Lab #1
Conservation of Momentum and Energy in Collisions

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Introduction

Energy is a scalar quantity measured in joules ($1\ J = 1\ N \cdot m$) that exists in various forms. Mechanical energy, which consists of kinetic energy and potential energies, can be defined as the ability to do work. For example, a flying cannonball does work on a brick wall by knocking it down thus, the cannonball possess energy. Translational kinetic energy (E_K) is the energy an object has due to its translational motion and is calculated using $E_K = \frac{1}{2}mv^2$, m being the mass of the object in kilograms and v being the speed of the object in meters per second. For example, a 1000 kg car travelling at a speed of 72 km/h has $E_K = \frac{1}{2}(1000\ kg)(20\ m/s)^2 = 200{,}000$ J. Potential energy is a stored energy and it is the energy an object has dues to its position or configuration relative to its surrounding. Specifically, gravitational potential energy (E_G) is the energy an object has due to its position above a reference level and the applied gravitational force acting on it. It is calculated using $E_G = mgh$, m being the mass of the object in kilograms, g being the acceleration due to gravity ($9.8\ m/s^2$) and h being the vertical height in meters of the object above a reference point. For example, a 5kg ball held stationary 10m above the ground has $E_G = (5\ kg)(9.8\ m/s^2)(10\ m) = 490$ J. Elastic potential energy is the energy stored in objects that are compressed or stretched. It is calculated using $E_E = \frac{1}{2}kx^2$. In terms of a simple coil spring, k is the spring stiffness constant in N/m and x is the distance in meters that the spring is stretched or compressed from its equilibrium (rest) position. For example, a spring with a stiffness constant of 10 N/m that is stretched 20 cm from its equilibrium position has $E_E = \frac{1}{2}(10\ N/m)(0.2\ m)^2 = 0.2$ J. The law of conservation of energy states that the total energy remains constant in any process. Energy can be transformed from one form into another and from one object to another, but the total amount remains unchanged. Thus, for any system the total mechanical energy is always conserved such that it neither increases or decreases, but remains constant, meaning $E_i = E_f$. For example, if a 5 kg ball is held stationary at 10 m above the ground and then dropped, the ball's total mechanical energy at the start of its process when it is stationary, which is 490 J, is equal to the ball's total mechanical energy right before it hits the ground as all of the ball's initial gravitational potential energy is converted into kinetic energy at the end.

Linear momentum is a vector quantity that describes the motion of objects, the formula is stated to be $\overline{p} = m\overline{v}$. Impulse is a change in the momentum of an object that results from an external net force. In the collision of two objects, there is a consequent collision force that acts on each object. The forces abide by Newton's third law of motion which states that for every action force there is a reaction force that is identical in magnitude and opposite in direction. It is the action and reaction force that causes a change in momentum of the objects involved in a collision. Although the momentum of each individual object changes following a collision, the law of conservation of momentum assures that the total momentum of the system is conserved. The expression for the conservation of momentum is $m_1\overline{v_{i1}} + m_2\overline{v_{i2}} = m_1\overline{v_{f1}} + m_2\overline{v_{f2}}$ and more terms can be added depending on the number of objects in the system. Two types of collisions are elastic and inelastic and they differ by the total kinetic energy of the system before and after the collision. In elastic collisions the sum of kinetic energies of each object before the collision is equal to the sum of kinetic energies after the collision. In contrast, inelastic collisions do not conserve total kinetic energy as it converts to other forms of such as sound or thermal energy.

The velocities of objects after a collisions are directly proportional to the inertia of an object. Inertia is the resistance to a change in motion, hence lighter objects with smaller inertia accelerate much faster than larger objects with larger inertia when acted on by a collision force. Therefore when a light object such as ball hits the surface of the earth the final velocity of the ball is the same in magnitude as the initial velocity but opposite in direction. This is because the very large inertia of the earth allows it go relatively unaffected by the collision.

The conduction of the experiment will test whether momentum and energy are in fact conserved in a real world situation.

Testable Question

What is the effect on the overall momentum and energy of the system when a tennis ball is dropped with a basketball in an inelastic collision ?

Hypothesis

If this is an isolated system, then momentum and energy will be conserved because of the law of conservation of momentum which states that for a collision of two objects in an isolated system the total momentum of the system will be the same before and after the collision.

Materials

- Electronic Balance
- Meter Stick
- Recording Devices (eg. GoPro, Smartphone, Video Camera etc…)
- Basketball (Well inflated)
- Tennis Ball
- Masking Tape
- Highly Visible Marker

Procedure

1. Measure and record masses of tennis ball and basketball, using electronic balance.
2. Mark every 5 cm on wall with tape and a marker to easily show height, marker line must be clear enough to be identified on the recording device upon playback.
3. Drop the basketball from height of 1 m, record the drop using recording device, and determine maximum height of bounce*, using playback of the recording.
4. Drop the Tennis ball from height of 1 m, record the drop using recording device, and determine height of bounce*, using playback of the recording.

5. Carefully place the tennis ball directly on top of basketball with the bottom of the basketball at a height of 1m drop both balls at the same time. Using 2 recording devices record i. The height the basket ball* bounces back up to after the drop ii. The height of the tennis ball^ bounces back up to after the drop. Record these values, note tennis ball's height will be height recorded minus the diameter of the basketball.
6. Repeat steps (3-5) at least 3 times EACH and average results..

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Procedure Appendix:

*: All measurements are to be recorded from the bottommost point on said object.

^: Calculations that use the height of the tennis ball when dropped with basket ball will be the value recorded height less diameter of the basketball.

Observations

Combined Drop	Mass	Trial 1	Trial 2	Trial 3	Avg.
Basketball	0.625 kg	0.497m	0.391m	0.368m	0.419m
Tennis ball	0.0561 kg	3.02m	3.15m	3.06m	3.08m

Individual drops	Trial 1	Trial 2	Avg.
Basketball	0.741m	0.754m	0.747m
Tennis ball	0.575m	0.599m	0.587m

Initial momentum (before collision): 2.519 kgm/s
Final momentum (after collision): 2.252 kgm/s
% Error: 10.60%

Initial energy (using gravitational potential energies at the start): 6.675J
Final energy (using gravitational potential energies from each ball's max height): 4.317J
% Efficiency: 64.68% (35.32% lost)

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Basketball only:
Initial energy (using gravitational potential energy at the start): 6.125J
Final energy (using gravitational potential energy at its max height after bounce: 4.579J
% Efficiency: 74.76% (25.24% lost)

Tennis ball only:
Initial energy (using gravitational potential energy at the start): 0.550J
Final energy (using gravitational potential energy at its max height after bounce: 0.323J
% Efficiency: 58.72% (41.27% lost)

Conclusion

It was determined from the data collected in the lab that kinetic energy was not conserved. This is due to the inelasticity of the collision itself and multiple variables including, but not limited to, recording velocity in one dimension, the conversion of energy to sound and rotational energy and neglecting air resistance and friction. Momentum however was conserved within reasonable error. This reasonable error is likely to be caused by our recording of velocities in one dimension when in reality three dimensions are required for exact results. From this information we can reason that the kinetic energy of the system in an inelastic collision is not conserved and that momentum should be, just as the law of conservation of momentum states.

Reference

Giancoli, D. (2009). *Giancoli Physics* (Sixth ed.). Upper Saddle River, New Jersey: Pearson Education.

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