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Article

Using Innovative Methods in Teaching The Working Mechanism of An Infrared (IR) Spectrometer

Abdinazarov Akbar[1], **Khudayarov Makhmasaid**[2], **Yuldashev Yusuf Toshpulatovich**[3]

1. Senior lecturer Department of Higher Mathematics, Tashkent State Agrarian University
2. Senior lecturer Department of Higher Mathematics, Tashkent State Agrarian University
3. Assistant Department of Higher Mathematics, Tashkent State Agrarian University

Correspondence: akbarabdinazarov@mail.ru, https://orcid.org/0009-0007-3662-309X, xudayarovmahmasaid@mail.ru, https://orcid.org/0009-0004-9851-7995, y.yuldashev@tdau.uz, https://orcid.org/0009-0001-4697-4164

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Abstract: This study examines the working principles of infrared (IR) spectrometers and emphasizes the application of innovative teaching methods in physics education. Fourier transform infrared (FTIR) spectroscopy, which is based on the interference of electromagnetic radiation, is analyzed with particular attention to the operation of the Michelson interferometer. The process of beam splitting, optical path difference formation, interference pattern generation, and Fourier transformation into an absorption spectrum is discussed in detail. In addition, the research highlights the importance of integrating modern pedagogical approaches into the teaching of complex physical concepts such as wave interference and spectroscopic analysis. Innovative methods, including interactive simulations, visual demonstrations, and problem-based learning, are considered as effective tools for improving students' conceptual understanding and engagement. The results indicate that the use of these methods significantly enhances the quality of education, facilitates deeper comprehension of abstract physical phenomena, and increases students' interest in the subject. The study concludes that combining theoretical knowledge with innovative teaching strategies is essential for effective physics instruction, particularly in topics related to modern optical and spectroscopic technologies.

Keywords: Infrared spectroscopy, FTIR, Michelson interferometer, interference of light, Fourier transform, spectrometry, physics education, teaching methodology, innovative teaching methods, interactive learning, optical phenomena, absorption spectrum.

Introduction

Fourier spectrometers operate based on the phenomenon of interference of electromagnetic radiation. Several types of interferometers are used in the design of these instruments, among which the Michelson interferometer is the most widely utilized.

In this device, infrared radiation emitted from the source is first converted into a parallel beam. The beam is then split into two parts by a beam splitter. One of the resulting beams is directed toward a movable mirror, while the other is sent to a fixed mirror. After reflection, both beams return to the beam splitter along the same optical path.Due to the difference in optical path length, and consequently the phase difference introduced by the movement of the mirror, the beams interfere with each other. The resulting interference forms a complex interferogram, representing the superposition of wave patterns corresponding to different path differences (Δl) and wavelengths (λ)[1]. The combined light beam then passes through the sample and reaches the detector. The detected signal is amplified and transmitted to a computer, where a Fourier transform is applied to the interferogram to obtain the absorption spectrum of the sample.Although the Fourier transform is computationally complex, modern computing technologies have enabled the integration of compact and high-speed computers into spectrometers, allowing rapid acquisition and processing of spectral data.In Fourier spectroscopy, three main types of interferometers are commonly used: Fabry–Perot, Michelson, and lamellar interferometers[2].

The recorded interferogram represents the dependence of the signal on the optical path difference and is a function of the source energy modified by the sample absorption. Using built-in software in modern Fourier spectrometers, the Fourier transform of the resulting interferogram provides the final absorption spectrum of the studied sample[3].

The available spectral range for analysis is determined by the beam splitter used. To cover the full infrared range, interchangeable beam splitters made of metal meshes, thin films, or dielectric coatings on various substrates are employed[4].

Fourier spectroscopy offers several important advantages. Unlike conventional spectrometers, interferometers provide two main benefits. The first is high energy efficiency, which allows simultaneous detection of the entire spectral range of wavelengths during scanning, rather than measuring narrow spectral intervals as in traditional monochromators. In other words, an interferometer collects information across the entire spectral range at once, whereas a conventional spectrometer measures only narrow spectral regions at different time intervals[5].

This advantage is particularly significant in the long-wavelength region, where source intensity is low and the signal-to-noise ratio is limited. Additionally, the increased energy throughput allows higher detection sensitivity without reducing radiation intensity[6].

The resolution of a Fourier spectrometer is proportional to the maximum optical path difference. For example, to double the spectral resolution, it is sufficient to double both the mirror displacement and the data acquisition time.

Materials and Methods

According to the Beer–Lambert law, the absorbance (or concentration in the case of mixtures or solutions) of the analyte and the optical path length in the sample are of great importance. These parameters should be selected in such a way as to obtain well-measurable optical signals within the transmittance (T) range of approximately 20% to 60% in modern spectrometers.To minimize background effects in the spectrum, particular attention must be paid to the homogeneity of the sample, the level of impurities, and the absorption of the solvent. The quality of the obtained spectral data largely depends on the chosen sampling technique. A brief overview of common sampling methods is presented in Figure 1.

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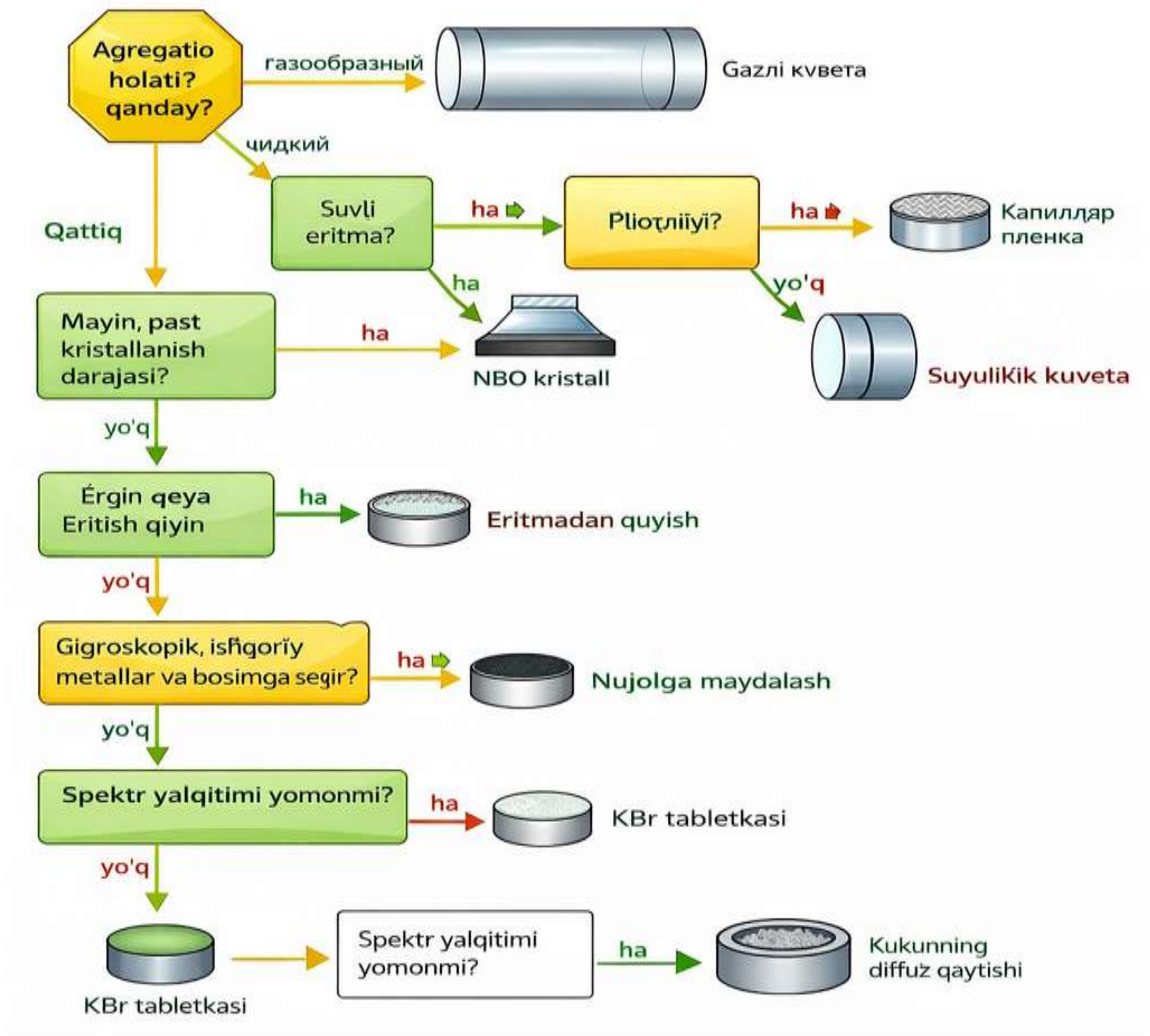
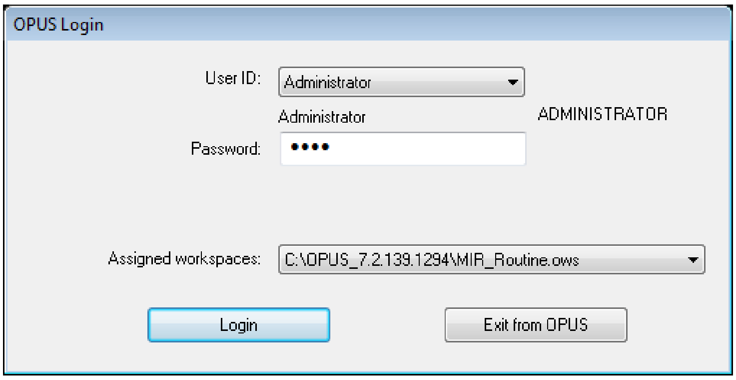


Figure 1. Overview of general IR analysis methods

Main Functions of the OPUS Software. Starting a Measurement

The Bruker FTIR spectrometer software is called "OPUS." To launch the program, double-click the OPUS icon on your desktop. This action will open the OPUS login window.



OPUS Login

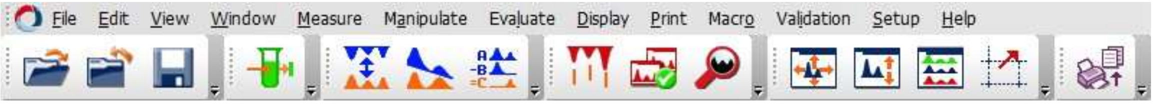
User ID: Administrator

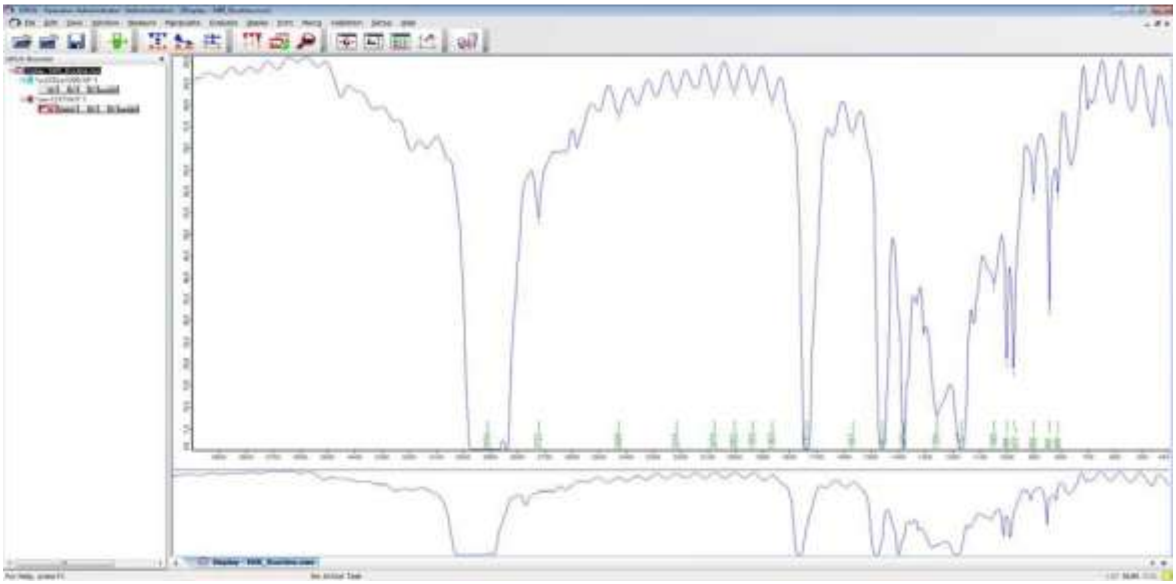
Administrator ADMINISTRATOR

Password: ••••

Assigned workspaces: C:\OPUS_7.2.139.1294\MIR_Routine.ows

No password is required to access the program.
After opening, the toolbar of the OPUS software will be displayed on the screen.

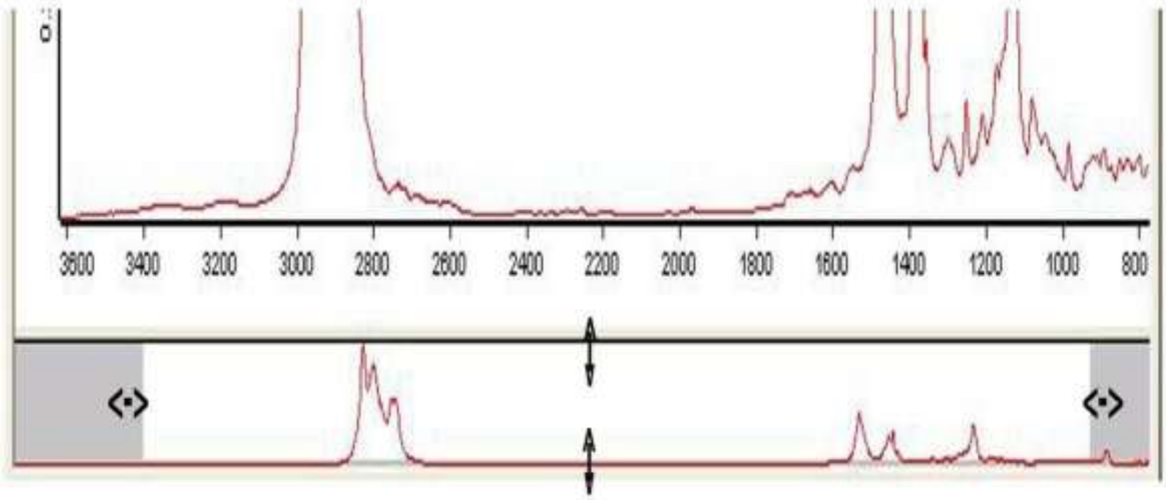




Using the icons on the toolbar, standard mid-infrared measurements and data processing can be performed. The function of each icon can be viewed by hovering the cursor over the corresponding button.

Results

After recording the spectrum, it should be displayed in both the Spectrum and Overview windows. Previously acquired data stored on the hard disk can also be accessed using the <Load> button[7].



Display Settings The spectral display limits can be adjusted either from the Overview window or the Spectrum window. In the Overview window, the display boundaries can be modified by using the left mouse button to zoom in along the X or Y direction[8].

Use the four buttons on the toolbar panel to navigate between different display functions.

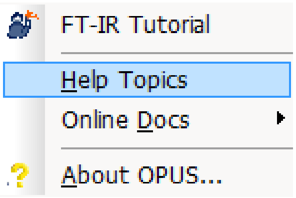
Baseline Correction A sloping baseline in a spectrum is usually caused by improper sample preparation. Before attempting peak identification (i.e., determining the position of absorption bands), the baseline must be corrected.

Click to open the **Baseline Correction** menu. In the file selection tab, choose the desired file. If an incorrect file is selected, it can be removed, and the required spectrum can be dragged from the browser panel using the mouse[9].

Make sure that the correction method selected is **“Rubberband”** using 64 reference points. Press the **<Correct>** button to apply the correction.

An **“Interactive”** mode can also be used. For details on the interactive mode, refer to the help section[10].

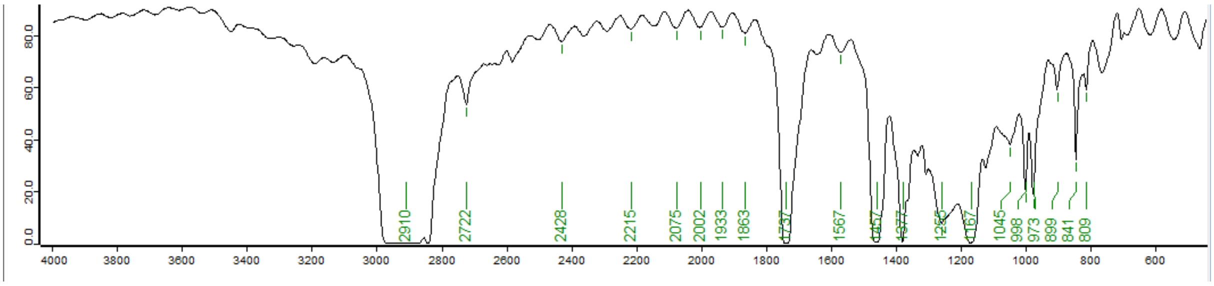
"C:\OPUS\DATA\Hexan1a.0" 1



Peak Picking (Selection of Maximum Peaks)

Double-click to automatically detect peaks in the displayed spectrum and highlight the most significant ones.

To modify the parameters used, click the icon once to open the **Peak Picking** window. To detect more peaks, adjust the sensitivity threshold to a lower value[11].

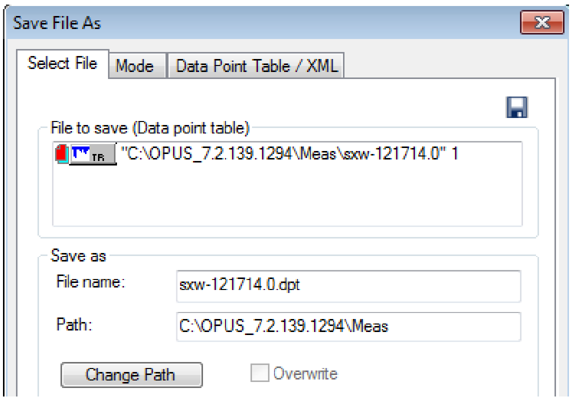


Saving Data

All data are automatically saved in the directory:**C:\Opus_7.2.139.1294\Meas\ATR\StudentsLab**.

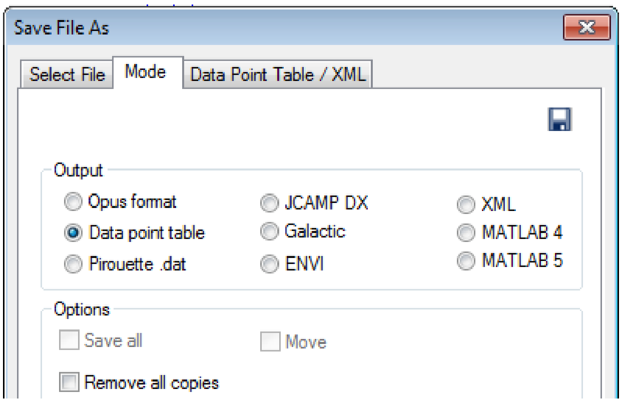
Save the file using the name you have specified. If the file is modified (e.g., baseline correction, peak picking, etc.), the OPUS software will prompt you to save or discard the changes when exiting the program[12].

If you wish to save the modified files or export them in a non-OPUS format for further processing elsewhere, use the **"Save As"** option. In this case, you can change the file path, file extension, and file name (for example: polyAAc_baseline).



File to save (Data point table)
"C:\OPUS_7.2.139.1294\Meas\sxw-121714.0" 1

Save as
File name: sxw-121714.0.dpt
Path: C:\OPUS_7.2.139.1294\Meas
☐ Overwrite



Output
○ Opus format ○ JCAMP DX ○ XML
● Data point table ○ Galactic ○ MATLAB 4
○ Pirouette .dat ○ ENVI ○ MATLAB 5

Options
☐ Save all ☐ Move
☐ Remove all copies

Discussion

The findings of this study indicate that the principles of Fourier transform infrared (FTIR) spectroscopy can be effectively incorporated into physics teaching through the use of innovative instructional approaches. Employing the Michelson interferometer as a conceptual and practical model enables learners to develop a clearer understanding of complex topics, including wave interference, phase differences, and optical path variation[13].

Conventional teaching strategies often rely heavily on theoretical explanations, which may not sufficiently support students in comprehending abstract spectroscopic processes. In contrast, the integration of interactive learning tools, visual modeling, and guided experimental activities facilitates a more comprehensive understanding of these concepts. Through such approaches, students are better able to interpret interferograms and establish connections between interference patterns and absorption spectra[14].

Additionally, the implementation of specialized software such as OPUS enhances the learning process by linking theoretical knowledge with real experimental data. Working with actual spectral outputs allows students to strengthen their analytical thinking and data interpretation skills. This hands-on experience contributes to increased engagement and a more active learning environment during laboratory sessions[15].

Despite these advantages, certain limitations should be acknowledged. Effective implementation requires access to appropriate instrumentation and a basic level of technical proficiency in operating spectroscopic equipment and software. Nevertheless, the combination of modern pedagogical methods with advanced spectroscopic techniques offers significant potential for improving the quality of physics education[16].

In general, the results suggest that blending conceptual explanations with practical and interactive elements leads to more meaningful learning outcomes and better prepares students for future academic and professional work in spectroscopy and related scientific fields.

Conclusion

In conclusion, this study demonstrates that the integration of Fourier transform infrared (FTIR) spectroscopy concepts into physics education can be significantly enhanced through the use of innovative teaching methods. The analysis of the Michelson interferometer and the fundamental principles of electromagnetic wave interference provides a solid theoretical foundation for understanding modern spectroscopic techniques.

The incorporation of interactive approaches, including visual simulations, experimental activities, and the use of specialized software such as OPUS, allows students to engage more actively with the learning process. These methods contribute to improved comprehension of complex physical phenomena, particularly in interpreting interferograms and absorption spectra.

Moreover, the combination of theoretical instruction with practical application helps develop students' analytical and problem-solving skills. It also increases motivation and interest in physics, especially in topics related to optical and spectroscopic technologies.

Although certain challenges exist, such as the need for appropriate equipment and technical training, the overall benefits of applying innovative teaching strategies outweigh these limitations.

Therefore, it can be concluded that the effective teaching of infrared spectrometry requires a balanced integration of theory, practice, and modern pedagogical tools. Such an approach not only improves the quality of education but also prepares students for future scientific research and professional activities in the field of physics.

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