I. Objectives

1. Use laboratory measuring devices to determine the physical characteristics of various objects.
2. Determine the capabilities and limitations of each measuring device.
3. Identify the sources of error in making measurements.

II. Introduction

In physics, you will measure fundamental quantities and performing calculations based on collected data. You will utilize basic measuring devices to determine the dimensions of various objects. There is often more than one way to make a particular measurement and the best results can usually be obtained using a particular measuring device and procedure. In some cases you'll be asked to compare your experimental results with some theoretical or accepted standard and determine "how good" your results are. You will need to consider:

- What are the best results that can be expected from an experiment?
- Is there a better way to make particular measurements?
- What errors are associated with given measurements?
- Is one measuring device more precise than another?

III. Calculations

Using a given measuring device, you will determine the dimensions of several objects, record data in the appropriate table, and perform simple calculations to determine area and volume. For each measuring device and object pair you will record the smallest readable increment that can be determined using the measuring device.

<u>Part 3 Measuring Angles</u>

The Pythagorean formula for a right triangle is written as:

$$c^2 = a^2 + b^2$$

where *a* and *b* are the lengths of the short sides of the right triangle and *c* is the length of the long side, the hypotenuse.

If the lengths of any two sides of a right triangle are known the angles can be determined using trigonometry and any of the following formulas:

$$\theta = \sin^{-1}\left(\frac{opp}{hyp}\right)$$

$$\theta = \cos^{-1}\left(\frac{adj}{hyp}\right)$$

$$\theta = \tan^{-1}\left(\frac{opp}{adj}\right)$$

where *hyp* is the hypotenuse of the right triangle, *adj* is the side adjacent to the angle, and *opp* is the side opposite the angle. All three of these formulas should yield approximately the same result, depending on the precision of the measurements and the number of decimal places used in the calculations. Be sure that your calculator is set in degrees, not radians.

Part 4 Measuring Volume

The volume of water *V* in the graduated cylinder can be determined using the following, where *d* is the diameter of the graduated cylinder, *r* is the radius, and *h* is the height:

$$d = 2r \quad \rightarrow \quad r = \frac{d}{2} \quad \rightarrow \quad r^2 = \frac{d^2}{4}$$

then by substitution:

$$V = \pi r^2 h = \frac{\pi d^2 h}{4}$$

IV. Equipment and Materials

Ruler, meter stick, protractor, electronic balance, stopwatch, spring scale, thermometer, graduated cylinder, string, metal density rod, small ball, washer, globe, rectangular block.

V. Procedure

Part 1 Measuring Devices

1. Complete the appropriate row of Table 1 for each listed measuring device. Your "best guess" is how precisely you can read the measuring device, i.e., for a thermometer marked in degrees you may be able to measure +/- 0.5^0; for a ruler marked in cm you may be able to measure +/- 0.5 mm, etc.

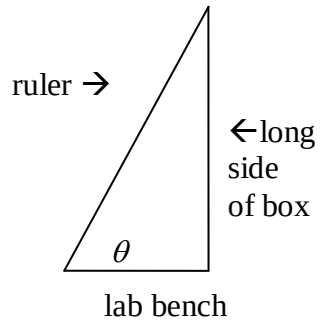
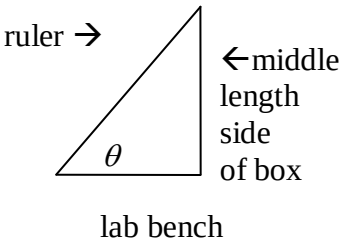
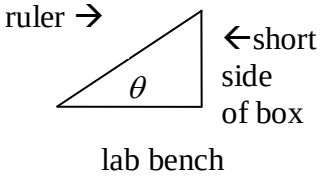
Part 2 Measuring Three Dimensional Objects

2. Measure the appropriate dimensions of each object listed in Table 2 and record the appropriate data, including units used to make the measurements and +/- values. You may select whichever metal density rod, small ball, globe, floor tile you like from those available, and any of the measuring devices to make the required measurements.

3. Measure the diameter of the entire washer, then measure the diameter of the hole. Complete Table 3.

Part 3 Measuring Angles

4. You will use two different methods to determine the angle θ formed by a ruler resting on a rectangular block and the lab bench. Use a rectangular block with different height, length, and width dimensions. First, using a protractor, read the angle formed by the ruler and the lab bench. Second, use trigonometry to calculate the angle. Record the data in Table 4 for each of the three possible orientations of the block, below:

Longest side vertical	Middle length side vertical	Short side vertical
		

Part 4 Measuring Volume

5. You will use three different methods to determine the volume of some water you put into a graduated cylinder. First, read the volume from the markings on the graduated cylinder. Second, measure the height and diameter of the water in the graduated cylinder and compute the volume of water using the formula above. Third, measure the mass of the water and the graduated cylinder, pour out the water, measure the mass of the empty graduated cylinder, and calculate the mass of the water. Important: The density of water is $1.0\ gm/mL = 1.0\ gm/cm^3$. Record the data in Table 5.

Part 5 Measuring Time and Rate

6. Record the pulse of a classmate for 10, 30 and 60 seconds, then repeat the process again for 10, 30, and 60 seconds. Record the data in Table 6.

VI. Data

Table 1 Measuring Devices and Units

A	B	C	D
Measuring Device	Maximum measurement capacity and units	Smallest increment	Best guess increment
ruler			
meter stick			
protractor			
electronic scale			
stop watch			
thermometer			
spring scale			
graduated cylinder			
string			

Table 2 Three Dimensional Objects and Dimensions

A	B	C	D	E	F
Object	Metal density rod	Small ball	Globe	Floor tile	Classroom
length in cm					
circumference in cm					
radius in cm					
width in cm					
height in cm					
mass in g					

Table 3 Washer Dimensions

A	B	C	D
Diameter of washer, including hole, in cm	Radius of washer, including hole, in cm	Diameter of hole in cm	Radius of hole in cm

Table 4 Rectangular Block Angle Measurements

A	B	C	D	E	F	G	H
	Method 1	Method 2					
Block config-uration	Protractor reading for angle θ in degrees	Vertical distance between top of block and lab bench, *opp*, in cm	Horizontal distance between bottom of block and bottom of ruler, *adj*, in cm	Distance along ruler from top of block to lab bench, *hyp*, in cm	$\theta = \sin^{-1}\left(\frac{opp}{hyp}\right)$ in degrees	$\theta = \cos^{-1}\left(\frac{adj}{hyp}\right)$ in degrees	$\theta = \tan^{-1}\left(\frac{opp}{adj}\right)$ in degrees
longest side vertical							
middle length side vertical							
shortest side vertical							

Table 5 Graduated Cylinder Volume

A	B	C	D	E	F	G = E – F	H
Volume 1	Volume 2			Volume 3			
Water volume = reading on graduated cylinder in mL	Water diameter in cm	Water height in cm	Water volume calculated from water diameter and height in mL	Water + graduated cylinder mass in g	Graduated cylinder mass in g	Water mass in g	Water volume calculated using the mass per cubic centimeter of water in mL

Table 6 Time and Heart Rate

A	B	C	D	E	F
	Number of beats		Average number	Calculated number	
Heart rate	Trial 1	Trial 2	of beats	of beats per minute	Time +/-
10 seconds					
30 seconds					
60 seconds					

VII. Discussion Questions

Part 1 Measuring Devices

1. What is precision?

2. What is accuracy?

Part 2 Three Dimensional Objects and Measurements

3. What characteristics of an object determine which measuring devices are used to determine its dimensions?

4. Different measuring devices are required to determine the dimensions of objects, based on the characteristics of those objects. List at least three of those characteristics and explain why different measuring devices are required.

5. When you calculated the dimensions of three dimensional objects, which dimension was the least precise? Which one was the most precise? Explain. What can you now say about the precision and accuracy of those measurements?

6. Of all the objects you measured, which provided the most precise results? Why?

7. Which ones gave you the least precise results? Why?

8. Does line of sight also affect the measurements of heights, lengths, and widths? Explain why or why not.

9. Calculate the metal surface area of one side of the washer you selected and show the steps used in your calculations. Hint: you will need to find the formula for the area of a circle. Be sure to subtract the interior area of the hole from the area of the entire washer and be sure your answer is reasonable.

10. Calculate the surface area of the globe and show the steps used in your calculations. Hint: you will need to find the formula for the surface area of a sphere. Be sure your answer is reasonable.

11. Calculate the volume of the globe and show the steps used in your calculations. Hint: you will need to find the formula for the volume of a sphere. Be sure your answer is reasonable.

12. What measuring devices and processes did you utilize to measure the length, width, and height of the classroom? Explain your methods and why you used these methods.

Part 3 Measuring Angles

13. Did the two methods yield the same angle measurements for a given block orientation? Explain why or why not and the possible sources of error.

14. Did each of the three trigonometric formulas yield the same angle measurement for a given block orientation? Explain why or why not and the possible sources of error.

Part 4 Measuring Volume

15. When reading liquid levels, how does your "sight line" affect the reading? This effect is known as "parallax".

16. What is a "meniscus" and how does it affect the measurements of liquid levels in graduated cylinders and beakers?

Part 5 Time and Heart Rate

17. Are there differences in heart rate measurements? If so, which measurements of the three used in this lab, 10 seconds, 30 seconds, and 60 seconds, are likely to be the most and the least accurate? Why?