



# Standard Test Methods for Electrical Conductivity and Resistivity of Water<sup>1</sup>

This standard is issued under the fixed designation D1125; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

*This standard has been approved for use by agencies of the U.S. Department of Defense.*

## 1. Scope

1.1 These test methods cover the determination of the electrical conductivity and resistivity of water. The following test methods are included:

Test Method	Range	Sections
Test Method A—Field and Routine Laboratory Measurement of Static (Non-Flowing) Samples	10 to 200 000 $\mu\text{S/cm}$	12 to 18
Test Method B—Continuous In-Line Measurement	5 to 200 000 $\mu\text{S/cm}$	19 to 23

1.2 These test methods have been tested in reagent water. It is the user’s responsibility to ensure the validity of these test methods for waters of untested matrices.

1.3 For measurements below the range of these test methods, refer to Test Method [D5391](#).

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this 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.*

## 2. Referenced Documents

### 2.1 ASTM Standards:<sup>2</sup>

- [D1066 Practice for Sampling Steam](#)
- [D1129 Terminology Relating to Water](#)
- [D1192 Guide for Equipment for Sampling Water and Steam in Closed Conduits \(Withdrawn 2003\)<sup>3</sup>](#)

<sup>1</sup> These test methods are under the jurisdiction of Committee [D19](#) on Water and are the direct responsibility of Subcommittee [D19.03](#) on Sampling Water and Water-Formed Deposits, Analysis of Water for Power Generation and Process Use, On-Line Water Analysis, and Surveillance of Water.

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<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard’s Document Summary page on the ASTM website.

<sup>3</sup> The last approved version of this historical standard is referenced on [www.astm.org](http://www.astm.org).

- [D1193 Specification for Reagent Water](#)
- [D2186 Test Methods for Deposit-Forming Impurities in Steam](#)
- [D2777 Practice for Determination of Precision and Bias of Applicable Test Methods of Committee D19 on Water](#)
- [D3370 Practices for Sampling Water from Closed Conduits](#)
- [D4519 Test Method for On-Line Determination of Anions and Carbon Dioxide in High Purity Water by Cation Exchange and Degassed Cation Conductivity](#)
- [D5391 Test Method for Electrical Conductivity and Resistivity of a Flowing High Purity Water Sample](#)
- [E2251 Specification for Liquid-in-Glass ASTM Thermometers with Low-Hazard Precision Liquids](#)

## 3. Terminology

### 3.1 Definitions:

3.1.1 *electrical conductivity, n*—the reciprocal of the a-c resistance in ohms measured between opposite faces of a centimetre cube of an aqueous solution at a specified temperature.

3.1.1.1 *Discussion*—The unit of electrical conductivity is siemens per centimetre. (The previously used units of mhos/cm are numerically equivalent to S/cm.) The actual resistance of the cell,  $R_x$ , is measured in ohms. The conductance,  $1/R_x$ , is directly proportional to the cross-sectional area,  $A$  (in  $\text{cm}^2$ ), and inversely proportional to the length of the path,  $L$  (in cm):

$$1/R_x = K \cdot A/L$$

The conductance measured between opposite faces of a centimetre cube,  $K$ , is called conductivity. Conductivity values are usually expressed in microsiemens/centimetre or in siemens/centimetre at a specified temperature, normally 25°C.

3.1.2 *electrical resistivity, n*—the a-c resistance in ohms measured between opposite faces of a centimetre cube of an aqueous solution at a specified temperature.

3.1.2.1 *Discussion*—The unit of electrical resistivity is ohm-centimetre. The actual resistance of the cell,  $R_x$ , is measured in ohms, and is directly proportional to the length of the path,  $L$  (in cm), and inversely proportional to the cross-sectional area,  $A$  (in  $\text{cm}^2$ ):

$$R_x = R \cdot L/A$$

The resistance measured between opposite faces of a centimetre cube,  $R$ , is called resistivity. Resistivity values are

**TABLE 1 Electrical Conductivity Values Assigned to the Potassium Chloride in the Reference Solution<sup>A</sup>**

Reference Solution	Approximate Normality of Solution	Method of Preparation	Temperature, °C	Electrical Conductivity, $\mu\text{S}/\text{cm}$
A	1	74.2460 g of KCl weighed in air per 1 L of solution at 20°C	0	65 176
			18	97 838
			25	111 342
B	0.1	7.4365 g of KCl weighed in air per 1 L of solution at 20°C	0	7 138
			18	11 167
			25	12 856
C	0.01	0.7440 g of KCl weighed in air per 1 L of solution at 20°C	0	773.6
			18	1 220.5
			25	1 408.8
D	0.001	Dilute 100 mL of Solution C to 1 L at 20°C	0	77.69 <sup>B</sup>
			18	127.54 <sup>B</sup>
			25	146.93

<sup>A</sup> Excluding the conductivity of the water used to prepare the solutions. (See 7.2 and Section 14.) These tabulated conductivity values are in international units. When using measuring instruments calibrated in absolute units, multiply the tabular values by 0.999505.

<sup>B</sup> From Glasstone (1).<sup>C</sup>

<sup>C</sup> The boldface numbers in parentheses refer to a list of references at the end of this standard.

usually expressed in ohm-centimetre, or in megohm · centimetre, at a specified temperature, normally 25°C.

3.1.3 For definitions of other terms used in these methods, refer to Terminology D1129.

### 3.2 Symbols:

3.2.1 Symbols used in the equations in Sections 14 and 16 are defined as follows:

$J$  = cell constant,  $\text{cm}^{-1}$ ,

$K$  = conductivity at 25°C,  $\mu\text{S}/\text{cm}$ ,

$K_x$  = measured conductance, S,

$K_1$  = conductivity of the KCl in the reference solution at the temperature of measurement (Table 1),  $\mu\text{S}/\text{cm}$ ,

$K_2$  = conductivity of the water used to prepare the reference solution, at the same temperature of measurement,  $\mu\text{S}/\text{cm}$ ,

$Q$  = temperature correction factor (see Section 11),

$R$  = resistivity at 25°C, ohm · cm,

$R_x$  = measured resistance, ohm.

## 4. Significance and Use

4.1 These test methods are applicable for such purposes as impurity detection and, in some cases, the quantitative measurement of ionic constituents dissolved in waters. These include dissolved electrolytes in natural and treated waters, such as boiler water, boiler feedwater, cooling water, and saline and brackish water.

4.1.1 Their concentration may range from trace levels in pure waters (2)<sup>4</sup> to significant levels in condensed steam (see Test Methods D2186 and D4519, and Ref (3)), or pure salt solutions.

4.1.2 Where the principal interest in the use of conductivity methods is to determine steam purity, see Ref (4). These test methods may also be used for checking the correctness of water analyses (5).

## 5. Interferences

5.1 Exposure of a sample to the atmosphere may cause changes in conductivity/resistivity, due to loss or gain of

dissolved gases. This is extremely important in the case of very pure waters with low concentrations of dissolved ionized materials. The carbon dioxide, normally present in the air, can drastically increase the conductivity of pure waters by approximately 1  $\mu\text{S}/\text{cm}$ . Contact with air should be avoided by using flow-through or in-line cell where feasible. Chemically pure inert gases, such as nitrogen or helium, may be used to blanket the surface of samples.

5.2 Undissolved or slowly precipitating materials in the sample can form a coating on the electrodes of the conductivity cell that may cause erroneous readings. For example, biofouling of the cell or a build-up of filming amines may cause poor cell response. In most cases these problems can be eliminated by washing the cells with appropriate solvents.

5.3 If an unshielded cell is used to measure the resistivity/conductivity of high resistivity water there is a possibility of electrical pickup causing erroneous reading. For this reason it is recommended that conductivity cells for this application be of coaxial shielded type or equivalent, and that the cables and instrument also be shielded.

5.4 Formation of bubbles on the surfaces of conductivity cell electrodes will cause erroneously low conductivity readings and must be prevented during calibration and measurement. Bubble formation can occur with measurements of water containing dissolved gases when the water is warming up or dropping in pressure or both. For laboratory samples, swirling or tapping the sensor on the bottom of the sample container can dislodge bubbles. For continuous measurements, cell installation in a high flow velocity location (within manufacturers recommendations) can prevent bubble adherence.

## 6. Apparatus

6.1 *Measuring Circuit*—The instrument may be a manually operated wheatstone bridge or the equivalent, or a direct reading analog or digital meter. Instruments shall energize the conductivity cell with alternating current and, together with the cell and any extension leadwire, shall be designed to reduce errors from the following sources:

6.1.1 *In Highly Conductive Solutions*—Uncompensated electrode polarization due to excessive current density at the

<sup>4</sup> The boldface numbers in parentheses refer to a list of references at the end of this standard.

**TABLE 2 Recommended Cell Constants for Various Conductivity Ranges Using a Laboratory Bridge**

Range of Conductivity, $\mu\text{S}/\text{cm}$	Cell Constant, $\text{cm}^{-1}$
0.05 to 10	0.01 to 0.1
10 to 200	0.1 to 1
200 to 5000	1 to 10
5000 to 1 000 000	10 to 100

electrode surfaces can cause negative conductivity errors. Insufficient series capacitance at the electrode/solution interface can allow charging effects to distort the a-c measurement and cause errors if not compensated. Leadwire resistance can add significantly to the measured resistance. Four-electrode type conductivity cells can reduce the effects of polarization by energizing two or more electrodes to create an a-c field across the sensing area and measuring from another pair of electrodes within the field with minimal current flow.

6.1.2 *In Low Conductivity Solutions*—Excessive parallel capacitance in the cell and extension leadwire can shunt the measurement and cause positive conductivity errors. Temperature compensation errors can be significant below  $5 \mu\text{S}/\text{cm}$  if variable coefficient algorithms are not employed as described in Test Method **D5391**.

6.1.3 These sources of error are minimized by an appropriate combination of a-c drive voltage, wave shape, frequency, phase correction, wave sampling technique and temperature compensation designed in by the instrument manufacturer. The instrument manufacturer's recommendations shall be followed in selecting the proper cell constant, leadwire size, and length and maintenance of the electrode surface condition for the range of measurement. Calibration may be in either conductivity or resistivity units.

6.1.4 When an output signal is required from an on-line instrument, it shall be electrically isolated from the cell drive circuit to prevent interaction between a solution ground at the cell and an external circuit ground.

## 6.2 Cells:

6.2.1 Flow-through or in-line cells shall be used for measuring conductivities lower than  $10 \mu\text{S}/\text{cm}$  (resistivities higher than  $100\,000 \text{ ohm} \cdot \text{cm}$ ), to avoid contamination from the atmosphere. However, samples with conductivity greater than  $10 \mu\text{S}/\text{cm}$  may also be measured. In all other cases, pipet-type or dip cells can also be used. Pipet or dip cells may be used to measure samples in the range of 1 to  $10 \mu\text{S}/\text{cm}$  if the sample is protected by an inert gaseous layer of nitrogen or helium.

6.2.2 A cell constant shall be chosen which will give a moderate cell resistance, matching the instrument manufacturer's requirements for the range of measurement. For laboratory bridges, **Table 2** provides conservative guidelines.

6.2.3 Flow-through and in-line cells shall be mounted so that continuous flow of the sample through or past it is possible. Flow rate should be maintained at a constant rate consistent with the manufacturer's recommendations for the cell being used, particularly at conductivities below  $10 \mu\text{S}/\text{cm}$ . The cell shall retain calibration under conditions of pressure, flow, and temperature change, and shall exclude the atmosphere and be constructed of corrosion resistant, chemically

inert materials. The chamber or cell shall be equipped with means for accurate measurement of the temperature.

6.2.4 Platinized cells shall not be used for measurement of conductivities below  $10 \mu\text{S}/\text{cm}$ , except that a trace or flash of platinum black may be used on cells for measurements in the range of 0.1 to  $10 \mu\text{S}/\text{cm}$  (see **9.4**). Because of the cost and fragility of platinum cells, it is common practice to use titanium, monel, hastelloy, stainless steel and graphite electrodes for measurements with accuracies on the order of 1 %. Note that these electrodes may require special surface preparation. Titanium and monel electrodes are especially suitable for high resistance solutions such as ultrapure water, but may introduce a small surface resistance which limits their accuracy when the measured resistance is less than a few thousand ohms **(2)**.

6.2.5 It is recommended that cells intended for the measurement of conductivities below  $10 \mu\text{S}/\text{cm}$  be reserved exclusively for such applications.

## 6.3 Temperature Probes:

6.3.1 *For Temperature Control*—The measurement of temperature is necessary for control of a temperature bath, manual temperature compensation, or automatic temperature compensation, or all of these. Thermometers, thermistors, and resistance temperature detectors with accuracies of  $\pm 0.1^\circ\text{C}$  or better are acceptable for this application. An ASTM precision thermometer, Number S63C, as defined in Specification **E2251**, is recommended. The calibration of temperature probes should be checked periodically by comparison to a reference temperature probe whose calibration is traceable to NIST or equivalent.

6.3.2 *For Temperature Correction*—A thermometer accurate to  $0.1^\circ\text{C}$  is acceptable for this application, when the instrument is not provided with manual or automatic temperature compensation. (See Section **11**).

## 7. Reagents

7.1 *Purity of Reagents*—Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.<sup>5</sup> Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

7.2 *Purity of Water*—Unless otherwise indicated, references to water shall be understood to mean reagent water conforming to the quantitative specifications of **D1193**, Type I. In making up the potassium chloride solutions for cell constant determinations, use water of conductivity not greater than  $1.5 \mu\text{S}/\text{cm}$ . If necessary, stabilize to the laboratory atmosphere by aspirating air through the water from a fritted glass or stainless

<sup>5</sup> *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 Pharmacopeia and National Formulary*, U.S. Pharmaceutical Convention, Inc. (USPC), Rockville, MD.

steel gas dispersion tube. The equilibrium point is reached when the conductivity remains constant but not greater than 1.5  $\mu\text{S}/\text{cm}$ . The equilibrium conductivity must be added to [Table 1](#).

7.3 *Alcohol*—95 % ethyl alcohol. Alternatively, use isopropyl alcohol or methyl alcohol.

7.4 *Aqua Regia* (3 + 1)—Mix 3 volumes of concentrated hydrochloric acid (HCl, sp gr 1.19) with 1 volume of concentrated nitric acid ( $\text{HNO}_3$ , sp gr 1.42). This reagent should be used immediately after its preparation.

7.5 *Ethyl Ether*.

7.6 *Hydrochloric Acid* (sp gr 1.19)—Concentrated HCl.

7.7 *Hydrochloric Acid* (1 + 1)—Mix 1 volume of concentrated HCl (sp gr 1.19) with 1 volume of water.

7.8 *Platinizing Solution*—Dissolve 1.5 g of chloroplatinic acid ( $\text{H}_2\text{PtCl}_6 \cdot 6\text{H}_2\text{O}$ ) in 50 mL of water containing 0.0125 g of lead acetate ( $\text{Pb}(\text{C}_2\text{H}_3\text{O}_2)_2$ ).

7.9 *Potassium Chloride* (KCl)—The assay of the potassium chloride must be  $100.0 \pm 0.1$  %. This standardization grade of KCl is available from NIST and from commercial sources. Dry at  $150^\circ\text{C}$  for 2 h or until weight loss is less than 0.02 %; store in desiccator.

7.10 *Potassium Chloride Reference Solution A*—Dissolve 74.2460 g of KCl (weighed in air) in water and dilute to 1 L at  $20 \pm 2^\circ\text{C}$  in a Class A volumetric flask.

7.11 *Potassium Chloride Reference Solution B*—Dissolve 7.4365 g of KCl (weighed in air) in water and dilute to 1 L at  $20 \pm 2^\circ\text{C}$  in a Class A volumetric flask.

7.12 *Potassium Chloride Reference Solution C*—Dissolve 0.7440 g of KCl (weighed in air) in water and to dilute 1 L at  $20 \pm 2^\circ\text{C}$  in a Class A volumetric flask.

7.13 *Potassium Chloride Reference Solution D*—Dilute 100 mL of reference solution C to 1 L with water at  $20 \pm 2^\circ\text{C}$  in a Class A volumetric flask shortly before using. Store the solution in a glass-stoppered bottle of chemically resistant glass which has only been used for storage of this solution.

NOTE 1—The electrical conductivity of each of the referenced solutions is given in [Table 1](#). The values for electrical conductivities for the solutions are those of G. Jones and B. C. Bradshaw (6), confirmed in 1987 (7) and 1989 (8) by the National Institute of Standards and Technology (NIST). The data of T. Shedlovsky (9) are used for Solution D. Solutions A, B, and C were prepared by Jones and Bradshaw using the molal or *demal* basis by dissolving 71.1352, 7.4191, and 0.7453 g, respectively, of KCl (in vacuum) per 1000 g of solution (in vacuum). The method of preparation given in [Table 1](#) includes the corrections to weights of KCl (in air against brass weights) per litre of solutions at  $20^\circ\text{C}$  and assumes the density of KCl = 1.98, density of brass = 8.4, and the density of air = 0.00118. The densities of 1.0 N, 0.10 N, and 0.010 N KCl at  $20^\circ\text{C}$ , 1.04420, 1.00280, and 0.99871 g/mL, respectively, were interpolated from the data in the International Critical Tables (10).

## 8. Sampling

8.1 Samples shall be collected in accordance with Practice [D1066](#), Specification [D1192](#), and Practices [D3370](#), as applicable.

8.2 Avoid exposure of the sample to atmospheres containing ammonia or acidic gases. Protect the sample to avoid gain or

loss of dissolved gases, particularly if there is some delay before the conductivity measurements are made. Preferably, use a flow-type cell for sampling and measuring condensed steam or water having a conductivity of less than 10  $\mu\text{S}/\text{cm}$ . For waters in the range of 5 to 10  $\mu\text{S}/\text{cm}$ , a dip-type cell may be used if a layer of chemically pure nitrogen or helium is maintained over the surface.

## 9. Preparation of Electrodes

9.1 If the cell constant as checked does not fall within reasonable limits of its nominal value, it is necessary to clean or replatinize the electrodes or replace the cell. In general, no mechanical cleaning should be attempted with platinum or graphite electrodes. In high purity water measurements, where the presence of finely divided platinum is undesirable due to its long retention of impurities, platinization of electrodes should be omitted, especially for testing of water having a conductivity below 10  $\mu\text{S}/\text{cm}$  (see [9.4](#)). On the other hand, clean and well-platinized electrodes are increasingly important in testing water of higher conductivities, particularly above 1000  $\mu\text{S}/\text{cm}$ .

9.2 The cell manufacturer's instructions may be followed for cleaning the electrodes as well as other parts of the cell. A suitable cleaning solution consists of a mixture of 1 part by volume of isopropyl alcohol, 1 part of ethyl ether, (with polymer cells, check compatibility) and 1 part of HCl (1 + 1). After cleaning, thoroughly flush the cell with water. If the old platinum black coating is to be removed, judicious application of aqua regia to the electrodes, or electrolysis in HCl (sp gr 1.19) is frequently successful.

9.3 Platinize the electrodes of the cell with  $\text{H}_2\text{PtCl}_6$  solution. A suitable plating apparatus consists of a 6 volt a-c supply, a variable resistor, milliammeter, and an electrode. The deposit should present a black, velvety appearance and should adhere well to the electrode surface. The procedure for platinizing is not critical. Follow the manufacturer's instructions or the following guidelines. Good platinized coatings are obtained using from 1.5 to 3 coulombs/ $\text{cm}^2$  of electrode area. For example, for an electrode having a total area (both sides) of 10  $\text{cm}^2$ , the plating time at a current of 20 mA would be from 12½ to 25 min. The current density may be from 1 to 4 mA/ $\text{cm}^2$  of electrode area. Plate the electrodes one at a time with the aid of an extra electrode. During the plating, agitate the solution gently, or use ultrasonic bath. When not in use, platinized cells should be filled with water to prevent the drying out of electrodes while in storage.

9.4 For measurement of conductivities in the range of 0.1 to 10  $\mu\text{S}/\text{cm}$ , a trace or flash coating of platinum black may be used. For a flash coating, the cell is left in the platinum chloride solution for only 2 or 3 s at a current of about 20 mA. A flash coating will leave the electrodes with their metallic appearance, but with a faint blackish tint.

9.5 Generally, cells with titanium, monel, stainless steel, hastelloy or graphite electrodes do not require any special preparation other than soaking in water or sample for at least 5 min before measurement, if they have been stored dry. This ensures that electrodes are fully wetted. Follow the manufacturer's recommendations for startup, cleaning and maintenance.

## 10. Calibration

10.1 *Measuring Instrument*—A calibrating resistor to be used in place of the conductivity cell may be furnished by the manufacturer, together with information as to the correct scale reading the instrument shall assume when this resistor is connected in place of the conductivity cell. Follow the manufacturer’s instructions and periodically check the instrument. Alternatively, standard resistors with certified accuracy of  $\pm 0.05\%$  may be used with appropriate calculations adapted to the instrument scale. Some instruments may be factory calibrated, taking into account the resistance of the cable wire attached to the conductivity cell; this may be indicated by a warning to avoid cutting or extending the cable length. When lead wires between the instrument and the cell are long, check the installation at least once by connecting the calibrating resistor at the far end of the lead wire and noting the difference, if any, in reading with the long lead wire in the circuit. Check portable or manually operated instruments in a similar manner with one or several calibrating resistors. Note errors of significant magnitude and correct subsequent conductivity readings. Calibration checks should be made at values as close as possible to the conductivity values expected in samples. This is especially important if the measurement is made at the extreme high or low end of an instrument’s range. Instruments subjected to field use may require more frequent checks of calibration. For direct reading instruments, the conductivity check resistance in ohms equals the cell constant ( $\text{cm}^{-1}$ ) divided by the conductivity desired ( $\text{S/cm}$ ) while the resistivity check resistance equals cell constant ( $\text{cm}^{-1}$ ) times the resistivity desired ( $\text{ohm} \cdot \text{cm}$ ).

10.2 *Conductivity Cells*—For field and routine laboratory testing, the calibration of conductivity cells may be checked by comparing instrument readings taken with the cell in question against readings on the same sample or series of samples taken with a conductivity cell of known or certified cell constant. Exercise care to ensure that both working and reference cells are at the same temperature or, alternatively, at different but known temperatures so that a correction as later described can be applied. Resistivity-reading instruments will indicate in direct proportion to the cell constant, while conductivity reading instruments will indicate in inverse proportion to cell constant. Conductivity cells may be calibrated with reference solutions in accordance with Section 14.

## 11. Temperature Coefficient of Conductivity/Resistivity

11.1 The conductivity/resistivity of water and aqueous solutions depends strongly upon the temperature. (See Table 3.) The normal practice is to report conductivity and resistivity values referenced to  $25.0^\circ\text{C}$ . The coefficient varies depending upon the nature and composition of the dissolved electrolytes, and upon the concentration. The dissociation of water contributes significantly to conductivities at  $5\ \mu\text{S/cm}$  or less and increases the temperature coefficient from near  $2\%$  per  $^\circ\text{C}$  at above  $5\ \mu\text{S/cm}$  to near  $5\%$  per  $^\circ\text{C}$  at  $0.055\ \mu\text{S/cm}$ . To avoid making a correction, it is necessary to hold the temperature of the sample to  $25 \pm 0.1^\circ\text{C}$ . If this cannot be done, the temperature coefficient must be determined and a correction applied. This requires a series of conductivity and temperature

**TABLE 3 Conductivity Values of Pure Water and Increases Due to Sodium Chloride**

Temperature, $^\circ\text{C}$	Conductivity of Pure Water, $\mu\text{S/cm}^A$	Conductivity Increase Due to 1 mg/L NaCl, $\mu\text{S/cm}^B$
0	0.01160	1.1463
5	0.01653	1.3311
10	0.02303	1.5261
15	0.03138	1.7297
20	0.04193	1.9435
25	0.05501	2.1642
30	0.07097	2.3935
35	0.09017	2.6296
40	0.1130	2.8760
45	0.1398	3.1257
50	0.1709	3.3841
55	0.2066	3.6476
60	0.2474	3.9179
65	0.2935	4.1882
70	0.3453	4.4773
75	0.4029	4.7648
80	0.4669	5.0556
85	0.5371	5.3550
90	0.6135	5.6527
95	0.6964	5.9264
100	0.7849	6.1933

<sup>A</sup> From Light (11).

<sup>B</sup> From Thornton (2).

measurements on the sample over the required temperature range. Where automatic temperature compensation is used, the temperature compensation algorithm should be chosen that best simulates the composition of the samples to be tested. In high purity water,  $5\ \mu\text{S/cm}$  or less, the variable coefficient shall be automatically determined and applied across the range of measurement for both the dissociation of water and its interaction with salt or other contaminations. (See Test Method D5391 and Refs (12), (13), and (14) for more information.)

11.2 In static systems, exercise care to avoid change of composition caused by loss of volatile constituents or by pick-up of contaminants from the air to the containing vessel during the series of measurements.

11.3 In flowing systems, provide means for variable heating or cooling so that the desired range of temperature will be covered. Regulate the rate of flow through each cell so as to keep the cell adequately flushed.

11.4 From the data obtained, plot conductivity against temperature. Make sure that the conductivity readings are uncompensated. From the curve a table of temperature correction factors may be prepared, or the ratio of conductivity at temperature  $T$  to conductivity at  $25^\circ\text{C}$  may be plotted against temperature  $T$ , and this ratio or correction factor,  $Q$ , taken from the smoothed curve.

NOTE 2—Depending on the type of compensation used, uncompensated readings may be obtained by setting temperature to  $25^\circ\text{C}$ , by putting the temperature probe in a  $25^\circ\text{C}$  bath, or by substituting an electrical resistance equivalent to  $25^\circ\text{C}$ .

11.5 When using an instrument provided with a manual or automatic temperature compensator, follow the manufacturer’s instructions to calibrate the compensator or check its accuracy and applicability to the sample being tested.

11.6 When using a microprocessor-based instrument, select the temperature compensation algorithm applicable to the sample being tested.

## TEST METHOD A—FIELD AND ROUTINE LABORATORY MEASUREMENT OF STATIC (NON-FLOWING) SAMPLES

### 12. Scope

12.1 This test method is applicable to field and routine laboratory measurements of the electrical conductivity of water using static samples.

### 13. Summary of Test Method

13.1 This test method utilizes dip-type or pipet-type conductivity cells for testing static samples having conductivities greater than 10  $\mu\text{S}/\text{cm}$ . Temperature control and correction methods are also provided.

### 14. Determination of Cell Constant

14.1 For the purposes of this test method, the cell constant of the conductivity cell used shall be known within  $\pm 1\%$ . The manufacturer's certification of the cell constant within this accuracy is generally considered satisfactory but the user is advised that damage could occur in shipment and it is best to recheck the cell constant when received. If the conductivity cell has been in service for a period subsequent to this certification, it shall be rechecked by the manufacturer, or in the laboratory.

14.2 Rinse the conductivity cell several times with water, then at least twice with the KCl reference solution that has a conductivity nearest to that of the sample under test (Table 1). Control the solution temperature to  $25 \pm 0.1^\circ\text{C}$ . Measure the resistance of the cell. Repeat the measurement on additional portions of the KCl reference solution until the value obtained remains constant to within the limits of precision in accordance with Section 18.

14.3 For instruments reading measured resistance in ohms, calculate the cell constant:

$$J = 10^{-6} \cdot R_x (K_1 + K_2)$$

14.4 For instruments reading measured conductance in Siemens, calculate the cell constant:

$$J = 10^{-6} \cdot (K_1 + K_2) / K_x$$

NOTE 3—Since the conductivities of a mixture of two solutions are not exactly additive, the use of  $K_1 + K_2$  is only an approximation and requires that  $K_2$  be much smaller than  $K_1$ .

### 15. Procedure

15.1 *Precision Method Using Temperature Control*—Use a dip-type or pipet-type cell. Rinse the cell, container, and thermometer thoroughly several times with water and then two or more times with the sample. Adjust the temperature to  $25 \pm 0.1^\circ\text{C}$  as indicated by a thermometer as described in 6.3.1. Allow sufficient time for equalization of temperatures. Read the conductance or resistance. Calculate conductivity or resistivity according to Section 16 using  $Q = 1$ , since no temperature correction is required.

15.2 *Routine Method Using Temperature Correction*—Use a dip-type or pipet-type cell. Rinse the conductivity cell thoroughly several times with water and then two or more times with the sample. Measure the resistance or the conductance, and the temperature (to the nearest  $0.1^\circ\text{C}$ ), on successive portions of the sample until a constant value is obtained. If the measuring instrument is provided with a manual temperature compensator, adjust this to the sample temperature value before reading the instrument. If an automatic temperature compensator is provided, no adjustment is necessary, but sufficient time must be allowed to permit equalization of temperature. If the instrument has no means of temperature compensation, determine a temperature correction factor in accordance with the instructions in Section 11 to convert readings to  $25^\circ\text{C}$ . If instrument temperature compensation is used, calculate conductivity or resistivity according to Section 16 using  $Q = 1$ , otherwise use  $Q$  as determined in Section 11.

### 16. Calculation

16.1 For instruments reading measured resistance in ohms, calculate the conductivity of the sample:

$$K = 10^6 \cdot J / R_x Q$$

16.2 For instruments reading measured resistance in ohms, calculate the resistivity of the sample:

$$R = R_x Q / J$$

16.3 For instruments reading measured conductance in Siemens, calculate the conductivity of the sample:

$$K = 10^6 \cdot J K_x / Q$$

16.4 For instruments reading measured conductance in Siemens, calculate the resistivity of the sample:

$$R = Q / J K_x$$

16.5 Automatic recorders and indicators provided with temperature compensators, when used with conductivity cells of the required cell constant, usually read directly in terms of siemens per centimetre or  $\mu\text{S}/\text{cm}$  referred to  $25^\circ\text{C}$ . No calculations are necessary if the compensator is corrected for the solution in the cell.

### 17. Report

17.1 Report the value of the conductivity at  $25^\circ\text{C}$  in terms of microsiemens per centimetre to the nearest 1 % of the determined conductivity.

17.2 Alternatively, report the value of the resistivity at  $25^\circ\text{C}$  in terms of ohm-centimetres to the nearest 1 % of the determined resistivity.

### 18. Precision and Bias<sup>6</sup>

18.1 This test method was tested by nine laboratories, at four concentration levels, with each operator analyzing each sample on three different days. These collaborative test data were obtained on reagent water. For other matrices, these data

<sup>6</sup> Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D19-1139. Contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org).

**TABLE 4 Precision of Test Method A**

Mean Concentration, $\mu\text{S}/\text{cm}$	Overall Precision, $S_o$ , $\mu\text{S}/\text{cm}$	Single-Operator Precision Pooled, $S_o$ , $\mu\text{S}/\text{cm}$
25.6	3.4	0.83
162.0	6.1	3.8
1378.8	60.9	14.1
108169	6600	2918

may not apply. These data were developed using the routine method (temperature correction) described in 15.2. The actual temperature of samples tested by the participants ranged from 18.5 to 26.0°C.

18.1.1 *Precision*—The precision of this test method within its designated range appears in Table 4.

18.1.2 *Bias*—Recoveries of known amounts of conductivity values in a series of prepared standards appears in Table 5.

18.2 This test method meets requirements for precision and bias specified in Practice D2777 – 86.

## TEST METHOD B—CONTINUOUS, IN-LINE MEASUREMENT

### 19. Scope

19.1 This test method is applicable to the continuous, in-line measurement of the electrical conductivity of water.

### 20. Summary of Test Method

20.1 This test method utilizes a flow-type conductivity cell to sample a continuous stream of the water under test. Temperature control and correction methods are also provided.

### 21. Procedure

21.1 *Precision Method Using Temperature Control*—Use a flow-type conductivity cell. Adjust the sample stream, known to be free of corrosion products and other particulate contamination, to a proper flow rate and bring the temperature to  $25 \pm 0.1^\circ\text{C}$  as indicated by a thermometer as described in 6.3. Allow sufficient time to reach equalization of temperatures. Read the conductance or resistance. Calculate the conductivity or resistivity according to Section 16 using  $Q = 1$ , since no temperature correction is required.

21.2 *Routine Method Using Temperature Correction*—Use a flow-type conductivity cell. Adjust the sample stream, known to be free of corrosion products and other particulate contamination, to a proper flow rate and bring the temperature to a steady value as near  $25^\circ\text{C}$  as possible. Read the temperature to the nearest  $0.1^\circ\text{C}$ . If the measuring instrument is provided with a manual temperature compensator, adjust this to the sample temperature value. If an automatic temperature compensator is provided, no adjustment is necessary but sufficient time must be allowed to permit equalization of temperatures. Read the conductivity or resistivity. If the instrument has no means of temperature compensation, determine a temperature correction factor in accordance with Section 11 to convert readings to  $25^\circ\text{C}$ .

**TABLE 5 Bias of Test Method A**

Amounts Added, $\mu\text{S}/\text{cm}$	Mean Recovery, $x$ , $\mu\text{S}/\text{cm}$	Bias	% Bias	Statistically Significant
27.8	25.6	-2.2	-7.9	yes
167.6	162.0	-5.6	-3.3	yes
1408.8	1378.8	-30.0	-2.1	yes
111342	108169	-3173	-2.8	yes

### 22. Report

22.1 Report the value of the conductivity at  $25^\circ\text{C}$  in terms of microsiemens per centimetre to the nearest 1 % of the determined conductivity.

22.2 Alternatively, report the value of the resistivity at  $25^\circ\text{C}$  in terms of ohm-centimetres to the nearest 1 % of the determined resistivity.

### 23. Precision and Bias

23.1 Since this test method involves continuous sampling, a general statement of precision and bias is not applicable.

23.2 Experience has shown that errors of 1 to 30 % may be encountered, depending on the equipment and techniques used. Errors in temperature compensation are especially troublesome at conductivities below  $10 \mu\text{S}/\text{cm}$ . Additional errors may be encountered with low constant cells because of the difficulties involved in verifying the cell constant at low conductivity levels.

### 24. Quality Control

24.1 In order to be certain that analytical values obtained using these test methods are valid and accurate within the confidence limits of the test, the following QC procedures must be followed when running the test:

24.2 *Periodic Verification of Calibration of the Measurement System:*

24.2.1 Verify calibration of the conductivity cell constant in accordance with 10.2 on a daily to yearly basis as determined appropriate for the fouling tendency of samples and the robustness of the sensor. If results are outside the acceptable tolerance for the application, clean the sensor according to Section 9 and repeat the verification. If results are still outside acceptable limits, re-determine the sensor cell constant in accordance with Section 14. If the cell constant changes by more than 5 % of its initial value, replace the sensor.

24.3 *Initial Demonstration of Capability:*

24.3.1 Verify the conductivity measuring circuit (and temperature measuring circuit if used for temperature compensation) by installing precision resistor(s) in place of the conductivity cell and temperature sensor, if used, in accordance with 10.1. If temperature compensation cannot be disabled in the instrument, the resistor for temperature measurement must be selected to produce a reading of  $25^\circ\text{C}$ . The resistor for conductivity or resistivity should be selected to produce a reading within the anticipated range of measurements.

24.3.2 Calculate the expected conductivity or resistivity reading for the resistance based on 16.1 or 16.2 with  $Q = 1$  and using the cell constant stored in the instrument. If there is no

cell constant setting in the instrument, use a value of  $J = 1$  for the calculation. The conductivity or resistivity reading should be within  $\pm 1\%$  of the calculated value plus the tolerance of the resistor value. The temperature reading should be within the tolerance of the temperature resistor with its value converted into temperature units plus  $0.5^\circ\text{C}$ .

24.3.3 Alternatively for 24.3.1 and 24.3.2, use instrument manufacturer-certified resistance calibrators and procedures.

24.3.4 Confirm the sensor cell constant in accordance with Section 14. Confirm the temperature measurement, if used for temperature compensation, in accordance with 6.3.1.

24.4 *Method Blank*—Because conductivity and resistivity of water do not have zero values that can be measured with the apparatus for these methods, blank sample testing is not applicable. Pure water with the values in Table 3 can only be obtained in a closed system following very high quality deionization, which is beyond the scope of this method.

24.5 *Laboratory Control Sample Test*—Because conductivity and resistivity measurements do not involve reagents and the test is virtually instantaneous, it is not necessary to perform a laboratory control sample test with every measurement batch. See 24.2.

24.6 *Matrix Spike*—Because conductivity and resistivity measurements are not specific and respond to all ionic species, a matrix spike test is not applicable.

24.7 *Duplicate*—Duplicate analyses should be performed to determine individual or laboratory precision.

## 25. Keywords

25.1 cell constant; conductivity; resistivity; temperature coefficient; temperature compensation

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