

All data taken at the Pacific Northwest National Laboratory
FTS Operators: Yin-Fong Su, Ashley M. Oeck and John S. Loring
Data Analysis: Russell G. Tonkyn

Composite spectrum for: γ -Valerolactone

- First Column: Position in wavenumber (cm^{-1})
- Second column: Real refractive index $n(\tilde{\nu})$ (dispersion index)
- Third column: Imaginary refractive index, $k(\tilde{\nu})$ (absorption index per unit length in centimeters)

Where the complex refractive index $\hat{n} = n(\tilde{\nu}) + ik(\tilde{\nu})$

Following Bertie (in the references below) we define the absorbance as $A = -\log_{10}(I/I_0)$ and the linear absorption coefficient $K = A/d$, where d is the path length. The connection between the imaginary refractive index and the absorbance coefficient arises from the following: $2.303K = 4\pi\tilde{\nu}k$

See the following references for a detailed description of terms and units:

- 1) Bertie, J. E., Zhang, S. L., Eysel, H. H., Baluja, S., & Ahmed, M. K. (1993). Infrared Intensities of Liquids XI: Infrared Refractive Indices from 8000 to 2 cm^{-1} , Absolute Integrated Intensities, and Dipole Moment Derivatives of Methanol at 25°C . *Applied Spectroscopy*, 47(8), 1100-1114. doi:10.1366/0003702934067973
- 2) Bertie, J. E., Zhang, S. L., & Keefe, C. D. (1995). Measurement and use of absolute infrared absorption intensities of neat liquids. *Vibrational Spectroscopy*, 8(2), 215-229. doi:10.1016/0924-2031(94)00038-i

Sample:

- Chemical name, formula and CAS number: γ -Valerolactone, $\text{C}_5\text{H}_8\text{O}_2$, [108-29-2]
- IUPAC name: 5-methyloxolan-2-one
- Synonyms: gamma-Valerolactone; γ -Methyl- γ -butyrolactone; γ -Pentalactone; Pentanoic acid
- Physical properties: FW = 100.12 g/mole; mp = -31°C ; bp = $207\text{--}208^\circ\text{C}$; $\rho = 1.05\text{ g/cm}^3$
- Supplier and stated purity: Sigma-Aldrich, Analytical standard (Lot # BCBT7437)
- Temperature of sample: 26°C ($\pm 1^\circ\text{C}$)
- Individual samples were measured at the following path lengths: 4.48, 4.81, 9.14, 33.2, 60.5, 103, 208, 542, 1040, and 3101 micrometers (μm). Final data are a composite of these spectra.
- Sample cell window material is potassium bromide (KBr) except for 4.48 (MIR) which was potassium chloride (KCl).
- Preparation: None.

NIR Instrument Parameters:

- Bruker Vertex 70, purged with UHP nitrogen
- Spectral range: 10,000 to $3,000\text{ cm}^{-1}$ (1.0 to 3.33 microns)
- NIR source: Quartz tungsten bulb
- Beamsplitter: Broadband Potassium bromide (KBr)
- Detector: DLTGS at room temperature
- Aperture: 3 mm
- Folding limits: 31601 to 0 cm^{-1}

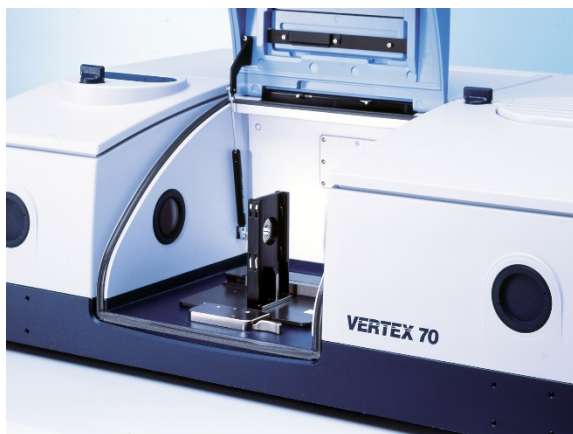
MIR Instrument Parameters:

- Tensor 27, purged with UHP nitrogen
- Spectral range: 7800 to 400 cm^{-1} (1.282 to 25 microns)
- IR source: Silicon carbide glow bar
- Beamsplitter: Broadband Potassium bromide (KBr)
- Detector: DLTGS at room temperature
- Aperture: 3 mm
- Folding limits: 15802 to 0 cm^{-1}

NIR/MIR Instrument Parameters:

- Instrument resolution: 2.0 cm⁻¹
- Number of interferograms averaged per single channel spectrum: 128
- Apodization: Norton-Beer, Medium
- Phase correction: Mertz
- Scanner velocity: 10 kHz
- Interferogram zerofill: 4x
- Spectral interval after zerofilling: 0.4823 cm⁻¹
- Aperture: 3 mm

a)



b)



Figure 1: The Bruker Vertex 70 FTIR (a) and Tensor 27 FTIR (b).

Measured Refractive Index:

The refractive index for γ -Valerolactone was measured at 25 °C using an Atago model DR-M2/1550 Abbe refractometer. Notch filters were employed in front of a white light source to make measurements at multiple wavelengths. An infrared viewer from Atago was used to detect signal at 1550 nm. The temperature was controlled to match that in the sample compartment of the FTIR using a heated circulating bath.

480 nm: $n = 1.4359$	486 nm: $n = 1.4350$	546 nm: $n = 1.4315$
589 nm: $n = 1.4295$	644 nm: $n = 1.4277$	656 nm: $n = 1.4273$
1550 nm: $n = 1.4105$		

The refractive index, n , vs. wavelength in microns, λ , was fit to an equation similar to that of Sellmeier:

$$n(\lambda) = \{a + b/(\lambda^2 - c)\}^{1/2}$$

The resulting best-fit equation was used to find the refractive index at the highest energy data point in our experimental spectra. For γ -Valerolactone, the result was

$$\begin{aligned} n(7800 \text{ cm}^{-1}) &= 1.4129 \text{ at } 25 \text{ }^\circ\text{C} \text{ for MIR data and} \\ n(10,000 \text{ cm}^{-1}) &= 1.4171 \text{ at } 25 \text{ }^\circ\text{C} \text{ for NIR and merged data.} \end{aligned}$$

Post Processing and Related Parameters:

For the MIR, a composite spectrum was created from 8 absorbance spectra (base-10) taken at 8 path lengths: 4.48, 4.81, 9.14, 33.2, 60.5, 103, 208, and 542 micrometers (μm). For the NIR, a composite spectrum was created from 5 absorbance spectra (base-10) taken at 5 path lengths: 103, 208, 542, 1040, and 3031 μm . The same cells for the 100, 200 and 500 μm path lengths were used for both spectral ranges. At each path length several spectra were measured and the results averaged for better signal to noise. The measured cell lengths were adjusted using Beer's law plots in which the NIR and MIR data were analyzed independently.

- 1) The imaginary part of the refractive index, or k vector, was determined for each absorbance file as per Bertie's program "RNJ46A" (see reference above). This takes into account the reflective losses due to the KBr windows.
- 2) A composite k vector is created via a classical, weighted, linear, least squares fit using the output files of program "RNJ46A": Intercept=0, slope is fitted, individual absorbance values weighted by T^2 (transmission squared), all absorbance values ≥ 2.5 are given zero weight. Four composite vectors were created and merged by hand.
 - a) The first k vector used the results from the 208 and 542 μm cells. This k vector determined the final values for the range from 7800 to 4900 cm^{-1} .
 - b) The second k vector used the results from the 60.5 through 542 μm cells. This k vector determined the final values for the range from 4900 to 3450 cm^{-1} .
 - c) The third k vector used the results from the 4.48 through 103 μm cells. This k vector determined the final values for the range from 3450 to 2800 cm^{-1} and from 1950 to 750 cm^{-1} .
 - d) The fourth k vector used the results from the 33.2 through 542 μm cells. This k vector determined the final values for the range from 2800 to 1950 cm^{-1} and from 750 to 400 cm^{-1} .
- 3) A frequency correction was applied to the resulting composite MIR k vector.
 - a) Frequency correction (already applied): $\tilde{\nu}(\text{corrected}) = [\tilde{\nu}(\text{instrument}) * 0.999848 + 0.010722]$ as determined by comparing measured atmospheric spectral lines (H_2O and CO_2) to values from the Northwest Infrared Spectral Library Database.
- 4) For the NIR, two composite vectors were created and merged by hand.
 - a) The first k vector used the results from the 1040 and 3031 μm cells. This k vector determined the final values for the range from 10000 to 6300 cm^{-1} .
 - b) The second k vector used the results from the 103 through 3101 μm cells. This k vector determined the final values for the range from 6300 to 400 cm^{-1} .
- 5) A frequency correction was applied to the resulting composite NIR k vector.
 - a) Frequency correction (already applied): $\tilde{\nu}(\text{corrected}) = [\tilde{\nu}(\text{instrument}) * 0.999869 + 0.0158818]$ as determined by comparing measured atmospheric spectral lines (H_2O and CO_2) to values from the Northwest Infrared Spectral Library Database.
- 6) Finally, the MIR data were mapped onto the NIR x-axis using an interpolation routine, i.e. the Make Compatible command in OPUS 5.5. Then the composite MIR and NIR k vectors were merged to generate a final composite k vector across the entire spectral range. The NIR data were used exclusively above 5040 cm^{-1} , and only the MIR data were used below 4840 cm^{-1} . A weighted average, with the weight of the MIR vector increasing linearly from 0 to 100% between 5040 and 4840 cm^{-1} was used in the overlapping spectral region. The resulting composite k vector and the refractive index at 10,000 cm^{-1} were used to create the final n vector using the Kramers-Kronig relation, as per Bertie's program "LZZKTB."

Photograph of Sample γ -Valerolactone:



Figure 2: γ -Valerolactone in Sigma-Aldrich container.