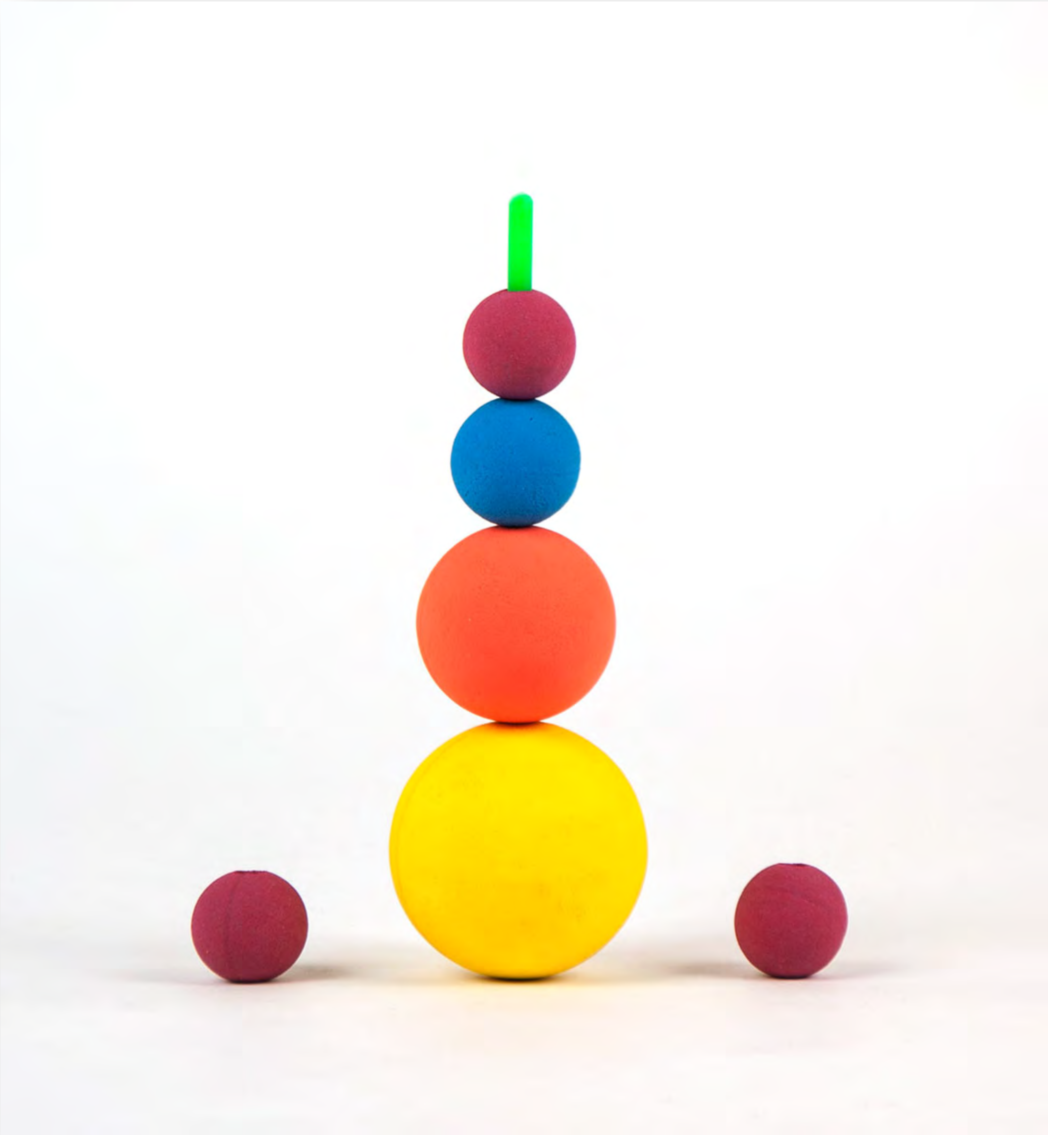
ELASTIC IMPACT – MOMENTUM CANNON

MED 08.04



Material

Item-no.	Qty.	Description
DM343-2S	1	Momentum cannon 02
P1100-1E	1	Measuring tape, L=300 cm

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The momentum cannon consists basically of 4 balls that are placed on top of each other; the balls have different masses and diameters. The bottommost ball is directly connected to the axis while the other balls on top of it are freely movable along the axis but cannot escape it - only the topmost ball is completely freely movable along the axis.

How does the momentum cannon work?

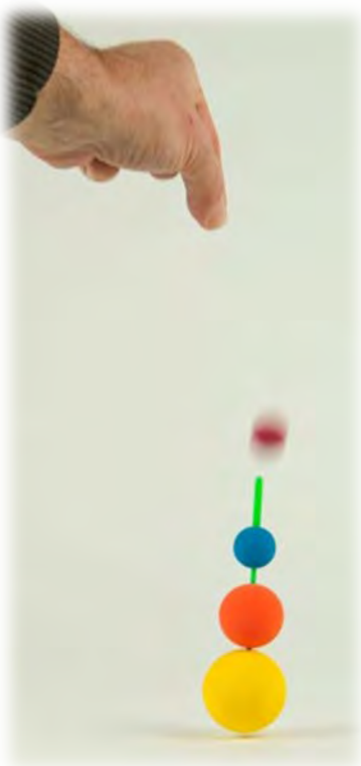
First place the small red ball on the axis of the momentum cannon.

Now hold the axis on its tip between the thumb and the index finger.

Place the beginning of the measuring tape on the table or on the ground and hold the momentum cannon next to it, thus the fall height can easily be determined.

Now let the momentum cannon drop on the table or on the floor.

The small red ball is flying after the momentum cannon has been dropped on the surface with a multiple of the falling speed v_0 upwards and can reach enormous heights.



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Preparation and experiment

A table with a smooth surface is pushed against an open wall. The measuring tape is rolled up about 50 cm, locked and held against the table surface with its beginning.

Hold the momentum cannon is held at a short distance in front of the measuring tape at the upper free end of the axis so that the lower edge of the largest rubber ball is at an initial height h_A of approx. 10 cm above the floor or the table.

The position of the lower edge of the largest rubber ball is noted in the chart on the next page.

Drop the momentum cannon vertically from this height after it has come to rest.

At every drop height, care must be taken to ensure that the momentum cannon does not receive any additional initial speed downwards and that the rubber ball that is flying away does not hit the ceiling.

The maximum height of the small rubber ball is marked on the wall (with removable stickers) and also noted in the chart on the next page. Two further maximum heights are determined for the same starting height.

These steps are repeated for three (or more) additional initial heights h_A .

The average value h_M is determined from the three values of the maximum height for each initial height h_A and also noted in the chart on the next table.

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Afterwards draw the values for the initial height h_A and the average value h_M into the diagram.

Initial height h_A/m	Max. height h_1/m	Max. height h_2/m	Max. height h_3/m	Average max. Height h_M/m

How are the initial height h_A and the average value of the max. height h_M connected?

Maximum height with the momentum cannon

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What is the physical background?
Two major factors are required to understand the momentum cannon:
The momentum $\vec{p}$ and the energy E.

Annotation
In our observations we assume from collinear, central collisions. The direction of the dynamic quantities is therefore only represented by the corresponding sign, the vector does not have to be taken into consideration for this representation.
At the beginning of the free fall the momentum cannon has its maximum potential energy E_p.
During the accelerated movement (gravitational force) downwards - our speed axis also points in this direction - the potential energy E_p decreases and the kinetic energy E_{kin} of the momentum cannon increases, the amount of kinetic energy is the greatest at the moment of impact:

$$E_{kin,0} = \frac{1}{2} \cdot m \cdot v_0^2.$$

During this impact the lowest rubber ball is deformed and (almost) the entire kinetic energy E_{kin} is stored. As the rubber ball expands again this energy is (almost) completely released again and the lowest rubber ball moves upwards. We call this (idealized) process in which no part of the energy is impacted into heat or other forms of energy an elastic impact.

For the sake of simplicity, we consider below a momentum cannon that consists of only two rubber balls. The explanation can be extended to any number of balls.
While the bottom rubber ball (1) is already moving upwards at the speed $-v_0$, the rubber ball (2) above it is just moving downwards at the speed v_0. The two rubber balls will therefore also collide in an elastic joint. With this elastic impact, the important physical quantities momentum p and kinetic energy E_{kin} are preserved, i.e. the total momentum p and the total kinetic energy E_{kin} of the two rubber balls (1) and (2) before and after the impact are the same:

(Conservation of momentum) $p_{1v} + p_{2v} = p_{1n} + p_{2n} \rightarrow -m_1 \cdot v_0 + m_2 \cdot v_0 = m_1 \cdot v_{1n} + m_2 \cdot v_{2n}$

(Conservation of energy) $E_{kin,1v} + E_{kin,2v} = E_{kin,1n} + E_{kin,2n} \rightarrow$

$$\frac{1}{2} \cdot m_1 \cdot v_0^2 + \frac{1}{2} \cdot m_2 \cdot v_0^2 = \frac{1}{2} \cdot m_1 \cdot v_{1n}^2 + \frac{1}{2} \cdot m_2 \cdot v_{2n}^2$$

The kinetic relationships, i.e. the velocities of the rubber balls after the impact are largely determined by the mass ratio m_1/m_2 of the two rubber balls (1) and (2).

Regardless of the true mass of the rubber balls in our momentum cannon, for this explanation we want to assume that the (bottom, largest) rubber ball (1) is three times as heavy as the rubber ball above it (2): $m_1/m_2 = 3$. Thus its speed after the impact is $v_{1n} = 0$ and the lighter rubber ball (2) moves up at twice the impact speed $-2v_0$.

If there are several rubber balls, this process is repeated according to the number of rubber balls (n).
Based on our present momentum cannon with four rubber balls this means for the uppermost, smallest rubber ball an escape speed $4v_0$ of four times the impact speed v_0 and thus (theoretical) 16 times the kinetic energy compared to its kinetic energy $E_{kin,(4),0}$ at Impact.
The actually attainable height of the uppermost, smallest rubber ball (4) depends not only on the true mass distribution of the rubber balls but also on the amount of energy that is converted into other forms of energy in the various (in reality inelastic shock) processes.

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Necessary physical basics to understand the momentum cannon:

- Coordinate systems
- The vector property of dynamic quantities (here especially the speed "v" $\vec{}$)
- The straightforward, accelerated movement
- The physical quantity energy E and its different forms of energy
  (here especially the potential energy E_p and the kinetic energy E_{kin})
- The physical quantity momentum "p" $\vec{}$
- Important conservation laws from physics: momentum conservation law and energy conservation law

The momentum cannon was invented by the American physicist and astrophysicist Stirling Colgate. He wanted to demonstrate the propagation of the shock wave in a supernova explosion.