How Accurate are Volume Measurements?

Background:

Lab measurements are often used on the AP® Chem exam to test your understanding of significant figures.

The greater the accuracy and precision of the lab equipment, the greater the number of significant figures that can be used in recording the data.

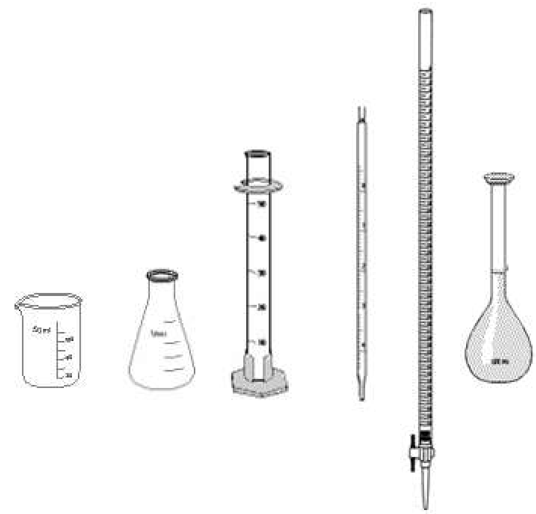
> Volume measurements are most often made using beakers, flasks, graduated cylinders, volumetric flasks and burettes. The accuracy of each instrument should be shown by recording measurements with these instruments with the proper number of significant figures.

You can increase accuracy of volume measurements (sig figs) by

(1) increasing measured amount of liquid

(2) using more accurate equipment (listed in order of increasing accuracy)

    Graduated beakers and graduated flasks
    Graduate Cylinders
    Burettes and Pipettes
    Volumetric Flasks



This lab will compare the accuracy of a graduate cylinder.

As a reminder, your procedure, observations, and data are to be entered in your lab notebook as you do the experiments. Do not write your data down on separate paper and then recopy it to your lab notebook. Using a lab notebook as you do the experiment may seem awkward at first, but after a few times it becomes second nature. This saves you time too since you won't have to rewrite anything.

Since the lab notebook is a live record, your lab notebook will look like it has been in a chemistry lab which is why you should use waterproof ink. Most ballpoint inks are waterproof enough for these labs. If you make an error, **cross out the error with a single line** so that the error can still be seen. NEVER ERASE OR SCRATCH OUT what you write in your lab notebook.

I advise that you write your experiment in first person past tense, but this is not a hard-and-fast rule. When writing labs for colleges, be sure to ask about and follow their requirements.

At the end of these instructions, I have written a sample lab report to show you how the report could be written.
If you like, you may use similar wording.

Equipment Needed for This Experiment

From ChemAdvantage Kit:

Electronic balance
Plastic dish, "weighing dish"

150-mL plastic beaker, 50mL glass beaker
digital thermometer (take off plastic shield to use probe for measuring temperature)
graduated pipette

Student Supplied:
Part I

A dime

Optional: 11.4 carat diamond or emerald

Distilled water (not spring water) You might as well get a gallon since you will be using this for other experiments.

Measuring Mass

Your Balance

You cannot do AP level labs without a balance that has at least centigram accuracy. A typical lab balance with 0.01 g accuracy costs from \$300 to \$500. These lab balances are designed to withstand student abuse.

Your balance is a jeweler's balance, the modern equivalent to Vermeer's balance in the painting, and will be just as accurate as a lab balance, but it is delicate. The balance cannot be used to weigh objects of more than 200 grams. Treat this balance as the delicate instrument it is. Always replace the cover when not using the balance to protect the balance pan from being overloaded.

Woman Holding a Balance by Jan Vermeer
1664 at the National Gallery of Art, Washington

Setting up a Location for your Balance, Setting its Default Parameters, and Taring

1. Decide on a balance location
   You will need a table area of about 3 feet wide by 18 inches deep so that you will have room for the balance, experiment and your lab notebook. It must be a stable surface (not a wobbly card table).

2. Install the batteries for your balance and press the ON button to turn it on.

3. Set your balance unit to grams.
   Check to make sure that your balance is set for measuring grams. The [MODE] button toggles through different units. Toggle so that the "g" symbol is next to the number display. **Always check to see that the units are in grams when you make your measurements.**

4. Learn how to use the auto tare function.
   Chemicals are never put directly on a balance. Traditionally you would place a weighing paper or weighing dish on the balance and find its weight. Then you would add the chemicals to the dish, weigh again and then subtract the two measurements. However, digital balances have an auto-zero function.

   (a) Place the plastic weighing boat onto the balance. If you don't have a weighing dish a simple creased piece of slick paper like magazine paper will do.
   (b) Rather than measuring the plastic weighing boat's weight, press the [TARE] button. The balance will reset to zero with the dish in place.
   (c) With the tared weighing dish on the balance, place a dime (or an 11.4 carat diamond or emerald) on your balance. The dime[1] or gem should weigh about 2.27 grams (+/- .02 g).
   (d) When you remove the dish and dime, diamond, or emerald, the balance will show a negative value which is the tared weight of the weighing dish.
   (e) Turn your balance off.

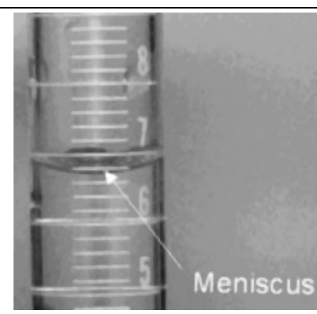
Now that you know how to tare your balance, a word of caution. If the balance is idle for a length of time, the balance will turn off and the tare weight is lost.
If there will be a delay between measurements, you should not use the tare function.

Measuring Volume
Measuring the volume of substances is important in chemistry too. You can use a graduate cylinder to measure volume of liquids. Since liquids and the volumetric labware[2] expand and contract with temperature, volume measurements are most accurate for the temperature the apparatus is designed for. The ideal temperature is normally marked on the apparatus and is usually 20°C.

When measuring volume, you must estimate liquid levels using the markings on the side of the container. This requires some skill.

First, you will often have to deal with a meniscus if you have glass labware.

Water molecules are attracted to glass. Water next to the glass walls of a cylinder will be pulled up the sides by this attraction. The result is a characteristic meniscus that you will see using glassware.
The glassware is calibrated to take this into account and the bottom of the meniscus should be used to determine the measurement.



6.7 mL

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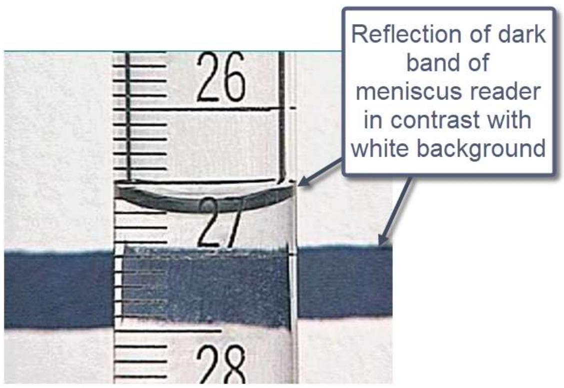
[1] If the dime was minted between 1853 and 1964, it is composed of a silver alloy and will weigh closer to 2.50 g. http://www.usmint.gov/about_the_mint/?action=coin_specifications
[2] Most volumetric lab apparatus is made from borosilicate glass that has a smaller coefficient of expansion than regular glass. Borosilicate glass is less likely to crack because of uneven heating.

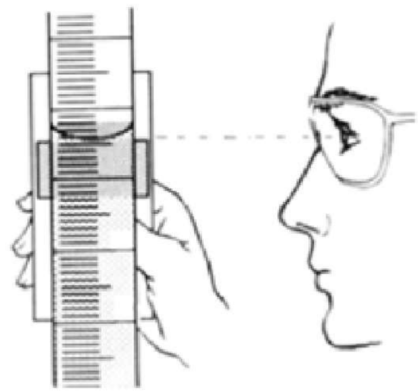
Viewing the bottom of the meniscus is not as easy as shown in diagrams.

An aid that can be used to make the meniscus more visible is a meniscus reader. It is a card with a dark band below a light area.

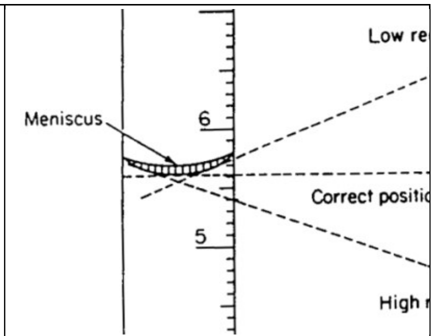
Held behind the labware so that the dark band is just below the meniscus allows the meniscus to reflect the black band in contrast to the light background. The meniscus reader is also useful because it blocks off background clutter as you measure the volume.



26.70 mL



You can cut out this meniscus reader for use in your experiment or make your own with a 3×5 card.

<table>
<tr>
<td>Another important factor is the angle at which you read the markings of the scale and bottom of the liquid meniscus. If you view the scale and meniscus at an angle, you will get a parallax error. The correct reading method is to have your eye parallel with the scale and bottom of the meniscus.</td>
<td>
</td>
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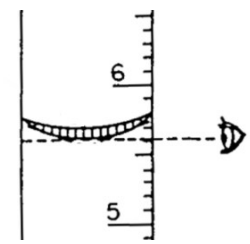
<tr>
<td>If the scale markings are far enough apart, you should estimate the value between the markings. In the diagram to the right, the hundredth of an mL can be estimated. The correct reading that would be entered in the lab notebook would be 5.60 mL.

The hundredth of an mL value is estimated, but it is still a significant measurement.

Your 10-mL graduate has 0.2 mL divisions. So, you will only be able to estimate the tenth of an mL for readings between the scale markings. However, I think it is possible to estimate to within ±2 hundredth of an mL if the water line is level with a marked division.</td>
<td>
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If you have a polymer (plastic) graduate cylinder water molecules are not attracted to the polymer (plastic) as with a glass graduated cylinder. Therefore, a polypropylene graduate cylinder will have a smaller meniscus than a glass graduate when filled with water. Also because of the opacity of the plastic a meniscus reader isn't that helpful.

Find the Accuracy and Precision of the Graduate Cylinder Using a Graph

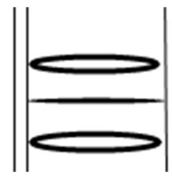
Graduate cylinders are not as accurate as volumetric flasks, but they can be used to measure different volumes. How accurate is the 10-mL graduate over its range of volume measurements? To do this you will find the mass of a series of volumes and then use a graph to plot the data.

Experimental Procedure

1. Pour about 125 ml of distilled water into your 150-mL plastic beaker and allow it to come to room temperature.

2. Take the temperature of the distilled water in the beaker with your digital thermometer. Be sure to switch your thermometer to °C.

3. Weigh the dry 10-mL graduate cylinder. You could zero the cylinder on the balance, but your balance could turn off during the experiment, losing its auto zero point and you would have to start over.



4. Take the cylinder off the balance and, using the plastic pipette, add water till the water level is at the 2.00 mL graduation. Since this is a marked level on the cylinder, I believe you are justified to record the volume to the hundredth of an mL. Estimating between the tenth's markings on these cylinders is difficult, so try to get the measurements to the whole mL. If you find it too difficult to get the meniscus to the exact line, estimate the volume by reading between the lines.

3. Reweigh the graduate with the 2- mL of water.

4. Add water and weigh the graduate with 4-mL, 6- mL, 8-mL and 10- mL of water.

Your calculation of accuracy and, in the case of multiple measurements. To analyze the data, graph the data by using a graphing program to determine the best fit line for the points in the graph.

Graphing tools are commonly used to analyze data. You may use the pre-made Excel graph from the ChemAdvantage lab page to analyze your data. Alternately, you may use a free internet graphing program[3] to perform the same task.

The volume of the water is plotted on the *x*-axis, and since mass of the water and graduate were the experimentally determined values, the mass of the graduate and water is plotted on the *y*-axis.

The Excel graph or an online graphing-analysis program will produce a best fit line so that the sum of the square of the deviation distances of the data points to the line are minimized. This is called a linear regression line which is the standard for best fit lines for linear data.

The equation for the best fit line should also be given in the form: $y = mx + b$
The slope, *m*, g/mL, is the experimental density of water based on the linear regression line.

[3] This site with adds is easy to use:
https://www.nctm.org/Classroom-Resources/Illuminations/Interactives/Line-of-Best-Fit/

Density Table for Distilled Water Mettler-Toledo Instruments

Density Table for Distilled Water (g/mL)

T/°C	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
10.	0.99973	0.99972	0.99971	0.99970	0.99969	0.99968	0.99967	0.99966	0.99965	0.99964
11.	0.99963	0.99962	0.99961	0.99960	0.99959	0.99958	0.99957	0.99956	0.99955	0.99954
12.	0.99953	0.99951	0.99950	0.99949	0.99948	0.99947	0.99946	0.99944	0.99943	0.99942
13.	0.99941	0.99939	0.99938	0.99937	0.99935	0.99934	0.99933	0.99931	0.99930	0.99929
14.	0.99927	0.99926	0.99924	0.99923	0.99922	0.99920	0.99919	0.99917	0.99916	0.99914
15.	0.99913	0.99911	0.99910	0.99908	0.99907	0.99905	0.99904	0.99902	0.99900	0.99899
16.	0.99897	0.99896	0.99894	0.99892	0.99891	0.99889	0.99887	0.99885	0.99884	0.99882
17.	0.99880	0.99879	0.99877	0.99875	0.99873	0.99871	0.99870	0.99868	0.99866	0.99864
18.	0.99862	0.99860	0.99859	0.99857	0.99855	0.99853	0.99851	0.99849	0.99847	0.99845
19.	0.99843	0.99841	0.99839	0.99837	0.99835	0.99833	0.99831	0.99829	0.99827	0.99825
20.	0.99823	0.99821	0.99819	0.99817	0.99815	0.99813	0.99811	0.99808	0.99806	0.99804
21.	0.99802	0.99800	0.99798	0.99795	0.99793	0.99791	0.99789	0.99786	0.99784	0.99782
22.	0.99780	0.99777	0.99775	0.99773	0.99771	0.99768	0.99766	0.99764	0.99761	0.99759
23.	0.99756	0.99754	0.99752	0.99749	0.99747	0.99744	0.99742	0.99740	0.99737	0.99735
24.	0.99732	0.99730	0.99727	0.99725	0.99722	0.99720	0.99717	0.99715	0.99712	0.99710
25.	0.99707	0.99704	0.99702	0.99699	0.99697	0.99694	0.99691	0.99689	0.99686	0.99684
26.	0.99681	0.99678	0.99676	0.99673	0.99670	0.99668	0.99665	0.99662	0.99659	0.99657
27.	0.99654	0.99651	0.99648	0.99646	0.99643	0.99640	0.99637	0.99634	0.99632	0.99629
28.	0.99626	0.99623	0.99620	0.99617	0.99614	0.99612	0.99609	0.99606	0.99603	0.99600
29.	0.99597	0.99594	0.99591	0.99588	0.99585	0.99582	0.99579	0.99576	0.99573	0.99570
30.	0.99567	0.99564	0.99561	0.99558	0.99555	0.99552	0.99549	0.99546	0.99543	0.99540

Density of water at 30.9°C
0.99540 g/mL

Once you have made the graph, print it, and paste it in your lab notebook on your data page.
Compare the slope value to the actual density of the water to determine the accuracy of your measurements.

In analyzing errors, use the slope of the best fit linear regression line to find the experimental density and compare that to the actual density based on the temperature of the water and the density table. This will determine your accuracy.

You can also find the degree of precision by examining how close your data points were to the best fit line. High precision would have your data points on or very close to the best fit line.

Find the deviation of your experimentally determined value of the density of water from the accepted dentistry of water for that temperature.

Once you have found the deviation, calculate the percent error to the nearest whole percent.

I am justifying that as a typical student graduate cylinder is made with a tolerance of 1%.

$$\text{Deviation} = \text{Experimental density} - \text{Correct density}$$

$$\%\ \text{Error} = \frac{\text{Deviation}}{\text{Correct density}} \times 100$$

Sample Lab Report

How Accurate are Volume Measurements?	DATE: *Unambiguous Date* [4]

The accuracy and precision of a 10-mL graduate cylinder

Procedure:

Detailed instructions for this experiment can be found in my Lab Binder.

I allowed 120 ml of distilled water to come to room temperature in a 150-mL plastic beaker.

I then measured the temperature of the water to the nearest 0.1°C.

Using the digital balance, I found the mass of the dry graduate cylinder

I removed the graduate cylinder from the balance and added the distilled water using the plastic dropper. I took care not to splatter water on the sides of the graduate. I added water up to the 2.00 mL mark and then reweighed the graduate.

I repeated adding water in 2 mL increments up to 10.00 mL.

I was able to adjust the volumes to a single drop of water except for the 2-mL measurement where I couldn't get the volume to the exact 2.00 mL mark. So I estimated the volume to be 2.01 mL.

Data: *Temperature of water 25.0 °C*

Volume of water (mL)	*Mass of grad cylinder and water (g)*
0 mL (empty)	*9.15*
2.01	*11.80*
4.00	*13.15*
6.00	*15.14*
8.00	*17.25*
10.00	*19.20*

I graphed the data (volume of water vs mass of grad cylinder and water) using Excel and used Excel's built-in linear regression equation to find the best fit line and equation. In addition, the R^2 *factor was calculated.*

I've taped the printed graph to this lab report.

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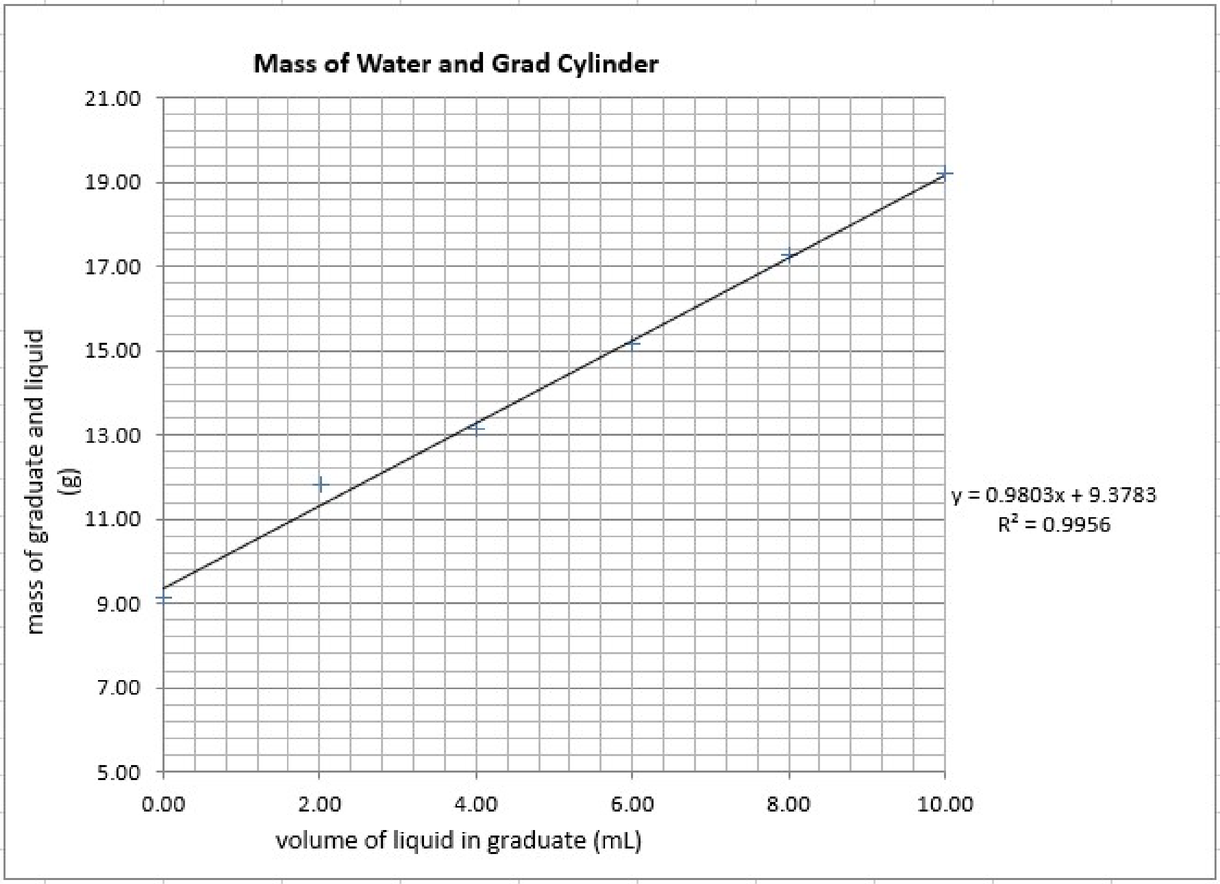
[4] Do not use numbers to denote the month, use the name of the month so that there is no ambiguity as to the date and month.
e.g. 1/12/2007 could mean either January 12th or December 1st depending on the format choice of the writer.



The average density based on the slope of the line (mass/volume) was 0.9803 g/mL rounding to the three sig fig accuracy of my measurements 0.980 g/mL

Using the Mettler table referenced in the instructions indicated that the density of water at this temperature is 0.99707 g/mL @25.0 °C

$$Deviation = Experimental\ density - Correct\ density$$
$$Deviation = 0.980\ g/mL - 0.99707\ g/mL$$

$$\%Error = \frac{-0.017\ g/mL}{0.99707\ mL} \times 100$$

$$\%Error = -2\%$$

The R^2 at 0.995 indicated that my precision was very high. The points are all on the line within the scale of the graph except for the 2-mL measurement.