**IMROVEMENT LINK**

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Introduction

* Summer Olympics Paris 2024
  + Many Sports
  + Many Variables that affect the sport such as equipment
  + Equipment should be equal / remain constant in different occasions to reflect the pure athletic potential and power of the Olympians
  + To make sure the performance of the Olympians is not influenced by other factors rather than their Ability to achieve the best in their sport
  + This can be observed through a football match between two teams
    - Where both teams have same variables in Equipment such as:
      * Football Field Size
      * Goal Size
      * Football Size
      * Football Shape
      * Football Internal Pressure
  + The most important / Tricky variable in Equipment in a Football match is the Football Size, Shape and internal Pressure,
  + This which influences the elasticity of the Football which converts to the change in its Bounce height, rebound height, grip, stability, trajectory, speed, control & durability during the minutes of the match.
* Hence, I wanted to test and observe the Relationship between the internal pressure and the elasticity of a football
  + This could be achieved by using the same initial Drop height and horizontal displacement of the Football, the surface the football bounces on and the Pressure and Temperature of the Surroundings

How does the internal pressure of a football affect its rebound height at six consecutive bounces to essentially determine its influence on the elasticity of the football through measurements of its consecutive coefficients of restitution?

Variables:

• Independent Variable:

o The internal air pressure of the football

• Dependent Variable: Max. Rebound height reached by the football

• Control Variables: initial Drop height, Surface football bounces on, Horizontal displacement of football, Position of camera recording football bounces, Pressure and temperature of surroundings

Background INFO

BEFORE COLLISION WITH THE GROUND (123 PDF)

* Kinetic Energy
  + Definition of Kinetic Energy
  + Connection to the experiment
    - As the object falls, in this case the Volleyball, the Kinetic energy increases, according to the Kinetic energy formula: ½ mv2 when the mass is the constant, and the v in the formula increases, the kinetic energy of the object increases.
* Gravitational potential energy
  + Definition of Gravitational potential energy
  + Connection to the experiment
    - As the object falls, in this case the Volleyball, the GPE decreases, according to the GPE Formula: mgh, when g and m are held as a constant while the object is falling, the deciding factor of the equation becomes the h which decreases when the objects fall and comes closer to the ground
* Conservation of Energy
  + Conservation of Energy Definition
  + Connection to the experiment
    - When the object falls, in this case the Volleyball, the Total Energy = Mechanical Energy used to get the ball from the initial height to the final height is equal to the sum of KE and GPE.
    - Before the Object falls the GPE is at its maximum, because the object is at maximum height and the KE is 0, because the object is at its minimum velocity which is 0 m/s.
    - When the object is released, the GPE gradually decreases in favor for the KE
    - In other words, there is a transition between GPE and KE
    - KE increases because the object accelerates downwards which increases the velocity of the object and the GPE decreases because the height decreases.
    - Right before the Collision with the ground, the GPE is entirely converted to KE
    - That means that the Total Energy of the Object Is constant, and the Total Energy of the System is Conserved

DURING THE COLLISION WITH THE GROUND

* Elasticity Definition
  + Restoring Force Definition (Hooke’s law)
  + The Ball will push the ground with equal and opposite restoring force proportional to its displacement from the equilibrium
* Connection to the Experiment
  + According to Hooke’s law, when distorting an elastic object from its equilibrium shape by extending or contracting the object, work must be done.
  + The Elastic Potential Energy is the energy stored in the object after extending or contracting it
  + The Elasticity of the ball comes from the elasticity of the material which comes due to the intermolecular force inside of the ball. The Intermolecular force inside of the ball is caused by the pressure of air inside the ball
* Pressure:
  + Definition of Pressure
    - Pressure is the Force exerted by a fluid on a unit area of a surface.
  + Connection to the Experiment
    - By pumping air into a Volleyball, the pressure inside of the ball increases which results to an increase in ball elasticity.
    - The Elasticity increases due to the difference between the air pressure inside of the ball and outside of the ball.
* Conservation of Energy2
  + As mentioned before the ball has gained KE, thus according to Newton’s 3rd law of motion, the ball exerts force on the ground which leads the ground to exert an equal and opposite force on the ball.
  + The Ball is compressed / Deformed which leads into an increase in the elastic potential energy according to Hooke’s law and thus the KE that the ball gained before the collision converts partially into elastic potential Energy during the Collision with the ground.
  + Some of the KE is lost due to converting the KE into thermal Energy (due to internal friction of the material’s particles), sound etc.
    - At some point the pressure inside of the ball doesn’t let the ball to be deformed, because the internal forces of the molecules are high thus resisting being compressed / Deformed
    - This Leads to less loss in energy because the object goes back to the equilibrium position more efficiently
* The Ball comes momentarily at rest

AFTER THE COLLSION WITH THE GROUND

* The same reaction that happened when the ball was released will happen again but with descending order
* The Elastic Potential Energy from the ball will deform the ball into re-expanding and going to its equilibrium
* The Elastic Potential Energy will convert into KE which will be at it maximum and decreases gradually in favor of the GPE which will be at its minimum and will increase as the ball goes higher up.
* The Law of Conservation of Energy is also seen here
* Some of the Elastic potential Energy get lost again due to thermal energy, friction or sound, which leads to the loss of some GPE and KE so that the ball won’t go back to its original height. This could be seen through calculating the coefficient of restitution.
* At the highest point at which the ball will be at v=0 it’s Kinetic Energy will be 0 and the Gravitational potential energy will be at its maximum

Coefficient of restitution:

* The Coefficient of restitution is the ratio of the final velocity to the initial velocity between two objects after their collision
* The Coefficient of restitution is the ratio of the velocity components along the normal plane of contact after and before the collision
* The Coefficient of restitution measures the elasticity of the collision
* Connection to Experiment
  + There are 3 types of elasticity in a collision
    - Perfectly inelastic collisions where the coefficient of restitution is equal to 0 where the maximum Kinetic Energy is lost (Different speed results to different KE)
    - Perfectly elastic collisions where the coefficient of restitution is equal to 1 where no Kinetic energy is lost (same speed results in same KE)
    - Inelastic collisions where the coefficient of restitution will be between 0 and 1

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Description automatically generated

In order to quantify the elasticity of the football - its tendency to return back to its original shape after being compressed.

Where:

The Independant variable of the experiment is the internal air pressure of the football that will be changed six times in the following pressures: 2.9 psi, 5.8 psi, 8.7 psi, 11.6 psi, 14.5 psi, 17.4 psi converted to 20kPA, 40kPA, 60kPA, 80 kPa, 100kPa & 120 kPa

Through the information in the Background information we can hypothesis, that as the internal pressure of a football increases, the rebound height over six consecutive bounces will increase, because the heigher the pressure is, the heigher the intermolecular forces in the ball is, thus enhances the elasticity of the ball which leds to a more effeicient energy transfer during the collisions with the ground. Thus, the coefficient of restitution will be higher at at heigher pressures. In other word, both the coefficient of restitution and the pressure inside of the ball have a linear increasing rate. Holding into account the smaller effect of the intermolecular Forces of the ball on it's coeffiecient of restitution, the graph will start decreasing after one point and continues to decrease to tend towards a limit

Figure 2: Hypothetical relationship between the Pressure and the coefficient of restitution (self-designed using GeoGebra & Canva)

**Table 1: Independent and Dependent Variables**

| **Variables** | **Explanation** | **Apparatus** | **Justification** |
| --- | --- | --- | --- |
| **Independent variable** | Internal pressure of the football | Pressure gauge (±0.01 bar)  Football pump with a needle attachment | The internal pressure directly impacts the elasticity of the football, which determines its ability to rebound effectively. |
| **Dependent variable** | Rebound height of the football over five consecutive bounces, used to calculate coefficients of restitution. | High-speed camera or video analysis software (*e.g., Tracker* ±0.001 m)  Ruler or measuring tape (±0.001 m) for calibration purposes | The rebound height provides measurable data to analyze how internal pressure influences the energy retained after each bounce. |

**Table 2: Controlled Variables**

| **Variable** | **Significance** | **Means of control** | **Justification** |
| --- | --- | --- | --- |
| **Type of football** | The material and surface of the football affect its elasticity and interaction with the surface. | Use the same football for all trials. | Changing the type of football would introduce additional variables, making it difficult to isolate the effect of internal pressure. |
| **Drop height** | Ensures consistent initial potential energy for all trials, affecting the rebound height. | Measure and release the football from a fixed height using a stand (e.g., 1.500 ± 0.001 m). | Consistent drop height ensures that the same initial potential energy is provided to each trial. |
| **Surface of impact** | Variations in the surface (e.g., hardness, friction) can influence energy loss during collisions. | Conduct the experiment on a flat, hard surface (e.g., concrete). | A uniform surface minimizes variability in energy transfer, ensuring rebound heights are influenced only by internal pressure. |
| **Temperature** | The elasticity of the football material and air inside varies with temperature. | Conduct the experiment in a controlled room temperature (e.g., 20.0 ± 0.1°C). | Elasticity and air pressure are highly sensitive to temperature, so maintaining a constant temperature ensures valid comparisons. |
| **Humidity** | Humidity can affect the material properties of the football and the surface. | Conduct the experiment in a controlled indoor environment to minimize humidity variations. | Humidity could alter the properties of both the football and the impact surface, affecting the rebound height. |
| **Air composition** | Variations in the type of gas used for inflation (e.g., air vs. nitrogen) affect the internal pressure and elasticity. | Inflate the football with standard air (composition ≈ 78% nitrogen, 21% oxygen). | Using the same air composition eliminates variability in the elasticity due to differences in the gas mixture. |
| **Video analysis setup** | Variations in camera angle, lighting, or calibration can introduce errors in data collection. | Maintain consistent camera angle, height, and lighting. Calibrate the software with a known length. | A consistent video setup ensures accurate and precise measurements of rebound height across all trials. |
| **Bounce sequence timing** | Intervals between bounces could affect measurements due to football deformation recovery. | Allow the ball to complete all bounces in one sequence before measuring. | Consistent bounce timing ensures that deformation recovery is the same across trials, minimizing variability in results. |

**Table 3: Uncontrolled Variables**

| **Variable** | **Significance** | **Justification** |
| --- | --- | --- |
| **Environmental factors** | Minor air currents, vibrations, or external noise might affect the rebound motion. | These factors are difficult to eliminate in a standard laboratory environment but are assumed to have minimal impact on the overall trends in data. |
| **Material aging** | Repeated trials might degrade the football’s elasticity slightly, impacting results over time. | While degradation may occur, it is assumed to be negligible within the timescale of the experiment. |
| **Surface imperfections** | Uneven surfaces or hidden imperfections on the football could cause slight deviations in rebound height. | Surface irregularities are assumed to be randomly distributed and thus would not introduce systematic errors into the experiment. |
|  |  |  |

PSI List

5.2 = 35.85

4.5 = 31.02

3.5 = 24.13

2.5 = 17.23

2.0 = 13.78

5.2 psi, 4.5 psi, 3.5 psi, 2.5 psi, 2.0 psi

On the other hand, since the Gravitational Field strength and the mass of the object are held constant while the object is falling, t

Processing DATA

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