Electrochemical Cell Voltage

How do changes in concentration within a cell change the voltage of the cell?

Why?

Batteries are simply electrochemical cells in a compact container. The most common are sold as 9-volt or 1.5-volt, but are these voltages reliable? Does the voltage of an electrochemical cell stay constant as the cell runs towards equilibrium? Can an electrochemical cell have a voltage other than its standard voltage?

Model 1 – Zinc and Copper Cell

$$\mathbf{Zn\,(s) + Cu^{2+}\,(aq) \leftrightarrow Zn^{2+}\,(aq) + Cu\,(s) \quad E^\circ = 1.100\ V}$$

Time (min)	$[Cu^{2+}]$ (M)	$[Zn^{2+}]$ (M)	Voltage (V)
1	1.750	0.250	1.077
2	1.500	0.500	1.087
3	1.250	0.750	1.094
4	1.000	1.000	1.100
5	0.750	1.250	1.106
6	0.500	1.500	1.113
7	0.250	1.750	1.123

1. Is the cell in Model 1 spontaneous or not? Use evidence from Model 1 to justify your answer.

2. Is the reaction in Model 1 favoring the reverse direction at any point during the experiment? Justify your answer.

3. Refer to Model 1.

   a. What is the standard cell potential for the reaction between zinc and copper?

   b. What are the concentrations of the zinc and copper solutions when the standard cell potential is obtained?

4. Sketch how the $Zn^{2+}(aq)/Cu(s)$ electrochemical cell in Model 1 may appear in a lab setup. Label the electrodes and solutions. Include a voltmeter in your drawing.

5. Is the reaction in Model 1 at equilibrium at any point during the experiment? If no, in which direction must the reaction proceed to reach equilibrium?

6. According to the data in Model 1, does an electrochemical cell provide a constant voltage as it proceeds?

7. Would you expect a 9-V battery to always provide 9 V? Justify your reasoning.

Model 2 – Concentration Effects in a Cell

$$\mathbf{Zn(s) + Cu^{2+}(aq) \leftrightarrow Zn^{2+}(aq) + Cu(s) \quad E^\circ = 1.100\ V}$$

Trial	Initial $[Cu^{2+}]$ (M)	Initial $[Zn^{2+}]$ (M)	Voltage (V)
1	1.00	0.25	1.116
2	1.00	0.50	1.108
3	1.00	0.75	1.103
4	1.00	1.00	1.100
5	0.75	1.00	1.097
6	0.50	1.00	1.092
7	0.25	1.00	1.084

8. In trials 1–7 in Model 2, what variables in the cell have been changed?

9. Consider the data in Model 2.

   a. Based on the principles of LeChâtelier, in which direction would you predict the reaction to shift when the concentration of copper ions is decreased?

   b. What happens to the cell's potential (voltage) when the concentration of copper ions is decreased?

   c. Based on the principles of LeChâtelier, in which direction would you predict the reaction to shift when the concentration of zinc ions is decreased?

   d. What happens to the cell's potential when the concentration of zinc ions is decreased?

STOP

10. Predict the effect on the cell's potential when the concentration of copper ions is increased. Use LeChâtelier's Principle to justify your prediction.

11. Using the reaction in Model 1, estimate the conditions that would be required to achieve a cell potential of 1.00 V.

12. Consider the following reaction:

$$F_2(g) + 2Cl^{1-}(aq) \leftrightarrow 2F^{1-}(aq) + Cl_2(g) \quad E° = 1.51\ V$$

   a. Describe the conditions that would provide a voltage of 1.51 V.

   b. Identify two changes to the cell that would increase the potential of the cell.

   c. Identify two changes to the cell that would decrease the potential of the cell.

STOP

Extension Questions

Model 3 – Chromium and Zinc

$$3Zn\,(s) + 2Cr^{3+}\,(aq) \leftrightarrow 2Cr\,(s) + 3Zn^{2+}\,(aq) \quad E° = 0.020\,V$$

Trial	Initial $[Cr^{3+}]$ (M)	Initial $[Zn^{2+}]$ (M)	Voltage (V)
1	1.00×10^{-3}	1.00	–0.034
2	1.00×10^{-2}	1.00	–0.016
3	1.00×10^{-1}	1.00	0.002
4	1.00	1.00	0.020
5	1.00	1.00×10^{-1}	0.047
6	1.00	1.00×10^{-2}	0.074
7	1.00	1.00×10^{-3}	0.101

13. Under standard conditions, is the reaction in Model 3 spontaneous? Justify your answer.

14. Describe a set of estimated conditions that would allow the reaction in Model 3 to be at equilibrium.

15. According to Model 3, is it possible to make the reaction in Model 3 nonspontaneous? If yes, what was done to make this happen?

16. Are the data in Model 3 consistent with LeChâtelier's principle? Justify your reasoning.