



Multiple Collision Accelerator

Take four high-bounce balls with different masses, thread them on a plastic spindle and drop them straight downward onto a hard surface . . . watch out - the small ball will fly off at great velocity.

Instructions

1. Remove the red ball, hold it about waist high above a smooth hard floor and drop it. Observe the re-bounce height: 40%; 50% ?
2. Now thread the red ball on top of the other three balls on the spindle. Wear the safety glasses.
3. Lift the spindle and four balls to the same height as before and drop them. Observe the new re-bounce height.

What is happening?

In all elastic collisions momentum and kinetic energy are conserved. In **inelastic collisions** only momentum is conserved and this is the situation here. When the balls are dropped and then separates, the process is known as an **explosion**. In terms of momentum it is the reverse of a completely inelastic **collision**.

The balls are dropped 'independently' of each other with a small space between them. The inelastic collision occurs when the upward traveling blue ball hits the green ball on its way down and **transfers its momentum** to the green ball. The green ball **changes direction** and a moment later transfers its momentum to the yellow ball and then the same happens between the yellow and red ball. (We assume here that the initial bounce of the blue ball on the floor was an inelastic collision and that the blue ball has attained all of its momentum).

They all have the same initial velocity on impact but then the three large balls cannot move much after impact so **all of their momentum is imparted on the small red ball**. And because the red ball has such a small mass it just has to have an impressive final velocity.

$$\begin{aligned}
 \Sigma p &= (m_1 + m_2 + m_3 + m_4)v_i &= m_1v_f + m_2v_f + m_3v_f + m_4v_f \\
 & &= 0 + 0 + 0 + m_4v_f \\
 & &= m_4v_f
 \end{aligned}$$

It has been shown that the maximum velocity of the red ball can be **4v_i** and the maximum height **16 times** the original height from the floor (with perfect elastic collisions). In real life with inelastic collisions (a restitution coefficient of 0.75), the height reached is closer to **10 times** the original height. See reference 1.

Extensions:

1. What happens when the yellow and green balls are inverted on the spindle? Try it. Hold the spindle tightly and slide the blue ball from the spindle. It is a tight fit. Then slide the yellow and green balls off and invert their positions. Put the red ball back and do the drop.
2. During the collision of the blue ball with the surface and during the collisions between the balls, there is an energy exchange. The success of the energy transfer can be described by the coefficient of restitution (ϵ). For $\epsilon = 1$ we get perfect elastic collisions. For this toy ϵ would be closer to 0.75
3. Compare and relate the results of the demonstration with the reason for wearing a seat belt in a car.
4. Why does a motorcyclist carry a much higher risk when involved in a car crash?

Reference:

Kires, M., Astroblaster - a fascinating game of multi-ball collisions, Physics Education, 44(2), March 2009, pp 159 - 164