Kindergarten Physics

Paul Pshenichka[1]

[1] Pr. Nezalezhnosti 84A/63
58005 Chernivtsi, Ukraine
Phone: +380372 54-53-72
Mobil: +380676864017
ppshenichka@gmail.com
www.ql.cv.ua

Abstract

The main idea of this article is to show how a very simple problem, observed by playing with the Newton's Cradle toy, can be investigated and developed to a very high and profund level of understanding. Such kind of "long-playing" problems is very often proposed at Physics Tournaments or Physics Olympiads.

1. Newton's Cradle: The Desk Collider

The toy consists of 5 or more steel balls tied in such a manner that they can move only in one dimension: along a circular arc (Fig 1). My 7-year-old granddaughter got the toy as a gift three years ago and it still attracts her interest. For that reason I named the article "Kindergarten Physics." Of course, the toy is highly interesting for people of any age. What is it that amazes us and keeps our attention ? First of all it is the variety of possibilities of playing with it. The colliding combinations are numerous and often it is hard to forecast the result of the spheres bouncing, especially for children. For example, it is not easy to foretell what happens if three balls hit the other group of two resting balls (Fig 2). If we take a deeper look at this colliding device, we can see that it's mainly about the relationship between physics and mathematics.

Fig 1.

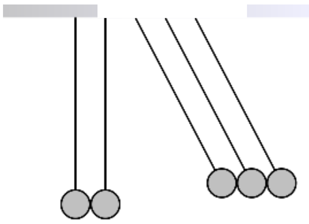

Fig 2.

But even the "simplest" case of two colliding balls conceals a lot of surprises. By the way, only our experience from observing elastic collisions allowed us to predict what would happen if the ball on the left hit the resting ball on the right (Fig 3). Symmetry would be the best keyword for the behaviour of the balls, symmetry both in space and time. The next impact (from the right to the left) is a reflection symmetrical in space or reversal in time, which gives us the pre-perception of choosing a very challenging path of investigation.

2. Trying to Explain.

Let us look what we can get with the help of mathematics. Assume that we observe a collision of two absolutely elastic balls of equal mass. Additionally we suppose that the first ball has the velocity *v*, and the second ball rests in our lab reference frame. The collision is also central. Using the conservation laws of energy and momentum (Fig 3) we will get two equations and *two solutions* (because the energy equation is of the second order):

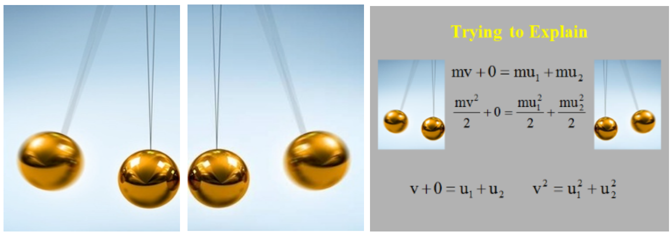

Fig 3.

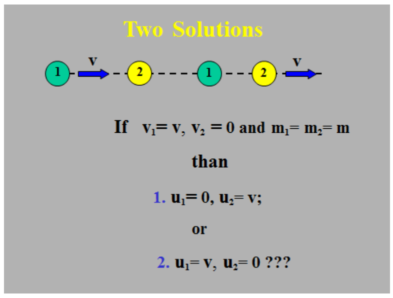

Fig 4.

$$u_1 = 0,\ u_2 = v \qquad (1)$$

$$\text{and}\ \ u_1 = v,\ u_2 = 0, \qquad (2)$$

where u_1 and u_2 are the expected velocities of the two balls respectively after the collision (Fig 4).

The first solution is exactly what we can observe in the experiment. But the second solution looks **absolutely impossible**: *the first ball keeps its velocity v and the second one still remains at rest*.

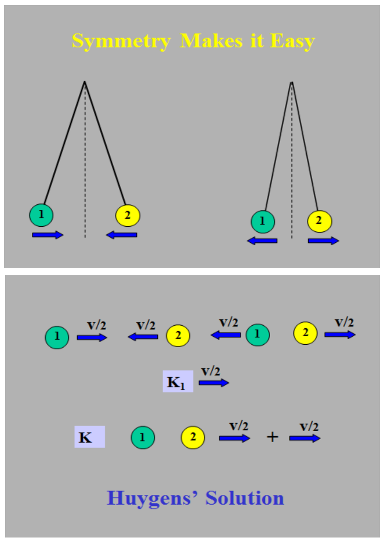

Fig 5.

Before we will find the proper possibility of realizing the second solution, we would like to remark that Huygens solved the problem without math (at first sight). If we chose a reference frame K' which travels at the velocity *v*/2 in the same direction as the first ball, we would get a symmetric situation (Fig 5). From the viewpoint of K' both balls approach one another at the velocity *v*/2 and -*v*/2. The result of the collision in that case is obvious: they bounce against one another at the same speed. Returning to the resting reference frame K, we have to add *v*/2 to the velocities of the balls relative to the frame K' (Fig 5). As a result we have 0 for the first ball and *v* for the second one. Let's remember that symmetry of space and time is the background of the conservation laws of momentum and energy.

3. The Compton Scattering

And now we will find the application for the second solution. Let us observe (Fig 6) the scattering of an incident X-ray photon (analogues to the first ball in the initial experiment) on a resting electron (the second "ball" respectively) which is described by the following equation:

$$\lambda_f - \lambda_i = \lambda_c(1-\cos\theta), \qquad (3)$$

where λ_f and λ_i are the final and initial wavelengths of the photon. Here $\lambda_c = h/mc$ is the Compton's wavelength, and m_e is the electron´s mass. The photon and the electron can scatter in different directions but in the case θ = 0 the result will be: $\lambda_f = \lambda_i$. It means that *the electron remains at rest and the photon travels at its initial velocity in the previous direction*!

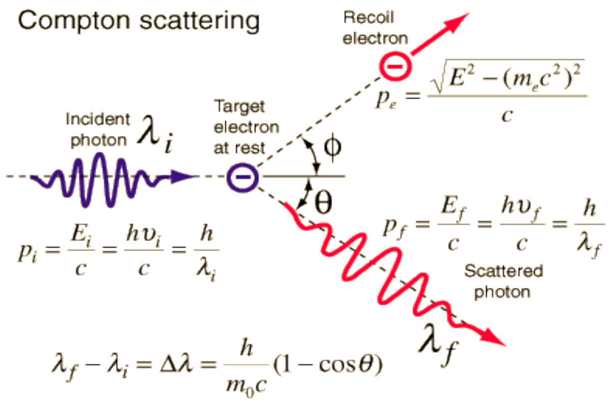

Fig 6.

Leaving aside the question how the photon has managed this stunt, we will concentrate on the increasing complexity of the initial task. In order to find the solution (3) we use the 4-Dimentional super relativistic energy-momentum equation $E^2 = (p_e c)^2 + (m_e c^2)^2$. The scattering of the photon is also possible to represent using the Feynman diagram and Lorentz group matrix (Fig 7).

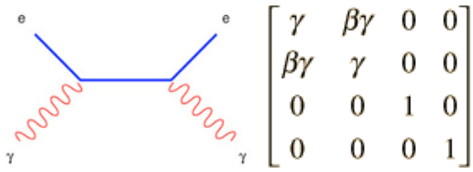

Fig 7.

4. Brief conclusion

Finally, we got something very far-fetched to the solution (2) of the collission of two balls. Of course, we used a very far-fetched analogy because the photon is both a quantum and a relativistic object. But look how far we had advanced starting with a simple classical mechanics problem and finally reaching the QED with its Feynman diagrams and 4-dimentional super relativistic energy-momentum equation.