E3 Redox: Transferring electrons

Session one of two
• First hour: Discussion
  (E1)
• 2nd and 3rd hour: Lab
  (E3, Parts 1 and 2A)

Oxidation-Reduction (Redox)

• Reactions involve electron transfer.
• Change in charge (oxidation state) of reactants.

Example: \( 2 \text{Na}_\text{(s)} + \text{Cl}_2\text{(g)} \rightarrow 2\text{NaCl}_\text{(s)} \)

- Loss of electrons (LEO) = oxidation
- Gain of electrons (GER) = reduction

Redox reaction

\[ 2 \text{Na} + \text{Cl}_2 \rightarrow 2\text{NaCl} + \text{energy} \]

**LEO the lion says “GER”**
- Loss of electrons (LEO) = oxidation
- Gain of electrons (GER) = reduction
**REDOX Half Reactions**

<table>
<thead>
<tr>
<th>Oxidation</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>(&gt; in oxidation state)</td>
<td>(&lt; in oxidation state)</td>
</tr>
<tr>
<td>$2 \text{Na} \rightarrow \text{Na}^+ + e^-$</td>
<td>$(\text{Cl}_2 + 2e^- \rightarrow 2\text{Cl}^-)$</td>
</tr>
</tbody>
</table>

*Half reactions always written to show electron GAIN.*
*The final equation reflects the sum of the balanced half reactions so that electrons lost = electrons gained:

$$2 \text{Na} + \text{Cl}_2 \rightarrow 2 \text{Na}^+ + 2 \text{Cl}^-$$

**OXIDIZING AGENT**
Gains electrons and **is reduced** (GER)

**REDUCING AGENT**
Loses electrons and **is oxidized** (LEO)

*An oxidizing agent brings about the oxidation of another substance.*
*A reducing agent brings about the reduction of another substance.*

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**Redox Agents**

Q. Identify the reducing agents (RA) and oxidizing agents (OA) in the reaction:

$$2 \text{Na} + \text{Cl}_2 \rightarrow 2 \text{Na}^+ + 2 \text{Cl}^- + \text{energy}$$

| RA | OA | OA | RA |

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**Oxidation State versus Family Number**

| Metals lose electrons | Non-metals gain electrons |

*Not all elements have official names.*
**Ions with multiple oxidation states**

Q. Sn (Group IVA) has oxidation states of zero, plus two, and plus four. Write half reactions depicting:

**Reduction of Sn^{2+} ion:**
\[ \text{Sn}^{2+} + 2 \text{e}^- \rightarrow \text{Sn} \]

**Oxidation of Sn^{2+} ion:**
\[ \text{Sn}^{2+} \rightarrow \text{Sn}^{3+} + 2 \text{e}^- \]

- Sn^{3+} can act as an oxidizing or reducing agent in redox reactions!
**Strength of Redox Agents**

Example:

\[ 2 \text{Na} + \text{Cl}_2 \rightarrow 2 \text{Na}^+ + 2 \text{Cl}^- \]

- The reactants are the stronger RA and OA and react spontaneously
- The non-reactive products are the weaker OA and RA.

RA: Na > Cl
OA: Cl$^-$ > Na$^+$

**Redox agent strength**

Q. Rank the strength of the reducing/oxidizing agents in the reaction below:

\[ 2 \text{Sb} + 3 \text{Cl}_2 \rightarrow 2 \text{Sb}^{3+} + 6 \text{Cl}^- \]

RA: Sb > Cl$^-$
OA: Cl$_2$ > Sb$^{3+}$

**Reaction and Redox Strength**

If RA: Cu > Ag, OA: Ag$^+$ > Cu$^{2+}$

If RA: Cu > Ag, OA: Ag$^+$ > Cu$^{2+}$

Cu(s) + Ag$^+(aq)$ → ?
Ag(s) + Cu$^{2+}(aq)$ → ?

**Reactions and Redox Strength**

- The stronger RA and OA react:
  
  Cu(s) + Ag$^+(aq)$ → reaction

- The weaker RA and OA do NOT react:
  
  Ag(s) + Cu$^{2+}(aq)$ → no reaction
**Part I B. Predicting Metal Reactivity.**

- Determine the reducing agent (RA) strength of four team-assigned metals where the metal ions of all four metals are available and only three of the four metals are available for experimental tests.

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**Experiment Design and Data Analysis**

**Example**

You need to determine the reducing agent strength of Zn, Cu, and Mg.

**Problem**

Available: Solutions of Zn$^{2+}$, Cu$^{2+}$, and Mg$^{2+}$, Zn and Cu only (i.e., Mg is unavailable)

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**Experiment Design for Part 1B.**

- Create a table for recording data (pre-lab).

<table>
<thead>
<tr>
<th></th>
<th>Zn$^{2+}$</th>
<th>Cu$^{2+}$</th>
<th>Mg$^{2+}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zn</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mg</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Reducing agent species (metals) on one side and oxidizing agents species (metal ions) on other side.

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**Experiment Design and Data Analysis**

- Test available metal and metal ion combinations
- Record observations

**Example:**

Zn(s) + Cu$^{2+}$ (aq) → reaction
Check data. Does it make sense?

<table>
<thead>
<tr>
<th></th>
<th>Zn$^{2+}$</th>
<th>Cu$^{2+}$</th>
<th># rxns.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zn</td>
<td>No</td>
<td>Rxn</td>
<td>1</td>
</tr>
<tr>
<td>Cu</td>
<td>Rxn</td>
<td>No</td>
<td>1</td>
</tr>
</tbody>
</table>

"These results don’t make sense!"

* Only one combination of metal and metal ion should react spontaneously -- the stronger RA and OA!

Data Analysis

<table>
<thead>
<tr>
<th></th>
<th>Zn$^{2+}$</th>
<th>Cu$^{2+}$</th>
<th># rxns.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zn</td>
<td>No</td>
<td>Reaction</td>
<td>1</td>
</tr>
<tr>
<td>Cu</td>
<td>No</td>
<td>No</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

This data makes sense:

* The stronger RA and OA show more reactions!
* RA and OA strength are inverse:

RA: Zn > Cu
OA: Cu$^{2+}$ > Zn$^{2+}$

Reducing Agent Strength of Mg, Zn, and Cu?

Q1. Complete the table below.

<table>
<thead>
<tr>
<th></th>
<th>Zn$^{2+}$</th>
<th>Cu$^{2+}$</th>
<th>Mg$^{2+}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zn</td>
<td>No</td>
<td>Rxn</td>
<td>No</td>
</tr>
<tr>
<td>Cu</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Mg</td>
<td>Rxn</td>
<td>Rxn</td>
<td>No</td>
</tr>
</tbody>
</table>

Q2. Comparative RA strength of the metals?

RA strength: Mg > Zn > Cu

Part I A. Metal reactions with water.

* Rank the reducing agent strength of the metals Na, K, Mg, and Ca from experimental observations.
* Correlate the results with the position of the metal in the periodic table.
Experimental Comparison of Ca and Mg

Metal + Water → metal hydroxide + \( \text{H}_2(g) \)

RA OA OA RA

Example:
\[ \text{Mg}(s) + 2\text{HOH}(l) \rightarrow \text{Mg(OH)}_2(s) + \text{H}_2(g) \]

RA: Ca > Mg

Experimental Comparison of K, Na, Ca, and Mg

Na skitters around the water surface
K skitters around the water surface and ignites

RA: K > Na > Ca > Mg

Reactivity of K and Na

- Experimental determination of the reactivity of K and Na compared to Ca and Mg.

RA and OA Predictions from Electronegativity values

= Electron pulling power of an atom when part of a bond

Electronegativity of the elements

<table>
<thead>
<tr>
<th>I A</th>
<th>I I A</th>
<th>I I B</th>
<th>I V B</th>
<th>I V</th>
<th>I V B</th>
<th>I V A</th>
<th>I I A</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>2.1</td>
<td>Li</td>
<td>1.0</td>
<td>1.5</td>
<td>Na</td>
<td>0.9</td>
<td>Mg</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td>Be</td>
<td>1.5</td>
<td>1.8</td>
<td>Al</td>
<td>1.3</td>
<td>Si</td>
</tr>
<tr>
<td>C</td>
<td>2.5</td>
<td>N</td>
<td>3.0</td>
<td>1.9</td>
<td>P</td>
<td>2.1</td>
<td>S</td>
</tr>
<tr>
<td>O</td>
<td>3.5</td>
<td>F</td>
<td>4.0</td>
<td>1.7</td>
<td>Cl</td>
<td>3.0</td>
<td>Br</td>
</tr>
<tr>
<td>K</td>
<td>0.8</td>
<td>Ca</td>
<td>1.0</td>
<td>1.6</td>
<td>Sc</td>
<td>1.3</td>
<td>Ti</td>
</tr>
<tr>
<td>Cr</td>
<td>1.5</td>
<td>Mn</td>
<td>1.6</td>
<td>1.5</td>
<td>Fe</td>
<td>1.8</td>
<td>Co</td>
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<td>Ni</td>
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<td>Cu</td>
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<td>As</td>
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<td>Se</td>
<td>2.1</td>
<td>Br</td>
</tr>
<tr>
<td>Rb</td>
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<td>Sr</td>
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<td>1.4</td>
<td>Y</td>
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<td>La</td>
</tr>
<tr>
<td>Ce</td>
<td>1.1</td>
<td>Pr</td>
<td>1.5</td>
<td>1.6</td>
<td>Nb</td>
<td>1.7</td>
<td>Ta</td>
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<tr>
<td>W</td>
<td>1.8</td>
<td>Re</td>
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<td>1.6</td>
<td>Mo</td>
<td>1.9</td>
<td>Hf</td>
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<td>Rh</td>
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<td>Pd</td>
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<td>Ag</td>
<td>2.1</td>
<td>W</td>
</tr>
<tr>
<td>Pt</td>
<td>2.2</td>
<td>Au</td>
<td>2.4</td>
<td>1.8</td>
<td>Hg</td>
<td>1.9</td>
<td>Tl</td>
</tr>
<tr>
<td>Pb</td>
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<td>Pb</td>
<td>2.0</td>
<td>Bi</td>
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<tr>
<td>Po</td>
<td>2.2</td>
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<td>2.0</td>
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<td>U</td>
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<td>Np</td>
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<td>U</td>
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<tr>
<td>Np</td>
<td>1.9</td>
<td>Pu</td>
<td>1.9</td>
<td>1.9</td>
<td>Am</td>
<td>1.9</td>
<td>N</td>
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</tbody>
</table>

= Metalloids = Nonmetals = Metals
Q. Predict the RA strength of K compared to Na, Mg, and Ca based on position and electronegativity values.

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<td>1.8</td>
<td>2.1</td>
<td>2.5</td>
<td>3.0</td>
</tr>
</tbody>
</table>

K > Na > Ca > Mg

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Q. Where are the best reducing and oxidizing agents located?

Caution: Attraction of metal or nonmetal ion for electrons in a bond is different from its metal or nonmetal element.

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Questions?
Contact nkerner@umich.edu