Redox Analogies

Voltaic Cells

Introduction

This simple classroom activity explains what's "standard" and provides an analogy for the position of metals in a table of standard reduction potentials.

Concepts

- Oxidation and reduction
- Standard reduction potentials

Materials

Chalk or dry-erase markers

Classroom chalkboard or dry-erase board

Standard reduction potential chart

Safety Precautions

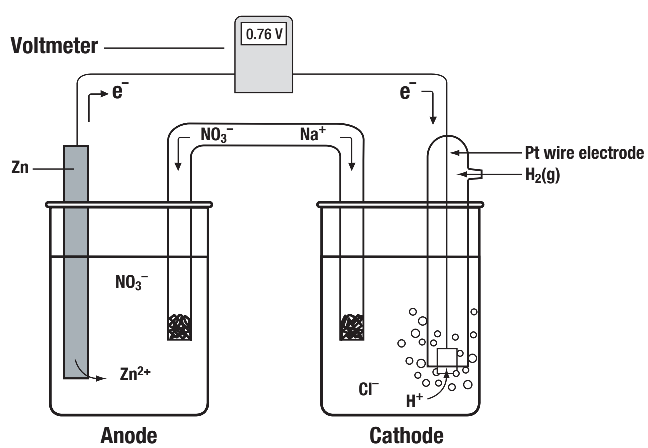
Although this activity is considered nonhazardous, please observe all normal laboratory safety guidelines.

Procedure

1. Select three students from the class, one with an "average" height and one shorter and one taller student.
2. Have the "average" student come up to the board. Mark the student's height on the board with a line labeled "reference."
3. Ask the shorter student to come up to the board and mark their height with a line labeled with their name. Measure the difference in height from the reference and mark as –Y units.
4. Ask the taller student to come up and mark their height on the board with a line labeled with their name. Measure the difference in height from the reference and mark as +X units.
5. Ask the class to determine the difference in height between the taller student and the shorter student without directly measuring the value.

Discussion

In an oxidation-reduction reaction, electrons flow from the substance that is oxidized, which loses electrons, to the substance that is reduced, which gains electrons. In a voltaic cell, the flow of electrons accompanying a spontaneous oxidation–reduction reaction occurs via an external pathway, and an electric current is produced.



The basic design of a *voltaic cell* is shown in Figure 1 for the net reaction of zinc and hydrochloric acid. The substances involved in each half-reaction are separated into two compartments connected by an external wire and a salt bridge.

Each half-reaction takes place on the surface of a metal plate or wire, or an *electrode*. The electrode at which oxidation occurs is called the *anode*, and the electrode at which reduction occurs is called the *cathode*. Electrons flow spontaneously from the anode (the negative electrode) to the cathode (the positive electrode). Charge buildup at the electrodes is neutralized by connecting the half-cells internally by means of a *salt bridge*, a porous barrier containing sodium nitrate or another electrolyte. Dissolved ions flow through the salt bridge to either electrode, thus completing the electric circuit.

The ability of a voltaic cell to produce an electric current is called the *cell potential* and is measured in volts. If the cell potential is large, there is a large "electromotive force" pushing or pulling electrons through the circuit from the anode to the cathode. The cell potential for a spontaneous chemical reaction in a voltaic cell is always positive. The *standard cell potential* (E^o_{cell}) is defined as the maximum potential difference between the electrodes of an electrochemical cell under standard conditions—25°C, 1 M concentrations of ions, and 1 atm pressure (for gases).

It is impossible to directly measure the potential for a single electrode, as standard reduction potentials for individual half-cell reactions have no intrinsic or absolute meaning. Cell potentials are only defined by difference. The overall cell potential for an electrochemical cell may be expressed, therefore, as the difference between the *standard reduction potentials* (E^o_{red}) for the reactions at the cathode and at the anode (Equation 1).

$$E^o_{cell} = E^o_{red}\text{ (cathode)} - E^o_{red}\text{ (anode)} \qquad \textit{Equation 1}$$

The standard reduction potential refers to the voltage that a reduction half-cell will develop under standard conditions when it is combined with the standard hydrogen electrode (SHE), which is arbitrarily assigned a potential of zero volts.

$$2H^+\text{(aq, 1 M)} + 2e^- \rightarrow H_2\text{(g, 1 atm)} \qquad \textit{Equation 2}$$

For the zinc/hydrochloric acid voltaic cell shown in Figure 1, the measured cell potential is equal to 0.76 V. Substituting this value and the zero potential for the SHE into Equation 1 gives a value of –0.76 V for the standard reduction potential of the Zn^{2+}/Zn half-cell.

$$E^o_{red}\text{ (cathode)} - E^o_{red}\text{ (anode)} = E^o_{cell}$$
$$E^o_{red}\text{ (SHE)} - E^o_{red}\text{ (}Zn^{2+}/Zn\text{)} = 0.76\text{ V}$$
$$0 - E^o_{red}\text{ (}Zn^{2+}/Zn\text{)} = 0.76\text{ V}$$
$$E^o_{red}\text{ (}Zn^{2+}/Zn\text{)} = -0.76\text{ V}$$

When two half-cells are combined in a voltaic cell, the reaction that has a more positive standard reduction potential will occur as reduction, while the reaction that has a less positive (or negative) standard reduction potential will be reversed and will take place as an oxidation. In the electromotive series, hydrogen is taken as the reference electrode and all other electrodes can be measured relative to hydrogen. Students can use the table of standard reduction potentials (Table 1) to determine the difference in potential and thus the standard cell potential of an electrochemical cell containing any two members of the series, just as they can determine the difference in height between any two students in the class if they are all measured relative to a standard.

Students can use experimentally measured cell potentials to calculate the standard reduction potential of one individual half-cell, provided the reduction potential of the other half-cell is known. For example, assuming that the standard reduction potential of zinc is known (–0.76 V), the measured cell potentials of either copper and iron versus zinc may be used to calculate the standard reduction potentials of copper and iron (Equations 3 and 4).

$$Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s) \qquad \textit{Equation 3}$$
$$E^o_{red}\text{ (cathode)} - E^o_{red}\text{ (anode)} = E^o_{cell}$$
$$E^o_{cell}\text{ (measured)} = 0.91\text{ V}$$
$$E^o_{red}\text{ (}Cu^{2+}/Cu\text{)} - {}^-0.76\text{ V} = 0.91\text{ V}$$
$$E^o_{red}\text{ (}Cu^{2+}/Cu\text{)} = 0.15\text{ V}$$

$$Zn(s) + Fe^{2+}(aq) \rightarrow Zn^{2+}(aq) + Fe(s) \qquad \textit{Equation 4}$$
$$E^o_{red}\text{ (cathode)} - E^o_{red}\text{ (anode)} = E^o_{cell}$$
$$E^o_{cell}\text{ (measured)} = 0.32\text{ V}$$
$$E^o_{red}\text{ (}Fe^{2+}/Fe\text{)} - {}^-0.76\text{ V} = 0.32\text{ V}$$
$$E^o_{red}\text{ (}Fe^{2+}/Fe\text{)} = -0.44\text{ V}$$

Standard Reduction Potentials in Aqueous Solutions at 25 °C

Oxidizing Agent				Reducing Agent	Reduction Potential (V)
F_2	+	$2e^-$	→	$2F^-$	2.87
H_2O_2	+	$2H^+ + 2e^-$	→	$2H_2O$	1.78
MnO_4^-	+	$8H^+ + 5e^-$	→	$Mn^{2+} + 4H_2O$	1.51
Au^{3+}	+	$3e^-$	→	Au	1.50
Cl_2	+	$2e^-$	→	$2Cl^-$	1.36
O_2	+	$4H^+ + 4e^-$	→	$2H_2O$	1.23
$Cr_2O_7^{2-}$	+	$14H^+ + 6e^-$	→	$2Cr^{3+} + 7H_2O$	1.23
Br_2	+	$2e^-$	→	$2Br^-$	1.07
NO_3^-	+	$4H^+ + 3e^-$	→	$NO + 2H_2O$	0.96
Ag^+	+	e^-	→	Ag	0.80
I_2	+	$2e^-$	→	$2I^-$	0.54
Cu^+	+	e^-	→	Cu	0.52
O_2	+	$2H_2O + 4e^-$	→	$4OH^-$	0.40
Cu^{2+}	+	$2e^-$	→	Cu	0.34
$2H_3O^+$	+	$2e^-$	→	$H_2 + 2H_2O$	0.00
Pb^{2+}	+	$2e^-$	→	Pb	–0.13
Sn^{2+}	+	$2e^-$	→	Sn	–0.14
Ni^{2+}	+	$2e^-$	→	Ni	–0.26
Fe^{2+}	+	$2e^-$	→	Fe	–0.45
Cr^{3+}	+	$3e^-$	→	Cr	–0.74
Zn^{2+}	+	$2e^-$	→	Zn	–0.76
$2H_2O$	+	$2e^-$	→	$H_2 + 2OH^-$	–0.83
Mn^{2+}	+	$2e^-$	→	Mn	–1.19
Al^{3+}	+	$3e^-$	→	Al	–1.66
Mg^{2+}	+	$2e^-$	→	Mg	–2.37
Na^+	+	e^-	→	Na	–2.71
Ca^{2+}	+	$2e^-$	→	Ca	–2.87
Ba^{2+}	+	$2e^-$	→	Ba	–2.91
K^+	+	e^-	→	K	–2.93
Li^+	+	e^-	→	Li	–3.04

Increasing Strength of Oxidizing Agent

Increasing Strength of Reducing Agent

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation
Content Standards: Grades 9–12
Content Standard A: Science as Inquiry
Content Standard B: Physical Science

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Redox Analogies* activity, presented by Annis Hapkiewicz, is available in *Voltaic Cells*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Redox Analogies* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP7228	Standard Reduction Potential, Notebook Size Chart, Pad of 30

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.