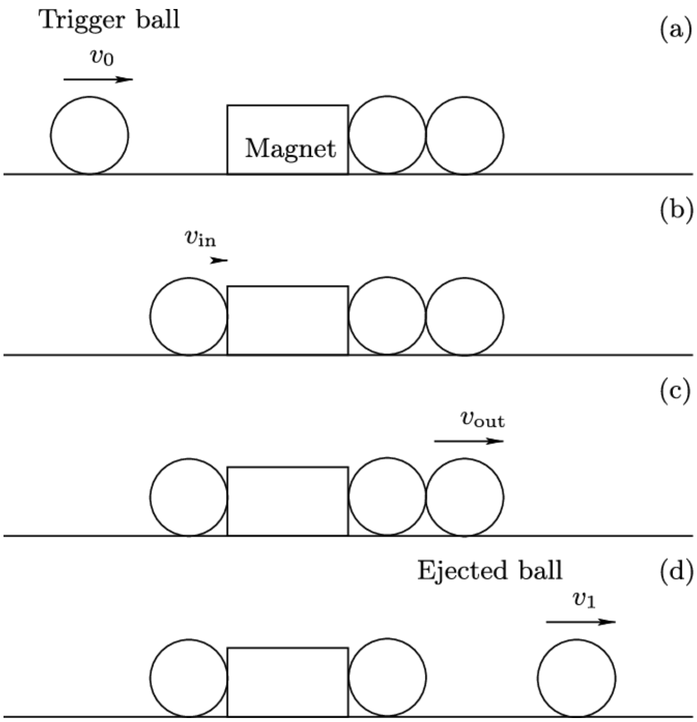
An Investigation Upon the Effects of the Stages of a Gaussian Cannon and its Relation to the Velocity of a Projectile Shot From it

RESEARCH QUESTION

How do the number of stages of a gaussian cannon affect the speed of its projectile?

INTRODUCTION

The Gaussian Cannon, a topic of interest for me since I was a child. After seeing many renditions of what it could be from pop culture and video games, dI had become interested in the applications as well as using my knowledge of physics gained from my IB Physics course to go more into depth about the relationships that create it.



The version of the Gaussian Cannon I will be using is the simplest one, which uses magnetic energy, as well as collisions in order to transfer kinetic energy.[1] Which sort of functions similarly to a Newton's Cradle. However, the use of multiple stages means that the force will be increasingly greater, as F=ma, as the ball bearings roll, and accelerate towards the magnet/stage, it should hit each stage with a faster speed, transferring more energy as it has accelerated more, leading to a faster velocity at the ending stage for the projectile. This concept is shown in the graphic on the side. [2]

This Internal Assessment aims to explore the relationship between the number of stages of a Gaussian cannon and how it affects the speed of the projectile.

[1] Chemin, Arsène, Pauline Besserve, Aude Caussarieu, Nicolas Taberlet, and Nicolas Plihon. 2017. "Magnetic Cannon: The Physics of the Gauss Rifle." *American Journal of Physics* 85 (7): 495

[2] Andersson, Åke & Karlsson, Carl-Joar & Lane, Hampus. (2017). The Gaussian cannon. Emergent Scientist. 1. 6. 10.1051

HYPOTHESIS

Due to the ability of a magnet to accelerate an object towards it, it can be used in a Gaussian Cannon, which uses elastic collisions from magnetic projectiles to magnets. The greater the amount of stages, the faster the projectile should go, due to increasing acceleration of the projectile leading to faster collisions due to the transference of magnetic energy into kinetic energy , and in turn, a faster projectile as the result. Which means that the relationship between the number of stages and the speed of the projectile should be exponential.

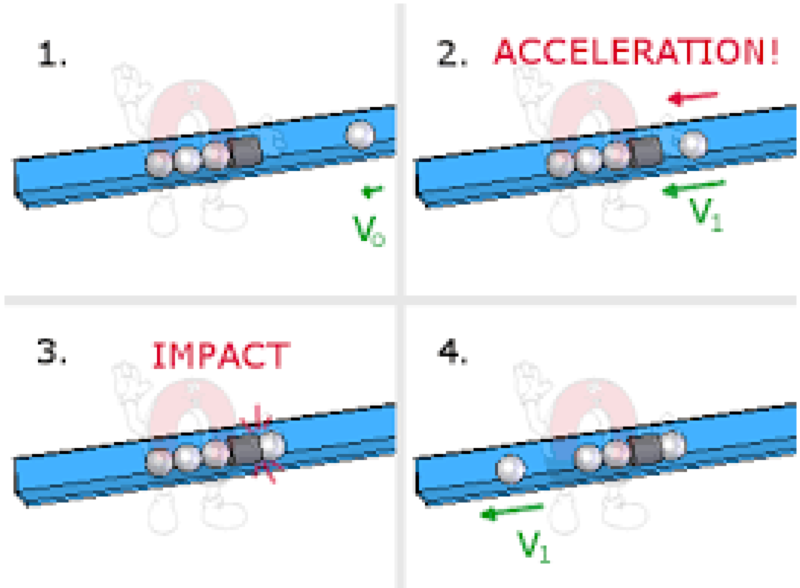
Independent Variable and Dependent Variables

Independent Variable: The amount of stages of a Gaussian Cannon (measured in amount of stages varying from 1 to 5). As the amount of stages increases, the speed should increase as well.
Dependent Variable: The Velocity of the Projectile (measured in ms^{-1}) This will be measured by the photogate, and should change as the amount of stages change.

Controlling variables

Variables will be kept consistent through various means. Variables such as the Gaussian cannon barrel will stay constant, as it is not changing, which will minimize the effect the barrel has on velocity from frictional forces. The projectile will be a steel ball bearing, as it is made of a magnetic material, which will keep the mass and air resistance at a relatively same value. The magnets used will be the same size and material and same magnetic strength. In order to find the velocity of the projectile, A photogate will be used in order to measure the velocity of the object. In order for the magnets to not interfere with the speeds, they will be placed a distance apart, where they do not pull on each other and create a chance for random error, the poles of the magnets will also be considered, as they will be placed in a position from varying poles, as the are placed in an alternating pole position. Where they will attract each other, this is just to make sure that the magnets will not repel the projectiles and affect the conservation of kinetic energy.

Apparatus and Materials



[3]

Materials used:

- A rail, which was at a 90 degree angle (Non-Magnetic). In my case I used an Aluminum rail.
- 5 Neodymium Magnets (same strength)
- 10 Ball Bearings (same size, magnetic material).
- A photogate (to measure the velocity of the projectile).
- A ruler in order to standardize the distance between each stage.

Method

The magnets will be placed on the rail in a way that they do attract each other, but they do not pull on each other so much that they will affect the stages. They are placed at an optimum distance where they do not pull on each other, this was determined by using the ruler to determine that each stage was placed best at 7.62 centimeters apart. Then, two ball bearings are placed in front of a magnet/stage, and one is put down behind the magnet, so that the magnet pulls it towards the magnet, allowing it to accelerate and hit the magnet, which transfers the energy into the two ball bearings, launching the second one. With multiple stages this process is the same, however the ball that is launched will be used to launch the next one on the next stage. The velocity of the last ball will be measured by the photogate, which is also placed 7.62 centimeters away from the barrel so that an error reading does not appear.

Number of	Velocity of	Trial 2	Trial 3	Trial 4	Trial 5

[3] "Gauss Guns." n.d. Www.kjmagnetics.com.https://www.kjmagnetics.com/blog.asp?p=gauss-guns.

Stages	projectile (ms^{-1}) Trial 1				
1	1.41	1.28	1.38	1.28	1.50
2	1.98	1.86	2.01	1.59	2.04
3	2.22	1.93	1.92	1.98	2.12
4	2.38	2.13	2.02	2.84	3.04
5	2.73	2.9	2.54	3.40	3.00

I calculate my average by getting all the velocity values per stage and dividing it by the number of trials, which is five, in this case.

$$Average = \frac{1.41 + 1.28 + 1.38 + 1.28 + 1.50}{5}$$

$$average \approx 1.37\, m/s$$

I then calculate the error for the trials by getting the highest and lowest values of velocity per number of stages.

$$\Delta x = \frac{x_{max} - x_{min}}{2}$$

$$ERROR\ for\ trial = \frac{.150 - .128}{2}$$

$$ERROR \approx \pm .110\, m/s$$

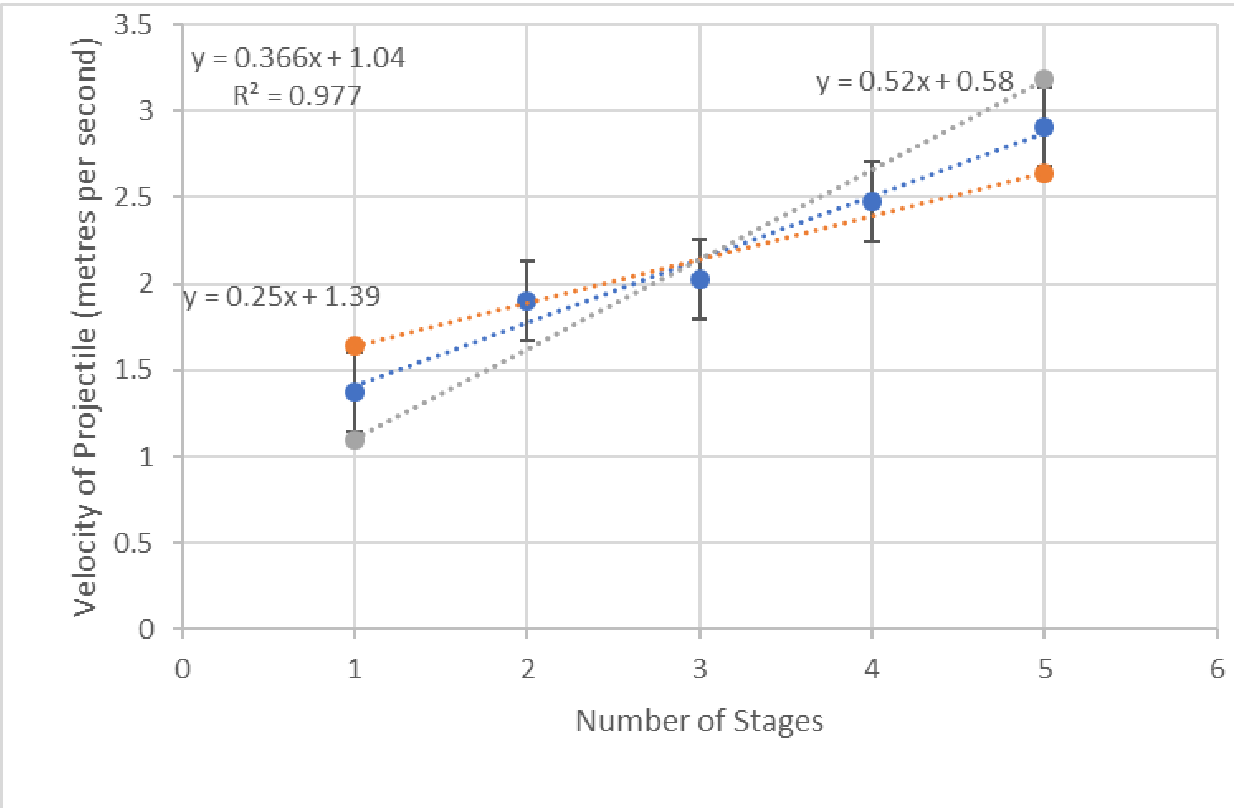
$$Average\ ERROR = \frac{.110 + .225 + .150 + .510 + .335}{5}$$

$$average\ ERROR \approx \pm .266\, m/s$$

In order to determine error, I got the lowest and highest value trials for each stage, subtracted them and divided them by two. I then calculated the average error in order to have a standardized error bar for my graph. Thus, using the data from the averages of the trials, we are able to input this into a graph in order to see the relationship between these stages.

Number of Stages	Velocity of projectile (ms^{-1}) ± .266 (ms^{-1})
1	1.37

2	1.90
3	2.03
4	2.48
5	2.91



(blue line equation on the top left, orange line equation on the left side and gray line equation top right)

$$ERROR\ in\ slope\ =\ \frac{0.52-0.25}{2}$$

$$ERROR\ in\ slope\ \approx\ \pm 0.54\ m/s$$

<u>Conclusion</u>

The results of the data correlate with my hypothesis, however it does not support it in the way I had previously thought, I thought that it would, increase almost exponentially, however it showed that there was a more linear relationship between the stages of a gauss gun and the velocity of the projectile shot from it. The graphs show that it is a linear relationship, as the trendline is linear with an equation of .336x ms^{-1} + 1.41ms^{-1}, with the x being the number of stages, which shows that for every stage, the velocity increases about .336 meters per second, with a correlation of .977,it shows how close the gradient is to the data, the correlation of .977 supports the idea that it is a linear relationship. The error in my slope was $\pm.54$ ms^{-1} .The y intercept value could show systematic error however is unlikely due to the strength of the magnet. Analyzing the error bars and calculations show that it is fairly accurate, with the highest percent uncertainty being at about twenty percent, and the average error being ±.266. However , if the error bars were to be included in the data, other gradients such as exponential or higher slope linear functions could be lines of best fit. This relationship is explained through the basis that, since it was more linear than all, that it is proportional to the exit velocity of the projectile. Which goes against my hypothesis, as I had believed the relationship to be exponential, which I am able to understand, as it increased in velocity, the ball bearings that were shot into the other stages had less acceleration than the initial ball bearing, as they already were approaching the magnet with velocity. Making the acceleration less, and hitting with less force, as Newton's Second law, F=ma explains it. Since F=ma and the relationship is linear, it means that F=m(v/t) which means that the velocity change over time was less since the ball bearing changed less in velocity than the initial ball bearing, which changed from 0. This relationship is important to know, as the applications of magnets in a more engineering based way, being applied in different ways, rather than serving purposes such as being stuck on fridge doors.

Strengths and Weaknesses

Some strengths in my experiment were that the process was very refined, and the gaussian cannon was very standardized in order to get a shot off. This allowed for accurate reading of the velocity of the cannon, however, this came with the problem of dealing with magnets, as they were hard to work with, which was why my process was methodical but still dealt with all the problems, such as setting them up for the impact, as the rail was used to prevent from slippage and to reduce dynamic friction. The placement of the stages at the optimum distance and standardized, as they were 7.62 centimeters apart. The random error was controlled through the process, which went through a lot of trial and error to be optimized in order to get correct data. The strength did cause a true improvement on the data, as previously in different attempts, the data would be extremely skewed, and made it incredibly difficult to read. Some things that may have been negligible to the experiment was the distance between the ball bearing on the first stage, as it did not seem to affect the speed, so standardization of that process was not that effective, but was done in order to reduce random error of the ball slipping/rolling into the magnet faster.

Some weaknesses and oversights in my experiment lie in the ability to track the speed of the projectile. I should have made sure there was no systematic error in the experiment, I could have done this by calculating the actual speed of the projectile through distance and the time it took to travel that distance. It was not considered that it could be faulty, and I did not check the measurement with another photogate. This could be a source for systematic error, which could be solved by using another photogate to measure it and check as well, as using one may have been an oversight and allowed for systematic error. Another weakness/oversight was the use of the magnets so close to an electronic, it may have messed with the reading, as the reading could have been wrong. As from my knowledge, strong magnets around electronics (the photogate) might not work well, I have no idea that it might have affected the readings of the photogate. A lot of the readings on the photogate were not captured as well, leading to me having to redo my trials. In order to increase precision, I could have had ten trials per stage as well, this would definitely have made my results more accurate, than only five trials per stage.

Extension

The purpose of this experiment was to find out how the amount of stages in a gaussian cannon was related to the velocity of its projectile. The real world application of this could be applicable to the use of projectile weapons. The same research could be done with stronger magnets in order to analyze the relationship more in depth. Other relationships that could be examined are magnetic strength of the gaussian cannon and the velocity of the projectile. It would provide insights into the ever growing world of magnets!

Works Cited

Chemin, Arsène, Pauline Besserve, Aude Caussarieu, Nicolas Taberlet, and Nicolas Plihon. 2017. "Magnetic Cannon: The Physics of the Gauss Rifle." *American Journal of Physics* 85 (7): 495–502. https://doi.org/10.1119/1.4979653.

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