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MODERN SPECTROSCOPIC MOTHODS FOR THE DETERMINATION OF PHARMACEUTICAL COMPOSITION

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Abstract: Determination of the composition, quality, safety, and efficacy of pharmaceutical preparations is one of the most important tasks in the modern pharmaceutical industry. Highly sensitive and selective analytical methods are required for the accurate identification and quantification of active pharmaceutical ingredients, excipients, and potential impurities. Modern spectroscopic techniques are widely used in pharmaceutical quality control because they provide valuable information about the chemical structure and composition of pharmaceutical substances. These techniques include ultraviolet-visible spectroscopy (UV-Vis), infrared spectroscopy (IR and FTIR), Raman spectroscopy, nuclear magnetic resonance (NMR) spectroscopy, and mass spectrometry. This article discusses the principles, advantages, and practical applications of modern spectroscopic methods for the analysis of pharmaceutical preparations.
Keywords: pharmaceutical preparations, spectroscopy, analytical chemistry, UV-Vis spectroscopy, FTIR, Raman spectroscopy, NMR, mass spectrometry, active pharmaceutical ingredient, quality control.

Annotatsiya: Farmatsevtik preparatlarning tarkibi, sifati, xavfsizligi va samaradorligini nazorat qilish zamonaviy farmatsevtika sanoatining muhim vazifalaridan biridir. Dori vositalari tarkibidagi faol farmatsevtik ingredientlar, yordamchi moddalar va potensial aralashmalarni aniq aniqlash uchun yuqori sezgirlik va selektivlikka ega analitik usullardan foydalaniladi. Zamonaviy spektroskopik usullar farmatsevtik preparatlarning sifat nazoratida keng qo‘llanilib, moddalarning kimyoviy tuzilishi va miqdoriy tarkibi haqida muhim ma’lumot beradi. Ularga ultrabinafsha-ko‘rinadigan spektroskopiya (UV-Vis), infraqizil spektroskopiya (IR va FTIR), Raman spektroskopiyasi, yadro magnit rezonansi (NMR) spektroskopiyasi va mass-spektrometriya kabi usullar kiradi. Ushbu maqolada farmatsevtik preparatlar tarkibini aniqlashda zamonaviy spektroskopik usullarning nazariy asoslari, afzalliklari va amaliy qo‘llanilishi yoritilgan.
Kalit so‘zlar: farmatsevtik preparatlar, spektroskopiya, analitik kimyo, UV-Vis spektroskopiya, FTIR, Raman spektroskopiyasi, NMR, mass-spektrometriya, faol farmatsevtik ingredient, sifat nazorati.

Аннотация: Определение состава, качества, безопасности и эффективности фармацевтических препаратов является одной из важнейших задач современной фармацевтической промышленности. Для точного определения активных фармацевтических ингредиентов, вспомогательных веществ и потенциальных примесей используются высокочувствительные и селективные аналитические методы. Современные спектроскопические методы широко применяются для контроля качества лекарственных препаратов и позволяют получать важную информацию о химической структуре и количественном составе веществ. К ним относятся ультрафиолетово-видимая спектроскопия (UV-Vis), инфракрасная спектроскопия (IR и FTIR), рамановская спектроскопия, ядерный магнитный резонанс (NMR) и масс-спектрометрия. В статье рассматриваются теоретические

основы, преимущества и практическое применение современных спектроскопических методов для определения состава фармацевтических препаратов.

Ключевые слова: фармацевтические препараты, спектроскопия, аналитическая химия, UV-Vis спектроскопия, FTIR, рамановская спектроскопия, NMR, масс-спектрометрия, активный фармацевтический ингредиент, контроль качества.

Pharmaceutical preparations contain active pharmaceutical ingredients together with various excipients that influence the stability, solubility, appearance, and delivery of the medicinal product. Accurate determination of their composition is essential for ensuring the quality and safety of medicines. Analytical chemistry provides a wide range of techniques for pharmaceutical analysis, and spectroscopic methods are among the most important because they can provide rapid and reliable information about molecular structure and chemical composition.

Spectroscopy is based on the interaction between electromagnetic radiation and matter. Different molecules absorb, emit, or scatter electromagnetic radiation in characteristic ways. These interactions produce analytical signals that can be used to identify substances and determine their concentrations. Modern spectroscopic instruments provide high sensitivity and precision and can often analyze pharmaceutical samples with limited sample preparation.

Ultraviolet-visible spectroscopy is one of the most commonly applied techniques in pharmaceutical analysis. It is based on the absorption of ultraviolet or visible radiation by molecules containing chromophoric groups. Many active pharmaceutical ingredients absorb radiation at characteristic wavelengths, allowing their identification and quantitative determination. UV-Vis spectroscopy is relatively simple, rapid, and cost-effective, making it suitable for routine quality-control laboratories.

Infrared spectroscopy provides information about the functional groups and molecular structure of pharmaceutical compounds. Different chemical bonds absorb infrared radiation at characteristic frequencies, producing a molecular fingerprint. Fourier-transform infrared spectroscopy, commonly known as FTIR, has become particularly important because of its rapid data acquisition, high resolution, and relatively simple operation. FTIR can be used to identify active ingredients, characterize raw materials, and detect certain forms of contamination or adulteration.

Raman spectroscopy is another valuable analytical technique for pharmaceutical applications. Raman spectra are produced as a result of the inelastic scattering of light by molecules. The resulting spectral patterns contain information about molecular structure and chemical composition. Raman spectroscopy is advantageous because it can often analyze samples without extensive preparation and can be applied to solid, liquid, and semisolid pharmaceutical products.

An important application of Raman spectroscopy is the identification of pharmaceutical ingredients and the monitoring of manufacturing processes. Raman instruments can sometimes be used directly through transparent packaging, which reduces the need to open or destroy the sample. This feature is useful for quality control and for rapid verification of pharmaceutical products.

Nuclear magnetic resonance spectroscopy provides detailed information about the molecular structure of pharmaceutical compounds. NMR is based on the behavior of certain atomic nuclei in a magnetic field. It can provide information about the chemical environment of atoms and their relationships within a molecule. NMR spectroscopy is particularly valuable for structure elucidation, identification of impurities, and confirmation of the identity of synthesized pharmaceutical compounds.

Mass spectrometry is another powerful analytical technique that is widely used in pharmaceutical research and quality control. It determines the mass-to-charge ratios of ions and can

provide highly specific information about molecular mass and structure. When coupled with separation techniques such as liquid chromatography, mass spectrometry can be used to identify active ingredients, degradation products, metabolites, and trace impurities.

The combination of spectroscopic methods with chromatographic techniques has significantly expanded the possibilities of pharmaceutical analysis. Liquid chromatography coupled with mass spectrometry, for example, can separate complex mixtures and subsequently identify individual components with high sensitivity. Such approaches are especially important when pharmaceutical formulations contain several active ingredients or when impurities occur at very low concentrations.

Spectroscopic methods are also useful for studying the stability of pharmaceutical preparations. During storage, active pharmaceutical ingredients may undergo oxidation, hydrolysis, photodegradation, or other chemical transformations. Spectroscopic analysis can help detect changes in molecular structure and identify degradation products. This information is important for determining appropriate storage conditions and establishing the shelf life of pharmaceutical products.

Modern spectroscopy also contributes to the detection of counterfeit and substandard medicines. Counterfeit pharmaceutical products may contain incorrect amounts of active ingredients, inappropriate substances, or no active ingredient at all. Rapid spectroscopic techniques such as FTIR and Raman spectroscopy can be used to compare the chemical fingerprints of suspicious products with reference materials. Portable spectroscopic instruments further increase the possibility of conducting analyses outside conventional laboratories.

Chemometric methods have become increasingly important in modern spectroscopic analysis. Spectral data can contain large numbers of variables, and advanced statistical and computational methods can be used to extract useful analytical information. Principal component analysis, partial least-squares regression, and other chemometric techniques can support classification, identification, and quantitative analysis of pharmaceutical samples.

The development of portable and handheld spectroscopic instruments has further increased the practical value of these methods. Portable Raman and near-infrared instruments can be used for rapid screening of raw materials and finished pharmaceutical products. Such technologies may reduce analysis time and support real-time quality control in pharmaceutical manufacturing.

Despite their advantages, spectroscopic methods also have certain limitations. Spectral overlap, matrix effects, instrument calibration, and the need for appropriate reference standards may influence analytical accuracy. Some techniques may also require specialized equipment and highly trained personnel. Therefore, spectroscopic analysis is often combined with complementary analytical methods to obtain more comprehensive and reliable results.

In conclusion, modern spectroscopic methods have become essential tools for determining the composition and quality of pharmaceutical preparations. UV-Vis, FTIR, Raman, NMR, and mass spectrometry provide complementary information about molecular structure, active ingredients, impurities, and degradation products. Their high sensitivity, selectivity, rapid analysis, and potential for non-destructive testing make them valuable in pharmaceutical research, manufacturing, and quality control. Further development of portable instruments, chemometric techniques, and integrated analytical systems is expected to make spectroscopic analysis even more efficient and accessible in the pharmaceutical industry.

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