

Rahel Gunaratne

PHYS 1001 A3

N.M.

No Partner

101067324

1.) **Purpose:** The purpose of this Lab is to introduce the student to the basic measurement procedures, handling data “manually” and using Logger Pro.

2.) **Theory:** In part A1, the zero of the micrometer was measured 4 times: $\{Mzero_k\}_{k=1}^4$ to provide a value; Mzero from which to subtract the diameter $\{CyD_k\}_{k=1}^4$ from to get a more accurate value. The average can be calculated from both: $Mzero_{av} = \frac{\sum_{k=1}^4 Mzero_k}{4}$ and

$$CyD_{av} = \frac{\sum_{k=1}^4 CyD_k}{4}, \text{ along with both their error: } \sigma_{Mzero} = \frac{Mzero_{max} - Mzero_{min}}{4} \text{ and } \sigma_{CyD} = \frac{CyD_{max} - CyD_{min}}{4}.$$

Using the averages, a more precise value can be calculated by $CyD - calc_{avg} = CyD_{avg} - Mzero_{avg}$ and

$$\text{its error: } \sigma_{CyD - calc_{avg}} = \sqrt{\sigma_{Mzero}^2 + \sigma_{CyD}^2}.$$

A more precise value for the cylinder’s diameter and error is labeled: $d = CyD - calc$.

To find length, the Vernier calipers are used to measure the length of the aluminum cylinder: $\{CyL_k\}_{k=1}^4$, it’s average: $CyL_{av} = \frac{\sum_{k=1}^4 CyL_k}{4}$ and its error: $\sigma_{CyL} = \frac{CyL_{max} - CyL_{min}}{4}$ using inefficient statistics. The length and error is labeled: $L = CyL$.

Using the length and diameter of the cylinder, the volume can be calculated: $V = \frac{\pi d^2 L}{4}$ and its error: $\sigma_V =$

$$\sqrt{\left(\frac{\pi d^2 \sigma_L}{4}\right)^2 + \left(\frac{2\pi d L \sigma_d}{4}\right)^2},$$

The mass of the aluminum cylinder can be measured using the Triple Beam Balance: $\{m_k\}_{k=1}^4$ and its average calculated: $m_{av} = \frac{\sum_{k=1}^4 m_k}{4}$, and error: $\sigma_m = \frac{m_{max} - m_{min}}{4}$.

Using the mass and volume, the density can be calculated: $\rho = \frac{m}{V}$ and its error: $\sigma_\rho = \rho \sqrt{\left(\frac{\sigma_m}{m}\right)^2 + \left(\frac{\sigma_V}{V}\right)^2}$.

In part B, the Lab clock was used to measure, five times, the time it takes for one’s heart to beat 30 times, labeled $t: \{t_k\}_{k=1}^5$. The average is calculated: $t_{av} = \frac{\sum_{k=1}^5 t_k}{5}$. And the error is taken from LoggerPro’s statistical data $\sigma_{t_{av}}$. The number of beats per minute is then calculated: $n = \frac{1800}{t_{av}^{(30)}(\text{in sec})} \pm \frac{1800}{(t_{av}^{(30)})^2} \sigma_{t_{av}}$.

In part C, the Motion Detector measures the movement of a hand moving to and away from it. The data automatically enters into a LoggerPro file and two graphs are generated: Position vs Time and Velocity vs Time. The average value of the Velocity graph is similar to the slope in the Position graph because the Velocity graph is a derivative of the Position graph. The average value in the Velocity graph is essentially a tangent line to the Position graph.

All the measured values enter into different LoggerPro files and the STAT function are applied to each graph (Linear fit function for Position vs Time graph). The STAT function provides information such as: min, max, mean, median and standard deviation. The linear fit function provides the slope and the y intercept given a range of x values. If the statistical error $> 2*$ reading error then the statistical error was used for measurements.

3.) Apparatus:

- Micrometer
- Vernier calipers
- Triple Beam Balance
- Lab Clock
- Motion Detector,
- Logger Pro files IL1, IL2 and IL3

4.) Procedure:

Part A1:

1. Measure zero of the micrometer and the diameter of the cylinder (four times using micrometer), calculate average and error for both using inefficient statistics.
2. Calculate a more precise value for the cylinder diameter using the averages.

Part A1b:

1. Measure the length of the cylinder (four times using Vernier Calipers), calculate average and error using inefficient statistics.
2. Calculate volume using diameter and length.

Part A2:

1. Measure mass of cylinder (four times using Triple Beam Balance), calculate average and error using inefficient statistics.
2. Calculate density using mass and volume.

Part B:

1. Measure time taken for heart to beat 30 times (5 times using Lab Clock) calculate average and use error from LoggerPro.
2. Calculate the number of beats n , per minute and its error.

Part C:

1. Move hand and use Motion Detector to detect its movement.
 - a. Compare slope of Positive vs Time graph to average value of Velocity vs Time graph.

5.) Analysis and Observations:

5.1) Part A - Measurement of Cylinder

5.1.1) Data Table

Trial	CyL(cm)	Mzero(mm)	CyDm(mm)	CyD-calc (mm)	Volume (cm³)	CyM (g)	CyDen (g/cm³)
1	10.04	-0.05000	25.29	25.34	50.65	431.2	8.511
2	10.04	-0.04000	25.30	25.34	50.65	432.2	8.531
3	10.04	-0.07000	25.34	25.41	50.93	432.2	8.484
4	10.07	-0.06000	25.31	25.37	50.92	432.7	8.495
Avg	10.05	-0.05500	25.31	25.37	50.79	432.0	8.506
Reading Error	±0.003	±0.0005	±0.0005	-	-	±0.5	-

Table 1: All measured (CyL, Mzero, CyDm, CyM) – includes reading errors - and calculated (CyD-calc, Volume, CyDen) values along with their averages. Taken from LoggerPro file.

5.2) Part B – Heart beat

5.2.1) Data Table

The lab clock was used to measure how long it takes for the user's heart to beat 30 times.

Trial	30HB(s)
1	22.693
2	22.301
3	20.641
4	21.289
5	20.705
Avg	21.526
Reading Error	± 0.002

Table 2: Time taken for user's heart to beat 30 times and it's average

5.2.2) Graph

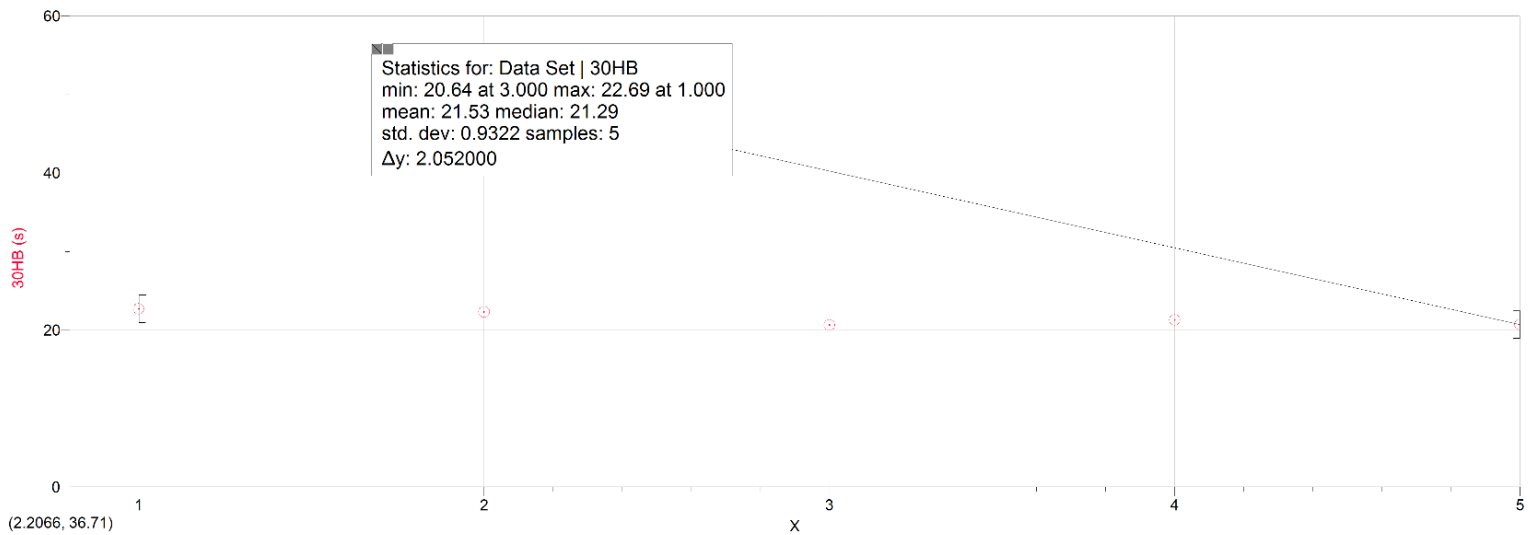


Figure 1: Graph of data points for time taken for heart to beat 30 times

5.3) Part C – Motion Detector

5.3.1) Graph - Position vs Time

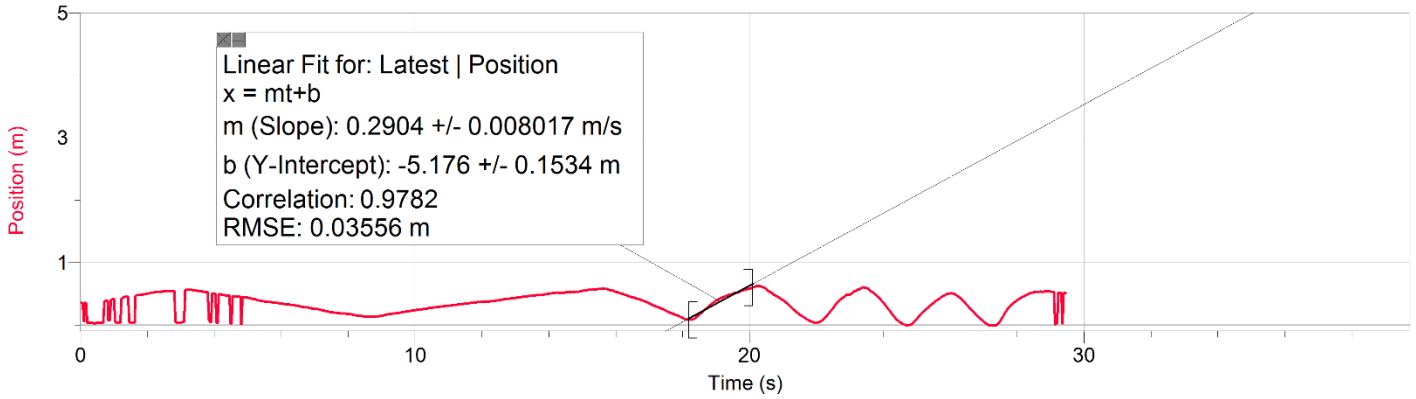


Figure 2: Graph of position of hand vs time.

5.3.2) Graph – Velocity vs Time

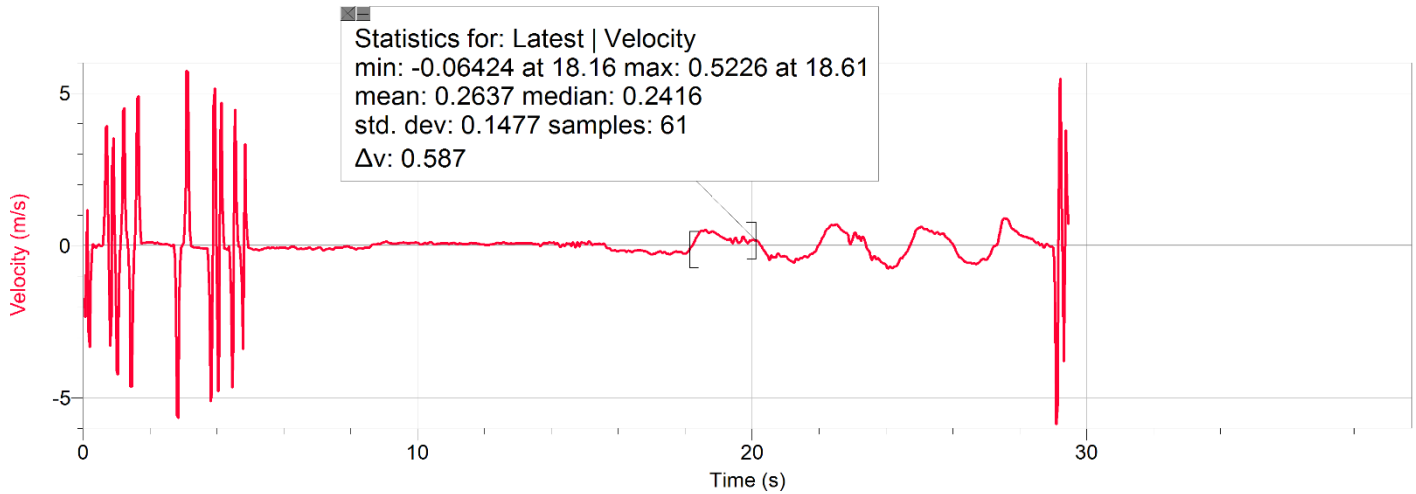


Figure 3: Graph of velocity of hand vs time. Or derivation of position vs time graph.

6.) Calculations:

6.1) Part A

6.1.1) Micrometer zero calculation and error:

$$Mzero_{av} = \frac{\sum_{k=1}^4 Mzero_k}{4} = -0.05500\text{mm} * \frac{1\text{cm}}{10\text{mm}} = -0.005500\text{cm}$$

$$\sigma_{Mzero} = \frac{Mzero_{max} - Mzero_{min}}{4} = 0.0075\text{mm} * \frac{1\text{cm}}{10\text{mm}} = \pm 0.00075\text{cm}$$

$$Mzero = -0.005500\text{cm} \pm 0.0005\text{cm} (\sigma_{Mzero} < 2\sigma_{ReadingError} ; \text{reading error is used})$$

6.1.1.1) Comparison between calculated value and LoggerPro Mzero average.

$$Mzero_{LoggerProValue} = -0.005500\text{cm} \pm 0.013\text{cm}$$

Value is calculated the same way. Error is different because LoggerPro uses standard deviation: $\sigma =$

$$\sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - \mu)^2} . \text{And also because reading error was used for Mzero.}$$

6.1.2) Cylinder diameter calculation and error:

$$CyD_{av} = \frac{\sum_{k=1}^4 CyD_k}{4} = 25.31\text{mm} * \frac{1\text{cm}}{10\text{mm}} = 2.531\text{cm}$$

$$\sigma_{CyD} = \frac{CyD_{max} - CyD_{min}}{4} = \pm 0.0013\text{mm} * \frac{1\text{cm}}{10\text{mm}} = \pm 0.00013\text{cm}$$

$$CyD = 2.531\text{cm} \pm 0.0005\text{cm} (\sigma_{Mzero} < 2\sigma_{ReadingError} ; \text{reading error is used})$$

6.1.2.1) For more accuracy:

$$CyD - calc_{av} = CyD_{av} - mZero_{av}$$

$$CyD - calc_{av} = 2.537\text{cm}$$

$$\sigma_{CyD - calc_{av}} = \sqrt{\sigma_{CyD}^2 + \sigma_{Mzero}^2}$$

$$\sigma_{CyD - calc_{av}} = \pm 0.00071\text{cm}$$

$$d = 2.537 \pm 0.00071\text{cm}$$

6.1.2.2) Comparison between calculated value and LoggerPro Cylinder Diameter average.

$$d_{LoggerProValue} = 2.537 \pm 0.033\text{cm}$$

Value is calculated the same way. Error is different because LoggerPro uses standard deviation: $\sigma =$

$$\sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - \mu)^2} .$$

6.1.3) Cylinder length calculation and error:

$$CyL_{av} = \frac{\sum_{k=1}^4 CyL_k}{4} = 10.05\text{cm}$$

$$\sigma_{CyL} = \frac{10.07 - 10.04}{4} = \pm 0.0075\text{cm} (\text{statistical error})$$

$$L = 10.05 \pm 0.0075\text{cm}$$

$$\sigma_{Reading\ error} = 0.003\text{cm} (\text{based on instruments doc provided})$$

Statistical error seems to be the more accurate option because it is greater than $2 \cdot \sigma_{\text{Reading error}}$. However, the statistical error doesn't even cover the number 10.07 from the average ($10.05 + 0.0075 = 10.0575$). It lies outside the range 2σ ($10.05 + 2(0.0075) = 10.065$). But 10.065 is very close to 10.07, so the data point (10.07) will not be rejected as bad data.

6.1.3.1) Comparison between calculated value and LoggerPro Cylinder Length average.

$$L_{\text{LoggerProValue}} = 10.05 \pm 0.015 \text{cm}$$

Value is calculated the same way. Error is different because LoggerPro uses standard deviation: $\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - \mu)^2}$.

6.1.4) Calculating Volume

$$L = 10.05 \text{cm} \pm 0.0075 \text{cm}$$

$$d = 2.537 \pm 0.00071 \text{cm} \text{ (inefficient statistics error)}$$

$$V = \frac{\pi d^2 L}{4} = \frac{\pi (2.537 \text{cm})^2 10.05 \text{cm}}{4} = 50.80 \text{cm}^3$$

$$\sigma_V = \sqrt{\left(\frac{\pi d^2 \sigma_L}{4}\right)^2 + \left(\frac{2\pi d L \sigma_d}{4}\right)^2} = \pm 0.047 \text{cm}^3$$

$$V = 50.80 \pm 0.047 \text{cm}^3$$

6.1.4.1) Comparison between calculated value and LoggerPro Volume average.

$$V_{\text{LoggerProValue}} = 50.79 \pm 0.1594 \text{cm}^3$$

The volumes are very close, the difference is due to rounding. The error difference is due to the error used for d, as it is based on inefficient statistics whereas LoggerPro uses standard deviation: $\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - \mu)^2}$. Also for some of the factors, the reading error was used whereas LoggerPro used purely statistical error.

6.2) Part A2

The triple beam balance was used to measure the mass of the cylinder 4 times, labeled CyM.

6.2.1) Mass Measurement

$$m_{av} = \frac{\sum_{k=1}^4 m_k}{4} = 432.0 \text{g}$$

$$\sigma_m = \frac{m_{max} - m_{min}}{4} = \pm 0.38 \text{g}$$

$$m = 432.0 \pm 0.5 \text{g} \text{ (Reading error is used)}$$

6.2.1.1) Comparison between calculated value and LoggerPro mass average.

$$m_{\text{LoggerProValue}} = 432.0 \pm 0.63 \text{g}$$

Value is calculated the same way. Error is different because LoggerPro uses standard deviation: $\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - \mu)^2}$.

6.2.2) Density Calculation

$$m = 432.0 \pm 0.5g$$

$$V = 50.79 \pm 0.14\text{cm}^3$$

$$\rho = \frac{m}{V} = \frac{432.0g}{50.79\text{cm}^3} = 8.506\text{g/cm}^3$$

$$\sigma_\rho = \rho \sqrt{\left(\frac{\sigma_m}{m}\right)^2 + \left(\frac{\sigma_V}{V}\right)^2} = \pm 0.029\text{g/cm}^3$$

$$\rho_{\text{HandCalculation}} = 8.506 \pm 0.029\text{g/cm}^3$$

6.2.2.1) Comparison between calculated value and LoggerPro average.

$$\rho_{\text{LoggerProValue}} = 8.506 \pm 0.020\text{g/cm}^3 \text{ (LoggerPro value)}$$

The density values are the same because the values were not rounded until the final value was calculated and the method in which they were calculated was the same. The difference in error can be accounted to the repeated use of inefficient statistics in hand calculations whereas LoggerPro uses standard deviation: $\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - \mu)^2}$. The accumulation of using such a different method to calculate error stacked up and this is the difference.

6.3) Part B

The lab clock was used to measure how long it takes for the user's heartbeat to beat 30 times.

$$t_{av} = \frac{\sum_{k=1}^5 t_k}{5} = \frac{21.53}{30 \text{ H.B.}}$$

$$\sigma_{t_{av\text{LoggerPro}}} = \frac{\pm 0.93s}{30 \text{ H.B.}}$$

$$t = \frac{21.53 \pm \pm 0.93s}{30 \text{ H.B.}}$$

$$n = \frac{1800}{21.53} \pm \frac{1800}{21.53^2} (0.93) = \frac{83.60 \pm 3.6 \text{ H.B.}}{60s}$$

6.4) Part C

The Motion detector was used to measure the movement of the hand some 50-60cm away.

The slope of the Position vs Time is 0.2904 and the average value from the Speed vs Time graph is 0.2637. They are slightly different because the domain used to calculate slope for Position vs Time graph is slightly different from the domain used to calculate average value from the Speed vs Time graph.

They are similar because if Position vs Time = $f(x)$, then Speed vs Time = $f'(x)$. This relation means that Speed vs Time is a derivative of Position vs Time. And so, the rate of change in Position vs Time is depicted by its derivative's average value.

- 7.) **Results:** The values measured were able to provide the student with practice and experience in precision, average and error calculations.
- 8.) **Discussion:** The values calculated by the student were always compared to the known value calculated by LoggerPro. The values were always consistent, but the errors were not. The method of error calculation was

different. LoggerPro uses standard deviation: $\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - \mu)^2}$, whereas the student's calculations for error were done using inefficient statistics: $\sigma = \frac{x_{max} - x_{min}}{N}$.

Talking about the values themselves, they were precise as they were rather consistent with one another. To improve accuracy, more trials should've been conducted and the removal of a time restriction would allow the student to take their time to be more accurate.

The instruments to measure were extremely precise, however, they did look quite old and that makes them subject to warp. Although they were quite sturdy and well-built, the repeated use dents the instrument making them less accurate.

The inconsistent use of instrument is also a subject of error, for example, the micrometer's thimble scale wasn't very clear on how tight it needed to be. This created discrepancies between some of the results as some were tightened harder than others. This can be labeled as human error. The heartbeat measurement is a strong case, as it relies on the user's ability to count his/her own heartbeats and also stop and start the Lab clock. The process of doing that also must've affected the user's normal heartbeat. Although the number's themselves were not important for the lab, it is still an imprecision because the user would get more relaxed as more tests were conducted and the heartbeat would slow, causing inconsistencies in conditions for the duration of the experiment.