DEPARTMENT OF COMMERCE ★ NATIONAL BUREAU OF STANDARDS

# NBS SPECIAL PUBLICATION 396-4

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

# Critical Surveys of Data Sources: Electrical and Magnetic Properties of Metals

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[2] Located at Boulder, Colorado 80302.

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# Foreword

The National Standard Reference Data System was established in 1963 for the purpose of promoting the critical evaluation and dissemination of numerical data of the physical sciences. The program is coordinated by the Office of Standard Reference Data of the National Bureau of Standards, but involves the efforts of many groups in universities, government laboratories, and private industry. The primary aim of the program is to provide compilations of critically evaluated physical and chemical property data. These tables are published in the *Journal of Physical and Chemical Reference Data*, in the NSRDS-NBS Series of the National Bureau of Standards, and through other appropriate channels.

The properties of commercial materials have thus far received rather limited coverage in the NSRDS program. However, many other groups select and compile data on the properties of such materials, using a variety of criteria for selection. Thus, identifying the best source for a given purpose requires something more detailed than an ordinary bibliographic listing.

This series is designed to provide such guides to data covering selected areas of materials and properties, with emphasis on commercial materials. Earlier publications covered Mechanical Properties of Metals (SP 396–1), Properties of Ceramics (SP 396–2), and Corrosion of Metals (SP 396–3). We would appreciate comments and suggestions about the need for and usefulness of additional surveys, and are prepared to consider the coverage of other materials when and if it appears warranted.

The present survey covers electrical and magnetic properties of metals. This is a very broad field, and there exists a wide variety of data sources, directed at different types of users. A truly comprehensive listing of such sources would be beyond the scope of this series. However, an effort has been made to include representative data sources which should prove helpful to various user communities. Many of the entries in this survey contain references to other valuable sources.

For each of these surveys we have sought assistance from specialists, with emphasis on those involved in the production and use of important commercial materials, and we have been extremely fortunate in obtaining such advice from panels of the relevant technical societies. For adequate coverage of the fields represented in this survey, we found it necessary to form a task force of individuals, rather than representatives of any single society. The assistance of these individuals, listed below, is gratefully acknowledged. We would also like to acknowledge the assistance in forming a qualified panel generously given us by H. F. Storm, Chairman of the Technical Committees Division of the Magnetics Society of the Institute of Electrical and Electronics Engineers, Inc., and by J. A. Dwyer, Assistant Manager, Standards Development Division of the American Society of Testing and Materials. L. H. Bennett, G. C. Carter, and G. Candela of the National Bureau of Standards made valuable suggestions about the sources and definitions to be included.

David R. Lide, Jr., Chief
Office of Standard Reference Data

The task force which reviewed the coverage and contents of this survey included the following individuals. Society and company affiliations are shown for identification only, and do not constitute an endorsement by these organizations.

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Disclaimer: The use of brand names in this publication is for identification purposes only and is not to be interpreted as a recommendation or endorsement by the National Bureau of Standards of any specific product or company.

# Abstract

This survey is intended to provide a directory of authoritative sources of numerical data on the electrical and magnetic properties of metals, with emphasis on commercial alloys. Fifty-nine sources, including handbooks and other publications, information centers, trade associations, and technical societies are described in detail, including information on the properties and materials covered and the criteria used in the selection of data. A few additional related publications are listed with brief descriptions.


Key words: Commercial alloys; data sources; electrical properties; magnetic properties; metals.

# *Critical Surveys of Data Sources:* Electrical and Magnetic Properties of Metals

**M. J. Carr, R. B. Gavert, R. L. Moore, H. W. Wawrousek, and J. H. Westbrook**

## Introduction

Necessary first steps in the selection and compilation of reference data on any group of properties are to locate the best existing compilations and to evaluate these critically. Unfortunately, in the case of many groups of properties, particularly those for commercial metals and alloys, no such compendium exists as is the case for thermodynamic properties with the JANAF Tables, for example. Furthermore, despite the recent publication of several bibliographic aids on metals information (1–4), as well as more general directories to information sources, e.g., (5), there is no ready guidebook to sources of information on the properties of metals that gives an adequate evaluation of the scope, currency and validity of the individual sources.

The National Bureau of Standards has, therefore, undertaken the preparation of a series of detailed critical surveys of the existent compilations of property data for materials. Emphasis has been placed on properties and materials of commercial interest because those have most often been neglected in the past. Scientific data and pure elements and compounds are by no means neglected; information on reference sources of this type are also included where appropriate. Each of these surveys is intended to assess the scope, assets and deficiencies of about forty of the most prominent surces of information. The types of sources included are: handbooks and technical compilations, information centers, foreign information sources, technical societies, and trade associations. The aim is to restrict the surveys to sources which actually have compilations of property data in some form. Thus, sources which offer only generalized guides to the literature, monographs, textbooks, or periodicals publishing original research or engineering articles are not to be included.

The first survey under this program treated compilations of data on the mechanical properties of metals and alloys (6): others deal with the properties of ceramics (7) and with corrosion data (8). The present study critically examines sources of electrical and magnetic property data on metals and alloys, again with emphasis on commercially available materials. The initial listing of sources to be reviewed was compiled by the authors with the advice and assistance of the Office of Standard Reference Data of the National Bureau of Standards and individual members of ASTM Committee B–1 on Wires for Electrical Conductors and of several committees of the Magnetics Society of IEEE. Sources from the initial listing which were found upon examination to fall outside the scope and criteria outlined above are grouped at the rear in a separate section, Miscellaneous Sources. In considering the selection of sources for inclusion in the survey, first priority was accorded those containing the most data, the best evaluated data, the broadest coverage of materials and properties, and the most current information Thus many were not included because a listed source covered the same ground much better or more broadly: and some few were included, even though they did only a fair job within their scope, simply because no other source covered it at all.

A survey of this type is never really complete or up-to-date. Descriptions of any given source need constant revision, new sources appear each year, and valuable but obscure sources are apt to be missed entirely. It is, therefore, hoped that readers and users of this survey will call all such errors and omissions to the attention of the authors.

The sources surveyed are arranged in a convenient, but arbitrary, grouping as set forth in the Contents. Many sources could as well have been classified in two or more categories and some readers might find another grouping more appropriate than that shown here. However, the listing is sufficiently short that locating a source of interest should pose no problem.

Finally, a few words on the possible uses of this survey. It should facilitate the determination of: what significant properties are generally available on important materials; what reasonably finite group of materials might provide a minimally representative list of well-documented property data sets; what property determinations are most conspicuously lacking, and what existent compilations might afford the best base for building a Standard Reference Data set for electrical and magnetic properties.

(1) Wilcox, V. L., Guide to Literature on Metals and Metallurgical Engineering, ASEE, Washington, DC (1970) 32 pp.

(2) Hyslop, M.R., A Brief Guide to Sources of Metals Information, Information Resouces Press, Washington, DC (1973) 180 pp.

(3) Gibson, E.B. and Topia, E.W., Guide to Metallurgical Information, 2nd ed., SLA Bibliog. No. 32, Special Libraries Association (1965) 222 pp.

(4) Carter, G.C., Bennett, L.H., Cuthill, J.R. and Kahan, D.J., The NBS Alloy Data Center: Function, Bibliographic System, Related Data Centers and Reference Books, NBS Tech. Note 464 (August 1968) 24 pp + 168 pp of appendices.

(5) Kruzar, A.T., Encyclopedia of Information Systems and Services, Academic Media, Orange, NJ (1971) 1109 pp.

(6) Gavert, R.B., Moore, R.L., and Westbrook, J.H., Critical Survey of Data Sources: Mechanical Properties of Metals, NBS Spec. Publ. 396–1 (Sept 1974) 81 pp.

(7) Johnson, D.M. and Lynch, J.F., Critical Survey of Data Sources: Ceramics, NBS Spec. Publ. 396–2 (December 1976) 47 pp.

(8) Diegle, R.B. and Boyd, W.K., Critical Survey of Data Sources: Corrosion of Metals, NBS Spec. Publ. 396–3 (January 1976) 29 pp.

# Handbooks and Technical Compilations (1–45)

**Source 1: Advances in Magnetics.**

Transactions on Magnetics, Volume MAG–7, The Institute of Electrical and Electronics Engineers, Inc., 345 East 47 St., New York, NY 10017. 1971. $7.00/IEEE members, $14.00/nonmembers.

Copies of Volume MAG–7 are available from IEEE's Plainfield, NJ office. Reprints of particular review articles may be obtained from the New York office. Minimum orders of 100 are necessary for reprints.

**Scope:** The annual "Advances in Magnetics" issue of IEEE Transactions on Magnetics contains review and tutorial papers on applied and fundamental topics in magnetism. The subject area for the reviews may be different each year. In the referenced 1971 issue, two out of eight review articles published contained compilations of magnetic property data for metals. These articles are "Iron and Silicon-Iron Alloys", M.F. Littmann, and "Soft Magnetic Structural Alloys for Elevated Temperature Applications", D.A. Colling.

**Properties Covered:** Soft magnetic property data are given for eleven steels, and eleven high permeability alloys. These include saturation magnetization, coercive force, initial and high field permeabilities, and core loss.

**Sources of Data:** Data are selected from journal articles or other data banks.

**Size of the Data Bank:** Typical articles in this series run from 10–12 pages.

**Data Storage and Search:** Data are usually presented in tabular form within an individual article. No index is given.

**Selectivity of the Data:** The data are compiled from selected sources by the author of each article. No statistical treatment of data is given.

**Timeliness of the Data:** References cited date primarily from the middle 1960's.

**General Comments:** The "Advances in Magnetics" series is intended to provide a forum for review articles in magnetics. The data found in them are not in condensed form, although they are generally the most up-to-date available. Locating specific data is difficult, since an index is not provided.

**Source 2: Alloy Digest.**

Engineering Alloys Digest, Inc., 356 North Mountain Ave., Box 823, Upper Montclair, NJ 07043. $20.00/year.

The Alloy Digest is available to both domestic and foreign subscribers. A set of back issues may be purchased for $135.00.

**Scope:** The Alloy Digest is a monthly compilation of data sheets on approximately 500 ferrous and nonferrous alloys, giving information on composition and general characteristics of commercial alloys. Electrical properties are generally given. Magnetic properties are not fully covered.

**Properties Covered:** Electrical properties include: electrical resistivity at room and elevated temperatures, resistivity versus degree of deformation, electrical conductivity percent IACS.

Magnetic properties include: B–H magnetization data, energy product data, residual induction, coercive force, initial permeability, maximum permeability, hysteresis loss, saturation induction, residual flux density, Curie temperature, permeance coefficient, recoil permeability, reversible effect of temperature change.

**Sources of Data:** Data are extracted from vendor data sheets and industry-wide specifications.

**Size of the Data Bank:** There are over 1600 data sheets in the system in looseleaf binders. Less than 3 percent of the data pertains to electrical and magnetic properties. There are less than 50 data sheets on magnetic materials.

**Data Storage and Search:** The data are coded generally by chemical symbols, as follows:

| Code No. | Type or Class of Alloy | Approximate Number of Data Sheets |
|---|---|---|
| Ag | Silver-base | 5 |
| Al | Aluminum base | 196 |
| Au | Gold-base | 11 |
| Cb | Columbium-base | 17 |
| CI | Cast-Iron | 35 |
| Co | Cobalt-base | 59 |
| Cr | Chromium-base | 2 |
| CS | Carbon Steels | 38 |
| Cu | Copper-base | 219 |
| Fe | Iron-base (contains most magnetic data) | 43 |
| Mg | Magnesium-base | 69 |
| Mn | Manganese-base | 2 |
| Mo | Molybdenum-base | 8 |
| Ni | Nickel-base | 157 |
| Pb | Lead-base | 6 |
| Pt | Platinum | 1 |
| Re | Rhenium | 1 |
| SA | Steel-Alloys (Alloy Steels) | 253 |
| Sn | Tin-base | 2 |
| SS | Stainless and Heat Resistant Steels | 239 |
| Ta | Tantalum | 1 |
| Ti | Titanium-base | 58 |
| TS | Tool Steels | 222 |
| W | Tungsten-base | 14 |
| Zn | Zinc-base | 13 |
| Zr | Zirconium-base | 5 |

There is a General Index which cross references trade names of the ferrous and nonferrous alloys to the Code Numbers. As an example:

| Trade Name | Code No. |
|---|---|
| Alnico V | Fe–17 |

**Selectivity of the Data:** Data are selected by the Editor of the Alloy Digest who is professionally trained. Reliability of the data varies with the quality of the vendor data sheets and specifications from which the data are taken. There is no statistical treatment of the data by Alloy Digest.

**Timeliness of the Data:** Each Data sheet is dated. The dates cover the period from the early 1950's to the 1970's. Most of the data comes from the 1960's. New sheets are issued monthly with the selections at the convenience of the editor.

**General Comments:** The system is useful where it is inconvenient to send directly to vendors for data. This is particularly true for scattered electrical properties. For magnetic properties, where the number of vendors is small, it may be easier to contact the vendors directly. Broad vendor claims are avoided in the Alloy Digest data sheets. Values used for design should be verified with other sources. The unique value of this publication is in its trade name index, and this source has been included here mainly due to this feature.

**Source 3: Aluminum Standards & Data.**
The Aluminum Association, 750 Third Ave., New York, NY 10017, 1974-75, 200 pp, $2.00.

**Scope:** Provides composition and properties data on 41 wrought and 13 cast aluminum materials. These are the commercial aluminum and aluminum alloys used in the United States.

**Properties Covered:** The following table lists the electrical properties covered:

| Type Property | Electrical Property | Materials Covered |
|---|---|---|
| Typical | Conductivity | All 41 commercial wrought aluminum alloys |
| Typical | Resistivity | All 41 commercial wroght aluminum alloys |
| Minimum limits * | Conductivity | The 5 commercial aluminum conductor materials |

* For design purposes.

This publication also includes a cross index to the principal specification systems used in the United States, to Federal and Military specifications, and to similar foreign alloys.

**Sources of Data:** The Aluminum Association is an industry-wide organization representing over 70 companies which includes all the primary producers of aluminum in the United States, leading manufacturers of aluminum products and principal foundries and smelters.

Committees from the above companies have prepared and published standards and data (including electrical properties) for all commercial aluminum and aluminum alloys. These committees meet at regular intervals to maintain the publications up-to-date.

**Size of the Data Bank:** Electrical data for commercial aluminum and aluminum alloys are covered in 4 pages of this 200 page book.

**Data Storage and Search:** Electrical properties are listed in two sections. The first section covers typical electrical properties for commercial aluminum and aluminum alloys in various tempers. The second section covers electrical properties limits (electrical conductivity) for commercial aluminum and aluminum alloys in the various wrought forms and tempers (i.e., redraw rod, wire, rod, bar, tube, pipe and structural shapes).

**Selectivity of the Data:** Data are reviewed by a committee made up of technical people from the manufacturers of aluminum and aluminum alloys. The data are revised periodically to keep abreast of advances in production methods, to add data on new alloys and to delete those which become inactive.

**General Comments:** This publication provides an excellent basis in preparing electrical properties tables. The Aluminum Association should provide a direct access to the most knowledgeable people and data banks in this area.

While the individual companies representing The Aluminum Association have their own literature covering electrical properties, they recommend the use of the data from The Aluminum Association in preference to that published by individual manufacturers. Where specific data are not covered, the companies also recommend that inquiry by made through The Aluminum Association as the above mentioned committees could be working on such data; if not, the inquiry would be referred to the companies where such information might be available.

**Source 4: American Institute of Physics Handbook.**

D. E. Gray, Coordinating Editor, American Institute of Physics, McGraw-Hill, New York, NY, 3rd Edition, 1972, 1100 pp, $49.50.

**Scope:** This handbook provides definitions, nomenclature, and material property data grouped into eight (8) major divisions of physics. Provides authoritative reference material described with a minimum of narration.

**Properties Covered:** Magnetic property data are found in section 5 and include: saturation magnetization, Curie point and/or Néel point for 11 ferromagnetic elements. Magnetic moment and critical temperatures for rare earth metals and 300 R.E. compounds. Magnetization and Curie point of iron group alloys as a function of electron concentration.

Properties of 25 high D.C. permeability materials in sheet form are covered.

Constants for 19 permanent magnet materials, including: coercive force, residual flux, and maximum energy product.

Data for over 50 anti-ferromagnetic metals and alloys studied by neutron diffraction. Data given include: crystal class, Néel point, magnetic structure, and magnetic moment and direction.

Pressure effects on Curie and Néel points.

Magnetocrystalline anisotropy constants and magnetostriction constants for over 50 metals and alloys.

Hall constants, magneto-optical rotation constants and atomic susceptibilities for four pure elements.

Electrical properties data include: Electrical resistivities of pure elements near room temperature at normal and at elevated pressures.

Hall coefficients: Electronic structure of pure metals characterized by band structure, Fermi surface form, charge carrier type and effective mass.

Critical temperatures and fields for hundreds of superconducting materials are also found in section 9.

**Sources of Data:** Sections on magnetic and electrical properties are compiled and edited by distinguished authories in each field, drawn from government, industry, and educational institutions. Data are primarily from journal articles.

**Size of the Data Bank:** About 150 out of 1100 pages are devoted to magnetic and electrical properties of metals and alloys.

**Data Storage and Search:** Data are presented in tabular and graphical form. Magnetic property data are grouped in section 5–f; electrical properties in section 9–d; superconducting data in section 9–g. The index at the back of the book is used to find specific property data.

**Selectivity of the Data:** Data are obtained from highly regarded sources. Source references are given for each table and figure. Usually, individual table entries are referenced.

**Timeliness of the Data:** The third edition was published in 1972. The data are mostly from middle and late 1960's, some 1950's and a few late 1930's and early 1970's.

**General Comments:** This handbook is strongest in its coverage of magnetic and superconducting metals.

**Source 5: Bibliography of Magnetic Materials and Tabulation of Magnetic Transition Temperatures.**

ORNL–RMIC–7 (Rev 2), T. F. Connolly and E. D. Copenhaven, Oak Ridge National Laboratory, Oak Ridge TN, National Technical Information Service, Springfield, VA 22161, 1970, 116 pp., $3.00, $0.65 fiche.

**Scope:** A tabulation of the Curie and Néel temperatures for magnetic materials.

**Properties Covered:**

Curie temperature
Néel temperature

**Sources of Data:** This is a bibliography of magnetic materials and 1773 references are listed.

**Size of the Data Bank:** The publication contains 116 pages of which 23 are listings for Curie temperature, and 23 are listings for Néel temperature. The remaining 65 pages contain the listing of the references used.

**Data Storage and Search:** Materials are arranged alphabetically and appear in two lists, one for Curie and one for Néel temperature.

**Selectivity of the Data:** Input data comes from the 1773 references listed. All data are referenced to the source.

**Timeliness of the Data:** The tabulation is based on papers and reports received through May 1970.

**General Comments:** This book is a most useful reference, of particular value to those interested in magnetic transition temperatures. It may also serve as a guide to additional magnetic properties data through the 1773 references which are listed.

**Source 6: Electrical Engineers' Handbook: Electric Communication and Electronics.**

H. Pender & K. McIlwain, John Wiley & Sons, Inc., 605 Third Ave., New York, NY 10016, 4th Edition, 1950, 1500 pp. $16.00.

**Scope:** This handbook provides information for engineers in the specific areas of electric communication and electronics. Fundamental engineering material underlying all engineering is published in a separate volume.

**Properties Covered:** Resistivity and its temperature coefficient for approximately 179 metals and alloys. Resistivity of 67 metals and metal oxides at high temperatures. Wire tables on resistance for copper wire, aluminum wire, steel wire and copper-clad steel wire.

Magnetic properties for 17 high-permeability magnetic materials and for 22 permanent-magnet materials.

**Sources of Data:** Data for this book were supplied from industry, government and universities by specialists in their respective fields.

**Size of the Data Bank:** This book consists of 1500 pages of which 19 provide electrical and magnetic properties of metals.

**Data Storage and Search:** Data are presented in tabular form. One section is devoted to Properties of Materials. The electrical and magnetic properties are indexed in the front of this section.

**Selectivity of the Data:** Most of the data represent typical values.

For both electric and magnetic properties the approximate chemical composition is given for the alloys listed.

**Timeliness of the Data:** The 4th edition was issued in 1950. This material was updated previously in 1922 and 1936.

**General Comments:** This is an excellent source of data for electrical properties of materials other than the commercial electrical conductor materials.

**Source 7: Electrical Engineers' Handbook: Electric Power.**

H. Pender & W. A. Del Mar, John Wiley & Sons, Inc., 605 Third Ave., New York, NY 10016, 4th Edition, 1950, 1640 pp, $19.95.

**Scope:** This handbook provides information for engineers in the specific area of electric power. Fundamental engineering material underlying all engineering is published in a separate volume.

**Properties Covered:** Electrical conductivity and temperature coefficient of resistance for the following conductor materials: copper, copper alloys, aluminum and some special purpose conductor metals and alloys.

Resistance, temperature coefficient of resistance and maximum working temperature for 14 metals and alloys used in resistors.

Magnetic properties for 13 commercial materials (ferrous) used in electro-magnetic circuits of electrical equipment and for 21 permanent magnet materials.

**Sources of Data:** Data for this book were supplied from industry, government and universities by 71 specialists in their respective fields.

**Size of the Data Bank:** This book consists of 1640 pages of which 10 provide electrical and magnetic properties of metals.

**Data Storage and Search:** Data are presented in tabular form. One section is devoted to Properties of Materials. The electrical and magnetic properties are indexed in the front of this section.

**Selectivity of the Data:** Most of the data represent typical values. For electrical properties the nominal chemical composition is given for the alloys listed.

For magnetic properties the materials are identified by tradename or type.

**Timeliness of the Data:** The 4th edition was issued in 1950. This material was updated previously in 1922 and 1936.

**General Comments:** A good source of data for electrical conductor materials. Resistor materials are identified by trade name and the characteristics may have been changed since data were published. Magnetic properties and permanent magnet properties are given for materials identified by tradenames which may have changed in composition and characteristics since the data in the book were tabulated.

**Source 8: Electrical and Magnetic Properties of Metals.**

J. K. Stanley, American Society for Metals, Metals Park, OH 44073, 1963, 359 pp, $12.50.

The book is out of print. Inquiries should be directed to ASM.

**Scope:** The book concerns: electrical conduction, electron emission, superconductivity, thermoelectricity, origins of magnetism, electrical steels, permanent magnets, and indications of how electrical and magnetic materials are employed. Electrical conductivity data on approximately 85 metals and alloys are given. Superconductivity data on approximately 60 metals and alloys are given. Around 25 contact metals are covered and approximately 30 soft and special magnetic materials and 42 hard magnetic materials are covered.

**Properties Covered:** Electrical properties include: electrical resistivity around room temperature, temperature coefficient of resistivity, relative resistance of single crystals, resistivity changes with pressure and composition, conductivity percent IACS copper, and specific resistance of contact materials.

Superconductivity properties include: critical temperatures, and critical magnetic field. Mass and volume susceptivities are listed for magnetic phenomena.

Magnetic properties for soft ferrites include: magnetic saturation, Curie temperature, initial permeability, and coercive force.

Soft magnetic properties for metals include: permeability, coercive force, saturation induction, Curie temperature, B-H curves, core loss, and aging effects on hysteresis.

Permanent magnet data include: residual flux density, coercive force, maximum energy product, remanence, and induction at (B-H) max.

**Sources of Data:** Data are taken from technical articles appearing in a wide variety of journals from the fields of physics, metallurgy, and electrical engineering.

**Size of the Data Bank:** The data are included in a bound volume with text 359 pages in length. Approximately one-fourth of the book presents tabulated data.

**Data Storage and Search:** Data are presented as tables and graphs and can be searched through the table of contents and the index.

**Selectivity of the Data:** The data presented are as-taken from various technical journals and must be considered as typical. The author draws on a wealth of experience with the Crucible Steel Company, a prominent magnetic materials supplier. Effort on the part of the reader would be required to search out the original data to determine the experimental and statistical quality.

**Timeliness of the Data:** The text has a 1963 copyright. References go back to original papers extending as far back as the early 1800's. The latest references are from the early 1960's with most references from the prior 30 years.

**General Comments:** The text is very well organized with theory and data clearly presented. A designer could use the data to make rough checks on observed phenomena but he would need other sources of statistical data for his design calculations. Although an updated printing is necessary, this source was included in this survey because of its comprehensiveness and its excellent match with the scope of the survey.

**Source 9: Electrical and Thermal Conductivities of Metals Over Their Entire Liquid Range.**
*Rev. Hautes Temper. et Refract.*, **3** (1966), 115–146, A. V. Grosse.

**Scope:** Electrical and thermal conductivities of 16 metals over their entire liquid range. (Metals covered are listed under the paragraph Data Storage and Search below.)

**Properties Covered:** Electrical and thermal properties from melting point to critical point.

**Sources of Data:** From high temperature research conducted by Research Institute of Temple University supplemented by the referenced work of others doing research in this area.

**Size of the Data Bank:** Ten pages covering electrical conductivities of which approximately 4 pages consist of tables and charts of conductivity versus temperature.

**Data Storage and Search:** Data are stored in tables and graphs. The data include:
Data over the entire liquid range for: mercury, potassium, sodium, rubidium, and cesium.
Data over a portion of the liquid range for: copper, silver, gold, aluminum, lithium, and zinc.
Extrapolated data for: tantalum, niobium, tungsten, molybdenum, and rhenium.
No index is provided; the above metals are in the order they appear in the publication.

**Selectivity of the Data:** The values given for electrical properties are based on experimental data and that taken from sources listed in the Bibliography.

**General Comments:** This is one of the few sources available for electrical conductivities of metals in their liquid ranges.

**Source 10: Electrodeposition of Alloys.**
Volumes 1 & 2, A. Brenner, Academic Press Inc., 111 Fifth Avenue, New York, NY 10003, 1963, $37.50/ volume.

**Scope:** These two volumes provide information for preparing and operating alloy plating baths and scientific presentations of the facts and theory of alloy plating. A limited amount of data is given on the electrical and magnetic properties of these electrodeposited alloys.

**Properties Covered:** Curves of electrical resistivity plotted against percent alloying element are given for: nickel-phosphorus, cobalt-tungsten, cobalt-nickel, and copper-lead.
Permeability, coercive force and residual induction properties are listed for: nickel, nickel-iron alloys, cobalt-nickel, and cobalt.

**Sources of Data:** Data are taken from original literature or from previous compilations of data. Reference is provided either to the primary or secondary source.

**Size of the Data Bank:** The present edition is published in two bound volumes of about 650 pages each. Approximately 12 pages are devoted to Electrical and Magnetic Properties.

**Data Storage and Search:** Tabulated electrical and magnetic properties are in Volume I in a section titled "Properties of Electrodeposited Alloys." There are also occasional references to electrical resistivity in the sections devoted to specific alloys throughout both Volume 1 and Volume 2.

**Selectivity of the Data:** The data are typical average values selected by the author.

**Timeliness of the Data:** The Electrodeposition of Alloys volumes were issued in 1963. The data covered are basic and do not change with time.

**General Comments:** This is an excellent source for electrical and magnetic properties of electrodeposited alloys which are not readily available from other sources.

**Source 11: Electronic Engineer's Reference Book.**
L.E.C. Hughes & F. W. Holland, Heywood Books, of Iliffe Books Ltd., Dorset House, Stamford St., London S.E.1., England, 3rd Edition, 1967, 1500 pp, $17.40.

**Scope:** This handbook is intended to be a desktop source of practical information useful to an engineer or designer working with electronic devices of all sorts.

**Properties Covered:** Electrical resistivity: data are given only for copper wire in standard gauges.

Hard magnetic properties including energy product, remanence, effect of mechanical shock, and ageing behavior in alternating fields are given for 60 American and British commercial permanent magnet materials.

Soft magnetic properties including initial and maximum permeabilities, saturation, remanence, coercivity, hysteresis loss, and Curie temperature are given for about 15 commercial British materials.

**Sources of Data:** Data are primarily taken from supplier's specifications and trade journals.

**Size of the Data Bank:** Approximately 50 out of 1500 pages are devoted to magnetic properties of metals.

**Data Storage and Search:** Data on magnetic properties of metals are given in chapter 5 of the book. Property data are generally in tabular format; an index at the back of the book is useful for locating specific properties quickly.

**Selectivity of the Data:** This book presents typical property data for commercial materials. Sources are given for the data presented.

**Timeliness of the Data:** The 3rd Edition was published in 1967. Property data are typical of commercial materials available at that time.

**General Comments:** The book meets its objective of providing practical data to the electronic engineer. It is weak in the area of electrical resistivity. It is strong in the area of hard and soft magnet materials, especially for comparing American and British commercial materials.

**Source 12: Electronic Properties of Materials; A Guide to the Literature.**

H. Thayne Johnson, Editor, Plenum Press, 277 West 17th St., New York, NY 10011, 1st Edition, (1965) $150.00, supplements (1967) and (1971), D. L. Grigsby et. al., editors.

All three editions may be purchased at one time for $395.00.

**Scope:** These volumes comprise an index to sources of property data for electrical, magnetic, and semiconducting materials, including, but not exclusively, metals. No actual data at all are contained in these volumes, only references.

**Properties Covered:** Properties are referenced for hundreds of metallic materials, cross-indexed by generic name and commercial name.

Electrical properties listed include: electric hysteresis, intrinsic and extrinsic resistivity, mean free path, Hall coefficients, electrostriction, surface resistivity, volume resistivity, electrocaloric effect, and thermoelectric properties.

Magnetic properties listed include: magnetic hysteresis (heading a list of over 35 pertinent properties), magnetoelectric properties (13 subheadings), magnetomechanical properties (about 15 subheadings), magnetic susceptibility (7 subheadings), thermomagnetic properties (5 subheadings).

Superconductor properties include: threshold field, critical temperatures, supercurrent penetration depth.

**Sources of Data:** Data are derived from over 12,000 individual sources listed in the bibliography. Most sources are journal articles, manufacturer's data sheets, government agency reprints, or handbooks. Some are foreign sources.

**Size of the Data Bank:** Two (2) volumes, totaling over 1700 pages of references and cross-indices thereto.

**Data Storage and Search:** Volume 2 contains a list of over 12,000 titles or references to data sources. Volume 1 contains a master index and two cross reference indices (by property and material), as well as instructions and a glossary of terms defining properties.

The master index is arranged alphabetically by material name.

A cross-reference index is used to convert commercial names or common names to the material name used in the master index: e.g. Inconel 702, see Aluminum Chromium Nickel Systems: e.g. Brass, see Copper Zinc Systems.

A second cross-reference index is used to convert material property names to the term used in the master index: e.g. Magnetostriction coefficient, see Magnetomechanical Properties.

The master index listing for each material contains a number of property subheadings. Under these subheadings are the identification numbers for the sources in volume 2 that contain the relevant data. The user would then have to obtain a copy of the indicated source by his own means.

**Selectivity of the Data:** This index is the result of the work of The Electronic Properties Information Center, an independent agency, formerly funded by the Air Force and aided by the library staff of The Hughes Aircraft Company. It has recently been incorporated with the Thermophysical Properties Information Center at Purdue University. Items considered for inclusion into the Center are individually examined. About 10 percent of materials proposed for consideration pass examination and are abstracted and indexed. Final responsibility for accuracy naturally remains with the author of each source.

**Timeliness of the Data:** Sources indexed in the first edition are mostly from the 1950's and early 1960's.

**General Comments:** This index provides a quick, easy means of locating and characterizing sources of magnetic and electrical properties of metals, oxides, glass, and plastics.

**Source 13: Encyclopedia of Physics.**

S. Flugge, Springer-Verlag, Berlin, Germany, Vols. 18 and 19: Volume 18, Part 1, (1966) 592 pp. Part 2, (1968), 500 pp, $88.20: Volume 19, (1956), 411 pp, $42.70.

**Scope:** Intended as an encyclopedic source book on physics. Electrical and magnetic properties are primarily included in volumes 18 and 19.

**Properties Covered:** Electrical conductivity, resistivity, temperature coefficient of resistivity are found primarily in volume 19, "Electrical Conductivity I" of the 54 volume set. Magnetic information is found in volume 18 "Magnetism." It covers ferromagnetic theory and paramagnetic theory and includes information on magnetic semiconductors.

**Sources of Data:** Data are taken primarily from German publications as well as other world-wide sources.

**Size of the Data Bank:** There are 54 hard bound volumes. Each volume is approximately 400 pages in length. There are several pages of graphs and tabulated information in volume 19 on electrical conductivity.

**Data Storage and Search:** Data are stored in the hard bound volumes in graphs and tables. Data are searched by volume titles and by the Table of Contents in each volume. Parallel German and English entries are found in the volumes.

**Selectivity of the Data:** Input data were selected by the editor from established works in physics. Data are referenced by a footnote system. Statistical treatment depends on each section author's work and was not generally observed.

**Timeliness of the Data:** Information dates back from the 1950's to the 40's and 30's.

**General Comments:** The volumes are mostly theoretical treatments. The electrical conductivity data are generally over 20 years old. Despite this the book is still important as a source of information. The two part volume on magnetism is of little value to a design engineer as it deals with the theory of ferromagnetism and paramagnetism rather than design properties. The Encyclopedia is of most use to research scientists.

**Source 14: Engineering Materials Handbook.**
C. L. Mantell, McGraw-Hill, Inc., 1221 Avenue of the Americas, New York, NY 10020, 1958, $37.50.

**Scope:** Presents the practicing engineer and designer with an authoritative reference work on engineering materials with emphasis on the fabricated forms.

**Properties Covered:** Electrical resistivity or conductivity is given for most materials: magnetic susceptibility for nonferrous materials; magnetic permeability, hysteresis loss and magnetization curves for ferrous materials and extensive magnetic data for permanent magnet alloys.

**Sources of Data:** This Handbook was prepared by a staff of specialists who were authorities in their area and they selected the data.

**Size of the Data Bank:** The Handbook has approximately 1800 pages of which electrical and magnetic data comprise approximately 12 pages.

**Data Storage and Search:** Data are arranged by classes of related or similar materials. Electrical or magnetic properties for a specific material are located by use of the index.

**Selectivity of the Data:** The data for electrical and magnetic properties are nominal values.

**General Comments:** This Handbook provides a limited amount of data on a wide variety of metals.

**Source 15: Ferromagnetism.**
Richard M. Bozorth, D. Van Nostrand Company, 1951, $26.50.

**Scope:** The book is divided into two parts, that which describes the properties of magnetic materials and that which describes the nature of magnetic phenomena. The material in this book has been found useful to scientists engaged in research and development and engineers interested in the properties and behavior of magnetic materials.

**Properties Covered:** The magnetic properties of both soft and hard magnetic materials are presented. These include saturation induction ($B_s$), Curie point ($\Theta$), magnetostriction at saturation ($\lambda_s$), crystal anisotropy constant ($K$), permeability ($\mu$), coercive force ($H_c$) remanence ($B_r$) and hysteresis loss ($W_h$). The materials are limited to the elements, iron, nickel, cobalt, and manganese, and alloys of these materials. In addition to the magnetic properties many other physical properties are presented. Much discussion is devoted to the effect of chemical constitution, impurities and processing upon the structure-sensitive magnetic properties.

**Sources of Data:** Data were taken from the greater part of 1500 published references which document the work of industrial and university laboratories.

**Size of the Data Bank:** The volume containing these data consists of approximately 900 pages.

**Data Storage and Search:** Data are presented in both graphic and tabular form. The contents of the book are indexed primarily on the basis of the material whose magnetic properties are being considered.

**Selectivity of the Data:** The data were selected by a prominent magnetics specialist from highly regarded technical and scientific literature and represent the most significant values available.

**Timeliness of the Data:** This book has a 1951 copyright and was reprinted January 1953. The sources of data cover the time interval 1842–1951.

**General Comments:** The book is limited to the magnetic properties of the transition elements—iron, nickel, cobalt, and alloys thereof. Although almost 25 years have passed since its initial publication, "Bozorth" is a well established classic reference treatise on the magnetic properties of the transition metals and alloys. It remains a first reference guide to the literature for both scientists and engineers interested in the properties and behavior of magnetic materials.

**Source 16: Ferromagnetismus.**
E. Kneller, Springer-Verlag New York, Inc., 175 Fifth Ave., New York, NY 10010, 1962, 791 pp, $48.60. Text in German.

**Scope:** This book is an encyclopedic text which treats all aspects of ferromagnetic behavior of materials. Magnetic data for metals and alloys are presented in the context of illustrating particular effects, usually accompanied by pertinent theoretical derivations.

**Properties Covered:** Magnetic property data given generally apply to Fe, Ni, or Co based systems, including certain commercial materials such as Fe–Si and Supermalloy.

Property data are given for: magnetostriction, susceptibility, saturation magnetization, Curie temperature, exchange energy constant, crystal anisotropy effects, domain wall energies, Barkhausen effect, coercive force, remanence, hysteresis loss, magnetic resonance, magnetomechanical damping, and quantum mechanical treatments of ferromagnetism.

**Sources of Data:** Data are referenced to original journal articles in most cases.

**Size of the Data Bank:** Data are given in more than 600 graphs or tables dispersed throughout the book.

**Data Storage and Search:** Data on a specific property are most likely to be found in the chapter devoted to that property. Data are generally presented graphically, occasionally in tabular form.

Data on a specific alloy are best located by using the index at the back of the book. This index is alphabetically arranged according to the principal alloying element's symbol.

**Selectivity of the Data:** The data used in the text were compiled by the author with the assistance of his associates at the Max-Planck Institute for Metals Research at Stuttgart and from industry. The data are not statistically treated.

**Timeliness of the Data:** The book was published in 1962. Journal references date mostly from the 1950's and 1940's.

**General Comments:** This book is a good review of theoretical and empirical aspects of ferromagnetism, as of the early 1960's. It presents a summary of the level of general understanding of ferromagnetic phenomena and uses data in an illustrative manner. So, while the data it contains may be of a practical nature, this book is not primarily intended to be a source of magnetic property data for metals.

**Source 17: Gmelin's Handbuch der anorganischen Chemie.**
Springer-Verlag New York, Inc., 175 Fifth Ave., New York, NY 10010, 8th Edition.
(Text in German). There are over 80 volumes in this series, with prices varying from $18.00 to $325.00. Most do not contain electrical or magnetic property data, however. Such data are found in volumes labeled "Teil A" (Part A) for each element. Typically, "Teil A" can be purchased for $150.00 (Average price for "Teil A's" for Iron, Nickel and Cobalt).

**Scope:** This multivolume handbook is a comprehensive source of preparation methods and property data for inorganic chemical compounds, including elements and metallic alloys.

**Properties Covered:** Properties are given for pure elements and some binary systems.
Electrical properties for pure elements include: bulk and thin film resistivities, Hall effect, Thomson effect, and the effects of impurities, radiation, and cold work on electrical properties.
Magnetic data are given for all the significant magnetic effects displayed by the material in bulk, single crystal, or thin film forms.

**Sources of Data:** Data were obtained from journal articles and other technical publications.

**Size of the Data Bank:** There are over eighty (80) volumes in this handbook each devoted to a single element or binary system. Data on electrical and magnetic properties typically occupy less than ½ of 1 percent of a given volume.

**Data Storage and Search:** Data are usually presented in tabular format. In addition, references to additional sources of data are given for each property subsection.
The indexing system is unique to this handbook. Property data for a given alloy system will be found in the volumes devoted to the principal component, usually in "Teil A" (Part A). Consult the index in the front of "Teil A" for the specific location of the data.

**Selectivity of the Data:** The data in the tables are the most up-to-date available, drawn from reputable journals, both American and foreign. References are given for all data cited. The data are not statistically treated.

**Timeliness of the Data:** The volumes for each element may carry different publication dates. Updated supplements are published on a continuing basis. For example, the volume containing electrical and magnetic properties of nickel is dated 1967, with literature reference up to 1963.

**General Comments:** This handbook is primarily a source of information on the preparation and properties of inorganic compounds. Although it is so broad in its scope, the coverage of magnetic and electrical properties of pure elements is quite complete, providing information on all significant electrical and magnetic properties and effects.

**Source 18: Handbook of Engineering Materials.**
D. F. Miner & J. B. Seastone, John Wiley & Sons, Inc., 605 Third Ave., New York, NY 10016, 1st Edition, 1955, 1379 pp.
This publication is out of print.

**Scope:** Provides a single source of authentic and useful information on the usual materials of manufacture and construction.

**Properties Covered:** The book presents data by material types. For metals used as electrical conductors extensive data are given, for most other metals only the electrical conductivity or resistivity is given. For magnetic materials, including permanent magnet materials, the following properties are covered where applicable: electrical resistivity, magnetization data, core loss, magnetizing force, permeability, magnetization and stablization, hysteresis loop and demagnetization curve.

**Sources of Data:** The contributors who prepared each part of the book were authorities on the subject matter and they selected the data.

**Size of the Data Bank:** The Handbook is 1379 pages in length. Properties of metals are covered in section 2 which is 575 pages in length. Approximately 100 of these pages apply to electrical and magnetic properties.

**Data Storage and Search:** Data are arranged by classes of related or similar materials. Specific properties for a metal are located by use of the index.

**Selectivity of the Data:** Electrical and magnetic properties are presented as nominal values. These data were compiled at a professional level for engineering designers.

**General Comments:** This handbook presents data on a wide variety of metals many of which are identified by tradename. While the basic electrical and magnetic properties for a material do not change, the Handbook needs updating to include the current materials.

**Source 19: Handbook of Materials and Processes for Electronics.**
C. A. Harper, McGraw-Hill Book Company, Inc., 1221 Avenue of the Americas, New York, NY 10020, 1970, 1288 pp, $33.50.

**Scope:** This book was prepared to cover the basic and practical knowledge of modern materials and processes in the electronic industries. Many current materials and processes used by the electrical industries have their origin in the electronic area. Information is provided on electrical properties for aluminum and aluminum alloys, copper and copper alloys, titanium alloys, refractory alloys, and precious metals. Magnetic properties are provided for ferrous materials.

**Properties Covered:** Electrical conductivity is covered for ferrous and nonferrous metals including the magnetic materials. Permeability, coercive force, magnetic saturation, magnetizing force and Curie temperature data are listed for magnetic materials.

**Sources of Data:** Primary emphasis is on current published and unpublished literature, bulletins and handbooks of the suppliers of the materials involved.

**Size of the Data Bank:** The book consists of 1288 pages of which approximately 10 pages are devoted to electrical properties and 22 pages to magnetic properties.

**Data Storage and Search:** The book consists of 15 chapters of which the following three contain data which are presented in tabular form:

Chapter 4—Wires and Cables
Chapter 8—Ferrous Metals
Chapter 9—Nonferrous Metals

**Selectivity of the Data:** Each chapter was prepared by an expert for the area covered. This expert gathered and selected the data which are included in these chapters.

**Timeliness of the Data:** The "Handbook of Materials and Processes for Electronics" was published in 1970.

**General Comments:** This is an excellent source for electrical and magnetic properties.

**Source 20: Handbook on Materials for Superconducting Machinery.**

MCIC–HB–04 (1974), $35.00 Sponsored by Advanced Research Projects Agency. Available from Metals and Ceramics Information Center, Battelle Columbus Laboratories, 505 King Avenue, Columbus, OH 43201; or National Technical Information Service, Springfield, VA 22161.

Order Number AD/A–002698.

First Supplement (1976), $20.00, AD/A–023228.

Second Supplement scheduled for 1977.

**Scope:** Provides mechanical, thermal, electrical and magnetic properties of structural and conducting materials including: aluminum and aluminum alloys, copper and copper alloys, nickel alloys, alloy steels, stainless steels, titanium and titanium alloys, and special metals and alloys (niobium and its compounds). These metals and alloys were selected on the basis that (1) the metal or alloy is suitable for certain cryogenic components or it has certain intrinsic properties at cryogenic temperatures for super-conducting machinery, and (2) property data are available on the material at cryogenic temperatures.

**Properties Covered:** Electrical resistivity in the temperature range from 0 to 300 K. Magnetic susceptibility at various cryogenic temperatures. Critical current density versus temperature and critical field versus temperature for superconductive materials.

**Sources of Data:** The data presented are based on compilations of data collected from documents in the files of the Metals and Ceramics Information Center (MCIC). The reference section lists about 740 references on these materials.

**Size of the Data Bank:** The handbook is a single volume looseleaf notebook containing approximately 500 pages, with about 10 percent providing data on electrical and magnetic properties.

**Data Storage and Search:** The handbook is divided into sections by material type and all properties are presented with each material. Electrical resistivity is given in tabular form and charts are plotted from these data with the curves visually fitted. Magnetic properties are given in tabular form. The electrical and magnetic data for the superconducting state are presented in chart form.

**Selectivity of the Data:** Input data come from a wide variety of test programs and literature in the MCIC Data Bank. These data were reduced to best values. The designer must make his own analysis, referring to the original sources for more detailed information if needed.

**Timeliness of the Data:** Majority of the data comes from the 1960's period with a sizeable amount from the 1970's.

**General Comments:** This is a good comprehensive reference source on electrical and magnetic properties at cryogenic temperatures. The data are of particular interest to designers and material engineers.

**Source 21: Handbook of Tables for Applied Engineering Science.**

R. E. Baltz & G. L. Tuve, CRC Press, 18901 Cranwood Parkway, Cleveland, OH 44128, 2nd Edition, 1973, 1166 pp, $33.50.

**Scope:** The handbook is intended as a desktop source of numerical data related to many fields of engineering required for preliminary study of a subject and for planning, reviewing, and evaluating the feasibility of engineering projects.

**Properties Covered:** Electrical conductivity data for metals are found in several locations and include: electrical resistivity of 35 pure metals at room temperature, temperature coefficient of resistivity, bulk resistivity, thin film resistivity, magnetic materials resistivity, high temperature metals resistivity, rare earth metals electrical resistivity at 298 K and residual resistivity at 4.2 K, resistivity of tin, lead and antimony solders as a ratio to copper, flat cable nominal conductor resistance, integrated circuit bonding wire resistance, maximum amperes for AWG wire sizes.

Soft magnetic properties of metals for over 50 alloys and compounds include: permeability, coercivity, retentivity, flux density maximum, DC flux density saturation, residual flux density (residual induction), coercive force, Curie temperature.

Hard magnetic properties for over 40 alloys and compounds include: remanence, coercive force, and maximum energy product.

Other magnetic properties include: rare earth metal magnetic constants, Néel point, asymptotic Curie point, electronic state, and magnetic moment.

Superconductive properties include: critical temperatures and Type I critical magnetic fields for over 800 alloys and compounds. Critical magnetic field values for Type II superconductors are given for $H_{c1}$ (diamagnetic) $H_{c2}$ (mixed state) and $H_{c3}$ (sheathed state) for over 100 alloys and compounds.

**Sources of Data:** Data were supplied by over 35 contributors selected from industry, government and university laboratories.

**Size of the Data Bank:** Approximately 2 percent of the 1166 page handbook is devoted to electrical and magnetic properties of metals.

**Data Storage and Search:** Data are presented in tabular format. The index of properties presented at the beginning of the handbook lists the location of conductivity, electrical and magnetic properties information. Two sections cover most of the magnetic and electrical properties of interest: section 1—Engineering Materials and their Properties and section 2—Electrical Science and Radiation.

**Selectivity of the Data:** The book presents data obtained from highly regarded sources. The sources are indicated on each table of data presented. Additional references are provided at the end of each subsection in the book. Reasonable effort has been given to provide reliable data but the editors do not assume responsibility for the validity of all information.

**Timeliness of the Data:** The 2nd edition was issued in 1973. The data are primarily from the 1960's but information from the 1940's to the 1970's is also included.

**General Comments:** The handbook meets its objective of providing preliminary numerical data for engineering projects.

**Source 22: Landolt-Börnstein Tabellen.**

K. H. and A. M. Hellwege, Springer-Verlag New York, Inc., 175 Fifth Ave., New York, NY 10010. (Text in German)

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| Band II, 6. Teil: Elektrische Eigenschaften I (1959), | $190.60 |
| Band II, 7. Teil: Elektrische Eigenschaften II (1960), | 203.50 |
| Band II, 9. Teil: Magnetische Eigenschaften I (1962), | 210.90 |
| Band II, 10. Teil: Magnetische Eigenschaften II (1967), | 45.20 |

**Scope:** This handbook is a concise summary of physical-chemical properties of metallic, organic, and inorganic materials.

**Properties Covered:** Electrical resistivity data for pure metals and alloys are given as functions of temperature and pressure.

Magnetic property data for metallic elements and alloys cover ferromagnetic, paramagnetic, and diamagnetic behavior, and include: permeability, saturation magnetization, remanence, coercive force, hysteresis loss, Curie temperatures, Hall constant, and magnetic moment.

Properties for liquid metals and alloys are also included.

**Sources of Data:** Data are primarily from journal articles and other existing data banks.

**Size of the Data Bank:** Four (4) books out of a total of thirty (30) in the series contain electrical and magnetic property data for metallic materials. Of these four, totaling over 4000 pages, large sections are devoted to nonmetallic materials.

**Data Storage and Search:** Electrical property data for metals are found in Teillen 6 and 7, and similarly, magnetic property data are found in Teillen 9 and 10.

An index at the back of each book is arranged alphabetically by material name and provides an easy means of locating data on a specific material.

**Selectivity of the Data:** Compilations of data included in these tables are made by a large number of contributors using many different sources. The quality and completeness of the data, therefore, vary.

**Timeliness of the Data:** Current as of the time of publication.

**General Comments:** Exhaustive search of literature but exceedingly concise treatment of data extracted. Better for elements than for alloys, most of which are simple binaries rather than complex commercial alloys.

**Source 23: Magnetic Alloys and Ferrites.**

M. G. Say, George Newnes Limited, Tower House, Southampton St., London W.C.2 England, 1954, 196 pp. Out of print.

**Scope:** This book covers magnetic theory followed by an application section for each class of magnetic material.

**Properties Covered:** Magnetic properties of both soft and hard magnetic materials are covered including curves for: magnetization, permeability, hysteresis loop, Langevin magnetization, and saturation. Tables are also given for remanence, energy product and coercivity.

**Sources of Data:** Each section of the book was prepared by an expert in that field and the sources of the data are listed.

**Size of the Data Bank:** The book has 196 pages and the data are distributed through all sections.

**Data Storage and Search:** The book consists of eight sections with the following section headings:

1. Ferromagnetic Theory
2. (a) Soft Magnetic Materials
   (b) Magnetically-soft Ferrites
3. (a) Permanent Magnet Steels and Alloys
   (b) Micropowder Magnets
4. Permanent Magnet Ferrites
5. Magnetic Powder Cores
6. Nonmagnetic Ferrous and Magnetic Compensating Alloys
7. Magnetic Recording Materials

**Selectivity of the Data:** Data were selected by the author of each section from reliable sources. Source references are given.

**General Comments:** This book provides a broad coverage of magnetic materials but because of age does not include the developments of the last twenty years.

**Source 24: Magnetic Materials.**
R. S. Tebble & D. J. Craik, Wiley—Interscience, a division of John Wiley & Sons, Ltd., 1969, $36.25.

**Scope:** The largest fraction of this book is a presentation of the intrinsic magnetic properties of magnetically ordered materials, i.e., ferromagnetic, ferrimagnetic or anti-ferromagnetic. The smaller fraction is devoted to the extrinsic, structure-sensitive magnetic properties of both soft and hard commercial magnetic materials.

**Properties Covered:** Intrinsic magnetic properties of the transition series metals and many of their alloys are discussed and presented. These include magnetic susceptibility ($\chi$), Hall constant ($R_o$), anisotropy constants ($K$), saturation magnetization ($\sigma$) and saturation magnetostriction ($\lambda$). Room temperature susceptibility ($\chi$) and Hall constants ($R_o$) are presented for diamagnetic elements.

The temperature dependence of susceptibility, magnetostriction and saturation magnetization for the transition elements and certain of their alloys is also presented.

The structure-sensitive magnetic properties of the Spinels and Orthoferrites, including saturation magnetization, Curie temperature ($T_c$), anisotropy constants ($K$) and magnetostriction constant are presented.

The permanent magnet properties, remanence ($B_r$), coercive force ($H_c$) and energy-product $(BH)_{max}$ are given for many commercial alloys.

The soft magnetic properties: coercive force ($H_c$), saturation induction ($B_s$) and hysteresis loss at 10 kilogauss are also given for many of the commercial magnetic materials.

**Sources of Data:** The greater part of the data were taken from 600 published references which document the work of industrial and university laboratories.

**Size of the Data Bank:** These data are contained in a single volume of approximately 700 pages.

**Data Storage and Search:** Data are presented in both tabular and graphic form. The book is divided into two parts. The larger part covers the intrinsic magnetic properties and the second and smaller part covers the structure-sensitive extrinsic magnetic properties of more commercially oriented materials. The book is structured primarily on a material and/or alloy basis and is indexed accordingly.

**Selectivity of the Data:** The data were selected from highly regarded technical and scientific literature and represent the most significant values available.

**Timeliness of the Data:** This book has a 1960 copyright. The data cover primarily the decades of the 1950's and 1960's.

**General Comments:** The book does serve the purpose of being a handbook for both scientists and engineers. The book is somewhat unique in that structure-sensitive properties are presented with auxiliary information such as material purity, heat treatment, and microstructure.

**Source 25: Magnetic Materials in the Electrical Industry.**
P. R. Bardell, Philosophical Library, Inc., 15 East 40th Street, New York, NY 10016, 1955, 285 pp, $12.00.

**Scope:** This book aims to link the properties of materials with their application. Magnetic properties data are given for representative permanent magnet materials. Electrical and magnetic properties data are given for representative soft magnetic materials.

**Properties Covered:** Permanent magnet materials: magnetizing force, magnetic induction, and permeability.

Soft magnetic materials: Permeability, saturation, hysteresis loss, remanence, coercivity, electrical resistivity, and core loss.

**Sources of Data:** The sources for the data are not listed, the author in the Preface indicates indebtedness to many writers and commercial firms for the information.

**Size of the Data Bank:** The book has 285 pages with magnetic data on permanent magnet materials covering approximately 4 pages. Electrical and magnetic data for soft magnetic materials cover approximately 6 pages.

**Data Storage and Search:** Most data are given in reference tables which are indexed by title of the reference table and also by the properties covered by the data in the tables.

**Selectivity of the Data:** The data presented are typical values and in many cases selected to be representative of a type of material, not of a specific substance.

**General Comments:** This book is intended to be helpful to senior students in physics and electrical engineering and to physicists and engineers in industry. One of the purposes of this book which influences the selection of data presented is to show the link between properties of materials and their application. For this reason much of the data shown are typical values for typical materials. This text is not a source of data for design purposes.

**Source 26: Magnetic Materials and Their Applications.**

C. Heck: Crane, Russak & Company, Inc., 52 Vanderbilt Avenue, New York, NY 10017, 1974, 770 pp, $49.50.

Translated from German by: S.S. Hill

**Scope:** This book covers the requirements of magnetic materials in the various technically important fields and the problems of particular material applications.

**Properties Covered:** Properties covered are: chemical composition, density, electrical resistance, Curie temperature, hysteresis loop, flux density, and permeability.

**Sources of Data:** The references of the sources are listed and the data are derived principally from the manufacturers.

**Size of the Data Bank:** The book is 770 pages in size. There are approximately 46 pages of data in the chapter "Tables of Materials" and an estimated 90 additional pages of data scattered throughout the other chapters.

**Data Storage and Search:** Data are stored in tabular form in chapter 19 which is a rough guide to the magnetic materials available today and their magnetic characteristics. This chapter also includes a listing of the tradenames and producers of magnetic materials. In addition there are many data scattered throughout the entire book.

**Selectivity of the Data:** The data represent values quoted by the manufacturers for materials which are quite often tailored to meet the specific need of their customers.

**Timeliness of the Data:** The book was revised and updated when translated into English for publication in 1974.

**General Comments:** This book provides excellent coverage of the entire field of magnetic materials and includes detailed information on most of the magnetic materials available today on the market.

**Source 27: Materials Data Book for Engineers and Scientists.**
E. R. Parker, McGraw-Hill, 1221 Avenue of the Americas, New York, NY 10020, 1967, 398 pp, $11.50.

**Scope:** The objective of the book is to provide up-to-date tabulated engineering data on solid materials.

**Properties Covered:** Electrical properties include: electrical conductivity percent IACS at 70 °F and electrical resistivity at 70 °F. There are no reported magnetic properties.

**Sources of Data:** Data have been taken from handbooks and specifications of government and industry.

**Size of the Data Bank:** The book is 398 pages in length. Less than ten percent of the book is devoted to electrical properties data.

**Data Storage and Search:** The Table of Contents groups the data under the metal involved, specifically: iron alloys, aluminum alloys, copper alloys, nickel alloys, magnesium alloys, titanium alloys, lead alloys, zinc alloys, tin alloys, and refractory metals. Material suppliers and their addresses are listed in the back of the book.

**Selectivity of the Data:** The data are typical values. There is no statistical treatment. Influence of internal structure and environment on reported properties is not fully treated. References are given and footnotes also provide reference information.

**Timeliness of the Data:** The book was published in 1967. References cover the 1960's as well as some sources from the 1950's and 40's.

**General Comments:** The book does not have a broad coverage of electrical properties, however the metals are well categorized and cross referenced. The listing of vendors and their addresses is useful and permits the designer to go directly to the manufacturer for detailed information on electrical properties.

**Source 28: Materials Data Handbooks.**
Western Applied Research & Development, Inc., 1403–07 Industrial Rd., San Carlos, CA 94070.
Copies are available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

| Materials Data Handbook | Date Published | Cost |
|---|---|---|
| Aluminum alloy 2014 | 5–72 | $8.50 |
| Aluminum alloy 2219 | 3–72 | $9.50 |
| Aluminum alloy 5456 | 6–72 | $7.25 |
| Aluminum alloy 6061 | 5–72 | $7.75 |
| Aluminum alloy 7075 | 4–72 | $9.25 |
| Inconel alloy 718 | 4–72 | $7.75 |
| Stainless steel alloy A–286 | 6–72 | $7.50 |
| Stainless steel type 301 | 4–72 | $7.50 |
| Titanium 6A1–4V | 5–72 | $8.25 |

**Scope:** This is a series of nine handbooks, each covering a specific alloy, which provides information on physical, mechanical, cryogenic, and corrosion properties for the following alloys: Aluminum alloys 2014, 2219, 5456, 6061, and 7075; Inconel alloy 718; Stainless Steel alloy A–286, Stainless Steel type 301; and Titanium 6A1–4V.

**Properties Covered:** Electrical properties include: electrical resistivity, conductivity percent IACS.
Magnetic properties are not included as most of the alloys are non-magnetic.

**Sources of Data:** Data listed as design properties are based on procurement specifications, such as Military, Federal, AMS, and ASTM specifications.
Properties are based on such sources as "Aluminum Standards and Data," "Alloy Digest" and "Metals Handbook."

**Size of the Data Bank:** A typical handbook is made-up of 100 pages. Electrical properties data are scattered throughout the nine volumes.

**Data Storage and Search:** Electrical properties data are searched under the alloy designation presented in each handbook.

**Selectivity of the Data:** The intent of these handbooks is to present a summary of the materials property information presently available. Typical data are presented. There is no formal statistical presentation of the data.

**Timeliness of the Data:** Current as of time of publication.

**General Comments:** These handbooks are useful for general reference on aluminum, stainless steel and titanium for the alloys listed. The data are up-to-date and may be expanded in the future.

**Source 29: Materials for Magnetic Functions.**
F. N. Bradley, Hayden Book Company, Inc., New York, NY, 1971, 300 pp, $17.50.

**Scope:** This book presents an overview of magnetic materials and the devices that employ them by examining the theory that determines their limits as well as by describing them in terms of chemistry and processing. The book is not intended as a compilation of data, and specific design data are generally not presented. The materials considered fall into three categories, the ferrites and the soft and hard magnetic metals.

**Properties Covered:** The following properties of selected ferrites are presented; Curie temp., initial permeability ($\mu$), coercive force ($H_c$), D.C. resistivity, saturation magnetization ($4\pi M_s$), energy product ($BH$). Selected soft magnetic metals are characterized by such data as: saturation magnetization, Curie temperature, saturation magnetostriction, hysteresis loss and maximium permeability. Certain of the data characterizing hard magnetic metals such as energy product ($BH$), coercive force ($H_c$) and remanence ($B_r$) are also presented.

**Sources of Data:** Data were taken from approximately 120 published references which document the work of industrial and university laboratories.

**Size of the Data Bank:** The data are scattered throughout the 300-page volume.

**Data Storage and Search:** Data are presented mostly in graphic form. Very few data are presented in tabular form. The data are presented under the categories of ferrites, soft magnetic metals and hard magnetic metals.

**Selectivity of the Data:** The data were selected from highly regarded technical and scientific literature.

**Timeliness of the Data:** The book has a 1971 copyright. The sources of data cover the time period of the 1950's and the 1960's.

**General Comments:** This book is not really intended as a compilation of magnetic data but is oriented more to the phenomenology of magnetics and applications of magnetic materials to specific devices. As a result this book contains very limited design data.

**Source 30: Metal Progress Data Book.**
American Society for Metals, Metals Park, OH 44073, 1974, $10.00.

**Scope:** Paperback notebook containing data sheets for materials selection, process engineering and fabrication technology extracted from past issues of "Metal Progress" magazine. Metals covered include: carbon steel, alloy steels, low alloy steels, tool steels, titanium, magnesium, aluminum, copper, die casting alloys, superalloys, cryogenic alloys, noble metals and refractory metals.

**Properties Covered:** Electrical properties include: electrical conductivity percent IACS, electrical resistivity, temperature coefficient of resistivity, and volume resistivity.
Magnetic properties include: magnetic permeability.

**Sources of Data:** In-field experts from the membership of ASM plus written works of industry, government, university and foreign sources.

**Size of the Data Bank:** The data book is over 250 pages in length. Less than one percent of the data is devoted to electrical and magnetic properties.

**Data Storage and Search:** The data are presented in three sections, (1) Materials Selection, (2) Process Engineering, and (3) Fabrication Technology. There are only scattered amounts of data in sections 2 and 3. The data are presented in tables and charts. Section 1 on Material Selection covers: irons and steels, nonferrous metals and alloys, superalloys, and special duty metals.

**Selectivity of the Data:** The material is selected by the editors of "Metal Progress" magazine. There is no statistical treatment of the data by the ASM. No references are given.

**Timeliness of the Data:** The data book is an annual publication.

**General Comments:** The amount of data is small. Some direct alloy electrical properties are provided which are not found in places other than vendor's literature.

**Source 31: Metals Handbook.**
American Society for Metals, Metals Park, OH 44073, 8th Edition, Volumes 1–9.
Volume 1, (1961), $45.00
Volume 2, (1964), $42.50
Volume 3, (1967), $42.50
Volume 4, (1969), $42.50
Volume 5, (1970), $37.50 (in two volumes)
Volume 6, (1971), $45.00
Volume 7, (1972), $42.50
Volume 8, (1973), $42.50
Volume 9, (1974), $45.00
Outside the USA and Canada an added charge of $5.00 is required per volume.

**Scope:** Provides information on electrical and magnetic properties of over 200 metals and alloys including: copper, aluminum, contact materials, heating alloys, control alloys and thermostat metals, permanent magnets, soft magnets, relay steels, stainless and heat resisting alloys. Volume 1 which covers the properties and selection of metals is of most interest to users of electrical and magnetic materials.

**Properties Covered:** Electrical properties include: electrical resistivity at room temperature, temperature coefficient of resistivity, liquid resistivity, conductivity percent IACS at room and elevated temperatures, conductivity versus deformation curves, conductivity versus composition curves, change of resistance versus time and temperature curves, and contact resistance. Magnetic properties include: saturation magnetization, coercive force, maximum permeability, magnetic susceptibility, hysteresis loss curves, D–C magnetization, B–H curves, residual induction, intrinsic induction, retentivity, and maximum energy product demagnetization curves.

**Sources of Data:** Data are obtained from 300 to 1300 technical experts, mostly members or associates of The American Society for Metals, and from up to 600 plants in the metalworking field. The data for the most part come from direct experience and testing.

**Size of the Data Bank:** There are nine volumes published to-date in the 9th edition of the Metals Handbook and others are in progress. Volume 1, the largest covering 1300 pages, contains most of the electrical and magnetic property information. The remaining volumes are from 300 to 700 pages in length and contain small and scattered electrical and magnetic property information. Volume 1 consists of 430 compilations of data on different metals and alloys. In addition there are 100 major articles, 1500 detailed "case method" examples, 6700 illustrations, 132 tables of recommended selections for 4400 combinations of service conditions, 2800 definitions and a 64-page index.

**Data Storage and Search:** Data are stored as tables, illustrations, and example problems in bound volume form. Data are searched through use of the table of contents and indices given respectively in the front and back of each volume.

Volume 1: Properties and Selection—This volume presents classes of materials as follows:

Carbon and Low-Alloy Steels
Cast Irons
Stainless Steels and Heat-Resisting Alloys
Tool Materials
Magnetic, Electrical and Other Special-Purpose Materials
Aluminum and Aluminum Alloys
Copper and Copper Alloys
Lead and Lead Alloys
Magnesium and Magnesium Alloys
Nickel and Nickel Alloys
Tin and Tin Alloys
Titanium and Titanium Alloys
Zinc and Zinc Alloys
Precious Metals
Pure Metals

The data are presented to convey specific properties of the metals covered and to guide the reader in selecting a material for a particular application. There are also included: a section of metallurgical definitions, and special reference tables on physical properties, conversion factors, compositions, and sizes.

Volume 2: Heat Treating, Cleaning and Finishing

Volume 3: Machining
Volume 4: Forming
Volume 5: Forging and Casting
Volume 6: Welding and Brazing
Volume 7: Atlas of Microstructures
Volume 8: Metallographic Structures and Phase Diagrams
Volume 9: Fractography and Atlas of Fractographs

**Selectivity of the Data:** The data are presented without references to specific originating reports. Different committees of experts are responsible for each major topic in the various volumes. Each topic represents their combined experiences. Statistical treatment of the electrical or magnetic property data is seldom shown.

**Timeliness of the Data:** Volume 1 of the 8th edition was issued in 1961. Previous to that time, the Metals Handbook was issued as a single volume (1948). Volume 2 was issued in 1964, volume 3 in 1967, volume 4 in 1969, volume 5 in 1970, volume 6 in 1971, volume 8 in 1973, and volume 9 in 1974.

**General Comments:** Volume 1 is the most important reference for electrical and magnetic property data. Less than 25 percent of this volume is devoted to electrical and magnetic properties. The volume emphasizes selection for properties and economy. The number of metals covered is small compared to the volume of material presented. Volumes 2 through 9 emphasize industrial metal processing operations, such as metal stamping for electrical sheet, rather than direct magnetic or electrical properties. Volumes 7 and 8 deal with some electrical and magnetic metal microstructures. Identification of sources of data is limited; there is only a listing of contributing authors for reference. The large size of these volumes and the focus on manufacturing details makes the Metals Handbook less of an engineering first reference for metal properties than the previous 1948 single volume edition. The Metals Handbook has enjoyed a reputation among metallurgists as being of reasonably good reliability.

**Source 32: Metals Reference Book.**

C. J. Smithells, Butterworth's, London, England, 1967, 4th Edition, 3 Volumes, $92.50.
Copies are also available from Plenum Press, New York, NY.

**Scope:** A concise summarization of physical, chemical and mechanical data on elemental metals and common alloys, including electrical and magnetic properties of copper, aluminum, steel and nonferrous alloys and compounds.

**Properties Covered:** Electrical properties include: resistivity, temperature coefficient of resistivity, resistivity versus alloy composition curves, percent increases over room temperature resistance values, resistance of nickel alloy strips, ohms per foot for wire sizes, resistance per foot of copper and aluminum bars and strip.

Superconducting properties include: $R_t/R_0$ ratios and transition temperature for superconducting metals.

Magnetic properties include: flux density, permeability, remanence, coercive force, energy product, hysteresis loop, eddy current losses, and Curie temperature.

**Sources of Data:** Data are taken from the original literature or from previous compilations of data.

**Size of the Data Bank:** The present edition is published in three bound volumes of about 500 pages each. Volume 2 contains the electrical and magnetic properties. Approximately 5 percent of the volume involves these properties.

**Data Storage and Search:** Data are presented very concisely in tables and graphs with minimal introductory text or footnote explanation. Data are organized by alloy group as follows: aluminum and its alloys, copper and its alloys, lead and its alloys, magnesium and its alloys, nickel and its alloys, titanium and its alloys, zinc and its alloys, steels, cast irons and cast steels, bearing alloys, and other industrially important metals. Alloys are designated by their nominal composition and with approximate British Standard and U.S. Specification numbers.

**Selectivity of the Data:** The data are typical average values selected by the editor. Contradictory or discrepant data are sometimes presented in parallel without comment. Reference is provided to either the primary or the secondary source.

**Timeliness of the Data:** Since its inception, a new edition of Smithells has appeared every 5 to 6 years. Each has represented an expansion, rearrangement, correction and up-dating over its predecessors. The present 4th edition was published in 1967; a new edition should be forthcoming within a year or two.

**General Comments:** The lack of criticality, the frequent use of secondary sources and the absence of explanatory material limit its utility to rough comparisons, or calculations. The data are not suitable for design or calibration work. The amount of data on electrical and magnetic properties is small.

**Source 33: Permanent Magnets.**

F. E. Luborsky & R. J. Parker, Report No. 66–C–252, Information Sciences Laboratory, General Electric Co. Research & Development Center, Schenectady, NY 12345, 1966, 170 pp.

**Scope:** Presents a comprehensive review of permanent magnets, including chemical composition, processing practices, and magnetic properties. Commercial magnet materials of both foreign and domestic origin are considered.

**Properties Covered:** Intrinsic magnet properties include anisotropy constants ($K_1$ and $K_2$), coercive force ($H_{ci}$) and intrinsic saturation induction. The principal extensive properties include maximum energy product ($BH_m$), coercive force ($H_c$) and residual induction ($B_r$). The materials are categorized into groups according to the mechanism which operates to promote the high ($H_c$) and/or ($BH_m$). These groups are the magnetic steels, precipitation hardenable alloys, order-disorder alloys and fine particle alloys.

The effect of addition elements upon the magnetic properties ($H_c$, $B_r$ and $BH_m$) of magnet steels is also presented.

The temperature dependence of the magnetic properties is also considered. Demagnetization curves for many commercial alloys are also presented.

**Sources of Data:** Data were obtained from over 250 publications, domestic and foreign. These data were generated primarily in university and industrial laboratories.

**Size of the Data Bank:** The book consists of 170 pages with the greater fraction of the data compiled in the 37 pages of appendices.

**Data Storage and Search:** Data are presented in both graphic and tabular form with half being distributed throughout the text and the other half presented in a series of appendices to the book, all of which are indexed in the table of contents.

**Selectivity of the Data:** The data were selected from highly regarded technical and scientific literature and represent values with a level of significance beyond that of so called typical values.

**Timeliness of the Data:** This book was issued in 1966. Most of the data are from the 1950's and the 1960's with a smaller fraction dating back to the 1930's and 1940's.

**General Comments:** This publication provides a very concise and comprehensive presentation of permanent magnet history—chemistry, processing and magnet properties which could find useful application in both scientific and engineering activities.

**Source 34: Permanent Magnets 2-Examination of Commercial Alloys.**

Electro-Technology, Vol. 70, No. 2, August 1962, 94–102 pp., F. E. Luborsky, Conover—Mast Technical Publications Corporation, 205 East 42 Street, New York, NY 10017.

**Scope:** The article presents a review of the basic magnetic properties of approximately forty (40) standard commercial permanent magnet alloys. The alloys surveyed are categorized under the headings of martensitic steels, precipitation hardened alloys, order hardened magnetic alloys and fine particle magnetic alloys.

**Properties Covered:** The hard magnetic properties are presented in tabular form with reference to trade names and nominal chemical composition. The properties include maximum energy product ($BH_{max}$), coercive force ($H_c$), remanence ($B_r$) and the Curie temperature.

**Sources of Data:** Data were obtained from over forty (40) sources selected largely from the published results of industrial and university research. These data emanated mostly from foreign sources: Japanese, Russian, Dutch, and German.

**Size of the Data Bank:** The data are confined to nine (9) pages of a periodical.

**Data Storage and Search:** Data are presented in tabular form under the broad headings of martensitic steels, precipitation hardened magnet alloys, cast Alnico alloys, order-disorder permanent magnets and fine particle magnets.

**Selectivity of the Data:** These data were selected by a magnetics specialist from highly regarded technical and scientific literature. The level of significance would be beyond that of so called typical or nominal values.

**Timeliness of the Data:** These data were generated in the time span bounded by the turn of the century and the early 1960's.

**General Comments:** These data represent good information which can be used for both scientific and engineering purposes. The materials under consideration include complex commercial alloys referred to by trade names.

**Source 35: Permanent Magnets and Their Applications.**

R. J. Parker & R. J. Studders, John Wiley and Sons, Inc., 605 Third Avenue, New York, NY 10016, 1962, 400 pp, $20.25.

**Scope:** This book is directed primarily toward the engineer concerned with application of the permanent magnet. The permanent magnet materials covered are as follows:

Aluminum–Nickel–Iron Alloy
Copper–Nickel–Cobalt Alloys
Copper–Nickel–Iron Alloys
Iron–Cobalt–Molybdenum Alloys
Iron–Cobalt–Vanadium Alloys

Manganese–Aluminum Alloys
Manganese Bismuthide
Martensitic Steels
Nonmetallic Materials
Platinum Alloys
Silver–Manganese–Aluminum Alloys

**Properties Covered:**
*Electrical Properties:*
Resistivity
*Magnetic Properties:*
Peak $H$, oersteds
Peak induction, $B$, gausses
Residual induction, $B_r$, gausses
Coercive force, $H_c$, oersteds
Maximum energy product, $(BH_{max})$
Loss of $(W \cdot s/cycle)$/lb
Recoil permeability
Demagnetization curves

**Sources of Data:** The data presented are based on information furnished by the companies producing permanent magnet materials.

**Size of the Data Bank:** The book has 400 pages with electrical and magnetic data covering approximately 28 pages.

**Data Storage and Search:** Most data are provided in one chapter covering permanent magnet materials, however there is much additional material scattered throughout the book, usually a comparison of several materials in chart or tabular form.

**Selectivity of the Data:** The data are based on information furnished by the companies producing permanent magnet materials.

**General Comments:** This book provides typical data for magnetic properties of commercially important permanent magnet materials up to 1962.

**Source 36: The Properties of Electrodeposited Metals and Alloys—A Handbook.**
W. H. Safranek, American Elsevier Publishing Company, Inc., 52 Vanderbilt Ave., New York, NY 10017, 1974. 517 pp, $24.50.

**Scope:** The Handbook has organized quantitative data on the magnetic and electrical properties of electrodeposited metals. It also presents physical and mechanical properties.

**Properties Covered:** Electrical data include: resistivity range of electrodeposits, minimum resistivity of metal electrodeposits and resistivity of unplated wrought metals.

Magnetic property data include: coercivity values of electrodeposits and the ratio of remanence to saturation magnetization ($B_r/B_m$ ratio) which is a measure of squareness of the hysteresis loop.

Plating metals include: aluminum, cadmium, chromium, cobalt, copper, gold, iron, lead, nickel, palladium, rhodium, silver, tin, and zinc.

**Sources of Data:** The author organized and correlated information found in more than 1500 separate articles. Approximately 20 percent of the references appeared in "Plating" or "Technical Proceedings" of the American Electroplaters Society Inc. Many foreign data sources are included.

**Size of the Data Bank:** Approximately ten percent or less of the 517-page handbook is devoted to electrical and magnetic properties.

**Data Storage and Search:** Data are presented in tabular format. The handbook has 23 chapters titled by the deposited metal including: aluminum, cadmium, chromium, cobalt, copper, gold, iron, lead, manganese, nickel, platinum, rhenium, silver, tin, zinc, uncommon metals, and alloys of these metals.

**Selectivity of the Data:** The author is the manager of the Electrochemical Engineering Technology Section, Battelle, Columbus Laboratories and has authored many publications on electrodeposition. The data selections were made by the author with assistance of the staff of Battelle's Columbus Laboratories. References are provided after each chapter in the Handbook.

**Timeliness of the Data:** The Handbook was issued in 1974. The data cover primarily the 1960's with additional information from the 1950's and earlier.

**General Comments:** The data are of practical value. Electrodeposits providing good conductivity are needed for high strength steel wire, printed circuits, electrical contacts and radar waveguides. Electrodeposits with magnetic properties are needed for applications such as memory storage and memory switching devices. The researcher or design engineer should develop new application ideas knowing the availability of these data.

**Source 37: Properties of Magnetic Materials for use in High-Temperature Space Power Systems.**
P. E. Kueser, D. M. Pavlovic, D. H. Lane, J. J. Clark, & M. Spewock, Westinghouse Electric Corportion, Lima, OH, Scientific and Technical Information Division, Office of Technology Utilization, National Aeronautics and Space Administration, Washington, DC, 1967, 318 pp, $2.25.
Copies are available from: Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

**Scope:** Collection of information on the properties of eight selected materials found suitable for use in high-temperature advanced electric power systems.

**Properties Covered:** Discussion of magnetic material properties up to 760 °C (1400 °F) ambient and frequencies to 3200 Hz.

Radiation effects on magnetic materials.

Tables are given for: electrical resistivity, DC magnetization, AC magnetization, core loss, constant current flux reset, and magnetic stability.

**Sources of Data:** A literature search was conducted and there are 8 pages listing the References and Bibliography.

**Size of the Data Bank:** Data are stored in paperback book form. There are 318 pages. Over 50 percent of the book is comprised of magnetic and electrical property data.

**Data Storage and Search:** The publication is indexed by properties which are further broken down into sections on each of the alloys covered. Most of the data is presented in graph form.

**Selectivity of the Data:** A thorough search of literature was made for magnetic material properties of the following materials: Cubex alloy; Hiperco 50 alloy; Supermendur; Hiperco 27 alloy; Iron 1-percent silicon investment casting (AMS5210); 15-percent Nickel maraging steel; AISI grade H–11 steel, Premium quality (AMS6487 and 6437); and Nivco alloy.

**General Comments:** This is a prime source for high temperature magnetic properties for the alloys covered.

**Source 38: Standard Handbook for Electrical Engineers.**

(Knowlton's Handbook), D. G. Finke, McGraw-Hill Book Company, Inc., 1221 Avenue of the Americas, New York, NY 1968, 10th Edition, $33.50.

**Scope:** This handbook is intended to be a desktop source of practical data for engineers and designers.

**Properties Covered:** Electrical properties include: conductor properties of standard copper, aluminum, or iron conductors, properties of (over 50) resistance metals and alloys, and properties of 12 fusible metals and alloys.

Soft magnetic properties of ten common commercial grades of motor and transformer steels are given. These include: induction curves, maximum core loss curves, permeability and saturation magnetization data.

Hard magnetic properties for 21 commercial permanent magnet materials are given. These include: coercive force, residual induction, and energy product.

**Sources of Data:** Data are acquired from magnetic and electrical textbooks, manufacturer's specification sheets, journal articles, and other handbooks.

**Size of the Data Bank:** About 350 pages are devoted to electrical and magnetic properties of metals out of a total of over 2200 pages.

**Data Storage and Search:** Electrical and magnetic data are collected within the first 360 pages of Section 4 of the handbook. Data are usually presented in tables, occasionally as graphs. A straightforward index is given at the beginning of section 4.

**Selectivity of the Data:** Each subsection was edited by a specialist in the field. Every effort is made to up-date the information contained in each new edition to conform with the latest ASTM standards. References for the sources of individual bits of data are given in the text that precedes or describes each table or graph.

**Timeliness of the Data:** Sources for the electrical and magnetic data in the 9th edition (published in 1957) are mostly from the 1940's and 1950's.

The 10th edition was published in 1968.

**General Comments:** This handbook meets its objective of being a desktop source of practical property data for commercial materials and would be of use to engineers and designers.

**Source 39: Properties of Selected Superconductive Materials.**

NBS Technical Notes 724 and 825. Nat. Bur. Stand. (U.S.), B. W. Roberts, United States Department of Commerce.

These booklets are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

NBS Technical Note 724, 1972, $1.40

NBS Technical Note 825, 1974, Supplemental $1.25

**Scope:** Tabulation of superconductive materials (including proven non-superconductors) with critical temperature and field, crystal struture data where determined, and references.

**Properties Covered:** Critical temperatures, fields and crystal structure data.

**Sources of Data:** All data are referenced as to the source.

**Size of the Data Bank:** These data are contained in two booklets of approximately 175 pages.

**Data Storage and Search:** Data are tabulated and listed alphabetically by material.

**Selectivity of the Data:** The booklets present 4 tables. In the first table are listed data for the elements, selected generally from recent studies in which the sample purity and perfection appear to have been seriously considered. The second table contains information on superconductive materials plus all materials that have been reported to be tested specifically for a superconducting transition down to some temperature $T_n$ without discovery of a transition. The third table covers superconductive materials with organic constituents. The fourth table lists high magnetic field superconductors.

**Timeliness of the Data:** NBS Technical Note 724 was issued in June 1972. NBS Technical Note 825, 1974 supplement, was issued in April 1974.

**General Comments:** These are an excellent comprehensive reference source on superconductive materials.

**Source 40: Standard Handbook; Wrought Copper and Copper Alloy Mill Products.**
**Standard Handbook; Cast Copper and Copper Alloy Products.**

Copper Development Association, 405 Lexington Ave., New York, NY 10017. No charge to customers of the copper and brass industry.

**Scope:** Provides electrical properties on over 300 commercial copper-based materials.

**Properties Covered:** The following electrical properties are listed for each material:

| Wrought Materials | Cast Materials |
|---|---|
| Electrical resistivity | Electrical resistivity |
| Electrical conductivity | |

Magnetic properties are not covered.

Included is a cross index of the principal specification systems used in the United States for wrought and cast copper and copper alloys. These systems have used different codes to identify the same materials.

**Sources of Data:** Prepared by a committee of technical experts in the copper industry.

**Size of the Data Bank:** All standard coppers and copper-based alloys are covered in these publications; there are 238 alloys covered in the handbook on wrought alloys which includes approximately 450 pages and 93 alloys in the cast products handbook which has 241 pages.

**Data Storage and Search:** "The Standards Handbook; Wrought Copper and Copper Alloy Products" is compiled in six separately bound parts:

Part I—Tolerances
Part 2—Alloy Data
Part 3—Terminology

Part 4—Engineering Data
Part 5—Sources
Part 6—Specifications Cross Index

"The Standards Handbook; Cast Copper and Copper Alloy Products" is compiled in one bound book:
Part 7—Data/Specifications

Electrical Properties data are listed in the following two parts of the Standards Handbook.
Part 2—Alloy Data
Part 7—Data/Specifications for cast materials

Data are listed by CDA copper alloy numbers, for a cross reference to other material identification systems, refer to the following:
Part 6—Specifications cross reference for wrought materials
Part 7—Data/Specifications for cast materials.

**Selectivity of the Data:** The data are based on years of experience in the production, specification and purchase of all copper products and are used by the mill product producers as applicable to commercial material.

**Timeliness of the Data:** The parts of the Standards Handbook which are of interest for electrical data were issued at the following times.

Part 2—1973
Part 7—1970

These parts have been updated in the past approximately every four years.

**General Comments:** These data were developed for CDA by a committee which represented nearly all of the producers in the copper and brass industry.

If contacted, CDA will make a search through its Copper Data Center for any properties or values which are not presently covered by the "Standards Handbooks."

While literature of the individual companies in the copper industry is available, the companies recommend CDA Handbook data be used for general purposes, since values presented by one manufacturer may vary slightly from the industry in general, due to their particular manufacturing set-up or customer requirements.

**Source 41: Superconducting Materials.**

E. M. Savitskii, V. V. Baron, Y. V. Efimov, M. I. Bychkova, and L. F. Myzenkova, Plenum Publishing Corp., 227 West 17th St., New York, NY 10011, 1973, 459 pp. $27.50.

**Scope:** A comprehensive review and summary of superconducting materials.

**Properties Covered:** The temperature of transition into the superconducting state ($T_c$), the critical magnetic field ($H_c$), and the critical current ($I_c$) for the twenty-seven superconducting elements and many superconducting compounds.

**Sources of Data:** A most thorough review of the literature on this subject was made when originally prepared by the Russian authors in 1969 and it has been specifically updated for this translation.

**Size of the Data Bank:** The data are included in a bound volume text, 459 pages in length. There are approximately 10 pages of tabulated data. However, the major portion of the text is devoted to the effect of various factors on the electrical and magnetic properties.

**Data Storage and Search:** The tabulated data are in one section of the text titled "Properties of Superconducting Elements." Scattered throughout the text are curves showing the effect of different factors on the subject properties.

**Selectivity of the Data:** The data were selected by the authors and the source literature cited.

**Timeliness of the Data:** The text was published in Russian in 1969 and was updated to include the results of recent publications when prepared for the American edition which was published in 1973.

**General Comments:** Superconductivity of a material is defined by the electrical and magnetic properties. This is a complete and authoritative summary and review of superconducting materials to 1973.

**Source 42: Superconducting Materials—A Survey.**

Cryogenics, Volume 12, October 1972, P. A. Battams, IPC Science and Technology Press Ltd, IPC House, 32 High St., Guilford, GU1 3EW, Surrey, England, 6 pp, $7.50.

**Scope:** A tabulation of superconducting materials from a survey of all major producers throughout the world of the materials they produce and the operating performance expected.

**Properties Covered:** Nature of material, ratio superconductor/stabilizer, range of diameters available, number of filaments available, highest operating temperature, highest operating field, and price per unit length.

**Sources of Data:** These data were furnished by the leading manufacturers throughout the world on their own products.

**Size of the Data Bank:** This is a six page article of which 5½ pages are data.

**Data Storage and Search:** Each producer is listed alphabetically and the data for a producer's materials are tabulated after the producer's name.

**Selectivity of the Data:** The data represent the operating performance expected from each material by the firms furnishing these materials.

**Timeliness of the Data:** The survey from which these data were obtained was conducted late in 1971.

**General Comments:** This is a very complete coverage of the operating characteristics of the commercial superconductors available up to 1972.

**Source 43: Survey of Electrical Resistivity Measurements on 16 Pure Metals in the Temperature Range 0 to 273 K.**

NBS Technical Note 365 & 365-1, Nat. Bur. Stand. (U.S.), L. A. Hall, United States Department of Commerce, National Bureau of Standards, 1968, Out of Print.

**Scope:** Experimental electrical resistivity data for 16 pure metals have been compiled, tabulated and graphically illustrated for a temperature range 0 to 273 K. A section has been prepared for each particular metal which includes references, brief comments concerned with preparation of sample, purity, and any other pertinent information, tabulated data and graphs.

**Properties Covered:** As the title implies, electrical resistivity is the only property covered in this booklet. Experimentally determined electrical resistivity data measured at room temperature and below are presented for a total of 16 pure metals including: aluminum, beryllium, cadmium, chromium, cobalt, copper, gold, indium, iron, lead, magnesium, manganese, molybdenum, nickel, niobium, platinum, silver, tantalum, tin, titanium, tungsten, vanadium, zinc, and zirconium.

**Sources of Data:** Over 300 sources of data are referenced in addition to over 400 additional references representing work of industrial as well as university laboratories.

**Size of the Data Bank:** These data are contained in a booklet of approximately 100 pages.

**Data Storage and Search:** Data are presented in both tabular and graphic form.

**Selectivity of the Data:** The booklet presents data obtained from highly regarded sources. The sources are indicated on each table and graph of the presentations.

**Timeliness of the Data:** This booklet was issued in 1968. The sources of data cover the time span of the 1930's thru the 1960's.

**General Comments:** These data are limited to a small group of pure metals which probably would be of more interest to scientists than to engineers. Out of print but available in photocopy or microfiche from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

**Source 44: Temperature, Its Measurement and Control in Science and Industry.**
Vol. 4, Parts 1, 2 and 3, H. H. Plumb, Instrument Society of America, 400 Stanwix Street, Pittsburgh, PA 15222, 2380 pp, $110.00.

**Scope:** Volume four represents the change and development in thermometry from the time the previous volume three was issued in 1962 up to June 1971. During this period, the adoption of the International Practical Temperature Scale of 1968 (IPTS–68) stimulated research and development for precision thermometry.

**Properties Covered:** Electrical and magnetic properties used to determine thermometric fixed points, i.e. transition temperature for superconductors, emf versus temperature for thermocouples, and mutual inductance for germanium thermometers.

**Sources of Data:** These data are from papers presented at the "Fifth Symposium on Temperature" and most are values selected or observed by the authors.

**Size of the Data Bank:** There are 2380 pages in the three parts of Volume four. Electrical and magnetic data are limited to a few pages.

**Data Storage and Search:** There are 10 sections in the three parts of volume four. Electrical and magnetic data are limited to:

Section I. Temperature Scales and Fixed Points
Section V. Magnetic and Quantum Electronic Thermometry
Section VIII. Thermoelectric Thermometry

**Selectivity of the Data:** The data presented are selected or observed by the authors of the articles. There is a very limited amount of data on materials. Most data are on materials used as a part of a temperature measuring device. Data are to show the accuracy and limitations of these devices.

**Timeliness of the Data:** This source covers data developed up to June, 1971.

**General Comments:** While "Temperature, Its Measurement and Control in Science and Industry" include electrical and magnetic data, such information is not segregated in any way and hence is very difficult to retrieve.

**Source 45: Thermophysical Properties of High Temperature Solid Materials.**

Y.S. Touloukian, Purdue Research Foundation, Purdue University, MacMillan Publishing Co., 866 3rd Avenue, New York, NY, 1967, 6 vols., $250.00.

Volumes 2 and 3 are available separately at $100.00 and $60.00 respectively.

**Scope:** This series, prepared by the Thermophysical Properties Research Center at Purdue University, attempts to bring together in a single work a large portion of the available data on the thermophysical properties of high temperature materials. This current work is an up-dated version of the original work titled "Handbook of Thermophysical Properties of Solid Materials."

**Properties Covered:** Electrical resistivity data for most pure elements and hundreds of alloys are given as a function of temperature, usually from room temperature, often up to near the melting point.

**Sources of Data:** Data are taken from journal articles, government reports, industry reports, and manufacturer's data sheets.

**Size of the Data Bank:** There are six volumes in this book, of which the first three apply to metallic materials. Electrical resistivity is one of 15 selected properties given for each material.

**Data Storage and Search:** Electrical resistivity data for metals are given in volumes 1, 2, and 3. Graphs of $\rho$ versus $T$ are given for each element or alloy listed. Materials are grouped into Elements, Nonferrous Alloys, and Ferrous Alloys. An alphabetical index in each of the pertinent volumes guides the user to the location of the data. Materials are listed by generic type and commercial name.

**Selectivity of the Data:** The book presents data from all available sources. Each given value is identified as to its source, reported probable error, and method or technique used to obtain it.

**Timeliness of the Data:** This work was published in 1967. Most of the references are from the early 1960's and 1950's.

**General Comments:** This is excellent source for electrical resistivity data, including high temperature data for a large number of metals and alloys used for high temperature applications. The compilation of scattered data into a single book is a valuable asset.

# Information Centers (46–49)

**Source 46: Copper Data Center,** Battelle Memorial Institute, 505 King Avenue. Columbus, Ohio 43201.

**Publisher or Custodian:** Copper Development Association Inc., 405 Lexington Avenue, New York, New York 10017.

**Scope:** Covers copper technology from the refining of metal through the end-use performance of parts, components and systems made from its mill products. Materials included: copper, copper alloys, iron and steel with copper as an alloying element, copper chemicals and also materials which compete with copper.

**Properties Covered:** The intent is to provide information on all properties, including electrical and magnetic properties under all conditions of use.

**Sources of Data:** Primary emphasis is on current published and unpublished material from world sources. Published world literature dating back to 1959 is included in a computerized retrieval system.

**Size of the Data Bank:** The data bank now contains information and data based on pertinent published material from 107 sources.

There are over 5,000 terms and 20,000 interrelationships stored on computer tape.

Each document put in the system is given a serial number and this number is stored behind each term used to index it.

**Data Storage and Search:** Data are correlated and stored in a computerized data bank and are immediately available through technical specialists at the Data Center.

**Selectivity of the Data:** Information and data from both published and unpublished sources are collected and screened by specialists at Battelle. Each document selected for inclusion is sent for evaluation to one of 90 engineers and scientists who are the staff of experts that guides the program technically.

**Timeliness of the Data:** The latest information from world-wide technical data and information is continually collected and screened for inclusion.

**Availability:** The Copper Data Center serves the users of copper and copper alloys in two ways:

User-Oriented Data: Using the Data Center facilities, specialists prepare application data sheets, technical reports, and handbooks. A comprehensive, computer-coded field-of-interest register is maintained for prompt and accurate distribution of these publications. Requests for individual listing in this interest-register may be addressed to CDA in New York or to Copper Data Center at Battelle in Columbus.

Special Service: Engineers needing special information and data on the application and performance of copper and copper alloys can contact CDA or Battelle for assistance. The same technical specialists working in the Data Center program who monitor and evaluate information on copper technology going into the Center also research and respond to written or telephoned requests for assistance on specific topics. When required, computer searches are made. The requestor gets the information or data as soon as possible and in usable form.

**Cost of Access to Data:** No charge. It is a technical service to the customers of the copper and brass industry.

**General Comments:** This is an excellent source for electrical and magnetic properties of copper based alloys which are not readily available from other sources.

**Source 47: Cryogenics Data Center,** National Bureau of Standards.

**Publisher or Custodian:** Cryogenics Data Center, National Bureau of Standards, Boulder, Colorado 80302, and National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161.

**Scope:** Acquire and catalogue for bibliographic purposes all literature and data of interest in cryogenics and evaluate and compile low-temperature data on properties of materials.

Published quarterly: "Superconducting Devices and Materials Literature Survey."

**Properties Covered:** The intent is to provide information on all properties including electrical and magnetic properties under low-temperature conditions.

**Sources of Data:** All literature and data of interest to cryogenics.

**Size of the Data Bank:** There are 80,000 to 85,000 documents on file.

**Data Storage and Search:** Documents are correlated, evaluated, compiled, and stored in a computerized data system.

**Selectivity of the Data:** Information and data from all sources are evaluated and compiled by a staff of experts.

**Timeliness of the Data:** The latest information from world-wide technical literature and data are continually collected and screened for inclusion in the data book.

**Availability:** The data are available to anyone on inquiry to the Data Center at Boulder. The "Superconducting Devices and Materials Literature Survey" may be ordered from the National Technical Information Service, Springfield, Va. 22161.

**Cost of Access to Data:** The cost of time required for search. Average cost is approximately $50.00 per search.

Price of "Superconducting Devices and Materials Literature Survey" is $20.00 per year.

**General Comments:** The Data Center at Boulder is an excellent source for electrical properties under low-temperature conditions which are not available from other sources.

**Source 48: National Aeronautics and Space Administration's Network of University-based Regional Dissemination Centers (RDC's).**

**Publisher or Custodian:** The National Aeronautics and Space Administration is the sponsor of the National Network of University-based Regional Dissemination Centers (RDC's). The NASA Regional Dissemination Centers include:

| Area | RDC | Phone |
|---|---|---|
| Midwest | Aerospace Research Applications Center (ARAC)<br>Indiana University Foundation<br>Bloomington, Indiana 47405 | (812) 337–7970 |
| East | Knowledge Availability Systems Center (KASC)<br>University of Pittsburgh, Pittsburgh, PA 15113 | (411) 624–5212 |

| | | |
|---|---|---|
| Southwest | Technology Application Center (TAC)<br>University of New Mexico, Box 185<br>Albuquerque, New Mexico 87106 | (505) 277–3118 |
| New England and North East | New England Research Application Center (NERAC)<br>University of Connecticut<br>Storrs, Connecticut 06268 | (203) 429–6616 |
| South East | North Carolina Science & Technology Research Center (NCSTRC), P.O. Box 12235<br>Research Triangle Park, N.C. 27709 | (919) 549–8291 |
| West | Western Research Applications Center (WESRAC)<br>University of Southern California<br>Los Angeles, California 90007 | (213) 746–6133 |

**Scope:** Each center has the mission to solicit and service fee-paying subscribers for services involving the selective provision of scientific, technical and other information from a miscellany of information sources. This mission includes the provision of available technical information on the electrical and magnetic properties of metals.

**Properties Covered:** Data can be searched on all key electrical and magnetic properties such as: electrical resistivity, temperature coefficient of resistivity, core loss, maximum permeability, B–H magnetization data, maximum energy product, coercive force, remanence, Curie temperature, and superconducting data.

**Sources of Data:** NASA's RDC's include data from: NASA, the Department of Defense, the Atomic Energy Commission and foreign sources. The Regional Dissemination Centers are depositories for the U.S. Government publications. In addition, the RDC's University libraries provide additional information from books and periodicals. Some examples of computerized information sources reported by an RDC (NERAC) include material from:

National Technical Information Service (NTIS, DoD, GRAI)
PADEX (McMillian Index of Technical Literature)
TRANS DEX (US Joint Publications Research Service)
NASA File
American Society for Metals
Chemical Abstracts Condensates
Engineering Index (Compendex)
Institute for Scientific Information
Science Information Exchange
Tie-ins with all world-wide specialized information centers
INSPEC/Physics
INSPEC/Electrical Engineering

The Regional Dissemination Centers can also search computer "software" such as tapes, cards, program listings, and machine-run instructions that come from the NASA COSMIC Center at the University of Georgia.

**Size of the Data Bank:** The NASA data bank includes approximately ten million records with 400,000 to 500,000 reports on 16,000 to 18,000 subjects. Individual centers also have local libraries for access to reference books and periodicals. An estimate of 5 percent or less of the data is related to the electrical and magnetic properties of metals.

**Data Storage and Search:** Data are stored in hard copy form and computer tape form. Computerized search makes it possible to search as many as one million documents in an eight hour shift. A client subscriber may ask for a retrospective search on electrical or magnetic properties of metals which would include:

1. Presearch analysis and search strategy set for obtaining specific electrical or magnetic property data by an assigned specialist.
2. Computerized or manual retrieval of the data and data compilation.
3. Delivery of the data in: evaluated print-out form, hard copy form or microfiche form along with analysis where necessary.

In addition to the retrospective search, a selective dissemination service provides:

1. Development, updating and use of any specific electrical or magnetic property interest file by the assigned specialist for a regular period of time, such as a year.
2. Development of general interest files for a regular period of time.

**Selectivity of the Data:** The quality of data retrieved depends in part on the skill of the university-type search specialists in interrogating the data bank and in the selection and elimination procedures used in handling the data retrieved. The data bank has an entire spectrum of data quality from high to mediocre. Any statistical treatment of the data is only as dependable as was done in any original investigation.

**Timeliness of the Data:** The data come primarily from the 1960's as well as from earlier periods and the 1970's.

**Availability:** The open literature information is available on a world-wide basis. The system encourages use by small business organizations.

**Cost of Access to Data:** New clients may pay for searches as performed through a letter of intent or a blanket purchase order. The price of individual searches has varied between $90.00 and $900.00. Clients are encouraged to prepay an annual retainer for which they receive a ten percent discount. The minimum annual retainer is $1000.00.

**General Comments:** A good source for superconductivity information. There are some high temperature and high energy product magnetic properties data available. The pricing system tends to discourage usage where the nature of the data feedback is unknown in terms of quality and quantity.

**Source 49: Superconducting Materials Data Center.**

**Publisher or Custodian:** General Electric Company, Corporate Research and Development Center, Schenectady, N.Y. 12345.

Sponsored by: The National Bureau of Standards

**Scope:** The purpose of the Superconducting Materials Data Center is to collect data on superconducting materials and to provide qualified information to workers in the field of superconductivity.

**Properties Covered:** Superconducting properties include: critical temperatures along with purity and structure information.

Magnetic properties include: critical magnetic field $H_{c1}$, $H_{c2}$, $H_{c3}$, and low temperature data where a material is found not to be superconductive ($T_n$). Thermodynamic data, $\Theta_{Debye}$ and electronic specific heat, related to superconductivity are also provided.

**Sources of Data:** Data are taken from original world-wide literature. Unpublished results by recognized workers in the field are also included in the data input.

**Size of the Data Bank:** IBM card entries covering 10,000 specific alloys and compositions are in the data bank. A popular material may include up to 50 entries whereas perhaps only one card maybe provided for a lesser known material.

**Data Storage and Search:** Data are stored on IBM cards. Keypunched and written data are included. The cards are sorted on alloy composition and critical temperature. Cards are made up after reading the literature and surveying original data. New original data are separated from other data repeated in more than one publication.

**Selectivity of the Data:** There is some statistical evaluation using a hand calculator. The date of measurements is given consideration since it can qualify the value of the data due to purity and processing improvements. Mechanical variables such as dislocations and cold work, which can influence the data values, are also considered. The data are keyed to literature through references.

**Timeliness of the Data:** The data goes back to 1911 when the phenomenon was discovered. Bulk of the working data is from 1955 and later. Approximately 500–700 new entries are made per year.

**Cost of Access to Data:** Reports are published by NBS as technical notes. Approximately 500–600 copies of these reports are distributed at no charge to workers in the field. There is no charge for short questions made by letter or telephone.

**General Comments:** The program operates on a modest budget but is quite effective in reaching world-wide sources of information. The data are given a good review and are properly referenced. The Center is a useful tool to workers in the area of superconductivity.

# Commercial Sources and Trade Associations (50–56)

**Source 50: Alloys for Electronic, Magnetic and Electrical Applications.**
Carpenter Technology Corporation, 150 W. Bern St., Reading, PA 19603, 66 pp.
Bulletins are supplied at no cost.

**Scope:** This bulletin covers the magnetic properties of 17 commercial alloys identified by Carpenter tradenames and electrical properties of 1 resistance alloy identified by the Carpenter tradename.

**Properties Covered:** This bulletin provides the following data:
High permeability alloys; permeability, hysteresis curves, and core loss.
Magnetostrictive alloys; permeability and magnetostriction coefficient.
Core irons; hysteresis curves, and permeability.
Resistance alloy; electrical resistance, and thermal coefficient of resistance.

**Sources of Data:** Carpenter Technology Corporation has a technical staff which is the primary source of data on these alloys.

**Size of the Data Bank:** This bulletin has 66 pages, 42 of which are devoted to magnetic and electrical properties.

**Data Storage and Search:** The bulletin is divided into sections by the general type of magnetic materials. The alloys covered for each section are indexed in front of the Handbook.

**Selectivity of the Data:** The data presented are based on data used in Carpenter's quality control program to insure that every lot of magnetic alloy meets the same standard of quality and uniformity.

**Timeliness of the Data:** The bulletins are revised as necessary to keep them up-to-date, usually to add new alloys.

**General Comments:** This publication is the basic source for magnetic properties of alloys for electronic, magnetic and electrical applications supplied by Carpenter Technology Corporation. In contrast to many handbook compilations, these data are usable for design purposes with this vendor's products.

**Source 51: Armco Electrical Steels and Magnetic Alloys Handbook.**

**Publisher or Custodian:** Armco Steel Corporation, Middletown, Ohio.

**Scope:** The Armco Design Manuals are made for designers of electric apparatus. They provide specific information on the advantages of each class of Armco magnetic material as well as pertinent data on fabrication and extensive design curves.

**Properties Covered:** The design manual on "Armco Nonoriented Electrical Steels" includes data on hot and cold rolled fully processed and semiprocessed sheet steel in AISI grades M–45, M–43, M–36, M–22, M–15, and high silicon TRANCOR A–6. The design manual on "Armco Oriented Electrical Steels" includes design curves for AISI materials M–4, M–5, and M–6. The design manual 'Armco Thin Electrical Steels" presents electrical design data on three trade name types, ORIENTED T, ORIENTED T–S, and TRAN–COR T in five different thicknesses. Armco Steel also has property sheets on core loss, exciting RMS amperes per pound, AC permeability, DC magnetization, DC hysteresis loops, AC flux-current loops, exciting power, reactive power, inductance permeability, flux control curves, induction versus frequency curves, figure of merit at induction of 5 gausses, and lamination factor curves.

**Sources of Data:** Data were obtained primarily from research and development work involving the testing of Armco products at the Armco Steel Corporation's plants and laboratories.

**Size of the Data Bank:** Data are provided in three ring-bound volumes. Approximately 76 pages are devoted to nonoriented electrical steels, 70 pages to oriented electrical steels, and 50 pages to thin electrical steels. Data for other materials, such as electromagnetic iron and nickel-iron magnetic alloys are supplied as small vendor booklets or sheets.

**Data Storage and Search:** Data are presented primarily as curves. Data are searched by a Table of Contents and Trade Name page finder on the first page of each booklet.

**Selectivity of the Data:** The data were developed using Armco material rather than typical AISI material. These are no statistical presentations in the data presented. No references are given.

**Timeliness of the Data:** "Armco Nonoriented Electrical Steel" is dated 1974. "Armco Oriented Electrical Steels" is dated 1973. These booklets are updated around every five years. Most of the data curves come from the 1960's.

**Availability:** Available to potential customers from the publisher.

**Cost of Access to Data:** The handbooks are supplied free of charge upon request to potential customers and related people.

**General Comments:** The handbooks contain good engineering data based on Armco produced material. The designer is left with the uncertainty of the data spread if he should use a competitor's material for the same AISI standard class.

**Source 52: Electrical Materials Handbook.** Allegheny Ludlum Steel Corporation.

**Publisher or Custodian:** Allegheny Ludlum Steel Corporation, Division of Allegheny Ludlum Industries, Inc., Oliver Building, Pittsburgh, Pennsylvania 15222.

**Scope:** Intended as a single source of information about magnetic and electrical properties of steels and alloys produced in various forms by Allegheny Ludlum Steel Corporation.

**Properties Covered:** Magnetic core materials include: AISI types M–6, 7, 8, 14, 15, 17, 19, 22, 27, 32, 36, 43, and 50. Properties given are: electrical resistivity at room temperature, core loss, saturation induction, DC permeability, DC hysteresis, initial permeability, permeability at 200 gausses, maximum permeability, induction at maximum permeability and coercive force.

Nonoriented and oriented silicon steel data also include: magnetization curves, core loss curves, and DC hysteresis loops.

Nickel-iron alloy properties are given for: mumetal, 4750 monimax, 4–79 permalloy, deltamax, and vanadium permendur. The nickel-iron data include: performance range curves at high and low induction, magnetization curves at various thicknesses, core loss curves, 60 cycle incremental permeability curves, effect of temperature on permeability curves, DC hysteresis loop curves. The properties data also include: Curie temperature, saturation induction, electrical resistivity, coercive force, and hysteresis loss values.

Permanent magnetic materials include: Alnico 1, 2, 3, 4, 5, 5cc, 6, 7, 8, X–900, 17 percent cobalt alloy, 36 percent cobalt alloy, 3 1/3 chromium alloy and Vicalloy. Permanent magnet properties include: demagnetization and energy-product curves, typical normal magnetization curves, typical hysteresis loss curves, temperature and mechanical shock effects on magnetic remanence curves, and dimension ratio curves for permanent magnets.

Special materials data include: resistivity, temperature-resistivity curves, magnetization curves for Ohmalloy and 400 series stainless steel as well as magnetic permeability and resistivity data on nonmagnetic alloy steels. Tape core data are also presented for nickel-iron alloys and Selectron steel. Powder core data for Molybdenum Permalloy are also presented.

**Sources of Data:** Data were generated primarily at the Allegheny Ludlum shops and laboratories. Other data were generated by Arnold Engineering Company or taken from outside references.

**Size of the Data Bank:** The data are provided in a permanent bound book, 334 pages in length.

**Data Storage and Search:** Data are provided in the form of graphs and tables: Data are searched by using the Table of Contents and by using finder charts related to desired considerations such as: low core loss, high permeability, low or high retentivity or high frequency operation using laminated cores, relay cores, powder or wound cores or permanent magnets.

**Selectivity of the Data:** The data are typical. References are given in some chapters. In other chapters, it must be assumed that the data were generated by Allegheny Ludlum.

**Timeliness of the Data:** The handbook was copyrighted in 1961. Available references date back through the 20's, 30's, 40's, and 50's.

**Availability:** Available to potential customers from the publisher.

**Cost of Access to Data:** The handbook is supplied free of charge upon request to potential customers and related people.

**General Comments:** The handbook is unique in the wide range of coverage of soft and permanent magnetic materials properties. The design data are at least ten years old and are only typical rather than statistical. Older grades discussed in the book may not be commercially available. A new revision is needed.

**Source 53: Technical Data Centers.**

Publications of the manufacturers of electrical resistance alloys for instrumentation and control and of resistance materials for electrical heating elements.

These technical data catalogs are available at no cost from the manufacturers.

The following is a partial list of the companies who manufacture these materials:

W. M. Chace Co. (GTE Sylvania Inc.), 1614 Beard Ave., Detroit, MI 48209
Driver-Harris Company, Harrison, NJ 07029
J. M. Ney Co., 27 Maplewood Ave., Bloomfield, CT 06002
Ohmite Mfg. Co. (North American Philips Co.), 3604 Howard St., Skokie, IL 60076
Westinghouse Electric Corp., Specialty Metals Division, Blairsville, PA 15717
Wilber B. Driver, 1875 McCarter Highway, Newark, NJ 07104
Hoskins Manufacturing Company, 4445 Lawton Ave., Detroit, MI 48208
The Kanthal Corporation, Wooster St., Bethel, CT 06801

**Scope:** The subject materials are with few exceptions identified by tradename. Each manufacturer provides publications with complete technical data on their own materials. The following explanations are typical of the information provided by each manufacturer.

**Properties Covered:** Properties include: electrical resistivity, temperature coefficient of resistance, EMF vs copper (for electrical resistance alloys), maximum continuous service temperature, temperature-resistance curves, and detailed tables of resistance per foot by wire size or strip dimensions.

**Sources of Data:** Data are provided by the manufacturer of each alloy and they are the sole source of this information.

**Size of the Data Bank:** Approximately 4 pages are used to cover the properties for each alloy. Total pages of data from a supplier depends on the number of alloys they supply.

**Data Storage and Search:** It is necessary to go to the supplier's literature for data on a specific alloy. All data, except comparison tables with other alloys, are published on consecutive pages under the tradename of the alloy.

**Selectivity of the Data:** Values assigned represent the most probable values that would be obtained under given conditions. Some critical values such as resistance are guaranteed to be within certain tolerances.

**Timeliness of the Data:** The data represent up-to-date properties on commercially available materials.

**General Comments:** Inasmuch as the majority of alloys in this class are proprietary formulations, detailed property data are not found in handbook compilations but only in the technical publications of each manufacturer.

**Source 54: Magnetic Materials Producers' Association.**

**Publisher or Custodian:** Magnetic Materials Producers Association, 1717 Howard Street, Evanston, Illinois 60202.

**Scope:** The Association embraces ten of the important producers of permanent magnet materials, namely: Allen-Bradley Co., Arnold Engineering Co., Colt Industries, General Electric Co., General Magnetics Co., Indiana General Corp., The Permanent Magnet Co., Inc., Raytheon Co., Stackpole Carbon Co., and Thomas and Skinner, Inc. Each company distributes its own literature. The Association itself has two current booklets that it sells: "Standard Specifications for Permanent Magnet Materials" and "Permanent Magnet Guidelines."

**Properties Covered:** The Association lists 36 permanent magnet materials of importance:

| | | | | |
|---|---|---|---|---|
| 3½% Co Steel | Alnico 1* | Ceramic 1** | ESD31*** | Cunife 1 (Cu,Ni,Fe) |
| 3% Co Steel | Alnico 2 | Ceramic 2 | ESD32 | Vicalloy 1 (V,Co,Fe) |
| 17% Co Steel | Alnico 3 | Ceramic 3 | ESD41 | Remalloy (Co,Mo,Fe) |
| 36% Co Steel | Alnico 4 | Ceramic 4 | ESD42 | |
| Sintered Alnico 2* | Alnico 5DG | Ceramic 5 | | |
| Sintered Alnico 5 | Alnico 5 Col. | Ceramic 6 | | |
| Sintered Alnico 8 | Alnico 8 | Ceramic 8 | | |
| Sintered Alnico 8 HC | Alnico 8HC | | | |
| | Alnico 9 | | | |

* Alnicos are Al-Ni-Co alloys.

** Ceramic refers to $MO \cdot 6Fe_2O_3$ where M represents one or more of the metals Ba, Sr, Pb.

*** ESD refers to Elongated Single Domain particles of Fe-Co in a metal matrix.

Data in the booklet "Permanent Magnet Guidelines" are limited to flux loss with time data and irreversible flux loss at service temperatures of 350, 200, −20 and −60 °C. The booklet "Standard Specifications for Permanent Magnet Materials" lists nominal chemistries, residual flux density, coercive force and maximum energy product values for the 36 materials with major emphasis on dimensions and tolerances.

**Sources of Data:** Detailed data derive from each individual member company of the Association.

**Size of the Data Bank:** The Association itself has very little technical data. The members collectively, however, are caretakers of practically all the known information on permanent magnet materials. The booklets are 12 to 17 pages in length.

**Data Storage and Search:** Data in the two Association booklets are found by random page turning. Data held by individual member companies are best searched by a direct call to the company of interest. Each company has its own trade names for the 36 materials but they also recognize the nomenclature of the Association.

**Selectivity of the Data:** The data in the Association booklets are typical. Data provided by each individual member company include typical magnetic and material characteristics along with energy product design curves. Statistical confidence limits are not provided in nearly all cases. Bibliography is provided by the Association. The " Standard Specification for Permanent Magnet Materials" is a recognized Department of Defense document.

**Timeliness of the Data:** The two Association booklets are updated every one to three years. The bibliography covers primarily the 1960's.

**Availability:** Available to all from the publisher.

**Cost of Access to Data:** The Association booklets are priced at $2.00 each. Individual company literature is supplied free of charge to potential customers.

**General Comments:** The Magnetic Materials Producer Association provides a useful standardization function for the permanent magnet industry. Although data from present Association publications are limited, they can lead a designer to the company that will give him the magnetic data he desires.

**Source 55: Nonoriented Electrical Steel Sheets; Oriented Electrical Steel Sheets.**
United States Steel Corporation Handbooks on Electrical Steel Sheets.

**Publisher or Custodian:** United States Steel Corporation, 525 William Penn Place, Pittsburgh, Pennsylvania 15230.

**Scope:** The handbooks provide engineering details on the characteristics of U.S. Steel Nonoriented and Oriented Electrical Steels.

**Properties Covered:** For the nonoriented steels, properties include: core loss curves, volt-ampere characteristics, AC magnetization curves, DC magnetization curves, DC permeability curves, core loss-frequency curves and hysteresis loops.

For the oriented electrical steels, properties include: core loss curves, AC magnetization curves, exciting RMS curves, polydirectional exciting RMS volt-ampere curves for high induction and core loss, AC permeability and exciting RMS volt-amperes curves for low inductions. Core loss-frequency curves are also given.

Electrical resistivity data are given for both nonoriented and oriented electrical steels.

**Sources of Data:** Data were obtained from research and development work done at the US Steel's laboratory and processing locations.

**Size of the Data Bank:** Data are provided on looseleaf pages. Approximately 230 pages are devoted to nonoriented electrical steels and 80 pages to oriented electrical steels.

**Data Storage and Search:** Data are presented primarily as curves and tabulated information. Data in the Nonoriented Electrical Steel Handbook are indexed according to core loss quality by trade name and AISI standard designations as follows: LAMINEX A and STATOR A Motor Laminations, AISI M–45, M–43, M–36, M–27, M–22, and M–19.

Data in the Oriented Electrical Steel Handbook are indexed according to the thickness of the sheet laminations as follows: 0.011, .012, .014, .025 inches. Within each section, data for the AISI grades M–4, M–5, M–6, and M–7 are presented.

**Selectivity of the Data:** The data were developed as typical design information using US Steel material rather than typical AISI material. There are no statistical presentations in the data presented. No references are given.

**Timeliness of the Data:** The handbooks have looseleaf pages which facilitates updating. Most of the data appear to have been prepared in the mid 1960's.

**Availability:** Available to potential customers from the publisher.

**Cost of Access to Data:** The Handbooks are supplied free of charge upon request to potential customers and related people.

**General Comments:** The handbook data are good typical engineering information based on the US Steel produced material. The designer is left with uncertainty as to the data spread if he should use a competitor's material for the same AISI standard class. The designer can also be uncertain as to what the mean values of magnetic properties really are for the cheaper grades of the nonoriented electrical steels covered in the Handbook.

**Source 56: Permanent Magnet Handbook.**

E. M. Underhill, Ed., Colt Industries, Crucible Magnetics Division, Box 100, Elizabethtown, KY 42701. 357 pp. $25.00.

This handbook is out of print. There are a limited number still available.

**Scope:** Presents a history of the development and design of permanent magnets. This is broken down into details of each type of material and ends with a section on the specifications and data for important magnetic materials.

**Properties Covered:** Nominal magnetic, physical and mechanical data as well as demagnetization curves, energy product and B-H values.

**Sources of Data:** Much of the data were developed at the Crucible Steel Company of America or selected by the chapter authors.

**Size of the Data Bank:** Permanent Magnet Handbook is 357 pages in length with approximately 125 of these pages devoted to magnetic properties of individual magnetic materials.

**Data Storage and Search:** The handbook is divided into sections with general information on each type of permanent magnet material followed by one section, Specifications and Data, which contains the magnetic properties data for each individual magnetic material. These individual magnetic materials are listed in the index by tradename or by commercial type and referenced to the page which has the applicable data.

**Selectivity of the Data:** The data are based on years of experience by the publisher in the production of permanent magnet materials.

**Timeliness of the Data:** This handbook was published in looseleaf form in 1957 and new data sheets and revisions of the various sections were issued as new developments were recorded. The latest sheets were issued in 1965.

**General Comments:** The Permanent Magnet Handbook is an excellent source of data for the magnetic properties of the commercially important permanent magnet materials up to 1965. The book is not being updated and several commercially important new materials have not been covered.

# Technical Society Data Publications (57–59)

**Source 57: American National Standards.**
"American National Standards"

**Publisher or Custodian:** American National Standards Institute, 1430 Broadway, New York, New York 10018.

**Scope:** Provides information on electrical and magnetic properties for ANSI's 420 commercial standards on metals and alloys. Less then 10 percent of the standards involve electrical and magnetic properties.

**Properties Covered:** ANSI standards for metals and alloys are all ASTM specifications. They usually define the chemical composition and those electrical and magnetic properties that are necessary to control the quality of the product. For a more detailed description refer to the write-up on ASTM.

**Sources of Data:** ANSI does not prepare or develop property data for materials. These data were prepared by ASTM.

**Size of the Data Bank:** There are approximately 420 standards for metals and alloys.

**Data Storage and Search:** Each standard is published as a separate document and is listed in the ANSI 1973 catalogue under one of the following sections:

G—Ferrous materials and metallurgy
H—Nonferrous materials and metallurgy

**Selectivity of the Data:** Since these data are prepared by ASTM, please refer to the write-up on them for this information.

**Timeliness of the Data:** Same as above.

**Availability:** Distribution is unlimited. Copies are available from American National Standards Institute.

**Cost of Access to Data:** The applicable standards are all priced at $1.50 per copy.

**General Comments:** These specifications are a duplicate of ASTM specifications but at present do not include all of the ASTM specifications in this area. The amount of electrical and magnetic data is small.

**Source 58: Publications of The American Society for Metals.**

**Publisher or Custodian:** American Society for Metals, Metals Park, Ohio 44073.

**Scope:** The American Society for Metals in a 38,000 member organization with six major promotional goals in the field of metals and engineering materials: (1) Communications, (2) Meetings, (3) Education, (4) Unity of Field, i.e., interdisciplinary field of metals, (5) Interrelationship among Engineers, Scientists, and Technologists, (6) Professional responsibility and public understanding. The organization allocates 62 percent of its resources to technical periodical and reference publications, 14 percent to scientific and engineering conferences and exhibits, 9 percent to metals information, 8 percent to education with the balance going to membership and general services. Electrical and magnetic properties are presented at random in all of the above activities.

**Properties Covered:** Electrical resistivity for around 800 alloys has been randomly reported in the various activities of the ASM. Standard magnetic properties, including *B–H* curves and energy product curves of approximately 200 soft and hard magnetic materials, have been also randomly reported. (See also "Metals Handbook" and "Metal Progress Data Book").

**Sources of Data:** In-field experts from the membership plus associates from all over the world prepare the various publications and services. A small permanent ASM staff of less than 100 people coordinate the activities.

**Size of the Data Bank:** The accumulated knowledge and recorded data of the 38,000 members of the ASM.

**Data Storage and Search:** Random storage and search for electrical and magnetic properties is the general mode for all the ASM books, conferences, journals, and magazines. The Information Retrieval Service of the ASM is the easiest way to get at the data for a fee.

**Selectivity of the Data:** Input data are selected by the editors of The American Society for Metals and by member-selected special panels of experts. There is no statistical treatment of the data unless individual authors choose to do so.

**Timeliness of the Data:** Abstract information dates back to January 1967. Magazines, journals, conferences, and courses are highly current representing work now being done or done within the past two years approximately.

**Availability:** Publications and conferences are open to the technical people of the entire world. Most of the ASM activities are within North America. The ASM in Metals Park, Ohio should be consulted for specific publications.

**Cost of Access to Data:** Cost varies, consult ASM, Metals Park, Ohio.

**General Comments:** The ASM information on electrical and magnetic properties other than what is found in the "Metals Handbook" is not very recent or given much attention. In 1958 ASM put on a seminar and issued the book "Magnetic Properties of Metals and Alloys" by R. M. Bozorth and others. The book contained mostly theory. In 1963 another book was issued, "Electrical and Magnetic Properties of Metals" by J. K. Stanley; see Source 8. New conferences are needed in the electrical and magnetic properties area. Manufacturing process information dominates most of the ASM technical publications.

**Source 59: ASTM Annual Book of Standards** and the associated data services of the American Society for Testing and Materials.

**Publisher or Custodian:** American Society for Testing & Materials, 1916 Race Street, Philadelphia, Pa. 19103.

**Scope:** Provides information on electrical and magnetic properties for approximately 1100 metals and alloys in the "ASTM Annual Book of Standards" and in its special technical publications.

**Properties Covered:** In the ASTM Annual Book of Standards, electrical or magnetic properties are specified only where they are necessary to control the quality of the product. Occasionally, supplemental information is provided with expanded electrical or magnetic properties requirements. There are also appendices and footnotes to the specification standards which provide added electrical and magnetic property information. Part 44 "Magnetic Propeties; Metallic Materials for Thermostats, Electrical Resistance Heating, Contacts; Temperature Measurement" is one of the more important volumes related to electrical and magnetic properties. Electrical properties include: volume resistivity, weight resistivity, temperature coefficient of resistance, conductivity percent IACS, conductivity of contact alloys, contact resistance, resistance changes, and DC voltage of film breakdowns. Magnetic materials cover ingot iron, silicon-iron alloys up to 5.25 percent Si, nickel-iron alloys, cobalt-iron alloys, permanent magnet alloys, Alfenol and some stainless steel alloys. Part 6, "Copper and Copper Alloys" includes another concentration of electrical properties. Other electrical and magnetic properties are scattered throughout the volumes involved with metallic materials (Parts 1 through 12).

In addition to the ASTM Annual Book of Standards, there are other data services of ASTM, including: "Standardization News", a magazine, also "Special Technical Publications and Data Series," some of which are directly involved with electrical and magnetic properties.

**Sources of Data:** Data originate with the members of ASTM, including consumers, producers and a general interest group composed of engineers, scientists, educators, testing experts, and research workers. Specification standards are adopted for publication only when approved by a series of votes by the membership. ASTM technical papers are edited by special committees made-up of members and staff of the ASTM. Data obtained by the Metal Properties Council are frequently presented in these technical papers.

**Size of the Data Bank:** There are 48 bound parts in the "ASTM Annual Book of Standards." Each part is 500 to 1000 pages in length. There are over 38,000 total pages and over 5800 standards. Fourteen of the parts or nearly one-third of the total number of standards are devoted to metallic materials. The quantity of electrical and magnetic properties in the fourteen parts is small and scattered. ASTM data services also include electrical and magnetic property data in special technical publications. As an example, the publication STP371–51 covers "Direct-Current Magnetic Measurements for Soft Magnetic Materials," presenting over 72 pages of magnetic property data.

**Data Storage and Search:** Data for the "ASTM Annual Book of Standards" are stored as printed pages in annual bound parts. Data are searched using a Subject Index (Part 48) for situations where the specification number is unknown or a Numeric List when the specification number is known. The following Parts include electrical or magnetic property as well as other information on metals and alloys:

- Part 1 Steel Piping, Tubing and Fittings
- Part 2 Ferrous Castings; Ferro-Alloys
- Part 3 Steel Plate, Sheet, Strip, and Wire; Metallic Coated Products
- Part 4 Structural Steel; Concrete Reinforcing Steel, Pressure Vessel Plate and Forgings; Steel Rails, Wheels and Tires
- Part 5 Steel Bars, Chain, and Springs; Bearing Steel; Steel Forgings
- Part 6 Copper and Copper Alloys
- Part 7 Die-Cast Metals; Light Metals and Alloys
- Part 8 Nonferrous Metals—Nickel, Lead, and Tin Alloys, Precious Metals; Primary Metals; Reactive Metals
- Part 9 Electro-deposited Metallic Coatings; Metal Powders, Sintered P/M Structural Parts
- Part 41 General Test Methods
- Part 43 Electronics
- Part 44 Magnetic Properties; Metallic Materials for Thermostats and for Electrical Resistance Heating and Contacts; Temperature Measurement

To assist in promoting the knowledge of materials of engineering, ASTM issues a five year Index to ASTM Technical Papers and Reports. The index provides detailed author and subject listings to all proceedings, Materials Research and Standards reports, and special technical publications issued in the five year time span. There is also a yearly report called "ASTM Publications."

**Selectivity of the Data:** Proposed standards are drawn up by ASTM members who contribute the input technical data on property requirements. The Society then follows a three step procedure:

(1) Technically qualified committees and members of ASTM study proposed standards extensively, debate on their acceptability, and vote on adoption of the standards.

(2) Before standards are formally adopted, the principal persons concerned—consumers, producers, and general interest—agree on the necessary requirements.
(3) As developments take place, requirements for standards are revised.

The ASTM Committee on Papers and Publications has jurisdiction in all matters relating to publications such as: papers from technical symposia, reports by ASTM technical committees, special books and compilations of data developed in special Society groups with many organizations cooperating. Some criteria used in judging the publications are:

(1) Whether or not subject matter promotes the knowledge of the properties of materials.
(2) Whether or not contents are of an advertising value.
(3) Whether or not subject matter is of a speculative nature.
(4) Whether or not subject matter is new.
(5) Literary form, ethical and legal considerations.

**Timeliness of the Data:** The "Annual Book of ASTM Standards" has on the average 30 percent of each part revised or presented new each year. They are issued annually as new bound books. Each standard has the year of last revision or approval suffixed to its numeric designation. There is a five year revision or reapproval requirement for published standards to remain in the system. The specifications in the "ASTM Annual Book of Standards" nearly all fall within the 1964 to 1972 time span. For other ASTM papers and publications, a lead time of approximately two years lies between the originating date and the final publication date.

**Availability:** Distribution is unlimited. Copies are available from ASTM.

**Cost of Access to Data:** Separate standards for the "ASTM Annual Book of Standards" are priced at $1.75 each. The complete set is $904.00. Special quantity prices are also available. Papers and publications generally are priced from under $10.00 up to around $50.00 each. No search function is provided by the publisher or custodian.

**General Comments:** The amount of electrical and magnetic property data that can be extracted from the "ASTM Book of Standards" is small. Searching is not easy except for Part 44. The data that are given are key requirement data. In contrast to the "ASTM Annual Book of Standards," the ASTM papers and special publications are presented opportunistically as information becomes available and there is no procedure to update, correct or revise past publications.

# Appendix:
# Miscellaneous Sources
# Glossary
# Indices

**Source: Direct-Current Magnetic Measurements for Soft Magnetic Materials,** ASTM Special Technical Publication 371 S1, American Society for Testing and Materials, 1916 Race St., Philadelphia, PA 19103, 1970.

**Scope:** Provides in a simple and understandable manner the theory and practice basic to the art of direct-current testing of magnetically soft, ferromagnetic materials.

**General Comments:** Principally devoted to exposition of the theory underlying the magnetic tests and the procedures for conducting such tests. Only such data are included as are necessary for illustrative purposes.

**Source: General Electric EMPIS System**

**Publisher or Custodian:** General Electric Company, Materials Information Services, Building 5–327, 1 River Road, Schenectady, New York 12345.

**Scope:** Provides electrical and magnetic property information, including specification requirements and ordering lists for approximately 2000 ferrous and nonferrous materials used in the General Electric Company.

**Properties Covered:** Typical electrical and magnetic properties as well as required properties are presented for each GE specification in the EMPIS system. Property data are given primarily at room temperature but elevated and low temperature data are also presented. Properties include:

*Electrical:* Volume and weight resistivity, Conductivity percent of copper standard

*Magnetic:*

Magnetizing force
Magnetic induction
Biased induction
Remanent induction
Energy product
Maximum energy product
Intrinsic induction (ferric induction)
Maximum induction in a hysteresis loop
Residual induction
Retentivity
Saturation induction
Incremental induction
Demagnetizing coefficient
Magnetomotive force
Frequency
Form factor
Biasing magnetizing force
Coercive force
Intrinsic coercive force
Relaxation coercive force
Coercivity
Demagnetizing force
Incremental magnetizing force
Maximum magnetizing force in hysteresis loop
Permeance
Apparent core loss
Core loss (iron loss)
Eddy current loss
Specific core loss
Hysteresis loss
Incremental core loss
Reluctance
Lamination factor
Permeability
Alternating current permeability
Differential permeability
Intrinsic permeability
Maximum permeability
Initial permeability
Reversible permeability
Space permeability
Incremental permeability
Reluctivity
Magnetic flux

Included is a system of indices and tables to facilitate material identification, selection, specification and procurement.

**Sources of Data:** Handbooks; trade association compilations; original technical literature; industrial, national, and international standards; research reports, GE test reports and in-service failure records.

**Selectivity of the Data:** Input of data into the EMPIS system is primarily initiated by requests for specification and property documentation from GE departments. For each specification grade there is an associated property sheet which details the properties of the grade. The data for each grade are collected and screened by Materials Engineers within the GE Corporate staff. Data reference cards are maintained for important entries identifying the source of the data entered into the system. Files are maintained on each listed material. They contain vendor responses, originating correspondence, and chronological documentation. Specimen types and test methods are established by ASTM or EMPIS referee methods for specification properties. Statistical confidence is not listed.

**Timeliness of the Data:** The EMPIS data sheets are issued in groups of new and updated documents three or four times per year. The majority of the published data sheets are dated in the late 1960's with the remainder primarily in the early 1970's and early 1960's.

**Availability:** The EMPIS system is an internal document system of the General Electric Company and is not generally available to the outside. Only the specifications portion of the system is regarded as public information and hence, is available to all.

**Cost of Access to Data:** Individual specifications are free to active suppliers; grouped specification sets, e.g. steels, fasteners, etc., are specially priced. Data questions may be directed to General Electric Company (EMPIS), Schenectady, New York 12345 where special inquiries are sometimes accommodated on a professional courtesy basis. Regular data search assistance in the EMPIS system is provided only to subscribing GE departments.

**General Comments:** This data source is strong in the area of magnetic materials properties. The presentation of metals is biased to the specification needs of the General Electric Company. The electrical and magnetic property information represents mostly typical data and/or maximum-minimum property limits of the specifications. Reliability of the data is based on a "used successfully elsewhere in GE" criterion.

**Source: Industrial Electronics Handbook,** W. D. Cockrell, McGraw-Hill Book Company, Inc., 1221 Avenue of the Americas, New York, NY 10020, 1958, 1355 pp, $32.50.

**Scope:** Provides data for industrial electronics except for communication and nuclear fields. There are electrical data for structural and conductor materials, and also a copper wire table.

**Data Storage and Search:** The "Industrial Electronics Handbook" is divided into 10 sections. The electrical properties are covered in Sections 1 and 2.

**Selectivity of the Data:** Typical data are given for 19 structural and conductor materials.

**General Comments:** This book provides a very limited amount of data, most of which are available from a number of other sources, and therefore has been excluded from the main body of this report.

**Source: INSPEC Information Service,** The Institution of Electrical Engineers, Savoy Place, London WC2R OBL, England.

**Scope:** Includes—Physics Abstracts, Electrical and Electronics Abstracts, Current Papers in Electrical & Electronic Engineering.

**General Comments:** INSPEC services are provided in the following ways:

| | |
|---|---|
| Science Abstracts | —for retrospective searching. |
| Current Papers | —for current awareness |
| SDI | —for recovery of items by secondary aspects |
| Topics | —for recovery of items by secondary aspects |

These services are basically designed to retrieve articles and papers for electrical engineers and not for data retrieval.

**Source: Insulation Directory/Encyclopedia Issue,** Lake Publishing Corporation, 700 Peterson Road, Libertyville, IL 60048, June/July 1975.

Product Information—Magnet Wire, Strip, Hollow Conductors, and Superconductors

Prepared by: Harry L. Saums, Magnet Wire Consultant

**Scope:** This product information for the most part deals with magnet wire insulation. There are several pages on aluminum conductors, copper conductors and superconductors.

**General Comments:** There are no data on electrical or magnetic properties of the conductors. It describes the various configurations of insulated aluminum and copper conductors. For superconductors, a listing and description is given for those now commercially available.

**Source: Magnetism and Magnetic Materials,** J. C. Anderson, Chapman and Hall Ltd., 11 New Fetter Lane, London, EC4, England, 1968, 240 pp, $8.00.

Available from Halsted Press, 605 3rd Ave., New York, NY 10016

**Scope:** To provide fundamental treatment of magnetism for undergraduates and post graduates embarking on study and research in some branch of magnetism.

**General Comments:** This book is intended to provide a fundamental treatment of magnetism and not to provide data of properties of these materials. Data, where provided, are used to show relative values for the different magnetic materials.

**Source: Materials Selector,** Reinhold Publishing Company, Inc., 600 Summer Street, Stamford, CT 06904, 1975.

Domestic subscriptions are $18.00 per year. Foreign subscriptions are $36.00 per year. Qualified individuals may receive free copies. Subscription also includes receiving monthly copies of "Materials Engineering" magazine.

**Scope:** Provides a materials reference guide to individuals who function in materials evaluation and selection, design, development, production, and management or wherever there is an involvement in the application and selection of metals, nonmetallics, forms, and finishes.

**Size of the Data Bank:** The "Materials Selector" is approximately 500 pages in size. Less than 3% of the 115 pages dealing with metallic materials are devoted to electrical and magnetic properties.

**General Comments:** The "Materials Selector" has a good comparison chart for selecting a material based on electrical resistivity. The rest of the data is scattered and randomly organized. Use of the data for direct design is questionable unless supported by other data sources.

**Source: Newnes Concise Encyclopedia of Electrical Engineering,** M. G. Say, George Newnes Limited, Tower House, Southhampton St., London, W.C. 2, England, 1962, 906 pp.

**Properties Covered:** This is an encyclopedia of electrical engineering terms and provides a description of all electrical and magnetic terms.

**General Comments:** This book is no longer in print and provides a very limited amount of data.

**Source: NFPA Handbook of The National Electrical Code,** Third edition, 1972, Editor: John H. Watt

**Scope:** The handbook has as its purpose aiding those concerned with electrical safety in understanding the scope and intent of the 1971 National Electrical Code.

**Publishers:** McGraw-Hill Book Company, New York, New York

**Properties Covered:** One short table of properties of copper and aluminum conductors. The rest of the 748 pages are concerned with giving and explaining specifications contained in the 1971 National Electrical Code.

**General Comments:** This is not a source for electrical and magnetic properties.

**Source: Properties of Materials for Electrical Engineers,** Pascoe, John Wiley & Sons, Ltd., 605 Third Ave., New York, NY 10016.

**Scope:** The purpose of this book is to introduce the reader to structure and properties of materials and elaborate particular facets to the stage where he can understand the function and behavior of electrical materials and the ever growing number of ways in which they are applied.

**General Comments:** Electrical data are only presented as an example or to supplement an explanation in the text. Data are typical and this text is not recommended as a source for electrical or magnetic data.

## Glossary

During the compilation of the indices for this Survey it became evident that a set of definitions would be extremely helpful. However, we could not find any existing set which covered all the properties listed, and drawing from two or three sets introduces inconsistencies and other problems. To cover the magnetic terms we reproduce here, with the kind permission of the American Society for Testing and Materials, ASTM Standard A 340–65, from Part 44 of the 1974 Annual Book of ASTM Standards. For terms not covered in A 340 we suggest reference to IEEE Standard Dictionary of Electrical and Electronics Terms, Wiley-Interscience, 1972, or The International Dictionary of Physics and Electronics, 2nd edition, W. C. Michels, Editor in Chief, Van Nostrand, 1961.

Designation: A 340 – 65 (Reapproved 1970)[ε]

# AMERICAN SOCIETY FOR TESTING AND MATERIALS

1916 Race St., Philadelphia, Pa., 19103



## Standard Definitions of TERMS, SYMBOLS, AND CONVERSION FACTORS RELATING TO MAGNETIC TESTING[1]

This Standard is issued under the fixed designation A 340; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

[ε]NOTE—The definition for magnetization was corrected editorially and symbols $N_p$ and $N_s$ were replaced with $N_1$ and $N_2$, respectively, in December 1970.

### INTRODUCTION

In preparing this glossary of terms, an attempt has been made to avoid, where possible, vector analysis and differential equations so as to make the definitions more intelligible to the average worker in the field of magnetic testing. In some cases, rigorous treatment has been sacrificed to secure simplicity, but it is believed that none of the definitions will prove to be misleading.

When ANSI Sectional Committee C42 on Definitions of Electrical Terms (functioning under the sponsorship of the Institute of Electrical and Electronics Engineers) completes and approves the American Standard Definitions of Electrical Terms, it is planned, so far as is consistent with the above aims, to use the same wording for selected terms of this glossary. The definitions identical with those of the American National Standard will be so designated.

Terms primarily related to magnetostatics are indicated by the symbol * and those related to magnetodynamics are indicated by the symbol ** General (non-restricted) terms are not marked.

### PART 1—SYMBOLS USED IN MAGNETIC TESTING

| SYMBOL | TERM |
|---|---|
| $a$ | cross-sectional area of $B$ coil |
| $A$ | cross-sectional area of specimen |
| $A'$ | solid area |
| $B$ | magnetic induction<br>normal induction<br>magnetic flux density |
| $\Delta B$ | excursion range of induction |
| $B_b$ | biased induction |
| $B_d$ | remanent induction |
| $B_{dm}$ | remanence |
| $B_dH_d$ | energy product |
| $(B_dH_d)_m$ | maximum energy product |
| $B_\Delta$ | incremental induction |
| $B_i$ | intrinsic induction |
| $B_m$ | maximum induction in a hysteresis loop |
| $B_{max}$ | maximum induction in a flux current loop |
| $B_r$ | residual induction |
| $B'_r$ | apparent residual induction |
| $B_{rs}$ | retentivity |
| $B_s$ | saturation induction |
| $cf$ | crest factor |

[1] These definitions are under the jurisdiction of ASTM Committee A-6 on Magnetic Testing.

Current edition effective Dec. 27, 1965. Originally issued 1949 to replace A 127. Replaces A 340 – 64.

| Symbol | Term |
|---|---|
| $CM$ | cyclically magnetized condition |
| $d$ | lamination thickness |
| $D_B$ | demagnetizing coefficient |
| $df$ | distortion factor |
| $D_m$ | magnetic dissipation factor |
| $E_1$ | exciting voltage |
| $E_f$ | flux volts |
| $E_s$ | secondary induced voltage |
| $f$ | cyclic frequency in hertz |
| $\mathfrak{F}$ | magnetomotive force |
| $ff$ | form factor |
| $H$ | magnetizing force; magnetic field strength |
| $H'$ | apparent magnetizing force |
| $\Delta H$ | excursion range of magnetizing force |
| $H_b$ | biasing magnetizing force |
| $H_c$ | coercive force |
| $H'_c$ | apparent coercive force |
| $H_{ci}$ | intrinsic coercive force |
| $H_{cs}$ | coercivity |
| $H_d$ | demagnetizing force |
| $H_\Delta$ | incremental magnetizing force |
| $H'_\Delta$ | apparent incremental magnetizing force |
| $H_g$ | air gap magnetizing force |
| $H_L$ | a-c magnetizing force (from an assumed peak value of magnetizing current) |
| $H_m$ | maximum magnetizing force in a hysteresis loop |
| $H_{max}$ | maximum magnetizing force in a flux-current loop |
| $H'_{max}$ | apparent maximum magnetizing force in a flux-current loop |
| $H_p$ | a-c magnetizing force (from a measured peak value of exciting current) |
| $H_t$ | instantaneous magnetizing force (coincident with $B_{max}$) |
| $H_z$ | a-c magnetizing force (from an assumed peak value of exciting current) |
| $I$ | a-c exciting current (rms value) |
| $I_c$ | a-c core loss current (rms value) |
| $I_{dc}$ | constant current |
| $I_m$ | a-c magnetizing current (rms value) |
| $J$ | magnetic polarization |
| $k'$ | coupling coefficient |
| $\ell$ | flux path length |
| $\ell_1$ | effective flux path length |
| $\ell_g$ | gap length |

| Symbol | Term |
|---|---|
| $\mathfrak{L}$ | (also $\phi N$) flux linkage |
| $\mathfrak{L}_m$ | mutual flux linkage |
| $L$ | self inductance |
| $L_1$ | core inductance |
| $L_\Delta$ | incremental inductance |
| $L_i$ | intrinsic inductance |
| $L_m$ | mutual inductance |
| $L_0$ | initial inductance |
| $L_s$ | series inductance |
| $L_w$ | winding inductance |
| $\mathfrak{m}$ | magnetic moment |
| $M$ | magnetization |
| $m$ | total mass of a specimen |
| $m_1$ | active mass of a specimen |
| $N_D$ | demagnetizing factor |
| $N_1$ | turns in a primary winding |
| $N_2$ | turns in a secondary winding |
| $N_1 I/\ell_1$ | a-c excitation |
| $p$ | magnetic pole strength |
| $\mathcal{P}$ | permeance |
| $P$ | active (real) power |
| $P_a$ | apparent power |
| $P_{a\,(B;f)}$ | specific apparent power |
| $P_c$ | total core loss |
| $P_{c\,(B;f)}$ | specific core loss |
| $P_{c\Delta}$ | incremental core loss |
| $P_e$ | normal eddy-current core loss |
| $P_{\Delta e}$ | incremental eddy-current core loss |
| $P_h$ | normal hysteresis core loss |
| $P_{\Delta h}$ | incremental hysteresis core loss |
| $P_q$ | reactive (quadrature) power |
| $P_r$ | residual core loss |
| $P_w$ | winding loss (copper loss) |
| $P_z$ | exciting power |
| $P_{z\,(B;f)}$ | specific exciting power |
| $Q_m$ | magnetic storage factor |
| $\mathcal{R}$ | reluctance |
| $R_1$ | core resistance |
| $R_s$ | insulation resistance |
| $R_w$ | winding resistance |
| $S$ | lamination factor (stacking factor) |
| $SCM$ | symmetrically cyclically magnetized condition |
| $T_c$ | Curie temperature |
| $w$ | lamination width |
| $W_h$ | hysteresis loop loss |
| $\beta$ | hysteretic angle |
| $\gamma$ | loss angle |
| $\cos \gamma$ | magnetic power factor |
| $\gamma_p$ | proton gyromagnetic ratio |
| $\Gamma_m$ | magnetic constant |

| SYMBOL | TERM |
|---|---|
| $\delta$ | density |
| $\kappa$ | susceptibility |
| *A-C Permeabilities:* | |
| $\mu_a$ | ideal permeability |
| $\mu_L$ | inductance permeability |
| $\mu_{\Delta L}$ | incremental inductance permeability |
| $\mu_{od}$ | initial dynamic permeability |
| $\mu_p$ | peak permeability |
| $\mu_{\Delta p}$ | incremental peak permeability |
| $\mu_t$ | instantaneous permeability |
| $\mu_z$ | inpedance permeability |
| $\mu_{\Delta z}$ | incremental impedance permeability |
| *D-C Permeabilities:* | |
| $\mu$ | normal permeability |
| $\mu_{abs}$ | absolute permeability |
| $\mu_d$ | differential permeability |

| SYMBOL | TERM |
|---|---|
| $\mu_\Delta$ | incremental permeability |
| $\mu_{eff}$ | effective circuit permeability |
| $\mu_i$ | intrinsic permeability |
| $\mu_{\Delta i}$ | incremental intrinsic permeability |
| $\mu_m$ | maximum permeability |
| $\mu_0$ | initial permeability |
| $\mu_r$ | relative permeability |
| $\mu_v$ (also $\Gamma_m$) | space permeability |
| $\mu_{rev}$ | reversible permeability |
| $\mu'/\cot\gamma$ | figure of merit |
| $\nu$ | reluctivity |
| $\pi$ | the numeric 3.1416 |
| $\phi$ | magnetic flux |
| $\phi N$ | flux linkage (see $\mathcal{L}$) |
| $\chi$ | mass susceptibility |
| $\omega$ | angular frequency in radians per second |

## PART 2—DEFINITION OF TERMS USED IN MAGNETIC TESTING

****a-c excitation,** $N_1I/\ell_1$—The ratio of the rms ampere-turns of exciting current in the primary winding of an inductor to the effective length of the magnetic path.

****active (real) power,** $P$—The product of the rms, current, $I$, in an electrical circuit, the rms voltage, $E$, across the circuit, and the cosine of the angular phase difference, $\theta$ between the current and the voltage.

$$P = EI\cos\theta$$

NOTE—The portion of the active power that is expended in a magnetic core is the total core loss, $P_c$.

**aging coefficient**—the percentage change in a specific magnetic property resulting from a specified aging treatment.

NOTE—The aging treatments usually specified are:
(*a*) 100 h at 150 C, or
(*b*) 600 h at 100 C.

**aging, magnetic**—the change in the magnetic properties of a material resulting from metallurgical change. This term applies whether the change results from a continued normal or a specified accelerated aging condition.

NOTE—This term implies a deterioration of the magnetic properties of magnetic materials for electronic and electrical applications, unless otherwise specified.

***air-gap magnetizing force,** $H_g$—the magnetizing force required to produce the induction existing at some point in a nonmagnetic gap in a magnetic circuit. In the cgs system, $H_g$ is numerically equal to the induction existing at such a point and exceeds the magnetizing force in the magnetic material.

**ampere-turn**—unit of magnetomotive force in the rationalized mksa system. One ampere-turn equals $4\pi/10$ or 1.257 gilberts.

**ampere-turn per meter**—unit of magnetizing force (magnetic field strength) in the rationalized mksa system. One ampere-turn per meter is $4\pi \times 10^{-3}$ or 0.01257 oersted.

**anisotropic material**—a material in which the magnetic properties differ in various directions.

**antiferromagnetic material**—a feebly magnetic material in which almost equal magnetic moments are lined up antiparallel to each other. Its susceptibility increases as the temperature is raised until a critical (Neél) temperature is reached; above this temperature the material becomes paramagnetic.

****apparent coercive force,** $H'_c$—the value of apparent magnetizing force on a flux-current loop coincident with zero induction.

****apparent magnetizing force,** $H'$—the abscissa value of a point on a flux-current loop computed in terms of the instantaneous exciting current, $i$, using the magnetostatic equation:

$$H' = 0.4\pi N_1 I / \ell_1$$

**apparent magnetizing force, incremental, $H'_\Delta$**—the apparent $H'$ value for a point on an incremental flux-current loop.

**apparent magnetizing force, maximum, $H'_{max}$**—the maximum value of $H'$ attained in a flux-current loop.

**apparent power, $P_a$**—the product (volt-amperes) of the rms exciting current and the applied rms *terminal* voltage in an *electric* circuit containing inductive impedance. The components of this impedance due to the winding will be linear, while the components due to the magnetic core will be non-linear.

**apparent power; specific, $P_{a(B;f)}$**—the value of the apparent power divided by the active mass of the specimen (volt-amperes per unit mass) taken at a specified maximum value of cyclically varying induction $B$ and at a specified frequency $f$.

**apparent residual induction, $B'_r$**—the value of induction on a flux-current loop when the apparent magnetizing force has a zero value.

**area, $A$**—the geometric cross-sectional area of a magnetic path which is perpendicular to the direction of the induction.

**cgs-em system of units**—system for measuring physical quantities in which the basic units are the centimeter, gram, and second, and the numerical value of the magnetic constant, $\Gamma_m$, is unity.

*__coercive force, $H_c$__—the (d-c) magnetizing force at which the magnetic induction is zero when the material is in a symmetrically cyclically magnetized condition.

*__coercive force, intrinsic, $H_{ci}$__—the (d-c) magnetizing force at which the intrinsic induction is zero when the material is in a symmetrically cyclically magnetized condition.

*__coercivity, $H_{cs}$__—the maximum value of coercive force.

**core, powder (dust)**—a magnetic core comprised of small particles of electrically insulated metallic ferromagnetic material. These cores are characterized by low hysteresis and eddy-current losses.

**core, laminated**—a magnetic core constructed by stacking thin pieces of suitable shape, which are stamped or sheared from sheet or strip material. Individual pieces usually have an insulating surface coating to minimize eddy-current losses in the assembled core.

**core, tape-wound**—a magnetic core constructed by the spiral winding of strip material onto a suitable mandrel. The strip material usually has an insulating surface coating which reduces interlaminar eddy-current losses in the finished core.

**core loss current, a-c $I_c$**—See **current, a-c core loss.**

**core loss, incremental, $P_{c\Delta}$**—the core loss in a magnetic material when subjected simultaneously to a d-c biasing magnetizing force and an alternating magnetizing force.

**core loss, residual, $P_r$**—that portion of the core loss power, $P_c$, which is not attributed to hysteresis or eddy-current losses from classical assumptions.

**core loss, specific, $P_{c(B;f)}$**—the active power (watts) expended per unit mass of magnetic material in which there is a cyclically varying induction of a specified maximum value, $B$, at a specified frequency, $f$.

**core loss, (total), $P_c$**—the active power (watts) expended in a magnetic circuit in which there is a cyclically alternating induction.

NOTE—Measurements of core loss are normally made with sinusoidally alternating induction, or the results are corrected for deviations from the sinusoidal condition.

**core plate**—a generic term for any insulating material, formed metallurgically or applied externally as a thin surface coating, on sheet or strip stock used in the construction of laminated and tape wound cores.

**coupling coefficient, $k'$**—the ratio of the mutual inductance between two windings and the geometric mean of the individual self-inductances of the windings.

**crest factor, $cf$**—the ratio of the maximum value of a periodically alternating quantity to its rms value.

NOTE—For a sinusoidal variation the crest factor is $\sqrt{2}$.

**Curie temperature, $T_c$**—the temperature above which a ferromagnetic material becomes paramagnetic.

**current, a-c core loss, $I_c$**—the rms value of the in-phase component (with respect to the induced voltage) of the exciting current supplied to a coil which is linked with a ferromagnetic core.

**current, a-c exciting, $I$—the rms value of the total current supplied to a coil that is linked with a ferromagnetic core.

NOTE—Exciting current is measured under the condition that any other coil linking the same core carries no current.

**current, a-c magnetizing, $I_m$—the rms value of the quadrature component (leading with respect to the induced voltage) of the exciting current supplied to a coil that is linked with a ferromagnetic core.

*current, constant, $I_{d\text{-}c}$—the steady current which is located in a winding and which produces a magnetostatic condition.

**cyclically magnetized condition,** $CM$—a magnetic material is in a cyclically magnetized condition when, after having been subjected to a suffcient number of identical cycles of magnetizing force, it follows identical hysteresis or flux-current loops on successive cycles which are not symmetrical with respect to the origin of the axes.

***demagnetization curve**—that portion of a normal (d-c) hysteresis loop which lies in the second or fourth quadrant, that is, between the residual induction point, $B_r$, and the coercive force point, $H_c$. Points on this curve are designated by the coordinates $B_d$ and $H_d$.

**demagnetizing coefficient,** $D_B$—is defined by the equation:

$$D_B = [\Gamma_m(H_a - H)]/B_i$$

where:

$H_a$ = applied magnetizing force,
$H$ = magnetizing force actually existing in the magnetic material, and
$B_i$ = intrinsic induction.
$\Gamma_m$ = 1 in the cgs system and $4\pi \times 10^{-7}$ henry/meter in the mksa system (rationalized).

NOTE—For a closed, uniform magnetic circuit the demagnetizing coefficient is zero.

**demagnetizing factor,** $N_D$—defined as $4\pi$ times the demagnetizing coefficient, $D_B$.

***demagnetizing force,** $H_d$—a magnetizing force (on the demagnetization curve) applied in such a direction as to reduce the induction in a magnetized body. See **demagnetization curve.**

**density,** $\delta$—the ratio of the mass to the volume of a magnetic material, g/cm.³

**diamagnetic material**—a material whose relative permeability is less than unity.

NOTE—the intrinsic induction, $B_i$, is oppositely directed to the applied magnetizing force $H$.

****dissipation factor, magnetic,** $D_m$—the tangent of the hysteretic angle that is equal to the ratio of the core loss current, $I_c$, to the magnetizing current, $I_m$. Thus:

$$D_m = \tan\beta = \cot\gamma = I_c/I_m = \omega L_1/R_1 = 1/D_m$$

NOTE—This dissipation factor is also given by the ratio of the energy dissipated in the core per cycle of a periodic $SCM$ excitation (hysteresis and eddy current heat loss) to $2\pi$ times the maximum energy stored in the core.

****distortion, harmonic**—the departure of any periodically varying waveform from a pure sinusoidal waveform.

NOTE—The distorted waveform which is symmetrical about the zero amplitude axis and which is most frequently encountered in magnetic testing, contains only the odd harmonic components, that is fundamental, 3rd harmonic, 5th harmonic, etc. Nonsymmetrical distorted waveforms must contain some even harmonic components, in addition to the fundamental and, perhaps, some odd harmonic components.

****distortion factor,** $df$—A numerical measure of the distortion in any nonsinusoidal waveform. For example, if by Fourier analysis or direct measurement $E_1$, $E_2$, $E_3$, etc., are the effective values of the pure sinusoidal harmonic components of a distorted voltage waveform, then the distortion factor is the ratio of the root mean square of the second and all higher harmonic components to the fundamental component.

$$df = [E_2^2 + E_3^2 + E_4^2 + \cdots]^{1/2}/E_1$$

NOTE—There are no d-c components ($E_0$) in the distortion factor.

**domains, ferromagnetic**—magnetized regions, either macroscopic or microscopic in size, within ferromagnetic materials. Each domain, per se, is magnetized to intrinsic saturation at all times, and this saturation induction is unidrectional within the domain.

****eddy-current loss, incremental,** $P_{\Delta e}$—the active power (watts) due to eddy currents and expended in a ferromagnetic material which is subjected to $CM$ excitation.

****eddy current loss, normal,** $P_e$—that portion of the core loss which is due to induced currents circulating in the magnetic material subject to a $SCM$ excitation.

**electrical steel**—a term used commercially to designate a flat-rolled iron-silicon alloy used for its magnetic properties.

***energy product,** $B_dH_d$—the product of the coordinate values of any point on a demagnetization curve.

***energy-product curve, magnetic**—the curve obtained by plotting the product of the corresponding coordinates, $B_d$ and $H_d$, of points on the demagnetization curve as abscissa against the induction, $B_d$, as ordinates.

NOTE 1—The maximum value of the energy product, $(B_dH_d)_m$, corresponds to the maximum value of the external energy.

NOTE 2—The demagnetization curve is plotted to the left of the vertical axis and usually the energy-product curve to the right.

***energy product, maximum** $(B_dH_d)_m$—for a given demagnetization curve, the maximum value of the energy product.

****exciting current, a-c,** $I$—See **current, a-c exciting.**

****exciting power, rms,** $P_z$—the product of the rms exciting current and the rms voltage induced in the exciting (primary) winding on a magnetic core.

NOTE—This is the apparent volt-amperes required for the excitation of the magnetic core only. When the core has a secondary winding the induced primary voltage is obtained from the measured open-circuit secondary voltage multiplied by the appropriate turns ratio.

****exciting power, specific,** $P_{z(B;f)}$—the value of the rms exciting power divided by the active mass of the specimen (volt-amperes/unit mass) taken at a specified maximum value of cyclically varying induction $B$ and at a specified frequency $f$.

****exciting voltage,** $E_1$—the rms value of the a-c voltage existing across the assumed parallel combination of core inductance $L_1$ and core resistance $R_1$.

**feebly magnetic material**—a material generally classified as "nonmagnetic," whose maximum normal permeability is less than 4.

**ferrimagnetic material**—a material in which unequal magnetic moments are lined up antiparallel to each other. Permeabilities are of the same order of magnitude as those of ferromagnetic materials, but are lower than they would be if all atomic moments were parallel and in the same direction. Under ordinary conditions the magnetic characteristics of ferrimagnetic materials are quite similar to those of ferromagnetic materials.

**ferromagnetic material**—a material that, in general, exhibits the phenomena of hysteresis and saturation, and whose permeability is dependent on the magnetizing force.

****figure of merit, magnetic,** $\mu'$/cot —the ratio of the real part of the complex relative permeability to the dissipation factor of a ferromagnetic material.

NOTE—The figure of merit is a useful index of the magnetic efficiency of the core in various a-c electromagnetic devices.

****flux-current loop, incremental (biased)**—a flux-current loop resulting from *CM* excitation and having both d-c and a-c components of exciting current or magnetic induction, or both. Such a loop will not be symmetrical about the $B$ and $H$ axes.

****flux-current loop, normal**—a dynamic loop of flux, $\phi$, versus current, $I$, or induction, $B$, versus magnetizing force, $H$, that is obtained by using a symmetrically alternating magnetizing force to produce a *SCM* excitation in the core material.

NOTE—The area of the loop is proportional to the sum of the static hysteresis loss and all dynamic losses.

**flux linkage,** $\mathcal{L}$—in a coil having $N$ turns the flux linkage

$$\mathcal{L} = \phi_1 + \phi_2 + \phi_3 + \cdots \phi_N$$

where:

$\phi_1$ = flux linking turn 1,
$\phi_2$ = flux linking turn 2, etc., and
$\phi_N$ = flux linking the $N$th turn.

NOTE—When the coupling coefficient, $k'$, is less than unity, the flux linkage equals the product of the average flux linking the turns and the total number of turns. When the coupling coefficient is equal to unity, the flux linkage equals the product of the total flux linking the coil and the total number of turns.

**flux linkage, mutual,** $\mathcal{L}_m$—the flux linkage existing between two windings on a magnetic circuit. Mutual linkage is maximum when the coupling coefficient is unity.

**flux path length,** $\ell$—the distance along a flux loop.

**flux path length, effective,** $\ell_1$—in a magnetic core, the equivalent mean length of the flux path which is used in the calculation of certain magnetic parameters.

****flux volts,** $E_f$—the average emf induced in a winding on a magnetic circuit (multiplied by

1.1107) when subjected to repeated *SCM* magnetization having a maximum induction value $B_{max}$, or having a *CM* incremental excursion range $\Delta B$.

$E_f$ = 4.443 $B_{max} A'Nf \times 10^{-8}$ volts (*SCM* excitation)
$E_f$ = 2.221 $\Delta BA'Nf \times 10^{-8}$ volts (*CM* excitation)
$E_f$ = 1.1107 $E_{avg}$

in which $A'$ = solid cross-sectional area of the core in $cm^2$; $N$ = number of winding turns, and $f$ = the frequency in hertz.

**form factor, $ff$—The ratio of the rms value of a periodically alternating quantity to its average absolute value.

NOTE—For a sinusoidal variation the form factor is:

$$\pi/2\sqrt{2} = 1.1107$$

**frequency, angular, $\omega$—the number of radians per second traversed by a rotating vector that represents any periodically varying quantity.

NOTE—Angular frequency, $\omega$, is equal to $2\pi$ times the cyclic frequency, $f$.

**frequency, cyclic, $f$—the number of hertz (cycles/second) of a periodic quantity.

**gap length, $\ell_g$**—the distance which the flux tranverses in the central region of a gap in a core having an "air" (nonmagnetic) gap in the flux path. Relative permeability may be considered unity (cgs) in the gap.

**gauss (plural gausses)**—the unit of magnetic induction in the cgs electromagnetic system. The gauss is equal to 1 maxwell per square centimeter or $10^{-4}$ tesla. See **magnetic induction (flux density)**.

**gilbert**—the unit of magnetomotive force in the cgs electromagnetic system. The gilbert is a magnetomotive force of $10/4\pi$ ampere-turns. See **magnetomotive force.**

**gyromagnetic ratio, proton, $\gamma_p$**—the ratio of the magnetic moment of a hydrogen nucleus to its angular momentum.

NOTE—The gyromagnetic ratio is used to calculate the magnetic field from a measured resonance frequency when using the nuclear magnetic resonance technique.

The relationship is:

$$B = (2\pi f/\gamma_p) \text{ gausses} = (2\pi f/\gamma_p) \times 10^{-4} \text{ teslas}$$

where:

$f$ = the resonance frequency in cycles/second (hertz)
$\gamma_p$ = the gyromagnetic ratio (the accepted value at present for water is 2.67512 $\times 10^4$ $gauss^{-1} s^{-1}$).

**henry (plural henries)**—the unit of self- or mutual inductance in the mksa (Giorgi) and in the practical system. The henry is the inductance of a circuit in which an electromotive force of 1 V is induced by a uniform rate of change of 1 A/s in the circuit. Alternatively, it is the inductance of a circuit in which 1 A produces a flux linkage of 1 Wb·turn or $10^8$ maxwell-turns. See **inductance, mutual, and inductance, self-.**

**hertz—the unit of cyclic frequency, $f$. 1 Hz = 1 cps.

***hysteresis loop, biased**—an incremental hysteresis loop that lies entirely in any one quadrant.

NOTE—In this case both of the limiting values of $H$ and $B$ are in the same direction.

***hysteresis loop, incremental**—the hysteresis loop, nonsymmetrical with respect to the $B$ and $H$ axes, exhibited by a ferromagnetic material in a *CM* condition.

NOTE—In this case both of the limiting values $H$ may have opposite polarity, but definitely have different absolute values of $H_m$. An incremental loop may be initiated at either some point on a normal hysteresis loop or at some point on the normal induction curve of the specimen.

***hysteresis loop, intrinsic**—a hysteresis loop obtained with a ferromagnetic material by plotting (usually to rectangular coordinates) corresponding d-c values of intrinsic induction, $B_i$, for ordinates and magnetizing force $H$ for abscissae.

***hysteresis loop, normal**—a closed curve obtained with a ferromagnetic material by plotting (usually to rectangular coordinates) corresponding d-c values of magnetic induction ($B$) for ordinates and magnetizing force ($H$) for abscissa when the material is passing through a complete cycle between equal definite limits of either magnetizing force, $\pm H_m$, or magnetic induction, $\pm B_m$. In general the normal hysteresis loop has mirror symmetry with respect to the origin of the $B$ and $H$ axes but this may not be true for special materials.

***hysteresis loop loss, $W_h$**—the energy expended in a single slow excursion around a normal hysteresis loop is given by the following equation:

$$W_h = (\int HdB/4\pi) \text{ ergs}$$

where the integrated area enclosed by the loop is measured in gauss-oersteds.

** **hysteresis loss, incremental,** $P_{\Delta h}$—the active power (watts) due to hysteresis expended in a ferromagnetic material while being driven through an incremental flux-current loop by a *CM* type of excitation.

** **hysteresis loss, normal,** $P_h$—(*1*) the power expended in a ferromagnetic material, as a result of hysteresis, when the material is subjected to a *SCM* excitation.

(*2*) The energy loss/cycle in a magnetic material as a result of magnetic hysteresis when the induction is cyclic (but not necessarily periodic).

**hysteresis, magnetic**—the property of a ferromagnetic material exhibited by the lack of correspondence between the changes in induction resulting from increasing magnetizing force and from decreasing magnetizing force.

** **hysteretic angle, magnetic,** $\beta$—the mean angle by which the fundamental component of exciting current leads the fundamental component of magnetizing current, $I_m$, in an inductor having a ferromagnetic core.

NOTE—Due to hysteresis, the instantaneous value of the hysteretic angle will vary during the cycle of *SCM* excitation. However, $\beta$ is taken to be the mean effective value of this angle.

** **induced voltage, secondary,** $E_s$—the open circuit rms voltage induced in a secondary winding on an inductor. If the coupling coefficient has the maximum value of unity, then each winding has the same induced volts/turn so that:

$$E_s = N_2 E_1 / N_1$$

where:

$N_2$ = number of turns in secondary winding,
$N_1$ = number of turns in primary winding, and
$E_1$ = rms voltage induced in the primary winding.

** **inductance, core,** $L_1$—the effective parallel inductance of a hypothetical path that is considered to carry exclusively the magnetizing current, $I_m$.

NOTE 1—The product $I_m^2 \omega L_1$ equals the quadrature power delivered to the core.

NOTE 2—The core inductance is related to the intrinsic induction in the core material.

** **inductance, incremental,** $L_\Delta$—the self-inductance of an electrical circuit when the ferromagnetic core has a *CM* excitation produced by specified values of both a-c and d-c components of the exciting current.

** **inductance, initial,** $L_0$—the limiting value of the core inductance, $L_1$ reached in a ferromagnetic core when, under *SCM* excitation, the magnetizing current has been progressively and gradually reduced from a comparatively high value to a zero value.

NOTE—Initial inductance may be obtained by highly sensitive ASTM bridge methods working in the range where $\mu_L$ is a linear function of $H$. A series of decreasing values of $\mu_L$ is measured and plotted versus corresponding values of magnetizing current, $I_m$ (or other suitable excitation parameter) and the data extrapolated to zero excitation. See **permeability, initial dynamic.**

**inductance, intrinsic (ferric),** $L_i$—that portion of the self-inductance which is due to the intrinsic induction in a ferromagnetic core.

NOTE—It is determined at a specified value of the magnetizing current

**inductance, mutual,** $L_m$—the common property of two electrical circuits that determines the flux linkage in one circuit (the secondary) produced by a given current in the other circuit (the primary). The mutual inductance, $L_m$, is defined by the equation:

$$L_m = \mathcal{L}_2 I_1$$

where:

$\mathcal{L}_2$ = flux linkage in the secondary, and
$I_1$ = current in the primary, assuming no current in the secondary.

NOTE 1—If $\mathcal{L}_2$ is in maxwell-turns and $I_1$ is in amperes, then the mutual inductance in henries is defined by the equation:

$$L_m = (\mathcal{L}_2/I_1) \times 10^{-8}$$

NOTE 2—If the linkage is proportional to the current (no ferromagnetic material present) the inductance is constant and may be obtained from the equation:

$$e_2 = -L_m(di_1/dt)$$

where:

$e_2$ = instantaneous induced emf in the secondary, and
$di_1/dt$ = time rate of change of the current in the primary.

NOTE 3—If ferromagnetic materials or eddy currents are present, the mutual inductance must be regarded as a function of the primary current, its rate of change, and the magnetic history of the material. Thus:

$$e_2 = -(d(L_m i_1)/dt) = -[L_m(di_1/dt) + i_1(dL_m/dt)]$$

**inductance, self,** $L$—that property of an electric circuit which determines the flux linkage produced by a given current in the circuit. The self-inductance, $L$, is defined by the equation:

$$L = \mathcal{L}/I$$

where:
$\mathcal{L}$ = flux linkage, and
$I$ = the current.

NOTE 1—If $\mathcal{L}$ is in maxwell-turns and $I$ in amperes, then the self-inductance in henries is defined by the equation:

$$L = (\mathcal{L}/I) \times 10^{-8}$$

NOTE 2—If the linkage is proportional to the current (no ferromagnetic material present) the inductance is constant and may be obtained from the equation:

$$e = -L(di/dt)$$

where:
$e$ = instantaneous induced emf, and
$di/dt$ = time rate of change of the current.

NOTE 3—If ferromagnetic material or eddy currents are present, the self-inductance must be regarded as a function of the circuit current, its rate of change, and the magnetic history of the material. Thus:

$$e = -(d(Li)/dt) = -[L(di/dt) + i(dL/dt)]$$

** **induction, series,** $L_s$—the effective series a-c self-inductance exhibited by an inductor having a ferromagnetic core and subjected to an *SCM* excitation after the core has been demagnetized.

NOTE—The value of series inductance is a function of the level of excitation.

** **inductance, winding,** $L_w$—the effective a-c series inductance of an inductor when no ferromagnetic materials are present.

NOTE—The winding inductance, $L_w$, is not changed when ferromagnetic materials are present.

**induction,** $B$—See **magnetic induction (flux density)**.

** **induction, biased,** $B_b$—the value of the apparent d-c magnetic induction around which the a-c cyclic changes are occurring in a magnetic material resulting from the biasing magnetizing force. This value is a function of the incremental magnetizing force and is not determined by the normal induction curve.

** **induction, incremental,** $B_\Delta$—one half the algebraic difference of the extreme values of the magnetic induction during a cycle in a magnetic material that is subjected simultaneously to a biasing magnetizing force and a symmetrically cyclically varying magnetizing force. Twice the incremental induction is indicated by the symbol $\Delta B$, thus:

$$B_\Delta = \Delta B/2$$

* **induction, intrinsic,** $B_i$—the vector difference between the magnetic induction in a magnetic material and the magnetic induction that would exist in a vacuum under the influence of the same magnetizing force. This is expressed by the equation:

$$B_i = B - \Gamma_m H$$

NOTE—In the cgs-em system $B_i/4\pi$ is often called magnetic polarization.

**induction, maximum:**

*(*1*) $B_m$—the maximum value of $B$ in a hysteresis loop. The tip of this loop has the magnetostatic coordinates $H_m$, $B_m$, which exist simultaneously.

**(*2*) $B_{max}$—the maximum value of induction in a flux-current loop.

NOTE—In a flux-current loop, the magnetodynamic values $B_{max}$ and $H_{max}$ do not exist simultaneously; $B_{max}$ occurs later than $H_{max}$.

* **induction, normal,** $B$—the maximum induction, in a magnetic material that is in a symmetrically cyclically magnetized condition.

NOTE—Normal induction is a magnetostatic parameter usually measured by ballistic methods.

* **induction, remanent,** $B_d$—the magnetic induction that remains in a magnetic circuit after the removal of an applied magnetomotive force.

NOTE—If there are no air gaps or other inhomogeneities in the magnetic circuit the remanent induction, $B_d$, will equal the residual induction, $B_r$; if air gaps or other inhomogeneities are present, $B_d$ will be less than $B_r$.

* **induction, residual,** $B_r$—the magnetic induction corresponding to zero magnetizing force in a magnetic material that is in a symmetrically cyclically magnetized condition.

* **induction, saturation,** $B_s$—the maximum intrinsic induction possible in a material.

* **induction curve, intrinsic (ferric)**—a curve of a previously demagnetized specimen depicting the relation between intrinsic induction and corresponding ascending values of

magnetizing force. This curve starts at the origin of the $B_i$ and $H$ axes.

* **induction curve, normal**—a curve of a previously demagnetized specimen depicting the relation between normal induction and corresponding ascending values of magnetizing force. This curve starts at the origin of the $B$ and $H$ axes.

**insulation resistance,** $R_s$—the apparent resistance between adjacent contacting laminations, calculated as a ratio of the applied voltage to conduction current. This parameter is normally a function of the applied force and voltage.

**isotropic material**—material in which the magnetic properties are the same for all directions.

**joule**—the unit of energy in the mksa (Giorgi) and the practical systems. One joule is one watt-second.

**lamination factor (space factor, stacking factor),** $S$—the ratio of the calculated volume of a stack of laminations to the measured volume under a given pressure. It is usually expressed as a percentage.

NOTE—The calculated volume is the equivalent solid volume based on the weight of the material and on assumed or measured density.

**lamination stack resistance**—the electrical resistance measured in the direction perpendicular to the plane of lamination in a stack of laminations.

**lamination surface insulation**—the insulation between core laminations produced by a surface condition or layer either formed or applied for this purpose.

NOTE—In commercial practice, this insulating layer is frequently designated as core plate.

**lamination thickness,** $d$—the active thickness of a single lamination cut from sheet stock, excluding any core plate material.

**lamination width,** $w$—the width of a core lamination perpendicular to the direction of the induction therein.

**leakage flux**—the flux outside the boundary of the practical magnetic circuit.

**lines/in²**—the unit of induction frequently used in commercial practice. One line/in² equals 0.1550 gauss and $1.550 \times 10^{-5}$ tesla.

** **loss angle, magnetic,** $\gamma$—the mean angle by which the fundamental component of core loss current leads the fundamental component of exciting current, $I$, in an inductor having a ferromagnetic core.

NOTE 1—The loss angle, $\gamma$, is the complement of the hysteretic angle, $\beta$.

NOTE 2—Due to hysteresis, the instantaneous value of the loss angle will vary during the cycle of $SCM$ excitation; however, $\bar{\gamma}$ is taken to be the mean effective value of this angle.

**magnet**—a body that produces a magnetic field external to itself.

NOTE 1—By convention, the north-seeking pole of a magnet is marked with an $N$, +, or is colored red.

NOTE 2—Natural magnets consist of certain ores such as magnetite (loadstone); artificial (permanent) magnets are made of magnetically hard materials; electromagnets have cores made of magnetically soft materials which are energized by a current carrying winding.

**magnetic circuit**—a region at whose surface the magnetic induction is tangential.

NOTE—A practical magnetic circuit is the region containing the flux of practical interest, such as the core of a transformer. It may consist of ferromagnetic material with or without air gaps or other feebly magnetic materials such as procelain, brass, etc.

**magnetic constant (permeability of space),** $\Gamma_m$—the dimensional scalar factor that relates the mechanical force between two currents to their intensities and geometrical configurations. That is:

$$dF = \Gamma_m I_1 I_2 dl_1 \times (dl_2 \times r_1)/nr^2$$

where:

$\Gamma_m$ = magnetic constant when the element of force, $dF$, of a current element $I_1dl_1$ on another current element $I_2dl_2$ is at a distance $r$,

$r_1$ = unit vector in the direction from $dl_1$ to $dl_2$, and

$n$ = dimensionless factor. The symbol $n$ is unity in unrationalized systems and $4\pi$ in rationalized systems.

NOTE 1—The numerical values of $\Gamma_m$ depend upon the system of units employed. In the cgs-em system $\Gamma_m = 1$, in the rationalized mksa system $\Gamma_m = 4\pi \times 10^{-7}\ h/m$.

NOTE 2—The magnetic constant expresses the ratio of magnetic induction to the corresponding magnetizing force at any point in a vacuum and therefore is sometimes called the permeability of space, $\mu_v$.

NOTE 3—The magnetic constant times the relative permeability is equal to the absolute permeability.

$$\mu_{abs} = \Gamma_m \mu_r$$

**magnetic excursion range,** $\Delta B$, $\Delta H$—for any hysteresis loop or any flux-current loop, the excursion ranges equal the algebraic differences between the upper and lower values of $B$, and between the upper and lower values of $H$, obtained in the loop.

**magnetic field of induction**—a state of a region such that a conductor carrying a current in the region would be subjected to a mechanical force, and an electromotive force would be induced in an elementary loop rotated with respect to the field in such a manner as to change the flux linkage.

**magnetic field strength,** $H$—See **magnetizing force.**

**magnetic flux,** $\phi$—the product of the magnetic induction, $B$, and the area of a surface (or cross-section), $A$, when the magnetic induction $B$ is uniformly distributed and normal to the plane of the surface.

$$\phi = BA$$

where:
$\phi$ = magnetic flux,
$B$ = magnetic induction, and
$A$ = area of the surface.

NOTE 1—If the magnetic induction is not uniformly distributed over the surface, the flux, $\phi$, is the surface integral of the normal component of $B$ over the area.

$$\phi = \iint_s B \cdot dA$$

NOTE 2—Magnetic flux in a scalar and has no direction.

**magnetic flux density,** $B$—See **magnetic induction (flux density).**

**magnetic induction (flux density),** $B$—that magnetic vector quantity which at any point in a magnetic field is measured either by the mechanical force experienced by an element of electric current at the point, or by the electromotive force induced in an elementary loop during any change in flux linkages with the loop at the point.

NOTE 2—If the magnetic induction, $B$, is uniformly distributed and normal to a surface or cross-section, then the magnetic induction is:

$$B = \phi / A$$

where:
$B$ = magnetic induction,
$\phi$ = total flux, and
$A$ = area.

NOTE 2—$B_{in}$ is the instantaneous value of the magnetic induction and $B_m$ is the maximum value of the magnetic induction.

**magnetic line of force**—an imaginary line in a magnetic field which at every point has the direction of magnetic induction at that point.

NOTE—Extended lines of force must always form nonintersecting closed loops.

**magnetic moment,** $m$—a measure of the magnetizing force, $H$, produced at points in space by a plane current loop or a magnetized body.

NOTE 1—The magnetic moment of a plane current loop is a vector, the magnitude of which is the product of the area of the loop and the current; the direction of the vector is normal to the plane of the loop in that direction around which the current has a clockwise rotation when viewed along the vector.

NOTE 2—The magnetic moment of a magnetized body is the volume integral of the magnetization, $M$.

NOTE 3—In the cgs-em system magnetic moment is usually defined as the pole strength multiplied by the distance between poles. This is sometimes called the magnetic dipole moment.

**magnetic ohm**—the unit of reluctance sometimes used in the cgs-em system. One magnetic ohm equals one gilbert/maxwell or $4\pi/10^9$ ampere-turns/weber.

***magnetic particle inspection method**—a method for detecting magnetic discontinuities or inhomogeneities on or near the surface in suitably magnetized materials, that employs finely divided magnetic particles that tend to congregate in regions of magnetic nonuniformity associated with the magnetic discontinuities or inhomogeneities.

NOTE—Magnetic particle inspection is an accepted method for the detection of defects.

***magnetic polarization,** $J$—in the cgs-em system, the intrinsic induction divided by $4\pi$ is sometimes called magnetic polarization or magnetic dipole moment per unit volume.

***magnetic pole**—the magnetic poles of a magnet are those portions of the magnet toward which or from which the external magnetic induction appears to converge or diverge respectively.

NOTE 1—In the hypothetical case of a uniformly magnetized body of constant cross-sectional area the poles would be located at its ends.

NOTE 2—By convention, the north-seeking pole is marked with an $N$, or +, or is colored red.

***magnetic pole strength,** $p$—the magnetic moment divided by the distance between the poles.

$$p = m/l$$

where:
$p$ = pole strength,
$m$ = magnetic moment, and
$l$ = distance between the poles.

**magnetics (magnetism)**—that branch of science which deals with the laws of magnetic phenomena and their application to practice.

**magnetician**—one skilled in the theory and practice of magnetics.

***magnetization,** $M$—the component of the total magnetizing force that produces the intrinsic induction in a magnetic material.

$$M = (B - \Gamma_m H)/\Gamma_m \mu_r = B_i/\mu_{abs}$$

where:
$M$ = magnetization,
$H$ = applied magnetizing force,
$\Gamma_m$ = magnetic constant,
$B$ = total magnetic induction,
$\mu_r$ = relative permeability,
$\mu_{abs}$ = absolute permeability, and
$B_i$ = intrinsic induction.

NOTE—The magnetization can be interpreted as the volume density of magnetic moment.

****magnetizing current, a-c,** $I_m$—See **current, a-c magnetizing.**

**magnetizing force (magnetic field strength),** $H$—that magnetic vector quantity at a point in a magnetic field which measures the ability of electric currents or magnetized bodies to produce magnetic induction at the given point.

NOTE 1—The magnetizing force, $H$, may be calculated from the current and the geometry of certain magnetizing circuits. For example, in the center of a uniformly-wound long solenoid.

$$H = C(NI/l)$$

where:
$H$ = magnetizing force,
$C$ = constant whose value depends on the system of units,
$N$ = number of turns,
$I$ = current, and
$l$ = axial length of the coil.

If $I$ is expressed in amperes and $l$ is expressed in centimeters, then $C = 4\pi/10$ in order to obtain $H$ in the cgs-em unit, the oersted.

If $I$ is expressed in amperes and $l$ is expressed in meters, then $C = 1$ in order to obtain $H$ in the mksa unit, ampere-turn per meter.

NOTE 2—The magnetizing force, $H$, at a point in air may be calculated from the measured value of induction at the point by dividing this value by the magnetic constant $\Gamma_m$.

****magnetizing force, a-c**—three different values of dynamic magnetizing force parameters are in common use:

(*a*) $H_L$—an assumed peak value computed in terms of peak magnetizing current (considered to be sinusoidal).

(*b*) $H_z$—an assumed peak value computed in terms of measured rms exciting current (considered to be sinusoidal).

(*c*) $H_p$—computed in terms of a measured peak value of exciting current, and thus equal to the value $H'_{max}$.

****magnetizing force, biasing,** $H_b$—the algebraic mean value of the magnetizing force in a magnetic material that is subjected simultaneously to a constant magnetizing force and a periodically varying magnetizing force.

NOTE 1—The biasing magnetizing force and the biased magnetic induction are corresponding coordinates of a single point on the $B$-$H$ plane but not necessarily on the normal induction curve.

NOTE 2—The biasing magnetizing force, $H_b$, is equal to the applied constant magnetizing force only when the applied periodically varying magnetizing force is symmetrical.

****magnetizing force, incremental,** $H_\Delta$—one half the algebraic difference of the maximum and minimum values of the magnetizing force during a cycle in a magnetic material that is subjected simultaneously to a biasing magnetizing force and a symmetrical periodically varying magnetizing force.

Twice the incremental magnetizing force is indicated by the symbol $\Delta H$.

Thus:

$$H_\Delta = \Delta H/2$$

****magnetizing force, instantaneous,** (*coincident with* $B_{max}$) $H_t$—in an *SCM* flux-current loop, at the instant when $B_{max}$ occurs, the exciting voltage is zero and the instantaneous exciting current, $i$, is assumed to be all magnetizing current so that:

$$H_t = 0.4\pi N_1 I/\ell_1$$

**magnetizing force, maximum:**

*(*a*) $H_m$—the maximum value of $H$ in a hysteresis loop.

**(*b*) $H_{max}$—the maximum value of $H$ in a flux-current loop.

****magnetodynamic**—the magnetic condition when the values of magnetizing force and induction vary, usually periodically and repetitively, between two extreme limits.

**magnetomotive force,** $\mathfrak{F}$—the line integral of the magnetizing force around any flux loop in space.

$$\mathfrak{F} = \oint H \cdot dl$$

where:

$\mathfrak{F}$ = magnetomotive force,
$H$ = magnetizing force, and
$dl$ = unit length along the loop.

NOTE—The magnetomotive force is proportional to the net current linked with any closed loop of flux or closed path.

$$\mathfrak{F} = CNI$$

where:

$\mathfrak{F}$ = magnetomotive force,
$N$ = number of turns linked with the loop,
$I$ = current in amperes, and
$C$ = constant whose value depends on the system of units. In the cgs system $C = 4\pi/10$. In the mksa system $C = 1$.

***magnetostatic**—the magnetic condition when the values of magnetizing force and induction are considered to remain invariant with time during the period of measurement. This is often referred to as a d-c (direct current) condition.

**magnetostriction**—changes in dimensions of a body resulting from magnetization.

**mass, active,** $m_1$—a value of mass, which may be used with $\ell_1$ and $A'$ to evaluate a magnetic core as though it has an equivalent uniform flux path having the same induction at all points.

**mass, total,** $m$—the actual mass of a magnetic core.

**maxwell**—the unit of magnetic flux in the cgs electromagnetic system. One maxwell equals $10^{-8}$ weber. See **magnetic flux.**

NOTE—

$$e = -N\, d\phi/dt \times 10^{-8}$$

where:

$e$ = induced instantaneous emf in volts,
$d\phi/dt$ = time rate of change of flux in maxwells per second, and
$N$ = number of turns surrounding the flux, assuming each turn is linked with all the flux.

**mksa (Giorgi) rationalized system of units**—system for measuring physical quantities in which the basic units are the meter, kilogram, and second, and the ampere is a derived unit defined by assigning the magnitude $4\pi \times 10^{-7}$ to the rationalized magnetic constant (sometimes called the permeability of space).

NOTE 1—The electrical units of this system were formerly called the "practical" electrical units.

NOTE 2—In this system dimensional analysis is customarily used with the four independent (basic) dimensions: length, mass, time, and current.

**nonmagnetic**—a relative term describing a material which, for practical purposes, may be considered to have a relative permeability close to unity.

NOTE—Certain materials may be nonmagnetic only under limited conditions.

**nonoriented electrical steel**—a flat-rolled electrical steel which has approximately the same magnetic properties in all directions.

**oersted**—the unit of magnetizing force (magnetic field strength) in the cgs electromagnetic system. One oersted equals a magnetomotive force of 1 gilbert/cm of flux path. One oersted equals $1000/4\pi$ or 79.58 ampere-turns per meter. See **magnetizing force (magnetic field strength).**

**paramagnetic material**—a material having a relative permeability which is slightly greater than unity, and which is practically independent of the magnetizing force.

****permeability a-c**—a generic term used to express various dynamic relationships between magnetic induction, $B$, and magnetizing force, $H$, for magnetic material subjected to a cyclic excitation by alternating or pulsating current. The values of a-c permeability obtained for a given material depend fundamentally upon the excursion limits of dynamic excitation and induction, the method and conditions of measurement, and also upon such factors as resistivity, thickness of laminations, frequency of excitation, etc.

NOTE—The numerical value for any permeability is meaningless unless the corresponding $B$ or $H$ excitation level is specified. For incremental permeabilities not only the corresponding d-c $B$ or $H$ excitation level must be specified, but also the dynamic excursion limits of dynamic excitation range ($\Delta B$ or $\Delta H$).

A-C permeabilities in common use for magnetic testing are:

(*a*) ****impedance (rms) permeability,** $\mu_z$—the ratio of the measured peak value of magnetic induction to the value of the apparent magnetizing force, $H_z$, calculated from the measured rms value of the exciting current, for a material in the *SCM* condition.

NOTE—The value of the current used to compute $H_z$ is obtained by multiplying the measured value of rms exciting current by 1.414. This assumes that the total exciting current is magnetizing current and is sinusoidal.

(*b*) ****inductance permeability,** $\mu_L$—for a material in an *SCM* condition, the permeability is evaluated from the measured inductive component of the electrical circuit representing the magnetic specimen. This circuit is assumed to be composed of paralleled linear inductive and resistive elements, $\omega L_1$ and $R_1$.

(*c*) ****peak permeability,** $\mu_p$—the ratio of the measured peak value of magnetic induction to the peak value of the magnetizing force, $H_p$, calculated from the measured peak value of the exciting current, for a material in the *SCM* condition.

Other a-c permeabilities are:

(*d*) ****ideal permeability,** $\mu_a$—the ratio of the magnetic induction to the corresponding magnetizing force after the material has been simultaneously subjected to a value of a-c magnetizing force approaching saturation (of approximate sine waveform) superimposed on a given d-c magnetizing force, and the a-c magnetizing force has thereafter been gradually reduced to zero. The resulting ideal permeability is thus a function of the d-c magnetizing force used.

NOTE—Ideal permeability, sometimes called anhysteretic permeability, is principally significant to feebly magnetic material and to the Rayleigh range of soft magnetic material.

(*e*) ****impedance, permeability, incremental,** $\mu_{\Delta z}$—impedance permeability, $\mu_z$, obtained when an a-c excitation is superimposed on a d-c excitation, *CM* condition.

(*f*) ****inductance permeability, incremental,** $\mu_{\Delta L}$—inductance permeability, $\mu_L$, obtained when an a-c excitation is superimposed on a d-c excitation, *CM* condition.

(*g*) ****initial dynamic permeability,** $\mu_{0d}$—the limiting value of inductance permeability, $\mu_L$, reached in a ferromagnetic core when, under *SCM* excitation, the magnetizing current has been progressively and gradually reduced from a comparatively high value to zero value. (See **initial inductance**)

NOTE—This same value, $\mu_{0d}$, is also equal to the initial values of both impedance permeability, $\mu_z$, and peak permeability, $\mu_p$.

(*h*) ****instantaneous permeability**—(Coincident with $B_{max}$), $\mu_t$—with *SCM* excitation, the ratio of the maximum induction $B_{max}$ to the instantaneous magnetizing force, $H_t$, which is the value of apparent magnetizing force, $H'$, determined at the instant when $B$ reaches a maximum.

(*i*) ****peak permeability, incremental,** $\mu_{\Delta p}$—peak permeability, $\mu_p$, obtained when an a-c excitation is superimposed on a d-c excitation, *CM* condition.

* **permeability, d-c**—permeability is a general term used to express relationships between magnetic induction, $B$, and magnetizing force, $H$, under various conditions of magnetic excitation. These relationships are either (*1*) absolute permeability, which in general is the quotient of a change in magnetic induction divided by the corresponding change in magnetizing force, or (*2*) relative permeability, which is the ratio of the absolute permeability to the magnetic constant ($\Gamma_m$).

NOTE 1—The magnetic constant $\Gamma_m$ is a scalar quantity differing in value and uniquely determined by each electromagnetic system of units. In the unrationalized cgs system $\Gamma_m$ is 1 gauss/oersted and in the mksa rationalized system $\Gamma_m = 4\pi \times 10^{-7}$ H/m.

NOTE 2—Relative permeability is a pure number which is the same in all unit systems. The value and dimension of absolute permeability depends on the system of units employed.

NOTE 3—For any ferromagnetic material permeability is a function of the degree of magnetization. However, initial permeability, $\mu_0$, and maximum permeability, $\mu_m$, are unique values for a given specimen under specified conditions.

NOTE 4—Except for initial permeability, $\mu_0$, a numerical value for any of the d-c permeabilities is meaningless unless the corresponding $B$ or $H$ excitation level is specified.

NOTE 5—For the incremental permeabilities, $\mu_\Delta$ and $\mu_{\Delta i}$, a numerical value is meaningless unless both the corresponding values of mean excitation level ($B$ or $H$) and the excursion range ($\Delta B$ or $\Delta H$) are specified.

The following d-c permeabilities are frequently used in magnetostatic measurements primarily concerned with the testing of materials destined for use with permanent or d-c excited magnets.

(*a*) * **absolute permeability,** $\mu_{abs}$—The sum of the magnetic constant and the intrinsic permeability. It is also equal to the product of the magnetic constant and the relative permeability:

$$\mu_{abs} = \Gamma_m + \mu_i = \Gamma_m \mu_r$$

(*b*) * **differential permeability,** $\mu_d$—the absolute value of the slope of the hysteresis loop at any point, or the slope of the normal magnetizing curve at any point.

(*c*) * **effective circuit permeability,** $\mu_{eff}$—when a magnetic circuit consists of two or more components, each individually homogeneous throughout but having different permeability values, the effective (over-all) permeability of the circuit is that value computed in terms of the total magnetomotive force, the total resulting flux, and the geometry of the circuit.

NOTE—For a symmetrical series circuit in which each component has the same cross-sectional area, reluctance values add directly giving:

$$\mu_{eff} = \frac{l_1 + l_2 + l_3 + \ldots}{\frac{l_1}{\mu_1} + \frac{l_2}{\mu_2} + \frac{l_3}{\mu_3} + \ldots}$$

For a symmetrical parallel circuit in which each component has the same flux path length, permeance values add directly giving:

$$\mu_{eff} = \frac{\mu_1 A_1 + \mu_2 A_2 + \mu_3 A_3 + \ldots}{A_1 + A_2 + A_3 + \ldots}$$

(*d*) * **incremental intrinsic permeability,** $\mu_{\Delta i}$—the ratio of the change in intrinsic induction to the corresponding change in magnetizing force when the mean induction differs from zero.

(*e*) * **incremental permeability,** $\mu_\Delta$—the ratio of a change in magnetic induction to the corresponding change in magnetizing force when the mean induction differs from zero. It equals the slope of a straight line joining the excursion limits of an incremental hysteresis loop.

NOTE—When the change in $H$ is reduced to zero, the incremental permeability, $\mu_\Delta$, becomes the reversible permeability, $\mu_{rev}$.

(*f*) * **initial permeability,** $\mu_0$—the limiting value approached by the normal permeability as the applied magnetizing force, $H$, is reduced to zero. The permeability is equal to the slope of the normal induction curve at the origin of linear $B$ and $H$ axes.

(*g*) * **intrinsic permeability,** $\mu_i$—the ratio of intrinsic induction to the corresponding magnetizing force.

NOTE—See definition of susceptibility.

(*h*) * **maximum permeability,** $\mu_m$—the value of normal permeability for a given material where a straight line from the origin of linear $B$ and $H$ axes becomes tangent to the normal induction curve.

(*i*) * **normal permeability,** $\mu$—(without subscript)—the ratio of the normal induction to the corresponding magnetizing force. It is equal to the slope of a straight line joining the excrusion limits of a normal hysteresis loop, or the slope of a straight line joining any point ($H_m$, $B_m$) on the normal induction curve to the origin of the linear $B$ and $H$ axes.

(*j*) * **relative permeability,** $\mu_r$—the ratio of the absolute permeability of a material to the magnetic constant $\Gamma_m$, giving a pure numeric parameter.

NOTE—In the cgs-em system of units the relative permeability is numerically the same as the absolute permeability.

(*k*) **reversible permeability,** $\mu_{rev}$—the limit of the incremental permeability as the change in magnetizing force approaches zero.

(*l*) **space permeability,** $\mu_v$—the permeability of space (vacuum), identical with the magnetic constant, $\Gamma_m$.

**permeance,** $\mathcal{P}$—the reciprocal of the reluctance.

** **power factor, magnetic,** cos $\gamma$—the cosine of the magnetic loss angle. (The sine of the magnetic hysteretic angle.)

** **reactive power (quadrature power),** $P_q$—the product of the rms current in an electrical circuit, the rms voltage across the circuit, and the sine of the angular phase difference between the current and the voltage.

$$P_q = EI \sin \theta$$

where:

$P_q$ = reactive power in vars,
$E$ = voltage in volts,
$I$ = current in amperes, and
$\theta$ = angular phase by which $E$ leads $I$.

NOTE—The reactive power supplied to a magnetic core having an *SCM* excitation is the product of the magnetizing current and the voltage induced in the exciting winding.

**reluctance,** $\mathcal{R}$—that quantity which determined the magnetic flux, $\phi$, resulting from a given magnetomotive force, $\mathcal{F}$, around a magnetic circuit.

$$\mathcal{R} = \mathcal{F}/\phi$$

where:

$\mathcal{R}$ = magnetic reluctance,

$\mathcal{F}$ = magnetomotive force, and

$\phi$ = flux.

The reluctance is measured in gilberts per maxwell (magnetic ohms) in the cgs-em system and in ampere-turns per weber in the mksa system.

**reluctivity,** $\nu$—the reciprocal of the permeability of a medium.

* **remanence,** $B_{dm}$—the maximum value of the remanent induction for a given geometry of the magnetic circuit.

NOTE—If there are no air gaps or other inhomogeneities in the magnetic circuit the remanence, $B_{dm}$, is equal to the retentivity, $B_{rs}$; if air gaps or other inhomogeneities are present, $B_{dm}$ will be less than $B_{rs}$.

* **remanent induction,** $B_d$—See **induction, remanent.**

* **residual induction,** $B_r$—See **induction, residual.**

** **resistance, core,** $R_1$—the effective parallel a-c resistance of a hypothetical path that is considered to carry exclusively the core loss current, $I_c$.

NOTE—The product, $I_c^2R_1$, equals the total core loss, $P_c$.

** **resistance, winding,** $R_w$—the effective a-c series resistance of an inductor when no ferromagnetic materials are present.

NOTE 1—At low frequencies, $R_w$ is only slightly greater than the d-c resistance of the winding.

NOTE 2—The product $I^2R_w$ equals the sum of the copper, eddy current, and dielectric losses in the winding.

NOTE 3—The total active power, $P$, delivered to an inductor having a ferromagnetic core is:

$$P = P_c + I^2R_w$$

* **retentivity,** $B_{rs}$—that property of a magnetic material which is measured by its maximum value of the residual induction.

NOTE—Retentivity is usually associated with saturation induction.

** **skin effect, magnetic**—this magnetodynamic term applies to the nonuniform distribution of induction existing at various points in the cross section of a magnetic core. Skin effect is produced, primarily by eddy-current phenomena and it increases with the frequency of a-c excitation. It can ordinarily be neglected in testing at commercial power frequencies.

**solid area,** $A'$—the effective solid portion of the cross section of a core (perpendicular to the induction) which is composed of magnetic material.

**stabilization**—a treatment of magnetic material designed to increase the permanency of its magnetic properties or conditions.

** **storage factor, magnetic,** $Q_m$—the cotangent of the hysteretic angle that is equal to the ratio of the magnetizing current, $I_m$, to the core loss current, $I_c$.

$$Q_m = \cot \beta = \tan \gamma| = 1/\bar{D}_m = I_m/I_c = R_1/\omega L_1$$

NOTE—The storage factor is also given by the ratio of $2\pi$ times the maximum energy stored in the core to the energy dissipated in the core (hysteresis and eddy-current heat loss) per cycle of a periodic *SCM* excitation.

* **susceptibility,** $\kappa$—the ratio of the intrinsic induction, $B_i$, due to the magnetization of a material to the induction in space due to the influence of the corresponding magnetizing force, $H$.

$$\kappa = B_i/\Gamma_m H = \mu_r - 1$$

where:

$\Gamma_m$ = magnetic constant, and

$\mu_r$ = relative permeability.

NOTE 1—The above equations apply to an isotropic material if the mksa system of units are used.

NOTE 2—In the classical cgs-em system of units:

$$\kappa = B_i/4\pi\Gamma_m H = (\mu_r - 1)/4\pi$$

* **susceptibility, mass,** $\chi$—the susceptibility divided by the density of a body is called the susceptibility per unit mass, $\chi$, or simply the mass susceptibility.

$$\chi = \kappa/\delta$$

where $\delta$ = density.

**symmetrically cyclically magnetized condition,** *SCM*—a magnetic material is in a *SCM* condition when, under the influence of a magnetizing force that varies cyclically between two equal positive and negative limits, its successive hysteresis loops or flux-current loops are both identical and symmetrical with respect to the origin of the axes.

**tesla**—the unit of magnetic induction in the mksa (Giorgi) system. The tesla is equal to 1 Wb/m² or $10^4$ gausses.

**var**—the unit of reactive (quadrature) power in the mksa (Giorgi) and the practical systems.

**volt-ampere**—the unit of apparent power in the mksa (Giorgi) and the practical systems.

**watt**—the unit of active power in the mksa (Giorgi) and the practical systems. One watt is a power of one joule/second.

**weber**—the unit of magnetic flux in the mksa and in the practical system. The weber is the magnetic flux whose decrease to zero when linked with a single turn induces in the turn a voltage whose time integral is one volt-second. One weber equals $10^8$ maxwells. See **magnetic flux.**

**winding loss, (copper loss),** $P_w$—the power expended, as heat, in the conductors of an inductor or resistor, or both, due to the electric current in them.

## Part 3—Selected Conversion Factors

**TABLE 1 Selected Conversion Factors**

| Multiply | By | To Obtain |
|---|---|---|
| | Weight | |
| Pounds | 453.59 | grams |
| Pounds | 0.45359 | kilograms |
| Grams | 0.0022046 | pounds |
| Kilograms | 2.2046 | pounds |
| | Length | |
| Feet | 30.480 | centimeters |
| Inches | 2.5400 | centimeters |
| Centimeters | 0.032808 | feet |
| Centimeters | 0.39370 | inches |
| Inches | 0.025400 | meters |
| Meters | 39.370 | inches |
| | Area | |
| Square feet | 929.04 | square centimeters |
| Square inches | 6.4516 | square centimeters |
| Square centimeters | $1.0764 \times 10^{-3}$ | square feet |
| Square centimeters | 0.15500 | square inches |
| Square inches | $6.4516 \times 10^{-4}$ | square meters |
| Square meters | $1.5500 \times 10^{-3}$ | square inches |
| Square centimeters | $10^{-4}$ | square meters |
| Square meters | $10^4$ | square centimeters |
| | Sinusoidal Waveform | |
| Peak current or voltage | 0.70711 | rms current or voltage |
| Peak current or voltage | 0.63662 | average current or voltage |
| Rms current or voltage | 1.4142 | peak current or voltage |
| Rms current or voltage | 0.90032 | average current or voltage |
| Average current or voltage | 1.5708 | peak current or voltage |
| Average current or voltage | 1.1107 | rms current or voltage |
| | Magnetic Induction, $B$ | |
| Gausses | 6.4516 | lines per square inch |
| Gausses | $6.4516 \times 10^{-8}$ | webers per square inch |
| Gausses | $10^{-4}$ | webers per square meter (teslas) |
| Lines per square inch | 0.15500 | gauses |
| Lines per square inch | $1.5500 \times 10^{-5}$ | webers per square meter (teslas) |
| Lines per square inch | $10^{-8}$ | webers per square inch |
| Webers per square inch | $1.5500 \times 10^7$ | gausses |
| Webers per square inch | $10^8$ | lines per square inch |
| Webers per square inch | 1550 | webers per square meter (teslas) |

TABLE 1—*Continued*

| Multiply | By | To Obtain |
|---|---|---|
| Magnetizing Force, *H* | | |
| Oersteds | 2.0213 | ampere-turns per inch |
| Oersteds | 0.79577 | ampere-turns per centimeter |
| Oersteds | 79.577 | ampere-turns per meter |
| Ampere-turns per centimeter | 1.2566 | oersteds |
| Ampere-turns per centimeter | 2.5400 | ampere-turns per inch |
| Ampere-turns per centimeter | 100.00 | ampere-turns per meter |
| Ampere-turns per inch | 0.49474 | oersteds |
| Ampere-turns per inch | 0.39370 | ampere-turns per centimeter |
| Ampere-turns per inch | 39.370 | ampere-turns per meter |
| Ampere-turns per meter | 0.012566 | oersteds |
| Ampere-turns per meter | $10^{-2}$ | ampere-turns per centimeter |
| Ampere-turns per meter | 0.025400 | ampere-turns per inch |
| Permeability | | |
| Gausses per oersted | 3.1918 | lines per ampere-turn inch |
| Gausses per oersted | $3.1918 \times 10^{-8}$ | webers per ampere-turn inch |
| Gausses per oersted | $1.2566 \times 10^{-6}$ | webers per ampere-turn meter |
| Webers per ampere-turn meter | $7.9577 \times 10^{5}$ | gausses per oersted |
| Webers per ampere-turn meter | $2.5400 \times 10^{6}$ | lines per ampere-turn inch |
| Webers per ampere-turn meter | 0.025400 | webers per ampere-turn inch |
| Webers per ampere-turn inch | $3.1330 \times 10^{7}$ | gausses per oersted |
| Webers per ampere-turn inch | $10^{8}$ | lines per ampere-turn inch |
| Webers per ampere-turn inch | 39.370 | webers per ampere-turn meter |
| Lines per ampere-turn inch | 0.31330 | gausses per oersted |
| Lines per ampere-turn inch | $39.370 \times 10^{-8}$ | webers per ampere-turn meter |
| Lines per ampere-turn inch | $10^{-8}$ | webers per ampere-turn inch |

# Materials Index

# Properties Index




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This survey is intended to provide a directory of authoritative sources of numerical data on the electrical and magnetic properties of metals, with emphasis on commercial alloys. Fifty-nine sources, including handbooks and other publications, information centers, trade associations, and technical societies are described in detail, including information on the properties and materials covered and the criteria used in the selection of data. A few additional related publications are listed with brief descriptions.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

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