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Composition of an Aluminum-Zinc Alloy

In 1886 a relatively inexpensive electrolytic process capable of mass-producing aluminum was invented by Charles Hall and Paul Heroult. Today the widespread use of aluminum metal in so many products requires an enormous consumption of energy. About 5% of the total electrical energy produced in the USA is used to meet consumer demand for aluminum metal. This energy consumption is so large that conservation and recycling is necessary.

In this experiment you will be determining the amount of aluminum present in an aluminum-zinc alloy. In order to make this determination, we must first understand how aluminum and zinc react with strong acids. Aluminum reacts spontaneously with a strong acid, producing a solution of a salt of the metal and hydrogen gas:

$$2\ Al_{(s)} + 6\ H^{+}_{(aq)} \rightarrow 2\ Al^{3+}_{(aq)} + 3\ H_{2(g)} \qquad (1)$$

From this equation it is clear that two moles of aluminum produce three moles of hydrogen gas in this reaction.

Zinc also reacts spontaneously with strong acids in a manner similar to that shown above:

$$Zn_{(s)} + 2\ H^{+}_{(aq)} \rightarrow Zn^{2+}_{(aq)} + H_{2(g)} \qquad (2)$$

From this equation it is apparent that one mole of zinc produces one mole of hydrogen gas. If we had a pure sample of aluminum (or a pure sample of zinc), it would be possible to calculate the mass of the metal simply by measuring the amount of the hydrogen gas liberated upon reaction with a strong acid. Determination of the amount of each metal present in an alloy is also possible. We will exploit the fact that the amount of hydrogen produced by one gram of zinc is different from the amount of hydrogen produced by one gram of aluminum:

1 mol zinc (65.4 g) → 1 mol of hydrogen gas

$$1.00 \text{ g Zn} \rightarrow 0.0153 \text{ mol } H_2(g) \quad (3)$$

2 mol aluminum (54.0 g) → 3 mol hydrogen gas

$$1.00 \text{ g Al} \rightarrow 0.0556 \text{ mol } H_2(g) \quad (4)$$

We can react an alloy of aluminum and zinc (of known mass) with a strong acid, measure the amount of hydrogen gas evolved, and determine the percentages of aluminum and zinc in the alloy using the equations above.

You will be using the experimental apparatus as shown in Figure 3.2 to collect the hydrogen gas produced by the reaction. You can calculate the number of moles of hydrogen produced (n) by using the Ideal Gas Law:

$$P_{Hydrogen} V = n_{(Hydrogen)} R T \quad (5)$$

$$n_{(Hydrogen)} = (P_{Hydrogen} V) / (R T) \quad (6)$$

The volume (V) and temperature (T) of the hydrogen can be easily determined. The pressure exerted by the dry hydrogen ($P_{Hydrogen}$) is less trivial. The total pressure (P) of gas (according to Dalton's Law) is equal to the partial pressure of the hydrogen ($P_{Hydrogen}$) plus the the partial pressure of the water vapor (P_{Water}):

$$P = P_{Hydrogen} + P_{Water} \quad (7)$$

If we assume the gas is saturated with water vapor (since the water vapor in the apparatus is present with liquid water), then the water vapor pressure (P_{Water}) is equal to the vapor pressure of water ($V.P._{Water}$) at the temperature of the experiment. The vapor pressure of water ($V.P._{Water}$) for various temperatures is found in Appendix H. The total gas pressure (P) is nearly equal to the barometric pressure (P_{bar}). If there is not a barometer in your laboratory, the barometric pressure (P_{bar}) will be given to you by your Teaching Assistant. Substituting these values into the equation above gives:

$$P_{Hydrogen} = P_{bar} - V.P._{Water} \quad (8)$$

Substitution into the Ideal Gas Law gives us an equation which we can use to calculate the number of moles of hydrogen produced by your sample:

$$n_{(Hydrogen)} = \frac{(P_{bar} - V.P._{Water}) \cdot V}{R T} \quad (9)$$

Equations 3 and 4 can be applied to calculate the percentages of aluminum and zinc in your sample. For a sample containing *a* grams of aluminum and *z* grams of zinc:

$$n_{(Hydrogen)} = (a \cdot 0.0556) + (z \cdot 0.0153) \quad (10)$$

The number of moles of hydrogen produced per gram of sample can be calculated from:

$$n^*_{Hydrogen} = \left(\frac{\%Al}{100}\right)(0.0556) + \left(\frac{\%Zn}{100}\right)(0.0153) \quad (11)$$

where $n^*_{Hydrogen}$ is the number of moles of hydrogen *per gram of sample*. Since the %Al and the %Zn must add up to be 100% (*i.e.* %Zn = 100 – %Al), equation (11) can be re-written as:

$$n^*_{Hydrogen} = \left(\frac{\%Al}{100}\right)(0.0556) + \left(\frac{100 - \%Al}{100}\right)(0.0153) \quad (12)$$

If you determine the number of moles of hydrogen gas evolved *per gram of sample* ($n^*_{Hydrogen}$) from equation (11), you can use equation (12) to calculate the percentage of aluminum (%Al) in your sample. The graph you prepare for the pre-lab assignment (a graph giving n^*_{Hydrogen} as a function of %Al) will be extremely useful during the laboratory. Your T.A. will spot-check your graph rather than have you turn it in before class.

Experimental Procedure

Wear your safety goggles while performing this experiment.

CAUTION—This experiment generates hydrogen gas, which is explosive. No open flames are allowed in the laboratory.

Assemble the apparatus as shown in Figure 3.1. Fill the suction flask and your beaker about ⅔ full of water. Moisten the stopper on the flask and insert it firmly into the flask. Open the pinch clamp and apply suction using a pipet bulb attached to the glass tube, as shown in Figure 3.1. Pull water into the suction flask (from the beaker) until the water level in the flask is approximately 5 cm below the side arm. Close the pinch clamp. Make sure that the tubing from the beaker to the flask is completely full of water. There should be no air bubbles present in this tubing!

Remove the tubing from the beaker and place it on the lab bench. Check to make sure that water is not leaking out of the end of the tubing. Weigh a plastic 250-mL beaker to the nearest 0.001 g. Place the 250-mL beaker inside a clean, dry 400-mL beaker. Assemble the rest of the apparatus as shown in Figure 3.2.

Obtain an unknown alloy sample and record the number. You will be doing two determinations, so make sure you use the same unknown alloy for the two trials. Use only small pieces of alloy; the larger pieces take too long to dissolve.

Place between 0.08–0.10 grams of the alloy in a gelatin capsule and weigh the sample and capsule to the nearest 0.001 g. Your TA will tell you the barometric pressure in the room. Record this data.

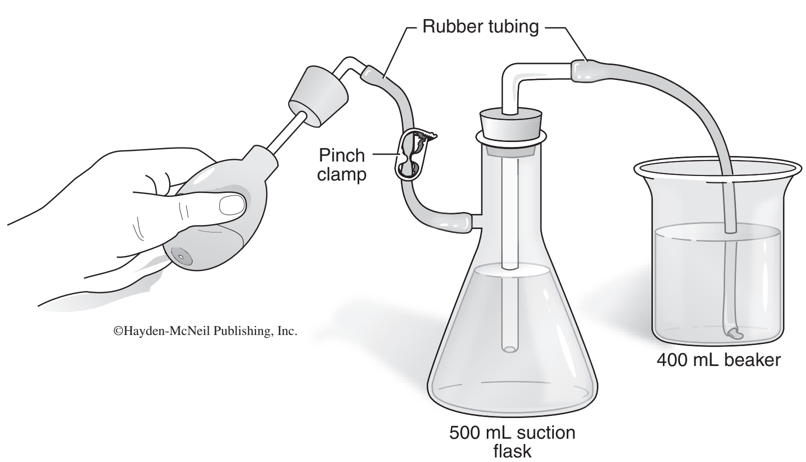

Figure 3.1. Apparatus set up to fill the tubing with water

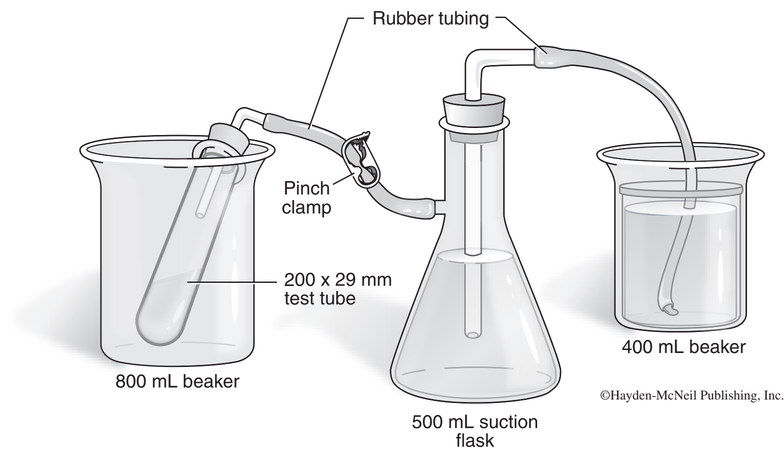

Figure 3.2. Experimental apparatus

Make sure the stopper fits tightly into your largest test tube before continuing. Exchange the tube for another one if it does not fit snugly. Pour 10 mL of 6 M HCl (hydrochloric acid) into your test tube (use your graduated cylinder to measure 10 mL). Drop the gelatin capsule containing your alloy into the HCl solution. If the capsule sticks to the side of the test tube, push it down to the bottom with your stirring rod. Place the stopper firmly onto the test tube and open the pinch clamp. If a small amount of water immediately goes into the plastic beaker, pour the water out and let the beaker drain for a couple of seconds.

Within 4 minutes the acid will eat through the gelatin capsule and will begin to react with the alloy to form hydrogen gas. This gas will go into the suction flask and displace water from the suction flask into the beaker. The volume of water displaced will be equal to the volume of hydrogen gas produced. The reaction may foam, and room is needed for the foam to expand. Hold the test tube and shake the foam down gently if necessary. Hold the test tube at the top; this is an exothermic reaction and the lower part of the test tube will get HOT. The foam may carry some of the alloy into the upper part of the test tube. If this is the case, shake the tube gently to get the alloy back into the acid. The reaction should be over within 10 minutes. You will know the reaction is over if the liquid solution is once again clear, the capsule is dissolved, and all the alloy has reacted. Once the reaction is complete, weigh the plastic beaker containing the displaced water to the nearest 0.001 g. Measure the temperature of the water, which you will assume to be equal to the temperature of the hydrogen gas. Reassemble the apparatus and repeat the experiment. The %Al that you calculate will be the average from your two trials.

Waste Disposal: Pour all liquid waste into the designated waste container. Any unused alloy should be discarded in the trash.

Composition of an Aluminum-Zinc Alloy

3 Lab Report

Name

Time

M T W R F

	Trial 1	Trial 2
Mass of gelatin capsule	g	g
Mass of capsule and alloy	g	g
Mass of empty beaker	g	g
Mass of beaker and displaced water	g	g
Barometric pressure (given by TA)	mm Hg	
Temperature of water	°C	

Calculations	Trial 1	Trial 2
Mass of alloy	g	g
Mass of displaced water	g	g
Volume of displaced water (see Appendix H)	mL	mL
Volume of hydrogen gas ($V_{Hydrogen}$)	L	L
Temperature of hydrogen gas *(assume to be equal to temperature of the water)*	K	
Vapor pressure of water (VP_{H_2O}) (at temp. of H_2 gas, see Appendix H)	mm Hg	
Pressure of dry hydrogen gas	mm Hg	mm Hg
Moles of hydrogen gas ($n_{Hydrogen}$)	mol	mol
Moles of hydrogen per g sample ($n^*_{Hydrogen}$)	mol/g	mol/g
%Al (use pre-lab graph, or plug into equation 12)	%	%
Average %Al	%	
Unknown alloy number		

Composition of an Aluminum-Zinc Alloy

3 Prelab

Name

Time

M T W R F

1. On the following page, construct a graph of n^{*}_{Hydrogen} (moles hydrogen per gram of sample) vs. %Al. Use equation (12):

$$n^{*}_{\text{Hydrogen}} = \left(\frac{\%\text{Al}}{100}\right)(0.0556) + \left(\frac{100 - \%\text{Al}}{100}\right)(0.0153) \quad (12)$$

   Simply solve this equation for n^{*}_{Hydrogen} using %Al = 0 and %Al=100, then draw a straight line through these points. You will need this graph during Experiment 3, so do not hand this graph in before the lab period. Your T.A. will come around to spot-check your graph.

2. Two students weigh a gelatin capsule (0.117 g). Next they add pieces of aluminum/zinc alloy to the capsule and weigh the capsule and alloy (0.200 g). They weigh out an empty beaker (112.600 g) and begin the experiment. After the reaction, they determine the mass of the beaker (with displaced water) to be 202.437 g. The temperature of the water was 22°C and the barometric pressure was 735.8 mm Hg. Fill in the rest of the Calculations section on the following page:

Mass of gelatin capsule	0.117 g
Mass of capsule and alloy	0.200 g
Mass of empty beaker	112.600 g
Mass of beaker and displaced water	202.437 g
Barometric pressure	735.8 mm Hg
Temperature of water	22°C

Calculations	
Mass of alloy	g
Mass of displaced water	g
Volume of displaced water (see Appendix H)	mL
Volume of hydrogen gas ($V_{Hydrogen}$)	L
Temperature of hydrogen gas *(assume to be equal to temperature of the water*	K
Vapor pressure of water (VP_{H_2O}) (at temp. of H_2 gas, see Appendix H)	mm Hg
Pressure of dry hydrogen gas	mm Hg
Moles of hydrogen gas ($n_{Hydrogen}$)	mol
Moles of hydrogen per g sample ($n^*_{Hydrogen}$)	mol/g
%Al (use graph or Equation 12)	%

Graph of n^*_{Hydrogen} vs. %Al

Temperature (°C)	Pressure (mm Hg)	Density (g/mL)
12	10.5	
13	11.2	
14	12.0	
15	12.8	0.9991
16	13.6	
17	14.5	
18	15.5	0.9986
19	16.5	
20	17.5	0.9982
21	18.7	0.9980
22	19.8	0.9977
23	21.1	0.9975
24	22.4	0.9973
25	23.8	0.9971
26	25.2	0.9968
27	26.7	0.9965
28	28.3	0.9963
29	30.0	0.9960
30	31.8	0.9957
31	33.7	

Temperature (°C)	Pressure (mm Hg)	Density (g/mL)
32	35.7	
33	37.7	
34	39.9	
35	42.2	0.9941
40	55.3	0.9922
45	71.9	0.9903
50	92.5	0.9881
55	118.0	0.9857
60	149.4	0.9832
65	187.5	0.9806
70	233.7	0.9778
75	289.1	0.9749
80	355.1	0.9718
85	433.6	0.9687
90	525.8	0.9653
95	633.9	0.9619
97	682.1	
99	733.2	
100	760.0	0.9584
101	787.6	