Ullmann's Encyclopedia of Industrial Chemistry

Sixth, Completely Revised Edition

Volume 18

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Volumes 1 - 39: Alphabetically Arranged Articles
Volume 40: Index

Symbols and Units

Symbols and units agree with SI standards (for conversion factors see page IX). The following list gives the most important symbols used in the encyclopedia. Articles with many specific units and symbols have a similar list as front matter.

Symbol	Unit	Physical Quantity
a_B		activity of substance B
A_r		relative atomic mass (atomic weight)
A	m^2	area
c_B	mol/m^3, mol/L (M)	concentration of substance B
C	C/V	electric capacity
c_p, c_v	$J\,kg^{-1}K^{-1}$	specific heat capacity
d	cm, m	diameter
d		relative density (ϱ/ϱ_{water})
D	m^2/s	diffusion coefficient
D	Gy (= J/kg)	absorbed dose
e	C	elementary charge
E	J	energy
E	V/m	electric field strength
E	V	electromotive force
E_A	J	activation energy
f		activity coefficient
F	C/mol	Faraday constant
F	N	force
g	m/s^2	acceleration due to gravity
G	J	Gibbs free energy
h	m	height
$\hbar$	$W \cdot s^2$	Planck constant
H	J	enthalpy
I	A	electric current
I	cd	luminous intensity
k	(variable)	rate constant of a chemical reaction
k	J/K	Boltzmann constant
K	(variable)	equilibrium constant
l	m	length
m	g, kg, t	mass
M_r		relative molecular mass (molecular weight)
n_D^{20}		refractive index (sodium D-line, 20 °C)
n	mol	amount of substance
N_A	mol^{-1}	Avogadro constant (6.023×10^{23} mol^{-1})
p	Pa, bar *	pressure
Q	J	quantity of heat
r	m	radius
R	$J\,K^{-1}mol^{-1}$	gas constant
R	Ω	electric resistance
S	J/K	entropy
t	s, min, h, d, month, a	time

Symbols and Units (Continued from p. VII)

Symbol	Unit	Physical Quantity
t	°C	temperature
T	K	absolute temperature
u	m/s	velocity
U	V	electric potential
U	J	internal energy
V	m^3, L, mL, μL	volume
w		mass fraction
W	J	work
x_B		mole fraction of substance B
Z		proton number, atomic number
α		cubic expansion coefficient
α	$W\,m^{-2}K^{-1}$	heat-transfer coefficient (heat-transfer number)
α		degree of dissociation of electrolyte
$[\alpha]$	$10^{-2}deg\,cm^2g^{-1}$	specific rotation
η	Pa · s	dynamic viscosity
θ	°C	temperature
$\varkappa$		c_p/c_v
λ	$W\,m^{-1}K^{-1}$	thermal conductivity
λ	nm, m	wavelength
μ		chemical potential
ν	Hz, s^{-1}	frequency
ν	m^2/s	kinematic viscosity (η/ϱ)
π	Pa	osmotic pressure
ϱ	g/cm^3	density
σ	N/m	surface tension
τ	Pa (N/m^2)	shear stress
φ		volume fraction
χ	Pa^{-1} (m^2/N)	compressibility

* The official unit of pressure is the pascal (Pa).

Conversion Factors

SI unit	Non-SI unit	From SI to non-SI multiply by
Mass		
kg	pound (avoirdupois)	2.205
kg	ton (long)	9.842×10^{-4}
kg	ton (short)	1.102×10^{-3}
Volume		
m^3	cubic inch	6.102×10^{4}
m^3	cubic foot	35.315
m^3	gallon (U.S., liquid)	2.642×10^{2}
m^3	gallon (Imperial)	2.200×10^{2}
Temperature		
°C	°F	$°C \times 1.8 + 32$
Force		
N	dyne	1.0×10^{5}
Energy, Work		
J	Btu (int.)	9.480×10^{-4}
J	cal (int.)	2.389×10^{-1}
J	eV	6.242×10^{18}
J	erg	1.0×10^{7}
J	kW · h	2.778×10^{-7}
J	kp · m	1.020×10^{-1}
Pressure		
MPa	at	10.20
MPa	atm	9.869
MPa	bar	10
kPa	mbar	10
kPa	mm Hg	7.502
kPa	psi	0.145
kPa	torr	7.502

Powers of Ten

E (exa)	10^{18}	d (deci)	10^{-1}
P (peta)	10^{15}	c (centi)	10^{-2}
T (tera)	10^{12}	m (milli)	10^{-3}
G (giga)	10^{9}	µ (micro)	10^{-6}
M (mega)	10^{6}	n (nano)	10^{-9}
k (kilo)	10^{3}	p (pico)	10^{-12}
h (hecto)	10^{2}	f (femto)	10^{-15}
da (deca)	10	a (atto)	10^{-18}

Abbreviations

The following is a list of the abbreviations used in the text. Common terms, the names of publications and institutions, and legal agreements are included along with their full identities. Other abbreviations will be defined wherever they first occur in an article. For further abbreviations, see page VII, Symbols and Units; page XIV, Frequently Cited Companies (Abbreviations), and page XV, Country Codes in patent references. The names of periodical publications are abbreviated exactly as done by Chemical Abstracts Service.

abs.	absolute
a.c.	alternating current
ACGIH	American Conference of Governmental Industrial Hygienists
ACS	American Chemical Society
ADI	acceptable daily intake
ADN	accord européen relatif au transport international des marchandises dangereuses par voie de navigation interieure (European agreement concerning the international transportation of dangerous goods by inland waterways)
ADNR	ADN par le Rhin (regulation concerning the transportation of dangerous goods on the Rhine and all national waterways of the countries concerned)
ADP	adenosine 5′-diphosphate
ADR	accord européen relatif au transport international des marchandises dangereuses par route (European agreement concerning the international transportation of dangerous goods by road)
AEC	Atomic Energy Commission (United States)
a.i.	Active ingredient
AIChE	American Institute of Chemical Engineers
AIME	American Institute of Mining, Metallurgical, and Petroleum Engineers
ANSI	American National Standards Institute
AMP	adenosine 5′-monophosphate
APhA	American Pharmaceutical Association
API	American Petroleum Institute
ASTM	American Society for Testing and Materials
ATP	adenosine 5′-triphosphate
BAM	Bundesanstalt für Materialprüfung (Federal Republic of Germany)
BAT	Biologischer Arbeitsstoff-Toleranz-Wert (biological tolerance value for a working material, established by MAK Commission, see MAK)
Beilstein	Beilstein's Handbook of Organic Chemistry, Springer, Berlin – Heidelberg – New York
BET	Brunauer – Emmett – Teller
BGA	Bundesgesundheitsamt (Federal Republic of Germany)
BGBl.	Bundesgesetzblatt (Federal Republic of Germany)
BIOS	British Intelligence Objectives Subcommitee Report (see also FIAT)
BOD	biological oxygen demand
bp	boiling point
B.P.	British Pharmacopeia
BS	British Standard
ca.	circa
calcd.	calculated
CAS	Chemical Abstracts Service
cat.	catalyst, catalyzed
CEN	Comité Européen de Normalisation
cf.	compare
CFR	Code of Federal Regulations (United States)
cfu	colony forming units
Chap.	chapter
ChemG	Chemikaliengesetz (Federal Republic of Germany)
C.I.	Colour Index
CIOS	Combined Intelligence Objectives Subcommitee Report (see also FIAT)
CNS	central nervous system
Co.	Company
COD	chemical oxygen demand
conc.	concentrated
const.	constant
Corp.	Corporation
crit.	critical

p., pp.	page, pages
Patty	G. D. Clayton, F. E. Clayton (eds.): Patty's Industrial Hygiene and Toxicology, 3rd ed., Wiley Interscience, New York
PB report	Publication Board Report (U.S. Department of Commerce, Scientific and Industrial Reports)
PEL	permitted exposure limit
Ph	phenyl substituent ($-C_6H_5$)
Ph. Eur.	European Pharmacopoeia, 2nd. ed., Council of Europe, Strasbourg 1981
phr	part per hundred rubber (resin)
PNS	peripheral nervous system
ppm	parts per million
q. v.	which see (quod vide)
ref.	refer, reference
resp.	respectively
R_f	retention factor (TLC)
R. H.	relative humidity
RID	règlement international concernant le transport des marchandises dangereuses par chemin de fer (international convention concerning the transportation of dangerous goods by rail)
RNA	ribonucleic acid
R phrase (R-Satz)	risk phrase according to ChemG and GefStoffV (Federal Republic of Germany)
rpm	revolutions per minute
RTECS	Registry of Toxic Effects of Chemical Substances, edited by the National Institute of Occupational Safety and Health (United States)
(s)	solid
SAE	Society of Automotive Engineers (United States)
s.c.	subcutaneous
SI	International System of Units
SIMS	secondary ion mass spectrometry
S phrase (S-Satz)	safety phrase according to ChemG and GefStoffV (Federal Republic of Germany)
STEL	Short Term Exposure Limit (see TLV)
STP	standard temperature and pressure (0° C, 101.325 kPa)
T_g	glass transition temperature
TA Luft	Technische Anleitung zur Reinhaltung der Luft (clean air regulation in Federal Republic of Germany)
TA Lärm	Technische Anleitung zum Schutz gegen Lärm (low noise regulation in Federal Republic of Germany)
TDLo	lowest published toxic dose
THF	tetrahydrofuran
TLC	thin layer chromatography
TLV	Threshold Limit Value (TWA and STEL); published annually by the American Conference of Governmental Industrial Hygienists (ACGIH), Cincinnati, Ohio
TOD	total oxygen demand
TRK	Technische Richtkonzentration (lowest technically feasible level)
TSCA	Toxic Substances Control Act (United States)
TÜV	Technischer Überwachungsverein (Technical Control Board of the Federal Republic of Germany)
TWA	Time Weighted Average
UBA	Umweltbundesamt (Federal Environmental Agency)
Ullmann	Ullmann's Encyclopedia of Industrial Chemistry, 5th ed., VCH Verlagsgesellschaft, Weinheim, 1985 – 1996; Ullmanns Encyklopädie der Technischen Chemie, 4th ed., Verlag Chemie, Weinheim 1972 – 1984; 3rd ed., Urban und Schwarzenberg, München 1951 – 1970
USAEC	United States Atomic Energy Commission
USAN	United States Adopted Names
USD	United States Dispensatory
USDA	United States Department of Agriculture
U.S.P.	United States Pharmacopeia
UV	ultraviolet
UVV	Unfallverhütungsvorschriften der Berufsgenossenschaft (workplace safety regulations in the Federal Republic of Germany)
VbF	Verordnung in der Bundesrepublik Deutschland über die Errichtung und den Betrieb von Anlagen zur Lagerung, Abfüllung und Beförderung brennbarer Flüssigkeiten (regulation in the Federal Republic of Germany

concerning the construction and operation of plants for storage, filling, and transportation of flammable liquids; classification according to the flash point of liquids, in accordance with the classification in the United States)

VDE	Verband Deutscher Elektroingenieure (Federal Republic of Germany)
VDI	Verein Deutscher Ingenieure (Federal Republic of Germany)
vol	volume
vol.	volume (of a series of books)
vs.	versus
WGK	Wassergefährdungsklasse (water hazard class)
WHO	World Health Organization (United Nations)
Winnacker-Küchler	Chemische Technologie, 4th ed., Carl Hanser Verlag, München, 1982-1986; Winnacker-Küchler, Chemische Technik: Prozesse und Produkte, Wiley-VCH, Weinheim, from 2003
wt	weight
$	U.S. dollar, unless otherwise stated

Frequently Cited Companies (Abbreviations)

Air Products	Air Products and Chemicals
Akzo	Algemene Koninklijke Zout Organon
Alcoa	Aluminum Company of America
Allied	Allied Corporation
Amer. Cyanamid	American Cyanamid Company
BASF	BASF Aktiengesellschaft
Bayer	Bayer AG
BP	British Petroleum Company
Celanese	Celanese Corporation
Daicel	Daicel Chemical Industries
Dainippon	Dainippon Ink and Chemicals Inc.
Dow Chemical	The Dow Chemical Company
DSM	Dutch Staats Mijnen
Du Pont	E.I. du Pont de Nemours & Company
Exxon	Exxon Corporation
FMC	Food Machinery & Chemical Corporation
GAF	General Aniline & Film Corporation
W.R. Grace	W.R. Grace & Company
Hoechst	Hoechst Aktiengesellschaft
IBM	International Business Machines Corporation
ICI	Imperial Chemical Industries
IFP	Institut Français du Pétrole
INCO	International Nickel Company
3M	Minnesota Mining and Manufacturing Company
Mitsubishi Chemical	Mitsubishi Chemical Industries
Monsanto	Monsanto Company
Nippon Shokubai	Nippon Shokubai Kagaku Kogyo
PCUK	Pechiney Ugine Kuhlmann
PPG	Pittsburg Plate Glass Industries
Searle	G.D. Searle & Company
SKF	Smith Kline & French Laboratories
SNAM	Societá Nazionale Metandotti
Sohio	Standard Oil of Ohio
Stauffer	Stauffer Chemical Company
Sumitomo	Sumitomo Chemical Company
Toray	Toray Industries Inc.
UCB	Union Chimique Belge
Union Carbide	Union Carbide Corporation
UOP	Universal Oil Products Company
VEBA	Vereinigte Elektrizitäts- und Bergwerks-AG
Wacker	Wacker Chemie GmbH

Country Codes

The following list contains a selection of standard country codes used in the patent references.

AT	Austria	ID	Indonesia
AU	Australia	IL	Israel
BE	Belgium	IT	Italy
BG	Bulgaria	JP	Japan *
BR	Brazil	LU	Luxembourg
CA	Canada	MA	Morocco
CH	Switzerland	NL	Netherlands *
CS	Czechoslovakia	NO	Norway
DD	German Democratic Republic	NZ	New Zealand
DE	Federal Republic of Germany (and Germany before 1949) *	PL	Poland
		PT	Portugal
DK	Denmark	SE	Sweden
ES	Spain	SU	Soviet Union
FI	Finland	US	United States of America
FR	France	YU	Yugoslavia
GB	United Kingdom	ZA	South Africa
GR	Greece	EP	European Patent Office *
HU	Hungary	WO	World Intellectual Property Organization

* For Europe, Federal Republic of Germany, Japan, and the Netherlands, the type of patent is specified: EP (patent), EP-A (application), DE (patent), DE-OS (Offenlegungsschrift), DE-AS (Auslegeschrift), JP (patent), JP-Kokai (Kokai tokkyo koho), NL (patent), and NL-A (application).

Periodic Table of Elements

element symbol, atomic number, and relative atomic mass (atomic weight)

1A "European" group designation and old IUPAC recommendation
1 group designation to 1986 IUPAC proposal
IA "American" group designation, also used by the Chemical Abstracts Service until the end of 1986

1A 1 IA	2A 2 IIA	3A 3 IIIB	4A 4 IVB	5A 5 VB	6A 6 VIB	7A 7 VIIB	8 8 VIII	8 9 VIII	8 10 VIII	1B 11 IB	2B 12 IIB	3B 13 IIIA	4B 14 IVA	5B 15 VA	6B 16 VIA	7B 17 VIA	0 18 VIIIA
1 **H** 1.0079																	2 **He** 4.0026
3 **Li** 6.941	4 **Be** 9.0122											5 **B** 10.811	6 **C** 12.011	7 **N** 14.007	8 **O** 15.999	9 **F** 18.998	10 **Ne** 20.180
11 **Na** 22.990	12 **Mg** 24.305											13 **Al** 26.982	14 **Si** 28.086	15 **P** 30.974	16 **S** 32.066	17 **Cl** 35.453	18 **Ar** 39.948
19 **K** 39.098	20 **Ca** 40.078	21 **Sc** 44.956	22 **Ti** 47.867	23 **V** 50.942	24 **Cr** 51.996	25 **Mn** 54.938	26 **Fe** 55.845	27 **Co** 58.933	28 **Ni** 58.693	29 **Cu** 63.546	30 **Zn** 65.409	31 **Ga** 69.723	32 **Ge** 72.61	33 **As** 74.922	34 **Se** 78.96	35 **Br** 79.904	36 **Kr** 83.80
37 **Rb** 85.468	38 **Sr** 87.62	39 **Y** 88.906	40 **Zr** 91.224	41 **Nb** 92.906	42 **Mo** 95.94	43 **Tc*** 98.906	44 **Ru** 101.07	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.29
55 **Cs** 132.91	56 **Ba** 137.33		72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.84	75 **Re** 186.21	76 **Os** 190.23	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po*** 208.98	85 **At*** 209.99	86 **Rn*** 222.02
87 **Fr*** 223.02	88 **Ra*** 226.03		104 **Rf*** 261.11	105 **Db*** 262.11	106 **Sg**	107 **Bh**	108 **Hs**	109 **Mt**	110 **Uun**[a]	111 **Uuu**[a]	112 **Uub**[a]		114 **Uuq**[a]		116 **Uuh**[a]		

[a] provisional IUPAC symbol

57 **La** 138.91	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm*** 146.92	62 **Sm** 150.36	63 **Eu** 151.97	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.04	71 **Lu** 174.97
89 **Ac*** 227.03	90 **Th*** 232.04	91 **Pa*** 231.04	92 **U*** 238.03	93 **Np*** 237.05	94 **Pu*** 244.06	95 **Am*** 243.06	96 **Cm*** 247.07	97 **Bk*** 247.07	98 **Cf*** 251.08	99 **Es*** 252.08	100 **Fm*** 257.10	101 **Md*** 258.10	102 **No*** 259.10	103 **Lr*** 260.11

* radioactive element; mass of most important isotope given.

Contents

Cross References

Information Storage Materials

BARRY K. MIDDLETON, Department of Computer Science, Manchester University, Oxford Road, Manchester, M13 9PL, United Kingdom (Chapter 1)

HENK VAN HOUTEN, Philips Research Laboratories, Eindhoven, The Netherlands (Section 2.1)

JOHAN P. W. B. DUCHATEAU, Philips Research Laboratories, Eindhoven, The Netherlands (Section 2.1)

HANS J. G. KLOOSTERBOER, Philips Research Laboratories, Eindhoven, The Netherlands (Sections 2.2 and 2.3)

JAN A. TH. VERHOEVEN, Toolex International N.V., Veldhoven, The Netherlands (Section 2.2)

RENÉ VAN VLIMMEREN, Toolex International N.V., Veldhoven, The Netherlands (Section 2.2)

PETER E. J. LEGIERSE, Optical Disc Mastering (ODM), Eindhoven, The Netherlands (Sections 2.2 and 2.3)

DIRK J. GRAVESTEIJN, Philips Research Laboratories, Eindhoven, The Netherlands (Sections 2.4 and 2.5)

C. DAVID WRIGHT, Manchester School of Engineering, University of Manchester, United Kingdom (Section 2.5.1)

HERMAN J. BORG, Philips Research Laboratories, Eindhoven, The Netherlands (Sections 2.5 and 2.5.2)

HEINRICH HEITMANN, Philips Research Laboratories, Hamburg, Federal Republic of Germany (Section 2.5)

JACQUES HEEMSKERK, Philips, Eindhoven, The Netherlands (Section 2.6)

1. Magnetic Recording

1.1. Introduction

Magnetic recording technology is widespread in its adoption and its impact on our lives. Be it in portable audio recorders, hi-fi audio systems, video recorders, or in floppy or rigid disk systems in computers, the products of the technology are widely used and appreciated today. Novel data storage systems are being prepared and queuing up for possible launch into the market place. All these are propelled by mighty industrial concerns in various parts of the world primarily in America and Japan, but also in Europe.

The majority of audio and video recording has traditionally taken place using analogue techniques although in recent times products operating in the digital domain have been introduced. The future will see an accelerated shift to digital techniques and this means that there is a continued convergence of most recording technologies into the data storage arena where all information from whatever source can be recorded and manipulated using digital methods.

1.1.1. History

Magnetic recording [1] was first demonstrated by the Danish inventor VALDEMAR POULSEN in 1898. He developed a machine for recording voice messages onto steel wire and was able to demonstrate recording and replay in a recognizable form. This achievement quickly received acclaim. Despite the low signal levels and high levels of distortion in the recordings, developments of this equipment were made and a telephone message recording machine called a Telegraphone was eventually put on the market. However the Telegraphone was not widely adopted, partly through its lack of clarity, and the full exploitation of the technology had to await the later developments of electronic technology and the means to reduce distortions.

A major step forward came in 1935 with the development in Germany by BASF and AEG of a machine called the Magnetophone. This machine, and its later variants, brought into play two new developments which remain today as the core of many magnetic recording systems. The first was the introduction of magnetic particles as the recording medium and the second was the use of a.c. bias to linearize the characteristics of the recording medium. With these developments record and replay with high clarity was achieved and it led eventually, with further progress, to the widespread adoption of a.c. biased recording systems. The most popular current manifestation of the technology is in the compact cassette audio system introduced by Philips in 1963.

Digital recording emerged during the late 1940s and 1950s in response to the need for back-up storage for computer devices. By these times magnetic tape recording for audio was in widespread use and the technology was adapted for the recording of digital waveforms without the use of a.c. bias. In the early machines bit packing densities were very low but this increased rapidly with successive generations of equipment. Record and replay took place at data rates which were slow compared with the processing rates of computers and access times to information became a critical issue. This led to the development of faster access mechanical systems such as the magnetic drum and later the very successful magnetic disk. The latter is now the mainstay of storage for computers and disk systems exist in a variety of forms and formats employing rigid and flexible disk media.

Video recording first took place in "fixed head" systems similar to those used in audio and data recording. However, the wide bandwidths required by video signals meant that very high tape speeds had to be used and this required very long tapes for program length recordings. To alleviate this problem scanning head technology was developed in which tracks were recorded very close together in directions across the tape length to give very high area packing densities of information. First came the transverse scan technology introduced by Ampex in 1956 and later the helical scan technologies were introduced for domestic use and are now most widely manifested in VHS recorders [2]. Helical scan technology has now been adapted for use in data storage systems especially for computer back-up applications.

Recording technology continues to move forward and new developments invariably break fresh ground in terms of the amount of data stored per unit area of recording surface. Here comes the pressure for new and advanced recording media.

1.1.2. Magnetism and Magnetic Materials: Definitions (→ Magnetic Materials)

For a more detailed description of the terms used in the specification of magnetic materials, particularly those used in recording media and in magnetic heads, see, e.g., [3].

The magnetic properties of materials are often characterized by the *magnetic induction* or *flux density* within them. This quantity is represented by the symbol B and measured in units of tesla (T). In free space B is given by

$$B = \mu H 0 \tag{1}$$

where $\mu_0 = 4\pi \cdot 10^{-7}$ H/m is the permeability of free space and H is the magnetic field strength measured in A/m. The magnetic field is usually generated by a coil carrying a current and the magnitude of the field depends on that current and the geometry of the coil hence leading to a field strength which is expressed in A/m.

When the induction is measured inside a magnetic material it may be represented by

$$B = \mu (H + M) 0 \tag{2}$$

where H is the applied field strength and M is an additional contribution, measured in A/m, arising from the magnetic material and which is usually referred to as its magnetization. Sometimes Equation (2) is written in a modified form

$$B = \mu H + J 0 \tag{3}$$

where J (sometimes the symbol I is used) is also referred to as the magnetization but it is now in units of Tesla. Both representations of magnetization appear in the literature but in this article both M and H will be quoted in the same units of A/m. This is the approach adopted in most publications although there is still a widespread use in many parts of industry and academia of cgs and some imperial units.

In ferromagnetic and ferrimagnetic materials the relationship between the magnetization produced in a material and the applied magnetic field is usually nonlinear. A typical relationship is shown in Figure 1. Starting with a demagnetized sample, that is one with zero net magnetization, the application of a magnetic field increasing from zero takes the magnetization along the curve a. First of all the magnetization rises very slowly, but as the field increases the rate of rise increases. Eventually the magnetization approaches a value known as the saturation magnetization M_s. This curve is known as the initial magnetization curve. On removal of the field the magnetization drops back to the value M_r, known as the remanent magnetization. On increasing the field in a negative direction the magnetization eventually starts to reduce and is brought to zero at a field labeled $-H_c$ which is the negative value of the coercivity. Further increase of this field in the negative direction eventually takes the magnetization through to its negative saturation value of $-M_s$. Bringing the field back to zero and then increasing it again in a positive direction traces out a curve with the positive going arrows, which is a mirror image of that produced by negative going fields, and brings the material back to the positively saturated state. The curve just traversed is known as the major hysteresis loop and the quantities coercivity H_c, remanent magnetization M_r, saturation magnetization M_s, and hysteresis and loop