The relationship between dropping a tennis ball from various heights and impulse

Juliana Villanueva

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Introduction .:. Top

Background

During my usual tennis practices, one thought would linger in my mind, and that is, how the mechanics of tennis is dependent on physics. After attaining enough knowledge in IB Physics, I understood and was amazed to find that everywhere I go, even on the tennis courts, the world revolves around physics. The movement of a tennis ball depends on physics. How it can accelerate in speed over the net, and how it bounces up and down all comes down to physics. Something most tennis players relate to is that they have some sort of ritual for good luck. My ritual is to bounce a tennis ball on the floor 3 times before executing any serve. This action made me wonder about the underlying physics behind it.

This round, yellow ball of fuzz, possesses many properties dealing with force. During a tennis match, a tennis ball can reach up to speeds of 263.4 kilometers per hour or 73.17 meters per second, which is the fastest serve ever recorded, hit by Australian player Sam Groth at an International Tennis Federation event in 2012 (Czermak). In order to achieve a feat such as this one, a player must swing their racket rapidly and hit the falling tennis ball at a downwards angle, resulting to the ball being "propelled toward the other side of the court," Wall Street Journal writer Daniela Hernandez stated (00:02:00-00:02:02). The serve I am describing is a kick serve, which uses topspin or a fast forward spinning motion. The racket does not simply push the ball and propel it forward, but the physical properties such as the friction caused by the ball's felt gliding on the racket's strings gives it an upward tug, resulting in its topspin. Friction is a type of force that affects an object's motion over another's. With the forces in tennis at play, the ball's motion or "momentum" is changed due to the impact of the racket. Momentum can be calculated through the equation $p = m\Delta v$, and its change is called impulse, where impulse can be calculated using $\Delta p = m\Delta v$. Momentum is measured in kilograms-meters per second, while impulse is measured in newton-seconds.

Each time a tennis ball bounces, it experiences an impulse caused by a surface it bounces off of. The height the tennis ball is dropped from can impact the speed. When dropped, the ball would enter free-fall, a term used to describe a falling object mid-air. As the drop height of a tennis ball increases, so does the speed of the ball. This is due to the time it takes for the ball to reach a surface, and a larger height would increase time because an object in free-fall would experience a constant acceleration of 9.81 meters per second per second. Once the tennis ball reaches the surface and bounces off, it would rebound to some height.

Statement of the Problem and Variables

The purpose of this investigation is to determine the relationship between the drop height of a tennis ball and the impulse needed for its rebound. For the variables that will be used, the independent variable is the height (in centimeters); the dependent variable is the impulse (in newton-seconds), and the controlled variables are the mass and the radius of a tennis ball.

Hypothesis

I believe that the relationship between the drop height of a tennis ball and its impulse share a direct relationship. Referring back to the impulse equation, $\Delta p = m\Delta v$, when velocity increases, impulse would increase. Velocity is affected by height, where $v = \frac{s}{t}$. If velocity were to increase, then both the impulse and drop height would increase.

Method and Procedure .:. Top

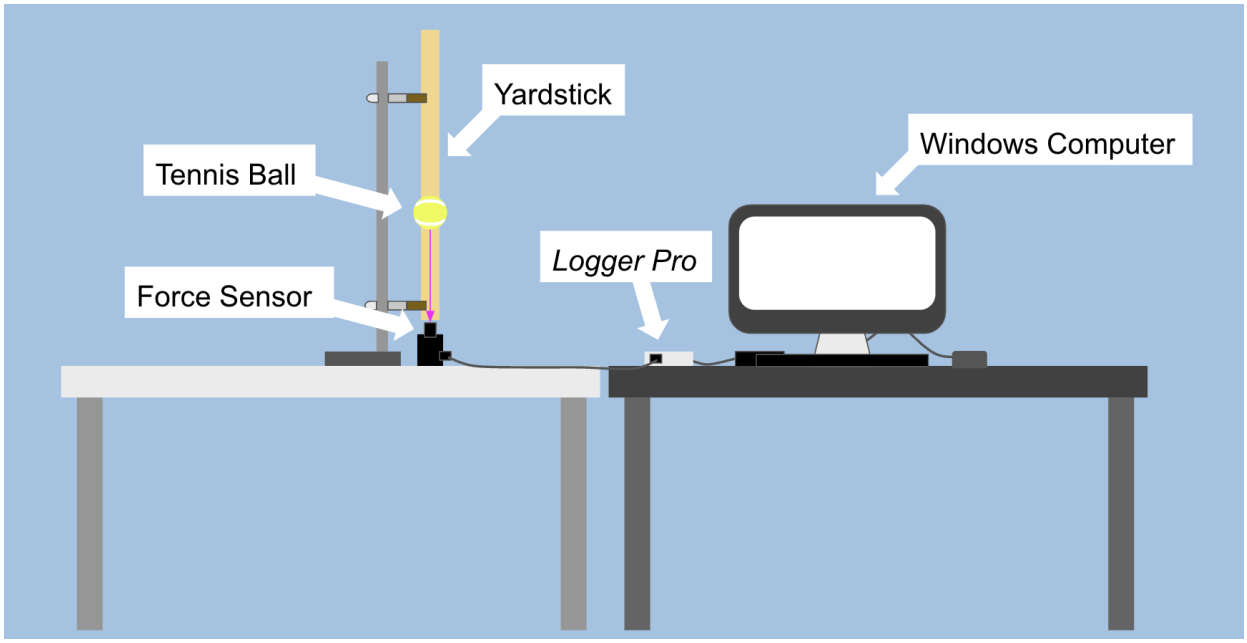
Collecting Data

I collected data for my dependent variable, the impulse of the ball, by using a computer connected to a data-collection software called *Logger Pro* in the back of my IB Physics classroom (as seen in **Figure 1**). Finding the impulse from calculating the equation $\Delta p = m\Delta v$ seemed inefficient because I would have to calculate the velocity by using the equation $v = \frac{s}{t}$. I found it easy to measure the height with a suspended yardstick, but I find it difficult to measure the time and record it as data, while pressing the spacebar of the keyboard to activate the *Logger Pro*. If I had multitasked like this, it would have led to the impulse containing discrepancies, as the velocity may be incorrectly calculated because of the imprecise time I recorded each trial with a stopwatch and my not so strong reaction time. Recording the time manually would have been possible if I had a second person. Unfortunately, I did not have anyone to turn to, which is why I chose to collect data of the impulse on the *Logger Pro*.

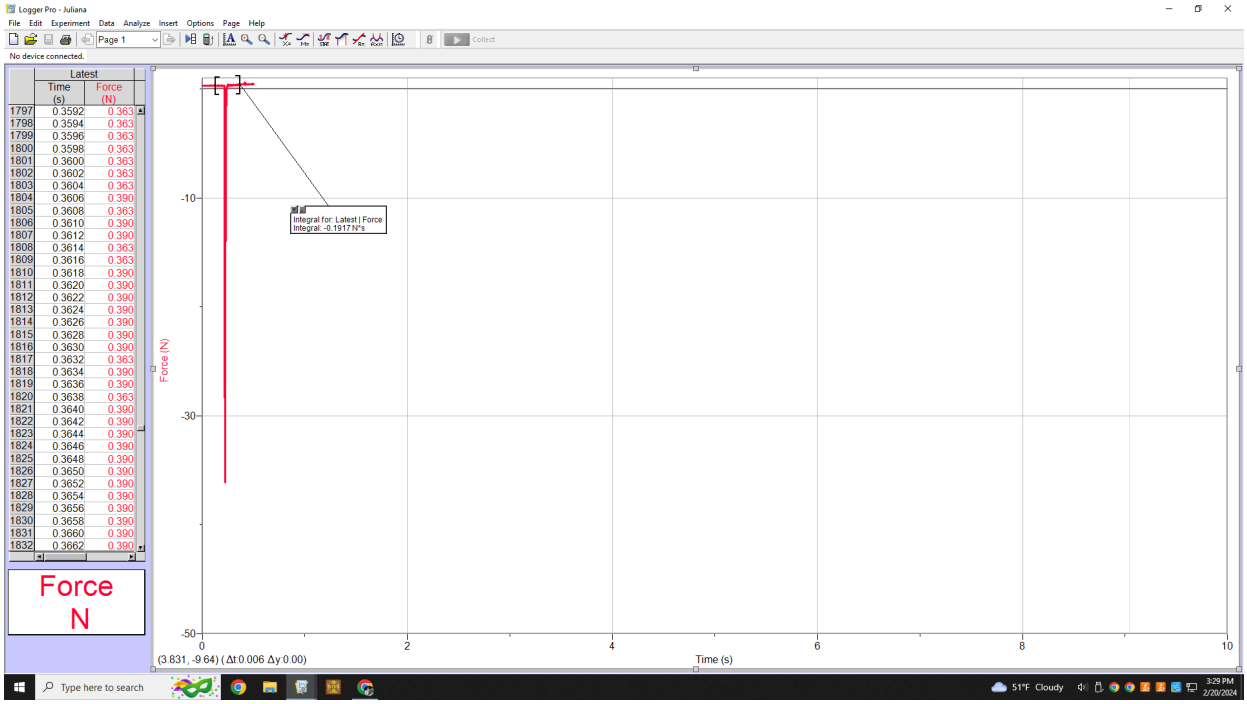
For my independent variable, I measured the height (in centimeters) by using a suspended yardstick just above the force sensor. Measuring in meters would be best for calculating velocity, however, meters are much larger than centimeters and for my 5'5" stature. That would require myself to stand on a chair and possibly be prone to fall later. Measuring in centimeters was best, so that I would not have to put myself in harm's way. Of course, for calculating the velocity of the average impulses, I will convert the drop heights to meters by dividing by 100.

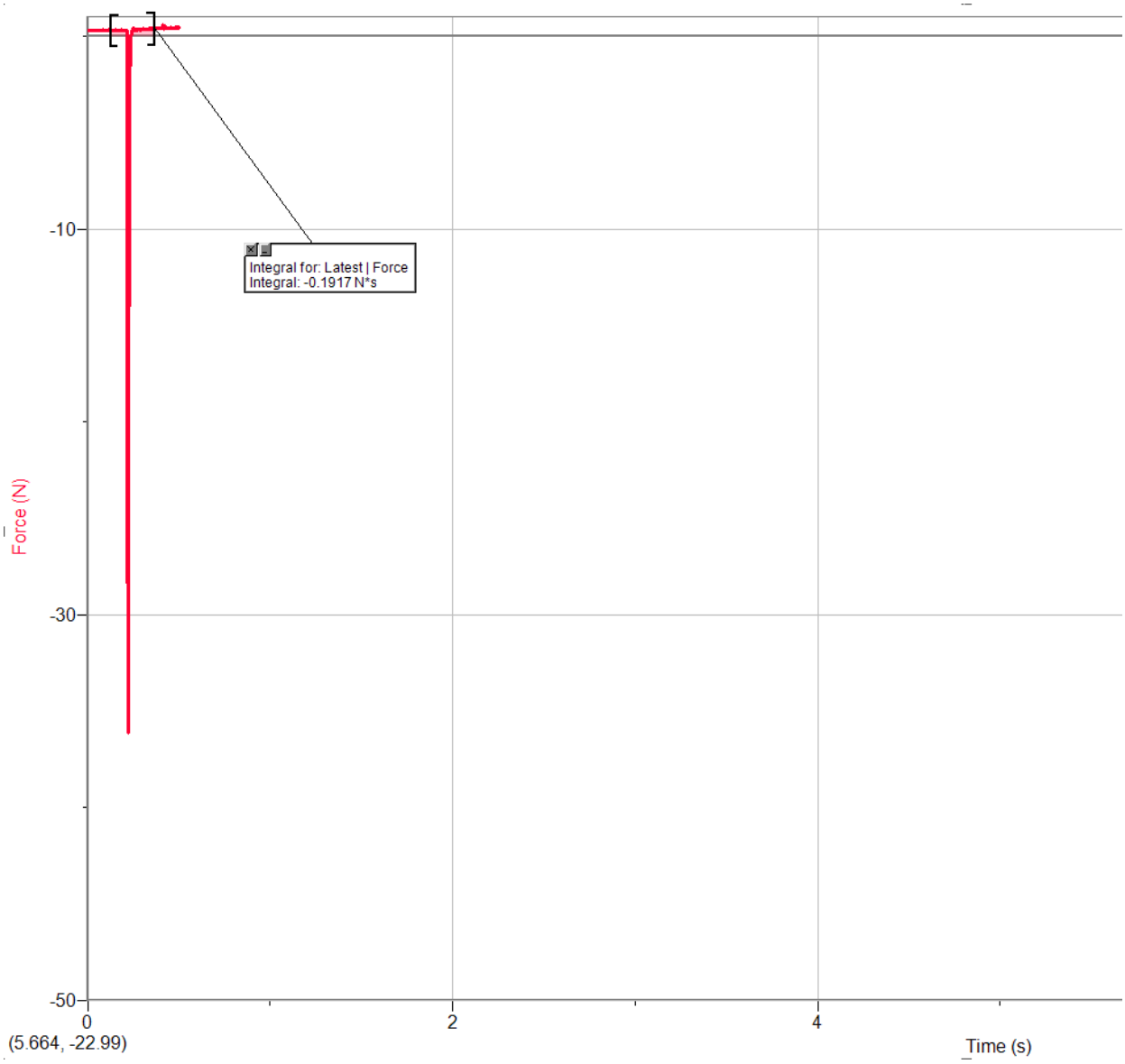
The controlled variables, which were the mass and radius of a tennis ball, were kept constant because I used the same ball throughout my data collection. The mass of the tennis ball I used is 60 grams. I decided to use this tennis ball because the value of its mass is just like any other ball someone can find at a store carrying them.

Figure 1: Diagram of Set Up



Figures 2 and 3: Data Acquisition Through Logger Pro


Logger Pro - Juliana
File Edit Experiment Data Analyze Insert Options Page Help
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Latest
Time (s)
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The force sensor as seen in **Figure 1**, is hooked up to the *Logger Pro,* and then hooked up to the Windows computer. The tennis ball would bounce off the force sensor that would thereby determine the force provided by the bounce, while the *Logger Pro* recorded the seconds that had passed in the data table in **Figure 2**. **Figures 2 and 3** show one of the trials I conducted during my data acquisition. I used the mouse of the computer and selected the area under the force versus time curve to integrate it. By integrating the area under the curve, I was able to find the impulses, but I found them to be negative. The negative is deemed to be negligible, as impulse is the change of momentum, and it can either be a positive value or negative value. I was able to efficiently manipulate and measure the heights by suspending the yardstick in the air, just high enough so that the force sensor meets it at the bottom.

I chose to do 15 variations for the variating heights, with each variation consisting of 5 trials. The 15 variations include heights of 5 cm, 7 cm, 10 cm, 13 cm, 15 cm, 17 cm, 20 cm, 22 cm, 25 cm, 27 cm, 30 cm, 33 cm, 35 cm, 37 cm, and 40 cm. For the trials, I recorded 5 trials per variation to be more accurate. As for my variations, I chose variations that have little difference from one another because I wanted to investigate whether the impulse substantially increased as the different heights were minimally displaced.

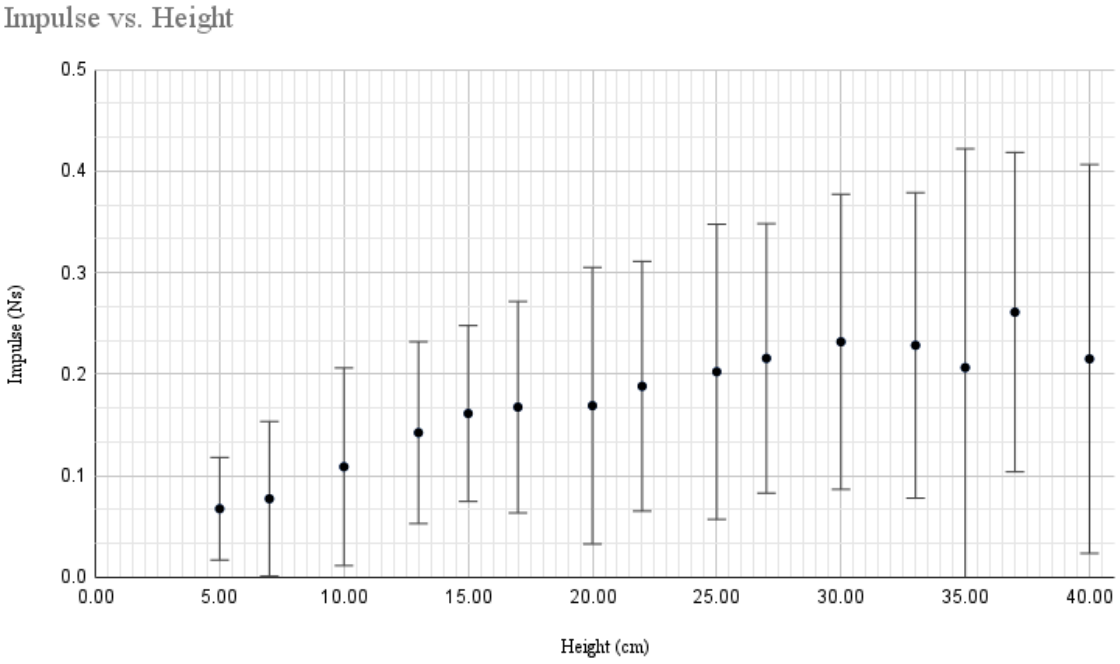
Results and Analysis .:. Data File .:. Top

Data Table

Height (cm)	Impulse (Ns)					Average	Uncertainty
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5		
5.00	0.07807	0.06373	0.05514	0.06886	0.07231	0.067622	±0.0505
7.00	0.05397	0.09872	0.07095	0.06045	0.1032	0.077458	±0.076215
10.0	0.1411	0.06042	0.1083	0.1275	0.1075	0.108964	±0.09729
13.0	0.1233	0.1512	0.1382	0.1508	0.1492	0.14254	±0.08955
15.0	0.1660	0.1591	0.1642	0.1589	0.1590	0.16144	±0.08655
17.0	0.1468	0.1665	0.1719	0.1759	0.1775	0.16772	±0.1041
20.0	0.1420	0.2072	0.1602	0.1929	0.1434	0.16914	±0.1362
22.0	0.2071	0.1681	0.1775	0.2055	0.1832	0.18828	±0.12305
25.0	0.1615	0.1997	0.2108	0.2260	0.2147	0.20254	±0.14525
27.0	0.2098	0.2098	0.2209	0.2038	0.2346	0.21578	±0.1327
30.0	0.2344	0.2343	0.2534	0.2218	0.2163	0.23204	±0.14525
33.0	0.2426	0.2456	0.2491	0.2082	0.1974	0.22858	±0.1504
35.0	0.2651	0.1058	0.2684	0.1364	0.2576	0.20666	±0.2155
37.0	0.2631	0.2731	0.2316	0.2687	0.2697	0.26124	±0.1573
40.0	0.2873	0.2033	0.1969	0.1969	0.1917	0.21522	±0.19145

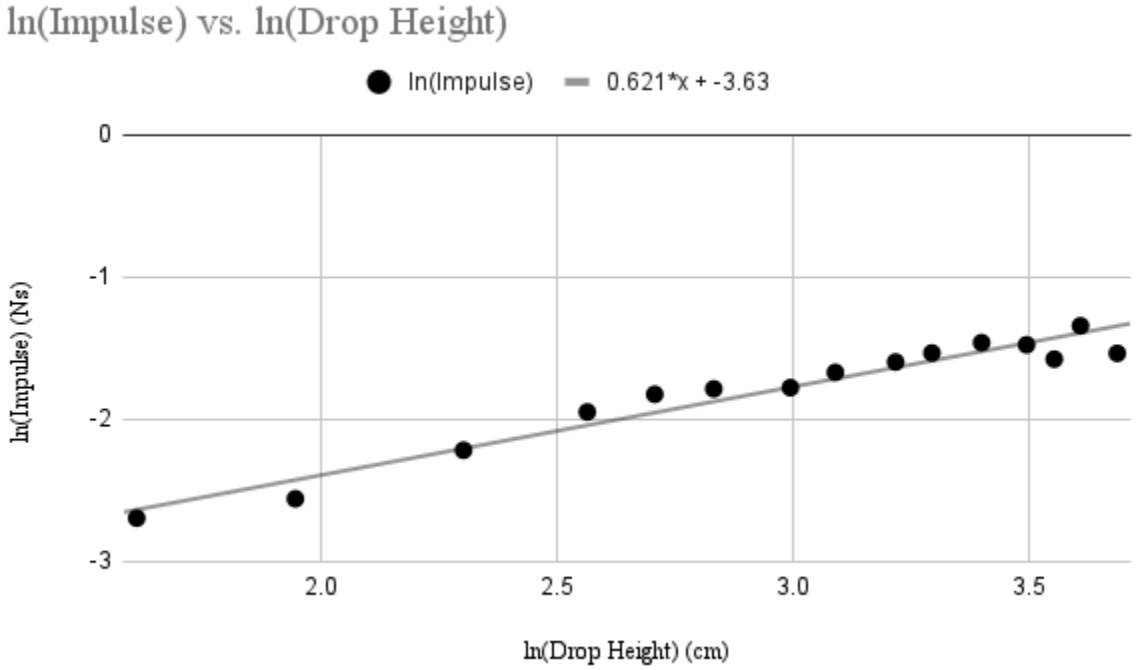
From the data table above, I calculated the averages of each impulse by adding up the 5 trials and dividing by 5. For finding the uncertainties of the averages, I used the equation of finding uncertainty, which is $\frac{max-min}{2}$.

Raw Data with Error Bars

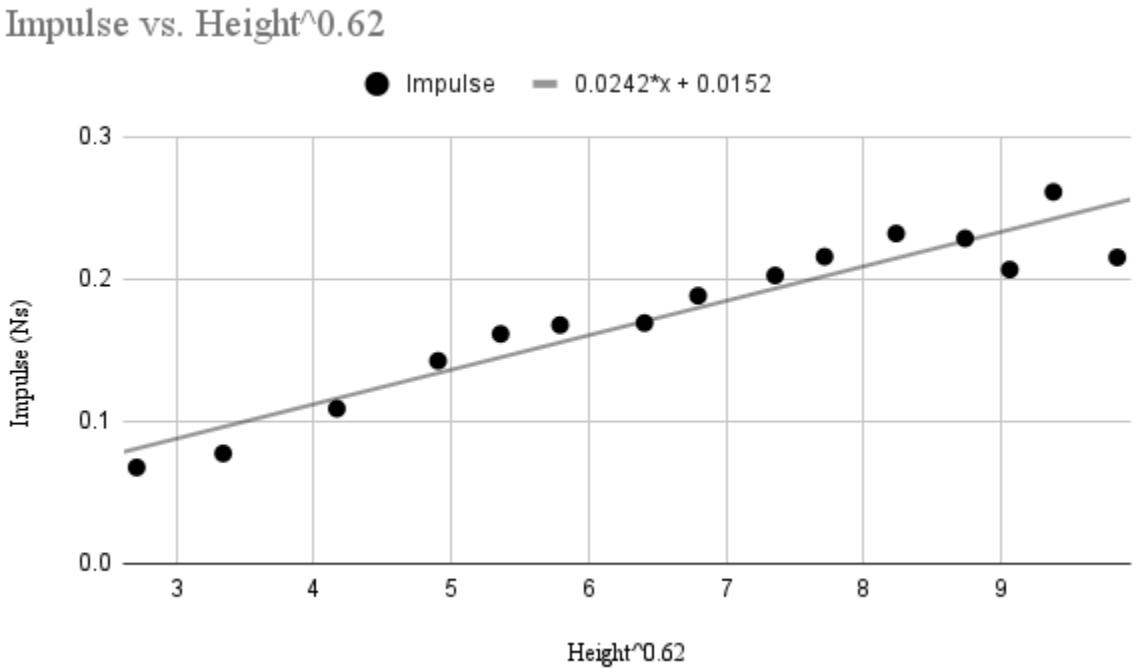


From the raw data graph, it suggests a fractional power function because the graph is not linear. If the graph steadily increases, that means that the impulse increases as height increases.

Log Log Graph

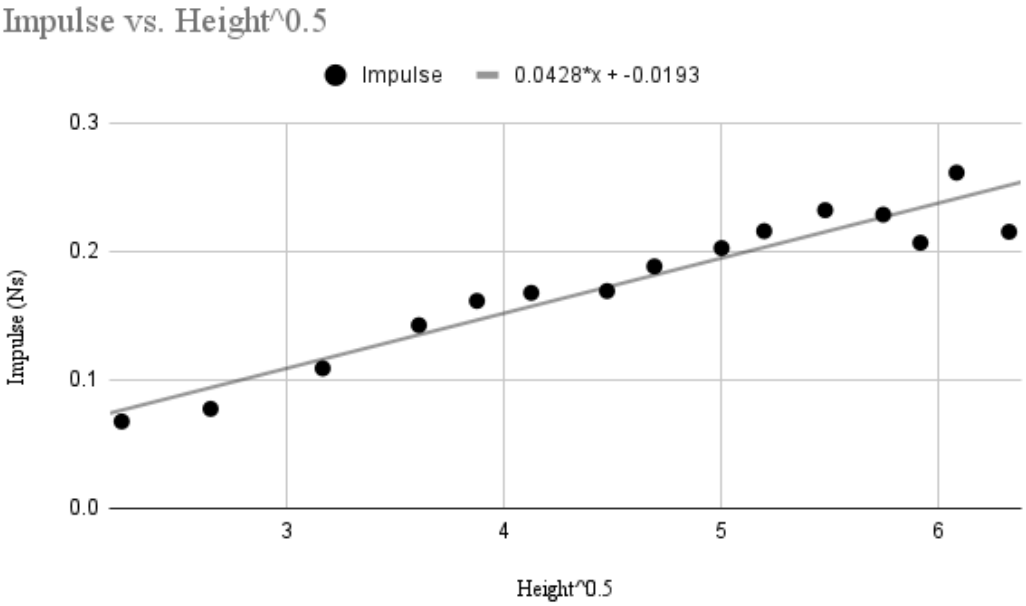


Linearized Graph #1



Both the log log graph and the linearized graph show that impulse and height still increase with one another, with the linearized graph showing a steeper and greater slope than the log log graph.

Linearized Graph #2



In both linearized graphs, the intercepts are minutely different in value. A difference between both linearized graphs is that the slope in the second linearized graph is almost double the slope from the first linearized graph. Even if the value for height decreases, the impulse remains the same, and still shows an increasing graph nonetheless.

I then proceeded to calculate the velocities of the balls being dropped from each variation. I used the SUVAT equation $v^2 = u^2 + 2as$. The initial velocity, "u", would be 0 meters per second because the ball was suspended in my hand before being dropped. Velocity would then be solvable with the equation of $v = \sqrt{2gh}$. I converted the various heights to meters and converted the mass of the ball, which was 60 grams, to kilograms.

Velocity vs. Height Data Table

Height (m)	0.05	0.07	0.1	0.13	0.15	0.17	0.2	0.22	0.25	0.27	0.3	0.33	0.35	0.37	0.4
Velocity (m/s)	0.9905	1.172	1.401	1.597	1.716	1.826	1.981	2.0776	2.215	2.302	2.426	2.545	2.6205	2.6943	2.8014

Conclusion and Evaluation .:. Top

Conclusion

This investigation aimed towards determining the relationship between the drop height of a tennis ball and its impulse. For the log log graph I conjuncted, I used the power function $y = Ax^n$. For the power function, $ln(y) = nln(x) + ln(A)$. This means the y-intercept is equal to ln(A). Calculating for A, I get the equation $e^{-3.63} = A$. I calculated and got 0.0265, which is relatively close to the coefficient of 0.0242 in my linearized graph.

Through the velocity versus height data table, I found that velocity does increase with height, and additionally, increase with impulse as well.

As I hypothesized earlier, the drop height and impulse share a direct relationship, in which they both increase due to velocity. Through the data table of the raw data, graphs, and later the , these 3 variables increase steadily, which means that my hypothesis was correct.

Evaluation

While I did come to a conclusion, there are still some limitations in my experiment I would like to discuss. One limitation to my experiment was how the surface area of the force sensor is very small. This would make it highly difficult to drop the ball directly on top of it and prevent the ball from bouncing on the force sensor's edge. I believe this limitation impacted my results because of how large my uncertainties were. The uncertainties were doubled on my graph, visually plus and minus on my graph on each point to display the error bars. Another limitation that may have also affected my results was how I measured my variating heights. I measured my varying heights by holding the tennis ball in front of the yardstick at whatever height I wanted, eyeballing the height the ball was at. This might have caused my variating heights to be off by a couple centimeters and possibly inaccurate.

Some improvements I may implement in future experiments I will partake in are to use a force sensor with a wider surface area and to use an effective measuring device. Rather than hovering the tennis ball in front of the yardstick, it would have been better to suspend the ball and let it go. Of course, a suspension tool that opens and closes easily would be more effective than one that requires immense strength. Using a wider surface area force sensor would allow for more accurate determinations of force.

For further research, investigating the specific times it takes for a floating lantern to reach different heights would be an interesting experiment I would possibly take on in the near future. This way, I can venture off to a lantern festival if I wanted to and conduct the experiment there. The height the floating lantern travels could be the dependent variable, and varying times can be the independent variable. The controlled variable could be the lantern itself, but may change if it were to become incapable for the experiment by overuse. Physics itself is in a way a fun way to really explore the outside world, and this experiment could be perfect for exploration and investigation.

Related Links .:. Top

- https://van.physics.illinois.edu/ask/listing/17514 - An explanation of energy conversion in releasing a tennis ball at a certain height on top of a surface
- https://prezi.com/wrs3etvxsuwr/momentum-in-tennis/#:~:text=P%3Dmv,momentum%20is%20 also%20a%20 vector - A slideshow about the momentum of a tennis ball and additional information about energy
- https://en.wikipedia.org/wiki/Tennis_ball - A Wikipedia page about the tennis ball and further explanations of different types of tennis balls and properties of aerodynamics
- https://soles.michelin.com/science-tennis-technique/ - Explains the techniques tennis players do in game and the physics behind them
- https://www.physicsforums.com/threads/physics-of-a-vibration-dampener-tennis-shock-absorber.178132/ - A physics forum that garners comments and answers about what a tennis shock absorber really does

Bibliography .:. Top

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https://www.wsj.com/video/series/daniela-hernandez/the-physics-that-give-tennis-pros-their-edge/B83AE759-0107-409D-90D4-A268742D860A. Accessed 7 January 2024.