

All data taken at the Pacific Northwest National Laboratory
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Composite spectrum for: Thiophosphoryl chloride

- 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: Thiophosphoryl chloride, PSCl_3 , [3982-91-0]
- IUPAC name: Phosphorothioic trichloride
- Synonyms: Phosphorus sulfochloride, Phosphorus thiochloride
- Physical properties: FW = 169.40 g/mole; mp = -35°C ; bp = 125°C ; $\rho = 1.668\text{ g/cm}^3$
- Supplier and stated purity: Aldrich, 98% (Lot # SHBF7815V)
- Temperature of sample: 26°C ($\pm 1^\circ\text{C}$)
- Individual samples were measured at the following path lengths: 0.896, 3.50, 3.92, 8.88, 14.8, 35.6, 101, 205 and 540 micrometers (μm). Final data are a composite of these spectra.
- Sample cell window material is potassium bromide (KBr).
- Preparation: None.
- Trace amounts of hydroxyl-containing impurities may be present.

Instrument Parameters:

- Bruker Tensor 27 FTIR, purged with UHP nitrogen
- Spectral range: 7800 to 400 cm^{-1} (1.282 to 25 microns)
- 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
- Folding limits: 15802 to 0 cm^{-1}
- Interferogram zerofill: 4x
- Spectral interval after zerofilling: 0.4823 cm^{-1}
- IR source: Silicon carbide glow bar
- Beamsplitter: Broadband potassium bromide (KBr)
- Detector: DLTGS at room temperature
- Aperture: 3 mm

Measured Refractive Index:

The refractive index for Thiophosphoryl chloride was measured at 27 °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 InGaAs camera 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: $n = -$	486 nm: $n = -$	546 nm: $n = -$
589 nm: $n = -$	644 nm: $n = -$	656 nm: $n = -$
1550 nm: $n = 1.530$		

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

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

Then, the resulting best-fit equation is used to find the refractive index at the highest energy data point in our experimental spectra. For Thiophosphoryl chloride, however, only one measurement was obtained so that an estimate of the change in refractive index between 1550 nm and 7800 cm^{-1} was calculated from prior measurements of 53 other liquids. The change in refractive index from these other liquids was calculated to be $.0013 \pm .0006$. Thus, for Thiophosphoryl chloride, the result was

$$n(7800 \text{ cm}^{-1}) = 1.5313 \text{ at } 27 \text{ }^\circ\text{C}.$$

a)



b)



Figure 1: The Bruker Tensor 27 FTIR (a) and Abbe refractometer (b).

Post Processing and Related Parameters:

A composite spectrum was created from 9 absorbance spectra (base-10) taken at 9 path lengths: 0.896, 3.50, 3.92, 8.88, 14.8, 35.6, 101, 205 and 540 micrometers (μm). 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.

- 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. Five composite vectors were created and merged by hand. Additionally, a single non-merged spectrum taken from the 540 μm cell was used in certain regions as indicated below.
 - a) The first k vector used the results from the 540 and 205 μm cells. This k vector determined the final values for the range from 1569 to 782 cm^{-1} and 407 to 400 cm^{-1} .

- b) The second k vector used the results from the 205 and 101 μm cells. This k vector determined the final values for the range from 2972 to 2811 cm^{-1} and 670 to 567 cm^{-1} .
 - c) The third k vector used the results from the 35.6 and 14.8 μm cells. This k vector determined the final values for the range from 493 to 407 cm^{-1} .
 - d) The fourth k vector used the results from the 8.88 and 3.92 μm cells. This k vector determined the final values for the range from 782 to 773 cm^{-1} , 745 to 670 cm^{-1} and 567 to 498 cm^{-1} .
 - e) The fifth k vector used the results from the 3.50 and 0.896 μm cells. This k vector determined the final values for the range from 773 to 745 cm^{-1} and 498 to 493 cm^{-1} .
 - f) The spectrum obtained from the 540 μm cell was used to determine the final values for the range from 7800 to 2972 cm^{-1} and 2811 to 1569 cm^{-1} .
- 3) The resulting composite k vector and the refractive index at 7800 cm^{-1} were used to create the real or n vector using the Kramers-Kronig relation, as per Bertie's program "LZZKTB."
- a) Calculated and estimated errors: Type A = 0.7%.
 - b) Frequency correction (already applied): $\tilde{\nu}(\text{corrected}) = [\tilde{\nu}(\text{instrument}) * .99977 - .01872]$ as determined by comparing measured atmospheric spectral lines (H_2O and CO_2) to values from the Northwest Infrared Spectral Library Database.
 - c) Axis units: X= Wavenumbers (cm^{-1}); Y = Absorbance (base 10).

Photograph of Sample Thiophosphoryl chloride:



Figure 2: Thiophosphoryl chloride in Aldrich container.