University of Capetown
Department of Physics
PHY1004W
1-D Motion,Measuring Gravitational Acceleration

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0.1 Introduction and aim

When Newton set out to explain the interactions in the cosmos, he came to create the most accurate theories (at the time) to explain the motions of the celestial objects, particularly, he came up with gravitational theories. Newton's theory explained that every body exerts a force of inertia on other bodies, over a distance, this means that he could explain the motions of the celestial objects, including the motion of the moon around the earth. The presence of the gravitational force means that smaller objects close to the earth would fall towards the earth with a gravitational acceleration, the acceleration is approxiamated at around $9.8m.s^{-2}$ The aim of this experiment is to measure the gravitational acceleration due to the gravitational force exerted by the earth. Different objects and the Tracker Video Analysis and Modelling Tool software will be used to determine the position versus time data for these objects and that data will be used to find the gravitational acceleration.

0.2 Apparatus and method

For this experiment, the following apparatus was used: a camera, Tracker Video Analysis Software and several objects including a soccer ball, a Tape Roll, a SquashBall, a Bottle, a PaperCup, a Bucket and a PaintBrush. We started by dropping ($yi = 0$ and $vi = 0$) the objects from a fixed height ,one at a time, while recording the objects in free-fall using the camera, from this point, we had videos of the objects in freefall. We then moved on to use the Tracker Video Analysis and Modelling Tool software to collect the position versus time data of each object. Using this data we continued to use the data to draw up the linear graph of position versus time squared, $y(m)$ vs $t^2(s^2)$, using the linearfit software. Using the equation of motion, $y = yi + (vi) \times (t) + 0.5 \times (g) \times (t^2)$, where the y axis is the axis of motion and downward motion is in the $+y$ direction. From the equation of motion, we accounted for the fact that in our experiment, $yi = 0$ and $vi = 0$.We then used the software to retrieve the gradient of the graph of $y(m)$ vs $t^2(s^2)$ and using the equation, $y = 0.5 \times g \times (t^2)$, we could solve for gravitational acceleration since the gradient of $y(m)$ vs $t^2(s^2)$ is equal to $0.5 \times g$.

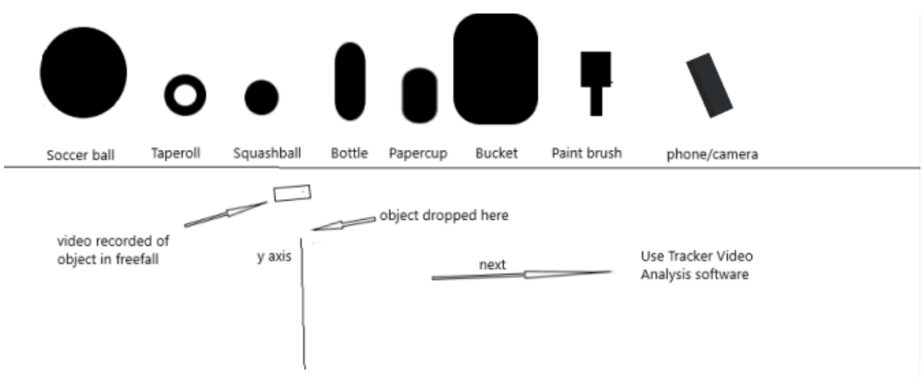


Figure 1: Diagram showing the apparatus and process.

0.3 Data and Results

0.3.1 Data of position vs time for objects in freefall

TapeRoll data of position vs time.

$t(s)$	$y(m)$
0.00	0.00173
0.03	0.0293
0.07	0.0648
0.10	0.1200
0.13	0.1830
0.17	0.2658
0.20	0.3564
0.23	0.4510
0.27	0.5613
0.30	0.6914
0.33	0.8254
0.37	0.9633
0.40	1.117
0.43	1.263
0.47	1.436
0.50	1.606
0.53	1.791
0.57	1.964
0.60	2.161

Bucket data of position vs time.

$t(s)$	$y(m)$
0.00	0.01195
0.03	0.07970
0.06	0.2032
0.10	0.2590
0.13	0.4025
0.17	0.5180
0.20	0.6336
0.23	0.7771
0.27	0.9205
0.30	1.096
0.33	1.263
0.37	1.431
0.40	1.634
0.43	1.821
0.47	2.024
0.50	2.244
0.53	2.450
0.57	2.690

Bottle data of position vs time.

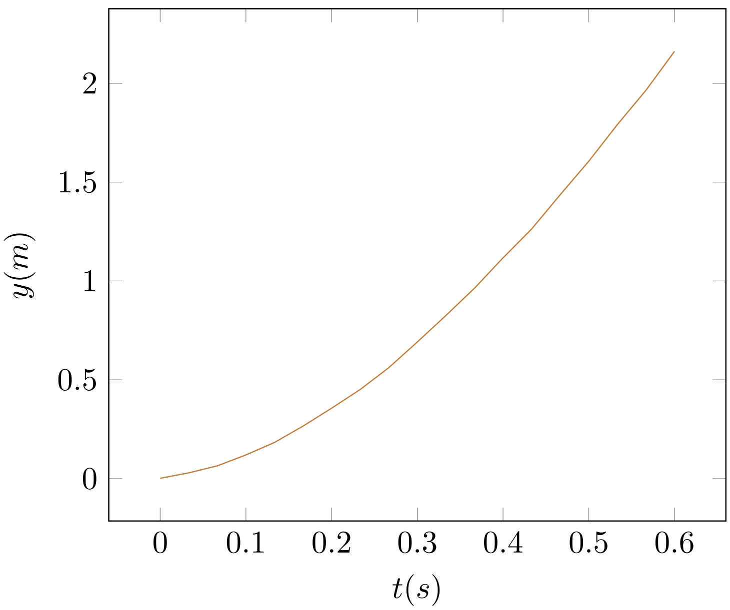
$t(s)$	$y(m)$
0.00	0.01161
0.03	0.01161
0.07	0.09107
0.10	0.1264
0.13	0.1705
0.17	0.2456
0.20	0.3515
0.23	0.4487
0.27	0.5590
0.30	0.6694
0.33	0.8018
0.37	0.9343
0.40	1.093
0.43	1.274
0.47	1.420
0.50	1.619
0.53	1.813
0.57	2.011

Soccerball data of position vs time.

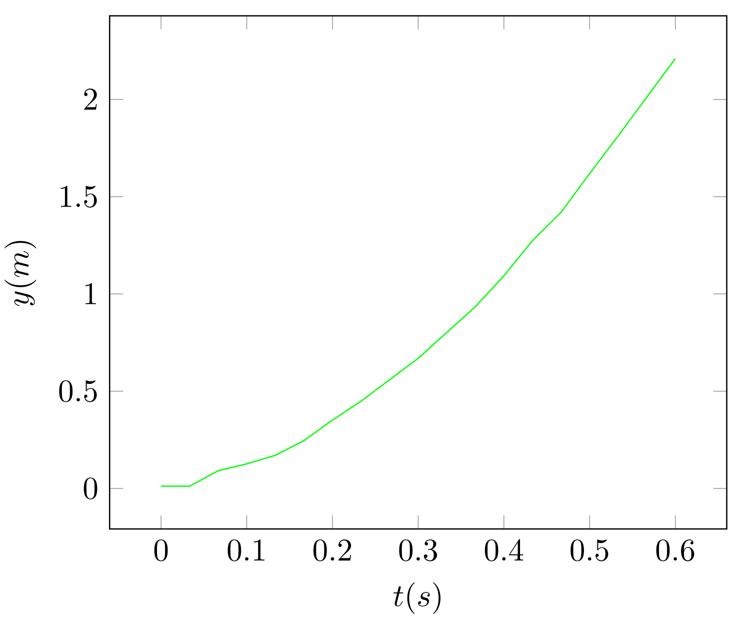
$t(s)$	$y(m)$
0.00	0.0081
0.03	0.0447
0.07	0.1097
0.10	0.1787
0.13	0.2599
0.17	0.3574
0.20	0.4549
0.23	0.5808
0.27	0.7107
0.30	0.8529
0.33	0.9990
0.37	1.162
0.40	1.312
0.43	1.486
0.47	1.669
0.50	1.868
0.53	2.079
0.57	2.291
0.60	2.534

0.3.2 Graphs of position vs time for objects in freefall

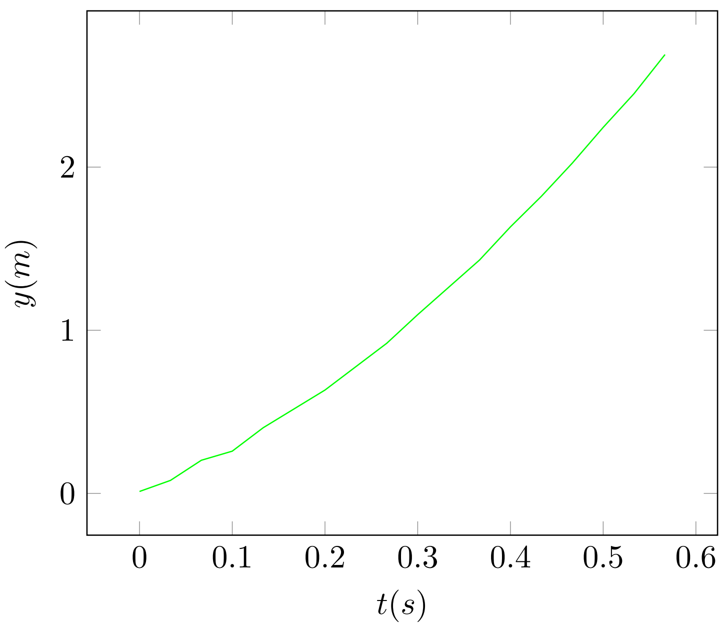
TapeRoll data of position versus time



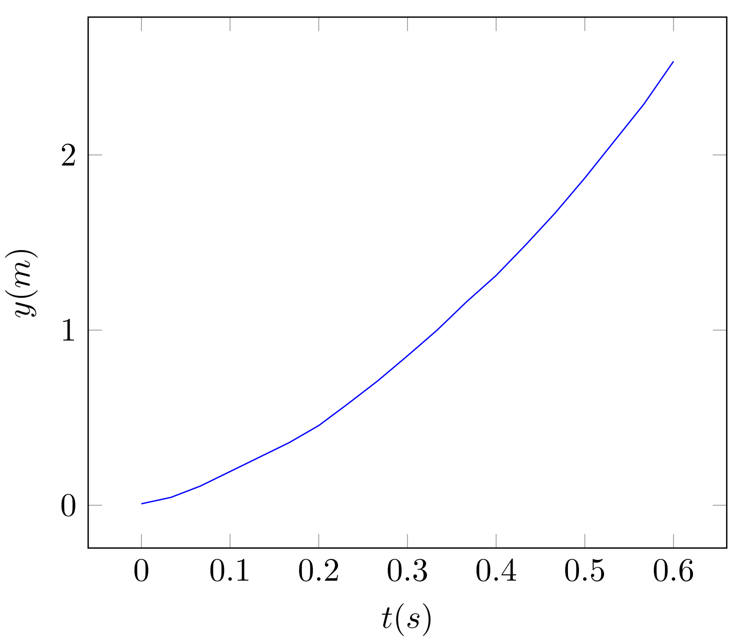
Bottle data of position versus time



Bucket data of position versus time



Soccer ball data of position versus time



0.3.3 plotting the linear graphs and finding the gradients

Tape roll data of the graph of $t^2(s^2)$ versus $y(m)$.

$t^2(s^2)$	$y(m)$
0.00	0.00173
0.0009	0.0293
0.0049	0.0648
0.01	0.1200
0.0169	0.1830
0.0289	0.2658
0.04	0.3564
0.0529	0.4510
0.0729	0.5613
0.09	0.614
0.1089	0.8254
0.1369	0.9633
0.16	1.117
0.1849	1.263
0.2209	1.436
0.25	1.606
0.2809	1.791
0.3249	1.964
0.36	2.161

From Linear-fit software:

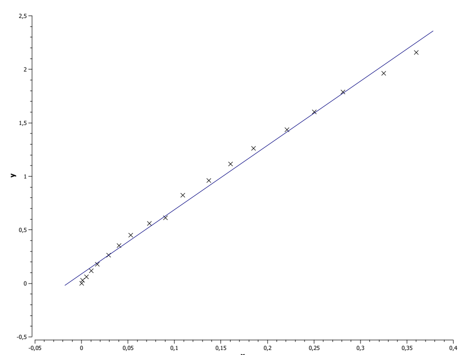


Figure 2: Linear graph of the $t^2(s^2)$ versus $y(m)$ for the taperoll.

$$
\begin{aligned}
m &= 5.99671 \pm 0.112278 \\
c &= 0.090155 \pm 0.0188373 \\
correlation(R^2) &= 0.994076
\end{aligned}
$$

Bucket data of the graph of $t^2(s^2)$ versus $y(m)$.

$t^2(s^2)$	$y(m)$
0.00	0.01195
0.0009	0.07970
0.036	0.2032
0.01	0.2590
0.0169	0.4025
0.0289	0.5180
0.04	0.6336
0.0529	0.7771
0.0729	0.9205
0.09	1.096
0.1089	1.263
0.1369	1.431
0.16	1.634
0.1849	1.821
0.2209	2.024
0.25	2.244
0.2809	2.450
0.3249	2.690

From Linear-fit software:

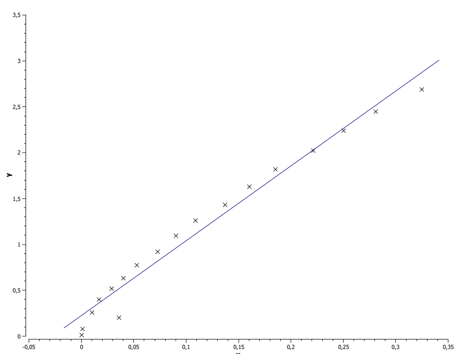


Figure 3: Linear graph of the $t^2(s^2)$ versus $y(m)$ for the bucket.

$$\begin{aligned} m &= 8.15985 \pm 0.329263 \\ c &= 0.222728 \pm 0.0494796 \\ correlation(R^2) &= 0.974609 \end{aligned}$$

Bottle data of the graph of $t^2(s^2)$ versus $y(m)$.

$t^2(s^2)$	$y(m)$
0.00	0.01161
0.0003	0.01161
0.0049	0.09107
0.01	0.1264
0.0169	0.1705
0.0289	0.2456
0.04	0.3515
0.0529	0.4487
0.0729	0.5590
0.09	0.6694
0.1089	0.8018
0.1369	0.9343
0.16	1.093
0.1849	1.274
0.2209	1.420
0.25	1.619
0.2809	1.813
0.3249	2.011

From Linear-fit software:

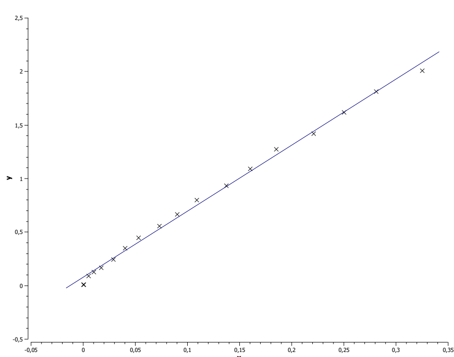


Figure 4: Linear graph of the $t^2(s^2)$ versus $y(m)$ for the bottle.

$$\begin{aligned} m &= 6.17951 \pm 0.0950276 \\ c &= 0.0772281 \pm 0.0142578 \\ correlation(R^2) &= 0.996231 \end{aligned}$$

Soccerball data of the graph of $t^2(s^2)$ versus $y(m)$.

$t^2(s^2)$	$y(m)$
0.00	0.0081
0.0009	0.0447
0.0049	0.1097
0.01	0.1787
0.0169	0.2599
0.0289	0.3574
0.04	0.4549
0.0529	0.5808
0.0729	0.7107
0.09	0.8529
0.1089	0.9990
0.1369	1.162
0.16	1.312
0.1849	1.486
0.2209	1.669
0.25	1.868
0.2809	2.079
0.3249	2.291
0.36	2.534

From Linear-fit software:

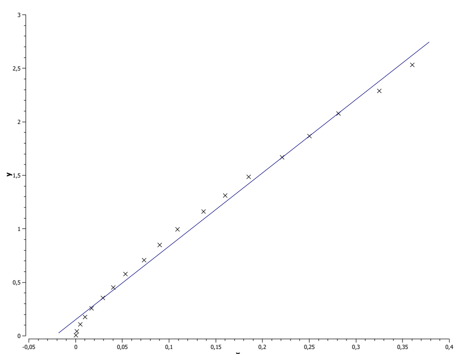


Figure 5: Linear graph of the $t^2(s^2)$ versus $y(m)$ for the soccerball.

$$\begin{aligned} m &= 6.86042 \pm 0.151462 \\ c &= 0.15113 \pm 0.0254113 \\ correlation(R^2) &= 0.991782 \end{aligned}$$

0.4 Analysis, intepretation and discussion

0.4.1 Intepretation of data and results

In section 0.3.1 on page 3, the given guidelines (document named READ ME Freefall lab) were used to reduce the position data to 3 decimal places and the time data to 2 two decimal places. Knowing that linearfit (the software I used) does not allow for the input of uncertainties for the values of x and y, I did not consider calculating the uncertainties of position and time.
In section 0.3.3 on page 7, I calculated t^2 for each value of t and drew up tables of t^2 vs y for each object, these coordinates were later used in linear fit to plot graphs shown in figures 5, 4, 3 an 2 in order to retrieve the gradients of the different graphs (m).
Using the equation, $y = 0.5gt^2$,detailed in section 0.2 on page 2, I will calculate g as I can see that the gradients of the t^2 vs y graphs are equal to $0.5g$.

0.4.2 Calculation of g and the uncertainty of g

Formulae:

$$\begin{aligned} m &= 0.5g \\ g &= 2m \end{aligned}$$

and using the equations for the propagation of uncertainties through calculations:

$$u(g) = \sqrt{(1 \times \frac{u(m)}{m})^2}$$

For the taperoll:

$$\begin{aligned} g_{taperoll} &= 2 \times 5.99671 \\ g_{taperoll} &= 11.99342 \\ u(g)_{taperoll} &= \sqrt{(1 \times \frac{0.112278}{5.99671})^2} \\ u(g)_{taperoll} &= 0.01872 \end{aligned}$$

For the bucket:

$$\begin{aligned} g_{bucket} &= 2 \times 8.15985 \\ g_{bucket} &= 16.31970 \\ u(g)_{bucket} &= \sqrt{(1 \times \frac{0.329263}{8.15985})^2} \\ u(g)_{bucket} &= 0.04035 \end{aligned}$$

For the bottle:

$$\begin{aligned}
g_{bottle} &= 2 \times 6.17951 \\
g_{bottle} &= 12.35902 \\
u(g)_{bottle} &= \sqrt{(1 \times \frac{0.0950276}{6.17951})^2} \\
u(g)_{bottle} &= 0.01537
\end{aligned}$$

For the soccerball:

$$\begin{aligned}
g_{soccerball} &= 2 \times 6.86042 \\
g_{soccerball} &= 13.72084 \\
u(g)_{soccerball} &= \sqrt{(1 \times \frac{0.151462}{6.86042})^2} \\
u(g)_{soccerball} &= 0.02208
\end{aligned}$$

Now, to find the average of the gravitational acceleration (g) and the uncertainty of the gravitational acceleration $u(g)$:

$$\begin{aligned}
g_{average} &= \frac{\Sigma_{i=1}^{4} g_i}{4} \\
g_{average} &= \frac{(11.99342 + 16.3197 + 12.35902 + 13.72084)}{(4)} \\
g_{average} &= 13.59825
\end{aligned}$$

$$\begin{aligned}
u(g)_{average} &= \frac{\sqrt{u(g)_{soccerball} + u(g)_{bottle} + u(g)_{bucket} + u(g)_{taperoll}}}{4} \\
u(g)_{average} &= \frac{\sqrt{0.02208 + 0.01537 + 0.04035 + 0.01872}}{4} \\
u(g)_{average} &= 0.07767
\end{aligned}$$

The result is:

$$g = 13.59825 \pm 0.07767 m.s^{-2}$$

0.5 Conclusion and recommendations

This experiment has shown that eventhough the physics model shows that objects in freefall have the same acceleration, this is not the case in an unisolated environment as the values of g were observerd to be closer to the accepted value of $9.8m.s^{-1}$ for objects that have a smaller surface area and vice versa.
The value of g as a result of the experiment was calculated to be the following:$g = g = 13.59825 \pm 0.07767m.s^{-2}$. The result of g in this experiment is not precisely the standard value of $9.8m.s^{-1}$.
This outcome is due to some sources of uncertainty, namely the following sources of uncertainty: The air resistance changes the net force acting on the object, thus changing the acceleration of the object (but this is a small change), the fact that the radius of the earth is variable on different parts of the world also contributes to the uncertainty and the last source of uncertainty is the precision of the person that drops the object when they place it at the initial position taking into account, the center of mass (this also contributes a small amount).
Furthermore, the experiment could be improved with the purpose of minimising the uncertainty, this can be done by dropping objects with a small surface area to decrease the effects of air resistance and it can also be improved by using an automated mechanism to drop the objects at an identical point every time taking into account, the center of mass.