Debouncing a Superball

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Superballs can be purchased in local toy stores. They are described as being highly elastic. For bounces on a wooden bench top, the coefficient of restitution, defined as the ratio of the velocity after collision to the velocity before collision, can be determined from the heights reached on successive rebounds. The value obtained is typically about $e = 0.8$.

To debounce a superball means that on striking the bench top there will be no rebound, just a single thud. Debouncing could be achieved crudely by placing a larger softer ball just above the superball. When the two are released and fall together onto the bench top, the rebound of the smaller ball will be smothered as if the softer ball were a pillow.

A far more interesting example of debouncing is both surprising and instructive. It is surprising because instead of the upper ball being soft, it is a second superball! Two superballs debouncing is a great demonstration of the basic physics of collisions.

In Fig. 1(a) the two superballs that have been released from the same height are approaching the bench top, both with speed $u$. Figure 1(b) shows the situation after the first ball has rebounded from the bench top, just before colliding with the upper ball. The bottom ball of mass $m_B$ rebounds with speed $eu$, where $e$ is the coefficient of restitution. The top ball $m_T$ is still falling with downward speed $u$. Figure 1(c) shows the situation after the collision with the velocity of the lower ball set to zero, the condition for debouncing. The upper ball heads upward with a recoil speed $v$. Do we expect $m_T > m_B$, $m_T = m_B$, or $m_T < m_B$?

The answer can be found by applying the law of conservation of momentum to the collision,

$$m_T v = -m_T u + m_B eu. \quad (1)$$

The mass ratio is then

$$\frac{m_T}{m_B} = \frac{eu}{v + u}. \quad (2)$$

To eliminate the speed of the upper ball from this...
equation, we can use the definition of the coefficient of restitution,\(^\text{1}\)

\[ e = \frac{v}{u + eu}, \]  

(3)

to write

\[ v = (e^2 + e)u. \]  

(4)

Substituting Eq. (4) into Eq. (2) gives the mass ratio,

\[ \frac{m_R}{m_B} = \frac{e}{e^2 + e + 1}. \]  

(5)

From Eq. (4) and Eq. (5), we see that for \( e = 1 \),

\[ \frac{m_R}{m_B} = \frac{1}{3} \]  

and \( v = 2u \),

while for \( e = 0.8 \),

\[ \frac{m_R}{m_B} = \frac{1}{3.05} \]  

and \( v = 1.44u \).

Evidently, the mass ratio needed for debouncing is not very sensitive to \( e \). The fact that the ratio decreases as \( e \) increases can lead to useful class discussion.

Building an apparatus to demonstrate the debouncing of a superball is straightforward. A steel needle was embedded in a wooden block. The needle is used to guide the balls as they begin their fall toward the bench top. Slightly larger holes were drilled in both balls. Our apparatus is shown in Fig. 3. The radii of the superballs are 5 cm and 3.5 cm. So the ratio of their masses is \((5/3.5)^3 = 2.97\).

An effective method of illustrating the idea is to first release the larger ball on its own from a height of around 25 cm. The wooden block is held by hand close and firmly to the chest and one listens for successive bounces of the ball. Second the two balls are released using the needle as a guide. There is a single thud of the larger ball and sometimes one is able to catch the smaller ball at the top of its flight for added dramatic effect. The larger superball has been debounced.

**An Extension Activity**

The magic of the 3-to-1 mass ratio can be further examined using a Newton’s Cradle type apparatus. For simplicity all collisions will be considered to be perfectly elastic, \( e = 1 \). Figure 2 shows the two balls, hung from strings, and their repeated collisions. The collisions occurring in (a) and (b) have been discussed above. The collisions occurring in (c) and (d) result in the balls having equal but opposite velocities. Finally, collision (e) is identical to collision (a) as the system cycles indefinitely.\(^\text{2}\) The Newton’s Cradle can use superballs or steel spheres.\(^\text{3}\) The one shown in Fig. 4 has a Plexiglas frame so it can be placed on an overhead projector. To give the balls equal and opposite velocities, start from the situation of Fig. 2(c) by pulling the smaller mass to one side and then releasing it.

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**References**

1. For a head-on collision of two masses, the coefficient of restitution \( e \) is defined as the ratio of their relative speed of separation to their relative speed of approach.
3. Our steel spheres have diameters of 1 in and 1-7/16 in, so the ratio of their masses is 2.97.

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