Experiment **5**

Cyclic Voltammetry Basics: Ohm's Law

The Go Direct Cyclic Voltammetry System (CVS) is designed for use with real chemical systems. However, you can also perform a simple experiment with the instrument itself to familiarize yourself with the hardware and software, confirm operation of the unit, and explore Ohm's law. The experiments described here avoid the added complexity of chemistry and allow you to interrogate the CVS directly by engaging the internal resistor.

Built into the CVS is a 1,000 Ω resistor that can be placed in parallel with the screen-printed electrode connector. Without a screen-printed electrode (SPE) loaded into the CVS, the "cell" is simply a 1,000 Ω resistor. A resistor is a straightforward system to study, free of chemistry complications.

To describe resistance in an electrochemical context, Ohm's law can be used. Ohm's law states that the current (i, expressed in amperes) through a conductor (electrolyte solution) is proportional to the voltage (E) across two points, where the resistance (R, expressed in ohms) is the constant of proportionality:

$$E = iR$$

where E is potential (in volts, V), i is current (in amperes, A), and R is resistance (in ohms, Ω).

Ohm's law is readily used to describe solution resistance and the change in current or voltage measured in the laboratory. When the internal resistor is employed, resultant data can be rationalized with Ohm's law, verifying instrument performance and providing a simple and uncomplicated experiment experience.

In the case of Cyclic Voltammetry, potential changes linearly as a function of time; therefore, you can calculate the instantaneous current as a function of the potential (along the ramp) in the same manner as for bulk electrolysis. The slope of the cyclic voltammogram can also be used. Since a cyclic voltammogram is the linear plot of measured current (y) *vs*. applied potential (x), the slope follows Ohm's law and is equal to $1/R$:

$$i = \left(\frac{1}{R}\right)E$$

$$y = mx + b$$

OBJECTIVES

- Familiarize yourself with the Go Direct Cyclic Voltammetry System.
- Explore Ohm's law.

MATERIALS

One of the following
- Chromebook, computer, or mobile device with Vernier Instrumental Analysis app[1]
- LabQuest 2 (software is pre-installed; v2.8.7 or newer required)[2]
- LabQuest 3 (software is pre-installed; v3.0.6 or newer required)[2]

Go Direct Cyclic Voltammetry System

PROCEDURE

Part I Bulk electrolysis with internal resistor

1. Set up the Cyclic Voltammetry System by following the directions for your equipment:

Instrumental Analysis

a. Launch Instrumental Analysis.
b. Connect the Go Direct Cyclic Voltammetry System (CVS) to your device via USB or Bluetooth wireless technology. If using Bluetooth, click or tap Connect an Instrument, connect to your CVS, and click or tap Done.
c. Click or tap Voltammetry.
d. Click or tap the [+] for the CVS and enable the Use Internal Resistor option.
e. Set the Voltammetry Mode to Bulk Electrolysis.
f. Set the BE Profile settings to the values in Table 1.

LabQuest

a. Connect the Go Direct Cyclic Voltammetry System (CVS) to your device via USB or Bluetooth wireless technology. If using Bluetooth, tap the Sensors menu and choose Wireless Device Setup►Go Direct. Select your instrument and tap OK.
b. Choose Data Collection from the Sensors menu.
c. Set the Voltammetry mode to Bulk Electrolysis.
d. Set the BE Profile settings to the values in Table 1.
e. Enable the Use Internal Resistor option. Tap OK.

Table 1	
Sample rate (sample/s)	10
Duration (s)	30
Electrolysis potential (mV)	500
Current range	High

[1] Instrumental Analysis v1.2 or newer required; download the most recent version for free at **www.vernier.com/ia**

[2] Download the most recent version of LabQuest software for free at **www.vernier.com/downloads**

2. Adjust the graphs by following the directions for your equipment:

   Instrumental Analysis

   a. To adjust the view, click or tap View, ⊞, and choose 2 Graphs.
   b. Click or tap the axes labels of each graph to modify the graphs. Adjust the displayed columns such that one graph is current (y) *vs*. time (x) and the other graph is voltage (y) *vs*. time (x). Make sure Data Set 1 is enabled on both graphs. **Note**: You may need to adjust the data set throughout the experiment to make sure you are analyzing the correct data.

   LabQuest

   a. By default, your graphs should be set up properly. If you would like to adjust the view, select Show Graph from the Analyze menu. Choose the All Graphs option.
   b. Make such that one graph is current (y) *vs*. time (x) and the other graph is voltage (y) *vs*. time (x). **Note**: You may need to adjust the data set throughout the experiment to make sure you are analyzing the correct data.

3. Collect and analyze data.
   a. Start data collection. As the experiment is running, the applied potential (500 mV) is being applied across the internal 1,000 Ω resistor. Data collection will stop automatically. **Note**: Do not insert a screen-printed electrode into the instrument when using the internal cell.
   b. Name your sample appropriately.
   c. Analyze the data.
      - Instrumental Analysis: Click or tap Graph Tools, , and choose Statistics for each graph. Record the mean for each graph in Table 4.
      - LabQuest: Choose Statistics from the Analyze menu. Record the mean for each graph in Table 4.

4. Adjust the potential and collect additional data.
   - Instrumental Analysis: Click or tap Voltammetry Settings, , and adjust the potential to 1000 mV. Then, repeat Step 3.
   - LabQuest: Choose Data Collection from the Sensors menu on the Meter screen. Adjust the potential to 1000 mV, and then, repeat Step 3.

5. Adjust the potential to –250 mV, and then repeat Step 3.

Part II Cyclic voltammetry with internal resistor

6. Adjust the data-collection mode and parameters.
   a. To adjust the mode, following the directions for your equipment:
      - Instrumental Analysis: Click or tap Voltammetry Settings, ⚙, and set the Voltammetry Mode to Cyclic Voltammetry.
      - LabQuest: Choose Data Collection from the Sensors menu, and set the Voltammetry Mode to Cyclic Voltammetry.

   b. Set the CV Profile settings to the values in Table 2.

Table 2	
Number of segments	2
Initial potential (mV)	–500
Switching potential 1 (mV)	500
Final potential (mV)	–500
Sweep rate (mV/s)	100
Current range	High (±1000 μA)

7. Collect and analyze data.
   a. Start data collection. As the experiment is running, the cyclic voltammetry waveform is being applied across the internal 1,000 Ω resistor. Data collection will stop automatically. **Note**: Do not insert a screen-printed electrode into the instrument when using the internal cell.
   b. Your cyclic voltammogram is plotted on the bottom graph. You may want to enable both the current and the voltage on the y-axis on the top graph to ensure the instrument is doing what you expect. This can also be useful when answering the data analysis questions.
   c. Name your sample appropriately.
   d. Click or tap the graph to examine the data. **Note**: You can also adjust the Examine line by dragging the line or tapping along the graph.

8. Repeat Steps 6–7 to collect additional data. For this trial, adjust the parameters to the values in Table 3.

Table 3	
Number of segments	3
Initial potential (mV)	500
Switching potential 1 (mV)	–200
Switching potential 2 (mV)	1200
Final potential (mV)	500
Sweep rate (mV/s)	100
Current range	High (±1000 μA)

9. When you are finished collecting all of your data, save or export your data as instructed.

DATA TABLE

Table 4		
Potential, (mV)	Mean current (y) *vs*. time (x)	Mean voltage (y) *vs*. time (x)
500		
1000		
–250		

DATA ANALYSIS

1. Consider the bulk electrolysis experiment. When 500 mV is applied across a 1,000 Ω resistor, a known current can be calculated and compared to the instrumental response. From Ohm's law, when 500 mV is applied, what is the required response in current? Does the instrument follow Ohm's law?

2. Review your graphs from Step 7. Was the cyclic voltammetry potential waveform set in the software actually what was measured by the instrument? Include a graph.

3. Do the initial and final potential and current agree with Ohm's law when using the internal 1,000 Ω resistor? Include applicable calculations.

4. What is the slope of the cyclic voltammogram? Is it consistent with what would be predicted by Ohm's law? Include appropriate graphs. **Hint**: To apply a linear fit, follow the directions for your equipment:
   - Instrumental Analysis: Click or tap Graph Tools, . Select Apply Curve Fit, select Linear as the curve fit, and click or tap Apply.
   - LabQuest: Choose Curve Fit from the Analyze menu. Select Linear as the curve fit, and tap OK.