Investigating an Intriguing Effect When One or Several Highly Elastic Balls Collide on Each Other or on the Surface

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ABSTRACT

When two objects collide in a short time, they exert forces on each other, they can either stick together or bounce off one another. In this study by different balls such as basketball, volleyball, soccer ball, tennis ball and ping-pong ball elastic collision when the objects separate after impact and don't lose any of their kinetic energy and momentum is conserved is compared with inelastic collision which the total kinetic energy is not constant are studied . The time of collision and different materials are studied and the results and data are analyzed to find these collisions deeper.

Keywords : *: Elasticity , Collision , kinetic energy, momentum, time of collision*

1. Introduction

Momentum is a quantity that describes the amount of force required to stop an object. Also there are two types of collisions related to the momentum: elastic and inelastic.

Elasticity is the reversible deformation property of the environment and materials which in elastic collision the total kinetic energy of the two things before and after colliding is equal but in inelastic collision this energy is not constant. In the real world, there are no purely elastic or inelastic collisions.

Perfectly elastic collisions can happen only with subatomic particles. Everyday observable examples of perfectly elastic collisions don't exist, some kinetic energy is converted into heat transfer due to friction but when the surfaces are nearly frictionless ,collisions between everyday objects can be considered as elastic.

Examples of elastic collisions are seen in a game of billiards and Newtonian pendulum. When a moving ball hits a stationary billiard ball, the moving ball stops when it hits, but transfers all of its momentum to the other ball, resulting in the stationary ball spinning at the initial speed of the moving ball again it is supposed the friction can be neglected.

Also it should be noticed that if an isolated system is subject only to conservative forces, then the mechanical energy (sum of the kinetic energy(K) and potential energy (U)) $E=U+K$, is constant.

In this study all the impacts are free fall which refers to the movement of any object that is only under the force of gravity which has two different modes :

- With air resistance: In this mode two opposite forces enter the object, the first is gravity and the other is friction. The force of constant gravity is downward, but the force of friction is variable and upward and depends on the speed of the object .
- Without air resistance: In this mode the only force on the object when falling is its weight, and according to Newton's second law, the acceleration on the object will be downward, which is known as gravitational acceleration.

2. Theory

Momentum describes the motion of objects when collide to each other. In an elastic collision, where kinetic energy is conserved, the total momentum of the system as the conservation of momentum, before the collision is equal to the total momentum after the collision (Eqs. 1, 2).

$$\mathbf{p}_1 + \mathbf{p}_2 = \mathbf{p'}_1 + \mathbf{p'}_2 \tag{1}$$

$$m_1\mathbf{v}_1 + m_2\mathbf{v}_2 = m_1\mathbf{v'}_1 + m_2\mathbf{v'}_2 \tag{2}$$

But in an inelastic collision kinetic energy is not conserved and is one in which objects stick together after impact, and the maximum amount of kinetic energy is lost. This lack of conservation means that the forces between colliding objects may convert kinetic energy to other forms of energy, such as potential energy or thermal energy. For example two objects that have equal masses head toward each other at equal speeds and then stick together. The two objects come to rest after sticking together, conserving momentum but not kinetic energy after they collide. Some of the energy of motion gets converted to thermal energy, or heat (Eqs. 3, 4).

$$m_1\mathbf{v}_1 + m_2\mathbf{v}_2 = m_1\mathbf{v'}_1 + m_2\mathbf{v'}_2 \tag{3}$$

$$m_1\mathbf{v}_1 + m_2\mathbf{v}_2 = (m_1 + m_2)\,\mathbf{v'} \tag{4}$$

In inelastic collisions, v′ is the final velocity for both objects as they are stuck together, either in motion or at rest.

3. Materials and Methods

3.1. Practical Experience: Elastic Collision in Basketball Game

In Basketball game, two parameters should be fixed for the best condition of playing:

- Ground Elasticity
- Ball Elasticity

These two parameters are very important because the elasticity of the ground and ball should be fixed in a condition which after ball collision with ground, the ball returns to the normal height .In basketball game, the material which is used for ball is leather which has high

elasticity to have a good return height and also the ground material is a maple wood which has a middle elasticity so with the collision of the ball with ground, the ball will have a logical return height .

Table 1: Different types of balls

Balls			Collision Surfaces	
Type	Ball's Material	Mass (g)	Hard	Soft
Basketball	Leather and Rubber	534.3	Granite	Grass
Soccer Ball	PVC	424.5		
Volleyball	Leather	275.8		
Tennis Ball	Rubber and Cloth	55		
Ping-Pong Ball	Celluloid	1		

4. Qualitative Experiment

4.1. Test 1 – Effect of materials of surface and balls on time which balls need to run out kinetic energy

In this test, all 5 balls were released separately from constant height (167 cm from collision surface), once on hard surface and once on soft surface. After releasing, time which took from the first collision of ball with surface up to when it stops was measured.

Table 2: Effect of the material of surface and ball on time which balls need to run out kinetic energy (Test 1)

Tests	Basketball	Football	Volleyball	Tennis ball	Table tennis ball
On Grass	3.49 s	1.65 s	3.39 s	2.57 s	1.38 s
On Granite	4.99 s	1.92 s	4.11 s	3.68 s	10.59 s

4.2. Test 2 - Quantitative height measuring after first collision

In this test, 2 modes were designed to measure height which balls get after first collision.

4.2.1. Test 2.1 – Effect of the materials of surface and ball on return height

In this test, all 5 balls were released separately from constant height (167 cm from collision surface), once on hard surface and once on soft surface. After releasing, height which ball return after first collision was measured.

Table 3: Effect of surface material and ball material on return height (Test 2.1)

Tests	Basketball	Football	Volleyball	Tennis ball	Table tennis ball
On Grass	80 cm	37 cm	72 cm	63 cm	35 cm
On Granite	92 Cm	52 cm	78 cm	71 cm	97 cm

4.2.2. Test 2.2 – Effect of ball temperature on return height

In this test, tennis ball was released from constant height (167 cm from collision surface), on hard surface, once with 24 and once with -8 ℃ . After releasing, height which ball return after first collision was measured.

Table 4: Effect of ball temperature on return height(Test 2.2)

Tests	Tennis ball in 28°C	Tennis ball in -8°C
On Granite	28 cm	71 cm

4.3. Test 3 - Qualitative height measuring after first collision

In this test, 2 modes were designed to measure height which balls get after first collision

4.3.1. Test 3.1- Effect of two balls on top of each other releasing height on return quality

In this test, Tennis ball on Basketball was released concurrent from 3 different heights (49 cm, 88 cm, and 170 cm from collision surface), once on hard surface and once on soft surface. After releasing, height which tennis ball returned, because it cannot be measured, effect of changing releasing height on return quality was analyzed.

4.3.2. Test 3.2- Effect of putting 3 balls on each other on return quality

In this test, Tennis ball on Volleyball on Basketball was released concurrent from constant height (167 cm from collision surface), on soft surface. After releasing, height which tennis ball returned, because it cannot be measured, effect of putting 3 balls on each other on return quality was analyzed.

5. Quantitative Experiment

When a highly elastic super ball collides with a rigid surface how can one determine the collision time? In this problem we want to find the collision time by different methods. The definition of collision time is the time when the ball touches the surface till leaves the surface (Fig. 1).

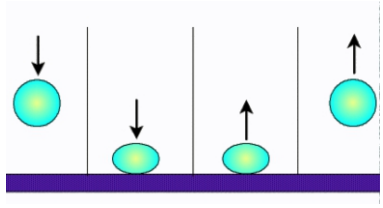

Fig. 1: Highly elastic super ball collides with a rigid surface

In inelastic collision the height of a ball when it falls, h_1 is not the same as the height it returns back, h_2 (Fig. 2).

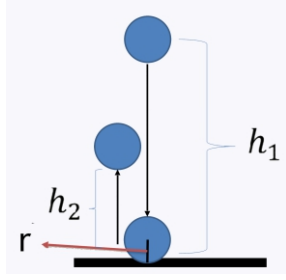

Fig. 2: Impact and return height of a ball in an inelastic collision

By the theory and experiment the collision time is measured (Eqs. 5-9).

$$mgh = \frac{1}{2}mv^2 + mgr \quad (5)$$

$$v_1 = \sqrt{2g(h_1 - r)} \quad (6)$$

$$v_2 = \sqrt{2g(h_2 - r)} \quad (7)$$

$$\left|\frac{m(v_2 - v_1)}{\Delta t}\right| = F \quad (8)$$

$$\left|\frac{mv_1(e-1)}{F}\right| = \Delta t \quad (9)$$

where;

mgr= kinetic energy
mgh = gravitational energy
h_1= Height which leaves the ball
h_2= Height which the ball comes up

Then the ratio of velocity of return ball to falling (Eq. 10) is measured.

$$\frac{v_2}{v_1} = e = \sqrt{\frac{h_2 - r}{h_1 - r}} \quad (10)$$

Theory and experiment will give the collision time as Δt when the ball is releasing from different heights (Eq. 11) (Fig. 3).

$$\left|\frac{mv_1(e-1)}{F}\right| = \Delta t \quad (11)$$

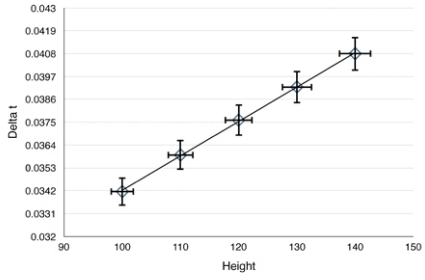

Fig. 3: The collision time vs height

we found that whenever we release the ball from higher height the time of the collision (Δt) will be more.

In the next experiment we tried the same thing on different surfaces (asphalt , stone , ceramic) (Fig. 4).

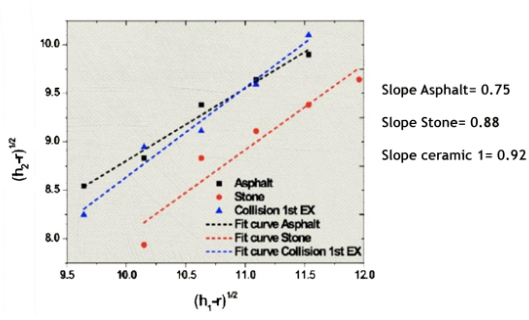

Fig 4: Collision on different materials

According to Equation (10) , in conclusion we can say that the time of a collision is different in different materials and in our experiment is like below:

Ceramic surface > stone surface > asphalt surface

6. Results and Analysis

Data which table 2 shows, basketball on the soft surface took more time to run out kinetic energy comparing with hard surface so soft surface took more energy from the basketball, so it can be said:

Granite surface has more elasticity than grass surface.

For analyzing the effect of ball material on time which balls need to run out kinetic energy , 5 balls were tested on hard surface and as data of table 2 shows , the order of the elasticity of the balls from the most to the least are:

1-Ping-Pong Ball
2-Basketball
3-Volleyball
4-Tennis Ball
5-Football

So due to table 1 (ball's material column), celluloid has the most elasticity and PVC has the least and the elasticity of materials from the most to the least can be mentioned as follows:

1-Celluloid
2-Leather and Rubber
3-Leather
4-Rubber and Cloth
5-PVC

Of course, it is obvious that the mass of the ball is also effective and depends on the material and dimensions of the ball which will be studied in our next project completely.

Data in table 4 shows, tennis ball with 24 ℃returns more comparing with tennis ball with -8 ℃ so a ball that has been placed in a cold space returns a lower height because in a cold object, due to the low molecular movement, part of the energy is used to reach environment temperature which reduces the kinetic energy for the ball's return after hitting the surface.

Qualitative analyzing shows when we drop two balls together (same balls) from a higher height, the top ball goes much higher because it stores more energy and therefore transfers more energy and the tennis ball it rises with more kinetic energy, so it will have a greater height.

By quantitative experiments we found that the collision time is increased as the height increased too.

Also in different materials the time of collision in ceramic is more than two other stone and asphalt surfaces.

6. Discussion

Elastic collisions are known as collisions which kinetic energy is equal before and after the collision but there is no purely elastic collision in the real world due to the usual wasting energy in converting potential energy into kinetic energy. So in this study , when collisions occur , due to the air resistance it is not exactly elastic collision .

Also this relationship between elasticity of ball and surface should be fixed for ball games as like as basketball. Because in sports like basketball, controlling the time and height of the ball's return after hitting the ground is an important factor in maintaining and improving the quality of the game.

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