# Short Video Projects on Physics Education: The Physics of a Roller Coaster


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# Abstract

Learning physics for the first time is not the most intuitive concept. Whether you are learning kinematics, rotational motion, electromagnetism or even quantum mechanics, the materials that one is provided in class may not be enough for a student to grasp the concepts. The goal of this project is to assist students learning physics through the multimedia platform like YouTube with interactive videos. The aim is to create physics demonstrations on a multimedia platform to teach introductory physics concepts in an engaging and simplistic manner. In this project, we have adopted a roller coaster as a model system to teach force and energy conceptually.

# Acknowledgements

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# 1 Introduction

Have you ever wondered what is the most effective way to teach students? Is it through lectures, problem solving, or exams? What if instead of teaching students in these traditional ways of learning there was another option? In the past decade, with the development of interactive multimedia, the use of video education has come to the forefront of teachers and professors' minds globally [5].

With the increasing use of technology in education, online resources have become a vital part of learning. Since being developed in 2005, YouTube has offered interactive short videos on to teach students a myriad of topics. As one of the most popular online platforms for accessible education, YouTube hosts millions of videos including many for introductory physics concepts allowing students all over the world to access educational content at the click of a button [5]. This approach has proven to be an effective way of enhancing students' understanding of physics, as it allows them to visualize and engage with the concepts in a more meaningful way.

Video-based instruction is extremely effective because it provides a visual and auditory experience for abstract concepts. Additionally, videos that allow for interaction have the potential to promote active learning, which can lead to better retention of information. Interactive videos also provide immediate feedback, allowing students to correct their misconceptions in real-time, which can further enhance their understanding of the subject matter [6].

Furthermore, YouTube's accessibility and convenience make it an ideal platform for learning. With over 2 billion active users, YouTube provides a vast array of videos that can be accessed by anyone with an internet connection. In addition, YouTube's algorithms provide personalized recommendations that can help students discover new videos related to the concepts they are studying. This feature allows students to explore physics concepts at their own pace and on their own terms.

In this project, six videos have been developed, and five videos have been produced to be utilized by students around the world to learn about Newton's Laws, energy conservation principles, kinematics, projectile motion, and rotational motion. These videos are based off of the roller coaster demonstration. The goal of this project is to further assist students in learning these concepts with accessible and interactive material.

# 2 Background

In recent years, there has been an increasing trend towards using interactive media to enhance students' learning experiences. Interactive media can provide students with an immersive learning experience that allows them to engage with concepts in a more meaningful way [7]. YouTube, in particular, has emerged as a popular platform for educational videos due to its accessibility and ease of use.

## 2.1 Multimedia Education

Multimedia use within the classroom setting has been on the rise with the intent to better student learning outcomes. In traditional classroom settings, students learn mostly via lecture which is completely auditory. According to Computer technology research (CTR), people can only remember 20 percent of material from fully visual learning and 30 percent from fully auditory learning. Yet when visual and auditory learning are heavily combined with multimedia videos, it can be seen that people can remember 80 percent of the information that is presented. [8].

This provides evidence that the integration of multimedia has been shown to have a positive impact on student learning outcomes, engagement, and motivation. Past case studies on the implementation of video learning with traditional learning have shown to improve students' overall understanding of concepts [8]. Videos can provide students with visual and auditory stimulation, making it easier for them to process and retain information. Additionally, videos can provide a platform for interactive learning and discussion.

In the field of physics education, the use of videos has become a popular tool to enhance introductory physics courses. Videos can be used to introduce students to fundamental concepts and principles, providing visual demonstrations that help to illustrate and reinforce delivered concepts. The visual and interactive nature of videos can help students develop a deeper understanding of physics concepts, as they can see them in action and observe how they apply in real-world scenarios [9].

Videos can also be used to assist in problem-solving exercises. By watching videos of physics problems being solved, students can learn problem-solving strategies and techniques. This approach has been shown to improve students' problem-solving abilities and confidence in their abilities to tackle complex physics problems.

One of the main advantages of using videos in introductory physics courses is their accessibility. Videos can be accessed at any time, providing students with the flexibility to review concepts at their own pace and convenience [5]. This is particularly beneficial for students who may struggle with traditional lecture-based learning, as videos provide an alternative learning format that is more engaging and interactive.

Moreover, the use of videos in physics education can help to bridge the gap between theoretical concepts and real-world applications. By providing students with visual demonstrations of how physics principles apply in the real world, students can develop a deeper appreciation and understanding of the relevance of physics to everyday life.

## 2.2 Developing Interactive Educational Content

One example of developing an interactive video education was studied by faculty at Universitas Lambung Mangkurat. A set of teachers made an interactive media platform on the topics of kinetic gas theory to see if this form of multimedia education benefited the students learning [8].

The video was designed to teach senior high school students about the concept of sound waves and how they are affected by changes in temperature and pressure. The video consisted of interactive animations and simulations that allowed students to explore the physics concepts in a visual and engaging way. The video also included interactive quiz questions that allowed students to test their understanding of the concepts covered in the video.

The development of the video was informed by the principles of multimedia learning, which emphasize the importance of providing students with engaging and interactive learning experiences. The video was designed to be accessible to students with varying levels of prior knowledge and was structured to facilitate active learning and engagement.

To evaluate the effectiveness of the video, the researchers conducted a pre-test and post-test study with a group of senior high school students. The results showed a significant improvement in students' understanding of the physics concepts covered in the video, with students reporting a greater level of engagement and motivation when learning through the video [8].

The success of this video highlights the potential of interactive multimedia as a tool for enhancing physics education. By providing students with engaging and interactive learning experiences, videos can help to improve student learning outcomes and facilitate deeper understanding of complex physics concepts. Furthermore, the accessibility of videos makes them a valuable tool for reaching a wider audience and promoting a more inclusive learning environment.

## 2.3 Roller Coaster Demonstration

One commonly used demonstration to show basic mechanical physics principles is the roller coaster track. Shown in Figure 1, the roller coaster track is constructed of two wood boards in an L shape with a metal track attached. The metal track has a long down slope then a loop followed by an up slope portion that is the same height as the loop.

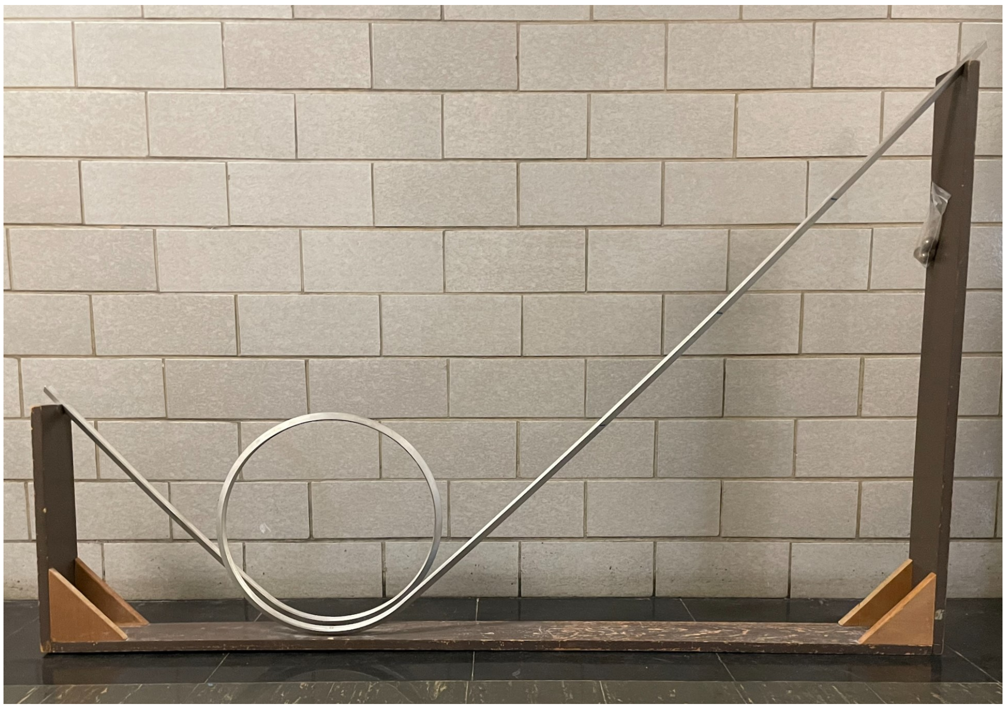


Figure 1: Roller Coaster Track

The purpose of this demonstration is to teach students about Newton's Laws, energy conservation, kinematics, rotational motion, and projectile motion.

### 2.3.1 Newton's Laws

The created videos emphasize Newton's Laws to describe the motion of an object on the roller coaster track. Newton's First Law is referred to as the law of inertia. The law of inertia states that if an object is at rest or if an object is moving with a constant velocity then it will respectively stay at rest or at that constant velocity. Shown is Figure 2 , the ball will stay in the same state whether at rest or in motion since there is no net force acting on it [10].

Newton's Second Law is the time rate of change in an object's momentum; however for the purposes of most introductory physics courses it is referred to as the $\vec{F} = m\vec{a}$ law. This law states that the sum of all


Figure 2: Newton's First Law of Motion: The Law of Inertia [1]

forces in a system must be equal to mass times acceleration [10]. This can be shown in Figure 3. The top of Figure 3 shows one person pulling a box with one unit of mass. Due to Newton's Second law of motion, this means that there will only be one unit of acceleration. The middle part of Figure 3 shows two people pulling a box with one unit of mass. Due to Newton's Second law of motion, this means that there will only be two units of acceleration. The bottom part of Figure 3 shows two people pulling a box with two units of mass. Due to Newton's Second law of motion, this means that there will only be one unit of acceleration.

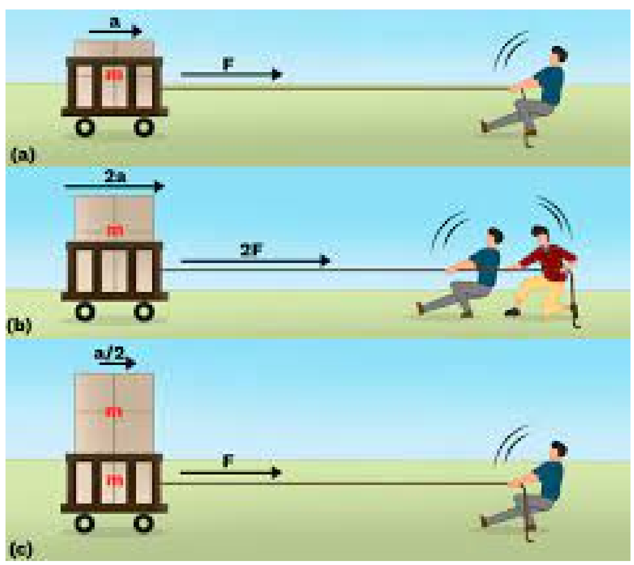



Figure 3: Newton's Second Law of Motion: $\vec{F} = m\vec{a}$ [2]

Newton's Third Law of Motion is referred to as the law of action and reaction. This law states that when two bodies interact they will apply an equal but opposite force upon one another [10]. As shown in Figure 4, when the stick figure pushes on the wall, the wall exerts and equal and opposite force back onto the stick figure.

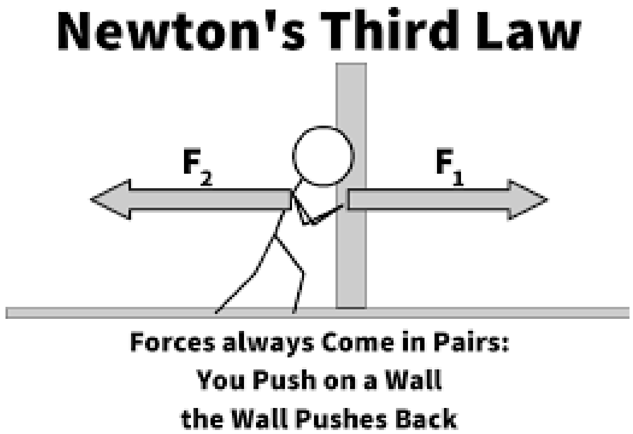



Figure 4: Newton's Third Law of Motion: Law of Action and Reaction [3]

#### 2.3.2 Conservation of Energy

Conservation of energy is the concept that energy cannot be created or destroyed, but rather transferred. Energy can exist in many forms. For example, moving objects have kinetic energy, and objects can also store energy, such as with gravitational potential energy. Conservation of energy occurs in isolated systems when the sum of all energies at the initial point and equivalent to the sum of energies at the final point [11]. For simplicity, there will only be transnational kinetic energy and gravitational potential energy for this example. In this case, transnational kinetic energy is specified to be:

$$KE = \frac{1}{2}mv^2 \tag{1}$$

where m is mass and v is the magnitude of velocity. Gravitational potential energy is specified as:

$$PE = mgh \tag{2}$$

where m is mass, g is gravitational acceleration, and h is the height of the object from the respective ground. When writing out the conservation of energy, there must be a sum of both these energies. This will result in:

$$KE_i + PE_i = KE_f + PE_f \tag{3}$$

$$\frac{1}{2}mv_i^2 + mgh_i = \frac{1}{2}mv_f^2 + mgh_f \tag{4}$$

This is the most simple conservation of energy equation that you can have without initial condition. Once initial conditions are placed into the formula, one can solve for any unknown.

### 2.3.3 Kinematics: Projectile Motion

Kinematics helps to explain projectile motion. Projectile motion is the motion of an object that is thrown or projected into the air. The path in which the object takes is called the trajectory. For reference of the videos that are being made, the projectile motion will be 2D. Therefore the motion will be with respect to the x-direction and the y-direction. For both directions there are the same set of equations that are used. For the x - direction, the variables used are:

| Variable Name | Symbol |
|---|---|
| Initial Position | $x_0$ |
| Final Position | $x$ |
| Initial Velocity | $v_{0x}$ |
| Final Velocity | $v_x$ |
| Time | t |
| Acceleration | $a_x = 0$ |

Acceleration will be zero for the x-direction for all 2D projectile motion problems. The projectile motion equations for the x-direction are:

$$x = x_0 + \frac{1}{2}(v_x + v_{0x})t \tag{5}$$

$$v_x = v_{0x} + a_x t \tag{6}$$

$$x = x_0 + v_{0x}t + \frac{1}{2}a_x t^2 \tag{7}$$

$$v_x^2 = v_{0x}^2 + 2a_x(x - x_0) \tag{8}$$

For the y-direction, the variables used are:

| Variable Name | Symbol |
|---|---|
| Initial Position | $y_0$ |
| Final Position | $y$ |
| Initial Velocity | $v_{0y}$ |
| Final Velocity | $v_y$ |
| Time | t |
| Acceleration | $a_y = -g$ |

The acceleration for the y-direction for all projectile motion problems will be the acceleration to due to gravity. The y-direction projectile motion equations are:

$$y = y_0 + \frac{1}{2}(v_y + v_{0y})t \tag{9}$$

$$v_y = v_{0y} + a_y t \tag{10}$$

$$y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2 \tag{11}$$

$$v_y^2 = v_{0y}^2 + 2a_y(y - y_0) \tag{12}$$

One of the ways to better understand why there is no acceleration in the x-direction and there is acceleration due to gravity in the y-direction is through Figure 5.

From Figure 5, it can be seen that the acceleration of the object changes as it is in air. Since there is no force in the x-direction, there will be no x-direction acceleration. The reason that the y-direction velocity changes over time is due to the acceleration due to gravity acting only in the y-direction. The acceleration due to gravity changes the velocity over time. For example, near the surface of the Earth, this value is 9.8 $m/s^2$. As the objects moves upwards, its velocity and acceleration vectors are in opposition, so the object's velocity is decreasing by 9.8 m/s for every second of its motion until it reaches its peak. At this point, the object stops and changes its direction. The velocity and acceleration vectors now point in the same direction, thus the magnitude of the velocity increases by 9.8 m/s for every second of motion.

Using the variables and the equations for both the x- and y-directions, one is able to solve for any unknown. When asked to solve for the initial and final velocity there are components in both the x- and y-directions. Therefore one needs to use trigonometry to solve the problem as shown in Figure 5.

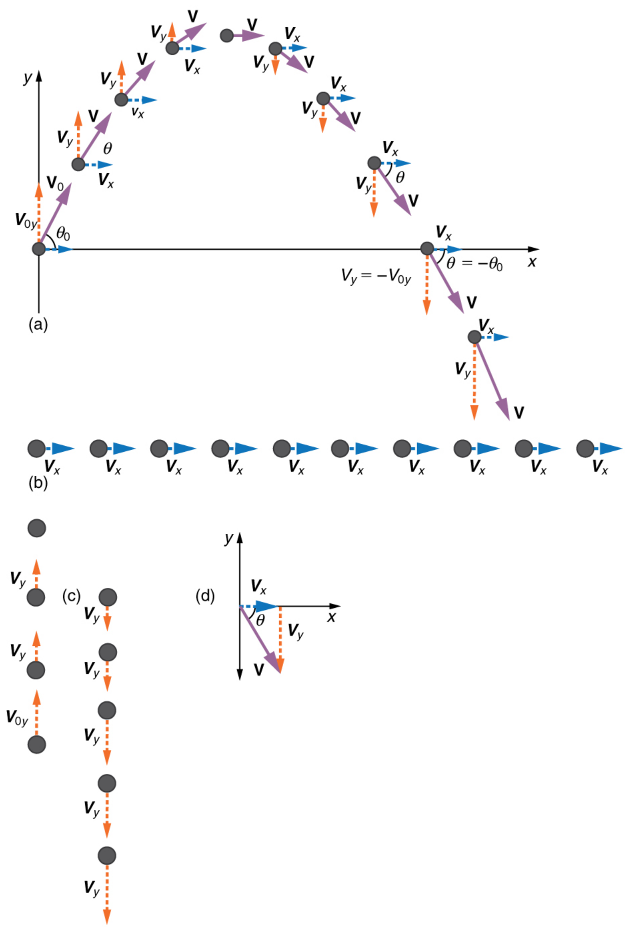



Figure 5: Projectile Motion Velocity Graphs [4]

#### 2.3.4 Rotational Motion

Rotational motion occurs when objects rotate or roll. Rotational motion problems must be solved with respect to angular terms. Radians are commonly used in problem solving involving rotational motion. One radian is the angle at which the arc length a has the same length as the radius $r$ with one complete rotation be equivalent to $2\pi$ radians or 360 degrees. This is important as it allows us to use the same units for any size of circular or rotating object.

There are three main terms used in rotational motion: angular position, $\theta$, angular velocity, $\omega$, and angular acceleration,$\alpha$. Angular position, which must be measured in radians, is defined as:

$$\theta = \frac{s}{r} \tag{13}$$

where s is the arc length of the object, and r is the radius of the object. It is important to note that even when angular position goes in one full rotation of $2\pi$, it keeps on adding up. From angular position, one can determine the angular displacement of an object. Angular displacement is defined as:

$$\Delta\theta = \theta_{final} - \theta_{initial} \tag{14}$$

The next key parameter in rotational motion is angular velocity, which is measured in radians per second. Angular velocity is defined as:

$$\omega_{ave} = \frac{\theta_{final} - \theta_{initial}}{t_{final} - t_{initial}} \Rightarrow \omega = \lim_{\Delta t \to 0} \frac{\Delta\theta}{\Delta t} \tag{15}$$

where $\Delta t$ is the change in time. The final variable in rotational motion is angular acceleration, which is measured in radians per second squared. Angular acceleration is defined as:

$$\alpha_{ave} = \frac{\omega_{final} - \omega_{initial}}{t_{final} - t_{initial}} \Rightarrow \alpha = \lim_{\Delta t \to 0} \frac{\Delta\omega}{\Delta t} \tag{16}$$

These variables are all important as they allow for the conversion between linear and rotational motion. The change in velocity from linear to rotational motion is shown as:

$$v = \omega r \tag{17}$$

The change in acceleration from linear to angular is:

$$a = \alpha r \tag{18}$$

It is important to be able to change between these as rotational variables also can have kinematics. The kinematic equations for rotational motion are:

$$\theta = \omega t \tag{19}$$

$$\omega = \omega_0 + \alpha t \tag{20}$$

$$\theta = \omega_0 t + \frac{1}{2}\alpha t^2 \tag{21}$$

$$\omega^2 = \omega_0^2 + 2\alpha\theta \tag{22}$$

On top of there being rotational kinematics, there is also rotational kinetic energy. This is an additional term that is added into energy balances for problems that have any rotational motion. Rotational kinetic energy is defined as:

$$KE_{rotational} = \frac{1}{2} I \omega^2 \tag{23}$$

where $I$ is the moment of inertia for an object. The moment of inertia of an object is defined by the shape of the object as shown in Figure 6 [12].

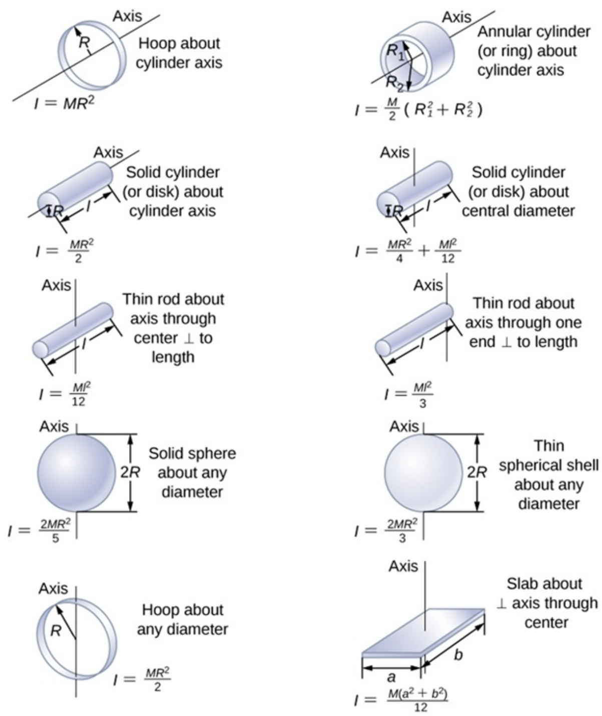



Figure 6: Moment of Inertia Equations for Different objects

Another important quantity in rotational motion is torque, also called the moment of force, and is given by the following formula:

$$\vec{\tau} = \vec{r} \times \vec{F} = (rF \sin\theta)\hat{n} \tag{24}$$

where $\vec{F}$ is the force, and $\vec{r}$ is radius vector, and $\theta$ is the angle between the directions of the force and the radius vector. The direction of the torque vector denoted by $\hat{n}$ is determined by the Right Hand Rule.

The final concept with rotational motion is rolling with and without slipping. The motion of a rolling wheel is the sum of the translational motion or linear motion plus the rotational motion. If the object is respectively at rest when it is touching the ground meaning that there is no friction, then the object is rolling without slipping. This is better illustrated in Figure 7 [12].

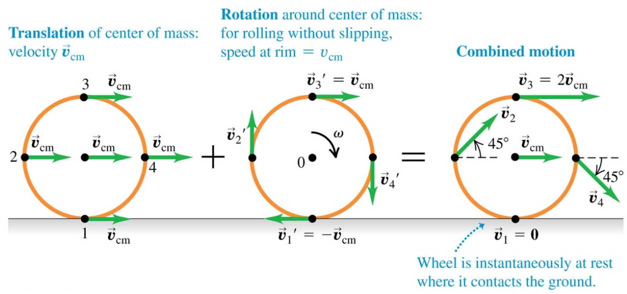



Figure 7: Rolling without Slipping

# 3 Methodology

In order to teach students around the world the concepts of physics as discussed in Section 2.3, six different physics educational videos were developed and five videos were produced. Videos one through four all focus on the Roller Coaster Demonstration. Videos 0.5 and 3.5 focus on supplementary material that is needed in order to understand what is in the demonstration videos. The naming of the videos goes as follows:

1. Video 0.5: Newton's Laws
   - https://www.youtube.com/watch?v=98IdOQvUmSA
2. Video 1: Introduction to Roller Coaster Track
   - https://www.youtube.com/watch?v=2Dc1dzqMiLg
3. Video 2: Roller Coaster Demonstration
   - https://www.youtube.com/watch?v=UpuiH3lgHPI
4. Video 3: Projectile Motion
5. Video 3.5: Rotational Motion
   - https://www.youtube.com/watch?v=rEt0-h516ug
6. Video 4: Demonstration with Friction
   - https://www.youtube.com/watch?v=gUdtroiUHaQ

All of the transcripts for these videos can be found in Appendix B. All of these videos were shot and recorded in the Worcester Polytechnic Institute Global Labs multimedia studio. The videos are a mixture of both animated sections and live demonstrations. The animated sections of these videos were developed in PowerPoint and can be found in Appendix C. The live demonstrations were all recorded using a GoPro 4. The editing of videos was done using Premiere Pro Editing Software.

## 3.1 Video-by-video breakdown

### 3.1.1 Newton's Laws

For Video 0.5, which covered Newton's Laws of Motion, the first logical step was to state the three laws and provide a easy-to-understand visual for each law. For Newton's First Law, two balls were depicted similar to the ones shown in Figure 2: one to represent an object staying at rest, and another to represent an object in constant motion. The use of this visual helps viewers understand how an object at rest will continue to stay at rest in cases where the forces acting on the object are balanced, while an object in constant motion will stay in constant motion in cases where the forces acting on the object are balanced. For Newton's Second Law, Figure 3 was recreated using a block to represent the mass and an arrow to represent the force acting on the block. By showing several different cases where the mass and acceleration changed, it was proved that the product of the mass and acceleration would equal the net force acting on the block. For Newton's Third Law, Figure 4 was recreated to explain how two objects will apply an equal but opposite force on each other when the two objects interact. Then, a breakdown was given for each of the three forces that were relevant for this project: the gravitational force, normal force, and frictional force. Simple diagrams were used in tandem with a voice-over to explain each of the three forces. The second half of the video presented useful information on force vector decomposition, as well drawing free body diagrams and performing a summation of forces.

### 3.1.2 Introduction to Roller Coaster Track

Video 1 started off with a basic introduction of the roller coaster track and what the purpose of the track is. The remainder of the video was dedicated to explaining the physics involved in the roller coaster track. In order to add an interactive element to the video, several different options were given for both the normal force and the gravitational force, with the video asking the viewers where they think the two forces should be placed on a free-body diagram of the block on the ramp. Then, the video started to explain both potential and kinetic energy, using visuals and questions to help demonstrate what causes the energies to change as the block moves down the ramp on the track. The transformation and conservation of energy was touched upon towards the end of the video to explain how important those two are in the calculations that go behind determining if the block will make it through the loop.

#### 3.1.3 Roller Coaster Demonstration

Video 2 was all about trying to figure out what height the block would need to be released from so that it could make it around the loop. As done in Video 1, a free-body diagram was presented with the block at the top of the loop and viewers were asked to choose between several options about where they think the normal force and gravitational force should be placed on the block. Then, the correct answer was revealed along with an explanation of why the answer is correct. It is important to note that the the positive direction for force balance was taken to be towards to center of the loop, which resulted in the normal force and gravitational force to both be in the positive direction. Information provided in Video 0.5 was used to perform a force balance of all the forces acting on the block. Next, a series of calculations and some algebraic manipulations were used to find the velocity of the block at the top of the loop. Since the block is on the verge of losing contact with the track when it is at the top of the loop, the normal force was set equal to 0. A detailed breakdown of each calculation was provided in the voice-over. Then, the conservation of energy equation was used between the release point of the block and when the block is at the top of the loop to solve for the height at which the block would need to be released from so it could make it around the loop. The transcript presented in Appendix B.3 mentions using the conservation of energy equation with the bottom of the loop and the top of the loop. However, to simplify the calculations, the two points taken for the equation were the release point of the and when the block is at the top of the loop. The same as before, an explanation of each calculation was provided to ensure that the viewers could follow along with the video. The video then ended off with a demonstration with the roller coaster track to show that when the block is dropped from at least the height solved for, the block does indeed make it around the loop.

#### 3.1.4 Projectile Motion

Video 3 was about projectile motion. The equations presented in Section 2.3.3 can be applied once the object leaves the end of the track. As seen in Appendix B.4, the plan for this video was to first define what a projectile motion problem is and then present the equations and variables used to solve projectile motion problems. Then, an example problem was provided to help viewers apply the equations. Initial conditions were given and calculations were presented to solve for the maximum height that the projectile would reach, the time taken to reach that maximum height, as well as the horizontal distance that the projectile would travel. The next step was to apply the same projectile motion equations to the roller coaster track demonstrations. However, to due time constraints, no further work was able to be done for this video.

### 3.1.5 Rotational Motion

Video 3.5 was a supplementary video that introduces the concept of rotational motion. The video first starts off by providing an overview on angular coordinates using radians. Then, the concepts of angular position, angular displacement, angular velocity, and angular acceleration are explained. The right-hand rule for rotational motion was used to provide viewers an easy way to determine the direction of angular velocity. To help viewers understand these concepts, visuals with arrows and labels were illustrated. Next, a series of equations were presented and explained through voice-over about how linear variables can be converted to their rotational counterparts. In the next part of the video, the concepts of rotational kinetic energy and moment of inertia were introduced. The conservation of energy was again brought up, but this time including the rotational kinetic energy term, which was ignored in previous videos. The video ended with a previous discussion on torque and the concept an object rolling without slipping. The equations to find torque depending on where the torque acts on the object were presented and broken down into detail. To help illustrate the concept of a rolling object, a diagram was presented and gone over in detail to explain how objects can roll with and without slipping.

### 3.1.6 Demonstration with Friction

Video 4 was very similar to Video 2, except that the rotational motion of the ball was considered. The first step was to draw a free-body diagram of the ball at the top of the loop. As a matter of fact, this free-body diagram has the same forces as the free-body diagram in Video 2, with the only difference being that the object is now a ball instead of a block. The equation for the linear velocity of the ball when it is at the top of the loop was found by performing a force balance with the normal force and gravitational force. As was the case with Video 2, the normal force was set equal to 0 to help simplify the required calculations. Then, the conservation of energy equation was used with the initial point being the release point of the ball and the final point being when the ball is at the top of the loop. The rotational kinetic energy term presented in Video 3.5 was added to the right hand side of the equation. Next, a series of calculations were performed with voice-overs explaining each step and simplification being made. The calculation yielded a result for the height that the ball would need to be dropped at in order to make it through the loop. Finally, a comparison was drawn between the result obtained from Video 2 and the result obtained from Video

4. Since the rotational kinetic energy was now being considered, the height that the object needed to be dropped from increased to account for the energy being lost in rotational kinetic energy. Throughout this video, visuals were used as necessary and explained in great detail to ensure that any viewer could easily follow along with the information that was being presented.

# 4 Results

For this project, a total of six videos were developed, with five videos being produced. As the trend towards short-video content continues to reach new heights, a goal of this project was to produce relatively short videos that would keep viewers captivated the entire time. Of the five videos produced, three videos (Videos 1, 2 and 4) apply physics concepts to a roller coaster track that was available on-campus. The roller coaster track was chosen due to its ease of access, as well as being relatable to the target audience of the produced videos. The remaining two videos (Videos 0.5 and 3.5) were produced as supplementary material that introduces the concepts that the other videos build upon to apply to the chosen roller coaster model.

## 4.1 Recommendations for Future Work

As mentioned in Section 3.1.4, Video 3 covering projectile motion was unable to be produced due to time constraints. An example problem that uses initial conditions to solve for various parameters has already been created and solved out in Appendix C.4. The next step is to apply the projectile motion problems to the roller coaster track demonstration to prove how the same equations can be used to calculate several quantities such as the maximum height and range of the object being ”launched” from the track.

Additionally, the effects of friction were ignored for the majority of the videos developed to simplify all calculations, even though friction is inevitable in the demonstration. For a future work on this project, friction could be factored into the calculations and compared with the results obtained from this project to compare how much of an effect would friction have on the results.

Furthermore, with the increasing use of technology, open-source software such as Tracker could be used as an aid to help prove concepts that were presented solely through the use of equations in this project. Such software has the capability to track moving objects and makes understanding the physics behind such objects easier to understand. Since Tracker is an open-source software, it can be accessed by many across the world. Adding tutorials on how to use Tracker would also help those trying to understand more about how software and physics can go hand-in-hand.

## 5 Conclusion

Many important lessons were learned throughout the course of the project. First and foremost, there was a newfound appreciation for physics. Physics is a part of our daily lives, whether we believe it or not. Even the smallest aspect of our lives involves physics, so it was interesting to see how physics can be applied to a myriad of situations. For example, many of us have had the experience to ride a roller coaster, but we often fail to think about all of the work that goes behind creating such an attraction. The demonstrations performed in this project are only a small-scale version of what engineers must have to go through as part of their daily lives designing such complex systems. Secondly, a lot of useful information was learned about the video production process and how videos can play a large role in ones' education. Every part of the video production process had to be carefully thought out: from brainstorming ideas to writing transcripts to getting familiar with recording to editing a video. As the use of videos to provide meaningful education is on the rise, it was interesting analyzing existing videos pedagogically to come up with ways to make videos produced for this project easy to understand. The use of visual aids throughout hands-on demonstrations and PowerPoint animations to illustrate otherwise tough to imagine concepts helps viewers retain more information, as opposed to having no sort of visual cue. Additionally, the videos produced aimed to interact with the viewers through the use of questions, further engaging the viewers and making them feel as if they are a part of the video themselves. This project has laid the foundation for creating video projects for physics education with the hopes that much more future work can be done to expand to cover a lot more topics within the field of physics.

# Appendices

## A Appendix A: Roller Coaster Demonstration Work Sheet

## *Activity-2:* Building a roller coaster

A roller coaster is an elevated railway (as in an amusement park) constructed with sharp curves, steep inclines and loops. It gives a fun-ride to the brave passengers!

We construct a model roller coaster and do force and energy analyses on it.

**Materials required:**

Foam insulation pipes, tape, glue, staples, scissors, marbles (roller-coaster cars)

Figure-1 shows a simple sketch of a roller-coaster track. Design and construct a roller-coaster consisting of the following:

**(a)** At least two hills and a loop,

**(b)** The cars (marbles) make loop-the-loop successfully, provide good thrill to the riders, and make a smooth stop at the end.

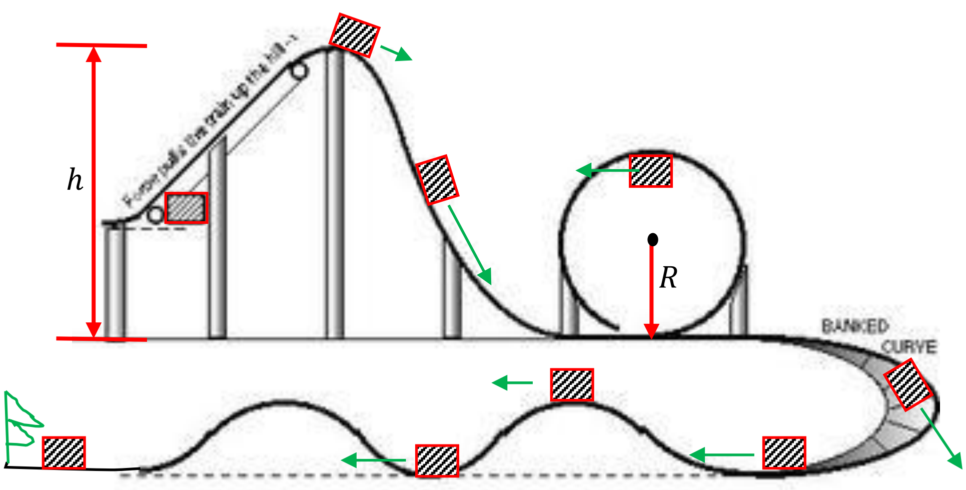



Figure-1

## **Physics of roller coaster**

We deal with forces and energies in a roller coaster. The forces in a roller coaster are gravity (always acting vertically downwards), normal reactions from the seats on the riders, and friction (the force between the car-wheels and the track). There is tension force on the chains pulling the coaster all the way to the maximum height.

When the coaster is at highest point, it has gravitational *potential energy* (*PE*). If we refer to the zero-level of the gravitational energy at the starting point and the highest point is $h$ above the reference level, the potential energy

$PE = mgh$. ------------------------------ (1)

When the car goes downhill, this potential energy is converted to *kinetic energy* (*KE*), which is the energy due to the motion:

$KE = \frac{1}{2}mv^2$. ------------------------------ (2)

Since there is friction between the roller and the track, some of the energy is dissipated as heat energy.

What make the ride fun are - a sudden fall, loop-the-loop, and a sudden rise where the rider experiences various weights because of different amount of accelerations.

**Loop-the-loop:**

Suppose a roller coaster car making a vertical loop successfully, has its speed $v_t$ at the top of the loop. At this point, its acceleration is vertically downward toward the center of the loop. The force diagram of the car at this point is as shown in the Figure-2.

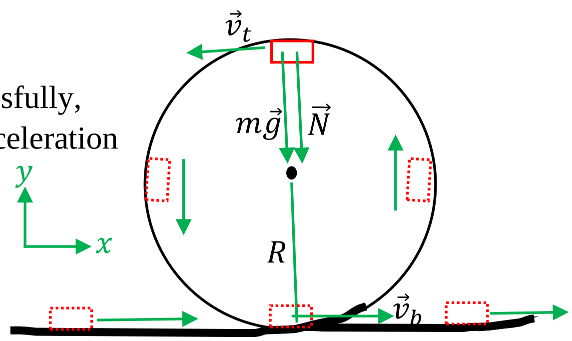



Figure-2

The forces at the top of the loop are the weight $W = mg$ of the car and the normal reaction $N$ due to the track. Both of these forces act vertically downward. The car has acceleration $a$ toward the center of the loop. From Newton's Second Law of motion:

$-N - mg = ma$. ------------------------------ (3)

In a circular path,

$a = -\frac{v_t^2}{R}$. ------------------------------ (4)

Solving Equations (3) and (4) for the normal reaction,

$N = m\left(\frac{v_t^2}{R} - g\right)$. ------------------------------ (5)

If the car is *on the verge of* losing contact from the surface of the track, $N = 0$. Solving Equation (5) gives the speed at the top,

$v_t = \sqrt{Rg}$ . ------------------------------ (6)

**What would be the speed of the car at the bottom?**

Neglecting the frictional loss, the total mechanical energy of the car at the top of the loop is equal to its total mechanical energy at the bottom of the loop (Energy Conservation Principle):

$KE_b + PE_b = KE_t + PE_t$. ------------------------------ (7)

Take the gravitational potential energy at the bottom equal to zero. Then, from Equations (1), (2), and (7),

$\frac{1}{2}mv_b^2 + 0 = \frac{1}{2}mv_t^2 + mgh$ . ------------------------------ (8)

For $h = 2R$, and $v_t = \sqrt{Rg}$, solving Equation (8) for $v_b$ gives

$v_b = \sqrt{5Rg}$ . ------------------------------ (9)

From what height should a car be dropped to make loop the loop?

Neglecting friction, Energy Conservation Principle gives

$mgh = \frac{1}{2}mv_b^2$. ------------------------------ (10)

Solving for h gives,

$h = \frac{5}{2}R$. ------------------------------ (11)

The car must start from the height two-and-half times the radius of the loop to make the loop and come out of the loop successfully.

**Roller coaster: worksheet**

**(1)** What forces are involved in your roller coaster?

**(2)** Explain the energy conversion involved in a roller coaster.

**(3)** A roller-coaster car at rest must start from the height two-and-half times the radius of the loop to make the loop and come out of the loop successfully. What will happen if we drop the car from (i) a larger height, and (ii) a smaller height than this height?

**(4)** In what ways is your model roller coaster similar to a real roller coaster? How is it different?

# B Appendix B: Video Transcripts

All of the transcripts have speech written in italics and what was to be put on the animations written normally.

## B.1 Video 0.5 Transcript

# Video 0.5: Newton's Laws

1

## Newton’s First Law (Time: 0:00 to 0:15)

*“Hello everyone. This is a supplementary video on Newton's laws, Force Interactions, and their applications. The reason we need to understand forces, how to draw free body diagrams, and how to do a summation of force is due to Newton’s Laws of motion. Newton’s Laws of Motion are the foundations of classical physics as they describe how objects and their surroundings have forces on each other.*

2

*Newton's First Law is that an object is at equilibrium when the object is either at rest or moving with a constant velocity. This means that when we sum all of the forces in the system they will equal zero. This is called the Law of Inertia. Most commonly we hear it as an object in motion stays in motion and an object at rest stays at rest unless acted upon by an unbalanced net force."*

Show summation under newton's 1st law

3

## Newton's Second Law (Time: 0:20 to 0:35)

*"Newton's Second Law states that the acceleration of an object is directly proportional to the net external forces acting on the object and inversely proportional to the mass of the object. This means that when we sum all of the forces in the system they will be equal to mass of the object time the acceleration of the object."*

Show equation under newtons 2nd law

4

## Newton’s Third Law (Time: 0:35 to 0:50)

*“Newton’s Third Law of motion is that if object a exerts a force on object b, the object b exerts and equal magnitude but opposite direction force back onto a. This equal and opposite force is normally denoted as the normal force. For instance, if we have a person push against a wall, the wall will not fall down. Instead, the wall will push back on the person with the same force to ensure that it can stay standing.”*

Under netwon’s third law show diagram of this

5

## Forces and Interactions (Time: 0:50 - 1:05)

*“In order to better understand Newton’s Laws we first need to know what a force is. A force can be defined as a push or a pull. It is an interaction between two objects. A force is also always a vector quantity, therefore we denote it with an arrow above the vector.”*

Forces and Their Interactions, Graphics. Force Vector

6

## Gravitational Force (Time: 1:05 to 1:20)

(Mass vs. Weight)

*“The first force we will discuss is gravitational force. This can also be called the weight of an object. This force is the pull of gravity on an object, therefore it can be found by multiplying the mass of the object by the gravitational acceleration acting on the object. Most commonly we are solving for gravitational force on Earth so gravitational acceleration will be 9.81 meters per second squared or 32 feet per seconds squared. When drawing gravitational forces, they are always directed straight down to Earth or planet we are taking into account.”*

Force Equation, g=9.81 m/s^2 or 32 ft/s^2 and a few forces in different orientations with Fg drawn on them

7

## Normal Force (Time: 1:20 to 1:40

*“The next force we are going to discuss in Normal force. This forces happens when an object is on a surface. Because the object exerts a force onto the surface, the surface exerts an equal but opposite force on the object. When drawing Normal force, it is always perpendicular to the surface that the object is touching. Think about a person standing on a scale. The weight that is shown on the scale is the normal force. If someone were to push down on the person on the scale, that person’s weight won’t change but the reading on the scale will because there is more force being put on it. ”*

Normal Force, Fn, drawings in multiple locations

8

## Friction Force (Time: 1:40 to 2:00)

*"The next important force to discuss is friction force. In addition to the normal force, a surface may also exert a friction force on an object since friction is a contact force. Friction force is solved as the coefficient of friction, denoted as mu, times the normal force.In most cases, this force is drawn parallel to the surface and in the opposite direction in which the object is moving. If the object is moving right, this will be the friction force. If the object is moving to the left this will be the friction force."*

Ff, Equation, multiple drawings in both directions of movement

9

## Tension Force (Time: 2:00 to 2:20)

*"The next force that we will work with is tension force. Tension is the pulling force exerted on an object by a rope or cord. Tension is always the same throughout the entire rope or cord if there is one or no pulleys involved. When drawing tension force, it is parallel and on top of where the rope is attached to the object."*

Ft, Diagrams

10

## Spring Force (Time: 2:20 to 2:40)

*"The next force is spring force. This is the force from a spring as it is stretched from its equilibrium. This for is denoted as the negative spring constant K times the change in position from equilibrium. When drawing the spring force, it is parallel to the direction that the spring is moving. Looking at these four cases, the spring force will be as shown."*

Fs, two diagrams in x and y direction of stretching and contracting

11

## Contact Forces (Time: 2:40 to 3:00)

*"The final force we will discuss is contact force. Contact force happens when two bodies are in contact with one another. In this case our forces are because of Newton's first law. Say we have block a and block b and they are apply  force on each other since they are together, then we will draw our contact for like this."*

Contact Force, Diagram

12

## Drawing Force Vectors (Time: 2:00 to 2:20)

*"And there are many other forces, such as tension, spring, and contact forces. Now that we know all of the forces that we commonly see in physics problems, it is time to draw forces. In the figure below we have a box being pulled by a rope at an angle of theta. When drawing this force, we denote the for with a vector. Since our force is not parallel or perpendicular to the object, we need to decompose the vector into x and y components to help solve the problem. Our Fx will look like this and our Fy will look like this. In order to find what the components forces are equal to, we use trigonometry. Looking at our figure, Fx till be the tension force time cosine theta and Fy will be our tension force time sine theta."*

Diagram

13

## Decomposition of Force Vectors (Time: 2:20 to 2:40)

*"One of the reasons we decompose our force vectors is for when our object is on a ramp. Looking at the figure below, we can see that the object is at an angle and the force on the object is at an angle. If we draw our Normal force, gravitational force, and the pulling force as vectors on our diagram, we will see that nothing is simple angles to find of forces in the x and y direction if we have our axis looking like this. Let us instead shift our axis to be in respect with our object. Now of normal force will be in the positive y direction, and gravitational and pulling forces can be put into components only using the theta angle."*

Diagram 1 with normal axis, then shift the axis

14

## Free Body Diagrams (Time: 2:40 to 3:00)

*“In order to solve physics problems, we start by drawing a free body diagram. These diagrams have the object that we are focussing on and all of the forces acting on the object. Earlier we discussed how we draw all of our forces that would act on our object and what they would look like on the diagram. Lets practice using this example of a problem, how would we draw our free body diagram. Pause the video to draw all of the forces acting on our box.”*

Diagram: Box on ramp with tension, spring friction

15

## Summation of Forces + Question (Time: 3:00 to 3:20)

*“From the diagram we can find the the free body diagram will look like this. The normal force perpendicular to the ramp, the gravitational force directly down, the spring force ____, the tension force parallel to the rope, and friction force in the negative parallel to the direction our box is moving.We draw free body diagrams to allow us to sum all of our forces in order to solve for unknowns in our problem. Using the free body diagram that we just made, we can sum all of our forces together. The summation of forces will be:______. And if we sum of forces by x and y directions, the sum of forces in the x direction will be ___ and in the y direction they will be ____.”*

Correct FBD and then the summations underneath

16

### B.2 Video 1 Transcript

# Video One: Introduction to Roller Coaster Track

1

## What is this demo (Time: 0:00-0:10)

Video Opening: Title Slide with Names of group members, advisors, and WPI logo

Fade out on opening page to the roller coaster track on a table with a black background and a person standing behind it

*"Hello. In this video we begin to discuss the roller coaster demo track"*

Hands motions around track

*"This track is made out of wood panels and a metal rail. We also have a metal block that was constructed to slide from the top of the track to the bottom"*

Point to wood panels and the metal rail then hold up the block in one hand and some the course in which it would take down the track

2

## What is this demo (Time: 0:10-0:20)

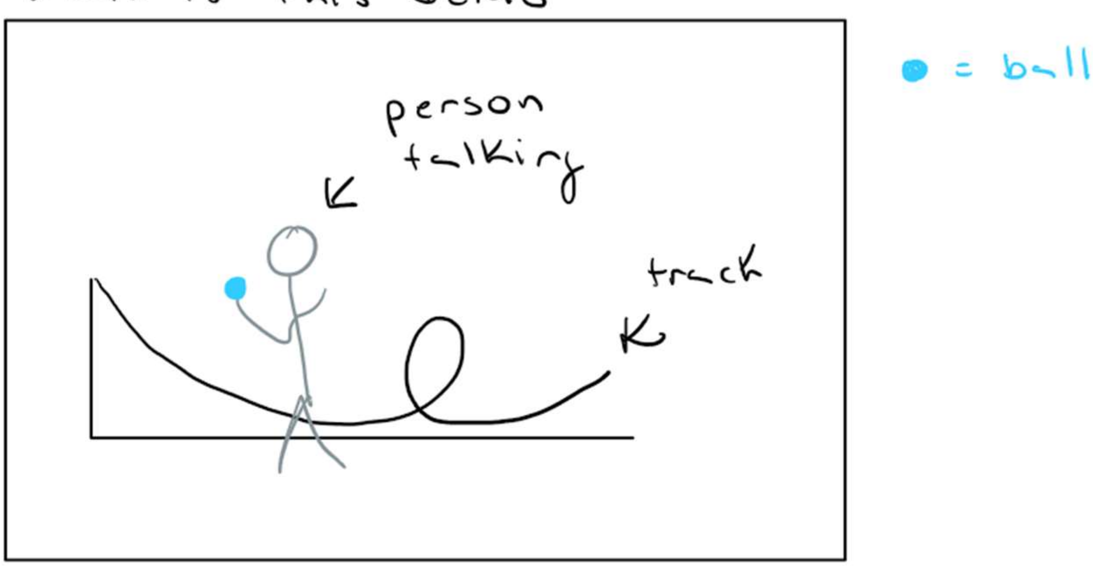
*“The purpose of this demo is to observe how a block will interact with the track and the loop.”*

Move block over the track then into the loop

*“In order to understand how the block will make it from the top of the track to the bottom of the track, we need to understand the physics behind this demo”*

3

What is this demo




4

## Forces on the block (Time: 0:20-0:30)

Fade into a black screen where writing will appear as the voice over is still happening

*"First we need to know what forces act upon the block as it travels from the top of the track, around the loop, and out of the loop at the bottom"*

*TEXT: Forces acting upon the block*

*"There are two main forces acting on the block, normal force and gravitational force"*

*TEXT: Normal force*

*Gravitational Force*

5

Forces on the ball

Forces Acting upon the ball

Normal Force (N)

Gravitational Force (mg)

6

## FBD + Question 1 (Time: 0:30-1:00)

Still on typed out word screen

*"In order to understand how these forces affect the block let us draw a free body diagram of the block while it is at the top of the ramp."*

*block* appears on the right of the screen with a silver line under it labeled metal ramp with axis and angles

*"Here we have the block on the ramp. Looking at the start of this diagram, where will we put the normal force and the gravitational force?"*

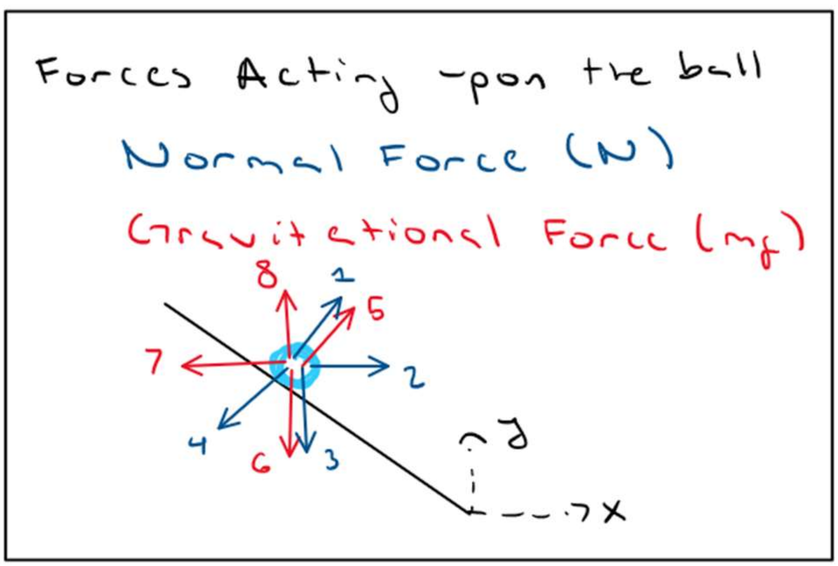
Have two sets of arrows appear on in blue representing the normal force (1-4) on the *block* and on in red representing gravity(5-8)

*"Take a second to think which of the four forces 1,2,3 or 4 will denote the normal force and which of the four forces 5,6,7, or 8 will be the gravitational force. You can pause the video to take your time to think"*

Pause speaking for 5-10 seconds

7

FBD + Question Part 1




8

## FBD Part 2 (Time: 1:00-1:20)

*"Now that you have had a second to think, the normal force will be 1 and the gravitational force will be 6"*

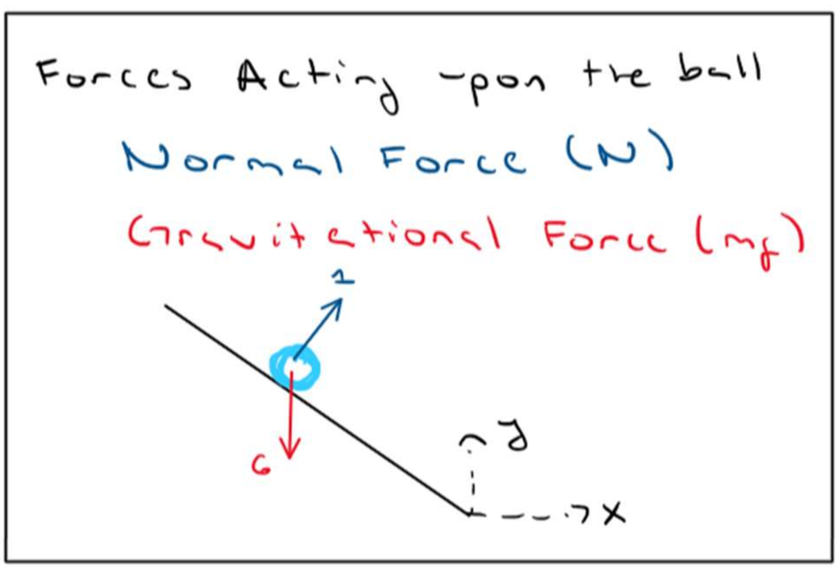
Remove incorrect arrows and change numbers on correct arrows to be N and G

*"It might look odd having the normal force not be directly up in the y direction, but we have to remember that normal force is perpendicular to the surface at which the moving object in connect to. In our case, the ramp is not flat therefore the normal force comes out at a 90 degree angle from the angle that the ramp sits at"*

*"And the gravitational force is down. The gravitational force will always be directed to Earth so for the demo earth is directly down in the y direction"*

9

## FBD + Question Part 2




10

# Energy (Time: 1:20 to 1:35)

*“Now that we know the forces that are acting on the block at the top of the track, we also need to understand how energy will be affected as the block rolls down the track”*

Fade out from screen with forces to new black screen with text and a diagram of the track underneath it.

*TEXT: Energy of the Moving Object*

*“There are two types of energy that we will focus on Potential energy and Kinetic Energy”*

Both types are written on the screen with their base equations written below them.

11

Energy

Energy of our Moving Object

Potential Energy (PE)

$PE = mgh$

Kinetic Energy (KE)

$KE = \frac{1}{2} mv^2$

Maybe change colors as to not match forces

12

## Potential Energy + Question(Time: 1:35 to 1:50)

“Potential Energy is based on gravity. Looking at the equation for Potential Energy, we can see that this is the mass times gravity times the height at which an object is”

Show again ramp with a height marker and *block* 1 at the top *block* 2 at the middle and *block* 3 at the bottom keep up Potential energy and the equation

*“Let's consider what the potential energy would be for each of these blocks. Which of these block would have the greatest Potential Energy? block 1, block 2, or block 3 all with the same mass. Look at the equation and pause the video if you need to answer.”*

TEXT: Which of these *block* would have the greatest Potential Energy? 1,2,3

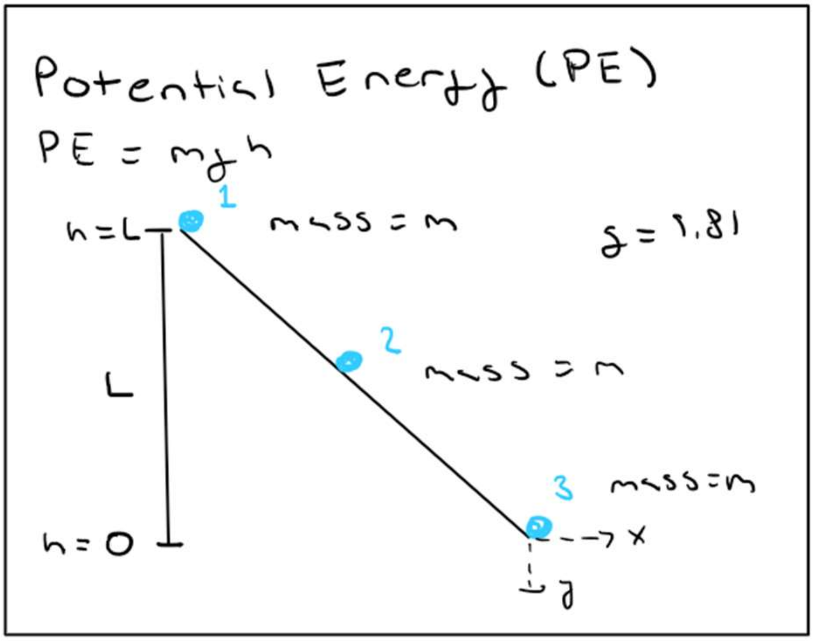
13

## Potential Energy (Time: 1:50 to 2:10)

*“The block with the most potential energy will be block 1. In order to understand why we need to look at the Potential Energy equation. block 1, 2, and 3 all have the same mass and are affected by the same amount of gravity, because of this, the only thing that is affecting the potential energy of the block is the height it is off of the ground. Since block 1 is at the highest point on the ramp it will have the most Potential energy”*

14

PE




15

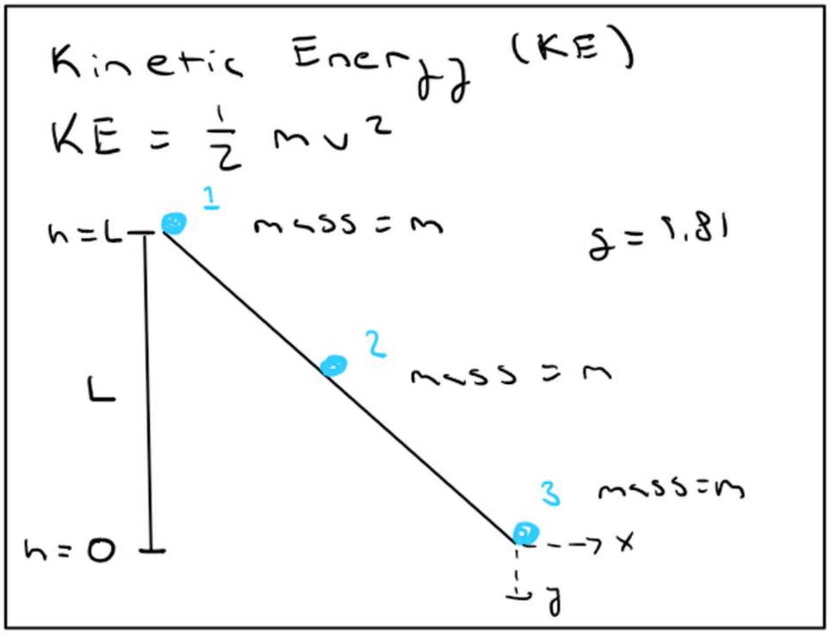
## Kinetic Energy (Time: 2:10 to 2:30)

*“Kinetic energy is based on the mass and the velocity squared of an object. If the block starts at rest as block one, then it will gain in kinetic energy as it becomes block 2 then block 3. This is due to the increase in velocity that the moving block will have as it goes down the ramp.”*

Show again ramp with a height marker and block 1 at the top block 2 at the middle and block 3 at the bottom keep up Kinetic energy and the equation

16

KE




17

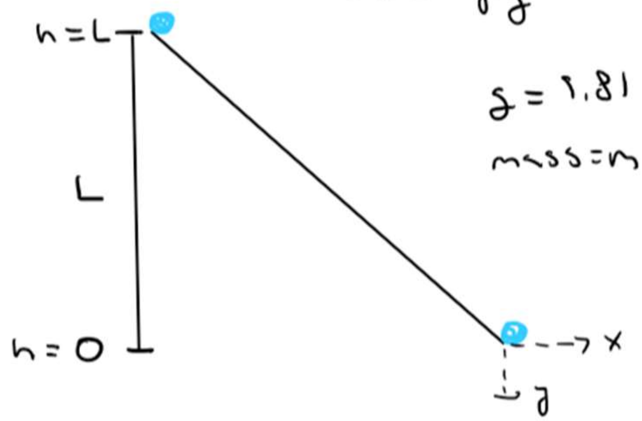
## Why do we care about energy (2:30 to 3:00)

*"The reason why we care so much about Potential and Kinetic Energy is due to transformation of energy and conservation of energy. Transformation and conservation of energy work hand in hand. As no energy can be lost within the system, the energies acting upon the block must change when the block is at the highest point shown in 1, we have the most potential energy and 0 kinetic energy as the block is at rest. When the block is released, the height of the block decreases, decreasing the amount of potential energy while the velocity increases, increasing the amount of kinetic energy. If the block every reaches a height of 0, this would be the point where there is no more potential energy and kinetic energy is at the highest. These energies are important to know as well as the forces on the block so that we can find out whether or not the block will make it around the loop of the roller coaster track. Watch the second video in this series to see the calculations of the block going through the loop!"*

18

why do we care about energy

Transformation + Conservation of Energy




19

### B.3 Video 2 Transcript

# Video 2: Roller Coaster Demo

1

## Intro (Time: 0:00 to 0:15)

*"During the first video of this series, we learned about the forces acting on the block and the energies that are acting on the block. Now that we know and understand these concepts, it is time to see the demo."*

Video starts on title screen. As person begins to talk fade into them standing behind the demo track with a black background.

*"Let's start by running the demo with the block ___ cm off the ground. For this roller coaster loop, this is the same as the height of the loop. Do you think that the block will make it over?"*

Place the block at the height but pause video to show the question on the side of the screen with options yes, no, and unsure.

2

## Running the Demo (Time: 0:15 to 0:30)

*"Let's allow the block to slide from here to see if it will make it through the loop"*

Let the block go from that height. Remove sound from video possibly

*"As we can see the block will not make it over the loop at this low of a height. So let's do some math to see how high we need to position the block in order to let it slide through the loop"*

Fade to black screen with the FBD of the block in the loop

3

## FBD of the loop (Time: 0:30 to 0:50)

Fade to black screen with the FBD of the *block* in the loop with the loop and the *block* at the top of the loop

*"In order to ensure that the block will make it around the loop, we need to do a force balance of the block at the top of the of the loop to see how normal force, gravitational force and velocity will affect the block."*

*"Lets first draw all of our forces Looking at the start of this diagram, where will we put the normal force, and the gravitational force?"*

Have two sets of arrows appear on in blue representing the normal force (1-3) on the block and on in red representing gravity(4-6).

*"Take a second to think which of the three forces 1,2, or3 will denote the normal force, which of the three forces 4,5, or 6 will be the gravitational force. You can pause the video to take your time to think"*

Pause speaking for 5-10 second

4

## Newton's Laws (Time: 0:50 to 1:10)

*"Now that you have had a second to think, the normal force will be (insert number chosen), the gravitational force will be (insert number chosen) If we think back to video one, we know that normal force is always perpendicular to the ramp and gravity will always be down.*

*"With our forces set, we need to do a force balance, we need to think about Newton's Laws as discussing in Video 1.5. When we are summing all of the forces acting on the moving object to find any unknowns."*

5

## Newton's Laws take 2 (Time: 1:10 to 1:30)

*"Using Newton's Second Law, we know that our object will have a force equal to mass times acceleration. Therefore our Force equation will look like this will all of the components."*

Have F=ma pop up onto the screen them ma = +mg+ N below it

*"The gravitational force is the mass of the object times gravity. And both gravitational force and normal force are positive in this case since we will assume that forces towards the center of the loop are positive and forces away from the center of the loop are negative. Now we need to solve for our unknowns. We know gravity and the mass of the object. We also know what the acceleration is since the mass is moving in circular motion. Because of this motion, acceleration will be velocity squared over the radius of our loop."*

Put up the equation for the acceleration and the force equation with this in it

6

## Normal Force (Time: 1:30 to 1:50)

*"With all of our force balance equation known besides the normal force, let's solve for this unknown. Using some algebra we can determine the that normal force will be equal to the mass times the positive acceleration minus gravity."*

Show the algebraic steps to find the normal force and the finally equation.

*"Now that we have all of our equations, we need to make some assumptions about the block in order to find our velocity at the top of the loop in constants we know. When the block is at the top of the loop, it is on the verge of losing contact with the surface of the track therefore we can assume that our normal force will be zero. By substituting sero in for the normal force we can find through algebra that the speed at the top of the loop is the square root of the loop's radius times gravity"*

*Display on screen (EXPLAIN WHY N DROPS MORE and how we get velocity)*

7

## Energy Conservation Principle (Time: 1:50 to 2:05)

*"Now we have the velocity of the block at the top of the loop, we need to do a force balance using the Energy Conservation Principle discussed in Video 1 to determine what height we can drop the block from so that it will go around the loop."*

New black screen with vt displaying at the top as well as a diagram of the loop with radius marked

*"Let's start with the Energy COnservation Principle equation."*

KEb +PEb = KEt +PEt

*"We need to ensure that the energy when the block is at the top of the loop is the same as when the block is at the bottom of the loop."*

8

## Energy Conservation + Question (Time: 2:05 to 2:20)

*“We will be neglecting frictional forces here. But using what we learned in Video 1, take a second to decide what each component of the Energy Conservation equation will be.”*

Below each of the components of the equation have a-d with options of what can be in the equation.

*“Take a moment to pause the video if you need to determine the currency parts of the equation”*

9

## Energy Conservation Principle (Time: 2:20 to 2:45)

*“Now that we have taken a second to think, the kinetic energy at the bottom will be __, the potential energy at the bottom will be __, the kinetic energy at the top will be __ and the potential energy at the top will be __. If we remember from video one, the kinetic energy will always be in the form of ½ the mass times the velocity squared. So for our equation we just need the velocity to be with respect of the location it is at. And the potential energy represents the height at which our block lies. At the bottom of the loop, the block is at a height of 0 so our potential energy component goes to zero. At the top of the loop, the potential energy is at a height of twice the radius. Now that we have our equation set, let us substitute in the values for the velocity at the top and height being twice the radius.”*

Put the correct energy equation under the basic one. As we discuss the kinetic and potential show why they are what they are. Add height = 2R to the top in with vt as a constant.

10

## What is h? (Time: 2:45 to 3:05)

*"By simplify our conservation of energy equation, we get the the velocity at the bottom of the track will be the square root of 5 times the Radius times the gravity. This is the final value that we need to solve for the height at which the block needs to be to make it through the loop. Using the principles of conservation of energy, we know that we will have all of our potential energy at the top of the loop and only kinetic energy at the bottom of the loop, because of this we can simplify the energy equation to mgh is equal to one half times mass times the velocity at the bottom of the track. Since we know mass, gravity, and the velocity at the bottom of the loop, we can substitutes those into the energy equation. With some simplification, we can obtain that the height the block needs to be dropped from is five halves the radius."*

11

## Final demo (Time: 3:05 to 3:20)

Back to person talking in front of the track

*"Now that we know the height that the block needs to be dropped from, let us test it out to see if it will make it through the loop"*

Run demo

*"(I want to add a line here about how physics is fun but I am still deciding)"*

12

### B.4 Video 3 Transcript

# Video 3: Projectile Motion

1

## What next? (Time: 0:00 to 0:20)

*"Now that we have done the calculations to find out how high the block needs to be to make it through the loop, let us take the problem on step further. If we decide to release the block from higher than the needed height to make it through the loop, what will happen? Let us test this."*

Release block from higher

*"As you can see the block flys off of the end of the track. When the block leaves the end of the track, we will have a projectile motion problem."*

2

## Projectile Motion (Time: 0:20 to 0:40)

*"Projectile motion is the motion of an object that is thrown or released into the air. During projectile motion, the only acceleration on the moving object will be gravity in the y direction. When solving projectile motion problems, we have seven variables that we use and five equations to solve our problems for unknowns. The seven variables that we use are in x not and/or y not which mark the original position, x and/or y which is our final position, v not which is our initial velocity, v which is our final velocity, t which it time, a which is acceleration, and theta which is the angle at which the object is released."*

Table with variable and what they mean and diagram to show variables

*"Using these seven variables, projectile motion can be described by these five equations. You may notice that theta is not in the five projectile motion equations. This is since theta will give us the x and y decomposition of our velocity"*

Show equations of motion

3

## Solving projectile Motion (time: 0:40 to 1:00)

*"Let's start with a practice problem first. When we see a projectile motion problem, our first step is to write down which of the seven variable are known and which we are trying to solve for."*

Diagram of block projectile motion

*"In this problem, we are given the initial velocity, and the release angle. By looking at the diagram, we can also find out acceleration and final velocities in both directions. Since the block is moving in an x/y coordinate system, the block will have acceleration in the y direction of gravity and will have no acceleration in the x direction. In many projectile motion problems we use mark x as the landing distance away from the start and y as the peak height that an object flies. This means that the ball will also have a final velocity of zero in the x direction when it lands. The ball will also have a final velocity of zero at the peak height because acceleration is continually acting downward and affecting the vertical velocity till there vertical velocity is zero."*

4

## X/Y direction acceleration (Time: 1:20 to 1:40)

*"On of the ways to better understand why we break up velocity and acceleration by the x and y direction is through the diagram looking like this."*

Diagram with block at different points

*"If we look at the block in the first position, we will have velocity by components looking like this. As the block goes to it's peak height, the y direction velocity goes to zero, this is because when the ball is at the top of the motion, it is at rest with respect to the y direction. As the ball goes from the peak of the y position to its final landing place, we will get y velocity again in the negative directing due to the direction that the block is moving. The entire time the ball is moving, the x direction velocity will be the same."*

5

## Velocity and acceleration (Time: 1:40 to 2:00 )

*"Now let us write down all of the known variables and all of the unknown variables. Since the object is moving in both the x and y direction let us have a xnot, y not, x, y, v not in x direction. V not in y direction, v in x direction, v in y direction, and acceleration in both x and y directions. Since the ball starts on the ground, x not and y not will both be zero. Since the distance away that the ball lands is unknown, x will be that distance. For now we will leave y as the unknown maximum height so we can solve for it later. Using trigonometry, we will find the the initial velocity in the x and y direction to be v initial times cos theta and v initial times sin theta. The acceleration in the x direction will be zero since the velocity is constant and the acceleration in the y direction will be gravity since this affects it."*

6

## Solving Example (Time: 2:00 to 2:20)

*"Since we now have all of our known conditions, we can use the equations for projectile motion to solve for unknowns. For this problems the only unknowns are x and y. Take a second to review the equations and solve for the three unknowns. Pause the video if you need more time."*

Diagram, knowns and unknown, Equations

*"In order to solve for y, since we do not have time we will use equation __. All we need to do is substitute in our known conditions. This will give us that the peak height is ___. To solve for x, we will use equation __. Again all we need to do is substitute in our knowns and we will find the displacement to be ___."*

7

## Solving (Time 2:20 to 2:35)

*"Now that we have done a practice problem, let's solve for the projectile motion of the ball of of the roller coaster track. We know x not, y not, the release angle, and the time it takes to land from the demo. The only other initial condition that we need to solve for is v."*

A diagram or the full track

*"In order to solve for v, we will need to use conservation of energy from the past videos."*

8

## Solve for v using Energy (Time: 2:35 to 2:50)

*"Looking at the full diagram, we can sum the energies on both from the initial release of the block to where the block exits the ramp. We will use KEi+PEi is equal to KEf+PEf. Using what we learned in the past videos, take a second and solve for the final velocity of the block leaving the ramp. Pause the video if you need more time."*

Diagram of full ramp, energy equation as KE and PE

*"If we remember correctly from the past videos, KE is ½*m*v^2 and PE is m*g*height. At the start when the block is released, we will only have PE. At the end we will have KE with our final velocity, and PE for the height that the block is released. Looking at the equation we have we can solve for final velocity to be __"*

9

## Variables for Motion (Time: 2:50 to 3:10)

*"Now that we have have all of our initial conditions, let us work through the problem. Using this diagram, let us figure out what variables we have and where they are on the diagram. Take a second to write down everything that we know. Pause the video if you need more time."*

Have all of the variables with equal signs

*"Looking at our diagram, we will have x not as __, x final as d which is where our block will land, y not as ___, y as up to represent the peak height, v not will be the initial velocity from the end of the track with the x direction being multiplied by cosine theta and the y direction being multiplied by sine theta, v finial will be zero for both the x and y direction, a in the y direction will be gravity in the y which is denoted as g, we will have no x direction acceleration, and we will have time at which the ball lands."*

10

## Finish solving (Time: 3:10 to 3:30)

*"The only thing left to do is solve for our unknowns. In the case, we are solving for the distance the block lands away from the start, and the peak height of the block. In order to solve for y, since we do not have time we will use equation __. All we need to do is substitute in our known conditions. This will give us that the peak height is ___. To solve for x, we will use equation __. Again all we need to do is substitute in our knowns and we will find the displacement to be ___. Now that we have solved everything, let us run the demo one more time to see how we did."*

Run demo show we land in the right spot (Discuss Friction?)

11

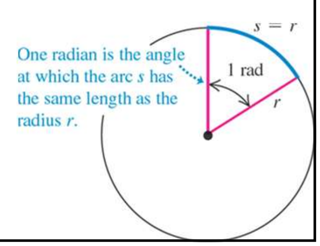
### B.5 Video 3.5 Transcript

# Video 3.5: Rotational

1

## Angular Coordinates

*"In this video, we will be going over rotational motion. Rotational motion happens when objects rotate or roll. When working on rotational motion problems, we must use angular coordinates. This means that we only use radians when solving problems. One radian is the angle at which the arc length a has the same length as the radius r with one complete rotation be equivalent to 2 pi radians or 360 degrees. This is important as it allows us to use the same units for any size of circular or rotating object."*




2

## Angular Displacement

*"Now that we know angular coordinates, let's look at all of the rotational variables we will encounter in rotational motion problems. First we will go over angular position denoted as theta. This must be measured in radians. And the equation for angular position is arc length over the radius of an object. Note that after there is a full rotation, theta does not go back to zero after a full rotation. Instead it keeps adding up. This is important for solving for angular displacement which is the final angular position minus the initial angular position."*

Display Angular Position, eq, Angular Displacement, eqs

3

## Angular Velocity

*"The next rotational variable is angular velocity denoted as omega. The equation for average angular velocity is the angular displacement divided by the change in time. The magnitude of angular velocity is called angular speed. When we are deciding the direction of angular velocity we choose the angle theta to increase in the counterclockwise direction and decrease in the clockwise direction."*

Display Angular velocity, eq and direction diagrams

4

## Right Hand Rule + Question

*“Angular velocity is a vector whose direction is given using the right hand rule. You can find the direction of angular velocity by curling your fingers on your right hand in the direction of rotation. You thumb will then point in the direction of angular velocity. Let’s practice this. Looking at the four diagrams below, what will be the direction of angular velocity for each of them? Pause the video if you need more time to solve these.”*

Right Hand Rule. Practice Diagams

*“The first diagram will have an angular velocity in ___. The second diagram will have an angular velocity in ___. The third diagram will have an angular velocity in ___. The fourth diagram will have an angular velocity in ___.”*

5

## Angular Acceleration

*“The final rotational variable is average angular acceleration denoted as alpha. This is found by the change in angular velocity divided by the change in time. Angular acceleration is also a vector. The direction of angular acceleration will be the same at angular velocity is the rotation is speeding up and it will be the opposite of angular velocity is the rotation is slowing down.”*

Angular acceleration, eq, direction examples

6

## Linear to Rotational Variable Changes

*“Now that we have all of our rotational variables, we need to learn how to convert between linear and angular kinematics. Linear speed, v, is angular speed times radius. Linear acceleration,a, is related to tangential acceleration by angular acceleration times radius. And linear acceleration is related to radial acceleration by angular velocity squared times radius.It is important to know these conversions as linear kinematics equations can be shown as angular kinematic equations as well.”*

Variable connections, table with linear and angular kinematics

7

**Table 10-3 Some Corresponding Relations for Translational and Rotational Motion**

| Pure Translation (Fixed Direction) | | Pure Rotation (Fixed Axis) | |
|---|---|---|---|
| Position | $x$ | Angular position | $\theta$ |
| Velocity | $v = dx/dt$ | Angular velocity | $\omega = d\theta/dt$ |
| Acceleration | $a = dv/dt$ | Angular acceleration | $\alpha = d\omega/dt$ |
| Mass | $m$ | Rotational inertia | $I$ |
| Newton’s second law | $F_{net} = ma$ | Newton’s second law | $\tau_{net} = I\alpha$ |
| Work | $W = \int F\,dx$ | Work | $W = \int \tau\,d\theta$ |
| Kinetic energy | $K = \frac{1}{2}mv^2$ | Kinetic energy | $K = \frac{1}{2}I\omega^2$ |
| Power (constant force) | $P = Fv$ | Power (constant torque) | $P = \tau\omega$ |
| Work–kinetic energy theorem | $W = \Delta K$ | Work–kinetic energy theorem | $W = \Delta K$ |

8

## Rotational Kinetic Energy

*"As well as having Rotational kinematics, we also have rotational kinetic energy. Rotational Kinetic Energy is one half times the moment of inertia times the angular speed squared. We use rotational kinetic energy in parallel with linear conservation of energy when we have a rotating object"*

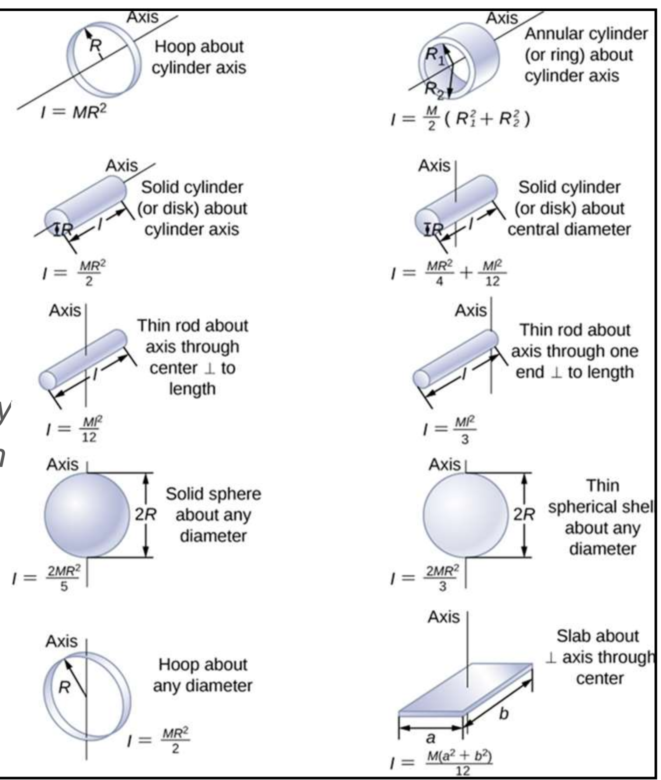
K = eq, diagram

9

## Moment of Inertia

*"The moment of inertia, denoted as I, is obtained by multiplying the mass of each part of an object by the squared distance that the object is from the axis of rotation. When we are are working with only one rotating object, we have a set of known moments of iberia for that object."*

I eq + table with known I




10

## Parallel-Axis Theorem + Question

*"If we are given an object that does not follow the the known inertia table, we can calculate the rotational inertia using the parallel-axis theorem. This theorem stated that the moment of inertia of an object is the inertia at the center of mass + the mass times the distance away from the center of mass. Let's practice finding the inertia for different objects. Looking at the two figures below, what would the moments of inertia be? Pause the video if you need more time to solve."*

Parallel-axis theorem, two diagrams

*"(Answer)"*

11

## Conservation of Energy

*"Rotational Motion also follows the work-kinetic energy theorem stating the the changing in kinetic energy it the work. If we think back to conservation of energy, we have initial energy is equal to the final energy of a system. In the case of rotational energy we would have the initial linear kinetic and potential energy plus the rotational work is equation to the final linear kinetic and potential energy."*

Equations

12

## Torque

*"Another component of rotational motion is torque*. Torque can be calculated using three different equations depending on where the torque is on an object. If the torque is in the same line of action as the force, torque will be Force times the length of the lever arm. When the torque force is at an angle from the force, it is force times length of lever arm times sin theta. If there are more than one toques, the sum can be found by multiply the moment of inertia by angular acceleration. Also torque is a vector as well. We can find the direction of torque using the right hand rule, by wrapping our fingers in the direction of the force around the rotational axis, our thumb will point in the direction of torque."

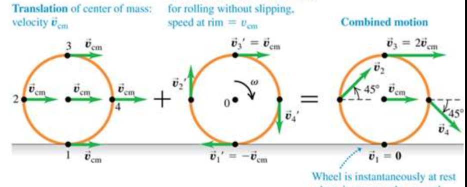
Equations, right hand rule

13

## Rolling Object

*"The final concept with rotational motion is rolling with and without slipping. The motion of a rolling wheel is the sum of the translational motion or linear motion plus the rotational motion. If the point of contact with the ground is at rest, then the object is rolling without slipping. For simplicity, we will imagine that all of our rotation in these videos will be without slipping."*

Diagram ->




14

**Table 11-1 More Corresponding Variables and Relations for Translational and Rotational Motion**[a]

| Translational | | Rotational | |
|---|---|---|---|
| Force | $\vec{F}$ | Torque | $\vec{\tau}\ (= \vec{r} \times \vec{F})$ |
| Linear momentum | $\vec{p}$ | Angular momentum | $\vec{\ell}\ (= \vec{r} \times \vec{p})$ |
| Linear momentum[b] | $\vec{P}\ (= \Sigma \vec{p}_i)$ | Angular momentum[b] | $\vec{L}\ (= \Sigma \vec{\ell}_i)$ |
| Linear momentum[b] | $\vec{P} = M\vec{v}_{com}$ | Angular momentum[c] | $L = I\omega$ |
| Newton's second law[b] | $\vec{F}_{net} = \dfrac{d\vec{P}}{dt}$ | Newton's second law[b] | $\vec{\tau}_{net} = \dfrac{d\vec{L}}{dt}$ |
| Conservation law[d] | $\vec{P} =$ a constant | Conservation law[d] | $\vec{L} =$ a constant |

15

### B.6 Video 4 Transcript

# Video 4: Demo w/ Friction

1

## Ball Instead? (Time: 0:00 to 0:15)

*"In videos 1-3, we went over the simplified version of solving the roller coaster track problem. In these videos, we had a block moving down the track and we ignored friction. To make the roller coaster track a bit more challenging, let us now have a ball that is rolling down the track with Friction. Just like with the block, we are solving to find the minimum height that the ball can be released from in order to make it through the loop."*

2

## Diagram (Time: 0:15 to 0:30)

*"To start this problem, let us draw a diagram of what the track looks like. We will have the ball at the top of the loop initially, then it will roll down the track to the final point of observation at the top of the loop. When drawing the path of the ball, since it is rolling, we need to take into account the radius of the ball since we have rotational motion. We must take into account that the center of mass due to rotational motion will be the center of the ball. So we draw the path of the ball at the radius on the ball all the way from the initial to the final position of observation."*

3

## FBD at top of loop (Time: 0:30 to 0:45)

*"Now that we have the diagram for the motion of the ball, let us draw a free body diagram of the ball at the top of the loop. There will be two forces acting on the ball, normal force and gravitational force. Can you draw where both of the forces will be on the ball?*

*Both of the forces in the y direction are pointing to the center of the loop so they will both be positive. Now if we sum the forces in the y direction, we know that they will be equal to mass times centripetal acceleration from Newton's laws. Now since the ball is at the top of the loop, normal force will go to zero, leaving gravitational force equal to mass times acceleration."*

Diagram, FBD, Eqs

4

## Velocity of the ball (Time: 0:45 to 1:00)

*"Now we want to solve for velocity at this point. We know that centripetal acceleration is equal to velocity squared over the radius. In our case, the radius will be the radius of the loop. This gives us that the velocity of the ball is the square root of acceleration due to gravity times the loop radius minus the ball radius."*

5

## Energy Balance (Time: 1:00 to 1:20)

*"Now that we know the velocity of the ball, Let us write down the conservation of energy equation. We have the initial kinetic and potential energy, and the final kinetic and potential energy. For the initial side of the equation, we will have mgh for the potential energy with h being the height that the ball is released from. We will have zero initial kinetic energy as the ball is being released from rest. We will have a Final potential energy of mg(2R) since we want to make sure the ball can make it through the loop so the height will be twice the radius of the loop. For final kinetic energy we will have both final linear and final rotational kinetic energy added together."*

Diagram and EQs

6

## Final Kinetic Energy (Time: 1:20 to 1:40)

*"To find the final kinetic energy, we want the final linear kinetic energy which is ½ m v^2 plus the final rotational kinetic energy ½ I omega^2. Now we are able to simplify the linear portion of this by substituting in the velocity that was solved for before.We also know what Inertia and omega are so we can simplify the rotational potion of the final kinetic energy. The inertia of the ball will be ⅖ m r^2 and the rotational velocity omega can be converted to linear velocity divided by the radius of the ball. This will all need to be squared as omega is squared in the original equation."*

7

## Solving for height (Time: 1:40 to 2:00)

*"With all of these substitutions made, the last thing to do is to solve for the height at which the ball needs to be released from. Since all components of the energy conservation equation have mass and gravity, that can be canceled out. This leaves us with an equation of only height, the loop radius and the ball radius. With some algebraic simplification, we get that the height the ball needs to be released from is 27 tenths of the loops radius"*

Equations

8

## Demo (Time: 2:00 to 2:20)

*"Let us now try releasing the ball from the height that we just solved for."*

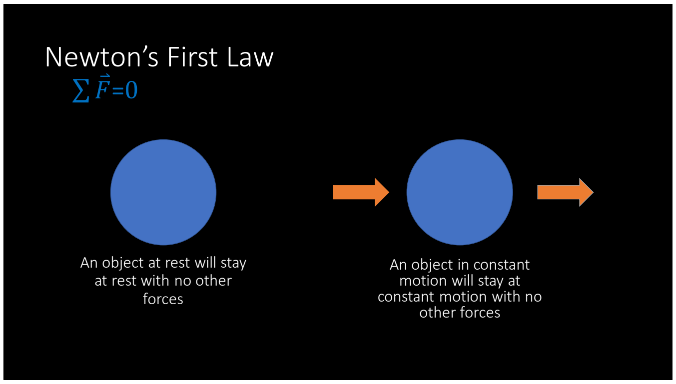
Do the demo

**Funny Comment**

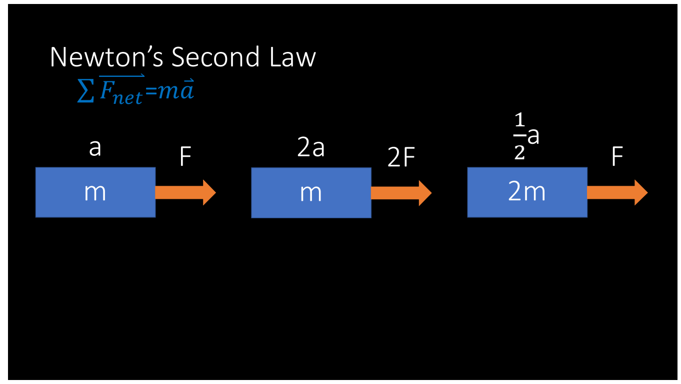
9

# C Appendix C: Video Animations

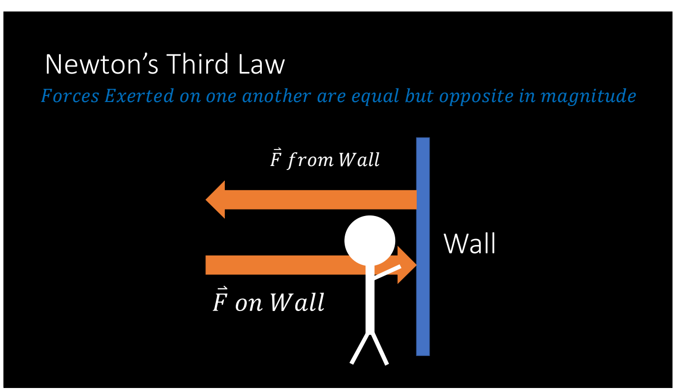
## C.1 Video .5 Animations


Newton's First Law
$\sum \vec{F} = 0$
An object at rest will stay at rest with no other forces
An object in constant motion will stay at constant motion with no other forces

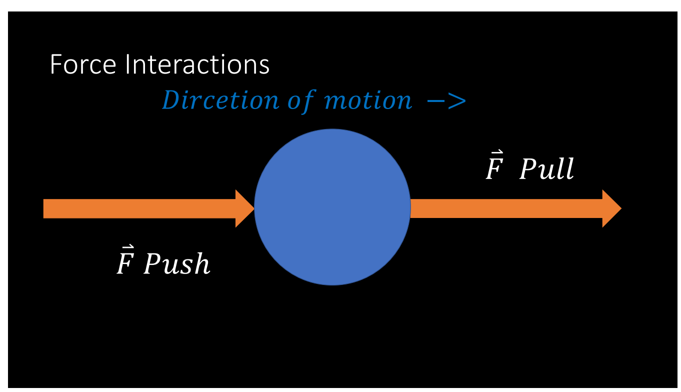
1


Newton's Second Law
$\sum \overrightarrow{F_{net}} = m\vec{a}$
a
F
m
2a
2F
m
$\frac{1}{2}$a
F
2m

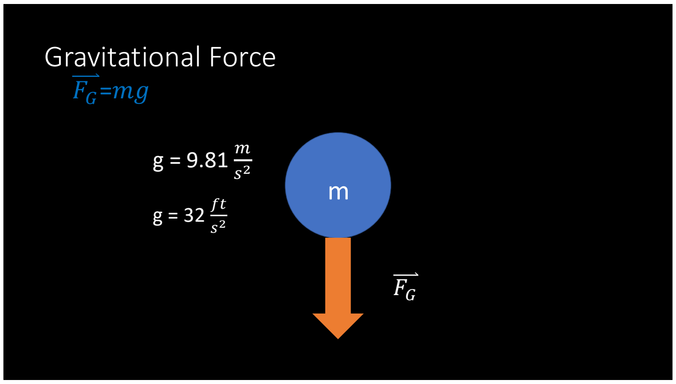
2


Newton's Third Law
Forces Exerted on one another are equal but opposite in magnitude
$\vec{F}$ from Wall
Wall
$\vec{F}$ on Wall

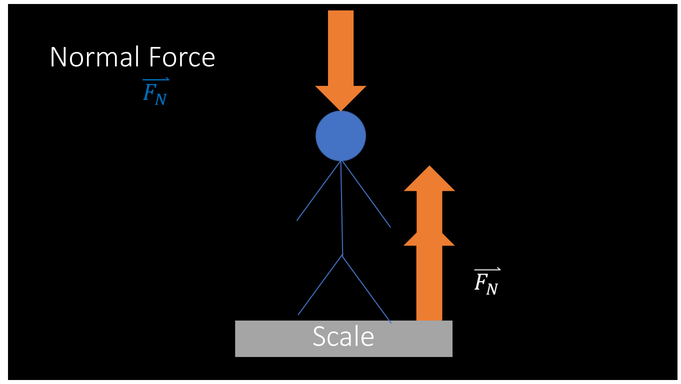
3


Force Interactions
Dircetion of motion ->
$\vec{F}$ Pull
$\vec{F}$ Push

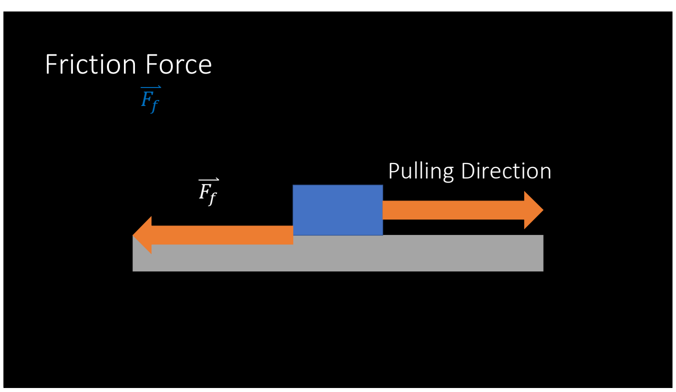
4


Gravitational Force
$\overrightarrow{F_G} = mg$
g = 9.81 $\frac{m}{s^2}$
g = 32 $\frac{ft}{s^2}$
m
$\overrightarrow{F_G}$

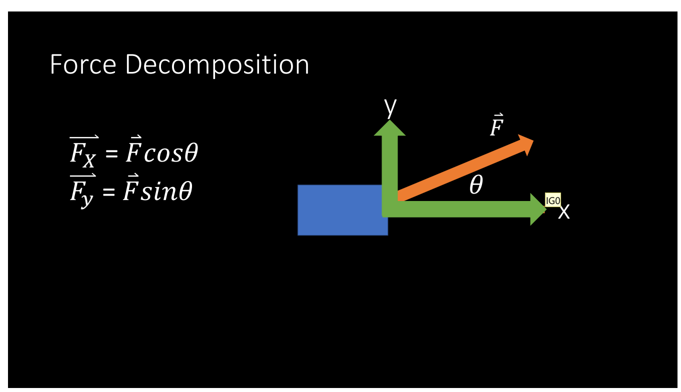
5


Normal Force
$\overrightarrow{F_N}$
$\overrightarrow{F_N}$
Scale

6


Friction Force
$\overrightarrow{F_f}$
$\overrightarrow{F_f}$
Pulling Direction

7


Force Decomposition
$\overrightarrow{F_X} = \vec{F}cos\theta$
$\overrightarrow{F_y} = \vec{F}sin\theta$
y
$\vec{F}$
$\theta$
x

8

## Slide 8

**IG0** APPEAR on click

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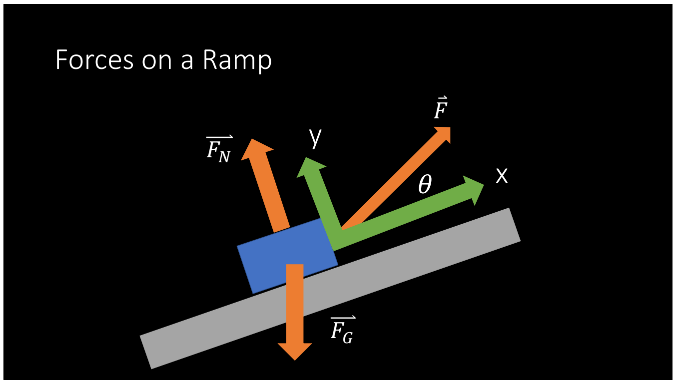
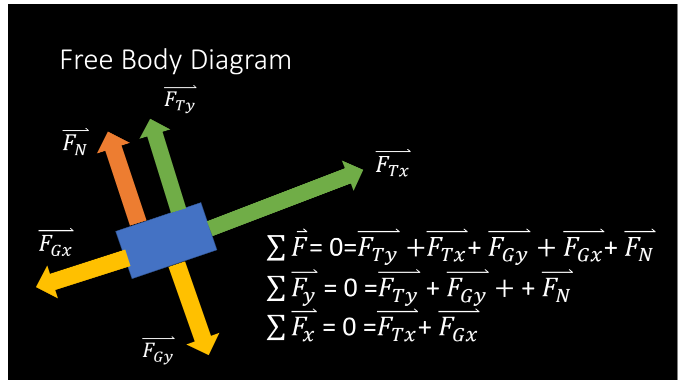


Forces on a Ramp
$\vec{F}$
$\overrightarrow{F_N}$
y
$\theta$
x
$\overrightarrow{F_G}$

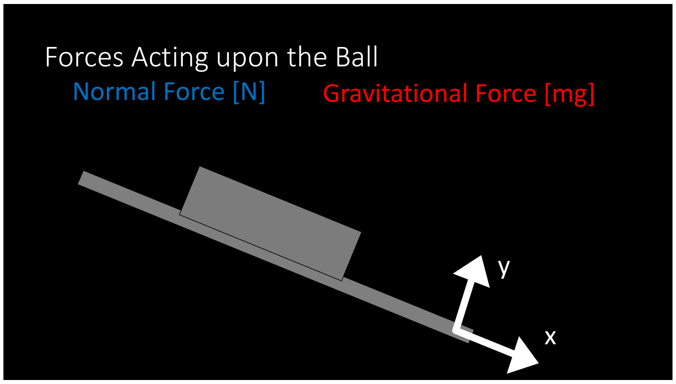

9



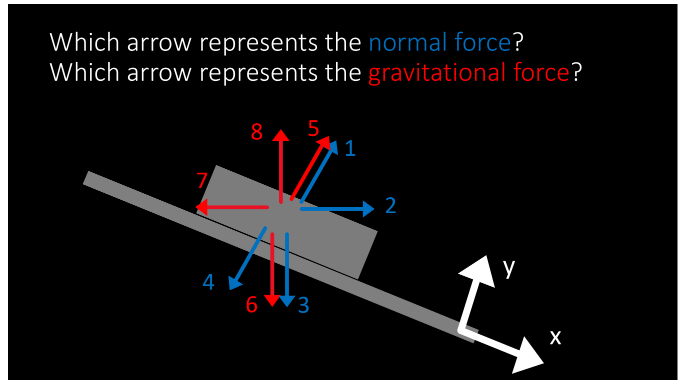
Free Body Diagram
$\overrightarrow{F_{Ty}}$
$\overrightarrow{F_N}$
$\overrightarrow{F_{Tx}}$
$\overrightarrow{F_{Gx}}$
$\sum \vec{F} = 0 = \overrightarrow{F_{Ty}} + \overrightarrow{F_{Tx}} + \overrightarrow{F_{Gy}} + \overrightarrow{F_{Gx}} + \overrightarrow{F_N}$
$\sum \overrightarrow{F_y} = 0 = \overrightarrow{F_{Ty}} + \overrightarrow{F_{Gy}} + + \overrightarrow{F_N}$
$\sum \overrightarrow{F_x} = 0 = \overrightarrow{F_{Tx}} + \overrightarrow{F_{Gx}}$
$\overrightarrow{F_{Gy}}$


10

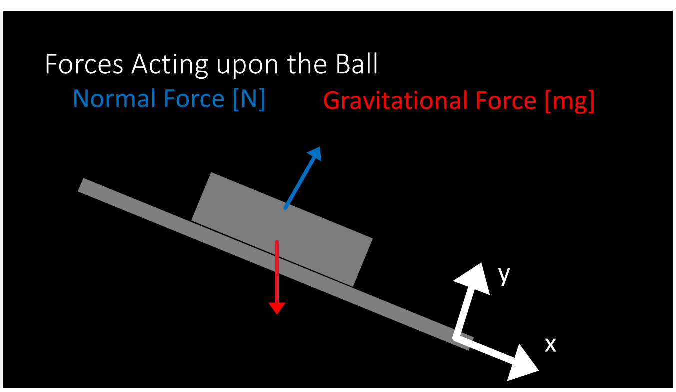
## C.2 Video 1 Animations




1




2




3

Energy of the Moving Object

Potential Energy

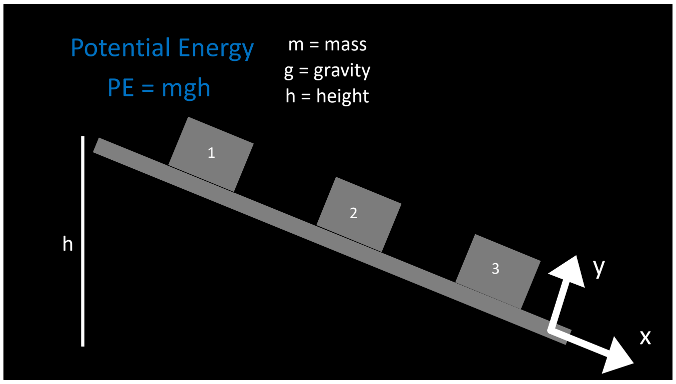
PE = mgh

Kinetic Energy [KE]

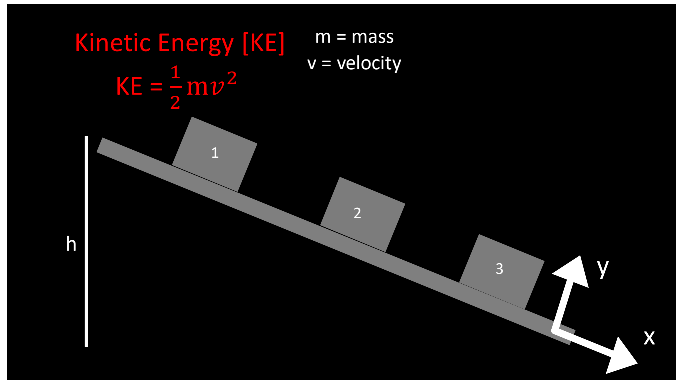
KE = $\frac{1}{2}mv^2$

m = mass
g = gravity
h = height
v = velocity

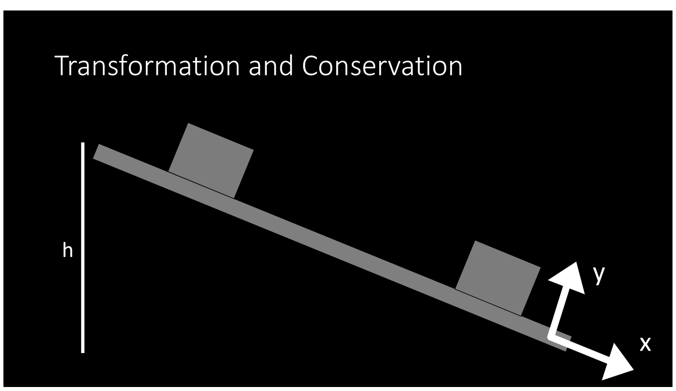
4


Potential Energy
PE = mgh
m = mass
g = gravity
h = height
1
2
3
h
y
x

5


Kinetic Energy [KE]
KE = $\frac{1}{2}mv^2$
m = mass
v = velocity
1
2
3
h
y
x

6


Transformation and Conservation
h
y
x

7

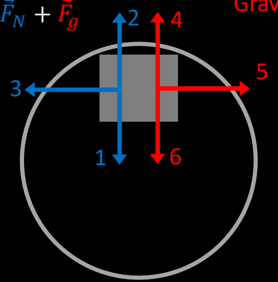
### C.3 Video 2 Animations

## Free Body Diagram

$\sum F = ma = \vec{F}_N + \vec{F}_g$

Normal Force $\vec{F}_N$

Gravitational Force $\vec{F}_g$




1

## Free Body Diagram

$$\sum F = ma = \vec{F}_N + \vec{F}_g = N + mg$$

$$a = \frac{v^2}{R}$$

$$\sum F = m\frac{v^2}{R} = N + mg$$

$$N = m\frac{v^2}{R} - mg$$

$$0 = m\frac{v^2}{R} - mg \rightarrow v = \sqrt{gR}$$

2

## Conservation of Energy

$$KE_{release} + PE_{release} = KE_{top} + PE_{top}$$

$$0 + mgh = \frac{1}{2}m\left(\sqrt{gR}\right)^2 + mg(2R)$$

$$mgh = \frac{1}{2}mgR + 2mgR$$

$$h = \frac{1}{2}R + 2R = \frac{5}{2}R$$

3

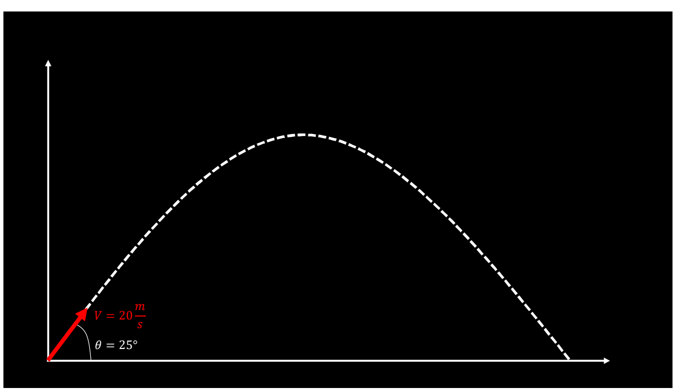
### C.4 Video 3 Animations

| Variables | What the Variables Mean |
|---|---|
| $x_0$ and $y_0$ | original position |
| $x$ and $y$ | final position |
| $v_0$ | initial velocity |
| $v$ | final velocity |
| $t$ | time |
| $a$ | acceleration |
| $\theta$ | release angle |

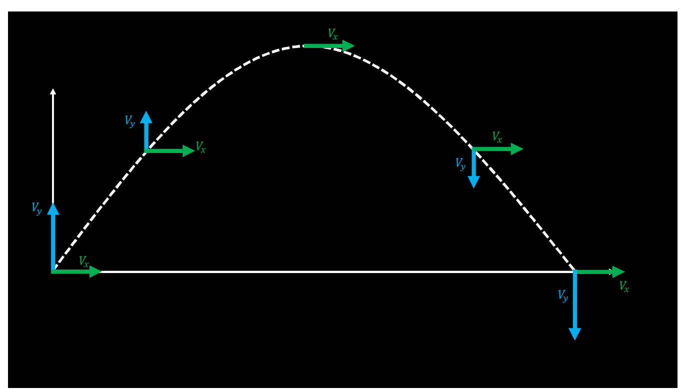
1

| Kinematic Equations for Projectile Motion |
|---|
| $x = x_0 + vt$ |
| $v = \frac{v_0 + v}{2}$ |
| $v = v_0 + at$ |
| $x = x_0 + v_0 t + \frac{1}{2}at^2$ |
| $v^2 = v_0^2 + 2a(x - x_0)$ |

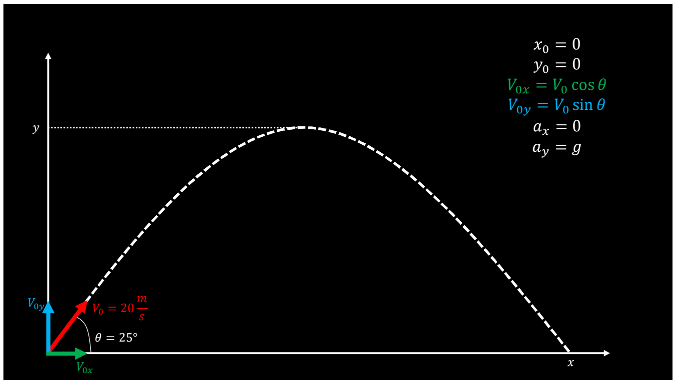
2




3




4




5

$$V_{0y} = V_0 \sin\theta = \left(20\ \frac{m}{s}\right)(\sin 25°) \approx 8.452\frac{m}{s}$$

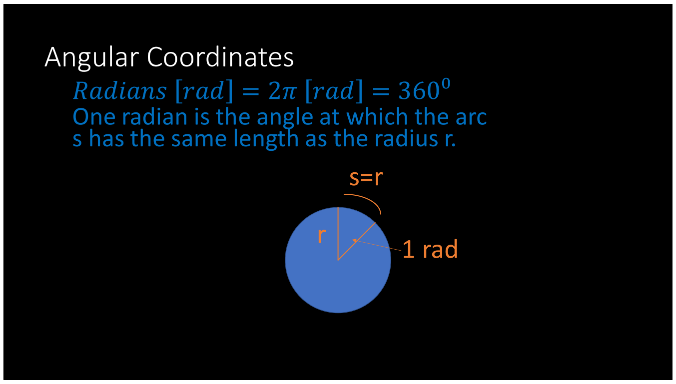
$$v^2 = v_0^2 + 2a(x - x_0) \rightarrow 0^2 = V_{0y}^2 - 2gy \rightarrow y = \frac{V_{0y}^2}{2g} \rightarrow y = \frac{\left(8.452\frac{m}{s}\right)^2}{2\left(9.81\frac{m}{s^2}\right)} \approx 3.641\ m$$

$$v = v_0 + at \rightarrow V_y = V_{0y} - gt \rightarrow 0 = V_{0y} - gt \rightarrow t = \frac{V_{0y}}{g} = \frac{8.452\frac{m}{s}}{9.81\frac{m}{s^2}} \approx 0.862\ s$$

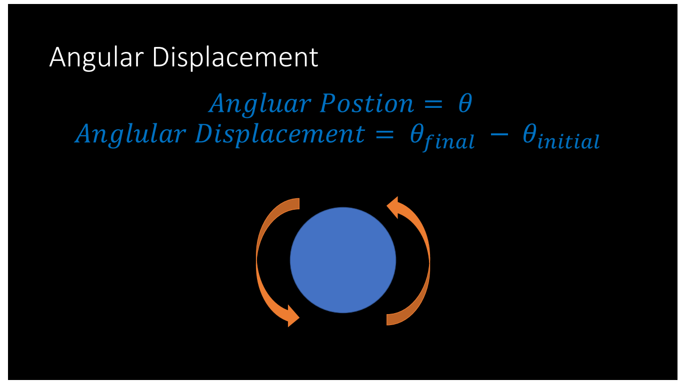
$$x = v_x * 2t_{max} = V_0 \cos\theta \cdot 2t_{max} = \left(20\frac{m}{s}\right)(\cos 25°)\ \cdot 2(0.862\ s) \approx 31.25\ m$$

6

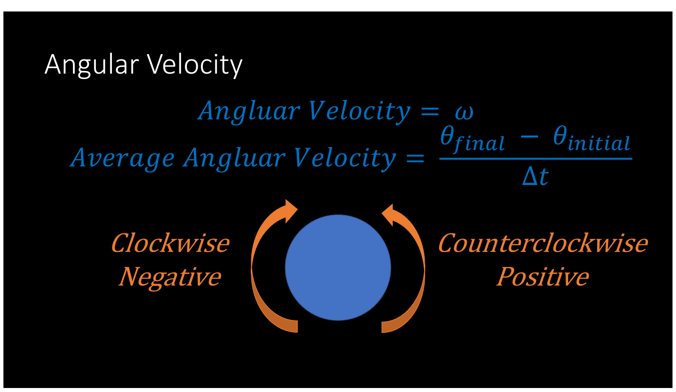
## C.5 Video 3.5 Animations


Angular Coordinates
$Radians\ [rad] = 2\pi\ [rad] = 360^0$
One radian is the angle at which the arc
s has the same length as the radius r.
s=r
r
1 rad

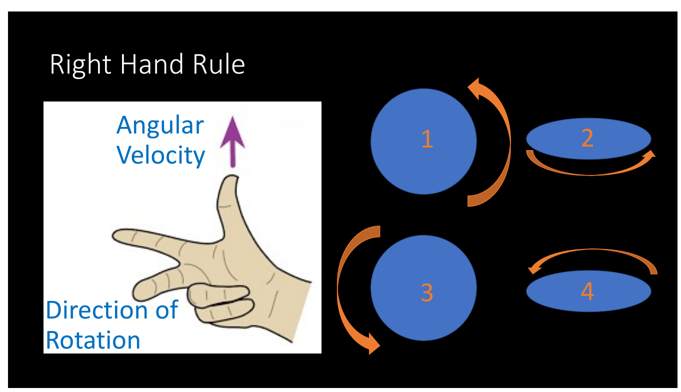
1


Angular Displacement
$Angluar\ Postion = \theta$
$Anglular\ Displacement = \theta_{final} - \theta_{initial}$

2


Angular Velocity
$Angluar\ Velocity = \omega$
$Average\ Angluar\ Velocity = \frac{\theta_{final} - \theta_{initial}}{\Delta t}$
*Clockwise*
*Negative*
*Counterclockwise*
*Positive*

3


Right Hand Rule
Angular
Velocity
Direction of
Rotation
1
2
3
4

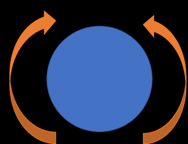
4

## Angular Acceleration

$$Angluar\ Acceleration = \vec{\alpha}$$

$$\vec{\alpha} = \frac{\omega_{final} - \omega_{initial}}{\Delta t}$$

*Slowing Down*
*Negative*



*Speeding Up*
*Positive*

5

## Linear to Rotational Variables

*Linear to Angular Velocity*

$$v = \omega r$$

*Linear to Angular Acceleration*

$$a = \alpha r = v^2 r$$

*Rotational Kinematics*

$$\theta = \varpi t$$

$$\omega = \omega_0 + \alpha t$$

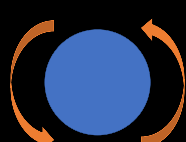
$$\theta = \omega_0 t + \frac{1}{2}\alpha t^2$$

$$\omega^2 = \omega_0^2 + 2\alpha\theta$$

6

## Rotational Kinetic Energy

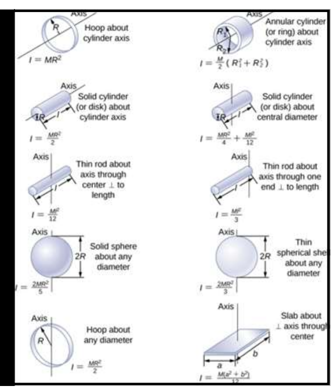
$$KE_{rotational} = \frac{1}{2} I \omega^2$$



7

## Moment of Inertia

$$Moment\ of\ Inertia = I$$




8

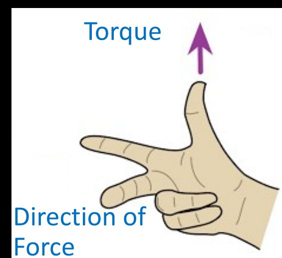
## Conservation of Energy

$$KE_{initial} + PE_{initial} = KE_{final} + PE_{final} + KE_{rotational}$$

$$\frac{1}{2}mv_{initial}^2 + mgh_{inital} = \frac{1}{2}mv_{final}^2 + mgh_{final} + \frac{1}{2}I\omega^2$$

9

## Torque



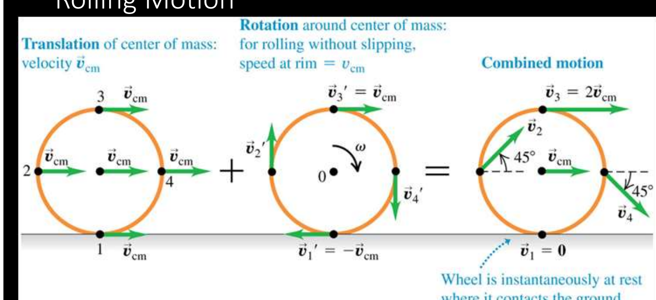

$$\tau = Fd$$

$$\tau = Fd \sin\theta$$

$$\tau = \sum Fd \sin\theta$$

10

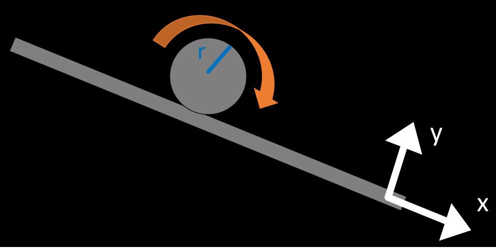
## Rolling Motion




11

### C.6 Video 4 Animations

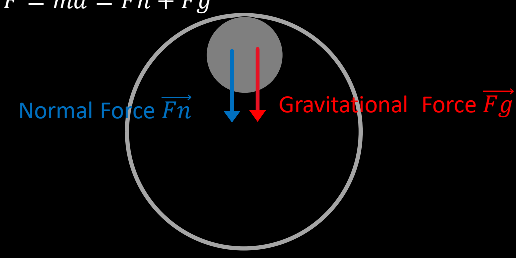
Rotational Diagram




1

Free Body Diagram

$$\sum F = ma = \overrightarrow{Fn} + \overrightarrow{Fg}$$




2

Velocity on Ball

$$a = \frac{v^2}{r}$$

$$\sum F = ma = m\frac{v^2}{R}$$

$$mg = m\frac{v^2}{R}$$

$$v = \sqrt{gR}$$

3

Conservation of Energy

$$KE_{initial} + PE_{initial} = KE_{final} + PE_{final} + KE_{rotational}$$

$$\frac{1}{2}mv_{initial}^2 + mgh_{inital} = \frac{1}{2}mv_{final}^2 + mgh_{final} + \frac{1}{2}I\omega^2$$

$$0 + mgh = \frac{1}{2}mv_{final}^2 + mg2R + \frac{1}{2}I\omega^2$$

$$mg(h - 2R) = \frac{1}{2}mgR + \frac{1}{2}\frac{2}{5}mr^2\omega^2$$

$$g(h - 2R) = \frac{1}{2}gR + \frac{1}{2}\frac{2}{5}r^2\omega^2$$

4

Conservation of Energy

$$g(h-2R)=\frac{1}{2}gR+\frac{1}{2}\frac{2}{5}r^2\omega^2$$

$$\omega=\frac{v}{r}$$

$$\omega^2=\frac{gR}{r^2}$$

$$g(h-2R)=\frac{1}{2}gR+\frac{1}{2}\frac{2}{5}r^2\frac{gR}{r^2}$$

$$h-2R=\frac{7}{10}R$$

$$h=\frac{27}{10}R$$

5

# D Appendix D: Post Video Questionnaire

Photos Credit: [12]

Video 1:

This video was an overview of the roller coaster demonstration. In this video we went over the forces acting on the ball: normal and gravitational. We also discussed energy and conservation of energy.

Equations from Video 1:

$PE = mgh$

$KE = (\frac{1}{2})mv^2$

Variables from Video 1:

m = mass

g = gravity

h = height

v = velocity

Post Video Questions:

1. What are the differences and comparisons of Kinetic Energy and Potential Energy?
2. What happens to an object's Potential energy as it is higher off of the ground?
3. What is the proportionality between mass and velocity for the equation of Kinetic Energy?
4. What direction would normal be facing if an object hits the ceiling? What about the gravitational force?
5. Why is energy conserved in a system (Hint: Think about the Conservation of Energy Equation)?

Video 2:

This video was the final part of the basic roller coaster demonstration. In this video we went over Free Body Diagrams, summing of forces, and conservation of energy. We did all of this to find the height that we need to release the block from in order for it to make it around the loop.

Equations from Video 2:

F = ma = Fn + Fg
Fn = N
Fg = mg
A = (v^2)/r
KEinitial + PEinitial = KEfinal + PEfinal (Conservation of Energy)

Variables from Video 2:

m = mass
g = gravity
h = height
v = velocity
N = Normal Force
R = radius = 19.5 cm

Post Video Questions:

1. Why is the normal force on the block at the top of the loop 0?
2. Does the mass of the object matter at all when trying to calculate the object's velocity at the top of the loop?
3. How would the height be affected if the block weighed more? Or less?
4. What can we change to make the block have a faster velocity?

Video 3:

This video goes over projectile motion. We learn how to solve projectile motion equations with a practice problem as well as we have a projectile motion off of the end of the track by releasing the ball from a higher point.

Equations from Video 3:

$$x = x_0 + \frac{1}{2}(v_x + v_{0x})t \qquad y = y_0 + \frac{1}{2}(v_y + v_{0y})t$$

$$v_x = v_{0x} + a_x t \qquad v_y = v_{0y} + a_y t$$

$$x = x_0 + v_{0x}t + \frac{1}{2}a_x t^2 \qquad y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2$$

$$v_x^2 = v_{0x}^2 + 2a_x(x - x_0) \qquad v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$$

Variables from Video 3:

| Variable Name | Symbol |
|---|---|
| Initial Position | $x_0$ |
| Final Position | $x$ |
| Initial Velocity | $v_{0x}$ |
| Final Velocity | $v_x$ |
| Time | t |
| Acceleration | $a_x = 0$ |

| Variable Name | Symbol |
|---|---|
| Initial Position | $y_0$ |
| Final Position | $y$ |
| Initial Velocity | $v_{0y}$ |
| Final Velocity | $v_y$ |
| Time | t |
| Acceleration | $a_y = -g$ |

Post Video Questions:

1. What happens to projectile motion if the block is released from even higher than we tried to do?
2. What happens to projectile motion is the release angle of the block is 30 degrees? What if it is 60 degrees?
3. What happens to the final x position if the mass of the block is tripled?
4. What would happen if instead of being on earth, this projectile motion problem happened on the moon where gravity is 1.62 $m/s^2$? How would this affect the peak height of the block? How would this affect the final x position?

Video 4:

Video 4 shows the roller coaster demonstration when we have a ball going down the track instead of a block. By using a ball instead of a block, we are able to have rotational motion affect the way that the ball is moving.

Equations and Variables from Video 4:

**Table 11-1 More Corresponding Variables and Relations for Translational and Rotational Motion**[a]

| Translational | | Rotational | |
|---|---|---|---|
| Force | $\vec{F}$ | Torque | $\vec{\tau}\ (= \vec{r} \times \vec{F})$ |
| Linear momentum | $\vec{p}$ | Angular momentum | $\vec{\ell}\ (= \vec{r} \times \vec{p})$ |
| Linear momentum[b] | $\vec{P}\ (= \Sigma \vec{p}_i)$ | Angular momentum[b] | $\vec{L}\ (= \Sigma \vec{\ell}_i)$ |
| Linear momentum[b] | $\vec{P} = M\vec{v}_{com}$ | Angular momentum[c] | $L = I\omega$ |
| Newton's second law[b] | $\vec{F}_{net} = \frac{d\vec{P}}{dt}$ | Newton's second law[b] | $\vec{\tau}_{net} = \frac{d\vec{L}}{dt}$ |
| Conservation law[d] | $\vec{P}$ = a constant | Conservation law[d] | $\vec{L}$ = a constant |

Post Video Questions:

1. What happens with changes to the mass of the ball, increase and decrease?
2. What will happen to the motion of the ball if the friction coefficient is increased due to a change in material of the ramp?
3. When comparing the results from Video 2 and Video 4, how much of an effect does the rotational kinetic energy have on the height that the ball/block needs to be released from?

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