

## **Mechanistic Insights into Morphine Electrooxidation on Morphology-Controlled Cu/Co<sub>3</sub>O<sub>4</sub>@Graphene Nanoplatelet Nanocomposites: Experimental Validation and DFT Analysis**

**Satish Kumar \***

School of Forensic Science, National Forensic Sciences University, Bhopal, Madhya Pradesh, India

**Ruturaj Solanki**

School of Forensic Science, National Forensic Sciences University, Gandhinagar, Gujarat, India

**Satish Kumar**

School of Forensic Science, National Forensic Sciences University, Bhopal, Madhya Pradesh, India

**Bappi Paul**

School of Forensic Science, National Forensic Sciences University, Gandhinagar, Gujarat, India

### **Abstract**

In this experimental study, a series of spinel metal/carbon nanocomposites, namely Au/Co<sub>3</sub>O<sub>4</sub>@GNP, Ag/Co<sub>3</sub>O<sub>4</sub>@GNP, Cu/Co<sub>3</sub>O<sub>4</sub>@GNP, and Ni/Co<sub>3</sub>O<sub>4</sub>@GNP, were synthesized through hydrothermal synthesis using graphene nanoplatelets as a supportive material and studied for the electrochemical sensing of morphine. Structural and surface characterization was evaluated through XRD, BET, XPS, SEM, and TEM, which confirmed the desired formation of crystalline metal-Co<sub>3</sub>O<sub>4</sub> nanostructures loaded on the graphene network with mesoporous characteristics and good surface integration. Among the prepared nanocomposites, Cu/Co<sub>3</sub>O<sub>4</sub>@GNP revealed a unique porous cabbage-like morphology with a highly interconnected framework, providing numerous active sites and effective electron-transfer pathways. Electrochemical studies were performed using EIS, CV, and DPV, demonstrating that the nanocomposite-Cu/Co<sub>3</sub>O<sub>4</sub>@GNP exhibited the highest electrocatalytic activity toward morphine oxidation in 0.1 M PBS at pH 7.0. Under optimally configured conditions, the synthesized sensor was fabricated for a sequential detection range of 0.2–30  $\mu$ M which delivered a lowest detection threshold of 0.2  $\mu$ M. The electrode modified with Cu/Co<sub>3</sub>O<sub>4</sub>@GNP also showed good stability, with repeatability and its practical applicability in a biological sample, demonstrating its reliable potential for morphine analysis. Density functional theory calculations revealed that metal decoration modulates both morphine adsorption and the electronic structure of the Co<sub>3</sub>O<sub>4</sub>/graphene heterostructure, while Cu decoration provides favourable adsorption characteristics and enhanced electronic states near the Fermi level, supporting efficient charge-transfer processes during sensing. The superior sensing performance can be assigned to the synergistic connection between Co<sub>3</sub>O<sub>4</sub>, Cu metal, and graphene nanoplatelets, together promoting rapid electron transfer, enhancing the electroactive surface area, and supporting the oxidation of morphine. This research study delivers Cu/Co<sub>3</sub>O<sub>4</sub>@GNP as a highly effective nanocomposite platform for sensitive and reliable electrochemical sensing of morphine under optimal conditions.