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Effect of the Angle of the Ramp on the Coefficient of Restitution

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Keywords

Angle of the Ramp, Coefficient of Restitution, Collision, Energy Loss, Hollow Tube.

Abstract

Choosing an angle of 20°, 25°, 30°, 35°, 40°, or 45° for the hollow tube was driven by the need to study how various angles affected the energy loss and coefficient of restitution in a collision between two similar spheres. We chose these angles because they cover a wide range of values that might have a major impact on the dynamics of the collision. When two similar spheres collide, the mechanics of the collision can be better understood by looking at how the energy loss and coefficient of restitution relate to the angle of a hollow tube. Because understanding collision behavior is critical when building and developing systems, this has practical applications in fields like physics and engineering.

1. Background Information

Equation 1:

$$v = \frac{d}{t}$$

Where,
t= time (seconds)
d= distance (meters)
v= velocity (m/s)

Kinetic energy is the energy that an object possesses due to its motion. This energy is calculated by figuring out how much work it would take to get the object moving from a standstill to its current speed, based on its weight. Kinetic energy doesn't have a direction, it's just a measurement of how much energy the object has due to its motion.[1]

[1]"Kinetic and Potential Energy." *Department of Chemistry – College of Letters & Science – UW–Madison*, www2.chem.wisc.edu/deptfiles/genchem/netorial/modules/thermodynamics/energy/energy2.htm. Accessed 8 Apr. 2023.

Equation 2:

$$KE = \frac{1}{2}m * v^2$$

Where,
KE= kinetic energy (joules)
m= mass (grams)
v= velocity (m/s)

An **elastic collision** refers to a scenario in which the total kinetic energy of colliding objects remains constant. In other words, the energy is conserved throughout the collision process, with no loss to other forms of energy. Conversely, an **inelastic collision** involves a transformation of kinetic energy into other forms, leading to a reduction in the total kinetic energy of the system[2].

The **coefficient of restitution** (COR) is a useful measure of the elasticity of a collision between two objects. It is a dimensionless number that describes the ratio of the relative velocity of separation to the relative velocity of impact. A value of 1 implies that the collision is perfectly elastic, meaning that no kinetic energy is lost during the collision. On the other hand, a value less than 1 suggests an inelastic collision, where some kinetic energy is transformed into other forms of energy. It's worth noting that a value greater than 1 isn't feasible in real-world scenarios and would imply a super elastic collision.[3]

[2]"What Are Elastic and Inelastic Collisions? (article)." *Khan Academy*, www.khanacademy.org/science/physics/linear-momentum/elastic-and-inelastic-collisions/a/what-are-elastic-and-inelastic-collisions. Accessed 8 Apr. 2023.

[3]"Coefficient Of Restitution: Definition, Explanation And Formula." *Science ABC*, 9 July 2022, www.scienceabc.com/pure-sciences/coefficient-of-restitution-definition-explanation-and-formula.html. Accessed 8 Apr. 2023.

Equation 3:

$$\text{coefficient of restitution} = \sqrt{\frac{\frac{1}{2}mv^2}{\frac{1}{2}mu^2}}$$

Where,
m= mass of the spheres (grams)
v= final velocity (m/s): after collision
u= initial velocity (m/s): before collision

Equation 4:

Kinetic Energy Conservation Equation when two bodies collide:

$$\frac{1}{2}m_a * v^2{}_a + \frac{1}{2}m_b * v^2{}_b = \frac{1}{2}m_a * v'^2{}_a + \frac{1}{2}m_b * v'^2{}_b$$

There is no change is total momentum, momentum is always conserved. When a ball collides with another, the momentum is transferred. [4]

Therefore,

$$\text{Intial Kinetic Energy} - \text{Final Kinetic Energy} = \text{Energy Loss}$$

2. Hypothesis

Experimental Hypothesis: As the angle of the pipe increases the coefficient of restitution increases.

Null Hypothesis: As the angle of the pipe increases the coefficient of restitution stays constant

[4]"Conservation of Momentum." *IIS Windows Server*, labman.phys.utk.edu/phys221core/modules/m5/conservation_of_momentum.html. Accessed 8 Apr. 2023.

Second Experimental Hypothesis: As the angle of the pipe increases the energy loss decrease.

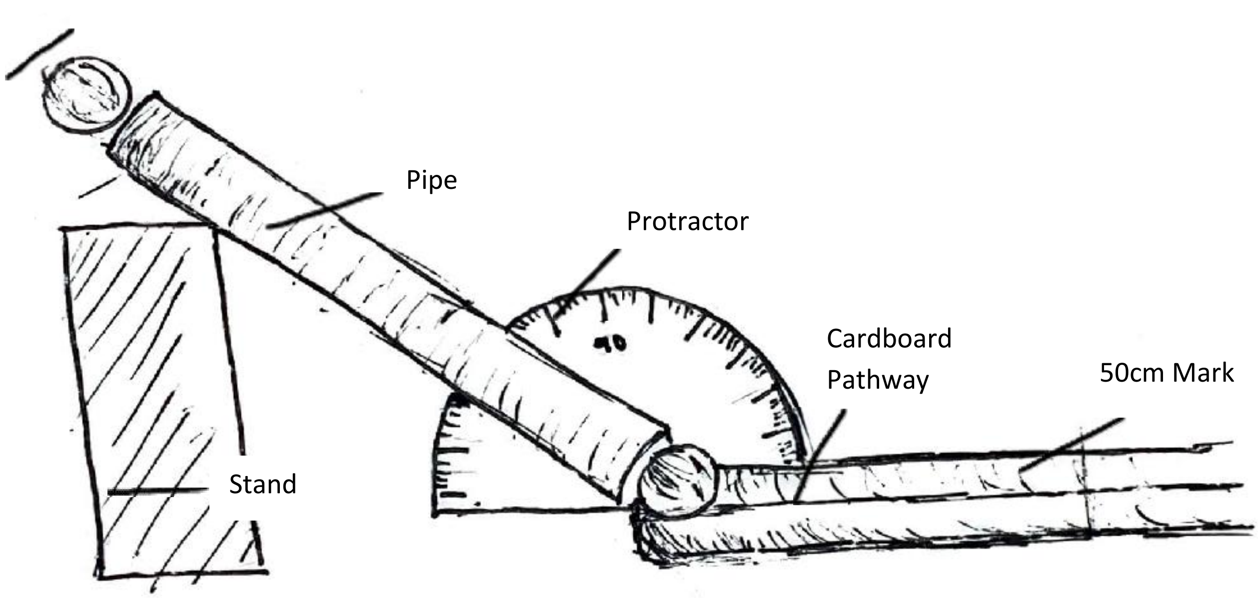
Null Hypothesis: As the angle of the pipe increases the energy loss stays constant

Variables

Independent Variable	Angle of the pipe(20°, 25°, 30°, 35°, 40°, 45°)
Dependent Variable	Coefficient of Restitution

Controlled variable	How is it controlled	Why it is controlled
Mass of both themetal balls	Taking metal spheres of the same material and diameter, and measured with weigh scale to check if the mass is equal	Mass effects the total momentum. Therefore, keeping it constant will allow us to calculate the accurate energy loss.
Length of the plastic pipe	The same pipe is used for all the trials and angles	Initial K.E is affected by the distance of the pipe.
Diameter of the metal spheres	Vernier Calliper was used to ensure both of the spheres are equal	A change in the diameter could affect the results
Distance after collision	The carboard pathway was marked at the 50cm marked	To reduce uncertainty, an alternate to measuring both distance and time taken for the sphere
Diameter of the Pipe	The pipe was kept constant	Increasing the length of the pipe would affect the results
Distance between the spheres	The sphere was released from the end of the pipe and the second sphere was placed at the end of the pipe	Changing the distance of the pipe would affect the speed gained by the sphere, affecting the overall values, and producing inaccurate values.

Diagram (Apparatus Set Up)



Apparatus

Apparatus	Quantity	Uncertainty	Type of apparatus
Camera	1	-	Digital
Plastic Pipe	1	±0.1%	-
Cardboard Pathway	1	-	-
Weigh balance	1	±0.05 grams	Digital
Metal Bobs	2	-	-
Measuring Tape	1	±0.05 cm	Analogue
Protractor	1	±0.5°	Analogue
Marker	1	-	-
Vernier Calliper	1	±0.001 cm	Analogue
Tracker Software	1	-	Digital

Preliminary Trials:

- Initially tennis balls were used, but due to its light weight and size it made it inefficient for the procedure, so I switched to metal bobs.
- A ruler was used to push the metal bob across but was then substituted with a plastic pipe when the ball kept rolling off.
- When the metal bob reached the bottom, after colliding they would move to various other directions making it difficult to measure the distance, a plastic pipe was then cut into half so that the metal bobs can move across it after colliding.
- The half cut piped was circular and would affect the results, so a cardboard pathway was made
- I was initially measuring the distance and the time taken for both the spheres to stop, due to the high uncertainty and inefficiency I made the distance an independent variable.

3. Method

1. Measure the mass of both of the spheres to assure that they are equal
2. Measure the length of the pipe
3. Place a cardboard frame and measure 50cm and mark it
4. Mark the place from which the uncut pipe starts and make sure it does not move
5. Use protractor to measure 20° from the ground to the bottom of pipe
6. Start recording using a camera
7. Drop the bob from the top of the pipe
8. Measure the time it takes to cross the 50 cm mark
9. Repeat the same for all 6 angles taking 3 trial each to reduce random uncertainty
10. Using a tracker, track the time it takes for the bob to reach the bottom for initial velocity and the time it take for it to cross the 50 cm mark from the ending of the pipe.

Raw data

Angle	Time before collision (Seconds)	Time after collision (Seconds)
20°	0.8	1.835
	0.867	1.968
	0.933	2.035
25°	0.635	1.233
	0.635	1.267
	0.667	1.435
30°	0.633	1.1
	0.633	1.02
	0.633	1.135
35°	0.567	0.800
	0.468	0.800
	0.502	0.833
40°	0.467	0.767
	0.467	0.802
	0.467	0.835
45°	0.400	0.768
	0.400	0.788
	0.435	0.800

Processed data

Angle	Trial	Time before collision	Velocity before collision	KE before collision	Time after collision	Velocity after collision	KE after collision	Coefficient of Restitution	Energy Loss
20°	1	0.800	0.572	0.0111	1.835	0.272	0.0025	0.474579	0.0086
	2	0.867	0.527	0.0094	1.968	0.254	0.0022	0.48377945	0.0072
	3	0.933	0.490	0.0082	2.035	0.246	0.0021	0.50606083	0.0061
25°	1	0.635	0.720	0.0176	1.233	0.406	0.0056	0.56407607	0.012
	2	0.635	0.720	0.0176	1.267	0.395	0.0053	0.54875893	0.0123
	3	0.667	0.685	0.0160	1.435	0.348	0.0041	0.50621142	0.0119
30°	1	0.633	0.722	0.0177	1.100	0.455	0.0070	0.62887219	0.0107
	2	0.633	0.722	0.0177	1.020	0.490	0.0082	0.68064443	0.0095
	3	0.633	0.722	0.0177	1.135	0.441	0.0066	0.61064012	0.0111
35°	1	0.567	0.806	0.0221	0.800	0.625	0.0133	0.77576411	0.0088
	2	0.468	0.977	0.0325	0.800	0.625	0.0133	0.63971147	0.0192
	3	0.502	0.911	0.0282	0.833	0.600	0.0122	0.65774168	0.016
40°	1	0.467	0.979	0.0326	0.767	0.652	0.0145	0.66692224	0.0181
	2	0.467	0.979	0.0326	0.802	0.623	0.0132	0.6363238	0.0194
	3	0.467	0.979	0.0326	0.835	0.599	0.0122	0.61174597	0.0204
45°	1	0.400	1.143	0.0444	0.768	0.651	0.0144	0.5694948	0.03
	2	0.400	1.143	0.0444	0.788	0.635	0.0137	0.55548048	0.0307
	3	0.435	1.051	0.0376	0.800	0.625	0.0133	0.5947465	0.0243

Example Calculation

Pipe: 0.4572 m,
Length: 0.5 m,
Ball mass: 0.068 kg,
Time Before collision: 0.800,
Time After collision: 1.835

Initial Velocity = $\frac{0.4572}{0.800}$ = 0.5715

Final Velocity = $\frac{0.5}{1.835}$ = 0.2724796

Initial Kinetic Energy = $\frac{1}{2} \times 0.068 \times 0.5715^2$ = 0.0111

Final Kinetic Energy = $\frac{1}{2} \times 0.068 \times 0.272^2$ = 0.0025

Coefficient of restitution = $\sqrt{\frac{0.0025}{0.0111}}$ = 0.474579

Energy Loss = 0.0111- 0.0025= 0.0086

Uncertainty = $\sqrt{[\Sigma(xi - \bar{x})^2/(n - 1)]}$

Mean COR = (0.474579 + 0.48377945 + 0.50606083) / 3 = 0.488473

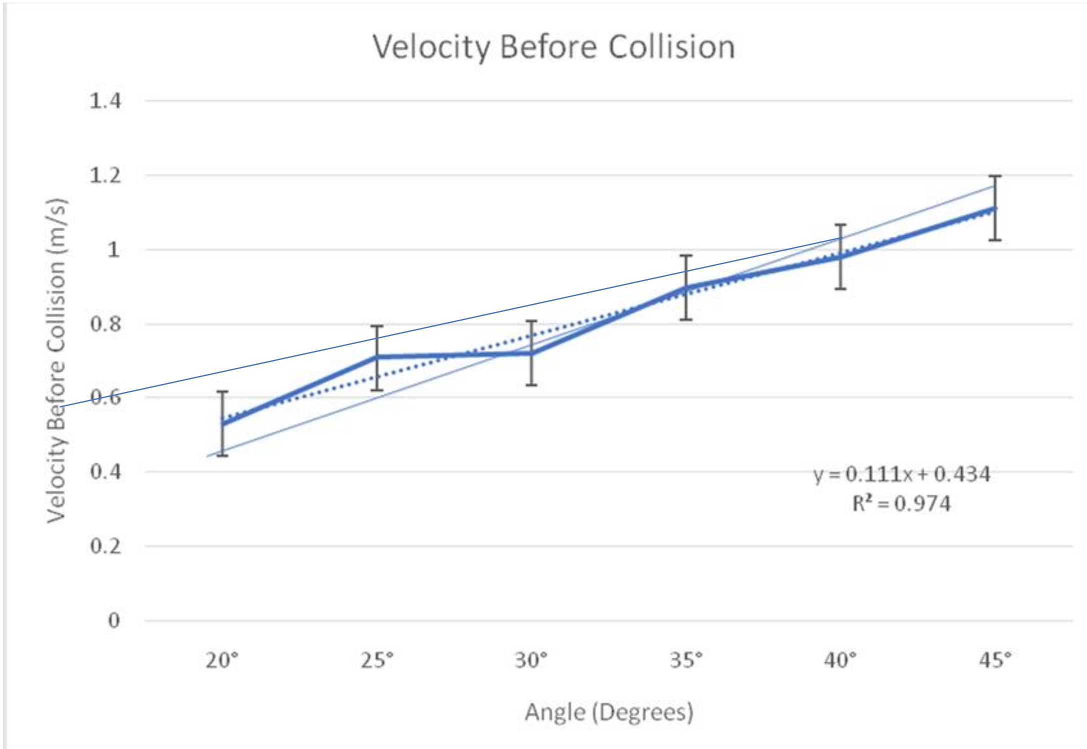
σ=

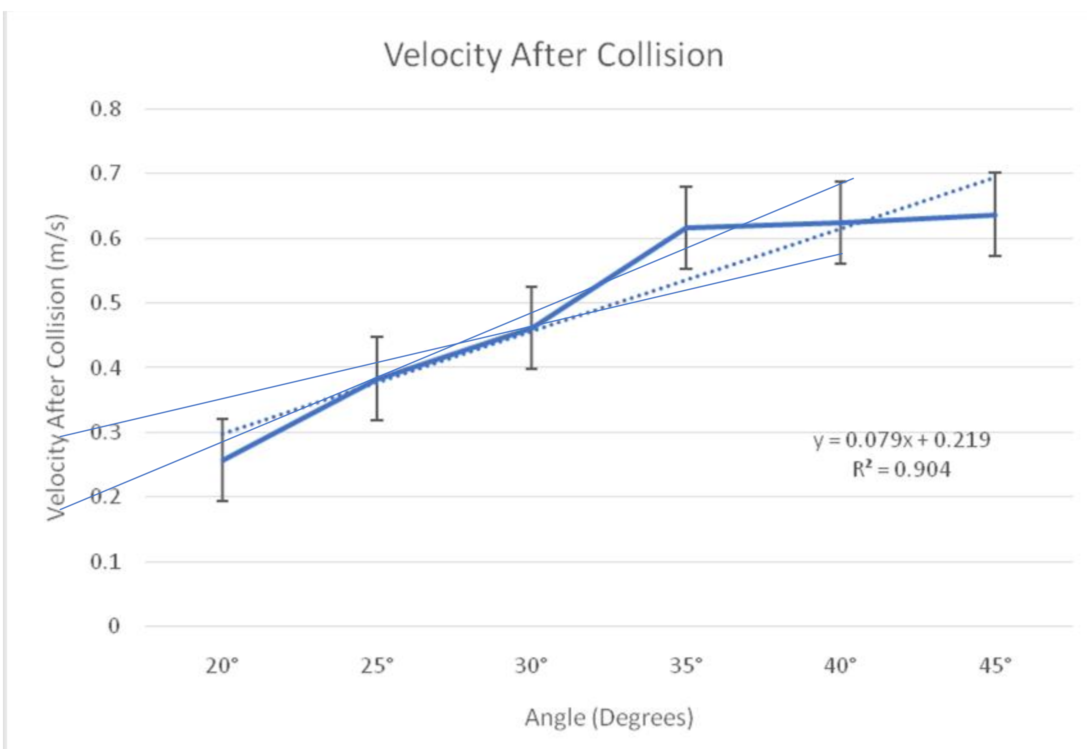
$\sqrt{[(0.474579 - 0.438473)^2 + (0.48377945 - 0.488473)^2 + (0.50606083 - 0.483473)^2 / (3 - 1)]}$
 = 0.015558

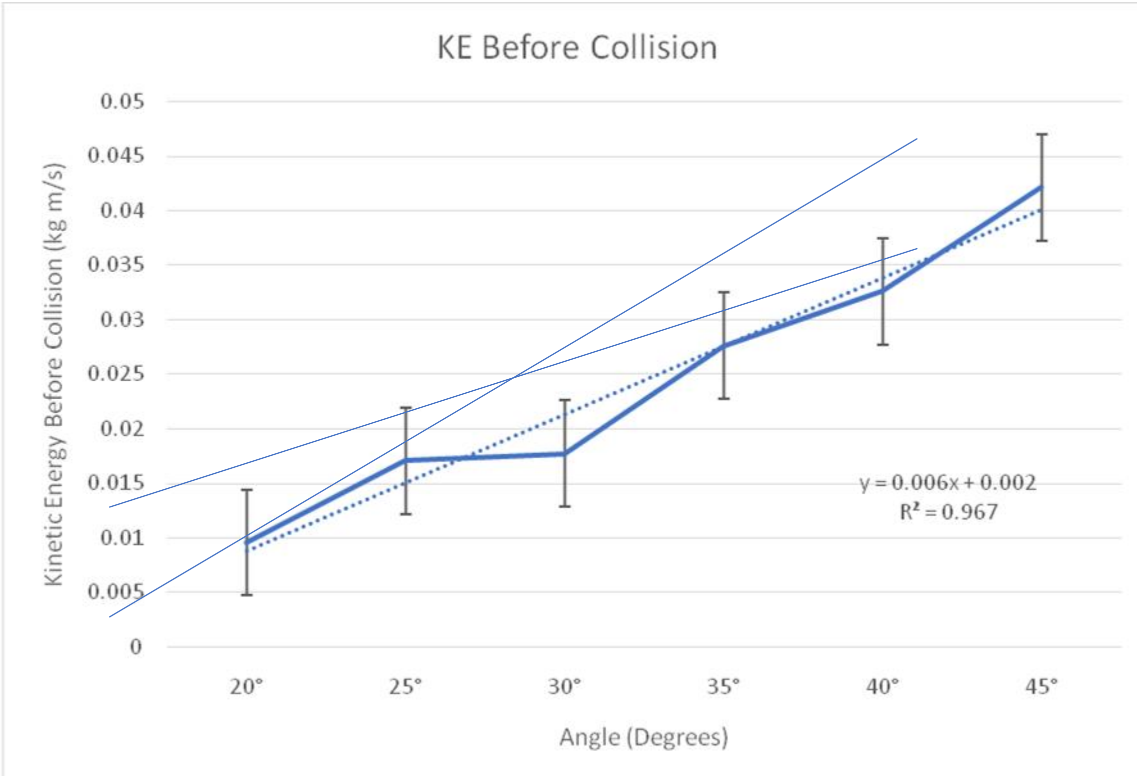
Graphs

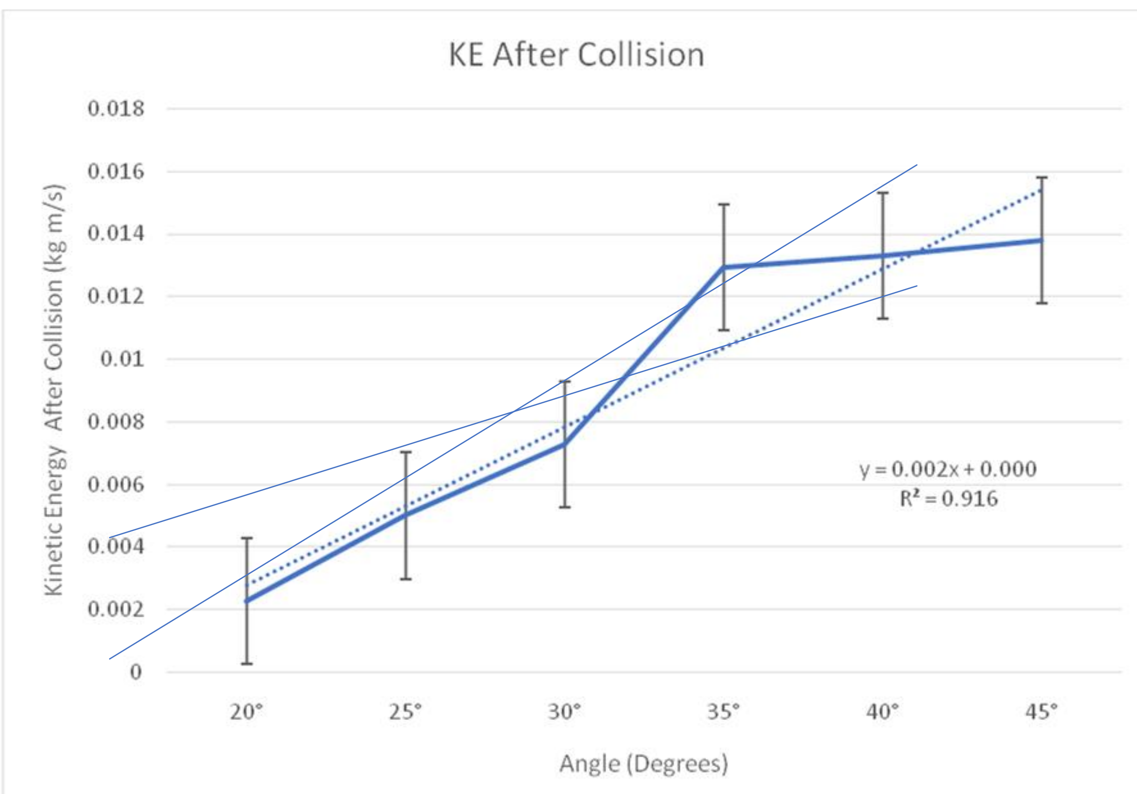
The average of the trials for the following variables were taken to show the relation between the angle and its effect on various factors.

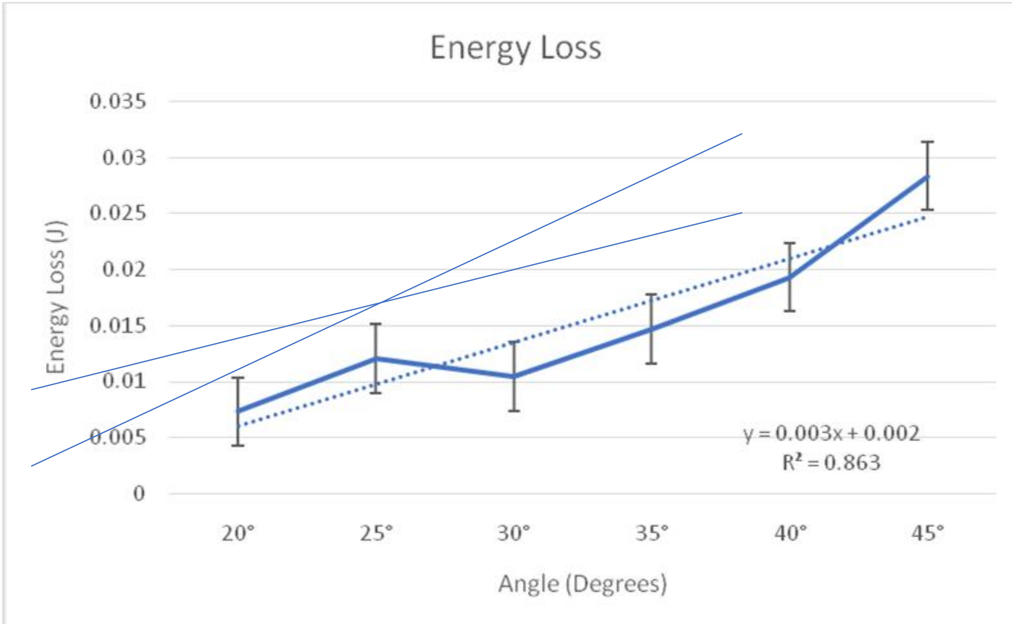
Average= Sum of trials/Number of trials

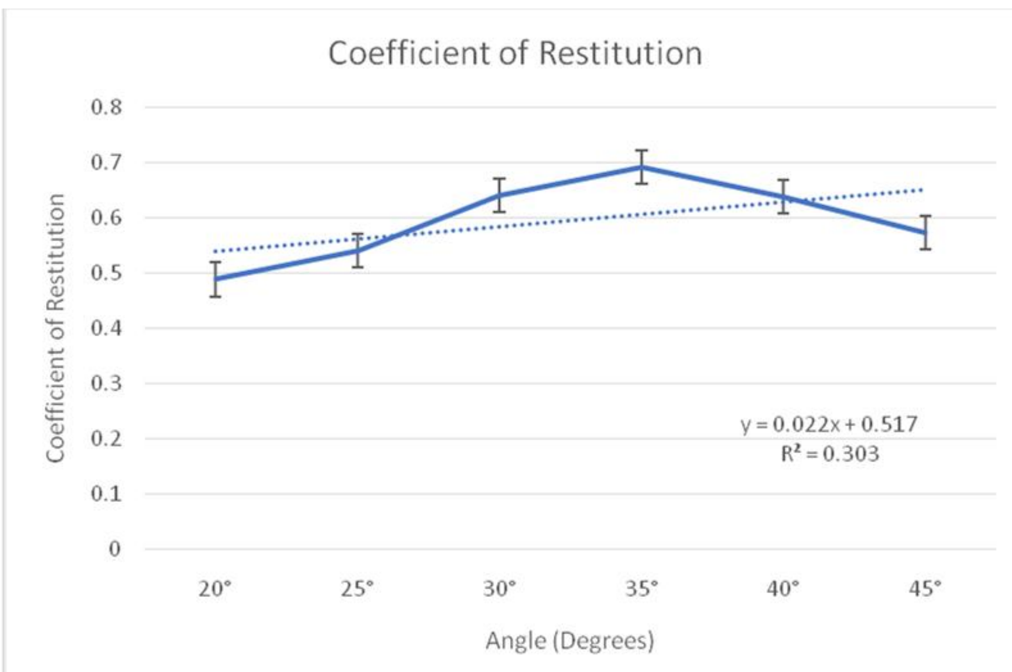





KE Before Collision
Kinetic Energy Before Collision (kg m/s)
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
20°
25°
30°
35°
40°
45°
Angle (Degrees)
y = 0.006x + 0.002
R² = 0.967


KE After Collision
Kinetic Energy After Collision (kg m/s)
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
20°
25°
30°
35°
40°
45°
Angle (Degrees)
y = 0.002x + 0.000
R² = 0.916





Analysis

According to the results, when the angle of the hollow tube increases, the energy loss grows and the coefficient of restitution shrinks. If the coefficient of restitution is large, then the spheres were able to keep more of their collision-induced kinetic energy. The data demonstrates that the coefficient of restitution decreases with increasing angle of the hollow tube. As an example, the spheres retain less kinetic energy following a collision at higher angles, as the coefficient of restitution decreases from 0.64 at 30° to 0.573 at 45°.The data also reveals that the energy loss grows with increasing hollow tube angle. Collisions at higher angles result in more energy loss; for instance, at 45°, the loss goes up from 0.0073 at 20° to 0.028.Additionally, the highly significant R-squared value of 0.9748 for Velocity Before impact suggests a robust relationship between the angle of the hollow tube and the velocity prior to impact. In a similar vein, the velocity after contact has a rather high R-squared value of 0.9046, indicating a strong association with the hollow tube angle. In addition, the high R-squared values of 0.9671 for KE Before Collision and 0.9169 for KE After Collision show that the kinetic energy before and after the collision are strongly correlated with the angle of the hollow tube.

Evaluation

Environmental factors, such as humidity and temperature, can have a major influence on collision energy loss and coefficient of restitution. Consequently, it is of the utmost importance to minimize their influence during tests. The experiment can be carried out in a controlled environment with consistent humidity and temperature to accomplish this. When the weather is unpredictable, you can control the temperature and humidity with the help of sensors. The collision's outcome can also be affected by airborne particles or changes in air pressure. Experimentation should take place in a dust-free, clean room with constant air pressure to reduce the impact of these variables. Proper safety precautions, such as donning protective gear and firmly securing the hollow tube, should also be put in place to guarantee safety and avoid equipment damage or personal injury. Lastly, it is important to follow good environmental practices by recycling or reusing the plastic pipe appropriately.

Strengths of Experiment	Impact and significance
Multiple trials were taken	To reduce random error and improve the accuracy.

Problem Identified	Impact and significance	How it can be overcome
Pressure at which the metal ball was pushed across the plastic pipe	If the ball is pushed with high amounts of pressure, it will affect the initial velocity therefore giving inaccurate results.	Conducting multiple trials or using equipment to ensure the same amount of pressure is given
The plastic pipe is thick and adds to some degree of angle therefore when measuring the angle from the bottom of the pipe we don’t measure from the surface from which the bob rolls	This can impact the measurement, this thickness can offset the angle being measured, giving rise to uncertainty.	To overcome the issue, we can either subject the offset angle or measure from the surface at which the ball rolls instead of the bottom of the pipe.
The bobs at times knock against the cardboard frame.	This effects the velocity at which it is going, due to external force from the frame.	The use of smoother surface, larger frame of cardboard or the improvement of stability can overcome the issue.

Conclusion

The data indicates that in a collision between two similar spheres, the quantity of energy lost and the coefficient of restitution are affected by the angle of the hollow tube through which the spheres are carried. On average, the energy loss and coefficient of restitution both tend to decrease as the angle of the tube increases. Keep in mind that these findings may not apply to other situations because they are based on a limited number of experiments. Our current understanding of the connection between tube angle and collision effects needs further investigation and analysis. In general, this field has implications for understanding collision mechanics and could be useful in fields such as engineering and materials research.

Appendix- I

Further Scope

We can further investigate the relationship between the angle of the tube and other variables such as the:

- Diameter and mass of the spheres
- The material properties of the spheres and the tube
- Initial velocity of the spheres.

Additionally, we can explore the effects of other factors on the energy loss and coefficient of restitution, such as friction, deformation, and other sources of energy dissipation.

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