Objective 7. Single replacement reactions: balancing, apply Activity Series, write net ionic equations to predict whether a reaction occurs, perform mole-mass and mole ratio calculations

Quiz Practice problems:

Key ideas:

In a single replacement reaction, an element reacts with an ionic compound or acid to form a new element and new ionic compound. The element in the reactant becomes an ion and replaces an ion in the ionic compound; the ion that is replaced becomes an element.

A + BC ---> B + AC

A single replacement reaction is also an oxidation-reduction reaction.

If Element A is a metal,

- Metal A loses electrons (it is oxidized) to become a cation (charge or oxidation number increases).
- Ion B gains electrons (it is reduced) to become an element (charge or oxidation number decreases).
- Metal A, which is oxidized, is also called a reducing agent because it is reducing another substance.
- Ion B, which is reduced, is also called an oxidizing agent because it is oxidizing another substance.

If Element A is a non-metal,

- Non-metal A gains electrons (it is reduced) to become an anion (charge or oxidation number decreases).
- Ion C loses electrons (it is oxidized) to become an element (charge or oxidation number increases).
- Non-metal A, which is reduced, is also called an oxidizing agent because it is oxidizing another substance.
- Ion C, which is oxidized, is also called a reducing agent because it is reducing another substance.

Oxidation-reduction reactions are like acid-base reactions, except electrons are transferred instead of H^+.

Skills: Use Table of common monoatomic and polyatomic ions.
Given reactants, predict the product (write chemical formulas) of products.
Balance single replacement reactions.
Use Activity Series – identify more active metal, determine whether a reaction occurs.
Write a net ionic equation to predict whether a reaction occurs.
Perform chemical calculations involving an acid-base reaction.

1. a. Determine the oxidation number of each element in the following substances: $CuSO_4$, $NiCl_2$, $FeSO_4$, $Al(NO_3)_3$, $SnCl_2$, $AgNO_3$, HCl, Cu, Zn, Al.
b. Heavy metals are considered toxic and hazardous. What makes a metal "heavy"?
c. Does an oxidizing agent give or take electrons? Does a reducing agent give or take electrons?

Answers:
a. $CuSO_4$. Ionic compound so Cu = +2, SO_4^{-2} ion so S = +6, O = -2
$NiCl_2$. Ionic compound so Ni = +2, Cl = -1
$FeSO_4$. Ionic compound so Fe = +2, SO_4^{-2} ion so S = +6, O = -2
$Al(NO_3)_3$. Ionic compound so Al = +3, NO_3^- ion so N = +5, O = -2
$SnCl_2$. Ionic compound so Sn = +2, Cl = -1
$AgNO_3$. Ionic compound so Ag = +1, NO_3^- ion so N = +5, O = -2
HCl. H^+ and Cl^-.
Cu = 0. Elements are neutral.
Zn = 0. Elements are neutral.
Al = 0. Elements are neutral.

2. You can gold plate a piece of iron by placing the iron in a gold ion solution.

$Fe (s) + AuCl_3 (aq) \rightarrow Au (s) + FeCl_3 (aq)$

a. What is being oxidized? Fe because it loses electrons (Fe^0 ---> Fe^{3+}). Fe is the reducing agent.
b. Write an ionic equation: $Fe (s) + Au^{3+} (aq) + 3\ Cl^- (aq) \rightarrow Au (s) + Fe^{3+} (aq) + 3\ Cl^- (aq)$
c. Write a net ionic equation.
d. ID the spectator ions.

Answers:
a. Fe is oxidized and Au^{3+} in $AuCl_3$ is reduced.
b.
c. $Fe (s) + Au^{3+} (aq) \rightarrow Au (s) + Fe^{3+} (aq)$
Note Fe (s) is not the same as Fe^{3+} (aq) and Au^{3+} (aq) is not the same as Au (s).
d. spectator ions: Cl^-

3. When rust reacts with Al, molten iron is produced. This reaction is known as the thermite process (go to YouTube to see this reaction).
a. Write a chemical equation that represents this reaction. Identify the oxidizing agent and reducing agent. What is it about this reaction that makes iron molten?

b. Write a net ionic equation.

Answers: remember A + BC --> B + AC

a. 2 Al + Fe_2O_3 --> 2 Fe + Al_2O_3

Al is oxidized (Al (0) --> Al^{3+} in Al_2O_3) so it is the reducing agent. Metal elements are reducing agents.

The Fe in Fe_2O_3 is reduced (Fe^{3+} in Fe_2O_3 --> in Fe (0)) so it is the oxidizing agent. Metal ions are oxidizing agents.

This reaction releases a lot of heat – enough heat to melt iron.

b. None of the substances are soluble in water so net ionic equation is: 2 Al + Fe_2O_3 --> 2 Fe + Al_2O_3

4. Different metals have a different ability to lose electrons. A metal that loses electrons easily is called an active metal. The Activity Series of Metals ranks the ability of metals to lose electrons.

Lithium is the most active metal (best reducing agent), which means it very easily loses its electron to form Li^+. Li^+ does not want to gain an electron to re-form Li metal and is the worst oxidizing agent.

Gold is the least active metal (worst reducing agent), which means it does not easily lose its electrons to form Au^{3+}. Au^{3+} wants to gain electrons to re-form Au metal and is the best oxidizing agent.

The Activity Series is used to predict which metal reduces which metal ion. A metal will reduce any metal ion below it in the Activity Series.

Examples: Fe is above Au^{3+} so Fe reacts with Au^{3+} (see Problem 2).

Fe is below Cr^{3+} so Fe will not react with Cr^{3+}.

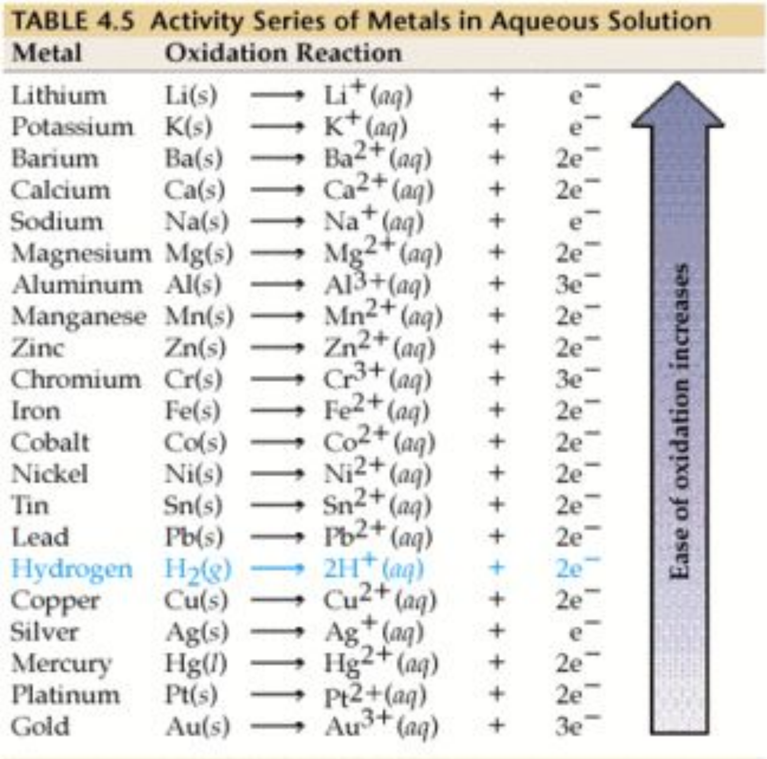

TABLE 4.5 Activity Series of Metals in Aqueous Solution

Metal	Oxidation Reaction				
Lithium	$Li(s)$	$\longrightarrow$	$Li^+(aq)$	+	e^-
Potassium	$K(s)$	$\longrightarrow$	$K^+(aq)$	+	e^-
Barium	$Ba(s)$	$\longrightarrow$	$Ba^{2+}(aq)$	+	$2e^-$
Calcium	$Ca(s)$	$\longrightarrow$	$Ca^{2+}(aq)$	+	$2e^-$
Sodium	$Na(s)$	$\longrightarrow$	$Na^+(aq)$	+	e^-
Magnesium	$Mg(s)$	$\longrightarrow$	$Mg^{2+}(aq)$	+	$2e^-$
Aluminum	$Al(s)$	$\longrightarrow$	$Al^{3+}(aq)$	+	$3e^-$
Manganese	$Mn(s)$	$\longrightarrow$	$Mn^{2+}(aq)$	+	$2e^-$
Zinc	$Zn(s)$	$\longrightarrow$	$Zn^{2+}(aq)$	+	$2e^-$
Chromium	$Cr(s)$	$\longrightarrow$	$Cr^{3+}(aq)$	+	$3e^-$
Iron	$Fe(s)$	$\longrightarrow$	$Fe^{2+}(aq)$	+	$2e^-$
Cobalt	$Co(s)$	$\longrightarrow$	$Co^{2+}(aq)$	+	$2e^-$
Nickel	$Ni(s)$	$\longrightarrow$	$Ni^{2+}(aq)$	+	$2e^-$
Tin	$Sn(s)$	$\longrightarrow$	$Sn^{2+}(aq)$	+	$2e^-$
Lead	$Pb(s)$	$\longrightarrow$	$Pb^{2+}(aq)$	+	$2e^-$
Hydrogen	$H_2(g)$	$\longrightarrow$	$2H^+(aq)$	+	$2e^-$
Copper	$Cu(s)$	$\longrightarrow$	$Cu^{2+}(aq)$	+	$2e^-$
Silver	$Ag(s)$	$\longrightarrow$	$Ag^+(aq)$	+	e^-
Mercury	$Hg(l)$	$\longrightarrow$	$Hg^{2+}(aq)$	+	$2e^-$
Platinum	$Pt(s)$	$\longrightarrow$	$Pt^{2+}(aq)$	+	$2e^-$
Gold	$Au(s)$	$\longrightarrow$	$Au^{3+}(aq)$	+	$3e^-$

Reference: https://www.pinterest.com/pin/572520171356648614

a. Al is above Fe^{2+} so the thermite reaction occurs. What metal other than Al could you use to make molten iron? Give reasons. Write a chemical equation to support your answer.

b. Use the Activity Series of Metals to explain why Reaction (i) does not occur but Reaction (ii) does.

(i) Au (s) + $AgNO_3$ (aq) → no reaction

(ii) 3 Ag (s) + $AuCl_3$ (aq) → Au + 3 AgCl

Identify the oxidizing agent and reducing agent.

Could you silver plate gold or gold plate silver? Give reasons.

c. One of the reactions occurs but the other does not. Predict which reaction occurs. If a reaction occurs, write a net ionic equation. Identify the oxidizing agent and reducing agent.

(i) $CuSO_4$ (aq) + Zn (s) →

(ii) $ZnCl_2$ (aq) + Cu (s) →

Answers:

a. According to the Activity Series, Li is the strongest (best) reducing agent and gold is the weakest (worst) reducing agent.

Reducing agent strength decreases going down the series.

Au^{3+} ion is the strongest (best) oxidizing agent and Li^+ ion is the weakest (worst) oxidizing agent.

Oxidizing agent strength increases going down the series.
So a reducing agent needs a strong enough oxidizing agent for a reaction to occur.
Or an oxidizing agent needs a strong enough reducing agent for a reaction to occur.
So any metal above Iron will react with rust to form iron metal.
Fe^{3+} in Fe_2O_3 is an oxidizing agent. Fe^{3+} needs a strong enough reducing agent to remove its electrons to form Fe metal.
The metals above Fe in the Activity Series are strong enough reducing agents.
E.g., $2\ Cr + Fe_2O_3 \dashrightarrow 2\ Fe + Cr_2O_3$

b. Use the Activity Series of Metals to explain why Reaction (i) does not occur but Reaction (ii) does.
(i) Au (s) + $AgNO_3$ (aq) → no reaction.
Au is below Ag in the Activity Series – Au is not a strong enough reducing agent to reduce Ag^+ to Ag.
(ii) 3 Ag (s) + $AuCl_3$ (aq) → Au + 3 AgCl
Ag is above Au in the Activity Series – Ag is a strong enough reducing agent to reduce Au^{+3} to Au.
Ag is the reducing agent. $AuCl_3$ (specifically Au^{+3}) is the oxidizing agent.
Could you silver plate gold or gold plate silver? Give reasons.
To silver plate gold: $Au + Ag^+$ --> no reaction. So gold cannot be silver plated.
To gold plate silver: $Ag + Au^{+3}$ --> $Au + Ag^+$. So silver can be gold plated.

c. (i) $CuSO_4$ (aq) + Zn (s) → Cu + $ZnSO_4$ (aq)
Zn is the reducing agent. $CuSO_4$ (specifically Cu^{+2}) is the oxidizing agent.

$CuSO_4$ (aq) and $ZnSO_4$ (aq) are soluble in water.
Ionic equation: $Cu^{2+} + SO_4^{2-}$ (aq) + Zn (s) → $Cu + Zn^{2+} + SO_4^{2-}$ (aq)
Net ionic equation: Cu^{2+} + Zn (s) → $Cu + Zn^{2+}$
Spectator ion: SO_4^{2-} (aq)
(ii) $ZnCl_2$ (aq) + Cu (s) → no reaction. Cu is below Zn in the Activity Series – Cu is not a strong enough reducing agent to reduce Zn^{+2} to Zn.

5. You are trying to prevent an iron drain pipe from rusting. Your high school chemistry teacher, who usually teaches PE, suggests wrapping the iron pipe in copper foil whereas your grandmother tells you to wrap the iron pipe in magnesium foil. Which person's advice will you follow? Give reasons. (Pick one or the other. Do not say neither.)

Answer: Follow the advice of your grandmother (of course!).
Mg is more active than Fe so the Mg is preferentially oxidized.

6. When exposed to air, silver tarnishes because the silver reacts with hydrogen sulfide in the air to form a layer of black silver sulfide. The tarnish can be chemically removed by using a solution of baking soda and aluminum foil. In this electrochemical process, electrons move from the aluminum atoms to the silver ions in the tarnish, reducing the silver ions to silver atoms while the aluminum atoms are oxidized to aluminum ions. The baking soda provides an electrolyte solution for the flow of electrons and also helps remove the aluminum oxide coating from the surface of the aluminum foil. This method of cleaning silverware is better than using polish because the tarnish is restored to silver on the silverware. Polish removes the Ag_2S, including the silver it contains. (Reference: Moore et al., "The Chemical World", 2nd ed., p. 840)
Write a balanced chemical equation that represents the tarnish removing reaction. Explain why aluminum is used in this reaction. What other metal could be used besides aluminum? Give reasons.
Answers:
2 Al (s) + 3 Ag_2S --> 6 Ag + Al_2S_3
Al is more active than Ag.
Al is a strong enough reducing agent to reduce Ag^+ to Ag.
Any metal above Ag in the Activity Series can be used to remove silver tarnish.

Another type of oxidation-reduction reaction is a combustion reaction. For a carbon based fuel:
Fuel + O_2 ---> $CO_2 + H_2O$

7. Natural gas is methane, CH_4, which is burned in a Bunsen burner:
$CH_4 + 2\ O_2$ --> $CO_2 + 2\ H_2O$
a. Identify the reactant that is oxidized.
b. Identify the reducing agent.
Answers:
a. CH_4 is oxidized: the C in CH_4 has a -4 charge --> the C in CO_2 has a +4 charge.
b. CH_4 is the reducing agent. It reduces O_2 (charge = 0) to H_2O (charge on O = -2).

8. Butane (C_4H_{10}) is used in lighter fluid:

___ C_4H_{10} + ___ O_2 --> ___ CO_2 + ____ H_2O

a. Balance the chemical equation.
b. (i) 1 mole of butane reacts with ____ moles of oxygen.
(ii) How many moles of CO_2 are produced? (What is the conversion factor?)
c. 1.0 g of butane reacts.
(i) Calculate the moles of butane.
(ii) How many moles of H_2O are produced? (Answer: between 0.08 and 0.09 moles)
d. 1.0 g of butane reacts. How many g of O_2 reacts with 1.0 g of butane? (Answer: between 3.5 and 3.7 g)
Answers:
a. 2 C_4H_{10} + 13 O_2 --> 8 CO_2 + 10 H_2O
b. (i) 1 mole of butane reacts with 6.5 moles of oxygen.
1 mole C_4H_{10} (13 moles O_2 /2 moles C_4H_{10}) = 6.5 moles of O_2.
(ii) How many moles of CO_2 are produced? (What is the conversion factor?)
1 mole C_4H_{10} (8 moles CO_2 /2 moles C_4H_{10}) = 4 moles of O_2.
c. 1.0 g of butane reacts.
(i) Calculate the moles of butane.
1.0 g C_4H_{10} (1 mole C_4H_{10} /58 g C_4H_{10}) = 0.017 moles C_4H_{10}
(ii) How many moles of H_2O are produced? (Answer: between 0.08 and 0.09 moles)
1.0 g C_4H_{10} (1 mole C_4H_{10} /58 g C_4H_{10}) (10 mole H_2O /2 mole C_4H_{10}) = 0.086 moles H_2O
d. 1.0 g of butane reacts. How many g of O_2 reacts with 1.0 g of butane? (Answer: between 3.5 and 3.7 g)
1.0 g C_4H_{10} (1 mole C_4H_{10} /58 g C_4H_{10}) (13 mole H_2O /2 mole C_4H_{10})(32 g O_2/1 mole O_2) = 3.6 g O_2