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Investigating the Change in the Impulse of a Falling Metal Ball on a Glass Slide with Change in Height

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Abstract—*When a metal ball bounces after hitting a rigid surface, there is an obvious change in the momentum of the ball. (the direction of the velocity is reversed) The change in momentum suggests that the ball exerts an impulse on the surface of the rigid material that it hits. In the following research, change in impulse exerted by a 6.4g metal ball hitting a glass slide at different velocities is investigated. The ball was dropped from different heights such that it hit the surface of the glass at different velocities. The data points for the different heights were spread uniformly between the maximum height (at which the glass slide breaks) and the minimum height (the least height that gives sufficient rebound height to the ball to be recorded). The velocity of the ball just before and after hitting the glass slide was calculated using the tracker software. Using the Law of Conversation of kinetic and potential energy and using the Impulse-Momentum Theorem,* $J^2 = 8m^2gh$ *was derived. After this* $J^2 vs\ h$ *graph was plotted, and the slope was equated with the value of g. The value of g came out to be 9.7656*N/m^2 *indicating that the hypothesis is correct.*

1. INTRODUCTION

The Impulse-Momentum Theorem states that :

$$F = \frac{\Delta p}{\Delta t}$$

This implies that –

$$\Delta p = F \times \Delta t$$

Since, $F = ma$, where $a = \frac{\Delta v}{\Delta t}$;

$$J = \left(m \times \frac{\Delta v}{\Delta t}\right) \times \Delta t$$

$$J = m \times \Delta v$$

$$J = m(v - u)$$

Thus, the velocity of the ball before and after it hits the glass slide could be used to calculate the momentum. The collision was assumed to an elastic collision, implying that $(v = -u)$. This resulted in:

$$J = -2mu \qquad (1)$$

On the other hand, the Law of conservation of mechanical energy states that the total mechanical energy of a freely dropping body would be conserved, i.e., the sum of potential and kinetic energy would be a constant. At the release height of the ball, the potential energy would be mgh_{max}, while the kinetic energy would be 0 since the ball is at rest. When the ball is just about to hit the glass slide, the potential energy of the ball can be assumed to be 0, while the kinetic energy would be $\frac{1}{2}mu^2$, where u is the velocity of the ball before hitting the glass slide. The Law of conservation of momentum states that these two energies would be equal, ignoring the energy lost in overcoming the air resistance. Mathematically:

$$mgh_{max} = \frac{1}{2}mu^2 \qquad (2)$$

Thus, $u = \sqrt{2gh_{max}}$. Substituting this in Eq. 1, we get:

$$J = -2m\sqrt{2gh_{max}}$$

Squaring both sides, we get-

$$J^2 = 8m^2gh_{max}$$

where h_{max} refers to the release height of the ball.

Thus, the hypothesis statesthat the graph $J^2 vs h_{max}$ should give a straight-line graph through the origin, where the value of slope should be equal to $8m^2g$.

2. METHODOLOGY

To determine h_{max}(the release-height), the velocity of the ball just before hitting the glass had to be recorded, since:

$h_{max} = \frac{u^2}{2g}$ from Eq. 2. The value of g was used as $9.7N$ in the equation. The velocity before impact was recorded by shooting a high-frame per second video (240fps) through a Go-Pro Camera and analyzing the video in the Tracker Software.

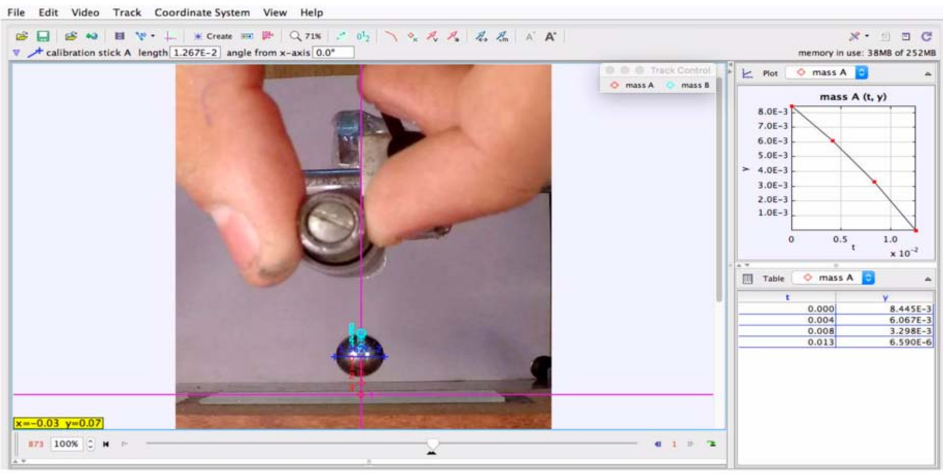

Figure 1: Screenshot from Tracker analysis of the ball's position vs time for velocity before and after hitting the slide.

As can be seen from the tracker analysis screenshot, the experimental setup consists of a strew gauge which was held by a clamp. This gauge was used as a ball-dropping mechanism, in order to ensure that the ball was dropped with zero initial velocity (zero kinetic energy). The $position vs. time$graph of the ball just before it hit the slide, helped determine$u$, which in turn determined h_{max}, the release-height.

The ball was released from 12 different height, and five times from each height. The data are summarized below –

Table 1: Data from Tracker analysis of the ball's velocity before and after hitting the slide.

	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
S. no	**Velocity before collision (ms-1)**	**Velocity after collision (ms-1)**	**Velocity before collision (ms-1)**	**Velocity after collision (ms-1)**	**Velocity before collision (ms-1)**	**Velocity after collision (ms-1)**	**Velocity before collision (ms-1)**	**Velocity after collision (ms-1)**	**Velocity before collision (ms-1)**	**Velocity after collision (ms-1)**
1	-0.7129	0.2422	-0.7366	0.2585	-0.7317	0.2457	-0.7198	0.2336	-0.7214	0.2483
2	-1.0783	0.3815	-1.0604	0.3926	-1.0201	0.3702	-1.067	0.3906	-1.0908	0.3801
3	-1.3347	0.4666	-1.3434	0.4627	-1.389	0.4584	-1.3209	0.4737	-1.3504	0.4523
4	-1.4547	0.4905	-1.4223	0.4898	-1.424	0.4978	-1.4694	0.4886	-1.4571	0.493
5	-1.4976	0.5304	-1.5014	0.5467	-1.4807	0.5599	-1.4968	0.5324	-1.4961	0.5489
6	-1.5459	0.6515	-1.5309	0.6496	-1.5496	0.6519	-1.5223	0.6635	-1.533	0.6402
7	-1.5615	0.7002	-1.5631	0.7214	-1.5852	0.7128	-1.5737	0.7029	-1.5644	0.7186
8	-1.6566	0.8131	-1.6477	0.8196	-1.6611	0.8067	-1.6467	0.8222	-1.6575	0.8072
9	-1.878	0.8598	-1.8613	0.8401	-1.8727	0.8525	-1.861	0.8632	-1.8771	0.8541
10	-1.989	0.9367	-1.9748	0.9327	-1.9964	0.9395	-1.9804	0.945	-1.9853	0.9367
11	-2.0755	1.0091	-2.0602	1.0005	-2.0827	1.0057	-2.0948	1.0144	-2.0698	1.0035

3. RESULTS AND DISCUSSION

This data discussed in the previous section was processed using the hypothesis to calculate the release height h_{max}, the impulse exerted, and the impulse squared. The following table summarizes the processed data-

	Drop Height (m)	Velocity before collision (ms^{-1})	Velocity after collision (ms^{-1})	Impulse(Nm)	Impulse squared (N^2m^2)
1	0.027	-0.724	0.246	0.008	0.00007
2	0.058	-1.063	0.383	0.012	0.00015
3	0.093	-1.348	0.463	0.015	0.00023
4	0.107	-1.446	0.492	0.016	0.00026
5	0.114	-1.495	0.544	0.017	0.00029
6	0.120	-1.536	0.651	0.018	0.00034
7	0.126	-1.570	0.711	0.019	0.00037
8	0.140	-1.654	0.814	0.021	0.00043
9	0.178	-1.870	0.854	0.023	0.00052
10	0.201	-1.985	0.938	0.025	0.00060
11	0.220	-2.077	1.007	0.026	0.00067

Using the processed data, $J^2 vs. h$ graph was plotted:

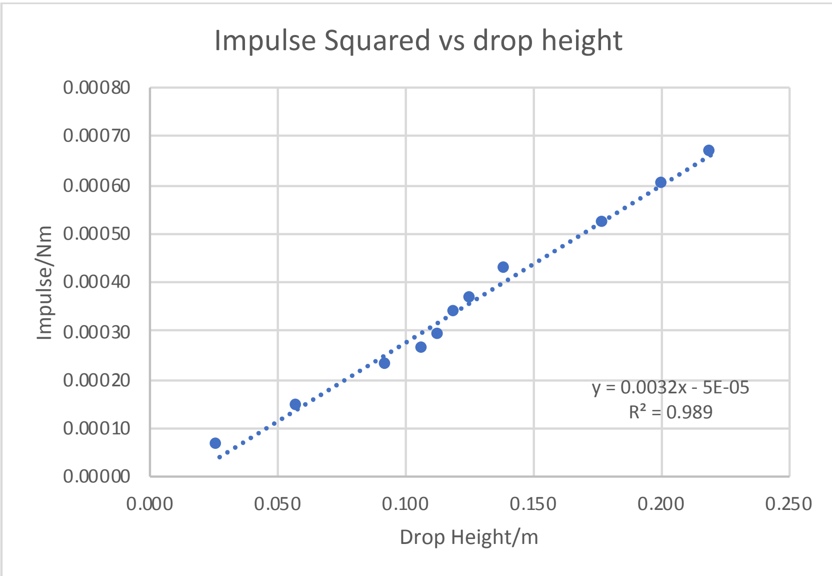

Figure 2: Impulse squared vs drop height

The slope was found to be 0.0032, and the R^2 value was found to be 0.989, suggesting a good linear fit. Using the value of slope to verify the hypothesis, the value of the gravitational force on earth was calculated.

$$slope = 8m^2g$$

$$0.0032 = 8 \times (0.0064)^2 \times g$$

$$g = 9.7656N$$

4. CONCLUSION

As the value was of g was verified with reasonable accuracy, it can be stated that the proposed hypothesis is correct. Hence, it is proved that the$impulse^2$ by a falling metal ball on a glass slide increases proportionately with height. It is also confirmed that the metal ball suffers an elastic collision on hitting the glass slide.

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