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Lab 1 - Laboratory Instruments

Types of Errors

- **Systematic Error** - Errors that follow a consistent and predictable pattern such as zero error or parallax error.
- **Random Error** - errors that do not follow a predictable pattern such as the effect of the fan or seismic waves.
- **Absolute Error** - difference between the true and the measured value.
- **Fractional Error** - ratio of the absolute error to the true value

Diagram of Vernier Caliper:



Diagram of Micrometer Screw Gauge:



Measurements

With a Ruler

Measurement of table top

Measurement	Value	Absolute Error	Percent Error
Length	229cm	± 1mm	± 0.043%
Width	120cm	± 1mm	± 0.083%
Thickness	3cm	± 1mm	± 3.333%
Volume	82440cm ³	± 2852cm ³	± 3.459%

Calculations

Average Thickness of Table:

$$\frac{2.9\text{cm} + 3.0\text{cm} + 3.1\text{cm}}{3} = 3\text{cm}$$

Percent Error for Length:

$$\frac{\Delta x}{x} \times 100 = \frac{\pm 1\text{mm}}{229\text{cm}} = \frac{\pm 0.1\text{cm}}{229\text{cm}} \times 100 = 0.004\%$$

Percent Error for Width:

$$\frac{\Delta x}{x} \times 100 = \frac{\pm 1\text{mm}}{120\text{cm}} = \frac{\pm 0.1\text{cm}}{120\text{cm}} \times 100 = 0.083\%$$

Percent Error for Thickness:

$$\frac{\Delta x}{x} \times 100 = \frac{\pm 1\text{mm}}{3\text{cm}} = \frac{\pm 0.1\text{cm}}{3\text{cm}} \times 100 = 3.333\%$$

Percent Error for Length:

$$\frac{\Delta x}{x} \times 100 = \frac{\pm 1\text{mm}}{229\text{cm}} = \frac{\pm 0.1\text{cm}}{229\text{cm}} \times 100 = 0.004\%$$

Percent Error for Volume:

$$0.0043 + 0.083 + 3.333 = 3.459\%$$

Absolute Error for Volume:

$$3.459\% \times 82440\text{cm}^3 = 2852\text{cm}^3$$

With Vernier Caliper

Measurement of the glass block

Measurement	Value	Absolute Error	Fractional Error
Length	4.58cm	$\pm 10\mu m$	4.58×10^{-3}
Width	10cm	$\pm 10\mu m$	0.01
Thickness	2.5cm	$\pm 10\mu m$	2.5×10^{-3}
Volume	114.5cm^3	$\pm 1.38\text{cm}^3$	0.012

Calculation

Average Length of Glass Block:

$$\frac{4.58\text{cm} + 4.58\text{cm} + 4.58\text{cm}}{3} = 4.58\text{cm}$$

Average Width of Glass Block:

$$\frac{9.99\text{cm} + 10\text{cm} + 10\text{cm}}{3} \approx 10\text{cm}$$

Average Thickness of Glass Block:

$$\frac{2.5\text{cm} + 2.5\text{cm} + 2.5\text{cm}}{3} = 2.5\text{cm}$$

Volume of Glass Block:

$$V = L \times W \times H = 4.5cm \times 10cm \times 2.5cm = 114.5cm^3$$

Fractional Error of Volume:

$$4.58 \times 10^{-3} + 2.5 \times 10^{-3} + 0.01 \approx 0.012$$

Absolute Error in the Volume:

$$0.0012 \times 114.5cm^3 \approx 1.3cm^3$$

With Micrometer Screw Gauge

Measurement of the marble

Measurement	Value	Absolute Error	Fractional Error
Diameter	15.3cm	$\pm 10\mu m$	6.53×10^{-5}
Volume	15002cm ³	$\pm 2.94cm$	1.96×10^{-4}
Surface Area	2942cm ²	$\pm 0.38cm$	1.3×10^{-4}

Calculation

Volume of a sphere:

$$V = \frac{4}{3}\pi r^3 = 4.1887... \times 15.3^3 \approx 15002cm$$

Surface Area of a sphere:

$$A = 4\pi r^2$$

Fractional Error for Volume:

$$3 \times 6.53 \times 10^{-5} = 1.96 \times 10^{-4}$$

Absolute Error for Volume:

$$1.96 \times 10^{-4} \times 15002cm^3 = 2.94cm^3$$

Fractional Error for Surface Area:

$$2 \times 6.53 \times 10^{-5} = 1.3 \times 10^{-4}$$

Absolute Error for Surface Area:

$$1.3 \times 10^{-4} \times 2942cm^2 = 0.38cm^2$$

With Triple Beam Balance

Measurement of the beaker and water.

Measurement	Value	Absolute Error	Percent Error
Mass of empty beaker	58.1g	$\pm 0.1g$	
Mass of beaker with water	139.4g	$\pm 0.1g$	
Mass of Water	81.3g	$\pm 0.2g$	0.246%
Volume of Water	70mL	$\pm 10mL$	14.29%
Density of Water	1.16g/mL	$\pm 0.169g/L$	14.54%

Measurement of beaker with 70ml water added

Calculation

Mass of the Water:

$$139.4g - 58.1g = 81.3g$$

Density of Water:

$$\rho = \frac{m}{V} = \frac{81.3g}{70mL} = 1.16g/mL$$

Percent Error in mass:

$$\frac{\Delta x}{x} \times 100 = \frac{0.2g}{81.3g} = 0.246\%$$

Percent Error in volume:

$$\frac{\Delta x}{x} \times 100 = \frac{10mL}{70mL} = 14.29\%$$

Percent Error in density:

$$0.246\% + 14.26\% = 14.54\%$$

Absolute Error in density:

$$14.56\% \times 1.16g/mL = 0.169\%$$

Accuracy of Result:

We found a density of $(1.16 \pm 0.169)g/mL = (1160 \pm 169)kgm^{-3}$, which is greater than the true value for the density of water $\sim 1000kg$. We however note that the true value is just within the margin of error obtained from the experiment, and is thus consistent with the true value. Moreover, the large error clearly results from the beaker, which in addition to note having markings smaller than $10mL$, it also had the label “approximate” next to the units.

Discussion

After completing the measurements with each of the instruments, we noticed a pattern. The smaller measurements all had a higher fractional or percent error. For example, when we measured the thickness of the table, we noticed a much higher percent error than for the length and width, even though we had used the same ruler to measure it. Even worse, when we attempted to determine the volume from these measurements, the percent errors add. Thus, I can say the accuracy of this whole measurement was thrown off by our attempt to measure the small thickness with the ruler.

One suggestion to fix this is to use more precise instruments like the vernier caliper when attempting to measure smaller quantities like thickness. This way we reduce the overall error in the measurement.

One more thing to mention: when we were working with the triple beam balance, we were having trouble with zeroing the balance. It remains unclear whether this was due to a mechanical failure, the effect of the external environment, or an uneven surface. We tried our best to work around this difficulty. Yet, as all the errors in our experiment are explainable by the imprecision of the beaker, it remains unclear to what extent—if any at all—this zero error would have on our experiment.

Conclusion

The results of our experiments show clearly the importance of choosing the correct instruments to obtain the most accurate results possible in an experiment.