The Spin Rate of a Ping Pong Ball and the Deflection Ratio

EXPLORATION & PERSONAL ENGAGEMENT

Introduction

I have played sports all my life. Soccer is my passion. I play it, I watch it, I love it, the beautiful game! To me, there is nothing better than when a penalty kick curves around the wall of defenders and into the corner of the goal. As a child, I was always curious as to why that works. I was interested to know, "What is the physics behind a curving soccer ball?" Now that I'm in IB Physics, I know enough to be able to finally learn about this topic for myself. So, for this investigation, I decided to investigate the physics of a curving soccer ball.

As a Ping-Pong player, I know that you can curve a Ping-Pong ball even more sharply than you can curve a soccer ball. It's also quicker and easier to work with hitting a Ping-Pong ball in the limited space of our school lab. So I decided to experiment with a curving Ping-Pong ball instead of with a soccer ball, since the physics is the same for both.

Background Theory

When a Ping-Pong ball is hit with a paddle, the amount of spin that is put onto the ball affects the amount of curvature it experiences during its flight. The part of the ball spinning in the direction of the air flow will cause the air on that side to travel faster, allowing the air to travel faster as well, while on the other side, the oppositely spinning area will cause that portion of the air to travel slower, causing that portion of the air to travel less quickly. The air will exert a force on the side of the ball spinning in the direction of the air and due to Newton's third law of motion the ball will exert an equal force towards the air, which is known as the Magnus Force. Ultimately the Magnus Force causes the ball to bend towards a certain direction, depending on the spin. (http://ffden-phys.uaf.edu/211_fall2010.web.dir/Patrick_Brandon/what_is_the_magnus_effect.html) Assuming that the Ping-Pong and the environment are kept constant, the two main factors affecting the Magnus Force produced is the spin rate, or angular frequency, of the ball and the velocity at which the ball travels. This investigation serves to study how the spin rate of a Ping-Pong ball affects the amount of curvature produced.

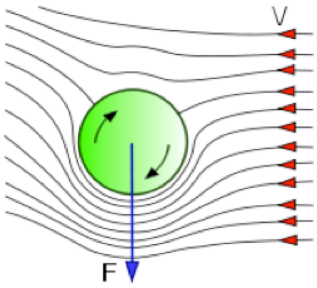

Figure 1: Graphical representation of the Magnus Effect. Clearly, the spin is causing a perpendicular force, which causes the ball to curve.

Research Question: How does the spin rate of a Ping-Pong ball affect its deflection ratio (defined below)?

According to the Journal of Physics of the University of Leicester (https://physics.le.ac.uk/journals/index.php/pst/article/view/458/256), the effect of a spherical object's spin rate on the amount of curvature it undergoes can be modeled by the following equation[i]:

$$D = \frac{\pi R^3 \rho \omega}{vm} x^2 \qquad \text{[Equation 1]}$$

where D is the distance the ball travelled in the direction of the Magnus Force, R is the radius of the Ping-Pong ball, ρ is the density of the air in the room, ω is the spin rate, v is the velocity of the ball, m is the mass of the ball, and x is the distance travelled. The equation was specifically designed to fit the motion of soccer balls, but it fit the motion of Ping-Pong balls equally accurately since the assumptions set forth applied for smaller sized spherical objects. Equation 1, however, called for three independent variables, ω, v, and x; therefore another equation was derived to keep all the values except ω and D constant. Since velocity can be expressed as $v = x/t$, t was

Comment [1]: The evidence of personal engagement with the exploration is clear with significant independent thinking, initiative or creativity.

The justification given for choosing the research question and/or the topic under investigation demonstrates **personal significance**, **interest or curiosity**.

Comment [2]: The background information provided for the investigation is entirely appropriate and relevant and enhances the understanding of the context of the investigation.

There is evidence of **personal input and initiative** in the designing, implementation or presentation of the investigation

Comment [3]: The topic of the investigation is identified and a relevant and fully focused research question is clearly described.

Comment [4]: The evidence of personal engagement with the exploration is clear with significant independent thinking, initiative or creativity.

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substituted into Equation 1 and an equation with one independent variable, the spin rate, was derived.

$$\frac{D}{x} = \frac{\pi R^3 \rho t}{m}\omega \qquad \text{[Equation 2]}$$

Reducing the number of independent variables did not show a direct relationship between spin rate and the horizontal curvature, D, but instead with the value of $\frac{D}{x}$, the deflection ratio, defined as the amount of curvature in the direction of the Magnus Force set as the y-axis over the total distance travelled in the x-axis.

The final derived equation shows a direct relationship between the spin rate of the Ping-Pong ball and the deflection ratio, $\frac{D}{x}$. The relationship best fits the form of a proportional fit, $y = Ax$; therefore, $\frac{D}{x}$ is predicted to be proportional to ω with a proportionality constant of $\frac{\pi R^3 \rho t}{m}$. The final graph is predicted to be a $\frac{D}{x}$ versus ω proportional graph with a gradient of $\frac{\pi R^3 \rho t}{m}$.

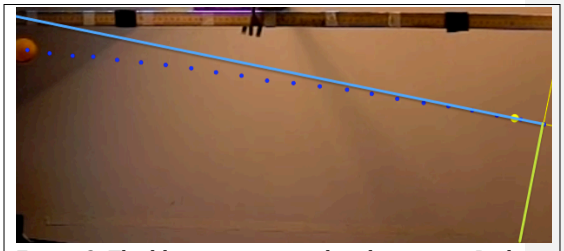

Figure 2: The blue axis was used to determine, D, the amount the ball travelled in the direction of the Magnus Force and the green axis was used to determine, x, the distance travelled in the direction of the initial hit. The two values were written as ratios of $\frac{D}{x}$, which ultimately was defined as the deflection ratio of the ball.

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Methods

Variables

Independent Variable: Spin rate of the Ping-Pong ball
Dependent Variable: Deflection Ratio
Controlled Variable(s):

- Ping-Pong Ball: The same Ping-Pong ball was used throughout the experiment in order to maintain consistency in the data. A "Changyun 1 star" Ping-Pong ball with a mass of 2.36 ± 0.01 grams and a diameter of 4.00 ± 0.01 cm was used.
- High Speed Camera: The same camera was used in recording all the videos in order to make sure that all the footage came from the same source and was kept consistent. A Casio EX-F1 camera was used and set at 600 frames per second (fps) as this provided enough quality to analyze the videos.
- Temperature of Environment: The temperature was controlled by staying in the same area of the room throughout the experiment. The temperature of the room was 25 ± 1°C.
- Elapsed Time: Since Equation 3 required time to be a constant value, the same number of frames were analyzed in all the trials. Exactly 105 frames were analyzed for all the trials in order to keep time constant.

Safety, Ethical, or Environmental Issues

Reasonable safety precautions were taken during the setup and conduct of the experiment. The high speed camera was firmly secured in position so it could not fall and break or injure the ping-pong hitter. The hot spotlights were placed far enough away from the ping-pong hitter to ensure that he did not accidentally touch them. Fragile items (glassware) were removed from the area the ping-pong was being hit towards so it wouldn't knock them over.

There were no identified ethical or environmental issues that needed to be addressed in this investigation.

Comment [7]: The report shows evidence of full awareness of the significant safety, ethical or environmental issues that are **relevant to the methodology of the investigation**

Procedure

First, in order to detect the full motion of the Ping-Pong ball accurately, the camera was placed over the Ping-Pong table to view the system in a 'bird's eye view'. The camera was connected to a tripod and then clamped to a cabinet shelf using metal clamps in order to get enough distance between the table and the camera. The high-speed feature on the camera required abundant space due to its limited field of vision. To increase the quality of the videos, two spotlights were placed beside the table. Before the hits were recorded, a line was drawn around the center of the ball where the two semi-spheres of the ball came together and formed a narrow ridge. Then a short line perpendicular to the central line was drawn in order to act as a guide in detecting the ball's spins during the video analysis process. The spotlights were turned on and at first the Ping-Pong ball was hit with very little, or almost no spin at all. Since it was impossible to have three trials with the same amount of spin, 40 trials were recorded and the amount of spin added was increased every time alternating between left and right spin.

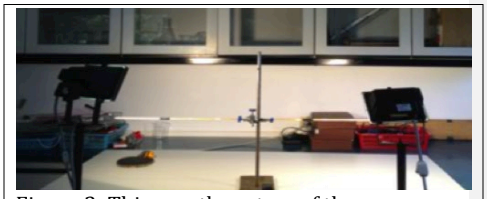

Figure 3: This was the set up of the experiment. The camera was set up on top and a ruler was set up in order to keep the hits around its height. Lighting was used to increase the quality of the videos and the Ping-Pong ball was hit with a wide variety of sidespins, from 0 to 164 rad/s.

After all the hits were recorded, 20 good trials, ranging from no spin to maximum spin, were picked out and analyzed. First, the spin rate was measured by seeing how long it took the ball to spin horizontally a certain number of times. Then the central point of the ball was tracked for exactly 105 frames at a five-frame interval. Afterwards, the origin of the graph was set on the first data point which gave two sets of data points, one representing ball's movement in the direction of the Magnus Force and the other the movement in the direction the ball was hit. A quadratic equation was used to best fit the former and a linear equation for the latter. Using the equations, the final and initial times were substituted into the quadratic equation and subtracted from each other to find the value of D, and the same process was repeated with the linear equation to find the value of x. Then the absolute value of the difference was used as the final values of D and x since only the magnitude of the movements was needed.

Comment [8]: The methodology of the investigation is highly appropriate to address the research question because it takes into consideration all, or nearly all, of the significant factors that may influence the relevance, reliability and sufficiency of the collected data.