

Supporting Information for

Reagentless Voltammetric Identification of Cocaine from Complex Powders

Kathryn J. Vannoy^a, Lynn E. Krushinski^a, Edgar F. Kong^a, Jeffrey E. Dick^{a,b*}

^aDepartment of Chemistry, The University of North Carolina at Chapel Hill, Chapel Hill, NC 27599, USA

^bLineberger Comprehensive Cancer Center, School of Medicine, The University of North Carolina at Chapel Hill, Chapel Hill, NC 27599, USA

To whom correspondence should be addressed: jedick@email.unc.edu

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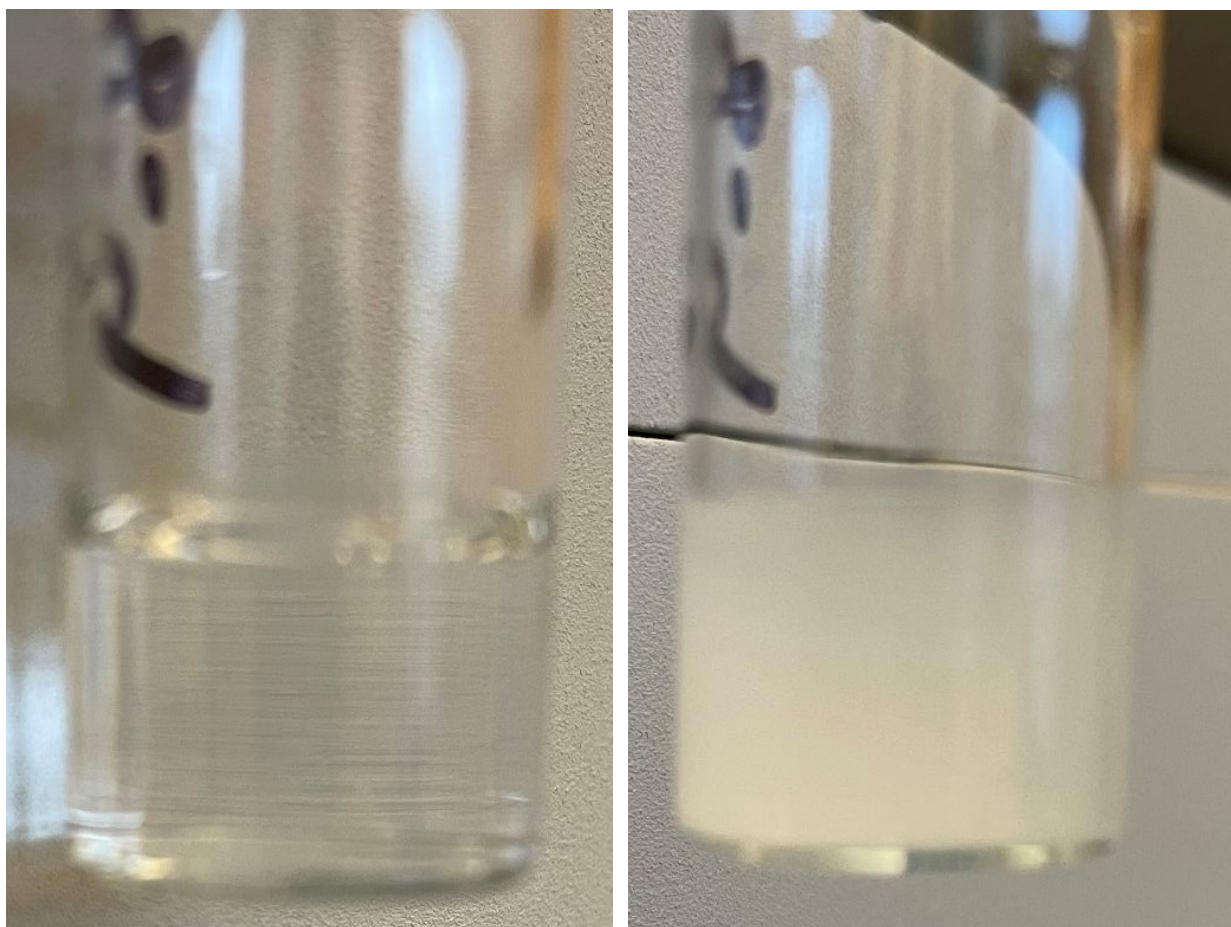


Figure S1. Image showing a solution of 10 mM cocaine hydrochloride in 0.5 M KCl at pH = 8.4 (left) and pH = 9 (right).

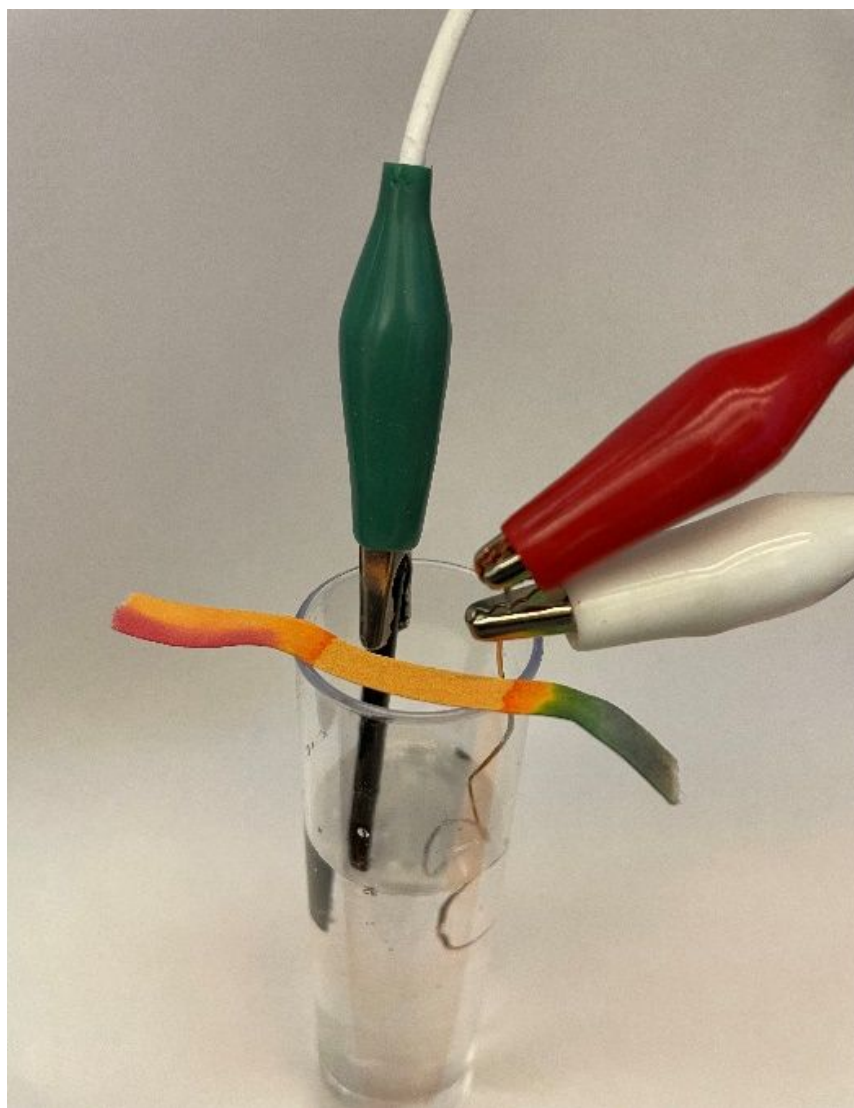


Figure S2. Image showing a solution of 0.5 M KCl after the working electrode (glassy carbon rod) was biased with 4 V vs platinum wire. One end of the litmus paper was dipped near the working electrode (pink) and the other end was dipped near the reference/counter electrode (blue) during the amperometry. Pink coloration on the litmus paper is indicative of an acidic solution and blue indicates an alkaline solution.

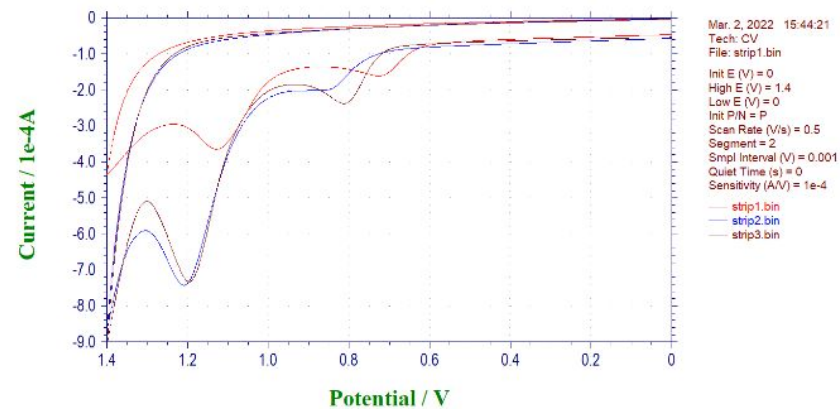
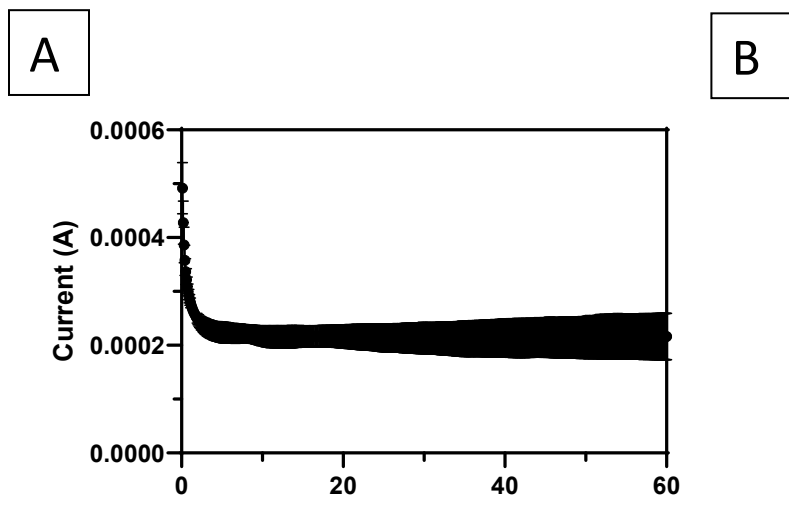


Figure S3. (A) Average electro-precipitation current ($N = 3$) for a solution of 10 mM cocaine in 0.5 M KCl ($\text{pH} = 7$). (B) Voltammetry in clean 0.5 M KCl after each amperogram. Voltammetry was collected with a glassy carbon working electrode ($d = 3$ mm) from 0.5 to 1.4 V vs Ag/AgCl at 0.5 V/s. In line with the polarographic convention, the cathodic current is represented as positive and the anodic current is negative in this figure.

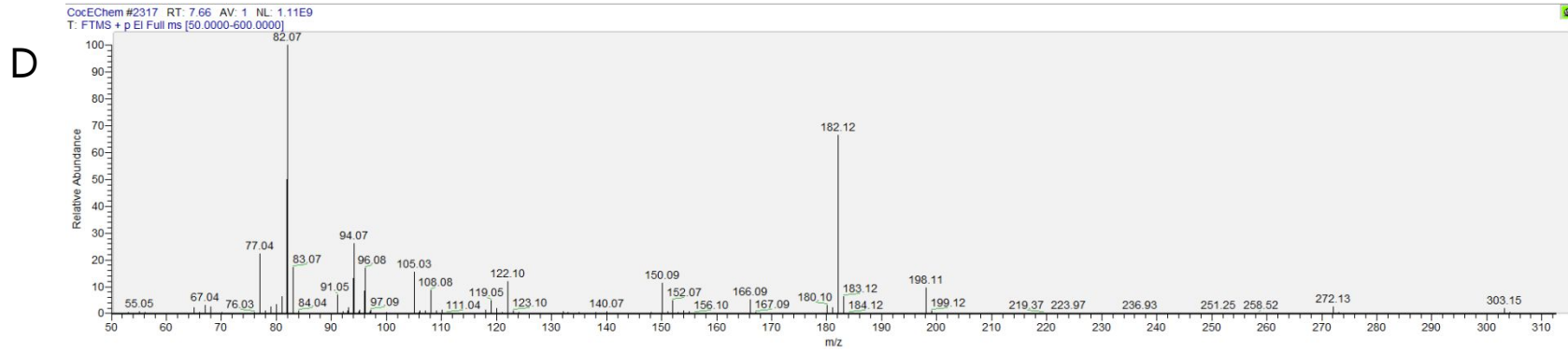
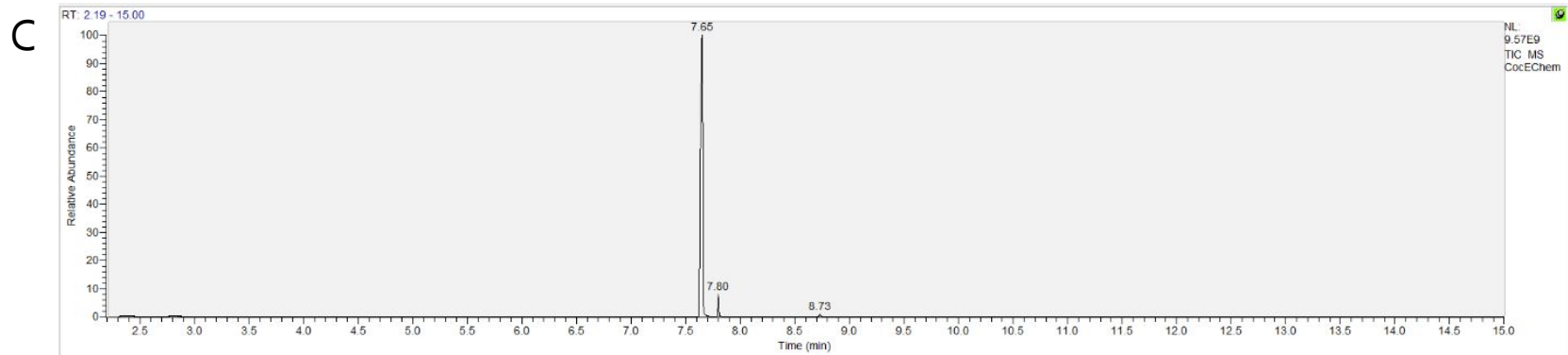
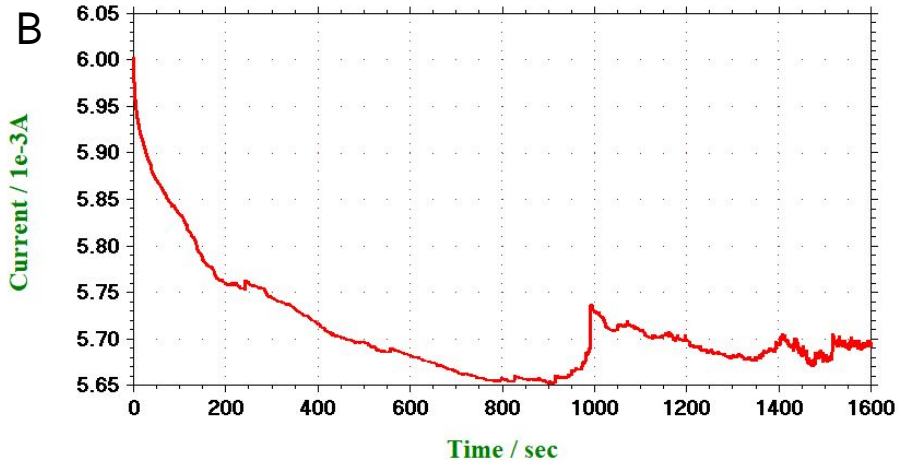
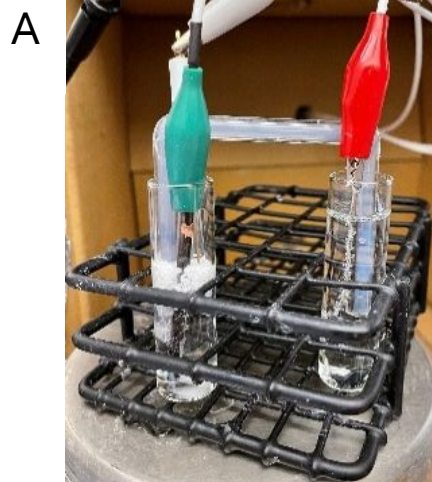
Mass spectrometry determination of precipitate

Precipitate is generated by the application of -2.1 V vs Ag/AgCl on a glassy carbon rod in 10 mM cocaine in 0.5 M KCl, where the platinum wire counter electrode was in 0.5 M KCl and electrochemically connected to the working electrode cell by a salt bridge. The working and reference electrodes were separated from the counter electrode such that the potential could be applied over long times and on a larger electrode (to create enough precipitate to easily isolate) without the cathodic product being influenced by the anodic reaction occurring at the counter electrode. The cocaine solution was stirred using a stir plate to allow for more product to be generated by increasing mass transfer to the electrode. This experimental setup is shown in the Supporting Information (Figure S4).

The precipitate was filtered with quantitative filter paper and then placed into a glass vial, which was then purged with argon gas for ~10 minutes to dry the powder. The precipitate was brought up in chloroform and was analyzed with a ThermoScientific Exactive GC with an Electron Ionization (EI) source. Samples were acquired in positive mode with a scan range of 50-600 m/z and a resolution of 60,000. The ion source was set to 230 °C and the MS transfer line was set to 280 °C. The AGC target was set to 1×10^6 .

Gas chromatography separation was performed using a TraceGOLD TG-5SilMS column. Injection volume for samples was 1 μ L. GC oven initialized at 100 °C. At 1.5 minute the GC oven started ramping at a rate of 30 °C/minute until 8 minutes. The temperature was held at 300 °C for 6.83 minutes.

Xcalibur (ThermoFisher, Bremen, Germany) was used to analyze the data. Solutions were analyzed at 0.1 mg/mL or less based on responsiveness to the EI mechanism. Molecular formula assignments were determined with Molecular Formula Calculator (v 1.2.3). All observed species were singly charged, as verified by unit m/z separation between mass spectral peaks corresponding to the ^{12}C and ^{13}C isotopes for each elemental composition.



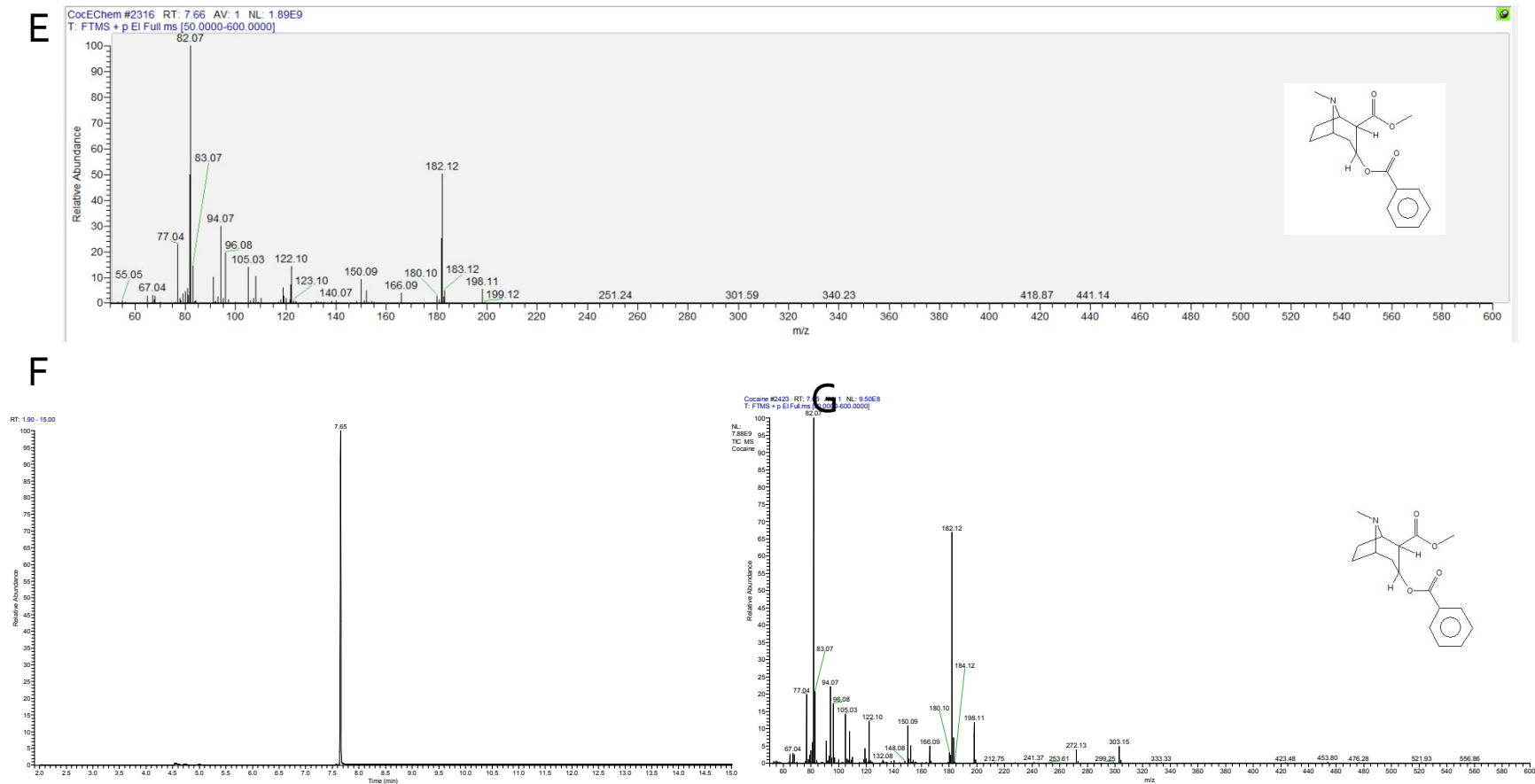

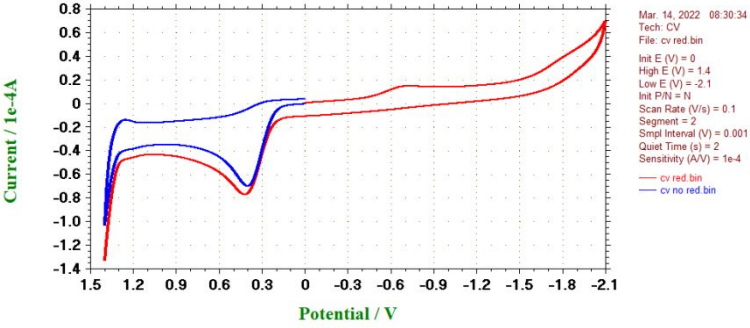
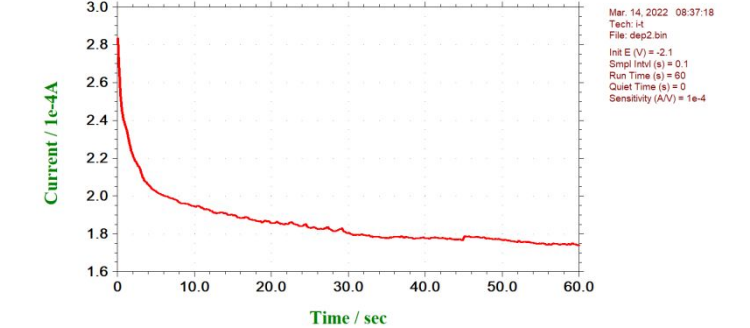
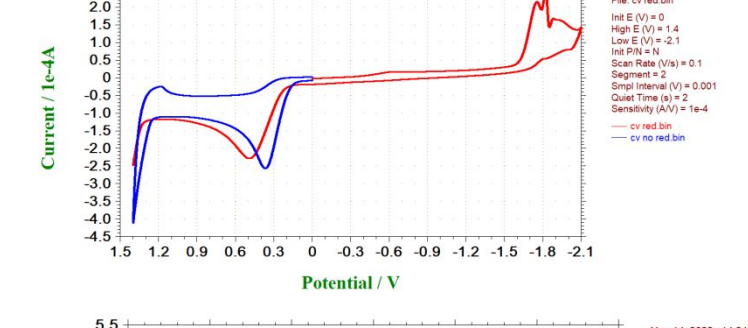
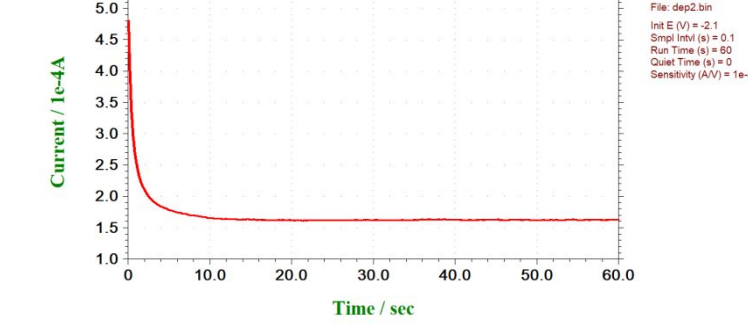
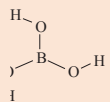


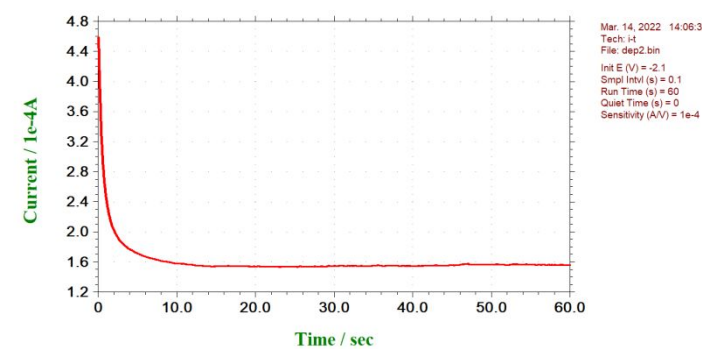
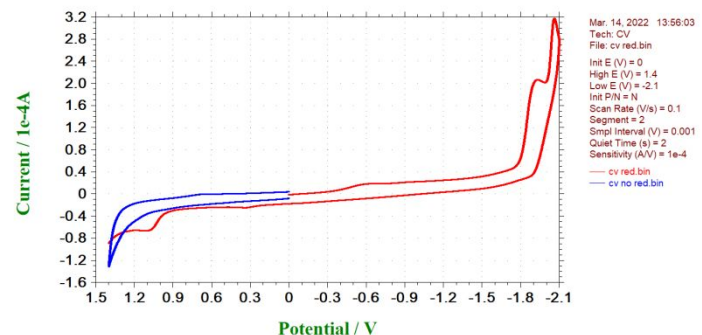
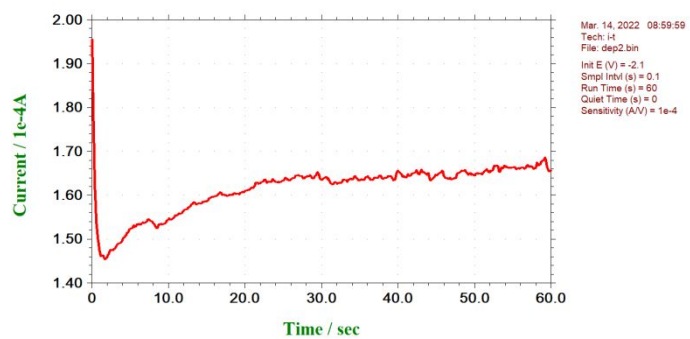
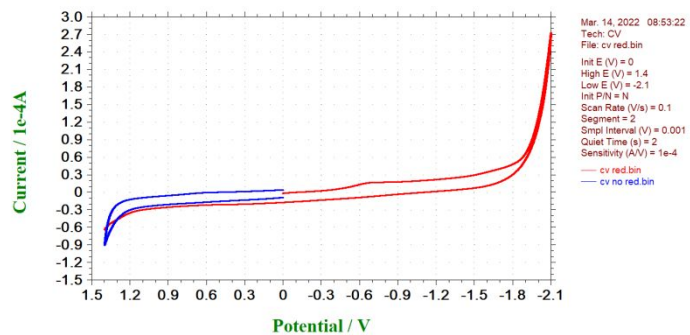
Figure S4. (A) Experimental setup for the bulk production of the precipitate product and (B) the corresponding amperogram biasing the glassy carbon rod at -2.1 vs Ag/AgCl for 1600 s. (C) Gas chromatogram for the precipitate created at the electrode (D) Electron ionization mass spectrum for the eluent at 7.65 minutes, zoomed in. (E) Electron ionization mass spectrum full scan. The observed masses and isotope distribution are consistent with the formula and structure shown as an inset. (F) Cocaine standard gas chromatogram (G) Cocaine standard electron ionization mass spectrum for the eluent at 7.65 full scan. The structure of cocaine is shown as an inset.

Table S1. The molecular structures and pKa values for each species (column 1). Cyclic voltammetry and representative amperograms for 10 mM interferent in 0.5 M KCl (column 2). Cyclic voltammetry and representative amperograms for 10 mM interferent mixed with 10 mM cocaine in 0.5 M KCl (column 3).

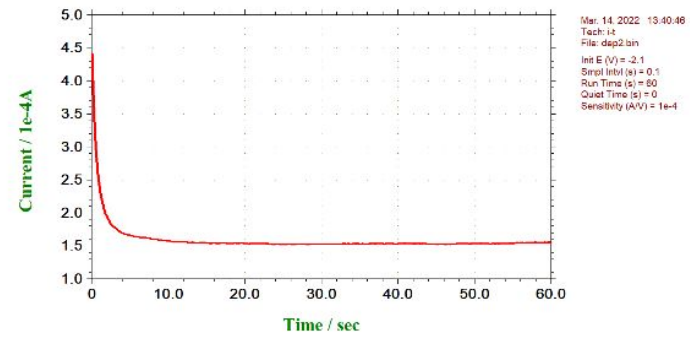
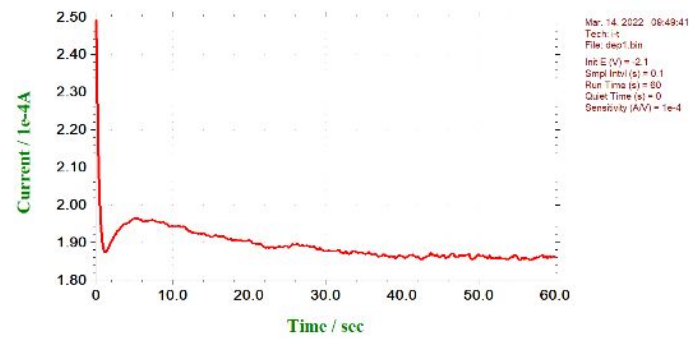
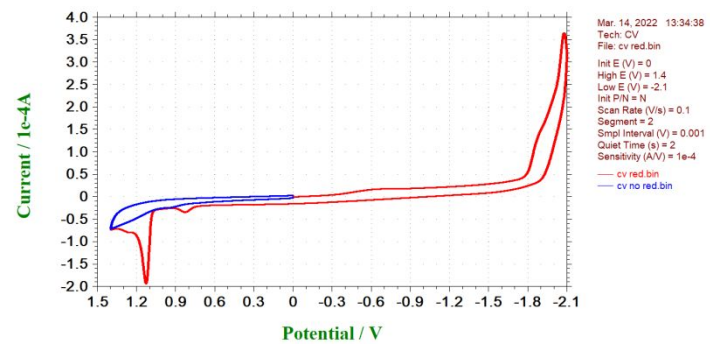
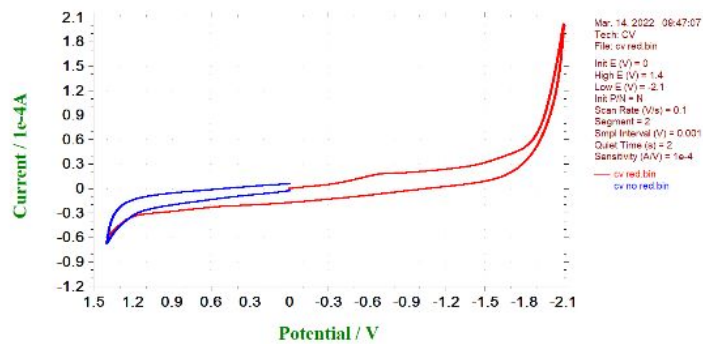
Interferent	10 mM interferent alone Cyclic voltammograms and representative amperometry	10 mM interferent and 10 mM cocaine
<div style="text-align: center;">  <p>Ascorbic acid pKa = 4.2, 11.6</p> </div>	<div style="text-align: center;">  <p>Mar. 14, 2022 08:30:34 Tech: CV File: cv red bin Init E (V) = 0 High E (V) = 1.4 Low E (V) = -2.1 Init P/N = N Scan Rate (V/s) = 0.1 Segment = 2 Smpl Interval (V) = 0.001 Quiet Time (s) = 2 Sensitivity (A/V) = 1e-4</p> </div> <div style="text-align: center;">  <p>Mar. 14, 2022 08:37:18 Tech: I4 File: dep2 bin Init E (V) = -2.1 Smpl Intvl (s) = 0.1 Run Time (s) = 60 Quiet Time (s) = 0 Sensitivity (A/V) = 1e-4</p> </div>	<div style="text-align: center;">  <p>Mar. 14, 2022 14:17:14 Tech: CV File: cv red bin Init E (V) = 0 High E (V) = 1.4 Low E (V) = -2.1 Init P/N = N Scan Rate (V/s) = 0.1 Segment = 2 Smpl Interval (V) = 0.001 Quiet Time (s) = 2 Sensitivity (A/V) = 1e-4</p> </div> <div style="text-align: center;">  <p>Mar. 14, 2022 14:24:03 Tech: I4 File: dep2 bin Init E (V) = -2.1 Smpl Intvl (s) = 0.1 Run Time (s) = 60 Quiet Time (s) = 0 Sensitivity (A/V) = 1e-4</p> </div>



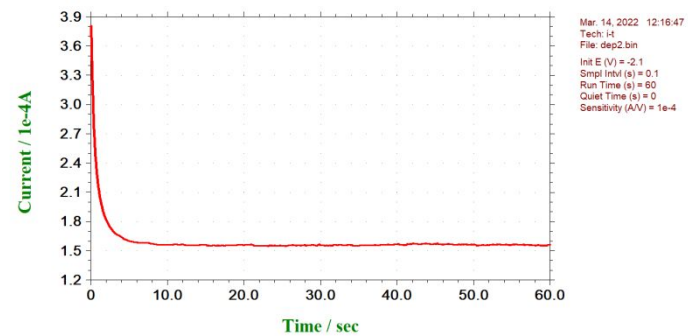
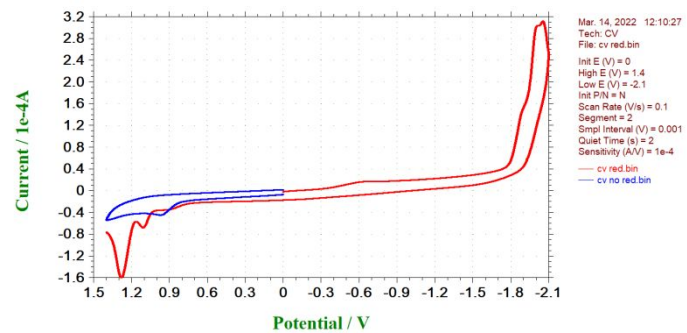
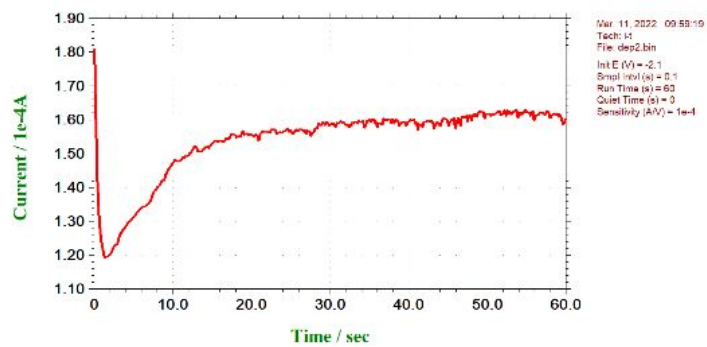
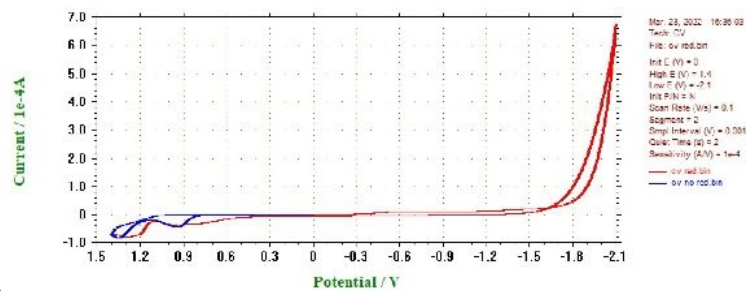
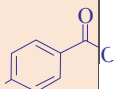
Boric acid
pKa = 9.2



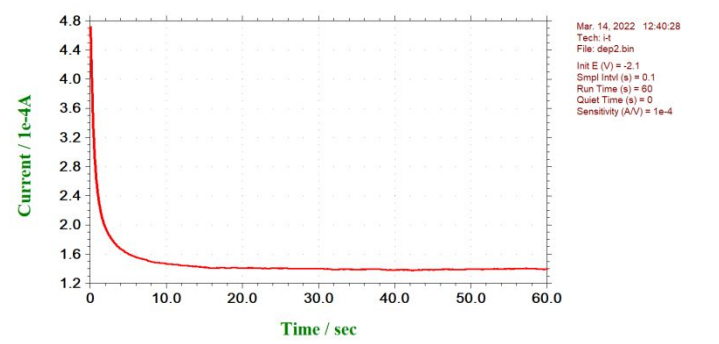
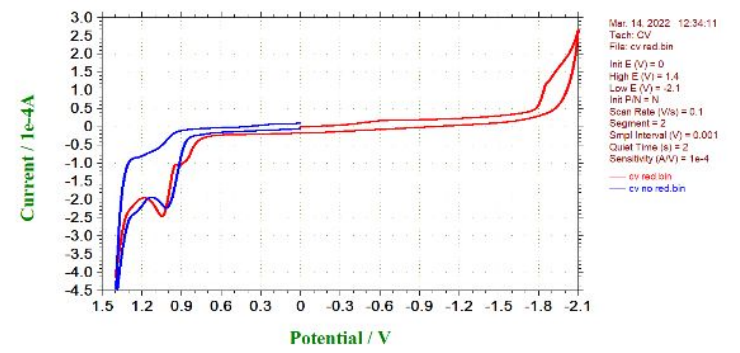
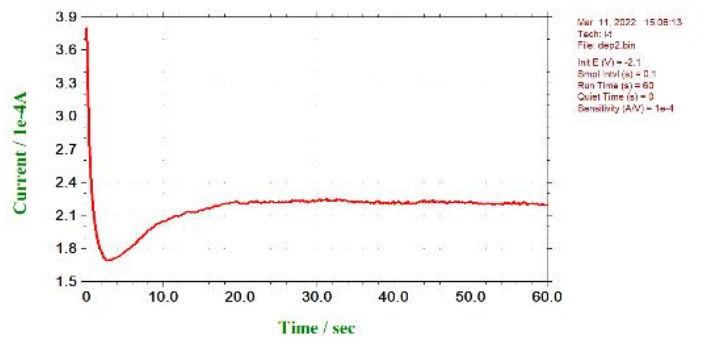
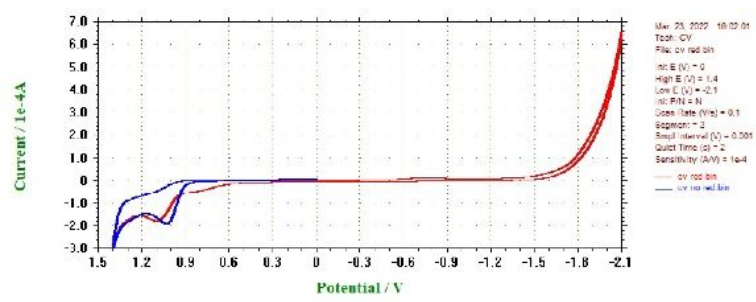
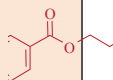
Sodium bicarbonate
pKa = 6.4, 10.3



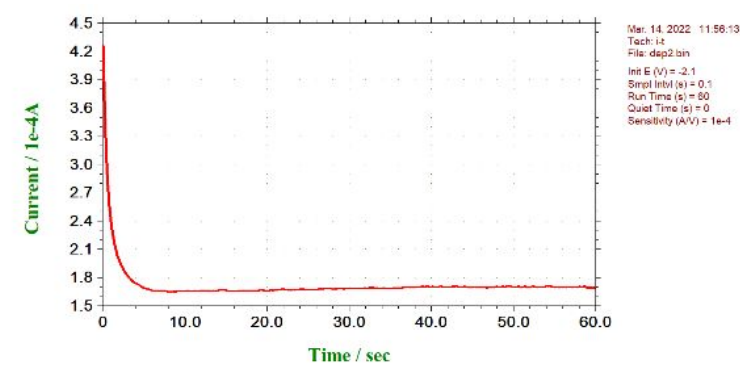
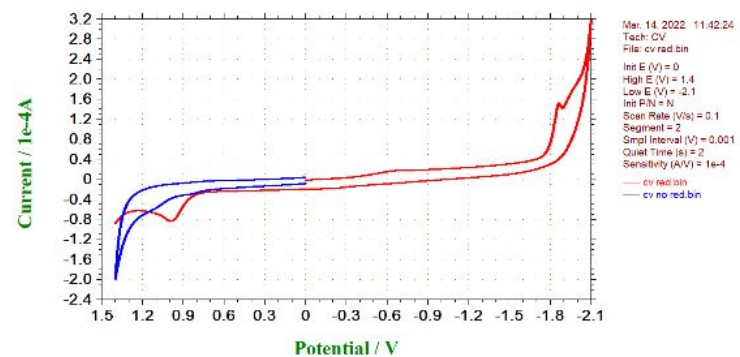
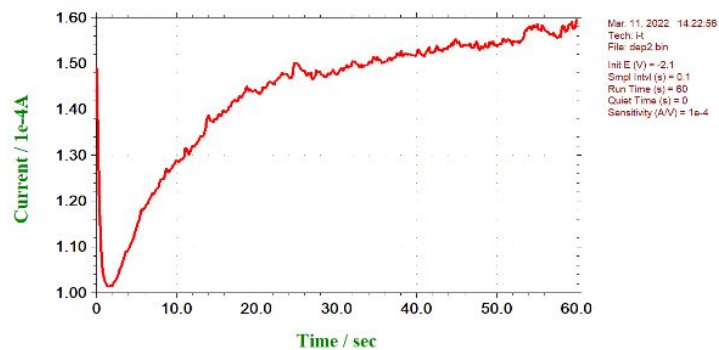
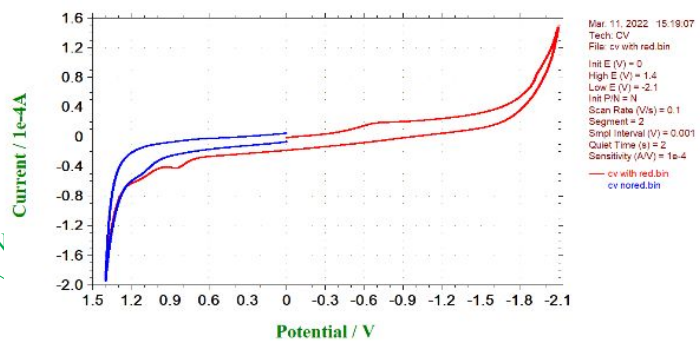
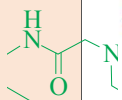
Benzocaine
pKa = 2.5



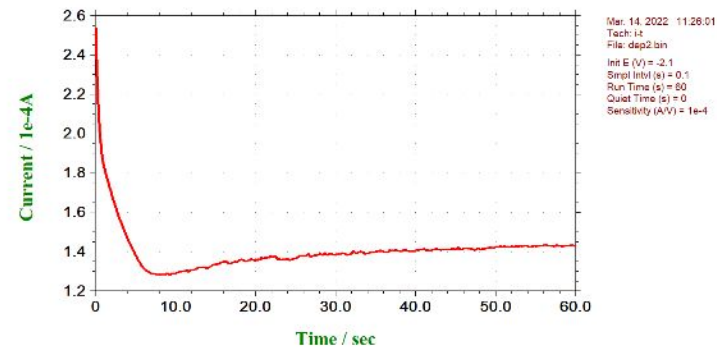
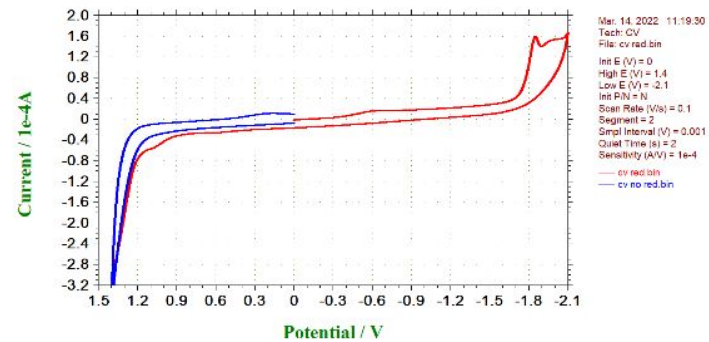
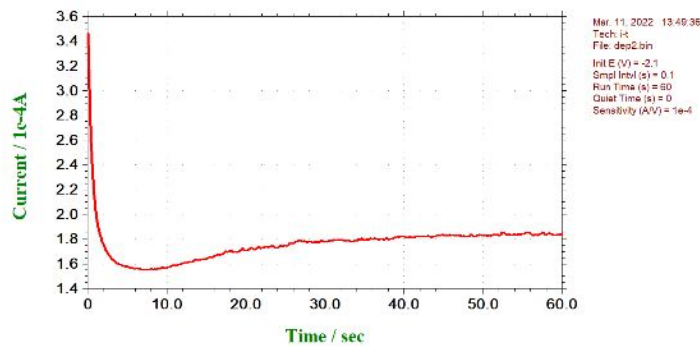
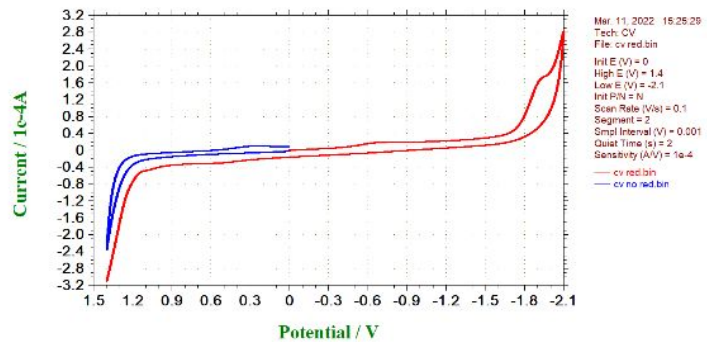
Procaine
pKa = 8.1

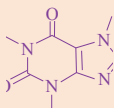


Lidocaine
pKa = 7.8

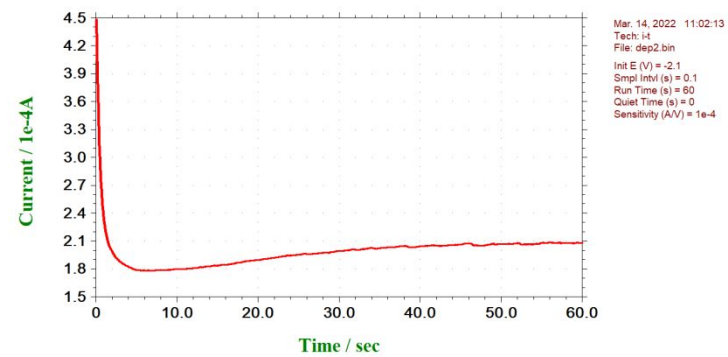
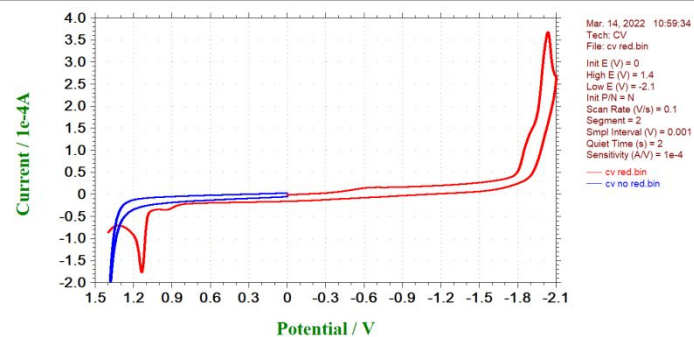
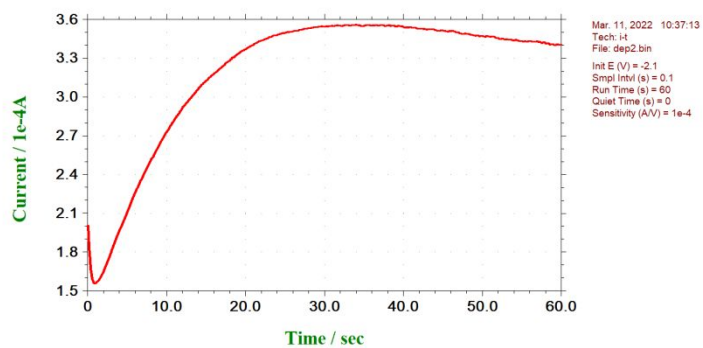
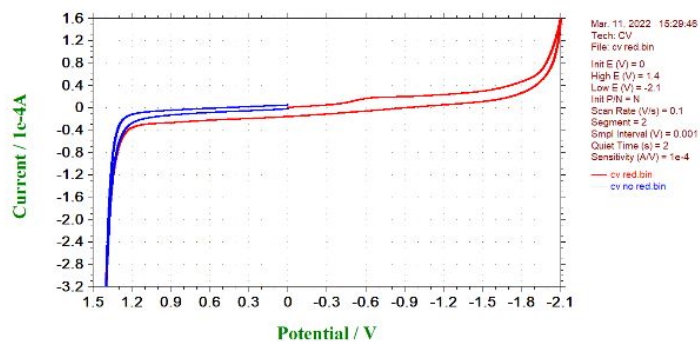


Levamisole
pKa = 7.0

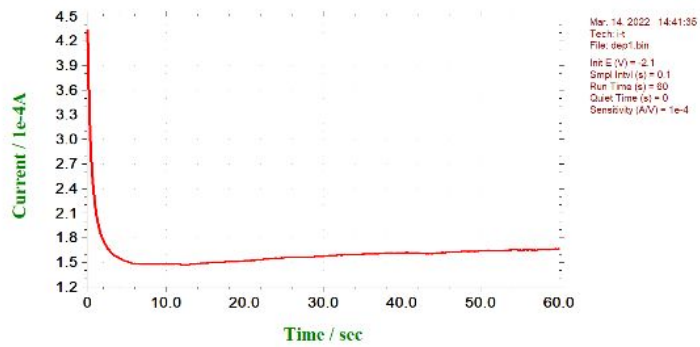
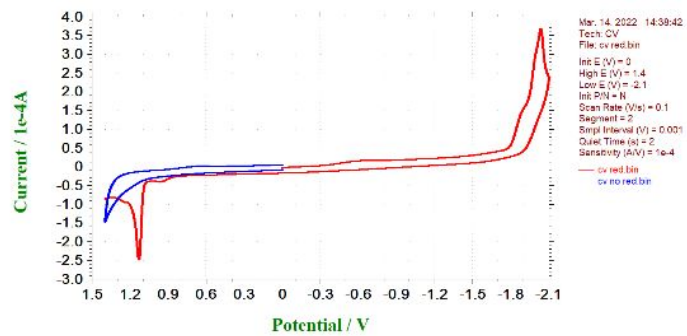




Caffeine
pKa = 10.4



Cocaine
pKa = 8.6



N/A

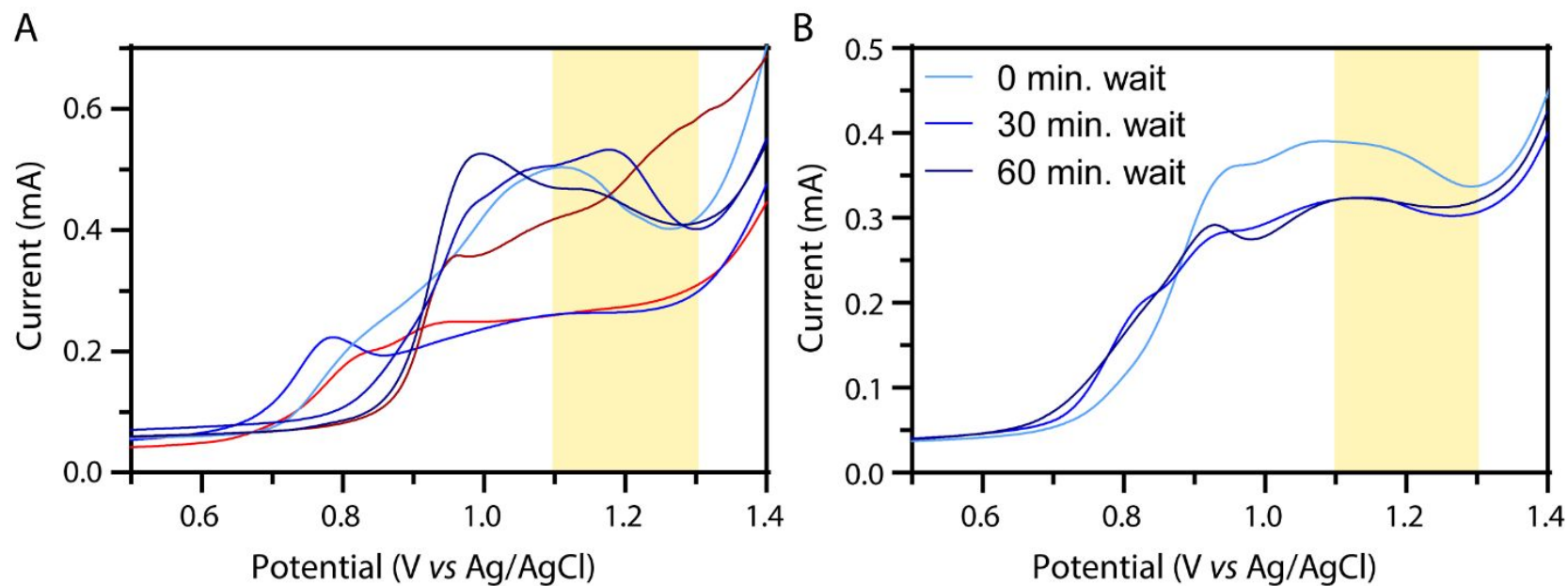


Figure S5. Overlay of voltammograms of 10 mM procaine with 10 mM cocaine in 0.5 M KCl. (A) The blue sweeps indicate a true positive result and the red sweeps indicate a false negative result. **(B)** Overlay of voltammetry taken in the same solution over the course of one hour after the solution was made. For all voltammetry in this figure, a glassy carbon ($d = 3$ mm) working electrode and a scan rate of 0.5 V/s was used. In line with the IUPAC convention, anodic current is represented as positive.

Masked Study

A first year graduate student researcher that was not involved in the development of the sensor was given six powder mixtures. The powder mixtures were prepared in weights such that each species would be 10 mM if the provided sample was solubilized in 2 mL. On average, this was <5 mg per substance and 10-15 mg for the sample dissolved in 0.5 M KCl.

1: levamisole, lidocaine, cocaine

2: procaine, lidocaine, cocaine

3: levamisole, caffeine, cocaine

4: benzocaine, lidocaine, cocaine

5: levamisole, benzocaine, caffeine

6: procaine, caffeine, lidocaine

The student was given the necessary materials and the following instructions (provided below as given):

Prepare two test tubes with 2 mL of 0.5 M KCl. Add the unknown sample (~ 10 mg) to one of the 2 mL (0.5 M KCl) containers. Open the saved files for the electro-precipitation method and the voltammetry method in the CH Instruments software. Place the electrodes in the sample solution, then clip the counter electrode, reference electrode, and then the glassy carbon working electrode. Run the electro-precipitation method. Carefully unclip the working electrode, reference electrode, and then the counter electrode and lift electrodes straight out of solution. Please note that the order that the electrodes are removed from electrical connection is important for the protection of the working electrode and subsequent measurements. Place the electrodes in the clean 0.5 M KCl solution, then clip the counter electrode, reference electrode, and then the working electrode. Be careful not to touch the surface of the working electrode at any time during this transfer. Run the voltammetry method ~5 s after connecting the working electrode.

Between measurements, store the Ag/AgCl reference electrode in a KCl storage solution (matching the filling solution specified by the manufacturer). Making small figure-8 motions and gentle pressure, polish the working electrode on a wet polishing pad with 0.05 μm alumina powder for about 20 s. Rinse the disk of the working electrode directly with water for ~5 s and wipe gently with a Kim wipe. Repeat these steps for each unknown sample.

Report a positive result for samples when the associated voltammograms peak between 1.1 and 1.3 V vs Ag/AgCl with a signal at least 2x the capacitive current.

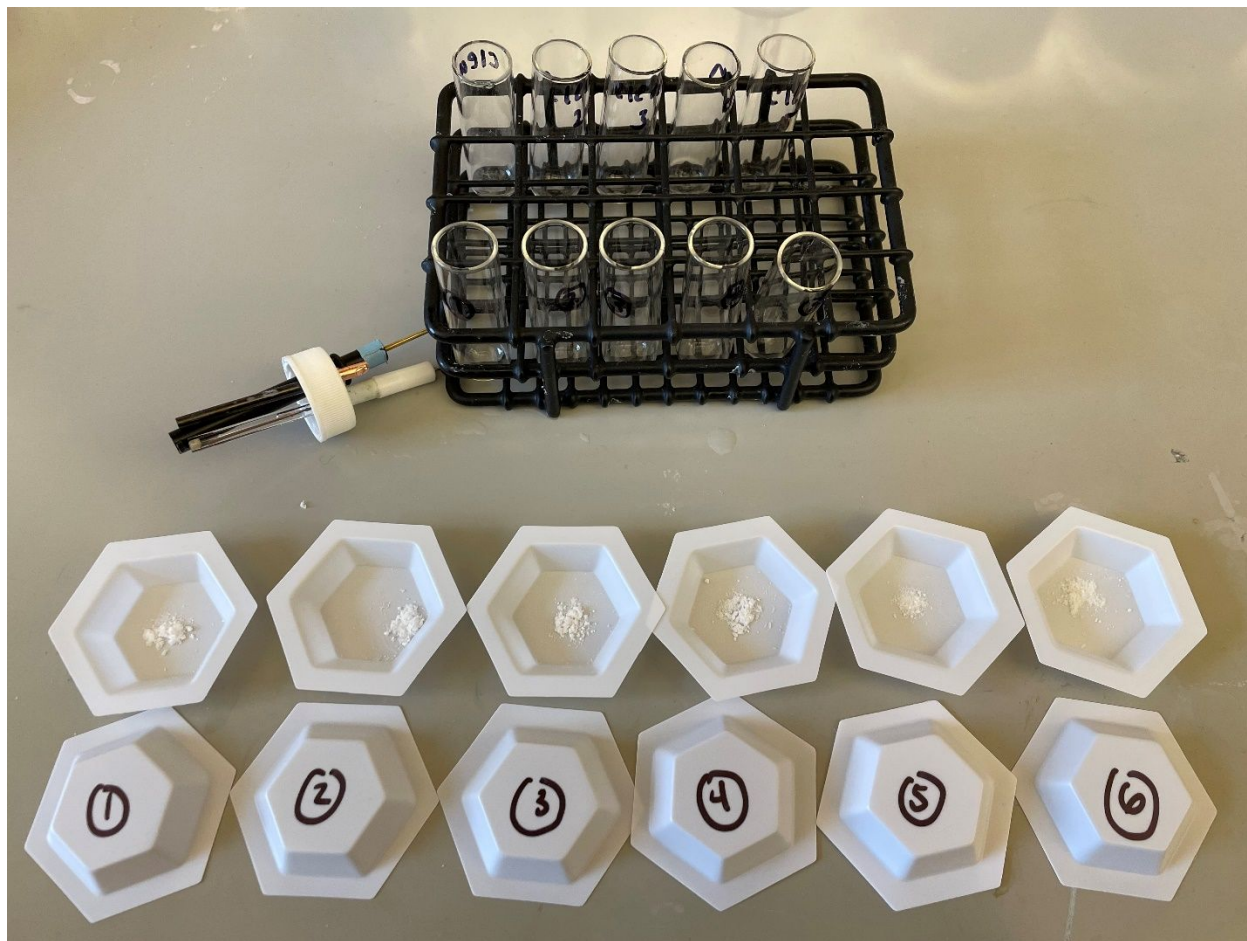


Figure S6. Image showing the materials provided for the masked study, including six unknown powder mixtures 12 test tubes (2 for each sample), and a bundle of three commercial electrodes (glassy carbon working electrode, Ag/AgCl reference electrode, and glassy carbon rod counter electrode).

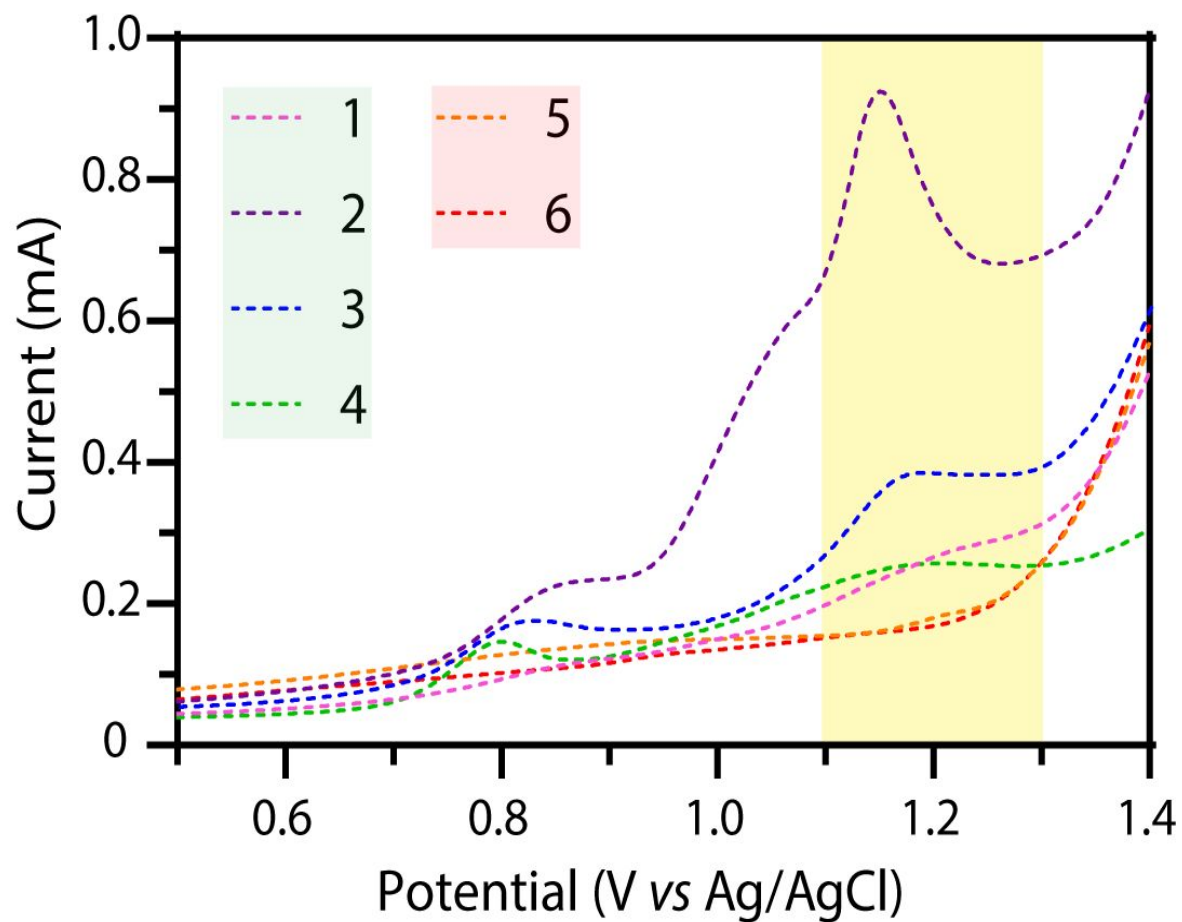


Figure S7. Voltammograms collected in the masked study. Samples 1-4 contain 10 mM cocaine mixed with two interferents (10 mM, each). Samples 5 and 6 do not contain cocaine but are comprised of three interferents (10 mM, each). Each sample was deposited and measured in 0.5 M KCl, with a glassy carbon working electrode ($d = 3$ mm), Ag/AgCl reference electrode and a glassy carbon rod counter electrode. Voltammetry was performed 0 V to 1.4 V vs Ag/AgCl at 0.5 V/s. In line with the IUPAC convention, anodic current is represented as positive.

Carbon fiber microelectrode fabrication

A capillary (sealed on one end) was scored and halved, keeping the half with the sealed end. A carbon fiber (4 μm radius) was cut (~ 3 cm shorter than the capillary tube) and pushed down the capillary until the carbon fiber reached the sealed bottom. The capillary was attached to vacuum for approximately 15 minutes and then placed with the sealed end entering a metal coil. A variable power supply (Powerstat) attached to the coil applied approximately 28 V to evenly melt the borosilicate capillary around the fiber. The capillary was attached to vacuum through the duration of the sealing. Using a micropositioner, the capillary was slowly moved down into the coil until about an inch of glass was sealed (~ 30 minutes). Electrical connection with the carbon fiber was made by stripping approximately 7 cm of an electrical wire, dipping the exposed wire into liquid gallium, and pushing the coated wire down the unsealed end of the capillary until visible connection with the fiber was made. Hot glue from a commercially-available hot glue gun was used to secure the open end of the capillary tube with the insulated portion of the electrical wire. The remaining end of the electrical wire was then stripped and copper tape was wrapped around the exposed portion of the electrical wire to make connection to potentiostat leads. To expose a disk of the carbon fiber, the sealed end of the capillary was scored and cut off. The cut end was then polished using 1500 CW sandpaper, followed by polishing with 0.05 μm alumina on a wet MicroCloth polishing pad for approximately 5 minutes in a small figure 8 pattern. The microelectrode was rinsed with Milli-Q water and placed in a 1 mM ferrocene methanol solution and voltammetry was performed from 0 V to 0.5 V vs Ag/AgCl at 0.05 V/s. The radius of the microelectrode was calculated and polished until the electrochemically-determined electrode radius agreed with the optically-determined fiber radius (Figure S8).

Characterizing the carbon fiber microelectrode

$$i_l = 4nFDCr_e$$

Where i_l is the limiting current (1.1 nA), n is the number of electrons (1 electron), F is Faraday's constant (96485 C/mol), D is the diffusion coefficient for ferrocene methanol (7×10^{-10} m²/s), C is the concentration of solution (1 mM), and r_e is the radius of the electrode. Based on the measured limiting current, the fabricated disk electrode has a radius of 4.0 μm , falling in line with the optically-observed radius of the wire (4 μm).

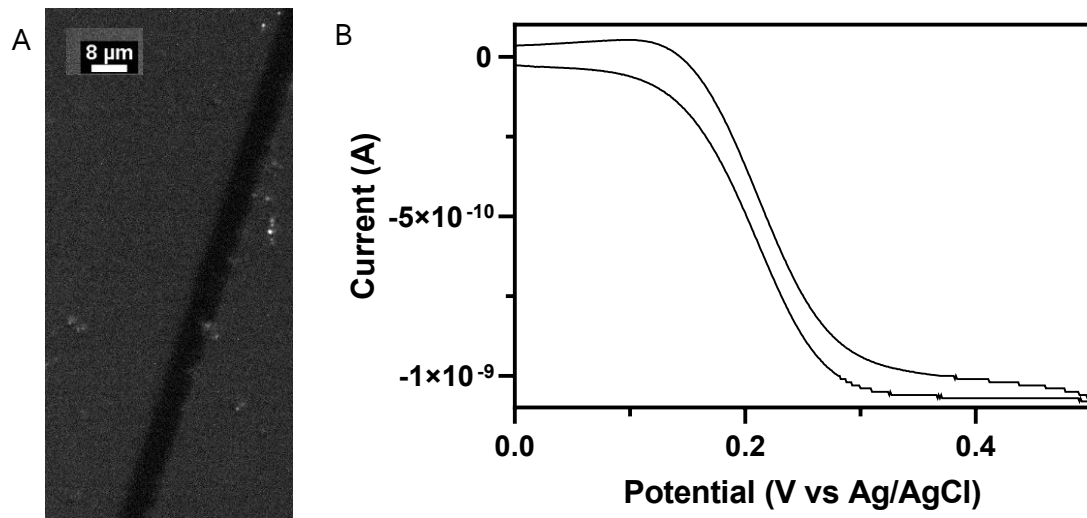


Figure S8. (A) Microscope image of carbon fiber ($d = 8 \mu\text{m}$). (B) Cyclic voltammogram of 1 mM ferrocene methanol collected with a carbon fiber microelectrode as the working electrode ($r = 4 \mu\text{m}$), a Ag/AgCl reference electrode, and carbon rod counter electrode. In line with polarographic convention, the anodic current is represented as negative.