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A BIBLIOGRAPHY OF THE THERMOPHYSICAL PROPERTIES OF OXYGEN AT LOW TEMPERATURES

BY J. C. HUST, L. D. WALLACE, J. A. CRIM,
L. A. HALL, AND R. B. STEWART

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Technical Note

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A BIBLIOGRAPHY OF THE THERMOPHYSICAL PROPERTIES OF OXYGEN AT LOW TEMPERATURES*

J. G. Hust L. D. Wallace J. A. Crim L. A. Hall R. B. Stewart

ABSTRACT

This bibliography of the mechanical, thermodynamic and transport properties of oxygen below 0°C presents 325 references and is the result of a thorough search of the world's scientific and engineering literature. In addition to searching abstracting journals and bibliographies, the authors reviewed each document for property data and for additional references. Listed for each reference are the properties and the corresponding temperature and pressure range, together with additional pertinent information such as the type of data (i.e., whether the data are derived from experimental measurements, theoretical considerations or as a compilation from other sources), the form and amount of data, etc. An index according to property, sub-indexed for temperature and pressure ranges, and an author index are included.

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* This bibliography is a result of a study made under contract with the National Aeronautics and Space Administration by the Cryogenic Data Center of the Cryogenic Engineering Laboratory.

1. INTRODUCTION

This bibliography presents the results of a search of the world's scientific and engineering literature for the mechanical, thermodynamic, and transport properties of oxygen at low temperatures. While the primary objective was to catalog the literature for the properties of oxygen at cryogenic temperatures, references including information on properties up to 0°C were included. A list of references was first compiled from the abstracting journals and bibliographies (See Section 3. below). Following this review, copies of the documents were procured and the bibliography and other references cited in each document surveyed. Copies of additional documents pertaining to this subject were in turn obtained and inspected for inclusion in this bibliography and also for additional references. In addition to this rather comprehensive coverage of the open literature, citations of company reports and other corporate publications containing information on the properties of oxygen at low temperatures have also been included whenever copies of these documents could be obtained. All pertinent literature reviewed has been listed with no attempt made to evaluate the documents.

The citations have been arranged alphabetically and numbered; the alphabetical sequence has been maintained by assigning to late additions the number of the preceeding item followed by an A, B, etc. Following each citation in the bibliography, there is a listing of the properties of oxygen presented in the document together with the temperature and pressure range for which the properties are given. The form of data is indicated, and for tabular material the number of values are reported. From the information listed for each citation, the property index together with a sub-index for temperature and pressure ranges were prepared with a computer program. It should be particularly noted that the remarks on the contents of each document pertain only to the information available on oxygen.

During the time this bibliography was being compiled, the Cryogenic Data Center prepared a digital computer system for bibliography retrieval and completed the coding for the system of the Data Center's bibliography file for properties of fluids. The Data Center made an automated search for the properties of oxygen as the manuscript for this bibliography was being finished and, as a consequence, forty-nine more references were added.

2. FORMAT FOR LISTING CITATION AND CONTENT OF DOCUMENTS

The general form for the listing of references is: (1) author, (2) title of the document and (3) publication citation. Abbreviations of the journal names for the listing of references are in agreement with Chemical Abstracts (Chemical Abstracts Service, Ohio State University, Columbus 10, Ohio). Titles of articles published in other than the English language are listed in the original languages of the documents followed by the English translation of the titles, except for a few articles in languages with other than the Roman alphabet, where only the English translation is given.

The documents were coded and the following information listed for each citation:

a. The properties of oxygen that are included in the documents together with the temperature and pressure range. (The temperature and pressure range follows the list of properties to which it pertains.)*
b. The fluids for which property data were included in a document are listed if these fluids are not identified in the title of the paper. This notation is omitted for articles containing information on oxygen only.
c. The type of data is noted, i.e. whether the data are derived from experimental measurements, theoretical considerations or as a compilation from other sources. The type of data is also indicated in the property index following each citation number by the letters E, T, C, which identifies that citation as (E) experimental, (T) theoretical, and/or (C) compilation.
d. The form of the data is noted following the type of data together with the amount of tabular data, i.e., tables (number of tabular values), graphs, and/or equations.
e. The notation apparatus refers to a pictorial or narrative description of apparatus in the document.
f. The source of data for those documents designated as compilations is referenced by the source document number in this bibliography.
g. The original language of the publication is noted if it was other than English. In addition, if translations are known to be available for foreign language documents, that information is also given.
h. Documents that came to our attention too late for copies to be obtained were coded from the abstract only and are so indicated on the last line of the document description.

3. ABSTRACTING JOURNALS AND BIBLIOGRAPHIES SEARCHED

The search for references to literature containing information on the thermophysical properties of oxygen was made in the following areas:

a. Chemical Abstracts, Vol. 19 through 54, (Nov. 13, 1925 through July 10, 1960).
b. Engineering Index, (1918 through 1959).
c. ASME Seventy-Seven Year Index, Technical Papers, (1880 through 1956). Index of ASME Transactions, No. 78 through 81, (1956 through 1959).

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* Most reference books and handbooks were generally coded for property only and no temperature range or pressure range was included with the properties listed. In addition, the temperature and pressure ranges were also omitted on references to state points such as triple point, normal boiling point, critical point, etc. In many cases the pressures and occasionally the temperatures were not given in the document reference. This is most often the case for properties near atmospheric pressure that are essentially temperature dependent only.

d. Index of the Journal of the American Rocket Society, Vol. 26 through 30, (1956 through 1960).
e. Retrieval Guide to Thermophysical Properties Research Literature, Y. S. Touloukian, Thermophysical Properties Research Center, Purdue University, Lafayette, Indiana.
f. Bibliographies and references cited in each document listed in this bibliography.

4. ACKNOWLEDGEMENTS

The literature search for this bibliography has been pursued in part by each of the authors. The original search was started in June 1960, and was not concluded until the manuscript was completed. In addition to the authors listed, the entire staff of the Cryogenic Data Center have contributed by their constant alertness for documents pertinent to this bibliography. In particular, the authors wish to acknowledge the following contributions: Dr. F. E. E. Germann for reviewing and coding all documents written in French or German and for translations of the titles of these papers; Robert Smith for completing his computer retrieval system for the Cryogenic Data Center's bibliography in time to check the completeness of our literature survey; Mrs. Billie Green and Mrs. Jo Ann Kirby for reviewing the bibliography citations; and V. J. Johnson for his many suggestions and criticisms as the search progressed and for review of the final manuscript.

5. INDEX OF PROPERTIES

The letters E, T, C following each citation number refer to the type of data, i.e., E = experimental, T = theoretical and C = compilation. The letters A, B, etc. immediately following the citation number are a part of that number and have been used for late additions to maintain the alphabetical arrangement of the bibliography (documents are arranged alphabetically by first author).

Most reference books and handbooks were coded by property only and were not sub-indexed for temperature and pressure ranges. These reference works are indicated by an (*) following the citation number instead of the E, T, C coding. Other documents which have not been sub-indexed for either or both the temperature and pressure ranges for all or a part of the data are indicated by a (+) following the citation number in addition to the E, T, C code.

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ABOVE 50 ATM.

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EXPERIMENTAL - TABLE (7 VALUES), GRAPH, EQUATION
RUSSIAN

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ON THE HEAT OF VAPORIZATION OF LIQUID OXYGEN AND LIQUID NITROGEN AND THEIR CHANGE WITH TEMPERATURE
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EXPERIMENTAL - TABLES (100 VALUES), GRAPH
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BOILING POINT (NORMAL)
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THE VAPOR TENSIONS OF OXYGEN AND NITROGEN IN THE SOLID STATE
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THEORETICAL - EQUATION, GRAPHS

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A NEW EQUATION OF STATE FOR FLUIDS. II. APPLICATION TO HELIUM, NEON, ARGON, HYDROGEN, NITROGEN, OXYGEN, AND METHANE
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P-V-T, EQUATION OF STATE
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THEORETICAL - NOMOGRAPHS

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EXPERIMENTAL - TABLE (37 VALUES), GRAPH

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EXPERIMENTAL - TABLE (60 VALUES), GRAPHS
APPARATUS

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UBER DIE DAMPFDRUCKKURVE DES SAUERSTOFFS UND UBER EINE BESTIMMUNG
DER KRITSCHEN DATEN VON WASSERSTOFF
VAPOR PRESSURE CURVE OF OXYGEN AND A DETERMINATION OF THE CRITICAL
DATA FOR HYDROGEN
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REVIEW - DATA FROM 73
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NITROGEN
EXPERIMENTAL - TABLES (71 VALUES), GRAPH
APPARATUS

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EXPERIMENTAL - TABLE (1 VALUE)
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EXPERIMENTAL - TABLE (1 VALUE)
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EXPERIMENTAL - TABLE (14 VALUES), EQUATION
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APPARATUS
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VELOCITY OF SOUND (74 TO 164 DEGREES K AND 0 TO 0.9 ATM.), PV PRODUCT, REDUCED DENSITY (121 TO 293 DEGREES K AND 3 TO 60 ATM.)
OXYGEN, NITROGEN, ARGON, AIR
THEORETICAL - EQUATION, GRAPH
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EXPERIMENTAL - TABLES (55 VALUES), GRAPHS
APPARATUS

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UBER DIE SPEZIFISCHE WARME EINIGER KONDENSIERTER GASE ZWISCHEN 10 GRAD ABS. UND IHREM TRIPELPUNKT
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EXPERIMENTAL - TABLES (65 VALUES), GRAPH
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ERGEBNISSE DER TIEFTEMPERATURFORSCHUNG. VI. KALORIMETRISCHE MESSUNGEN DER VERDAMPFUNGSWARME DES SAUERSTOFFS BEI NORMALEM DRUCK SOWIE DES AETHYLENS UND PROPYLENS UNTERHALB UND OBERHALB VOM ATMOSPHARENDRUCK
RESULTS OF LOW TEMPERATURE INVESTIGATION. VI. CALORIMETRIC MEASUREMENTS OF THE LATENT HEAT OF VAPORIZATION OF OXYGEN AT NORMAL PRESSURE AS WELL AS ETHYLENE AND PROPYLENE BELOW AND ABOVE ATMOSPHERIC PRESSURE
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EXPERIMENTAL - TABLE (1 VALUE)
APPARATUS
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DYNAMIC VISCOSITY OF GASES AND VAPORS
ATTI. ACCAD. SCI. TORINO CLASSE SCI. FIS. MAT. E NAT. VOL.86, 126-8 (1951 - 2)

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OXYGEN AND 14 GASES
THEORETICAL - GRAPH, EQUATIONS
ITALIAN

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LES NOMBRES DE PRANDTL DES FLUIDES FRIGORIFIQUES
THE PRANDTL NUMBER OF REFRIGERANTS
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OXYGEN AND 22 GASES
THEORETICAL - TABLE (1 VALUE), GRAPHS, EQUATIONS
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OXYGEN AND 18 OTHER GASES
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OXYGEN, AIR
EXPERIMENTAL - TABLES (30 VALUES), GRAPHS, EQUATIONS
APPARATUS

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OXYGEN, HELIUM, NEON, ARGON, NITROGEN, CARBON MONOXIDE, HYDROGEN, CARBON DIOXIDE, METHANE
THEORETICAL - TABLE (1 VALUE)

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EXPERIMENTAL - TABLE (48 VALUES), GRAPH
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APPARATUS

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UTILIZAREA DIAGRAMELOR TERMODINAMICE IN STUDIUL PRODUCERII OXIGENULUI INDUSTRIAL
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OXYGEN, AIR, NITROGEN
SURVEY
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OXYGEN AND 32 GASES
COMPILATION - NOMOGRAPH, DATA FROM 220

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OXYGEN AND 5 ORGANIC COMPOUNDS
EXPERIMENTAL - TABLES (8 VALUES), GRAPHS
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OXYGEN AND 10 GASES
THEORETICAL - TABLE, EQUATIONS

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P-V-T (91 TO 109 DEGREES K AND 1 TO 95 ATM.)
OXYGEN, NITROGEN, CARBON MONOXIDE, METHANE
EXPERIMENTAL - TABLE (10 VALUES)
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OXYGEN, NITROGEN, HYDROGEN, AND 26 COMPOUNDS
EXPERIMENTAL - TABLES (3 VALUES)

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CRITICAL CONSTANTS
OXYGEN, NITROGEN, HYDROGEN AND 21 COMPOUNDS
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ARGON, CARBON MONOXIDE
EXPERIMENTAL - TABLES (5 VALUES), EQUATIONS
THEORETICAL - EQUATIONS

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TRIPLE POINT
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EXPERIMENTAL - TABLE (2 VALUES)
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OXYGEN, NITROGEN, HYDROGEN, AIR
EXPERIMENTAL - TABLES (1 VALUE)

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EXPERIMENTAL - TABLES (11 VALUES), GRAPHS
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EXPERIMENTAL - TABLE (43 VALUES), GRAPHS, EQUATIONS

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EXPERIMENTAL - TABLES (77 VALUES), GRAPHS, EQUATIONS
APPARATUS

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EXPERIMENTAL - TABLE (2 VALUES)
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THEORETICAL - TABLES (35 VALUES), GRAPHS, EQUATIONS
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THEORIE DES GAZ. XV. ETATS CORRESPONDANTS ARGON, OXYGENE, NEON
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COMPRESSIBILITY, CORRESPONDING STATES (173 TO 273 DEGREES K AND 70 TO 100 ATM.)
THEORETICAL - GRAPH
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OXYGEN, NITROGEN, ARGON
THEORETICAL - TABLES (61 VALUES), GRAPHS
COMPILATION - DATA FROM 163, 107, 156
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OXYGEN, NITROGEN, HYDROGEN, ARGON, CARBON DIOXIDE, CARBON MONOXIDE, AIR AND BENZENE
THEORETICAL - GRAPH, EQUATIONS

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SPECIFIC HEAT (P=CONSTANT)(V=CONSTANT), CONSTANTS FOR BEATTIE-BRIDGEMAN EQUATION OF STATE
THEORETICAL - EQUATIONS, GRAPHS
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EXPERIMENTAL - TABLES (83 VALUES)
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APPARATUS

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UBER DAS WARMELEITVERMOGEN, DIE SPEZIFISCHE WARME UND DIE INNERE REIBUNG DER GASE
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THERMAL CONDUCTIVITY, SPECIFIC HEAT (V=CONSTANT), VISCOSITY (81 TO 273 DEGREES K AND 1 ATM.), PRANDTL NUMBER
OXYGEN, 15 OTHER GASES
EXPERIMENTAL - TABLE (4 VALUES), EQUATIONS
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UBER DIE TEMPERATURABHANGIGKEIT DER WARMELEITFAHIGKEIT EINIGER GASE
CONCERNING THE TEMPERATURE DEPENDENCE OF THERMAL CONDUCTIVITY OF SEVERAL GASES
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OXYGEN, NITROGEN, HYDROGEN, AIR, CARBON DIOXIDE, HELIUM, ARGON
EXPERIMENTAL - TABLES (20 VALUES)
APPARATUS
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UBER DAS THERMISCHE VERHALTEN EINIGER KOMPRIMIERTER UND KONDENSIERTER GASE BEI TIEFEN TEMPERATUREN
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OXYGEN, NITROGEN, HYDROGEN, ARGON, CARBON MONOXIDE
EXPERIMENTAL - TABLE (41 VALUES), EQUATIONS
APPARATUS
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OXYGEN AND 13 OTHER GASES
COMPILATION - TABLES
CODED FROM ABSTRACT

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EXPERIMENTAL - TABLES (5 VALUES), GRAPHS, EQUATIONS
APPARATUS
RUSSIAN

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RUSSIAN

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APPARATUS
RUSSIAN

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EXPERIMENTAL - TABLE (13 VALUES), GRAPH
APPARATUS
RUSSIAN

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CONTRIBUTION A L'ETUDE DE LA VISCOSITE DE L'AIR ET DES GAZ
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OXYGEN, NITROGEN, HYDROGEN
EXPERIMENTAL - TABLES (17 VALUES), GRAPHS
THEORETICAL - EQUATIONS
APPARATUS
FRENCH

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ZUR TEMPERATURABHANGIGKEIT DER WARMELEITFAHIGKEIT EINIGER GASE
TEMPERATURE DEPENDENCE OF THE THERMAL CONDUCTIVITY OF SEVERAL GASES
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OXYGEN AND 10 GASES
EXPERIMENTAL - TABLES (15 VALUES), EQUATIONS
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P-V-T, COMPRESSIBILITY FACTOR, ENTHALPY, ENTROPY, HEAT CAPACITY (P=CONSTANT), VAPOR PRESSURE, PHASE TRANSITION HEATS (80 TO 2300 DEGREES K AND 0.5 TO 1500 ATM.), CRITICAL CONSTANTS
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146 MADAN, M. P.
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DIFFUSION COEFFICIENT (100 TO 300 DEGREES K)
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ABSORPTION OF SOUND IN FLUIDS
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VELOCITY AND ABSORPTION OF SOUND, THERMAL CONDUCTIVITY, VISCOSITY (87 DEGREES K)
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147 MASI, J.F.
SURVEY OF EXPERIMENTAL DETERMINATIONS OF HEAT CAPACITY OF TEN TECHNICALLY IMPORTANT GASES
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HEAT CAPACITY (P=CONSTANT) (100 TO 3000 DEGREES K AND 1 ATM.)
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148 MATHIAS, E.
L'ETUDE DE LA COURBE DES DENSITES A BASSE TEMPERATURE AU LABORATOIRE CRYOGENE DE LEIDEN
STUDY OF DENSITY CURVES AT LOW TEMPERATURES
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THE PHYSICAL LABORATORY AT THE STATE UNIVERSITY AT LEIDEN IN THE YEARS 1904-22
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DENSITY (63 TO 153 DEGREES K AND 50 ATM.), CRITICAL CONSTANTS
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REPORT ON THE WORK DONE IN THE LEIDEN CRYOGENIC LABORATORY CONCERNING THE EQUATION OF STATE OF ARGON, NEON AND HYDROGEN BETWEEN THE THIRD AND THE FOURTH INTERNATIONAL CONGRESS OF REFRIGERATION
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149 MATHIAS, E., CROMMELIN, C.A. AND ONNES, H.K.
LA CHALEUR DE VAPORISATION ET LA DIFFERENCE M'-M DES CHALEURS SPECIFIQUES A L'ETAT DE SATURATION POUR L'ARGON, L'OXYGENE, L'AZOTE ET L'HYDROGENE
THE HEAT OF VAPORIZATION AND THE DIFFERENCE OF SPECIFIC HEATS AT SATURATION CONDITIONS FOR ARGON, OXYGEN, NITROGEN AND HYDROGEN
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SPECIFIC HEAT (P=CONSTANT), PHASE TRANSITION HEATS (63 TO 153 DEGREES K AND 0.01 TO 46 ATM.)
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RECTILINEAR DIAMETER FOR OXYGEN
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DENSITY, VAPOR PRESSURE, RECTILINEAR DIAMETER (63 TO 153 DEGREES K AND 0.01 TO 46 ATM.), CRITICAL CONSTANTS
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150A MC KINLEY, C. AND WANG, E.S.J.
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PRESSURE - VOLUME - TEMPERATURE DATA FOR OXYGEN
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P-V-T, SECOND AND THIRD VIRIAL COEFFICIENTS, EQUATION OF STATE (100 TO 473 DEGREES K AND 0 TO 400 ATM.)
COMPILATION - DATA FROM 220

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153 MILLS, R.L. AND GRILLY, E.R.
MELTING CURVES FOR HELIUM 3, HELIUM 4, HYDROGEN, DEUTERIUM, NEON, NITROGEN AND OXYGEN UP TO 3500 KG/SQUARE CENTIMETERS
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MELTING POINT (54 TO 85 DEGREES K AND 0 TO 4000 ATM.)
EXPERIMENTAL - GRAPHS, EQUATIONS
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THE THERMODYNAMIC TEMPERATURE SCALE BELOW 90 DEGREES K. THE NORMAL BOILING POINT OF OXYGEN ON THE THERMODYNAMIC SCALE. THE NORMAL BOILING POINT OF NORMAL HYDROGEN ON THE THERMODYNAMIC SCALE
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BOILING POINT (NORMAL)
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LA RELACION DE DENSIDADES NORMALES DE CARBON OXYDE Y OXYGEN. PESOS ATOMICOS DEL CARBANO Y DEL NITROGENO
THE RELATION BETWEEN THE NORMAL DENSITIES OF CARBON MONOXIDE AND OXYGEN. THE ATOMIC WEIGHT OF CARBON AND NITROGEN
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DENSITY (200 TO 258 DEGREES K AND 0.5 TO 1 ATM.)
EXPERIMENTAL - TABLES (7 VALUES)
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OXYGEN, NITROGEN
EXPERIMENTAL - GRAPHS
APPARATUS

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ISOTHERMS OF DIATOMIC SUBSTANCES AND THEIR BINARY MIXTURES. XXXIII. ISOTHERMS OF OXYGEN BETWEEN -40 AND -152.5 DEGREES C AND 3 TO 9 ATM.
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VISCOSITY (45 TO 90 DEGREES K AND 1 ATM.)
OXYGEN AND APPROXIMATELY 75 OTHER ELEMENTS AND COMPOUNDS
THEORETICAL - GRAPH, EQUATIONS

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OXYGEN AND 40 ROCKET OXIDANTS AND PROPELLANTS
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DENSITY, EQUATION OF STATE, SPECIFIC HEAT RATIOS, SONIC VELOCITY, CRITICAL CONSTANTS (TEMPERATURE AND PRESSURE NOT STATED)
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58A NUTTALL, R.L.
THERMAL PROPERTIES OF GASES, TABLE 9.42. MOLECULAR OXYGEN. THERMAL CONDUCTIVITY
NATL. BUR. STANDARDS, HEAT AND POWER DIVISION
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ON THE LIQUEFACTION OF GASES
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DENSITY (90 DEGREES K AND 1 ATM.), CRITICAL POINT, BOILING POINT
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160 ONNES, H.K. AND BRAAK, C.
ON THE MEASUREMENT OF VERY LOW TEMPERATURES. XXI. ON THE STANDARDIZING OF TEMPERATURES BY MEANS OF BOILING POINTS OF PURE SUBSTANCES. THE DETERMINATION OF THE VAPOR PRESSURE OF OXYGEN AT THREE TEMPERATURES
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MELTING POINT (55 DEGREES K AND NEAR 0.002 ATM.)
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ISOTHERMS OF DIATOMIC SUBSTANCES AND THEIR BINARY MIXTURES. XXV. ON THE ISOTHERMS OF OXYGEN AT LOW TEMPERATURES
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P-V-T (156 TO 233 DEGREES K AND 20 TO 60 ATM.)
EXPERIMENTAL - TABLE (76 VALUES), GRAPH

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OXYGEN AND 34 OTHER GASES
COMPILATION - SOURCES NOT GIVEN
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BOILING POINT (NORMAL)
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SU UNA NUOVA COSTANTE ISOTERMA DEI GAS
ON A NEW ISOTHERMAL CONSTANT OF GASES
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EXPERIMENTAL - TABLES (13 VALUES), GRAPHS, EQUATIONS
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ARGON-OXYGEN, ARGON-NITROGEN
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ON THE MELTING POINT AND INTERMOLECULAR FORCES
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EXPERIMENTAL - TABLES (55 VALUES), GRAPH
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APPLICATION OF THE PRINCIPLE OF CORRESPONDING STATES TO THE TRANSPORT PROPERTIES OF GASES
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VISCOSITY, SELF-DIFFUSION COEFFICIENTS, SECOND VIRIAL COEFFICIENTS (75 TO 300 DEGREES K)
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MOLECULAR WEIGHT, DENSITY AND VISCOSITY OF LIQUIFIED GASES
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DENSITY, VISCOSITY (0 TO 150 DEGREES K), MOLECULAR WEIGHT
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DIE VISKOSITAT VON FLUSSIGEM STICKSTOFF, KOHLENOXYD, ARGON UND SAUERSTOFF IN ABHANGIGKEIT VON DER TEMPERATUR
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EXPERIMENTAL - TABLES (18 VALUES), GRAPH
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ZUSTANDSDIAGRAMME NIEDRIG SCHMELZENDER GEMISCHE II. DAS SCHMELZDIAGRAMM SAUERSTOFF-STICKSTOFF UND DAS ZUSTANDSDIAGRAMM STICKSTOFF-KOHLENOXYD
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181A SARNER, S.
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185 SCHMIDT, W.
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MEASUREMENTS RELATIVE TO THE DETERMINATION OF THERMODYNAMIC EQUATIONS OF SOLID ARGON
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THE HARDNESS OF NITROGEN, OXYGEN, ARGON AND OF NITROGEN-OXYGEN MIXTURES
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204B VAN ITTERBEEK, A.
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VERHANDL. KONINKL. VLAAM. ACAD. WETENSCHAP. BELG. (3), VOL.3, 3-59 (1941)

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Radio Propagation Engineering. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time Interval Standards. Electronic Calibration Center. Millimeter-Wave Research. Microwave Circuit Standards.

Radio Systems. Applied Electromagnetic Theory. High Frequency and Very High Frequency Research. Modulation Research. Antenna Research. Navigation Systems.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.


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