Chapter 5 Specific Gravity and Hardness of Gemstones

Introduction

In this exercise you will learn about critical properties that can be used to help identify gemstones. One, **density measurement**, is harmless to most gemstones when they are tested. The other, **hardness**, is destructive and should only be done to uncut (rough) gem materials and even then care should be taken not to break off a piece of the specimen.

Density and Matter

When you think about matter, most people forget that or don't know that, it is mostly empty space. The fact is that electrons flying around atoms fill most of the space in any solid. It seems very far from our ordinary experience. That a very dense nucleus takes up very little space in the atom, but has most of the mass is also a bit of a surprise. The average person probably knows that the nucleus of an atom holds most of the atomic mass and that the electrons orbit at a relatively far distance from that nucleus. But they may not equate any of that with density (or the other related term specific gravity = SG). Figure 1 shows a model of an atom.

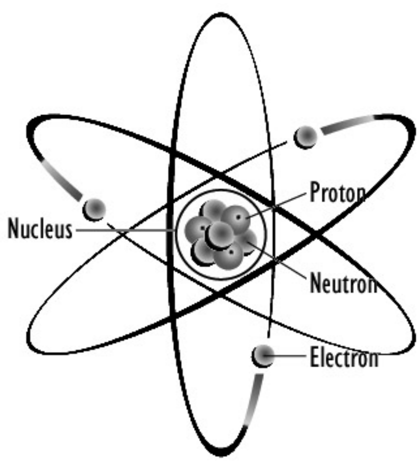


Figure 1. Lithium atom. Most of the space in any matter is empty.

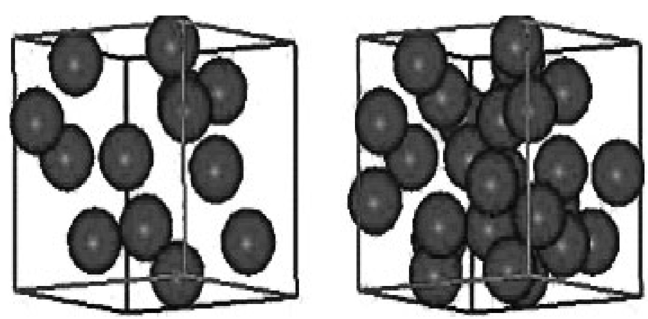


Figure 2. If these atoms are in boxes of equal volume, clearly the one on the right has a higher density.

When asked what is the densest thing, people will remember the black hole out in space menacing everything around it, but they may not have a good idea how density effects their lives. What is density? It is the amount of mass or weight per unit of volume of a substance (Figure 2). All substances have density, but that of gases is very small and metals such as gold and platinum have very high densities. Usually density is noted in grams per cm^3 (centimeters $^{\textbf{cubed}}$), but it could be in pounds per cubic foot, etc. Specific gravity, a related numerical expression has no units at all (It is called a dimensionless quantity [number] because the units cancel and you only write a number.)

Density itself is a factor of at least several things when it comes to gems and minerals. 1) **chemical composition** (atomic mass), 2) **chemical bonding or packing**, 3) **Mixed density** due to more than one substance combined or nonuniform mixing, 4) **temperature** of the substance. Water density changes considerably with temperature (vapor, liquid, solid)!

Four Reasons for Density Variation

1) Atomic Mass: Different atoms and isotopes have different masses due to the number of protons and neutrons that the atoms are made up of.

2) Atomic and Molecular Bond's: The strength and structure of the chemical bonds determines the distance between atoms (hence two substance made of carbon, diamond and graphite, have very different densities.

3) Mixed Density or Nonuniform Density: When there are two or more substances that compose the object or substance, it is mixed density. As an example, the amount of peanuts in Cracker Jack would make its density variable. More peanuts, denser Cracker Jack.

4) Temperature: Substances may expand or contract as temperature changes.

No gem mineral is too dense to wear as a ring stone, but some gems are certainly much denser than others. The difference in density of gems may be used to distinguish between them, but this assumes that they are uniform throughout and have no inclusions, cracks, or empty spaces within them. As well, **density is not unique, and gems may overlap in density**.

The word “overlap” is because some gem minerals have a range of density. One reason for this is solid solution. For instance, **peridot** (the **ultramafic** mineral **olivine**) has a simple solid solution. The ratio of magnesium (Mg) and iron (Fe) varies between the two endmembers of the **solid solution series**: **forsterite** (Mg-endmember) and **fayalite** (Fe-endmember). When ions of equal charge and nearly equal size substitute for one another, the solid solution is said to be simple. Generally if the sizes of the ions are nearly the same, such as in olivine where Mg and Fe are, the solid solution can occur over the complete range of possible compositions and the solid solution series is said to be complete. Fe^{+2} <=> Mg^{+2} Fe^{+2} ionic radius is 0.78 angstroms and Mg^{+2} is 0.72 (very close in size) allowing complete substution: Olivines’ formula can be Mg_2SiO_4 (forsterite) 3.27 gm/cm^3-Fe_2SiO_4 (fayalite) 4.39 gm/cm^3. Clearly iron is denser than magnesium. Interestingly their hardness are the same at Mohs 6.5!

Volume

Volume a quantity. It is the three-dimensional space occupied by a liquid, solid, or gas. Common units used to measure volume include liters, cubic meters, gallons, milliliters, teaspoons, and fluid ounces.

We will use the milliliter, which is the volume of a cube, one centimeter on each dimension.

Because gems are small, solid, and **irregular in shape**, it is not easy to measure their volume. The mineralogist or gemologist who constantly is faced with identifying stones can not spend the time or may not have enough material to cut a cubic centimeter of material. What is to be done?

The answer is simple rather than cutting a piece of stone of a known volume, why not **displace water with the gem**? The displaced volume is the gem or mineral's volume.

Specific Gravity

Well, as it turns out, it is **even easier and more accurate to weigh a gem in water** and in again in air and figure out a gems "**specific gravity**" than it is to measure its volume. As we will learn, specific gravity is almost the same a density. For us they are identical except for small differences in water density varying with temperature (water is at its densest at 4^{o} C).

Density/**Specific gravity** is a **non-destructive** method of testing that requires at least two steps. 1) a measurement of a minerals mass (or weight) in air and 2) a second measurement in water. Actually, this is generally the easiest way to calculate specific gravity, but there are other methods.

Hardness

Hardness is destructive, in that is requires a sample be scratched or at least proven to be harder than all test objects by scratching them.

It is best to do a hardness test on a piece of gem rough (uncut material). *Scratching a cut gem is wasteful at best.* Some books suggest scratching on an inconspicuous part of a gem. This may work with opaque gems.

Geologists and gemologists use **Friedrich Mohs**' scale that was created in 1812 and is one of several ways of testing hardness of materials. It is essentially "scratchibility," what mineral scratches what. In the good old days, jewelers felt that anything harder than a hardened steel file, about 6.5 was a gemstone. The file may have wrecked good stones by applying too much stress! Mohs' scale is only relative and lists 10 minerals in order of scratchibility (Figure 3). Compared to another commonly used scale, diamond is quite a lot harder than everything else on the scale, while talc is the softest.

1. Talc.
2. Gypsum.
3. Calcite.
4. Fluorite.
5. Apatite.
6. Orthoclase (feldspar).
7. Quartz.
8. Topaz.
9. Corundum.
10. Diamond.

Figure 3. Mohs' Scale of hardness.

Uses of These Test

Both of these methods lend themselves to a quantitative approach to identification (See **Table 1** a separate handout). You can compare your results to tabulated results from published sources. They are relatively easy tests, but precision is important. Other physical properties such as color, luster, optical properties, etc., can be used to help eliminate choices when it is found that more than one substance has the same value. It is certainly possible for two gems to have fairly close densities and hardness's because gems must be durable and are usually harder than quartz (7 on Mohs' Scale). Since silica/quartz dust is everywhere, you don't want a softer gem that will lose its polish.

Hardness, of course, also means that you should store different gems in different parcels or you could experience scratching and stone ware. Even diamonds can and do scratch each other because their hardness is directional. One mineral, kyanite, varies from H = 5 to 7 dependent on mutually perpendicular crystal directions. So kyanite gems should clearly not be stored together while traveling.

Procedure

In this lab you will collect data on unknown samples. The samples will be used again in future labs and data from this exercise could be needed for later. Students should all begin by determining the density/specific gravity of their samples. Later we will compare everyone's results and any results that differ greatly from the norm will be eliminated.

You will test density/specific gravity several different ways so that you learn to be flexible and able to use what is at hand.

After you have tested the density/specific gravity you can test the hardness as needed. Both density/specific gravity and hardness are tabulated together (see Table 1). If gem rough is not available, **check with your instructor before trying to scratch a cut stone**! Refer to Lab One or the chart below (**Table 1**) for testing the hardness of minerals using **Mohs' scale** of hardness.

As you are recording specific gravity or hardness you will also have an opportunity to observe color, luster, cleavage (**on gem rough only; do not break samples!**), and fracture. Record these in Table 1.

Density/Specific Gravity

Specific gravity (SG) is the weight (or mass) of a mineral in air divided by the weight of an equal volume of water to that of the mineral (See Figure 4). Water varies only slightly in weight over our accustomed living temperatures, but keep in mind that the water will be room temperature and not much colder or hotter.

How do we get an accurate volume of the mineral? **Firstly the easiest way to get an accurate volume is to not measure it's volume at all!**

Instead use **Archimedes' Principle** that states "*when an object is immersed in water, its weight is precisely less than its weight in air by the amount of water displaced by the object*."

$$SG \equiv \frac{Weight\ of\ object\ in\ air}{Weight\ of\ object\ in\ air - Weight\ of\ object\ in\ water}$$

Figure 4. The calculation of specific gravity.

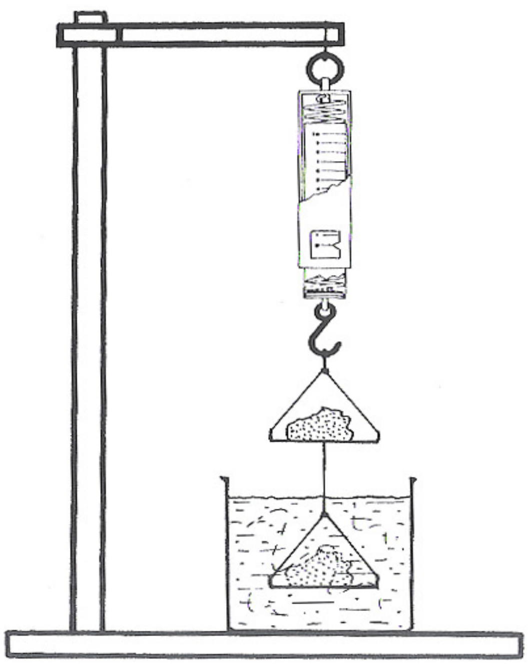


Figure 5. Weighing a mineral in air or water.

It is easy to do this with an scale and a contraption (see Figure 5) that weighs samples in water.

$$Density = \frac{Weight}{volume\ of\ \ water\ displaced} = \frac{Weight}{volume\ raised}$$

Figure 6. This measure of density is essentially the same number as SG.

But first let us try a few simpler methods.

Doing a little extra work will give you an idea of the different methods. The experiments are ordered to give rough estimates first and then lastly you will go to the electric balance for several more accurate results!

A. Determining Density by Weight and Displacement

Four (4) samples of mineral are available determine their weight and then use a graduated cylinder to determine their volume. **Each group member is responsible for one measurement.** Record your results below and then later they will be presented to the class for tabulation and later evaluation.

Before you measure any volumes, look at Figure 7; the **meniscus** is a curve in the upper surface of a liquid close to the top of the container. It happens because of surface tension. In our case, using water, the meniscus will be concave. By convention, the water level is measured from the bottom of the meniscus curve to the closest line of the graduated cylinder or other container (See Figure 8).

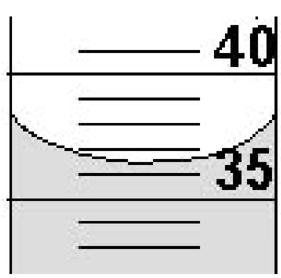


Figure 7. Using the meniscus, the volume reads as 36.5 ml.

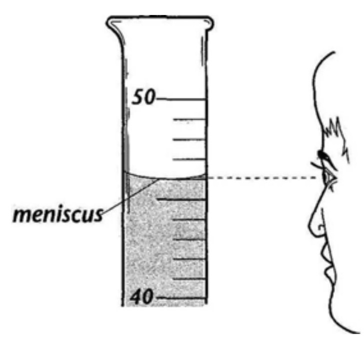


Figure 8. Everyone attempt this. What is the volume in mls?

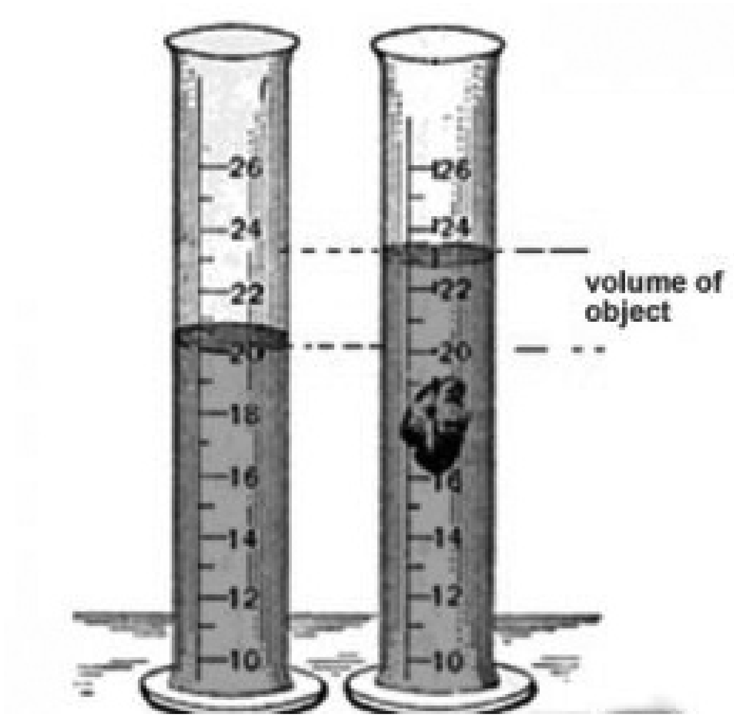


Figure 9. A volume change. The mineral is suspended on a piece of string.

Procedure:
Step 1 Choose one sample at a time; all students watch and help, but one student does all steps; “Practice makes perfect.”). All students try all the steps for one sample.

Step 2 Weigh the sample tied with a string in air (the weight of string is negligible).
Sample # = _____ Weight = _________

Step 3. Fill a graduated cylinder with water and record the volume. V_1= ________

Step 4. Immerse the sample in the water and record water level. V_2=________

Step 5. Calculated displaced volume by subtraction, which equals the volume of the sample in milliliters.

V_2 - V_1 =__________= the volume of the sample (or volume raised) (Figure. 9).

Use Figure 3's calculation to get the density of the sample. Record results on the next page.

Sample number	Weight of sample in air	Volume of water displaced	Density (several values may be recorded for each sample)

We Can't Do this today, a demo later when the overflow buckets arrive!

B. Determination of Density/Specific gravity by the overflow method

If you can get a container of water that is just filled and then immerse a stone of known weight into it, the overflow will be a volume of water equal to that of the stone (Figure 2). The volume of water can be carefully measured using a well-calibrated and accurate volumetric flask or graduated cylinder. This method is particularly valuable for larger objects.

Though the illustration clearly shows how to set this up, remember to use the **meniscus** to get the most accurate result. Only do one mineral assigned by your instructor.

Sample number	Weight of sample in air	Volume of water displaced	SG (several values may be recorded for each sample)

C. Determine the specific gravity using the Jolly Balance

Each student should do only one sample in this experiment. Group samples will again be tabulated.

The Jolly balance is a simple yet relatively precise instrument for measuring the specific gravity of a sample. With the set up shown, you should be able to calculate specific gravity; however, this method is still more complicated than using the electronic balance method.

The idea here is that the length to which a spring is stretched is proportional to the mass of the object suspended on the balance. The spring's behavior may change slightly as it stretches but we will consider this to be negligible.

<u>Be careful! The spring is very delicate!</u>

$$SG = \frac{L_2 - L_1}{L_2 - L_3}$$

You can use the two pan systems illustrated below to first weigh (or stretch the spring) without immersing in water (**It is critical that you leave the lower pan immersed in water for both weighings**!) and then use the lower pan for weighing with water. Warning 1) once the sample is wet you can not use it again for dry weight until thoroughly dry, and 2) at all cost keep the upper pan dry!

The spring will not stretch as far when the sample is immersed because of **Archimedes' principle** (p. 5), but the difference for a small sample will not be very much, so you must be very careful (See Figure 11 below).

Specific gravity is determined by noting the **original length of the spring (L_1)** (See Figure 11 **Example A** below)., the amount of lengthening of a spring when the mineral is placed in the upper pan **in air (L_2)** (See Figure 11 **Example B** below)., and the lesser stretching amount **when the same sample in the lower pan it is immersed in water (L_3)** (See Figure 11 (See Figure 11 **Example C** below).

Step 1. Before adding any sample set up the balance and make an initial measurement, L_1. To do this place the lower pan (Pan 2) into a beaker of water so that the straight up wire breaks the water and three "pan" wires are immersed (See Figure 11 Example A).

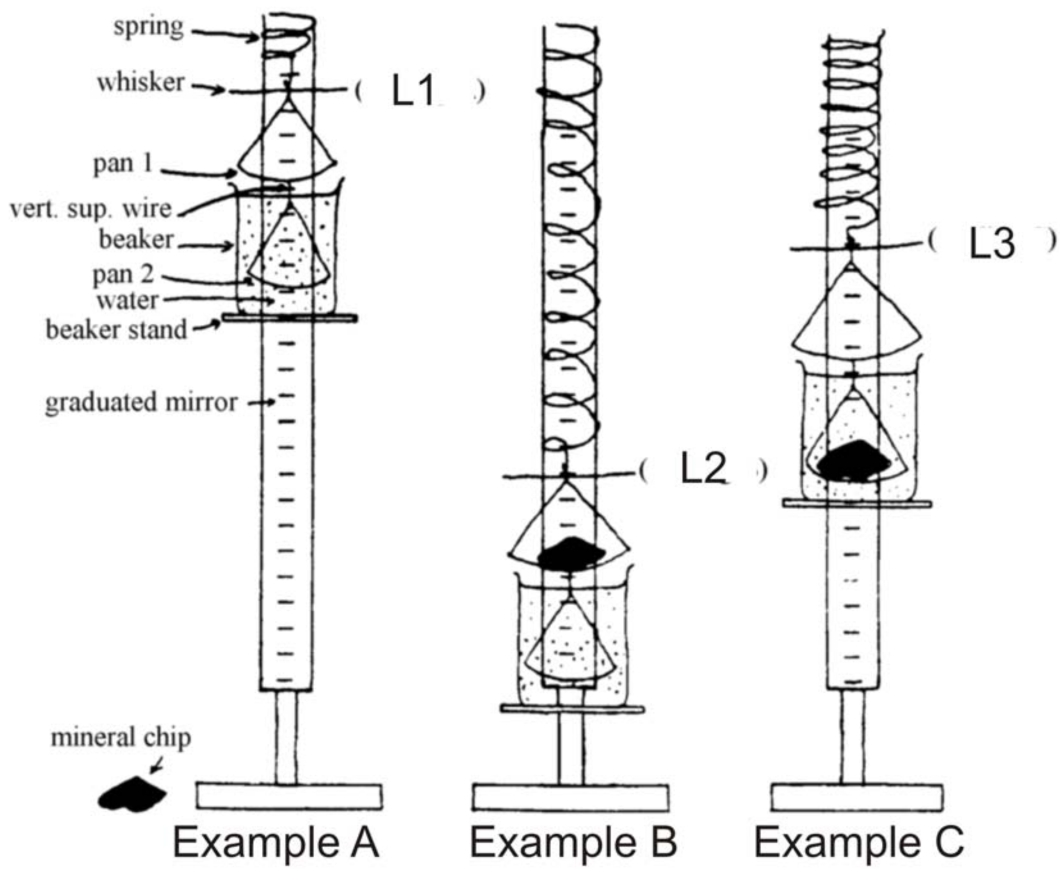
Then use the **parallax method** to look at the horizontal whisker and level your eye (and your body) so that you see only **one whisker when you look at the mirror and the real whisker**.

At this point you can read L_1 and record it in the table below. [Parallax in optical sights–You do this because of in optical sights parallax refers to the apparent movement of the reticle, or whisker, in relationship to the target when the user moves his/her head laterally behind the sight (up/down or left/right), that is it is an error where the whisker does not stay aligned with the eye's view of the ruler next to the mirror in the Jolly Balance.]

Step 2. Put a moderate sized piece or pieces in the top pan (Pan 1) (See Figure, Example B B); make sure that the lower pan's wires are immersed and that only a single wire from the lower pan cuts the surface of the water. With the platform loosened, move the platform holding the beaker downward until the spring stops stretching. Measure L_2 (this will be the greatest length measured today for any sample).

Step 3. Remove the sample from the upper pan carefully so that they do not fall in the water.

Step 3. Immerse the same samples in the lower pan. Remember that the spring will move upward this time (since the weight of the water displaced is taken off the spring). Level your eye on the scale and read off L_3 (Figure 11 Example C). Record results on the next page.



Rec ord

Figure 11. How to use the Jolly Balance. From Rance et al. 2011.

your results below and those of your classmates for the samples. Several students may have been assigned the same sample so 3 spaces are given for each SG result below.

Sample #	L1	L2	L3	SG	SG	SG

D. Determine the specific gravity using an electronic scale

This is the preferred method for accuracy (the ability of a measurement to match the actual value of the quantity being measured) and precision (in this case the number of significant digits [decimal places] to which a value has been reliably measured).

The electronic scale gives a reading to 0.0001 grams.

Step 1. Use the lower pan =P1 in Figure to weight the sample. Record your result.

Step 2. Put the gem in the immersion pan, try and avoid bubbles! Record your weight in water.

Use the formula:

$$SG \equiv \frac{Weight\ of\ object\ in\ air}{Weight\ of\ object\ in\ air - Weight\ of\ object\ in\ water}$$

Figure 12. Calculation using a digital scale.

Record your SG results in the table on the next page.

Sample number	Weight of sample in air	Weight of sample in water	SG value. Use calculation from Figure 12

Hardness

After you have completed the specific gravity measurements, look at your boxes of rough gem materials and use the test tools, glass plate, fingernail to quickly divide your samples into 3 categories: **hard, intermediate, and soft**. This makes 3 groups, harder than 5.5, softer than 5.5 but harder than 2.5, and softer than 2.5.

Now that you have these groups, you can arrange minerals according to increasing hardness by seeing if one mineral scratches another in the box, then you can use the hardness test points (if time is short we will skip this; we do not have hardness points yet).

Make as small a scratches as possible remembering to always make the scratches in *a direction away from you to avoid getting scratched by the test tools or hit by breaking mineral fragments*!

Now compare your hardness range to that in Table 1 (also you can look in your book). Do you find mineral names that are within the hardness and specific gravity ranges of our specimens?

It is quite probable that they are the correct mineral names. However, if some of our samples overlap in range on the table, you may consider other properties learned in Lab 1 on minerals, such as color, luster, streak, cleavage and fracture, or more specific tests such as reaction to hydrochloric acid.

Many of the minerals you may already know by sight, but this lab was intended to give you experience making accurate and reproducible measurement of density and SG.

Results Table

Sample #	SG/Density	H	Other properties	Mineral name

Notes

Given that water has a density of 1gm/milliliter (at 4º C), you can convert the value of volume directly to weight of water displaced and divide that weight directly into the weight of the sample. The 4º C is because that is the temperature when water is densest and water will vary with temperature. Presumably filling a greater volume if either cooled or heated beyond that temperature.

One milliliter of water is 1 g at 4 °C.
Typical coins: a euro is 7.5 g and a US penny is 2.5