

*Supplementary Material*

**Quantitative enantioselective Raman spectroscopy**

Johannes Kiefer\*<sup>[a][b][c]</sup>

<sup>[a]</sup> Technische Thermodynamik, Universität Bremen, Badgasteiner Str. 1, 28359 Bremen, Germany

<sup>[b]</sup> School of Engineering, University of Aberdeen, Fraser Noble Building, Aberdeen AB24 3UE, UK

<sup>[c]</sup> Erlangen Graduate School in Advanced Optical Technologies, Universität Erlangen-Nürnberg, 91052 Erlangen, Germany

\*Corresponding author. E-mail: [jkiefer@uni-bremen.de](mailto:jkiefer@uni-bremen.de)

## Method

A schematic setup of the approach is shown in Fig. S1 and has been discussed in detail previously.<sup>1</sup> The beam of a linearly polarized laser passes the sample in a cuvette and is eventually blocked in a beam dump. In direction perpendicular to the laser the scattered light is collected and collimated using an achromatic lens. The collimated light passes a half-wave retarder, e.g. an achromatic half-wave plate or a Fresnel rhomb, before its vertically and horizontally polarized components are separated in a polarizing beam splitter. Each signal component is spectrally dispersed and recorded in a spectrometer.

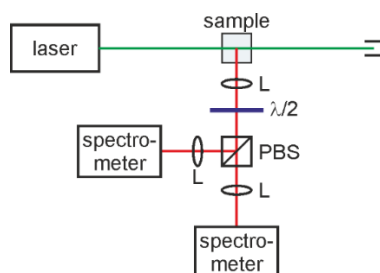


Figure S1. Schematic experimental setup.  $L$  = lens,  $\lambda/2$  = half-wave retarder, PBS = polarizing beam splitter.

The main parameters to characterize the propagation of a linearly polarized laser beam and the polarized and depolarized Raman scattering intensities in the sample, e.g. a liquid in a glass cuvette, are illustrated in Fig. S2. In direction perpendicular to the laser beam, the scattered light is collected. A polarizing beam splitter separates the vertically and horizontally polarized fractions of the signal before they are spectrally dispersed and recorded.

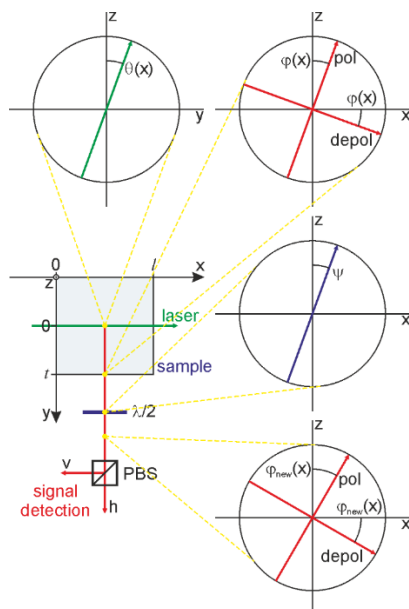


Figure S2. Schematic illustration of the laser beam and Raman signal propagation in the sample. The polarization diagrams indicate the nomenclature of the polarization angles with respect to the axes of the coordinate system used in the theoretical description and the discussion.  $\lambda/2$  = half-wave retarder,  $l$  = length of cuvette,  $t$  = distance the signal travels inside the cuvette, PBS = polarizing beam splitter,  $v$  = vertically polarized signal,  $h$  = horizontally polarized signal.

The  $x$ -axis denotes the beam direction and the  $y$ -axis corresponds to the direction in which the signal is detected. The  $z$ -axis is orthogonal to both and represents the initial polarization direction of the laser. In this configuration and under the assumption that the sample is not optically active, there will be the polarized Raman signal oscillating in  $z$ -direction and two depolarized components in  $x$ - and  $y$ -direction. When the sample is optically active, however, we need to take into account that the laser polarization is rotated when travelling through the sample. The angle by which the laser beam polarization is rotated at a position  $x$  is  $\theta(x)$  and the corresponding signal rotation angle is  $\varphi(x,y)$ . A detailed theoretical framework is given and discussed in reference <sup>2</sup>. In the present work, an infinitesimally small laser beam, and a signal collection with infinitesimally small solid angle is considered to simplify matter. In this case, the detected vertically and horizontally polarized intensities can be written as<sup>1</sup>

$$I_{vertical} = I_{pol} \cdot |\cos \theta| \cdot |\cos \varphi| + \frac{I_{depol}}{2} \cdot (|\sin \theta| \cdot |\cos \varphi| + |\sin \varphi|) \quad (S1)$$

$$I_{horizontal} = I_{pol} \cdot |\cos \theta| \cdot |\sin \varphi| + \frac{I_{depol}}{2} \cdot (|\sin \theta| \cdot |\sin \varphi| + |\cos \varphi|) \quad (S2)$$

where  $I_{pol}$  and  $I_{depol}$  represent the scattered polarized and depolarized intensities in the infinitesimal probe volume, respectively. The parameter  $\theta = \theta(l/2)$  is the angle by which the laser polarization is rotated in the probe volume located at  $x = l/2$ , and  $\varphi = \varphi(l/2,t)$  is the rotation angle of the signal when it leaves the cuvette. Subsequently, the signal passes a half-wave retarder, for example an achromatic half-wave plate, the optical axis of which is rotated by an angle  $\psi$  with respect to the  $z$ -axis.

For studying the effects of the retarder orientation, the Raman depolarization ratio, and the enantiomer concentration on the signal, a simple spectroscopic model case is used. We consider an isolated Raman line centered at  $100 \text{ cm}^{-1}$  and exhibiting a Gaussian line profile with  $10 \text{ cm}^{-1}$  full width at half maximum. The polarized intensity  $I_{pol}$  is set 100 and a depolarization ratio of 0.2 is assumed. The measurement position is located at  $x = 5 \text{ mm}$  and the length of the cuvette is  $l = 10 \text{ mm}$ . The signal is traveling inside the sample for a distance of  $t = 10 \text{ mm}$ , and the specific rotation is  $10^\circ/\text{cm}$  for a normalized concentration of 1. In other words, the angle  $\varphi$  is  $+10^\circ$  or  $-10^\circ$  for the L- and D-enantiomers of our notional chiral substance, respectively. The concept of enantioselective Raman spectroscopy of this particular system is illustrated in Fig. S3.

In order to illustrate the principle of enantioselective Raman spectroscopy in the described system, Figure S3 shows the detected vertically (v) and horizontally (h) polarized signal components as well as the difference of the two for three different cases. In all cases, enantiopure samples containing either the D- or the L-enantiomer are considered. The reference case A shows the situation when the sample does not exhibit optical activity and no retarder is inserted. In case B, the sample is optically active, but there is still no retarder, and in case C a half-wave retarder with an angle  $\psi = -10^\circ$  is inserted. The latter means that the optical axis coincides with the polarization direction of the D-enantiomer. The spectra demonstrate that enantioselective discrimination is only possible when the retarder is used. Furthermore, the data show that either the vertically or the horizontally polarized signal component is in principle sufficient to distinguish between the enantiomers, but the observation of both certainly helps to establish further confidence.

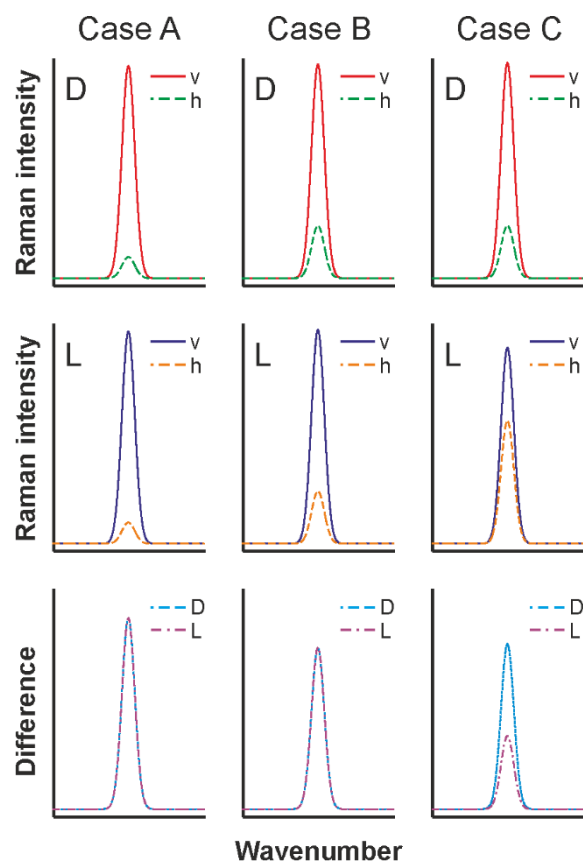


Figure S3. Intensity of the vertically and horizontally polarized signal components for samples without optical activity (case A), with optical activity but without retarder (case B), and with optical activity and with retarder (case C). The upper and center rows represent the three cases for the D- and L-enantiomers, and the lower row shows the difference intensities.

## References

1. J. Kiefer and K. Noack, *Analyst*, 2015, **140**, 1787-1790.
2. J. Kiefer and M. Kasperleit, *Analytical Methods*, 2013, **5**, 797-800.