

Standard Test Methods for pH Measurement of Water of Low Conductivity¹

This standard is issued under the fixed designation D 5464; 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 approval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 These test methods are applicable to determine the pH of water samples with a conductivity lower than 100 $\mu\text{S}/\text{cm}$ (see Annex A1 and Table A1.1 and Table A1.2) over the pH range of 3 to 11 (see Fig. 1). pH measurements of water of low conductivity are problematical (see Annex A2). Specifically, these test methods avoid contamination of the sample with atmospheric gases (see Section 7) and prevent volatile components of the sample from escaping. These test methods provide for pH electrodes and apparatus that address the considerations discussed in Annex A2. These test methods also minimize problems associated with the sample's pH temperature coefficient when the operator uses these test methods to calibrate an on-line pH monitor or controller (see Appendix X1). Two test methods are given as follows:

Test Method	Sections
Test Method A—Precise pH Measurement of Low Conductivity Water Utilizing the Real-Time Flowing Sample Procedure	5 to 12
Test Method B—pH Measurement of Low Conductivity Water Utilizing the Static Grab Sample Procedure	13 to 20

1.2 Test Method A covers the precise measurement of pH in water of low conductivity utilizing a real-time, short duration, flowing sample procedure.

1.3 Test Method B covers the measurement of pH in water of low conductivity with a lower limit of 2.0 $\mu\text{S}/\text{cm}$, utilizing a static grab-sample procedure where it is not practicable to take a real-time flowing sample.

NOTE 1—Test Method A is preferred over Test Method B whenever possible. Test Method A is not subject to the limited conductivity range, temperature interferences, potential KCl contamination, and time limitations found with Test Method B.

1.4 The values stated in SI units are to be regarded as 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.*

¹ These test methods are under the jurisdiction of ASTM Committee D19 on Water and are the direct responsibility of Subcommittee D19.03 on Sampling of Water and Water-Formed Deposits, Surveillance of Water, and Flow Measurement of Water.

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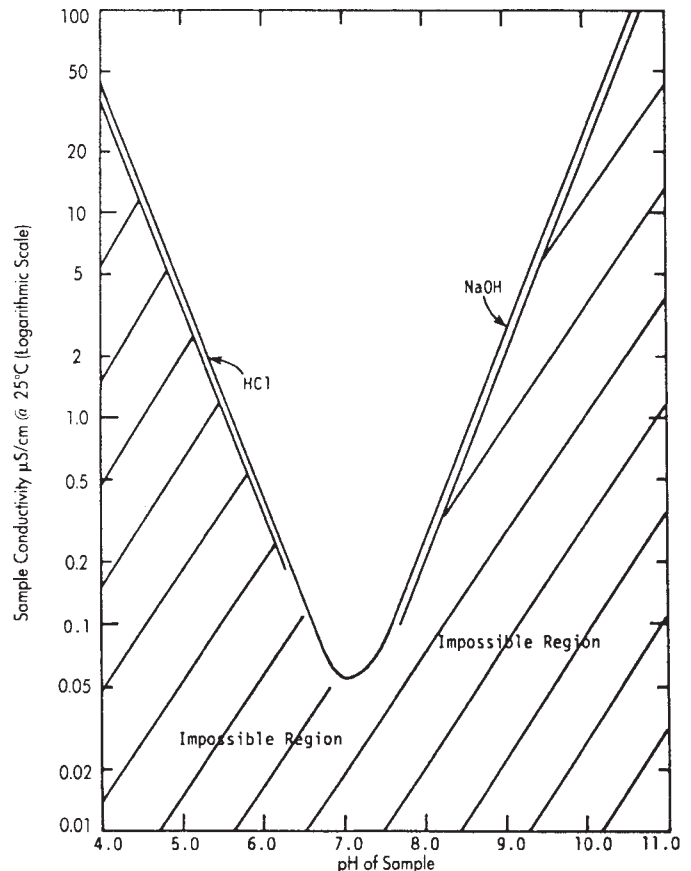


FIG. 1 Restrictions Imposed by the Conductivity-pH Relationship

2. Referenced Documents

2.1 ASTM Standards:

- D 1067 Test Methods for Acidity or Alkalinity of Water²
- D 1129 Terminology Relating to Water²
- D 1193 Specification for Reagent Water²
- D 1293 Test Methods for pH of Water²
- D 2777 Practice for Determination of Precision and Bias of Applicable Methods of Committee D-19 on Water²
- D 4453 Practice for Handling Ultra-Pure Water Samples²
- D 5128 Test Method for On-Line pH Measurement of Water of Low Conductivity²

² Annual Book of ASTM Standards, Vol 11.01.

3. Terminology

3.1 *Definitions*—For definitions of terms used in these test methods, refer to Terminology D 1129.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *liquid junction potential*—a dc potential which appears at the point of contact between the reference electrode's salt bridge and the sample solution. Ideally this potential is near zero, and is stable. However, in low conductivity water it becomes larger by an unknown amount, and is a zero offset (1).³

4. Reagents

4.1 *Purity of Reagents*—Reagent grade 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.⁴ 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.

4.2 *Purity of Water*— Unless otherwise indicated, references to water shall be understood to mean reagent water as defined by Type II of Specification D 1193.

4.3 *Commercial Buffer Solutions*—Commercially available prepared buffers traceable to NIST standards should be adequate to perform the calibration procedures in 10.1-10.4. These commercial buffer solutions usually have pH values near 4.01, 6.86, and 10.01 pH at 25°C. The exact pH of the buffer will change with temperature and this pH versus temperature data will be provided by the purveyor of the specific buffer. Refer to Test Methods D 1293, Method A for the preparation of reference buffer solutions if desired.

4.4 *Buffer A*—Commercially available 7.00 pH buffer.

4.5 *Buffer B*—Commercially available 4.00 pH buffer.

4.6 *Buffer C*—Commercially available 10.00 pH buffer.

TEST METHOD A—PRECISE pH MEASUREMENT OF LOW CONDUCTIVITY WATER UTILIZING THE REAL-TIME FLOWING SAMPLE PROCEDURE

5. Summary of Test Method

5.1 The pH meter and associated electrodes are first standardized with two calibration pH buffers. The pH and reference electrodes and the automatic temperature compensator (if used) must be removed from the sample chamber (see Fig. 2) to proceed with this calibration. The complete calibration procedure is given in Section 10 of this test method.

5.2 A real-time flowing grab sample is taken by means of a flow-through sample chamber with the inlet located at the bottom and the outlet located at the top of the chamber. The

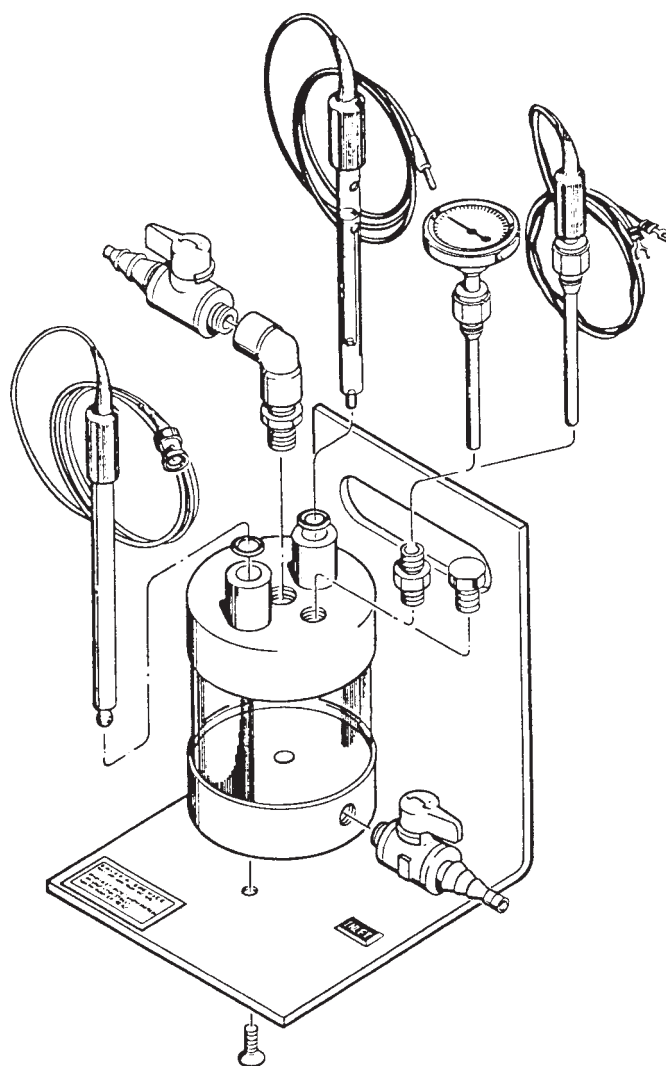


FIG. 2 Exploded View of Sample Chamber

sample chamber prevents the flowing sample from being exposed to the atmosphere. This sample chamber has the pH and reference electrode inserted into the top through gas tight fittings. The temperature compensator (if used) is inserted in a like manner (see Fig. 2 and Fig. 3). The pH of the flowing sample is measured only after the sample chamber has been flushed out with sample water and purged of all air.

5.3 pH measurement of the sample is made with a high purity water pH calibration kit⁵ comprised of a sample chamber, pH and reference electrodes, and automatic temperature compensator (if used). No other type of electrode(s) and pH calibration kit have yet been validated for use with this test method. The sample chamber should accommodate electrodes with an outside diameter of 12 mm ± 0.20 mm (0.472 in. ± 0.008 in.). This is the standard outside diameter size for most pH electrodes manufactured in the United States and Europe.

³ The boldface numbers in parentheses refer to the list of references at the end of this standard.

⁴ *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. Pharmacopeial Convention, Inc. (USPC), Rockville, MD.

⁵ Commercially available from Broadley-James Corporation, HPW pH Cal-Kit Series, Santa Ana, CA; Leeds & Northrup, 7082-90/7773 Series, North Wales, PA.; or equivalent.

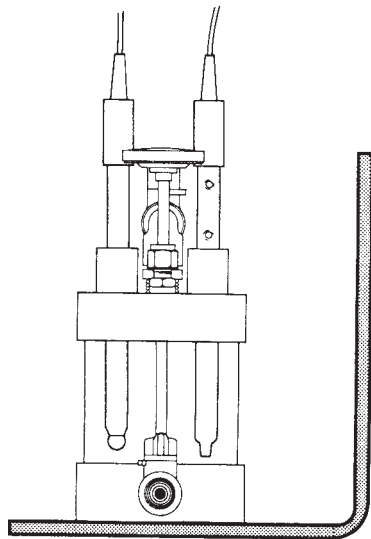
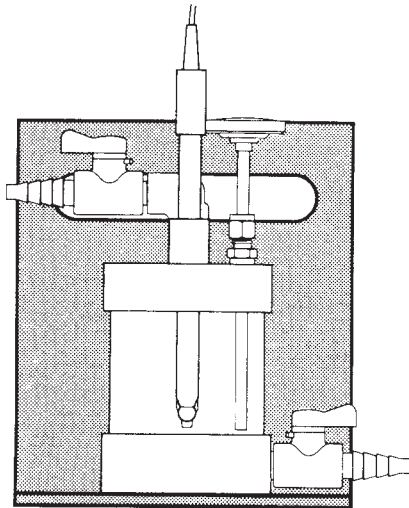


FIG. 3 High Purity Water pH Calibration Sample Chamber

5.4 A trace amount of KCl electrolyte is introduced to calibration buffers and to samples via the controlled leakage rate of the reference electrode liquid junction which stabilizes the liquid junction potential. Excessive KCl introduction from the electrode liquid junction into low ionic strength samples should be avoided. The use of proper apparatus which includes a sample chamber that prevents intrusion of atmospheric gases and a reference electrode with a positive electrolyte leakage rate not to exceed a rate of 10 $\mu\text{L/h}$, will prevent excessive KCl introduction to the sample. Higher rates of up to 50 $\mu\text{L/h}$ of electrolyte leakage can be used if the sample chamber design positions the reference electrode far enough down stream from the glass pH electrode to prevent these impurities from affecting the pH of the sample at the pH electrode site.

5.5 Temperature must be measured and both Solution Temperature Coefficient (STC) and Nernstian effects compensated for, either manually or automatically. The sample chamber, pH electrode pair, and temperature device must be exposed to the

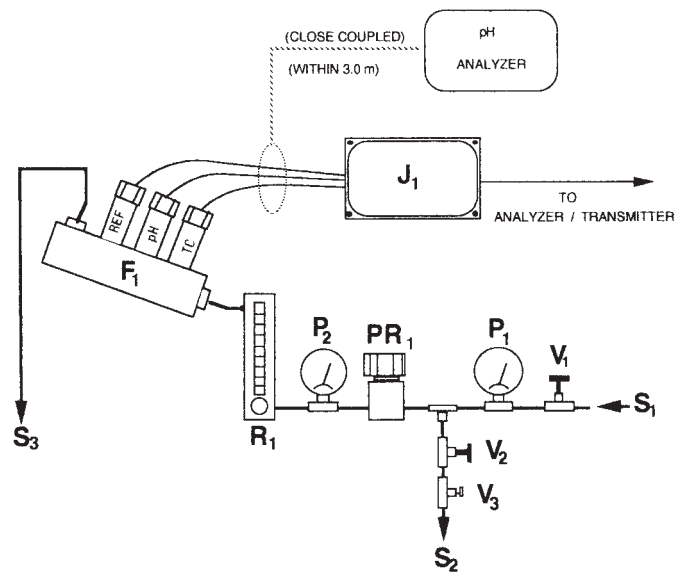
flowing sample long enough to permit temperature equilibration before any measurements are taken.

5.6 The flow rate of the sample through the chamber must be controlled and held constant in order to obtain repeatable results. Each manufacturer of sample chamber must specify a constant flowrate that is optimum for their particular apparatus. To meet this specified constant flowrate, either the grab sample outlet should be controlled with a tamper resistant valve (see Fig. 4 and Fig. 5) or the sample chamber itself should be equipped with an optional rotameter (see Fig. 6). The flowrate should be held constant in the 100 to 300 mL/min range with a constant flowrate of 200 ± 25 mL/min being typically optimal.

6. Significance and Use

6.1 The pH determination of water is a relatively reliable indication of its acidic or alkaline tendency. It is not a measure of the quantity of acidity or alkalinity in a water sample (refer to Test Methods D 1067 and Appendix X1). A pH value less than 7.0 at 25°C shows a tendency toward acidity while a value greater than 7.0 shows a tendency toward alkalinity.

6.2 High purity water is highly unbuffered and the slightest amount of contamination can change the pH significantly. Specifically, high purity water rapidly absorbs CO_2 gas from the atmosphere, which lowers the pH of the sample. The



S₁ SAMPLE INLET, 6.35 mm (1/4 in.) STAINLESS STEEL TUBE FITTING	PR₁ SECONDARY PRESSURE REGULATOR, 0 - 172.4 kPa (gage) (0 - 25 psig)
V₁ HIGH PRESSURE SAMPLE INLET SHUT - OFF VALVE	R₁ ROTAMETER, WITH CONTROL VALVE, 0 - 600 mL/min
P₁ SAMPLE INLET PRESSURE GAUGE 0 - 689.4 kPa (gage) (0 - 100 psig)	P₂ FLOW-CELL PRESSURE GAUGE, 0 - 172.4 kPa (gage) (0 - 25 psig)
V₂ GRAB SAMPLE VALVE / ON-OFF	F₁ HIGH PURITY WATER pH SENSOR
V₃ TAMPER RESISTANT FLOW RATE VALVE, MAX. 200 mL/min AT SPECIFIED SYSTEM PRESSURE	S₃ SAMPLE OUTLET, TO DRAIN, 6.35 mm (1/4 in.), STAINLESS STEEL TUBE FITTING
S₂ GRAB SAMPLE OUTLET	J₁ JUNCTION BOX WITH INTERFACE MODULE

FIG. 4 Schematic for In-Line pH Sensor System with Grab Sample Outlet

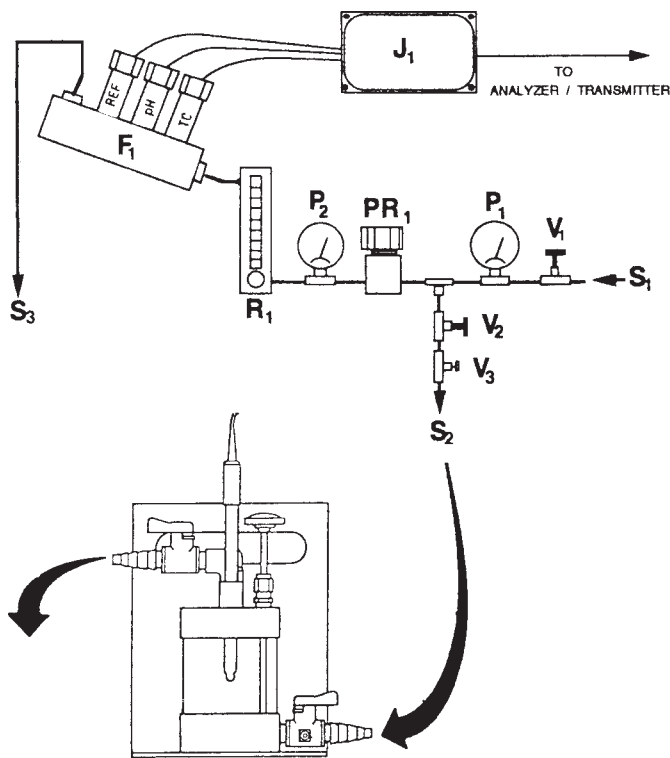


FIG. 5 Sample Chamber Flow Scheme

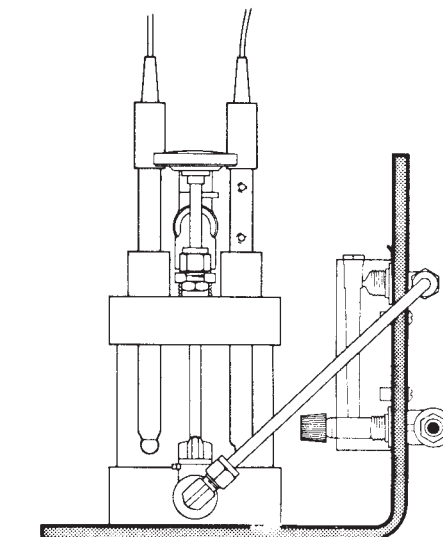


FIG. 6 Sample Chamber with Integral Rotameter

sample chamber and accompanying pH measurement technique avoid exposure of the high purity water sample to the atmosphere.

6.3 The high purity water sample may contain volatile trace components that will rapidly dissipate from the sample if exposed to the atmosphere. The sample chamber used in this test method will prevent these losses.

6.4 High purity water has a significant solution temperature coefficient. For greatest accuracy the sample to be measured should be at the same temperature as the sample stream. By taking a flowing grab sample at the sample line, the operator will use the sample water itself to bring the sample chamber and the measurement electrodes to the sample-line temperature.

7. Interferences

7.1 High purity, low conductivity samples are especially sensitive to contamination from atmospheric gases, from sample containers, and from sample handling techniques and excessive KCl contamination from reference electrode or sample preparation such as a KCl “dosing” technique. Refer to Practice D 4453 and *ASTM STP 823 (2)* for discussions of sample handling and avoidance of sample contamination.

7.2 Specifically, high purity water will rapidly absorb CO_2 from the atmosphere and this will lower the pH of the sample. See Appendix X4, Table X4.1, and Fig. X4.1.

7.3 The temperature stability of the sample and how closely the sample’s temperature matches the sample stream’s temperature will have a direct effect on accuracy of the pH determination. For a discussion of temperature effects on pH measurements of high purity water see Appendix X1.

8. Apparatus

8.1 *Laboratory pH Meter*—See 10.1 in Test Methods D 1293; or use an equivalent portable pH meter.

8.2 *Sample Chamber*— A high purity water pH calibration chamber⁵ is required (refer to Fig. 3). The chamber enables the operator to measure the pH of a real-time flowing sample of water without exposing the sample to atmospheric gases. The chamber is connected to the sample line via a vinyl tube. Vinyl tubing shall be a laboratory grade which will not affect analyses made on solutions or gases which are put through it. The sample flows into the chamber through the bottom port and out of the chamber through the top port. The chamber has o-ring sealed access ports for the insertion of a pH electrode and a reference electrode. Additionally, the chamber has a 316 stainless steel gland fitting for an automatic temperature compensator or a direct-reading temperature measurement device. The chamber is portable, with an integral stand and carrying handle (see Fig. 2 and Fig. 3).

8.3 *Rotameter (optional)*—The flow rate of the sample chamber must be controlled and stabilized in order to obtain repeatable results (see Fig. 6). Some chambers are available with an integral rotameter.

8.4 *pH Glass Electrode*—The pH response of the glass electrode shall conform to the requirements set forth in 12.1 through 12.5 of Test Methods D 1293. New glass electrodes and those that have been stored dry shall be conditioned and maintained as recommended by the manufacturer.

8.5 *Reference Electrode*—Double junction design, having a flowing junction with a positive electrolyte leakage rate not to exceed a rate of 10 $\mu\text{L/h}$ (see 5.4). Prepare and maintain the reference electrode according to the manufacturer's instructions. When using a sample chamber designed for high electrolyte leakage rates, a reference electrode with a maximum rate of 50 $\mu\text{L/h}$ may be used.

8.6 *Temperature Compensator*—See paragraph 10.4 in Test Methods D 1293. The automatic temperature compensator must adapt for use with the sample chamber to measure the temperature of the water within the chamber.

8.7 *Temperature Indicator*—A direct temperature indicating device must be used to measure sample water temperature within the sample chamber if an automatic temperature compensator is not used.

9. Sampling and Sample Handling

9.1 Equipment as described in apparatus Section 8 should be dedicated for high purity water use only.

9.2 The sample chamber should be rinsed three times before use, twice with sample or tap water and once with reagent water. The electrodes, temperature compensator, or temperature reading device, or all of these, should be rinsed three times, using the same procedure as with the sample chamber, after each calibration in pH buffer solutions and before they are inserted into the sample chamber.

9.3 Real-time samples are taken via vinyl tubing attached to the sample take-off point (see Fig. 5) on the sample line. The other end of the tubing is attached to the bottom port of the sample chamber. The sample flows through the vinyl tube, into the bottom of the chamber, and then out the top of the chamber to an atmospheric discharge trough. The pH measurement is made in a continuous flowing sample, which is completely sealed from the atmosphere.

10. Calibration

10.1 Turn on the pH meter and allow it to warm up according to the manufacturer's instructions.

10.2 Remove the pH and reference electrode and temperature compensator (if used) from the sample chamber. After removal, check the reference electrode for proper electrolyte level as recommended by the manufacturer.

10.3 *Two point*—calibrate the electrode pair and pH meter according to manufacturer's instructions. Also, refer to Section 12 of Test Methods D 1293 for guidelines on the standardization of a pH meter and electrode assembly. Use a quiescent sample of Buffer A and Buffer B if the sample point of interest is *below* 7.0 pH. Use a quiescent sample of Buffer A and Buffer C if the sample point of interest is *above* 7.0 pH. Use laboratory glassware dedicated for this service only. Thoroughly

rinse electrode pair and glassware with water three times between each buffer calibration.

10.4 Obtain calibration precision of the pH electrode pair and the pH meter by repeating the two-point calibration described in 10.3, making any necessary readjustments to the pH meter. If the electrode slope (efficiency) is less than 94 % or greater than 101 %, refer to manufacturer's instructions for repair or replacement of electrodes. Thoroughly rinse electrode pair and glassware with water three times between each buffer calibration.

NOTE 2—The pH electrodes in use may pass the above calibration procedures (see 10.1-10.4), but caution should be taken. pH electrodes that are not specifically designed for use in high purity water may develop problems with liquid junction potential during actual test measurements.

10.5 Determine the frequency of the two-point calibration of the electrode pair and the pH meter based on usage. Perform calibration at least daily when pure water sample testing is performed daily. For less frequent pure water sample testing, perform calibration procedures just prior to a consecutive series of sample tests.

10.6 Thoroughly rinse the electrode pair, the temperature compensator, or the temperature reading device, or all of these, and the sample chamber three times (twice with sample water or tap water and once with water), before inserting the probes into the sample chamber.

11. Procedure

11.1 Before starting the procedure, make certain the sample chamber is empty of water. If the chamber contains any water from the last calibration or storage, empty it. This "old" water will only contaminate the highly sensitive high purity water which will flow into the chamber.

11.2 The sample chamber is designed for a constant optimum flow rate of 200 ± 25 mL/min. Either preset a tamper-resistant valve at the grab sample outlet point (see V_3 and S_2 in Fig. 4) or equip the sample chamber with the optional rotameter (see Fig. 6). Do not allow by either means, the flow rate of sample through the sample chamber to exceed 225 mL/min. The flow rate should be held constant.

11.3 Make sure the bottom valve of the sample chamber is closed and the top valve is opened.

11.4 Connect the sample chamber to the sample outlet S_2 with vinyl tubing (see Fig. 5).

NOTE 3—If on-line pH sensors are to be calibrated by this test method (refer to Test Method D 5128), steps must be taken to prevent the disturbance of the on-line pressure and flow rate while the grab sample is being taken. The equipment set-up shown in Fig. 4 will control and stabilize this on-line pressure and flow rate by means of rotameter R_1 and secondary pressure regulator PR_1 even when a sample is taken at grab sample point S_2 (see Appendix X2).

11.5 Open valve V_2 and pull sample without interrupting the sample flow-rate or pressure of the on-line pH sensor assembly (see on-line pH sensor manufacturer's instructions for optimum settings of pressure regulator, rotameter, and valves). The optimum flow-rate through the high purity water sample chamber is a constant 200 ± 25 mL/min. (This flow rate will automatically be obtained after the on-off valve V_2 is opened

and the tamper resistant flow-rate valve V_3 is set as instructed by on-line pH sensor manufacturer.)

11.5.1 If the chamber with the optional integral rotameter is being used, then adjust the rotameter for a constant flow rate of 200 ± 25 mL/min.

11.5.2 Starting with an empty chamber, thoroughly flush the high purity water sample chamber with sample water for at least 15 min at a flow rate of 200 ± 25 mL/min.

11.6 Observe the temperature of the water as indicated on the chamber thermometer and record it for future reference. If the portable pH meter being used has manual temperature compensation, adjust the Temp. Comp. control to the temperature of the sample water in the chamber.

11.7 After the 15 to 30 min sample water flush is complete, allow the water to continue flowing through the chamber. The pH electrode pair will have reached equilibrium by now and the pH meter will be indicating the pH of the sample water. Call this reading R_1 and list the temperature of the sample along with the pH value.

11.8 To use this pH measurement to calibrate an on-line pH sensor, refer to the procedure presented in Appendix X2.

11.9 Close sample valve V_2 followed by the sample chamber's lower inlet valve and finally the upper outlet valve.

NOTE 4—If no further samples are to be taken, the calibrated pH electrode pair may be kept stored in the sample chamber containing a trace amount of the last pure water sample not in contact with either electrode (with inlet and outlet valves shut tight) until the next calibration or sample requirement. For long-term storage of the pH electrode pair, replace them in their respective soaker bottles and appropriate storage solutions (refer to manufacturer's instructions).

12. Precision and Bias

12.1 Since this test method takes a measurement on a flowing sample, a true precision and bias cannot be determined, as stated in Practice D 2777.

12.2 For the results of a study comparing Test Methods A and B, see Annex A3.

TEST METHOD B—pH MEASUREMENT OF LOW CONDUCTIVITY WATER UTILIZING THE STATIC GRAB SAMPLE PROCEDURE

13. Summary of Test Method

13.1 The pH meter and associated electrodes are first standardized with two calibration pH buffers. The pH and reference electrodes and the automatic temperature compensator (if used) must be removed from the sample chamber (see Fig. 2) to proceed with this calibration. The complete calibration procedure is given in Section 10 of Test Method A.

13.2 A grab sample of high purity water is taken by means of filling a sample chamber with the inlet located at the bottom and the outlet located at the top of the chamber. Both inlet and outlet ports are equipped with shut-off valves suitable for attaching the vinyl sample tubing. Once the chamber is filled with a representative sample, the valves can be shut off and the sample may be transported back to a laboratory for analysis. The sample chamber is equipped with o-ring sealed access ports for the pH electrode pair and a 316 stainless steel gland fitting for the temperature indicator or optional automatic

temperature compensator. A suitable stand with carrying handle is provided for portability of the sample chamber (see Fig. 2 and Fig. 3).

13.3 pH measurement of the sample is made with a high purity water pH calibration kit⁵ comprised of a sample chamber, pH and reference electrodes, and automatic temperature compensator (if used). No other type of electrode(s) and pH calibration kit have yet been validated for use with this test method. The sample chamber should accommodate electrodes with an outside diameter of $12 \text{ mm} \pm 0.20 \text{ mm}$ ($0.472 \text{ in.} \pm 0.008 \text{ in.}$). This is the standard outside diameter size for most pH electrodes manufactured in the United States and Europe.

13.4 A trace amount of KCl electrolyte is introduced to calibration buffers and to samples via the controlled leakage rate of the reference electrode liquid junction to stabilize the liquid junction potential. Excessive KCl introduction from the electrode liquid junction into low ionic strength samples will increase solution conductivity, and alter solution pH, and should be avoided. The use of proper apparatus which includes a sealed sample chamber in conjunction with a reference electrode with a positive electrolyte leakage rate not to exceed a rate of $10 \mu\text{L/h}$, will prevent excessive KCl introduction to the sample.

13.5 Temperature must be measured and both Solution Temperature Coefficient (STC) and Nernstian effects compensated for, either manually or automatically on the pH meter. See Appendix X1 for a discussion on temperature effects.

13.6 The chamber should not be filled at a rate of greater than 225 mL/min . Either the grab sample outlet should be controlled with a tamper resistant valve (as in Fig. 4) or the sample chamber should be equipped with an optional rotameter (as in Fig. 6).

14. Significance and Use

14.1 Although there are similarities between Test Methods A and B, there are also valid reasons for considering one test method versus the other. Whenever Test Method A, which requires a real-time, short duration, flowing sample, cannot be utilized for practical reasons such as physical plant layout, location of on-line equipment sample points, or availability of dedicated test equipment, Test Method B offers a viable alternative procedure.

14.1.1 The most significant difference between the two test methods is that Test Method A obtains a *real-time* pH measurement from a flowing sample and Test Method B obtains a *time delayed* pH measurement from a static grab sample.

14.2 pH measurements of low conductivity water are plagued with interferences (see 7.1-7.3) and Test Method A is more effective in eliminating these interferences especially with regard to temperature effects. The static grab sample (Test Method B) is more prone to contamination and temperature-induced errors because of the time lag between the sampling in the plant and sample pH reading which is taken in the laboratory.

14.3 If the purpose of these pH measurements is to verify or calibrate, or both, an on-line pH sensor, refer to Test Method D 5128 which requires a real-time, flowing sample technique

in order to minimize interference errors introduced by both streaming and liquid junction potentials as well as temperature effects.

14.4 For additional information on significance and use see 6.1-6.4.

15. Interferences

15.1 See 7.1-7.3 and Appendix X1.

16. Apparatus

16.1 *Laboratory pH Meter*—See 8.1.

16.2 *Sample Chamber*— See 8.2.

16.3 *Rotameter (optional)*—See 8.3.

16.4 *pH Glass Electrode*—See 8.4.

16.5 *Reference Electrode*—Double junction design, having a flowing junction with a positive electrolyte leakage rate not to exceed a rate of 10 $\mu\text{L}/\text{h}$ (see 13.4). Prepare and maintain the reference electrode according to the manufacturer's instructions.

16.6 *Temperature Compensator*—See 8.6.

16.7 *Temperature Indicator*—See 8.7.

17. Sampling and Sample Handling

17.1 For information on sampling and sample handling see 9.1 and 9.2.

17.2 Static grab samples are taken via vinyl tubing attached to the sample take-off point (see Fig. 5) on the sample line. The other end of the tubing is attached to the bottom port of the sample chamber. The sample flows through the vinyl tube, into the bottom of the chamber, and then out the top of the chamber to an atmospheric discharge trough. After a 15- to 30-min flush of the chamber with the sample water, the chamber's bottom valve is first shut off and then the top valve is shut off. This seals the chamber and isolates the sample from the atmosphere. The pH reading of the sample should be taken while the sample is at the same temperature as the on-line sample.

18. Calibration

18.1 See 10.1-10.6.

19. Procedure

19.1 See 11.1-11.6.

19.2 Close sample valve V_2 followed by the high purity water calibration kit's lower inlet valve and finally the upper outlet valve.

19.3 Without removing the high purity water pH electrode pair or temperature device, transport the entire sample chamber to the laboratory without delay. The measurement with the pH meter must be taken within 3 min of the grab sample in order to minimize KCl contamination from the reference electrode and prevent a change in the temperature of the grab sample.

NOTE 5—This grab sample must be kept at the exact temperature as the flowing stream for measurement in the lab. If not, appropriate STC correction procedures must be implemented. See Appendix X1 for more information.

19.4 In the laboratory, attach the high purity water pH electrodes to the dedicated high purity water lab pH meter (to which the electrode pair has already been calibrated) and record the pH reading. Call this reading R_1 .

19.5 To use this pH measurement to calibrate an on-line pH sensor, refer to the procedure addendum in Appendix X3.

NOTE 6—If no further samples are to be taken, the calibrated pH electrode pair may be kept stored in the high purity water pH calibration kit sample chamber containing a trace amount of the last pure water sample not in contact with either electrode (with inlet and outlet valves shut tight) until the next calibration or sample requirement. For long term storage of the pH electrode pair, replace them in their respective soaker bottles and appropriate storage solutions (see manufacturer's instructions).

20. Precision and Bias

20.1 Since this test method relies on the capture of a flowing sample, and since this sample must remain captive until after the measurement is taken, a true precision and bias cannot be determined, as stated in Practice D 2777.

20.2 For the results of a study comparing Test Methods A and B, see Annex A3.

21. Keywords

21.1 automatic temperature compensator; controlled leakage rate; flowing liquid junction; high purity water; liquid junction potential; low conductivity water; pH glass electrode; pH temperature coefficient; reference electrode; solution temperature coefficient

ANNEXES

(Mandatory Information)

A1. DISCUSSION OF THE CONDUCTIVITY RANGE FOR THESE TEST METHODS

A1.1 The scope of these test methods provides the user with a guideline conductivity range ($<100 \mu\text{S}/\text{cm}$) for what is considered low conductivity or pure water. This conductivity range is not a specific cut-off or limit, but is intended to provide the user of these test methods with an indication of when to apply these test methods for reliable pH measurements of waters with low conductivity. A number of known interferences and problems apply to pH measurement apparatus and methods when attempting pH measurement of waters with low

conductivities. These interferences (see 7.1-7.3) are not necessarily applicable to highly buffered waters typified by conductivity levels above $100 \mu\text{S}/\text{cm}$. Table A1.1 and Table A1.2 illustrate the high pH sensitivity of low ionic strength water samples containing low concentrations of trace contaminants. The source of these contaminants can be the atmosphere (see Table X4.1), the pH measurement apparatus, and improper procedures. The user of these test methods is well advised to use the specialized apparatus and procedures given in these test

TABLE A1.1 Calculated Conductivity and pH Values at 25°C of Low Concentrations of NaOH in Pure Water^{A, B}

NOTE 1—This table tabulates the theoretical conductivity and pH values of low levels of NaOH in pure water as calculated from available thermodynamic data.

NOTE 2—To illustrate the high sensitivity of the sample pH at these low concentrations to contaminants, the last column lists errors that would result if the sample were contaminated with an additional 1 mg/L through sample or equipment handling errors.

Sample Concentration, mg/L	Sample Conductivity, $\mu\text{S/cm}$	Sample pH	ΔpH Error from Additional 1 mg/L NaOH Contaminate
0.001	0.055	7.05	$\Delta 2.35$
0.010	0.082	7.45	$\Delta 1.95$
0.100	0.625	8.40	$\Delta 1.03$
1.0	6.229	9.40	$\Delta 0.30$
8.0	49.830	10.30	$\Delta 0.05$

^AData courtesy of R. C. Hunt, "Calculated pH and Conductivity Values," Sensor Development, Inc., June 1986.

^BThis data was developed from algorithms originally published in *Ultrapure Water* as: Hunt, Robert C., "A Review of pH and Conductivity Measurement Techniques in High Purity Water, with Bibliography," *Ultrapure Water*, Vol 4, 1987, p. 26.

TABLE A1.2 Calculated Conductivity and pH Values at 25°C of Low Concentrations of HCl in Pure Water^{A, B}

NOTE 1—This table tabulates the theoretical conductivity and pH values of low levels of HCl in pure water as calculated from available thermodynamic data.

NOTE 2—To illustrate the high sensitivity of the sample pH at these low concentrations to contaminants, the last column lists errors that would result if the sample were contaminated with an additional 1 mg/L through sample or equipment handling errors.

Sample Concentration, mg/L	Sample Conductivity, $\mu\text{S/cm}$	Sample pH	ΔpH Error from Additional 1 mg/L HCl Contaminate
0.001	0.060	6.94	$\Delta 2.38$
0.010	0.134	6.51	$\Delta 1.95$
0.100	1.166	5.56	$\Delta 1.03$
1.0	11.645	4.56	$\Delta 0.30$
8.0	93.163	3.66	$\Delta 0.05$

^AData courtesy of R. C. Hunt, "Calculated pH and Conductivity Values," Sensor Development, Inc., June 1986.

^BThis data was developed from algorithms originally published in *Ultrapure Water* as: Hunt, Robert C., "A Review of pH and Conductivity Measurement Techniques in High Purity Water, with Bibliography," *Ultrapure Water*, Vol 4, 1987, p. 26.

methods when attempting pH measurements of waters with a

conductivity <100 $\mu\text{S/cm}$.

A2. CONSIDERATIONS FOR THE REQUIREMENT OF SPECIALIZED pH MEASUREMENT APPARATUS

A2.1 pH electrodes are available in many different configurations containing a wide variety of membrane and liquid junction designs as well as a variety of internal electrolyte formulations. Selection of the appropriate pH electrode features required for pH measurement of low conductivity water is not necessarily obvious. This section offers assistance in this area.

A2.1.1 The temperature coefficient of the measurement electrodes will affect the accuracy and repeatability of the measurement. Electrodes which quickly equilibrate to each other and the sample temperature must be selected for this service. Refer to X1.2 in Test Method D 1293 and *ASTM STP 190* (3).

A2.1.2 Continuous exposure of the pH electrode to low ionic strength solutions may result in the degradation of the glass membrane portion of some pH electrodes (4). Electrodes suitable for continuous service in low conductivity water should be included in the pH electrode selection.

A2.1.3 The development of changes in liquid junction potentials (1) with time and eventual degradation of the reference half-cell caused by diffusion of low ionic strength

sample water into the high ionic strength electrolyte of the half cell must be avoided in order to effect an accurate and stable pH measurement.

A2.2 All sorts of laboratory glassware and plasticware containers have been used to grab and contain low conductivity water samples for pH measurement. A sample container used for this service should be dedicated for use with only low conductivity water samples to avoid carry-over contamination. Further, such a container should be designed such that it seals the sample from atmospheric gas contaminants (see Table X4.1) while preventing volatile sample constituents from escaping for the duration of each sample measurement. The sample container should contain the pH electrodes and temperature compensator in such a manner that the sample is not opened to the atmosphere to permit exposure of the sample to these electrodes. This chamber should permit a short duration real-time flowing or grab sample to be taken in such a manner that the sample temperature is not altered. Incorporation of these design features for the sample chamber apparatus will help to eliminate the known interferences and problems associated with pH measurements of low conductivity water samples.

A3. COMPARISON OF TEST METHODS A AND B

A3.1 A series of comparison readings, using Test Methods A and B, were performed on a PWR secondary side feedwater system. Five hundred sixty-six comparison measurements were taken by 14 operators on the system during a 14-month period. The pH range of the system was 8.25 to 9.45.

A3.2 Based on a root-mean-square sum of difference (5), the two methods agree to within 0.30 pH units 95 % of the time.

A3.3 A comparison study was performed on these data to determine if there is a bias between the two test methods (6). The average measurement difference between these two test methods is 0.007 pH units, with a standard deviation of 0.106, and a standard error of the mean equal to 0.004, based on 565 degrees of freedom. This calculates to a Z-value of 1.54, which is not significant at the 90 % confidence level. Therefore, there is no bias between these two test methods.

APPENDIXES

(Nonmandatory Information)

X1. TEMPERATURE EFFECTS IN ULTRA-PURE WATER

X1.1 There are two types of temperature effects that are of main concern during the pH measurement of ultra-pure water:

X1.1.1 Standard Nernst equation temperature factor;

X1.1.2 Solution Temperature Coefficient (STC) effect of ultra-pure water.

X1.2 The standard Nernstian compensation is provided, as usual, by the automatic temperature compensation (ATC) feature of most pH meters and the temperature sensor provided with the pH electrodes or sensor assembly.

X1.2.1 pH meters with manual temperature compensation can accomplish the same result as long as the operator accurately measures the sample temperature and selects that temperature on the pH meter.

X1.3 The STC effect is the rate at which a particular water sample changes its pH with changes in temperature. This rate is unique for the amounts and types of trace constituents that are found in a particular sample of high purity water. Since high purity water is highly unbuffered, the STC can be significant. Small amounts (of the order in milligrams per litre) of contaminants can cause samples to have temperature coefficients as large as -0.03 pH unit/ $^{\circ}$ C.

X1.4 The STC poses a significant problem when the Test Method B pH determination is done with a static grab sample or when the complete Grab Sample Calibration (GSC) technique is used to calibrate on-line pH sensors (see Appendix X3). In these procedures, the sample to be measured is transported back to the lab for analysis. By that time, the sample may have cooled down by as much as 15° C and its pH may have increased by as much as 0.5 pH unit.

X1.4.1 The chemical composition of the sample at the temperature of interest (the on-line sample temperature) has not changed. Thus, if lab technicians conclude that the on-line water stream is high in alkali because the pH reading in the lab is high, they may be wrong. That same water at the higher on-line temperature might have just the right pH and chemical composition.

X1.5 The STC effect poses no problems when the Test Method A pH determination is done with a flowing sample or the complete flowing sample calibration (FSC) technique is used to calibrate on-line pH sensors (see Appendix X2). In these procedures the sample used for measurement is the same temperature as the on-line water stream and thus they are at the same pH.

X1.6 Avoid STC effect errors. If Test Method A or the complete FSC procedure is used, then nothing more need be done. Both the Test Method A and the FSC procedures avoid the temperature differentials between sample and stream that cause the problem. If the Test Method B or the complete GSC procedure is used, then the technician must try one of the following correction schemes.

X1.6.1 If Test Method B or the complete GSC procedure must be used, then the technician must try to determine the solution temperature coefficient (STC) that predicts the pH of the sample stream at whatever temperature it might be. For example, the technician can measure the pH in the laboratory at 22° C and then calculate what the on-line pH must be at 25° C by applying the STC.

X1.6.2 A first-order approximation can be made for a system if the technician makes the assumption that the system consists of only water and ammonia (NH_3). However, determining the STC for low ionic strength solutions becomes quite complex if the water contains more than one constituent, as is usually the case in actual industrial systems. Such a determination requires specially derived algorithms that depend on the number of constituents and their concentration in the low ionic strength solution. A large assumption must then be made that the concentration of only one of the constituents will vary in the process (that is, for NH_3).

X1.6.3 This derived STC is only as good as the technician's knowledge of the actual water chemistry. If the analysis of the trace constituents of the water is inaccurate, the derived STC can produce significant errors. An unknown trace constituent can change the pH of the solution in ways the derived STC will

not predict. Water chemistry can be changed by pipe corrosion, contaminants plated out on pipe walls, resin spills, and air leaks.

X1.6.4 The technician may attempt to empirically derive the STC by measuring the pH of a known solution at two or more different temperatures. The technician must observe and record the pH of the high purity water at various temperatures over a period of time during which the water chemistry is constant and representative. This technique has many practical pitfalls that leave much to be desired. However, for water chemistries that remain fairly constant, it may be possible to empirically derive a STC correction factor which can then be used to reference all pH readings of that particular water stream (or samples taken from it) to 25°C.

X1.6.5 Table X1.1 and Table X1.2 list pH values and temperature corrections for normalizing pH measurements to 25°C as calculated by NUS Corporation. These calculated values may be applicable for the following solutions:

X1.6.5.1 Pure water;

X1.6.5.2 Matrix No. 1: 4.84 mg/L sulfate (prepared from sulfuric acid), which represents an acidic solution at pH 4.0 at 25°C;

X1.6.5.3 Matrix No. 2: 0.272 mg/L ammonia and 20 µg/L hydrazine, which represents average conditions for steam cycle all-volatile chemistry control (pH 9.0 at 25°C);

X1.6.5.4 Matrix No. 3: 1.832 mg/L ammonia, 10 mg/L morpholine, and 50µ g/L hydrazine, which represents conditions for all-volatile chemistry control at high pH with amines (pH 9.6 at 25°C);

X1.6.5.5 Matrix No. 4: 3 mg/L phosphate with a sodium-to-phosphate molar ratio of 2.7 with 0.3 mg/L ammonia, which represents average conditions for phosphate chemistry control.

X1.6.6 The results of the calculated pH values for these solutions and temperature corrections are given in Table X1.1 and Table X1.2. Observe that the temperature corrections for the basic solutions are essentially the same, and approximately twice the correction for pure water.

X1.6.7 Solutions other than the ones identified in X1.6.5.1-X1.6.5.5 require specific information on the matrix. Generally, acidic solutions require no temperature correction for pH (the moles per litre does not change as a function of temperature; just the solution density and activity coefficients for a strong acid), a pure water solution changes about 0.015 pH unit per °C, and a basic solution changes approximately 0.033 pH unit per °C.

X1.7 In summary, it is recommended that for greatest accuracy and repeatability to use Test Method A or the complete flowing sample calibration (FSC) technique at the on-line sample site and avoid any problems associated with the STC.

X1.7.1 If Test Method B is used, then care must be taken to avoid STC effect errors by maintaining a constant sample

TABLE X1.1 pH as a Function of Temperature for Different Matrixes^{A, B}

Temperature, °C	Matrix No. 1 pH	Matrix No. 2 pH	Matrix No. 3 pH	Matrix No. 4 pH
0	4.004	9.924	10.491	10.388
1	4.004	9.882	10.451	10.345
2	4.004	9.840	10.411	10.303
3	4.004	9.800	10.372	10.261
4	4.004	9.759	10.333	10.219
5	4.004	9.719	10.294	10.178
6	4.004	9.680	10.256	10.138
7	4.004	9.640	10.218	10.098
8	4.004	9.602	10.181	10.058
9	4.004	9.563	10.144	10.019
10	4.004	9.525	10.108	9.981
11	4.004	9.488	10.072	9.943
12	4.004	9.451	10.036	9.905
13	4.004	9.414	10.001	9.868
14	4.005	9.378	9.966	9.831
15	4.005	9.342	9.932	9.795
16	4.005	9.307	9.898	9.759
17	4.005	9.272	9.864	9.723
18	4.005	9.237	9.831	9.688
19	4.005	9.203	9.798	9.654
20	4.005	9.169	9.765	9.619
21	4.005	9.135	9.732	9.583
22	4.006	9.102	9.700	9.552
23	4.006	9.069	9.669	9.519
24	4.006	9.036	9.637	9.486
25	4.006	9.002	9.604	9.451
26	4.006	8.972	9.576	9.421
27	4.006	8.940	9.545	9.390
28	4.007	8.909	9.515	9.358
29	4.007	8.878	9.485	9.327
30	4.007	8.847	9.456	9.296
31	4.007	8.817	9.426	9.266
32	4.007	8.787	9.397	9.236
33	4.008	8.757	9.369	9.206
34	4.008	8.728	9.340	9.177
35	4.008	8.699	9.312	9.148
36	4.008	8.670	9.284	9.119
37	4.009	8.641	9.257	9.091
38	4.009	8.613	9.229	9.063
39	4.009	8.585	9.202	9.035
40	4.010	8.557	9.175	9.007
41	4.010	8.529	9.149	8.980
42	4.010	8.502	9.122	8.953
43	4.010	8.475	9.096	8.925
44	4.011	8.448	9.070	8.900
45	4.011	8.422	9.044	8.874
46	4.011	8.396	9.019	8.848
47	4.012	8.370	8.994	8.823
48	4.012	8.344	8.969	8.757
49	4.012	8.318	8.944	8.772
50	4.013	8.293	8.919	8.748

^ASee X1.6.3.

Matrix No. 1: 4.84 mg/L SO₄⁼ (from sulfuric acid),
 2: 0.272 mg/L NH₃ + 20 µg/L N₂H₄,
 3: 1.832 mg/L NH₃ + 10.0 mg/L morpholine + 50 µg/L N₂H₄, and
 4: 3.0 mg/L PO₄⁼ at 2.7 Na⁺:PO₄⁼ + 0.30 mg/L NH₃.

^BValues calculated by John Riddle, NUS Corporation, Pittsburgh, PA.

temperature or by using tables such as Table X1.1 and Table X1.2 to normalize the pH measurement to 25°C.

X1.7.2 pH instrumentation with programmable algorithms for the STC correction factor enables both the sample pH calibration measurements and continuous on-line pH measurements to be more error free (7).

TABLE X1.2 Temperature Corrections of pH Measurements for Different Matrixes^{A, B}

Temperature, ° C	Pure Water Temperature Correction	Matrix No. 1 Temperature Correction	Matrix No. 2 Temperature Correction	Matrix No. 3 Temperature Correction	Matrix No. 4 Temperature Correction
0	-0.477	-0.002	-0.923	-0.887	-0.937
1	-0.455	-0.002	-0.881	-0.847	-0.894
2	-0.433	-0.002	-0.838	-0.807	-0.851
3	-0.412	-0.002	-0.798	-0.767	-0.809
4	-0.390	-0.002	-0.757	-0.728	-0.768
5	-0.369	-0.002	-0.717	-0.690	-0.727
6	-0.349	-0.002	-0.678	-0.652	-0.686
7	-0.328	-0.002	-0.639	-0.614	-0.647
8	-0.308	-0.002	-0.600	-0.577	-0.607
9	-0.288	-0.002	-0.561	-0.540	-0.568
10	-0.269	-0.002	-0.524	-0.504	-0.530
11	-0.249	-0.002	-0.486	-0.468	-0.491
12	-0.230	-0.002	-0.449	-0.432	-0.454
13	-0.211	-0.002	-0.412	-0.397	-0.417
14	-0.193	-0.002	-0.376	-0.362	-0.380
15	-0.174	-0.001	-0.340	-0.327	-0.343
16	-0.156	-0.001	-0.305	-0.293	-0.308
17	-0.138	-0.001	-0.270	-0.260	-0.272
18	-0.120	-0.001	-0.235	-0.226	-0.237
19	-0.102	-0.001	-0.201	-0.193	-0.202
20	-0.085	-0.001	-0.167	-0.160	-0.168
21	-0.068	-0.001	-0.133	-0.128	-0.132
22	-0.051	-0.001	-0.100	-0.096	-0.100
23	-0.034	-0.000	-0.067	-0.064	-0.057
24	-0.017	-0.000	-0.034	-0.033	-0.034
25	0.000	0.000	0.000	0.000	0.000
26	0.015	0.000	0.030	0.029	0.030
27	0.031	0.000	0.062	0.059	0.062
28	0.047	0.001	0.093	0.089	0.093
29	0.063	0.001	0.124	0.119	0.124
30	0.078	0.001	0.154	0.149	0.155
31	0.094	0.001	0.185	0.178	0.185
32	0.109	0.001	0.215	0.207	0.215
33	0.124	0.002	0.245	0.236	0.245
34	0.139	0.002	0.274	0.264	0.274
35	0.153	0.002	0.303	0.292	0.304
36	0.168	0.002	0.332	0.320	0.332
37	0.182	0.003	0.361	0.348	0.361
38	0.196	0.003	0.389	0.375	0.389
39	0.210	0.003	0.417	0.402	0.417
40	0.224	0.004	0.445	0.429	0.444
41	0.238	0.004	0.472	0.456	0.471
42	0.252	0.004	0.500	0.482	0.498
43	0.265	0.004	0.527	0.508	0.525
44	0.278	0.005	0.553	0.534	0.551
45	0.292	0.005	0.580	0.560	0.577
46	0.305	0.005	0.606	0.585	0.603
47	0.318	0.006	0.632	0.611	0.629
48	0.330	0.006	0.658	0.636	0.654
49	0.343	0.006	0.684	0.661	0.679
50	0.356	0.007	0.709	0.685	0.704

^ASee X1.6.3.

Matrix No. 1: 4.84 mg/L SO₄ = (from sulfuric acid),

2: 0.272 mg/L NH₃ + 20 µg/L N₂H₄,

3: 1.832 mg/L NH₃ + 10.0 mg/L morpholine + 50 µg/L N₂H₄, and

4: 3.0 mg/L PO₄ at 2.7 Na⁺:PO₄⁻ = + 0.30 mg/L NH₃.

^BValues calculated by John Riddle, NUS Corporation, Pittsburgh, PA.

X2. SUPPLEMENT TO TEST METHOD A—THE FLOWING SAMPLE CALIBRATION (FSC) PROCEDURE TO CALIBRATE ON-LINE pH SENSORS

X2.1 The following is an addendum to Test Method A that details how to use the Test Method A high purity water pH determination to calibrate an on-line pH sensor.

sample stream) has been recorded, immediately record the pH of the sample stream as indicated by the on-line pH instrumentation. Designate this reading R_2 .

X2.2 Regarding Section 11, after R_1 (the pH of the flowing

X2.3 Now compare portable pH meter reading, R_1 , with the

on-line pH instrumentation reading, R_2 . If the two readings differ by more than 0.1 pH unit, adjust the standardization (e.g., zero or offset) control of the on-line pH instrument.

X2.4 If the on-line adjustment can be made while you can simultaneously watch the portable pH meter reading R_1 , then simply adjust the on-line instrument until it agrees with the portable pH meter reading R_1 .

X2.5 If the on-line instrument *cannot* be adjusted simultaneously as you watch the portable pH reading, then adjust the on-line pH instrument as follows:

X2.5.1 Adjust the on-line instrument by adding the difference between the first two readings, R_1 and R_2 . Some microprocessor based on-line pH instruments provide this differential calibration automatically.

X3. SUPPLEMENT TO TEST METHOD B—THE GRAB SAMPLE CALIBRATION (GSC) PROCEDURE TO CALIBRATE ON-LINE pH SENSORS

X3.1 The following is an addendum to Test Method B that details how to use the Test Method B high purity water pH determination to calibrate an on-line pH sensor.

X3.2 Regarding Section 20, after the grab sample has been taken at the point of interest, immediately record the pH of the flowing sample stream as indicated by the on-line pH instrumentation. Designate this reading R_2 .

X3.3 Close sample valve V_2 followed by the HPW Cal-Kit's lower inlet valve and finally the upper outlet valve.

X3.4 Without removing the HPW electrode pair, transport the entire HPW Cal-Kit chamber to the laboratory without delay. This grab sample must be kept at the exact temperature as the flowing stream for measurement in the lab. If not, appropriate solution temperature coefficient correction proce-

dures must be implemented (see X1.6).

X3.5 In the lab, attach the HPW electrodes to the dedicated high purity water lab pH meter (to which the electrodes have been previously calibrated) and record the pH reading. Designate this reading R_1 .

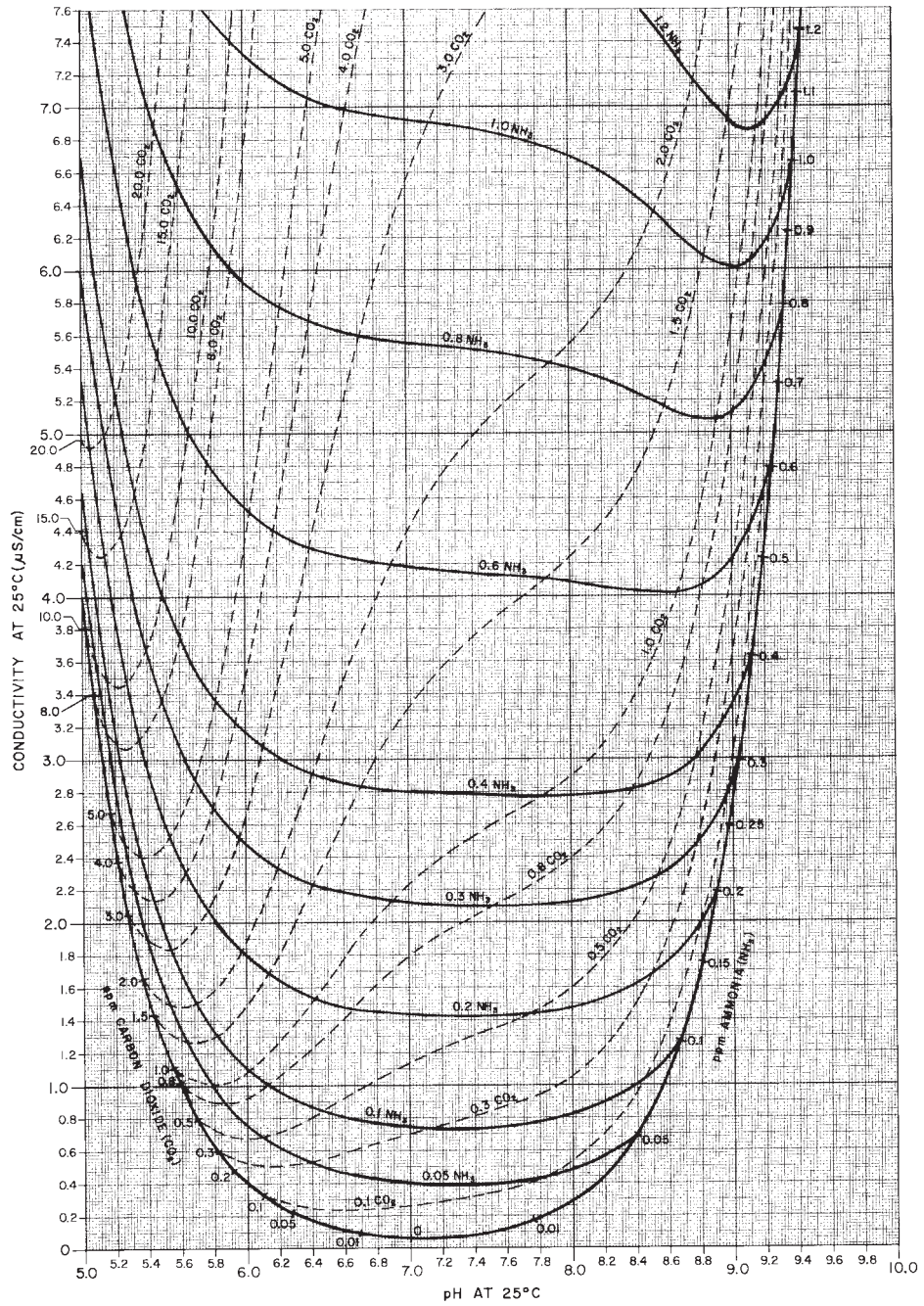
X3.6 Now compare lab pH meter reading, R_1 , with the on-line pH instrumentation reading, R_2 . If the two readings differ by more than 0.1 pH unit, adjust the standardization (that is, zero or offset) control of the on-line pH instrument as follows:

X3.6.1 Adjust the on-line instrument by adding the difference between the first two readings, R_1 and R_2 . Some microprocessor based on-line pH instruments provide this differential calibration automatically.

X4. EFFECTS OF CO₂ ON pH MEASUREMENTS OF HIGH PURITY WATER

X4.1 High purity water will rapidly absorb carbon dioxide when exposed to the atmosphere. Carbon dioxide levels in the atmosphere are slightly greater than 300 ppm by volume. Pure water by definition does not contain carbon dioxide. However, in practice CO₂ is present in trace to very low levels in most low conductivity water samples. High purity water on-line pH sensor assemblies and related sample system hardware should be designed and installed in such a manner as to prevent the intrusion of carbon dioxide from the atmosphere. See Fig. X4.1

for the theoretical pH and conductivity values of ammonia solutions at various carbon dioxide levels. Also, see Table X4.1 for the theoretical pH shift caused by 0.2 mg/L CO₂ contamination of a high purity water sample. This information is provided to give the user an indication of the level of pH measurement error introduced by the presence of CO₂. The user should determine the actual effects of CO₂ contamination for the user's specific operating conditions as they may differ from application to application.



NOTE 1—Calculated by John Riddle, NUS Corporation, Pittsburgh, PA.

FIG. X4.1 pH and Conductivity of Ammonia Solutions at Various Carbon Dioxide Levels

TABLE X4.1 Calculated pH and Conductivity Values at 25°C of Water Solutions Containing only Ammonia and Carbon Dioxide^A

Ammonia, mg/L	Carbon Dioxide, 0 mg/L		Carbon Dioxide, 0.2 mg/L		pH Shift Caused by 0.2 mg/L CO ₂ Contamination of Sample
	μS/cm	pH	μS/cm	pH	
0	0.056	7.00	0.508	5.89	Δ1.11 pH
0.12	1.462	8.73	1.006	8.18	Δ0.55 pH
0.51	4.308	9.20	4.014	9.09	Δ0.11 pH
0.85	6.036	9.34	5.788	9.26	Δ0.08 pH
1.19	7.467	9.44	7.246	9.38	Δ0.06 pH

^AData extracted from CERL Laboratory Memorandum # RD/L/M 474 "Theoretical Calculation of the Electrical Conductivity of Power Station Waters," W. G. Cummings and K. Torrance, CERL Laboratories, United Kingdom, Oct. 9, 1974.

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