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Anything included in this report in RED (with the exception of the equations which are in black) was added by me (Bill) and represents the data I obtained when I ran the experiment. *Use your own data you collected and perform the calculations for your own data!*

For PES 1150 ONLY: You do NOT need to type your answers into the document, but can hand write the values and equations. Feel free to add more hard returns to areas to increase the space for answers or add drawing and pictures if they enhance the responses you provide. You may use any pictures I provide, as long as the proper reference is made (in accordance with the regulations against plagiarism as specified by the University).

NOTE: Sometimes the notes you take in class can be a little “garbled”. If you use a sheet similar to this one in class to take your notes and record your measurements, it is sometimes “better” if you re-write your notes into a more legible form to be turned in. If you took good lab notes, then this process should be fairly trivial. Remember that neatness will get you far. If something is hard to read or follow, it is more likely to be counted off!

Title: Error in Measurements

Name: _____

Objective

For this lab we will perform simple measurements. This will involve measuring length with a meter stick and with vernier calipers. A digital scale will be used to get a weight measurement and a stopwatch to measure time. Simple calculations using these measurements will be performed to find the density of a penny. The material make up of a “new” penny will be determined from its density. Uncertainty will be explored as well as the methods needed to find the error of a calculated result.

Data and Calculations

Meter Stick

- With the meter stick measure the width of the lab bench (should be less than 1 meter). Do not forget to give the error in all measurements.

Width = 75.63 cm δ Width = $\pm$ 0.05 cm

- Measure the diameter and thickness of the penny in centimeters.

Diameter 1.90 cm δ Diameter = $\pm$ 0.05 cm

Thickness = 0.14 cm δ Thickness = $\pm$ 0.05 cm

- Now try to measure the diameter of the steel ball.

Diameter 2.50 cm δ Diameter = $\pm$ 0.05 cm

Vernier Caliper

- Measure the thickness and diameter of the penny in centimeters.

Thickness = 0.13 cm δ Thickness = $\pm$ 0.05 cm

Diameter 1.90 cm δ Diameter = $\pm$ 0.05 cm

- Measure the diameter of the steel ball.

Diameter 2.51 cm δ Diameter = $\pm$ 0.05 cm

Stopwatch

Uncertainty in time measurement

As stated earlier the error involved with the stopwatch has everything to do with the reaction time of the user and not the instrument. To get a measurement of your reaction time try the following experiment: Start the stopwatch and try to stop the counter such that the final reading is exactly 1.00s. Record your results below.

Trial #	Stopwatch reading	Difference between target and reading (Absolute value)
1	1.13 s	0.13 s
2	1.09 s	0.09 s
3	0.97 s	0.03 s
4	0.92 s	0.08 s
5	1.22 s	0.22 s
Average Difference Values		0.11 s

This average value will be your average uncertainty in all your time measurements gathered by the stopwatch. Show your work here:

$$\langle \Delta t \rangle = \frac{1}{5} \sum_{i=1}^5 \Delta t_i$$

$$\langle \Delta t \rangle = \frac{1}{5} (0.13 \text{ s} + 0.09 \text{ s} + 0.03 \text{ s} + 0.08 \text{ s} + 0.22 \text{ s})$$

$$\langle \Delta t \rangle = \frac{1}{5} (0.55 \text{ s})$$

$$\boxed{\langle \Delta t \rangle = 0.11 \text{ sec}}$$

- Measure a height against the wall somewhere between 1 and 2 meters. Drop a steel ball from this height and measure the time it takes for the steel ball to hit the ground. Use a stopwatch to measure this time. Make several practice measurements in order to get the timing down between you and your lab partners.
- *Note:* To reduce the error incurred with communication between lab partners have the person running the stopwatch drop the ball.
- Repeating a measurement and then performing an average helps by removing some of the random events that cause uncertainty. In general the greater the number of trials the closer your measurement will be to the actual value.
- Record the time and the distance for a series of drops in the following table.

This may seem silly to re-measure the distance, but you never know what errors might be present in a single measurement.

Trial	Distance	Time
1	1.53 m	0.56 s
2	1.54 m	0.52 s
3	1.53 m	0.55 s
Average value	1.533 m	0.543 s

Avg. Distance 1.533 m

δ Distance = $\pm$ 0.0005 m

Avg. Time 0.543 s

δ Time = $\pm$ 0.11 s

Blank work space provided if needed.

To find the average distance and time:

$$\langle d \rangle = \frac{1}{3} \sum_{i=1}^3 d_i$$

$$\langle d \rangle = \frac{1}{3} (1.53 \text{ m} + 1.54 \text{ m} + 1.53 \text{ m})$$

$$\langle d \rangle = \frac{1}{3} (4.60 \text{ m})$$

$$\langle d \rangle = 1.533 \text{ m}$$

$$\langle t \rangle = \frac{1}{3} \sum_{i=1}^3 t_i$$

$$\langle t \rangle = \frac{1}{3} (0.56 \text{ s} + 0.52 \text{ s} + 0.55 \text{ s})$$

$$\langle t \rangle = \frac{1}{3} (1.63 \text{ s})$$

$$\langle t \rangle = 0.543 \text{ sec}$$

Balance

- First hold an “old” penny in one hand and a “new” penny in the other hand. Can you feel the difference in their weights?

No. They feel the same. I suspect this is due to the fact that the difference in their weights is so subtle that we cannot resolve the difference (if there is indeed one).

- Use the balance to get a more precise weight measurement of both pennies in grams.

Old Penny (1973) 3.1 g

δ Old Penny = $\pm$ 0.05 g

New Penny (2002) 2.4 g

δ New Penny = $\pm$ 0.05 g

- Use the data you collected earlier to find the volume of the pennies. They are both the same size so it does not matter which one you measured. Find the uncertainty in the volume by the use of propagation of error.

There is a problem with the thickness measurement. A penny is stamped, which forces an increase in the thickness measurement. We need to adjust the thickness measurement to account for this increase. Use a thickness value of 0.12 ± 0.005 cm. This should be less than the value you measured and correct for the height of the engraving.

It makes life a lot easier and makes your report easier to read if all your relevant data is located together.

Results of penny measurements:

Thickness (t)	=	<u>0.12</u>	±	<u>0.005</u>	cm
Diameter (d)	=	<u>1.90</u>	±	<u>0.05</u>	cm
Mass of older penny	=	<u>3.1</u>	±	<u>0.05</u>	g
Mass of newer penny	=	<u>2.4</u>	±	<u>0.05</u>	g

Volume of a cylinder (a penny) = $\pi r^2 t$, where $r = \frac{1}{2}d$.

First thing is to find the radius:

$$r = \underline{0.95} \text{ cm}$$

Use r and t to calculate the volume of the penny.

$$\begin{aligned} \text{Volume} &= \pi r^2 t = 3.14 \times (\text{radius})^2 \times \text{thickness} \\ &= 3.14 \times (\underline{0.95 \text{ cm}})^2 \times (\underline{0.12 \text{ cm}}) \end{aligned}$$

$$\text{Volume} = \underline{0.340062} \text{ cm}^3$$

The uncertainty of the radius (δr) is given by:

$$\delta r = \frac{1}{2} \delta d = \pm \underline{0.025} \text{ cm}$$

Now we need the uncertainty in the volume:

$$\text{Since } r^2 = r \cdot r$$

$$\delta V = |V| \left| \pi \left(\frac{\delta r}{r} + \frac{\delta r}{r} + \frac{\delta t}{t} \right) \right|$$

$$= | \underline{0.340062 \text{ cm}^3} | \times | \underline{3.14} | \times \left(\frac{0.025 \text{ cm}}{0.95 \text{ cm}} + \frac{0.025 \text{ cm}}{0.95 \text{ cm}} + \frac{0.005 \text{ s}}{0.12 \text{ s}} \right)$$

$$= \pm \underline{0.1006911} \text{ cm}^3$$

- Now find the density of each penny and the uncertainty in the density. Since this is most likely your first experience with propagation of error, I will give you some further guidance.

To calculate ρ and $\delta\rho$:

The density: $\rho = \frac{\text{mass}}{\text{volume}}$.

Calculate the density of the “new” penny:

$$\rho = m/V = \left(\frac{2.4 \text{ g}}{0.340062 \text{ cm}^3} \right) = \underline{7.0575} \text{ g/cm}^3$$

The uncertainty in the density of the “new” penny:

$$\delta\rho = |\rho| \left(\frac{\delta V}{|V|} + \frac{\delta m}{|m|} \right)$$

Show your work here:

$$\delta\rho = |\rho| \left(\frac{\delta m}{|m|} + \frac{\delta\tau}{|\tau|} \right) = \left(7.0575366 \frac{\text{g}}{\text{cm}^3} \right) \left(\frac{0.05 \text{ g}}{2.4 \text{ g}} + \frac{0.1006911 \text{ cm}^3}{0.340062 \text{ cm}^3} \right)$$

$$\delta\rho = \pm 2.2367425 \frac{\text{g}}{\text{cm}^3}$$

$$\rho_{\text{New Penny}} = 7.0575 \pm 2.2367425 \frac{\text{g}}{\text{cm}^3}$$

<You should be getting the idea by now – do some yourself.>

Follow the same steps to find the density of the “old” penny. **Note:** since the dimensions of each penny is the same the volume will be the same.

Calculate the density of the “old” penny:

$$\rho = m/V = \left(\frac{\quad}{\quad} \right) = \quad \text{g/cm}^3$$

The uncertainty in the density of the “old” penny:

$$\delta\rho = \rho \left(\frac{\delta V}{V} + \frac{\delta m}{m} \right)$$

Show your work here:

$$\delta\rho = \pm \text{_____} \frac{\text{g}}{\text{cm}^3}$$

It's always nice to be organized.

Penny	Volume	δV	Density	$\delta\rho$
"New"				
"Old"				

Results and Questions

- Comment on the advantages and disadvantages of using a meter stick. (in what situations is it best suited, and what are its limitations)

The meter stick is useful for measure medium sized objects when a very precise measurement is not necessarily required. For example, we measured the workbench with the meter stick and obtained a relatively decent value. We were not looking for the length of the workbench down to the millimeter, but rather on the order of centimeters. However, when we tried to measure the thickness of the penny, the meter stick was too bulky and not sub-divided enough to obtain a very accurate reading.

- Compare and contrast the measurements made on the penny with the meter stick and the vernier calipers.

The measurements of the penny are fairly close using both tools. However, the micrometer was more useful for measuring the penny when considering the uncertainty of the equipment.

- Can you measure the width of the lab bench with the calipers? Would it be practical? **Why?**

The jaws on the micrometer just do not open wide enough to measure the bench and if we were to move the micrometer for a tip-to-tail measurement, the human error included in that would provide a very erroneous measurement.

- Comment on the advantages and disadvantages of using the vernier calipers.

The micrometer's advantages lies in its use for relatively small objects (like the penny and steel ball). Likewise, it provides a much more accurate measurement (from an uncertainty perspective). The micrometer it is not very useful for measuring larger (or medium-sized) objects (like the workbench).

- Which penny felt heavier?

When we held the two pennies in our hands, one in each hand, we could not distinguish between the weights of the pennies. We suspect this is due to the fact that our hands are not as sensitive to the measure of the weights. The balance was especially sensitive providing an accurate weight for each of the pennies.

- Discuss problems and sources of error involved with the ball drop measurement.

While performing the ball drop experiment, we found a potential problem could arrive in the measuring of the height of the drop mark. We had to move the meter stick (since it was only 1 meter long) to measure the total height off the ground. Since we moved it there may be included error in that measurement then just the 0.0005 m that we got from the smallest division on the stick. Likewise, we didn't consider the smoothness of the ball, air resistance, gravitational variance of the Earth and many other potential sources of error.

- Use the list of metals and their densities to find out which metal the "new" penny is made from!

metal	density ($\frac{\text{g}}{\text{cm}^3}$)
Copper (Cu)	8.92
Lead (Pb)	11.4
Zinc (Zn)	7.14
Uranium (U)	19.05
Silver (Ag)	10.50

Restate your density measurements

Penny	Density	Material
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"New"	7.06 g/cm ³	Zinc (Zn)
"Old"	8.87 g/cm ³	Copper (Cu)

Conclusion (later in life this is what your boss will look at first!)

- This closing paragraph is where it is appropriate to conclude and express your opinions about the results of the experiment and all its parts. Only the final result(s) needs to be restated.

Since this is your first lab I will give you some extra guidance.

- The results of the measurements made with the meter stick and vernier caliper were not the primary objective of the lab, but your impressions about their accuracy and limitations are relevant.

We compared the value of density for the new penny with known densities of metals; we found out that the new pennies are being made of zinc instead of copper. Zinc is cheaper than copper, so it makes sense to use it as a substitute.

- Concluding paragraph on meter stick/ vernier caliper:

We successfully used a meter stick, vernier calipers, a digital scale and a stopwatch to make several measurements for the lab. Finally, we noticed that the uncertainty from measurements could become significantly large and the need for more accurate measuring instruments.

- The results of the measurements on the "old" and "new" pennies were the primary goals of this lab. Restate the results and questions here (in paragraph form):

Through the use of this lab's equipment, we found that "new" pennies are made of zinc instead of copper.

- Was your error excessive? If so what, and how would you recommend it be corrected? Make sure that the reason you are stating as the cause of your error predicts whether your results will be too high or too low.

<You all are intelligent scientists. What do you think? See if I mentioned anything above in any of the comments which may have introduced or increased error for this lab.>