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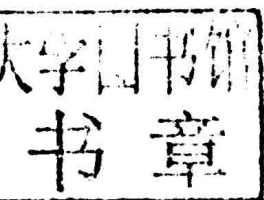
Energy: Resources, Processes, Products

Volume 3



Ullmann's Energy: Resources, Processes, Products

Volume 3



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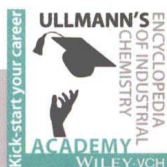
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Ullmann's Energy: Resources, Processes, Products

Volume 3

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Preface

This handbook features selected articles from the 7th edition of *ULLMANN'S Encyclopedia of Industrial Chemistry*, including newly written articles that have not been published in a printed edition before. True to the tradition of the ULLMANN'S Encyclopedia, products and processes are addressed from an industrial perspective, including production figures, quality standards and patent protection issues where appropriate. Safety and environmental aspects which are a key concern for modern process industries are likewise considered.

More content on related topics can be found in the complete edition of the ULLMANN'S Encyclopedia.

About ULLMANN'S

ULLMANN'S Encyclopedia is the world's largest reference in applied chemistry, industrial chemistry, and chemical engineering. In its current edition, the Encyclopedia contains more than 30,000 pages, 15,000 tables, 25,000 figures, and innumerable literature sources and cross-references, offering a wealth of comprehensive and well-structured information on all facets of industrial chemistry.

1,100 major articles cover the following main areas:

- Agrochemicals
- Analytical Techniques
- Biochemistry and Biotechnology
- Chemical Reactions
- Dyes and Pigments
- Energy
- Environmental Protection and Industrial Safety
- Fat, Oil, Food and Feed, Cosmetics
- Inorganic Chemicals
- Materials
- Metals and Alloys
- Organic Chemicals
- Pharmaceuticals
- Polymers and Plastics
- Processes and Process Engineering
- Renewable Resources
- Special Topics

First published in 1914 by Professor Fritz Ullmann in Berlin, the *Enzyklopädie der Technischen Chemie* (as the German title read) quickly became the standard reference work in industrial chemistry. Generations of chemists have since relied on ULLMANN'S as their prime reference source. Three further German editions followed in 1928–1932, 1951–1970, and in 1972–1984. From 1985 to 1996, the 5th edition of ULLMANN'S Encyclopedia of Industrial Chemistry was the first edition to be published in English rather than German language. So far, two more complete English editions have been published; the 6th edition of 40 volumes in 2002, and the 7th edition in 2011, again comprising 40 volumes. In addition, a number of smaller topic-oriented editions have been published.

Since 1997, *ULLMANN'S Encyclopedia of Industrial Chemistry* has also been available in electronic format, first in a CD-ROM edition and, since 2000, in an enhanced online edition. Both electronic editions feature powerful search and navigation functions as well as regular content updates.

Symbols and Units

Symbols and units agree with SI standards (for conversion factors see page XI). 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	$\text{J kg}^{-1} \text{K}^{-1}$	specific heat capacity
d	cm , m	diameter
d		relative density (q/q_{water})
D	m^2/s	diffusion coefficient
D	Gy ($=\text{J/kg}$)	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	$\text{W}\cdot\text{s}^2$	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 ($6.023 \times 10^{23} \text{ mol}^{-1}$)
P	Pa , bar^*	pressure
Q	J	quantity of heat
r	m	radius
R	$\text{J K}^{-1} \text{ mol}^{-1}$	gas constant
R	Ω	electric resistance
S	J/K	entropy
t	s , min , h , d , month , a	time
t	$^\circ\text{C}$	temperature
T	K	absolute temperature
u	m/s	velocity
U	V	electric potential

Symbols and Units (Continued from p. IX)

Symbol	Unit	Physical Quantity
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	$\text{Wm}^{-2}\text{K}^{-1}$	heat-transfer coefficient (heat-transfer number)
α		degree of dissociation of electrolyte
$[\alpha]$	$10^{-2}\text{deg cm}^2\text{g}^{-1}$	specific rotation
η	$\text{Pa}\cdot\text{s}$	dynamic viscosity
θ	$^{\circ}\text{C}$	temperature
κ		c_p/c_v
λ	$\text{Wm}^{-1}\text{K}^{-1}$	thermal conductivity
λ	nm, m	wavelength
μ		chemical potential
ν	Hz , s^{-1}	frequency
ν	m^2/s	kinematic viscosity (η/Q)
π	Pa	osmotic pressure
Q	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
<i>Mass</i>		
kg	pound (avoirdupois)	2.205
kg	ton (long)	9.842×10^{-4}
kg	ton (short)	1.102×10^{-3}
<i>Volume</i>		
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
<i>Temperature</i>		
°C	°F	$^{\circ}\text{C} \times 1.8 + 32$
<i>Force</i>		
N	dyne	1.0×10^5
<i>Energy, Work</i>		
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}
<i>Pressure</i>		
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 IX, Symbols and Units; page XVII, Frequently Cited Companies (Abbreviations), and page XVIII, Country Codes in patent references. The names of periodical publications are abbreviated exactly as done by Chemical Abstracts Service.

abs.	absolute	BGA	Bundesgesundheitsamt (Federal Republic of Germany)
a.c.	alternating current	BGBI.	Bundesgesetzblatt (Federal Republic of Germany)
ACGIH	American Conference of Governmental Industrial Hygienists	BIOS	British Intelligence Objectives Subcommittee Report (see also FIAT)
ACS	American Chemical Society	BOD	biological oxygen demand
ADI	acceptable daily intake	<i>bp</i>	boiling point
ADN	accord européen relatif au transport international des marchandises dangereuses par voie de navigation intérieure (European agreement concerning the international transportation of dangerous goods by inland waterways)	B.P.	British Pharmacopeia
		BS	British Standard
		ca.	circa
ADNR	ADN par le Rhin (regulation concerning the transportation of dangerous goods on the Rhine and all national waterways of the countries concerned)	calcd.	calculated
		CAS	Chemical Abstracts Service
ADP	adenosine 5'-diphosphate	cat.	catalyst, catalyzed
ADR	accord européen relatif au transport international des marchandises dangereuses par route (European agreement concerning the international transportation of dangerous goods by road)	CEN	Comité Européen de Normalisation
		cf.	compare
AEC	Atomic Energy Commission (United States)	CFR	Code of Federal Regulations (United States)
a.i.	active ingredient	cfu	colony forming units
AICHe	American Institute of Chemical Engineers	Chap.	chapter
AIME	American Institute of Mining, Metallurgical, and Petroleum Engineers	ChemG	Chemikaliengesetz (Federal Republic of Germany)
ANSI	American National Standards Institute	C.I.	Colour Index
AMP	adenosine 5'-monophosphate	CIOS	Combined Intelligence Objectives Subcommittee Report (see also FIAT)
APhA	American Pharmaceutical Association	CLP	Classification, Labelling and Packaging
API	American Petroleum Institute	CNS	central nervous system
ASTM	American Society for Testing and Materials	Co.	Company
ATP	adenosine 5'-triphosphate	COD	chemical oxygen demand
BAM	Bundesanstalt für Materialprüfung (Federal Republic of Germany)	conc.	concentrated
BAT	Biologischer Arbeitsstofftoleranzwert (biological tolerance value for a working material, established by MAK Commission, see MAK)	const.	constant
Beilstein	Beilstein's Handbook of Organic Chemistry, Springer, Berlin – Heidelberg – New York	Corp.	Corporation
BET	Brunauer – Emmett – Teller	crit.	critical
		CSA	Chemical Safety Assessment according to REACH
		CSR	Chemical Safety Report according to REACH
		CTFA	The Cosmetic, Toiletry and Fragrance Association (United States)
		DAB	Deutsches Arzneibuch, Deutscher Apotheker-Verlag, Stuttgart
		d.c.	direct current
		decomp.	decompose, decomposition
		DFG	Deutsche Forschungsgemeinschaft (German Science Foundation)
		dil.	dilute, diluted

DIN	Deutsche Industrienorm (Federal Republic of Germany)		(regulation in the Federal Republic of Germany concerning the transportation of dangerous goods by rail)
DMF	dimethylformamide		
DNA	deoxyribonucleic acid	GGVS	Verordnung in der Bundesrepublik Deutschland über die Beförderung gefährlicher Güter auf der Straße
DOE	Department of Energy (United States)		(regulation in the Federal Republic of Germany concerning the transportation of dangerous goods by road)
DOT	Department of Transportation – Materials Transportation Bureau (United States)	GGVSee	Verordnung in der Bundesrepublik Deutschland über die Beförderung gefährlicher Güter mit Seeschiffen
DTA	differential thermal analysis		(regulation in the Federal Republic of Germany concerning the transportation of dangerous goods by sea-going vessels)
EC	effective concentration	GHS	Globally Harmonised System of Chemicals (internationally agreed-upon system, created by the UN, designed to replace the various classification and labeling standards used in different countries by using consistent criteria for classification and labeling on a global level)
EC	European Community	GLC	gas-liquid chromatography
ed.	editor, edition, edited	Gmelin	Gmelin's Handbook of Inorganic Chemistry, 8th ed., Springer, Berlin – Heidelberg – New York
e.g.	for example	GRAS	generally recognized as safe
emf	electromotive force	Hal	halogen substituent (–F, –Cl, –Br, –I)
EmS	Emergency Schedule	Houben-Weyl	Methoden der organischen Chemie, 4th ed., Georg Thieme Verlag, Stuttgart
EN	European Standard (European Community)	HPLC	high performance liquid chromatography
EPA	Environmental Protection Agency (United States)	H statement	hazard statement in GHS
EPR	electron paramagnetic resonance	IAEA	International Atomic Energy Agency
Eq.	equation	IARC	International Agency for Research on Cancer, Lyon, France
ESCA	electron spectroscopy for chemical analysis	IATA-DGR	International Air Transport Association, Dangerous Goods Regulations
esp.	especially	ICAO	International Civil Aviation Organization
ESR	electron spin resonance	i.e.	that is
Et	ethyl substituent (–C ₂ H ₅)	i.m.	intramuscular
et al.	and others	IMDG	International Maritime Dangerous Goods Code
etc.	et cetera	IMO	Inter-Governmental Maritime Consultative Organization (in the past: IMCO)
EVO	Eisenbahnverkehrsordnung (Federal Republic of Germany)	Inst.	Institute
exp (. . .)	e ^(. . .) , mathematical exponent	i.p.	intraperitoneal
FAO	Food and Agriculture Organization (United Nations)	IR	infrared
FDA	Food and Drug Administration (United States)	ISO	International Organization for Standardization
FD&C	Food, Drug and Cosmetic Act (United States)	IUPAC	International Union of Pure and Applied Chemistry
FHSA	Federal Hazardous Substances Act (United States)	i.v.	intravenous
FIAT	Field Information Agency, Technical (United States reports on the chemical industry in Germany, 1945)		
Fig.	figure		
<i>fp</i>	freezing point		
Friedländer	P. Friedländer, Fortschritte der Teerfarbenfabrikation und verwandter Industriezweige Vol. 1–25, Springer, Berlin 1888–1942		
FT	Fourier transform		
(g)	gas, gaseous		
GC	gas chromatography		
GefStoffV	Gefahrstoffverordnung (regulations in the Federal Republic of Germany concerning hazardous substances)		
GGVE	Verordnung in der Bundesrepublik Deutschland über die Beförderung gefährlicher Güter mit der Eisenbahn		

Kirk-Othmer	Encyclopedia of Chemical Technology, 3rd ed., 1991–1998, 5th ed., 2004–2007, John Wiley & Sons, Hoboken	no.	number
(1)	liquid	NOEL	no observed effect level
Landolt-Börnstein	Zahlenwerte u. Funktionen aus Physik, Chemie, Astronomie, Geophysik u. Technik, Springer, Heidelberg 1950–1980; Zahlenwerte und Funktionen aus Naturwissenschaften und Technik, Neue Serie, Springer, Heidelberg, since 1961	NRC	Nuclear Regulatory Commission (United States)
LC ₅₀	lethal concentration for 50 % of the test animals	NRDC	National Research Development Corporation (United States)
LCLo	lowest published lethal concentration	NSC	National Service Center (United States)
LD ₅₀	lethal dose for 50 % of the test animals	NSF	National Science Foundation (United States)
LDLo	lowest published lethal dose	NTSB	National Transportation Safety Board (United States)
ln	logarithm (base e)	OECD	Organization for Economic Cooperation and Development
LNG	liquefied natural gas	OSHA	Occupational Safety and Health Administration (United States)
log	logarithm (base 10)	p., pp.	page, pages
LPG	liquefied petroleum gas	Patty	G.D. Clayton, F.E. Clayton (eds.): Patty's Industrial Hygiene and Toxicology, 3rd ed., Wiley Interscience, New York
M	mol/L	PB	Publication Board Report (U.S. Department of Commerce, Scientific and Industrial Reports)
M	metal (in chemical formulas)	report	
MAK	Maximale Arbeitsplatzkonzentration (maximum concentration at the workplace in the Federal Republic of Germany); cf. Deutsche Forschungsgemeinschaft (ed.): Maximale Arbeitsplatzkonzentrationen (MAK) und Biologische Arbeitsstofftoleranzwerte (BAT), WILEY-VCH Verlag, Weinheim (published annually)	PEL	permitted exposure limit
max.	maximum	Ph	phenyl substituent ($-\text{C}_6\text{H}_5$)
MCA	Manufacturing Chemists Association (United States)	Ph. Eur.	European Pharmacopoeia, Council of Europe, Strasbourg
Me	methyl substituent ($-\text{CH}_3$)	phr	part per hundred rubber (resin)
Methodicum Chemicum	Methodicum Chemicum, Georg Thieme Chemicum Verlag, Stuttgart	PNS	peripheral nervous system
MFAG	Medical First Aid Guide for Use in Accidents Involving Dangerous Goods	ppm	parts per million
MIK	maximale Immissionskonzentration (maximum immission concentration)	P statement	precautionary statement in GHS
min.	minimum	q.v.	which see (quod vide)
mp	melting point	REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals (EU regulation addressing the production and use of chemical substances, and their potential impacts on both human health and the environment)
MS	mass spectrum, mass spectrometry	ref.	refer, reference
NAS	National Academy of Sciences (United States)	resp.	respectively
NASA	National Aeronautics and Space Administration (United States)	R_f	retention factor (TLC)
NBS	National Bureau of Standards (United States)	R.H.	relative humidity
NCTC	National Collection of Type Cultures (United States)	RID	réglement international concernant le transport des marchandises dangereuses par chemin de fer (international convention concerning the transportation of dangerous goods by rail)
NIH	National Institutes of Health (United States)	RNA	ribonucleic acid
NIOSH	National Institute for Occupational Safety and Health (United States)	R phrase (R-Satz)	risk phrase according to ChemG and GefStoffV (Federal Republic of Germany)
NMR	nuclear magnetic resonance	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)		der Technischen Chemie, 4th ed., Verlag Chemie, Weinheim 1972–1984; 3rd ed., Urban und Schwarzenberg, München 1951–1970
SAICM	Strategic Approach on International Chemicals Management (international framework to foster the sound management of chemicals)	USAEC	United States Atomic Energy Commission
s.c.	subcutaneous	USAN	United States Adopted Names
SI	International System of Units	USD	United States Dispensatory
SIMS	secondary ion mass spectrometry	USDA	United States Department of Agriculture
S phrase	safety phrase according to	U.S.P.	United States Pharmacopeia
(S-Satz)	ChemG and GefStoffV (Federal Republic of Germany)	UV	ultraviolet
STEL	Short Term Exposure Limit (see TLV)	UVV	Unfallverhütungsvorschriften der Berufsgenossenschaft (workplace safety regulations in the Federal Republic of Germany)
STP	standard temperature and pressure (0°C, 101.325 kPa)		
T_g	glass transition temperature	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)
TA Luft	Technische Anleitung zur Reinhaltung der Luft (clean air regulation in Federal Republic of Germany)	VDE	Verband Deutscher Elektroingenieure (Federal Republic of Germany)
TA Lärm	Technische Anleitung zum Schutz gegen Lärm (low noise regulation in Federal Republic of Germany)	VDI	Verein Deutscher Ingenieure (Federal Republic of Germany)
TDL ₀	lowest published toxic dose	vol	volume
THF	tetrahydrofuran	vol.	volume (of a series of books)
TLC	thin layer chromatography	vs.	versus
TLV	Threshold Limit Value (TWA and STEL); published annually by the American Conference of Governmental Industrial Hygienists (ACGIH), Cincinnati, Ohio	WGK	Wassergefährdungsklasse (water hazard class)
TOD	total oxygen demand	WHO	World Health Organization (United Nations)
TRK	Technische Richtkonzentration (lowest technically feasible level)	Winnacker-Küchler	Chemische Technologie, 4th ed., Carl Hanser Verlag, München, 1982–1986; Winnacker-Küchler, Chemische Technik: Prozesse und Produkte, Wiley-VCH, Weinheim, 2003–2006
TSCA	Toxic Substances Control Act (United States)	wt	weight
TÜV	Technischer Überwachungsverein (Technical Control Board of the Federal Republic of Germany)	\$	U.S. dollar, unless otherwise stated
TWA	Time Weighted Average		
UBA	Umweltbundesamt (Federal Environmental Agency)		
Ullmann	Ullmann's Encyclopedia of Industrial Chemistry, 6th ed., Wiley-VCH, Weinheim 2002; Ullmann's Encyclopedia of Industrial Chemistry, 5th ed., VCH Verlagsgesellschaft, Weinheim 1985–1996; Ullmanns Encyklopädie		

Frequently Cited Companies (Abbreviations)

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

Country Codes

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

AT	Austria	IL	Israel
AU	Australia	IT	Italy
BE	Belgium	JP	Japan*
BG	Bulgaria	LU	Luxembourg
BR	Brazil	MA	Morocco
CA	Canada	NL	Netherlands*
CH	Switzerland	NO	Norway
CS	Czechoslovakia	NZ	New Zealand
DD	German Democratic Republic	PL	Poland
DE	Federal Republic of Germany (and Germany before 1949)*	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
ID	Indonesia		

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