National Institute of Standards & Technology

Certificate of Analysis

Standard Reference Material® 2514

Wavelength Calibration Reference for 1560 nm to 1595 nm
(Carbon Monoxide $^{12}C^{16}O$)

Serial No.:

This Standard Reference Material (SRM) is intended for wavelength calibration in the spectral region from 1560 nm to 1595 nm. SRM 2514 is a single-mode optical-fiber-coupled absorption cell containing carbon monoxide ($^{12}C^{16}O$) gas at a pressure of 133 kPa (1000 Torr). The absorption path length is 80 cm and the absorption lines are about 50 pm wide. The cell is packaged in a small instrument box (approximately 32 cm long x 12.5 cm wide x 9 cm high) with two FC/PC fiber connectors for the input and output of a user-supplied light source. This SRM can be used for calibrating a variety of wavelength-measuring instruments, such as optical spectrum analyzers, tunable lasers, and wavelength meters. Carbon monoxide $^{12}C^{16}O$ has about 40 accurately measured absorption lines in the 1560 nm to 1595 nm wavelength region.

Certified Wavelength Values: The vacuum wavelengths of absorption lines in the R and P branches of the 3ν rotational-vibrational band of $^{12}C^{16}O$ have been determined previously to high accuracy and are tabulated in the HITRAN database [1]. These literature values for the vacuum wavelengths were adjusted for the pressure shift due to the collisions between carbon monoxide molecules at the 133 kPa (1000 Torr) pressure within the SRM cell to obtain the certified wavelength values for this SRM. Details of the measurement procedure and data analysis for the determination of the pressure shift can be found in Reference 2, and the uncertainty analysis for the SRM is documented in Reference 3. A spectrum of the absorption band is shown in Figure 1 and certified wavelength values are given in Table 1. Figure 2 shows an expanded scan near lines R6, R7, and R8. Figure 3 shows a high resolution scan of line R7. The center wavelengths of the lines listed in Table 1 are certified with uncertainties ranging from 0.4 pm to 0.7 pm. These uncertainties are the expanded uncertainties using a coverage factor $k = 2$, i.e., our quoted uncertainty is $\pm 2\sigma$.

Expiration of Certification: The certification of this SRM is valid indefinitely within the measurement uncertainties specified, provided the SRM is handled, stored, and used in accordance with the instructions given in this certificate (see Instructions for Use). The gas is contained in a glass cell with all-glass seals at the windows and the fill port. In the unlikely event of cell leakage, the linewidths and the small pressure shift of the line centers will change. Contact NIST if the linewidths or depths differ significantly from those shown in Figures 1 through 3, when measured using comparable resolution (see specific criteria in the section Suggested Procedure for High-*Accuracy Requirements*).

Development of this SRM and supporting measurements were performed by W.C. Swann and S.L. Gilbert of the NIST Optoelectronics Division.

Statistical consultation was provided by C.M. Wang of the NIST Statistical Engineering Division.

The support aspects involved in the preparation, certification, and issuance of this SRM were coordinated through the NIST Standard Reference Materials Program by J.W.L. Thomas.

Gordon W. Day, Chief
Optoelectronics Division

Gaithersburg, MD 20899
Certificate Issue Date: 17 May 2002

John Rumble, Jr., Acting Chief
Standard Reference Materials Program

Table 1. Certified Wavelengths for SRM 2514

Literature values from Reference 1 adjusted for the pressure shift due to the 133 kPa (1000 Torr) cell pressure. These vacuum wavelengths of the 3ν band of $^{12}C^{16}O$ are certified with the uncertainty indicated in parenthesis for the last digits. The uncertainties quoted are the expanded uncertainty using a coverage factor $k = 2$, i.e., our quoted uncertainty is $\pm 2\sigma$.

R Branch	Wavelength (nm)	P Branch	Wavelength (nm)
21	1560.5025(6)	1	1575.6498(4)
20	1560.8680(7)	2	1576.6311(4)
19	1561.2600(7)	3	1577.6397(6)
18	1561.6786(7)	4	1578.6758(4)
17	1562.1237(7)	5	1579.7392(5)
16	1562.5953(5)	6	1580.8300(5)
15	1563.0935(5)	7	1581.9485(4)
14	1563.6183(5)	8	1583.0945(5)
13	1564.1697(5)	9	1584.2683(5)
12	1564.7477(4)	10	1585.4698(5)
11	1565.3523(4)	11	1586.6993(5)
10	1565.9835(4)	12	1587.9567(6)
9	1566.6414(4)	13	1589.2422(6)
8	1567.3261(4)	14	1590.5559(6)
7	1568.0375(4)	15	1591.8978(5)
6	1568.7756(5)	16	1593.2681(6)
5	1569.5405(4)	17	1594.6669(6)
4	1570.3323(4)	18	1596.0942(7)
3	1571.1509(5)	19	1597.5502(6)
2	1571.9965(5)		
1	1572.8691(4)		
0	1573.7687(4)		

Storage and Handling: The protective caps provided for the FC/PC fiber connectors should be replaced when the SRM is not in use. This SRM is intended to be used in a laboratory environment near ambient room temperature (22 °C ± 5 °C). The user should avoid exposing the unit to large temperature variations, temperature cycling, or mechanical shock, as these may cause the optical alignment to degrade. Such optical misalignment affects the throughput of the SRM but will not shift the centers of the absorption lines.

Certification Measurement Conditions and Procedure: The long term stability of carbon monoxide and the use of fundamental molecular absorption lines render the SRM insensitive to changes in environmental conditions. The purpose of the certification procedure is to verify that the unit contains the correct pressure of $^{12}C^{16}O$ gas, has no significant contaminants, and shows no evidence of cell leakage. Measurements of the spectral band, similar to that shown in Figure 1, are made using a broadband source and an optical spectrum analyzer. Higher resolution measurements are made using a tunable diode laser (~1 MHz linewidth) and a calibrated wavelength meter; spectra similar to that shown in Figure 3 are taken of each SRM unit and one or more lines are accurately fit to verify the line's center and width using the procedure described in Reference 2.

INSTRUCTIONS FOR USE

General Considerations: The SRM can be used to calibrate a laser or wavelength measuring instrument in the 1560 nm to 1595 nm region. The values in Table 1 are vacuum wavelengths; if the user requires the wavelength in air, the appropriate correction for the index of refraction of air must be applied (see Reference 4). Depending on what type of instrument is being calibrated, a user-supplied broadband source or a tunable narrowband source may be used. Typical optical connections are shown in Figure 4. The unit is bi-directional (has no preferred input/output port); connections to the unit should be made using single-mode optical fibers terminated with clean FC/PC connectors.

Use With a Broadband Source: A broadband source in the 1560 nm to 1595 nm region such as a light emitting diode, white light, or amplified spontaneous emission source is useful when calibrating an instrument, such as a diffraction grating based optical spectrum analyzer. A schematic for this type of calibration is shown in Figure 4(a). Light from the broadband source is coupled into the SRM and the output (transmission through the SRM) is connected to the instrument that is being calibrated. The absorption lines of carbon monoxide appear as dips in the spectrum of the light source.

Use With a Tunable Source: The SRM can be used to calibrate the wavelength scale of a tunable source in the 1560 nm to 1595 nm region (such as a diode laser, a fiber laser, or a source filtered by a tunable filter). A schematic for this type of calibration is shown in Figure 4(b). The laser is tuned over one or more of the carbon monoxide absorption lines. The transmission through the SRM is monitored by a detector; the transmitted power passes through a minimum at the center of an absorption line. Alternatively, a tunable laser source and the SRM can be used to check the calibration of a wavelength meter by measuring the wavelength of the laser (using the wavelength meter) as the laser is tuned through an absorption line.

Suggested Procedure for Low-Accuracy Requirements; Calibration Uncertainty > 30 pm: If calibrating an instrument using a broadband source, use an instrument resolution of ≤ 0.1 nm. If using a tunable source, use a data point density of at least one point every 0.005 nm (5 pm). After identifying a particular absorption line by comparing to the spectrum in Figure 1, find the center or minimum point of the line. Calibrate the instrument to the center wavelength of this line (from Table 1) using the calibration procedure specified by the instrument manufacturer. The instrument's linearity can be checked by repeating the procedure for a different absorption line and comparing it to the value listed in Table 1.

Suggested Procedure for Moderate-Accuracy Requirements; Calibration Uncertainty in the Approximate Range of 3 pm to 30 pm: If the source power varies significantly with wavelength, divide the SRM transmission spectrum by the source spectrum to obtain a normalized trace. After identifying a particular absorption line by comparing to the spectrum in Figure 1, make a high resolution scan of the line. If calibrating an instrument using a broadband source, use an instrument resolution of ≤ 0.05 nm. If using a tunable source, use a data point density of at least one point every 0.002 nm (2 pm). Find the wavelength readings on both sides of the line where the absorption is 50 % of the maximum; the line center is half-way between these two wavelength readings. For higher accuracy results, repeat this procedure five times and take the average of the measurements. Alternatively, the line center can be determined by fitting the central portion using a fourth order polynomial function. Calibrate the instrument to the center wavelength of this line (from Table 1) using the calibration procedure specified by the instrument manufacturer. The instrument's linearity can be checked by repeating the procedure for a different absorption line and comparing it to the value listed in Table 1.

NOTE: Highly reproducible *relative* wavelength measurements can be made using the procedure described for moderate-accuracy requirements. However, the procedure described in the following section is recommended to achieve high-accuracy *absolute* wavelength calibration.

Suggested Procedure for High-Accuracy Requirements; Calibration Uncertainty < 3 pm: Connect a narrowband tunable light source (source bandwidth ≤ 1 pm) to one of the fiber connectors on the SRM unit. After identifying a particular absorption line by comparing to the spectrum in Figure 1, make a high resolution scan of the line. Use a data point density of at least one point every 1 pm and divide the SRM transmission spectrum by the source spectrum to obtain a normalized trace. Using a fitting technique such as the least squares technique, fit the absorption data to a Lorentzian or Voigt lineshape. Details of a line fitting procedure and potential errors sources can be found in Reference 2, which is also included as an appendix in Reference 3. Calibrate the instrument to the center wavelength of this line (from Table 1) using the calibration procedure specified by the instrument manufacturer. The instrument's linearity can be checked by repeating the procedure for a different absorption line and comparing it to the value listed in Table 1. Contact NIST if the width of line R7 differs by more than 25 % from the width shown in Figure 3. A large change in linewidth could indicate cell leakage.

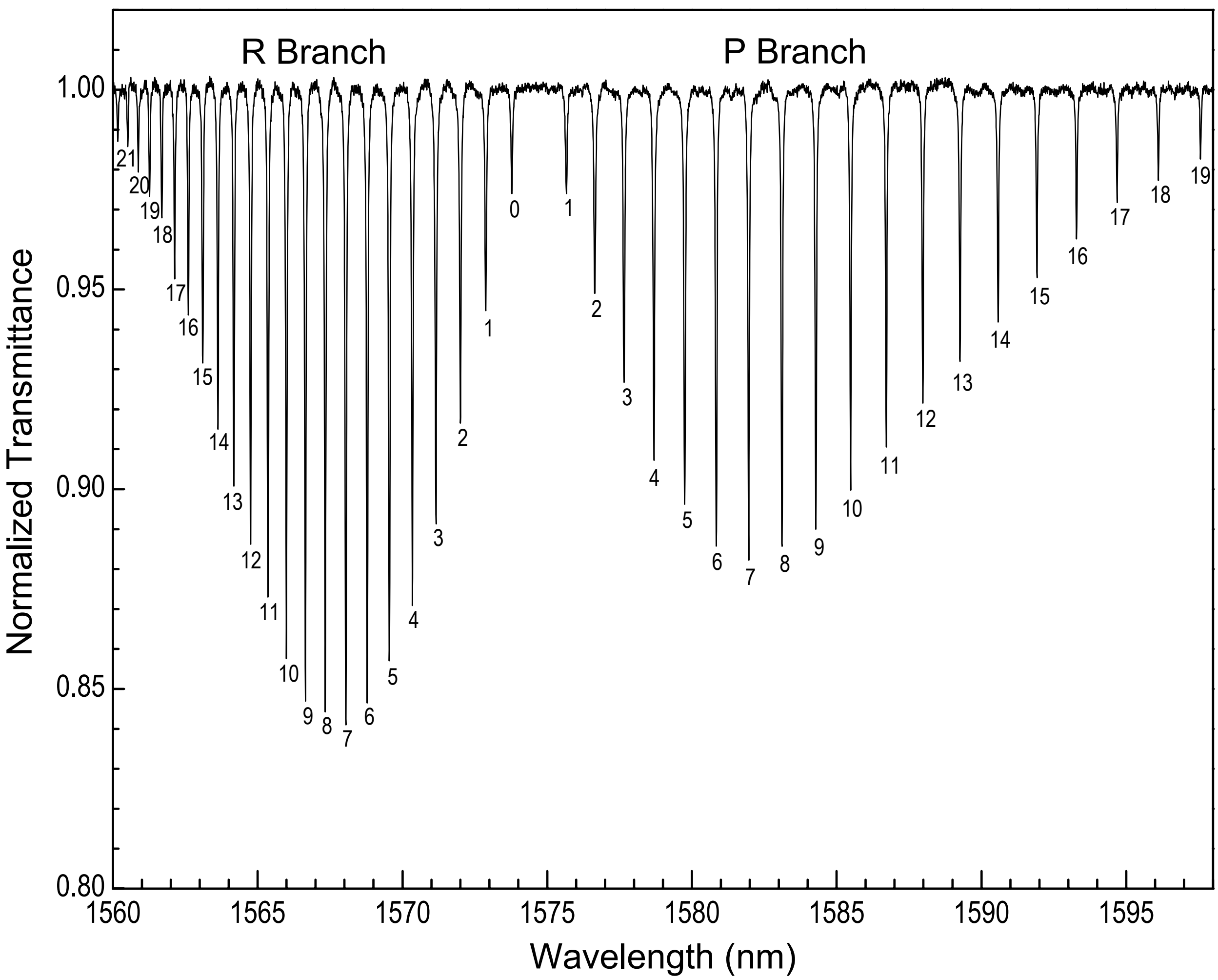

Figure 1. Normalized spectrum of the 3ν band of $^{12}C^{16}O$ obtained by passing LED light through an SRM 2514 unit and recording the spectrum of the transmitted light using an optical spectrum analyzer set to a resolution bandwidth of 0.05 nm. The figure shows the recorded spectrum divided by the LED spectrum. The $^{12}C^{16}O$ gas pressure is 133 kPa (1000 Torr); light makes four passes through a 20 cm long cell for a total optical path length of 80 cm.

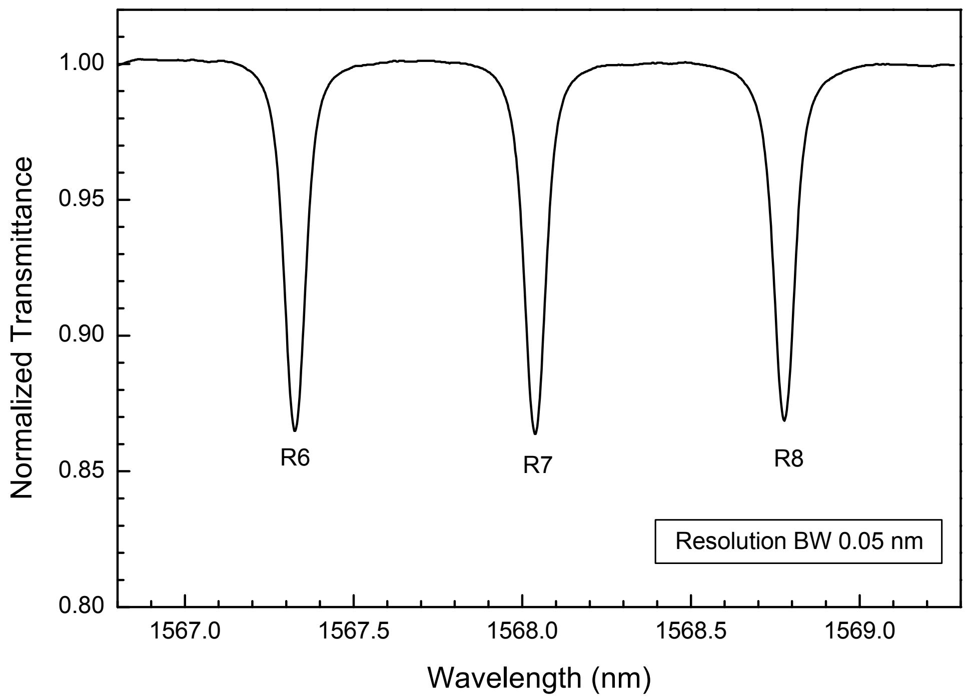

Figure 2. Spectrum of the R6, R7, and R8 lines obtained by passing LED light through an SRM 2514 unit and recording the spectrum using an optical spectrum analyzer set to a resolution bandwidth of 0.05 nm.

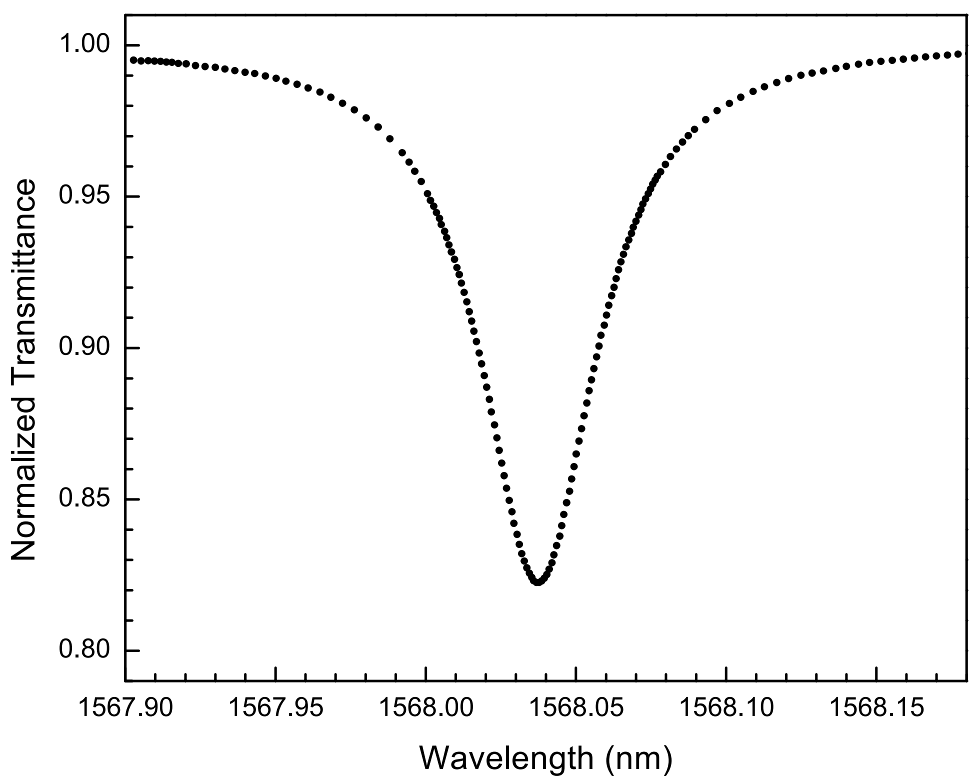

Figure 3. High resolution spectrum of line R7 obtained by passing tunable diode laser light through an SRM 2514 unit and recording the transmittance as the laser is scanned.

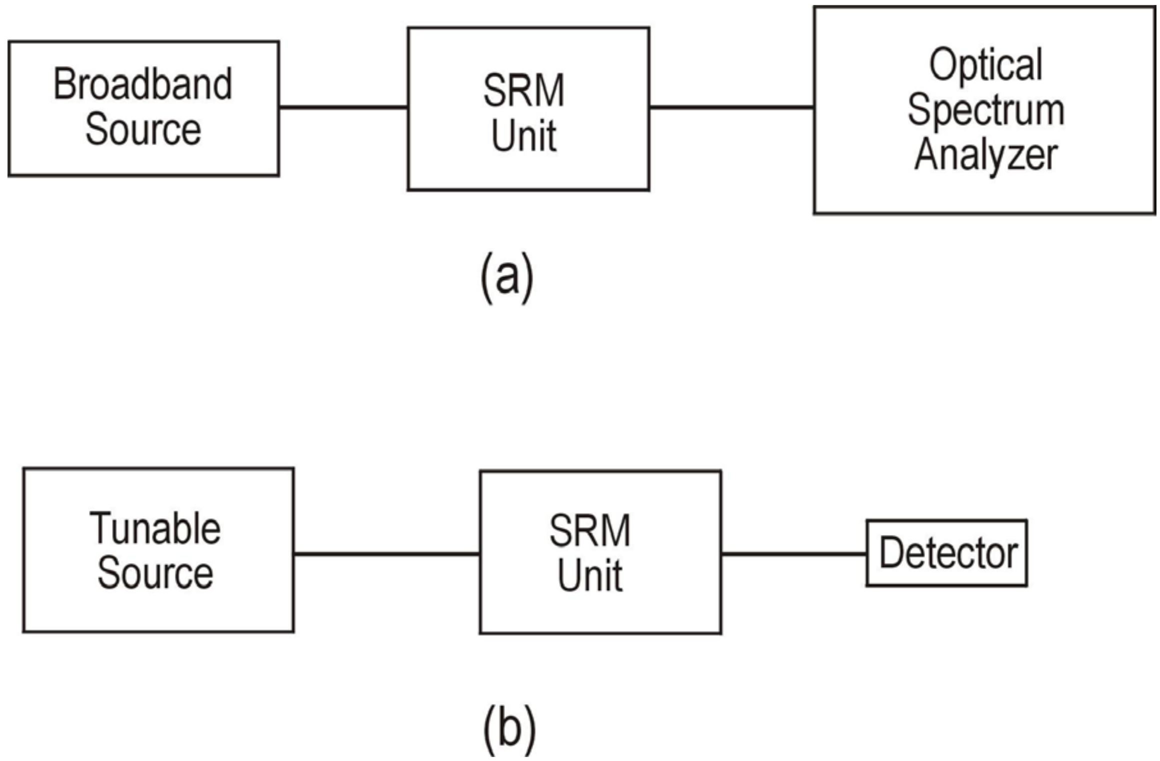

Figure 4. (a) Schematic of technique when using the SRM and a broadband source to calibrate an optical spectrum analyzer. (b) Schematic of technique when using the SRM to calibrate a tunable source. A wavelength meter can be calibrated by using a tunable laser in the configuration shown in (b) and measuring its wavelength using the wavelength meter.

REFERENCES

[1] Rothman, L.S. et al.; *The HITRAN Molecular Spectroscopic Database and HAWKS (HITRAN atmospheric workstation): 1996 Edition*; J. Quant. Spectrosc. Rad. Transf. Vol. 60, pp. 665-710 (1998); available at http://www.hitran.com/.

[2] Swann, W.C.; Gilbert, S.L.; *Pressure-Induced Shift and Broadening of 1560–1630 nm Carbon Monoxide Wavelength Calibration Lines*; Submitted to J. Opt. Soc. Am. B. Note: This paper is included as an appendix in Reference 3 (below).

[3] Gilbert, S.L.; Swann, W.C.; *Carbon Monoxide Absorption References for 1560 nm to 1630 nm Wavelength Calibration – SRM 2514 ($^{12}C^{16}O$) and SRM 2515 ($^{13}C^{16}O$)*; NIST Special Publication 260-146, In Press.

[4] Edlen, B.; *The Refractive Index of Air, Metrologia;* Vol. 2, p. 12 (1966); CRC Handbook of Chemistry and Physics 77th Ed., pp. 10-266 (1996).

Users of this SRM should ensure that the certificate in their possession is current. This can be accomplished by contacting the SRM Program at: telephone (301) 975-6776; fax (301) 926-4751; e-mail srminfo@nist.gov; or via the Internet http://www.nist.gov/srm.