Measurements and Significant Figures

IN THIS EXPERIMENT, YOU WILL

- ❑ Make measurements using devices having different uncertainties.
- ❑ Express measured quantities in a way that correctly shows the uncertainties of the measurements.
- ❑ Use significant figures to properly represent measured and calculated quantities.
- ❑ Investigate how to increase the number of significant figures in measured and calculated quantities by properly using measuring devices.

INTRODUCTION

Measurement is an important activity in most scientific studies. Every measurement contains an uncertainty that comes from the device or technique used to make the measurement. The numbers used to record a scientific measurement normally indicate the uncertainty in the measurement. For example, a mass recorded as 2.87 g indicates that the measurement has an uncertainty in the hundredths (.01) of a gram. This fact could be represented by recording the mass as $2.87 \pm .01$ g, but usually this is not done. The value is simply recognized as having an uncertainty of $+1$ or -1 in the last recorded number.

The numbers used to represent the certain part of a measurement (the 2 and 8 in the example), plus one number representing the uncertain part (the 7 in the example), are called **significant figures** or significant digits. Thus, the quantity 2.87 g contains three significant figures.

The necessity of using zeros to express measurements raises the question of when zeros are considered to be significant figures. The measured mass expressed as 2.87 g could also be expressed as .00287 kg. The significance of a measurement cannot be changed simply by changing the units used to express the measurement. Thus, .00287 kg must contain three significant figures just as 2.87 g does. This is an example of one rule concerning zeros. Zeros not preceded on the left by nonzeros do not count as significant figures. Other zeros, those located between nonzeros and those to the right of nonzeros, are counted as significant figures. Thus, 3.509 g and 2.870 g both contain four significant figures, and both indicate that the measurement uncertainty is $+.001$ or $-.001$ g.

In this experiment, you will make some measurements using different devices. You will express these measurements and results calculated from them using the correct number of significant figures.

EXPERIMENTAL PROCEDURE

A. Measurement with Ruler A

The area of a rectangle is equal to the product of the width, w, and length, l, (area $= w \times l$). The perimeter of a rectangle is equal to the sum of the four sides (perimeter $= w + w + l + l$). In this procedure, you will measure the length and width of four different rectangles. These quantities will be measured with a ruler that has divisions to the nearest centimeter. When measuring devices like rulers are used, the measurement uncertainty is expressed by estimating the value of the measured quantity to one decimal place more than the smallest scale division of the measuring device. Thus, all measurements made with ruler A should be expressed to the nearest .1 cm.

To calculate rectangular areas, you will have to multiply together two measured quantities. The area that results should be expressed using the correct number of significant figures. In the case of multiplication or division, the results of the calculation must have the same number of significant figures as the least significant measured number used in the calculation. For example, the product 1.1186×0.064 is equal to 0.07159. However, only two significant figures are used in the answer to match the two significant figures in 0.064. Thus, the answer is 0.072, where the last significant figure (1) was rounded up to 2 because the first number being dropped (5) was equal to 5. In general, the last significant figure retained during rounding will be increased by 1 in the rounded answer when the first number being dropped is equal to or greater than 5. When the first number being dropped is less than 5, the last significant figure in the rounded answer is not changed.

Rectangle perimeters are obtained by adding a series of numbers. When numbers are added or subtracted, significant figure rules require that the answer be rounded so that it contains the same number of places to the right of the decimal as the smallest number of places in the quantities added or subtracted. For example, the sum $3.527 + 0.041 + 7.12$ is equal to 10.688. However, in this answer only two places to the right of the decimal are used to match the two places in 7.12. When the same rounding rules given earlier are used, the correctly rounded answer is 10.69. Note that this answer has four significant figures, even though the numbers added had four, two, and three significant figures, respectively.

Procedure

1. Use a pair of scissors and carefully cut out ruler A from page 5. Cut inside the bottom line to remove the bottom line from the ruler. Do not cut out the rectangles.
2. Use ruler A to measure the length and width of rectangles W, X, Y, and Z that are drawn on page 5. Note that the smallest division on ruler A is 1 cm, so measured values should be estimated to the nearest .1 cm. Record your measured values in cm in Table 1.1 of the Data and Report Sheet, with the longest side designated as the length.

B. Measurement with Ruler B

Procedure

1. Use a pair of scissors and carefully cut out ruler B from page 5. Cut inside the bottom line to remove the bottom line from the ruler.
2. Use ruler B to measure the length and width of rectangles W, X, Y, and Z that are drawn on page 5. Note the smallest division on ruler B is 0.1 cm, so measured values should be estimated to the nearest .01 cm. Record your measured values in cm in Table 1.5 of the Data and Report Sheet.

C. Improving the Significance of Measurements

The number of significant figures in a measured quantity and in quantities calculated from measured quantities depends on the way the measuring device is used.

Procedure

1. Obtain 10 one-cent coins from the stockroom.
2. Use ruler B to measure the diameter of a single coin; be sure to make an appropriate estimate and include it in your value. Record the measured value in Table 1.9 of the Data and Report Sheet.
3. Use ruler B to measure the thickness of a single coin and the thickness (height) of stacks of coins containing 3, 5, 7, and 10 coins. Include appropriate estimates in your measurements and record the values in Table 1.9 of the Data and Report Sheet.

CALCULATIONS AND REPORT

A. Measurement with Ruler A

1. Transfer the measured length and width values from Table 1.1 to Table 1.2 of the Data and Report Sheet.
2. Complete Table 1.2 by writing the number of significant figures found in each measured quantity.
3. Refer to the rules given earlier for multiplication calculations, and determine the correct number of significant figures that should be used in the calculated area of each rectangle. Record that number in Table 1.3.
4. Calculate the area of each rectangle and record the unrounded value (the value given by your calculator) and the value rounded to the correct number of significant figures in Table 1.3.
5. Refer to the rules given earlier for addition calculations, and determine the correct number of places to the right of the decimal that should be used in the calculated perimeter of each rectangle. Record that number in Table 1.4.
6. Calculate the perimeter of each rectangle and record the unrounded and properly rounded values in Table 1.4.

B. Measurement with Ruler B

1. Transfer the measured length and width values from Table 1.5 to Table 1.6 of the Data and Report Sheet.
2. Complete Table 1.6 by writing the number of significant figures found in each measured quantity.

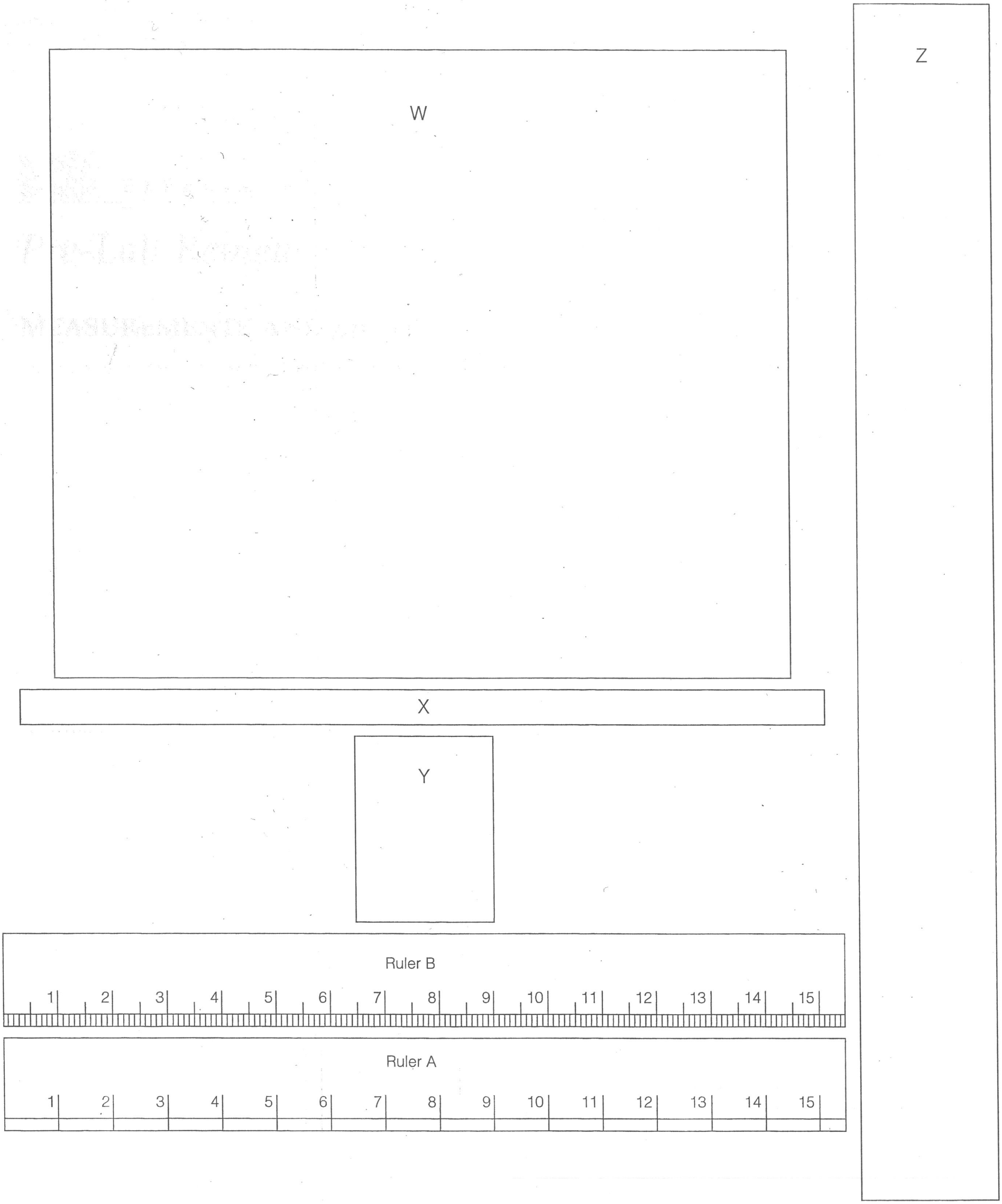
3. Refer to the rules given earlier for multiplication calculations, and determine the correct number of significant figures that should be used in the calculated area of each rectangle. Record that number in Table 1.7.
4. Calculate the area of each rectangle and record the unrounded and properly rounded values in Table 1.7.
5. Refer to the rules given earlier for addition calculations, and determine the correct number of places to the right of the decimal that should be used in the calculated perimeter of each rectangle. Record that number in Table 1.8.
6. Calculate the perimeter of each rectangle and record the unrounded and properly rounded values in Table 1.8.

C. Improving the Significance of Measurements

1. Transfer the measured thickness values for each coin stack from Table 1.9 to Table 1.10 of the Data and Report Sheet.
2. Determine the number of significant figures in each thickness value and record that number in Table 1.10.
3. Refer to the rules given earlier for division calculations, and determine the correct number of significant figures that should be used in a calculated value of the average thickness of a coin. This average is obtained by dividing the measured thickness of a stack by the number of coins in the stack. The number of coins in a stack is a counting number that is known exactly and does not influence the number of significant figures used in the calculated value. Record the correct number of significant figures in Table 1.10.
4. Calculate the average thickness of a coin from the data for each stack and record the unrounded and properly rounded values in Table 1.10.
5. The volume of a coin is given by

$$V = \frac{1}{4}\pi d^2 t$$

where $\pi = 3.1416$, $d =$ the measured diameter, $t =$ the calculated average thickness, and 1/4 is an exact fraction that does not influence the number of significant figures used in the calculated volume. Use the most significant calculated value for the average coin thickness t recorded in Table 1.10, the measured diameter d from Table 1.9, and determine the correct number of significant figures that should be used in a calculated volume V. If two or more coins have the same number of significant figures in their calculated average thickness, either value can be used in the volume calculation. Record the correct number of significant figures that should be used for the volume in Table 1.11.
6. Calculate the volume of a coin and record the unrounded and properly rounded values in Table 1.11.


W
X
Y
Z
Ruler B
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Ruler A
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

name ______ section ______ date ______

1 EXPERIMENT 1

Pre-Lab Review

MEASUREMENTS AND SIGNIFICANT FIGURES

1. Are any specific safety alerts given in the experiment? List any that are given.

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2. Are any specific disposal directions given in the experiment? List any that are given.

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3. A quantity has a measured value of 8.4126. Which of the five numbers in the measured value has an uncertainty?

______

4. How many significant figures are contained in each of the following measurements?

2.46 g ______ 10.00 mL ______ 0.0109 cm ______

5. What uncertainty (± an amount) is represented by the following measurements?

1.0569 g ______ 7.56 mL ______ 1.815 cm ______

6. You are measuring a quantity with a measuring device on which the smallest scale division is 0.1 unit. A measurement appears to have a value of exactly 3.2 units. How should you record the measurement in order to properly indicate where the uncertainty is located? ______

7. Round the following numbers so they contain the number of significant figures indicated in parentheses.

1.513 (3) ______ 0.0155 (2) ______ 1.494 (1) ______
0.9866 (2) ______ 12.689 (2) ______ 0.04020 (3) ______

8. Carry out the following calculations and write each result using the correct number of significant figures. Assume all numbers represent measured quantities.

$0.521 \times 2.1 =$ ______ $\frac{4.400}{3.92} =$ ______

$0.713 + 6.12 + 11.2 =$ ______ $5.472 - 4.001 + 0.0119 =$ ______

name section date

1 EXPERIMENT 1

Data and Report Sheet

MEASUREMENTS AND SIGNIFICANT FIGURES

A. Measurement with Ruler A

Table 1.1 *(data)*

	Rectangle W	*Rectangle X*	*Rectangle Y*	*Rectangle Z*
Measured length (cm)				
Measured width (cm)				

Table 1.2 *(report)*

Rectangle	*Measured Length (cm)*	*Number of Sig. Figures in Length*	*Measured Width (cm)*	*Number of Sig. Figures in Width*
W				
X				
Y				
Z				

Table 1.3 *(report)*

Rectangle	*Correct Number of Sig. Figures in Calculated Area*	*Calculated Area Unrounded (cm^2)*	*Calculated Area Rounded (cm^2)*
W			
X			
Y			
Z			

Table 1.4 *(report)*

Rectangle	*Correct Number of Decimal Places for Calculated Perimeter*	*Calculated Perimeter Unrounded (cm)*	*Calculated Perimeter Rounded (cm)*
W			
X			
Y			
Z			

B. Measurement with Ruler B

Table 1.5 *(data)*

	Rectangle W	*Rectangle X*	*Rectangle Y*	*Rectangle Z*
Measured length (cm)				
Measured width (cm)				

Table 1.6 *(report)*

Rectangle	*Measured Length (cm)*	*Number of Sig. Figures in Length*	*Measured Width (cm)*	*Number of Sig. Figures in Width*
W				
X				
Y				
Z				

Table 1.7 *(report)*

Rectangle	*Correct Number of Sig. Figures in Calculated Area*	*Calculated Area Unrounded (cm^2)*	*Calculated Area Rounded (cm^2)*
W			
X			
Y			
Z			

Table 1.8 *(report)*

Rectangle	*Correct Number of Decimal Places for Calculated Perimeter*	*Calculated Perimeter Unrounded (cm)*	*Calculated Perimeter Rounded (cm)*
W			
X			
Y			
Z			

C. Improving the Significance of Measurements

Table 1.9 *(data)*

Measured coin diameter (cm)					
Number of coins in stack	1	3	5	7	10
Measured stack thickness (cm)					

Table 1.10 *(report)*

Number of Coins in Stack	*Measured Stack Thickness (cm)*	*Number of Sig. Figures in Measured Thickness*	*Correct Number of Sig. Figures in Calculated Avg. Thickness*	*Calculated Avg. Thickness Unrounded (cm)*	*Calculated Avg. Thickness Rounded (cm)*
1					
3					
5					
7					
10					

Table 1.11 *(report)*

Correct number of significant figures in a calculated coin volume	
Calculated coin volume—unrounded (cm^3)	
Calculated coin volume—rounded (cm^3)	

Questions

1. Suppose the area of rectangle Y was calculated using the length from Table 1.1 and the width from Table 1.5. How many significant figures would be correct in the calculated area?

a. 1 b. 2 c. 3 d. 4

Explain your answer: ______________________________

____

2. Suppose the perimeter of rectangle X was calculated using the length from Table 1.1 and the width from Table 1.5. How many significant figures would be found in the calculated perimeter after proper rounding?

a. 1 b. 2 c. 3 d. 4

Explain your answer: ______________________________

____

3. A buret is a tubular device used to deliver measured volumes of liquids. The smallest division on the scale of a buret is 0.1 mL. Suppose a buret reading was exactly on the 10-mL mark. How should this reading be recorded?

a. 10 mL b. 10.0 mL c. 10.00 mL d. 10.000 mL

Explain your answer: ______________________________

____

4. Refer to Table 1.10. How can the number of significant figures in a measurement be increased without changing the measuring device?

a. Estimate two decimals beyond the smallest scale division of the measuring device.

b. Increase the size of the quantity being measured.

c. Decrease the size of the quantity being measured.

Explain your answer: ______________________________

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5. What is the shortest length that could be measured with ruler B that would contain four significant figures?

a. Exactly 1 cm b. Exactly 5 cm c. Exactly 10 cm d. Exactly 15 cm

Explain your answer: ______________________________

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