Conservation of Linear Momentum Lab

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***Abstract*— Our research objective is to verify the Law of Conservation of Momentum of a system over time. We will estimate the correlation of the data point to come up with a conclusion about whether the total linear momentum is conserved in various 2D kinetic motions of the marbles.**

I. Theory

- The Law of Conservation of Linear Momentum: $\sum p = \sum mv_{initial} = \sum mv_{final}$ or $(p_{system} = m_{system}v_{CM})$. The equation suggests that the total linear momentum of a system in unchanged during collisions between multiple objects that have total mass m_{system} and center of mass velocity v_{CM}. In our experiment, we use this equation to calculate the sum of total linear momentum of all the marbles at each time frame.

II. Procedure

1) We positioned a camera around 1 meter above the surface of the floor on a flat table with large friction to capture the motion of the marbles perpendicularly to the surface where the collision happens. We used hands to hold the camera in place.
2) We positioned our marbles (weighted 226g) on a flat floor with different arrangements for different trails:
   a) For the first experiment, we rolled and collided one moving marble with a stationary marble.
   b) For the second experiment, we rolled and collided both of the marbles with the same direction but different speed.
   c) For the third experiment, we rolled and collided both of the marble in the opposite direction with positive and negative velocity respectively.
   d) For the fourth experiment, we rolled and collided one moving marble with two stationary marbles that are close together.
3) Once the person who accelerates the marbles is ready, we started to record the motion of the marbles and stop recording once the marbles lose all their momentum or out of the range where our camera can capture.

III. Data

In all four experiments, the velocity of individual marbles changed during the collision. However, the center of mass velocity was not hugely affected by the collision. Notice the speed of each of individual marble decreases as the time increase. This resulted in a trend of decreasing or increasing (depending on the net direction) net velocity of the marbles.

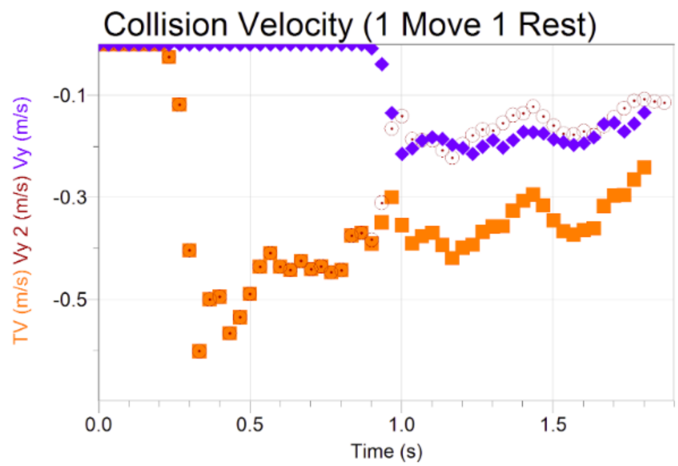

Fig. 1. The graph captured the velocity of each individual marbles as well as the total velocity. In this trial, one moving marble collided with a stationary marble. After the collision, the speed of the stationary marble increased and the speed of the moving marble decreased. The net speed decreases as time increases.

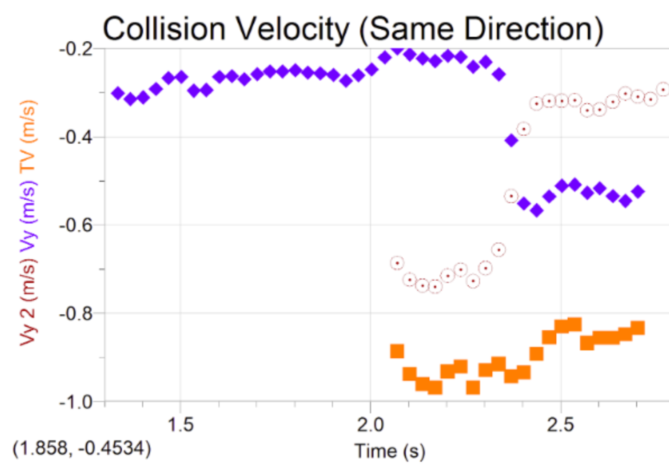

Fig. 2. The graph captured the velocity of each individual marbles as well as the total velocity. In this trail, one moving marble collided with another moving marble with lower speed. After the collision, the speed of the slowly moving marble increased and the speed of the fast-moving marble decreased. The net speed decreases as time increases.

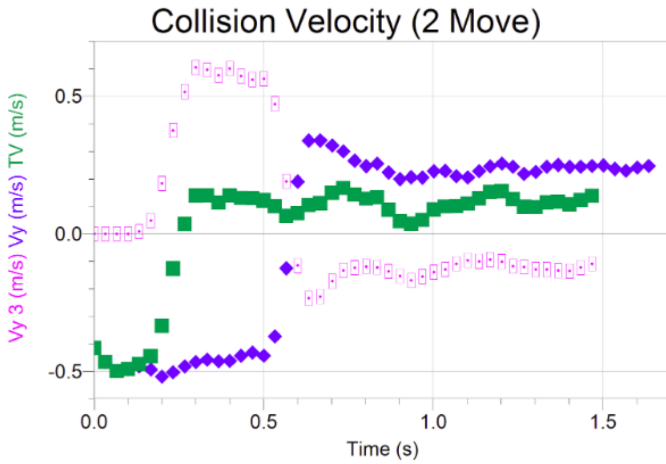

Fig. 3. The graph captured the velocity of each individual marbles as well as the total velocity. In this trail, one moving marble with a positive velocity collided with another moving marble with negative velocity. After the collision, two marbles (with the same mass) switch the velocity. The net speed decreases as time increases.

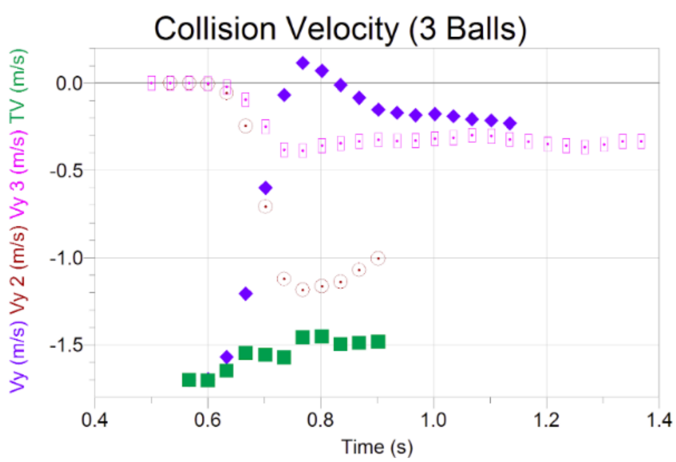

Fig. 4. The graph captured the velocity of each individual marbles as well as the total velocity. In this trail, one moving marble collided with two stationary marble. After the collision, the speed of the two stationary marbles increased and the speed of the moving marble decreased. Notice that once the moving marble's velocity increased to zero, it kept increasing for 0.025 seconds and then decreased to -0.25. The net speed decreases as time increases.

IV. Analysis

From the data above, the center of the mass velocity changes as the time increases. However, we did not observe a significant jump in the net velocity before and after the collision. The maximum difference between the net velocity 0.1 seconds before and 0.1 seconds after the collision is smaller than 0.1 m/s for all four graphs. This difference in speed can be explained by random noise in the data because the same difference exists before and after the collision. Besides, the upward trends of net velocity can be explained by sources of errors such as air resistance. These suggest that the constant change in the center of mass velocity is independent of the collision. Thus the center of mass velocity is conserved in this experiment. Because the total mass is unchanged during the process, the total momentum is conserved: $\sum p = \sum m v_{CMinitial} = \sum m v_{CMfinal}$.

V. Source of Error

There are some sources of error in our experiment:

- During the experiment, our camera may not perfectly be aliened perpendicularly with the surface where the collision happens. Besides, there may be a small movement of the camera that resulted in a random error, creating fluctuated velocity in our graph. Our experimental design minimizes the error by setting the camera on a relatively perpendicular table with big friction. A person also stabilized the camera by pressing the camera down on the table, creating even more static friction that resists the movement of the camera.
- Our method of processing the raw data may be biased. Since the pictures captured by the camera are often blurred, the location of the marbles became subjective. Thus there may be noise in the velocity as the result of imprecisely determined the exact location of the marbles. We tried to minimize the error by setting up a standard location to be used for velocity calculation: the edge of the marble along its top of the velocity vector.
- There may be a significant error in which the air resistance and the kinetic friction gradually slow down the speed of marbles. These factors resulted in a relatively constant decreases in the speed of each marble. Our experimental design tried to minimize this error by choosing smaller marbles for the experiment because they have lower air resistance.
- During the experiment, we observed that some of the marbles slipped after the collision. In our last trail, a marble changed its direction of the motion immediately after the collision and began rolling with slipping. Then, the friction between the marble and the surface of the floor provide a backward acceleration that changed its velocity back again. However, besides the force of kinetic friction provided by the environment (the floor), the phenomenon has a limited effect on the net velocity after the collision once the marble started rolling.

VI. Conclusion

In this experiment, we accomplished our research objective by verifying the Law of Conservation of Linear Momentum in the system of marbles.

We collided marbles with different motions and measured the net speed of the marbles system to verify the theory of Conservation of Linear Momentum. Although there are expected noise in our data, the continuity of the net velocity clearly suggests the conservation of the momentum. Because we observed that the change in net velocity is independent of the collision, the momentum of the system does not change due to the collision. Since total linear momentum is conserved in various 2D kinetic motions of the marbles, the Conservation of Linear Momentum is verified. Our experiment was considered successful because we verified the theory.