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# Advances in Electroanalysis of Pharmaceuticals Using Nanosensors

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## Abstract

This mini review delves into the advancements in the analysis of pharmaceuticals using nanosensors, emphasizing their valuable role in modern analytical chemistry. Nanosensors, including carbon-based, metal and metal oxide, polymer-based, and composite types, offer outstanding sensitivity and selectivity for detection of active pharmaceutical ingredients, monitoring drug stability, and ensuring quality control. The review also highlights the key electrochemical detection mechanisms-voltammetry, amperometry, and impedimetry-demonstrating their application in real-time and trace analysis. Through this comprehensive overview, the review highlights the transformative potential of nanosensor-based electroanalysis in enhancing pharmaceutical research, development, and quality assurance, paving the way for more precise and efficient pharmaceutical practices.

**Keywords:** Pharmaceuticals, Nanosensor, Electroanalysis

## Introduction

Analytical chemistry has been described as the art and science of determining what matter is and how much of it exists. It is useful in determining and deploying the physical properties of materials [1]. It takes a noticeable spot among all arenas of experimental sciences, ranging from fundamental studies of nature to industrial or clinical purposes. This branch of chemistry underwent a huge transformation between the years 1920 and 1950, which has been described as 'the second chemical revolution'. The revolution seen in the past was the result of the convergence of numerous incidents all of which revealed how the introduction and advancement of physically based instrumental techniques would benefit the analytical chemists. Many changes were observed in the practice of analytical chemistry due to this transformation.

This revolution was responsible for promotion of a new kind of scientific knowledge and scientific instrumentation in this field [2]. Analytical chemistry being a central part of much industrial research and control is primarily used to retrieve reliable knowledge of the utmost possible quality by consuming increasingly less material, time and resources, taking the least possible hazards and minimizing large expenditures. Realization of this multiple goal has presently been simplified by developments in automation, miniaturization and computers among others [3-5]. Directed by pharmacology and clinical sciences, and maneuvered by chemistry, pharmaceutical research in the past has played a crucial part in the development of pharmaceuticals.

The progress seen in the field of pharmaceutical research was responsible for revolutionizing human health. The drugs serve their desired purpose only when they are highly pure and are given in a proper amount. To make pharmaceuticals serve their purpose, different chemical and instrumental procedures were established to estimate their quality. Analytical instrumentation and procedures play a significant role in detecting the impurities present in the drugs and quantifying them with a high degree of accuracy [6]. Electroanalysis is a potent analytical methodology that is expanding its usefulness in the pharmaceutical industry.

Historically, the branch of electrochemistry we now call voltammetry developed from the discovery of polarography in 1922 by the Czech chemist, Jaroslav Heyrovsky, for which he received the 1959 Nobel Prize in Chemistry [7]. The application of electroanalytical methods to analyze pharmaceuticals has increased many folds over the last few decades. Electrochemical methods are effective and versatile analytical procedures that provide high sensitivity, accuracy and precision with comparatively cheap instrumentation. Electroanalysis is being more frequently employed in analysis of pharmaceuticals in their dosage forms and particularly in biological samples. Electroanalytical techniques possess several merits and one of the main advantages is that the excipients do not interfere, and usually the separation and extraction process is not required. Hence, sample preparation generally involves dissolution of the active ingredient from the drug with an appropriate solvent.

Then an aliquot portion of this solution is taken for further analysis. Measurements done in electroanalysis are two-dimensional, where the peak potential at which the target molecule undergoes oxidation/reduction is related to qualitative properties and the peak current is related to quantitative properties. Therefore, an analyte molecule can be selectively detected by electroanalytical procedures. Besides providing analytical information, electroanalysis is also useful in establishing the electroanalytical behavior of a given analyte molecule through mechanistic investigations. In various instances, there is a direct relation between voltammetry and pharmaceutical dosage forms, and the understanding of the mechanism of their reactions can provide valuable evidence in interpretation of the mechanism of their interaction with living cells in the human body after administration [8].

## Types of Nanosensors Used in Electroanalysis

Recently, analysts are interested in deliberately modifying the surface of an electrode for improving its performance towards detection of a plethora of compounds. Chemically Modified Electrodes (CMEs) possess several distinctive merits due to the chemical nature and microstructure of synthesized electrode surfaces [9]. CMEs are extensively being used in the field of voltammetry due to their unique and wonderful properties. Nanosensors used in the electrochemical quantification of pharmaceuticals are diverse, indicating their tailored functionalities and material properties. Carbon-based modified electrodes, including graphene [10], carbon nanotubes [11], and carbon nanofibers [12], are widely employed due to their high electrical conductivity, large surface area, and robust chemical stability.

Metal and metal oxide sensors, such as those made from gold [13], silver [14], platinum [15] offer excellent catalytic properties and sensitivity, making them ideal for detecting trace amounts of pharmaceutical compounds. Polymer-based nanoelectrodes, which include conductive polymers like polyaniline [16] and polypyrrole [17], provide flexibility and tunable surface chemistry for selective analyte binding. Additionally, composite and hybrid nanosensors, which are a combination of multiple materials, harness the synergistic effects to enhance performance characteristics such as sensitivity, selectivity, and response time [18]. These diverse nanosensors have collectively developed the field of pharmaceutical analysis and enabled more precise and efficient detection and quantification of different pharmaceutical compounds.

## Mechanisms of Electrochemical Detection

Electrochemical detection mechanisms in pharmaceutical analysis predominantly include voltammetric, amperometric, and impedimetric techniques. Voltammetry involves measuring the current as a function of applied voltage, providing an understanding of the redox behavior of pharmaceutical compounds [19]. Amperometry, on the other hand, monitors the current at a fixed potential, enabling real-time detection of analyte concentration changes [20]. Impedimetric techniques measure the resistance and capacitance of the fabricated sensor interface, offering a label-free method to detect binding events [21]. These electrochemical techniques, leveraged by the unique properties of nanosensors, facilitate high sensitivity and specificity in the detection and quantification of pharmaceutical substances.

## Applications of Nanosensor-Based Electroanalysis in Pharmaceuticals

Nanosensor-based electroanalysis has revolutionized pharmaceutical detection, offering a range of applications from drug development to quality control. One primary application is the detection of Active Pharmaceutical Ingredients (APIs) in formulations, ensuring correct dosages and identifying counterfeit products [22]. In quality control and assurance, these sensors enable precise and rapid analysis, enhancing manufacturing standards and compliance with regulatory requirements. Additionally, nanosensors are invaluable in detecting contaminants and adulterants in pharmaceutical products, ensuring patient safety by identifying harmful substances that may compromise therapeutic efficacy [23,24]. Their high sensitivity, selectivity, and rapid response time make nanosensors essential tools in the pharmaceutical industry, facilitating stringent quality checks and advancing the development of safer, more effective drugs. These diverse applications highlight the transformative impact of nanosensor technology on pharmaceutical analysis.

## Conclusion

The application of nanosensors in electroanalytical chemistry has enjoyed huge success and has lately encouraged extensive activity. Electrochemical techniques have proved their efficiency in the analysis of pharmaceuticals over the last few years. Lower investment and running costs, speed, sensitivity, universality, and wide applicability speaks in favor of the voltammetric techniques. The upsurge of interest in the field of electroanalysis can be attributed to more advanced instrumentation. Whatever the future holds, it seems certain that electroanalytical methods will maintain their significance in the coming years and will continue to be a repository of many new and revolutionary ideas.

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