REAGENT CHEMICALS

SEVENTH EDITION

AMERICAN CHEMICAL SOCIETY SPECIFICATIONS

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ATOMIC WEIGHTS OF THE ELEMENTS 1983
scaled to the relative atomic mass, $A_r(^{12}C) = 12$

The atomic weights of many elements are not invariant but depend on the origin and treatment of the material. The footnotes to this table elaborate the types of variation to be expected for individual elements. The values of $A_r(E)$ given here apply to elements as they exist naturally on earth and to certain artificial elements. When used with due regard to the footnotes they are considered reliable to ±1 in the last digit, unless otherwise stated. Values in parentheses are used for radioactive elements whose atomic weights cannot be quoted precisely without knowledge of the origin of the elements; the value given is the atomic mass number of the isotope of that element of longest known half-life.

Name	*Symbol*	*Atomic number*	*Atomic weight*	*Footnotes*
Actinium	Ac	89	227.0278	a
Aluminum	Al	13	26.98154	
Americium	Am	95	(243)	
Antimony	Sb	51	121.75 ±3	
Argon	Ar	18	39.948	b, c
Arsenic	As	33	74.9216	
Astatine	At	85	(210)	
Barium	Ba	56	137.33	c
Berkelium	Bk	97	(247)	
Beryllium	Be	4	9.01218	
Bismuth	Bi	83	208.9804	
Boron	B	5	10.811 ±5	b, d
Bromine	Br	35	79.904	
Cadmium	Cd	48	112.41	c
Calcium	Ca	20	40.078 ±4	c
Californium	Cf	98	(251)	
Carbon	C	6	12.011	b
Cerium	Ce	58	140.12	c
Cesium	Cs	55	132.9054	
Chlorine	Cl	17	35.453	
Chromium	Cr	24	51.9961 ±6	
Cobalt	Co	27	58.9332	
Copper	Cu	29	63.546 ±3	b
Curium	Cm	96	(247)	
Dysprosium	Dy	66	162.50 ±3	c
Einsteinium	Es	99	(252)	
Erbium	Er	68	167.26 ±3	c
Europium	Eu	63	151.96	c
Fermium	Fm	100	(257)	
Fluorine	F	9	18.998403	
Francium	Fr	87	(223)	
Gadolinium	Gd	64	157.25 ±3	c
Gallium	Ga	31	69.723 ±4	
Germanium	Ge	32	72.59 ±3	
Gold	Au	79	196.9665	
Hafnium	Hf	72	178.49 ±3	
Helium	He	2	4.002602 ±2	b, c
Holmium	Ho	67	164.9304	
Hydrogen	H	1	1.00794 ±7	b, c, d
Indium	In	49	114.82	c
Iodine	I	53	126.9045	
Iridium	Ir	77	192.22 ±3	
Iron	Fe	26	55.847 ±3	
Krypton	Kr	36	83.80	c, d
Lanthanum	La	57	138.9055 ±3	c
Lawrencium	Lr	103	(260)	
Lead	Pb	82	207.2	b, c
Lithium	Li	3	6.941 ±2	b, c, d
Lutetium	Lu	71	174.967	c
Magnesium	Mg	12	24.305	
Manganese	Mn	25	54.9380	
Mendelevium	Md	101	(258)	
Mercury	Hg	80	200.59 ±3	

Name	Symbol	Atomic number	Atomic weight	Footnotes
Molybdenum	Mo	42	95.94	
Neodymium	Nd	60	144.24 ±3	c
Neon	Ne	10	20.179	c, d
Neptunium	Np	93	237.0482	a
Nickel	Ni	28	58.69	
Niobium	Nb	41	92.9064	
Nitrogen	N	7	14.0067	c
Nobelium	No	102	(259)	
Osmium	Os	76	190.2	c
Oxygen	O	8	15.9994 ±3	b, c
Palladium	Pd	46	106.42	c
Phosphorus	P	15	30.97376	
Platinum	Pt	78	195.08 ±3	
Plutonium	Pu	94	(244)	
Polonium	Po	84	(209)	
Potassium	K	19	39.0983	
Praseodymium	Pr	59	140.9077	
Promethium	Pm	61	(145)	
Protactinium	Pa	91	231.0359	a
Radium	Ra	88	226.0254	a
Radon	Rn	86	(222)	
Rhenium	Re	75	186.207	
Rhodium	Rh	45	102.9055	
Rubidium	Rb	37	85.4678 ±3	c
Ruthenium	Ru	44	101.07 ±2	c
Samarium	Sm	62	150.36 ±3	c
Scandium	Sc	21	44.95591	
Selenium	Se	34	78.96 ±3	
Silicon	Si	14	28.0855 ±3	b
Silver	Ag	47	107.8682 ±3	c
Sodium	Na	11	22.98977	
Strontium	Sr	38	87.62	c
Sulfur	S	16	32.066 ±6	b
Tantalum	Ta	73	180.9479	
Technetium	Tc	43	(98)	
Tellurium	Te	52	127.60 ±3	c
Terbium	Tb	65	158.9254	
Thallium	Tl	81	204.383	
Thorium	Th	90	232.0381	a, c
Thulium	Tm	69	168.9342	
Tin	Sn	50	118.710 ±7	
Titanium	Ti	22	47.88 ±3	
Tungsten (Wolfram)	W	74	183.85 ±3	
(Unnilhexium)	(Unh)	106	(263)	
(Unnilpentium)	(Unp)	105	(262)	
(Unnilquadium)	(Unq)	104	(261)	
(Unnilseptium)	(Uns)	107	(262)	
Uranium	U	92	238.0289	c, d
Vanadium	V	23	50.9415	
Xenon	Xe	54	131.29 ±3	c, d
Ytterbium	Yb	70	173.04 ±3	
Yttrium	Y	39	88.9059	c
Zinc	Zn	30	65.39 ±2	
Zirconium	Zr	40	91.224 ±2	c

a Element for which the value A_r is that of the radioisotope of longest half-life.

b Element for which range in isotopic composition of normal terrestrial material prevents a more precise $A_r(E)$ being given; the listed value should be applicable to any normal material.

c Element for which geologically exceptional specimens are known in which the element has an isotopic composition outside the limits for normal material. The difference between the atomic weight of the element in such specimens and that given in the table may exceed considerably the implied uncertainty.

d Element for which modified isotopic compositions may be found in commercially available material because it has been subjected to an undisclosed or inadvertent isotopic separation. Substantial deviations in atomic weight of the element from that given in the table can occur.

REAGENT CHEMICALS

Prepared by the
COMMITTEE ON ANALYTICAL REAGENTS
(1981–86)

Wallace G. Rohrbough, Chairman 1981–85
Clarence Lowery, Chairman 1985–

Alfred J. Barnard, Jr.
Donald E. Campbell
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Clifford A. Flanders
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Richard S. Juvet
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Vernon A. Stenger
Cyrus M. Strauss
Samuel M. Tuthill
Paul S. Von Bacho, Jr.
Frank G. Walthall
Donald H. Wilkins

William E. Schmidt, Secretary

Edward Wichers
1892–1984

This edition of *Reagent Chemicals* is respectfully and affectionately dedicated to the memory of Dr. Edward Wichers. Dr. Wichers was a member of the ACS Committee on Analytical Reagents for 44 years, 1925–69, and served as its chairman from 1943 to 1955. Under his able chairmanship, the first two editions of this book were published. He was the leader who charted the course that the present committee still follows.

One of the world's outstanding authorities on analytical chemistry, Dr. Wichers retired from the National Bureau of Standards (NBS) in 1962 after a career of 44 years. He joined NBS in 1917, the year he received his Ph.D. degree in inorganic chemistry from the University of Illinois. Three years later, he became chief of the section dealing with platinum metals and reagent chemicals, and in 1948, he was named Chief of the Chemistry Division. He was appointed NBS Associate Director for Chemistry in 1958.

Dr. Wichers was chairman of the Commission on Atomic Weights of the International Union of Pure and Applied Chemistry (IUPAC) from 1949 to 1969. In this role, he was a major influence in the adoption in 1961 of the unified scale of atomic weights, which replaced the different scales used by chemists and physicists. During this period, he also served as President of the Inorganic Division of IUPAC from 1955 to 1959.

PREFACE

The ACS Committee on Analytical Reagents evolved from the Committee on the Purity of Chemical Reagents established in 1903. Changes in the name and role occurred before the current name was adopted in 1927. Standards in a style close to that now used were proposed in 1917 for ammonium hydroxide, hydrochloric acid, nitric acid, and sulfuric acid and appeared in 1921 in *Industrial and Engineering Chemistry.* Policies for Standards begun in 1924–25 have been pursued continually. Initially, Standards appeared in *Industrial and Engineering Chemistry* and its *Analytical Edition.* In 1941, existing Standards were reprinted in a single pamphlet. Eventually, revisions and new Standards were gathered together into a single book, the 1950 Edition of *Reagent Chemicals.* This edition was followed by the 1955 and 1960 Editions and by the Fourth, Fifth, and Sixth Editions in 1968, 1974, and 1981, respectively.

The number of reagents for which ACS Standards have been adopted continues to increase. This Seventh Edition includes 32 new Standards, 21 of which appeared in Supplement No. 1 to the Sixth Edition issued in 1984, and 10, thereafter, in *Analytical Chemistry, 58,* No. 6, May 1986, pp. 1276–80 (*see Chemical and Engineering News,* June 2, 1986, p. 26, for an additional Standard).

Two directions adopted with the Sixth Edition are continued: (1) establishing assay limits and procedures for hydrated salts and some other compounds and (2) unifying the text for general tests.

New practices include providing the Chemical Abstracts number for each Standard as an aid for on-line searching of literature and listing additional secondary names, as well as presenting the various Standards for acetonitrile, chloroform, dichloromethane, hexanes, and methanol in a combined format (suitable for general use, ultraviolet spectrophotometry, high-performance liquid chromatography, or pesticide residue analysis). As an aid to the user, the index is enlarged.

The choice of nomenclature, abbreviations, units, and editing policies has been guided generally by current ACS practices. Usually the degree of hydration of salts is explicitly stated rather than implied by the context. In Standards, secondary names for relevant metal compounds now include the use of Stock numbers, and those for organic com-

pounds include recent practices of *Chemical Abstracts*. Trademarked items appear with an initial capital letter and are listed with their owners on page 71.

The following lists the membership for each person serving on the Committee after issue of the Sixth Edition in 1981:

Alfred J. Barnard, Jr.	1981–
Donald E. Campbell	1974–84
Anthony D. Debolli	1979–81
Kishor A. Desai	1981–
Clifford A. Flanders	1954–81
Norman C. Jamieson	1982–
Richard S. Juvet	1986–
Lynn L. Lewis	1976–
Clarence Lowery	1974–
Chairman	1985–
Murugan Malaiyandi	1982–
Irving May	1969–81
Loren C. McBride	1983–
Thomas W. Mears	1966
	1973–
John R. Moody	1986–
Fred A. Morecombe (deceased)	1966–84
Thomas J. Murphy	1967–85
Robert Parmerter	1985
Anthony D. Pietrzykowski	1986–
Sterling Pomeroy	1976–81
Charles J. Pouchert	1978–
Wallace G. Rohrbough	1965–
Chairman	1981–85
William E. Schmidt	1967–
Secretary (nonvoting)	
Vernon A. Stenger	1962–
Chairman	1967–73
Cyrus M. Strauss	1982–
Samuel M. Tuthill	1958–
Chairman	1974–80
Consultant	1982–
Paul S. Von Bacho, Jr. (deceased)	1981–84
Frank G. Walthall	1982–
Donald H. Wilkins	1983–

Wallace G. Rohrbough served as chairman of the Committee during most of the revision; he was succeeded by Clarence Lowery in the fall of 1985.

The Committee normally meets in the spring and fall of each year. After each meeting, changes of an immediate nature are reported in *Chemical and Engineering News*. As such changes accumulate and as changes of a nonurgent nature, including new Standards, are approved, it is expected that they will appear in *Analytical Chemistry*. Such publications will be announced in *Chemical and Engineering News*.

The Committee plans at least one formal supplement, sized to fit this book, before publishing the next full edition. Interim changes published in *Chemical and Engineering News* or *Analytical Chemistry* will be included. The availability of such supplements will be announced in *Chemical and Engineering News*. Cards for requesting them are in the back of this book and should be filled in and returned—best when the book is first received, but also after announcement of the supplements.

Since the publication of the Sixth Edition of *Reagent Chemicals*, the

Committee has adopted written operating procedures that describe and govern its operations. Interested parties may obtain a copy of these procedures by addressing their requests to:

Secretary, ACS Committee on Analytical Reagents
c/o Books Department
American Chemical Society
1155 Sixteenth Street, NW
Washington, DC 20036

The Committee urges that any errors observed be reported, invites constructive criticism, and welcomes suggestions concerning added Standards and tests. Communications on these subjects should be sent to the secretary at the above address.

CONTENTS

DEFINITIONS, PROCEDURES, AND STANDARDS

SPECIFICATIONS AND TESTS

The specifications prepared by the Committee on Analytical Reagents of the American Chemical Society are intended to serve for reagents to be used in precise analytical work of a general nature. It is recognized that there may be special uses for which reagents conforming to other, or more rigorous, specifications may be needed. Therefore, where known and where feasible, some of the specifications herein include requirements and procedures for certain specialized uses. However, it is impossible to include specifications for all such uses, and thus there may be occasions when it will be necessary for the analyst to further purify reagents known to have special purity requirements for certain uses.

The requirements and the details of tests are based on published work, on the experience of members of the Committee in the examination of reagent chemicals on the market, and on studies of the tests made by members of the Committee. The limits and procedures are designed for application to reagents in freshly opened containers. Reagents in containers of extended age, in containers subject to constant changes in humidity or headspace gas content (as by repetitive opening and closing of the container), or subjected to potential inadvertent contamination by repeated opening of the container may not conform to the designated requirements. Where the possibility of change due to age, humidity, light, or headspace contamination is recognized, the Standard usually contains a warning; nonetheless, the analyst is cautioned to take appropriate steps to ensure the continued purity of his or her reagents, especially after opening the container.

In determining quality levels to be defined by new or revised specifications the committee is guided by the following general principles. When a specification is first prepared, it will usually be based on

the highest level of purity (of the reagent to which it applies) that is competitively available in the United States. Generally, the term "competitively available" is understood to mean that the material is available from two or more producers. If a significantly higher level of purity subsequently becomes available on the same competitive basis, the specification will generally be revised accordingly.

Because the requirements of a specification relating to the content of designated impurities must necessarily be expressed in terms of maximum permissible limits, products conforming to the specification will normally contain less than the maximum permissible proportion of some or all of these impurities. A given preparation of a reagent chemical that has less than the maximum content of one or more impurities permitted by the specification is, therefore, not considered as of higher quality than that defined by the specification.

A lower permissible limit for a given impurity will be adopted only if it is significantly different from the one it is intended to supersede. In general a new requirement for an impurity whose content is not greater than 0.01% will not be considered significantly different unless it decreases the maximum permissible content of the impurity by at least 50%. This principle will also be approximated in the revision of those requirements defined by the term, "To pass test."

Tests as written are considered to be applicable only to the accompanying requirements. Modification of a requirement, especially if the change is toward a higher level of purity, will necessitate reconsideration, and often revision, of the test to ensure its validity.

The assays and tests described herein constitute the methods upon which the ACS Reagent Standards are based. The analyst is not prevented, however, from applying alternative methods of analysis that produce results of at least equal reliability. In the event of doubt or disagreement concerning a substance purported to comply with the ACS Standards, only the methods described herein are applicable.

SOLVENTS FOR SPECIAL PURPOSES

For some solvents, the 6th Edition of *Reagent Chemicals* had separate Standards defining them as either "suitable for use in ultraviolet spectrophotometry" or "suitable for use in determining pesticide residues." In recent years, interest has developed in characterizing certain solvents as "suitable for use in high-performance liquid chromatography." In this edition, these special-use Standards have been treated in a single, integrated presentation. The seller shall designate in product labeling the suitability for one or more of these special uses on the basis of the relevant specifications and tests.

HAZARDOUS SUBSTANCES

Some of the reagent chemicals for which ACS Standards have been adopted are hazardous substances. The use of such reagents and the application of the various test methods specified by the ACS Committee on Analytical Reagents may involve hazardous substances, operations, and equipment. The ACS Committee on Analytical Reagents does not purport in its publications to address all of the safety problems associated with ACS Reagents, their use, or the methods prescribed for testing them. It is the responsibility of whoever uses ACS Reagents and the ACS testing methods to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to such use. Material Safety Data Sheets, which contain precautionary information related to safety and health concerns, are available for many chemicals from manufacturers and/or distributors of reagent chemicals and may be of assistance in carrying out the aforementioned responsibility.

CONTAINERS

The container is the device that holds the reagent and that is, or may be, in direct contact with the reagent. The closure is part of the container.

The container in which a reagent is sold and/or stored must be suitable for its intended purpose and should not interact physically or chemically with the contained reagent so as to alter its quality (within a reasonable period of time) beyond the requirements of the Standard.

Containers for solids normally have wide mouths to facilitate both the filling of the container and the removal of the contents. Containers for liquids normally have narrow mouths so that the contents may be easily poured into other, frequently smaller, containers.

Prior to its being filled, the container should be free from extraneous particulate matter, otherwise clean, and dry if necessary.

INTERPRETATION OF REQUIREMENTS

The requirements of reagent chemicals can be divided into two main classes: an assay or quantitative determination of the principal or active constituent and the determination of the impurities or minor constituents. By far, the majority of the requirements belong to the latter class. In some cases physical properties are specified.

For comparison of analytical results with requirements for assays and impurities, the observed or calculated values are rounded to the number of decimal places carried in the requirement. The method and the rounding procedure are in accord with the American Society for Testing and Materials Practice E 29, for "Indicating Which Places of Figures Are to Be Considered Significant in Specified Limiting Values."

The procedure is as follows: If the digit following the last place to be retained is not equal to 5, round to the nearest number; if the digit to be dropped is 5 or 5 followed by zeros, round to an even number. This rounding procedure is illustrated in the following table:

Rounding Procedure

Requirement	*Observed Value*	*Rounded Value*	*Pass/Fail*
Not less than 98	97.6	98	pass
	97.5	98	pass
	97.4	97	fail
Not less than 98.0	97.95	98.0	pass
	97.94	97.9	fail
Not more than 0.01	0.014	0.01	pass
	0.015	0.02	fail
	0.016	0.02	fail
Not more than 0.02	0.015	0.02	pass
	0.025	0.02	pass
	0.026	0.03	fail

(Observe that the foregoing procedure does not conform to the common electronic calculator and computer procedure of rounding up when the digit to be dropped is 5 or 5 followed by zeros.) The rounded value should be obtained in a single step by direct rounding of the most precise value available and not in two or more steps of successive rounding. For example, 97.5487 rounds to 97.5 against a requirement of 97.6 and not in two possible steps of 97.55 and then 97.6.

The formula weights and factors for computing results are based on the 1983 International Atomic Weights shown on the endpapers. The formula weights are rounded to two decimal places.

Assay Requirements

Assay requirements are included in many of the Standards in this book. An assay value, in the sense used herein, is the content or concentration of a stated major component in the reagent. Unless otherwise specified, assay requirements are on an as-is basis, that is, without drying, ignition, or other pretreatment of the sample.

Unless described in great detail and carried out with exceptional skill, available assay methods seldom are accurate enough to permit using

a weighed quantity of a reagent so assayed in an exacting stoichiometric operation. This use of reagent chemicals should be limited to those designated as standards (for example, acidimetric or reductometric standards) because especially exacting assay methods are provided for such reagents.

Except in the case of standards, assays, through their minimum and maximum limits, mainly serve to assure acceptable consistency of the strength of reagents offered in the marketplace. They are particularly useful, for example, in the requirements for acid–water systems to control strength; for alkalies to limit the content of water and carbonate; for oxidizing and reducing substances that may change strength during storage; and for hydrates to control, within reasonable limits, deviations in the amount of water from that indicated in the formula. If, however, it should be necessary to use such reagents in stoichiometric operations, the user should satisfy himself or herself as to the exact values to employ.

Chromatographic assays, where applicable, are advantageous in that they are selective in many cases for the substance being assayed and also may provide an indication of the impurities present.

Impurity Requirements

Requirements for impurities are expressed as one of the following: (1) as numerical limits; (2) in terms of the expression "To pass test," with an accompanying approximate numerical limit; (3) in terms of the expression "To pass test" without an approximate numerical limit. The distinction between these forms of expression is based on the committee's opinion as to the relative quantitative significance of the prescribed methods of test. The methods given for determining conformity to requirements of the first type are considered to yield, in competent hands, what are usually thought of as "quantitative" results whereas those of the second type can be expected to yield only approximate values. Those in class 3 give definitions that cannot be expressed in numbers. It is obvious, however, that these distinctions as to quantitative significance cannot be sharp and that even the numerically expressed requirements are not all defined with equal accuracy. The final and essential definition of any requirement must, therefore, reside in the prescribed method of test rather than in its numerical expression.

If a method of test yields results that are adequately reproducible on repeated trials in different laboratories, it offers a satisfactory definition of the content of an impurity whether or not the result can be expressed by a number. Although the committee has endeavored to base requirements, so far as possible, on methods of testing that meet this criterion, there are a considerable number that are based on essentially undefined statements such as "no turbidity," "no color," or "the color shall not be completely discharged in ..... minutes." While some of the requirements of this kind could be replaced by others based on quantitative compari-