Impedance Spectroscopy Analysis of Reduced Graphene Oxide Doped with Metal/Metal Oxide Nanocomposites – Carbon Paste Electrodes for Highly Sensitive Detection of Atenolol

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Abstract

The development of highly sensitive and selective electrochemical sensors is critical for pharmaceutical analysis to ensure drug quality and patient safety. In this study, carbon paste electrodes (CPEs) modified with reduced graphene oxide (rGO) doped with various metal and metal oxide nanocomposites—Ag, TiO_2, Ni, Bi, and Cu—were fabricated and evaluated for the electrochemical detection of atenolol, a clinically relevant β-blocker. The modified electrodes were characterized using Electrochemical Impedance Spectroscopy (EIS), which provided in-depth insights into interfacial charge transfer behavior and surface modifications. The synergistic combination of rGO's exceptional conductivity with the catalytic properties of metal/metal oxide nanoparticles significantly reduced the charge transfer resistance (R_{ct}) from 1023.82 Ω to 209.75 Ω, thereby improving electron transfer kinetics. Among the developed sensors, the electrodes based on TiO_2 and Ag exhibited the lowest charge transfer resistance (R_{ct}), indicating superior interfacial conductivity. In optimal conditions, the TiO_2 electrode demonstrated the best analytical performance, showing enhanced sensitivity, a wide linear detection range from 66.22 to 322.58 µM, and a low limit of detection of 0.16 µM for atenolol. These findings highlight the significant role of TiO_2 doping in improving the electrochemical properties of rGO-based electrodes, making them promising candidates for sensitive pharmaceutical sensing applications.

Keywords:
Electrochemical Impedance Spectroscopy; Reduced Graphene Oxide; Metal Oxide Nanocomposites; Carbon Paste Electrode; Atenolol Detection; Pharmaceutical Analysis; Electrochemical Sensor.

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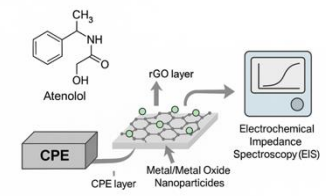

Figure 1: Schematic illustration of a rGO/metal oxide-modified carbon paste electrode used for atenolol detection via electrochemical impedance spectroscopy (EIS).