

All data taken at the Pacific Northwest National Laboratory  
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Data Analysis: Russell G. Tonkyn

**Composite spectrum for:** Diisopropyl methylphosphonate

- First Column: Position in wavenumber ( $\text{cm}^{-1}$ )
- 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  $2\text{ cm}^{-1}$ , Absolute Integrated Intensities, and Dipole Moment Derivatives of Methanol at  $25^\circ\text{C}$ . *Appl. Spec.* 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: Diisopropyl methylphosphonate,  $\text{C}_7\text{H}_{17}\text{O}_3\text{P}$ , [1445-75-6]
- IUPAC name: Diisopropyl methylphosphonate
- Synonyms: DIMP; Diisopropyl methanephosphonate; Methyl-phosphonic acid diisopropyl ester
- Physical properties: FW = 180.18 g/mole; mp = n/a; bp =  $50 - 51^\circ\text{C}/1\text{ mm Hg}$ ;  $\rho = 0.976\text{ g/cm}^3$
- Supplier and stated purity: Alfa Aesar, 95.0 % (Lot # R19D028)
- Temperature of sample:  $26^\circ\text{C}$  ( $\pm 1^\circ\text{C}$ )
- Individual samples were measured at the following path lengths: MIR: 1.8, 5.0, 7.4, 11.5, 17, 25, 50 and 95  $\mu\text{m}$ . NIR: 96, 204, 514, 995 and 2997  $\mu\text{m}$ . Final data are a composite of these spectra.
- Sample cell window material is potassium bromide (KBr).
- 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)
- IR source: Quartz tungsten bulb
- Beamsplitter: Broadband Potassium bromide (KBr)
- Detector: DLTGS at room temperature
- Aperture: 3 mm
- Folding limits: 15801 to  $0\text{ cm}^{-1}$

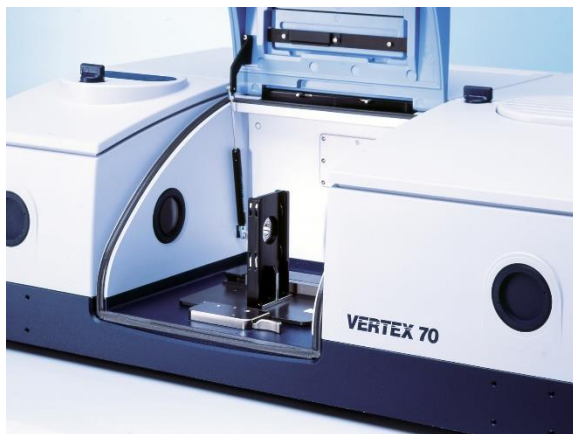
**MIR Instrument Parameters:**

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

**NIR/MIR Instrument Parameters:**

- Instrument resolution:  $2.0\text{ cm}^{-1}$
- 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:  $0.4823\text{ cm}^{-1}$

a)



b)



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

**Measured Refractive Index:**

The refractive index for DIMP was measured at  $25\text{ }^{\circ}\text{C}$  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  $1550\text{ nm}$ . The temperature was controlled to match that in the sample compartment of the FTIR using a heated circulating bath.

480 nm:  $n = 1.4128$ 486 nm:  $n = 1.4124$ 546 nm:  $n = 1.4095$ 589 nm:  $n = 1.4079$ 644 nm:  $n = 1.4062$ 656 nm:  $n = 1.4058$ 1550 nm:  $n = 1.3897$ 

The refractive index,  $n$ , vs. wavelength in microns,  $\lambda$ , 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 points in our experimental spectra. For DIMP, the results were

$$\begin{aligned} n(7800\text{ cm}^{-1}) &= 1.3922 \text{ at } 25\text{ }^{\circ}\text{C} \text{ for MIR data and} \\ n(10,000\text{ cm}^{-1}) &= 1.3965 \text{ at } 25\text{ }^{\circ}\text{C} \text{ for NIR and merged data.} \end{aligned}$$

### Post Processing and Related Parameters:

For the MIR, a composite spectrum was created from 8 absorbance spectra (base-10) taken at 8 path lengths: 1.8, 5.0, 7.4, 11.5, 17, 25, 50 and 95 micrometers ( $\mu\text{m}$ ). For the NIR, a composite spectrum was created from 5 absorbance spectra (base-10) taken at 5 path lengths: 96, 204, 514, 995 and 2997 micrometers ( $\mu\text{m}$ ). 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  $\geq 2.5$  are given zero weight. For the MIR, five composite vectors were created and merged by hand.
  - a) The first  $k$  vector used the results from the 50 through 95  $\mu\text{m}$  cells. This  $k$  vector determined the final values for the range from 7800 to 4500  $\text{cm}^{-1}$ .
  - b) The second  $k$  vector used the results from the 25 through 95  $\mu\text{m}$  cells. This  $k$  vector determined the final values for the range from 4500 to 3100  $\text{cm}^{-1}$  and 2800 to 1500  $\text{cm}^{-1}$ .
  - c) The third  $k$  vector used the results from the 2, 7 and 12  $\mu\text{m}$  cells. This  $k$  vector determined the final values for the range from 3100 to 2800  $\text{cm}^{-1}$ .
  - d) The fourth  $k$  vector used the results from the 2 through 50  $\mu\text{m}$  cells. This  $k$  vector determined the final values for the range from 1500 to 600  $\text{cm}^{-1}$ .
  - e) The fifth  $k$  vector used the results from the 15 through 95  $\mu\text{m}$  cells. This  $k$  vector determined the final values for the range from 600 to 400  $\text{cm}^{-1}$ .
- 3) The resulting composite MIR  $k$  vector and the refractive index at 7800  $\text{cm}^{-1}$  were used to create the real or  $n$  vector using the Kramers-Kronig relation, as per Bertie's program "LZZKTB."
  - a) Frequency correction (already applied):  $\tilde{\nu}(\text{corrected}) = [\tilde{\nu}(\text{instrument}) * 0.99994 + .010722]$  as determined by comparing measured atmospheric spectral lines ( $\text{H}_2\text{O}$  and  $\text{CO}_2$ ) to values from the Northwest Infrared Spectral Library Database.
- 4) For the NIR, three composite vectors were created and merged by hand.
  - a) The first  $k$  vector used the results from the 995 and 2997  $\mu\text{m}$  cells. This  $k$  vector determined the final values for the range from 10,000 to 8000  $\text{cm}^{-1}$ .
  - b) The second  $k$  vector used the results from the 514 through 2997  $\mu\text{m}$  cells. This  $k$  vector determined the final values for the range from 8000 to 5400  $\text{cm}^{-1}$ .
  - c) The second  $k$  vector used the results from the 96 through 2997  $\mu\text{m}$  cells. This  $k$  vector determined the final values for the range from 5400 to 400  $\text{cm}^{-1}$ .
- 5) The resulting composite NIR  $k$  vector and the refractive index at 10,000  $\text{cm}^{-1}$  were used to create the real or  $n$  vector using the Kramers-Kronig relation, as per Bertie's program "LZZKTB."
  - a) Frequency correction (already applied):  $\tilde{\nu}(\text{corrected}) = [\tilde{\nu}(\text{instrument}) * 0.99975 + .00400]$  as determined by comparing measured atmospheric spectral lines ( $\text{H}_2\text{O}$  and  $\text{CO}_2$ ) 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 by hand to generate a final composite  $k$  vector across the entire spectral range. The resulting composite  $k$  vector and the refractive index at 10,000  $\text{cm}^{-1}$  were used to create the final  $n$  vector using the Kramers-Kronig relation, as per Bertie's program "LZZKTB."

**Photograph of Sample Diisopropyl methylphosphonate:**



Figure 2: Diisopropyl methylphosphonate in Alfa Aesar container.