Purpose

This introductory exercise will familiarize you with a few of the measurements we make in the chemistry laboratory and the level of uncertainty associated with each one.

We use quite a few measuring devices in the chemistry lab, but we are typically measuring two simple properties - **mass** and **volume**. Mass measurements are typically made on **balances**, while volume measurements are made on a wide range of devices like **beakers**, **graduated cylinders**, **transfer pipets**, **burets**, and others.

We will look at three of these today - a mass measurement device and two volume measurement devices.

Measuring mass with the analytical balance

For measuring mass, our laboratory is equipped with **analytical balances**. The analytical balance is a high-quality instrument capable of measuring masses with both high accuracy (correctness) and high precision (reproducibility). The trade-off is that you cannot typically weigh large masses on an analytical balance.

Illustration 1 - A typical analytical balance

The balance has a pan, where samples are placed, and is surrounded by a glass cage to prevent air currents from altering the balance reading. Analytical balances usually have simple controls consisting of an on/off button and a "0/T" or "tare" button, which will reset the balance to zero. The balance should be zeroed **before each use**, since all electronic measuring devices have a tendency to "drift" over time.

If you are weighing an **object** like a beaker (i.e. not a chemical sample), here's how to use the balance.

1. Make sure the balance is on. If the balance is off, turn it on using the power button and **wait 15 minutes** for the balance to stabilize before using it.
2. With all glass doors **shut**, press the "Tare": or "0/T" button to **zero the balance**. All the numbers on the balance display should change to zero. Some of our balances will beep when zeroed, while others may display "Stable". One of our older balances will simply reset the display to all zeros with no other indication that it has done anything.
3. Open one of the glass doors and **set your object in the center of the pan**. **Shut all glass doors**.
4. When the balance reading stabilizes, **write down all digits** displayed by the balance Also **write down the units**, typically grams.
5. Remove your object from the pan and make sure all the glass doors are shut before leaving.

If you are weighing multiple objects, then **re-zero the balance** for each new object. If you are weighing the same object repeatedly, then **remove the object and re-zero the balance** for each repeat weighing.

If you are weighing a **powder or liquid**, you must protect the balance pan from the substance you are weighing. You can weigh a powder using a sheet of **weighing paper** or a **plastic weighing boat**. For liquids, you may use a small **flask** (50 mL to 100 mL size) or a **plastic weighing boat**.

Here's how to measure out a specific mass of powder.

1. Make sure the balance is on. If the balance is off, turn it on using the power button and **wait 15 minutes** for the balance to stabilize before using it.
2. Place your weighing paper or weighing boat in the center of the balance pan, then shut all glass doors. Press the "Tare" or "0/T" button to **zero the balance**. Zeroing the balance with the paper or boat in place will make the balance **subtract out the paper or boat weight for you** when you add your powder to the paper or boat.
3. Open one of the doors and **carefully add powder to the paper or boat**. Do **not** spill powder on the balance pan. If you're using a weighing boat, it may be easier to simply remove the boat from the balance, add powder, and put the boat back in the center of the pan after adding powder. Add powder until you get the mass you are trying to measure out. If you overshoot the mass, you may gently remove some powder using a spatula. **Do not press down on the balance pan with the spatula**, since a large force on the pan can damage the balance!
4. Close the glass door, wait for the balance reading to stabilize, then **write down all digits** displayed by the balance Also **write down the units**, typically grams.
5. Remove your paper or boat with your powder and shut the glass doors before leaving. If you have spilled any powder on the balance, gently brush it off the balance using one of the provided brushes. Some powders can corrode the balance pan and destroy the balance if not brushed off!

Do not assume that all papers or boats have the same mass. To weigh out a powder, always zero the balance with the piece of paper or boat that you are going to put your sample on. If you are using paper, use a different piece of paper for each sample. As with weighing objects, re-zero the balance between measurements.

Here's how to measure the mass of a liquid sample.

1. Make sure the balance is on. If the balance is off, turn it on using the power button and **wait 15 minutes** for the balance to stabilize before using it.
2. Place an empty small flask or weighing boat in the center of the balance pan, then shut all glass doors. Press the "Tare" or "0/T" button to **zero the balance**. Zeroing the balance with the beaker or boat in place will make the balance **subtract out the flask or boat weight for you** when you add the liquid.
3. Open one of the doors and remove the flask or boat. Pour the liquid into the flask or boat, then carefully place it onto the center of the balance pan.
4. Close the glass door, wait for the balance reading to stabilize, then **write down all digits** displayed by the balance Also **write down the units**, typically grams.
5. Remove your paper or boat with your liquid and shut the glass doors before leaving. If you have spilled any liquid on the balance, dry it off. Liquids can corrode the balance pan and destroy the balance if not removed!

If your liquid is volatile (evaporates easily), you may need to stopper the flask before weighing. Just make sure to zero the balance with the empty, stoppered flask.

A note on how precisely to measure chemicals: If you are told to measure 5.0 grams of powder, don't try to measure exactly 5.0000 grams. Just worry about matching the digits you are actually asked to measure For example, a mass of 5.0493 g or a mass of 4.9983 grams (rounds to 5.0) would satisfy the directions. Write down **all the digits** from the balance when you make the measurement, since you may need all the digits for a calculation.

Measuring volume with a beaker

A beaker is essentially a cup, and is primarily designed for holding liquids rather than measuring them. Many beakers have printed scales on the side that can be used for "quick and dirty" measurements, and we will occasionally use them for this purpose in our lab.

When you pour a liquid into a container, you might observe that the liquid takes the shape of the container except on the top surface. The top surface **appears** flat. If you look closely, the liquid surface is actually slightly curved. You can most easily see the curvature at the the edge of the liquid surface. Liquids that are similar to water (almost everything you will work with in this course) curve up at the edges, forming a **meniscus**. When reading a volume measuring device, always read the scale at the **bottom of the meniscus**. By convention, we design scales on volume measuring devices to be read this way.

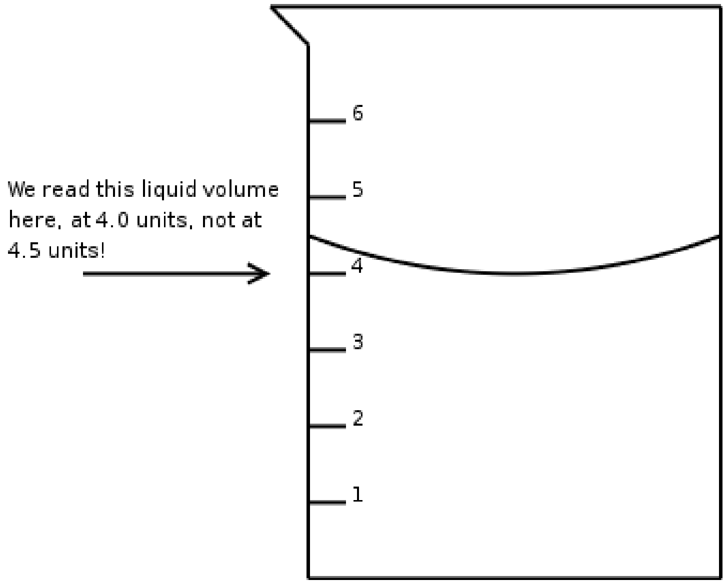

Illustration 2 - Cartoon diagram illustrating how to read the scale of a volume-measuring device

When reading a scale, always try to estimate a decimal place beyond the divisions on the scale. In the example in Illustration 2, we read the scale as 4.0 units, since the bottom of the meniscus appears to be right at the "4" mark. If it appeared to be between 4 and 5, we would try to guess how far it appeared to be and estimate the last digit. Numbers read from a scale should always include one estimated digit.

Measuring volume with a graduated cylinder

One of the most common volume measurement devices in the chemistry laboratory is the graduated cylinder - simply a glass cylinder printed with a scale.

Illustration 3 - Graduated cylinders in several colors and sizes

Cylinders have a scale that is more detailed than the scale on a beaker. Otherwise, they are read the same way.

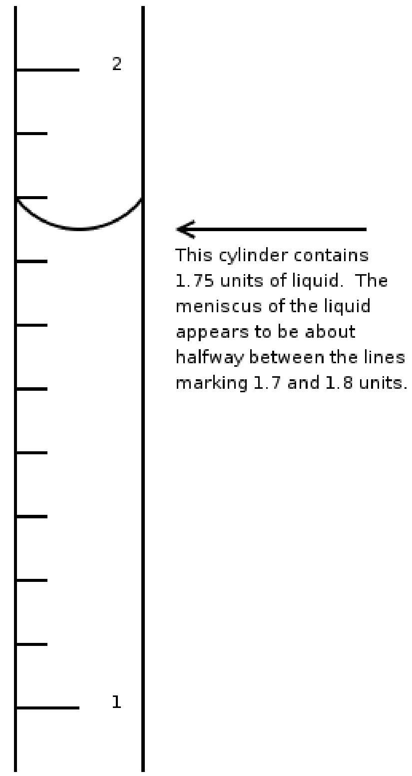

Illustration 4 - Cartoon diagram of part of a graduated cylinder scale

In Illustration 4, we can see that the bottom of the meniscus lies between 1.7 and 1.8 units. It appears to be approximately halfway between these marks, so we record a volume of 1.75 units.

Determining precision using the standard deviation

Statistics is a tool that we can use to describe the *quality* of measurements we make in the lab. A measurement is said to be *accurate* when the measured value is correct – if it matches the true value of the property we're trying to measure. Measurements are said to be *precise* when they are reproducible – when repeated measurements of the same property generate the same value. You might wonder, though, why measurements of the same property would generate different values. Shouldn't repeated measurements of the same thing give the same numbers?

Not necessarily. All measurements contain some *error*, which we define as any difference between the measured value and the true value. Some error is called *systematic error* or *bias*. Systematic errors are caused when a device is malfunctioning or is being used improperly in such a way that it gives readings that are always too high (or always too low). This sort of error can usually be eliminated by making sure instruments are properly calibrated and used correctly. Systematic error affects accuracy, but what kind of error affects precision?

Random error is a kind of error that is difficult to pin on a single cause. Random error is present in any measurement, and can make values be sometimes too high and sometimes too low. Since random error cannot be entirely eliminated, we often make more than one measurement of what we would like to know, then average those measurements. If we make enough measurements, the random error will cancel out and the average will be an accurate representation of what we're trying to measure.

How do we know how many measurements we should make? That depends on how much random error we have. To quantify the random error, we can use a statistical tool called the *standard deviation*, which is defined this way:

$$S_x = \sqrt{\frac{\sum (x_i - \bar{x})^2}{N-1}}$$

where
- S_x = sample standard deviation (used for small data sets)
- x_i = individual data points
- $\bar{x}$ = average (mean) of all data points
- N = number of data points

We will use the standard deviation as an estimate of the amount of random error in our measurements. **The smaller the value of the standard deviation, the more precise our data**. For a data set with nothing but random error, most of the data points (68+%) will be less than a standard deviation away from the average.

We can report our standard deviation along with our calculated average if we want to show how precise our data is. For example:

Average of all data points: 1.21987 g
Standard deviation: 0.012 g

For this example, we can also report the average this way:

1.22 +/- 0.01g

Notice the way the average was rounded – the **last** decimal place we kept in the average (the hundredths place in this example) was the same place as the **first** nonzero digit in the standard deviation. This is a fairly standard way to report averages of uncertain numbers. If we know the random error is +/- 0.01 g, we don't really know anything about decimal places further to the right, since those places are smaller than the random error in our measurements.

<u>Equipment for the experiment</u>

You will need a **50 mL graduated cylinder**, a **50 mL beaker**, a **50 mL Erlenmeyer flask**, a **#1 rubber stopper**, a **400 mL beaker**, a **Pasteur pipet with bulb**, and a **digital thermometer**.

Procedure

Important: Use the same analytical balance for the entire experiment!

Setting up

Fill the 400 mL beaker with deionized water. Allow the beaker to stand on your benchtop while you perform the next part of the experiment. Letting the water sit will allow it to come to a constant temperature.

The analytical balance

Weigh the 50 mL Erlenmeyer flask with the rubber stopper on the analytical balance **four times**. Make sure to re-zero the balance after each mass reading. Record the masses on page 11.

Density of water

Using a digital thermometer, measure the temperature of the water in the 400 mL beaker you set aside earlier. Record the Celsius temperature on the data sheets. Use water from this 400 mL beaker for the rest of the experiment.

The 50 mL beaker

Put 20 mL of deionized water into the 50 mL beaker. Use a Pasteur pipet to adjust the water level so that the bottom of the meniscus appears to lie on the 20 mL line. Go over to the analytical balance, and put your 50 mL **flask** with stopper in the center of the pan. Zero the balance - **with the flask inside** - then pour the water from the beaker into the flask. **Do not re-zero the balance at this point.** With the stopper in place and the glass doors shut, measure the mass of the water and record on page 11. **Empty the flask** into the sink and make sure the **outside** of the flask and stopper is dry. Repeat this entire section three times - with newly measured portions of water - for a total of four measurements of mass.

The flask should be stoppered during the zeroing of the balance and the actual weighing. The stopper will minimize any water loss due to evaporation during the measurement.

The 50 mL graduated cylinder

Put 20.0 mL of deionized water into the 50 mL graduated cylinder. Use a Pasteur pipet to adjust the water level so that the bottom of the meniscus appears to lie on the 20.0 mL line. Go over to the analytical balance, and put your 50 mL **flask** with stopper in the center of the pan. Zero the balance - **with the flask inside** - then pour the water from the cylinder into the flask. **Do not re-zero the balance at this point.** With the stopper in place and the glass doors shut, measure the mass of the water and record on page 11. **Empty the flask** into the sink and make sure the **outside** of the flask and stopper is dry. Repeat this entire section three times - with newly measured portions of water - for a total of four measurements of mass.

The flask should be stoppered during the zeroing of the balance and the actual weighing. The stopper will minimize any water loss due to evaporation during the measurement.

Data Analysis

First, look at the measurements of the mass of the empty stoppered flask from the analytical balance. These should vary by only about plus or minus 0.0001 grams from the average. To check this, we will use the standard deviation. The balance manufacturer claims a precision of +/- 0.0001 grams – in other words, a standard deviation of 0.0001 grams. You should be able to achieve this precision with simple mass measurements, since the analytical balance produces the most precise measurements of any instrument in our laboratory! Use the statistics features of your calculator to calculate the standard deviation of the empty stoppered flask mass measurements and record it on the data sheets. You will not use the empty stoppered flask mass measurements for any other calculations in this experiment.

Using the mass of each water sample, you will calculate the volume of water dispensed If you know the density of water (its mass per unit volume), then it is a simple matter to change the measured mass into a volume. This is how you will determine if the beaker and cylinder dispense the claimed amount of water.

Calculate the volume of each portion of water dispensed by the cylinder and beaker from the masses you recorded using this formula.

$$\text{Volume} = \frac{\text{Mass}}{\text{Density}}$$

Look up the density of water in Table 1 for the temperature of water you recorded at the beginning of the experiment and use that for all your calculations. Write the results for these calculations on page 12. Provide a sample calculation (showing the numbers plugged into the formula you used) in the space provided.

Now calculate the average volume dispensed by the beaker and the average volume dispensed by the cylinder. Also find (using the statistics features of your calculator) the standard deviations of each set of calculated volumes. You should have one standard deviation value for your beaker measurements, and one standard deviation value for your cylinder measurements.

Compare the averages of the volume measurements, remembering that we were supposed to dispense exactly 20 mL in each case. Which measuring device gives a more accurate (closer to 20 mL) result?

Now compare the standard deviations of the volume measurements. Remember smaller standard deviations indicate more precise measurements. Which measuring device provides you with a more precise (reproducible) volume?

Make sure the names of all your group members are filled in on page 11 and that you answer all questions on page 13, then turn pages 11, 12, and 13 in to your instructor.

Table 1 - Density of water at different temperatures*.

Temperature (°C)	***Density (g/mL)***
16	0.99895
17	0.99878
18	0.99860
19	0.99841
20	0.99821
21	0.99800
22	0.99777
23	0.99754
24	0.99730
25	0.99705
26	0.99679
27	0.99652
28	0.99624
29	0.99595

*Adapted from data at http://www.ncsu.edu/chemistry/resource/H2Odensity_vp.html

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Group information

Lab team information

- Member 1: ____
- Member 2: ____
- Member 3: ____
- Date of experiment: ____

Data

The analytical balance

Trial	Mass of dry stoppered 50 mL flask (g)
1	
2	
3	
4	

- Standard deviation of dry stoppered flask masses: ______________________________g

Density of water

Measured water temperature (C)	Density of water from table on page 8 (g/ml)

The 50 mL beaker

Trial	Mass of 20 mL portion of water, measured by beaker scale (g)
1	
2	
3	
4	

The 50 mL graduated cylinder

Trial	Mass of 20 mL portion of water, measured by cylinder scale (g)
1	
2	
3	
4	

Calculations

The 50 mL beaker

Fill in the chart below. Copy the masses from the data sheets, and calculate the volumes.

Portion	***Mass (g)***	***Calculated Volume (mL)***
1		
2		
3		
4		

- Average calculated volume of portions from the beaker: ______________________________mL
- Standard deviation of calculated volumes from the beaker: ______________________mL

Sample calculation: Show in the space below how you calculated the *volume* of the first portion of water from the beaker.

The 50 mL graduated cylinder

Fill in the chart below. Copy the masses from the data sheets, and calculate the volumes.

Portion	***Mass (g)***	***Calculated Volume (mL)***
1		
2		
3		
4		

- Average calculated volume of portions from the cylinder: ____________________________mL
- Standard deviation of calculated volumes from the cylinder: ______________________mL

Sample calculation: Show in the space below how you calculated the *volume* of the first portion of water from the graduated cylinder.

Questions

1) You were trying to measure out exactly 20 mL of water in both the beaker and graduated cylinder. Which measuring device, beaker or cylinder, gave a more accurate (correct) volume ? Explain your reasoning.

2) Which measuring device, beaker or graduated cylinder, gave more precise (reproducible) volume measurements? Explain your reasoning.

3) The manufacturer of the analytical balance used in our lab claims that the balance's precision (reproducibility) when used properly is +/- 0.0001g . Explain why your data does or does not support this claim. *Hint: Look at the standard deviation of the four dry stoppered flask masses – recorded on page 11!*

4) We allowed the water used in the experiment to sit on the benchtop before being used. This allowed the water to come to a constant temperature. **Why** was it necessary for the water to come to a constant temperature before using it in this experiment?