**Exploring the physics behind a pulley system**

Student ACB432 Word Count = 1596

**Introduction and Research Question**

Pulleys are machines in which a mechanical device can change the direction or increase the magnitude of a force. From elevators to curtains, a pulley is simple but versatile. This investigation involves basic physics and a pulley. My research question asks:

*How does the mass of brass weights influence the time it takes for the weights to fall a fixed distance onto the ground in a pulley system attached to a trolley?*

**Background Theory**

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| The set-up for my experiment is shown in  Diagram 1. A free body diagram of the trolley and the object are shown here. Both trolley and weights have the same tension as they are attached to each other (but in different directions). The force of the hanging weight is  *F = m g*. This force will affect the trolley via the string. The system is trolley mass *M* plus the object mass *m*.  Newton’s second law says the acceleration is directly proportional to the net force and inversely proportional to the mass. | Diagram 1  Diagram  Description automatically generated |

Since both objects have mass, they will affect the acceleration of the system. Therefore, we can find the acceleration of the objects by using **Equation 1.**



The dependent variable of this experiment is the time *t* it takes for the object to fall onto the ground from a fixed height s. This can be calculated if the acceleration *a* of the object is known from kinematic **Equation 2.** Here, the initial velocity is zero.



As the fall distance is constant, the equation can be substituted into equation 1 to find the relationship between the mass of the object and the time it takes to fall.

Re-arranging equation 1 so acceleration is the subject we find:



Substituting equation 1 into equation 2, we find:



Therefore:

This equation can be used to fine the proportionality between time and the mass of the object.

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Therefore, there is a relationship between the time-squared *t*2 it takes for the object to drop and the inverse of the mass *m*–1 of the object. The rest of the equation are constants: *s*, *M*

and *g*. We see the function:



A graph of the inverse mass of the object against the squared time should be a straight line. The *y-*intercept of a time-squared against the reciprocal of mass should be:



**Hypothesis**

*My hypothesis is that as the mass of the brass weights increases, the time taken for the weights to fall and touch the ground decreases.*

**Variables**

*Dependent Variable:* Time it takes for the brass weights to touch the ground. This will be measured with a stopwatch, looking as close to the bottom of the weights as possible to avoid parallax error. The uncertainty will be +0.05 seconds as there will be random error from my reaction time (with anticipation). There will be five trials for each of the five masses to reduce random error.

*Independent Variable:* The mass of the brass weights. This variable will be measured with a weighing scale. The range for this variable will be 50g, 100g, 150g, 200g and 500 g. Smaller values were chosen due to slower acceleration, as this will allow more time for my reaction and reduce random errors. The increment size (50g) is appropriate as one brass weight is 50 grams and large enough to make a reliable line of best-fit from my results. The uncertainty for this variable will be ±0.1 grams since the scale goes up to one decimal place.

*Controlled Variables:*

* The mass of the trolley. This is a constant of 1.760 kg.
* The angle of which the weights will drop. The string attached to the brass weights of the edge of the table must be as close to 90° as possible to the floor and is made sure that it is not swinging before being dropped. This is controlled by eye.
* Variables that were not controlled were friction and human reaction time. Avoiding parallax error was possible.

**Method**

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| 1 Set-up the equipment as shown here.  2 Attached 50g of brass weights on the string  and roll the trolley away from the pulley until   the bottom of the brass weight is parallel to  the top of the table. Make sure the strong is  perpendicular to the floor.  3 Let go of the trolley and start the recording of  the time with the stopwatch. | Diagram  Description automatically generated |

4 Stop the time when the brass weights reach the ground.

5 Record the time and repeat four more times.

6 Repeat steps 2 to 5 for the other four values (100g, 150g, 200g, 250g).

**Safety Precautions**

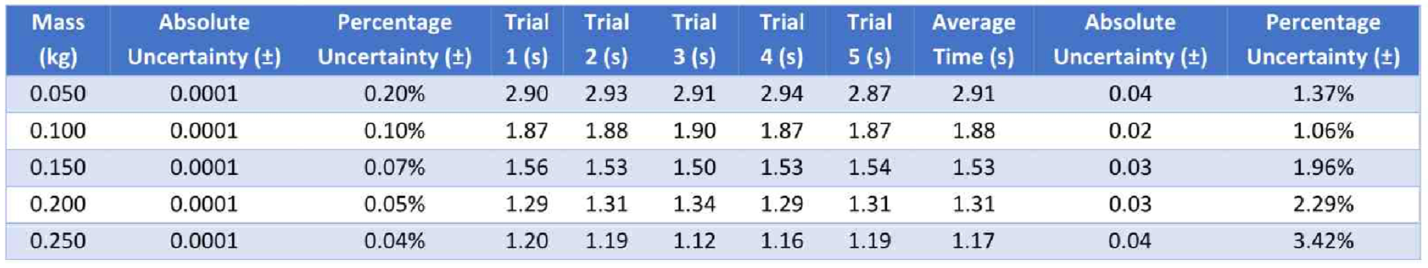
* Heavy equipment dropping on the ground.

The trolley may drop on the ground and hurt someone. This can be avoided by wearing shoes that cover the feet and by stopping the trolley before it reached the edge of the table. Therefore, the strong must be significantly longer than the dropping height so that trolley will not reach the edge of the table before the weights hit the floor. There are no other significant safety issues.

**Data**

Table 1 shows the experimental data of mass and time and uncertainties.

Table 1



The uncertainty for average time was calculated from the one-half the range rule. For example, the range time for the 0.0497kg mass is 2.94 – 2.87 = 0.07. Halving this gives an uncertainty of 0.035 (or 0.04 for three significant figures).

Graph 1 is the average times and masses with a best fit curve.

Graph 1

Chart, line chart, scatter chart

Description automatically generated

The equation for the best fit trendline of Graph 1 is *t* = 0.53 *m*–0.56

This experimental data supports the hypothesis: as the mass of the brass weights increase, the time it takes for the weights to fall decreases.

Again, the **theoretical equation** for the square of time is:

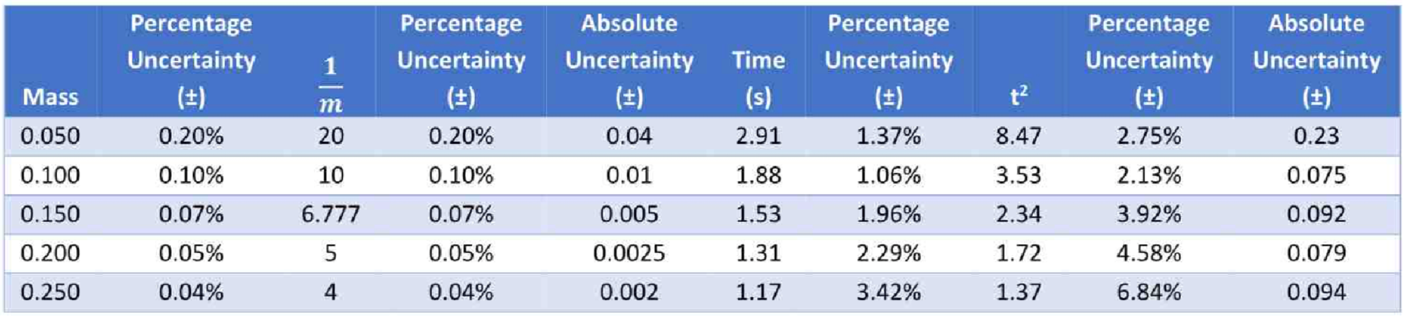


As the drop height is *s* = 0.95 m, gravity *g* = 9.81 m/s2 and trolley mas *M* = 1.760 kg, we find:



A linear graph was created by plotting time-squared against the inverse of the mass. The data processing for this in in Table 2.

Table 2



The inverse of mass has the same percentage of uncertainty as the mass, which is converted to absolute uncertainty. For example: 0.20% x 20 = ±0.04

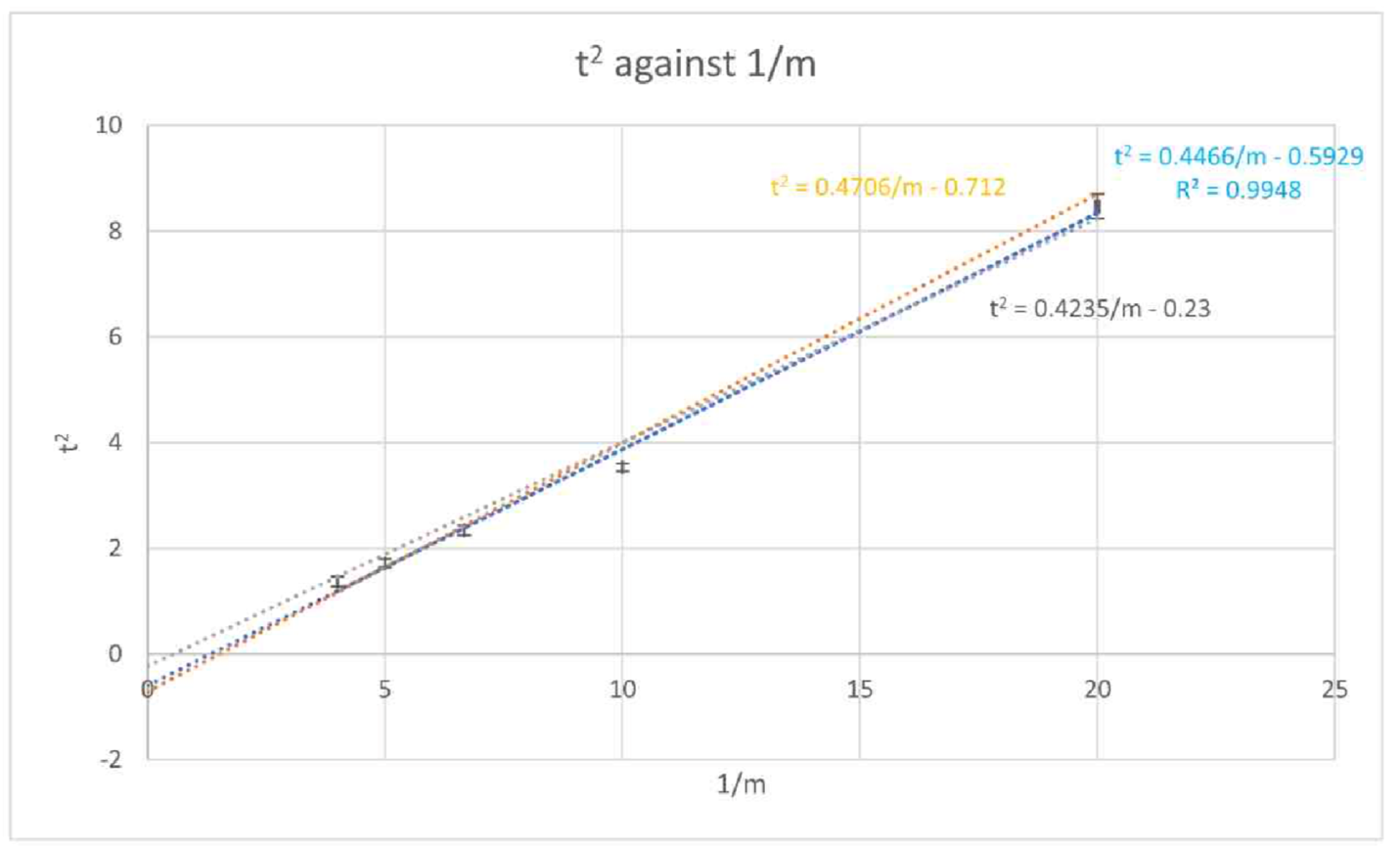
The percentage uncertainty of average time is multiplied by 2 to give the uncertainty of the square of the average time. Then the percentage can be converted into absolute uncertainty. For example: 1.37% x 2 = 2.75% (two significant figures). Then, 8.47 x 2.75% = ±0.23 which is the absolute uncertainty.

Graph 2 (below) now shows the relationship that I explained.

Below, the blue line is the line of best fit and the grey and orange lines are the lines of worst fit which are used to create the uncertainty of the gradient. The computer generated the best-fit equation:



Graph 2



The equations of the **maximum** and **minimum** lines are:

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There is a small **outlier** for 0.050 kg (point 20 in Graph 2) as the point lies furthest away from the. Best fit line. This is not caused by random error as the uncertainty is small. Therefore, this outlier may have caused a systematic error.

The best fit **gradient uncertainty** is one-half the difference between the minimum and maximum values: (0.47 – 0.42)/2 = ± 0.03 (2 SF).

The **uncertainty for the *y*-axis** is the same one-half rule: (0.71 – 0.42)/2 = ± 0.15

Therefore, the **experimental equation** with uncertainties can be compared to the theoretical:

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There is some difference between the experimental and the theoretical values. There is a 0.11 (±0.03) difference between the gradients, and a difference of 0.78 (±0.15) for the *y*-intercept.

As the uncertainties are small and the line of best fit has an R2 value of 0.9948, the experimental value can be said to be accurate. However, this experiment was not precise as the results did not fit the theoretical equation.

**Conclusion**

It can be concluded that the experimental data supports my hypothesis. As the mass of the brass weights increase, the time it takes for the brass weight to reach the ground decreases, and that the description of this is given by the equation:



This experiment was successful, and the results were reliable since there was a strong line of best fit with small error. Repeated trials and controlled variables helped reduce random errors.

Graph 2 produced a clear linear line, and the derived equation was used to explain the physics behind this pulley system. However, there is some difference between the experimental and theoretical results. There may have been a systematic error because of the difference in y-intercepts. There is also some difference in gradients.

**Evaluation, Strengths, and Weaknesses**

There were no major problems. I decided to increase the mass of the trolley so it would increase the time it took for the weights to reach the ground, giving me more time to react and reduce the timing error.

However, the velocity of the objects was still quite large for the heavier values of the brass weights which made it more difficult to record the time effectively as the smaller value. This may have influenced data.

The gradient of the theoretical value was smaller than the experimental value. The heavier values may have affected the gradients.

The mass of the brass weights and trolley were measured correctly, and the dropping height was carefully measured so these are reliable.

This experiment can be improved by lowering the speed of the system by using larger masses or a longer dropping distance. This would give more accurate results reducing the effect of reaction time. More values of weights would extend the range of data.

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23 August 2024