APPLICATION OF PHYSICS PRINCIPLES IN THE DESIGN OF A MODEL ROLLER COASTER

A Project Report

Submitted to

Department of STEM

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Submitted by

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Acknowledgment

I would like to express my sincere appreciation to the STEM department for providing me the opportunity to undertake this independent project entitled *Application of Physics Principles in the Design of a Model Roller Coaster*. This project has greatly enhanced my understanding of fundamental physics concepts and their practical application in real world engineering designs.

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Letter of Approval

This is to certify that this project prepared by **SUBIGYA RAJ KHAREL** entitled **"APPLICATION OF PHYSICS PRINCIPLES IN THE DESIGN OF A MODEL ROLLER COASTER"** has been well studied. In our opinion, it is satisfactory in the scope and quality as a project for the required academic level.

<u>Evaluation Committee</u>

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Ankur Raj Upadhyay	Bipin Rijal
Supervisor	**External Examiner**

Date: 03/09/2026

ABSTRACT

Roller coasters are one of the most popular amusement rides, yet their operation is strongly governed by fundamental principles of physics such as gravity, motion, and conservation of energy. Understanding how these principles work in real situations helps bridge the gap between theoretical physics learned in classrooms and practical engineering applications. The motivation behind this project is to demonstrate how basic physics concepts can be applied in the design of a roller coaster system. In this project, a physical model of a roller coaster track consisting of a tall initial hill, a descending dip, and a smaller subsequent hill supported by vertical stands was designed to study how changes in height affect the motion of a moving object.

To conduct the investigation, a toy car was released from different starting heights on the first hill of the model roller coaster track, and the height reached by the car on the following hill was observed and recorded. This allowed the conversion between gravitational potential energy and kinetic energy to be analyzed during the motion of the car along the curved metal track. The observations showed that the car consistently reached a lower height than its starting point due to energy loss caused by friction and air resistance, while still demonstrating the transformation of potential energy into kinetic energy and back again. The results confirm the principle of conservation of mechanical energy and illustrate how roller coaster designs rely on physics to control motion safely and efficiently. This model demonstrates how simplified experimental setups can effectively represent real engineering systems and help students understand the practical applications of physics principles.

Keywords: roller coaster model; conservation of energy; gravitational potential energy; kinetic energy; motion; friction; physics application

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CHAPTER I

1 Introduction

A roller coaster is a type of amusement ride in which a vehicle moves along a specially designed track consisting of hills, slopes, curves, and dips. The motion of the roller coaster is primarily controlled by gravity and the conversion of energy as the vehicle travels along the track. When the coaster begins from a high point, it possesses gravitational potential energy [1]. As it descends the slope, this potential energy is converted into kinetic energy, causing the vehicle to accelerate [1,2]. This continuous transformation of energy allows the coaster to move through the track without constant external power. Roller coasters therefore provide an excellent real-world example of the application of fundamental physics principles such as motion, gravity, and conservation of energy [1].

The concept of roller coasters has evolved significantly over time. The earliest forms of roller coaster-like rides can be traced back to the "Russian Mountains" built in the 17th century in Russia [4]. These structures consisted of large wooden slides covered with ice, where riders would slide down using sleds. During the 19th century, the idea spread to Europe and later to the United States, where engineers began constructing wheeled vehicles that ran along wooden tracks. Over time, advancements in engineering and technology led to the development of more complex roller coasters made of steel with sophisticated safety systems [4]. Today, roller coasters are found in amusement parks across the world and are designed using advanced computer simulations and engineering techniques.

The design and construction of a roller coaster require careful consideration of several physical factors. Engineers must ensure that the height of the first hill is sufficient to provide the energy needed for the entire ride [2]. The shape of the track, including slopes and curves, must be carefully designed to maintain safe speeds while still providing excitement for riders. Materials such as steel and wood are commonly used to construct the tracks and support structures, ensuring both strength and durability. Modern roller coaster design also relies heavily on physics calculations to determine forces, speeds, and energy transformations throughout the ride [3].

Roller coasters are significant not only as sources of entertainment but also as practical examples of applied science and engineering. They demonstrate how theoretical principles of physics can be used to solve real-world problems in transportation, safety, and mechanical design. By studying roller coasters, students and engineers can better understand how energy, motion, and forces interact within a dynamic system. The model roller coaster constructed in this project serves as a simplified representation of these principles, allowing the concepts of energy transformation and motion to be observed and analyzed in a controlled experimental setup.

1.1 Real-World Engineering Applications of Roller Coasters

Roller coasters are highly engineered amusement rides that demonstrate the practical application of scientific and engineering principles. When designing a roller coaster, engineers must very carefully plan the structure of the track so that the vehicle moves smoothly while maintaining safe speeds throughout the ride. The height of the first hill, the steepness of the slopes, and the curvature of the track all influence how the coaster moves [1]. Engineers analyze these factors to ensure that the vehicle can travel through the entire track using the energy it gains from the initial height. Proper design also helps prevent excessive speeds that could cause discomfort or safety risks for riders.

Modern roller coaster construction involves the use of strong materials such as steel and reinforced structures that can support both the track and the forces produced during motion [4]. Engineers must consider structural stability, rider safety, and the durability of the materials used. The track is supported by a framework of beams and columns that hold the rails firmly in position while allowing the vehicle to move freely along the path. In addition, safety mechanisms such as secure wheel assemblies, braking systems, and track restraints are incorporated into the design to ensure that the ride operates safely under different conditions.

Before a full scale roller coaster is built, engineers often test their designs through computer simulations and scaled physical models [3]. These preliminary models allow designers to observe how the vehicle will move along the track and whether the design meets safety and performance requirements. By studying these smaller systems, engineers can identify potential design issues and improve the layout before constructing the actual ride. This process demonstrates how theoretical knowledge from physics and engineering is applied in real-world situations to create safe and efficient amusement rides.

1.2 Energy and Motion in Roller Coasters

The motion of a roller coaster is primarily controlled by the interaction between gravity and the energy possessed by the moving vehicle. At the beginning of a ride, the coaster is lifted to a high point on the track, which gives it stored energy due to its height above the ground [1]. As the coaster moves down the slope, this stored energy is converted into motion, allowing the vehicle to accelerate along the track. When the coaster climbs another hill, part of this motion is converted back into stored energy as the height increases again. This continuous change between stored energy and motion enables the coaster to travel through the track without requiring constant external power.

The design of a roller coaster track must therefore take into account how energy changes throughout the ride. The first hill is usually the highest point because it provides the energy needed for the rest of the track. As the vehicle moves through slopes and curves, some of this energy is gradually lost due to friction between the wheels and the track, as well as air resistance [2, 3]. Engineers must carefully design the track so that the vehicle still has enough energy to complete the entire course safely. Understanding these energy changes is essential for explaining how roller coasters operate and why their tracks are designed with specific heights and shapes.

CHAPTER II

2 Objectives

1. To design and construct a model roller coaster that represents the basic structure of a real roller coaster track

2. To demonstrate the transformation between gravitational potential energy and kinetic energy during the motion of a car along the roller coaster track

3. To investigate how the starting height of the car influences the height it reaches after descending and climbing the track

4. To observe the effects of friction and other energy losses on the motion of the car in the model roller coaster system

CHAPTER III

3 Theory

The motion of a roller coaster can be explained using fundamental principles of physics, particularly the concepts of energy and motion. A roller coaster vehicle moves along a track mainly due to the influence of gravity and the design of the track itself. When the vehicle begins at a high point on the track, it possesses stored energy due to its height above the ground. As the vehicle moves downward along the slope, this stored energy begins to convert into energy of motion, causing the vehicle to accelerate. When the vehicle climbs another section of the track, its motion slows down as some of its energy is converted back into stored energy due to the increase in height. This continuous transformation between different forms of energy is what allows the roller coaster to travel through the track without requiring continuous external power.

One of the key forms of energy involved in this process is gravitational potential energy. Gravitational potential energy is the energy that an object possesses due to its position or height relative to a reference level [1]. The higher an object is positioned, the greater the gravitational potential energy it possesses. In the context of a roller coaster, the car placed at the top of the first hill has the maximum gravitational potential energy because it is at the greatest height above the ground. The gravitational potential energy of an object can be expressed using the relation $PE = m \times g \times h$ [1], where m represents the mass of the object, g represents the acceleration due to gravity, and h represents the height of the object above the reference level.

As the roller coaster car begins to move down the slope, its gravitational potential energy is gradually converted into kinetic energy [1, 2]. Kinetic energy is the energy that an object possesses due to its motion. The faster the object moves, the greater its kinetic energy. At the lowest point of the roller coaster track, the speed of the car is at its highest, and therefore the kinetic energy is at its maximum. The kinetic energy of a moving object can be represented by the expression $KE = \frac{1}{2} \times mv^2$ [1], where m represents the mass of the object and v represents its velocity. This relationship shows that the kinetic energy of an object increases rapidly as its speed increases.

The relationship between potential energy and kinetic energy in a roller coaster is explained by the law of conservation of energy. According to this law, energy cannot be created or destroyed; it can only be transformed from one form to another [1, 3]. In an ideal system with no energy losses, the total mechanical energy of the roller coaster would remain constant throughout the motion. Mechanical energy is defined as the sum of gravitational potential energy and kinetic energy. As the roller coaster car moves along the track, potential energy decreases while kinetic energy increases, and vice versa. However, the total amount of energy in the system remains the same.

In real systems, however, some energy is lost due to external factors such as friction and air resistance. Friction occurs between the wheels of the roller coaster car and the metal rails of the track, while air resistance acts against the motion of the moving vehicle. These forces convert a portion of the mechanical energy into heat and sound energy. As a result, the roller coaster car does not return to exactly the same height from which it started. Instead, it reaches a slightly lower height on the following hill because part of the original energy has been dissipated.

In the model roller coaster used in this project, these theoretical concepts can be observed in a simplified form. When the toy car is released from a certain height on the first hill of the track, it initially possesses gravitational potential energy. As the car moves down the slope, this energy is converted into kinetic energy, causing the car to move faster. When the car begins to climb the second hill, some of the kinetic energy is converted back into gravitational potential energy. The maximum height reached by the car on the second hill depends on the amount of energy remaining after losses due to friction and other resistive forces. By observing how the car moves along the track and measuring the heights involved, the principles of energy transformation and conservation can be demonstrated using this model system.

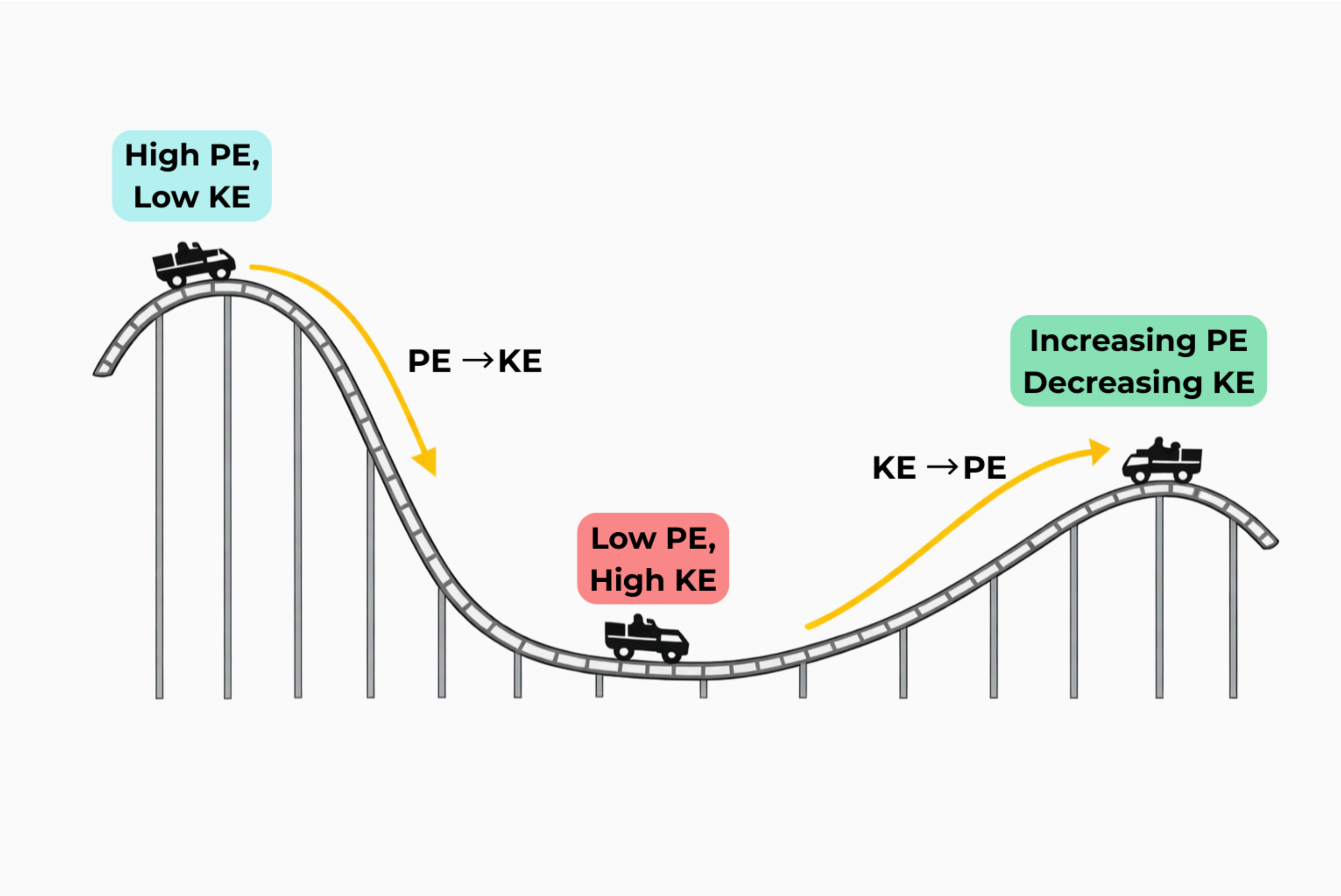

Figure 1: Diagram showing the conversion of potential energy and kinetic energy in the roller coaster model

Figure 1 illustrates the transformation of gravitational potential energy into kinetic energy as the car moves along the roller coaster track and then converts part of that kinetic energy back into potential energy while climbing the second hill.

CHAPTER IV

4 Material Required and Methodology

The materials required for this project are illustrated in the table below:

S.N	Material	Specification / Measurement	Purpose
1	Metal rods	Total track length: 2 m	Forms the roller coaster track
2	Metal rods (rails)	Thickness: 5 mm	Provides strength and smooth movement
3	Rail spacing	7.4 cm (center to center)	Allows the toy car wheels to move properly on the track
4	Cross ties	Spacing: 25 cm	Maintains equal distance between rails
5	Cardboard pieces	14 pieces of 4 cm length and 1 cm breadth	To further enhance the rail spacing
6	Metal pillars	Maximum height: 42 cm	Creates elevation for hills
7	Second hill support	Height: 34 cm	Forms the smaller hill in the track
8	Toy car	Wheel span approx. 9 cm	Moves along the track to demonstrate motion
9	Ruler	Measurement tool	Used for measuring heights and distances
10	Spray Paint (Black)	Polishing the looks of the model	Used to refine and increase the visual appeal of the model
11	Hot glue gun	1 Refill Stick	To glue the cardboard pieces to the metal structure

The model roller coaster track was constructed using two parallel metal rods welded together to form a rigid iron frame. The metal rods had a thickness of 5 mm and were positioned at a center to center spacing of 7.4 cm so that the wheels of a toy car could move along the track. Cross ties made from the same metal material were welded between the rails at intervals of approximately 25 cm to maintain a consistent distance between the rails and provide structural stability.

The track structure was supported by welded metal stands positioned at different points along the track to create changes in elevation. The overall length of the track was approximately 2 meters. The first hill was constructed with a height of 42 cm and served as the primary starting point of the roller coaster. After descending from this height, the track formed a valley and then rose again to form a second hill with a height of 34 cm before descending toward the final section of the track. These variations in height allowed the model to demonstrate the conversion of potential energy to kinetic energy during motion.

After the metal frame was fabricated, the entire structure was spray painted black. This coating helped protect the metal surface from corrosion and provided a smoother contact surface for the toy car wheels, which improved the overall movement of the car along the rails. It also enhanced the visual appeal of the coaster itself.

14 pieces of cardboard, each of 4 cm length and 1 cm breadth, were cut and then folded longitudinally. The pieces were then stuck in between the metal cross-ties from beneath the arch of the model. This was done to ensure that the wheels of the toy car were not stuck in between the spacing between the metal cross-ties.

Before conducting the experiment, the heights of the hills and the total length of the track were measured using a ruler to ensure that the structure matched the intended design specifications. Observation points were identified along the track to monitor the motion of the car during the experiment.

During the experiment, the toy car was placed at the top of the first hill and released without applying any external force. The motion of the car along the track occurred due to gravitational force. As the car moved down the first slope, gravitational potential energy decreased and was converted into kinetic energy, causing the car to accelerate. The maximum speed of the car occurred near the lowest point of the track.

When the car moved upward toward the second hill, its speed gradually decreased as kinetic energy was converted back into gravitational potential energy. Due to friction between the wheels and the rails and minor air resistance, the car did not reach the same height as the starting point. The car continued moving along the track until it eventually slowed down toward the end section.

The experiment was repeated several times to ensure consistent observations. The motion of the car along the track was observed and recorded to analyze how changes in height influenced the conversion of gravitational potential energy and kinetic energy in the roller coaster system.

Figure 2: Photograph of the toy car used

CHAPTER V

5 Results and Discussion

The experiment was conducted by releasing the toy car from two different starting points on the model roller coaster. The first starting point was the top of the first hill with a height of 42 cm, while the second starting point was the top of the second hill with a height of 34 cm. The motion of the car along the track was observed and the height reached after descending and climbing the track was recorded. Each starting position was tested multiple times to ensure reliability of the observations.

Trial	Starting Point	Starting Height (cm)	Maximum Height Reached After Dip (cm)	Time Taken (s)	Observation
1	First Hill	42	31	1.41	Car gained high speed and climbed most of the second hill
2	First Hill	42	30	1.43	Slight variation due to friction
3	First Hill	42	31	1.4	Motion remained consistent
4	Second Hill	34	20	1.18	Car climbed only a smaller portion of the track
5	Second Hill	34	19	1.2	Reduced height due to lower initial energy
6	Second Hill	34	20	1.19	Motion consistent with previous trial

From the results it can be observed that the starting height significantly affects the motion of the car along the roller coaster track. When the car starts from the first hill at a height of 42 cm, it possesses greater gravitational potential energy. As the car descends the slope, this energy is converted into kinetic energy, causing the car to accelerate rapidly. At the lowest point of the track, the car reaches its maximum speed.

When the car climbs the second hill, part of the kinetic energy is converted back into gravitational potential energy. However, the car does not reach the same height as its starting point. In the trials starting from the 42 cm hill, the car reached approximately 30–31 cm on the second hill. This difference occurs because some mechanical energy is lost due to friction between the wheels and the rails as well as air resistance.

When the car starts from the second hill at a height of 34 cm, the initial gravitational potential energy is lower. As a result, the car gains less kinetic energy while descending and therefore climbs a smaller height afterward. The results show that the car reached approximately 19–20 cm in these trials.

These observations demonstrate the transformation of gravitational potential energy into kinetic energy and back into potential energy as the car moves along the track. Although some energy is lost due to friction and air resistance, the overall motion clearly follows the principle of conservation of mechanical energy.

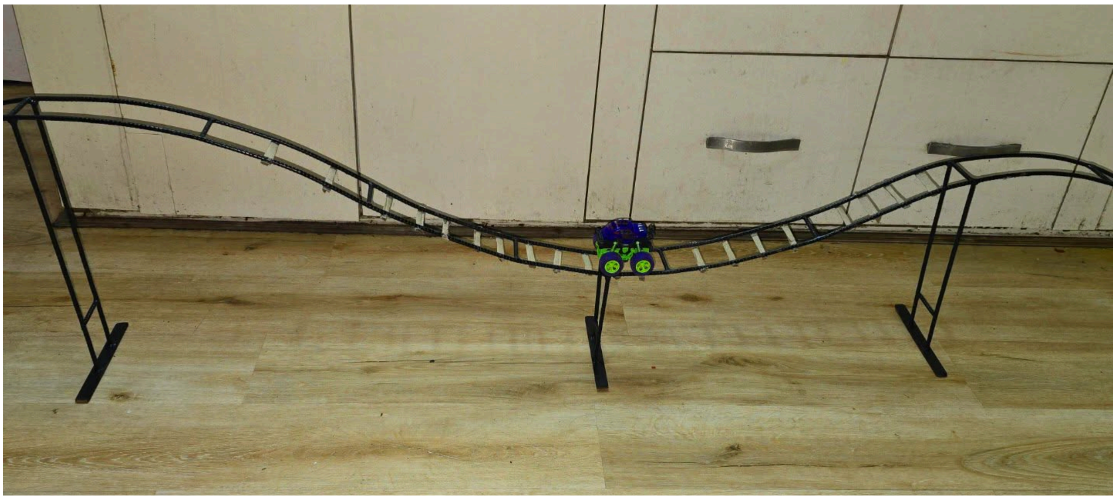

Figure 3: Photograph of the constructed model roller coaster used in the experiment

Figure 3 shows the constructed model roller coaster used in the experiment. The structure consists of two elevated hills connected by a downward slope and supported by vertical pillars. The design allows the motion of the toy car to illustrate the energy transformations described in this investigation.

CHAPTER VI

6 Conclusions

The model roller coaster successfully demonstrated the fundamental physics principles involved in the motion of roller coasters, particularly the transformation and conservation of energy. By releasing the toy car from two different starting heights of 42 cm and 34 cm, the experiment clearly showed how gravitational potential energy is converted into kinetic energy as the car moves down the track and then converted back into potential energy as the car climbs the following hill. The observations confirmed that a greater starting height results in greater initial potential energy, allowing the car to reach a higher point after descending the slope.

The results also showed that the car did not reach the same height as its starting point due to energy losses caused by friction between the wheels and the rails as well as air resistance. These factors reduced the total mechanical energy available in the system. Despite these losses, the experiment clearly illustrated the principle of conservation of mechanical energy and demonstrated how roller coaster motion can be explained using basic physics concepts. Therefore, the constructed model effectively served as a practical representation of how energy transformations govern the design and operation of roller coasters.

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