Section 9.3: Predicting Redox Reactions

Tutorial 1 Practice, page 621

1. (a) From the equation, the oxidizing agent is $Cu^{2+}(aq)$, since it is reduced.
The reducing agent is Co(aq), since it is oxidized.
The half-reaction equations are:
Reduction: $Cu^{2+}(aq) + 2\ e^- \rightarrow Cu(s) \qquad E°_r = 0.34\ V$
Oxidation: $Co(s) \rightarrow Co^{2+}(aq) + 2\ e^- \qquad E°_r = 0.28\ V$
Since cobalt occurs lower in the redox table, cobalt is the stronger reducing agent.
Therefore, the reaction is spontaneous.
(b) From the equation, the oxidizing agent is $Br_2(l)$, since it is reduced.
The reducing agent is $I^-(aq)$, since it is oxidized.
The half-reaction equations are:
Reduction: $Br_2(l) + 2\ e^- \rightarrow 2\ Br^-(aq) \qquad E°_r = 1.09\ V$
Oxidation: $2\ I^-(aq) \rightarrow I_2(l) + 2\ e^- \qquad E°_r = –0.54\ V$
Since iodine occurs lower in the redox table, iodine is the stronger reducing agent.
Therefore, the reaction is spontaneous.
(c) From the equation, the oxidizing agent is $Zn^{2+}(aq)$, since it is reduced.
The reducing agent is Ni(aq), since it is oxidized.
The half-reaction equations are:
Reduction: $Ni(s) \rightarrow Ni^{2+}(aq) + 2\ e^- \qquad E°_r = 0.23\ V$
Oxidation: $Zn^{2+}(aq) + 2\ e^- \rightarrow Zn(s) \qquad E°_r = –0.76\ V$
Since zinc occurs lower in the redox table, zinc is the stronger reducing agent, not the stronger oxidizing agent.
Therefore, the reaction is not spontaneous.
2. Solution:
Step 1: List all entities in the reaction mixture.
Since hydrochloric acid is a strong acid, it completely ionizes. So the reaction mixture contains Cu(s), $H^+(aq)$, $Cl^-(aq)$, and $H_2O(l)$.
Step 2: Using a redox table to determine the strongest oxidizing agent and the strongest reducing agent.
The only equations relating to chemicals in the reaction mixture as oxidizing agents are
$2\ H^+(aq) + 2\ e^- \rightarrow H_2(g) \qquad E°_r = 0\ V$
$2\ H_2O(l) + 2\ e^- \rightarrow H_2(g) + 2\ OH^-(aq) \qquad E°_r = –0.83\ V$
Since $H^+(aq)$ occurs higher in the table, $H^+(aq)$ is the stronger oxidizing agent.
The only equations relating to chemicals in the reaction mixture as reducing agents are:
$Cu^{2+}(aq) + 2\ e^- \rightarrow Cu(s) \qquad E°_r = 0.34\ V$
$Cl_2(g) + 2\ e^- \rightarrow 2\ Cl^-(aq) \qquad E°_r = 1.36\ V$
$O_2(g) + 4\ H^+(aq) + 4\ e^- \rightarrow 2\ H_2O(l) \qquad E°_r = 1.23\ V$
Since copper occurs lowest in the table, Cu(s) is the strongest reducing agent.
Step 3: Since the relative positions of $H^+(aq)$ and Cu(s) do not form a downward diagonal to the right on the redox table, a reaction will not occur spontaneously.

3. Solution:
Step 1: List all entities in the reaction mixture.
The reaction mixture contains: Ca(s) and $H_2O(l)$.
Step 2: Using a redox table to determine the strongest oxidizing agent and the strongest reducing agent.
The only equation relating to chemicals in the reaction mixture as oxidizing agent is:
$2\ H_2O(l) + 2\ e^- \rightarrow H_2(g) + 2\ OH^-(aq) \quad E°_r = -0.83$ V
Water is the only oxidizing agent.
The only equations relating to chemicals in the reaction mixture as reducing agents are:
$Ca^{2+}(aq) + 2\ e^- \rightarrow Ca(s) \quad E°_r = -2.76$ V
$O_2(g) + 4\ H^+(aq) + 4\ e^- \rightarrow 2\ H_2O(l) \quad E°_r = 1.23$ V
Since calcium occurs lower on the table, Ca(s) is the strong reducing agent.
Step 3: Since the relative positions of $H_2O(l)$ and Ca(s) form a downward diagonal to the right on the redox table, a reaction will occur spontaneously.
Statement: A redox reaction occurs when solid calcium is placed into water.
The half-reactions that occur are:
Reduction: $2\ H_2O(l) + 2\ e^- \rightarrow H_2(g) + 2\ OH^-(aq)$
Oxidation: $Ca(s) \rightarrow Ca^{2+}(aq) + 2\ e^-$
Ca(s) is a reducing agent so it is oxidized.
The balanced equation for the reaction is:
$Ca(s) + 2\ H_2O(l) \rightarrow Ca(OH)_2(aq) + H_2(g)$
4. Solution:
Step 1: List all entities in the reaction mixture.
The reaction mixture contains: $K^+(aq)$, $MnO_4^-(aq)$, $Cr^{2+}(aq)$, $SO_4^{2-}(aq)$, $H^+(aq)$, and $H_2O(l)$.
Step 2: Using a redox table to determine the strongest oxidizing agent and the strongest reducing agent.
The equations relating to chemicals in the reaction mixture as oxidizing agents are:
$K^+(aq) + e^- \rightarrow K(s) \quad E°_r = -2.92$ V
$MnO_4^-(aq) + e^- \rightarrow MnO_4^{2-}$ aq) $\quad E°_r = 0.56$ V
$MnO_4^-(aq) + 4\ H^+(aq) + 3\ e^- \rightarrow MnO_2(s) + 2\ H_2O(l) \quad E°_r = 1.68$ V
$MnO_4^-(aq) + 8\ H^+(aq) + 5\ e^- \rightarrow Mn^{2+}(aq) + 4\ H_2O(l) \quad E°_r = 1.51$ V
$Cr^{2+}(aq) + 2\ e^- \rightarrow Cr(s) \quad E°_r = -0.91$ V
$SO_4^{2-}(aq) + 4\ H^+(aq) + 2\ e^- \rightarrow H_2SO_3(aq) + H_2O(l) \quad E°_r = 0.20$ V
$2\ H^+(aq) + 2\ e^- \rightarrow H_2(g) \quad E°_r = 0$ V
$2\ H_2O(l) + 2\ e^- \rightarrow H_2(g) + 2\ OH^-(aq) \quad E°_r = -0.83$ V
Since $MnO_4^-(aq) + 4\ H^+(aq)$ occurs highest in the table, $MnO_4^-(aq) + 4\ H^+(aq)$ is the strongest oxidizing agent.
The only equations relating to chemicals in the reaction mixture as reducing agents are:
$Cr^{3+}(aq) + e^- \rightarrow Cr^{2+}(s) \quad E°_r = -0.50$ V
$O_2(g) + 4\ H^+(aq) + 4\ e^- \rightarrow 2\ H_2O(l) \quad E°_r = 1.23$ V
Since $Cr^{2+}(s)$ occurs lower on the table, $Cr^{2+}(s)$ is the stronger reducing agent.

Step 3: Since the relative positions of $MnO_4^-(aq) + 4\ H^+(aq)$ and $Cr^{2+}(s)$ form a downward diagonal to the right on the redox table, a reaction will occur spontaneously.
Statement: A redox reaction occurs with $MnO_4^-(aq) + 4\ H^+(aq)$ as the oxidizing agent and $Cr^{2+}(s)$ as the reducing agent.
The half-reactions that occur are:
Reduction: $MnO_4^-(aq) + 4\ H^+(aq) + 3\ e^- \rightarrow MnO_2(s) + 2\ H_2O(l)$
Oxidation: $Cr^{2+}(s) \rightarrow Cr^{3+}(aq) + e^-$
The balanced equation for the reaction is:
$MnO_4^-(aq) + 4\ H^+(aq) + 3\ Cr^{2+}(aq) \rightarrow MnO_2(s) + 3\ Cr^{3+}(aq) + 2\ H_2O(l)$

Research This: Which Bleach is Best?, page 622

1. Answers may vary. Sample answer: Mixing bleach with an acid cleaner will produce chlorine gas, which is a respiratory irritant, and is carcinogenic. When mixed with a basic cleaner containing ammonia, chloroamines and hydrazine can be made, both of which are toxic gases.
2. Answers may vary. Sample answer: Chlorine bleach can be used to remove stains on laundry, disinfect smooth surfaces, clean mold and mildew, kill weeds in walkways and driveways, and sterilize drinking water in emergencies.
3. Hydrogen peroxide is a safer bleaching agent than chlorine, since it decomposes to water and oxygen gas. It can be used as a sanitizer, although it is not as effective as chlorine at killing some viruses and bacteria. Hydrogen peroxide is also a good whitening agent that many industries, such as paper making, are using to replace chlorine bleach.
A. Answers may vary. Sample answer:

Chlorine	Cons	Pros
Safety concerns	• Produces toxic gases and other harmful products if mixed with acids or bases. • Releases chlorine gas • Damages skin and lungs • Must be used in a vented area	
Storage times		• Stable for long periods of time
Colour removal	• Removes colour from many materials	• Slightly better stain remover in general, although may react with some substances to produce a stain
Odour	• Strong chlorine odour	
Cost, availability		• Less expensive • Readily available

Hydrogen Peroxide	Cons	Pros
Safety concerns	• Very concentrated solutions can cause chemical burns	• Decomposes to water and oxygen gas
Storage times	• Should be stored out of sunlight and in a cool environment	• Breaks down fairly quickly
Colour removal	• Slow to work on mildew stains	• Removes many stains very well • Does not in general remove colour from materials
Odour		• Faint odour
Cost, availability	• More expensive	• Dilute form readily available

B. Answers may vary. Sample answer: When approving a product for use in the workplace, besides safety, you need to consider the effectiveness of the chemical, its cost, the environmental impact of the substance, and the cost to dispose of the by-products produced by the substance.

C. Answers may vary. Sample answer: Chlorine bleach is best used to kill mold and mildew quickly. It is also best for removing stains from white fabrics to whiten materials provided it does not react with the material. Hydrogen peroxide is best used for disinfection of cuts and sores on human and animal skin because it is not corrosive like bleach. As a general household cleaner, hydrogen peroxide is better than bleach because it does not produce noxious fumes and can be readily broken down into water and oxygen. It also can be stored more safely than bleach and is more stable than bleach.

Section 9.3 Questions, page 623

1. From a redox table, the order of the oxidizing agents from strongest to weakest is as follows: $Au^{3+}(aq) > Hg^{2+}(aq) > Cu^{2+}(aq) > Sn^{2+}(aq)$

2. Answer may vary. Sample answer: The half reaction that represents the formation of solid chromium metal, Cr(s), from chromium ions, $Cr^{2+}(aq)$, is:

$Cr^{2+}(aq) + 2\ e^{-} \rightarrow Cr(s)$

In this reaction, $Cr^{2+}(aq)$, is a reducing agent that is oxidized. So, any substance that is an oxidizing agent above $Cr^{2+}(s)$ on the redox table will react spontaneously. For example, fluorine gas, $F_2(g)$, will react spontaneously with $Cr^{2+}(aq)$ to produce Cr(s) and fluoride ions, $F^{-}(aq)$.

$Cr^{2+}(aq) + F_2(g) \rightarrow Cr(s) + 2\ F^{-}(aq)$

3. Equations (a) and (b) are spontaneous.

(a) From the reaction equation $Cu(s) + Br_2(l) \rightarrow Cu^{2+}(aq) + 2\ Br^{-}(aq)$, $Br_2(l)$ is the oxidizing agent and Cu(s) is the reducing agent. Since the relative positions of $Br_2(l)$ and Cu(s) form a downward diagonal to the right on the redox table, the reaction will occur spontaneously.

(b) From the reaction equation $2\ Al(s) + 3\ Pb^{2+}(aq) \rightarrow 2\ Al^{3+}(aq) + 3\ Pb(s)$, $Pb^{2+}(aq)$ is the oxidizing agent and Al(s) is the reducing agent. Since the relative positions of $Pb^{2+}(aq)$ and Al(s) form a downward diagonal to the right on the redox table, the reaction will occur spontaneously.

(c) From the reaction equation $Na^+(aq) + Cr^{2+}(aq) \rightarrow Cr^{3+}(aq) + 3\ Na(s)$, $Na^+(aq)$ is the oxidizing agent and $Cr^{2+}(aq)$ is the reducing agent. Since the relative positions of $Na^+(aq)$ and $Cr^{2+}(aq)$ do not form a downward diagonal to the right on the redox table, the reaction will not occur spontaneously.

4. (a) The chemical equation for the reaction that represents the reaction is:

$Fe(s) + Cu^{2+}(aq) \rightarrow Fe^{2+}(aq) + Cu(s)$

(b) From the reaction equation, $Cu^{2+}(aq)$ is the oxidizing agent and Fe(s) is the reducing agent. Since the relative positions of $Cu^{2+}(aq)$ and Fe(s) form a downward diagonal to the right on the redox table, the reaction will occur spontaneously.

5. (a) The reaction mixture contains $K^+(aq)$, $MnO_4^-(aq)$, $Fe^{2+}(aq)$, $SO_4^{2-}(aq)$, $H^+(aq)$, and $H_2O(l)$. They are all possible oxidizing agents.

The equations relating to chemicals in the reaction mixture as oxidizing agents are:

$K^+(aq) + e^- \rightarrow K(s) \quad E^\circ_r = -2.92\ V$

$MnO_4^-(aq) + e^- \rightarrow MnO_4^{2-}\ aq) \quad E^\circ_r = 0.56\ V$

$MnO_4^-(aq) + 4\ H^+(aq) + 3\ e^- \rightarrow MnO_2(s) + 2\ H_2O(l) \quad E^\circ_r = 1.68\ V$

$MnO_4^-(aq) + 8\ H^+(aq) + 5\ e^- \rightarrow Mn^{2+}(aq) + 4\ H_2O(l) \quad E^\circ_r = 1.51\ V$

$Fe^{2+}(aq) + 2\ e^- \rightarrow Fe(s) \quad E^\circ_r = -0.44\ V$

$SO_4^{2-}(aq) + 4\ H^+(aq) + 2\ e^- \rightarrow H_2SO_3(aq) + H_2O(l) \quad E^\circ_r = 0.20\ V$

$2\ H^+(aq) + 2\ e^- \rightarrow H_2(g) \quad E^\circ_r = 0\ V$

$2\ H_2O(l) + 2\ e^- \rightarrow H_2(g) + 2\ OH^-(aq) \quad E^\circ_r = -0.83\ V$

Since $MnO_4^-(aq)$ occurs highest in the table, $MnO_4^-(aq)$ is the strongest oxidizing agent.

(b) The possible reducing agents are $Fe^{2+}(aq)$ and $H_2O(l)$.

The equations relating to chemicals in the reaction mixture as reducing agents are:

$Fe^{3+}(aq) + e^- \rightarrow Fe^{2+}(aq) \quad E^\circ_r = -0.77\ V$

$O_2(g) + 4\ H^+(aq) + 4\ e^- \rightarrow 2\ H_2O(l) \quad E^\circ_r = 1.23\ V$

Since $Fe^{2+}(aq)$ occurs lower in the table, $Fe^{2+}(aq)$ is the stronger reducing agent.

6. (a) The two half-reaction equations for the reaction of nitric acid and gold forming a solution of $Au^{+3}(aq)$ are:

Reduction: $Au(s) \rightarrow Au^{+3}(aq) + 3\ e^-$

Oxidation: $NO_3^-(aq) + 4\ H^+(aq) + 3\ e^- \rightarrow NO(g) + H_2O(l)$

(b) From the half-reaction equations, $NO_3^-(aq)$ is the oxidizing agent and Au(s) is the reducing agent. Since the relative positions of $NO_3^-(aq)$ and Au(s) do not form a downward diagonal to the right on the redox table, the reaction will not occur spontaneously. Therefore, the nitric acid will not damage the ring.

7. (a) In spontaneous reactions of the metals and metal ions, the metal ion is the oxidizing agent and the metal is the reducing agent.

Since the relative positions of $Cu^+(aq)$ and Au(s) do not form a downward diagonal to the right on the redox table, the reaction will not occur spontaneously.

Since the relative positions of $Cu^+(aq)$ and Zn(s) form a downward diagonal to the right on the redox table, the reaction will occur spontaneously.

Since the relative positions of $Cu^+(aq)$ and Co(s) form a downward diagonal to the right on the redox table, the reaction will occur spontaneously.

Since the relative positions of $Au^{3+}(aq)$ and Cu(s) form a downward diagonal to the right on the redox table, the reaction will occur spontaneously.
Since the relative positions of $Au^{3+}(aq)$ and Zn(s) form a downward diagonal to the right on the redox table, the reaction will occur spontaneously.
Since the relative positions of $Au^{3+}(aq)$ and Co(s) form a downward diagonal to the right on the redox table, the reaction will occur spontaneously.
Since the relative positions of $Zn^{2+}(aq)$ and Cu(s) do not form a downward diagonal to the right on the redox table, the reaction will not occur spontaneously.
Since the relative positions of $Zn^{2+}(aq)$ and Au(s) do not form a downward diagonal to the right on the redox table, the reaction will not occur spontaneously.
Since the relative positions of $Zn^{2+}(aq)$ and Co(s) do not form a downward diagonal to the right on the redox table, the reaction will not occur spontaneously.
Since the relative positions of $Co^{2+}(aq)$ and Cu(s) do not form a downward diagonal to the right on the redox table, the reaction will not occur spontaneously.
Since the relative positions of $Co^{2+}(aq)$ and Au(s) do not form a downward diagonal to the right on the redox table, the reaction will not occur spontaneously.
Since the relative positions of $Co^{2+}(aq)$ and Zn(s) form a downward diagonal to the right on the redox table, the reaction will occur spontaneously.
Therefore, the following combination of metals and metal ions will react spontaneously.
$Cu^{+}(aq)$ and Zn(s); $Cu^{+}(aq)$ and Co(s); $Au^{3+}(aq)$ and Cu(s); $Au^{3+}(aq)$ and Zn(s); $Au^{3+}(aq)$ and Co(s); $Co^{2+}(aq)$ and Zn(s)
(b) Since $Au^{3+}(aq)$ occurs highest in the redox table, $Au^{3+}(aq)$ is the strongest oxidizing agent. Since Zn(s) occurs lowest in the table, Zn(s) is the strongest reducing agent.
8. (a) In spontaneous reactions of the metals and metal ions, the metal ion is the oxidizing agent and the metal is the reducing agent. Since $Cu^{2+}(aq)$ reacts with all other metals, it is the strongest oxidizing agent. Since $Ba^{2+}(aq)$ does not react with any of the metals, it is the weakest oxidizing agent. Therefore, the order of the metal ions as oxidizing agents from strongest to weakest is $Cu^{2+}(aq) > Pb^{2+}(aq) > Fe^{2+}(aq) > Ba^{2+}(aq)$.
(b) The balanced equation for the redox reaction of copper(II) ions with solid lead is
$Cu^{2+}(aq) + Pb(s) \rightarrow Pb^{2+}(aq) + Cu(s)$
(c) Since $Ba^{2+}(aq)$ is the weakest oxidizing agent, Ba(s) would be the strongest reducing agent.
(d) Since gold is a weaker reducing agent than copper, it will be a weaker reducing agent than all the other metals. Therefore, it will not react with each of the other metal ions in Table 4.
9. (a) Copper and hydrochloric acid:
The entities in the container are Cu(s), $H^{+}(aq)$, $Cl^{-}(aq)$, and $H_2O(l)$.
The equations relating to chemicals in the reaction mixture as oxidizing agents are:
$2\ H^{+}(aq) + 2\ e^{-} \rightarrow H_2(g) \quad E°_r = 0\ V$
$2\ H_2O(l) + 2\ e^{-} \rightarrow H_2(g) + 2\ OH^{-}(aq) \quad E°_r = -0.83\ V$
Since $H^{+}(aq)$ occurs higher in the table, $H^{+}(aq)$ is the stronger oxidizing agent.
The equations relating to chemicals in the reaction mixture as reducing agents are:
$Cu^{2+}(aq) + 2\ e^{-} \rightarrow Cu(s) \quad E°_r = 0.34\ V$
$Cl_2(g) + 2\ e^{-} \rightarrow 2\ Cl^{-}(aq) \quad E°_r = 1.36\ V$
$O_2(g) + 4\ H^{+}(aq) + 4\ e^{-} \rightarrow 2\ H_2O(l) \quad E°_r = 1.23\ V$

Since copper occurs lowest in the table, Cu(s) is the strongest reducing agent.
Since the relative positions of $H^+(aq)$ and Cu(s) do not form a downward diagonal to the right on the redox table, there is no spontaneous reaction between copper and hydrochloric acid.
Copper and nitric acid:
The entities in the container are Cu(s), $H^+(aq)$, $NO_3^-(aq)$, and $H_2O(l)$.
The equations relating to chemicals in the reaction mixture as oxidizing agents are:
$NO_3^-(aq) + 4\ H^+(aq) + 3\ e^- \rightarrow NO(g) + 2\ H_2O(l) \qquad E^\circ_r = 0.96\ V$
$2\ H^+(aq) + 2\ e^- \rightarrow H_2(g) \qquad E^\circ_r = 0\ V$
$2\ H_2O(l) + 2\ e^- \rightarrow H_2(g) + 2\ OH^-(aq) \qquad E^\circ_r = -0.83\ V$
Since $NO_3^-(aq)$ occurs highest in the table, $NO_3^-(aq)$ is the strongest oxidizing agent.
The equations relating to chemicals in the reaction mixture as reducing agents are:
$Cu^{2+}(aq) + 2\ e^- \rightarrow Cu(s) \qquad E^\circ_r = 0.34\ V$
$O_2(g) + 4\ H^+(aq) + 4\ e^- \rightarrow 2\ H_2O(l) \qquad E^\circ_r = 1.23\ V$
Since copper occurs lower in the table, Cu(s) is the stronger reducing agent.
Since the relative positions of $NO_3^-(aq)$ and Cu(s) form a downward diagonal to the right on the redox table, there is a spontaneous reaction between copper and nitric acid.
(b) The copper will react at different rates in different concentrations of nitric acid. Copper reacts faster in the nitric acid with the higher concentration, so more bubbles of the gaseous product are observed.