**Conservation of Momentum**

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**Abstract**

The theory in question in this week’s lab was a subtle one. On the surface, it was that momentum is conserved in a collision, but it was tested by measuring the displacements of the objects after the collisions. This was accomplished through the use of several equation substitutions and manipulations based on the fact that the resulting velocities are the link between the momentum before the collision and after the collision.

The results of the experiment did support the theory in question: that momentum is conserved during a collision and can be tested by comparing the distances traveled by the objects, assuming that distance traveled is a function of the object’s post-collision velocity. The results, which were evaluated through a percent difference from ideal approach, were, for the first condition: 33.5% in magnitude and 14.4% in angle, for the second condition: 41.9% in magnitude and 17.8% in angle, and for the third condition: 30.2% in magnitude, but the angle difference was not evaluated knowing that the mass difference would affect the trajectories in a less predictable manner. The % discrepancy approach could have been applied to condition 3, but the lab write-up did not call for such calculations. The standard vector that was referenced to produces these % differences was 0.470 m in magnitude and pointed straight ahead (had an angle of 0˚.

**Theory**

This experiment allowed us to test the theory that momentum is conserved in the case of a collision, through the fact that the initial velocity of on object before a collision is still implicit in the resulting velocities of objects of the same mass after the collision. This was accomplished by comparing the distances traveled by objects after colliding after falling from the same height.

Momentum is defined as being the product of an object’s mass multiplied by its velocity:

[ unit: ]

Momentum is a conserved quantity, meaning that in a closed system, the total momentum of the system will not change (under ideal conditions i.e. no friction loss, damage to the objects involved, etc.). In the case of a system involving the collision of two objects, the total momentum of the system before and after the collision will always be equal, despite any changes in velocity, which can be represented as:

[ units: kg, m/s ]

Once again, vectors were added, so the analytical procedure for summing vectors should be reviewed:

[ units: dependent on situation ]

Through various manipulations of the above equations, it becomes apparent that the distances traveled by the balls, S, can be related by:

[ units: meters, kilograms, degrees ]

Or if balls of the same mass are used:

[ units: meters, kilograms, degrees ]

Finally, experimental values were compared to accepted or expected values with a percent difference approach:

[unit: percent]

*Procedure*

This lab was conducted by staging the collision of two metallic balls at the edge of a table, the balls were then allowed to fall and strike the floor, then the displacement vectors the balls took in simple x and y coordinates relative to their starting position. The vertical distance, z, or the drop from table to floor was not measured, as it would be the same for both balls. A schematic of the entire experiment can be seen in Figure 1. Materials for the experiment included: three metallic balls (two of similar mass and one of different mass), a ramp/chute with a dimpled ledge (shaped to direct a ball straight off the table), a table on which to set the ramp, a large piece of blank paper, two smaller pieces of carbon paper, a plumb-bob for finding the position of the position of the end of the ramp relative to the paper when the ramp is on the table and the paper is on the floor, and a meter stick and protractor for measuring.

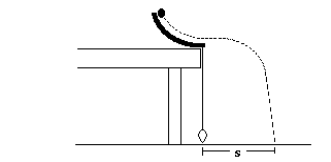


Figure 1. A side view of the experiment setup.

The first ball was given velocity by letting it roll down a small ramp, where at the end a second ball was carefully set on a very slight dimple in the ramp ledge. This small dimple aided in holding the second ball stationary while being small enough that the assumption could be made that it would not require any more than a negligible amount of energy to dislodge the ball. The dimple was offset so that the second ball would not sit directly in the path of the first ball, thus causing the balls to go in differing directions after the collision (illustrated in Figure 2). The balls were then allowed to fall where they would land on carbon paper layered over a larger sheet of normal paper to mark the impact. Displacement velocities were drawn and their angles and magnitudes were measured. It should be noted that individual trials were not measured, but rather 10 trials in each situation were conducted, and the vectors were drawn from the collision point to the visual approximation of the average impact position, as seen in figure 3.

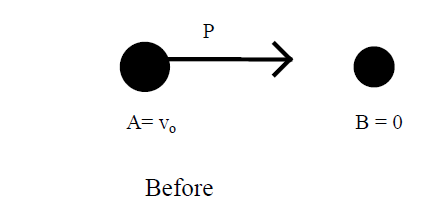
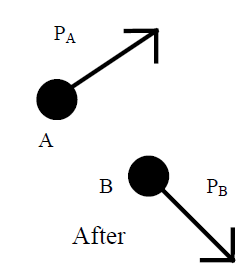
 

Figure 2. A bird’s eye view of the generalized displacement vectors of the balls before and after the collision. Note: these are not the actual vectors, just representative ones.

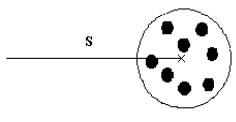


Figure 3. An illustration of the procedure for estimating the endpoints of the displacement vectors.

The reference position, or the position of the collision was indicated by marking the point on the paper directly below the end of the ramp using the plumb-bob, and a reference vector was created by letting a solitary ball run off the ramp without a collision and marking its average point of impact on the paper, labeled S. The magnitude of this vector was measured. Displacement magnitudes were measured relative to the end of the ramp and angles were measured relative to the S vector.

The experiment was conducted under three conditions: (1) with balls of equal mass and the second ball set on a dimple positioned slightly askew from the straight line path of ball 1, (2) again with balls of equal mass but with the second ball placed on a dimple slightly more askew, and (3) with balls of different mass, with the more massive of the two striking the ball of lesser mass. The trajectories were measured, and vectors were broken into components to compare them to the reference vector.

**Data**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Experiment Condition | Mass of Ball 1 (kg) | Ball 1 Displacement, S1 (m) | θ1  (˚) | S1X = S1\*cos(θ1)  (m) | S1Y = S1\*sin(θ1)  (m) |
| 1 | 0.0232 | 0.257 | 48.0 | 0.172 | 0.191 |
| 2 | 0.0232 | 0.180 | 34.0 | 0.150 | 0.101 |
| 3 | 0.0668 | 0.336 | 79.0 | 0.064 | 0.330 |
|  | Mass of Ball 2 (kg) | Ball 2 Displacement, S2 (m) | θ2  (˚) | S2X = S2\*cos(θ2)  (m) | S2Y = S2\*sin(θ2)  (m) |
| 1 | 0.0232 | 0.245 | -55.0 | 0.141 | -0.201 |
| 2 | 0.0232 | 0.399 | -72.0 | 0.123 | -0.380 |
| 3 | 0.0232 | 0.512 | -59.0 | 0.264 | -0.439 |

Table 1. Data relating to each ball and its displacement for each experiment condition.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Experiment Condition | S  (m) | θ1 + θ2  (˚) | S1X + S2X (m) | S1Y + S2Y (m) | % Difference between S and S1X + S2X  (%) | % Difference between  |θ1 + θ2 |  and 90˚  (%) |
| 1 | 0.470 | -7.0 | 0.313 | -0.010 | 33.5 | 14.4 |
| 2 | 0.470 | -38.0 | 0.273 | -0.279 | 41.9 | 17.8 |
| 3 | 0.470 | 20.0 | 0.328 | -0.109 | 30.2 | - |

Table 2. Data and calculated values for the experiment. The angle % difference was not valid for condition 3, the resulting angle between vectors should theoretically be something other than 90 degrees due to the differing masses of the balls.

**Computations**

Computations were performed through the use of Microsoft Excel. Sample calculations are as follows:

Vector components were used to compare the resulting momenta of the balls to that of the first ball before the collision, as seen here using data from the first ball of experiment condition one:

48.0˚)

.172 m

Magnitudes of the experimental values for the momenta could be compared to the theoretical value in this manner (data from experiment condition 1):

\*Note, for this computation, the Y components were assumed to sum to zero (as represented in the second equation), because theoretically they would, and the testing of this theory depends on utilizing the sums of the x components. This sheds some light on how error found its way into the results - the resultant vectors after the collision did not behave as predictably as expected.

Percent difference was used to compare summed values to accepted ones, such as the sum of resultant vector components and the standard vector:

*Uncertainty*

This week, the uncertainty section assignment was to define accuracy and precision, and identify examples of each from previous labs.

*Precision* is a measure of how finely a measuring device can report results, and further, how reproducible those results are. Higher levels of precision mean smaller increments of measurement and tighter clusters of results when measuring the same object or event.

*Accuracy* is a measure of proximity of measured values to the actual value the measurement is attempting to describe. Higher levels of accuracy mean smaller differences between the measured value and the true value.

Accuracy and precision are not interchangeable. A measurement device or procedure may produce superior precision, but if it introduces a large amount of bias, or fails to measure the desired quantity, it is not accurate. However, according to some definitions, if a measuring tool produces measurements for which the average is near the true value being measured, it is considered accurate. Precision may enhance a measuring device’s accuracy if the measurements were already near (or averaged to) the true value of the quantity measured.

Examples of accuracy and precision can be drawn from the previous lab, The Scalar Product. In that lab, work performed using the conservative force of a spring over a closed path was measured. The true value for the work done was known – no net work was done by the spring – and component quantities were measured using simple implements: a meter stick for distance, a protractor for angles, and a spring scale to both provide and measure the force. Each of these measuring devices had differing levels of precision in terms of finer increments of units measured, the meter stick had the highest precision, and the spring scale had the least. When evaluating precision in terms of measurement reproducibility, the ranking followed the same order: the meter stick had the best reproducibility, and the spring scale had the least reproducibility. This was due, in part, to the size of the incrementing of measurements, but also to variability in the measuring devices. The in this experiment, the meter stick and protractor could likely be considered accurate, because their measurements did sum to zero (a.k.a. a closed path), indicating that their measurements, or at least their average measurements, were good at ascertaining the true values, distance and angle, respectively. The spring scale, however, was not accurate, as the total force did not sum to zero (again, the forces applied by a conservative force over a closed path sum to zero), meaning this device was not as effective as might be desired at measuring the true value of force applied.

**Results**

Data and results of the experiment can be found in Tables 1-3, results of interest are found in Table 3.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Experiment Condition | S  (m) | Ball 1 Displacement, S1  (m) | θ1  (˚) | Ball 2 Displacement, S2  (m) | θ2  (˚) | % Difference between S and S1X + S2X  (%) | % Difference between  |θ1|+ |θ2|  and 90˚  (%) |
| 1 | 0.470 | 0.257 | 48.0 | 0.245 | -55.0 | 33.5 | 14.4 |
| 2 | 0.470 | 0.180 | 34.0 | 0.399 | -72.0 | 41.9 | 17.8 |
| 3 | 0.470 | 0.336 | 79.0 | 0.512 | -59.0 | 30.2 | - |

Table 3: A summary of the results of interest of the experiment.

The results of the experiment did support the theory in question: that momentum is conserved during a collision and can be tested by comparing the distances traveled by the objects, assuming that distance traveled is a function of the object’s post-collision velocity. The results, which were evaluated through a percent difference from ideal approach, were, for the first condition: 33.5% in magnitude and 14.4% in angle, for the second condition: 41.9% in magnitude and 17.8% in angle, and for the third condition: 30.2% in magnitude, but the angle difference was not evaluated knowing that the mass difference would affect the trajectories in a less predictable manner. The % discrepancy approach could have been applied to condition 3, but the lab write-up did not call for such calculations.

*Discussion*

This experiment tested the theory that momentum is conserved, and can be measured without directly measuring velocity, but rather by utilizing crafty substitutions and manipulations of equations. This was done by staging collisions between balls at the edge of a table and allowing the balls to fall to the floor. Their displacement vectors in the xy-plane were measured, and these distances and angles were used to evaluate if the experiment supported the theory in question. Again, the results were: for the second condition: 41.9% in magnitude and 17.8% in angle, and for the third condition: 30.2% in magnitude.

The results of this lab did support the theory in question. The percent errors were certainly larger than might be desired, but they were in an acceptable range, and it was evident that the balls did travel in directions that were at approximately a right angle directions. It is also feasible, based on this data, that the x-component of the post-collision vectors were nearly the same magnitude of the standard vector The method of approximation we used likely diluted the quality of the data, not necessarily evaluating collision by collision, which may have yielded better results. It is interesting to note that the sums of the resulting vector magnitudes were very close to the standard vector S, but it would be mathematically incorrect to make this comparison. Also interesting, is that in the third condition (one heavy and one light ball) the sum of the x components was actually larger than the standard vector. This demonstrates that the intrinsic properties of the balls (i.e. how they roll, how elastic they are, how well they can strike each other when they collide) was a factor that would have been a good topic to address in this lab.

Sources of error in this experiment were, for the most part, due to the types of balls used. The less massive balls I used were certainly lighter and smaller, and I believe this prevented them from making as good of a collision as they could have, especially when the second ball was placed on the second, more askew dimple. Also, the lighter balls had many flattened spots. I am unsure whether these flattened areas were a result of how the balls were manufactured or if they were signs of damage from collisions. I would hypothesize that the flat spots were dents, because the collisions did not seem to be as elastic as might be expected. The flat spots also likely impeded the way the ball was dislodged from the dimple or how the ball rolled down the chute. Another source of error was the estimation of the average landing points of the balls by visual approximation. This method of approximation was not scientific enough to really ensure that an accurate vector would be drawn. Otherwise, I believe there were relatively few sources of error, other than possible errors in measurement (which is unlikely, meter sticks and protractors are generally considered reliable).