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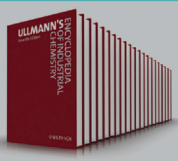

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Preface

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, food and feed 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 in print; 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.

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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 before the references.

Symbol	Unit	Physical Quantity
a_B		activity of substance B
A_r		relative atomic mass (atomic weight)
A	m^2	area
c_B	$\mathrm{mol/m}^3$, mol/L (M)	concentration of substance B
C	C/V	electric capacity
c_p, c_v	$\mathrm{J\,kg^{-1}\,K^{-1}}$	specific heat capacity
d	cm, m	diameter
d		relative density (ϱ/ϱwater)
D	$\mathrm{m}^2\mathrm{/s}$	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	$\mathrm{m/s}^2$	acceleration due to gravity
G	J	Gibbs free energy
h	m	height
$\hbar$	$\mathrm{W{\cdot}s}^2$	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 ($6.023 \times 10^{23}\ \mathrm{mol}^{-1}$)
P	Pa, bar*	pressure
Q	J	quantity of heat
r	m	radius
R	$\mathrm{JK^{-1}\,mol^{-1}}$	gas constant
R	Ω	electric resistance
S	J/K	entropy
t	s, min, h, d, month, a	time
t	°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	$Wm^{-2}K^{-1}$	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	$Wm^{-1}K^{-1}$	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 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
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 Arbeitsstofftoleranzwert (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)
BGB1.	Bundesgesetzblatt (Federal Republic of Germany)
BIOS	British Intelligence Objectives Subcommittee 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)
CLP	Classification, Labeling and Packaging
CNS	central nervous system
Co.	Company
COD	chemical oxygen demand
conc.	concentrated
const.	constant
Corp.	Corporation
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)
DMF	dimethylformamide
DNA	deoxyribonucleic acid
DOE	Department of Energy (United States)
DOT	Department of Transportation – Materials Transportation Bureau (United States)
DTA	differential thermal analysis
EC	effective concentration
EC	European Community
ed.	editor, edition, edited
e.g.	for example
emf	electromotive force
EmS	Emergency Schedule
EN	European Standard (European Community)
EPA	Environmental Protection Agency (United States)
EPR	electron paramagnetic resonance
Eq.	equation
ESCA	electron spectroscopy for chemical analysis
esp.	especially
ESR	electron spin resonance
Et	ethyl substituent ($-C_2H_5$)
et al.	and others
etc.	et cetera
EVO	Eisenbahnverkehrsordnung (Federal Republic of Germany)
exp (. . .)	$e^{(\ldots)}$, mathematical exponent
FAO	Food and Agriculture Organization (United Nations)
FDA	Food and Drug Administration (United States)
FD&C	Food, Drug and Cosmetic Act (United States)
FHSA	Federal Hazardous Substances Act (United States)
FIAT	Field Information Agency, Technical (United States reports on the chemical industry in Germany, 1945)
Fig.	figure
fp	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 (regulation in the Federal Republic of Germany concerning the transportation of dangerous goods by rail)
GGVS	Verordnung in der Bundesrepublik Deutschland über die Beförderung gefährlicher Güter auf der Straße (regulation in the Federal Republic of Germany concerning the transportation of dangerous goods by road)
GGVSee	Verordnung in der Bundesrepublik Deutschland über die Beförderung gefährlicher Güter mit Seeschiffen (regulation in the Federal Republic of Germany concerning the transportation of dangerous goods by sea-going vessels)
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)
GLC	gas-liquid chromatography
Gmelin	Gmelin's Handbook of Inorganic Chemistry, 8th ed., Springer, Berlin – Heidelberg –New York
GRAS	generally recognized as safe
Hal	halogen substituent (−F, −Cl, −Br, −I)
Houben-Weyl	Methoden der organischen Chemie, 4th ed., Georg Thieme Verlag, Stuttgart
HPLC	high performance liquid chromatography
H statement	hazard statement in GHS
IAEA	International Atomic Energy Agency
IARC	International Agency for Research on Cancer, Lyon, France
IATA-DGR	International Air Transport Association, Dangerous Goods Regulations
ICAO	International Civil Aviation Organization
i.e.	that is
i.m.	intramuscular
IMDG	International Maritime Dangerous Goods Code
IMO	Inter-Governmental Maritime Consultive Organization (in the past: IMCO)
Inst.	Institute
i.p.	intraperitoneal
IR	infrared
ISO	International Organization for Standardization
IUPAC	International Union of Pure and Applied Chemistry

i.v.	intravenous
Kirk-Othmer	Encyclopedia of Chemical Technology, 3rd ed., 1991–1998, 5th ed., 2004–2007, John Wiley & Sons, Hoboken
(1)	liquid
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
LC_{50}	lethal concentration for 50 % of the test animals
LCLo	lowest published lethal concentration
LD_{50}	lethal dose for 50 % of the test animals
LDLo	lowest published lethal dose
ln	logarithm (base e)
LNG	liquefied natural gas
log	logarithm (base 10)
LPG	liquefied petroleum gas
M	mol/L
M	metal (in chemical formulas)
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)
max.	maximum
MCA	Manufacturing Chemists Association (United States)
Me	methyl substituent ($-CH_3$)
Methodicum Chimicum	Methodicum Chimicum, Georg Thieme Verlag, Stuttgart
MFAG	Medical First Aid Guide for Use in Accidents Involving Dangerous Goods
MIK	maximale Immissionskonzentration (maximum immission concentration)
min.	minimum
mp	melting point
MS	mass spectrum, mass spectrometry
NAS	National Academy of Sciences (United States)
NASA	National Aeronautics and Space Administration (United States)
NBS	National Bureau of Standards (United States)
NCTC	National Collection of Type Cultures (United States)
NIH	National Institutes of Health (United States)
NIOSH	National Institute for Occupational Safety and Health (United States)
NMR	nuclear magnetic resonance
no.	number
NOEL	no observed effect level
NRC	Nuclear Regulatory Commission (United States)
NRDC	National Research Development Corporation (United States)
NSC	National Service Center (United States)
NSF	National Science Foundation (United States)
NTSB	National Transportation Safety Board (United States)
OECD	Organization for Economic Cooperation and Development
OSHA	Occupational Safety and Health Administration (United States)
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, Council of Europe, Strasbourg
phr	part per hundred rubber (resin)
PNS	peripheral nervous system
ppm	parts per million
P statement	precautionary statement in GHS
q.v.	which see (quod vide)
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)
ref.	refer, reference
resp.	respectively
R_f	retention factor (TLC)
R.H.	relative humidity
RID	réglement 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)
SAICM	Strategic Approach on International Chemicals Management (international framework to foster the sound management of chemicals)
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, 7th ed., Wiley-VCH, Weinheim 2011; 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 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, 2003–2006
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
AU	Australia
BE	Belgium
BG	Bulgaria
BR	Brazil
CA	Canada
CH	Switzerland
CS	Czechoslovakia
DD	German Democratic Republic
DE	Federal Republic of Germany (and Germany before 1949)[*]
DK	Denmark
ES	Spain
FI	Finland
FR	France
GB	United Kingdom
GR	Greece
HU	Hungary
ID	Indonesia
IL	Israel
IT	Italy
JP	Japan[*]
LU	Luxembourg
MA	Morocco
NL	Netherlands[*]
NO	Norway
NZ	New Zealand
PL	Poland
PT	Portugal
SE	Sweden
SU	Soviet Union
US	United States of America
YU	Yugoslavia
ZA	South Africa
EP	European Patent Office[*]
WO	World Intellectual Property Organization

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[*] 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

																	0 18 VIIIA
1 H 1.0079	2A 2 IIA											3B 13 IIIA	4B 14 IVA	5B 15 VA	6B 16 VIA	7B 17 VIA	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	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	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 Ds	111 Rg	112 Cn	113 Uut[a]	114 Fl	115 Uup[a]	116 Lv		118 Uuo[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.

Part I

Introduction

Foods, 1. Survey

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1. Introduction

Foods are mixtures of chemicals that are consumed by humans to satisfy their appetites for nourishment and pleasure. The nature and reactivity of the chemical constituents determine the properties of foods. The sensory properties, i.e., appearance, flavor, and texture, determine the acceptance of food and the pleasure derived from consuming it. Water-soluble components (salts, sugar, acids, and bitter substances) determine the taste, and volatile compounds determine the aroma. The texture is due to insoluble complexes or compounds such as proteins and polysaccharides; in some foods, lipids contribute to texture. Pigments are critical contributors to appearance. Most of the nutrients are provided by proteins, vitamins, and minerals, whereas carbohydrates and fats provide the energy. The ideal food should be both delicious and nutritious. Unfortunately, many nutritious foods are considered unappetizing by many people.

The following procedures or processes have been used to produce appealing, nutritious foods (for details, see → Foods, 2. Food Technology):

1. *mixing products*, e.g., fruit salads, vegetable salads, and fruit yogurts
2. *adding seasonings or other materials*, e.g., adding soy protein to sausage or smoking meats
3. *fractionating* to produce new products, e.g., separating milk to yield cream and skim milk
4. *homogenizing* to produce a more uniform product, e.g., peanut butter or milk
5. *fermenting* and *pickling* to produce new and more stable products, e.g., cheese manufacture
6. *enzymatic treatment*, e.g., enzymatic modification of starch to produce corn syrups of varying sweetness
7. *thermal processing* including cooking and baking, to destroy undesirable microbes, enzymes, and antinutrients such as trypsin inhibitors and enhance sensory appeal.

2. History of Food Production and Preservation

In the beginning, foods were selected from available natural products [1–8]. This led to the development of regional eating habits. The

Ullmann's Food and Feed

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origin of modern economic plants was possibly as follows [1]:

Central Asia	apple, barley, broad bean, carrot, celery, cherry, cucumber, date, eggplant, lentil, lettuce, melon, mulberry, mustard, olive, onion, pea, pear, plum, pomegranate, quince, radish, rye, spinach, turnip, wheat
Mediterranean	artichoke, asparagus, cabbage, cauliflower, fig, horseradish, parsley, parsnip
Southeast Asia	banana, breadfruit, orange, peach, persimmon, rice, soybean, sugar cane, yam
Central or South America	avocado, cassava, corn, cranberry, kidney and lima bean, pineapple, potato, pumpkin, squash, sweet potato, tomato

At first, selection of food from the available supply was based primarily on sensory properties. By trial and error, people learned that some products satisfied their appetites while others adversely affected their health. The people who made the right choices lived to pass on the information to the next generation.

In the days when humans were merely hunters or gatherers of foods, the adequacy of diet depended on the types and quantity of available plants and animals. The need to develop methods for preserving food for use throughout the year became obvious. Concern over the quantity and quality of food increased as population increased. These food problems stimulated development of methods for producing and preserving foods (→ Foods, 2. Food Technology). The progression of civilization from the food gathering stage to the early food production era, i.e., from the Old Stone Age to 400 AD, is shown in Table 1.

In Germany, substantial increases in agricultural production occurred after the introduction of the iron plow in the 6th century, the horseshoe in the 9th century, and the horsecollar soon after. The threefold rotation system (one-third of the land remained fallow, summer crops were raised on another third, and winter crops on the other third) also increased production.

Table 1. History of growing, processing, and preserving food [1]

Date (approximate) Period	Food	Farming–trading	Preserving–processing	Scientific–technological advances
Prior to 15 000 BC Paleolithic (second period of Stone Age)	eggs, fish, fruits, honey, insects, nuts, seeds, roots, small animals		drying, pounding, roasting	bags, baskets, clothes, language, "made" fire, painting, sculpture, stone and bone implements
15 000 BC Mesolithic (transitional period of Stone Age)	bigger selection of food, storing berries and wild fruits		boiling, drying fish, smoking, steaming, storing food	bow and arrow; dog, goat, reindeer, and sheep (domesticated); claycovered baskets
9000 BC Neolithic (last period of Stone Age) *villages*	domesticated animals, milk, butter, cheese, gruel, dates, olives, grapes, beer, vinegar, wine	cultivating cereals (seasonal) in permanent fields using hoes and hand plows, pruning	alcoholic fermentation, adding acetic acid, salting, baking, making bread, sieving, pressing primitively, seasoning	pottery wheel; spinning; weaving; wood, flint, and bone sickles; saddle quern; mortar; fishing with hooks and nets
3500 BC Bronze *cities*	soybeans, figs, rice, olive oil, vegetables, lentils, cabbage, cucumbers, onions	irrigating, plowing with horses and oxen, much trading locally and externally	filtering, lactic acid fermentation, more types of flavoring, flotating, leavening bread, making sausage, frying, pressing (sophisticated and complex), clarifying	architecture, smelting, wheeled carts, ships, writing, bronze tools, mathematics, rotary millstones, bronze weapons, astronomy, shadoofs, medicine, chemistry
1500 BC Iron	artichokes, beans, fruits, lettuce, sauces, spices	trading by land and sea, using heavier plows	refinement of flavoring and cooking	pulleys, glass, improved and cheaper tools and weapons, currency
600 BC–400 AD Roman	sugarcane, apples, asparagus, beets, oranges	using reaping machines, rotating legumes, using plows with wheels, trading extensively	food adulteration common	water mills, donkey mills, wooden cooperage

Table 2. Some components isolated from foods prior to 1800

Component	CAS registry number	Food	Investigator
Lactose	[63-42-3]	milk	F. Bartoletti (1586–1630)
Fructose	[57-48-7]	honey, raisins	J. R. Glauber (1604–1668)
Gluten	[8002-80-0]	flour	F. M. Grimaldi (1618–1663)
Tartar, ethanol	[868-14-4, 64-17-5]	wine	J. D. Portius (1636–1703)
Sucrose	[57-50-1]	beets	A. S. Marggraf (1709–1792)
Citric acid	[77-92-9]	lemon juice, gooseberries	C. W. Scheele (1742–1786)
Malic acid	[6915-15-7]	apples	
Glycerol	[56-81-5]	olive oil	

During the *Middle Ages* the variety of available foods increased as a result of increased traveling and trading. The discovery of America had a pronounced effect on the variety of food with the introduction of potatoes and corn, as well as other native American products, such as tomatoes, peanuts, lima beans, and turkeys.

The 16th century marked the beginning of the so-called *Golden Age of Science* [1], [6–10]. During this time, scholars investigated the nature and composition of foods. Some of the components discovered are listed in Table 2. These discoveries gave credibility to the scientific approach to biological problems and stimulated further research and technical developments (Table 3).

In the *last two centuries* considerable progress has been made in increasing the quantity and improving the quality of food [11, 12].

Food Quantity. Quantitative increases in the food supply have resulted from the following:

1. The use of better breeding practices and careful genetic selection, which led to the development of high yielding varieties of wheat and rice.
2. Replacing draft animals with mechanical power increased the acreage that could be farmed and released millions of hectares of land that had been devoted to raising feed for horses. However, mechanization of agriculture increased fossil fuel consumption.
3. Irrigation has converted vast areas from desert or semidesert to profitable food producing areas. Unfortunately, continuous irrigation has caused water logging and increased soil salinity.
4. The use of chemical fertilizers has created remarkable increases in production (→ Fertilizers, 1. General). The gains have been partially offset by the cost of the fertilizers in terms of dollars and expenditure of fossil fuel. In some cases the runoff of chemical

Table 3. Chronology of some developments in food technology

Date	Inventor	Process or product	Purpose
1679	Papin	digester	cooking in iron pot with clamped on lid
1809	N. Appert	appertization	cooking in sealed glass jars
1810	N. Appert	autoclave	cooking canned food under pressure
1830	A. Coffey	Coffey still	continuous distillation
1830	N. Rellieux	triple effect evaporator	energy efficient evaporation
1835	Sulzberger	roller milling	roller process for flour milling
1855	J. A. Just	roller dryer	energy-efficient drying
1856	G. Borden	evaporated milk	milk evaporated under vacuum and packed in hermetically sealed cans
1860	F. Carre	mechanical refrigerator	water–ammonia system for providing refrigeration
1865	L. Pasteur	heat treatment	initially to preserve wine, then used to destroy pathogens in grape juice and milk
1874	A. K. Shriver	retort	closed kettle using super-heated or live steam for canning
1877	G. de Laval	cream separator	rapid centrifugal separation of cream
1911	A. J. A. Ottesen	quick freezing process	minimizing adverse effects on food during freezing
1920	Kidd & West	controlled atmospheric storage	minimizing quality changes during storage of fruits
1931	C. Birdseye	multiple freezer	energy-efficient freezing
1945	E. W. Flosdorf	freeze-dryer	drying of frozen food under vacuum

fertilizers has polluted drinking water and increased the growth of algae in the streams, which has killed fish.

5. The use of pesticides has also contributed to the world food supply by eliminating pests that reduce yields or pests that consume harvested foods (→ Crop Protection). Because pesticides contribute to pollution and are hazardous to some species of animal life, alternative pest control methods have been and are being sought. Some success has been achieved in breeding disease-resistant varieties of plants and in developing biological methods, e.g., microbial parasites, that destroy the pests.
6. Reduction in postharvest losses has been achieved by using storage facilities and packages that protect the food from biological, chemical, and physical damage (→ Foods, 4. Packaging). In developing countries, postharvest losses can be as high as 50% for some commodities [13].
7. Recovery of foods and ingredients from underutilized products. For example, recovery of proteins from whey and blood [14–17], underutilized meats from chicken [18, 19] and fish [20, 21].

Food Quality. Much of the progress in solving food quality problems can be attributed to basic scientific studies that have identified the causes for changes in quality, e.g., LOUIS PASTEUR's studies, which led to pasteurization (→ 3.7 Foods, 2. Food Technology). In the process of studying the mechanism of thermal destruction of microbes, researchers noted that in some cases thermal processing also affected flavor, color, and texture [6], [7], [22–24]. Heating fluid dairy products produced cooked (custardlike) flavor, which was found to be due to the release of sulfhydryl groups from proteins [25]. More drastic heating of milk or other foods containing carbonyl and amino groups caused both flavor and color changes. In 1908, A. R. LING described this reaction, and in 1912 L. C. MAILLARD investigated the mechanism [26]. Direct heating of products with high sugar content produced both caramel color and flavor. Heating affected the texture of meat and eggs by altering the proteins. It was found that the activity of many endogenous food enzymes could be controlled by thermal processing [27], [28]. The importance and nature of enzymatic changes are discussed in Section 3.7 (→ Enzymes, 1. General).

Scientific studies have shown that many changes in food quality are due to either oxidative or hydrolytic reactions, and therefore, controlling them is important [6, 7, 29–31]. *Oxidative changes* have been minimized by (1) storing food in a controlled atmosphere, (2) using packages that are impervious to oxygen, (3) inactivating oxidative enzymes, (4) avoiding contamination with catalytic metals, or (5) addition of antioxidants (→ Antioxidants ; → Foods, 3. Food Additives). *Hydrolytic changes* have been inhibited by (1) inactivating hydrolytic enzymes, (2) maintaining the integrity of cell walls or membranes, which protect the substrate, or (3) adding inhibitors [32].

3. Components and Their Reactions

Foods range in complexity from a single compound (e.g., sugar) to multicomponent mixtures (e.g., meat). The properties of foods reflect the properties of the individual components and their interactions. *Food interactions* include all types of noncovalent (van der Waals, hydrogen, ionic, and hydrophobic) and covalent bonds. These interactions contribute to a variety of structural features such as cell walls, micelles, fat globules, fat globule membranes, three-dimensional gel structures, muscle fibers, and curds.

The *reactions of components* in foods are affected by pH, temperature, concentration of reactants, available water, catalysts, activators, and inhibitors. They may be catalyzed by light, enzymes, and nonenzymatic materials such as metals. Inhibitors can be substances that chelate metal catalysts or that interact with one of the reactants. Chelating agents can react with calcium or iron and thus reduce their nutritional availability. The nutritional quality of foods can also be reduced by oxidation of essential fatty acids or other nutrients, or by the interaction of proteins with tannins. The optimal sensory and nutritional properties can be obtained by controlling the reactions of the components.

3.1. Water

Occurrence. Water [7732-18-5] is one of the basic and most ubiquitous constituents of living organisms, [6, 7, 33–36]. The water content of raw fruits, vegetables, and meats exceeds 50 wt %, but the concentration in cereals, nuts and many processed foods is lower (→ Foods, 2. Food Technology).

Water exists naturally as an intracellular or extracellular component in plants and animal products. It is used as a solvent for sugars, salts, and acids in some foods, as a dispersing medium for hydrophilic macromolecular carbohydrates or proteins, and as a dispersed phase in emulsified products such as butter and margarine.

Properties. Compared to other substances with similar molecular masses, water is unique (→ Water, 1. Properties, Analysis, and Hydrological Cycle). Its ability to engage in three-dimensional hydrogen bonding enables it to bond with organic molecules that contain nitrogen, oxygen, fluorine, or chlorine. The dissolution of sugar is because of bonding between water and the polar groups of the sugar. Dissolution of salts involves electrostatic forces between water and the positive ions which are greater than the attraction between ions.

Effect on Food. Water acts as a dispersing medium for amphipathic molecules, such as polar lipids, which have both hydrophilic and hydrophobic groups. The water associates with the hydrophilic moieties, such as phosphate groups, to “solubilize” the molecules. The amphipathic molecules form macromolecular aggregates, which are called micelles. Introducing hydrophobic substances, such as apolar groups of fatty acids, amino acids, and proteins, into water leads to an association of the apolar groups, i.e., hydrophobic interactions.

Water may be present in food as “free” water or “bound” water. *Free water* behaves like pure water, whereas the behavior of bound water is limited. *Bound water* has been defined as water that is not available as a solvent and does not freeze at − 40 °C, although some scientists have suggested other definitions. The term “water binding” has been defined as the tendency of water to associate, with various degrees of tenacity, to hydrophilic substances. “Water-holding capacity” has been used to describe the ability of a matrix of molecules to entrap a large amount of water in such a manner that exudation is prevented [7]. Although the entrapped water does not flow freely from the product, it behaves very much like pure water during processing. The water-holding capacity of meats and gels have a profound effect on rheological properties. The water-holding capacity of meats is affected by pH and salts, especially phosphates. A classification of water–protein thermodynamic associations is as follows [34]:

Structural water is water that is hydrogen-bonded to specific groups; it participates in stabilization of structure and is unavailable for chemical reaction.

Hydrophobic hydration water is structured cagelike water surrounding apolar residues; like structural water, it is very much involved in stabilizing protein structure.

Monolayer water is the first adsorbed water monolayer; it is hydrogen-bonded and is unavailable as solvent, but may be available for chemical reactions; ranges from 4 to 9 g/100 g protein.

Unfreezable water includes roughly all water (structural monolayer, and perhaps some adsorbed multilayer water) that does not freeze at normal temperature; amounts to 0.3–0.5 g/g of protein and corresponds to water up to a_w= 0.9; amount varies with polar amino acid content and includes some water available for chemical reactions.

Capillary water is water that is held physically in clefts or by surface forces in the protein molecule (e.g., water entrapped in gels or cheese curd); its physical properties are similar to those of bulk water.

Hydrodynamic hydration water “loosely” surrounds the protein and is transported with the protein during diffusion (centrifugation); it has properties typical of normal water.

Water Activity [6]. A complete discussion of water activity can be found under → Foods, 2. Food Technology.

Perishability. A general correlation exists between the perishability of food and water content, but a better correlation exists between perishability and water activity (→ Foods, 2.

Food Technology). Both enzymatic and nonenzymatic reactions tend to increase as water activity increases. However, enzymatic reactions are less sensitive to water activity changes. Nonenzymatic browning reactions reach a maximum rate at $a_w \approx 0.80$. Lipid oxidation is inhibited by increasing water content. Under some conditions water may form a protective film around the fat. The destruction of vitamin C and chlorophyll increases rapidly as the water activity increases. The rate of vitamin B_1 destruction reaches a maximum at $a_w \approx 0.5$ [7].

Food Quality. A complete discussion of the effect of freezing the water in food has on food quality can be found under → Foods, 2. Food Technology.

3.2. Proteins (→ Amino Acids; → Proteins); [6, 7, 29, 37–44]

Structure. Proteins are polymers composed of amino acids linked together by peptide bonds. Proteins constitute ca. 50% of the dry matter of living cells and perform a vital role in the function and structure of the cells. Proteins containing only amino acids are called homoproteins, whereas those containing additional groups (i.e., prosthetic groups) are called heteroproteins. The heteroproteins include lipoproteins, glycoproteins, phosphoproteins, hemoproteins, metalloproteins, and nucleoproteins.

The complexity of proteins depends on the number and types of amino acids and other groups. The structural properties of some major food proteins are shown in Table 4.

Denaturation. The secondary and tertiary structures of proteins are fragile and, therefore, can be changed by a variety of treatments that do not cleave covalent bonds (with the exception of disulfide bonds). The term denaturation is applied to such processes. *Heating* is the most commonly used physical method for denaturing proteins. Most proteins are denatured or coagulated between 55 and 75 °C. The susceptibility of proteins to denaturation depends on the nature of the protein and environmental factors such as pH, water activity, ionic strength, and the types of ions present. The proteins of egg white are readily denatured by heat, whereas casein and gelatin are relatively resistant. This resistance is attributed to the presence of high amounts of proline and hydroxyproline and low levels of sulfur-containing amino acids. Thermal denaturation of proteins can result in the following:

1. inactivation of enzymes
2. destruction of microbes
3. detoxification of toxic proteins
4. increased protein digestibility
5. improved texture of protein-rich foods
6. increased exposure of hydrophilic groups

The exposure of hydrophobic groups can cause changes in water and flavor-binding capacity and in solubility.

Physical treatments other than heating can also cause protein denaturation or other protein alterations. *Freezing and low-temperature storage* can cause aggregation and precipitation of some proteins (e.g., gliadin, 11 S soy proteins, and some egg and milk proteins). Aggregation refers to clustering of protein molecules or particles. In food systems, aggregation usually involves hydrophobic forces, but other forces may be involved in some cases. Precipitation involves separation of the protein from the rest of the solution or suspension. In some cases aggregation leads to precipitation. After freezing, fish may become tough and rubbery and lose moisture as a result of protein destabilization. Some *mechanical treatments*, such as the rolling and kneading of bread, may denature proteins. *High hydrostatic pressure* may also have a denaturing effect. Ovalbumin and trypsin have been reported to be denatured at pressures of 50 and 60 kPa, respectively [7]. *Electromagnetic irradiation* can cause changes in the conformation of proteins. The extent of such changes depends on the wavelength and energy involved.

Proteins can also be denatured by *chemical reagents*. The structural stability of proteins is influenced by pH, with each protein having a characteristic stable range. Consequently, shifting the pH outside of this range with either acid or base denatures the protein. In some cases, native structure can be restored by readjusting the pH to within the stable range.