CHM 130LL: Reactivity of Metals

In one type of single-replacement reaction, a solid metal "replaces" the cation of another metal in solution. For example, in the following reaction,

$$Cd\ (s) + CuCl_2(aq) \rightarrow CdCl_2(aq) + Cu\ (s)$$

the Cd "replaces" the Cu^{+2} in the solution, so copper comes out in its natural elemental form, Cu (s), and solid Cd becomes Cd^{+2} in solution with the Cl^{-} ions.

To understand single-replacement reactions, you must make a careful distinction between the **free metal** in its elemental form, and the **metal cation** in solution**.**

The **free metal** still has all of its original electrons; it has **no charge** because the number of protons is equal to the number of electrons. The free metal is never part of a compound. It exists as a metallic-looking solid or a coating (if it plated out).

When the free metal loses electrons, it becomes positively charged because the number of protons (which does not change) is then greater than the number or electrons (since some electrons are lost). The **positively charged metal cation** is shown as being part of an **ionic compound in solution.** In the following single-replacement reaction,

$$2\ Al\ (s) + 3\ CdCl_2\ (aq) \rightarrow 2\ AlCl_3\ (aq) + 3\ Cd\ (s)$$

the free metals are Al on the reactant side and Cd on the product side. The metal ions are Cd^{+2} in the $CdCl_2$ compound on the reactant side and Al^{+3} in the $AlCl_3$ compound on the product side. Since the ionic compounds in this reaction are all soluble, the physical state is shown as aqueous, (aq).

Metals differ in their tendency to release valence electrons. Some metals give their electrons a forceful "push" while other metals can only manage a weaker "push." The chemical name for this tendency to release electrons is "**activity**." The **activity series** is the arrangement of elements according to their ability to release electrons. The activity series is shown below:

Li > K > Ba > Sr > Ca > Na > Mg > Al > Mn > Zn >
Fe > Cd > Co > Ni > Sn > Pb > (H) > Cu > Ag > Hg > Au

For a single-replacement reaction to occur, the free metal must be more active—i.e. be higher on the activity series—than the metal cation in solution. Note that in the following reaction,

$$2\ Al\ (s) + 3\ CdCl_2\ (aq) \rightarrow 2\ AlCl_3\ (aq) + 3\ Cd\ (s)$$

Al is higher than Cd on the activity series. Thus, it can force its electrons onto the Cd^{+2} ion to make it plate out as Cd (s) while the Al atoms go into solution as Al^{+3} cations. (Note: The formula for aluminum chloride, $AlCl_3$, is based on the charges for aluminum ion, Al^{+3}, and chloride ion, Cl^{-}.)

If the free metal is less active than the metal cation in solution, then it is not active enough to replace the cation in solution, and no reaction occurs. For example, consider what happens when a piece of silver, Ag (s), is placed in a $CdCl_2$ solution. Since Ag is lower on the activity series than Cd, it is not strong enough to replace Cd^{+2} in solution. Consequently, no reaction occurs, as shown below:

$$Ag\ (s) + CdCl_2\ (aq) \rightarrow NR$$

where NR means "no reaction."

One way to think about this is the more active metal is more likely to be an ion in a compound. The less active metal is more likely to be alone in its elemental state.

Even though hydrogen is a nonmetal, it can also behave like a metal under certain conditions. For example, like a metal, it can lose an electron to form H^+. Compounds of H^+ in solution are called acids—e.g. HCl(aq) is hydrochloric acid. Metals that are higher than hydrogen on the activity series react with acids to replace hydrogen in solution. Hydrogen is released in its elemental diatomic form, H_2(g). Consider the reaction between Cd metal and hydrochoric acid, HCl(aq):

$$Cd(s) \quad + \quad 2\,HCl(aq) \quad \rightarrow \quad CdCl_2(aq) \quad + \quad H_2\,(g).$$

The free metal is Cd on the reactant side, but the product is hydrogen gas, H_2(g). When the hydrogen gas is produced in this type of single-replacement reaction, bubbles are observed instead of a metal plating out. Note that all the metals above hydrogen on the activity series will react with any acid in a similar manner.

In this experiment,

- You will observe how each free metal reacts with metal solutions and an acid solution.
- You will rank each metal based on its reactivity to develop your own activity series.
- You will identify the four unknown metals by comparing the experimentally determined activity series with the accepted Activity Series.

You will be given four metals labeled A, B, C, and D, as well as four solutions of each metal cation also labeled A, B, C, and D. You will mix each solid metal with the metal cation or acid solutions and observe the results. You will record the results of each test in your Data Table. Using your results, you will make an abbreviated "activity series" indicating the free metal (A, B, C, or D) with the most reactions as the most active, then the next most active metal, etc., with the free metal having the least number of reactions as the least active. Use your activity series to match up the letters (A, B, C, or D) with the element symbols in the activity series provided to identify each metal.

Next, indicate which metals are more active than hydrogen based on the results.

Afterwards, you will write balanced chemical equations for many of the single-replacement reactions that did occur or "NR" for "no reaction".

Procedure

The experiment will be carried out in microplates. Follow the directions below:

1. To use the metals, hold the small metal strip and sandpaper both sides of it thoroughly. Then cut it into small squares as needed.
2. Add a few drops of liquid—enough to cover the metal. You need not completely fill the well on the microplates. (Note: You do not need to test the metal with its corresponding solution—i.e. you do not need to test free metal A in the metal cation A solution because it won't react with itself.) Allow each metal to react with each solution for at least 10-15 minutes.
3. If necessary, observe reactions through magnifying glasses. You will be looking for a plating reaction—a darkening or coating of the metal's surface. In the case of the metals in HCl*(aq)*

solution, you will be looking for bubbles of hydrogen gas. ***Note that HCl is the only hydrogen-producing solution. Bubbles in any other solution are due to a side-reaction and can be ignored.*** You should place the microplate on a piece of white paper since (depending on the reaction) it may be difficult to observe reactions over the dark surface of the lab table.

Note: Two metals that react have a similar color, so the appearance of the solid metal will not change dramatically when the metal in solution plates onto the solid. Look for any change in the luster (shine) of the original metal to determine if a reaction has occurred.

Do not allow large quantities of metal and HCl(aq) to mix. Hydrogen gas is very flammable.

Caution: Hydrochloric acid is corrosive and can cause chemical burns as well as damage clothing. Any hydrochloric acid spilled on skin must be rinsed immediately with water for 15 minutes. Any acid spilled on your work area must be neutralized, then the entire area should be washed and dried.

A. Identify the Four Metals (may be done in pairs)

1. Record any observed reactions (e.g. bubbles produced, the color or appearance of any solid forming, etc.) in Table I in the box matching the free metal and the cation in solution in your Data Table. If nothing happens, write "NR" for "no reaction" in the box.

2. Count the number of reactions for each free metal with the metal and acid solutions, and record the number in the bottom row of Table I. Rank each metal (A, B, C, and D) on the Activity Series below Table I based on the number of reactions, indicating the metal with the most reactions as the most active and so on. The number of reactions for each free metal should be different so you can rank them.

3. Identify each metal by matching it with the metal indicated on the Activity Series provided.

4. Indicate which of the four metals (Mg, Zn, Fe, and Cu) are more active than—i.e. higher on the Activity Series compared to—hydrogen (H_2).

Waste disposal: Dispose of your entire microplate of chemicals by carrying it to the tray in the hood and inverting it, being sure to remove any bits of unreacted metal with a cotton swab.

Use cotton swabs to clean the slots in the microplate, then wash the microplate with tap water and rinse with distilled water. Dispose of used cotton swabs in the trash.

Wash up your entire work area with a wet paper towel then dry it using clean paper towels. Wash your hands thoroughly before leaving lab.

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Name: ________________________

Partner: ________________________

Section Number: ________________

DATA

A. Identifying the Four Unknown Metals

Table I: Observations for Single-Replacement Reactions

	Metal A	**Metal B**	**Metal C**	**Metal D**
Solution A				
Solution B				
Solution C				
Solution D				
$\mathbf{H^+}$ in **HCl**(aq)				
# of Reactions				

Rank the four metals (A, B, C, and D) below, indicating the metal with the highest number of reactions as the "most active":

Your Activity series: most active = _____ > _____ > _____ > _____ = least active

Accepted Activity series: most active = Mg > Zn > Fe > Cu = least active

Identification of Metals:

A = ________, B=________, C=________, D=________

Circle all of the metals below that are *more active* than hydrogen:

Mg Cu Fe Zn

Reactions and Balanced Equations:

1. Refer to the activity series to complete the following reactions. If the reaction does not occur, write NR. If the reaction does occur, write the proper formulas (based on the charges) for the products first, write the correct states for each product, then balance the equation last. **Use Fe^{3+} for compounds containing iron ions and Cu^{2+} for compounds containing copper ions.**

a. ____$Mg(s)$ + ____$CuCl_2\,(aq)$ $\rightarrow$
b. ____$AgNO_3(aq)$ + ____$Cd(s)$ $\rightarrow$
c. ____$Mg(s)$ + ____$FeBr_3(aq)$ $\rightarrow$
d. ____$Co(NO_3)_3(aq)$ + ____$Pb(s)$ $\rightarrow$
e. ____$Cu(s)$ + ____$FeCl_3(aq)$ $\rightarrow$
f. ____$Zn(s)$ + ____$HNO_3(aq)$ $\rightarrow$
g. ____$Al(s)$ + ____$NiSO_4(aq)$ $\rightarrow$
h. ____$Fe(s)$ + ____$CuBr_2(aq)$ $\rightarrow$
i. ____$Cd(s)$ + _____$HCl(aq)$ $\rightarrow$
j. ____$Zn(s)$ + ____$Ni(NO_3)_3(aq)$ $\rightarrow$
k. ____$Sn(s)$ + ____$FeCl_3(aq)$ $\rightarrow$
l. ____$Fe(s)$ + ____$HBr\,(aq)$ $\rightarrow$

3. ***"Active metals" are the six highest metals on the Activity Series.*** These six metals are the **only** metals that react directly with water to produce hydrogen gas and a metal hydroxide. For example, consider the reaction between sodium metal and water:

$$\underset{\text{active metal}}{2\,Na(s)} + 2\,H_2O(l) \rightarrow H_2(g) + \underset{\text{metal hydroxide}}{2\,NaOH(aq)}$$

Because sodium ion is Na^+ and hydroxide ion is OH^-, sodium hydroxide's formula is **NaOH** (based on the charges). Use this information to write the products (including physical states) then balance the equation if a reaction occurs, or write "NR" for no reaction. The activity series does not apply to these.

a. ____$Pb\,(s)$ + ____$H_2O\,(l)$ $\rightarrow$
b. ____$Ba(s)$ + ____$H_2O\,(l)$ $\rightarrow$