

Experiment S-1 Teacher's Guide

Density: A Characteristic Property

Placement

Early in the year, with introductory/review of first few chapters

Approximate time for completion

45-50 minutes for both parts

Approximate preparation time

15 minutes; all that is necessary is to provide the materials and reagents

Materials

Apparatus (one per group unless otherwise noted)

Part A

Solid object, sphere or cylinder

Caliper, ± 0.01 cm (if possible), or ruler and two wood or plastic blocks

Balances, milligram sensitivity: at least three, but more is better

Graduated cylinder, 25- or 50-mL – smallest possible size to accommodate the solid object

Part B

Beakers, small, 20-30 mL or similar, 4 per group (if possible)

Volumetric pipets, 1 mL, 4 per group (Graduated pipets may be substituted; consider disposable serological pipets) – See Notes on the Procedure, below

Pipet filler bulb (if students have not used these before, extras might come in handy)

Glass sample vials, with secure caps (12, if possible) . Snap-on lids work best; must be glass, not plastic, for handling organic liquids

Inquiry

Balances, milligram sensitivity: at least three, but more is better

Graduated cylinders

10-mL graduated cylinder

Reagents (allowance is made for excess)

Part A:

Water – deionized/distilled or tap

Part B

Ethyl acetate (about 5 mL per group)

Hexane (about 5 mL per group)

Acetone (about 5 mL per group)

Unknown liquid (about 5 mL per group)

Inquiry

Silicon, small pieces to fit in graduate (about 8 g/group)

Tin, granular or small pieces, not foil (about 10 g/group)

Water (tap or distilled/deionized) (5-8 mL/group)

Preparation of Reagents None

Discussion and Prelaboratory Instruction

While students have been introduced to the rules for significant figures, and to the distinction between accuracy and precision, the odds are good that they haven't develop a real feel for most of it. The Introduction gives a fairly extensive discussion concerning accuracy and precision. Be sure students understand that the terms "relative error" and "percent error" are used interchangeably. As part of the prelab discussion, point out that their work in Parts A and B will be judged on two bases: how close they get to the actual densities of the solid object and the four liquids, and how consistent their results are. Point out that relative error measures accuracy while percent deviation tests precision.

For the Inquiry, the actual density of germanium (5.32 g/cm^3)¹ is not equal to the average of the densities of silicon (2.33 g/cm^3) and ordinary "white" tin (7.31 g/cm^3), but the experiment is valid nonetheless and illustrates why a single property is not enough to distinguish a substance.

Notes on the Procedure

Reasonable technique should give students good results in a short period of time, but you almost certainly will have to instruct students in the use of calipers. If calipers are not available, students can sandwich the sphere or cylinder in between two solid blocks, then use a ruler to measure the diameter.

Assuming this will be students' first experience with volumetric pipets and pipet filler bulbs, anticipate the need to practice a bit, especially on Part A. Ethyl acetate is the best liquid to start with, since it is the least volatile; hexane presents the greatest challenge. Provide separate containers for collecting used reagents. As an interesting alternative, the "disposable," 1 mL x 0.01 mL glass serological pipets that run less than 50 cents apiece are excellent for use here. Their diameter is too small for most filler bulbs; use a 2-3 cm length of clear vinyl tubing to connect the pipet to the tip of a plastic 3-mL syringe that has a Luer-lock tip. The author has a set of 6 pipets labeled for each of the three "known" liquids, and a separate set labeled for the unknowns. The calibrations on the pipets are not permanent, but remain readable for at least 5-6 years.

Even though 25-mL graduated cylinders would allow for larger pieces in the Inquiry, they generally are graduated in 0.2 mL divisions, making volume readings more difficult. The procedure assumes 10-mL x 0.1 mL graduations, so students should be able to report volumes to a precision of ± 0.02 mL.

Granular tin, available from most suppliers, works well, but you will need about 100 g for a typical class. Flinn Scientific, among others, sells silicon chips, but you will have to break them into pieces small enough to fit into the graduated cylinders. If supplies are limited, have half of the class start with Part B.

If multiple sections are involved, when the first class has transferred used tin and silicon bits to paper towels, as described in the Disposal section, collect the bits, rinse with acetone, and dry them for reuse, either in a drying oven or by running a stream of air over them, as from a small air compressor. The liquids for Part B can also be reused, if students have handled them properly.

The choice of unknown liquids is up to you, but not all should use the same one. Despite its problems with health hazard and disposal, methylene chloride is an interesting choice because it's the only one the students will use that has a density greater than that of water. Select unknowns that differ significantly from each other in density.

¹ All density/specific gravity values are from CRC, *Handbook of Chemistry and Physics*, 73rd edition.

Answers to Prelaboratory Questions

- $$\frac{|(0.750) - (0.735)|}{(0.750)} = \frac{0.015}{0.750} \times 100\% = 2.0\%$$
 (Two significant digits)
- Average the densities of the two metals: $\frac{(1.55 + 3.51)}{2} = \frac{5.06}{2} = 2.53 \text{ g/cm}^3$
 Relative error is found in the same way as in the previous question.

$$\frac{|(2.63) - (2.53)|}{(2.63)} \times 100\% = 3.8\% \text{ relative error}$$
- 2.63 g ; $1 \text{ m}^3 = 10^6 \text{ cm}^3$, so 1.00 m^3 of strontium has a mass of $2.63 \times 10^6 \text{ g}$
 Density = mass \div volume = $2.63 \times 10^6 \text{ g} \div 1.00 \times 10^6 \text{ cm}^3 = 2.63 \text{ g/cm}^3$; density is independent of sample size, so it is an intensive property)
- $(1 \text{ in} = 2.54 \text{ cm})^3$ gives $1 \text{ in}^3 = 16.387064 \text{ cm}^3$; $1 \text{ lb} = 453.6 \text{ g}$
 The conversion from g/cm^3 to lb/in^3 is $16.387064/453.6$ or $0.0361266843 \text{ cm}^3/\text{g}$ (not rounded)
 Water: $1.00 \text{ g/cm}^3 \times 0.0361266843 \text{ cm}^3/\text{g} = 0.0361 \text{ lb/in}^3$
 Aluminum: $2.70 \text{ g/cm}^3 \times 0.0361266843 \text{ cm}^3/\text{g} = 0.0975 \text{ lb/in}^3$
 The specific gravity of aluminum, for densities in lb/in^3 is $0.0975 \div 0.0361 = 2.70$ (units cancel)

Answers to Analysis and Conclusions

- Student answers. Don't be surprised to discover that they have forgotten the formula for the volume of a sphere ($V = \frac{4}{3}\pi r^3$) or cylinder ($V = \pi r^2 h$). If, as is likely, the diameter of the object is less than 2.00 cm, then its radius will be less than 1.00 cm, and students will be limited to two significant digits.
- Student answers. If the volume markings on the graduated cylinder allow estimating to the nearest 0.01 mL (albeit, ± 0.02 or 0.05 mL , for 25-mL graduates), students will probably get three significant digits here.
- Student answers, but make sure they answer all of the parts. Whichever density they choose for their "do or die" value, that becomes the "accepted value" in the equation for percent error, given on page 3.
- Student answers. Check sample calculations and correct use of significant figures. Average deviations should be under 5% and the mean values for densities should certainly be within 5% of the accepted values given in the Introduction: ethyl acetate, $0.857 - 0.947 \text{ g mL}^{-1}$; acetone, $0.751 - 0.831 \text{ g mL}^{-1}$; hexane, $0.626 - 0.692 \text{ g mL}^{-1}$.
- Student answers.
- Student answers. Percent uncertainties are found by dividing the uncertainty values calculated in the previous question (the average deviations) by the mean density found for that liquid. The resulting decimal is converted to a percent by multiplying by 100%.

The expected percent uncertainty for the unknown is the average of the percent uncertainties for the three knowns. To convert to an actual uncertainty, multiply this percent uncertainty by the mean density found for the unknown.

Consider the following example:

Density of ethyl acetate: 0.917 g/mL , with uncertainty of 0.022 g/mL , or 2.4%

Density of acetone: 0.772 g/mL , with uncertainty of 0.019 g/mL , or 2.5%

Density of hexane: 0.632 g/mL , with uncertainty of 0.030 g/mL , or 4.7%

The average percent deviation is $(2.4 + 2.5 + 4.7) \div 3$, or 3.2%

Now suppose the mean density for an ethanol unknown was 0.780 g/mL. The expected deviation is 3.2% of 0.780 g/mL, or 0.025 g/mL. The unknown must have a density of 0.780 ± 0.025 g/mL, so its density must be in the range 0.755—0.805 g/mL. Four of the liquids listed in Table 1 of the Introduction qualify: cyclohexane, ethyl alcohol, 2-propanol, and acetone (which, despite warnings about smelling chemicals, some students might eliminate by comparing odors).

Inquiry

Student answers; as noted earlier, the accepted value for the density of germanium is 5.32 g/cm^3 , which will not (assuming good lab skills on the students' part) fall in their predicted range. The key is for them to understand that this is only one predictor, that it would not be the only piece of identifying evidence to be used.

Experiment S-2 Teacher's Guide

Oxidation and Reduction

Placement

In Chapter 5 during discussion of oxidation reduction reactions

Approximate time for completion

45 minutes

Approximate preparation time

2 hours, including preparation of solutions and cutting small metal pieces

Materials

Apparatus (one per group unless otherwise noted)

24-well test plate
tweezers or forceps for handling small metal pieces
small beakers or Erlenmeyer flasks (4, 10-25 mL)
toothpicks for mixing
hot plate for heating solutions (may be shared)

Reagent Solutions (only a few drops to 1-2 mL are needed per group)

0.50 M solutions (1.0 M may be substituted, but more dilute solutions may not give obvious results)

Hydrochloric acid, HCl (aq)
Copper(II) nitrate, Cu(NO₃)₂(aq)
Zinc nitrate, Zn(NO₃)₂ (aq)
Sodium sulfite, Na₂SO₃(aq)

0.10 M solutions

Potassium permanganate, KMnO₄(aq)
Iron(III) chloride, FeCl₃ (aq)
Iron(II) sulfate, FeSO₄(aq)
Ammonium *meta*-vanadate, NH₄VO₃ (aq)
Oxalic acid, H₂C₂O₄(aq)

3 M sulfuric acid, H₂SO₄(aq)

Commercial solutions

3% hydrogen peroxide, H₂O₂ (household antiseptic)
Bleach, 5.25% sodium hypochlorite, NaOCl(aq) (e.g. Clorox™)

Solid reagents

Magnesium foil or ribbon (small pieces)
Copper foil (small pieces, ~2 mm x 2 mm), cut from sheet or strips
Zinc foil (small pieces), cut from sheet or strips

Preparation of Reagent Solutions

Masses of solid reagents are for preparation of 100. mL of solution. While this is far more than you will need for a single class of 24–30 students, making less saves no time and all but the permanganate and iron solutions are stable for long periods of time. Many of the solutions can be purchased in the

desired concentrations from suppliers. This saves significant preparation time, but increases cost. Formula weights (FW) of solid reagents have been given.

0.50 M solutions, quantities for 100.-mL of solution

Hydrochloric acid, HCl(aq): Gradually stir 4.2 mL of concentrated reagent into about 50 mL of distilled water. Dilute to 100. mL. Store indefinitely.

Copper(II) nitrate, Cu(NO₃)₂(aq): 12.1 g Cu(NO₃)₂ · 3H₂O (FW=241.60 g/mol) in water; stores well

Zinc nitrate, Zn(NO₃)₂ (aq): 14.9 g Zn(NO₃)₂ · 6H₂O (FW=297.49 g/mol) in water; stores well

Sodium sulfite, Na₂SO₃(aq): 6.3 g Na₂SO₃ (FW=126.05 g/mol) in water; stores well

0.10 M solutions, quantities for 100.-mL of solution

Potassium permanganate, KMnO₄(aq): 1.58 g KMnO₄ (FW=158.04 g/mol); does not store well

Iron(III) chloride, FeCl₃ (aq): 2.70 g FeCl₃ · 6H₂O (FW= 270.32 g/mol); can be stored for a few months

Iron(II) sulfate, FeSO₄(aq): 2.78 g FeSO₄ · 7H₂O (FW=278.03 g/mol); stores fairly well

Ammonium meta-vanadate, NH₄VO₃(aq): 1.17 g NH₄VO₃ (FW=116.99 g/mol); stable

Oxalic acid, H₂C₂O₄(aq): 1.26 g H₂C₂O₄ · 2H₂O (FW=126.07 g/mol); stable indefinitely

Discussion and Prelaboratory Instruction

This is a reagent-intensive experiment, calling for extensive preparation on your part, but the students can easily complete the entire exercise in a standard laboratory period. Although it isn't mentioned in the student manual, a second 24-well plate makes a good pipet holder. Plates that have become stained from use are quite suitable for this purpose.

If you have prepared 1.0 M solutions of HCl, Cu(NO₃)₂ and Zn(NO₃)₂, they can be substituted for the 0.50 M solutions in Part A, but solutions more dilute than 0.50 M may not give sufficiently obvious results. The copper nitrate and zinc nitrate solutions should have the same concentrations.

Be fairly precise with the KMnO₄, FeCl₃ and FeSO₄ solutions, as students are asked to quantify the stoichiometry involved.

Oxalic acid and hydrochloric acid solutions are corrosive; oxalic acid is a skin and eye irritant. The KMnO₄ solution will stain skin and clothing. In Step 6, sulfuric acid is used only in 6a; 6b uses peroxide and permanganate without sulfuric acid, while 6c uses only permanganate and oxalic acid solutions.

The reactions in Part D, Step 7, produce SO₂(g) and Cl₂(g), both of which have strong, unpleasant odors. If your laboratory is not well ventilated, consider doing that step in the fume hood.

Notes on the Procedure

Students will be concerned that some combinations don't produce reactions. Help them to understand that these reactions involve electron transfer, which can only go in one direction.

It is very important that they pay strict attention to drop quantities in Part B, as they will be asked to make a quantitative determination of the mol ratio involved in the iron(II)-permanganate system.

Small test tubes may be substituted for the beakers/flasks in Part D, but mixing is more difficult and less efficient.

Expected Results

Part A.

1. Bubbles of gas released as magnesium dissolves.

Part B.

2. Surface of zinc turns dark. More observant students will also notice that the blue color of the copper(II) solution turns to green or colorless.
3. No apparent reaction.

Part C.

4. The iron(II) sulfate takes away the purple color of the manganese. (A common error here is for students to think that the permanganate is changing the color of the iron(III) solution.)
5. After the 4th or 5th drop, the purple color of the permanganate persists.

Part D.

6.
 - a. The purple color of the permanganate ion is lost and bubbles of gas are evident.
 - b. Bubbles of gas, but mixture turns murky brown.
 - c. Heating causes the solution to turn from purple to reddish to colorless; gas evolution occurs, but may not be detected due to the slowness of the reaction.
7.
 - a. Heating speeds the change from yellow (VO_2^+) to blue (VO^{2+}). The pungent odor of SO_2 is detected.
 - b. Rapid return to yellow color and evolution of chlorine gas are both noted.

Answers to Prelaboratory Questions

1.
 - a. Aluminum Al^{3+}
 - b.

(i) $\text{Al}(s) \rightarrow$	$\frac{\text{Al}^{3+}}{4 e^-}$	+	$\frac{\text{Oxygen } \text{O}^{2-}}{3 e^-}$
(ii) $\text{O}_2(g) +$	$\frac{4 e^-}{2}$	\rightarrow	$\frac{\text{O}^{2-}}{2}$
 - c. (i) is a(n): oxidation (ii) is a(n): reduction
2. $4 \text{Al}(s) + 3 \text{O}_2(g) \rightarrow 2 \text{Al}_2\text{O}_3(s)$
3. Identify each of the following processes as an example of oxidation, reduction, or both.
 - a. Reduction
 - b. Oxidation
 - c. Both—iron is oxidized, oxygen gas (from the air) is reduced.
 - d. Both—oxygen from the peroxide is oxidized to O_2 and reduced to H_2O .
 - e. Both—the stain is oxidized by the bleach, bleach is reduced by the stain.
4. Hold the vessel about 15 cm (6") in front of your face and use your other hand to gently waft the vapors toward your nose.

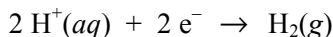
Answers to Analysis and Conclusions

Note: If you have not covered the ion-electron (half-reaction) method for balancing redox equations, you may choose to skip questions 7b, 11c, and 12c.

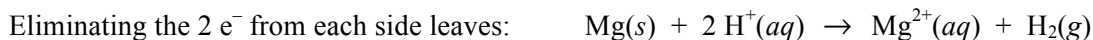
Part A.

1.
 - a. The metal, Mg.
 - b. +2 (or Mg^{2+})
 - c. Oxidized; electrons were lost.
 - d. $\text{Mg}(s) \rightarrow \text{Mg}^{2+}(aq) + 2 e^-$

2. The two possibilities are hydrogen ion being reduced to hydrogen gas and chloride ion being oxidized to chlorine gas. Since magnesium is being oxidized, the gas must be the result of reduction, thus, hydrogen.



3. Addition gives $\text{Mg}(s) + 2 \text{H}^+(aq) + 2 \text{e}^- \rightarrow \text{Mg}^{2+}(aq) + 2 \text{e}^- + \text{H}_2(g)$



Part B.

4. a. Zinc in contact with Cu^{2+} turns dark; reaction. Copper in contact with Zn^{2+} does nothing.
 b. $\text{Cu}^{2+} + \text{Zn} \rightarrow \text{Cu} + \text{Zn}^{2+}$; this shows copper ions reacting with zinc metal.
 c. (i) Cu^{2+} (ii) Zn
 (iii) Zn (iv) Cu^{2+}

The intent is for students to recognize that the substance that gets reduced is the oxidizing agent, and vice versa.

Part C.

5. a. FeSO_4 (or Fe^{2+}). Students have trouble recognizing that loss of color signifies reaction.
 b. Since the concentrations were the same but volumes were different, reaction must involve several iron(II) ions for each permanganate ion. (The actual ratio is 5:1, and many will come close to this, assuming they were careful in carrying out that step and added only one drop at a time.)
6. The color change was the result of one of the iron ions being converted to the other oxidation state.
- a. Reaction must have involved iron(II) reacting, so

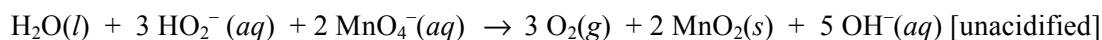
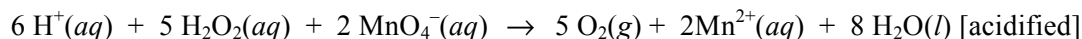
$$\text{Fe}^{2+} \rightarrow \text{Fe}^{3+} + \text{e}^-$$
- b. Oxidized; it must lose an electron to go from +2 to +3.
 c. Reduced; permanganate is acting as the oxidizing agent, so it must be reduced.
 d. The oxidizing agent is MnO_4^- , the reducing agent is Fe^{2+} . (Don't accept "iron" here. Insist on some indication of the charge.)
 e. $5 \text{Fe}^{2+}(aq) + \text{MnO}_4^-(aq) \rightarrow 5 \text{Fe}^{3+}(aq) + \text{Mn}^{2+}(aq)$

Part D.

7. For the reaction between hydrogen peroxide and potassium permanganate
- a. Presence of the acid causes a different product than is obtained without the acid. In acid, the oxidation state of manganese changes by 5, from +7 to +2. With no acid present, the change is from +7 to +4, a change of only 3. The stoichiometry of this reaction is pH-sensitive.

(**Note:** For the unacidified system, have students balance as though the reaction took place in basic solution, with H_2O_2 present as HO_2^- ; you will have to tell students this. If you'd prefer not to go into that, they will still get the correct mole ratio of peroxide to permanganate by using H_2O_2 , but water and hydroxide ions will be distributed differently.)

- b. Oxygen gas; hydrogen peroxide spontaneously decomposes to water and oxygen gas, the presence of permanganate ion simply speeds up the process.



8. The reaction is very slow at room temperature, but goes quickly above about 50 °C. Most students don't wait long enough to see any reaction before heating the container.

9. It was more like the reaction involving sulfuric acid—the product was a clear, colorless solution. The oxalic acid provided the hydrogen ions needed to convert permanganate ion to manganese(II).
10. Carbon dioxide, $\text{CO}_2(\text{g})$.
11. The sulfite ion changes vanadium from the +5 state to the +4 state.
- reduction
 - oxidized; sulfate, $\text{SO}_4^{2-}(\text{aq})$.
 - $\text{H}_2\text{O}(\text{l}) + 2 \text{VO}_2^+(\text{aq}) + \text{SO}_3^{2-}(\text{aq}) \rightarrow \text{SO}_4^{2-}(\text{aq}) + 2 \text{VO}^{2+}(\text{aq}) + 2 \text{OH}^-(\text{aq})$
12. a. oxidation
- changed back to $\text{VO}_2^+(\text{aq})$; turns from blue to yellow.
 - $2 \text{VO}^{2+}(\text{aq}) + 2 \text{OCl}^-(\text{aq}) \rightarrow 2 \text{VO}_2^+(\text{aq}) + \text{Cl}_2(\text{g})$

Experiment S-3 Teacher's Guide

Molar Volume of a Gas

Placement

In Chapter 5 during discussion of gas laws

Approximate time for completion

45-50 minutes

Approximate preparation time

About 30 minutes, depending on whether you already have the hydrochloric acid solution

Materials

Apparatus (one per group unless otherwise noted)

Analytical balance – one per class will suffice

Eudiometer (gas measuring tube), 50 x 0.1 mL

Rubber stopper, #00, 1- or 2-hole

Copper wire, about 5 cm – gauge is not critical, but not too stiff

Magnesium ribbon

Sand paper or steel wool for cleaning magnesium

Beaker, large – if you have tall-form (Berzelius) 1-L beakers, the leveling vessel will probably not be needed

Leveling vessel – large cylinder for equalizing liquid levels, 1 or 2 per class. 1-L plastic graduates work well for this.

Barometer – one per class

Thermometer

Reagent Solutions

6 M HCl(aq), 15-20 mL/group

Preparation of Reagent Solutions

The molarity is not critical here. If you're preparing just enough for this experiment, starting with concentrated (12 M) acid, enough for a class of 24 students working in pairs, slowly and with constant stirring, add 100. mL of concentrated acid to 100. mL of distilled or deionized water.

Discussion and Prelaboratory Instruction

It is very likely that students did essentially the same experiment in their first-year class, possibly the small-scale version, using a 10-mL graduated cylinder. If they did use a eudiometer (gas measuring tube), then the only procedural difference here is in how the mass of Mg ribbon is determined. In the usual protocol, the mass of magnesium is determined by comparing the length of ribbon used with a known mass for 100. cm of the same ribbon. This assumes that the ribbon has a uniform linear density, which may or may not be the case. In the present version, the student is directed to freshly clean the ribbon of oxidation, then weigh it directly, using an analytical balance. This should give three significant digit precision.

If your students are not familiar with the basic process, explain how the acid will migrate down the inverted tube and react with the magnesium, but not the copper (an interesting application of the relative activities and/or reduction potentials for the two metals, relative to hydrogen).

Remind students that the solution remaining after each trial is acidic, and must be neutralized. They will calculate the mass of baking soda needed for the neutralization, but it's pointless for them to actually weigh that amount out. Instead, they can use a plastic teaspoon to sprinkle about a level spoonful into the beaker containing the acidic solution. It will fizz, releasing $\text{CO}_2(g)$, until the acid has been consumed.

Students will need the barometric pressure (presumably from you) and the temperature of the solution remaining after reaction. They will also need access to a table showing the vapor pressure of water as a function of temperature. One is supplied at the end of this guide.

Notes on the Procedure

The first trial takes much longer than the 2nd and 3rd, so don't let students decide on their own that they can't possibly finish; they can. Place 2 or 3 large containers of water, to be used as leveling vessels, at locations around the lab, so that students don't have to transport the glass tubes too far. Make sure they notice that they only need to make the levels eve if the difference between inside and outside level exceeds about 5 cm.

Expected Results

Values obtained for R should be consistent from one trial to the next, but the average will probably only match the accepted value to two significant digits. Answers tend to run slightly above the expected $0.0821 \text{ L atm mol}^{-1} \text{ K}^{-1}$.

Answers to Prelaboratory Questions

1. The fizzing will stop; carbon dioxide is released as the baking soda reacts with excess acid.
2. It is insoluble in water, and less dense than water. (Students overlook the former.)
3. Leveling the water inside and out means that the total pressure in the tube is equal to the outside barometric pressure. Since the tube contains both hydrogen and water vapor, the pressure of hydrogen alone must be less than the barometric pressure. The vapor pressure of water at the experimental temperature will be subtracted from the barometric pressure.
4. (730 mm Hg was selected as a conservative approximation for the pressure of dry hydrogen.)

$$(3.0 \times 10^{-3} \text{ L}) \times \left(\frac{6.0 \text{ mol HCl}}{\text{L}}\right) \times \left(\frac{1 \text{ mol NaHCO}_3}{1 \text{ mol HCl}}\right) \times \frac{84.01 \text{ g NaHCO}_3}{1 \text{ mol NaHCO}_3} = 1.5 \text{ g NaHCO}_3$$

$$(0.08206 \text{ L atm/mol K}) \times \frac{10^3 \text{ mL}}{1 \text{ L}} \times \frac{760 \text{ torr}}{1 \text{ atm}} = 62,370 \text{ mL torr/mol K}$$

$$0.0179 \text{ mol Mg} \times 24.305 \text{ g mol}^{-1} = 0.0434 \text{ g Mg}$$

$$5. (3.0 \times 10^{-3} \text{ L}) \times \left(\frac{6.0 \text{ mol HCl}}{\text{L}}\right) \times \left(\frac{1 \text{ mol NaHCO}_3}{1 \text{ mol HCl}}\right) \times \frac{84.01 \text{ g NaHCO}_3}{1 \text{ mol NaHCO}_3} = 1.5 \text{ g NaHCO}_3$$

$$6. (0.08206 \text{ L atm/mol K}) \times \frac{10^3 \text{ mL}}{1 \text{ L}} \times \frac{760 \text{ torr}}{1 \text{ atm}} = 62,370 \text{ mL torr/mol K}$$

Answers to Analysis and Conclusions

1. Student answers. The parenthetical question is rhetorical, intended to direct the student to the stoichiometry of the reaction: magnesium and hydrogen are in a 1:1 mol ratio.
2. The vapor pressure of the water at the experimental temperature is subtracted from the ambient barometric pressure. Chances are that the number of decimal places shown in the table is greater than the number given in the barometric pressure reading. Students must follow the rules for addition with significant digits
3.
 - a. Make certain that students understand that they must use the combined gas law here (Equation 1 from the Introduction), and not the ideal gas law. P_1 and T_1 don't change, so the relationship is $V_1/n_1 = V_2/n_2$, where n_1 and V_1 are their experimental values (n_1 is their answer to question 1, above, and V_1 is their measured volume of hydrogen). Solve for V_2 , if $n_2 = 1$ mol.
 - b. Students can either use the same n_1 and V_1 as in 3.a, or just change P and T , using their answers to 3.a as V_1 , and again solving for V_2 .
4. Student answers. Once again, they use their experimental data for this, not calculated values.
5. Student answers. Average deviation, percentage error ("relative error") are discussed in detail in Experiment S-1. Expect the calculated value of R to be slightly greater than the accepted value.
6. The density of mercury is 13.6 g mL^{-1} , so a 50. mm height difference for water corresponds to a difference of $50. \text{ mm H}_2\text{O} \times (1 \text{ mmHg}/13.6 \text{ mm H}_2\text{O}) = 3.68 \text{ mm Hg}$. Since the total pressure is on the order of 760 mm Hg, this introduces an error of less than 0.5% (0.484%).

A table showing the vapor pressure of water as a function of temperature follows.

Vapor Pressure of Water at Various Temperatures

<i>Temperature, °C</i>	<i>Pressure, mm Hg</i>	<i>Temperature, °C</i>	<i>Pressure, mm Hg</i>
0	4.580	31	33.696
5	6.543	32	35.663
10	9.209	34	39.899
15	12.788	36	44.563
16	13.634	38	49.692
17	14.530	40	55.324
18	15.477	45	71.882
19	16.478	50	92.511
20	17.535	55	118.03
21	18.650	60	149.37
22	19.827	65	187.55
23	21.068	70	233.71
24	22.377	75	289.10
25	23.756	80	355.11
26	25.209	85	433.62
27	26.739	90	525.77
28	28.349	95	633.91
29	30.044	100	760.00
30	31.823		