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PHY 120

The Effects of Mass, Size, and Height on Acceleration Due to Gravity

INTRODUCTION

For centuries, people believed that heavier objects fall faster than lighter ones (Cobb 1988). Aristotle, the first one to write down this theory, believed that a ten pound stone would fall ten times faster than a one pound stone. His ideas went unchallenged until Galileo Galilei performed his own tests approximately two thousand years later, in the 16th and 17th centuries (Cobb 1988, Frazier 2001). Because Galileo had no accurate way of taking measurements—clocks had yet to be invented at this point—he was unable to measure how fast objects would free fall. To overcome this obstacle, he rolled objects down inclines, timing them by counting drops of water. Through his experiments he discovered that the weight of an object was not a factor in how fast the object fell—all objects fall at the same rate unless an outside force, such as friction, acts upon them (The Science Museum of Minnesota 1995). He also discovered that the object's distance of travel and time in motion were proportional.

Gravity is the force that pulls all objects toward the earth (The Science Museum of Minnesota 1995). It does not pull them at a constant velocity (Faughn et al. 1995, Bloomfield 1997, Frazier 2001, Rusk 2002). Rather, objects accelerate as they fall. Acceleration is defined as the change in velocity (Δv) over a given time (Δt); it can be found using the equation, $a=\Delta v/\Delta t$ (Faughn et al. 1995, Rolnick 1996, Bloomfield 1997, Frazier 2001, Howe and Stephenson 2002). The acceleration due to gravity, or g, can be found by the equation, $g=2d/t^2$ (Faughn et al. 1995). Near the earth's surface, the acceleration due to gravity is approximately 9.8 m/s^2. While this number may vary slightly for different places on earth, two objects falling near each other will have the same acceleration.

The greater mass an object has, the greater the earth's gravitational pull on it will be (The Science Museum of Minnesota 1995, Bloomfield 1997). This means that objects with greater mass feel heavier—not that free falling objects with greater mass have greater acceleration. Aristotle had believed otherwise, but Galileo proved him wrong (The Science Museum of Minnesota 1995). Mass is not included as a variable in the formula for acceleration due to gravity ($g=2d/t^2$) because any two free falling objects, falling near each other, will have the same acceleration—regardless of their mass (Moore 1996, Rusk 2002).

Although all free falling objects fall to the earth at the same rate, not all objects are free falling. Free falling objects are those that fall toward the earth with only the force of gravity acting on them (Moore 1996). Unless an object is in a vacuum, it will be acted on by air resistance as well as gravity. Air resistance, a type of friction, slows down objects moving through the air as they hit the air molecules (The Science Museum of Minnesota 1995). Without air resistance, all objects would all fall at the same rate. Air resistance is the main reason some objects fall faster than others (Faughn et al. 1995).

As an object falls toward the earth, two forces act upon it (Schlachter and Dixon 1996). Gravity pulls it to the earth, while air resistance pushes it away from the earth. As the object accelerates toward the earth, air resistance increases until the object reaches its terminal velocity, which is the maximum velocity it can reach (Terminal Velocity

2002). When the air resistance equals the weight of the object and the net force is zero, the object reaches its terminal velocity (Schlachter and Dixon 1996, Terminal Velocity 2002). At terminal velocity, the object ceases to accelerate and its velocity remains constant. If the object does not reach its terminal velocity, it will accelerate at a speed of 9.8 m/s^2 (Rusk 2002). If the object is dropped from a great enough height, it will reach its terminal velocity before it hits the ground. Because objects of different sizes and masses encounter different amounts of air resistance, they have different terminal velocities. Thus different objects may hit the ground at different times when dropped from the same height.

The purpose of our experiment is to determine whether an object’s mass, size, and the height affect its acceleration due to gravity.

METHODS

We tested three variables to see if they had an effect on an object’s acceleration due to gravity (g). The variables were mass, size, and the height. In order to test whether mass has an effect, we set up the Xplorer GLX mechanism (see Figure 1) according to the instructions given in the *Physics with the Xplorer Lab Manual* (Hanks 2005). We dropped two balls of the same size from the drop box at a height of 1 m and measured the time they took to fall using the time of flight program. One was cork, with mass 2.89 g, and the other was aluminum, with mass 24.17 g. A small washer taped to the cork ball served as a way to attach it to the magnet on the drop box. (The washer’s mass was included in the 2.89 g.) We dropped each ball from the drop box thirty times and recorded the times in an Excel spreadsheet. Using the equation $g=2d/t^2$, we found g for each trial, and then used these numbers to find the average g for each ball. We used

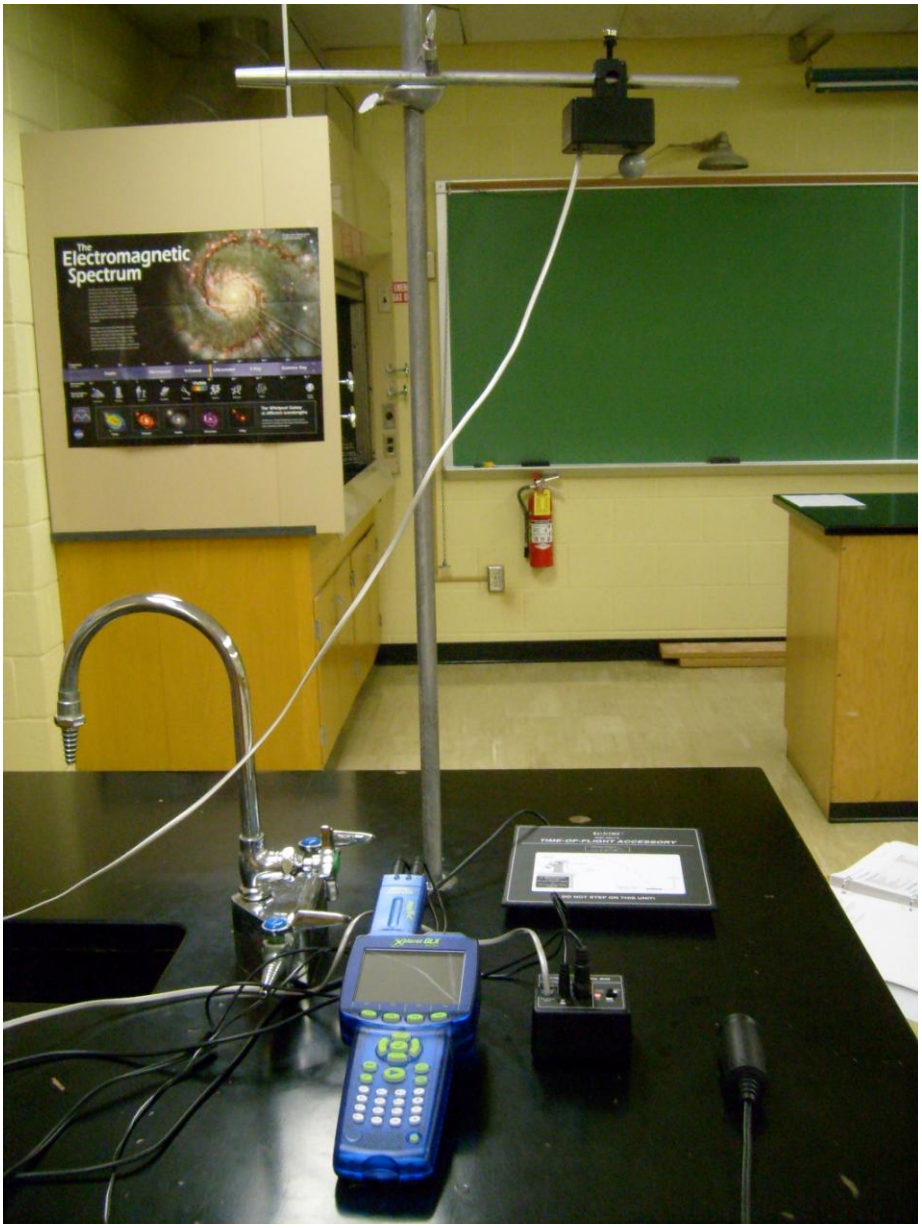

Figure 1. This picture shows the Xplorer GLX setup for the mass test. The equipment was also used for the size test, but the setup was different.

the Analyse-it tool in Excel to perform a t-test. Our null hypothesis was that the cork ball and the aluminum ball would have the same acceleration due to gravity (H_{m0}: $g_c = g_a$). Our alternative hypothesis was that the cork ball and the steel ball would have significantly different accelerations due to gravity (H_{m1}: $g_c \neq g_a$).

In order to test whether size has an effect on acceleration due to gravity, we placed a small plastic ball in a balloon that was blown up to a circumference of 41.2 cm. We set up the GLX as in the previous test, but used a height of 2.1 m (measuring from the bottom of the balloon to the time-of-flight accessory). We dropped the balloon thirty times and recorded the times in an Excel spreadsheet. We then took the same plastic ball and placed it in an identical balloon that was blown up to a circumference of 30 cm. Keeping the height and mass constant, we also dropped this balloon thirty times and recorded the times in the Excel spreadsheet. Using the equation $g=2d/t^2$, we found g for each trial, and then used these numbers to find the average g for each balloon. We used the Analyse-it tool in Excel to perform a t-test. Our null hypothesis was that the balloons would have the same acceleration due to gravity (H_{s0}: $g_{30.00} = g_{41.20}$). Our alternative hypothesis was that the balloons would have significantly different accelerations due to gravity (H_{s1}: $g_{30.00} \neq g_{41.20}$).

In order to test whether height has an effect on g, we dropped the same tennis ball from a height of 4.98 m and a height of 12.85 m. We did not use the Xplorer GLX for this test because a mass dropped from such a height would have damaged the machine. Instead, we used a procedure that required three people: one to call out “3, 2, 1, go” (the caller), one to drop the ball from the height (the dropper), and one to use the stopwatch to record the time of flight (the timer). By giving a three second countdown, both the dropper and the timer had a good sense of when the caller would say “go.”

This helped reduce the reaction time in both the dropper and the timer. We intentionally had a third person calling “go,” so both the dropper and timer would have the same delay in reaction. We dropped the ball from each height thirty times, and recorded the times in the Excel spreadsheet. Using the equation $g=2d/t^2$, we found g for each trial, and then used these numbers to find the average g for each height. We used the Analyse-it tool in Excel to perform a t-test. Our null hypothesis was that the ball would have the same acceleration due to gravity from each height (H_{h0}: $g_{4.98}=g_{12.85}$). Our alternative hypothesis was that the ball would have a different acceleration due to gravity from each height (H_{h1}: $g_{4.98} \neq g_{12.85}$).

RESULTS

The g value for the ball with mass 2.89 g was 8.48 m/s^2 and, for the ball with mass 24.17 g, it was 9.65 m/s^2 (see Figure 2). Using a t-test, we compared these values and got $t=-20.96$ and $p<0.0001$ (see Table 1). Because the ball with mass 2.89 g had a lower g value than the ball with mass 24.17 g and $p<0.05$, we rejected the null hypothesis and concluded that mass did have an effect on the acceleration due to gravity.

The g value for the balloon with circumference 30.00 cm was 8.09 m/s^2 and for the balloon with circumference 41.20 cm, it was 6.49 m/s^2 (see Figure 3). Using a t-test, we compared these values and got $t=41.66$ and $p<0.0001$ (see Table 2). Because the balloon with the greater circumference had a lower g value than the balloon with a smaller circumference and $p<0.05$, we rejected the null hypothesis and concluded that size did have an effect on g. The g value for the ball dropped from a height of 4.98

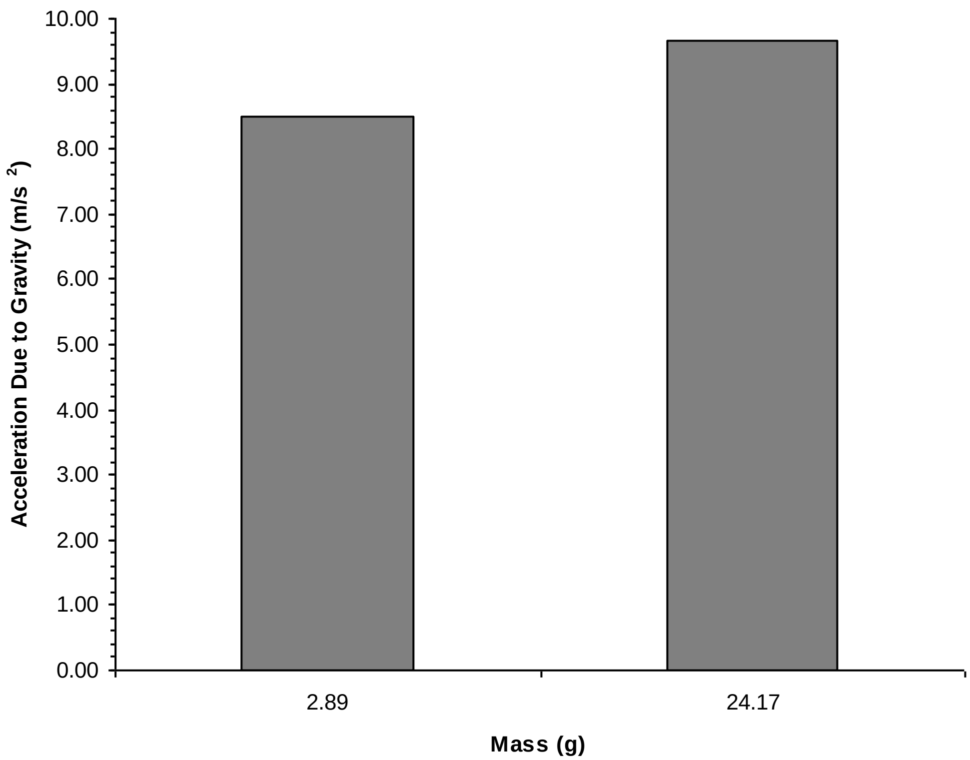

Figure 2. This graph shows g for two balls with masses of 2.89 g and 24.17 g dropped from a height of 1 m.

Table 1. This table shows the results of the t-test done for the mass experiment.

n	60

acccleration due to gravity (m/s2) - R2 by Mass (g)	n	Mean	SE	SD
2.89	30	8.483	0.0552	0.303
24.17	30	9.651	0.0071	0.039

Mean difference	-1.168	
95% CI	-1.279	to -1.056
SE	0.0557	

t statistic	-20.96
DF	58.0
2-tailed p	<0.0001

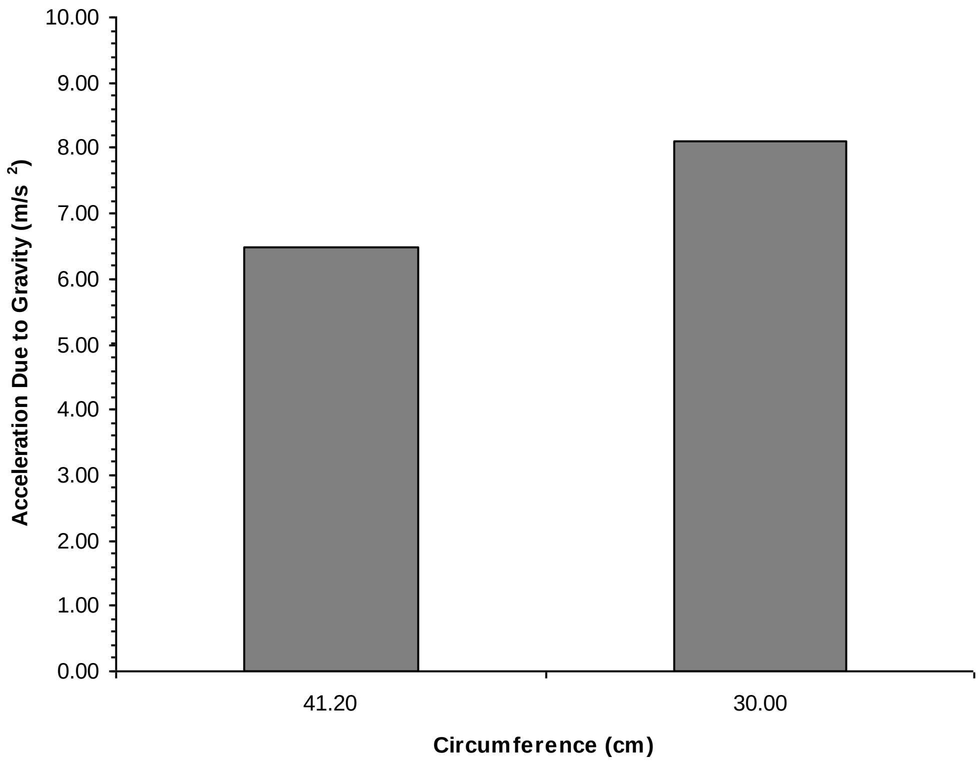

Figure 3. This graph shows g for two balloons with circumferences of 41.20 cm and 30.00 cm dropped from a height of 2.1 m.

Table 2. This table shows the results of the t-test done for the size experiment.

n	60

accceleration due to gravity (m/s2) - R3 by Circumference (cm)	n	Mean	SE	SD
30.00	30	8.090	0.0262	0.143
41.20	30	6.486	0.0282	0.155

Mean difference	1.604	
95% CI	1.527	to 1.681
SE	0.0385	

t statistic	41.66
DF	58.0
2-tailed p	<0.0001

was 7.87 m/s^2 and 8.10 m/s^2 when dropped from a height of 12.85 m (see Figure 4). Using a t-test, we compared these values and got t=-1.00 and p=.3231 (see Table 3). Because the ball dropped from a height of 12.85 m had the same g value as the ball dropped from a height of 4.98 m and p>0.05, we failed to reject our null hypothesis and concluded that height did not affect g.

DISCUSSION

In our experiment, the mass of the balls did affect their acceleration due to gravity, as Aristotle predicted (Cobb, 1988). However, this was unexpected because, according to the results of other studies, free falling objects of different masses have the same acceleration due to gravity (The Science Museum of Minnesota 1995, Moore 1996, Rusk 2002). Although the balls in our experiment were not free falling, Faughn et. al (1995) found that two objects falling near each other near the earth's surface will have the same acceleration, so we expected the same results. However, when we tested this variable, we found that the results were different. The ball with the greater mass had a higher g value. This was probably due to air resistance.Because the cork ball was so light, the air resistance would have slowed it significantly more than the aluminum ball. This agrees with the findings of Faughn et al. (1995) that air resistance is the primary cause of differences in g. We could not tell from our experiment whether the cork ball reached terminal velocity, but the fact that it slowed down noticeably demonstrated that it was approaching terminal velocity, as described by Schlachter and Dixon (1996) and in "Terminal Velocity" (2002).

We tested the effect of an object's size on it's acceleration due to gravity and found that it makes a significant difference. As we expected, the bigger balloon had a much lower acceleration due to gravity because it met greater air resistance than the smaller balloon. This confirms the findings of Faughn et al. that air resistance is the

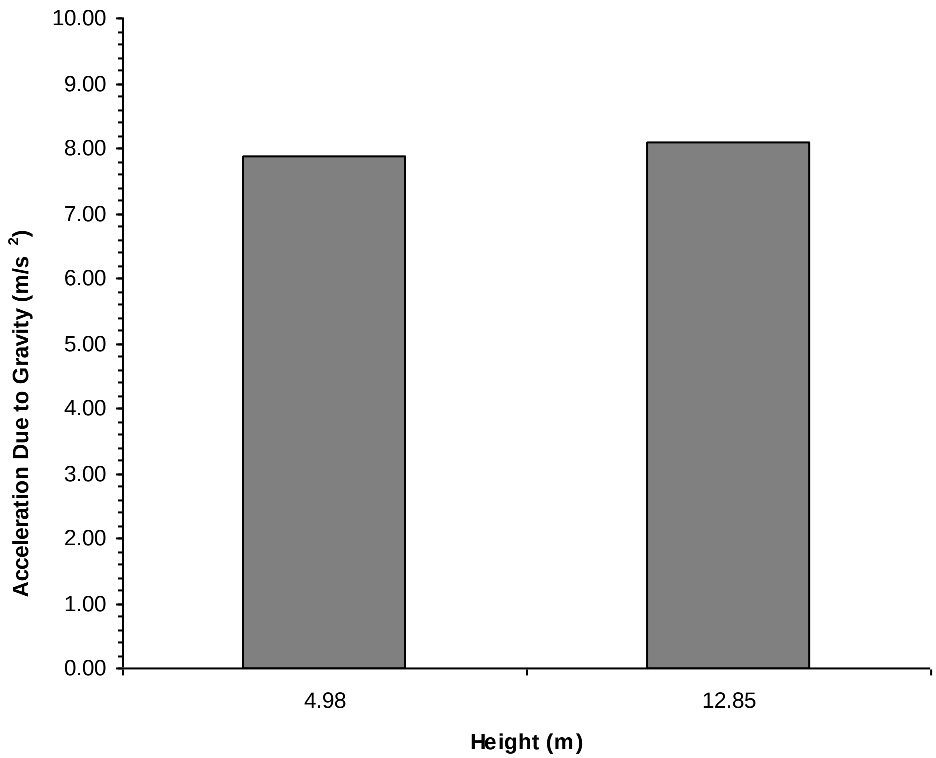

Figure 4. This graph shows g for a ball dropped from heights of 4.98 m and 12.85 m.

Table 3. This table shows the results of the t-test done for the height experiment.

n	60

accceleration due to gravity (m/s2) - R1 by Height (m)	n	Mean	SE	SD
4.98	30	7.868	0.2062	1.129
12.85	30	8.099	0.1056	0.579

Mean difference	-0.231	
95% CI	-0.695	to 0.233
SE	0.2317	

t statistic	-1.00
DF	58.0
2-tailed p	0.3231

primary reason some objects fall faster than others (1995).

When we tested height, there was no statistical difference between the values we got for average acceleration due to gravity. This agrees with the findings of Faughn et al. (1995) and Rusk (2002).

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