

Lab Session 6, Experiment 5: Hydrogen and the Activity Series of Metals

An activity series is a listing of chemical species in order of increasing (or decreasing) reactivity.

Metals (be sure you can locate them on the periodic table) tend to react by losing one or more electrons (per atom). Non-metals tend to gain electrons when they react. When a metal, or any chemical species, loses electrons, it is said to be *oxidized*. The word "oxidized" is used by chemists to refer to the process that usually happens when atoms react with oxygen. Metals are considered more active since they are more easily oxidized. One way an activity series may be determined is to observe the spontaneity of reaction of a set of metals with a single oxidizing agent.

The oxidizing agent used in most of the experiments in this lab session will be hydrochloric acid (aqueous hydrogen chloride). In fact, any strong acid would do because the chemical entity actually taking the electrons from the metals is the hydronium ion, $\text{H}_3\text{O}^+_{(\text{aq})}$, which is present in all strong aqueous acids. Frequently, this species is simply called the hydrogen ion, or even the hydrated proton, $\text{H}^+_{(\text{aq})}$, since in aqueous solution it is hydrated.

The product formed when $\text{H}^+_{(\text{aq})}$ is the oxidizing agent is $\text{H}_{2(\text{gas})}$, neutral molecular hydrogen, which can only be formed if $\text{H}^+_{(\text{aq})}$ can take an electron from the metal.

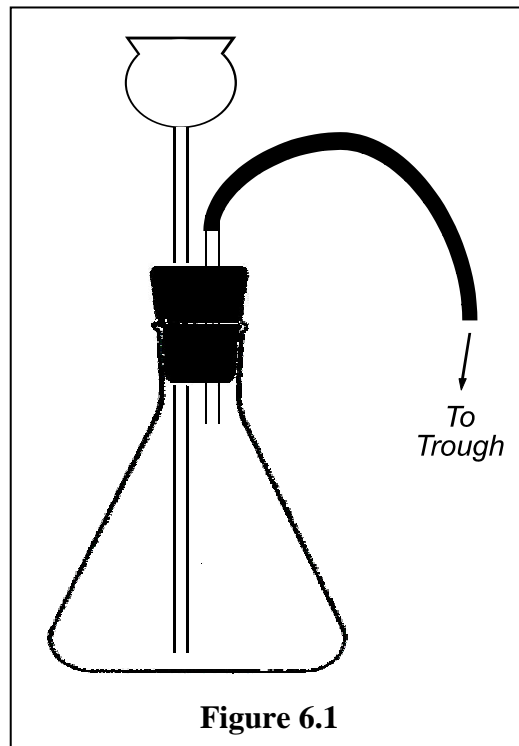
The ion formed from the metal in the reaction depends on the chemical nature of the metal. Periodic Groups IA, IIA, and IIIA are very consistent in this matter. Group IA metals form +1 ions, etc. Transition metals are not as predictable, but the charges on their cations are known from experiment. This knowledge is imparted to you by the charge shown in parentheses after these metals on the activity series furnished below.

Activity Series for Metals

Oxides reduced by H ₂ (gas)	K (K ¹⁺)	Metal + cold H ₂ O → H ₂ (gas) + hydroxide
	Ba (Ba ²⁺)	
	Sr (Sr ²⁺)	
	Ca (Ca ²⁺)	
	Na (Na ¹⁺)	
	Mg (Mg ²⁺)	
	Al (Al ³⁺)	
	Mn (Mn ²⁺)	
	Zn (Zn ²⁺)	
	Cr (Cr ³⁺)	
Oxides <u>not</u> reduced by H ₂ (gas)	Fe (Fe ^{2+,3+})	Metal + hot water → H ₂ (gas) + oxide or hydroxide
	Cd (Cd ²⁺)	
	Co (Co ²⁺)	
	Ni (Ni ²⁺)	
	Sn (Sn ²⁺)	
	Pb (Pb ²⁺)	
	H ₂ (H ¹⁺)	
	Sb (Sb ³⁺)	
	As (As ³⁺)	
	Bi (Bi ³⁺)	
Oxides reduced by heat alone	Cu (Cu ²⁺)	Metal + acid → H ₂ (gas) + salt
	Ag (Ag ¹⁺)	
	Pd (Pd ²⁺)	
	Hg (Hg ²⁺)	
	Pt (Pt ²⁺)	
Forms oxides only indirectly	Au (Au ³⁺)	Metal + O ₂ (1 atm) → oxide

5A Experiment

1. A single example of an acid reacting with a metal will be performed and the products noted.
2. Add 50 mL of concentrated HCl (12 M) to 50 mL of water to make 100 mL of 6 M HCl (save excess for later).
3. Using a 125 mL Erlenmeyer flask and a two-hole stopper fitted with a glass tube, assemble the hydrogen generator as shown in Figure 6.1. Make sure all fittings (thistle tube through the stopper, glass tube through the stopper, and rubber tubing to the glass tube) are tight. A hose clamp or wire winding may be needed.



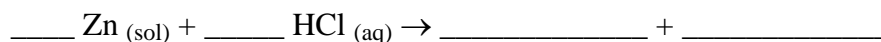
4. Place 5 g of granulated zinc in the flask, close it and add 25 mL 6 M HCl through the thistle tube. Be sure your thistle tube's lower end is submerged. Copious bubbles should form on the metal surface with release of heat.
5. Begin catching the effluent of this apparatus with a small test tube by letting it bubble into the water-filled, inverted tube under water in a pneumatic trough.
6. Being very careful to take the tube away from the generator in an *inverted* position, light the gas inside with a small flame. A small explosion will occur, making a barking sound. Continue this procedure periodically. Eventually, as the oxygen of the air is swept out of the generator, the product gas, hydrogen, will burn evenly with a nearly invisible flame. Make observations on the properties of hydrogen.

Density as compared to air _____

Solubility in water _____

Reactivity with oxygen (write an equation) _____

7. Now we turn our attention to the other product of the reaction. When you have finished testing the hydrogen, set your generator in the hood, open it and allow it to run down. Allow all the hydrogen to escape as it forms and to not build up. Later, each group of two students should decant a few mL of the solution off the metal and evaporate it over a steam bath. The solid residue is the salt zinc chloride. Complete the following reaction:



Be sure you can write a similar equation for each metal in our activity series that reacts with acid.

5B Experiment

1. The relative activity of some metals with acid will be observed.
2. While your hydrogen generator from Experiment 6A is exhausting itself, pick up a small sample of each of the following metals: granulated zinc, tin, lead, copper, iron, aluminum, and magnesium. If granules are not available, magnesium ribbon and aluminum turnings or wire will do. Place each metal in its own test tube. **The smallest amount you can see is the right amount.** Using too much of an active metal may cause the reaction contents to bubble out of the test tube.
3. To each in succession add 2 mL of 6 M HCl and observe the reaction.
4. When you have tested all the metals, list them in order of decreasing reactivity and compare your results with the order given in the activity series furnished. Judge the activity by speed of gas evolution and heat given off.

Most Least
Active _____ Active

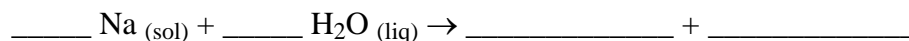
5C Experiment

A very active metal such as sodium reacts with cold water. Water is a considerably weaker oxidizing agent than 6 M HCl. Your instructor may choose to demonstrate this experiment.

1. The sodium is placed in a beaker of water placed behind a safety shield. Notice that the reaction is so exothermic that it will ignite the hydrogen released. If no ignition occurs, place the sodium on a small piece of filter paper floated on the water. The residual molten sodium oxide sphere has a tendency to burst into pieces some time after the reaction seems to be over.

BE CAREFUL -- Be sure you have your eye protection on while watching this!

2. Test the solution produced with red litmus paper. In addition to H_2 (gas), a strongly basic metal hydroxide is produced.
3. Complete the following equation:



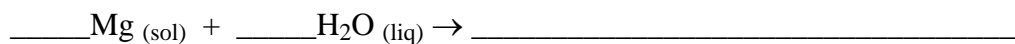
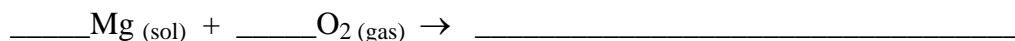
Be sure you can write a similar equation for each of the very active metals of the activity series that will react with cold water. This experiment may be repeated with calcium metal, if available.

5D Experiment

An active metal reacts with oxygen and also reacts with hot water. As shown on the activity series, most metals will react with oxygen at one atmosphere (in air, the partial pressure of O₂ is only 0.2 atm) to produce an oxide. Less active metals, which do not react with cold water, will react with hot water to release H₂.

1. Hold a 3 inch piece of magnesium ribbon by one end with your tongs. Light the other end in the burner flame. (Careful, do not look directly at the flame; it is very bright.) Now quickly plunge the burning ribbon into a 400 mL beaker of boiling water. How can it continue to burn without the oxygen of the air? _____

2. Complete the two following equations:



At an elevated temperature, Mg(OH)₂ will dehydrate to MgO as shown in the activity series, but here the sparingly soluble base, Mg(OH)₂, may be detected in water by turning litmus blue. Since either a metal hydroxide or oxide will react with an acid to form a salt (and water, in the case of hydroxide), the salt will always be a product when metal oxidation is done by acid, even if the most active metals are involved.

5E Experiment

Apparently, activity is affected by conditions of concentration and temperature.

Part 1: More concentrated acid is a stronger oxidizing agent than dilute acid.

1. Put 1 mL of 6 M HCl in a 10 mL graduated cylinder and add 9 mL of water, then mix.
2. Place two similarly sized pinches of granulated zinc in two test tubes. To one add 6 M HCl and to the other the dilute HCl.
3. What do you observe?

Part 2: If the metal is more finely subdivided, more contact between metal and acid occurs.

1. Place a pinch of zinc *dust* in a test tube and add 6 M HCl.
2. Compare this reaction to that of granulated zinc treated with 6 M HCl.

Part 3: The reaction rate activity should be enhanced at increased temperature.

1. Take a pinch of granulated tin and add 2 mL of 6 M HCl.
2. After noting the activity, heat carefully in a hot water bath.
3. What do you observe?

Report Form 5: Hydrogen and the Activity Series of Metals

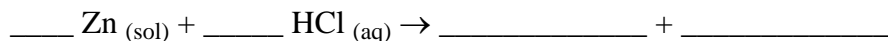
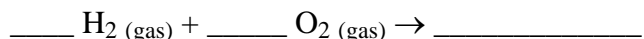
Name _____

Partner _____ Section # _____

5A Experiment

Density of H₂ gas as compared to air _____

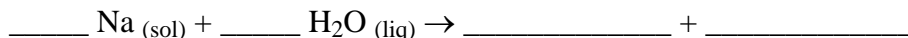
Solubility of H₂ gas in water _____



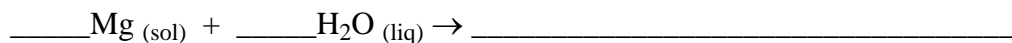
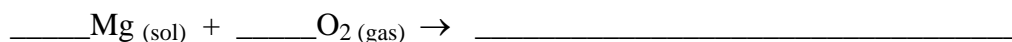
5B Experiment

Most Active _____ Least Active _____

5C Experiment



5D Experiment



5E Experiment

Part 1: Observation _____

Part 2: Observation _____

Part 3: Observation _____