Designation: E 1657 – 98 (Reapproved 2001)

# Standard Practice for Testing Variable-Wavelength Photometric Detectors Used in Liquid Chromatography[1]

This standard is issued under the fixed designation E 1657; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This practice is intended to serve as a guide for the testing of the performance of a variable-wavelength photometric detector (VWPD) used as the detection component of a liquid-chromatographic (LC) system operating at one or more wavelengths in the range 190 to 800 nm. Many of the measurements are made at 254 nm for consistency with Practice E 685. Measurements at other wavelengths are optional.

1.2 This practice is intended to describe the performance of the detector both independently of the chromatographic system (static conditions) and with flowing solvent (dynamic conditions).

1.3 For general liquid chromatographic procedures, consult Refs **(1-9)**.[2]

1.4 For general information concerning the principles, construction, operation, and evaluation of liquid-chromatography detectors, see Refs **(10, 11)** in addition to the sections devoted to detectors in Refs **(1-7)**.

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

1.6 *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:*

E 275 Practice for Describing and Measuring Performance of Ultraviolet, Visible, and Near-Infrared Spectrophotometers[3]

E 682 Practice for Liquid Chromatography Terms and Relationships[4]

E 685 Practice for Testing Fixed-Wavelength Photometric Detectors Used in Liquid Chromatography[4]

## 3. Terminology

3.1 *Definitions:*

3.1.1 *absorbance calibration*—the procedure that verifies that the absorbance scale is correct within ±5 %.

3.1.2 *drift*—the average slope of the noise envelope expressed in absorbance units per hour (AU/h) as measured over a period of 1 h.

3.1.3 *dynamic*—under conditions of a flow rate of 1.0 mL/min.

3.1.4 *linear range—of a VWPD*, the range of concentrations of a test substance in a test solvent over which the ratio of response of the detector versus concentration of test substance is constant to within 5 % as determined from the linearity plot specified in 7.1.2 and illustrated in Fig. 1. The *linear range* should be expressed as the ratio of the upper limit of linearity obtained from the plot to either a) the lower linear concentration, or b) the *minimum detectable* concentration, if the *minimum detectable* concentration is greater than the lower linear concentration.

3.1.5 *long-term noise*—the maximum amplitude in AU for all random variations of the detector signal of frequencies between 6 and 60 cycles per hour (0.1 and 1.0 cycles per min).

3.1.5.1 *Discussion*—It represents noise that can be mistaken for a late-eluting peak. This noise corresponds to the observed noise only and may not always be present.

3.1.6 *minimum detectability— of a VWPD*, that concentration of a specific solute in a specific solvent that results in a detector response corresponding to twice the static short-term noise.

3.1.6.1 *Discussion*—The static short-term noise is a measurement of peak-to-peak noise. A statistical approach to noise suggests that a value of three times the rms (root-mean-square) noise would insure that any value outside this range would not be noise with a confidence level of greater than 99 %. Since peak-to-peak noise is approximately five times the rms noise **(12)**, the minimum detectability defined in this practice is a more conservative estimate.

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

3.1.7.1 *Discussion*—Because the detector volume is very small and the transport rate is not diffusion dependent, the

[1] This practice is under the jurisdiction of ASTM Committee E13 on Molecular Spectroscopy and is the direct responsibility of Subcommittee E13.19 on Chromatography.

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[2] The boldface numbers in parentheses refer to the list of references at the end of this practice.

[3] *Annual Book of ASTM Standards*, Vol 03.06.

[4] *Annual Book of ASTM Standards*, Vol 14.02.

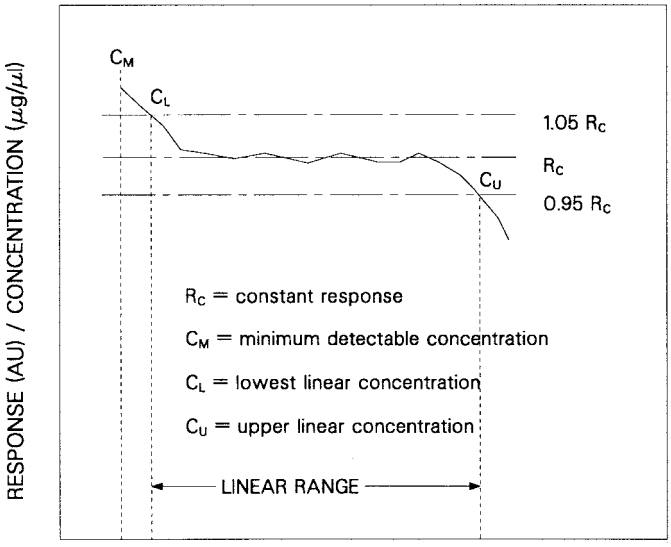


**FIG. 1 Example of Linearity Plot for a Variable-Wavelength Detector**

response time is generally fast enough to be unimportant. It is generally comparable to the response time of the recorder and dependent on the response time of the detector electrometer and on the recorder amplifier. Factors that affect the observed response time include the true detector response time, electronic filtering, and system band-broadening.

3.1.8 *short-term noise*—the maximum amplitude, peak to peak, in AU for all random variations of the detector signal of a frequency greater than one cycle per minute.

3.1.8.1 *Discussion*—It determines the smallest signal detectable by a VWPD, limits the precision attainable in quantitation of trace-level samples, and sets the lower limit on linearity. This noise corresponds to the observed noise only.

3.1.9 *static*—under conditions of no flow.

3.1.10 *wavelength accuracy*—the deviation of the observed wavelength maximum from the maximum of a known test substance.

3.1.11 *wavelength precision*—a measure of the ability of a VWPD to return to the same spectral position as measured by the reproducibility of absorbance values when the detector is reset to a wavelength maximum of a known test substance.

## 4. Significance and Use

4.1 Although it is possible to observe and measure each of the several characteristics of a detector under different and unique conditions, it is the intent of this practice that a complete set of detector specifications should be obtained *under the same operating conditions.* It should also be noted that to completely specify a detector's capability, 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 that they may be used regardless of the ultimate operating parameters.

4.2 Linearity and response time of the recorder or other readout device used should be such that they do not distort or otherwise interfere with the performance of the detector. This requires adjusting the gain, damping, and calibration in accordance with the manufacturer's directions. If additional electronic filters or amplifiers are used between the detector and the final readout device, their characteristics should also first be established.

## 5. Noise and Drift

5.1 *Test Conditions*—Pure, degassed methanol[5] shall be used in the sample cell. Air or nitrogen shall be used in the reference cell if there is one. Nitrogen is preferred where the presence of high-voltage equipment makes it likely that there is ozone in the air. Protect the entire system from temperature fluctuations because these will lead to detectable drift.

5.1.1 The detector should be located at the test site and turned on at least 24 h before the start of testing. Insufficient warm-up may result in drift in excess of the actual value for the detector. The detector wavelength should be set to 254 nm.

5.2 *Methods of Measurement*:

5.2.1 Connect a suitable device (see Note 1) between the pump and the detector to provide at least 75 kPa (500 psi) back pressure at 1.0 mL/min flow of methanol. Connect a short length (about 100 mm) of 0.25-mm (0.01-in.) internal-diameter stainless steel tubing to the outlet tube of the detector to retard bubble formation. Connect the recorder to the proper detector output channels.

NOTE 1—Suggested devices include (*a*) 2 to 4 m of 0.1-mm (0.004-in.) internal-diameter stainless steel tubing, ( *b*) about 250 mm of 0.25 to 0.5 mm (0.01 to 0.02-in.) internal-diameter stainless steel tubing crimped with pliers or cutters, or ( *c*) a constant back-pressure valve located between the pump and the injector.

5.2.2 Repeatedly rinse the reservoir and chromatographic system, including the detector, with degassed methanol to remove from the system all other solvents, any soluble material, and any entrained gasses. Fill the reservoir with methanol and pump this solvent through the system for at least 30 min to complete the system cleanup.

5.2.3 Air or nitrogen is used in the reference cell, if any. Ensure that the cell is clean, free of dust, and completely dry.

5.2.4 To perform the static test, cease pumping and allow the chromatographic system to stabilize for at least 1 h at room temperature without flow. Set the attenuator at maximum sensitivity (lowest attenuation), that is, the setting for the smallest value of absorbance units full-scale (AUFS). Adjust the response time as close as possible to 2 s for a VWPD that has a variable response time (see Note 2). Record the response time used. Adjust the detector output to near midscale on the readout device. Record at least 1 h of detector signal under these conditions, during which time the ambient temperature should not change by more than 2°C.

NOTE 2—Time constant is converted to response time by multiplying by the factor 2.2. The effect of electronic filtering on observed noise may be studied by repeating the noise measurements for a series of response-time settings.

5.2.5 Draw pairs of parallel lines, each pair corresponding to between 0.5 and 1 min in length, to form an envelope of *all*

[5] Distilled-in-glass or liquid-chromatography grade. Complete freedom from particles may require filtration, for example, through a 0.45-μm membrane filter.

observed random variations over any 15-min period (see Fig. 2). Draw the parallel lines in such a way as to minimize the distance between them. Measure the vertical distance, in AU, between the lines. Calculate the average value over all the segments. Divide this value by the cell length in centimeters to obtain the *static short-term noise*.

5.2.6 Now mark the center of each segment over the 15-min period of the static short-term noise measurement. Draw a series of parallel lines encompassing these centers, each pair corresponding to 10 min in length, and choose that pair of lines whose vertical distance apart is greatest (see Fig. 2). Divide this distance in AU by the cell length in centimeters to obtain the *static long-term noise*.

5.2.7 Draw the pair of parallel lines that minimizes the vertical distance separating these lines over the 1 h of measurement (Fig. 2). The slope of either line is the *static drift* expressed in AU/h.

5.2.8 Set the pump to deliver 1.0 mL/min under the same conditions of tubing, solvent, and temperature as in 5.2.1-5.2.3. Allow 15 min for the system to stabilize. Record at least 1 h of signal under these flowing conditions, during which time the ambient temperature should not change by more than 2°C.

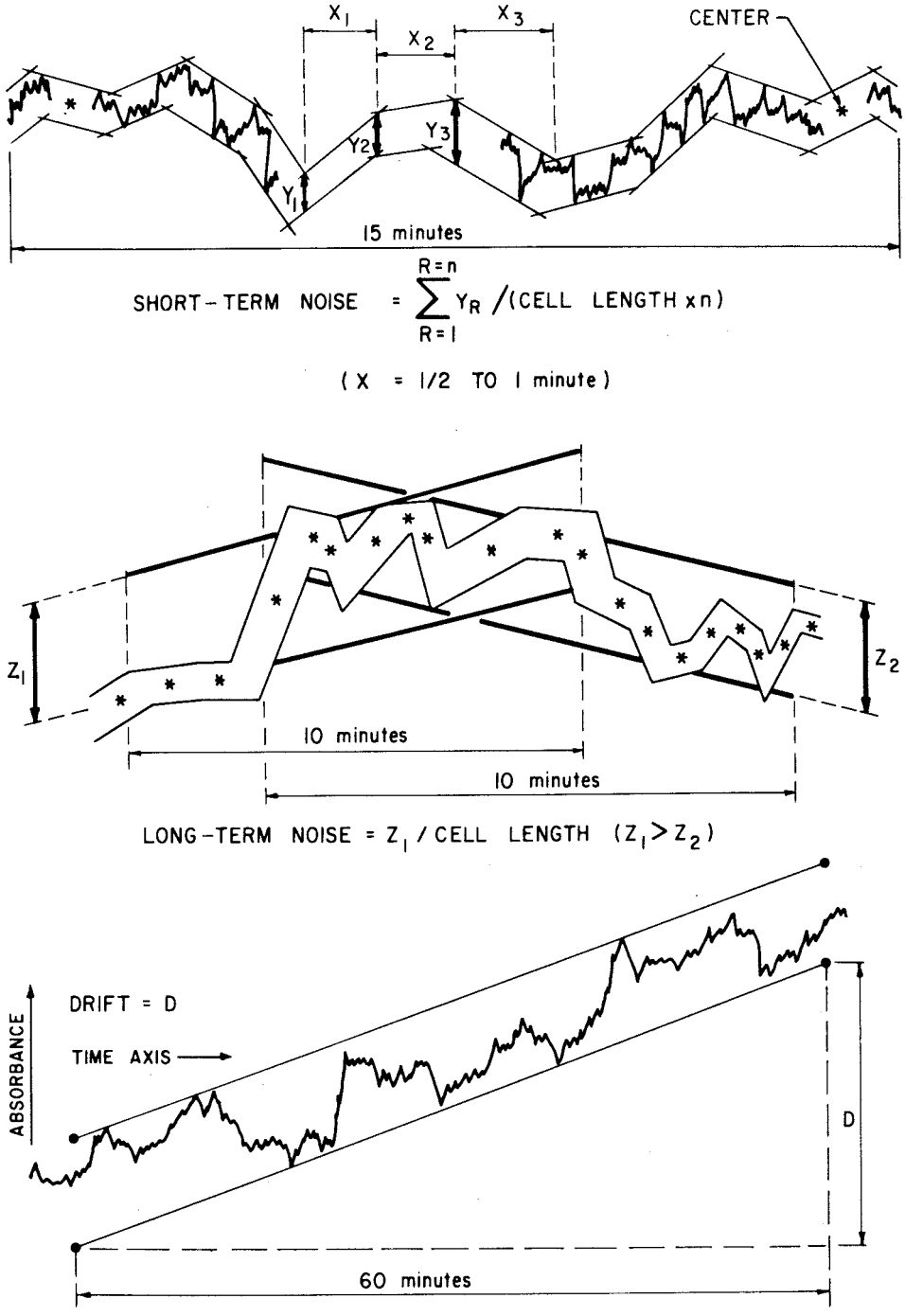


**FIG. 2 Example for the Measurement of the Noise and Drift of a VWD (Chart Recorder Output)**

5.2.9 Draw pairs of parallel lines, measure the vertical distances, and calculate the *dynamic short-term noise* following the procedure of 5.2.5.

5.2.10 Make the measurement for the *dynamic long-term noise* following the procedure outlined in 5.2.6.

5.2.11 Draw the pair of parallel lines as directed in 5.2.7. The slope of these lines is the *dynamic drift.*

5.2.12 The actual noise of the system may be larger or smaller than the observed values, depending upon the method of data collection, or signal monitoring of the detector, since observed noise is a function of the frequency, speed of response, and bandwidth of the readout device.

## 6. Wavelength Accuracy and Precision

6.1 The *wavelength accuracy and precision of a VWPD* are important parameters for the performance of chromatographic methods. The wavelength specified in the method may be critical to the detection of different compounds having different absorption spectra. The stated *linear range* of the method may be compromised if the wavelength is inaccurate. Further, the precision of adjusting the detector to the same wavelength should also be known. The wavelength of a VWPD is determined by the monochromator and the optical alignment of the detector. The optical alignment is performed by the manufacturer and usually does not need readjustment. Some detectors require alignment of the lamp after replacement. This procedure verifies that the detector is properly aligned and meets the manufacturer's specifications for *wavelength accuracy and precision.*

6.2 *Method of Measurement—Wavelength Accuracy*—For the determination of the *wavelength accuracy of a VWPD,* **(13)** a solution of a compound with known absorbance maxima is introduced into the cell. The measured maxima are compared to the known maxima for the compound. There are several acceptable compounds and solvents.[6] The following procedure is recommended (Note 3).

NOTE 3—The recommended procedure is covered under U.S. Patent 4,836,673. The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility. Alternative procedures will be considered.

6.2.1 Prepare the test solution. For example, dissolve 2 g of erbium perchlorate hexahydrate[7] in 25 mL water.[8] The nominal concentration is 0.14 M. Filter the solution with an appropriate filter[9] to ensure the sample is free of particles.

NOTE 4—This can be conveniently done by addng water to a 2 g vial of erbium perchlorate hexahydrate to dissolve the solid. Transfer the contents to a 25 mL volumetric flask and make up to volume with water. While reasonable care should be observed in transferring the dissolved erbium perchlorate into the volumetric flask, the final solution is not used quantitatively.

6.2.2 Turn on the detector and allow it to warm up according to the manufacturer's recommendations. Thoroughly flush the detector cell with water preferably from the same source as that to make up the test solution. (If using another test compound, be sure to use the same solvent as the test solution.) Set the detector wavelength to 250 nm. Zero the absorbance of the detector. (Some detectors will automatically zero the detector after changing wavelengths.) Flush the cell with at least 1 mL of the erbium test solution. Record the absorbance reading. Increase the wavelength by 1 nm. Flush the cell with at least 1 mL of water. Zero the absorbance of the detector. Flush the cell with the erbium test solution and record the absorbance. Repeat the procedure in 0.5 to 1.0 nm increments until reaching 260 nm.

6.2.3 Plot absorbance versus wavelength and determine the maximum absorbance. (See Fig. 3) Compare the calculated maximum to the maximum for erbium perchlorate of 255 nm (see Note 4). Report the nominal and calculated maximum of the test sample. The calculated maximum should be within the manufacturer's specification for *wavelength accuracy.* If the detector does not meet specifications, service on the detector to realign the lamp or the monochromator, or both, is indicated.

NOTE 5—Since VWPD detectors can have a large bandpass, it is not necessary to determine the wavelength accuracy to the same degree as that expected for spectrophotometers. The known wavelengths have been reported to the nearest whole nanometer.

6.2.4 The test may be repeated at a second wavelength such as 379 nm or 522 nm. The test at 522 nm would be critical if a second light source is used for detection in the visible range.

6.3 *Method of Measurement—Wavelength Precision*—For determination of the *wavelength precision of a VWPD,* the absorbance of a solution of a compound at the known wavelength maximum of the compound is measured repeated after the wavelength is reset by the operator. This procedure tests the mechanical and/or electronic mechanisms which position the

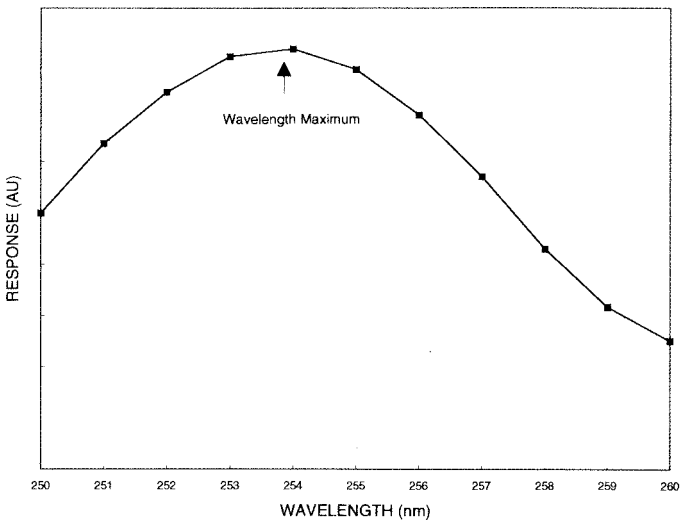


**FIG. 3 Example of Wavelength Accuracy Test Plot**

[6] In addition to erbium perchlorate, holium perchlorate in water (241 nm, 362 nm, 536–537 nm), and naphthalene in methanol (218 nm) are also possible standards.

[7] Perchlorates are strong oxidizing agents. Observe all precautions on the Material Safety Data Sheet. The test solution is stable for several weeks as a wavelength standard. However, since detector evaluation is normally infrequent, it is recommended that the solutions be prepared shortly before use and discarded after use. Use approval disposal procedures.

[8] Water, liquid chromatographic grade or equivalent.

[9] For example, a 0.45µ filter suitable for aqueous filtration.

selected wavelength of the detector. The following procedure is recommended.

6.3.1 After the *wavelength accuracy* has been verified, set the detector to the maximum for the test sample (255 nm for the erbium perchlorate solution). Flush the cell with at least 1 mL of water and zero the detector. Flush the cell with 1 mL of erbium perchlorate test solution. Record the absorbance. Reset the detector wavelength by moving at least 10 nm away from the maximum and then setting the detector at the maximum. Repeat flushing test solution, and recording the absorbance so that a total of 5 absorbance values are recorded.

6.3.2 Determine the *wavelength precision* by calculating the relative standard deviation (RSD) of the absorbance readings from Eq 1 :

$$RSD = (\sqrt{\Sigma(A_i - A_{aver})^2/(n-1)})/A_{aver} * 100\ \% \quad (1)$$

where:

$A_i$ = individual absorbance values,
$A_{aver}$ = average absorbance value, and
$n$ = number of observations.

Report *wavelength precision* as the calculated RSD (%). Compare this value to the manufacturer's specifications. If the detector does not meet specifications, service on the detector monochromator or mechanical or electronic setting device, or both, is indicated.

## 7. Minimum Detectability, Linear Range, and Calibration

7.1 *Methods of Measurement*—For the determination of the *linear range of a VWD*, **(14)** for a specific substance, the response to that test substance must be determined. The following procedure is designed to provide a worst-case procedure.

7.1.1 Dissolve in methanol a suitable compound with an ultraviolet spectra absorbance that changes rapidly near the wavelength of interest.[10] Choose a concentration that is expected to exceed the linear range, typically to give an absorbance above 2 AU. Dilute the solution accurately in a series to cover the linear range, that is, down to the *minimum detectable concentration.*[11] Rinse the sample cell with methanol and zero the detector with methanol in the cell. Rinse the cell with the solution of lowest concentration until a stable reading is obtained; usually rinsing the cell with 1 mL is sufficient. Record the detector output. After rinsing the syringe thoroughly with the next more concentrated solution, fill the cell with the solution from each dilution in turn. Obtain a minimum of five on-scale measurements. Measure under static conditions.

7.1.2 Calculate the ratio of detector response (AU) to concentration (µg/mL) for each solution and plot these ratios versus log concentration (see Fig. 1). The region of linearity will define a horizontal line of constant response ratio. At higher concentrations, there will typically be a negative deviation from linearity, while at lower concentrations there may be deviation in either direction. Draw horizontal line 5 % above and below the line of constant response ratio. The upper limit of linearity is the concentration at which the line of measured response ratio intersects one of the 5 % bracketing lines at the high concentration end. The lower limit of linearity is either the *minimum detectable concentration* (see 7.1.3) or the concentration at which the line of measured response ratio intersects one of the bracketing lines at the low concentration end, whichever is greater.

7.1.3 Determine the *minimum detectability (minimum detectable concentration)* of the test substance by calculating the concentration that would correspond to twice the *static short-term noise*. Specify the solute and solvent.

7.1.4 Calculate the ratio of the upper limit of linearity to the lower limit of linearity to give the *linear range* expressed as a number. As this procedure is a worst case situation, the *linear range* may be expected to be greater for compounds having a broad spectral band in the region of the chosen wavelength.

7.1.5 Plot or calculate the detector response (AU) versus concentrations (µg/mL) for the test substance of known molar absorptivity to find the best-fit line through the origin. Calculate the *molar absorptivity*, $\epsilon$, of the test solution as follows:

$$\epsilon = \frac{\text{slope} \times MW}{b} \quad (2)$$

where:

slope = the slope of the linear portion of the plot, AU·µl/µg,
$MW$ = molecular weight, g/mole, and
$b$ = nominal cell length, cm, as specified by the manufacturer.

Compare the value of $\epsilon$ obtained with an experimentally determined value or one from the literature (see Note 5). Should the values differ by more than 5 %, the VWPD may require adjustment. Consult the manufacturer's directions.

NOTE 6—For example, the values of molar absorptivity for uracil in methanol are $87.7 \times 10^3$ at 254 nm and $1.42 \times 10^3$ at 280 nm; for potassium dichromate in 0.01 N sulfuric acid they are $4.22 \times 10^3$ at 254 nm and $3.60 \times 10^3$ at 280 nm.

## 8. Response Time

8.1 The *response time* of the detector may become significant when a short micro-particle column and a high-speed recorder are used. Also, it is possible, by using an intentionally slow response time, to reduce the observed noise and hence increase the apparent *linear range*. Although this would have little effect on broad peaks, the signal from narrow peaks would be significantly degraded. Measure at the highest and lowest values of the electronic filter if it is variable.

8.2 *Method of Measurement*:

8.2.1 The composition of the mobile phase is changed in a stepwise manner and the output signal is recorded on the highest-speed device available. If the recorder has a response time not significantly faster than the detector, only the response time of the detector-recorder combination will be obtained, as it would be when the combination is used to record chromatograms.

[10] Benzaldehyde is suitable for testing at 214 and 254 mm, benzoic acid may be used as 280 mm.

[11] Stock solutions of 50 mg in 50 mL of liquid-chromatography grade methanol are useful for this purpose. Suggested concentration ranges for the series of standards are 2.5 to 25 µg/mL for benzaldehyde and 25 to 400 µg/mL for benzoic acid.

8.2.2 Set a flow rate of 2.0 mL/min.

8.2.3 A stepwise change may be obtained by means of a sample valve equipped with a 1-mL sample loop (or a loop having at least four times the total volume from the detector inlet to outlet) connected between the pump and the detector. Observe the recorder trace and verify that a plateau has been reached. If no plateau is reached, a larger sample volume is required. This is likely to occur at high response times. Fill the sample loop with a solution of a concentration of test substance (see 7.1.1) in methanol sufficient to give a recorder detection of between 50 % and 95 % of full scale at suitable attenuation. The concentration should be within the linear range of the detector.

8.2.4 Repeat the measurement at 3.0 mL/min. If the value obtained is decreased from that at 2.0 mL/min, repeat the test at higher flow rates until a constant value is obtained.

8.2.5 Determine the time required for the signal to rise from 10 % to 90 % of the new equilibrium value from the recorder trace to give the response time (see Fig. 4). The chart speed should be fast enough to obtain an accurate measurement.

## 9. Refractive Index (RI) Sensitivity

9.1 Ideally, to minimize change in baseline when running gradients, etc., a VWD should be insensitive to changes in refractive index of the mobile phase. In this test the sensitivity to RI effects is determined by measuring the change in baseline of the detector when the cell is filled with methanol (n = 1.329) and then with cyclohexane (n = 1.427).

9.2 *Method of Measurement*:

9.2.1 Switch on the detector and allow it to stabilize for at least 1 h or the warm-up time specified by the manufacturer.

9.2.2 Set the wavelength to 280 nm and the detector/recorder output to 0.01 AUFS.

9.2.3 Set the chart speed to 1 cm/min.

9.2.4 Using a 5 to 20 mL gas-tight syringe, fill the cell with methanol[5] by passing at least 1 mL through the cell. Leave the syringe connected to the inlet tubing and seal the cell by capping the detector outlet tubing with an appropriate cap or plug.

9.2.5 Record at least 5 min of the baseline.

9.2.6 Remove the tubing cap or plug and repeat the procedure until the baseline does not change significantly (0.001 AU).

9.2.7 Remove the cap or plug, fill the syringe with ethanol or denatured ethanol[12] and flush the cell.

9.2.8 Clean, dry, and refill the syringe with cyclohexane.[13] Repeat 9.2.4-9.2.6.

9.2.9 Measure and report the difference in the two baselines AUs. (See Fig. 5.)

## 10. Further Description of Detector

10.1 For a more complete evaluation of a VWPD, factors other than those previously described are important. These are listed below.

10.1.1 *Display Range of Attenuator*—The highest and lowest settings available at the detector output expressed in absorbance units full-scale detection (AUFS) for standard output voltage. This voltage is the millivolts full-scale deflections (mVFS) specified as standard for the recorder, so that the designated AU represents exactly full-scale detection of that recorder when zero signal is adjusted to recorder zero.

10.1.2 *Wavelength Range*—The range of wavelengths over which that the detector can be operated.

[12] Reagent Grade or equivalent.

[13] Distilled-in-glass or liquid-chromatography grade.

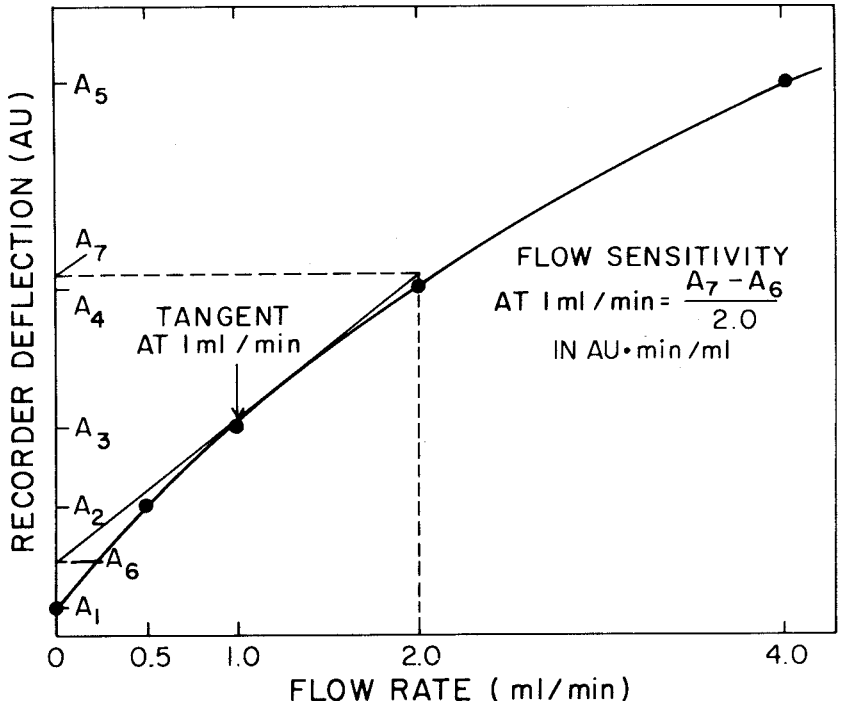


**FIG. 4 Example for the Measurement of Response Time of a Variable-Wavelength Detector**

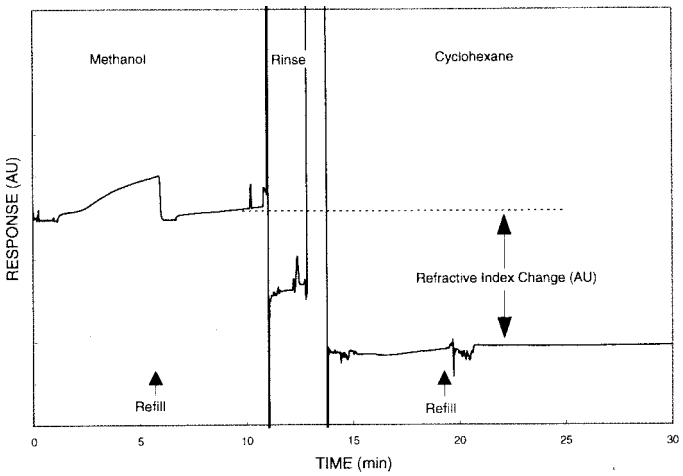


**FIG. 5 Example of the Measurement of Refractive Index Change for a Variable-Wavelength Detector**

10.1.3 *Bandpass*—The width of the spectral line at half maximum. For broad-band sources, this is determined by the bandpass of the optical filter.

10.1.4 *Cell Length*—The effective length of the fluid through which the light beam passes, measured along the cell axis.

10.1.5 *Cell Volume*—The volume of the effective part of the cell, where the absorption of light takes place and where mixing may occur.

10.1.6 *Detector Volume*—The total volume of the detector between the inlet and outlet fittings. The inlet fitting shall be one capable of connecting directly to a chromatographic column; the outlet shall be capable of connecting to the inlet fitting of a second detector.

10.1.7 *Reference*:

10.1.7.1 In the case of a single-beam instrument, the detector is "reference—none."

10.1.7.2 In the case of a double-beam instrument, the detector may have a reference cell. If so, this should be stated, or alternatively," reference—air."

10.1.7.3 If the ratio of light intensity is not 1:1 in balance on the sample and reference photodetectors (of a double-beam instrument), this should be stated.

10.1.8 *Monitor*—Presence or absence of a meter or other device to indicate the amount of light reaching the sample photodetector. State what the meter measures.

10.1.9 *Calibration Check*—Presence or absence of means to adjust the output of the detector to the specified absorbance value without use of an external device.

10.1.10 *Lamp Type*—Type of source lamp used in the detector.

10.1.11 *Estimated Average Lamp Life*—Average life of five or more lamps in continuous operation, usually to half intensity rather than failure.

10.1.12 *Pressure Limit*—Maximum operating pressure at which the cell is guaranteed to operate without leakage or hazard.

10.1.13 *Heat Exchanger*—The means, if any, by which the temperature of the influent is adjusted to a temperature similar to that of the detector cell.

10.1.14 *Wetted Materials of Cell*—All materials of the detector cell that are in contact with the mobile phase.

10.1.15 *Inlet Tube*—The material, length, and internal diameter of all tubing connecting the inlet fitting to the detector cell.

10.1.16 *Maximum Zero Offset*—The maximum amount by which the zero value of the detector can be changed ( *a*) by the fine control and (*b*) by the coarse and fine controls together.

10.1.17 *Type of Photodetector*:

10.1.18 *Stray Light Filter*—If present, indicate type or types and respective bandpass.

## 11. Keywords

11.1 linearity; noise measurement; photometric detector; variable wavelength; wavelength accuracy

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