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CONCENTRATION-DEPENDENT ANALYSIS OF ANILINE VIBRATIONAL MODES USING POLARIZED RAMAN AND GENERALIZED 2D RAMAN CORRELATION SPECTROSCOPY

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Abstract. In this paper, the characteristic vibrational modes of aniline were analyzed using polarized Raman and two-dimensional Raman correlation spectroscopy methods. Polarized Raman spectra revealed the presence of anomalous phenomena in the ring-breathing and C-H vibrational modes of aniline. The symmetry and asymmetry vibrational properties of these vibrations were fully manifested in the polarized Raman spectrum. In the case of N-H vibrations, the results that are usually observed were determined. To explain the anomalies observed in the polarized Raman spectra, two-dimensional Raman synchronous and asynchronous spectra were generated based on Raman spectral data of aniline in ethyl acetate at various concentrations. These spectra strongly supported the conclusions drawn from the polarized Raman spectra.

Keywords: aniline, polarized Raman, ring-breathing, two-dimensional correlation spectroscopy.

Anilinning tebranish modlarini polarizatsiyalangan raman va umumlashgan 2D Raman korelyatsion spektroskopiyasi yordamida konsentratsiyaga bog‘liq holda tahlil qilish

Annotatsiya. Ushbu maqolada anilinning xos tebranish rejimlari polarizatsiyalangan Raman va ikki o‘lchovli Raman korelyatsion spektroskopiya usullari yordamida tahlil qilindi. Polarizatsiyalangan Raman spektrlari anilinning halqa-tebranish va C-H tebranish rejimlarida anomal hodisalarning mavjudligini ko'rsatdi. Ushbu tebranishlarning simmetrik va assimetrik xususiyatlari polarizatsiyalangan Raman spektrida to‘liq namoyon bo‘ldi. N-H tebranishlari holatida odatda kuzatiladigan natijalar aniqlangan. Polarizatsiyalangan Raman spektrlarda kuzatilgan anomaliyalarni tushuntirish uchun anilinning turli konsentratsiyalarda etil asetatda Raman spektral ma'lumotlari asosida ikki o‘lchovli Raman sinxron va asinxron spektrlari yaratildi. Ushbu spektrlar polarizatsiyalangan Raman spektrlari asosida qilingan xulosalarni kuchli tasdiqladi.

Kalit so‘zlar: Anilin, halqa-tebranish, ikki o‘lchovli korelyatsion spektroskopiya, qutblangan Raman.

Анализ колебательных мод анилина в зависимости от концентрации с использованием поляризованной рамановской и обобщённой 2D Рамановской корреляционной спектроскопии

Аннотация. В данной статье характеристические колебательные моды анилина были проанализированы с использованием методов поляризованной Рамановской и двумерной Рамановской корреляционной спектроскопии. Поляризованные Рамановские спектры выявили наличие

аномальных явлений в колебательных модах кольцевого дыхания и C-H анилина. Симметричные и асимметричные колебательные свойства этих вибраций полностью проявились в поляризованном Рамановском спектре. В случае N-H колебаний были определены результаты, которые обычно наблюдаются. Для объяснения аномалий, наблюдаемых в поляризованных спектрах, на основе данных Рамановских спектров анилина в этилацетате при различных концентрациях были построены двумерные Рамановские синхронные и асинхронные спектры. Эти спектры значительно подтвердили выводы, сделанные на основе поляризованных Рамановских спектров.

Ключевые слова: анилин, двумерная корреляционная спектроскопия, кольцевое дыхание, поляризованная Рамановская спектроскопия.

1. Introduction. Investigating the nature of intermolecular interactions in biological systems has always been complex and relevant. In the analysis of intermolecular processes in these systems, it is crucial to estimate the molecular orientation accurately. Polarized Raman Spectroscopy (PRS) is the most efficient way to probe molecular orientation [1-4]. The PRS principle of operation depends on the relationship between the electric field strength of the excitation laser beam and the electric field strength vector of the light scattered from the sample. The spectrum recorded when the electric field intensity vector of the scattered light beam and the electric field intensity vector of the incident light are parallel to each other is a parallel Raman spectrum. If these lights' electric field strength vectors are perpendicular to each other, then the recorded spectrum is a perpendicular Raman spectrum. The orientation process of the polar bonds of the molecule can be investigated by comparing the peak frequencies of the parallel and perpendicular Raman spectra. The peak frequency difference between parallel and perpendicular components is called the Raman non-coincidence effect (NCE) [5-7]. Research has indicated that compounds with aromatic rings can also generate Raman NCE. Research targets typically identify the breathing vibrations of such molecules. A. Morresi et.al [8] have studied the Raman NCE of aromatic ring vibrations in detail. They analyzed the NCE of ring breathing vibrations of p-xylene and mesitylene molecules, which do not have a dipole moment, and toluene, o-xylene, and m-xylene molecules, which have a weak dipole moment. They confirmed that the resonance coupling mechanism could be used to explain Raman NCE in ring-breathing vibrations. The authors also found that the Raman NCE in ring-breathing vibrations is negative. This result means that the frequency of the isotropic ring-breathing vibration is located in the blue site relative to the frequency of the anisotropic vibration. G. Doge and D. Schneider studied the Raman NCE of total symmetrization ring-breathing vibrations of benzene, benzene-d6, pentafluorobenzene, hexafluorobenzene, cyclopentane, cycloheptane, cyclopentanone, and cyclohexanone [9]. They found that these ring-breathing vibrations also have negative Raman NCE. It has been suggested that this anomaly may be caused by repulsive resonance intermolecular vibrational coupling. G. Kalampounias and N. Papatheodorou investigated Raman NCE in the boroxol ring in the glassy, supercooled, and liquid states [10]. The authors investigated the effect of repulsive and attractive interactions on Raman NCE in different aggregate states. They concluded that Raman NCE is positive if the attraction forces dominate the molecular system.

As a whole, studying the properties of ring-breathing vibrations is an important task for understanding molecular dynamics, interactions, and orientation. Therefore, this paper discusses the ring-breathing vibrational properties of aniline and the mechanisms by which these properties are manifested in polarized Raman spectra. In addition, the effect of intermolecular interactions on the NH_2 symmetric and asymmetric vibrational modes of aniline was also investigated. To date, the properties of ring-breathing and other vibrational modes of aniline, both neat and in solution with various solvents, have been studied by spectroscopic methods such as Raman, infrared, and nuclear magnetic resonance. However, the isotropic and anisotropic components of these vibrational modes have hardly been studied through PRS. Another aspect that increases the relevance of this work is that the recorded Raman spectral results are discussed using two-dimensional correlation spectroscopy

(2D-COS). For spectroscopic investigations, one can benefit from the versatile data analysis technique known as generalized two-dimensional correlation spectroscopy (2D-COS) [11,12]. In 2D-COS, a spectral correlation intensity is obtained as a function of two independent spectral variables, like Raman or infrared frequencies, for a sample under the influence of some externally applied perturbation, such as a change in time, temperature, pressure, or concentration [13,14].

2. Methods. A Renishaw Invia Raman spectrometer with a constant of the diffraction grating of 1200 lines/mm was used to record polarized Raman spectra of neat aniline and its binary solutions with ethyl acetate at various concentrations (0.9, 0.7, 0.5, 0.3, and 0.1 m.f.). A Spectrum-Stabilized Laser Module with a wavelength of 532 nm and a power of 100 mW was utilized as the excitation light source. A Renishaw CCD camera detector with a 20x focus and a backscattering geometry arrangement that collects Raman scattering light was used to record the spectra.

The generalized 2D correlation analysis, which is based on Noda's approach [15], creates correlation maps using Raman spectra as input data.

3. Results and discussion. The aniline molecule consists of 14 atoms. According to the formula 3N-6, which finds the number of vibrations in a molecule, the number of vibrations in aniline is 36. However, according to the formation mechanism of the Raman scattering spectrum, only a certain fraction of these parts were active in this vibrational spectrum (Fig.1). The most Raman-active vibrations are ring-breathing, C-H, and N-H vibrations, as seen in Fig.1.

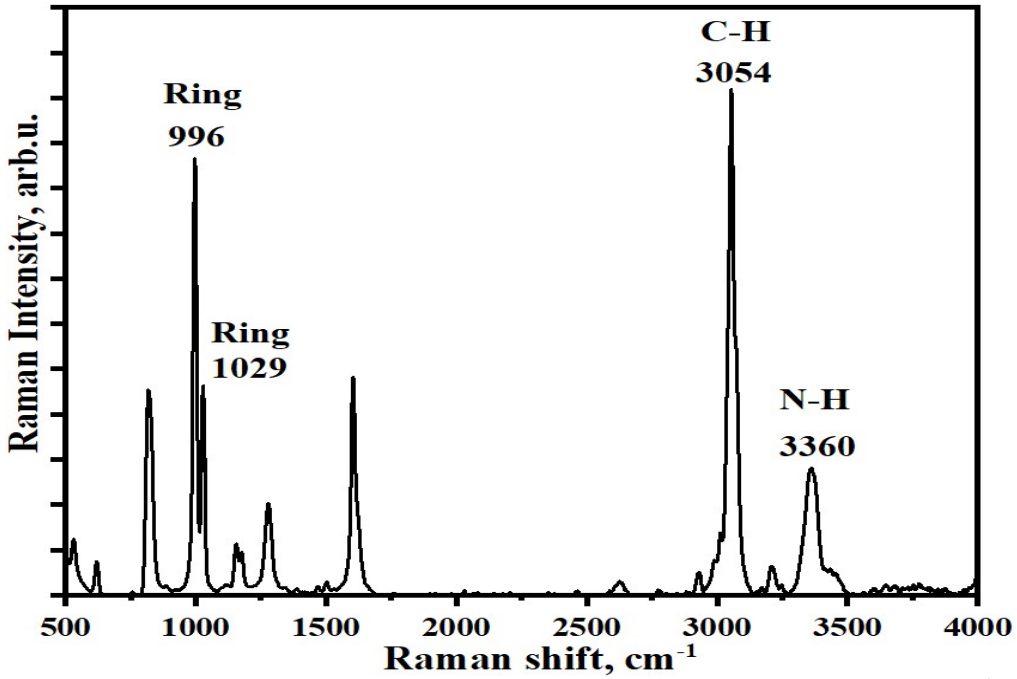


Figure 1. Raman spectrum of aniline in the spectral range 500-4000 cm^{-1}.

The wavenumbers of the ring-breathing vibrations are 996 and 1029 cm^{-1}, respectively. Also, the wavenumbers of C-H and N-H vibrations are 3054 and 3360 cm^{-1}, respectively. These results are exactly consistent with the results of previous research [16]. The figure shows that the spectral line at 3054 cm^{-1} has asymmetry at low frequencies, while the spectral line at 3360 cm^{-1} has asymmetry at high frequencies. Such asymmetry may be due to the different vibrational properties of these vibrational modes. That is, the symmetry or asymmetry of the vibrations strongly affects the formation of vibrational spectra. One of the most effective methods for studying the symmetry or asymmetry of vibrations is PRS. Figure 2 depicts the polarized Raman spectrum of aniline in the 500-2000 cm^{-1} spectral range. Figure 2 shows that the Raman activity of the perpendicular component of the 996 cm^{-1} peak is greater than that of the 1024 cm^{-1} peak. So, the vibrations corresponding to this peak are relatively more asymmetric. Also, the vibrations at 1605 cm^{-1} are asymmetric. In turn, the vibrations' symmetric and asymmetric characteristics depend on the molecule's polarizability. Because the orientation of the electron-rich region in the polar bond in intermolecular interactions directly affects

the vibrational properties. The shift of electrons is estimated using the polarizability tensor. It is possible to generate isotropic and anisotropic Raman spectra using parallel and perpendicular Raman spectra results.

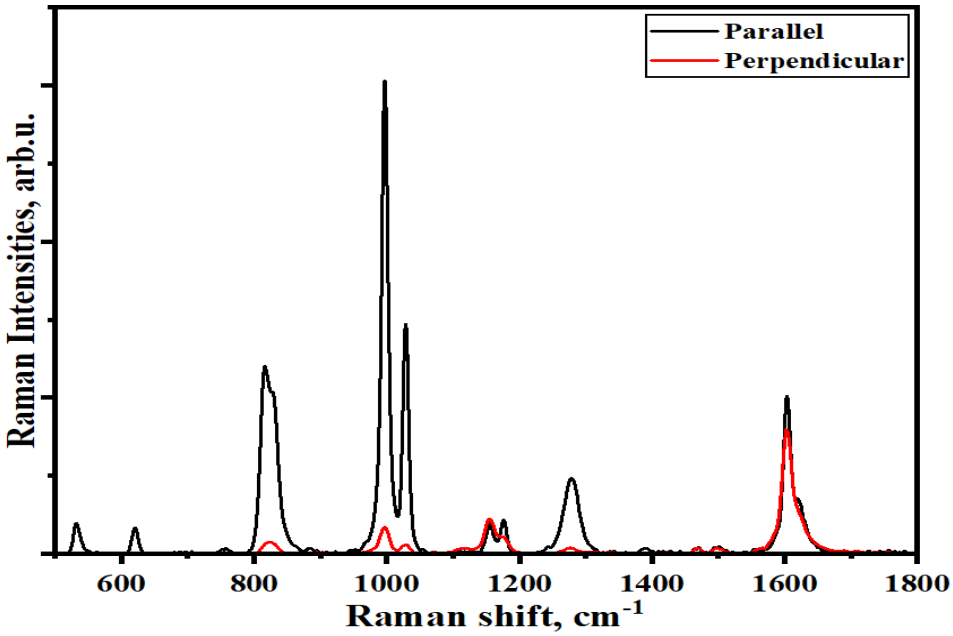


Figure 2. Polarized Raman spectra of aniline in the spectral range 500-2000 cm^{-1}.

The resonance energy transfer (RET) of the numerous vibrating polar bonds or ring-breathing vibrations of aniline can be determined from these spectra. The 2800-3500 cm^{-1} range yielded an intriguing result (Fig.3). It was observed that the peak wavenumbers of the parallel and perpendicular components of the C-H vibrations differ. The peak wavenumber of the parallel component was observed at 3054 cm^{-1}, while the wavenumber of the perpendicular component was determined to be 3048 cm^{-1}. This result reports the observation of Raman NCE in the C-H vibrational mode band. Another notable aspect of this spectrum is that the parallel peak wavenumber is located in the blue site relative to the perpendicular peak wavenumber. Therefore, the Raman NCE in this vibrational mode is negative. Typically, negative NCE occurs due to parallel dipole-dipole interactions [17]. Therefore, the effect of repulsive interactions on this vibrational region of aniline is relatively stronger. The dominance of repulsive interactions in the liquid phase is due to steric effects, which creates unique complications in the formation of molecular dynamics. Further research may be warranted to explain such complexity. One such research method is two-dimensional correlation spectroscopy. Using this method, it is possible to map the dynamics of the concentration-dependent changes in the various vibrational modes of aniline and the chronology of the interrelationship of these changes. This method was used to further discuss the spectral phenomena observed in PRS.

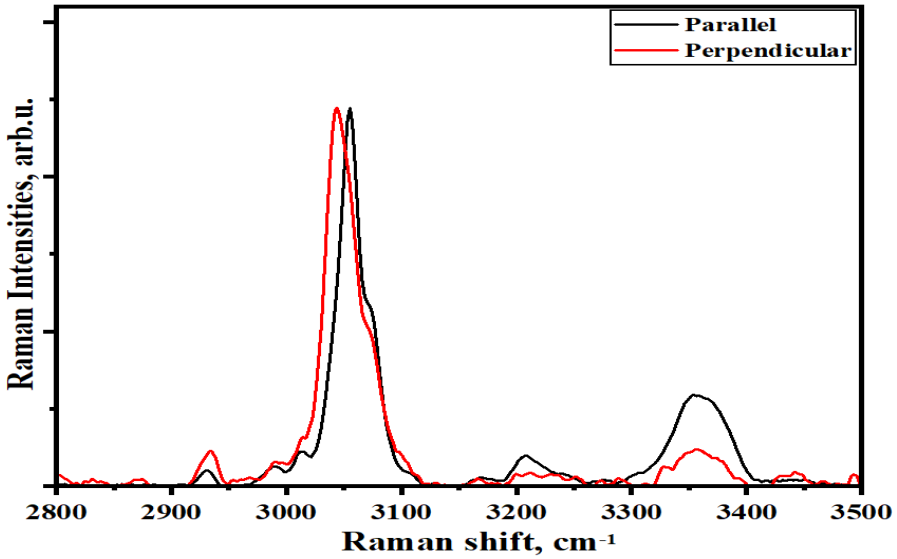


Figure 3. Polarized Raman spectra of aniline in the spectral range 2800-3500 cm^{-1}.

Synchronous and asynchronous 2D Raman correlation spectra of a solution of aniline with ethyl acetate at different concentrations were recorded (Fig.4). The correlation between two signals at the same time or frequency, which represents how closely various modes change in response to one another, is identified by synchronous 2D-COS [18-20]. The colour in synchronous 2D-COS indicates how strongly the signals correlate with one another. Typically displayed in red or warm colours (yellow or orange) to emphasise that the two signals or modes are positively correlated, meaning they change in the same direction. Typically, cool or blue colours are used to indicate that the modes are anticorrelated, or change in opposite directions. Asynchronous 2D-COS illustrates phase differences or time lags between modes by displaying how several signals change in frequency or time about one another. The phase difference between the signals in asynchronous 2D-COS is indicated by the colour intensity, which can provide insight into the time of interactions. The signal at the x-axis leads the signal at the y-axis when one signal is dominant, which is typically indicated by red or warm colours. Alternatively, cool or blue colours indicate that the y-axis signal is stronger than the x-axis signal [21-24].

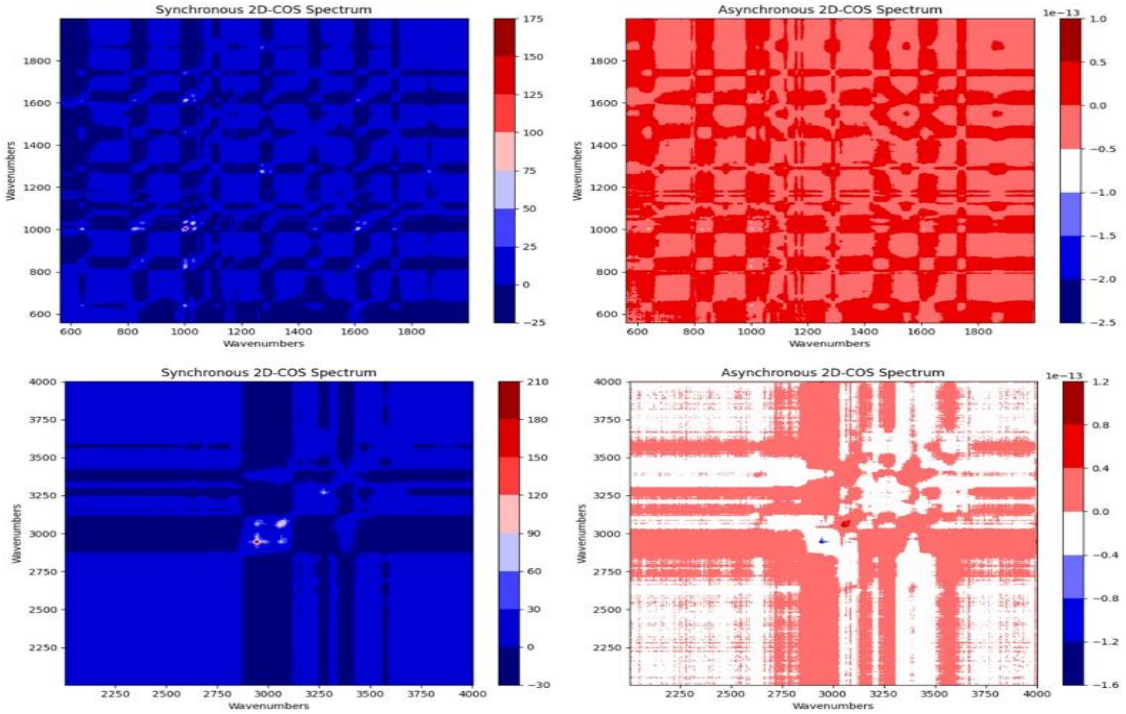


Figure 4. Synchronous and asynchronous 2D Raman correlation spectra of aniline.

The intensity of the colour shows the extent of this time delay or phase difference; larger phase shifts, or stronger correlations, are typically represented by more intense colour. Positive auto-peaks in 2D synchronous spectra are observed at 996 (ring), 1296 (C-N), and 2900 (C-H, symmetric) cm^{-1} for 532 nm excitation, respectively. Asynchronous cross-peaks are positive 1053 (ring asymmetric), 3054 (C-H, asymmetric), and negative 2900 (C-H, symmetric) cm^{-1}. In general, it was found that the ring-breathing and C-H vibrations of aniline are active in the synchronous Raman spectrum. From this, it can be concluded that the concentration-dependent changes in these vibrational modes are interdependent. All vibrational modes of aniline are inactive in the asynchronous spectrum. This means that there is no time delay in these vibrations.

4. Conclusions. This study investigates the vibrational modes of aniline using polarized Raman spectroscopy (PRS) and two-dimensional Raman correlation spectroscopy (2D-COS). The PRS revealed anomalous phenomena in the ring-breathing, C-H, and N-H vibrational modes, with distinct symmetry and asymmetry properties observed. Notably, negative Raman non-coincidence effects (NCE) were detected in the C-H vibrational mode at 3054 cm^{-1}, attributed to parallel dipole-dipole interactions. The study also highlights the role of polarizability in vibrational dynamics and the steric effects influencing repulsive interactions in the liquid phase. Using 2D-COS, synchronous spectra showed strong interdependence between concentration-dependent changes in ring-breathing and C-H vibrations, while asynchronous spectra confirmed no time delay between these modes. These findings provide a deeper understanding of molecular vibrational dynamics and their dependence on intermolecular interactions and concentration.

References

1. Frisk S., Ikeda R. M., Chase D. B., Rabolt J. F. (2004). Determination of the molecular orientation of poly (propylene terephthalate) fibers using polarized Raman spectroscopy: a comparison of methods. Applied spectroscopy, 58(3), 279-286. https://doi.org/10.1366/000370204322886618.
2. Richard-Lacroix, M., Pellerin, C. (2013). Novel method for quantifying molecular orientation by polarized Raman spectroscopy: a comparative simulations study. Applied spectroscopy, 67(4), 409-419. https://doi.org/10.1366/12-06879.
3. Bower D. I. (1972). Investigation of molecular orientation distributions by polarized Raman scattering and polarized fluorescence. Journal of Polymer Science: Polymer Physics Edition, 10(11), 2135-2153. https://doi.org/10.1002/pol.1972.180101103.
4. Jen S., Clark N. A., Pershan P. S., Priestley E. B. (1977). Polarized Raman scattering studies of orientational order in uniaxial liquid crystalline phases. The Journal of Chemical Physics, 66(10), 4635-4661. https://doi.org/10.1063/1.433720.
5. Logan D. E. (1986). The non-coincidence effect in the Raman spectra of polar liquids. Chemical physics, 103(2-3), 215-225. https://doi.org/10.1016/0301-0104(86)80022-2.
6. Tukhvatullin F. H., Pogorelov V. E., Tashkenbaev U. N., Jumaboev A., Hushvaktov H., Seit-Enon M., Osmanov S.A. (2003). Intermolecular interaction in liquid dimethylformamide and its manifestation in Raman spectra. Journal of Raman Spectroscopy, 34(10), 813-818. https://doi.org/10.1002/jrs.1057.
7. Tukhvatullin F.H., Pogorelov V.E., Jumabaev A., Hushvaktov H.A., Absanov A.A., Shaymanov A. (2008). Aggregation of molecules in liquid methyl alcohol and its solutions: Raman spectra and ab initio calculations. Journal of Molecular Structure, 881(1-3), 52-56. https://doi.org/10.1016/j.molstruc.2007.08.036.
8. Morresi A., Paolantoni M., Sassi P., Cataliotti R. S., Paliani G. (2000). Non-coincidence effect of aromatic ring vibrations. Journal of Physics: Condensed Matter, 12(15), 3631. http://dx.doi.org/10.1088/0953-8984/12/15/312.
9. Döge G., Schneider D., Morres, A. (1993). The negative Raman non-coincidence effect of ring vibrations. Molecular Physics, 80(3), 525-531. https://doi.org/10.1080/00268979300102441.
10. Kalampounias A. G., Papatheodorou G. N. (2018). Raman non-coincidence effect of boroxol ring: The interplay between repulsion and attraction forces in the glassy, supercooled, and

liquid state. Journal of Physics and Chemistry of Solids, 117, 70-75. https://doi.org/10.1016/j.jpcs.2018.02.023.
11. Noda I. (2004). Advances in two-dimensional correlation spectroscopy. Vibrational Spectroscopy, 36(2), 143-165. https://doi.org/10.1016/j.vibspec.2003.12.016.
12. Noda I., Ozaki Y. (2005). Two-dimensional correlation spectroscopy: applications in vibrational and optical spectroscopy. John Wiley & Sons. https://doi.org/10.1002/0470012404.
13. Lasch P., Noda I. (2019). Two-dimensional correlation spectroscopy (2D-COS) for analysis of spatially resolved vibrational spectra. Applied Spectroscopy, 73(4), 359-379. https://doi.org/10.1177/0003702818819880.
14. Park Y., Jin S., Noda I., Jung Y. M. (2023). Continuing progress in the field of two-dimensional correlation spectroscopy (2D-COS): Part III. Versatile applications. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 284, 121636. https://doi.org/10.1016/j.saa.2022.121636.
15. Noda I. J. A. S. (1993). Generalized two-dimensional correlation method applicable to infrared, Raman, and other types of spectroscopy. Applied spectroscopy, 47(9), 1329-1336. https://doi:10.1366/0003702934067694.
16. Jumabaev A., Khudaykulov B., Doroshenko I., Hushvaktov H., Absanov A. (2022). Raman and ab initio study of intermolecular interactions in aniline. Vibrational Spectroscopy, 122, 103422. https://doi.org/10.1016/j.vibspec.2022.103422.
17. Kirillov S.A. (2004). Anomalous non-coincidence effects in liquids: separation of attraction and repulsion contributions. Journal of molecular liquids, 110(1-3), 95-98. https://doi.org/10.1016/j.molliq.2003.09.005.
18. Noda I. (2017). Vibrational two-dimensional correlation spectroscopy (2DCOS) study of proteins. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 187, 119-129. https://doi.org/10.1016/j.saa.2017.06.034.
19. Menezes D. B., Reyer A., Musso M. (2018). Investigation of the Brill transition in nylon 6, 6 by Raman, THz-Raman, and two-dimensional correlation spectroscopy. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 190, 433-441. https://doi.org/10.1016/j.saa.2017.09.055.
20. Shashilov V. A., Lednev I. K. (2009). Two-dimensional correlation Raman spectroscopy for characterizing protein structure and dynamics. Journal of Raman Spectroscopy: An International Journal for Original Work in all aspects of Raman Spectroscopy, Including Higher Order Processes, and also Brillouin and Rayleigh Scattering, 40(12), 1749-1758. https://doi.org/10.1002/jrs.2544.
21. Park Y., Jin S., Noda I., Jung Y. M. (2022). Continuing progress in the field of two-dimensional correlation spectroscopy (2D-COS), part I. Yesterday and today. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 281, 121573. https://doi.org/10.1016/j.saa.2022.121573.
22. Park Y., Jin S., Noda I., Jung Y.M. (2023). Continuing progress in the field of two-dimensional correlation spectroscopy (2D-COS), part II. Recent noteworthy developments. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 284, 121750. https://doi.org/10.1016/j.saa.2022.121750.
23. Chen P., Shi M., Liu X., Wang X., Fang M., Guo Z., ... Wang Y. (2022). Comparison of the binding interactions of 4-hydroxyphenylpyruvate dioxygenase inhibitor herbicides with humic acid: Insights from multispectroscopic techniques, DFT and 2D-COS-FTIR. Ecotoxicology and Environmental Safety, 239, 113699. https://doi.org/10.1016/j.ecoenv.2022.113699.
24. Qiu J., Nguyen T. H., Kim S., Lee Y.J., Song M.T., Huang W. J., ... Yang I. S. (2022). Two-dimensional correlation spectroscopy analysis of Raman spectra of NiO nanoparticles. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 280, 121498. https://doi.org/10.1016/j.saa.2022.121498.