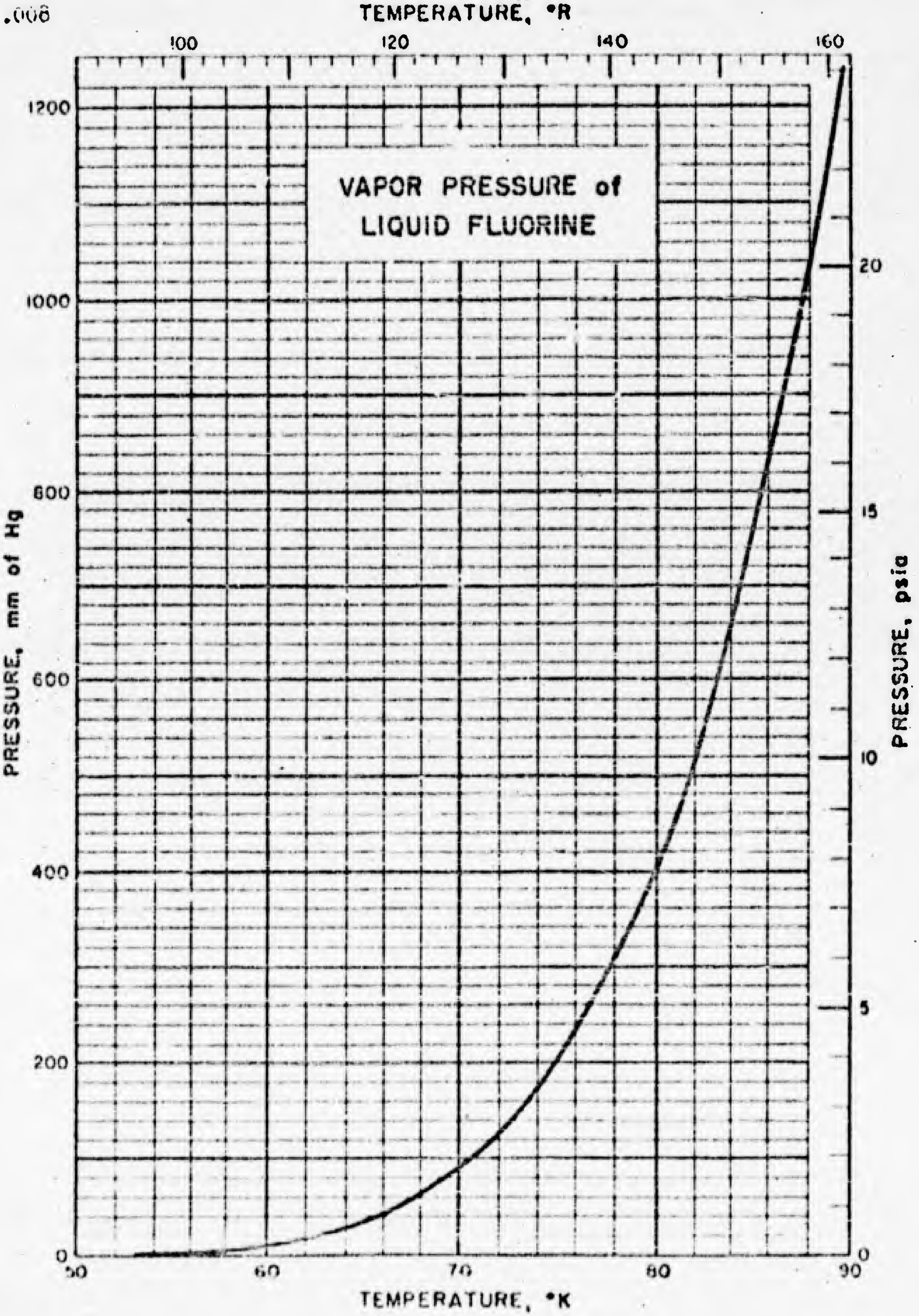
132.88°K and 34.529 atm: Crommelin, C. A., Bijleveld, W. J. and Brown, E. G., Commun. Kamerlingh Onnes Lab. Univ. Leiden, Commun. No. 217b (1931).

VI. Critical Volume – Other values available follow:

3.322 cm^3/gm: Crommelin, C. A., Bijleveld, W. and Brown, E. G., Commun. Kamerlingh Onnes Lab. Univ. Leiden, Commun. No. 217b (1931).

93.2 cm^3/gm-mole: Guggenheim, E. A., J. Chem. Phys. 13, 253-61 (1945).

6.008



VAPOR PRESSURE of LIQUID FLUORINE

VAPOR PRESSURE of LIQUID FLUORINE

Source of Data: Hu, White, and Johnston, J. Am. Chem. Soc., 75, 5642-5645 (1953).

Other References: Aoyama and Kanda, Bull. Chem. Soc. Japan, 12, 417-418 (1937); Cody and Hildebrand, J. Am. Chem. Soc., 52, 3839 (1930); Clauusen, J. Am. Chem. Soc., 56, 614 (1934).

Comments: Measurements of the vapor pressure have been made by many authors; agrrement is good. The data by Hu, et. al. extends over a wider range, and therefore are presented below and on the accompanying graph. The equations which the authors have fitted to their experimental data are presented below:

Reference — **Equation**

Hu, et. al.: $$\log_{10} P_{(\mathrm{mm\ Hg})} = 7.08718 - \frac{357.258}{T} - \frac{1.3155 \times 10^{13}}{T^8}$$

Aoyama and Kanda: $$\log_{10} P_{(\mathrm{mm\ Hg})} = -\frac{442.72}{T} + 9.1975 - 0.013150\,T$$

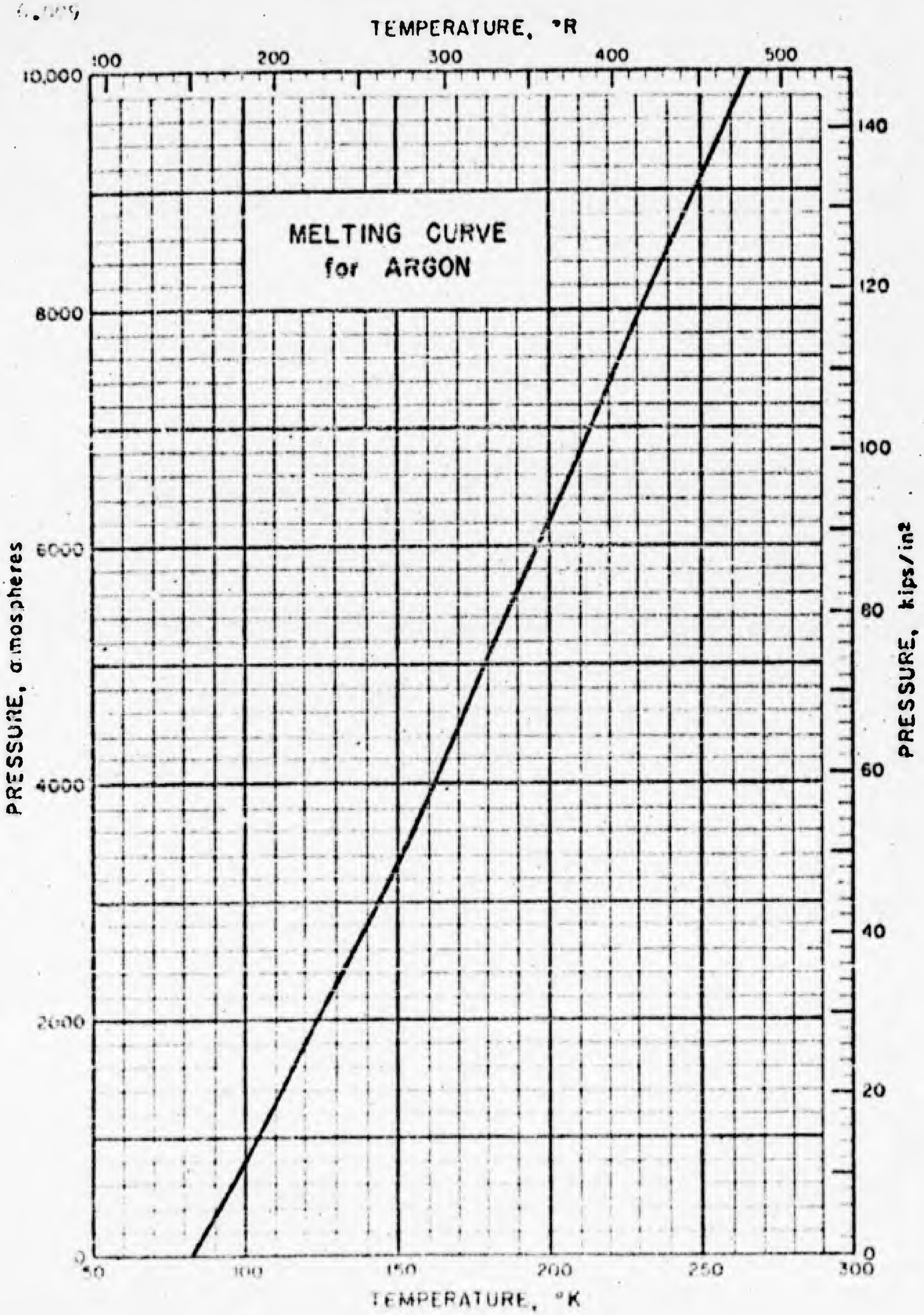
Cody and Hildebrand: $$\log_{10} P_{(\mathrm{cm\ Hg})} = -\frac{406.8}{T} + 7.3317 - 0.007785\,T$$

Claussen: $$\log_{10} P_{(\mathrm{cm\ Hg})} = -\frac{462.66}{T} + 8.7202 - 0.01656\,T$$

Table of Selected Values

Temp. °K	Press. (Exper'l) mm Hg	Press. (Calcd.) mm Hg	Deviation	Temp. °K	Press. (Exper'l) mm Hg	Press. (Calcd.) mm Hg	Deviation
53.56	1.67	1.67	0.00	72.56	139.67	140.06	-0.39
53.84	1.84	1.84	.00	75.59	223.73	223.19	.54
54.99	2.73	2.71	.02	77.17	280.40	280.14	.26
55.69	3.46	3.39	.07	78.54	338.89	338.44	.45
57.56	5.94	5.91	.03	80.03	412.75	412.50	.25
59.03	8.84	8.82	.02	81.59	504.10	503.42	.68
60.50	12.89	12.85	.04	83.06	604.12	603.03	1.09
61.95	18.26	18.18	.08	84.58	722.98	721.59	1.39
63.49	25.93	25.74	.19	85.05	763.08	761.60	1.48
65.02	35.28	35.59	-.31	86.60	907.07	907.32	-0.25
66.52	48.12	48.11	.01	87.52	1002.72	1003.07	-0.35
68.00	63.66	63.76	-.12	88.59	1122.29	1124.55	-2.26
69.57	84.30	84.72	-.42	89.40	1219.89	1223.57	-3.68
71.07	109.22	109.64	-.42				

RFR Issued: 7/15/59


TEMPERATURE, °R
100
200
300
400
500
MELTING CURVE
for ARGON
PRESSURE, atmospheres
10,000
8000
6000
4000
2000
0
PRESSURE, kips/in²
140
120
100
80
60
40
20
0
50
100
150
200
250
300
TEMPERATURE, °K

MELTING POINT TEMPERATURE of SOLID ARGON

Source of Data: Robinson, D. W., Proc. Roy. Soc. (London) A255 393-405 (1954).

Table of Selected Values

Pressure atm.	Temperature °K
1	83.2
1000	104.5
2000	124.0
3000	144.0
4000	162.0
5000	179.0
6000	197.0
7000	213.5
8000	231.5
8250	234.0
* 9000	*249.0
*10000	*266.0
P_c = 48.0	T_c = 150.7

* extrapolated values

PLB/RJR Issued: 5/25/59

PHASE TRANSITION TEMPERATURES OF ARGON

Sources of Data:

Clark, A. M., Din, F. and Robb, J., Physica 17, 876 (1951)

Clusius, K. and Frank, A., Z. Elektrochem. 49, 308 (1943)

Freeman, M. P. and Halsey, G. D., Jr., J. Phys. Chem. 60, 1119-25 (1956)

Michels, A., Wassenaar, T., Sluyters, Th. and Graaff, W. de., Physica 23, 89 (1957)

Pool, R. A. H., Shields, B. D. C. and Stavely, L. A. K., Nature 181, No. 4612, 831 (1958)

Comments:

Michels, et. al. measured the triple point temperature with a platinum resistance thermometer and it is offered as a calibration point for the international temperature scale.

Pool, et. al. found the triple point temperature by using the normal oxygen boiling point of 90.154°K.

The vapor pressure of argon is given to a high degree of accuracy (± 0.02%) by the equation:

$$\log_{10} p(\text{mm}) = A - B/T$$

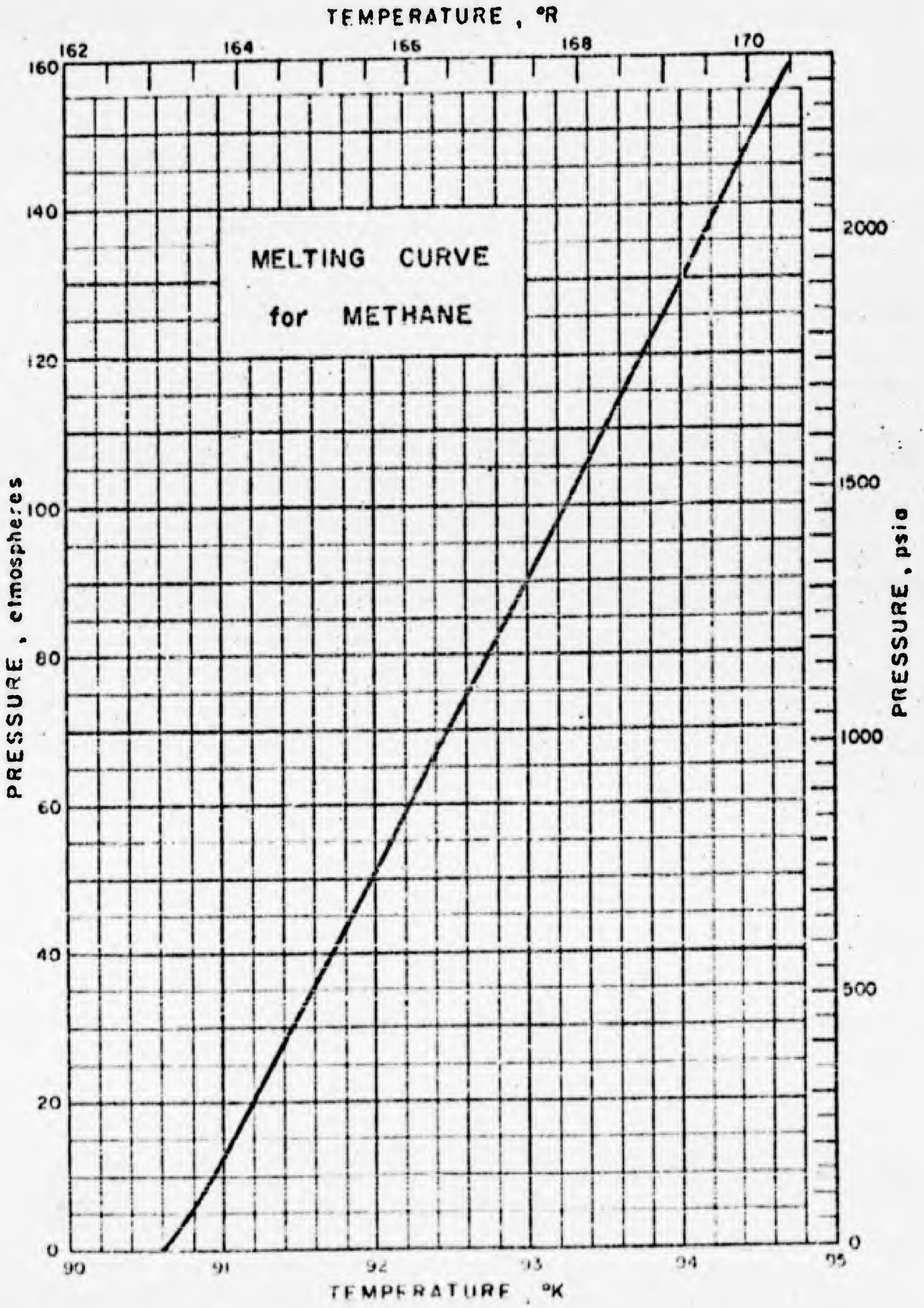
where:

T is in °K
Liquid
A = 6.9224 (from 83.77° to 88.2°K)
B = 352.8
Solid
A = 7.7393 (from 82° to 83.77°K)
B = 420.9

Table of Selected Values

Pressure mm Hg	Triple Point	Boiling Point	Source
	Temp. °K	Temp. °K	
514.1	83.77	87.29	Freeman et. al.
515.7	83.78	87.29	Clark " "
516.8	83.78	87.29	Clusius " "
	*83.79 ± .001		Michels " "
516 ± .04	83.783 ± .006		Pool " "

* 0°C taken as 273.13°K


TEMPERATURE , °R
162
164
166
168
170
MELTING CURVE
for METHANE
PRESSURE , atmospheres
0
20
40
60
80
100
120
140
160
PRESSURE , psia
0
500
1000
1500
2000
90
91
92
93
94
95
TEMPERATURE , °K

MELTING POINT TEMPERATURE of METHANE

Source of Data:

Clusius, K. and Weigand, K., Physik Chem. B46, 1 (1940)

Other References:

Clusius, K., Popp, L. and Frank, A., Physica 4, 1105-16 (1937)

Fischer, L. O., Bull. Soc. Chim. Belge. 49, 129 (1940)

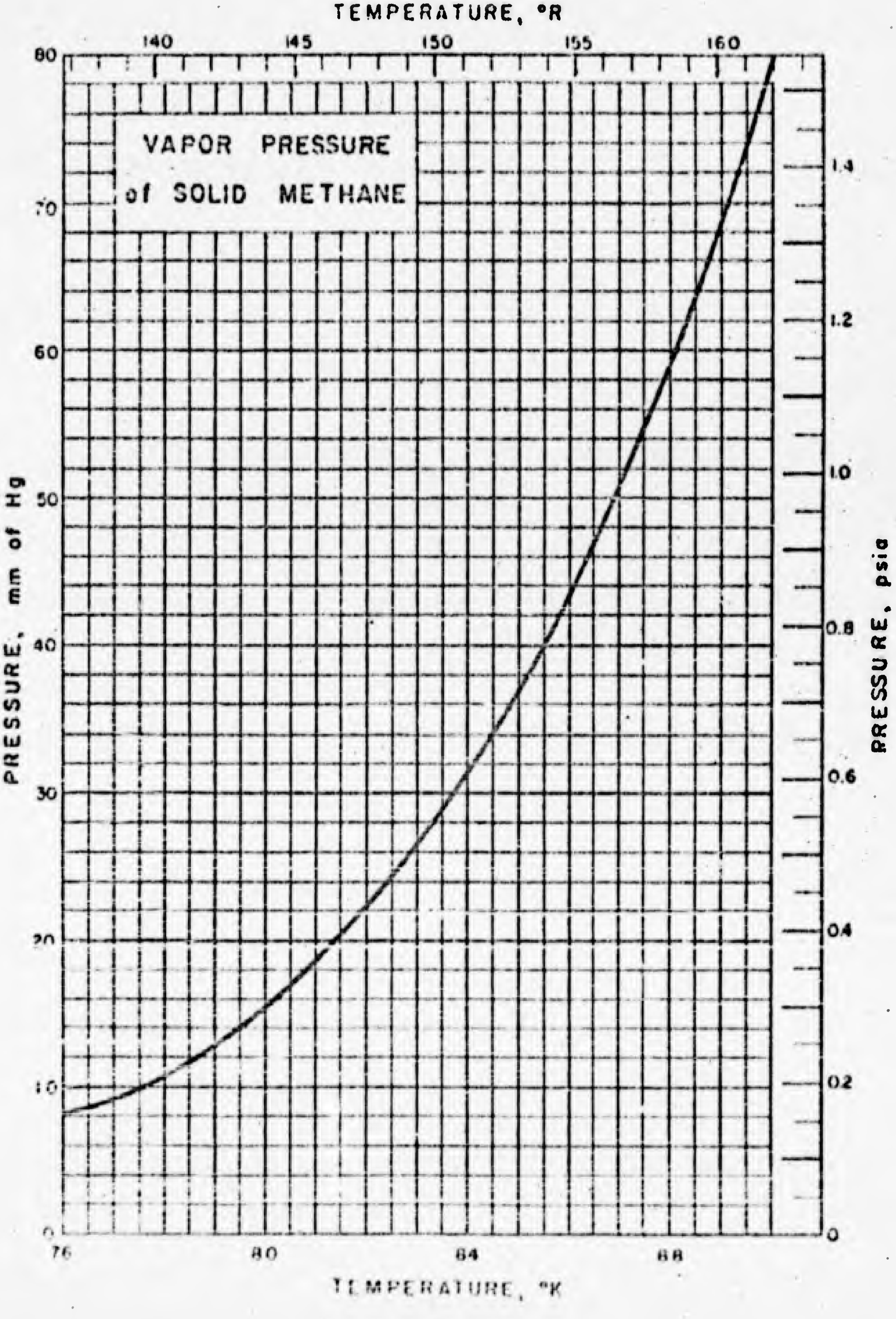
Van Itterbeek, A. and Verhaegen, L., Proc. Phys. Soc. (London) B62, 800-804 (1949)

Comments:

Inconsistencies in the data occur only at pressure below 1 atm. Clusius and Weigand did not report a value of the normal melting point but three other sources give a temperature of 90.6 ± .1°K for this value.

Table of Selected Values

Temp. °K	Pressure atm.
94.63	155.6
94.38	145.8
94.14	136.2
93.88	126.3
93.62	115.3
93.40	106.9
93.15	96.2
92.91	86.8
92.66	77.1
92.41	67.2
92.18	58.2
91.94	48.3
91.70	39.0
91.41	28.8
91.21	20.7
90.93	9.5
90.67	0.115


TEMPERATURE, °R
140
145
150
155
160
VAPOR PRESSURE
of SOLID METHANE
PRESSURE, mm of Hg
80
70
60
50
40
30
20
10
0
PRESSURE, psia
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
76
80
84
88
TEMPERATURE, °K

6.010

VAPOR PRESSURE of SOLID METHANE

Sources of Data:

Freeth, F. A. and Verschoyle, T. T. H., Proc. Roy. Soc. (London) A103, 453 (1931)

Kenning, F. and Stock, A., Z. Physik. 4, 226 (1921)

Rossini, F. D., et al., Selected Values of Physical and Thermodynamic Properties of Hydrocarbons and Related Compounds, Carnegie Press, Pittsburgh (1953)

Stock, A., Z. Elektrochem 29, 354 (1923)

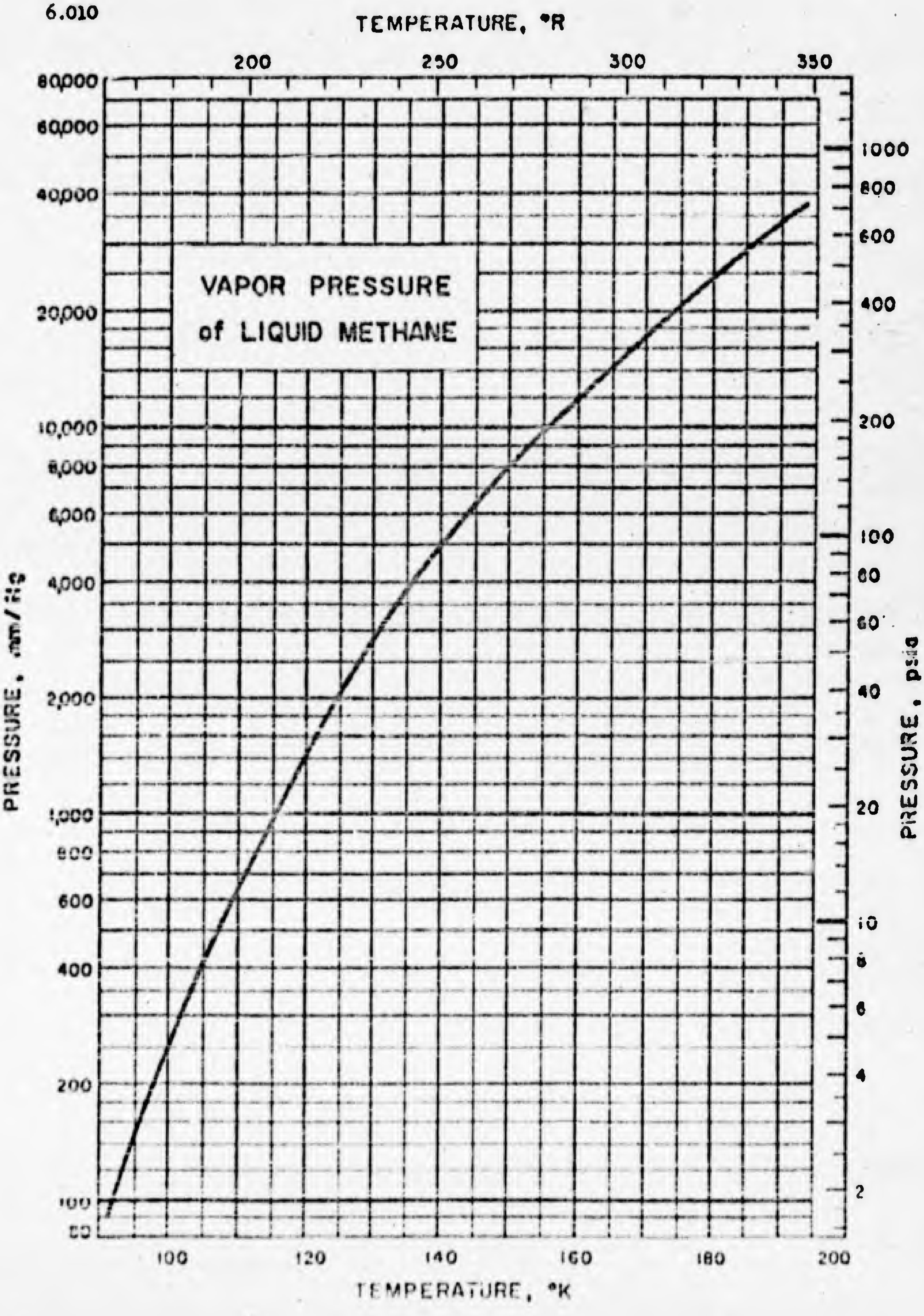
Table of Selected Values

Data from Rossini

Temp. °K	Pressure mm Hg
77.65	10
81.39	20
83.75	30
85.50	40
86.91	50
88.10	60
90.04	80

Data from Others

Temp. °K	Pressure mm Hg
73.46	4.24
73.46	4.33
79.00	13.04
79.00	13.27
80.27	16.00
84.67	35.72
86.49	46.7
89.16	71.0
90.16	81.1



TEMPERATURE, °R
200
250
300
350
VAPOR PRESSURE of LIQUID METHANE
80,000
60,000
40,000
20,000
10,000
8,000
6,000
4,000
2,000
1,000
800
600
400
200
100
80
PRESSURE, mm/Hg
1000
800
600
400
200
100
80
60
40
20
10
8
6
4
2
PRESSURE, psia
100
120
140
160
180
200
TEMPERATURE, °K

VAPOR PRESSURE of LIQUID METHANE

Sources of Data:

Keyes, F. G., Taylor, R. S. and Smith, L. B., J. Math. Phys. 1, 211 (1922) for temperature above 133°K.

Stock, A., Z. Elektrochem 29, 354 (1923) for temperature between 91 and 133°K.

Other References:

Hooper, I. H. D., Analyst 72, 513 (1947)

Lamb, A. B. and Roper, E. E., J. Am. Chem. Soc. 62, 806 (1940)

Maxwell, J. B., Data Book on Hydrocarbons, 3rd Printing, D. Van Nostrand Company, Inc., New York, N. Y. (1950) p. 27

Rossini, F. D., Petrol. Engr. 14, No. 5, 41 (1943)

Comments:

The original data from the above sources are compiled in:

Egloff, G., Physical Constants of Hydrocarbons, Reinhold Publishing Corp. New York, N. Y. (1953)

Table of Selected Values

Temp. °K	Vapor Pressure mm Hg	Temp. °K	Vapor Pressure mm Hg	Temp. °K	Vapor Pressure mm Hg
91.16	92.3	116.16	1,062	172.37	19,003
93.16	118.5	118.16	1,227	172.46	19.111
95.16	150.6	121.16	1,508	178.21	23,169
97.16	189.4	123.16	1,718	178.21	23,180
99.16	235.5	133.65	3,431	181.22	25,612
101.16	289.2	138.58	4,464	186.17	29,936
103.16	352.3	143.52	5,768	186.17	30,028
105.16	426.2	148.46	7,280	186.10	30,116
107.16	511.1	153.60	9,081	188.02	31.773
109.16	608.3	158.36	11,126	189.95	33,597
111.16	721.1	163.32	13,602	191.05	35,008
113.16	846	168.29	16,520		

Normal Boiling Temp. = 111.73°K

PHASE TRANSITION TEMPERATURES of METHANE

Sources of Data:

Critical Point

Pickering, S. F., Natl. Bur. Standards Sci. Paper 21, No. 541, 596-629 (Nov. 1926)

Rossini, F. D., et al., Selected Values of Physical and Thermodynamic Properties of Hydrocarbons and Related Compounds, Carnegie Press, Pittsburgh (1953)

Normal Boiling Point

Rossini, F. D., Anal. Chem. 20, 110 (1948)

Normal Melting Point

Clusius, K., Popp, L. and Frank, A., Physica 4, 1105-16 (1937)

Fischer, L. O., Bull. Soc. Chim. Belge. 49, 129-58 (1940)

Van Itterbeek, A. and Verhaegen, L., Proc. Phys. Soc. (London) 62B, 800-4 (1949)

Triple Point

Crommelin, C. A., Proc. Akad. Wetenschappen 15, 666 (1912)

Olszewski, K., Compt. rend. 100, 940 (1885)

Solid Transition

Gerritsen, A. N. and Van der Star, P., Physica 9, No. 5, 503-12 (May 1942)

Table of Selected Values

Property	Pressure		Temperature	
	atm	psia	°K	°R
Critical Point	45.8	673	190.7	343.3
Boiling Point	1	14.7	111.7	201.1
Melting Point*	1	14.7	90.6±.1	163.1±.2
Triple Point *	0.099	1.5	88.7	159.7
Solid Transition			20.4	36.7

Critical Density = 0.162 gm/cm3

* An average of values presented in the Sources of Data

(Other References on following page)

PHASE TRANSITION TEMPERATURES of METHANE (Cont.)

Other References:

Critical Point

Cardoso, E., Arch. sci. phys. nat. 36, 97-100 (1913)

Egloff, G., *Physical Constants of Hydrocarbons*, Reinhold Publishing Corp. N.Y. (1953) 7-10, 16-19

Guggenheim, E. A., J. Chem. Phys. 13, No. 7, 253-26 (July 1945)

Natural Gasoline Supply Men's Association, *Engineering Data Book*, Tulsa (1957), 7th Ed. 135, 138

Normal Boiling Point

Frank, A. and Clusius, K., Z. physik. Chem. 42B, 395 (1939)

Hooper, J. H. D., Analyst 72, 513 (1947)

Lamb, A. B. and Roper, E. E., J. Am. Chem. Soc. 62, 106 (1940)

Rossini, F. D., Petrol. Engr. 14, No. 5, 41 (1943)

Young, S., Proc. Roy. Irish Acad. 38, 65 (1928)

Triple Point

Maliseoff, W. and Egloff, G., J. Phys. Chem. 22, 529-575 (1919)

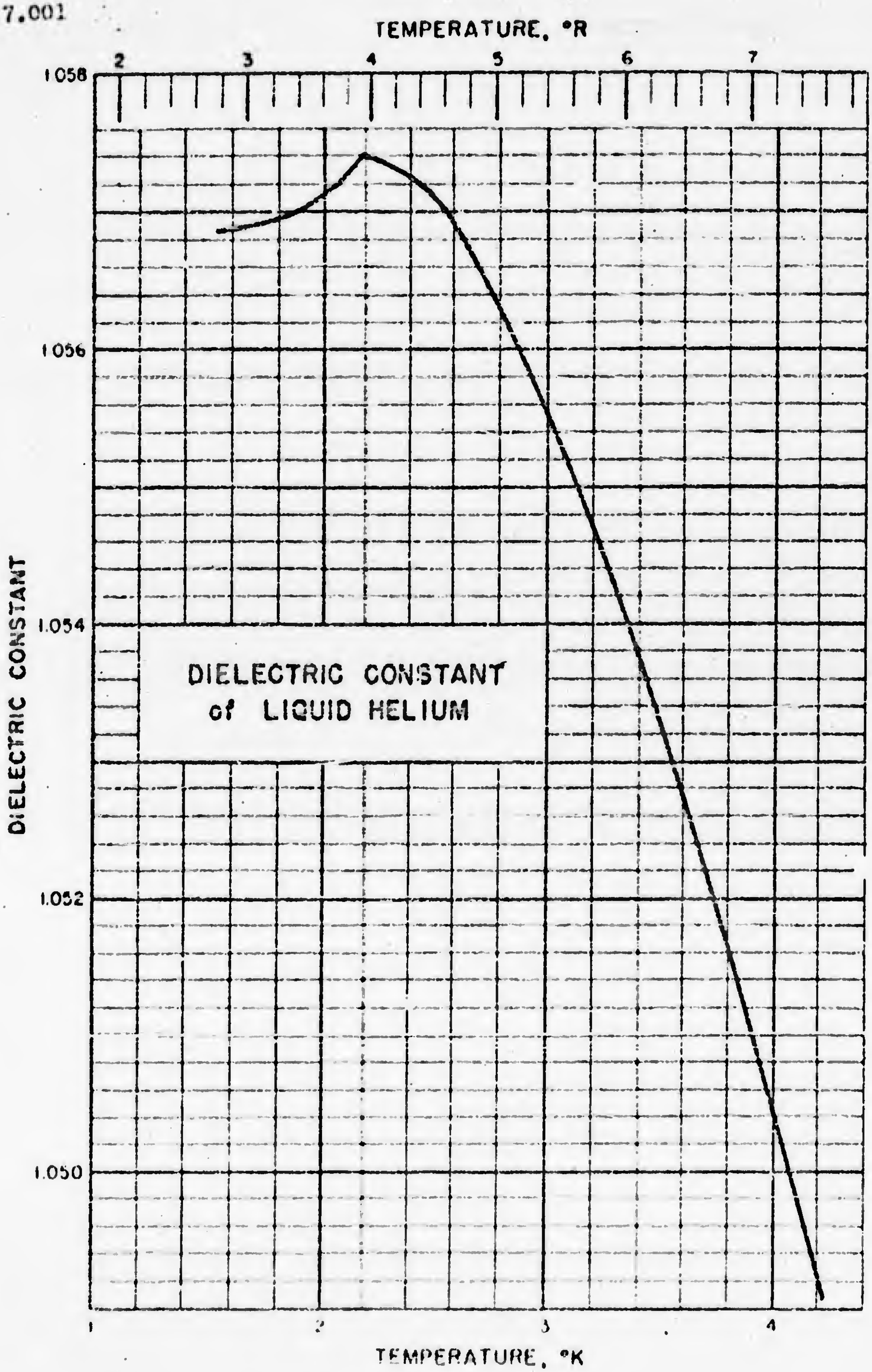
Solid Transition

Wheeler, J. A. and Cannon, C. V., Phys. Rev. 52, 684-685 (1937)

7.000

DIELECTRIC CONSTANT of CRYOGENIC FLUIDS

CONTENTS



DIELECTRIC CONSTANT of LIQUID HELIUM

DIELECTRIC CONSTANT of LIQUID HELIUM

Source of Data:

Grebenkemper, D. J. and Hagen, J. P., Phys. Rev. 80, 89 (Oct. 1950)

Other References:

Keesom, W. H., Helium, Elsevier, Amsterdam (1942) 494 pp.

Comments:

The absolute temperature scale (0°C = 273.16°K) was used in the table of selected values below.

Temperature		Dielectric Constant	Molar Polarization α in cm^3/mole
°K	°R		
4.21	7.56	1.0492	0.1236
3.04	5.47	1.0554	0.1233
2.64	4.75	1.0568	0.1231
2.25	4.06	1.0574	0.1231
2.19	3.94	1.0574	0.1231
1.97	3.54	1.0571	0.1228
1.62	2.92	1.0569	0.1228

Molar polarization is calculated from the Clausius-Masotti equation:

$$\alpha = \frac{3}{4\pi} \times \frac{M}{\delta} \times \left(\frac{\epsilon - 1}{\epsilon + 2}\right)$$

where:

α = molar polarizability
M = molecular weight
δ = density
ϵ = dielectric constant

The usefulness of this equation lies in the fact that it is valid over a large range of temperatures (and pressures) and is indeed valid for helium from above 300°K (gas) down to 1.62°K (liquid He II).

The dielectric constant at given conditions can be calculated provided that the density at those conditions is known.

DBM/GAR Issued: 7/2/59
HMR Revised: 5/2/60

7.001

DIELECTRIC CONSTANT of GASEOUS HELIUM

Sources of Data:

Maryott, A. A. and Buckely, F., Natl. Bur. Standards Cir. 537, 29 (June 1953)

Watson, H. E., Gundu, R. G. and Ramaswamy, K. L., Proc. Roy. Soc. (London) A132, 569 (1931)

Keesom, W. H., Helium, Elsevier, Amsterdam (1942) 494 pp.

Comments:

Maryott and Buckely report their value accurate to ±0.0000004 at 760 mm Hg pressure.

Temp. °K	Dielectric Constant	Molar Polarization α in cm^3/mole	Source
293	1.000 065	0.1235	NBS Circular 537
273	1.000 0728	0.1235	Watson et. al
82	1.000 231	0.1235	Watson et. al

Molar polarization is calculated from the Clausius-Mosotti equation:

$$\alpha = \frac{3}{4\pi} \times \frac{M}{\delta} \times \frac{(\epsilon - 1)}{(\epsilon + 2)}$$

where:
α = molar polarizability
M = molecular weight
δ = density
ϵ = dielectric constant

The usefulness of this equation lies in the fact that it is valid over a large range of temperatures (and pressures) and is indeed valid for helium from above 300°K (gas) down to 1.62°K (liquid He II).

The dielectric constant at given conditions can be calculated provided that the density at those conditions is known.

HMB/GAR Issued: 7/13/59
HMR Revised: 5/2/60

DIELECTRIC CONSTANT of LIQUID and SOLID NORMAL HYDROGEN

Sources of Data: Breit, O. and H. Kamerlingh Onnes, Proc. Acad. Sci. Amsterdam 27, 617 (1924), Comm. Phys. Lab. Univ. Leiden 171a (1924); Wolfke, M. and H. Kamerlingh Onnes, Proc. Acad. Sci. Amsterdam, 27, 627 (1924), Comm. Phys. Lab. Univ. Leiden, 171c (1924); Werner, W. and Keesom, W. H., Proc. Acad. Sci. Amsterdam, 29, 34 (1926), Comm. Phys. Lab. Univ. Leiden 178a, (1925); Guillien, Robert, J. phys. radium, 8 1, 29 (1940).

Comments: The following table is taken from the paper by Breit and Onnes:

Date	Pressure cm Hg	Temp. °K	Dielectric Constant
5/24/22	76.3	20.37	1.211
5/26/22	76.7	20.38	1.220
5/26/22	76.7	20.38	1.214
5/26/22	17.7	16.30	1.229
6/24/22	76.1	20.36	1.220
6/24/22	7.1	14.42	1.236

Data of 6/24/22 is regarded as preferable.

Wolfke and Onnes in a later paper report the following:

State	Pressure cm Hg	Temp. °K	Dielectric Constant
Liquid	75.5	20.33	1.225
"	35.7	18.05	1.234
"	8.0	14.64	1.241
Solid	5.8	14.0	1.248
"	4.2	13.5	1.224
"	3.5	13.3	1.212
"	3.2	13.2	1.211

(Continued)

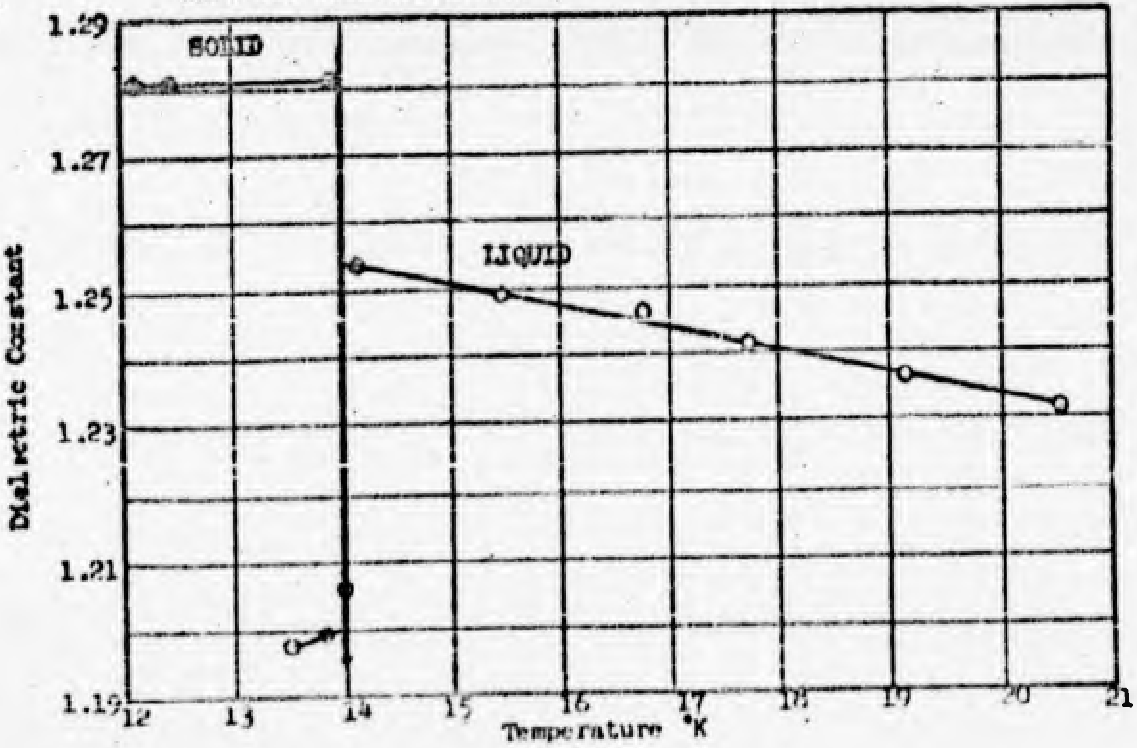
DIELECTRIC CONSTANT LIQUID and SOLID NORMAL HYDROGEN
(Continued)

The following table is that of Werner and Keesom:

State	Temp. °K	Dielectric Constant	State	Temp. °K	Dielectric Constant
Liquid	20.49	1.2305	Liquid	14.56	1.2497
"	20.40	1.2315	"	14.33	1.2591
"	20.40	1.2307	"	14.29	1.2505
"	19.11	1.2356	"	14.12	1.2523
"	17.73	1.2408	"	14.10	1.2533
"	16.73	1.2455			
"	15.47	1.2484	Solid	14.00	1.2059
"	14.71	1.2492	"	13.8	1.1987
"	14.69	1.2512	"	13.5	1.1972

Guillien agrees with Werner and Keesom at temperatures above the freezing point, but disagrees radically below the freezing point, as shown by the following figures: for 13.90°K the dielectric constant is 1.2808; for 12.46°K it is 1.2809; and for 12.10°K it is 1.2806; whereas Werner and Keesom found that the dielectric constant decreased by 4.5% at solidification, Guillien finds an increase of 2.6%.

The following graph shows the wide discrepancy between the last two sets of values.



DIELECTRIC CONSTANT of NORMAL HYDROGEN GAS

References: Boltzmann, L. Pogg., Ann. d. Physik u. Chemie 155, 403 (1875); Klemenčič, J., Sitzber. Akad. Wiss. Wien. 91 II, 712 (1885); Tangl, K., Ann. d. Physik 26, 59 (1908); Occhialini, A., Nuovo Cimento, 7, 108 (1914); Riegger, H., Ann. d. Physik, 59, 753 (1919); Fritts, E. C., Phys. Rev. [2] 23, 345 (1924); Zahn, C. T., Phys. Rev. [2] 24, 400 (1924); Braunmühl, H. J. v. Physik. Z. 28, 141 (1927); Watson, H. E., Rao, G. G., and Ramaswamy, K. L., Proc. Roy. Soc. London, A132, 569 (1931); Van Itterbeek, A. and Spaepen, J., Physica, 10, 173 (1943); Hector, L. G. and Woernley, D. L., Phys. Rev., [2] 69, 101 (1946); Van Itterbeek, A. and Clippeleir, K. de, Physica 14, 349 (1948); Zieman, C. M., J. Appl. Phys. 23, 154 (1952); Phys. Rev. [2] 83, 243 (1951).

Comments: The earliest recorded data on the dielectric constant of hydrogen appears to be that of Boltzmann, who in 1875 found the value of 1.000264 at 0°C and 76 cm Hg. Klemenčič in 1885 confirmed Boltzmann's value. Tangl in 1908 under similar standard conditions found 1.000273 and Occhialini in 1914 at 76 cm (temperature presumably 0°C, but not stated) reported 1.0002705. In 1923 Fritts gave the value at 0° 76 cm as 1.000263 and the work of Zahn under the same conditions yielded a value of 1.000265 in 1924. In 1927 Braunmühl reported 1.000275 at 288.8°K. Watson and co-workers in 1931 obtained a value of 1.0002518 at 25°C and 76 cm and the equivalent value of 1.0002749 at 0°C and 76 cm, both measured at 25°C. Van Itterbeek and Spaepen in 1943 reported 1.000258 at 291°K and 79.4 cm and 1.000252 at 293.3°K and 77.5 cm. Hector and Woernley in 1946 found 1.0002724 ± .0000010 at N.T.P. The meaning of N.T.P. is not stated, but the work was done at 25°C. It may therefore be assumed that the conditions employed were 25°C and 1 atmosphere. In conclusion, it turns out that Boltzmann, Klemenčič, Fritts and Zahn have results in the region of 1.000264 at 0°C and 76 cm, whereas Tangl, Occhialini, Hector, Woernley and Braunmühl under the same conditions find 1.000273. Watson and co-workers and Van Itterbeek and co-workers in the neighborhood of 25° give values of about 1.00025.

Tangl, Occhialini, Van Itterbeek and others worked also at pressures up to 200 atmospheres at temperatures above zero degrees centigrade. Riegger reported a value of 1.000928 at -191°C and 1 atm., and 1.000253 at 16.5°C and 1 atm. Van Itterbeek and Spaepen reported 1.000806 at 90°K and 77 cm. Gozzini, A. in Nuovo Cimento 8, 361 (1951) describes a new method using microwaves and reports a value of 1.000274 ± .000002 at 75.0 cm and room temperature. Zieman, using cavity comparator methods and a microwave refractometer for 9470 Mc and pressures from 2 to 740 mm found a value of 1.000356.

7.003

DIELECTRIC CONSTANT of NEON

Sources of Data: Hector, L. G. and Woernley, D. L., Phys. Rev. 69, 101-5 (1946).

Comments: Other values of the dielectric constant available are 1.000139 [Bryan, A. B., Phys. Rev. 34, 615-7 (1929)] 1.000148 (based on the dielectric constant of air to be 1.000589) [Bryan, A. B., Phys. Rev. 34, 615-7 (1929)], and 1.000134 [Watson, H. E. et. al., Proc. Roy. Soc. (London) A143, 558 (1934)].

The value of the dielectric constant given below is based on nine observations taken at 24.6°C and corrected to NTP (70°F, 1 atm). The range of values was from 1.0001267 to 1.0001280. The value given below is the average of these nine observations.

Dielectric constant at NTP = 1.0001274.

7.004

DIELECTRIC CONSTANT of NITROGEN

Sources of Data:

Birnbaum, G., Kryder, S. J. and Lyons, H., J. Appl. Phys. 22, 95-102 (1951)

Ebert, L. and Keesom, W. H., Verslag Akad. Wetenschappen Amsterdam 35, 875-9 (1926)

Essen, L. and Froome, K. D., Nature 167, 512-3 (1951)

Essen, L. and Froome, K. D., Proc. Phys. Soc. (London) 64B, 862-75 (1951)

Guillien, R., Compt. rend. 207, 393-5 (1938)

Hector, L. G. and Woernley, D. L., Phys. Rev. 69, 101-5 (1946)

Michels, A., Jaspers, A. and Sanders, P., Physica 1, 627-33 (1934)

Zahn, C. T., Phys. Rev. 27, 455-9 (1926)

Zieman, C. M., J. Appl. Phys. 23, 154 (1952)

Comments:

Additional values for the dielectric constant of nitrogen at 0°C and 1 atmosphere found in the literature but not considered as reliable as those selected are:

1.0005555 [Bädeker, Z. physik. Chem. 36, 305 (1901); and Fritts, E. C., Phys. Rev. 23, 345-56 (1924)]

1.000587 [Bodareu, E., Atti. Accad. Lincei 22, II, 400-2 (1914)]

1.000581 [Tangl, K., Ann. Physik 26, 59-78 (1908); and Zahn, C. T., Phys. Rev. 24, 400-17 (1924)].

All the data tabulated below are at 1 atmosphere unless otherwise noted.

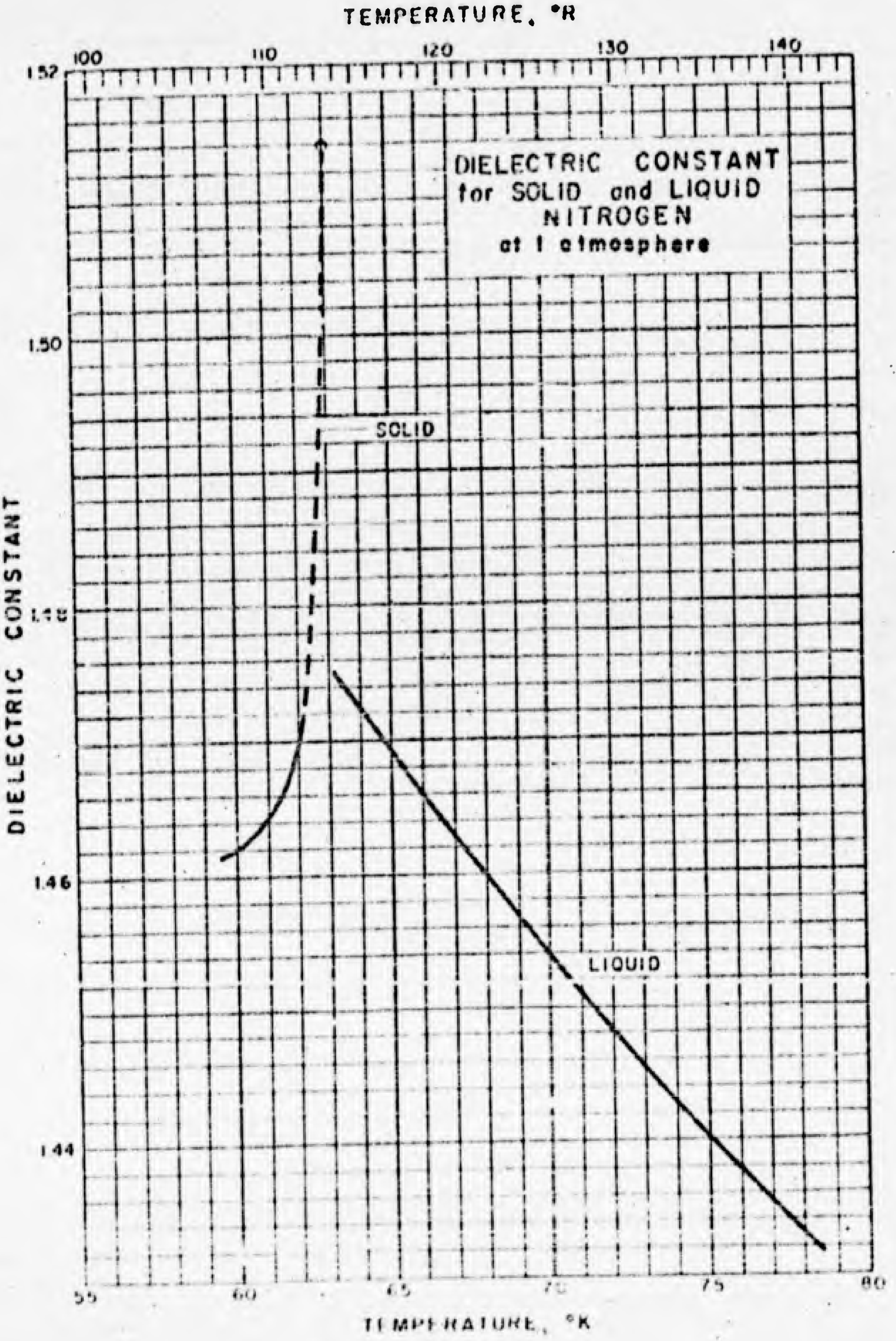
State	Temp. °K	Dielectric Constant	State	Temp. °K	Dielectric Constant
Solid	59.9	1.4620	Liquid	75	1.440 0
Solid	61.9	1.4690	Liquid	76.54	1.442 0
Solid	63.0	1.5140	Liquid	78	1.431 8ᵃ
Liquid	63.3	1.4745	Gas	84.1	1.001 898
Liquid	63.9	1.4720	Gas	197.8	1.000 792
Liquid	66	1.4657	Gas	273.16	1.000 5796
Liquid	66.7	1.4640	Gas	273.16	1.000 5869
Liquid	69	1.4568	Gas	273.16	1.000 5870
Liquid	72	1.4483	Gas	273.16	1.000 5883
Liquid	74.8	1.4380	Gas	298.44	1.000 52ᵇ

Normal Melting Temp. 63.1°K
Normal Boiling Temp. 77.350°K

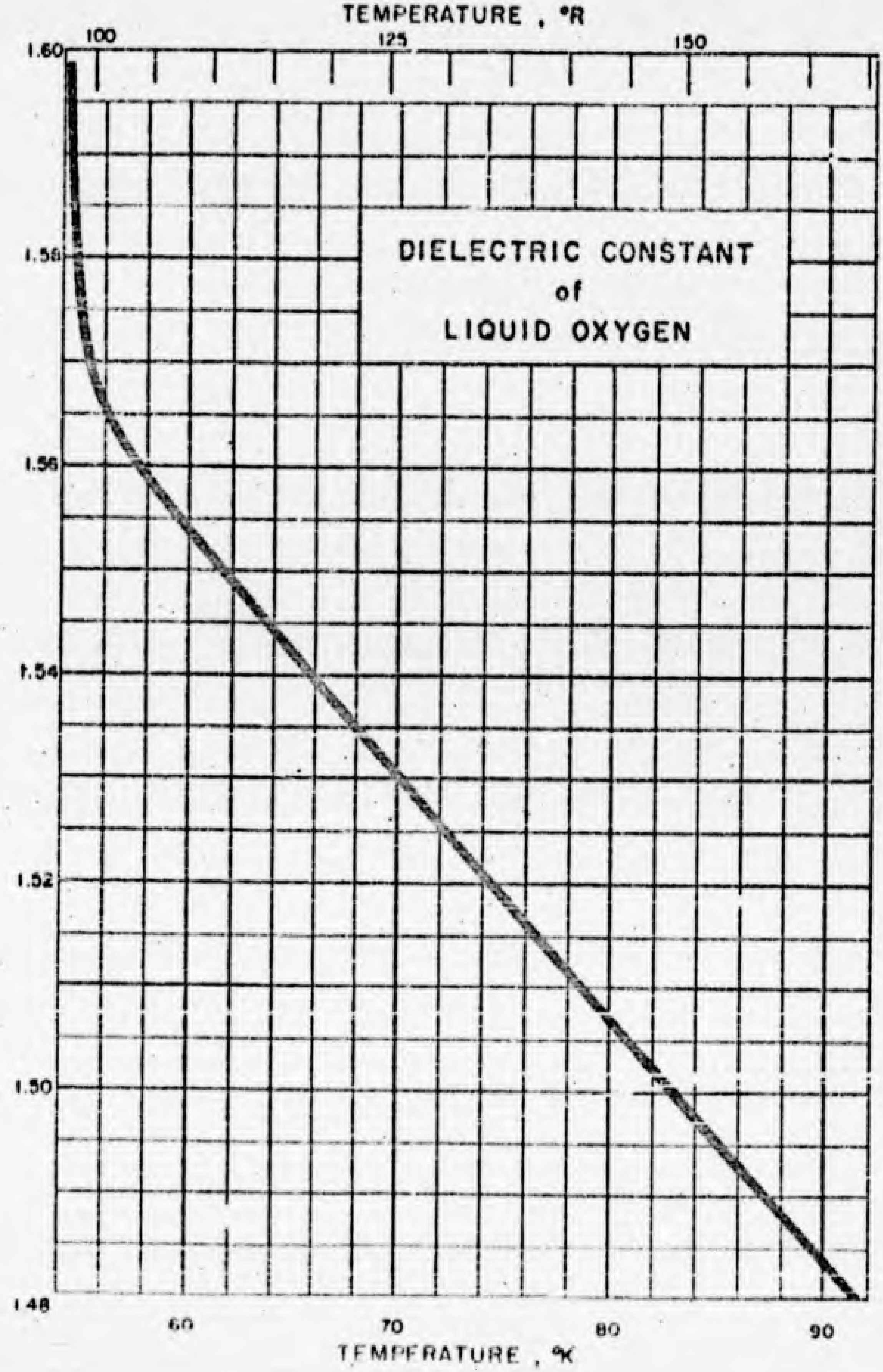
a - 1.07 atm
b - 1.02 atm

(A Plot of the Solid and Liquid Values is shown on the other side of this Data Sheet.)

KDT/RDF/VJJ Issued: 7/13/59


TEMPERATURE, °R
100
110
120
130
140
DIELECTRIC CONSTANT for SOLID and LIQUID NITROGEN at 1 atmosphere
1.52
1.50
1.48
1.46
1.44
DIELECTRIC CONSTANT
SOLID
LIQUID
55
60
65
70
75
80
TEMPERATURE, °K

7.005


TEMPERATURE , °R
100
125
150
DIELECTRIC CONSTANT
of
LIQUID OXYGEN
1.60
1.58
1.56
1.54
1.52
1.50
1.48
60
70
80
90
TEMPERATURE , °K

DIELECTRIC CONSTANT of LIQUID OXYGEN

Source of Data:

Werner, W. and Keesom, W. H., Communs. Phys. Lab. Univ. Leiden 178c, (1926)

Comments:

From the boiling point down to 58°K, ε, the dielectric constant varies rectilinearly. At 55°K, ε begins to increase and the increase is very obvious at 54.4°K. The Clausius-Mosotti function P is nearly constant and equal to

$$P = \frac{\epsilon - 1}{\epsilon + 2} \frac{1}{\rho} = 0.1211 \pm .05\% \text{ max.}$$

which points out that liquid oxygen is free from electric doublets. Wolfke, from the measurements, calculated the constants of Debye's formula

$$PT = a + bT$$

by the method of least squares and found

$$a = -0.01136 \qquad b = 0.1212$$

a is a small negative value assumed due to accidental errors and was considered zero; and, since a varies with μ^2, the molecular electric doublet moment, then $\mu = 0$.

Temp. °K	ϵ	ρ	$P = \frac{\epsilon-1}{\epsilon+2}\frac{1}{\rho}$	PT
54.33*	1.594	1.3105	0.1262	6.853
54.4	1.590	1.3102	.1255	6.826
55.0	1.570	1.3078	.1222	6.721
55.4	1.571	1.3060	.1225	6.785
58.1	1.559	1.2945	.1212	7.044
60.8	1.554	1.2829	.1216	7.393
61.50	1.549	1.2797	.1209	7.437
68.47	1.5346	1.2487	.1211	8.295
73.90	1.5216	1.2244	.1210	8.940
77.45	1.5145	1.2080	.1212	9.386
80.28	1.5045	1.1948	.1205	9.673
85.89	1.4932	1.1678	.1209	10.384
90.14**	1.4837	1.1466	.1211	10.916

* Triple Point ** Normal Boiling Temperature

7.005

DIELECTRIC CONSTANT of GASEOUS OXYGEN

Sources of Data:

Van Itterbeek, A. and Spaepen, J , Physica 10, No. 3, 173-84 (1943)

Jelatis, J. G., J. Appl. Phys. 19, 419-25 (1948)

Comments:

Other values of the dielectric constant at STP (1 atm, 0°C) available are:

1.0005300 (Watson, H. E., Rao, G. G. and Ramaswamy, K. L., Proc. Roy. Soc. A143, 558 (1934))

1.0005233 (Hector, L. G. and Woernley, D. L., Phys. Rev. 69, 101-5 (1946))

Table of Selected Values

Temp. °K	Pressure mm Hg	Dielectric Constant ϵ
89.75	765	1.001 67
	761	1.001 69
	757	1.001 64
	474	1.001 00
89.85	470	1.001 05
	243	1.000 56
	240	1.000 52
	238	1.000 43
90.00	743	1.001 63
	661	1.001 53
	553	1.001 37
90.07	732	1.001 61
	623	1.001 16
	550	1.001 25
90.10	750	1.001 68
	742	1.001 47
	520	1.001 22
	409	1.000 87
292.6	765	1.000 50

JH/PDP Issued: 8/3/59

7.007

DIELECTRIC CONSTANT of CARBON MONOXIDE

Sources of Data:

Van Itterbeek, A. and Spaepen, J., Physica 10, 173-84 (1943)

Wisniewski, F. J. von, Z. Physik 37, 126-36 (1926)

Zahn, C. T. and Miles, J. B., Jr., Phys. Rev. 32, 497-504 (1928)

Data from van Itterbeek and Spaepen

Press. mm Hg	Temp. °K	Dielectric Constant
249	77.30	1.000 781
424	77.30	1.001 489
427	77.30	1.001 500
443	77.30	1.000 859
245	77.40	1.000 870
250	77.40	1.000 900
432	77.40	1.001 538
434	77.40	1.001 540
760	89.85	1.002 298
607	89.90	1.001 847
430	90.00	1.001 325
510	90.00	1.001 554
627	90.00	1.001 940
206	90.12	1.000 612
207	90.12	1.000 601
207	90.12	1.000 634
760	90.18	1.002 310
774	90.18	1.002 321
214	90.25	1.000 660
381	90.25	1.001 169
770	90.25	1.002 305

Press. mm Hg	Temp. °K	Dielectric Constant
398	194.6	1.000 499
401	194.6	1.000 499
759	194.6	1.000 966
765	194.6	1.000 977
748	294.1	1.000 618
745	294.5	1.000 618
582	294.9	1.000 470
742	295.4	1.000 608

Data from von Wisniewski

Press. mm Hg	Temp. °C	Dielectric Constant
400	-189	1.001 384
600	-189	1.002 086
760	-189	1.002 633
60	17	1.000 645

Data from Zahn

Press. mm Hg	Temp. °K	Dielectric Constant
506.9	89.8	1.000 1557
507.7	293.8	1.000 636
506.6	295.7	1.000 434

KDT/EDT Issued: 6/18/59

7.008

DIELECTRIC CONSTANT of GASEOUS FLUORINE

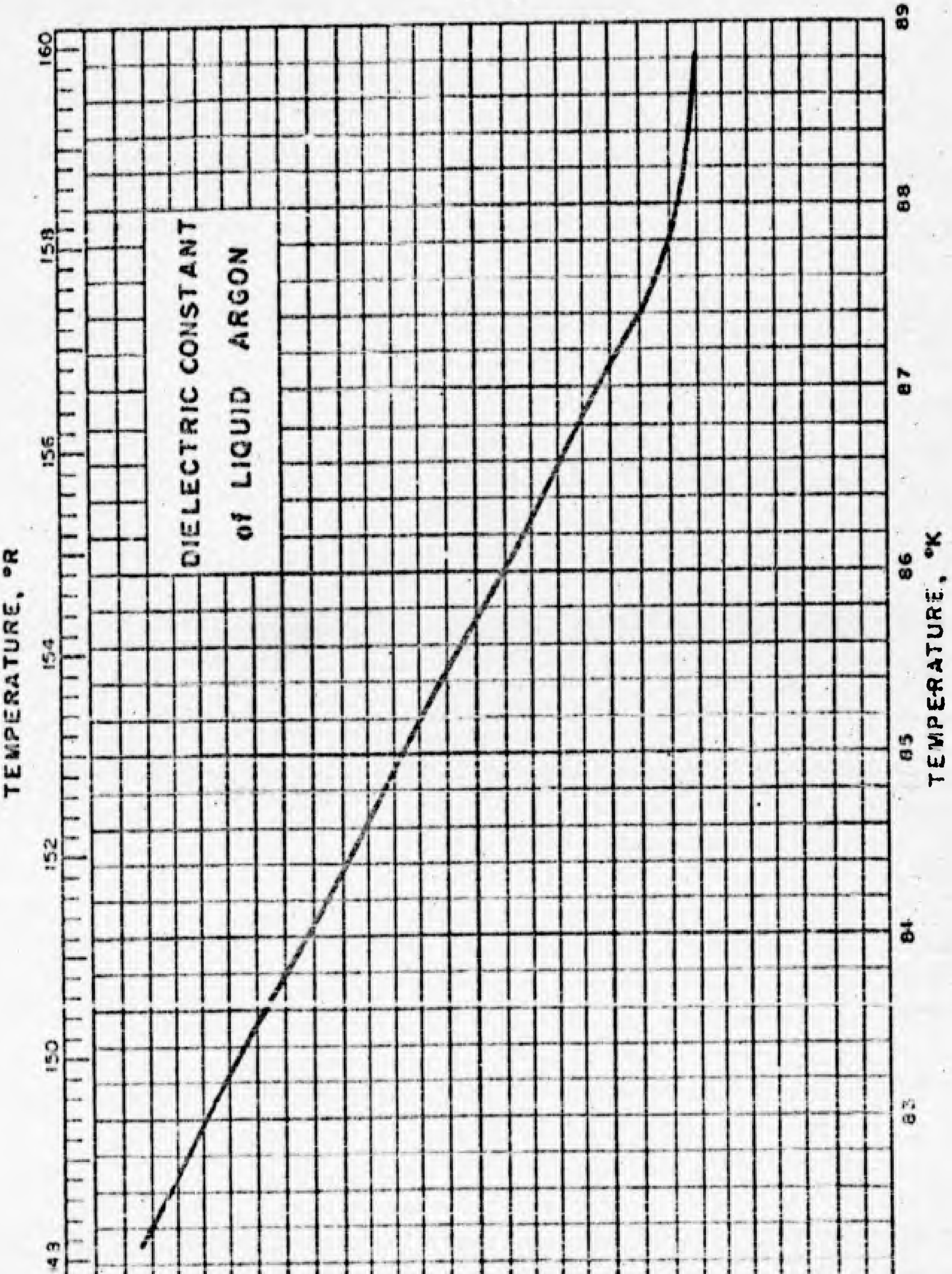
Source of Data:

Franck, E. U., Die Naturwissenschaften 41, 37 (1954).

Comments:

Franck gives a value of 1.43 for the dielectric constant at 85°K.

WFR Issued: 8/5/59


DIELECTRIC CONSTANT
of LIQUID ARGON
TEMPERATURE, °R
160
158
156
154
152
150
43
TEMPERATURE, °K
89
88
87
86
85
84
83
82
DIELECTRIC CONSTANT
1.54
1.53
1.52
1.51

7.009

DIELECTRIC CONSTANT of LIQUID ARGON

Sources of Data:

Kronig, R. and Vooren, A. I. van de, Physica 9, 139-44 (1942)

McLennan, J. C., Jacobsen, R. C. and Wilhelm, J. O., Trans. Roy. Soc. Can. 24, sect. 3, 37-46 (1930)

Comments:

By theory the Clausius-Mosotti Function

$$\frac{\epsilon - 1}{\epsilon + 2}\left(\frac{1}{\rho}\right)$$

should be a constant and independent of temperature provided the molecules of the liquid studied had no permanent dipole moment. For liquid argon this quantity was constant within the accuracy of the data. ϵ is the dielectric constant and ρ is the density. Table of Values is from McLennan, Jacobsen and Wilhelm.

Table of Selected Values

Temp. °K	Density gm/cm^3	Dielectric Constant (ref. to vacuum)
88.8	1.393	1.516
88.5	1.395	1.518
87.1	1.404	1.520
85.8	1.414	1.525
84.3	1.422	1.530
*82.4	1.434	1.537

* super-cooled liquid

PLB/RJR Issued: 5/25/59

DIELECTRIC CONSTANT of GASEOUS ARGON

Sources of Data:

Jelatis, J. G., J. Appl. Phys. 19, 419-25 (1948)

Hector, L. G. and Woernly, D. L., Phys. Rev. 69, 101-5 (1946)

Watson, H. E., Rao, G. G. and Ramaswamy, K. L., Proc. Roy. Soc. (London) A132, 569-85 (1931)

Zieman, C. M., J. Appl. Phys. 24, 110 (1953)

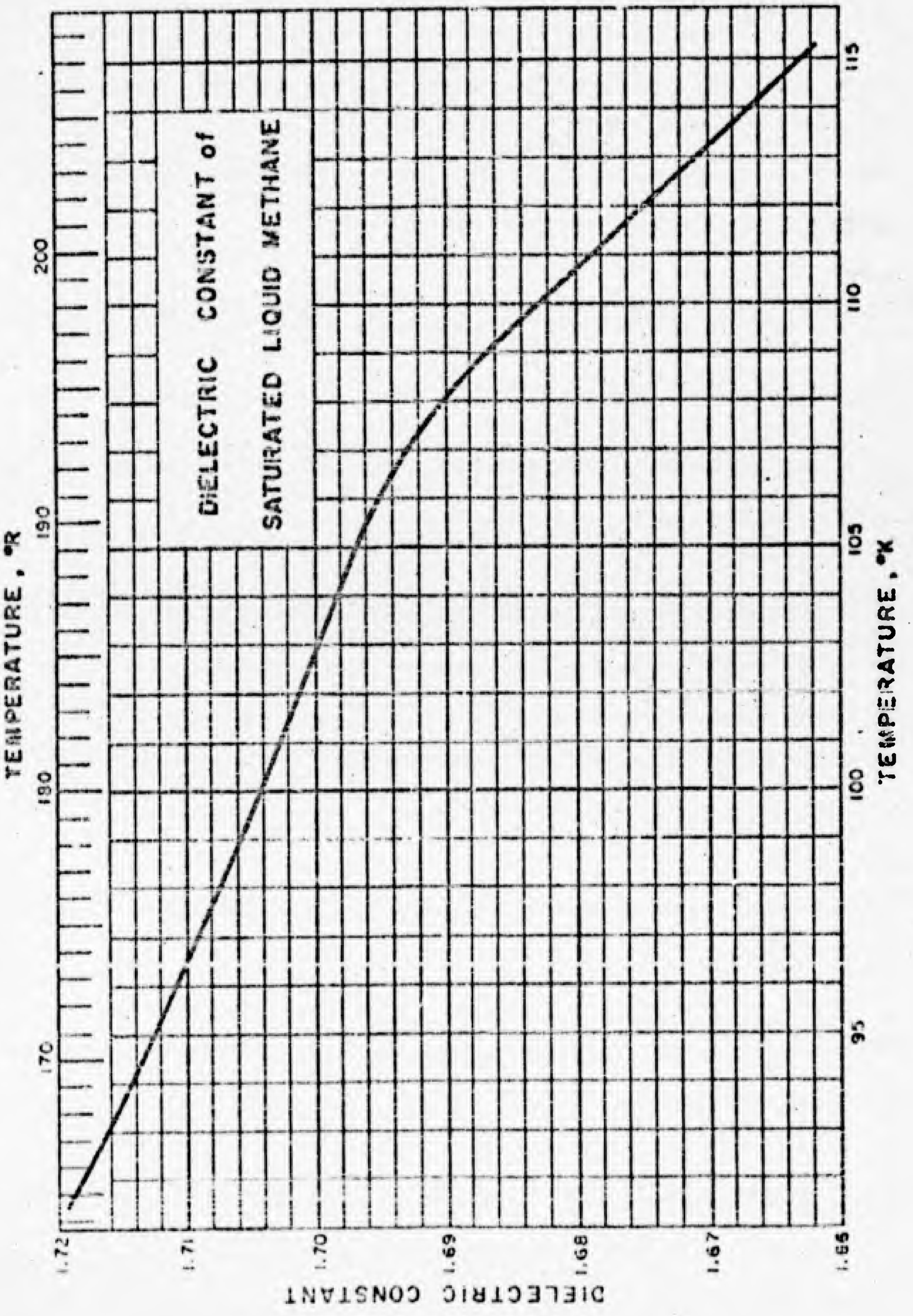
Comments:

Values for the dielectric constant are reduced to standard conditions of temperature and pressure. The value given by Jelatis is considered the best.

Table of Selected Values

Dielectric Constant	Source
1.000 554	Jelatis
1.000 545	Hector
1.000 550	Watson
1.000 5549	Zieman

PIJ/RJR Issued: 5/25/59


DIELECTRIC CONSTANT of
SATURATED LIQUID METHANE
TEMPERATURE, °R
170
180
190
200
TEMPERATURE, °K
95
100
105
110
115
DIELECTRIC CONSTANT
1.72
1.71
1.70
1.69
1.68
1.67
1.66

DIELECTRIC CONSTANT of LIQUID METHANE
(Saturated)

Source of Data:

McLennan, J. C., Jacobsen, R. C. and Wilhelm, J. O., Trans. Roy. Soc. Can. (3) 24, Sect. III, 37-46 (1930)

Other References:

Stock, A., Henning, F. and Kuss, E., Ber. Chem. Ges. 54, 1119-29 (1921)

Table of Selected Values

Temperature °K	Dielectric Constant
91.7	1.719
95.3	1.712
100.7	1.703
104.2	1.693
106.7	1.694
108.9	1.687
114.2	1.666

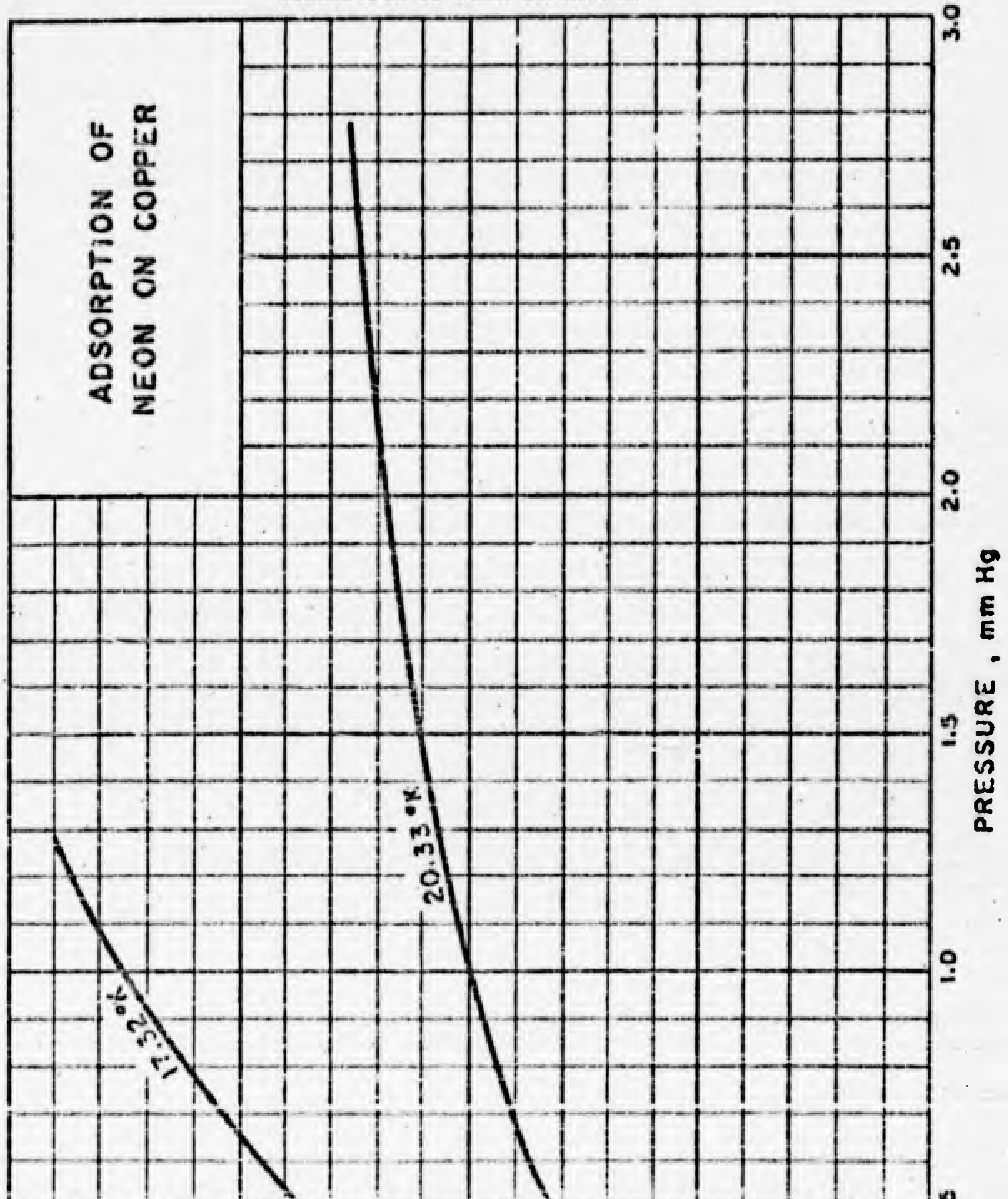
[illegible] Issued: 8/3/59

ADSORPTION of CRYOGENIC FLUIDS

CONTENTS

8.003

ADSORPTION of NEON on COPPER



8.003

ADSORPTION of NEON on COPPER

Sources of Data: Borghs, J. and van Itterbeek, A., Physica 7, 17-28 (1940).

Table of Selected Values

Temperature °K	Pressure mm Hg	cubic centimeters adsorbed per square meter of microscopic surface area
17.32	0.196	3.53
"	0.761	4.08
"	1.238	4.38
20.33	0.063	2.72
"	0.367	3.22
"	0.979	3.49
"	1.825	3.66
"	2.679	3.75

[illegible] Issued: [illegible]

ADSORPTION of NEON on OTHER MEDIA

A. Van Antropoff, A., et. al., Kolloid Z. 129, 1-10 (1952) reports that the adsorption of neon on coal shows fair agreement with Langmuir's theory.

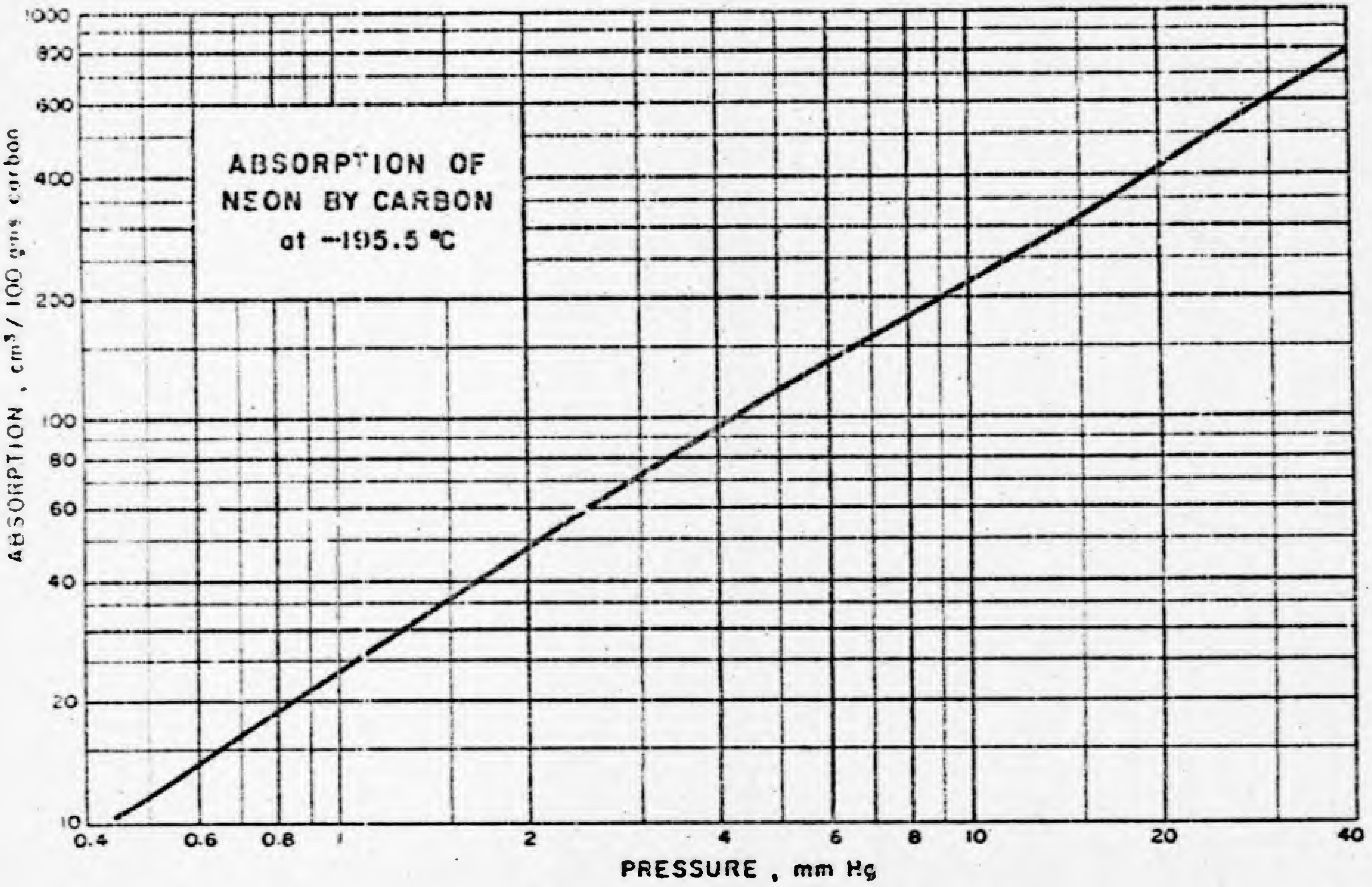
B. Armbruster, M. H., J. Am. Chem. Soc. 70, 1734-42 (1948) and Armbruster, M. H. and Austin, J. B., J. Am. Chem. Soc. 66, 159-71 (1944) report that neon is not measurably adsorbed at temperatures of -183°C, -78°C, and 20°C on plane surfaces of two stainless iron-chromium-nickel alloys studied.

C. van Itterbeck, A. and Borghs, J., Z. physik. Chem. B50, 128-42 (1942); Chem. Zentr. 1942 I, 1113 (1942) report the adsorption of neon on nickel at 20.34°K, 84.1°K, and 90.1°K.

D. Klarmann, M. E., Z. Physik 65, 358-84 (1930) reports that activated palladium readily absorbs neon gas.

E. Melkonian, G. A. and Reps, B., Z. Elektrochem. 58, 616-19 (1954) report that adsorption of neon on silica gel at 20.4°K results in a separation factor of 1.00 between the neon isotopes.

F. Seeliger, R., Physik. Z. 22, 563-8 (1921) reports that the adsorption of neon on chabazite is very small.



ABSORPTION OF NEON BY CARBON at −195.5 °C

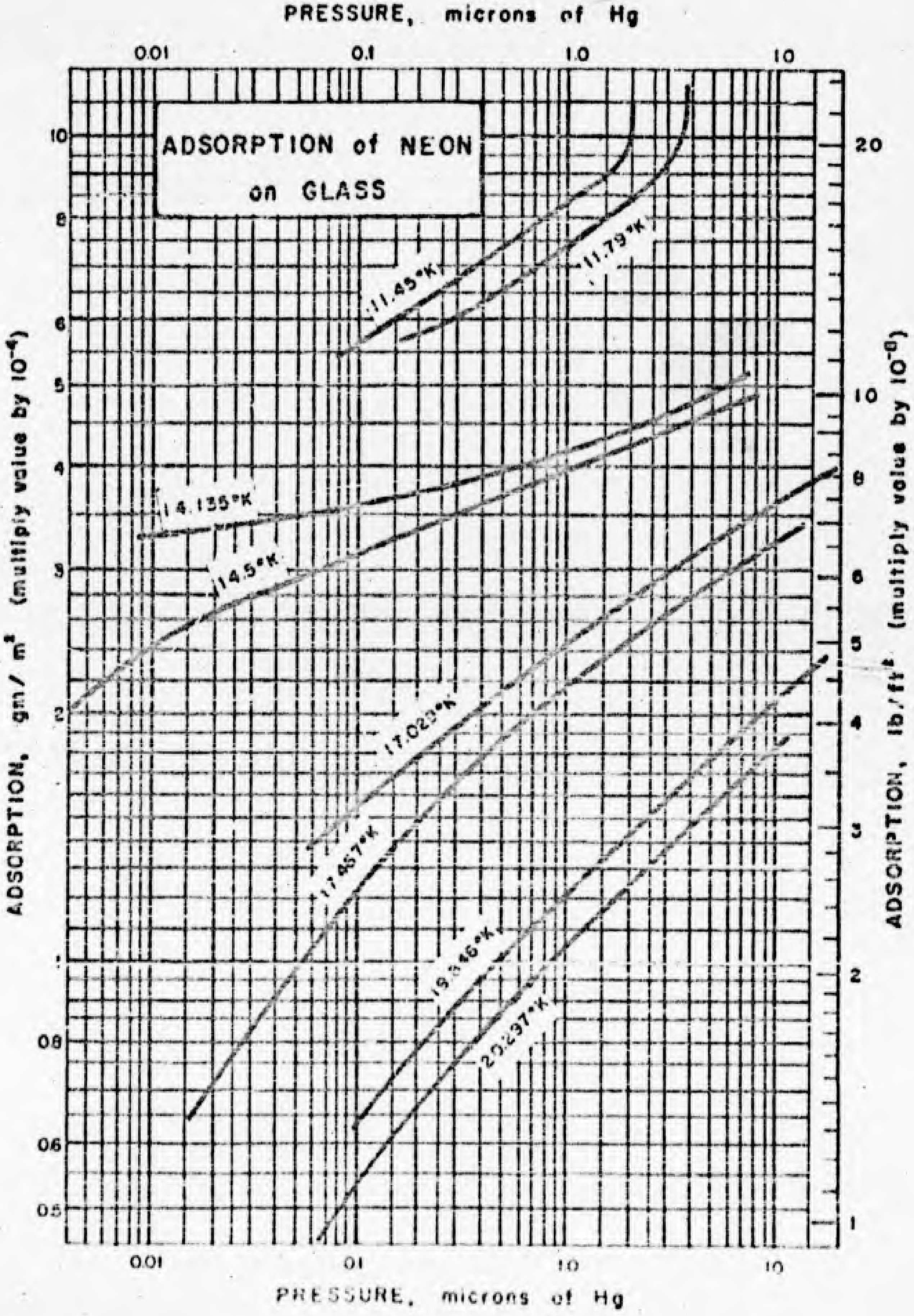
ABSORPTION of NEON by CARBON
(at -195.5°C)

Sources of Data: Claude, G., Compt. rend. **158**, 861-4 (1914).

Comments: The data given below are for a temperature of -195.5°C.

Table of Selected Values

Pressure mm Hg	cu cm absorbed per 100 gm carbon
0.45	10.5
0.88	21
1.30	32
1.74	42
3.50	84
5.30	122
7.20	163
11.30	244
15.50	325
19.40	406
30.50	618
40.50	801


PRESSURE, microns of Hg
0.01
0.1
1.0
10
ADSORPTION of NEON on GLASS
11.45°K
11.79°K
14.135°K
14.5°K
17.029°K
17.457°K
19.346°K
20.237°K
ADSORPTION, gm/m² (multiply value by 10⁻⁴)
10
8
6
5
4
3
2
1
.08
.06
.05
ADSORPTION, lb/ft² (multiply value by 10⁻⁸)
20
10
8
6
5
4
3
2
1
0.01
0.1
1.0
10
PRESSURE, microns of Hg

8.003

ADSORPTION of NEON on GLASS

Sources of Data:

Keesom, W. H. and Schwurs, J., Physica 8, 1020-31 (1941)

Keesom, W. H. and Schmidt, G., Proc. Acad. Sci. Amsterdam 36, 852-32

Comments:

The adsorption of neon on glass at liquid hydrogen temperature has been found to follow Langmiur's theory fairly well.

T = 11.45°K

Press. μ Hg	Adsorp. gm-mole/km^2
0.0931	27.37
0.176	30.72
0.324	33.95
0.544	37.07
0.830	40.08
1.20	42.96
1.61	45.80
1.91	48.79
1.93	52.20

T = 11.79°K

Press. μ Hg	Adsorp. gm-mole/km^2
0.195	28.37
0.441	31.59
0.757	34.71
1.17	37.67
1.67	40.46
2.34	43.07
2.96	45.83
3.55	48.55
3.66	51.98
3.70	55.52

T = 14.135°K

Press. μ Hg	Adsorp. gm-mole/km^2
0.01077	16.66
0.3660	18.75
0.9240	20.48
1.8490	21.76
2.982	22.81
4.236	23.69
5.540	24.53

T = 14.500°K

Press. μ Hg	Adsorp. gm-mole/km^2
0	3.41
0	6.82
0.00450	10.21
0.0450	14.25
0.324	17.53
1.23	20.05
2.86	21.72
4.88	22.93

T = 17.029°K

Press. μ Hg	Adsorp. gm-mole/km^2
0	3.59
0.0699	7.10
0.4368	10.38
1.472	12.98
3.187	14.77
5.460	16.10
8.037	17.13
10.88	17.91
14.170	18.24
17.270	18.75

T = 17.467°K

Press. μ Hg	Adsorp. gm-mole/km^2
0.0188	3.43
0.146	6.75
0.631	9.72
1.800	[illegible]
3.68	13.66
6.00	14.84
8.60	15.79
11.5	16.41

T = 19.846°K

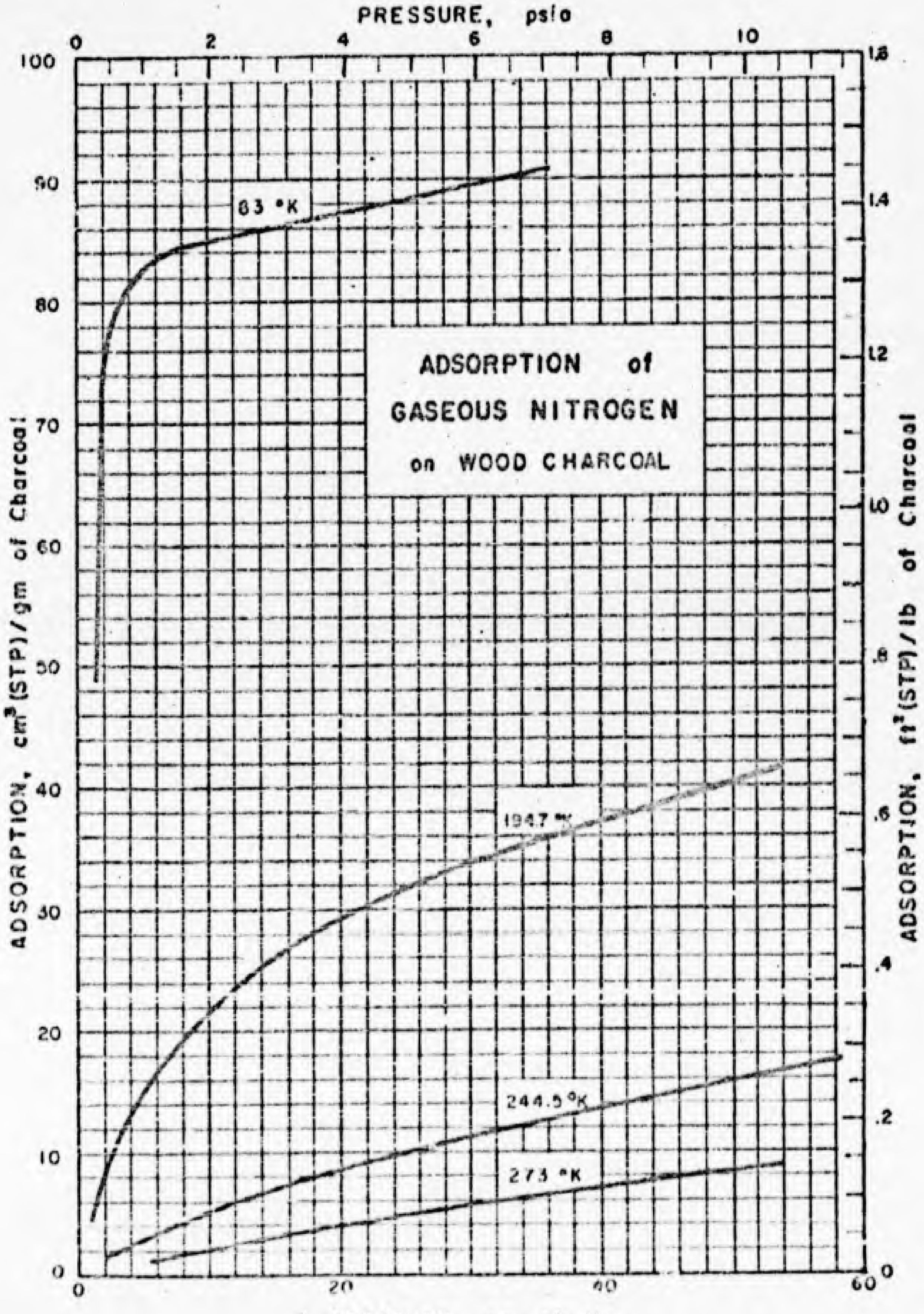
Press. μ Hg	Adsorp. gm-mole/km^2
0.1143	3.25
0.9429	[illegible]
2.741	7.66
5.260	[illegible]
8.05	9.84
11.2	10.53
14.5	11.00

T = 20.297°K

Press. μ Hg	Adsorp. gm-mole/km^2
0.0699	2.34
0.533	4.35
1.63	5.83
[illegible]	6.90
5.125	7.70
7.195	8.83
9.473	8.87

KWT/EDT/JFC/VJJ Issued: 7/14/59

3.008



ADSORPTION of
GASEOUS NITROGEN
on WOOD CHARCOAL

ADSORPTION of GASEOUS NITROGEN on WOOD CHARCOAL

Source of Data:

Homfray, I. F., Z. physik. Chem. 74, 129-201 (1910)

Comments:

X = cm^3 of gaseous nitrogen adsorbed per 2.964 grams of charcoal at the pressure and temperature indicated but measured at standard conditions (0°C, 1 atm.).

Table of Selected Values

T = 83°K

Pressure cm Hg	X $\frac{cm^3}{2.964gm}$
1.3	155.4
2.2	183.2
3.3	239.3
34.3	267.8

T = 194.7°K

Pressure cm Hg	X $\frac{cm^3}{2.964gm}$
1.4	15.0
4.6	42.3*
13.5	70.0
25.3	96.5
51.8	121.0

* average of 41.9 and 42.7 values given

T = 273°K

Pressure cm Hg	X $\frac{cm^3}{2.964gm}$
7.2	4.53
17.3	10.7
22.9	13.0
31.2	17.6
51.0	25.4

T = 244.5°K

Pressure cm Hg	X $\frac{cm^3}{2.964gm}$
2.5	5.04
7.5	11.8
13.6	19.5
23.6	28.2
37.3	38.5
57.3	51.2

KDT/BDT/VJJ Issued: 7/14/59

3.004

ADSORPTION of GASEOUS NITROGEN on COCONUT CHARCOAL

Sources of Data:

Dewar, J., Proc. Roy. Soc. (London) A74, 122-27 (1904)

Titoff, A., Z. phys. Chem. 74, 641-78 (1910)

Comments:

X = cm3 of gaseous nitrogen adsorbed per gram of charcoal at the pressure and temperature indicated but measured at standard conditions (0°C and 1 atm). Q is the heat evolved by this adsorption. One calorie = 4.1840 joules.

Table of Selected Values

Temp. °C	Pressure Range mm Hg	X $\frac{cm^3}{gm}$	Q joules
-185	0 - 760	155	106.7
0	0 - 10.7	0.258	0.35_6
0	10.7 - 91.6	2.210	2.12_2
0	91.6 - 178.9	4.169	3.75_4
0	178.9 - 342.2	7.237	6.46_3
0	342.2 - 524.4	10.052	8.93_4
0	524.4 - 748.9	13.049	11.58_7

RDT/BDT Issued: 5/25/59

ADSORPTION of CARBON MONOXIDE

Adsorption of Carbon Monoxide on Zinc Oxide

Garner, W. E. and Maggs, J., Trans. Faraday Soc., 32, 1744-8 (1936). This reference gives values for adsorbed CO on both oxidized and reduced ZnO for temperatures from 90° to 318°K.

Adsorption of Carbon Monoxide on Glass Plates

Itterbeek, van A., and Vereychen, W., Z. physik. Chem. B48, 131-47 (1941). This reference gives adsorption isotherms for CO on glass plates at low pressures for temperatures of 67.3°K, 72.92°K, 79.90°K, and 90.20°K.

Adsorption of Carbon Monoxide on Nickel Films

Beeck, O., Smith, A. E., and Wheeler, A., Proc. Roy. Soc. (London), A177, 62-90 (1940). This reference gives two isotherms for the adsorption of CO on Ni films as a function of pressure. The two temperatures are 23°C and -182°C. No tabulation of experimental data is given.

Adsorption of Carbon Monoxide on Various Iron Catalysts

Podgurski, H. H. and Emmett, P. H., J. Phys. Chem., 57, 159-64 (1953). This reference gives adsorption characteristics of various Fe catalysts for CO from 10^{-2} to 700 mm Hg and between -195° and 200°C. Very little tabulation of experimental data is given.

Adsorption of Carbon Monoxide on a Synthetic Iron-Ammonia Catalyst

Brunauer, S. and Emmett, P. H., J. Am. Chem. Soc. 57, 1754-5 (1935). This reference gives an adsorption isotherm for CO on an iron catalyst at -183°C. No tabulation of data is given, but the plot is large enough to read values with a fair amount of precision.

Adsorption of Carbon Monoxide on Desorex-B

Dingenen, van W., Physica 6, 353-63 (1939). This reference gives adsorption data for CO on Desorex-B (a commercial adsorbent) at temperatures of 56.18° to 87.54°K.

ADSORPTION of CARBON MONOXIDE (Cont.)

Adsorption of Carbon Monoxide on Mica

Armbruster, M. A. and Austin, J. B., J. Am. Chem. Soc. 60, 467-75 (1938). This reference gives experimental data for the adsorption of CO on mica at 183°K. Data for both surface baked mica and surface pumped mica are given at this temperature.

Adsorption of Carbon Monoxide on Copper

Beebe, R. A., Low, G. W. Jr., and Goldwasser, S., J. Am. Chem. Soc. 58, 2196-9 (1936). This reference gives experimental data for the adsorption and heat of adsorption of CO on Cu at -183°C.

Adsorption of Carbon Monoxide on Smooth Steel Surfaces

Armbruster, M. H. and Austin, J. B., J. Am. Chem. Soc. 66, 159-71 (1944). In this reference adsorption isotherms are plotted for CO on smooth surfaced steel at temperatures of -195°, -183°, and -78°C up to a pressure of 0.1 cm Hg.

Adsorption of Carbon Monoxide on Silver

Armbruster, M. H., J. Am. Chem. Soc. 64, 2545-53 (1942). This reference gives adsorption isotherms at -195° and -183°C for CO on Ag surfaces for pressures up to 0.1 cm Hg.

Adsorption of Carbon Monoxide on Platinum

Griffin, C. W., J. Am. Chem. Soc. 64, 2610-13 (1942). This reference gives data for the adsorption of CO on Pt from -78.5° to 0°C for three pressures.

Adsorption of Carbon Monoxide on Caesium Iodide

Tompkins, F. C. and Young, D. M., Trans. Faraday Soc. 47, 77-87 (1951). This reference plots adsorption isotherms from 79.52° to 91.58°K for CO on CsI up to a pressure of approximately 3.5 mm Hg.

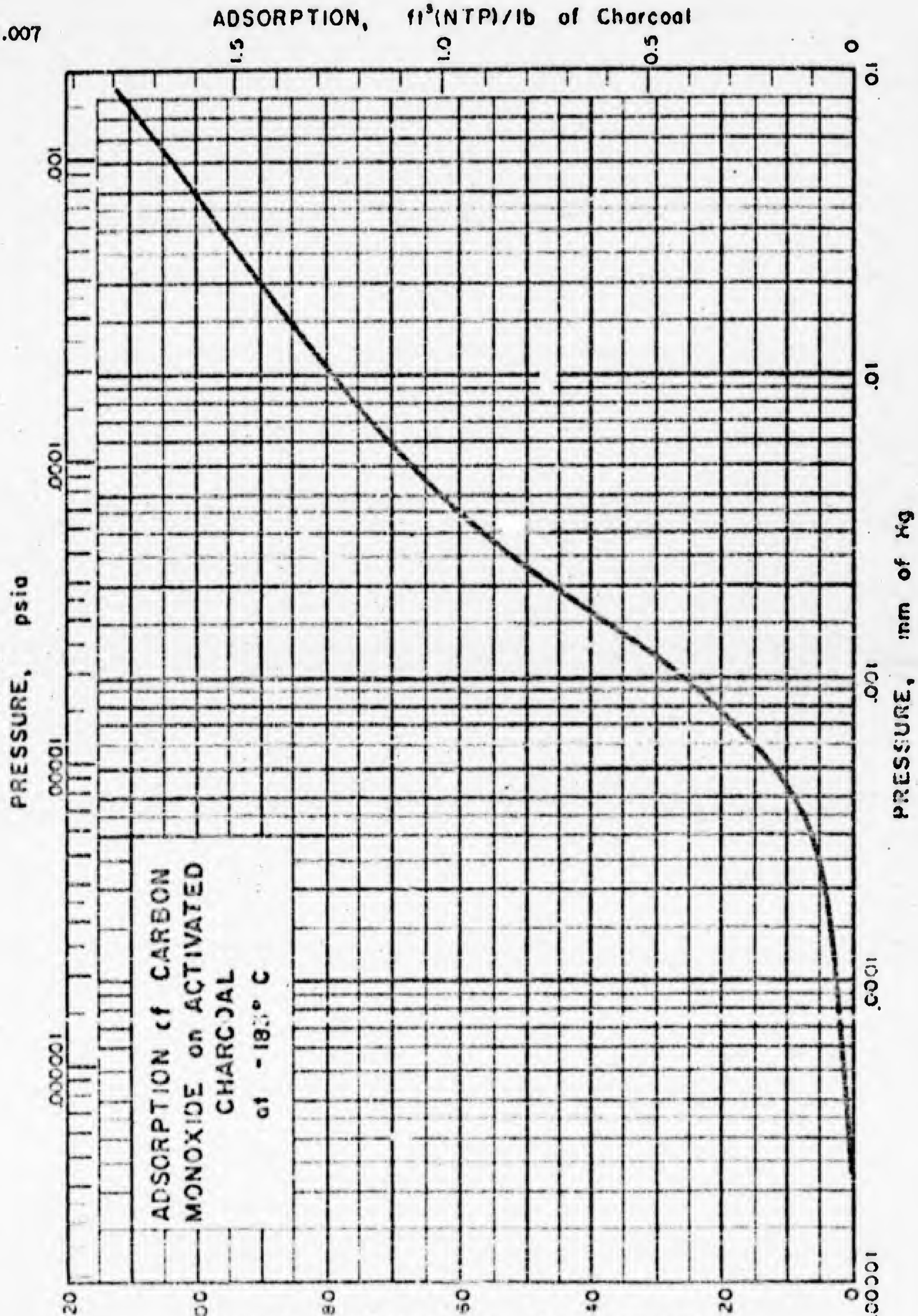
8.007

ADSORPTION of CARBON MONOXIDE on PLATINUM BLACK

Source of Data: Denton, A. F., J. Am. Chem. Soc. 48, 1850-61 (1926).

Comments: Denton reports the adsorption of CO on Pt black to be 7.72 cm^3/4.269 gm Pt black (reduced to 0°C and 1 atm) at 25°C and 770.5 mm Hg. He also reports that the average volume of CO adsorbed per unit volume of Pt black is 37.8 at 25°C and 1 atm.

KDT/BUT Issued: 6/16/59



ADSORPTION of CARBON MONOXIDE on ACTIVATED CHARCOAL at -183° C

8.007

ADSORPTION of CARBON MONOXIDE on ACTIVATED CHARCOAL
(at -183°C)

Source of Data:

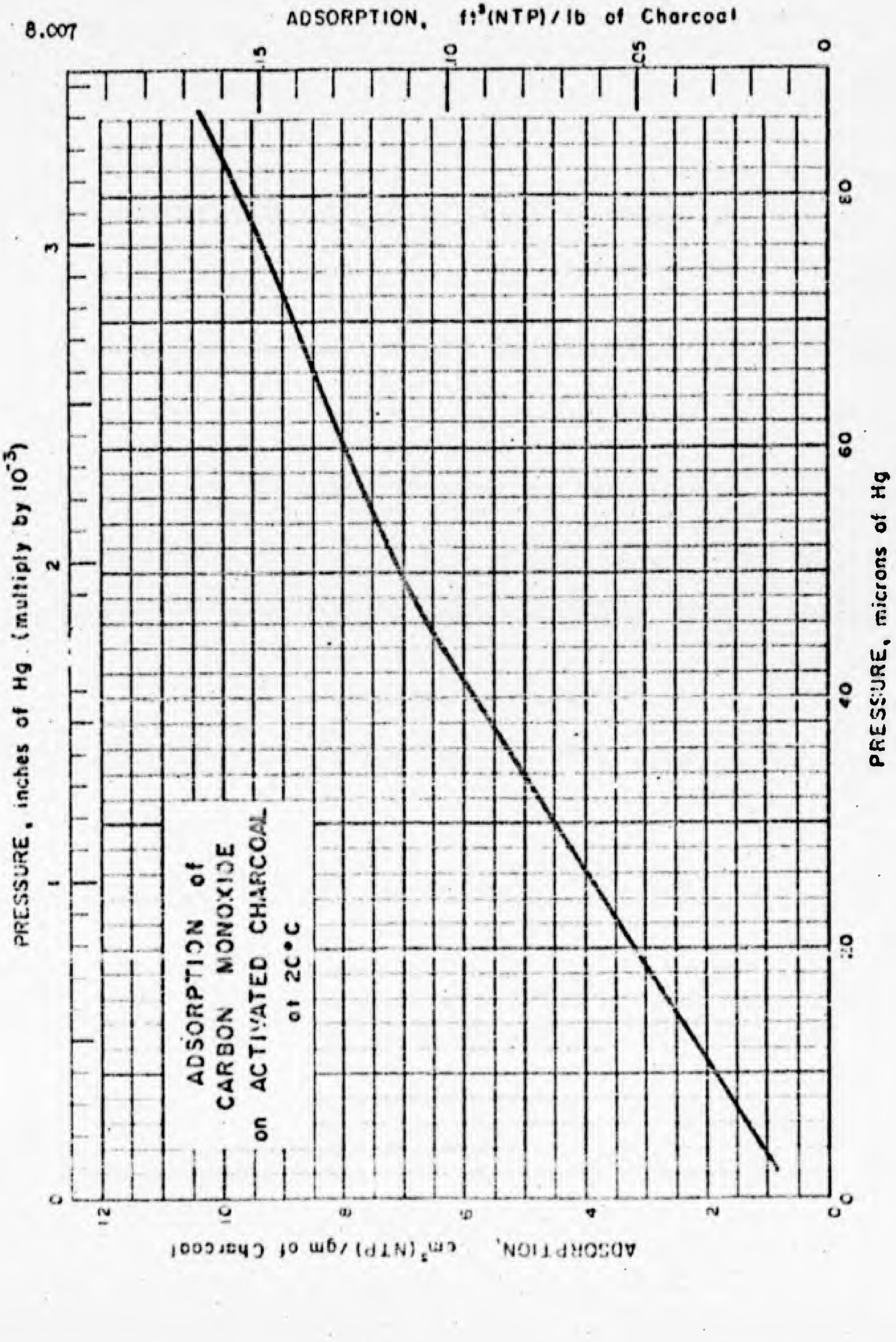
Rowe, H., Phil. Mag., (7), 1, 1042-54 (1926).

Comments:

The adsorption is given in equivalent cm^3 of carbon monoxide at normal temperature and pressure (0°C and 1 atmosphere) per gram of charcoal.

Table of Selected Values

Pressure mm Hg	Adsorption cm^3/gm
2.4×10^{-5}	0.339
9.8×10^{-5}	2.475
1.87×10^{-4}	4.007
6.77×10^{-4}	17.96
1.20×10^{-3}	30.01
1.46×10^{-3}	35.33
2.08×10^{-3}	47.78
3.08×10^{-3}	57.17
5.37×10^{-3}	67.53
11.80×10^{-3}	81.85
20.75×10^{-3}	91.82
40.24×10^{-3}	100.96
55.69×10^{-3}	104.75
83.01×10^{-3}	111.23


ADSORPTION, ft³(NTP)/lb of Charcoal
15
10
05
0
PRESSURE, inches of Hg (multiply by 10⁻³)
0
1
2
3
PRESSURE, microns of Hg
00
20
40
60
80
ADSORPTION, cm³(NTP)/gm of Charcoal
12
10
8
6
4
2
0
ADSORPTION of CARBON MONOXIDE on ACTIVATED CHARCOAL at 20°C

8.007

ADSORPTION of CARBON MONOXIDE on ACTIVATED CHARCOAL
(at 20°C)

Source of Data:

Rowe, H., Phil. Mag., (7), 1, 109-31 (1926).

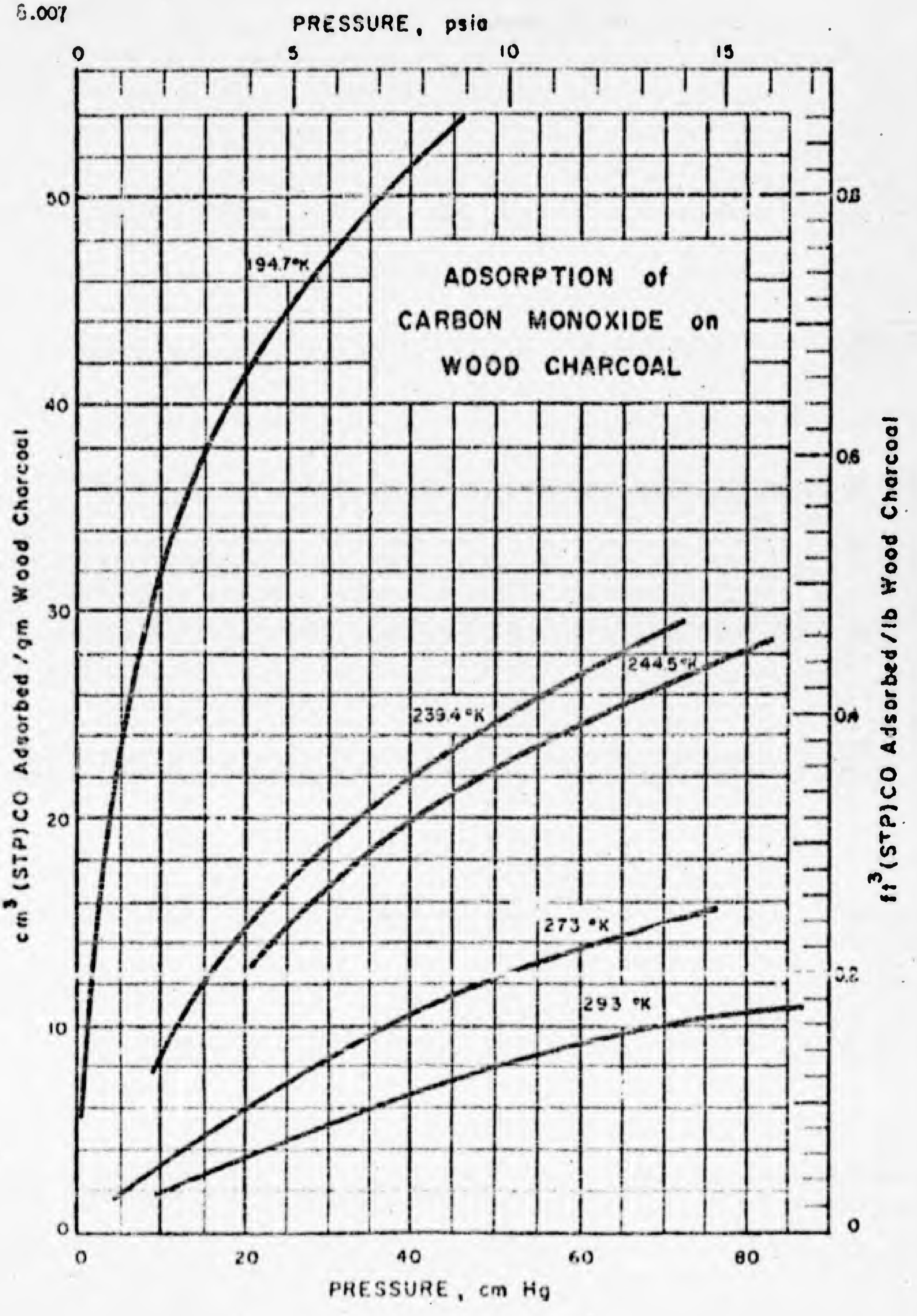
Comments:

The adsorption is given in equivalent cm^3 of carbon monoxide at normal temperature and pressure (0°C and 1 atmosphere) per gram of charcoal.

Table of Selected Values

Pressure mm Hg	Adsorption cm^3/gm
4.267×10^{-3}	1.181
9.279 "	1.874
14.42 "	2.417
19.21 "	3.152
24.27 "	3.730
29.23 "	4.445
34.36 "	4.986
44.26 "	6.463
55.09 "	7.551
69.09 "	8.694
86.96 "	10.31

KDP/RDP Issued: 6/22/59


PRESSURE, psia
0
5
10
15
ADSORPTION of
CARBON MONOXIDE on
WOOD CHARCOAL
194.7°K
239.4°K
244.5°K
273°K
293°K
50
40
30
20
10
0
0.8
0.6
0.4
0.2
0
20
40
60
80
PRESSURE, cm Hg
cm^3 (STP) CO Adsorbed/gm Wood Charcoal
ft^3 (STP) CO Adsorbed/lb Wood Charcoal

ADSORPTION of CARBON MONOXIDE on WOOD CHARCOAL

Source of Data:

Homfray, I. F., Z. physik. Chem. 74, 129-201 (1910)

Comments:

In the tabulation below X is the amount of carbon monoxide adsorbed on 2.964 grams of wood charcoal at the temperature and pressure indicated. X is expressed in equivalent cm3 at 0°C and 1 atmosphere (STP).

Table of Selected Values

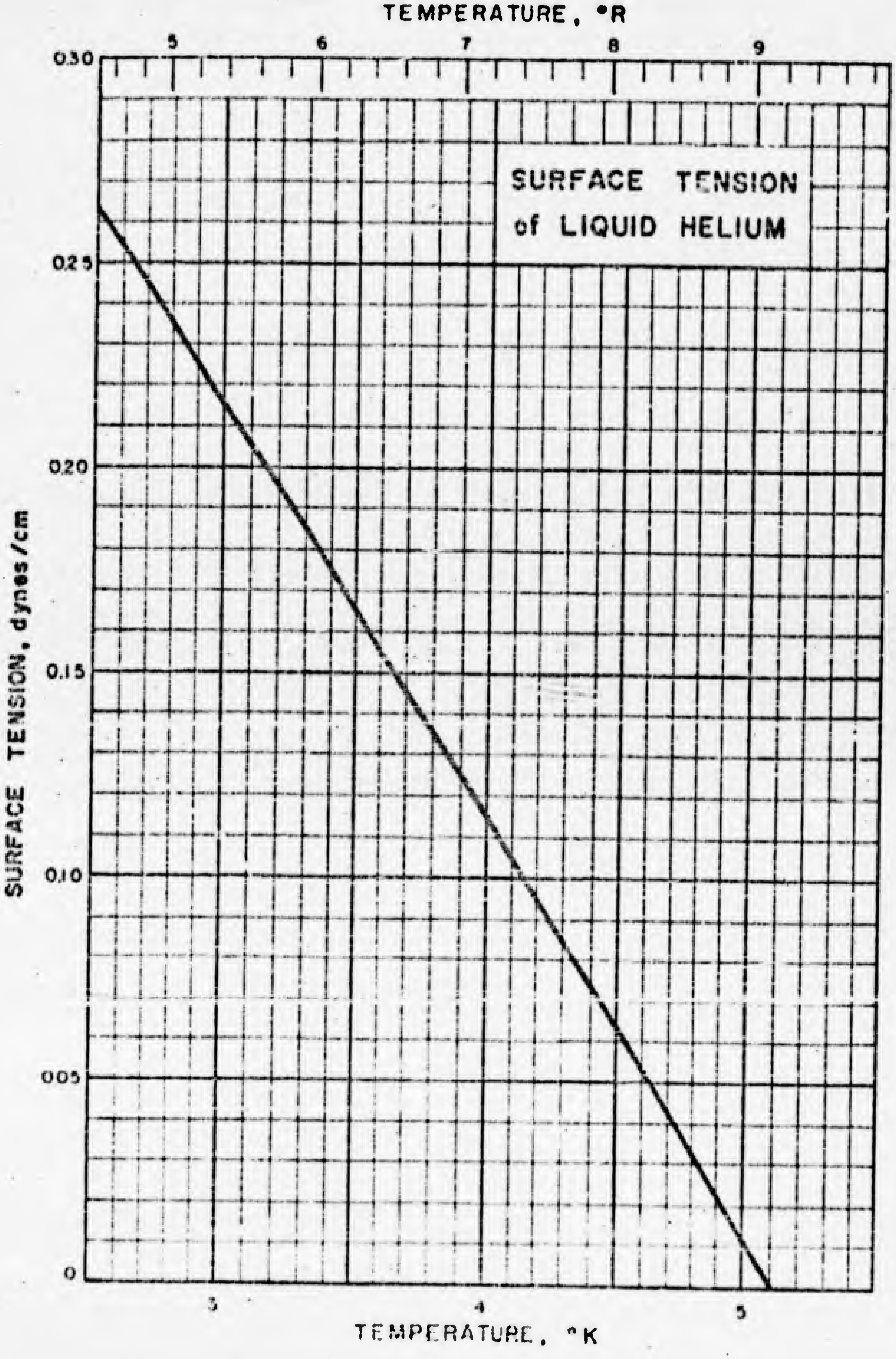
Temp. °K	Press. cm Hg	X cm^3
194.7	0.6	18.5
	3.0	51.26
	4.0	62.0
	7.2	82.0
	11.7	101.0
	14.8	101.7
	18.7	120.0
	28.8	138.5
	44.2	157.5
239.4	10.1	27.3
	18.8	42.0
	32.0	58.0
	43.0	67.0
	54.0	76.0
	67.0	84.0
244.5	22.9	41.4
	38.2	57.6
	50.0	66.2
	63.5	74.8
	78.6	82.7
273	7.3	7.5
	18.0	16.5
	30.4	25.1
	54.0	38.1
	71.3	44.52
	88.2	52.3
293	12.3	7.0
	30.0	15.4
	49.5	23.2
	85.6	35.0

SURFACE TENSION of CRYOGENIC LIQUIDS

CONTENTS

CONVERSION FACTORS for SURFACE TENSION

	$\frac{\text{dyne}}{\text{cm}}$	$\frac{\text{erg}}{\text{cm}^2}$	$\frac{\text{mgm}}{\text{mm}}$	$\frac{\text{mgm}}{\text{in}}$	$\frac{\text{lb}}{\text{ft}}$
1 $\frac{\text{dyne}}{\text{cm}}$ =	1.000	1.000	0.10197	2.5901	6.853×10^{-5}
1 $\frac{\text{erg}}{\text{cm}2}$ =	1.000	1.000	0.10197	2.5901	6.853×10^{-5}
1 $\frac{\text{mgm}}{\text{mm}}$ =	9.80665	9.80665	1.000	25.400051	5.573×10^{-4}
1 $\frac{\text{mgm}}{\text{in}}$ =	0.38609	0.38609	0.03937	1.000	2.6459×10^{-5}
1 $\frac{\text{lb}}{\text{ft}}$ =	14592.15	14592.15	1794.37	37794	1.000


TEMPERATURE, °R
5
6
7
8
9
SURFACE TENSION
of LIQUID HELIUM
0.30
0.25
0.20
0.15
0.10
0.05
0
SURFACE TENSION, dynes/cm
3
4
5
TEMPERATURE, °K

SURFACE TENSION of LIQUID HELIUM

Source of Data:

Keesom, W. H., *Helium*, Elsevier, Amsterdam (1942) 494 pp.

Other References:

Atkins, K. R., Can. J. Phys. 31, 1165-69 (1953)

Van Urk, T. A., Keesom, W. H. and Onnes, H. K., Commun. Phys. Lab. Univ. Leiden No. 179a (1925)

Comments:

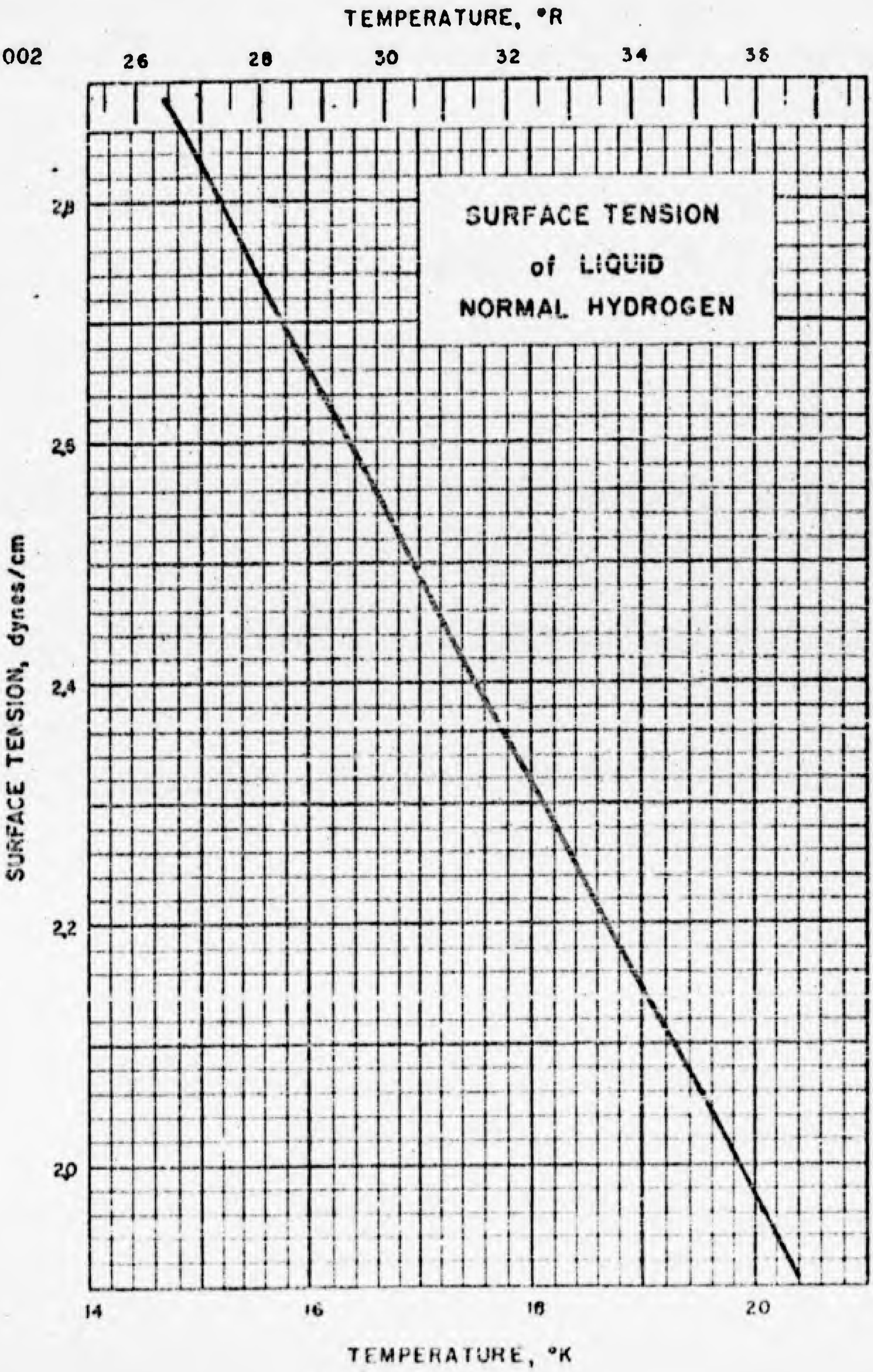
The absolute temperature scale (0°C = 273.16°K) was used in the table of selected values below.

Temperature		Surface Tension	
°K	°R	dynes/cm	lb/ft
2.5	4.50	0.264	1.81×10^{-5}
3.0	5.40	0.215	1.47 "
3.5	6.30	0.164	1.12 "
4.0	7.20	0.115	0.787 "
4.2	7.56	0.093	0.638 "
4.5	8.10	0.640 *	0.438 *
5.0	9.00	0.0115*	0.079* "
5.2	9.36	0.00 *	0.00 *

* Extrapolated Values

DPM/GAR Issued: 6/3/59

9.002


TEMPERATURE, °R
26
28
30
32
34
36
SURFACE TENSION
of LIQUID
NORMAL HYDROGEN
SURFACE TENSION, dynes/cm
2.8
2.6
2.4
2.2
2.0
14
16
18
20
TEMPERATURE, °K

9.002

SURFACE TENSION of LIQUID NORMAL HYDROGEN

Sources of Data:

Kammerlingh Onnes and Kuypers, Comm. Phys. Lab. Univ. Leiden No. 142

Proc. Roy. Acad. Amsterdam 17, 528 (1914)

International Critical Tables IV, 334-41

Comments:

The data of Kammerlingh Onnes and Kuypers appears to be the only available to date. It was obtained in 1914 and hence refers to normal hydrogen. Values given are for the liquid in contact with its own vapor, and are in dynes per centimeter. The experimental points fall on a perfectly straight line when surface tension is plotted against absolute temperature.

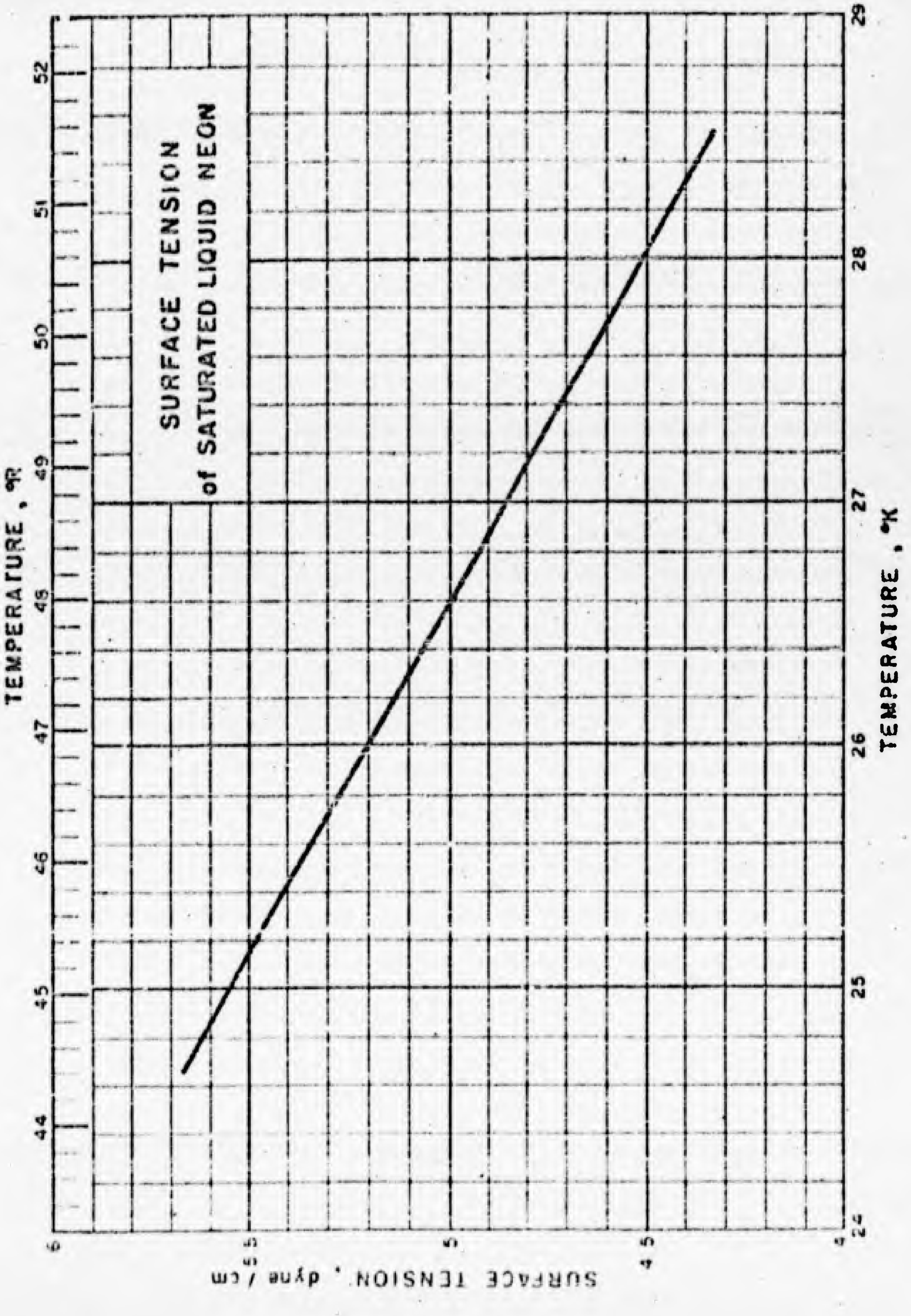
Temperature measurements were accurate to ±.02°K and surface tension measurements to ±0.1%

Table of Selected Values

Temp. °K	Surface Tension dynes/cm
20.40	1.91_2
18.70	2.19_7
17.99	2.318
16.16	2.63_3
14.68	2.88_2

FEEG/VJJ Issued: 9-23-59

SURFACE TENSION of NEON



SURFACE TENSION of SATURATED LIQUID NEON

Sources of Data:

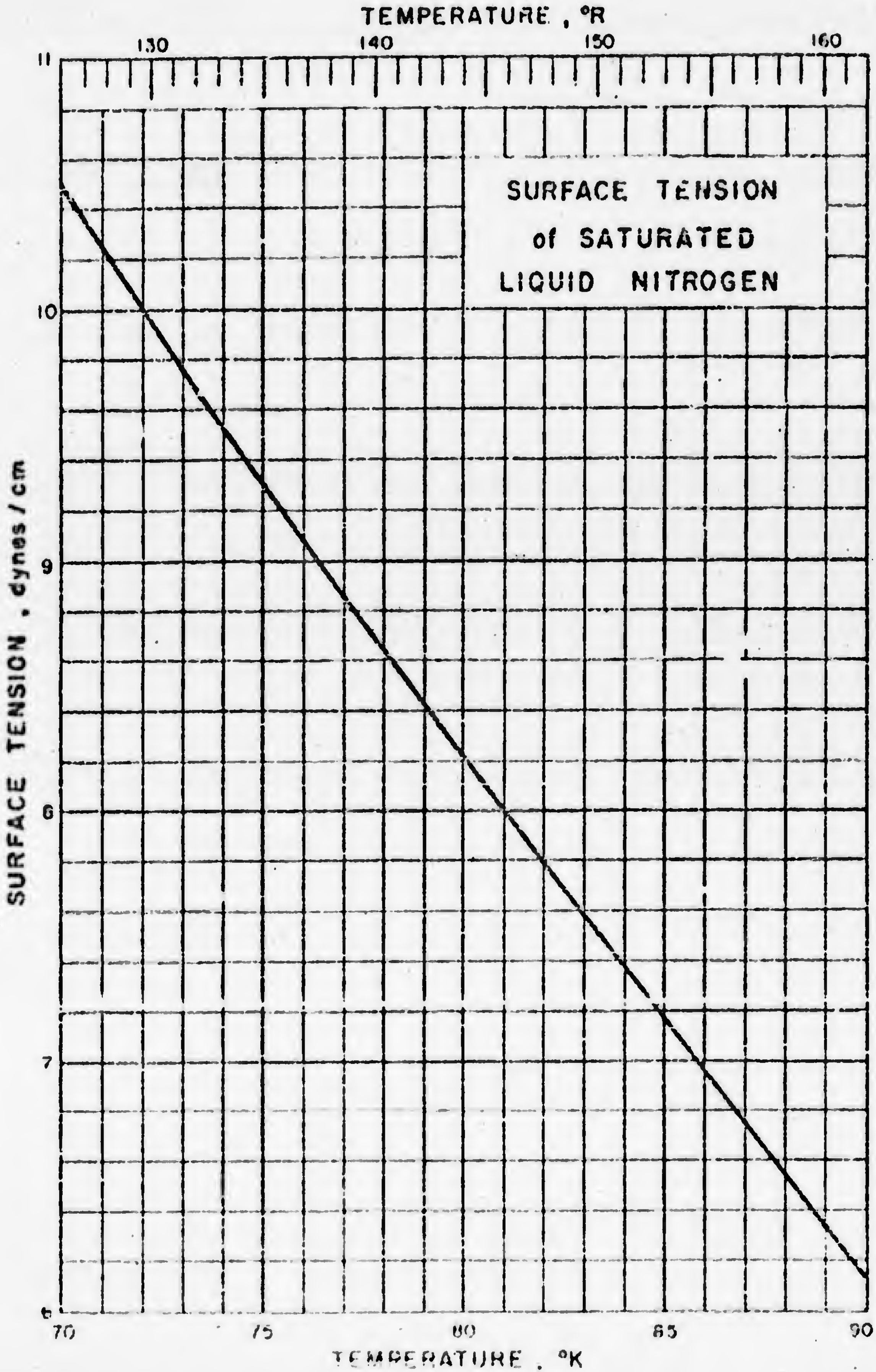
Guggenheim, E. A., J. Chem. Phys. 13, 253-61 (1945)

Van Urk, A. T., Keesom, W. H. and Nijhoff, G. P., Proc. Acad. Sci. Amsterdam 35, 482-4 (1926)

Table of Selected Values

Temperature °K	Surface Tension (γ), dyne/cm
24	5.90**
24.8	5.61*
25	5.50**
25.7	5.33*
26	5.15**
26.6	4.99*
27	4.80**
27.4	4.69*
28	4.45**
28.3	4.44*

* Experimental values
** Smoothed values



SURFACE TENSION of SATURATED LIQUID NITROGEN

9.004

SURFACE TENSION of SATURATED LIQUID NITROGEN

Sources of Data:

Baly, E. C. C. and Donnan, F. G., J. Chem. Soc. (London) 81, No. 93, 907-23 (1902)

Grunmach, L., Ann. Physik 22, 107-118 (1906)

Grunmach, L., Physik Z. 7, 740-4 (1906)

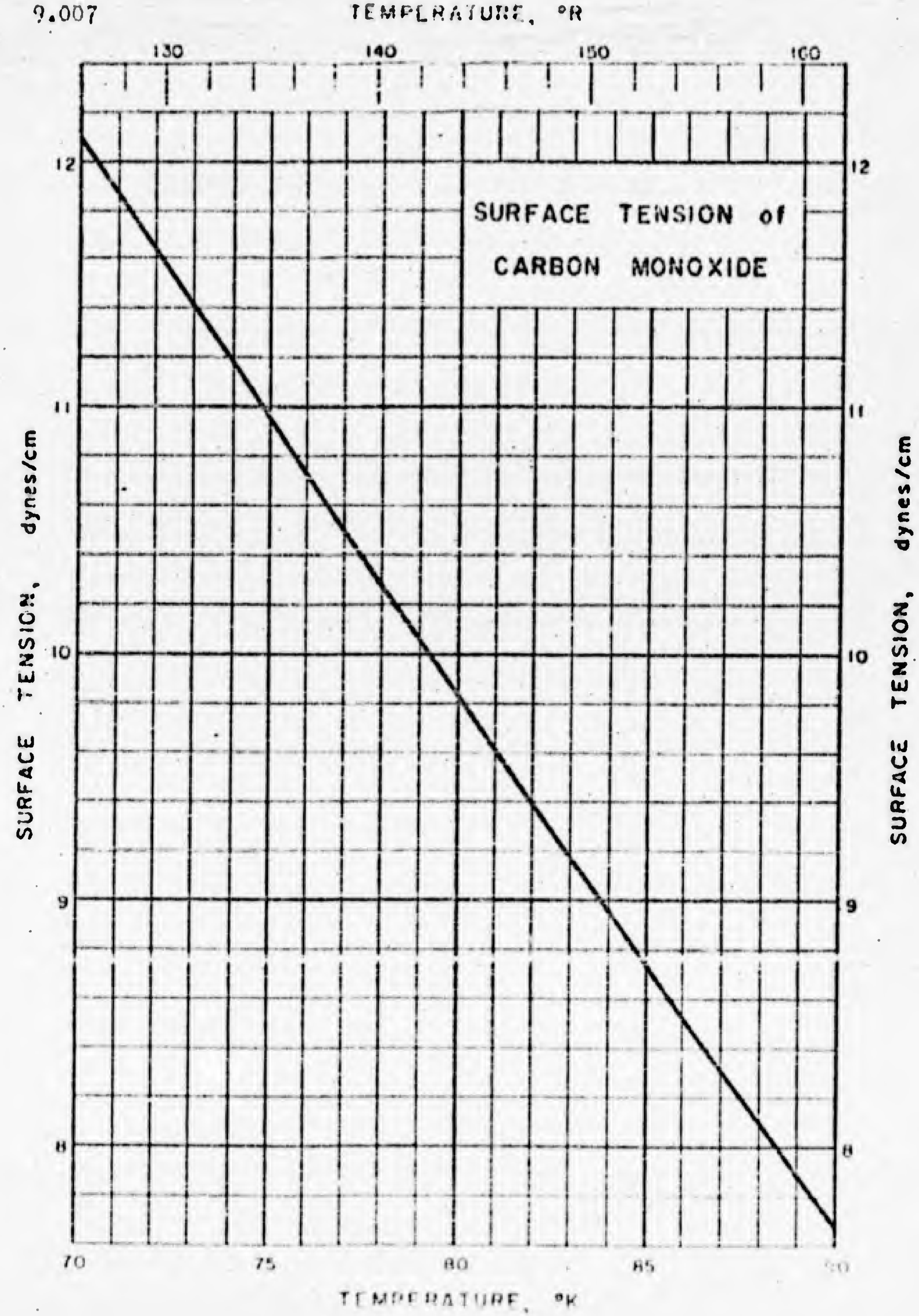
International Critical Tables (1938)

Table of Selected Values

Temp. °K	Surface Tension dyne/cm	Temp. °K	Surface Tension dyne/cm
68	11.00 ± 1%	78	8.72 ± 1%
69	10.76 ± 1%	79	8.50 ± 1%
70	10.53 ± 1%	80	8.27 ± 1%
71	10.30 ± 1%	81	8.06 ± 1%
72	10.07 ± 1%	82	7.84 ± 1%
73	9.84 ± 1%	83	7.63 ± 1%
74	9.62 ± 1%	84	7.42 ± 1%
75	9.39 ± 1%	85	7.20 ± 1%
76	9.16 ± 1%	86	6.99 ± 1%
77	8.94 ± 1%	87	6.78 ± 1%
77.3*	8.85 ± 1%	88	6.57 ± 1%
77.3*	8.77 ± 1%	89	6.37 ± 1%
77.3*	8.914	90	6.16 ± 1%

* Normal Boiling Temperature

EDP/RDP Issued: 5/25/59


TEMPERATURE, °R
130
140
150
160
SURFACE TENSION of
CARBON MONOXIDE
12
11
10
9
8
SURFACE TENSION, dynes/cm
SURFACE TENSION, dynes/cm
70
75
80
85
90
TEMPERATURE, °K

SURFACE TENSION of CARBON MONOXIDE

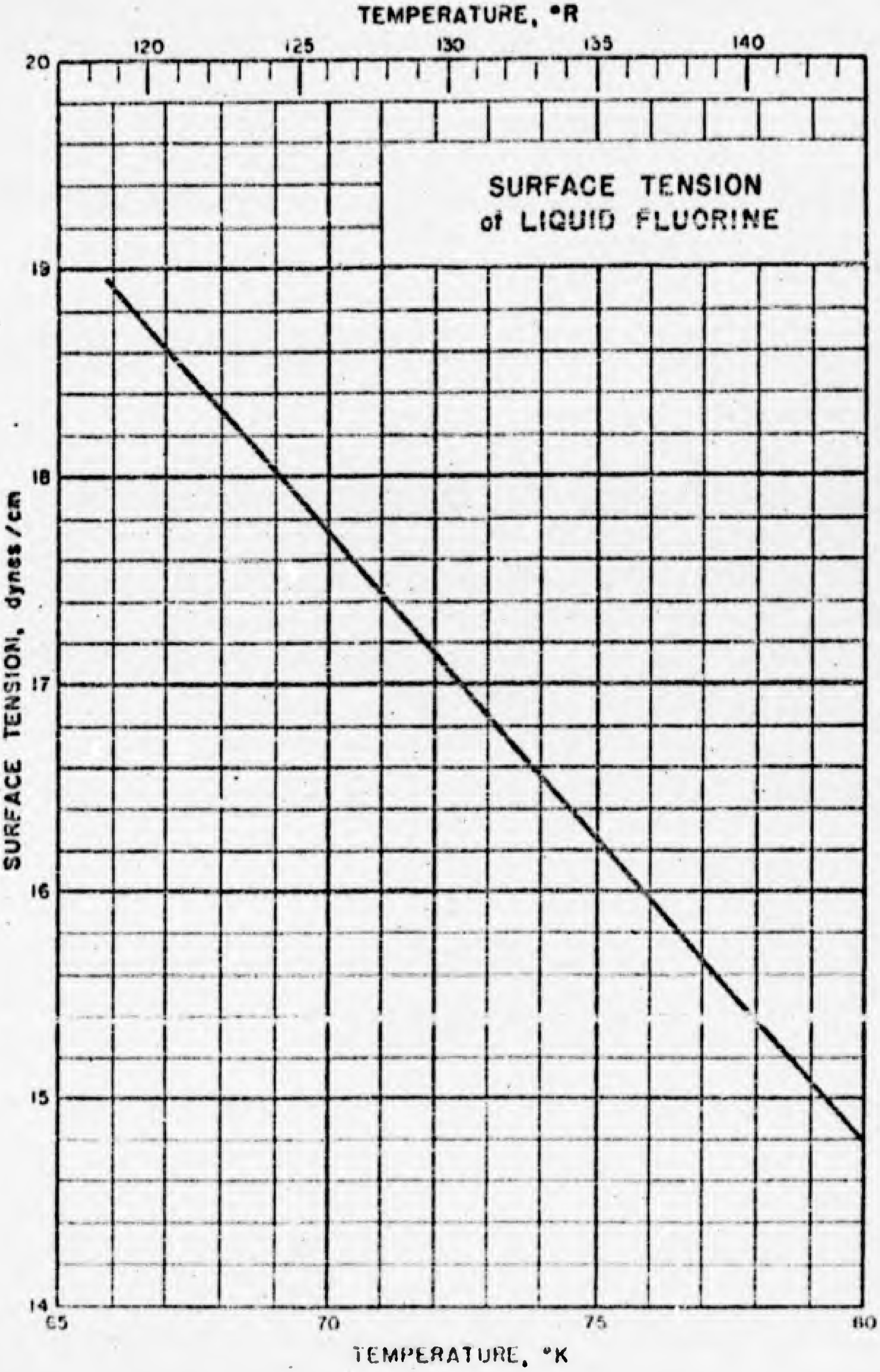
Source of Data: Crommelin, C. A., Proc. Chem. Soc. (London) 30, 248 (1914).

Comments: The above reference is a correction of Baly, E. C. C. and Donnan, F. G., J. Chem. Soc. (London) 81, 907-23 (1902).

Table of Selected Values

Temp. °K	Surface Tension dynes/cm	Temp. °K	Surface Tension dynes/cm
70	12.11	80	9.83
71	11.88	81	9.61
72	11.64	82	9.39
73	11.41	83	9.17
74	11.18	84	8.96
75	10.96	85	8.74
76	10.73	86	8.53
77	10.50	87	8.31
78	10.28	88	8.10
79	10.05	89	7.89
		90	7.69

KDT/BDT Issued: 6/10/59


TEMPERATURE, °R
120
125
130
135
140
SURFACE TENSION of LIQUID FLUORINE
SURFACE TENSION, dynes/cm
20
19
18
17
16
15
14
65
70
75
80
TEMPERATURE, °K

SURFACE TENSION of LIQUID FLUORINE

Source of Data:

White, D., Hu, J. H. and Johnston, H. L., J. Am. Chem. Soc. 76, 2584-6 (1954)

Other References:

Kanda, E., Bull. Chem. Soc. Japan 12, 472-9 (1937)

Wicke, E., Angew. Chem. 66, 701-10 (1954)

Elverum, G. W. and Doescher, R. N., J. Chem. Phys. 20, 1834-6 (1952)

Comments:

The surface tension of liquid fluorine measurements were made with a capillary tube and were calculated from the equation:

$$s = \frac{H}{\frac{1}{b_1} - \frac{1}{b_2}} \frac{g}{2} (d - d') \qquad (1)$$

where: b_1 and b_2 are radii of curvature of the two menisca;
d and d' the density of the liquid and gas, respectively;
H is the difference in height between the capillary and the reference tube;
g is 980.11 $\mathrm{cm/sec^2}$.

Hu, et al. found that surface tension data over the entire temperature range could be represented by the Macleod equation:

$$\frac{s^{\frac{1}{4}}}{d - d'} = C \qquad (2)$$

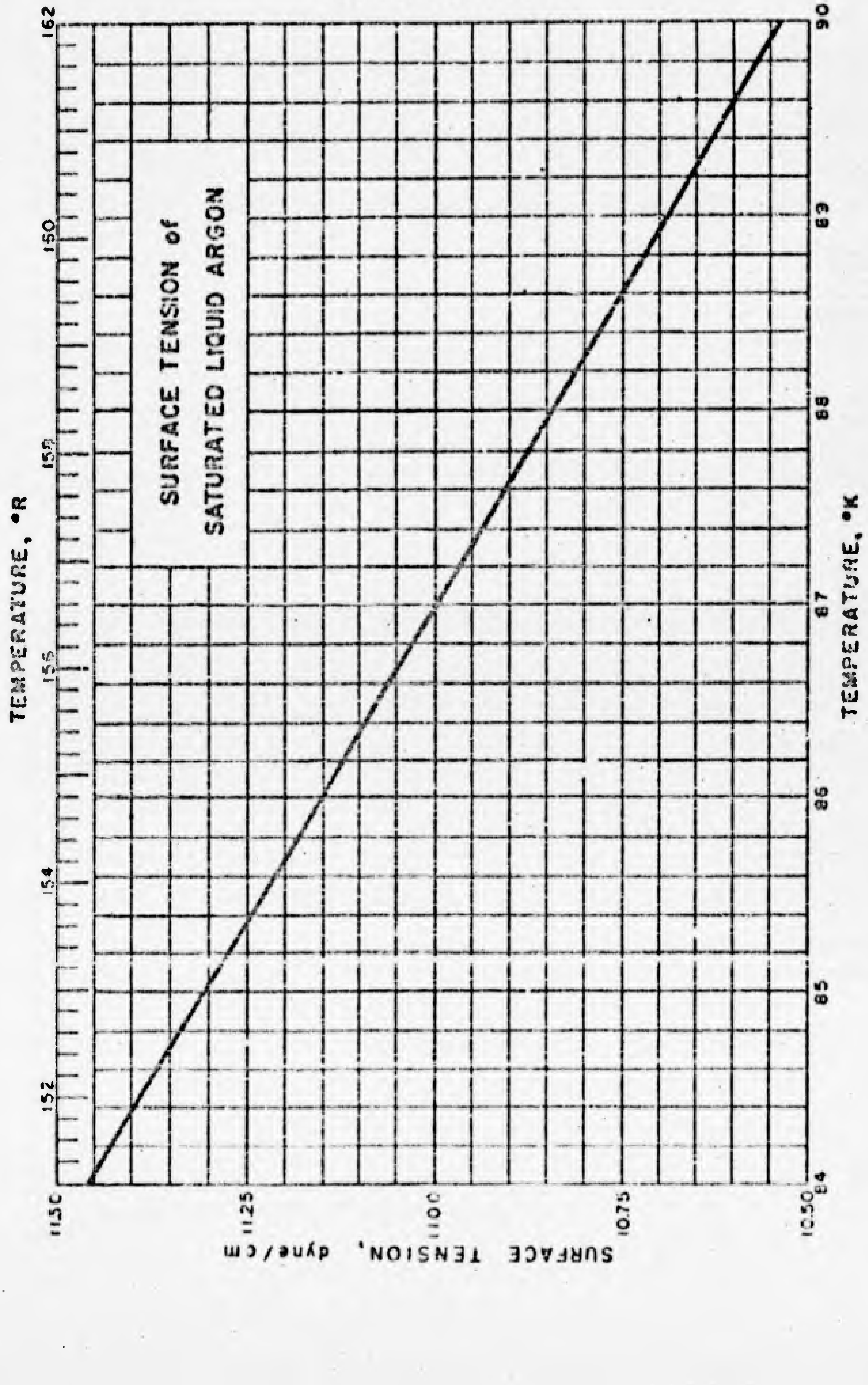
where: C = Macleod constant = 1.276 ± 0.002

Kanda's data were not in agreement with the other investigators. It was pointed out by Hu, et al. that the density measurements made by Kanda were 25% lower than the accepted values. If Kanda's data are corrected for density, the agreement with the other investigators is improved.

Table of Selected Values

Temp. °K	Surface Tension dyne/cm	Macleod Constant	Dev. from equa. 2 obsd - calcd
66.21	18.65	1.277	0.00
70.26	17.70	1.277	.07
70.68	17.40	1.275	- .09
72.05	17.02	1.274	- .10
73.35	16.86	1.278	.11
75.09	16.49	1.280	.20
75.19	16.28	1.277	.02
77.15	15.73	1.276	.01
79.90	14.81	1.272	- .19

RVR Issued: 8/4/59


SURFACE TENSION of
SATURATED LIQUID ARGON
TEMPERATURE, °R
162
160
158
156
154
152
TEMPERATURE, °K
84
85
86
87
88
89
90
SURFACE TENSION, dyne/cm
11.50
11.25
11.00
10.75
10.50

9.009

SURFACE TENSION of SATURATED LIQUID ARGON

Sources of Data:

Baly, E. C. C. and Donnan, F. G., J. Chem. Soc. 81, 907 (1902)

Frenkel, Ya. I. and Gubanov, A., J. Exptl. Theoret. Phys. (U.S.S.R.) 16, 435-50 (1946)

Inouye, T., J. Phys. Soc. Japan 6, 243-8 (1951)

Kirkwood, J. G. and Buff, F. P., J. Chem. Phys. 17, 338-43 (1949)

Comments:

The molecular surface energy was measured and surface tension was calculated by the expression:

$$\gamma \, (Mv)^{2/3} = 2.02 \, (145.44 - T)$$

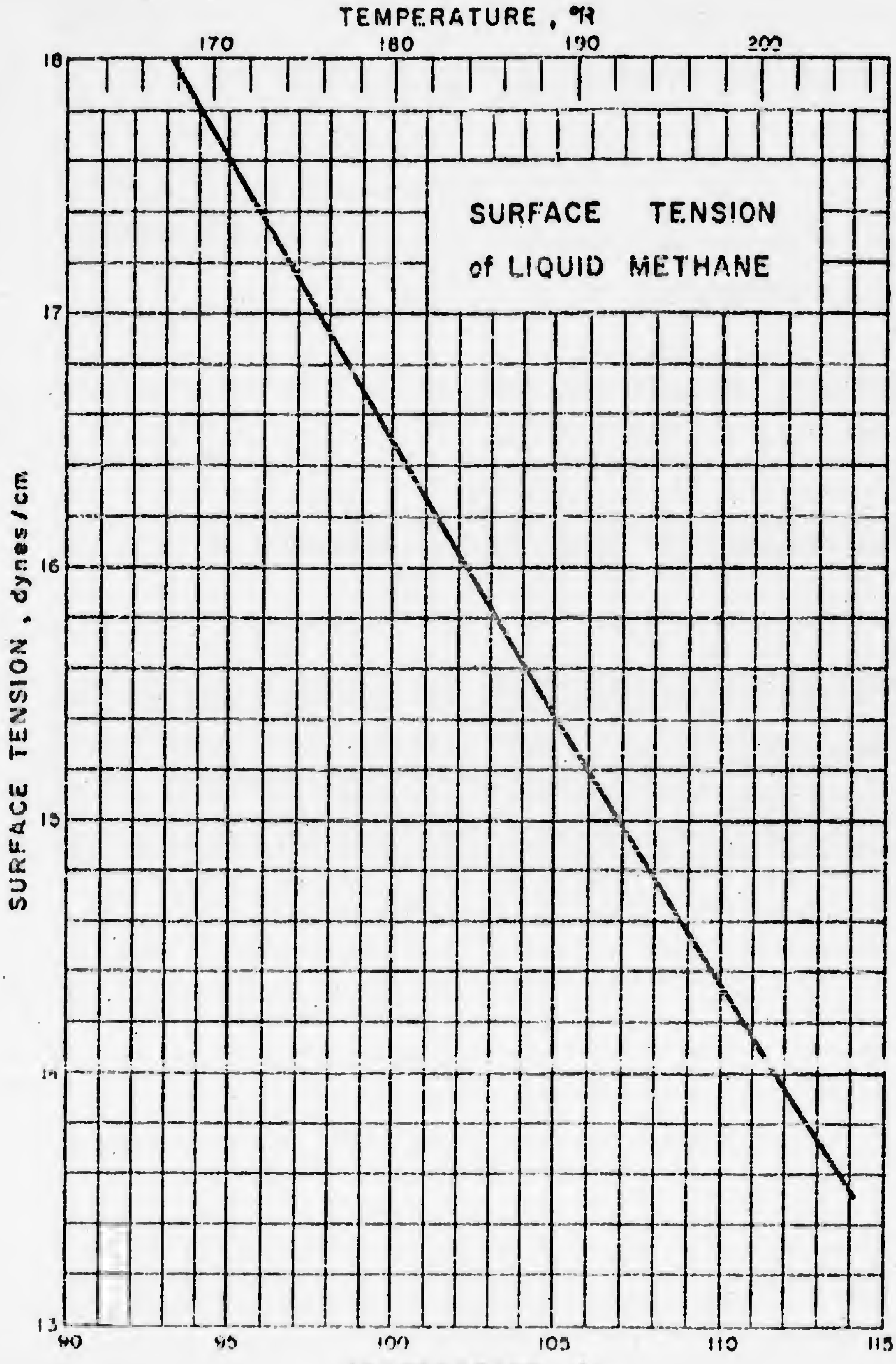
Where:

M = Molecular weight
v = Specific Volume, cm^3/gm
γ = Surface tension, dyne/cm
T = Temperature, °K

Table of Selected Values

Temperature °K	Surface tension dyne/cm
84	11.46
85	11.30
86	11.15
87	11.00
88	10.84
89	10.69
90	10.53

FLB/RJR Issued: 8/28/59


TEMPERATURE , °R
170
180
190
200
SURFACE TENSION
of LIQUID METHANE
18
17
16
15
14
13
SURFACE TENSION , dynes/cm
90
95
100
105
110
115
TEMPERATURE , °K

SURFACE TENSION of LIQUID METHANE

Source of Data: Rossini, F. D., et al., Selected Values of Physical and Thermodynamic Properties of Hydrocarbons and Related Compounds, Carnegie Press, Pittsburgh (1953), p. 318.

Comments: Values are at atmospheric pressure except for the value at 113.16°K, which is at saturation pressure.

Table of Selected Values

Temperature °K	Surface Tension dynes/cm
93.16	18.0
103.16	15.8
113.16	13.7

Normal Melting Temp. = 90.6°K
Normal Boiling Temp. = 111.7°K
Critical Temperature = 190.7°K

RFR Issued: 7/13/59

10.000

VISCOSITY of CRYOGENIC FLUIDS

CONTENTS

CONVERSION FACTORS for VISCOSITY*

	Poise	$\frac{\text{lb sec}}{\text{in}^2}$	$\frac{\text{lb sec}}{\text{ft}^2}$	$\frac{\text{lb hr}}{\text{in}^2}$	$\frac{\text{lb hr}}{\text{ft}^2}$
1 Poise =	1.000	1.4504×10^{-5}	2.0886×10^{-3}	4.0289×10^{-9}	5.8016×10^{-7}
$1 \frac{\text{lb sec}}{\text{in}^2}$ =	6.8947×10^{4}	1.000	1.4400×10^{2}	2.7778×10^{-4}	4.000×10^{-2}
$1 \frac{\text{lb sec}}{\text{ft}^2}$ =	4.7880×10^{2}	6.9445×10^{-3}	1.000	1.9290×10^{-6}	2.7778×10^{-4}
$1 \frac{\text{lb hr}}{\text{in}^2}$ =	2.4821×10^{8}	3.6000×10^{3}	5.18410×10^{5}	1.000	1.4400×10^{2}
$1 \frac{\text{lb hr}}{\text{ft}^2}$ =	1.7237×10^{6}	25.001	3.6000×10^{3}	6.9446×10^{-3}	1.000

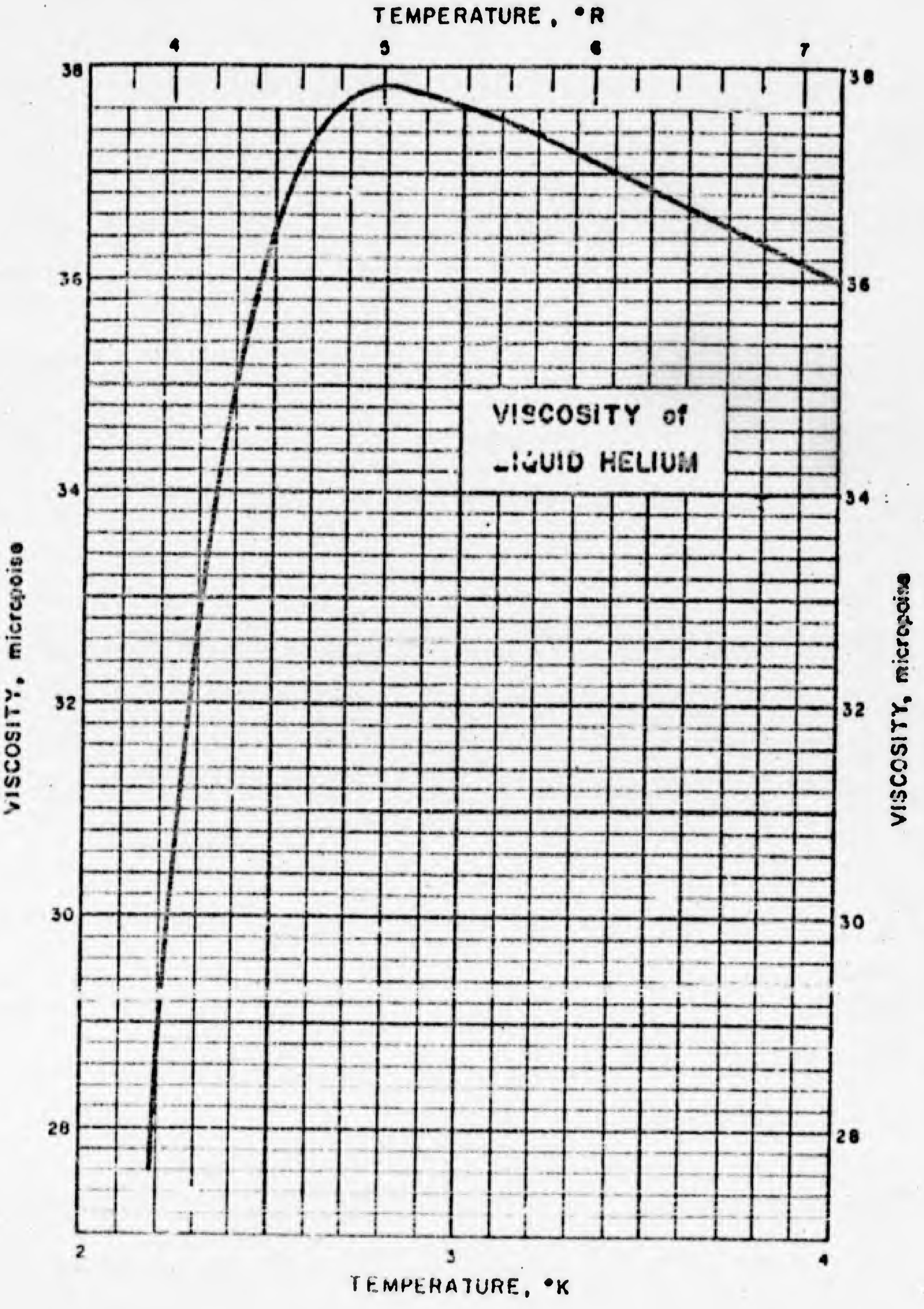
$$1 \text{ Poise} = 1 \frac{\text{dyne sec}}{\text{cm}^2} = 1 \frac{\text{gm}}{\text{cm sec}}; \quad 1 \frac{\text{lb sec}}{\text{ft}^2} = 1 \frac{\text{slug}}{\text{ft sec}}$$

Kinematic Viscosity = Absolute Viscosity/Density

* Refers to Absolute Viscosity

Note: lb as used throughout refers to a pound force (lb_f)

10.001



VISCOSITY of LIQUID HELIUM

10.001

VISCOSITY of LIQUID HELIUM

Source of Data:

Taylor, R. D. and Dash, J. G., Phys. Rev. 106, No. 3, 398-403 (May 1957).

Other References:

Giauque, W. R., et. al., J. Am. Chem. Soc. 61, 654-60 (March 1939)

Woods, A. D. B. and Hollis Hallett, A. C., Can. J. Phys. 36, 253-1125 (1958)

Dash, J. G. and Taylor, R. D., Phys. Rev. 107, No. 5, 1228-1237 (Sept. 1957)

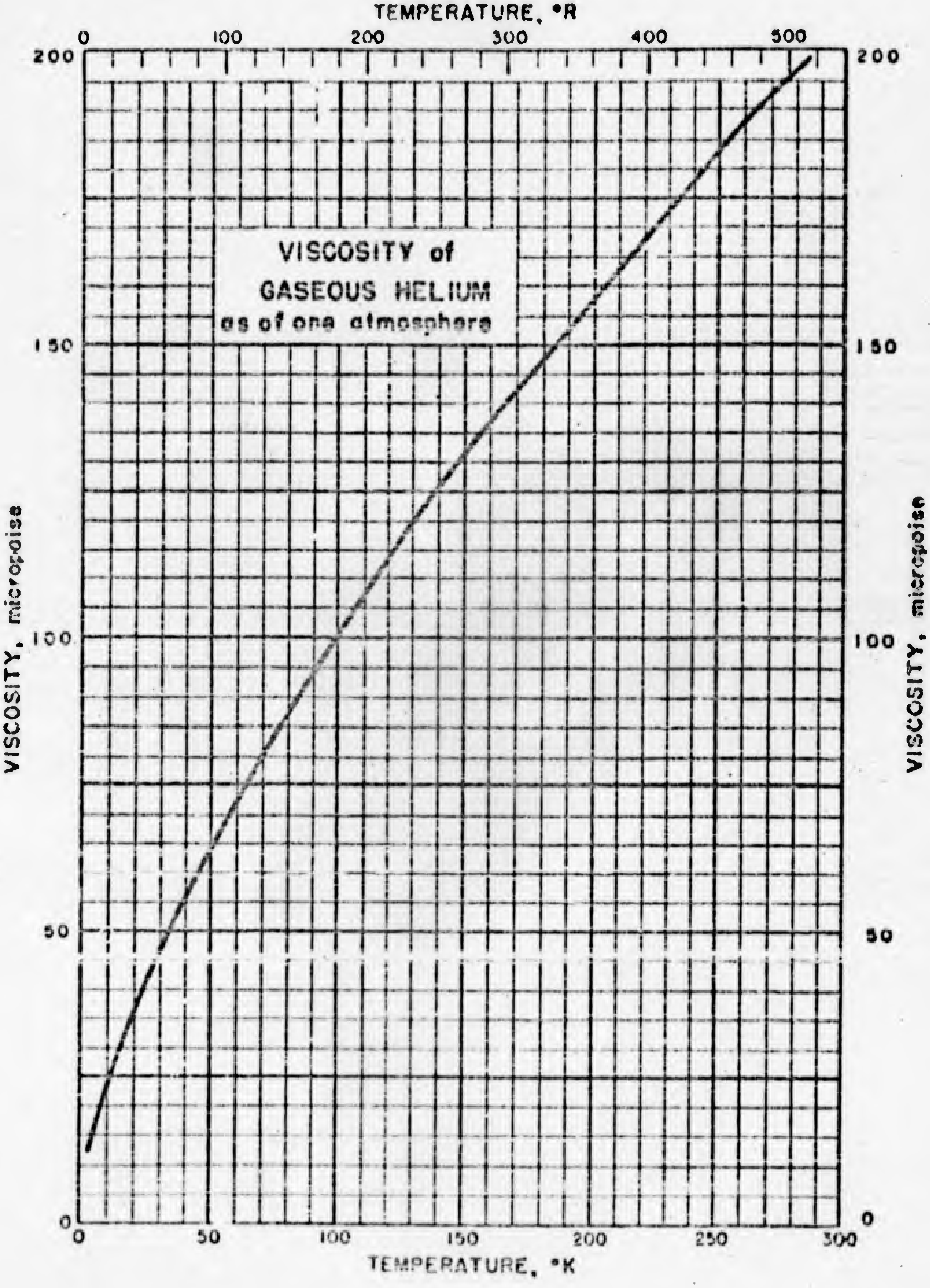
Comments:

The absolute temperature (0°C = 273.16°K) was used in the table of selected values below.

Temp. °K	Viscosity micropoise
2.186 *	27.8
2.2	29.9
2.3	32.6
2.4	35.0
2.6	37.3
2.8	37.8
3.0	37.6
3.2	37.4
3.4	37.0
3.6	36.7
3.8	36.3
4.0	36.0

* λ-Point Transition Temperature

LBM/GAR Issued: 8/3/59


TEMPERATURE, °R
0
100
200
300
400
500
200
150
100
50
0
VISCOSITY of
GASEOUS HELIUM
as of one atmosphere
VISCOSITY, micropoise
VISCOSITY, micropoise
0
50
100
150
200
250
300
TEMPERATURE, °K

10.001

VISCOSITY of GASEOUS HELIUM
(as of 1 atmosphere)

Source of Data:

Akin, S. W., Trans. ASME 72, 751-57 (Aug. 1950)

Other References:

Hawkins, G. A., Trans. ASME 70, 655 (1948)

Hilsenrath, J. and Touloukian, Y. S., Trans. ASME 76, No. 6 (Aug. 1954)

Keller, W. E., Phys. Rev. 105, 41-5 (Jan. 1957)

Keyes, F. G., Trans. ASME 73, 589 (July 1951)

Kestin, J. and Pilarczyk, K., Trans. ASME 76, 987-999 (1954)

Kestin, J. and Wang, H. E., Trans. ASME 80, 11 (1958)

Amdur, I., J. Chem. Phys. 15, No. 7 (July 1947)

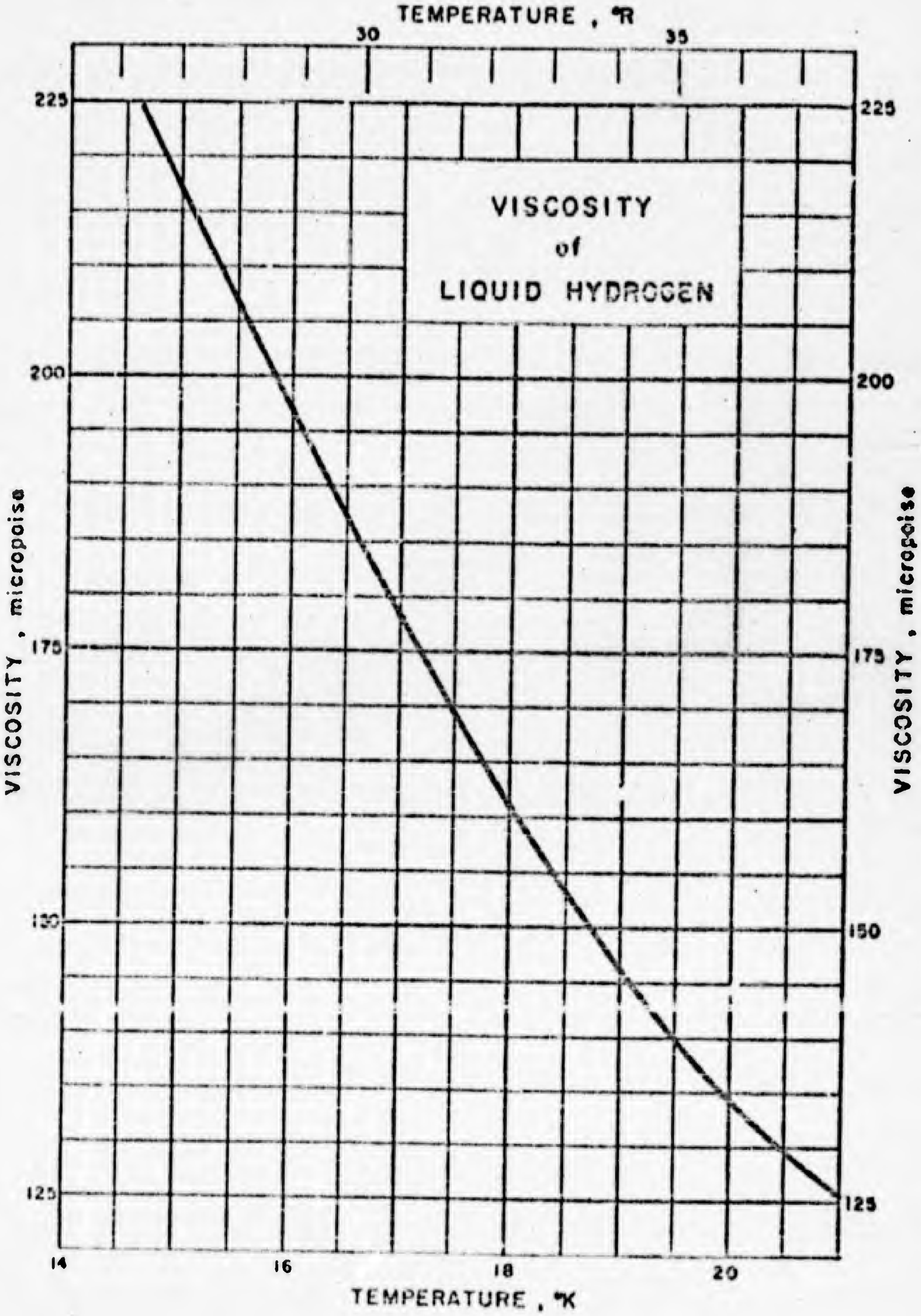
Van Itterbeek, F. W., Schapink, O. J., Van den Berg, G. J. and Van Beek, H. J. M., Physica XIX, 1158-1162 (1953)

Comments:

Values for viscosity are given for moderate pressures in the neighborhood of one atmosphere. In this region the viscosity is practically independent of pressure.

The absolute temperature scale (0°C = 273.16°K) was used in the table of selected values below.

Temp. °K	Viscosity micropoise	Temp. °K	Viscosity micropoise
5.5	10.4	125.0	114
10.0	22.3	150.0	128
20.0	35.0	175.0	142
30.0	45.4	200.0	155
40.0	54.8	225.0	166
50.0	63.3	250.0	178
75.0	81.9	275.0	191
100.0	99.0	300.0	201


TEMPERATURE , °R
30
35
VISCOSITY
of
LIQUID HYDROGEN
225
200
175
150
125
225
200
175
150
125
VISCOSITY , micropoise
VISCOSITY , micropoise
14
16
18
20
TEMPERATURE , °K

10.002

VISCOSITY of LIQUID HYDROGEN

Source of Data:

Woolley, H. W., Scott, R. B. and Brickwedde, F. G., J. Research Natl. Bur. Standards 41, 379-475 (1948); Research Paper RP 1932.

Other References:

Johns, H. E., Can. J. Research 17(A), 221 (1939)

Keesom, W. H. and MacWood, G. E., Physica 5, 745 (1938)

Van Itterbeek, A. and Van Paemel, O., Physica 7, 208 (1940)

Van Itterbeek, A. and Van Paemel, O., Physica 8, 133-43 (1941)

Verschaffelt, J. E. and Nicaise, C., Communs. Phys. Lab. Univ. Leiden No. 151g (1917)

Comments:

The first determination of the viscosity of liquid hydrogen was made at 20.36°K by Verschaffelt and Nicaise. Later, the viscosity of liquid hydrogen was measured from 15° to 20°K by Keesom and MacWood, using an oscillating disc, while Johns used the capillary flow method.

The selected values in the table below were taken from figure 17, page 452 of RP 1932. They represent the most probable values for viscosity of liquid hydrogen and were derived from the curve drawn principally between the data of Verschaffelt and Nicaise and that of Keesom and MacWood. Near the boiling point the curve was drawn approximately parallel to the curve obtained from Johns' data. Data from Van Itterbeek and Van Paemel is shown for comparison but was not used for plotting the graph on the preceding page.

The absolute temperature scale (0°C = 273.16°K) was used in the tabulation below.

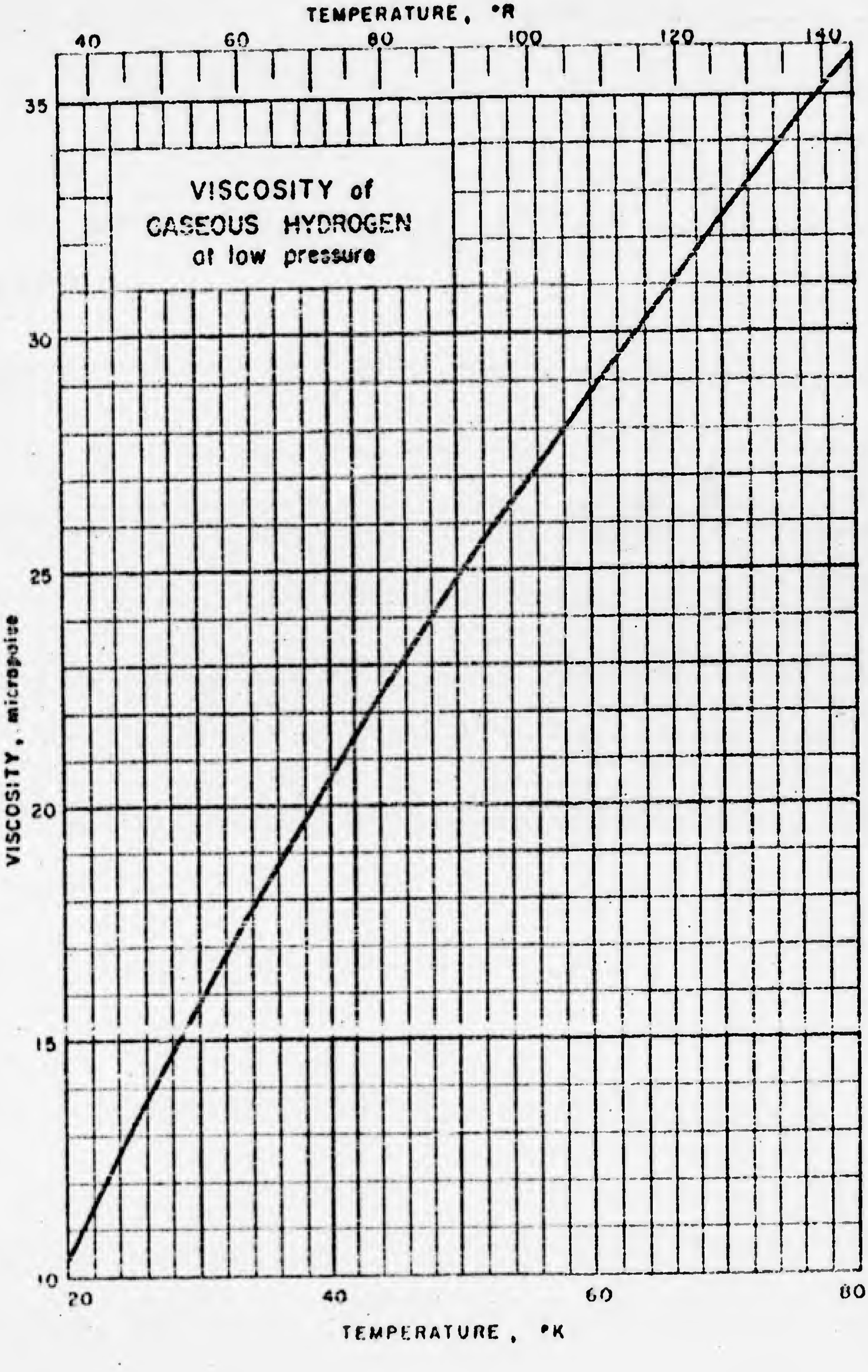
From RP 1932

Temperature °K	Viscosity micropoise
15	217
16	197
17	178
18	161
19	146
20	134.4
21	125.6

From Van Itterbeek and Van Paemel

Temperature °K	Viscosity micropoise
14.70	244.3
16.65	192.0
18.24	153.4
19.18	[illegible]
20.37	123.8

DKJ/VJJ Issued: 12/10/59


TEMPERATURE, °R
40
60
80
100
120
140
VISCOSITY of
GASEOUS HYDROGEN
at low pressure
35
30
25
20
15
10
VISCOSITY, micropoise
20
40
60
80
TEMPERATURE, °K

10.002

VISCOSITY of GASEOUS HYDROGEN at LOW PRESSURES

(From 20° to 80°K)

Source of Data: Coremans, J. M. J., Van Itterbeek, A., Beenakker, J. J. M., Knapp, H. F. P. and Zandbergen, P., Physica 24, 557 (1958).

Other References: Van Itterbeek, A. and Van Paemel, O., Physica 7, 265 (1940) (See 10.002, Viscosity of Gaseous Hydrogen from 10° to 300°K.)

Comments: The viscosity of gaseous Hydrogen measured at a constant pressure of 10 cm of Hg varies linearly between the temperatures 20° and 40°K and corresponds to a first approximation to

$$\eta = 0.5\ T + 0.32$$

While the viscosity measured at a constant pressure of 10 cm of Hg between 40° and 80°K varies as a function of temperature to a first approximation according to the equation

$$\eta = 0.4\ T + 4.7$$

Below 20°K, the above equations are no longer valid. The reduced viscosity of gaseous Hydrogen derived from quantum mechanical considerations deviates from the classical theoretical curve, and to a first approximation is represented by plotting

$$\frac{\eta^*}{\sqrt{T^*}} \text{ vs } T^*$$

η^* = reduced viscosity
T^* = reduced temperature

The data plotted are the smoothed values from the table of selected data and identified by an asterisk.

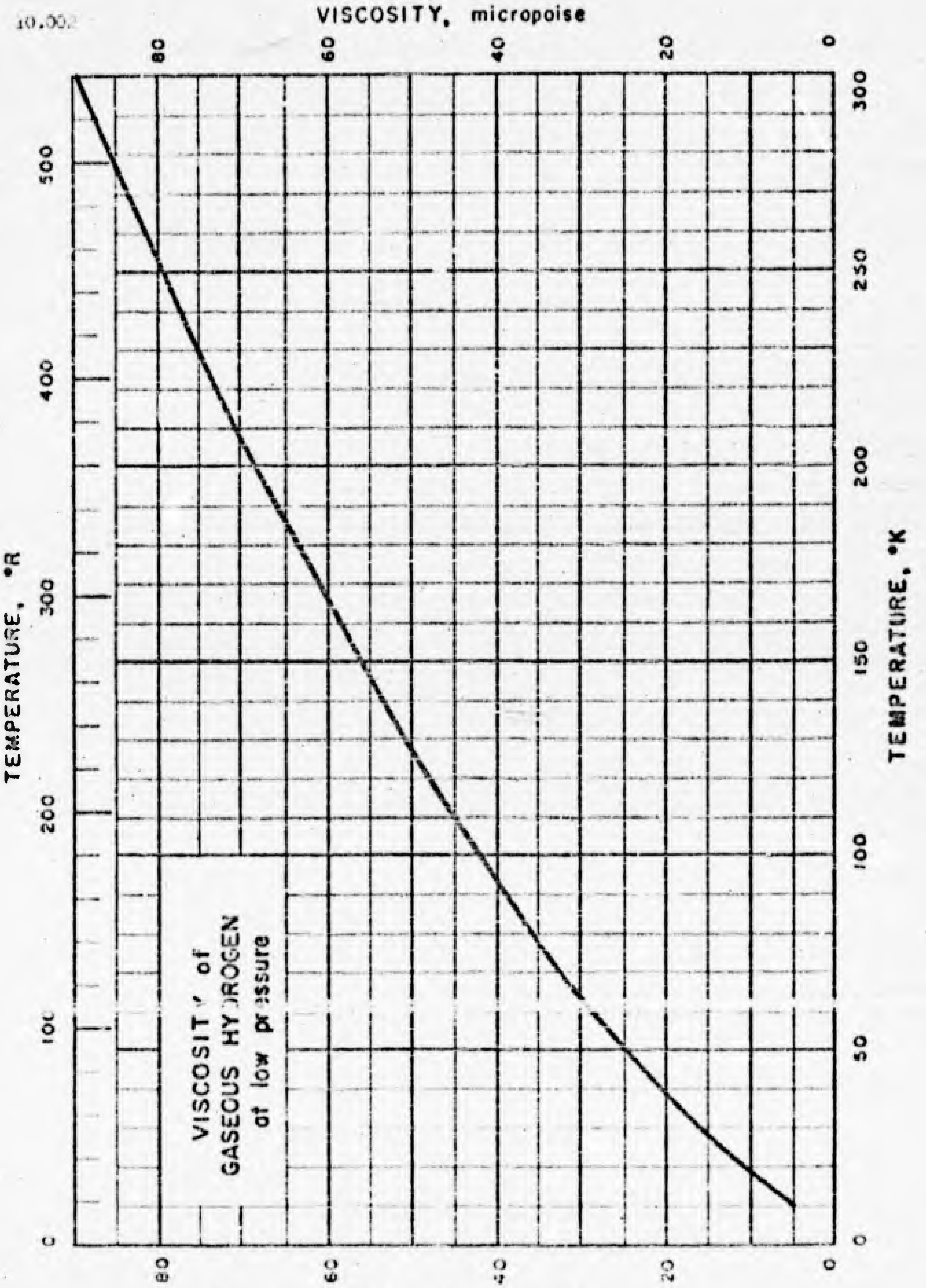
Table of Selected Values

Temp. °K	Viscosity micropoise	Temp. °K	Viscosity micropoise
20.00	10.4*	47.86	23.6
20.46	10.5	50.00	24.8*
27.42	14.6	55.45	26.9
28.87	15.1	59.68	28.5
29.20	15.5	60.00	28.7*
30.00	15.8*	70.00	32.4*
33.13	17.5	70.77	32.7
40.00	20.5*	71.77	35.3
40.03	21.2	80.00	35.9*
44.97	22.4		

* Smoothed Values

FEG/NJJ Issued: 8-27-59

10.002


VISCOSITY, micropoise
80
60
40
20
0
300
250
200
150
100
50
0
TEMPERATURE, °K
TEMPERATURE, °R
500
400
300
200
100
0
VISCOSITY, micropoise
VISCOSITY of GASEOUS HYDROGEN at low pressure

VISCOSITY of GASEOUS HYDROGEN at LOW PRESSURES

(From 10 to 300 °K)

Sources of Data: van Itterbeek and Claes, Physica 5, 938 (1938); van Itterbeek and van Paemel, Physica 7, 265 (1940); Becker and Stehl, Z. fur Physik 133, 615 (1952); Phys. Rev. 87, 525 (1952); Becker and Misenta, Z. fur Physik 140, 535 (1955); Nat. Bur. Standards Cir. 564, 234 (1955); Rietveld and van Itterbeek, Physica 23, 838 (1957).

Comments:

Values are given as of one atmosphere. Experimental data of Becker and Stehl on the difference in viscosity of ortho- and para-hydrogen at low temperatures show that para hydrogen has the greater value. However, the difference between equilibrium and ordinary hydrogen is of the order of 0.6%. Although the work of Rietveld and van Itterbeek, published in 1957, was not available at the time the N.B.S. Circular was prepared, the agreement is excellent down to 14.4 °K except for the temperatures 293 and 229 °K, as shown by the data of Rietveld and van Itterbeek shown below. The curve, as drawn, is that of N.B.S. Circular 564.

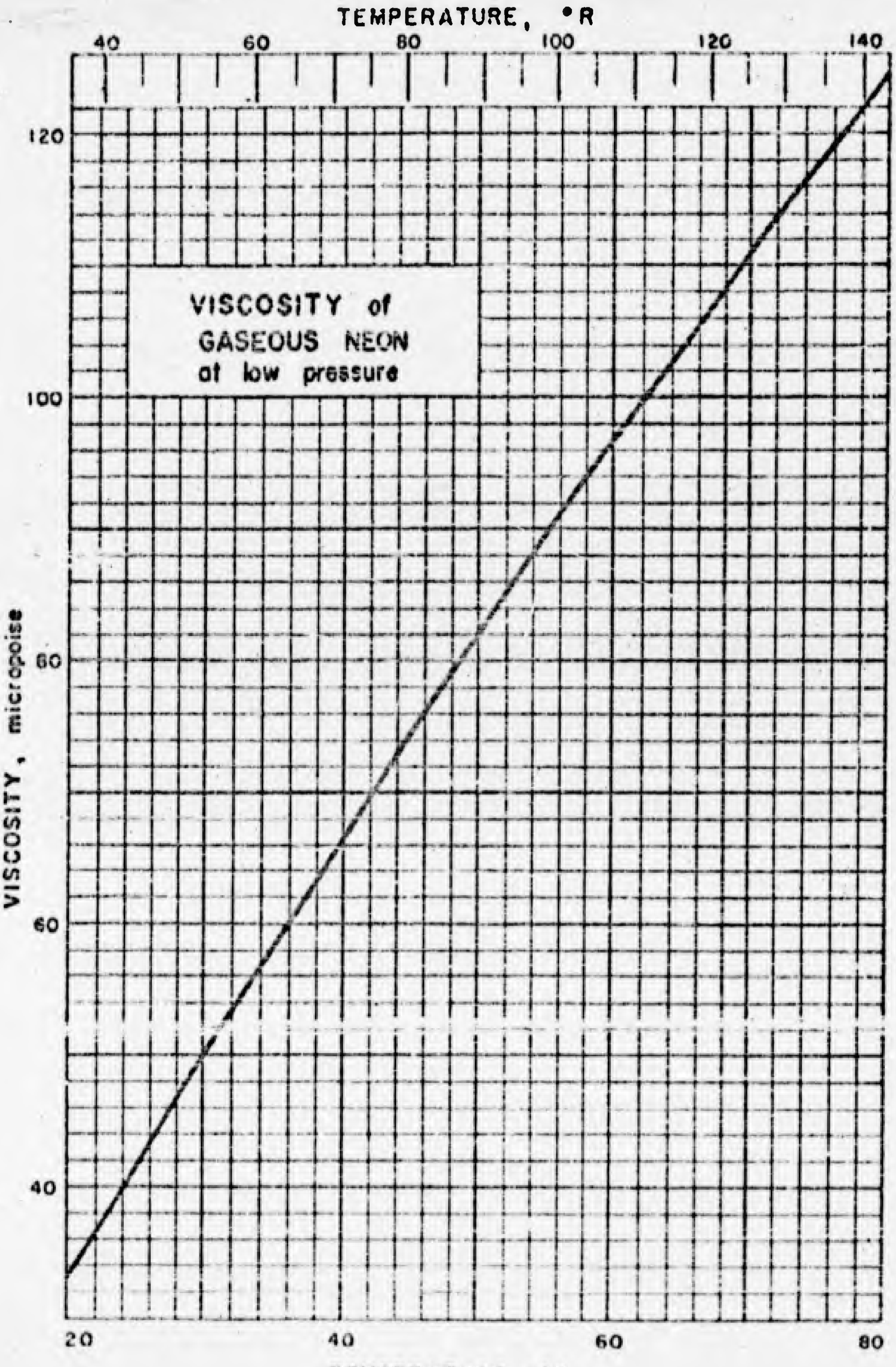
Data of Rietveld and van Itterbeek

Temp. °K	Pressure cm Hg	Viscosity micropoise
293.15	3.23	86.69
229.0	3.89	74.2
196.0	3.85	66.97
90.1	3.34	39.49
71.5	3.17	32.87
20.4	0.94	11.32
14.4	0.67	7.89

Data from NBS Circular 564

Temp. °K	Viscosity micropoise	Temp. °K	Viscosity micropoise
10	5.0971	160	58.515
20	10.926	180	63.427
30	16.065	200	68.129
40	20.674	220	72.679
50	24.888	240	77.078
60	28.757	260	81.351
80	35.789	270	83.454
100	42.105	280	85.523
120	47.926	300	89.594
140	53.376		

FERG/VJJ Issued: 9-3-59


TEMPERATURE, °R
40
60
80
100
120
140
VISCOSITY of
GASEOUS NEON
at low pressure
VISCOSITY, micropoise
120
100
80
60
40
20
40
60
80
TEMPERATURE, °K

10.003

VISCOSITY of GASEOUS NEON at LOW PRESSURES
(From 20° to 80°K)

Source of Data: Coremans, J. M. J., Van Itterbeek, A., Beenakker, J. J. M., Knapp, H. F. P. and Zandbergen, P., Physica 24, 557 (1958).

Other References: Van Itterbeek, A. and Van Paemel, O., Physica 7, 265 (1940). (See data sheet 10.003, Viscosity of Gaseous Neon at One Atmosphere Pressure, 20° to 300°K.)

Comments: The viscosity of gaseous Neon measured at a constant pressure, 3 cm of Hg, varies in a nearly linear manner between 20° and 80°K according to the equation

$$\eta = 1.55\, T + 2.4$$

Below 20°K the above equation is no longer valid. The reduced viscosity of gaseous Neon derived from quantum mechanical consideration is valid to a first approximation over a narrow temperature range and is represented by plotting

$$\frac{\eta^*}{\sqrt{T^*}} \text{ vs } T^*$$

η^* = reduced viscosity
T^* = reduced temperature

At the pressure used, 3 cm Hg, the viscosity of gaseous Neon is essentially constant for a given temperature. However, below a pressure of 1.0 cm Hg, the viscosity of gaseous Neon varies markedly at a given temperature.

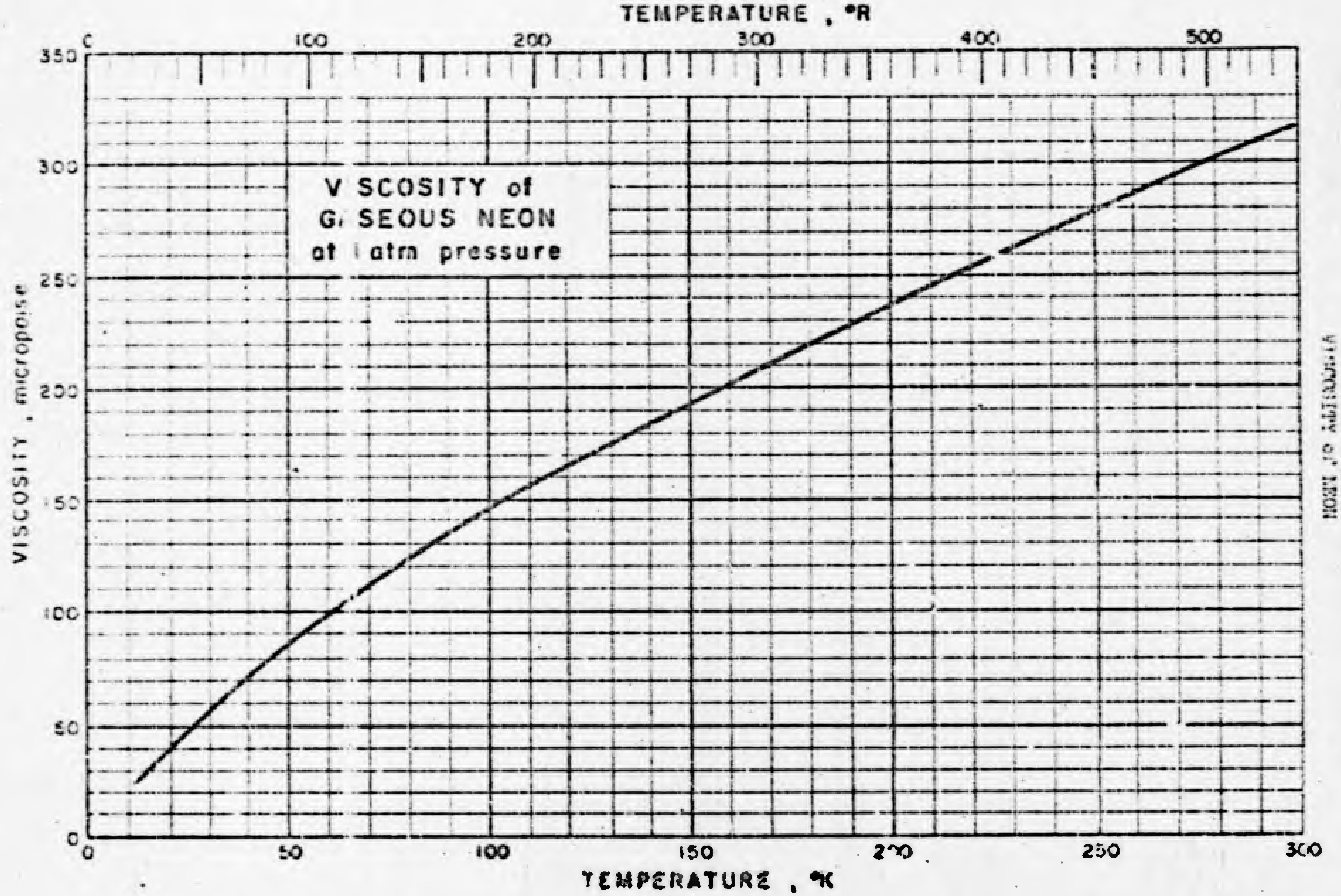
The data plotted are the smoothed values from the table of selected data and identified by an asterisk.

Table of Selected Values

Temp. °K	Viscosity micropoise	Temp. °K	Viscosity micropoise
20.00	33.0*	50.00	81.8*
20.43	33.6	52.11	85.4
20.47	33.9	59.98	96.4
[illegible]	[illegible]	[illegible]	[illegible]
26.31	43.0	60.71	97.4
29.64	50.3	61.64	98.9
30.00	50.0*	68.15	108.0
31.80	52.5	70.00	110.8*
39.52	64.9	70.18	111.2
40.00	66.3*	71.20	112.4
40.28	67.0	73.28	115.1
46.50	76.6	77.77	121.1
49.97	80.4	80.00	124.5*

* Smoothed Values

KDT/RJR Issued: 9/14/59


V SCOSITY of
G. SEOUS NEON
at 1 atm pressure
TEMPERATURE , °R
0
100
200
300
400
500
VISCOSITY , micropoise
0
50
100
150
200
250
300
350
TEMPERATURE , °K
0
50
100
150
200
250
300

VISCOSITY of GASEOUS NEON
(At one atmosphere pressure)

Source of Data: Edwards, R. S., Proc. Roy. Soc. (London), A119, 578-90 (1928); van Itterbeek, A. and van Paemel, O., Physica, 7, 265-72 (1940); Johnston, H. L. and Grilly, E. R., J. Phys. Chem., 46, 948-63 (1942); Rankine, A. O., Physik. Z., 11, 497-502 (1910); Rietveld, A. O., and van Itterbeek, A., Physica, 22, 785-90 (1956); Saulgeot, A. M., Compt. rend., 230, 922-3 (1950); Trautz, M. and Zink, R., Ann. Physik, 7, 427-52 (1930).

Comments: Two equations which may be used to calculate the viscosity of neon gas at one atmosphere are:

$$(1) \quad \frac{\mu}{\mu_0} = \left[\frac{T}{T_0}\right]^{0.77}$$

where μ_0 is measured at T_0 and the temperature is between -180 and 20 °C; and

$$(2) \quad \mu \cong \frac{T^{0.6}}{1 + \frac{2.0}{T}}$$

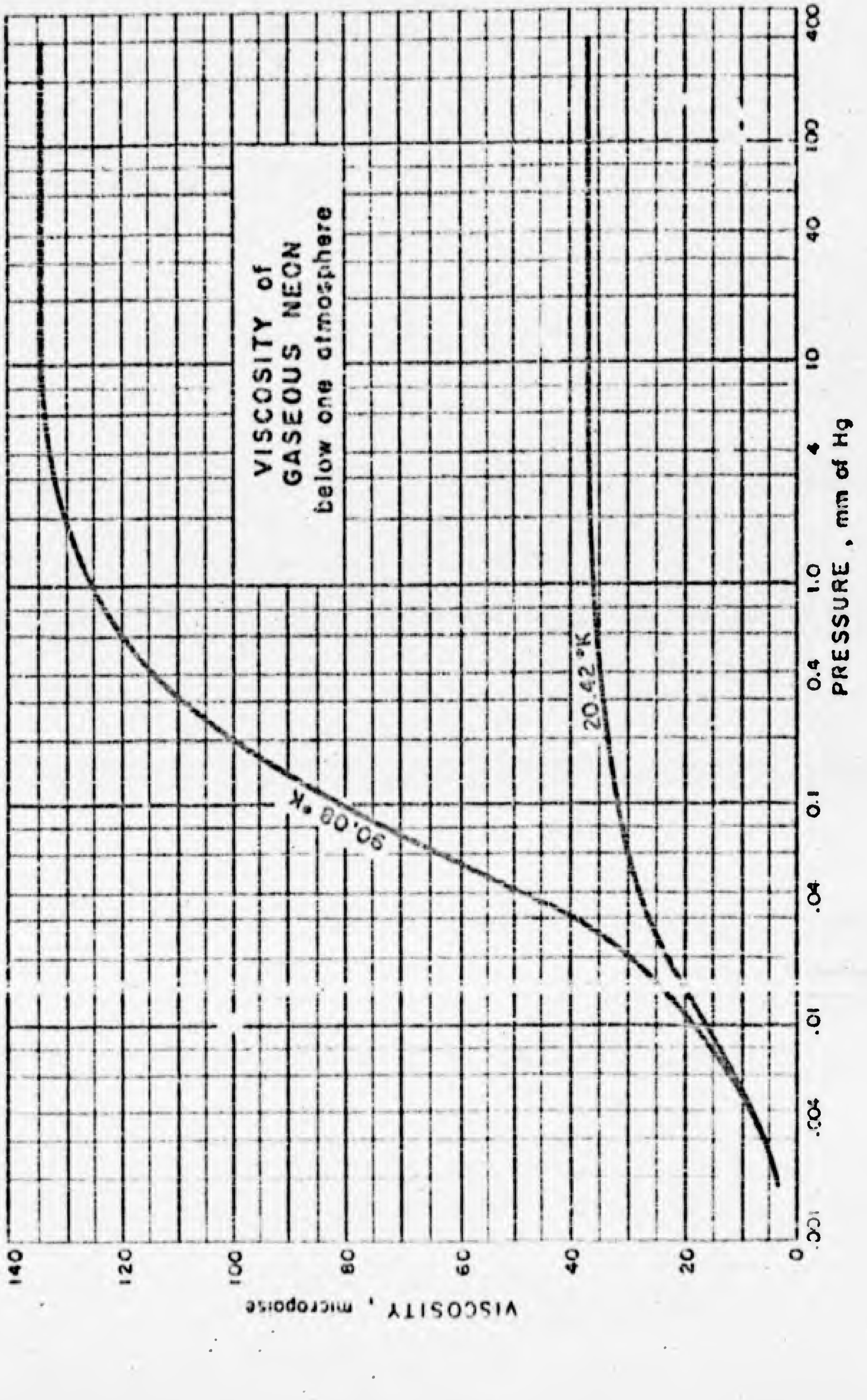
where the temperature is between 20° and 800 °C.

Table of Values

Temp. °K	Viscosity Centipoises	Temp. °K	Viscosity Centipoises	Temp. °K	Viscosity Centipoises
16.49	3.059 x 10^{-3}	100.0	14.345 x 10^{-3}	230.0	26.265 x 10^{-3}
17.76	3.218 "	110.0	15.425 "	240.0	27.080 "
19.04	3.396 "	120.0	16.460 "	250.0	27.880 "
20.42	3.593 "	130.0	17.450 "	260.0	28.665 "
58.60	9.48 x 10^{-3}	140.0	18.405 x 10^{-3}	270.0	29.435 x 10^{-3}
64.25	10.43 "	150.0	19.340 "	273.1	29.675 "
68.52	10.90 "	160.0	20.255 "	280.0	30.205 "
72.11	11.40 "	170.0	21.155 "	283.2	31.5 "
72.3	11.72 x 10^{-3}	180.0	22.040 x 10^{-3}	288.1	30.76 x 10^{-3}
77.37	12.08 "	190.0	22.910 "	290.0	30.965 "
80.0	11.980 "	193.4	23.52 "	291.1	31.29 "
83.45	12.89 "	194.7	23.67 "	291.1	31.40 "
90.0	13.200 x 10^{-3}	200.0	23.755 x 10^{-3}	292.6	31.32 x 10^{-3}
90.08	13.44 "	210.0	24.600 "	293.1	31.210 "
90.20	13.47 "	220.0	25.435 "	296.1	31.435 "
90.3	13.52 "	229.0	26.7 "	298.1	31.580 "
				300.0	31.725 "

KDT/BDT/VJJ Issued: 6/2/59

VISCOSITY of NEON



10.003

VISCOSITY of GASEOUS NEON

(Below 1 atmosphere at 20.42°K and 90.08°K)

Source of Data:

Van Itterbeek, A. and Van Paemel, O., Physica, 7: 273-83 (1940).

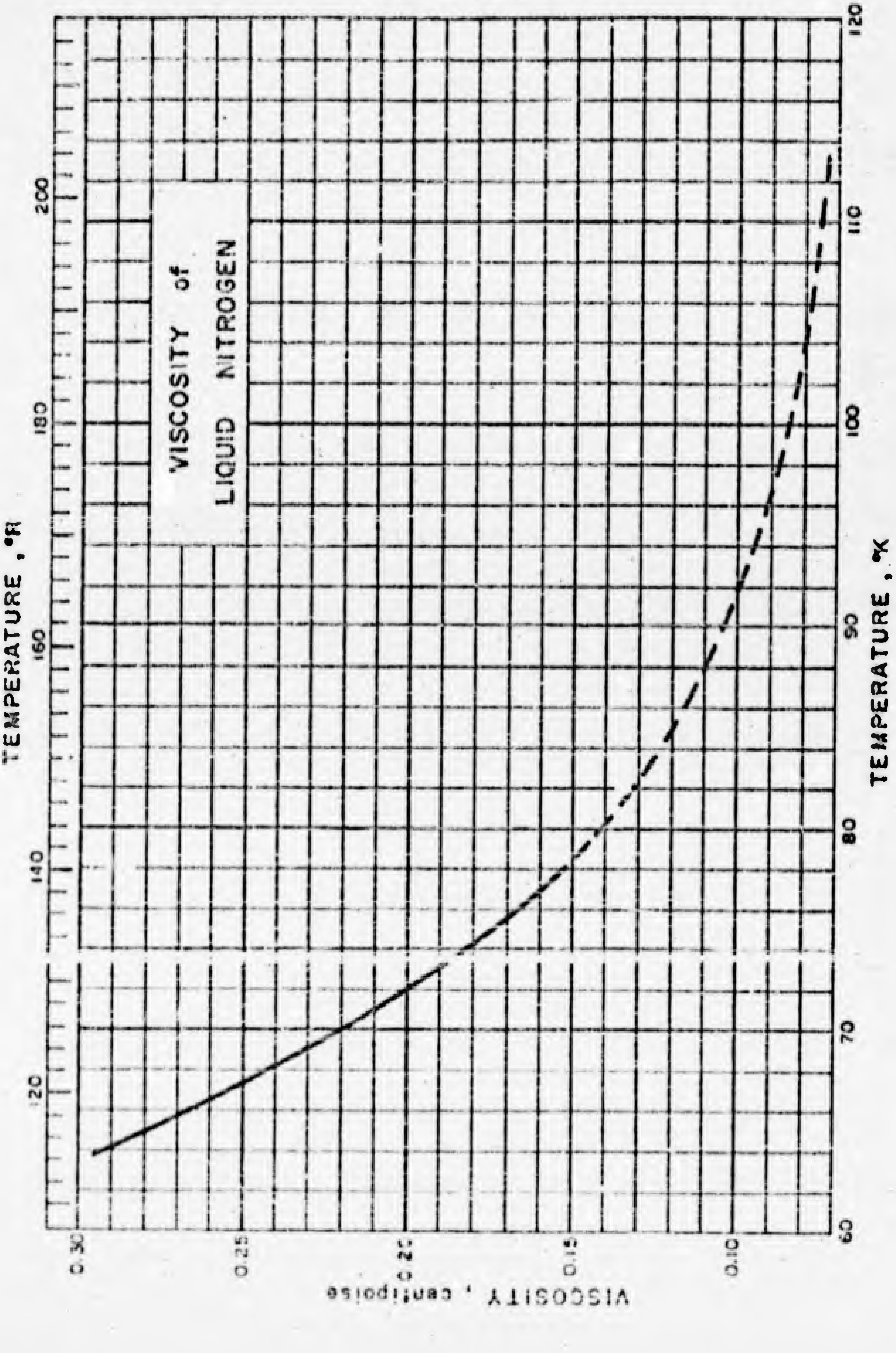
Table of Selected Values

T = 20.42°K			T = 90.08°K		
Observed Pressure mm Hg	Corrected Pressure mm Hg	Viscosity Centipoise	Observed Pressure mm Hg	Corrected Pressure mm Hg	Viscosity Centipoise
300.0		3.593×10^{-3}	300.0		13.44×10^{-3}
3.71		3.593 "	37.8		13.429 "
0.696		3.441 "	9.51		13.406 "
0.217	0.216	3.339 "	2.186		13.034 "
0.0970	0.0944	3.165 "	1.149		12.677 "
0.0465	0.0442	2.846 "	0.600		12.095 "
0.0245	0.0220	2.441 "	0.312		11.054 "
0.01107	0.00887	1.655 "	0.1528	0.1513	9.389 "
0.00498	0.00339	0.925 "	0.0772	0.0754	6.965 "
0.00218	0.00120	0.398 "	0.0352	0.0329	4.419 "
			0.0222	0.0200	3.139 "
			0.01083	0.00903	1.588 "
			0.00521	0.00395	0.775 "

KDT/BDT Issued: 6/5/59

10.004

VISCOSITY of NITROGEN



10.004

VISCOSITY of LIQUID NITROGEN

Source of Data:

Rudenko, N. S., J. Exptl. Theoret. Phys. (U.S.S.R.) 9, 1078-80 (1939)

Rudenko, N. S. and Shubnikov, L. V., Phys. Zeit. Sowjetunion 6, 470-7 (1934)

Table of Selected Values

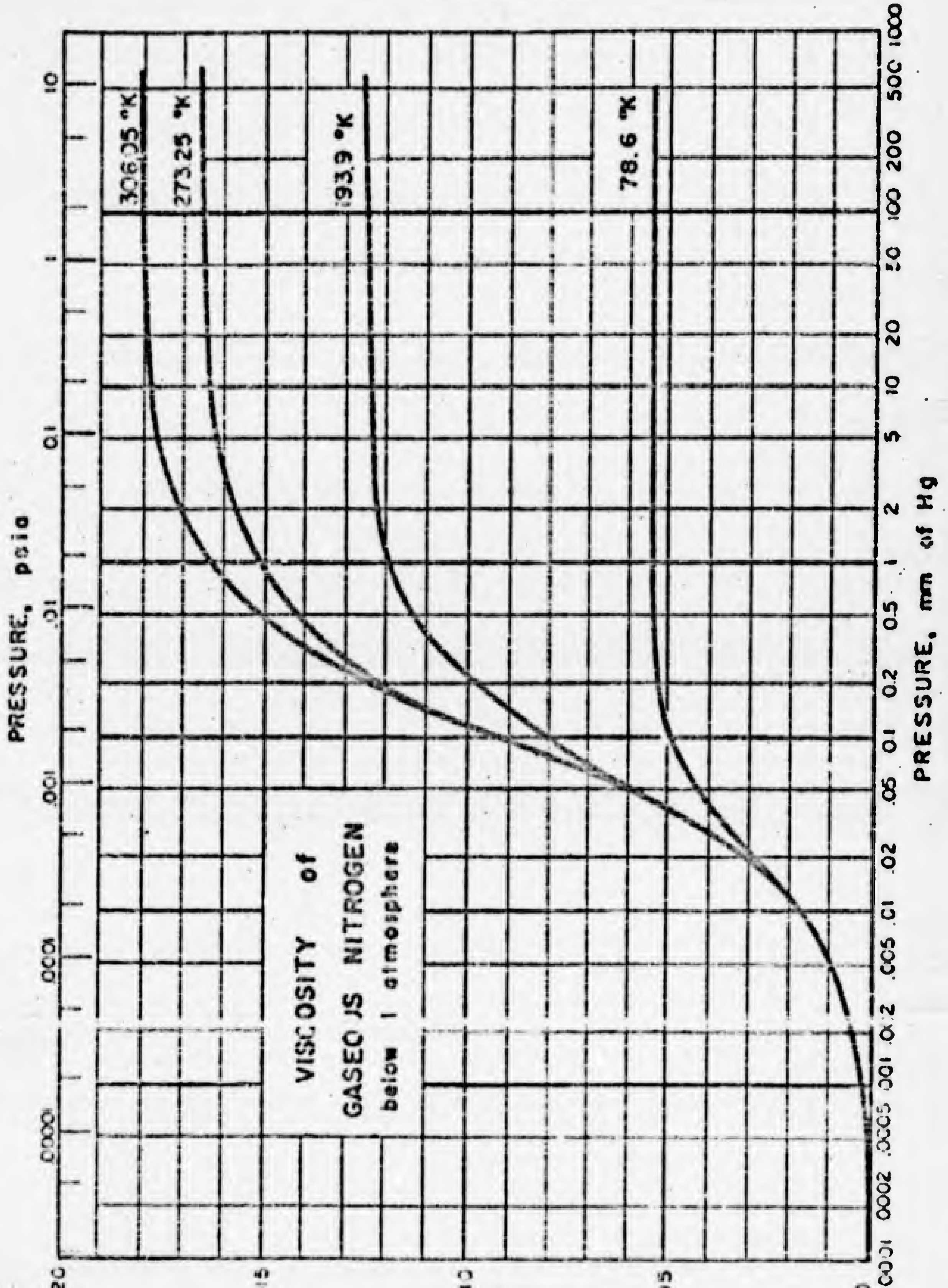
Temp. °K	Viscosity centipoise
63.9	0.292
64.3	0.290
64.8	0.284
69.1	0.231
69.25	0.228
71.4	0.209
76.1	0.165
77.33	0.158
111.7	0.074

Triple Point Temp. = 63.14°K
Normal Boiling Temp. = 77.35°K
Critical Temperature = 126.26°K

KDT/DDT Issued: 5-25-59

10.004

VISCOSITY of NITROGEN



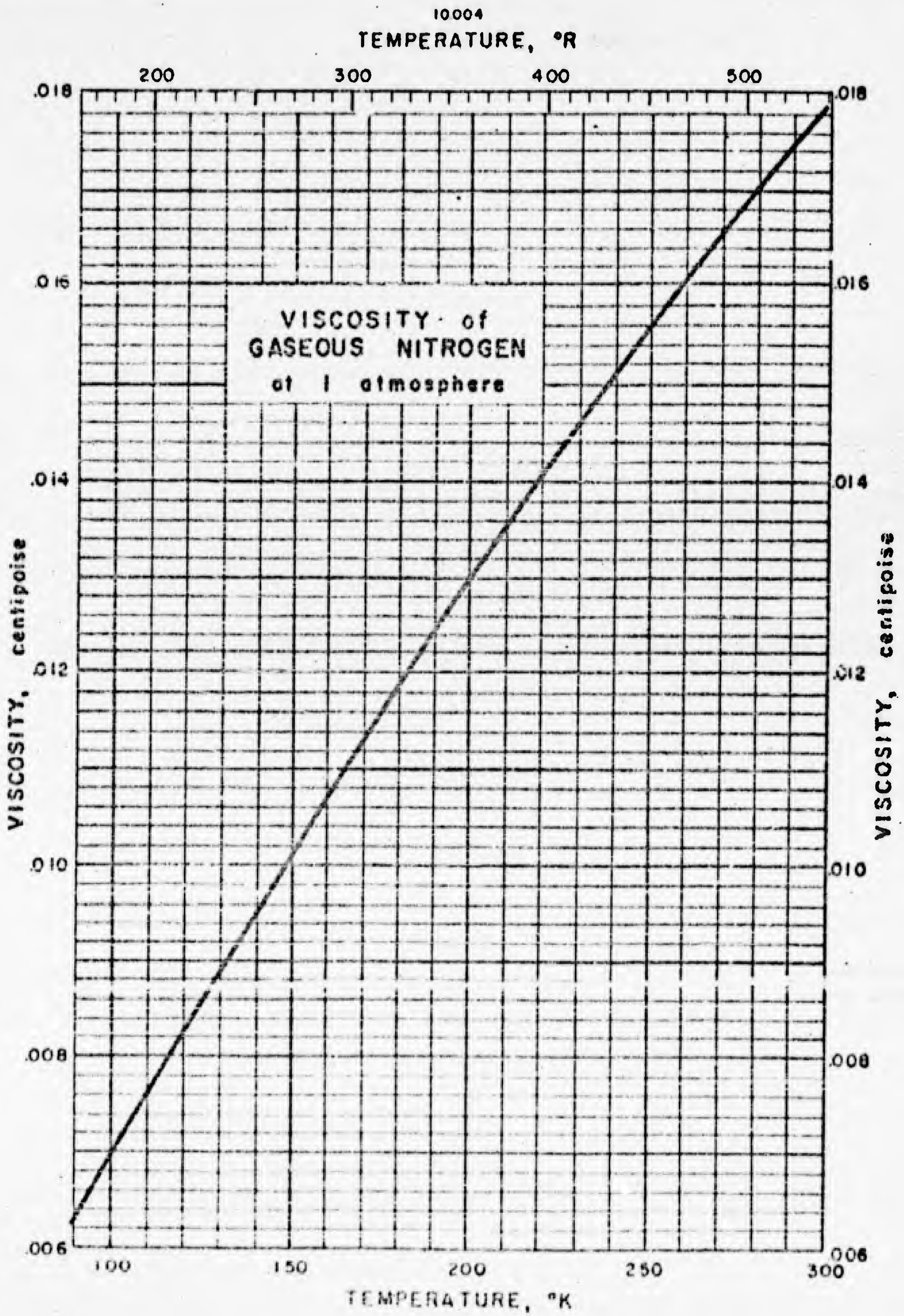
VISCOSITY of GASEOUS NITROGEN
(Below 1 Atmosphere)

Source of Data: Johnston, H. L., Mattox, R. W. and Powers, R. W., NACA Tech. Note 2546 (Nov. 1951).

Table of Selected Values

Press. mm Hg	Viscosity centipoise	Press. mm Hg	Viscosity centipoise
78.60°K		193.90°K	
0.132	0.005 162	0.353	0.010 790
0.220	.005 244	0.816	.011 778
0.440	.005 401	1.98	.012 270
1.17	.005 412	4.32	.012 433
2.60	.005 442	9.04	.012 503
4.76	.005 472	72.5	.012 563
8.56	.005 481	102.0	.012 576
70.0	.005 502*	417.5	.012 587
104.0	.005 495		
295.0	.005 495		
* doubtful			
273.25°K		306.05°K	
0.000 026	0.000 031	0.000 17	0.000 0675
0.000 41	.000 095	0.001 0	.000 234
0.003 0	.000 534	0.006 2	.001 033
0.011	.001 856	0.012	.001 993
0.022	.003 257	0.027	.003 594
0.034	.004 454	0.056	.006 142
0.097	.009 372	0.100	.009 [illegible]
0.270	.012 498	0.243	.013 084
0.485	.013 987	0.574	.015 257
1.12	.015 156	1.15	.016 513
2.34	.015 954	2.38	.017 355
[illegible]	[illegible]	[illegible]	[illegible]
6.66	.016 372	9.62	.017 882
70.0	.016 583	68.0	.018 048
98.0	.016 594	100.0	.018 071
403.0	.016 610	310.0	.018 092
550.0	.016 617	503.0	.018 092

KIT/EDT Issued: 5/25/59


10004
TEMPERATURE, °R
200
300
400
500
.018
.016
.014
.012
.010
.008
.006
VISCOSITY of
GASEOUS NITROGEN
at 1 atmosphere
VISCOSITY, centipoise
100
150
200
250
300
TEMPERATURE, °K

VISCOSITY of GASEOUS NITROGEN
(At 1 Atmosphere)

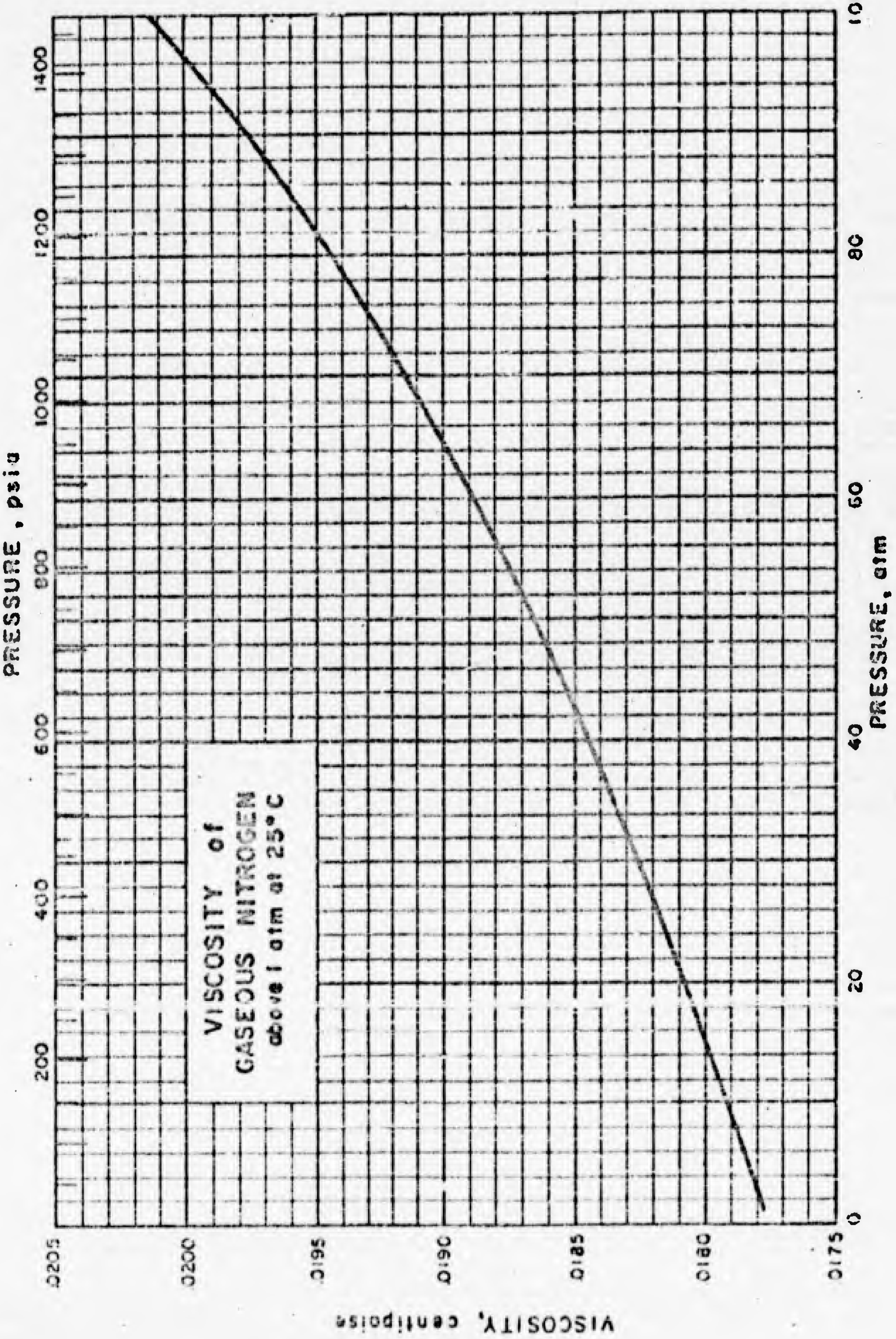
Source of Data: Johnston, H. L. and McCloskey, K. E., J. Phys. Chem. 44, No. 9, 1038-58 (1940).

Table of Selected Values

Temp. °K	Viscosity centipoise	Temp. °K	Viscosity centipoise
90	0.006 298	210	0.013 499
100	.006 975	220	.014 029
110	.007 631	230	.014 547
120	.008 264	240	.015 052
130	.008 876	250	.015 547
140	.009 484	260	.016 031
150	.010 083	270	.016 502
160	.010 676	280	.016 960
170	.011 253	290	.017 410
180	.011 829	298.1	.017 777
190	.012 394	300	.017 857
200	.012 954		

[illegible] Issued: 7/13/59

10.004 VISCOSITY of NITROGEN



10.004

VISCOSITY of GASEOUS NITROGEN
(Above 1 Atmosphere)

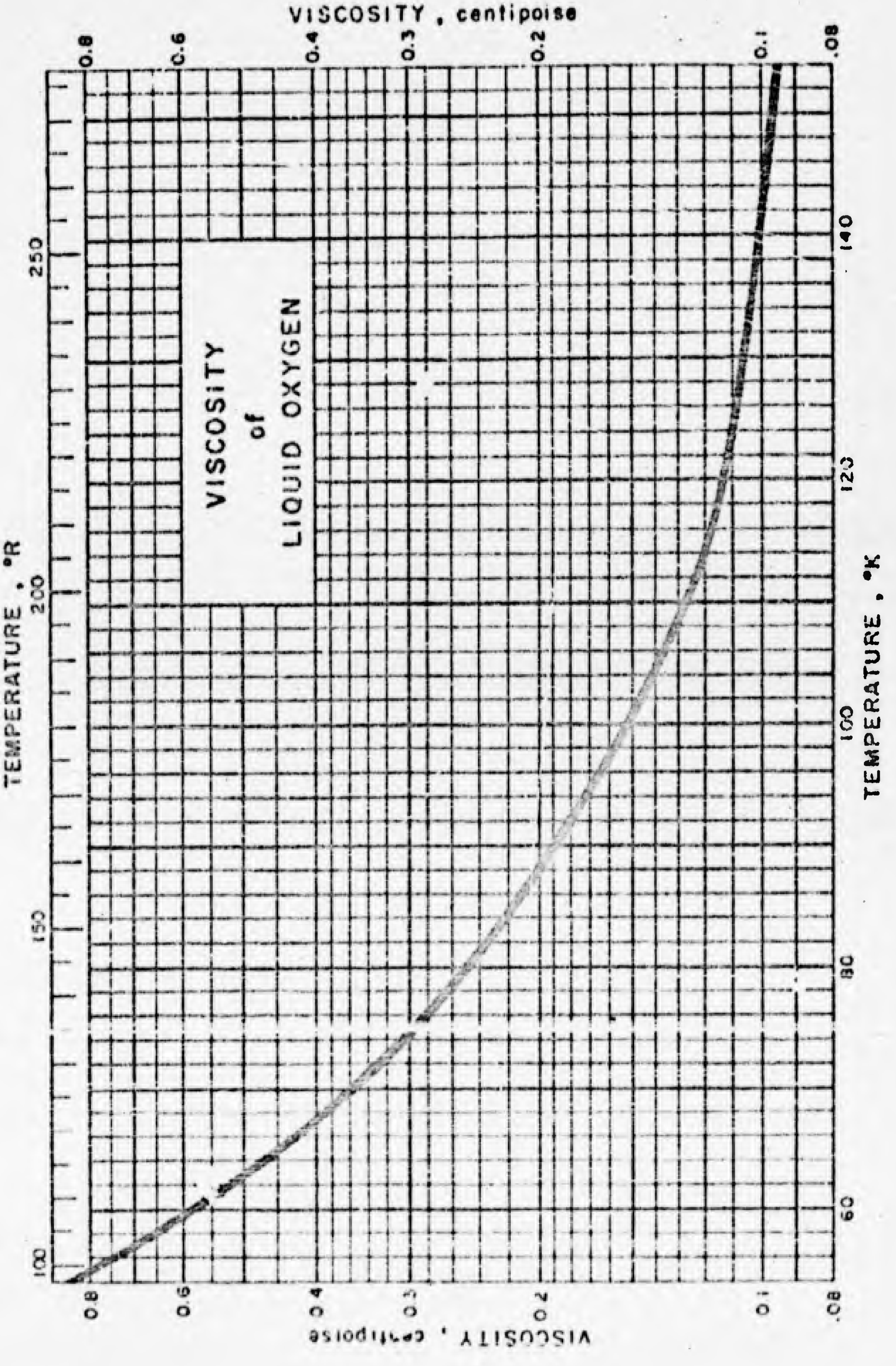
Source of Data: Kestin, J. and Wang, H. E., Trans. ASME 80, 11-17 (1958).

Comments: The best data available at 25°C seems to be that given below. It is to be preferred over that recommended by NBS Circular 564 (Nov. 1955) because the experimental values agree better with investigations made by other researchers. It is recommended over Savino, J. M., Ph. D. Dissertation; "Dynamic Viscosity of Nitrogen and Carbon Dioxide at High Pressures", Univ. of Purdue, (Jan. 1955) because a check on the viscosity of the latter at 1 atm and 25°C gives a value for viscosity which is low (0.01765 cp) as compared to that given by Kestin and Wang (0.01778 cp). Consequently, the values of Savino are low over the entire range. However, his values may be used to extend the values of Kestin and Wang out to 4000 psia.

Table of Selected Values

T = 25°C	
Pressure atm.	Viscosity centipoise
1	0.017 78
2	.017 80
5	.017 84
10	.017 93
20	.018 09
30	.018 27
40	.018 46
50	.018 67
60	.018 90
70	.019 16
80	.019 46*
90	.019 78*
100	.020 15*

* extrapolated


VISCOSITY , centipoise
0.8
0.6
0.4
0.3
0.2
0.1
.08
VISCOSITY of LIQUID OXYGEN
TEMPERATURE , °R
100
150
200
250
TEMPERATURE , °K
60
80
100
120
140
VISCOSITY , centipoise

10.005

VISCOSITY of LIQUID OXYGEN

Sources of Data:

Rudenko, N. S., J. Exptl. Theoret. Phys. (U.S.S.R.) 9, 1078 (1939)

Rudenko, N. S. and Shubnikow, L. V., Physik. Z. Sowjetunion 6, 470-7 (1934)

Other References:

Scott, R. B., Cryogenic Engineering, 1, D. Van Nostrand Co., Inc., New York, N. Y. (1959) p. 274.

Comments:

Rudenko and Shubnikow give values for viscosity of liquid oxygen from near the triple point (54.36°K) to near the normal boiling temperature (90.19°K). Values of viscosity from the normal boiling temperature to the critical temperature (154.7°K) were obtained from the graph found on page 274 of Cryogenic Engineering by Scott. These data are given in Tables I and II below respectively.

Table I

Data of Rudenko, N. S. and Shubnikov L. V.	
Temperature °K	Viscosity η (poise)
54.4	0.008 73
54.5	.008 63
54.6	.008 21
54.9	.007 72
56.4	.007 17
57.1	.006 38
57.4	.006 48
59.7	.006 31
61.7	.005 21
63.5	.004 76
65.4	.004 35
68.9	.003 77
72.3	.003 23
77.4	.002 73
[illegible]	[illegible]
90.1	.001 90

Table II

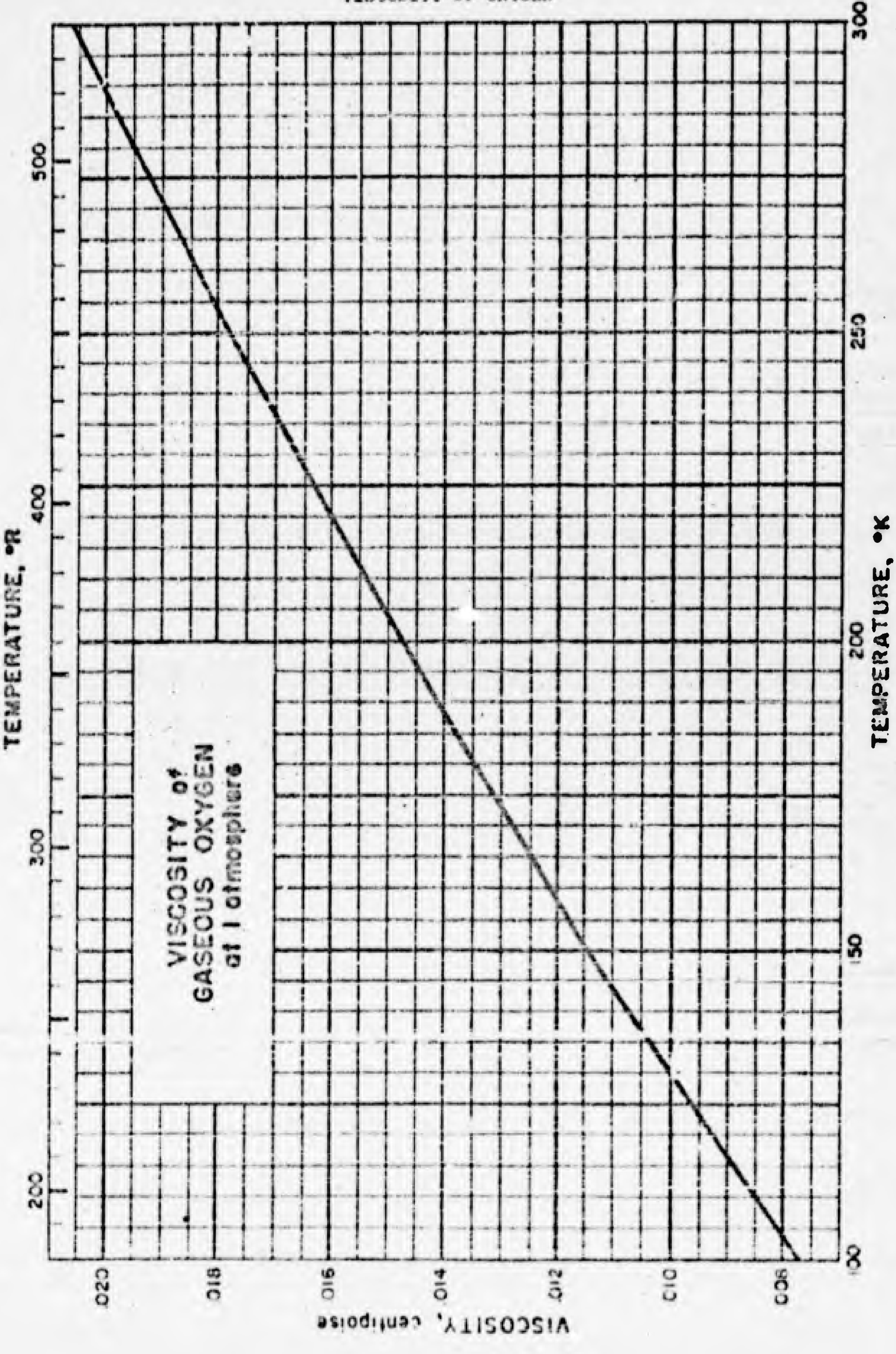
Data of Rudenko, N. S.*	
Temperature °K	Viscosity η (poise)
90	0.001 90
111	.001 23
112	.001 21
125.8	.001 10
138.2	.001 00
145.5	.000 98
154.1	.000 90

* Taken from graph p. 274 Cryogenic Engineering

DEJ/VJJ Issued: 12/10/59

10.005

VISCOSITY of OXYGEN



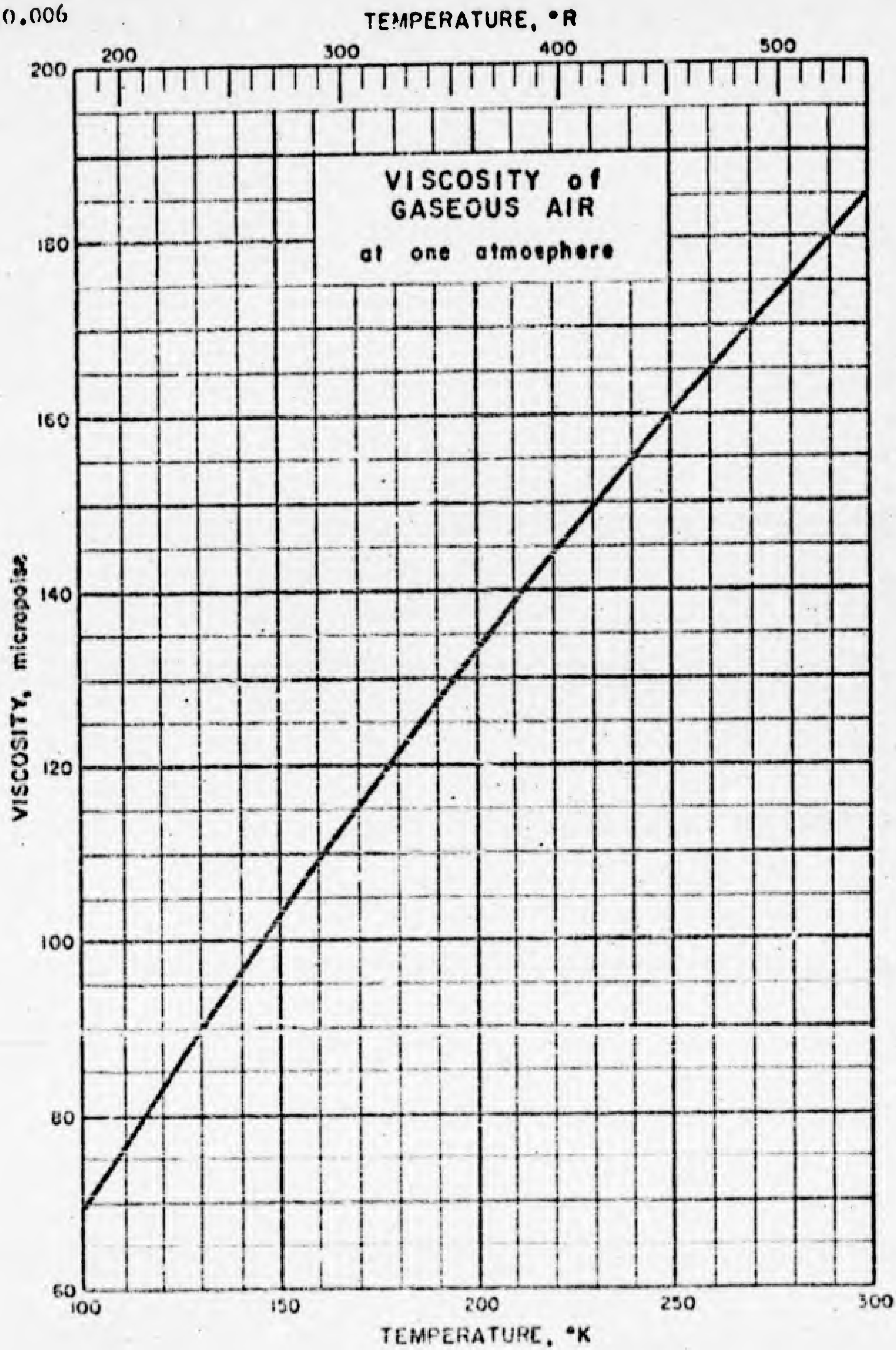
VISCOSITY of GASEOUS OXYGEN

Source of Data: Hilsenrath, J., et al., Nat. Bur. Standards Cir. 564, 424 (1955).

Comments: The data were presented in the form of μ/μ_0, the ratio of the actual viscosity to the viscosity at standard conditions (1 atm, 0°C). This ratio was converted to μ in centipoise by multiplying by 1.9192×10^{-2}. The values are given as of one atmosphere but do not vary significantly with pressure.

Temp. °K	Viscosity Centipoise	Temp. °K	Viscosity Centipoise
100	7.715×10^{-3}	200	14.775×10^{-3}
110	8.500 "	210	15.400 "
120	9.225 "	220	16.000 "
130	10.000 "	230	16.620 "
140	10.725 "	240	17.200 "
150	11.440 "	250	17.790 "
160	12.135 "	260	18.350 "
170	12.820 "	270	19.000 "
180	13.490 "	280	19.450 "
190	14.140 "	290	20.000 "
		300	20.645 "

JM/BDT Issued: 7/17/59


TEMPERATURE, °R
200
300
400
500
VISCOSITY of GASEOUS AIR
at one atmosphere
VISCOSITY, micropoise
200
180
160
140
120
100
80
60
100
150
200
250
300
TEMPERATURE, °K

VISCOSITY of GASEOUS AIR

Source of Data: NBS Circular 564 (1955)

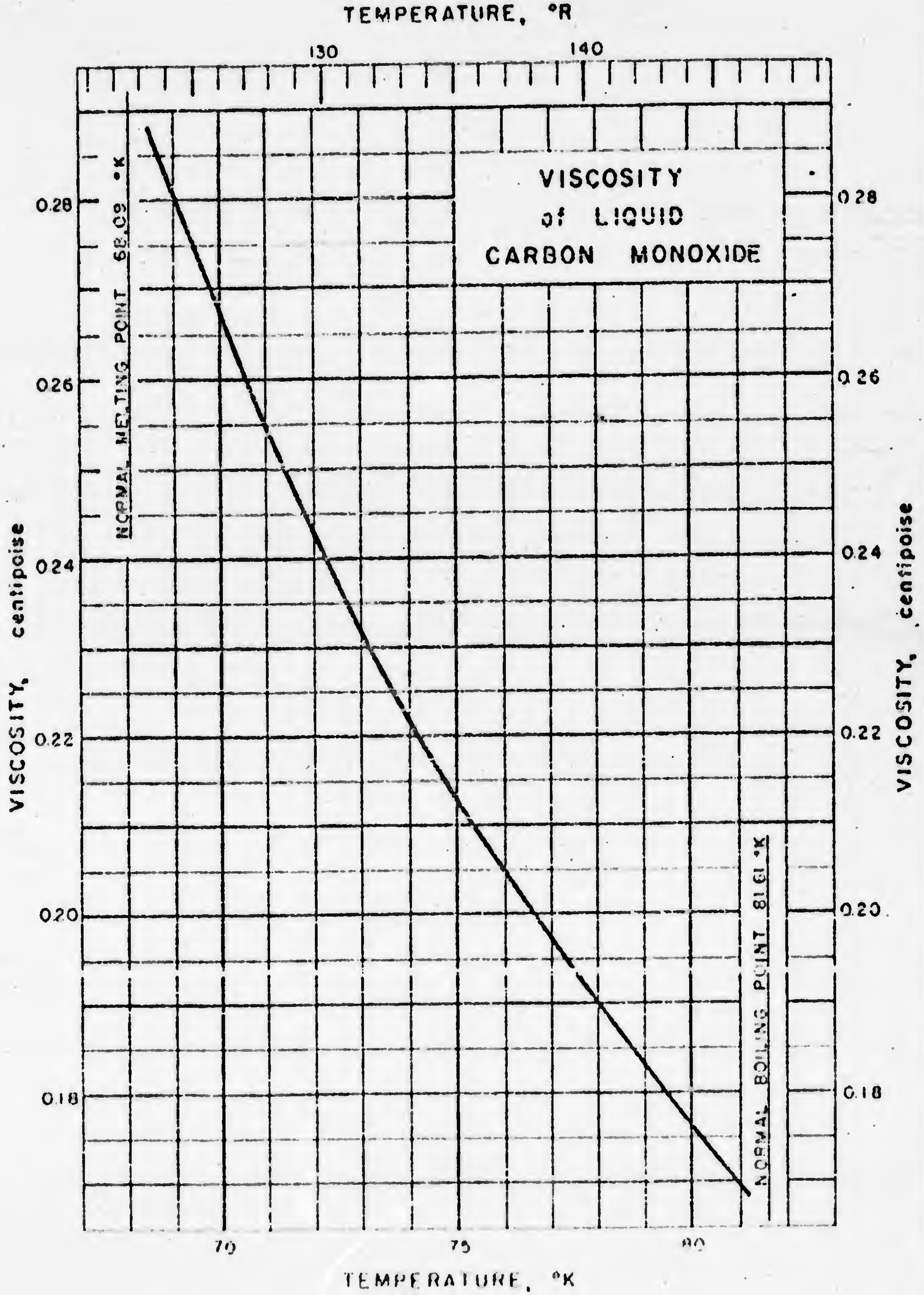
Other References: Johnston and McCloskey, J. of Phys. Chem., 44, 1038 (1940).

Comments: The data of Johnston and McCloskey are included in the data of NBS Circular 564. The data are presented at one atmosphere pressure.

Table of Selected Values

Temperature		Viscosity	
°K	°R	micropoise	lb/hr-ft
100	180	69.29	0.01676
120	216	83.19	.02012
140	252	96.46	.02333
160	288	109.1	.02640
180	324	121.2	.02933
200	360	132.8	.03214
220	396	144.0	.03483
240	432	154.7	.03742
260	468	165.0	.03992
280	504	175.0	.04234
300	540	184.6	.04466

DAV/WJV Issued: 8/4/59


TEMPERATURE, °R
130
140
VISCOSITY
of LIQUID
CARBON MONOXIDE
NORMAL MELTING POINT 68.09 °K
NORMAL BOILING POINT 81.61 °K
0.28
0.26
0.24
0.22
0.20
0.18
VISCOSITY, centipoise
70
75
80
TEMPERATURE, °K

VISCOSITY of LIQUID CARBON MONOXIDE

Sources of Data:

Itterbeek, van A., and Paemel, van O., Physica 8, 133-43 (1941).

Rudenko, N. S. and Shubnikov, L. V., Physik. Z. Sowjetunion 6, 470-7 (1934).

Comments:

The experimental points tabulated below fit the following equation:

$$\frac{1}{\mu} = 4440 - 4800\rho$$

μ = viscosity in poise
ρ = density in grams/cm^3

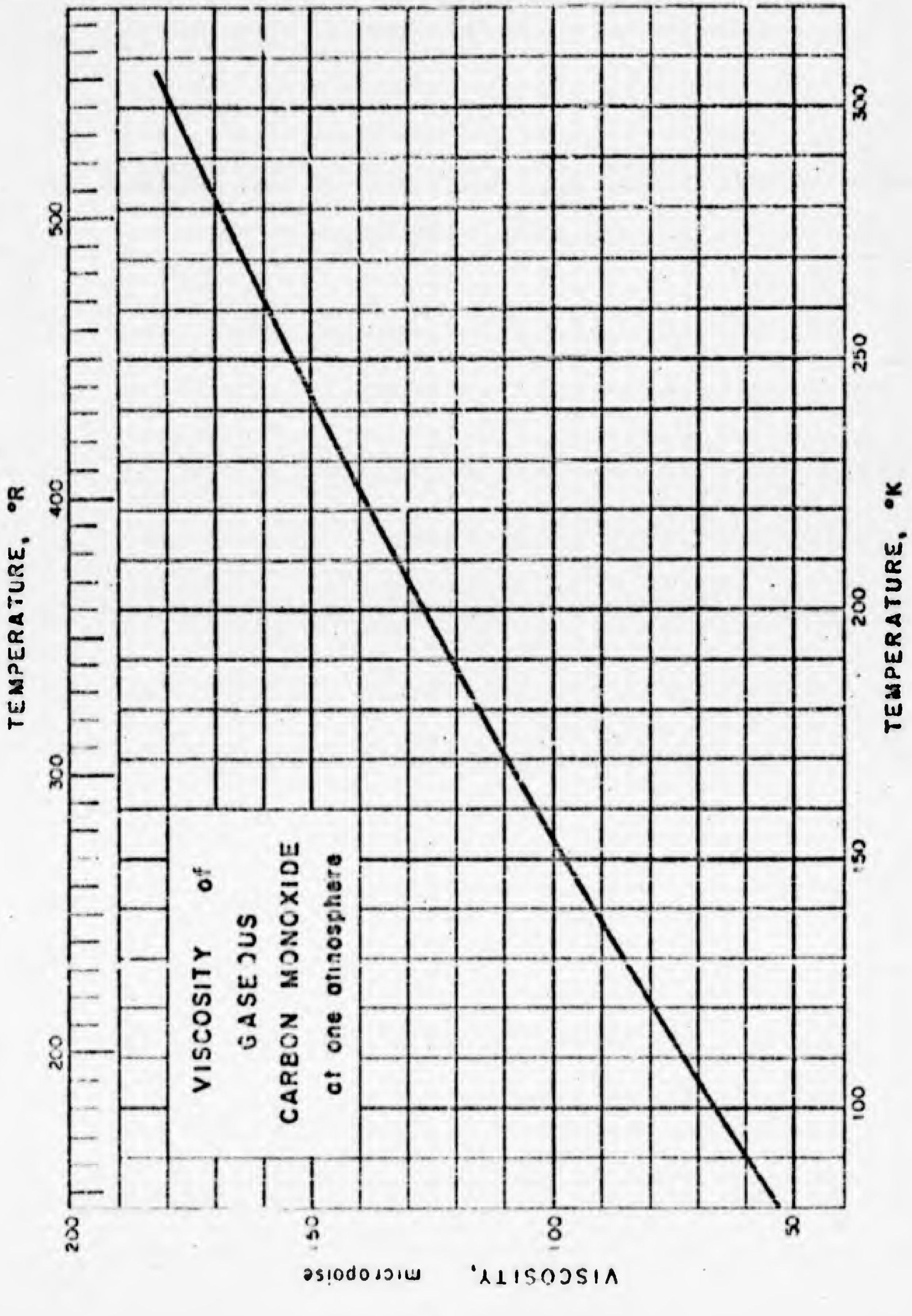
Table of Selected Values

Temp. °K	Viscosity centipoise
68.6	0.287
68.6	0.286
72.0	0.244
72.4	0.237
77.7	0.192
80.8	0.171
80.9	0.170

Normal Melting Temp. = 68.09°K
Normal Boiling Temp. = 81.61°K

10.007

VISCOSITY of GASEOUS CARBON MONOXIDE



10.007

VISCOSITY of GASEOUS CARBON MONOXIDE

(at one atmosphere)

Sources of Data: Johnston, H. L. and Grilly, E. R., J. Phys. Chem. 46, 948-63 (1942); Keyes, F. G., Trans. ASME 73, 589-96 (1951).

Comments: Johnston and Grilly's data agree quite well with the following: Smith, C. J., Proc. Phys. Soc. (London) 34, 155-65 (1922); Trautz, M. and Baumann, P. B., Ann. Physik [5] 2, 733-36 (1929); Trautz, M. and Melster, A., Ann. Physik [5] 7, 409-26 (1930); Wobser, R. and Muller, F., Kolloid-Beih. 52, 165-276 (1941); Vogel, H., Ann. Physik [4] 43, 1235-72 (1914).

An empirical equation for the prediction of viscosities of CO at low pressures is

$$\mu = \frac{1.495 \times 10^{-5}\sqrt{T}}{1 + \frac{143.2}{T}10^{-9.0/T}}$$

where: μ is in poise
and T is in °K and between 80 and 549°K

Table of Experimental Data

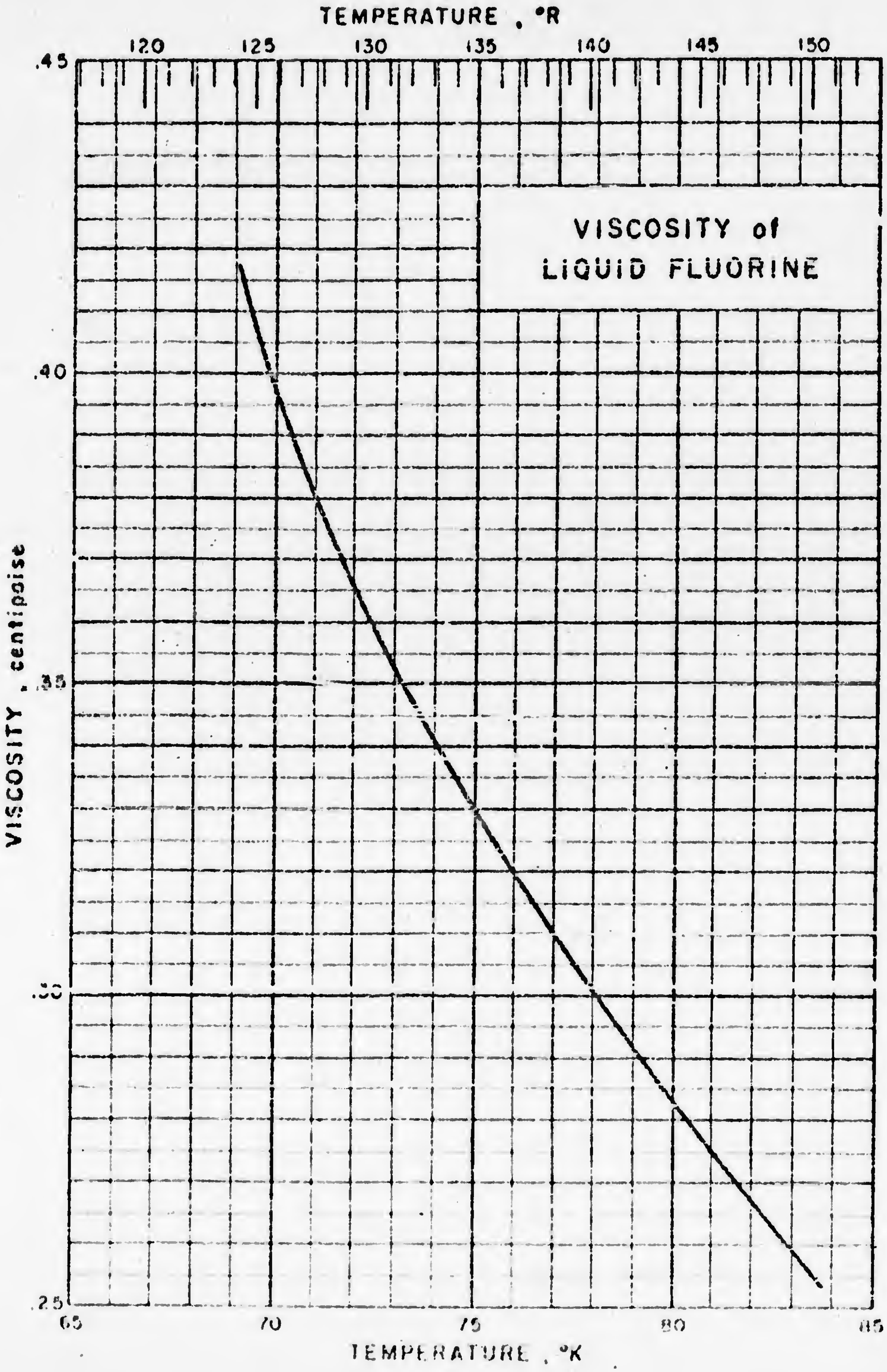
Temp. °K	Viscosity micropoise	Temp. °K	Viscosity micropoise
80.75	53.69	211.27	132.67
82.43	54.72	225.13	140.60
90.23	60.43	240.84	148.70
117.40	78.01	242.34	150.15
131.47	86.50	256.00	156.75
144.73	95.05	273.10	165.62
159.23	103.10	283.70	170.87
173.95	112.00	295.13	176.33
184.17	117.65	296.10	175.51
203.03	128.65	305.77	181.11

Table of Smoothed Data

Temp. °K	Viscosity micropoise	Temp. °K	Viscosity micropoise
80	53.30	210	132.35
90	60.20	220	137.85
100	66.85	230	143.30
110	73.30	240	148.60
120	79.60	250	153.80
130	85.80	260	158.90
140	91.90	270	163.90
150	97.90	273.1	165.50
160	103.80	280	168.80
170	109.60	290	173.45
180	115.40	293.1	175.30
190	121.15	296.1	176.50
200	126.80	298.1	177.35
		300	178.45

RIG/JDT Issued: 7/7/59

10.008


TEMPERATURE , °R
120
125
130
135
140
145
150
VISCOSITY of
LIQUID FLUORINE
.45
.40
.35
.30
.25
VISCOSITY , centipoise
65
70
75
80
85
TEMPERATURE , °K

VISCOSITY OF LIQUID FLUORINE

Source of Data: Elverum, G. W. and Doescher, R. N.: Journal of Chemistry and Physics, Vol. 20, 1834-6 (1952)

Comments: Experimental measurements needed to calculate the dynamic viscosity of the liquid were made by Elverum and Doescher, using a capillary tube. The viscosity was calculated using the following equation:

$$\eta = \frac{\pi r^4 g t}{8 L V} (\rho_l - \rho_v) \frac{h_1 - h_2}{\ln (h_1/h_2)} - \frac{\rho_l V}{\pi 8 L t}$$

where:
L = length of capillary tube
V = Volume of flow in time t
h_1 = difference in height between liquid levels in upper and lower reservoirs at beginning.
h_2 = Difference in height between liquid levels in upper and lower reservoirs at end.
ρ_l = density of liquid
ρ_v = density of vapor
η = Viscosity in poises when cgs units are used for all other quantities
r = radius of capillary tube

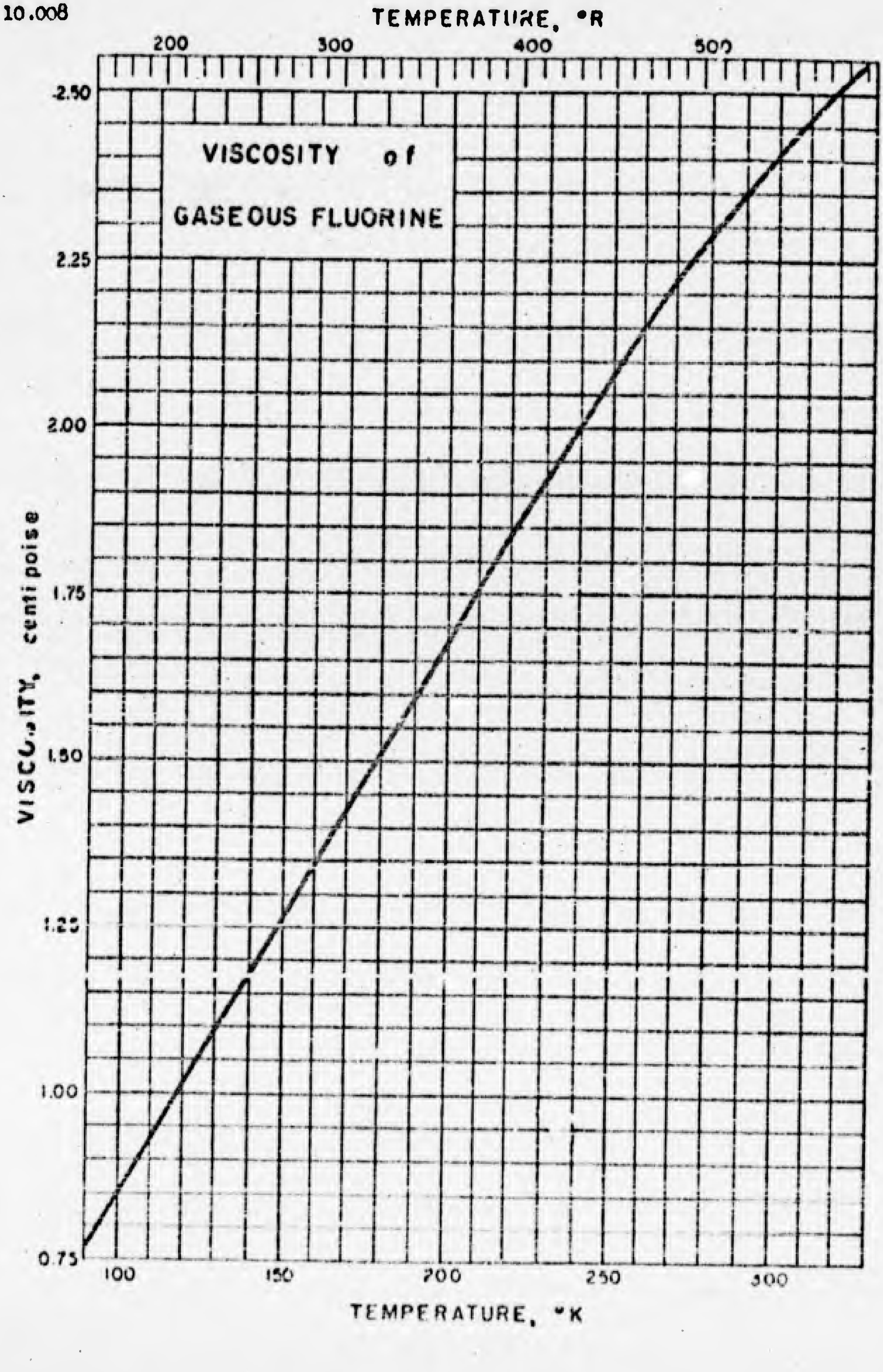
Viscosity of Liquid Fluorine

Temp. °K	Viscosity centipoises
69.2	0.414
73.2	0.349
75.3	0.328

Temp. °K	Viscosity centipoises
78.2	0.299
80.9	0.275
83.2	0.257

Normal Melting Temp. = 55.2°K   Normal Boiling Temp. = 85.24°K

10.008


VISCOSITY of
GASEOUS FLUORINE
TEMPERATURE, °R
200
300
400
500
VISCOSITY, centipoise
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
100
150
200
250
300
TEMPERATURE, °K

VISCOSITY of GASEOUS FLUORINE

Source of Data: Franck and Stober, Zeits für Naturforschung 7A, 622 (1952).

Other References: Kanda, Bull. Chem. Soc. Japan 12, 468 (1937).

Comments: The data of Franck are in close agreement with values predicted from the theoretical equation of Hirchfelder [Hirschfelder, Bird and Spotz, J. Chem. Phys. 16, 968 (1948)].

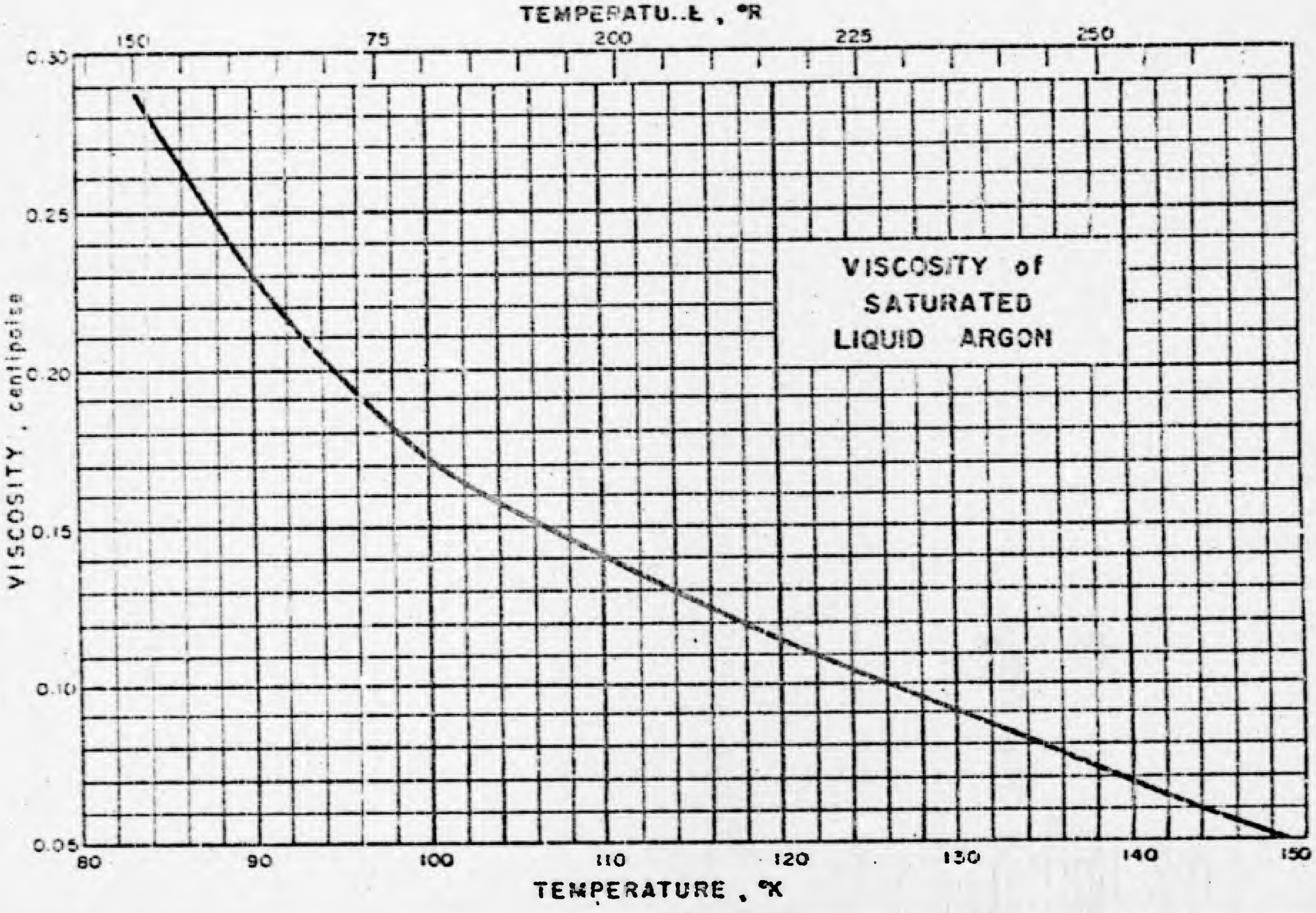
Table of Selected Values

Temp. °K	Viscosity centipoises
90.0	0.767
169.3	1.424
200.0	1.680
289.1	2.345
327.1	2.547

IFR Issued: 11/6/59

10.009

VISCOSITY of ARGON



10.009

VISCOSITY of LIQUID ARGON

(Saturated)

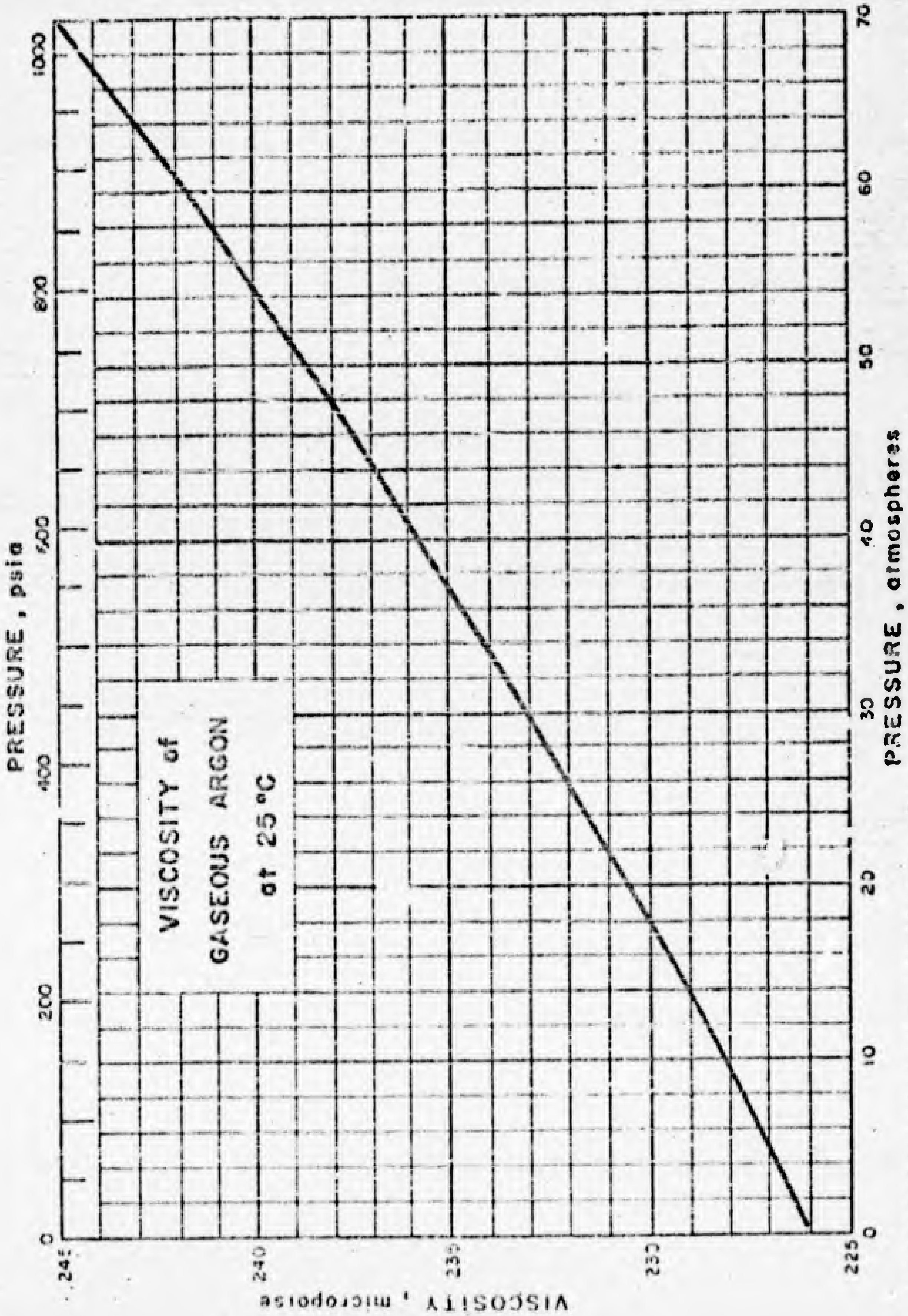
Sources of Data: Zhdanova, N. F., Zhur. Eksptl. i. Teoret. Fiz., 31, 724-5 (1956); Rudenko, N. S., J. Techn. Phys. (USSR), 18, 1123 (1948).

Other References: Andrade, E. N., Nature, 170, 794 (1952); Verkin, B. I. and Rudenko, N. S., Zhur. Eksptl. Teoret. Fiz., 20, 521-6 (1950).

Table of Selected Values

Temp. °K	Viscosity (Poise) gm/cm·sec	Source
84.25	0.002 82	Rudenko
86.25	.002 62	"
86.90	.002 56	"
87.30	.002 52	"
90.0	.002 32	Zhdanova
99.5	.001 62	"
111.0	.001 37	"
120	.001 16	"
127	.001 00	"
133.5	.000 77	"
138.7	.000 70	"
143	.000 63	"
147	.000 56	"
149	.000 50	"

Normal Melting Temp. = 83.78°K
Normal Boiling Temp. = 87.29°K
Critical Temperature = 150.7 °K


VISCOSITY of GASEOUS ARGON at 25 °C
PRESSURE , psia
0
200
400
600
800
1000
PRESSURE , atmospheres
0
10
20
30
40
50
60
70
VISCOSITY , micropoise
245
240
235
230
225

10.009

VISCOSITY of GASEOUS ARGON

Source of Data:

Kestin, J. and Wang, H. E., Trans. ASME 80, 11-17 (1958)

Other References:

Hilsenrath, J. and Touloukian, Y. S., Trans. ASME 76, 967 (1954)

Bateman, J. S., Proc. Conf. Thermodynamic and Transport Properties of Fluids (London) 1957

Bonilla, C. F., Wang, S. J. and Weiner, H., Trans. ASME 78, 1285 (1956)

Michels, A., Botzen, A. and Schuurman, W., Physica 20, 1141 (1954)

Comments:

The data correspond to the equation

$$\frac{\mu}{\mu_a} = 1 + 8.945 \times 10^{-4}(p-1) + 4.930 \times 10^{-6}(p-1)^2 - 7.200 \times 10^{-8}(p-1)^3 \text{ at } 25^\circ\text{C}$$

where:

μ_a = 2262 x 10^{-7} poise at 25°C

μ_a = viscosity of argon at 1 atm

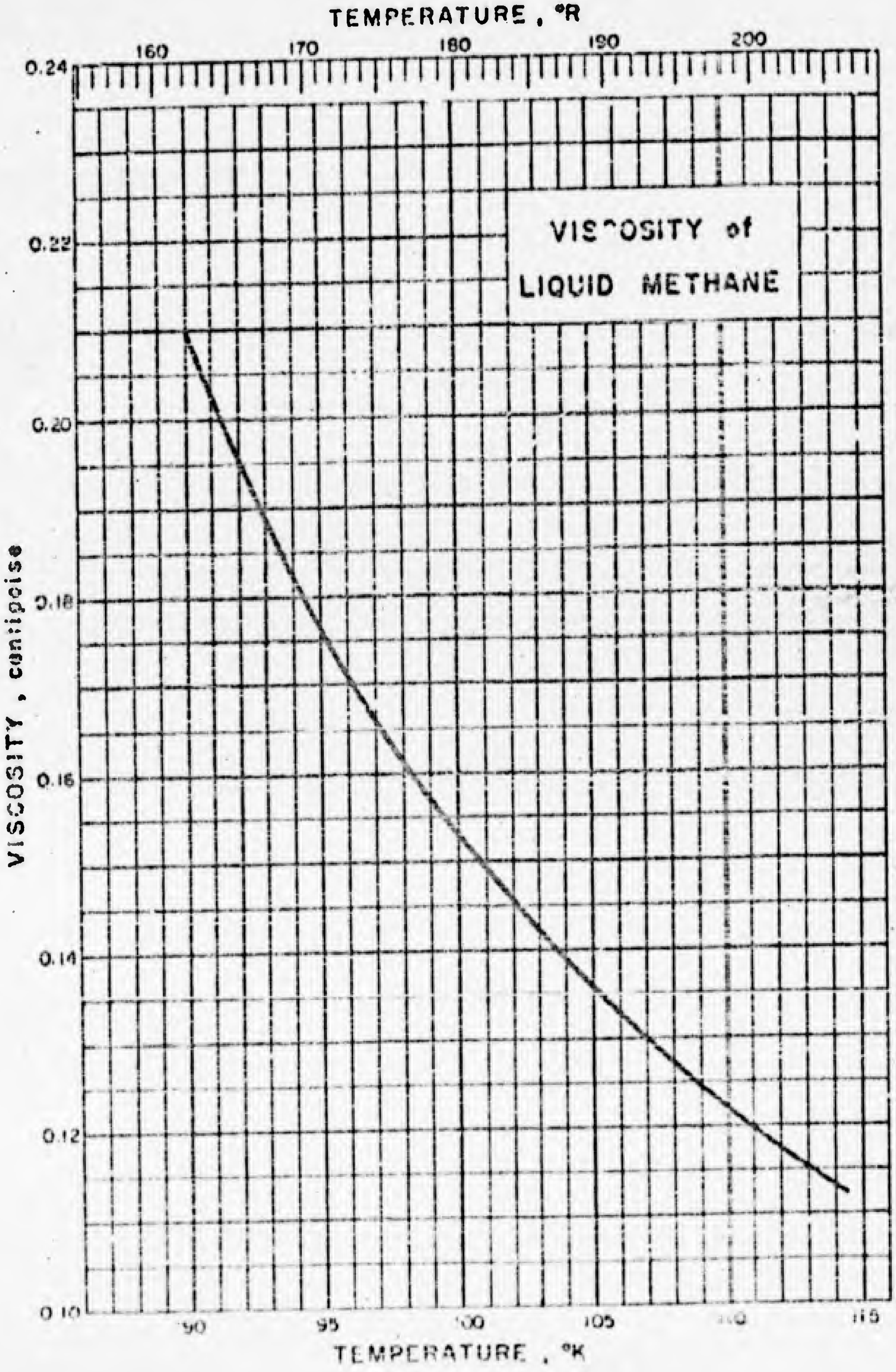
p = atmospheres

This equation reproduces the experimental data to 0.2 per cent.

Viscosity of Argon at 25°C

Pressure atm.	Viscosity micropoise
1	226.2
2	226.4
5	227.0
10	228.1
20	230.5
30	233.0
40	235.7
50	238.6
60	241.7
70	244.9

FLB/RJR Issued: 3/4/59


TEMPERATURE, °R
160
170
180
190
200
VISCOSITY of
LIQUID METHANE
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
VISCOSITY, centipoise
90
95
100
105
110
115
TEMPERATURE, °K

10.010

VISCOSITY of LIQUID METHANE

Source of Data:

Rossini, F. D., et al., Selected Values of Physical and Thermodynamic Properties of Hydrocarbons and Related Compounds, Carnegie Press, Pittsburgh (1953)

Comments:

The viscosity is referred to a value of 1.005 centipoises for water at 293°K. The viscosity of the liquid at 113.16°K was taken at saturation pressure, while for all other values the pressure was 1 atm.

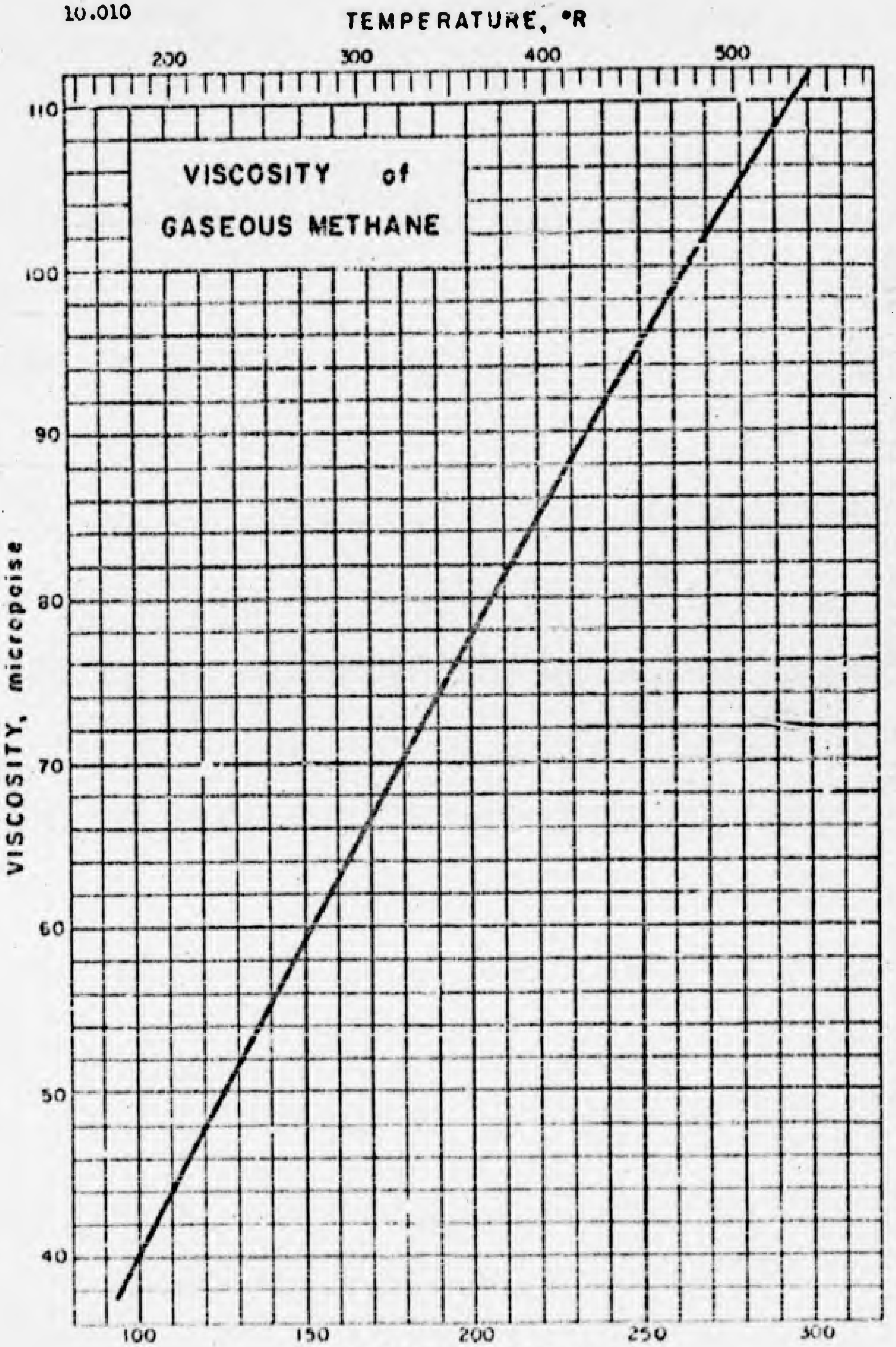
The absolute temperature scale (0°C = 273.16°K) was used in the table of selected values below.

Temperature °K	Viscosity centipoise
88.16 *	0.226
93.16	0.188
98.16	0.161
103.16	0.142
108.16	0.127
113.16	0.115

* Supercooled Liquid

Triple Point Temp. = 88.7°K
Normal Boiling Temp. = 111.7°K
Critical Temperature = 190.7°K

10.010


VISCOSITY of GASEOUS METHANE
TEMPERATURE, °R
200
300
400
500
VISCOSITY, micropoise
110
100
90
80
70
60
50
40
100
150
200
250
300
TEMPERATURE, °K

10.010

VISCOSITY of GASEOUS METHANE

Source of Data: Johnston, H. L., and McCloskey, K. E., J. Phys. Chem. 44, 1038-58 (1940).

Comments: Experiments indicate that the viscosity of a gas is independent of its pressure.

Table of Selected Values

Temp. °K	Viscosity micropoise
90.0	36.49
100.0	40.28
110.0	44.07
120.0	47.83
130.0	51.60
140.0	55.97
150.0	59.14
160.0	62.89
170.0	66.61
180.0	70.31
190.0	74.06
200.0	77.73
210.0	81.43
220.0	85.01
230.0	88.50
240.0	91.91
250.0	95.30
260.0	98.63
270.0	101.98
280.0	105.25
290.0	108.44
300.0	111.59

RFR Issued: 6/15/55

APPENDIXES

TEMPERATURE INTERCONVERSION TABLE

CONVERSION FACTORS FOR UNITS OF LENGTH

CONVERSION FACTORS FOR UNITS OF AREA

CONVERSION FACTORS FOR UNITS OF VOLUME

CONVERSION FACTORS FOR UNITS OF MASS

CONVERSION FACTORS FOR UNITS OF PRESSURE

CONVERSION FACTORS FOR UNITS OF ENERGY

DATA SHEET AUTHOR IDENTIFICATION BY INITIALS

APPENDIX

Temperature Interconversion Table
(0 to 200°K)

°K	°C	°F	°R
0.	-273.16	-459.69	0.
3.16	-270.	-454.00	5.69
5.38	-267.78	-450.	9.69
5.56	-267.60	-449.69	10.
10.	-263.16	-441.69	18.00
10.94	-262.22	-440.	19.69
11.11	-262.05	-439.69	20.
13.16	-260.	-436.00	23.69
16.49	-256.67	-430.	29.69
16.67	-256.49	-429.69	30.
20.	-253.16	-423.69	36.00
22.05	-251.11	-420.	39.69
22.22	-250.94	-419.69	40.
23.16	-250.	-418.00	41.69
27.60	-245.56	-410.	49.69
27.78	-245.38	-409.69	50.
30.	-243.16	-405.69	54.00
33.16	-240.	-400.	59.69
33.33	-239.83	-399.69	60.
38.72	-234.44	-390.	69.69
38.89	-234.27	-389.69	70.
40.	-233.16	-387.69	72.00
43.16	-230.	-382.00	77.69
44.27	-228.89	-380.	79.69
44.44	-228.72	-379.69	80.
49.83	-223.33	-370.	89.69
50.	-223.16	-369.69	90.
53.16	-220.	-364.00	95.69
55.38	-217.78	-360.	99.69
55.56	-217.60	-359.69	100.
60.	-213.16	-351.69	108.00
60.94	-212.22	-350.	109.69
61.11	-212.05	-349.69	110.
63.16	-210.	-346.00	113.69
66.49	-206.67	-340.	119.69
66.67	-206.49	-339.69	120.
70.	-203.16	-333.69	126.00
72.05	-201.11	-330.	129.69
72.22	-200.94	-329.69	130.
73.16	-200.	-328.00	131.69
77.60	-195.56	-320.	139.69
77.78	-195.38	-319.69	140.
80.	-193.16	-315.69	144.00
83.16	-190.	-310.	149.69
83.33	-189.83	-309.69	150.
88.72	-184.44	-300.	159.69
88.89	-184.27	-299.69	160.
90.	-183.16	-297.69	162.00
93.16	-180.	-292.00	167.69
94.27	-178.89	-290.	169.69
94.44	-178.72	-289.69	170.
99.83	-173.33	-280.	179.69
100.	-173.16	-279.69	180.
100.	-173.16	-279.69	180.
103.16	-170.	-274.00	185.69
105.38	-167.78	-270.	189.69
105.56	-167.60	-269.69	190.
110.	-163.16	-261.69	198.00
110.94	-162.22	-260.	199.69
111.11	-162.05	-259.69	200.
113.16	-160.	-256.00	203.69
116.49	-156.67	-250.	209.69
116.67	-156.49	-249.69	210.
120.	-153.16	-243.69	216.00
122.05	-151.11	-240.	219.69
122.22	-150.94	-239.69	220.
123.16	-150.	-238.00	221.69
127.60	-145.56	-230.	229.69
127.78	-145.38	-229.69	230.
130.	-143.16	-225.69	234.00
133.16	-140.	-220.	239.69
133.33	-139.83	-219.69	240.
138.72	-134.44	-210.	249.69
138.89	-134.27	-209.69	250.
140.	-133.16	-207.69	252.00
143.16	-130.	-202.00	257.69
144.27	-128.89	-200.	259.69
144.44	-128.72	-199.69	260.
149.83	-123.33	-190.	269.69
150.	-123.16	-189.69	270.
153.16	-120.	-184.00	275.69
155.38	-117.78	-180.	279.69
155.56	-117.60	-179.69	280.
160.	-113.16	-171.69	288.00
160.94	-112.22	-170.	289.69
161.11	-112.05	-169.69	290.
163.16	-110.	-166.00	293.69
166.49	-106.67	-160.	299.69
166.67	-106.49	-159.69	300.
170.	-103.16	-153.69	306.00
172.05	-101.11	-150.	309.69
172.22	-100.94	149.69	310.
173.16	-100.	-148.00	311.69
177.60	-95.56	-140.	319.69
177.78	-95.38	-139.69	320.
180.	-93.16	-135.69	324.00
183.16	-90.	-130.	329.69
183.33	-89.83	-129.69	330.
188.72	-84.44	-120.	339.69
188.89	-84.27	119.69	340.
190.	-83.16	-117.69	342.00
193.16	-80.	-112.00	347.69
194.27	-78.89	-110.	349.69
194.44	-78.72	-109.69	350.
199.83	-73.33	-100.	359.69
200.	-73.16	-99.69	360.

°K °C	°R °F
1	1.8
2	3.6
3	5.4
4	7.2
5	9.0
6	10.8
7	12.6
8	14.4
9	16.2
10	18.0
°R °F	°K °C
1	0.56
2	1.11
3	1.67
4	2.22
5	2.78
6	3.33
7	3.89
8	4.44
9	5.00
10	5.56
11	6.11
12	6.67
13	7.22
14	7.78
15	8.33
16	8.89
17	9.44
18	10.00

APPENDIX

Temperature Interconversion Table
(200 to 400°K)

°K	°C	°F	°R	°K	°C	°F	°R
200.	-73.16	-99.69	360.	300.	26.84	80.31	540.
203.16	-70.	-94.00	365.69	303.16	30.	86.00	545.69
205.38	-67.78	-90.	369.69	305.38	32.22	90.	549.69
205.56	-67.60	-89.69	370.	305.56	32.40	90.31	550.
210.	-63.16	-81.69	378.00	310.	36.84	98.31	558.00
210.94	-62.22	-80.	379.69	310.94	37.78	100.	559.69
211.11	-62.05	-79.69	380.	311.11	37.95	100.31	560.
213.16	-60.	-76.00	383.69	313.16	40.	104.00	563.69
216.49	-56.67	-70.	389.69	316.49	43.33	110.	569.69
216.67	-56.49	-69.69	390.	316.67	43.51	110.31	570.
220.	-53.16	-63.69	396.00	320.	46.84	116.31	576.00
222.05	-51.11	-60.	399.69	322.05	48.89	120.	579.69
222.22	-50.94	-59.69	400.	322.22	49.06	120.31	580.
223.16	-50.	-58.00	401.69	323.16	50.	122.00	581.69
227.60	-45.56	-50.	409.69	327.60	54.44	130.	589.69
227.78	-45.38	-49.69	410.	327.78	54.62	130.31	590.
230.	-43.16	-45.69	414.00	330.	56.84	134.31	594.00
233.16	-40.	-40.	419.69	333.16	60.	140.	599.69
233.33	-39.83	-39.69	420.	333.33	60.17	140.31	600.
238.72	-34.44	-30.	429.69	338.72	65.56	150.	609.69
238.89	-34.27	-29.69	430.	338.89	65.73	150.31	610.
240.	-33.16	-27.69	432.00	340.	66.84	152.31	612.00
243.16	-30.	-22.00	437.69	343.16	70.	158.00	617.69
244.27	-28.89	-20.	439.69	344.27	71.11	160.	619.69
244.44	-28.72	-19.69	440.	344.44	71.28	160.31	620.
249.83	-23.33	-10.	449.69	349.83	76.67	170.	629.69
250.	-23.16	-9.69	450.	350.	76.84	170.31	630.
253.16	-20.	-4.00	455.69	353.16	80.	176.00	635.69
255.38	-17.78	0.	459.69	355.38	82.22	180.	639.69
255.56	-17.60	+.31	460.	355.56	82.40	180.31	640.
260.	-13.16	+8.31	468.00	360.	86.84	188.31	648.00
260.94	-12.22	10.	469.69	360.94	87.78	190.	649.69
261.11	-12.05	10.31	470.	361.11	87.95	190.31	650.
263.16	-10.	14.00	473.69	363.16	90.	194.00	653.69
266.49	-6.67	20.	479.69	366.49	93.33	200.	659.69
266.67	-6.49	20.31	480.	366.67	93.51	200.31	660.
270.	-3.16	26.31	486.00	370.	96.84	206.31	666.00
272.05	-1.11	30.	489.69	372.05	98.89	210.	669.69
272.22	-.94	30.31	490.	372.22	99.06	210.31	670.
273.16	0.	32.00	491.69	373.16	100.	212.00	671.69
277.60	+4.44	40.	499.69	377.60	104.44	220.	679.69
277.78	4.62	40.31	500.	377.78	104.62	220.31	680.
280.	6.84	44.31	504.00	380.	106.84	224.31	684.00
283.16	10.	50.	509.69	383.16	110.	230.	689.69
283.33	10.17	50.31	510.	383.33	110.17	230.31	690.
288.72	15.56	60.	519.69	388.72	115.56	240.	699.69
288.89	15.73	60.31	520.	388.89	115.73	240.31	700.
290.	16.84	62.31	522.00	390.	116.84	242.31	702.00
293.16	20.	68.00	527.69	393.16	120.	248.00	707.69
294.27	21.11	70.	529.69	394.27	121.11	250.	709.69
294.44	21.28	70.31	530.	394.44	121.28	250.31	710.
299.83	26.67	80.	539.69	399.83	126.67	260.	719.69
300.	26.84	80.31	540.	400.	126.84	260.31	720.

°K °C	°R °F
1	1.8
2	3.6
3	5.4
4	7.2
5	9.0
6	10.8
7	12.6
8	14.4
9	16.2
10	18.0

°R °F	°K °C
1	0.56
2	1.11
3	1.67
4	2.22
5	2.78
6	3.33
7	3.89
8	4.44
9	5.00
10	5.56
11	6.11
12	6.67
13	7.22
14	7.78
15	8.33
16	8.89
17	9.44
18	10.00

APPENDIX

Conversion Factors
for
Units of Length and Area

CONVERSION FACTORS FOR UNITS OF LENGTH

Multiply ↓ by appropriate entry to obtain →	cm	mm	μ	mμ	λ
1 Centimeter (cm)	1	10	10^4	10^7	10^8
1 Millimeter (mm)	10^{-1}	1	10^3	10^6	10^7
1 Micron (μ)	10^{-4}	10^{-3}	1	10^3	10^4
1 Millimicron (mμ)	10^{-7}	10^{-6}	10^{-3}	1	10
1 Angstrom Unit (Å)	10^{-8}	10^{-7}	10^{-4}	10^{-1}	1

CONVERSION FACTORS FOR UNITS OF LENGTH - Cont.

Multiply ↓ by appropriate entry to obtain →	cm	m	in	ft	yd
1 cm	1	0.01	0.3937	0.032808333	0.010936111
1 m	100.	1	39.37	3.2808333	1.0936111
1 in	2.5400051	0.025400051	1	0.083333333	0.027777778
1 ft	30.480061	0.30480061	12.	1	0.33333333
1 yd	91.440183	0.91440183	36.	3.	1

CONVERSION FACTORS FOR UNITS OF AREA

Multiply ↓ by appropriate entry to obtain →	cm^2	m^2	sq in	sq ft	sq yd
1 cm^2	1	10^{-4}	0.15499969	1.0763867 $\times 10^{-3}$	1.1959853 $\times 10^{-4}$
1 m^2	10^4	1	1549.9969	10.763867	1.1959853
1 sq in	6.4516258	6.4516258 $\times 10^{-4}$	1	6.9444444 $\times 10^{-3}$	7.7160494 $\times 10^{-4}$
1 sq ft	929.03412	0.092903412	144.	1	0.11111111
1 sq yd	8361.3070	0.83613070	1296	9.	1

APPENDIX

Conversion Factors

CONVERSION FACTORS FOR UNITS OF VOLUME

Multiply by appropriate entry to obtain →	ml	liter	gal
1 cm^3	0.9999720	0.9999720×10^{-3}	2.6417047×10^{-4}
1 cu in	16.38670	1.638670×10^{-2}	4.3290043×10^{-3}
1 cu ft	28316.22	28.31622	7.4805195
1 ml	1	0.001	2.641779×10^{-4}
1 liter	1000.	1	0.2641779
1 gal	3785.329	3.785329	1

CONVERSION FACTORS FOR UNITS OF VOLUME - Cont.

Multiply by appropriate entry to obtain →	cm^3	cu in	cu ft
1 cm^3	1	0.061023378	3.5314455×10^{-5}
1 cu in	16.387162	1	5.7870370×10^{-4}
1 cu ft	28317.017	1728.	1
1 ml	1.000028	0.06102509	3.531544×10^{-5}
1 liter	1000.028	61.02509	0.03531544
1 gal	3785.4345	231.	0.13368056

APPENDIX

Conversion Factors

CONVERSION FACTORS FOR UNITS OF MASS

Multiply by appropriate entry to obtain →	g	kg	lb	metric ton	ton
1 g	1	10^{-3}	2.2046223×10^{-3}	10^{-6}	1.1023112×10^{-6}
1 kg	10^{3}	1	2.2046223	10^{-3}	1.1023112×10^{-3}
1 lb	453.59243	0.45359243	1	4.5359243×10^{-4}	0.0005
1 metric ton	10^{6}	10^{3}	2204.6223	1	1.1023112
1 ton	907184.86	907.18486	2000.	0.90718486	1

APPENDIX

Conversion Factors
for
Units of Pressure

CONVERSION FACTORS FOR UNITS OF PRESSURE

Multiply by appropriate entry to obtain →	dyne/cm.^{2}	bar	atm	kg(wt)/cm^2	mm Hg	in Hg	lb(wt)/sq in
1 dyne/cm^2	1	10^{-6}	0.9869233 x 10^{-6}	1.0197162 x 10^{-6}	7.500617 x 10^{-4}	2.9529983 x 10^{-5}	1.4503830 x 10^{-5}
1 bar	10^6	1	0.9869233	1.0197162	750.0617	29.52998	14.503830
1 atm	1013250.	1.013250	1	1.0332275	760.	29.92120	14.696006
1 kg(wt)/cm^2	980665.	0.980665	0.9678411	1	735.5592	28.95903	14.223343
1 mm Hg	1333.2237	1.3332237 x 10^{-3}	1.3157895 x 10^{-3}	1.3595098 x 10^{-3}	1	0.03937	0.019336850
1 in Hg	33863.95	0.03386395	0.03342112	0.03453162	25.40005	1	0.4911570
1 lb(wt)/sq in	68947.31	0.06894731	0.06804570	0.07030680	51.71473	2.036009	1

APPENDIX

Conversion Factors
for
Units of Energy

CONVERSION FACTORS FOR UNITS OF ENERGY

Multiply by appropriate entry to obtain →	g mass (energy equiv)	abs. joule	int. joule	cal	I. T. cal	BTU	int. kilowatt -hr
1 g mass (energy equiv)	1	8.98656 $\times 10^{13}$	8.98508 $\times 10^{13}$	2.14784 $\times 10^{13}$	2.14644 $\times 10^{13}$	8.51775 $\times 10^{10}$	2.49586 $\times 10^{7}$
1 abs. joule	1.112772 $\times 10^{-14}$	1	0.999835	0.239006	0.238849	0.947831 $\times 10^{-3}$	2.77732 $\times 10^{-7}$
1 int. joule	1.112956 $\times 10^{-14}$	1.000165	1	0.239045	0.238889	0.947988 $\times 10^{-3}$	2.777778 $\times 10^{-7}$
1 cal	4.65584 $\times 10^{-14}$	4.1840	4.1833	1	0.999346	3.96573 $\times 10^{-3}$	1.162030 $\times 10^{-6}$
1 I. T. cal	4.65888 $\times 10^{-14}$	4.18674	4.18605	1.000654	1	3.96832 $\times 10^{-3}$	1.162791 $\times 10^{-6}$
1 BTU	1.174019 $\times 10^{-11}$	1055.040	1054.866	252.161	251.996	1	2.93018 $\times 10^{-4}$
1 int. kilowatt-hr	4.00664 $\times 10^{-8}$	3,600,594.	3,600,000.	860,563.	860,000.	3412.76	1
1 horsepower-hr	2.98727 $\times 10^{-8}$	2,684,525.	2,684,082.	641,617.	641,197.	2544.48	0.745578
1 ft-lb(wt)	1.508720 $\times 10^{-14}$	1.355821	1.355597	0.324049	0.323837	1.285089 $\times 10^{-3}$	3.76555 $\times 10^{-7}$
1 cu ft - lb(wt)/sq in	2.17256 $\times 10^{-12}$	195.2382	195.2060	46.6630	46.6325	0.1850528	5.42239 $\times 10^{-5}$
1 liter-atm	1.127548 $\times 10^{-12}$	101.3278	101.3111	24.2173	24.2021	0.0960417	2.81420 $\times 10^{-5}$

APPENDIX

Conversion Factors

CONVERSION FACTORS FOR UNITS OF ENERGY - Cont.

Multiply by appropriate entry to obtain →	ft-lb(wt)	cu ft-lb(wt)/sq in.	liter-atm	horsepower-hr
1 g mass(energy equiv)	6.62814×10^{13}	4.60287×10^{11}	8.86880×10^{11}	3.34764×10^{7}
1 abs. joule	0.737561	5.12195×10^{-3}	9.86896×10^{-3}	3.72506×10^{-7}
1 int. joule	0.737682	5.12279×10^{-3}	9.87058×10^{-3}	3.72567×10^{-7}
1 cal	3.08595	2.14302×10^{-2}	4.12917×10^{-2}	1.558562×10^{-6}
1 I.T. cal	3.08727	2.14443×10^{-2}	4.12187×10^{-2}	1.559632×10^{-6}
1 BTU	778.156	5.40386	10.41215	3.93008×10^{-4}
1 int. kilowatt-hr	2,655,656.	18442.06	35534.1	1.341241
1 horsepower-hr	1,980,000.	13750.	26483.5	1
1 ft-lb(wt)	1	6.94444×10^{-3}	1.338054×10^{-2}	5.05051×10^{-7}
1 cu ft-lb(wt)/sq in	144.	1	1.926797	7.27273×10^{-5}
1 liter-atm	74.7354	5.18996	1	3.77452×10^{-5}

DATA SHEET AUTHOR IDENTIFICATION FROM INITIALS

VDA = Vincent D. Arp
EHB = Edmund H. Brown
JAB = James A. Brennan
PLB = Paul L. Barrick
WWB = William W. Bulla
JRC = Jerry R. Cahoon
DBC = Dudley B. Chelton
RJC = Robert J. Corruccini
FEEG = Frank E. E. Germann
JJG = John J. Gniewek
RDG = Robert D. Goodwin
DEJ = Donald E. Jordan
VJJ = Victor J. Johnson
DBM = Douglas B. Mann
GRM = Genevieve R. Michels
JM = John Macinko
RLP = Robert L. Powell
GAR = George A. Reynolds
RFR = Ross F. Robbins
HMR = Hans M. Roder
RBS = Russell B. Scott
RS = Richard Stewart
RVS = Raymond V. Smith
BDT = Bryce D. Troyer
KDT = Klaus D. Timmerhaus
DAV = Donald A. Van Gundy
WJV = William J. Veigele

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