**Play that track, ross!**  
**A rube goldberg machine**

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# Introduction and Background

A Rube Goldberg device exemplifies the harmony between the dynamic motion of objects. A simple cut of a string can cause huge implications if the device is designed to easily transfer potential into kinetic energy. People around the world have created systems that can be reset over and over to make a certain task easier to do every day. It also can lead a creative, student team to over complicate a simple task of turning on a record player. Voyager One, the first of two spacecraft to leave the solar system, brought with it a piece of human history unlike anything ever made before. A record consisting of the history, sounds and pictures of Earth was on board, wandering the universe to one day be picked up by lifeforms unknown to us. With the work of almost every country on Earth, our pale, blue dot collaborated together to bring forward the best of ourselves to maybe, one day, communicate with whoever else might be out there. We recently got our hands on this record, and was inspired to create a device that would turn it on with a simple light of a match.

# Description of the Device

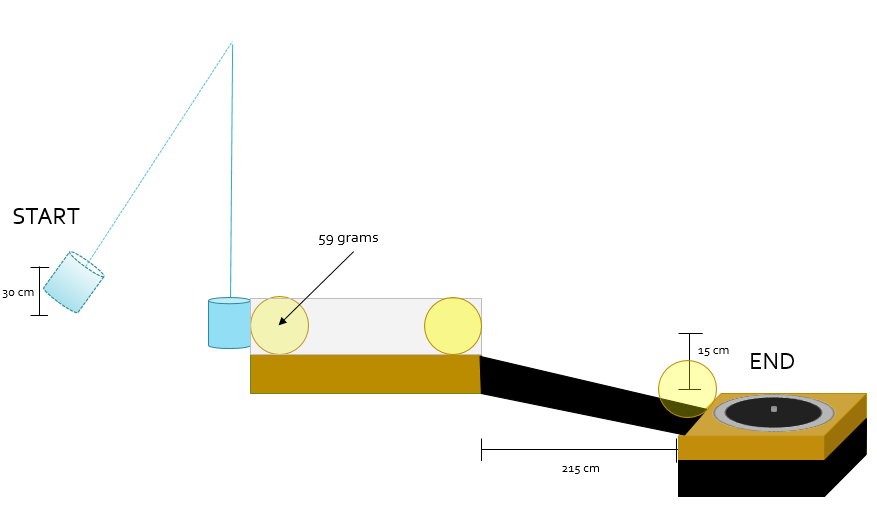


Figure 1 - 2D representation of the Rube Goldberg device with measurements recorded prior to test

The figure above illustrates our device and its basic function. The measurements added to the figure details the measurements taken prior to our test to help us fully analyze the motion once the test is complete. Several materials need to be obtained for this device to be functional. All of our materials were found in the UNH SEDS shop in Kingsbury Hall S172 and the machine shop in S172. The materials that brought this experiment to life were:

* Hanging electrical cord
* Lighter
* Tennis ball
* String
* Plexiglass plates
* Tape
* Piece of wood
* Scrap ramp
* Paper
* Record player
* Voyager track

# Description of Motion

Although it might be easier to manually turn the record player on by hitting a switch like most people, but being engineers, we wanted to think of a more complicated way to do the same thing. Our device takes the act of flipping on a record player to a more extreme level, requiring pendulum motion, rigid body collisions, and rolling dynamics along a straightaway with imparting force and a ramp. The following table details each process of the machine, explaining the types of motion and energy transferred from process to process.

Table 1 - Play That Track, Ross! processes explained with the types of energy and energy transfer observed

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Step** | **Type of Motion** | **Initial Energy** | **Energy Transfer** | **Final Energy** |
| **1** | Pendulum | Potential | Gravity | Kinetic |
| **2** | Collision | Kinetic | In-Elastic Collision | Kinetic |
| **3** | Flat Path | Kinetic | Impulse from Wall | Potential/Kinetic |
| **4** | Ramp | Potential/Kinetic | Gravity | Kinetic |

The table gives a clear representation that the initial energy of the system is from the pendulum, starting at a height large enough to impart an impulse to a tennis ball, waiting for the second Step to occur, collision. Once the collision is over, the tennis ball has a momentum that carries it through the constrained path that is constantly imparting an impulse as it bounces around the walls. Once it reaches the end of the path, or the end of Step 3, it begins Step 4 that uses potential energy to continues its momentum direction toward the switch of the record, where it then collides with the switch, turning the record player on. By not assuming an elastic collision, a coefficient of restitution must be found to understand the amount of energy loss was experienced during the collision. With that and the speed of the ball at the end of the machine, a simple “work backwards” technique can be used to calculate the total amount of impulse that the wall imparted on the ball during Step 3.

# Numerical Analysis

The first stage of the Rube Goldberg machine began with pendulum motion. This motion converts potential energy to kinetic energy with the following equation:

**(1)**

That reduces to solve for the velocity of the ball right before the collision of

**(2)**

The only unknown from above is the velocity at the end of its motion before its designed collision, with which we calculated a speed of 2.4 m/s. Using a high-speed camera at this collision, we measured an actual speed of 2.1 m/s. The actual speed before the collision can then be used with the measured speed of the ball after the collision, which was 1.7 m/s, to calculate the coefficient of restitution of 0.81 using the equation

**(3)**

which redulces to

**(4)**

with the velocity at point 3 and the velocity at point 2 are the actual velocitys after and before the collision, respectively. The next motion the ball undergoes, which is through the plexi-glass casing, imparts an impulse to slow down the ball before it enters the final process of the ramp. To calculate the magnitude of this impulse, we needed to work backwards with the measured speed of the ball at the end of the ramp using a high-speed camera. A speed of 1.2 m/s was measured, meaning we can use the conservation of energy equation to predict the speed at the top of the ramp. From the same equation used with the pendulum analysis, equation 1, we calculated a ball starting speed of 1 m/s at the top of the ramp. With those values, we are able to calculate the total impulse the wall imparted on the ball through its motion in the plexiglass casing with the equation

**(5)**

With only the total impulse as the unknown, we calulcated an total impulse of 0.102 Ns.

# Observations

When the Rube Goldberg machine was first designed, we expected a loss of a lot of energy due to friction, collisions and non-ideal motion. The primary factors of energy loss were observed to be the collision between the pendulum and the ball, and the non-ideal motion of the ball while inside the plexiglass casing. This resulted in allowing us to calculate the coefficient of restitution of the collision, which was below 1 because it was inelastic, and the total impulse the wall imparted on the ball while inside the plexiglass casing by implementing high-speed cameras to calculate the parameters needed. Once the ball reached the ramp, it behaved as we predicted, slowly picking up speed as it converts its potential energy of 15 centimeters above its collision point into kinetic energy. The final event was a collision between the ball and a switch, flipping on the record player.

# Comparison of Predicted and Observed Data

The Rube Goldberg machine began with the potential energy of being set 30 centimeters above its designed collision point while it has converted all of its potential energy into kinetic energy. By analyzing this transfer of energy, we calculated a predicted speed of the pendulum right before the collision would be 2.4 m/s. With the addition of a high-speed camera measuring its location with respect to time, we witnessed an actual pendulum speed of 2.1 m/s. This details that the assumption of an ideal pendulum and accurate measurements were incorrect slightly, causing an inconsistency between the predicted and actual collision speeds.

After the collision stage, we could not assume that the collision was perfectly elastic, so making numerical predictions beyond this point would be highly prone to error. Instead, the group decided to try to calculate a value for the coefficient of restitution. This was done using a high-speed camera and measurement devices set up along the plexiglass channel that the tennis ball originally travels through. Using the camera, we calculated the speed of the pendulum just before impact and the speed of the tennis ball just after impact. Using their respective masses, we were able to find a coefficient of restitution of 0.81.

Beyond that, another source of prediction error would have been from the impulse that the tennis ball imparted on the plexiglass walls, losing momentum sporadically over its motion through the channel. We decided to try to calculate this impulse using the initial speed of the tennis ball as found above and the speed of the tennis ball at the top of the inclined ramp. Using separate measurement devices and a separate high-speed camera, we found the velocity of the ball at the end of the ramp and used an energy analysis to calculate what the velocity of the ball was before rolling down the ramp. The total impulse between the ball and the plexiglass was found to be .102 Newton Seconds.

# Summary and Conclusion

The objective of this project was to choose a simple task and create a Rube Goldberg machine to complete this task. Using our understanding of Dynamics, we were asked to analyze the dynamic motion and interaction between the systems in our device. The first system in our device was a pendulum with potential energy that was held back by a string. The second system was the impact of the pendulum with the tennis ball where the tennis ball and the impulse that it imparted on the walls of the hand-made straight. The final system was when the tennis ball rolled down a ramp to gain enough kinetic energy to turn on our record player. Here the ball was assumed to be a particle and our knowledge of particle motion was used. We measured the height of the pendulum before release and the velocity of the tennis ball, using a high-speed camera, with the record player, prior to its impact. Using these measurements, concepts of work and energy, and particle motion, we were able to calculate a coefficient of restitution of 0.81 and the total impulse .102 Newton Seconds that was imparted on the tennis ball from the walls of our hand-made straight.