Simple measurements & free fall

Identification page

Instructions: Print this page and the following ones before your lab session to prepare your lab report. Staple them together with your graphs at the end. If you forgot to print it before your lab, you can reproduce it by hand but you have to follow the exact format (same number of pages, same items on each page, same space to answer question).

Complete <u>all the identification fields below</u> or 10% of the lab value will be deduced from your final mark for this lab.

For in-lab reports, hand in your report to your demonstrator at the end of the sessions or you will receive a zero for this lab.

For take-home reports, drop your report in the right box or 10% of the lab value will be deduced from your mark. Refer to the *General information* document for the details of the late report policy.

Experiment title: Simple measurements & free fall

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Lab group number:

Course code: PHY 1124

Demonstrator:

Date of the lab session: 23rd January, 2024

Partner's name: Nico Lamberti

Signed data stapled to back of report

Data sheet

Instructions: Use a pen to complete this section before the end of the lab session. Ask your TA to initialize your data before you leave the laboratory.

Part 1 – Length measurement

[1] **Table 1 – Mass measurements of various objects**

Object	Mass	
	m	Δm
	(g)	(g)
Rectangular prism	32.8	± 0.1
Hollow cylinder	52.1	± 0.1

[3] **Table 2 - Length measurements of a rectangular prism using various instruments**

Instrument	Length of short side		Length of medium side		Length of long side	
	a	Δa	b	Δb	c	Δc
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
meter stick	13	± 0.5	26	± 0.5	38	± 0.5
vernier caliper	12.7	± 0.05	25.4	± 0.05	38.0	± 0.05

[1] **Table 3 - Length measurements of a hollow cylinder using a vernier caliper**

Instrument	Length		Outer diameter		Inner diameter	
	l	Δl	D	ΔD	d	Δd
	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
vernier caliper	51.0	± 0.05	25.4	± 0.05	22.2	± 0.05

Part 2 – Time measurement

[1] **Table 4 - Calculating the period of oscillation of a mass-spring system**

Trial	Time for 10 oscillations	
	t	Δt
	(s)	(s)
1	10.1	± 0.3
2	10.46	± 0.3
3	11.03	± 0.3
4	10.28	± 0.3
5	10.03	± 0.3

Part 3 – Picket fence free fall

[4] Prepare Graph 1. Print it to a pdf file. Send the file to yourself by email or save it on a USB key. Print the graph and attach it at the end of your report.

[2] **Table 5 - Linear regression results for the free falling picket fence experiment**

Trial	Slope		y-intercept	
	m	Δm	b	Δb
1	9.490	± 0.03266	-78.54	± 0.2768
2	9.763	± 0.005819	-11.70	± 0.008225
3	9.730	± 0.01099	-24.70	± 0.03012
4	9.990	± 0.02221	-43.56	± 0.1012
5	9.791	± 0.012	-19.95	± 0.02693

Questions

Instructions: You can finish this section at home. We encourage you to start answering these questions while you are still in the lab and the TA is available to help you.

Part 1 – Length measurement

[2] Calculate the volume V of the rectangular prism (in mm^3) using the vernier caliper data (including the error calculation). Refer to the tutorial *How to present a calculation example* to know how to present such calculations.

$$\text{Length} = (25.4 \pm 0.05)\text{mm}$$
$$\text{Height} = (38.0 \pm 0.05)\text{mm}$$
$$\text{Width} = (12.7 \pm 0.05)\text{mm}$$

$$V = whl$$
$$V = (12.7\text{mm})(38.0\text{mm})(25.4\text{mm})$$
$$= 12258.04\ \text{mm}^3$$

$$\Delta V = |V|\sqrt{\frac{\Delta w^2}{w^2} + \frac{\Delta h^2}{h^2} + \frac{\Delta l^2}{l^2}}$$

$$\Delta V = (|12258.04|\text{mm}^3)\sqrt{\frac{0.05^2\text{mm}}{12.7^2\text{mm}} + \frac{0.05^2\text{mm}}{38^2\text{mm}} + \frac{0.05^2\text{mm}}{25.4^2\text{mm}}} = 56.31544\ \text{mm}^3$$

$$V = (12258.04 \pm 56.32)\text{mm}^3$$

[2] Calculate the density ρ (in kg/m^3) of the rectangular prism using the caliper data (including the error calculation).

$$\text{Volume} = (12258.04 \pm 56.32)\text{mm}^3 \Rightarrow (1.225804 \pm 0.005604)\cdot 10^{-5}\text{m}^3$$
$$\text{Mass} = (32.8 \pm 0.1)\text{g} \Rightarrow (0.0328 \pm 1\cdot 10^{-4})\text{kg}$$

$$\rho = \frac{m}{V}$$
$$\rho = \frac{0.0328\ \text{kg}}{1.225804\cdot 10^{-5}\ \text{m}^3} = 2675.7162\frac{\text{kg}}{\text{m}^3}$$

$$\Delta\rho = |\rho| = \sqrt{\frac{\Delta m^2}{m^2} + \frac{\Delta V^2}{V^2}}$$
$$\Delta\rho = |2675.7162\frac{\text{kg}}{\text{m}^3}|\sqrt{\frac{(1\cdot 10^{-4})^2\text{kg}}{0.0328^2\text{kg}} + \frac{(0.005604\cdot 10^{-5})^2\text{m}^3}{(1.225804\cdot 10^{-5})^2\text{m}^3}} = 14.708\frac{\text{kg}}{\text{m}^3}$$
$$\rho = (2675.7162 \pm 14.708)\frac{\text{kg}}{\text{m}^3}$$

[2] Calculate the volume V (in mm^3) of the hollow cylinder (including the error calculation).

$$R(\text{Outer Diameter}) = (25.4 \pm 0.05)\text{mm}$$
$$r(\text{Inner Diameter}) = (22.2 \pm 0.05)\text{mm}$$
$$h(\text{Height}) = (51.0 \pm 0.05)\text{mm}$$

$$V = \pi(R^2 - r^2)h$$
$$V = \pi(25.4^2\text{mm} - 22.2^2\text{mm})(51.0\text{mm})$$
$$= 24404.897\text{mm}^3$$
$$\Delta V = \sqrt{(\frac{dV}{dR})^2\Delta R^2 + (\frac{dV}{dr})^2\Delta r^2 + \frac{dV}{dh})^2\Delta h^2}$$
$$\Delta V = \sqrt{[\pi(2R - r^2)h]^2\Delta R^2 + [\pi(R^2 - 2r)h]^2\Delta r^2 + [\pi(R^2 - r^2)]^2\Delta h^2}$$
$$\Delta V = \sqrt{[\pi(2(25.4) - 22.2^2)51.0]^2\Delta 0.05^2 + [\pi(25.4^2 - 2(22.2))51.0]^2\Delta 0.05^2 + [\pi(25.4^2 - 22.2^2)]^2\Delta 0.05^2}$$
$$= 5975.204\text{mm}^3$$
$$V = (24404.897 \pm 5975.204)\text{mm}^3$$

[2] Calculate the density ρ (in kg/m^3) of the hollow cylinder (including the error calculation).

$$\text{Volume} = (24404.897 \pm 5975.204)\text{mm}^3 \Rightarrow (2.4404897 \pm 0.5975204) \cdot 10^{-5}\text{m}^3$$
$$\text{Mass} = (52.1 \pm 0.1)\text{g} \Rightarrow (0.0521 \pm 1 \cdot 10^{-4})\text{kg}$$

$$\rho = \frac{m}{V}$$
$$\rho = \frac{0.0521 \text{ kg}}{2.4404897 \cdot 10^{-5} \text{ m}^3} = 2134.81745\frac{\text{kg}}{\text{m}^3}$$

$$\Delta\rho = |\rho| = \sqrt{\frac{\Delta m^2}{m^2} + \frac{\Delta V^2}{V^2}}$$
$$\Delta\rho = |2134.817\frac{\text{kg}}{\text{m}^3}|\sqrt{\frac{(1 \cdot 10^{-4})^2\text{kg}}{0.0521^2\text{kg}} + \frac{(0.5975204 \cdot 10^{-5})^2\text{m}^3}{(2.4404897 \cdot 10^{-5})^2\text{m}^3}} = 522.7054\frac{\text{kg}}{\text{m}^3}$$

$$\rho = (2134.817 \pm 522.7054)\frac{\text{kg}}{\text{m}^3}$$

[4] Prepare a table for your volume and density measurements of both objects. You have to present the volumes and densities for the rectangular prism calculated using the two instruments and the one you calculated for the hollow cylinder (including uncertainties). Refer to the tutorial *How to prepare a table* to know how to prepare a table for the physics labs. Your table should contain columns for the objects, the measuring instruments, the volumes (in mm^3) and the densities (in kg/m^3).

Object	**Measuring Tools**	**Volume, V** mm^3	**Density, ρ** $\frac{\mathrm{kg}}{\mathrm{m}^3}$
Hollow Cylinder	Vernier Calliper	12258.04 ± 56.32	2134.817 ± 522.7054
Rectangular Prism	Meter Stick	12844 ± 577.59	2553.7216 ± 115.102
	Vernier Calliper	24404.897 ± 5975.2	2675.7162 ± 14.708

[1] Having evaluated the error associated with the density of the rectangular prism using the meter stick and the Vernier caliper, which instrument gives the smallest calculated error for density? Why?

The vernier calipers has a more precise scale that allows for one to account for 0.05mm error while a meter stick only accounts for 0.5mm error, making the vernier scale 10X more accurate. This is shown in the error propogation of the density, where the meter stick has an error of 115.102 $\mathrm{kg/m}^3$,the vernier calipers had a 14.708 $\mathrm{kg/m}^3$error.

[2] Compare your most precise density for the rectangular prism with the accepted values of various substances listed below and determine which type of metal it is made of.

You can use a percentage difference calculation to compare: $\%\mathrm{diff} = \left|\frac{\rho_{\mathrm{accepted}} - \rho_{\mathrm{experimental}}}{\rho_{\mathrm{accepted}}}\right| \times 100$.

$$\text{Rectangular Prism } \rho = (2675.7162 \pm 14.708)\frac{\mathrm{kg}}{\mathrm{m}^3}$$

$$\text{Aluminium } \rho = 2700\frac{\mathrm{kg}}{m}^3$$

$$\%\ \mathrm{diff} = |\frac{2700 - 2675.71}{2700}| \times 100 = 0.89996\%$$

Densities of common substances

Material	**Density, ρ (kg/m^3)×10^3**
Aluminum	2.7
Benzene	0.90
Blood	1.06
Brass	8.6
Concrete	2
Copper	8.9
Ethanol	0.81
Glycerin	1.26
Gold	19.3
Ice	0.92
Iron	7.8
Lead	11.3
Mercury	13.6
Platinum	21.4
Seawater	1.03
Silver	10.5
Steel	7.8

[2] Compare your density for the hollow cylinder with the accepted values of various metals listed above and determine which type of metal it is made of. Calculate the percentage difference.

$$\text{Rectangular Prism } \rho = (2134.817 \pm 522.7054)\frac{\text{kg}}{\text{m}^3}$$

$$\text{Aluminium } \rho = 2700\frac{\text{kg}}{m}^3$$

$$\%\text{ diff} = |\frac{2700 - 2134.81}{2700} \times 100 = 20.93296\%$$

Part 2 – Time measurement

[2] Using the data from your *Table 4*, fill the following table:

Table 6 - Calculating the period of oscillation of a mass-spring system

Trial	Period	
	T	ΔT
	(s)	(s)
1	10.1	± 0.3
2	10.46	± 0.3
3	11.03	± 0.3
4	10.28	± 0.3
5	10.03	± 0.3

[2] Using your values for T, calculate the average period $\overline{T}$ and its standard error.

$$\text{Average } T = \frac{\sum \text{trials}}{\#\text{ of trials}}$$

$$T_{avg} = \frac{10.1 + 10.46 + 11.03 + 10.28 + 10.03}{5} = 10.38\text{s}$$

$$\text{SE} = \frac{\sigma}{\sqrt{n}} = \frac{0.3}{\sqrt{5}} = 0.13416\text{s}$$

[2] How does the error on the average period $\overline{T}$ compares to the errors on the periods, T? What can you do to reduce the uncertainty on $\overline{T}$? What can you do to reduce the uncertainty on T?

The period values fall very close to the average period, except for trial 3, which is an outlier in the data. To reduce the uncertainty on the average period, one can perform more trials to get a lower standard error, and also a more refined average period. To reduce uncertainty during each trial, a more accurate recording method, such as a sensor, camera, or more accurate stopwatch to have a lower standard error during the trials

Part 3 – Picket fence free fall

[1] How does the Logger Pro software calculate the speed of the picket fence?

The Logger Pro is connected to a device with an infrared sensor. When it is turned on, the an infrared beam is shot across the device's arm and is registered with a light on the other . When an object passes through, the beam is obstructed and the software logs that. The picket fence was a mixture of black panes and clear panes. As the object passed through, it could instantaneously visualize the speed of the object

[1] Discuss what the slope and y-intercept represent in terms of the experimental parameters.

The slope is the line of best fit when calculating the instantaneous velocity of the object being dropped. The y-intercept is initial velocity of the object as it is dropped

[1] Predict whether the slope and/or the y-intercept would change if you were to drop the picket fence through the photogate starting from a higher point.

The y-intercept would change if you were to drop it from a higher point, the initial velocity as it passes through the sensor would be greater as the object has already accelerated a certain amount due to gravity. If dropped the higher slope of the graph would have minimal changes, as it doesn't effect acceleration due to gravity.

[2] Using your five fit results, calculate your average value for the gravitational acceleration, $\bar{g}$, and its standard error.

$$\text{Average } \vec{g} = \frac{\sum \text{trials}}{\# \text{ of trials}}$$

$$\vec{g}_{avg} = \frac{9.490 + 9.763 + 9.730 + 9.990 + 9.791}{5} = 9.74 \text{m/s}^2$$

$$\Delta\vec{g}_{avg} = \frac{0.03266 + 0.005819 + 0.01099 + 0.02221 + 0.012}{5} = 0.01674 \text{m/s}^2$$

$$\text{SE} = \frac{\sigma}{\sqrt{n}} = \frac{0.0167358}{\sqrt{5}} = 0.000748 \text{m/s}^2$$

$$\% \text{ diff} = |\frac{9.81 - 9.7366}{2700} \times 100 = 0.748\%$$

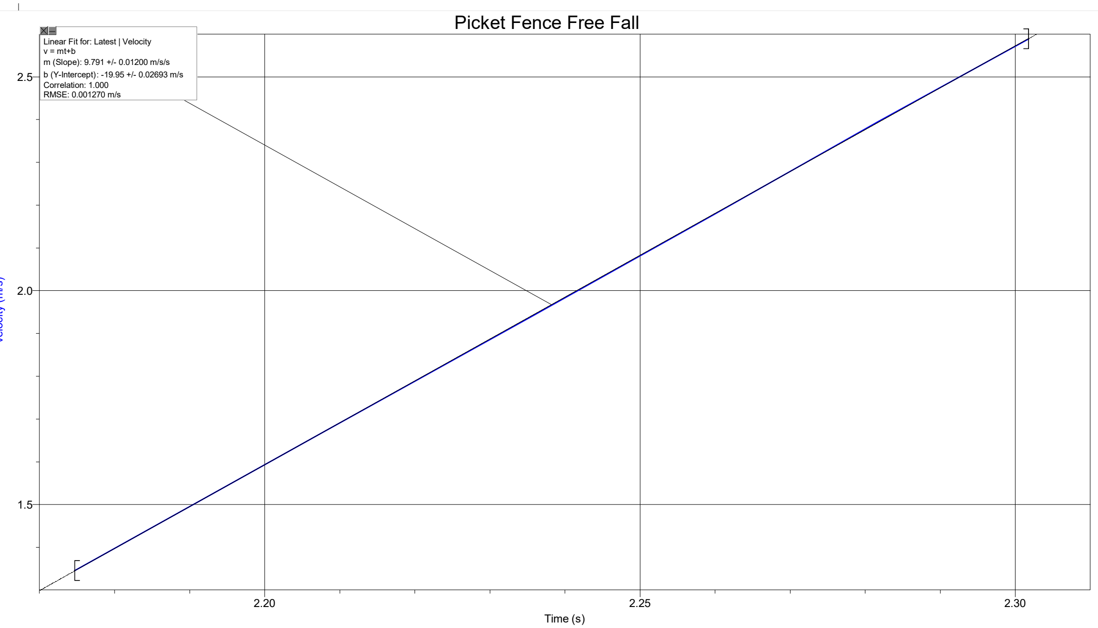
[1] Compare your value of $\bar{g}$ with the accepted value of 9.81 m/s^2. Use the percentage difference calculation:

$$\%\text{diff} = \left|\frac{g_{\text{acceted}} - \bar{g}}{g_{\text{accepted}}}\right| \times 100,$$

and discuss.

The error between the accepted value and experimental value is 0.748%. The uncertainty error is 0.000748 m/s^2 and fairly accurate.

Total : _______ / 41


Picket Fence Free Fall
Linear Fit for: Latest | Velocity
v = mt+b
m (Slope): 9.791 +/- 0.01200 m/s/s
b (Y-Intercept): -19.95 +/- 0.02693 m/s
Correlation: 1.000
RMSE: 0.001270 m/s
2.5
2.0
1.5
2.20
2.25
2.30
Time (s)