



Designation: ~~D4691 – 11~~ **D4691 – 17**

Standard Practice for Measuring Elements in Water by Flame Atomic Absorption Spectrophotometry¹

This standard is issued under the fixed designation D4691; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This practice covers general considerations for the quantitative determination of elements in water and waste water by flame atomic absorption spectrophotometry. Flame atomic absorption spectrophotometry is simple, rapid, and applicable to a large number of elements in drinking water, surface waters, and domestic and industrial wastes. While some waters may be analyzed directly, others will require pretreatment.

1.2 Detection limits, sensitivity, and optimum ranges of the elements will vary with the various makes and models of satisfactory atomic absorption spectrometers. The actual concentration ranges measurable by direct aspiration are given in the specific test method for each element of interest. In the majority of instances the concentration range may be extended lower by use of electrothermal atomization and conversely extended upwards by using a less sensitive wavelength or rotating the burner head. Detection limits by direct aspiration may also be extended through sample concentration, solvent extraction techniques, or both. Where direct aspiration atomic absorption techniques do not provide adequate sensitivity, the analyst is referred to Practice [D3919](#) or specialized procedures such as the gaseous hydride method for arsenic (Test Methods [D2972](#)) and selenium (Test Methods [D3859](#)), and the cold vapor technique for mercury (Test Method [D3223](#)).

1.3 Because of the differences among various makes and models of satisfactory instruments, no detailed operating instructions can be provided. Instead the analyst should follow the instructions provided by the manufacturer of a particular instrument.

1.4 The values stated in ~~either SI or inch-pound units~~ are to be regarded as the standard. The values given in parentheses are ~~for information only~~ mathematical conversion to inch-pound units that are provided for information only and are not considered standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific hazard statements see Section 9.

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 ASTM Standards:²

[D1129 Terminology Relating to Water](#)

[D1193 Specification for Reagent Water](#)

[D2972 Test Methods for Arsenic in Water](#)

[D3223 Test Method for Total Mercury in Water](#)

[D3370 Practices for Sampling Water from Closed Conduits](#)

[D3859 Test Methods for Selenium in Water](#)

[D3919 Practice for Measuring Trace Elements in Water by Graphite Furnace Atomic Absorption Spectrophotometry](#)

[D4453 Practice for Handling of High Purity Water Samples](#)

[D5810 Guide for Spiking into Aqueous Samples](#)

¹ This practice is under the jurisdiction of ASTM Committee [D19](#) on Water and is the direct responsibility of Subcommittee [D19.05](#) on Inorganic Constituents in Water. Current edition approved ~~Sept. 1, 2011~~ June 1, 2017. Published ~~September 2011~~ June 2017. Originally approved in 1987. Last previous edition approved in ~~2007~~ 2011 as ~~D4691 – 02~~ [D4691 – 11](#) (2007). DOI: ~~10.1520/D4691-11~~ [10.1520/D4691-17](#).

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

*A Summary of Changes section appears at the end of this standard

D5847 Practice for Writing Quality Control Specifications for Standard Test Methods for Water Analysis
E178 Practice for Dealing With Outlying Observations
E520 Practice for Describing Photomultiplier Detectors in Emission and Absorption Spectrometry
E863 Practice for Describing Atomic Absorption Spectrometric Equipment (Withdrawn 2004)³

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<https://standards.itih.ai/catalog/standards/sist/507a50fb-1068-4700-ada8-3e2f14d4a89a/astm-d4691-17>

³ The last approved version of this historical standard is referenced on www.astm.org.

3. Terminology

3.1 ~~Definitions:~~

3.1.1 For definition of terms used in this practice, refer to Terminology ~~D1129~~.

3.1 Definitions:

3.1.1 For definitions of terms used in this standard, refer to Terminology D1129.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *absorbance, n*—the logarithm to the base 10 of the reciprocal of the transmittance (T). $A = \log_{10} (1/T) = -\log_{10} T$.

3.2.2 *absorptivity, n*—the absorbance (A) divided by the product of the sample path length (b) and the concentration (c). $a = A/bc$.

3.2.3 *atomic absorption, n*—the absorption of electromagnetic radiation by an atom resulting in the elevation of electrons from their ground states to excited states.

3.2.3.1 *Discussion—*

Atomic-absorption spectrophotometry involves the measurement of light absorbed by atoms of interest as a function of the concentration of those atoms in a particular solution.

3.2.4 *continuing calibration blank, n*—a solution containing no analytes (of interest) which is used to verify blank response and freedom from carryover.

3.2.5 *continuing calibration verification, n*—a solution (or set of solutions) of known concentration used to verify freedom from excessive instrumental drift; the concentration is to cover the range of calibration curve.

3.2.6 *detection limit, n*—in atomic absorption, is a function of the sensitivity and the signal-to-noise ratio in the analysis of a specific element for a given set of parameters.

3.2.6.1 *Discussion—*

The instrument detection limit is determined statistically as some multiple, usually two or three times the standard deviation of the signal-to-noise ratio.

3.2.7 *laboratory control sample (LCS) (LCS), n*—a solution with the certified concentration(s) of the analytes.

3.2.8 *monochromator, n*—a device used for isolating a narrow portion of the spectrum by means of a grating or prism.

3.2.9 *nebulizer, n*—in atomic absorption, the burner-system portion where the sample solution is converted into fine mist.

3.2.10 *optimum concentration range, n*—a limited concentration range, that may be extended downward with scale expansion (used to measure very small concentrations) or upward by using a less sensitive wavelength or by rotating the burner head.

3.2.10.1 *Discussion—*

The range varies with the characteristic concentration of the instrument and the operating conditions employed.

3.2.11 *sensitivity, n*—the analyte concentration (sometimes referred to as the characteristic concentration) that produces an absorbance of 0.0044 absorbance units (1 % absorption) when compared to the analytical blanks.^{4,5,6}

⁴ Bennett, P. A., and Rothery, E., "Introducing Atomic Absorption Analysis," Varian Publication, Mulgrave, Australia, 1983; Bennett, P. A., and Rothery, E., *Introducing Atomic Absorption Analysis*, Varian Publication, Mulgrave, Australia, 1983.

⁵ Price, W. J., "Spectrochemical Analysis by Atomic Absorption," John Wiley & Sons, New York, NY, 1983; Price, W. J., *Spectrochemical Analysis by Atomic Absorption*, John Wiley & Sons, New York, NY, 1983.

⁶ VanLoon, J. C., "Analytical Atomic Absorption Spectroscopy—Selected Methods," Academic Press, New York, NY, 1980; VanLoon, J. C., *Analytical Atomic Absorption Spectroscopy—Selected Methods*, Academic Press, New York, NY, 1980.

3.2.11.1 *Discussion—*

The characteristic concentration varies with instrumental conditions and atomization efficiency, as well as other factors and should be determined as conditions change. The characteristic concentration is determined by the following equation:

$$\text{characteristic concentration} = C \times 0.0044/A \quad (1)$$

where:

C = concentration of the analyte, and

A = absorbance of analyte concentration used in the determination.

The characteristic concentration defines the slope of the calibration curve.

3.2.12 *spectral bandwidth, n* —the observed dispersion between absorption bands.

3.2.12.1 *Discussion*—

This bandwidth is expressed as the exit slit multiplied by the observed separation of two emission lines divided by the difference in wavelength between these lines.

3.2.13 *spectrophotometer, n* —an instrument that provides the ratio, or a function of the ratio, of the radiant power of a beam as a function of spectral wavelength.

4. Summary of Practice

4.1 In flame atomic absorption spectrophotometry, a standard or sample solution is aspirated as a fine mist into a flame where it is converted to an atomic vapor consisting of ground state atoms. The flame provides energy to the ground state atoms allowing them to absorb electromagnetic radiation from a series of very narrow, sharply defined wavelengths. Light (from a hollow cathode lamp or other source) consisting of the characteristic monochromatic radiation generated by excitation of the element of interest is passed through the flame. Light from the source beam is isolated by the monochromator and measured by the photodetector. The amount of light absorbed by the analyte is quantified by comparing the light transmitted through the flame during nebulization of a known concentration of the analyte to light transmitted during nebulization of a solution that does not contain any measurable concentration of the analyte.

4.2 An atomic absorption spectrophotometer may have a single or double beam system. The advantages of a single beam system are that the lamp used as a light source can be operated at much lower currents than those used in a double beam system, thereby minimizing the problem of line broadening. This provides for increased sensitivity and longer lamp life. The disadvantage of single beam instruments is that a longer warm-up time is required and there is no means of correcting for changes in intensity of the light source without continually zeroing the instrument between measurements.

4.3 The thermal energy provided by the flame causes the dissociation of metallic elements from their compounds and the reduction of the elements to the ground state. The richness or leanness of the flame may have a bearing on sensitivity. The variation in hydrocarbon content of the flame will have an effect on the number of atoms reduced to the ground state. The compounds of some elements, especially refractory elements such as aluminum or molybdenum are highly resistant to thermal decomposition and therefore require a higher temperature flame than less refractory elements such as iron or copper. This is the reason that the nitrous oxide-acetylene flame is required for these elements.

4.4 The amount of light absorbed in the flame is proportional to the concentration of the element in solution. The relationship between absorption and concentration is expressed by Beer's law:

$$I = I_o 10^{-abc} \quad (2)$$

where:

I = transmitted radiant power,

I_o = incident radiant power,

a = absorptivity,

b = sample path length, and

c = concentration of absorbing species within the path of the light beam, mg/L.

4.5 The atomic absorption spectrophotometer is calibrated with standard solutions containing known concentrations of the element of interest. A calibration curve is constructed for each analyte from which the concentration in the unknown sample is determined.

5. Significance and Use

5.1 Elemental constituents in water and wastewater need to be identified to support effective water quality monitoring and control programs. Currently, one of the most widely used and practical means for measuring concentrations of elements is by atomic absorption spectrophotometry.

5.2 The major advantage of atomic absorption over atomic emission is the almost total lack of spectral interferences. In atomic emission, the specificity of the technique is almost totally dependent on monochromator resolution. In atomic absorption, however, the detector sees only the narrow emission lines generated by the element of interest.

6. Interferences

6.1 Background absorption is caused by the formation of molecular species from the sample matrix that scatter or absorb the light emitted by the hollow cathode or electrodeless discharge line source. Without correction, this will cause the analytical results

to be erroneously high. If background correction is not available, a non-absorbing wavelength should be checked or the matrix of the standards and blank matched with the sample constituents. Background correction is usually not necessary unless the solids concentration of the sample is very high (>1 %), or the analysis is being carried out at very short wavelengths (<210 nm), or both. Preferably high solids type samples should be extracted. Three approaches exist for simultaneous background correction: continuum source, Zeeman, and Smith-Hieftje. There are different benefits for each of these background correction methods. The analyst should consult the manufacturer's literature for applicability to analytical requirements.

6.1.1 *Continuum Source*—The continuum source procedures involve the use of a hydrogen or deuterium arc source for the ultraviolet or a tungsten halide lamp for the visible region of the spectrum. Light from the primary spectral source and the appropriate continuum source are passed through the flame atomizer and alternately read. Narrow-band emission of the primary source is affected by the scatter and background absorption from the matrix as well as the absorption of light by analyte atoms. The broadband emission of the continuum source is significantly affected only by the background absorption. The effect of the background is virtually removed by taking a ratio of the energy of the two sources.

6.1.2 *Zeeman Correction*—The Zeeman correction system involves the use of an external magnetic field to split the atomic spectral line. When the magnetic field is off, both sample and background are measured. When the magnetic field is applied, the absorption line is shifted and only the background absorption is measured. Background correction is performed by electronically comparing the field-off and field-on measurements, yielding an analyte only absorption response.

6.1.3 *Smith-Hieftje System*—This system involves cycling the atomic line source at high currents for brief intervals. These intervals cause nonexcited atoms of the source element to undergo the process of self-reversal by emitting light at wavelengths other than those of the analyte. This light is absorbed only by the background, so that interspersing periods of high- and low-source current permit correction of the background.

6.2 Chemical interference is the most frequently encountered interference in atomic absorption spectrophotometry. A chemical interference may prevent, enhance, or suppress the formation of ground state atoms in the flame. For example, in the case of calcium determinations, the presence of phosphate or sulfate can result in the formation of a salt that hinders proper atomization of the solution when it is aspirated into an air-acetylene flame. This decreases the number of free, ground state atoms in the flame, resulting in lowered absorbance values. This interference can be eliminated by use of a nitrous oxide-acetylene flame. Likewise, aluminum can cause a similar interference when measuring magnesium. The addition of appropriate complexing agents to the sample solution is a technique intended to reduce or eliminate chemical interferences, and it may increase the sensitivity of the test method.

6.3 Alkali and alkaline earth metals, Groups I and II, such as sodium and potassium may undergo ionization in the air-acetylene and nitrous oxide-acetylene flames resulting in a decrease in ground state atoms available for measurement by atomic absorption. In the presence of an excess of an easily ionizable alkali element such as cesium, however, ionization of the alkali element will occur first and may minimize ionization of the element of interest.

6.4 If a sample containing low concentrations of the element being measured is analyzed immediately after a sample containing high concentrations, sample carryover may sometimes occur resulting in elevated readings. High concentrations are evidenced by marked flame coloration, a concentration reading higher than that of the highest standard, or a large fluctuation in the energy gage, or all of these conditions. To prevent this type of sample interference, routine aspiration of reagent water for about 15 s or more between samples is recommended, depending on the concentration of element in the last sample analyzed. Complete purging of the system is ascertained by aspirating water until the absorbance readout returns to near the baseline.

6.5 The physical properties of solutions being aspirated will not only change the nebulization uptake rate but will, for a variety of reasons, have a significant effect on sensitivity. Organic solvents such as those used in extraction techniques, will usually enhance sensitivity. Solutions with high dissolved solids will usually result in a reduction in sensitivity.

7. Apparatus

7.1 *Atomic Absorption Spectrophotometer*—A single or dual channel, single or double-beam instrument having a grating monochromator, photomultiplier detector adjustable spectral bandwidth, wavelength range from 190 to 800 nm, and provisions for interfacing with a strip chart recorder or a suitable data system. Refer to Practice E863.

7.2 *Burner*—The burner recommended by the manufacturer of the spectrophotometer should be used. For certain elements, a nitrous oxide burner is required.

7.3 *Hollow Cathode Lamps*—Single-element lamps are recommended. Multi-element lamps are available but have a shorter lifespan, are less sensitive, require a higher operating current, and increase the chances of spectral interferences. Electrode-less discharge lamps may also be used.

7.4 *Photomultiplier Tube*—A wide spectral range (160–900 nm) multiplier phototube is recommended. Refer to Practice E520.

7.5 *Strip Chart Recorder—Data Storage and Reduction Devices, Computer- and Microprocessor-Controlled Devices, or Strip Chart Recorders* A recorder is recommended so that there will be a permanent record and any problems with the analysis such shall be utilized for collection, storage, reduction, and problem recognition (such as drift, incomplete atomization, changes in sensitivity, etc., can be easily recognized etc.). Strip chart recorders shall have a full scale deflection time of 0.2 s or less to ensure accuracy.

8. Reagents and Materials

8.1 *Purity of Reagents*—Reagent grade or better chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society where such specifications are available.⁷ However, in some cases, these reagents may not be of sufficient purity due to the sensitivity of the technique. It is the responsibility of the user to verify that the purity of reagents used for this technique is sufficient.

8.2 *Purity of Water*—Unless otherwise indicated, reference to water shall be understood to mean reagent water conforming to Specification **D1193**, Type I. Other reagent water types may be used provided it is first ascertained that the water is of sufficiently high purity to permit its use without adversely affecting the precision and bias of the test method.

8.3 *Fuel, Acetylene (C₂H₂)*—Minimum acceptable acetylene purity is 99.5 vol %. Normally the cylinder is changed when the pressure reaches ~~53 g/m~~ **517 kPa²** (75 psig) if the acetylene is packed in acetone. Some manufacturers recommend different pressures. The analyst should check with the manufacturer for instructions. Prepurified grades use a proprietary solvent and can be used to ~~25–21 g/m~~ **206 kPa²** (30 psig) before replacement. The analyst should follow the manufacturer's instructions for the use of prepurified grades with proprietary solvents to prevent damage to gas control systems. Avoid introducing these solvents into the instrument or else abnormally high pulsating background noise and possible damage to the instrument's plumbing system may result. To prevent solvent carryover, allow acetylene cylinders to equilibrate for at least 24 h before use after moving.

8.4 *Fuel, Hydrogen (H₂)*—For some elements industrial grade hydrogen may be selected to achieve the desired flame characteristics.

8.5 *Oxidant (Air)*—The source may be a compressor or commercially bottled gas. Condition the air by passing it through a filter element to remove oil, water, and particles. Refer to the manufacturer's guidelines for minimum and maximum delivery pressures.

8.6 *Oxidant, Nitrous Oxide (N₂O)*—For certain elements, industrial or medical grade nitrous oxide may be required to achieve the necessary flame temperature.

8.7 *Stock Standard Solutions*—Stock standard solutions may be purchased as certified solutions or prepared from the American Chemical Society reagent grade materials. Store the solutions in high density polyethylene, glass or TFE-fluorocarbon containers at room temperature. Solutions should be labeled with the preparation and expiration dates. They should be inspected periodically for signs of deterioration.

NOTE 1—Polypropylene may be used for sample collection and storage. However, studies published by at least one atomic absorption spectrophotometer manufacturer indicate severe problems with metal adsorption onto the walls of polypropylene surfaces. The analyst should conduct loss studies with time to determine if adsorption is a problem.

8.8 *Filter Paper*—Purchase suitable filter paper. Typically the filter papers have a pore size of 0.45- μ m membrane. Material such as fine-textured, acid-washed, ashless paper, or glass fiber paper are acceptable. The user must first ascertain that the filter paper is of sufficient purity to use without adversely affecting the bias and precision of the test method.

9. Safety Precautions

9.1 The majority of calibration standards and sample types encountered in this practice pose no hazard to the analyst. Use of a hood, protective clothing, and safety glasses are required when preparing solutions where reaction between solvent and solute is exothermic, that is, lanthanum oxide in acid solution. The same precautions are required when diluting strong acids to avoid skin and respiratory contact.

9.2 A permanent ventilation system is required to eliminate the large quantity of hot and sometimes toxic exhaust gases produced by the burner during instrument operation. Since acetylene is a flammable gas proper precautions should be taken when using it. To avoid explosions, never pass acetylene through copper or high-copper alloy (brass, bronze) fittings or piping. If the spectrophotometer is not equipped with a protective shield, the operator's safety glasses must also attenuate the ultraviolet light emitted by the flame.

9.3 Oxidizing gases must be separated from reducing gases by a fire wall.

9.4 Follow manufacturer's operating guidelines carefully when optimizing gas flow rates. If proper caution is not exercised, a dangerous combustion within the gas mixing chamber may result.

9.5 To avoid in-line explosions, do not allow the pressure of acetylene being delivered to the instrument to exceed ~~10.6 g/m~~ **103.5 kPa²** (15 psig). Consideration should be given to including a commercially available flash arrestor in the line of all flammable or combustible gases.

9.6 The standard, 50.800 mm (2 in.) nitrous oxide burner head must be used when N₂O is an oxidant. A flashback will occur if a 101.60 mm (4 in.) burner head is used. The nitrous oxide flame must be lit by first using a combination of air/acetylene, then

⁷ *Reagent Chemicals, American Chemical Society Specifications*, American Chemical Society, Washington, DC. For suggestions on the testing of reagents not listed by the American Chemical Society, see *Analar Standards for Laboratory Chemicals*, BDH Ltd., Poole, Dorset, U.K., and the *United States Pharmacopoeia and National Formulary*, U.S. Pharmacopoeia Convention, Inc. (USPC), Rockville, MD.