Using Half-Reactions to Balance Redox Reactions

- **Half-reactions** are equations that describe the changes in only the compound that is oxidized *or* only the compound that is reduced
  - Half-reactions are still balanced reactions (both *atoms* and *charges*), but also show the loss or gain of electrons
  - An ionic or net ionic equation should never show the electron loss or gain.
- Consider the reaction of zinc with copper(II) sulphate

Reaction:

oxidation #'s: $Zn_{(s)}^{0} + CuSO_{4(aq)}^{+2\ +6\ -2} \longrightarrow ZnSO_{4(aq)}^{+2\ +6\ -2} + Cu_{(s)}^{0}$

Ionic Reaction:

$$Zn_{(s)} + Cu^{2+}_{(aq)} + SO_4^{2-}{}_{(aq)} \longrightarrow Zn^{2+}_{(aq)} + SO_4^{2-}{}_{(aq)} + Cu_{(s)}$$

Net Ionic Reaction:

oxidation #'s: $\overset{0}{Zn_{(s)}} + \overset{+2}{Cu^{2+}_{(aq)}} \longrightarrow \overset{+2}{Zn^{2+}_{(aq)}} + \overset{0}{Cu_{(s)}}$

reduced / OA — gained $2e^-$

∴ oxidized / RA — lost $2e^-$

Oxidation Half-Reaction:

$$Zn_{(s)} \longrightarrow Zn^{2+}_{(aq)} + 2e^-$$

* both atoms & charges are balanced *

Zinc atoms (Zn) are converted into zinc ions (Zn^{2+}) by losing two electrons

Reduction Half- Reaction:

$$Cu^{2+}_{(aq)} + 2e^- \longrightarrow Cu_{(s)}$$

Copper(II) ions (Cu^{+2}) are converted into copper atoms (Cu) by gaining 2 electrons.

***** Now pg. 442 #9-11*****

- Most redox reactions that we have seen so far can be balanced just by inspection (ie. our usual way of balancing any chemical reaction)
    - However, some reactions are more difficult to balance and we need a method/procedure for balancing redox reactions
    - A common technique is to use *half-reactions*

Balancing Redox Equations That Occur in Acidic

- Some redox reactions take place in acidic conditions and the hydrogen ions ($H^+_{(aq)}$) must be account for in the balanced redox reaction
    - Several steps are needed just to balance the half-reactions for acidic conditions (outlined in the first box)
    - Once the two half-reactions are balanced, it is necessary to balance the entire redox reaction (outlined as review in second box)

Balancing Half-Reactions Occurring in Acidic Solutions

Step 1 Write the unbalanced half-reactions showing the reactants and products.

Step2 Balance any atoms other than oxygen and hydrogen atoms first.

Step 3 Balance any oxygen atoms by adding water molecules.

Step 4 Balance any hydrogen atoms by adding hydrogen ions.

Step 5 Balance the charges by adding electrons.

Balancing Equations Using Half-Reactions

Step 1 Multiply one or both half-reactions by a number that will allow each half-reaction to have the same number of electrons. Lowest common multiple is best.

Step 2 Add the balanced half-reactions together.

Step 3 Cancel out electrons and any other atoms/molecules that are the same on opposite sides of the reaction.

Step 4 If spectator ions were removed, add them back to the equation.

easier to keep them in

EXAMPLES

1. The unbalanced equation for the reaction between permanganate ions, $MnO_4^-{}_{(aq)}$, and oxalate ions, $C_2O_4^{2-}{}_{(aq)}$, in acidic conditions is shown below. Use half-reaction method to balance the equation.

$$MnO_4^-{}_{(aq)} + C_2O_4^{2-}{}_{(aq)} \longrightarrow Mn^{2+}{}_{(aq)} + CO_{2(g)}$$

+7 -2 +3 -2 +2 +4 -2

gained e^- | lost e^-

$5e^- + 8H^+ + MnO_4^- \longrightarrow Mn^{2+} + 4H_2O$ reduction half-rxn

$C_2O_4^{2-} \longrightarrow 2CO_2 + 2e^-$ oxidation half-rxn

$5e^- + 8H^+ + 2MnO_4^- \longrightarrow 2Mn^{2+} + 4H_2O$ x 2

$5C_2O_4^{2-} \longrightarrow 10CO_2 + 2e^-$ x 5

$16H^+ + 2MnO_4^- + 5C_2O_4^{2-} \rightarrow 10CO_2 + 2Mn^{2+} + 8H_2O$

total charge: +4 total charge: +4

charge & atoms are balanced.

acidic conditions

2. Sulphur is oxidized by nitric acid in an aqueous solution, producing sulphur dioxide, nitrogen monoxide, and water as shown by the unbalanced equation. Use half-reaction method to balance the equation:

$$S_{8(s)} + HNO_{3(aq)} \longrightarrow SO_{2(g)} + NO_{(g)} + H_2O_{(l)}$$

(0 → +4: lost e⁻; +5 → +2: gain e⁻)

$16H_2O + S_8 \longrightarrow 8SO_2 + 32H^+ + 32e^-$ oxidation

$3e^- + 3H^+ + HNO_3 \longrightarrow NO + 2H_2O$ reduction

$48\ 16H_2O + 3S_8 \longrightarrow 24\ 8SO_2 + 96\ 32H^+ + 96\ 32e^-$ × 3

$3e^- + 3H^+ + 32HNO_3 \longrightarrow 32NO + 2H_2O$ × 32

(96 e⁻ ; 96 H⁺ ; 64 H₂O)

$$32HNO_3 + 3S_8 \longrightarrow 24SO_2 + 32NO + 16H_2O$$

total charge: 0 total charge: 0

charge : atoms balanced

Now try pg. 448 #1 & pg. 454 #1(a-c), 2(a, b)

Typo pg. 454 #2a: Should be Co^{2+}, not Co^{3+}

PRACTICE PROBLEMS

1.) Balance the following redox reactions using the half reaction method.

a) $ClO_3^-(aq) + I_2(s) \rightarrow IO_3^-(aq) + Cl^-(aq)$ (acidic)

b) $Cu(s) + SO_4^{2-}(aq) \rightarrow Cu^{2+}(aq) + SO_2(g)$ (acidic)

c) $C_2H_4(g) + MnO_4^-(aq) \rightarrow CO_2(g) + Mn^{2+}(aq)$ (acidic)

2.) Balance the following redox reactions:

a) $P_4(s) + NO_3^-(aq) \rightarrow H_3PO_4(aq) + NO(g)$ (acidic)

b) $MnO_2(s) + NO_2^-(aq) \rightarrow NO_3^-(aq) + Mn^{2+}(aq)$ (acidic)

c) $Br_2(\ell) + SO_2(g) \rightarrow Br^-(aq) + SO_4^{2-}(aq)$ (acidic)

d) $PbO_2(s) + Cl^-(aq) \rightarrow PbCl_2(aq) + Cl_2(g)$ (acidic)

Solutions

1) **a)** $5ClO_3^-(aq) + 3I_2(s) + 3H_2O(\ell) \rightarrow 6IO_3^-(aq) + 5Cl^-(aq) + 6H^+(aq)$

b) $Cu(s) + SO_4^{2-}(aq) + 4H^+(aq) \rightarrow Cu^{2+}(aq) + SO_2(g) + 2H_2O(\ell)$

c) $5C_2H_4(g) + 12MnO_4^-(aq) + 36H^+(aq) \rightarrow 10CO_2(g) + 12Mn^{2+}(aq) + 28H_2O(\ell)$

2.) **a)** $3P_4(s) + 20NO_3^-(aq) + 20H^+(aq) + 8H_2O(\ell) \rightarrow 12H_3PO_4(aq) + 20NO(g)$

b) $MnO_2(s) + NO_2^-(aq) + 2H^+(aq) \rightarrow NO_3^-(aq) + Mn^{2+}(aq) + H_2O(\ell)$

c) $Br_2(\ell) + SO_2(g) + 2H_2O(\ell) \rightarrow 2Br^-(aq) + SO_4^{2-}(aq) + 4H^+(aq)$

d) $PbO_2(s) + 4Cl^-(aq) + 4H^+(aq) \rightarrow PbCl_2(aq) + Cl_2(g) + 2H_2O(\ell)$

Section 12.2 Review Answers

Student Textbook page 454

1. (a) $Cr_2O_7^{2-} + 14H^+(aq) + 6e^- \rightarrow 2Cr^{3+}(aq) + 7H_2O(\ell)$; reduction half-reaction

(b) $2S_2O_3^{2-}(aq) \rightarrow S_4O_6^{2-}(aq) + 2e^-$; oxidation half-reaction

(c) Arsenic is reduced, so this is a reduction half-reaction. First balance the atoms other than oxygen and hydrogen.

$4AsO_4(aq) \rightarrow As_4O_6(aq)$

Add water to balance the oxygen atoms.

$4AsO_4^{3-}(aq) \rightarrow As_4O_6(aq) + 10H_2O(\ell)$

Add hydrogen ions (acidic solution) to balance the hydrogen atoms.

$4AsO_4^{3-}(aq) + 20H^+(aq) \rightarrow As_4O_6(aq) + 10H_2O(\ell)$

Add electrons to balance the charges on both sides.

$4AsO_4^{3-}(aq) + 20H^+(aq) + 8e^- \rightarrow As_4O_6(aq) + 10H_2O(\ell)$

(d) Bromine is oxidized, so this is an oxidation half-reaction. First balance the atoms other than oxygen and hydrogen.

$Br_2(\ell) \rightarrow 2BrO_3^-(aq)$

Add water to balance the oxygen atoms.

$Br_2(\ell) + 6H_2O(\ell) \rightarrow 2BrO_3^-(aq)$

Add hydrogen ions (acidic solution) to balance the hydrogen atoms.

$Br_2(\ell) + 6H_2O(\ell) \rightarrow 2BrO_3^-(aq) + 12H^+(aq)$

Adjust for basic conditions by adding hydroxide ions to both sides.

$Br_2(\ell) + 6H_2O(\ell) + 12OH^-(aq) \rightarrow 2BrO_3^-(aq) + 12H^+(aq) + 12OH^-(aq)$

Combine hydrogen and hydroxide ions and cancel any water found on both sides of the equation.

$Br_2(\ell) + 12OH^-(aq) \rightarrow 2BrO_3^-(aq) + 6H_2O(\ell)$

Add electrons to balance the charges on both sides.

$Br_2(\ell) + 12OH^-(aq) \rightarrow 2BrO_3^-(aq) + 6H_2O(\ell) + 10e^-$

2. (a) Balance this equation by balancing charge:

$3Co^{2+}(aq) + 2\,Au(s) \rightarrow 3Co(s) + 2Au^{3+}(aq)$

(b) Under acidic conditions, the balanced half-reactions are:

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

$NO_3^-(aq) + 3e^- + 4H^+(aq) \rightarrow NO(g) + 2H_2O(\ell)$

Write half-reactions with the LCM.

$3Cu(s) \rightarrow 3Cu^{2+}(aq) + 6e^-$

$2NO_3^-(aq) + 6e^- + 8H^+(aq) \rightarrow 2NO(g) + 4H_2O(\ell)$

Add half-reactions, remove electrons and chemical species present on both sides:

$3Cu(s) + 2NO_3^-(aq) + 8H^+(aq) \rightarrow 3Cu^{2+}(aq) + 2NO(g) + 4H_2O(\ell)$

(c) Under basic conditions, the balanced half-reactions are:

$Al(s) + 4OH^-(aq) \rightarrow AlO_2^-(aq) + 2H_2O(\ell) + 3e^-$

$NO_3^-(aq) + 6H_2O(\ell) + 8e^- \rightarrow NH_3(g) + 9OH^-(aq)$

Write half-reactions with the LCM.

$8Al(s) + 32OH^-(aq) \rightarrow 8AlO_2^-(aq) + 24e^- + 16H_2O(\ell)$

$3NO_3^-(aq) + 24e^- + 18H_2O(\ell) \rightarrow 3NH_3(g) + 27OH^-(aq)$

Add half-reactions, remove electrons and chemical species present on both sides:

$8Al(s) + 5OH^-(aq) + 3NO_3^-(aq) + 2H_2O(\ell) \rightarrow 8AlO_2^-(aq) + 3NH_3(g)$

Answers to Questions for Comprehension

Student Textbook page 442

Q9. The balanced half-reactions are as follows:

Oxidation: $Al(s) \rightarrow Al^{3+}(aq) + 3e^-$

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

Q10. The balanced half-reactions are as follows:

(a) Oxidation: $Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-$

Reduction: $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$

(b) Oxidation: $Cd(s) \rightarrow Cd^{2+}(aq) + 2e^-$

Reduction: $Ag^+(aq) + e^- \rightarrow Ag(s)$

Q11. The balanced half-reactions are as follows:

(a) Oxidation: $Sn(s) \rightarrow Sn^{2+}(aq) + 2e^-$

Reduction: $Pb^{2+}(aq) + 2e^- \rightarrow Pb(s)$

(b) Oxidation: $Ag(s) \rightarrow Ag^+(aq) + e^-$

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

(c) Oxidation: $Zn(s) \rightarrow Zn^{2+} + 2e^-$

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

Answers to Practice Problems 1–2

Student Textbook page 448

For full solutions to the practice problems, visit **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, Full Solutions.

1. (a) $5Ag(s) + MnO_4^-(aq) + 8H^+(aq) \rightarrow 5Ag^+(aq) + Mn^{2+}(aq) + 4H_2O(\ell)$

(b) $Hg(\ell) + 4Cl^-(aq) + 2NO_3^-(aq) + 4H^+(aq) \rightarrow HgCl_4^{2-}N(s) + 2NO_2(g) + 2H_2O(\ell)$

(c) $AsH_3(g) + 4H_20(\ell) + 4Zn^{2+}(aq) \rightarrow H_3AsO_4(aq) + 8H^+(aq) + 4Zn(s)$

(d) $I_2(s) + H_2O(\ell) + 5OCl^-(aq) \rightarrow 2IO_3^-(aq) + 2H^+(aq) + 5Cl^-(aq)$

2. (a) $I^-(aq) + 6OH^-(aq) + 6MnO_4\_(aq) \rightarrow 6MnO_4^{2-}(aq) + IO^{3-}(aq) + 3H_2O(\ell)$

(b) $3H_2O_2(aq) + 2OH^-(aq) + 2ClO_2(aq) \rightarrow 2ClO^- + 3O_2(g) + 4H_2O(\ell)$

(c) $2CrO_2^-(aq) + 6ClO^-(aq) + 2H_2O(\ell) \rightarrow 3Cl_2(g) + 4OH^-(aq) + 2CrO_4^{2-}(aq)$

(d) $4Al(s) + OH^-(aq) + 3NO^-(Aq) + 4H_2O(\ell) \rightarrow 3NH_3(g) + 4AlO_2^-(aq)$