EXPERIMENT 0

Chemistry and measurements

A. Goal

The goal of this laboratory experiment is to familiarize with estimating digits and accounting for significant figures in measurements through measuring in the chemistry laboratory.d

B. Materials

- ☐ 10ml measuring cylinder
- ☐ 50ml beaker
- ☐ any size stopper
- ☐ a spatula
- ☐ string
- ☐ set of measuring cylinders: 10, 25, 50, 100 and 250mL
- ☐ metallic cylinder
- ☐ 50mL-cylinder

C. Background

Significant Figures

Exact numbers result from counting. For example, think about how many eggs are there in your refrigerator, there might be three and this number is exact. Differently, numbers that result from a measurement are called measured values and they are subject to uncertainty–in other words error. For example, if you weigh a single egg on a scale depending on the type of scale you used and the person who carries out the measurement, you will measure 70g or 71g, or maybe 70.8g. The mass of an egg is a measured property and hence some of the digits of the measurement are uncertain. The goal of this section is, given a value, to calculate the number of significant figures of a number (we will refer to significant figures as SF, or SFs). Another goal is to estimate significant figures in the calculation to express the result with the right number of digits and significant figures.

Measured numbers

Measured numbers result from measuring a property such as the weight or length of an object. Those measurements result from using a measuring device such as a scale or a ruler, for example. Imagine we want to measure the length of both objects presented in Figure **??**. The metric rules presented have a set of marked divisions which determine the number of figures given by the measurement. For example, the ruler on the left has 1cm and 0.1cm divisions, whereas the rule on the right only has 1cm divisions, hence giving fewer figures.

Let us estimate the length of the object on the right. The end of the object on the right is located between 0cm and 1cm, therefore its length is less than 1cm. Still, we can estimate an extra digit by dividing the space between the lines. Still, this last *estimated digit* might differ from person to person. The final measurement would be 0.8cm. However, some people would read the length as 0.7cm whereas others 0.9cm. Let us now estimate the length of the object on the left. The end of the object on the right is located between 3.1cm and 3.2cm, therefore its length is less than 3.2cm. We can estimate an extra digit as well, giving a final measurement of 3.15cm.

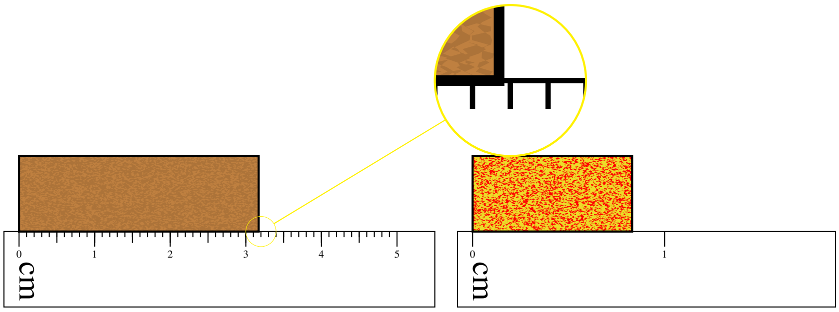

Figure ?? Some metric scales with two objects of different lengths. Measurements are (left) 3.15cm (right) and 0.8cm.

Sample Problem 1

Indicate the number of significant figures in the following numbers: 123, 4567, 1200, 340, 0.001, 0.023 and 0.0405.

SOLUTION

123 has three significant figures, whereas 4567 has four SF. 1200 has only 2SF as the last two zeros are not significant, and 340 has only 2SF as the last zero is not significant. 0.001 has only one significant figure as the first 3 zeros are not significant and 0.023 has only two SFs. Finally, 0.0405 has threee SFs as the first two zeros are not significant but the zero between 4 and 5 is indeed significant.

STUDY CHECK

Indicate the number of significant figures (SFs) in the following numbers: 4560, 0.123, 1000 and 0.0030.

▶Answer: 4560 has 3SF, 0.123 has 3SF, 1000 has 1SF and 0.0030 has 2SF.

Reading menisci

Reading a liquid meniscus is similar to reading any measuring scale. There are two types of menisci (see Figure **??**). A concave meniscus, which is what you normally will see, occurs when the molecules of the liquid are attracted to those of the container. This occurs with water and a glass tube. A convex meniscus occurs when the molecules have a stronger attraction to each other than to the container, as with mercury and glass. If the meniscus is concave, read at the lowest level of the curve. If the meniscus is convex, take your measurement at the highest point of the curve. Let us read the menisci from the image below. Readings are 16.0mL (left), 8.5mL (center left), 18.0mL (center right), and 18.5mL (right).

Exact numbers

Exact numbers are numbers obtained by counting and not by measuring or obtained by a relationship that compared two units in the same measuring system. For example, the number of students in a class is exact as we need to count to get this number. Similarly, the number of grams in a kilogram, a thousand, is exact as the relationship between kilogram and gram is exact. Exact numbers do not have significant figures and do not limit the number of figures in a calculation.

Significant figures of numbers

In general, all numbers different than zero are significant and for example, the number 123 has three significant figures. Similarly, the number 45 has two significant figures. Zeros are also significant except when:

Exception 1 *A zero is not significant when placed at the beginning of a decimal number.* For example, the number

0.123 has three significant figures, as the first zero is not significant. Similarly, the number 0.002340 has four significant figures as the first three zeros are not significant but the last zero it is. Mind the rule affects only the zeros at the beginning. A final example:

$$0.032 \ \text{(2SF)}$$

☡ **Exception 2** *A zero is not significant when used as a placeholder in a number without a decimal point.* For example, the number 1000 has only one significant figure, and the number 3400 has two. Let us consider more examples. The number 120 has two significant figures, as according to the second rule the last zero is not significant. Differently, the number 1203 has four significant figures, as the zero in between two numbers is not affected by either the first or the second rule. A final example,

$$3200 \ \text{(2SF)}$$

☡ **Exception 3** *A zero in a number expressed in scientific notation is significant.* For example, the zero in 3.0×10^{-2} is significant, and the number has 2SFs. A final example:

$$3.2020 \times 10^2 \ \text{(5SF)}$$

Significant figures in calculations

Two different rules allow you to express the result of calculations with the correct number of figures.

☡ **Rule 1** ($+ \ -$) *For additions or subtractions, the results has the same number of decimal places as the number with the least decimal places in the calculation.* For example:

$$34.3451 + 34.5 = 68.8 \ (+ \ - \text{less decimals})$$

If you add $34.3451 + 34.5$ you will obtain 68.8451, however, as 34.3451 has four decimal places (4DP) and 34.5 has one decimal place (1DP), the result of adding both numbers will have to have only one decimal place, therefore 68.8451 needs to be rounded to 68.8 (1DP). Overall, we have:

$$34.3451 \ \text{(4DP)} \ + 34.5 \ \text{(1DP)} \ = 68.8 \ \text{(1DP)}$$

☡ **Rule 2** ($\times \ \div$) *For multiplications and divisions, the number of significant figures of the result should be the same as the least number of significant figures involved.* For example, if you carry the following multiplication:

$$4500 \times 342 = 1500000 \ (\times \ \div \text{less SFs})$$

the number 4500 (2SF) has two significant figures, whereas the number 342 (3SF) has three significant figures. If we multiply both numbers the results should contain just two significant figures. The result of multiplying 4500×342 is 1539000 (4SF), however, this number needs to be rounded into two significant figures into 1500000 (2SF). Overall we have:

$$4500 \ \text{(2SF)} \ \times 342 \ \text{(3SF)} \ = 1500000 \ \text{(2SF)}$$

Sometimes we will have to add significant zeros in order to present the final result of a calculation with the correct number of digits. For example:

$$8.00 \ \text{(3SF)} \ \div 2.00 \ \text{(3SF)} \ = 4 \ \text{(shows in calculator)} \ = 4.00 \ \text{(3SF)}$$

Rounding

The following rules indicate how to round numbers:

☡ **Rule 1** If the digit to be removed is less than 5 then the preceding digit stays the same. For example, 1.123 rounds to 1.12.

Rule 2 If the digit to be removed is more or equal to 5 then the preceding digit is increased by one. For example, 1.126 rounds to 1.13
Rule 3 When rounding to a specific number of significant figures we need to look only to the first number to the right of the last significant figure. For example, 1.126 rounds to two SF as 1.1
Now, let us analyze a few use cases. Imagine we need to round the number 1234cm to two SF. The results would be 1200cm. Similarly, imagine we need to round the number 0.01264cm to two SF. The results would be 0.013cm.

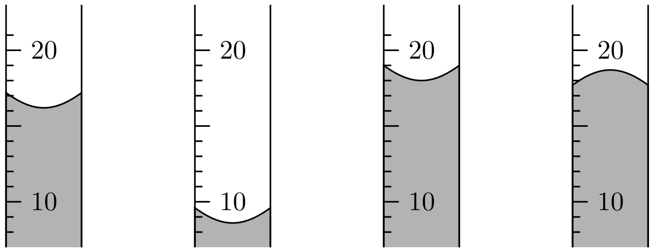

Figure ?? Some volumetric measurements in mL are presented in two types of meniscuses. The Left, center-right, and center-left are concave meniscuses, whereas the right image presents a convex meniscus. Readings are 16.0mL (left), 8.5mL (center left), 18.0mL (center right), and 18.5mL (right).

Sample Problem 2

Do the following calculation with the correct number of figures.

$$\frac{88.5 - 87.57}{345.13 \times 100}$$

SOLUTION

We will analyze each number indicating the number of SF and Digits (DP): 88.5(3SF, 1DP), 87.57(4SF, 2DP), 345.13(6SF, 2DP) and 100(1SF, 0DP). The result of doing the addition needs to be rounded to one single decimal place: $88.5 - 87.57 = 0.93 \simeq 0.9$. After that we have only multiplications and divisions and hence we will now focus on the number of SFs:

$$\frac{0.9\ (1SF)}{345.13\ (5SF)\ \times 100\ (1SF)}$$

The result of this operation needs to be rounded to one SF:

$$\frac{0.9}{345.13 \times 100} = 2.6077 \times 10^{-5} \simeq 3 \times 10^{5}\ (1SF)$$

STUDY CHECK

Do the following calculation with the correct number of figures: $(24.56 + 2.433) \times 0.013$

Answer: 0.35

D. Procedure

1. Measuring mass The goal of this mini-experiment is to measure the mass of several objects with a scale. Overall, the goal is to learn how to use laboratory scales and how to properly report measurements. Moreover, this experiment will help you getting familiarized with a chemistry laboratory environment:

Step 1: – Locate the following objects: a 10ml measuring cylinder, a 50ml beaker, a stopper of any size and a spatula.

Step 2: – Measure the mass of each of the object using a scale. Make sure the scale is set to zero before you measure.

Step 3: – Write down the values listing the name of the object. Do not forget to indicate the unit of the measurement.

Step 4: – Indicate the measured figure (e.g. for a measure number 345.8g the estimated would be written as 0.8g) and the number of significant figures of the measurement.

Step 5: – Return each object to its original location in the lab.

2. Measuring length In this mini-experiment you will familiarize with a meterstick (or a inch ruler). I am aware you have seen one before but perhaps you have not noticed some of the nuances of this very useful measuring tool.Think about the meaning of the large and small lines on the meterstick (or a inch ruler). Discuss with your coworkers this information. What do the large lines represent? And the small lines?

Step 1: – Write down the length of the following items. Mind you need to measure these values in the lab. In the case of your height, you will find a meter stick at the lab, near the entrance.

Step 2: – You can use a string to measure the length of your wrist .

Step 3: – Write down the measured digit of each measurement and the number of significant figures. Do not forget to indicate the unit near the measurement.

Step 4: – Measure the length of the following line and write down the value on the results section.

3. Measuring volume In this mini-experiment learn how to properly read a volume measurement using chemistry equipment. In the chemistry lab, volume can be measured with a measuring cylinder. However, liquid forms a meniscus on this object due to a property of water called surface tension. Therefore, to be able to read volume you will have to properly read the meniscus and use volumetric scales.

Step 1: – Locate the lab setup with measuring cylinders of 10, 25, 50, 100 and 250 mL.

Step 2: – Fill each cylinder with a random quantity if water within the volume of the cylinders. The cylinders might be already filled.

Step 3: – For each cylinder, read the meniscus and write down the volume. Make sure you read between the lines of the cylinder to indicate the estimated digit of the measurement. Do not forget to write down the unit close to the measurement.

Step 4: – Indicate the estimated digit of the measurement and the number of significant figures.

5. Measuring volume by displacement The volume of liquids is easy to measure. However, the volume of solids is a harder property to measure experimentally. The goal of this mini-experiment is to measure the volume of an object (a cylindric piece of metal) by displacing the liquid on a measuring cylinder.

Step 1: – Find a metallic cylinder you want to measure volume.

Step 2: – Use a 50mL-cylinder large enough to easily fit the object. Make sure the object will not be stuck inside the cylinder.

Step 3: – Add water to the cylinder and write down the volume. Make sure you read the estimated digits (e.g. 50.50mL).

Step 4: – Place the object on the cylinder. You will see the level of water rise. Make sure the level is beyond the size of the object so that the object is fully submerged on water. If not, you will have to repeat the experiment adding more water initially on the cylinder.

Step 5: – Calculate the volume of the object by subtracting the the volume of water after the object is submerged–the final volume–and the volume before–the initial volume.

STUDENT INFO

Name: ______________________ Date: ______

Pre-lab Questions

Chemistry and measurements

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1. Fill the gaps with the full unit name, the abbreviation and the property measured. Indicate also whether the unit contains a prefix:

Full unit Name	Abbreviation	Property measured	Prefix? (yes/no)
Kilogram	____________	____________	____________
____________	mL	____________	____________
Degree Celsius	____________	____________	____________
____________	in	____________	____________

2. Indicate whether the following numbers indicate a measured value or an exact number. Measured numbers result from measurements, and exact numbers result from counting.

20Kg	____________	10.5 cm	____________
3 apples	____________	10°C	____________
30.5L	____________	90mL	____________
1cm=10^{-2}m	____________	4g	____________

3. Explain what are significant figures.

4. You measure the mass of a beaker using a scale and the results is 28.27g. Indicate the estimated digit of the measurement.

5. You measure the length of a measuring cylinder using a meter stick with a scale that indicates centimeter as well as millimeters and the results is 25.15cm. Indicate the estimated digit of the measurement.

STUDENT INFO	
Name: ______________________	Date: ______

Results
EXPERIMENT

Chemistry and measurements

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1. Measuring mass

Object Name	Mass	Estimated digit	# significant Figures

2. Measuring length

Object Name	Length	Estimated digit	# SFs
Length of your right foot			
Length of one of your fingernails			
Length of one of your wrist			
Line below			

3. Measuring volume

Object Name	Volume	Estimated digit	# SFs

5. Measuring volume by displacement

		Volume	Estimated digit	# SFs
Initial volume	1			
Final volume	2			
Object volume	2 - 1			

STUDENT INFO

Name: ______________________ Date: ______

Post-lab Questions

Chemistry and measurements

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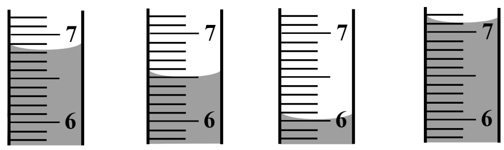
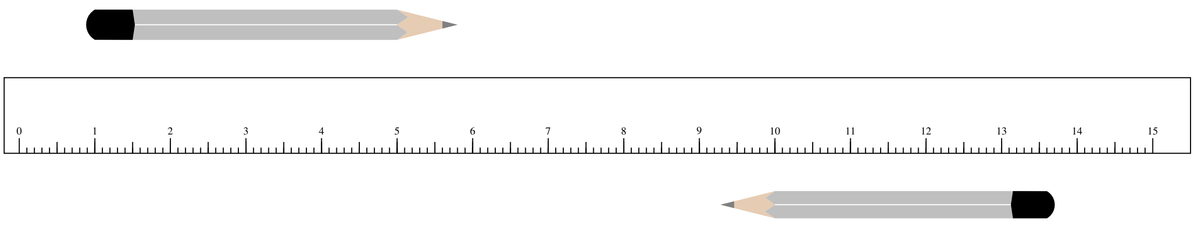
1. Indicate the measurement of the following meniscus (in mL):



2. Using the rule below in cm:



   (a) Measure the length of both pencils.

   (b) Indicate the estimated digits

3. Indicate the number of significant figures of the following measurements:

Measured number	**SFs**	**Measured number**	**SFs**
20.1Kg	________________	120.5 cm	________________
0.01 m	________________	100g	________________
0.010 s	________________	230.1dm	________________
5×10^{-5} dm	________________	6.500×10^{-1} dmg	________________