



Standard Practice for Testing Conductivity Detectors Used in Liquid and Ion Chromatography¹

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1. Scope

1.1 This practice covers the testing of the performance of conductivity detectors used as the detection component of a liquid or ion chromatography system.

1.2 The values stated in SI units are to be regarded as the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

E 1151 Practice for Ion Chromatography Terms and Relationships²

3. Terminology

3.1 See Practice E 1151.

3.2 *Definitions:*

3.2.1 *cell constant*—the cell constant (K) of a conductivity cell is equal to $1/A$, so $\kappa = G K$.

3.2.1.1 *Discussion*—If the cell constant of the flow-through cell used is equal to one, then the conductivity equals the conductance. Although the cell constant is often specified for conductivity detectors, there is little practical value in knowing the constant as long as the detector is properly calibrated for conductivity.

3.2.2 *conductance*—the conductance (G) of a solution is the inverse of the resistance measured between two electrodes in a cell, expressed in units of siemens (S), equal to inverse ohms.

3.2.2.1 *Discussion*—The term resistance refers specifically to the dc resistance to ionic current, independent of the capacitive reactance at the interfaces between the electrodes and the solution.

3.2.3 *conductivity*—since the conductance is dependent on both the conductive properties of the solution and on the dimensions of the electrodes and the cell, the conductivity (κ) of the solution is defined to be independent of electrode and cell dimensions. Specifically,

$$\kappa = G \frac{1}{A} \quad (1)$$

where l is the distance between two planer disk electrodes and A is the electrode's surface area.

3.2.3.1 *Discussion*—In liquid and ion chromatography, cell dimensions are commonly measured in centimetres, so the units of κ are S/cm. (Alternatively, the SI units of S/m may be used. S/m = 100 S/cm.)

3.2.4 *drift*—the average slope of the noise envelope expressed in nano siemens per centimetre per hour as measured over a period of 1 h.

3.2.5 *equivalent conductivity*—of an ionic solute, the contribution of the solute to the total conductivity of the solution, measured in microsiemens per centimetre, divided by its concentration in milliequivalents/litre.

3.2.6 *flow dependence rate*—the change in measured conductivity as a function of flow rate.

3.2.7 *limiting equivalent conductivity*—of an ionic solute, its equivalent conductivity extrapolated to infinite dilution.

3.2.8 *linear range*—of a conductivity detector for a given solute in a specific solvent, the concentration range of solute for which the detector response factor is within 5 % of the response factor in the middle of the range as determined from the linearity plot specified in Section 11.

3.2.8.1 *Discussion*—The lower limit may be limited by noise, and the upper limit by deviation from linearity. (The upper limit may instead be limited by the maximum full-scale deflection on the detector's least sensitive output range.)

3.2.9 *long-term noise*—the maximum amplitude in nano siemens per centimetre for all random variations of the detector output of frequencies between 2 and 60 cycles per hour.

3.2.9.1 *Discussion*—Long-term noise represents noise which can be mistaken for eluting peaks.

3.2.10 *minimum detectability*—of a conductivity detector, that concentration of solute in a specific solvent which corresponds to twice the short-term noise.

3.2.10.1 *Discussion*—Because of the difficulty of pumping solvents through the chromatographic system without any contamination of the solvents from the system, this quantity can only be measured with solutes retained by a column. Since minimum detectability is dependent on the chromatographic system used, it is not measured in this practice. However, if the minimum detectability of a solute is measured on one system with one detector, the minimum detectability can be predicted when other detectors are tested on the same system by

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² *Annual Book of ASTM Standards*, Vol 14.02.

comparing the measured values of short-term noise.

3.2.11 *response factor*—of a conductivity detector, the measured conductivity response of a solute divided by the solute concentration.

3.2.12 *response time of the detector*—the time required for the output of the detector to change from 10 % to 90 % of the new equilibrium value when the composition of the eluent is changed in a stepwise manner, within the linear range of the detector.

3.2.12.1 *Discussion*—A slow response time has the effect of limiting resolution for efficient peaks such as early eluting peaks and those from highly efficient columns or microbore columns. Response time is generally dependent on three factors: (a) cell volume, (b) volume of heat transfer tubing leading to the cell, and (c) electronic filtering of the output.

3.2.13 *sensitivity*—the detector response divided by concentration, which is also the response factor (11.1.1).

3.2.13.1 *Discussion*—Sensitivity is therefore by definition the same for all properly calibrated conductivity detectors. (Sensitivity is often confused with minimum detectability, which is dependent on both sensitivity and noise.) Therefore, the calibration of the detector should be measured, and if necessary, adjusted. Follow the manufacturer’s procedure for calibrating the detector. The procedure in Section 9 is used by many manufacturers and is useful for the tests in this practice.

3.2.14 *short-term noise*—the maximum amplitude in nano siemens per centimetre for all random variations of the detector output of a frequency greater than one cycle per minute.

3.2.14.1 *Discussion*—Short-term noise determines the smallest signal detectable by a conductivity detector, limits the precision available for the determination of trace samples, and may set the lower limit of linearity.

4. Summary of Practice

4.1 Four different tests are performed to characterize a detector.

4.1.1 *Noise and drift* are measured while a solution is flowing through the detector cell. The test is performed using two different solutions: deionized water (DI) and 1 mM potassium chloride (KCl).

4.1.2 *Linear range* is determined by preparing a plot of response factor versus the log of solute concentration using standard solutions of KCl and hydrochloric acid (HCl) as solutes.

4.1.3 *Dependence of response on flow rate* is measured by pumping 1 mM KCl through the conductivity cell at several flow rates and measuring the detector output.

4.1.4 *Response time* is measured by measuring the time required for the detector output to change from that measured with DI water to that measured with 1 mM KCl.

5. Significance and Use

5.1 This practice is intended to describe the performance of a conductivity detector independent of the chromatographic system in terms that the analyst can use to predict overall system performance when the detector is coupled to the column and other chromatography system components.

5.2 Although it is possible to observe each of the several characteristics of a detector under different and unique condi-

tions, it is the intent of this practice that a complete set of detector specifications should be obtained at the same operating conditions, including the setup used for testing, flow rates, and temperatures. It should be noted that to specify a detector’s capability completely, its performance should be measured at several sets of conditions within the useful range of the detector. The terms and tests described in this practice are sufficiently general so that they may be used at whatever conditions may be chosen for other reasons.

6. Reagents

6.1 Reagent chemicals are reagent grade or better.

6.1.1 *Deionized Water*, (DI water), 18 M-ohm.

6.1.2 *Potassium Chloride*, (KCl) dry powder.

6.1.3 *Hydrochloric Acid*, (HCl) standard 0.1000 N solution.

7. Preparation of Standards

7.1 *Potassium Chloride Standards*:

7.1.1 Prepare a 10-mM KCl standard stock solution. Weigh out 0.7455 g KCl (desiccated) and dissolve it in 18 M-ohm DI water in a 1-L plastic volumetric flask. Fill the flask to 1 L with DI water.

7.1.2 Prepare KCl standards from the 10-mM KCl standard stock solution. Using accurate Class A pipettes, pipette the volumes of the 10-mM standard stock solution listed below into 100-mL plastic volumetric flasks. For the 1-mM KCl standard, fill a 100-mL plastic volumetric flask with the 10-mM KCl solution and transfer to a 1-L plastic volumetric flask. Fill to the line with DI water.

KCl Concentration, mM	Volume in 100 mL DI Water, mL
0.05	0.5
0.1	1
0.2	2
0.5	5
1	100 mL in 1 L
2	20
5	50
10 mM	No dilution

7.2 *Hydrochloric Acid Standards*:

7.2.1 Prepare a 2.00-mM HCl standard stock solution by diluting 20.0 mL of standard 0.1000 N HCl into a 1-L plastic volumetric flask and filling to the line with DI water. If standard 0.1000 N HCl is not available, a 0.10-mM HCl solution can be prepared by diluting 8.3 mL of 12 N (37 %) concentration HCl into 1 L of DI water. (The concentration of this solution will be less accurate than that prepared from 0.1000 N HCl standard.)

7.2.2 Prepare the following HCl calibration standards from the 2.00-mM HCl standard stock solution. Use accurate Class A pipettes and 100- mL plastic volumetric flasks.

HCl Concentration, mM	Volume in 100 mL DI Water, mL
0.02	1
0.04	2
0.1	5
0.2	10
0.4	20
1	50
2	No dilution

8. Instrumentation Set-Up

8.1 Set up the chromatographic system according to the manufacturer's recommendation. Also, passivate the conductivity cell using the manufacturer's recommended procedure. Set the flow rate on the pump to 1.0 mL/min or to the flow rate normally used in your application. Fill the eluent bottle with 18 M-ohm DI water. Connect the outlet of the pump to the injection valve, and the outlet of the injection valve directly to the conductivity cell using as short a length of tubing as is practical. (Standard 0.25-mm (0.01-in.) internal diameter HPLC tubing may be used.) Do not install any columns or suppressors. To ensure smooth operation of the pump, it is necessary to supply more pressure than that normally provided by the detector cell and the standard tubing alone. This is accomplished by installing a 1-m coil of 0.25-mm internal diameter narrow bore tubing between the pump and the injection valve. Increase the length or decrease the diameter of the tubing if the pressure is not high enough to produce smooth pump operation. Generally, 500 to 1 000 psi will be sufficient. The waste line connected to the cell outlet should be of sufficient length to provide enough backpressure on the cell to prevent the formation of bubbles inside the cell. Inserting 20 cm of 0.25-mm internal diameter tubing between the cell and waste line should provide sufficient backpressure.

8.2 Install a sample injection loop of approximately 200 μ L on the injection valve. This can be constructed from 1 m of 0.5-mm (0.02-in.) internal diameter tubing. During the tests described in Sections 6 and 7, observe the recorder trace and verify that a plateau is reached after injection of the standard solutions. If no plateau is reached, then a larger sample injection loop is needed.

8.3 If the conductivity detector has a setting for temperature compensation, set it to 2.0. If not, the DI water eluent and all of the test solutions should be thermostated as close as possible to 25°C. Or, the detector cell may be thermostated at a higher temperature but be calibrated as if the cell were at 25°C. If the cell is thermostated, ensure that the cell temperature has stabilized. Refer to the manufacturer's procedure for cell temperature stabilization. Turn off any output filtering on the detector. The output from the detector should be monitored on a strip-chart recorder, integrator, or computer. The calibration and linearity tests can be performed with a voltmeter monitoring the detector output or, on some detectors, the output is monitored on the front panel readout.

9. Calibration

9.1 *Method*—The detector is calibrated by adjusting the detector output to 147.0 μ S/cm for a 1-mM solution of potassium chloride flowing through the conductivity cell at 1 mL/min.

9.1.1 Set up the chromatographic system according to the instructions in Section 8. Turn on the pump and ensure that the pump is pumping smoothly.

9.1.2 Monitor the detector output. The conductivity should be below 1 μ S/cm. If it is higher, continue flushing out the system to remove leftover salts until the conductivity stabilizes below 1 μ S/cm. (A higher reading is an indication of either an incompletely cleaned flow system or of poor deionized water

quality and may compromise noise and linearity tests.) Fill the sample injection loop with DI water and inject. Note the minimum conductivity reported during the elution of the DI water through the detector cell. Either calibrate the detector to zero using the injected DI water or subtract the conductivity of injected DI water from all subsequent measurements.

9.1.3 Fill the sample injection loop with the 1-mM KCl standard and inject the standard. Note the maximum conductivity reported during the elution through the detector cell of the 1-mM KCl standard. It should be 147.0 μ S/cm. If it is not, follow the manufacturer's procedure for calibrating the conductivity detector so that the reading will be 147.0 μ S/cm.

9.1.4 Some conductivity detectors do not report conductivity directly in siemens, but instead provide a voltage output proportional to conductivity. Instead of adjusting the detector output, calibrate these detectors by recording the known conductivity of the calibration solution (147.0 μ S/cm for 1 mM KCl), the detector sensitivity range, and the measured voltage output. (Be sure to subtract the voltage output for a blank of DI water.) Divide the known conductivity by the net voltage output reading and multiply all subsequent voltage output readings by this value.

10. Noise and Drift

10.1 *Method of Measurement*—Noise and drift are measured under two conditions. Pure, deionized water is pumped through the conductivity cell at 1 mL/min and the noise and drift measured. The procedure is then repeated using 1 mM KCl. The detector output may be sensitive to temperature changes. It is worthwhile to perform this test twice: once with the temperature of the eluents and of the laboratory held as constant as possible, and once with controlled changes in laboratory temperature of approximately 5°C. This may be accomplished by cycling on and off a room heater or air conditioner.

10.1.1 Set up the chromatographic system as described in Section 8. Calibrate the detector according to the procedure in Section 9. Pump DI water through the system for at least 1 h or until the detector output has stabilized below 1 μ S/cm. Set the detector to its maximum sensitivity setting and adjust the detector output to approximately midscale on the recorder. Adjust the response time or time constant of the detector output filter to 1 s or to the setting closest to 1 s. Record the baseline for at least 1 h. If the detector output goes off scale during the test, either reset the detector output to remain on scale during the entire test, or set the detector output to a less sensitive setting, or both.

10.1.2 Draw pairs of parallel lines, each pair corresponding to between $\frac{1}{2}$ and 2 min in length, to form an envelope of all observed random variations over any 15-min period (Fig. 1). Draw the parallel lines so as to minimize the distance between them. Measure the vertical distance, in nano siemens per centimetre, between the lines. Calculate the average value over all the segments to obtain the short-term noise.

10.1.3 Now mark the center of the noise envelope every 2 min over a 60-min period. Draw a series of parallel lines encompassing these centers, each pair corresponding to 30 min in length. Choose that pair of lines whose vertical distance is greatest to obtain the long-term noise (Fig. 1).

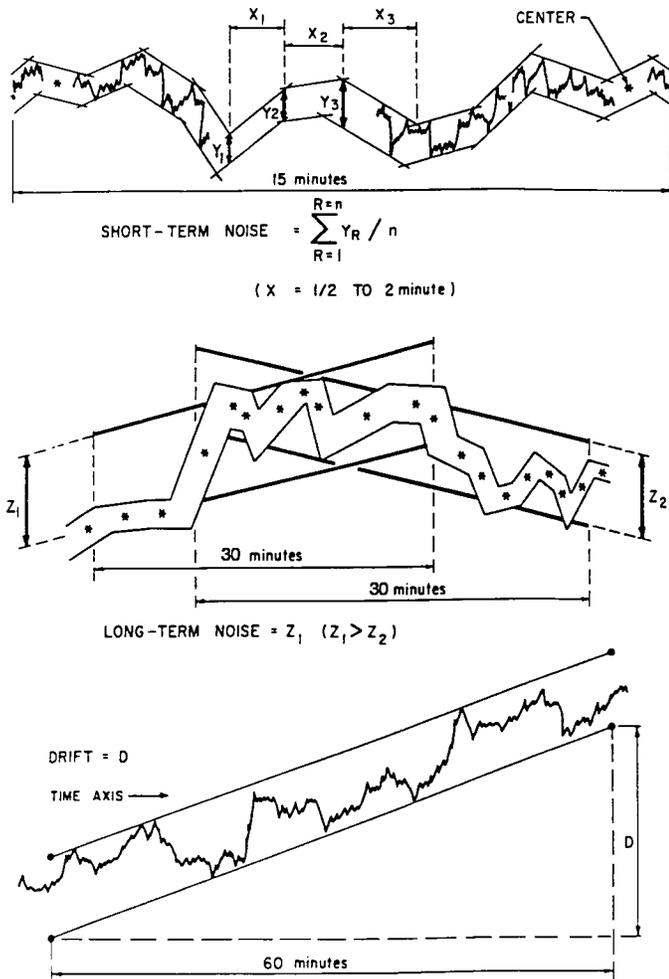
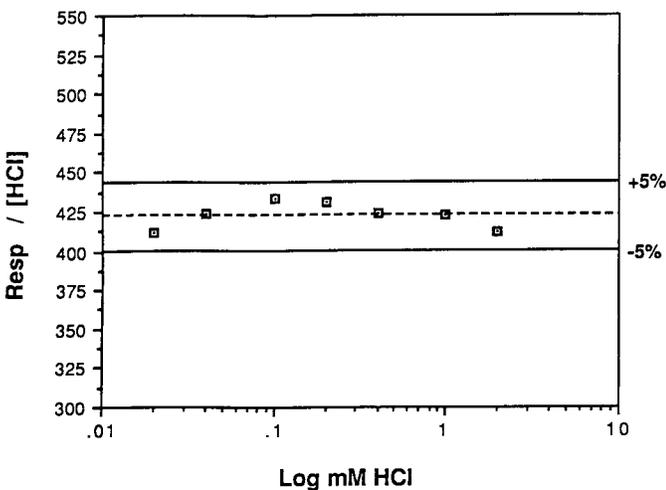


FIG. 1 Example for the Measurement of the Noise and Drift (Chart Recorder Output)

10.1.4 Draw the pair of vertical lines that minimizes the vertical distance separating these lines over the 1-h period of measurement. The slope of either line is the drift expressed in microsiemens per centimetre per hour.

10.1.5 Repeat the above test using 1 mM KCl as the eluent.



11. Linearity

11.1 *Method of Measurement*—The linear range of a conductivity detector is determined by preparing a plot of response factor versus the log of solute concentration. Deviation from linearity at high solute concentration is caused by two factors. First, the actual conductivity of an electrolyte solution is not linear; the response factor decreases as concentration increases. Second, capacitive reactance at the electrode/solution interface limits the measured conductivity. Since this reactance is dependent on the solutes used, two linearity plots should be obtained; one using a solute of relatively high equivalent conductivity (HCl) and one using a solute of moderate equivalent conductivity (KCl).

11.1.1 Set up the chromatograph according to the instructions in Section 8. Clean the conductivity cell using the manufacturer's recommended procedure. Calibrate the detector according to the procedure in Section 9.

11.1.2 Fill the sample injection loop with the 0.05-mM KCl standard and inject the standard. Record the maximum conductivity reported during the elution of the standard through the detector cell. Repeat this procedure for each KCl standard. Rinse the injection loop with DI water and repeat this procedure for each HCl standard. (Because of the possibility of HCl causing corrosion of stainless-steel systems, HCl solutions should not be pumped continuously through the chromatograph. Use only this small-volume injection method.)

11.1.3 Calculate the response factor for each KCl standard by dividing the measured conductivity in microsiemens by concentration in millimolar. Prepare a plot of response factor versus the log of concentration. Draw a best fit curve through the points. (Do not attempt to fit a linear regression through the points.) Find the widest concentration range over which the response factors differ by less than 5 % from the average value in the range. This is the linear range of the detector for KCl (Fig. 2).

11.1.3.1 Conductivity is not directly proportional to concentration. Plot the following values of concentration and response factor on the same graph to compare the performance of the detector to published literature values for KCl.³ The literature values of KCl conductivity are also listed.

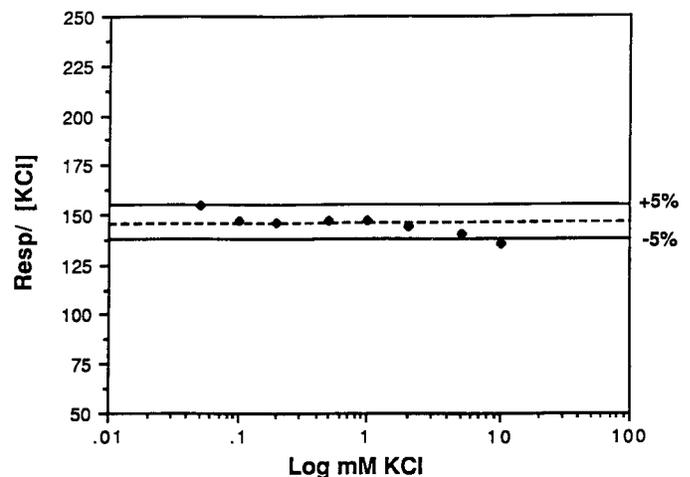


FIG. 2 Conductivity Response Linearity

KCl Concentration, mM	Response Factor, $\mu\text{S}/\text{cm}/\text{mM}$	Conductivity, $\mu\text{S}/\text{cm}$
0.05	149	7.5
0.1	149	14.9
0.2	148	29.8
0.5	148	73.9
1	147	147
2	145	292
5	143	717
10	141	1413

11.1.4 Repeat the procedure in 11.2.3 using the HCl standards. Find the linear range of the detector for HCl.

11.1.4.1 Use the following values to compare the performance of the detector to published literature values for HCl.³

KCl Concentration, mM	Response Factor, $\mu\text{S}/\text{cm}/\text{mM}$	Conductivity, $\mu\text{S}/\text{cm}$
0.02	424	8.5
0.04	424	17.0
0.1	424	42.4
0.2	424	84.7
0.4	423	169
1	421	421
2	419	838

11.1.5 The following alternative plot is useful for estimating the accuracy of the detector as a function of measured conductivity instead of as a function of concentration. Divide the measured response factors for each KCl and HCl standard by the corresponding reported response factors from the tables. Then multiply each ratio by 100. The resulting value is the percentage accuracy of each conductivity measurement. Prepare a plot of percentage accuracy versus the log of actual conductivity as listed in the tables. Draw a best fit curve through the KCl points and a second curve through the HCl points. (Do not attempt to fit a linear regression through the points.) A perfect detector will produce a straight horizontal line at 100 % for both sets of standards. A constant offset on the Y axis between the two sets of standards suggests an error in preparing at least one of the standard stock solutions.

12. Dependence of Response on Flow Rate

12.1 *Method of Measurement*—Flow rate dependence is measured by pumping 1 mM KCl through the conductivity cell at several flow rates and measuring the detector output. The detector output will be sensitive to temperature changes. Perform this test with the temperature of the eluents and of the laboratory held as constant as possible.

12.1.1 Set up the chromatographic system as described in

³ Values obtained from *CRC Handbook of Chemistry and Physics*, 56th Ed. (1975–1976), CRC Press, Cleveland, OH.

Section 8, using 1 mM KCl as the eluent. Be sure the detector is properly calibrated (Section 9). Pump 1 mM KCl through the system at a flow rate of 0.5 mL/min for at least 1 h or until the detector output has stabilized at or near 147 $\mu\text{S}/\text{cm}$. Set the detector to its maximum sensitivity setting, offset the background, and adjust the detector output to approximately mid-scale on the recorder. Record the detector output for approximately 15 min or until a steady state is reached. Increase the flow rate to 1 mL/min and record for 15 min or until a steady state is reached. Perform the same measurements at 2, 4, and 8 mL/min *if the pressure limit of the detector is not exceeded*, nor if the maximum flow rate of the pump is exceeded. If the detector output goes off scale during the test, either reset the detector offset to remain on scale during the entire test, or set the detector output to a less sensitive setting, or both.

12.1.2 Draw a horizontal line through the baseline produced at each flow rate after a steady state is reached. Measure the vertical displacement between these lines and record the results in nano siemens per centimetre. Plot the absolute values versus flow rate. Draw a smooth curve connecting the points and draw a tangent at 1 mL/min. Express the results as flow sensitivity in nano siemens per centimetre per millilitre per minute. Both the numerical value and the plot should be recorded.

13. Response Time

13.1 *Method of Measurement*—While pumping DI water through the cell, inject 1 mM KCl and measure the time required for the detector output to change from 10 % to 90 % of the new value.

13.1.1 Set up the chromatograph according to the instructions in Section 8. Calibrate the detector according to the procedure in Section 9. Pump DI water eluent through the cell at 1 mL/min. Turn off any electronic output filter. Set the detector output range such that a conductivity change of 147 $\mu\text{S}/\text{cm}$ will produce as large a deflection on the chart recorder as possible without going off scale, preferably between 50 % and 95 % of full scale. Set the chart recorder to a very fast chart speed: at least 10 cm/min, and preferably 60 cm/min (1 cm/s). It may be necessary to use a computer for this measurement.

13.1.2 Fill the sample injection loop with the 1 mM KCl standard and inject the standard. Observe the recorder trace and verify that a plateau is reached (8.2). Determine the time required for the detector output to rise from 10 % to 90 % of the value for 1 mM KCl, that is from 14.7 to 132 $\mu\text{S}/\text{cm}$.

14. Keywords

14.1 conductivity detector; detector drift; detector flow-rate dependence; detector linearity; detector linear range; detector noise; detector response time; IC; ion chromatography

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