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Elastic shock experiments

Experimentos de choque elástico

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Elastic shock is a phenomenon that occurs when an object or material experiences a sudden and large deformation, followed by a rapid return to its original shape. This type of deformation is typically caused by a high-impact force or pressure, such as a collision or explosion. Elastic shock is a type of elastic deformation, which means that the material returns to its original shape once the external force is removed. Elastic shock is important in physics, engineering, and daily life because it affects the behavior and performance of materials and structures under load. In this paper, the results of some experiments on the elastic shock are presented.

Keywords: Deformation, elastic shock, experiments, force

El choque elástico es un fenómeno que se produce cuando un objeto o material experimenta una gran deformación repentina, seguida de un rápido retorno a su forma original. Este tipo de deformación suele deberse a una fuerza o presión de gran impacto, como una colisión o una explosión. El choque elástico es un tipo de deformación elástica, lo que significa que el material vuelve a su forma original una vez que se elimina la fuerza externa. El choque elástico es importante en la física, la ingeniería y la vida cotidiana porque afecta al comportamiento y las prestaciones de los materiales y las estructuras bajo carga. En este artículo se presentan los resultados de algunos experimentos sobre el choque elástico.

Palabras clave: Choque elástico, deformación, experimentos, fuerza

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Introduction

As human beings, our social and intellectual development is primarily based on the supply of needs and problem solving (Logan & Goldberg, 1953). Problem solving, regardless of its nature, requires several processes and capabilities, among them: the abstraction of the world (as a mental operation) and its materialization (mathematically) (Falih & Shammari, 2019; Martínez et al., 2013).

With the help of the abstraction capacity, we separate the properties of an object and/or behavior through a mental operation, in order to understand its nature and the phenomena that govern it (Martínez & Acero, 2020). However, the purely mental abstraction of the world is not enough by itself, and the use of mathematical models is necessary, which allow the mental abstraction to be materialized in numbers (Martínez & Rendón, 2020). The combination of mental abstraction and mathematical modeling of phenomena is called physics.

One of the most important physical phenomena is collisions (Abdallah et al., 2019). From microscopic molecular collisions, such as the Kinetic Theory of Gases, based on the studies of Daniel Bernoulli, Ludwig Boltzmann and James Clerk Maxwell, to the Great Impact Theory, which postulates that, as a result of a collision between the young Earth and a protoplanet the size of Mars, the moon, the only natural satellite of the Earth, originated (Grozdanov et al., 2018). Collisions are present in many aspects and their study provides answers to a large number of events. In this article, an elastic collision between two bodies is analyzed, in order to abstract the nature of their behavior, and to prove that in an elastic motion the transfer of energy is complete.

Methods

The mobiles to be studied in this case will be a pair of glass marbles (Fig. 1).

In collisions, there are three particular cases of interest:

- $m_1 = m_2$
- $m_1 << m_2$
- $m_1 >> m_2$

To know which is our case, we will use Archimedes' principle of displacement, which states that the volume of the submerged body is equal to the volume of water displaced by it, being the volume, the quantification of the place occupied by an object in space (Fig. 2) (Resnick et al., 2005).

From the results we can make two statements:

- The marbles have the same volume.
- The marbles are made of the same material.

Since they meet the above statements, the marbles have the same mass, thus classifying our particular case of interest as (Eq. 1):

$$m_1 = m_2 \tag{1}$$

And in the interest of this exercise, we will assume that (Eq. 2):

$$m_1 = m_2 = 10\,\mathrm{g} \tag{2}$$

An elastic collision is characterized by conservation of momentum as well as conservation of kinetic energy, that is why we are going to use a soapy plastic rail, in order to minimize friction between the surfaces and minimize losses (Fig. 3).

To analyze the collision behavior of these masses in the laboratory, we will record the digital video of the experiment in slow motion (Fig. 4). This guarantees accuracy in the motion analysis, which will be performed in the Tracker software (Martínez et al., 2022). Having a higher FPS (frames per second) translates into more data to analyze (Martínez et al., 2016).

Video analysis

With the help of the simulation software Tracker - Video Analysis and Modeling Tool, one of the recorded videos of the experiment of two colliding mobiles will be analyzed. Tracker is free software that allows the analysis of movements (and other real situations) in one and two dimensions. The program allows us to extract in tables and graphs. The procedure is as follows:

1. We will proceed to load the video so that the simulator will be in charge of reconstructing the trajectory of the point to point collision of the mobiles.

2. The simulator requires the use of a calibration rod. The calibration rod (Fig. 5), will allow the software to abstract the dimensions of the place, playing its role as a measurement standard.

3. As in any other measurement, a coordinate system (Fig. 5) is needed to serve as a reference.

Mathematical analysis

The results shown in Table 1 were generated for mass 1.

Using the data in Table 1, the curve is reconstructed by linear regression (Fig. 6). The resulting equation (Eq. 3) describes the trajectory recorded in the experiment for this mass.

$$x_{m1}(t) = -1.6 \times t + 0.12 \tag{3}$$

Figure 1

Mobiles: glass marbles.

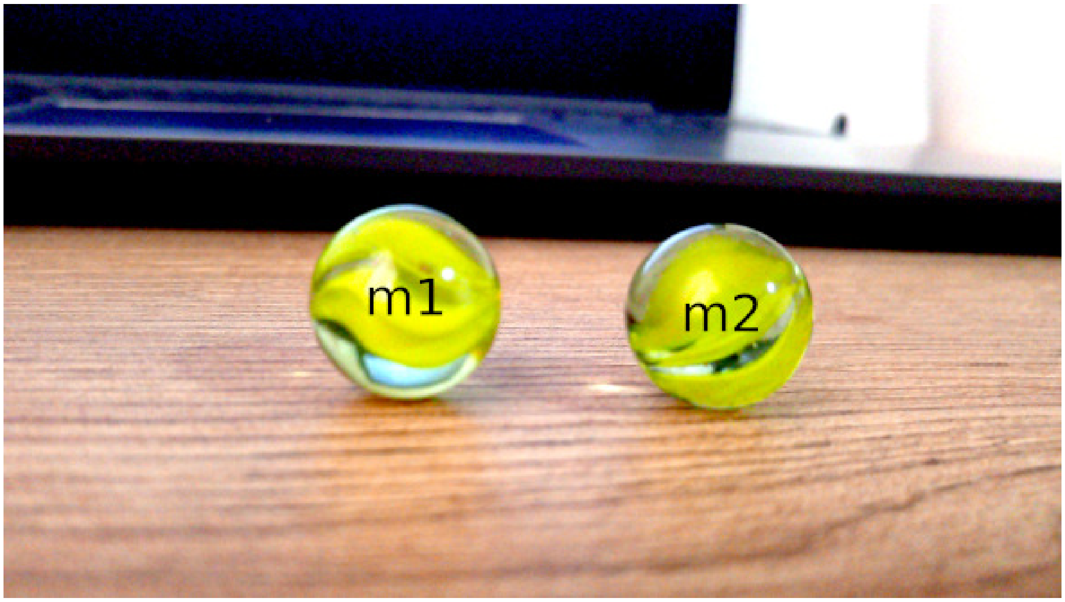


Table 1

Data provided by Tracker software (black), linear momentum and kinetic energy of the collision calculated from Tracker data (red) for m_1

Ball 1				
Time	Position	Speed	Linear momentum	Kinetic energy
$t\,[s]$	$x\,[m]$	$\lVert\bar{v}\rVert = \frac{\Delta x}{\Delta t}\left[\frac{m}{s}\right]$	$p = m * v\,[kg * \frac{m}{s}]$	$E_c = \frac{m*v^2}{2}\,[J]$
0,016676195	0,094064725	0,000000000	0	0,0000
0,025014292	0,080523982	1,687174754	0,01687174754	0,0142
0,033352389	0,065929101	1,650885245	0,01650885245	0,0136
0,041690487	0,052993860	1,576362902	0,01576362902	0,0124
0,050028584	0,039641369	1,502741648	0,01502741648	0,0113
0,058366682	0,027934752	1,572151303	0,01572151303	0,0124
0,066704779	0,013424508	1,662549753	0,01662549753	0,0138
0,075042876	0,000000000	0,000000000	0	0,0000

Deriving this equation we obtain:

$$x_{m1}(t) = -1.6 \times t + 0.12 \text{ [m]} \tag{4}$$

$$v_x = \frac{dx_{m1}}{dt} = -1.6 \left[\frac{\text{m}}{\text{s}}\right] \tag{5}$$

From Eq. 5, we calculate the magnitude of the velocity vector:

$$\|v_x\| = \sqrt{v_x^2 + v_y^2} \tag{6}$$

$$\|v_x\| = \sqrt{(-1.6)^2 + 0^2} = 1.6\,\frac{\text{m}}{\text{s}} \tag{7}$$

Calculating the average of the instantaneous velocities provided by the software, we obtain:

$$\bar{v} = 1.608644268\,\frac{\text{m}}{\text{s}} \tag{8}$$

Comparing the average value of the velocities with the value of the velocity obtained from the trajectory equation yields:

$$Error_{Experimental} = \frac{1.6 - 1.608644268}{1.6} = -0.5403\% \tag{9}$$

The results shown in Table 2 were generated for mass 2.

Using the data in Table 2, the curve is reconstructed by linear regression (Fig. 7). The resulting equation (Eq. 10) describes the trajectory recorded in the experiment for this mass.

$$x_{m2}(t) = -1.68 \times t + 0.117 \tag{10}$$

Deriving this equation we obtain:

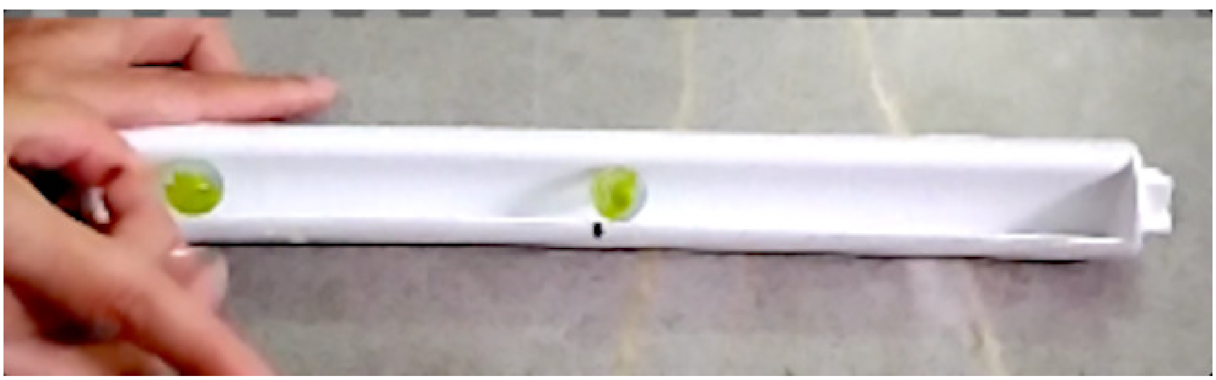
$$x_{m2}(t) = -1.68 \times t + 0.117 \text{ [m]} \tag{11}$$

Figure 2

Volume of the submerged body $Vm_1 = Vm_2$.

Figure 3

Soapy plastic rail.



$$v_x = \frac{dx_{m2}}{dt} = -1.68 \left[\frac{\text{m}}{\text{s}}\right] \tag{12}$$

From Eq. 12, we calculate the magnitude of the velocity vector:

$$\|v_x\| = \sqrt{(-1.68)^2 + 0^2} = 1.68 \, \frac{\text{m}}{\text{s}} \tag{13}$$

Calculating the average of the instantaneous velocities provided by the software, we obtain:

$$\bar{v} = 1.58127 \, \frac{\text{m}}{\text{s}} \tag{14}$$

Comparing the average value of the velocities with the value of the velocity obtained from the trajectory equation yields:

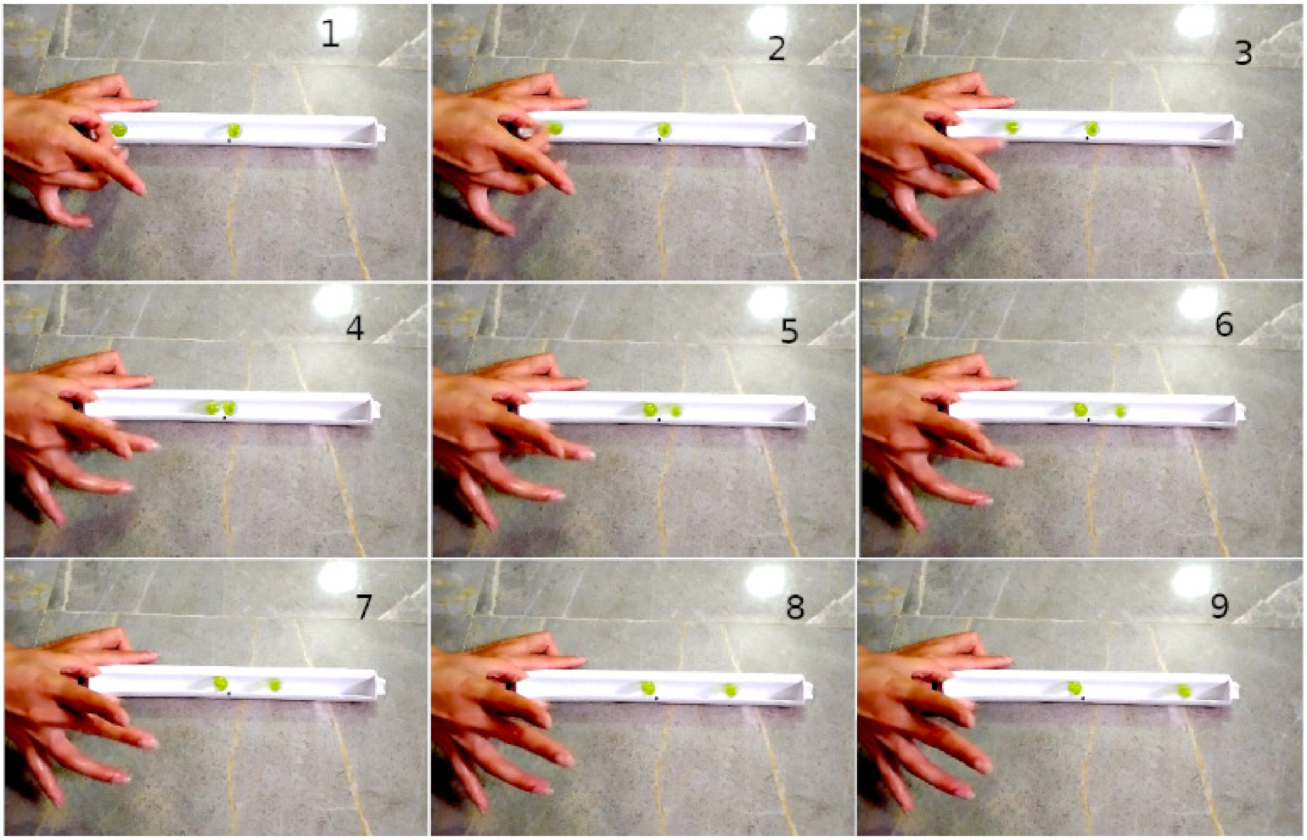
$$Error_{Experimental} = \frac{1.68 - 1.58127}{1.68} = 5.87655\% \tag{15}$$

Elastic collision

In an elastic collision it is observed that the mobiles have an intrinsic characteristic, due to the material from which they are made, they are rigid and non-deformable during the collision. Generally elastic collisions under ideal conditions are soundless, i.e. the kinetic energy is transferred during

Figure 4

Screenshots of the video under analysis.



the collision and is not converted into sound or heat, and therefore the internal forces do not do any work.

Fig. 8 shows the result of the experiment. It is observed that under the condition $m_1 = m_2$ there is a complete transfer of the quantity of motion. As a result, the mass m_1 remains stationary in the place of m_2, and the mass m_2 now moves. The collision occurs at 0.07504 second at the origin of the reference frame, which was chosen for convenience at the point of collision.

After the impact, m_1 remains static, while the mass that was at rest, m_2, acquires a velocity equal to that of the first mass $v_{fm1} = v_{im2}$ (Fig. 9). Thus, the linear momentum and kinetic energy are conserved (Eq. 16).

$$E_{kinetics\,m1} = E_{kinetics\,m2} \tag{16}$$

$$\frac{1}{2}m_1V_i^2 = \frac{1}{2}m_2V_i^2 \tag{17}$$

Despite fluctuations in the velocity values ranging from 1.5 to 1.69 m/s, they remain within this range, and although they should be constant all the time, the variation is not large

Table 2

Data provided by Tracker software (black), linear momentum and kinetic energy of the collision calculated from Tracker data (red) for m_2

Ball 2				
Time	Position	Speed	Linear momentum	Kinetic energy
$t\ [s]$	$x\ [m]$	$v = \frac{\Delta x}{\Delta t}\left[\frac{m}{s}\right]$	$p = m * v\ [kg * \frac{m}{s}]$	$E_c = \frac{1}{2} * m * V_i^2\ [J]$
0,066705	0,000000	0,00000	0,00000	0,00000
0,075043	0,000000	1,662549753	0,01663	0,01382
0,083381	-0,026986	1,55904	0,01559	0,01215
0,091719	-0,039042	1,592786072	0,01593	0,01268
0,100057	-0,053548	1,59290	0,01593	0,01269
0,108395	-0,065604	1,55858	0,01559	0,01215
0,116733	-0,079539	1,58446	0,01584	0,01255
0,125071	-0,092027	1,49772	0,01498	0,01122
0,133410	-0,104514	1,60215	0,01602	0,01283
0,141748	-0,118744	0,00000	0,00000	0,00000

Figure 5

Tracker simulator: Collision analysis, measuring rod (blue line) and coordinate axis (purple axis).

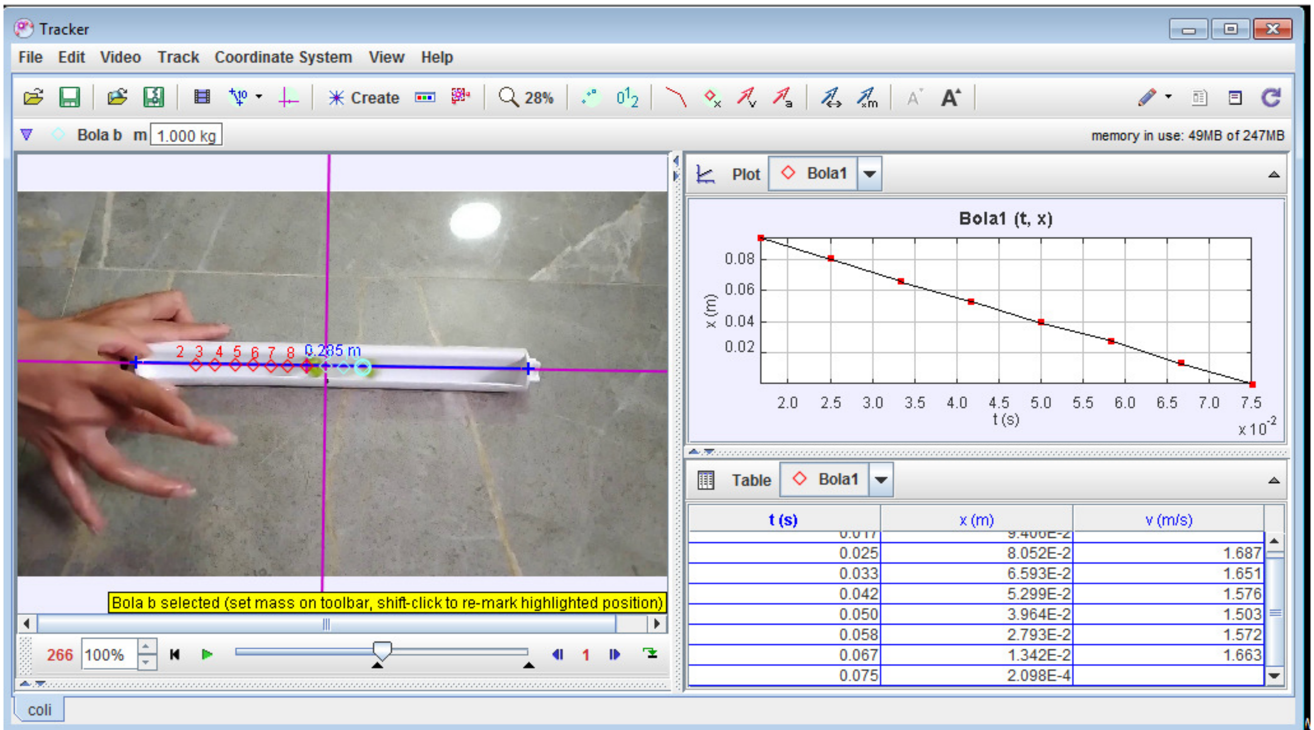


Figure 6

Plot of mass m_1, position versus time (blue tracker data). Linear regression of position versus time (pink).

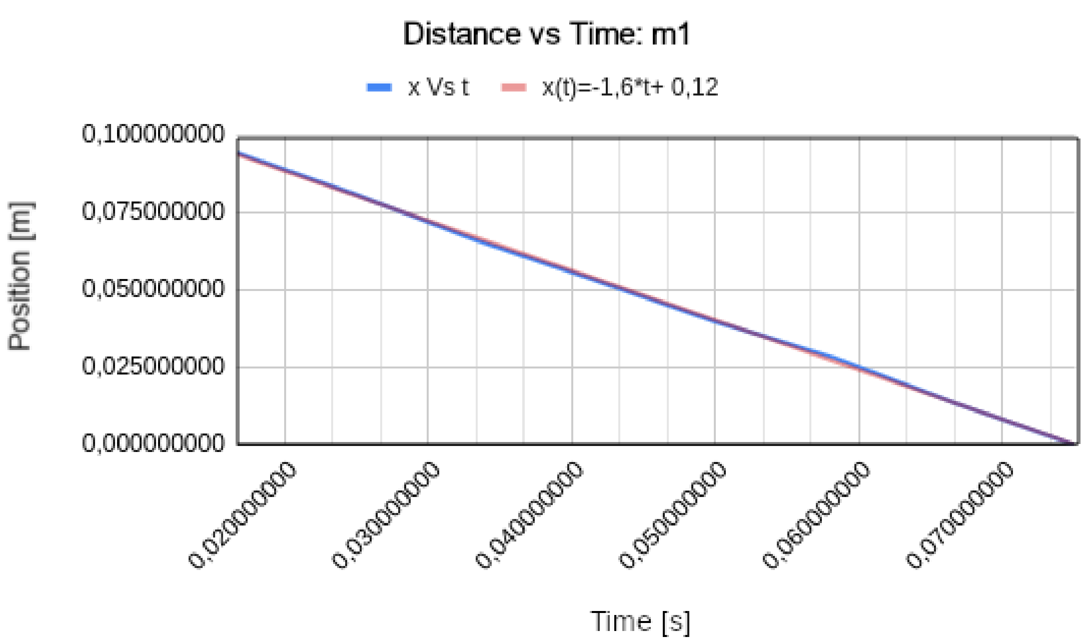


Figure 7

Plot of mass m_2, position versus time (blue tracker data). Linear regression of position versus time (pink).

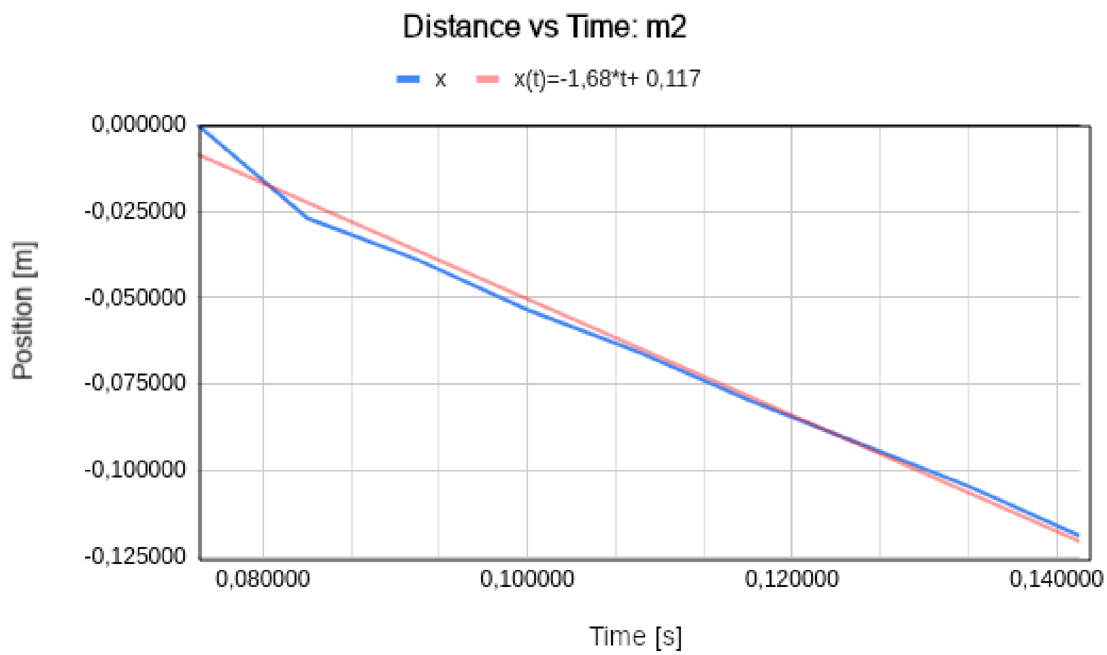


Figure 8

In the graphic: $x_{m1}(t)$ (blue), $x_{m2}(t)$ (orange), collision point (red).

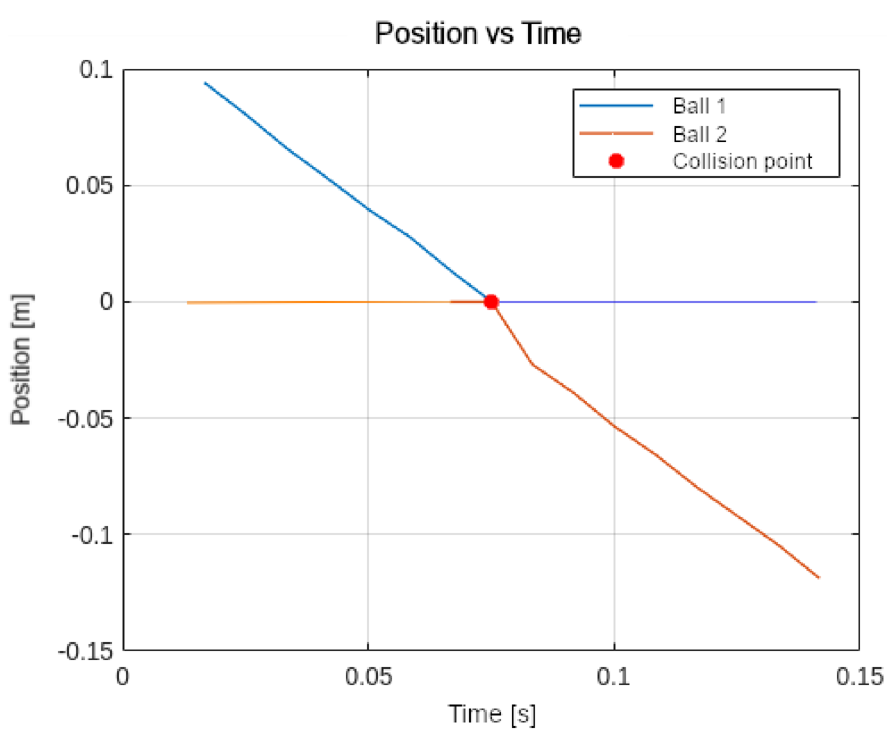
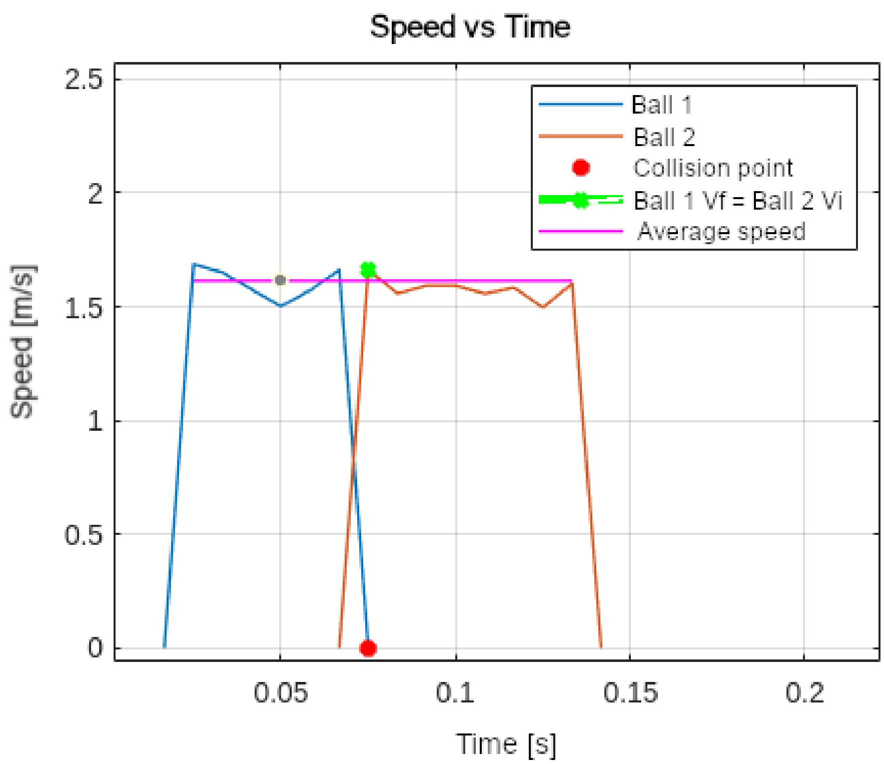


Figure 9

Speeds v_{m1} and v_{m2} along the time.



enough to affect the nature of the collision. On average the velocity is $v = 1.6149$ m/s (Fig. 9).

Table 3, and the corresponding Fig. 10, shows the behavior of the kinetic energy throughout the collision. The kinetic energy is not completely constant, but oscillates between the values of 0.011 J and 0.013 J, on average about 0.01274 J.

The amount of motion, momentum or linear momentum of the system, is also conserved as a consequence of all the forces involved in the collision are internal to the system of bodies (Eq. 18 and Fig. 11). On average the linear momentum along the collision is 0.0159 kg m/s, and oscillates between 0.015 and 0.016 kg m/s.

$$p_{m1} = p_{m2} \tag{18}$$

$$m_1 V = m_2 V \tag{19}$$

Conclusion

In this paper we document some experiments carried out in laboratory in a controlled manner to verify the properties of elastic collisions. In elastic collisions there is a complete transfer of the amount of motion and the kinetic energy remains constant at all times. In order to corroborate this phenomenon, a setup consisting of two marbles and a rail with low friction was performed. The results were digitally recorded and analyzed to determine the characteristics of

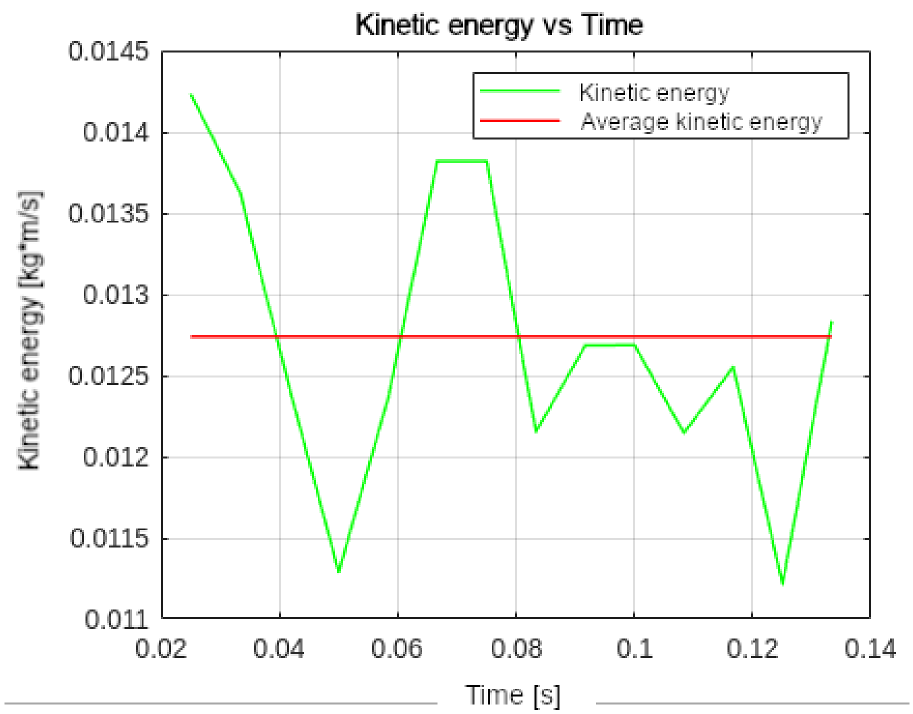
Table 3

Collision kinetic energy calculated from Tracker data (red) for m_1 and m_2

m_1	m_1	m_2	m_2
t [s]	$E_c = \frac{1}{2} * m_1 * V_i^2 [J]$	t [s]	$E_c = \frac{1}{2} * m_2 * V_i^2 [J]$
0,016676195	0,00000	**0,066705**	0,0000
0,025014292	0,014232	**0,075043**	0,0138
0,033352389	0,013627	**0,083381**	0,0122
0,041690487	0,012424	**0,091719**	0,0127
0,050028584	0,011291	**0,100057**	0,0127
0,058366682	0,012358	**0,108395**	0,0121
0,066704779	0,013820	**0,116733**	0,0126
0,075042876	0,000000	**0,125071**	0,0112
	0,000000	**0,133410**	0,0128
	0,000000	**0,141748**	0,0000

Figure 10

Kinetic energy of both masses (green), and average kinetic energy over time (red).



its behavior. In this work it was possible to demonstrate the characteristics of the phenomenon, with the normal variations attributable to non-ideal conditions. Although the physical variables such as the amount of motion and kinetic energy should be constant throughout the collision, the fluctuation they undergo is not significant enough to affect the nature of the elastic shock under study.

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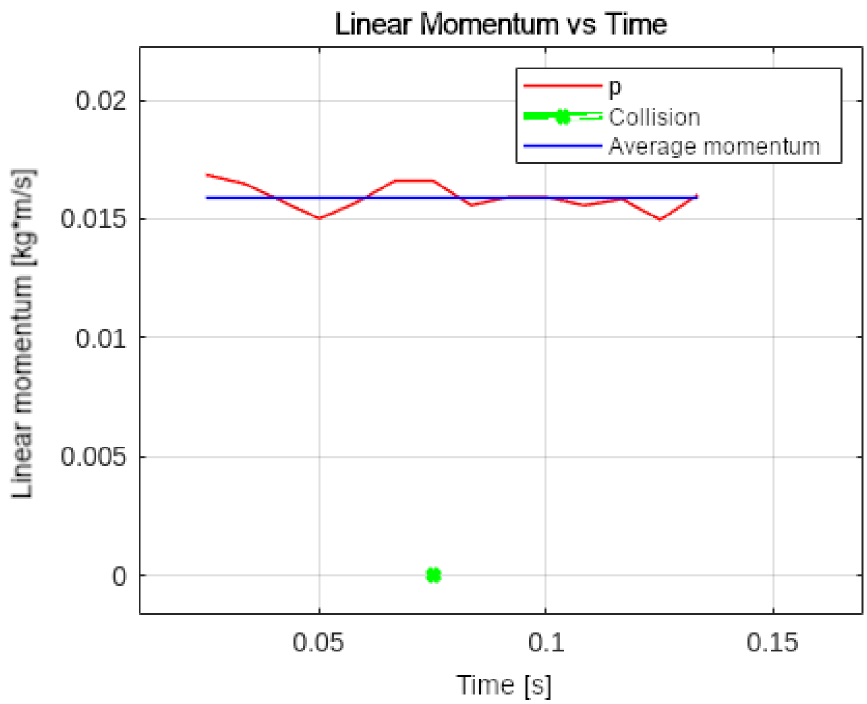
Figure 11

Linear momentum or amount of motion along collision.



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