Carowinds

"A Place Where Learning is Fun!"

Education Days

Student Manual High School

TO BE READ ON THE BUS ON YOUR WAY TO CAROWINDS!

Your bus pulls up to the entrance of **Carowinds** and you are about to jump out of your seat with excitement. After checking in, you run to the rollercoaster ride you have been hearing about for a year; Fury 325. You are now barreling down the track at 95 miles per hour, taking hairpin turns along its 6,602 feet of track. You're screaming at the top of your lungs in fear but enjoying every minute of it. The only thing holding you in your seat is a safety harness… but how does physics help keep you in your seat? How do the laws of physics affect amusement park ride design? Today you will learn how the basic principles of physics apply to the amusement rides at **Carowinds!**

All rides create forces through the use of engines…diesel, electric, steam, hydraulic, etc. They use lots of pulleys, gears, levers and other mechanical devices to transfer these forces throughout the ride and eventually to the riders. So why do you feel the forces you experience on the rides?

All can be explained by Newton's Three Laws of motion:

1. An object in motion tends to stay in motion and an object at rest tends to stay at rest until acted upon by an unbalanced force. (Inertia)
2. F = ma (force is equal to the mass of the object multiplied by its acceleration)
3. For every action (force) there is an equal and opposite reaction (force).

Before we move on, review some of the Vocabulary/Definitions of physics.

Acceleration: How quickly an object speeds up, slows down or changes direction. Is equal to change in velocity divided by time.

Centripetal force: A center seeking force; without this force, an object will simply continue moving in straight line motion.

Critical velocity: The speed needed at the top of a loop for a rollercoaster to make it through the loop.

Force: Any push or pull.

Friction: A force caused by a rubbing motion between two objects.

G-force: Also known as a gravitational force. Is equal to the force exerted on an object by the Earth's gravity at sea level.

Gravitational constant: The acceleration caused by Earth's gravity at sea level. Is equal to 9.81 m/sec^2 (32.2 ft./sec^2).

Gravity: A force that draws any two objects toward one another.

Inertia: The resistance of any physical object to any change in its state of motion (this includes changes to its speed, direction or state of rest). It is the tendency of objects to keep moving in a straight line at constant velocity.

Kinetic energy: The energy of an object in motion, which is directly related to its velocity and its mass.

Momentum: A measurement describing how much motion an object has. The more motion, the more momentum.

Potential energy: The energy stored by an object ready to be used. (In this lesson, we use gravitational potential energy, which is directly related to the height of an object and its mass.)

Speed: How fast an object moves. Is equal to the distance that object travels divided by the time it takes.

Velocity: A combination of speed and the direction in which an object travels.

THE PHYSICS OF ROLLERCOASTERS

When discussing the motion of rollercoasters, the following terms must first be defined:

- Distance: the total ground covered
- Displacement (d): the change in position
- Speed: the rate at which an object covers a distance
- Velocity (v): the rate at which an object changes position
- Acceleration (a): the rate at which an object changes velocity

From the given definitions above, the following equations can be derived:

- Speed = $\frac{distance}{time}$ Velocity = $\frac{displacement}{time}$

Using the definitions above, answer the questions below for The Intimidator.

1. When looking at The Intimidator, a rider will board the rollercoaster and get off it, in the exact same location after traveling along 5,316 feet of track.

   a. What is the displacement of the rider? ________________________

   b. What is the distance traveled by the rider? _____________________

2. Use your phone to time how long it takes for the Intimidator to complete the sections of track listed below and complete the speed and velocity chart using the equations provided.

SECTION	Start-Finish	Start to Top of First Hill	Top to Bottom of First Hill
TIME			
SPEED			
VELOCITY			

The velocity of an object is dependent on direction. Every time an object changes its direction of motion from up to down or vice versa, the velocity must equal zero at some point. Typically on a rollercoaster, this occurs at the top and bottom of hills.

3. Where does The Intimidator have a vertical velocity of zero?

   ____

THE PHYSICS OF ROLLERCOASTERS

Why do rollercoasters speed up as they move towards the ground and slow down as the move up? **Gravity** is a universal force that pulls all objects towards the ground at 32 ft/s^2. In other words, every single second, the velocity of an object falling towards Earth increases 32 ft/s every second. When an object is in free fall the acceleration (a) of the object equal to that of gravity. The velocity (v) and displacement (d) of an object in free fall can be modeled by the equations below:

$$v_f = v_i + a * t \qquad d = \frac{1}{2} * a * t^2 \qquad v_f^2 = v_i^2 + 2 * a * d$$

v_f = final velocity of object $\qquad$ v_i = initial velocity of object $\qquad$ t = time

Using the equations provided above, answer the following questions for The Drop Tower.

1. The Drop Tower lifts riders 174 feet into the air and allows them to drop 100 feet before the braking mechanisms kick in. Calculate the velocity of the riders immediately before the brakes kick in.

2. Using a stopwatch, time The Drop Tower from the moment the cars are released at the top of the ride to the moment the brakes kick in 100 feet below. Record this value below.

3. Use the equations above to calculate how long it should take for The Drop Tower to fall 100 feet. Compare this value to the observed value in question #2.

4. Once the braking mechanism kicks in, The Drop Tower car begins to slow down, or decelerate. Calculate the rate of deceleration for The Drop Tower, assuming it slows down at a constant rate for the remaining 74 feet.

THE PHYSICS OF ROLLERCOASTERS

Objects that move in a circular path undergo a different form of acceleration known as centripetal acceleration (a_c). Centripetal acceleration gives way to a force called centripetal force (F_c), which is the force that keeps an object in a circular path. As soon as the centripetal force is removed, the object would continue in straight path. The equations to calculate centripetal quantities are given below.

$$a_c = \frac{v^2}{r} \qquad F_c = m * a_c$$

v = velocity r = radius of circular path

Using the information and equations above, answer the following questions for the WindSeeker.

1. At its top speed, the WindSeeker rotates at 8 rotations per minute (rpm). How long does it take for the WindSeeker to make one rotation, also known as the period?

2. The diameter of the circle the rider travels in at top speed is 34.1 meters. What is the distance the rider travels every minute?

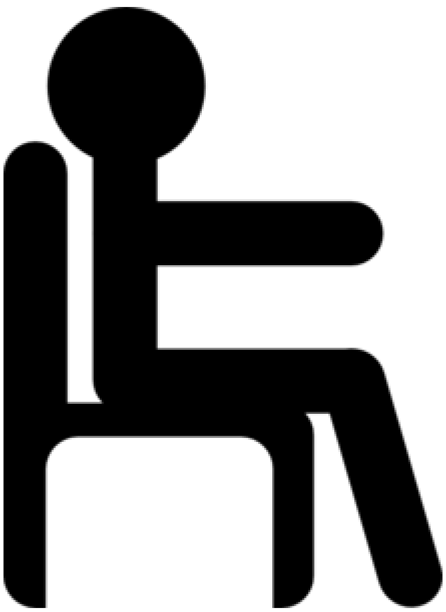
3. The WindSeeker travels at a top speed of 13.4 m/s. What is the centripetal acceleration of the rider at this speed?

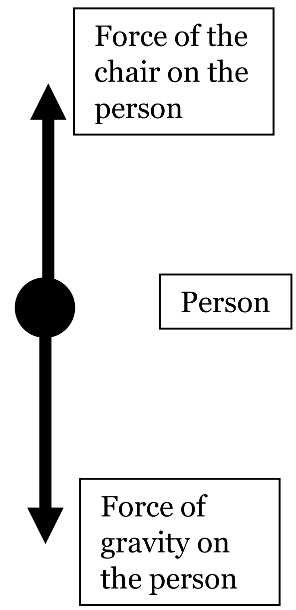
4. Suppose the average rider has a mass of 65 kg, what centripetal force would be required to keep the rider moving in a circular path?

5. How would your answer to Question #4 change if the diameter of the ride were cut in half?

THE PHYSICS OF ROLLERCOASTERS

All rollercoasters are a careful and artful balance of forces. In order for the rides to create extreme speeds, they must undergo some form of force to move them. These forces can be illustrated by free body diagrams which show all the forces acting on a single object by simplifying the object to a point and all forces as arrows acting on that point. The example of a person sitting in a chair is seen below.



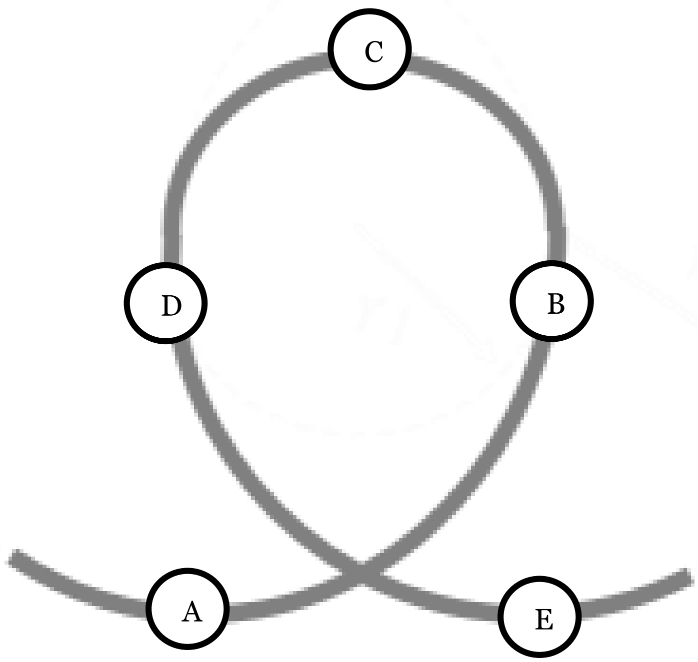


There are many different types of forces that an object can experience. Some of the most common ones are listed below.

- Tension Force (F_T): exerted on an object by a rope or string of negligible mass
- Frictional Force (F_f): results when two surfaces attempt to slide past one another, always opposes motion
- Normal Force (F_N): a force produced by a surface opposing an object resting on it, always acts perpendicular to the surface
- Gravitational Force (F_g): results when two objects pull one another together, most commonly the Earth pulling all objects on its surface towards the core
- Air Resistance Force (F_A): a type of frictional force that occurs when an object travels through the air
- Centripetal Force (F_c): the force that keep an object in a circular path, always points to the center of the circular path

THE PHYSICS OF ROLLERCOASTERS

Using the information provided above about forces, draw a free body diagram for a Carolina Cyclone rider in a loop at each of the specified points and label the forces present in the space provided below. Keep in mind, you are only considering the forces acting *directly* on the rider, not the rollercoaster itself.



A: ____

B: ____

C: ____

D: ____

E: ____

THE PHYSICS OF ROLLERCOASTERS

If forces get a rollercoaster to move, what keeps it in motion? Sir Isaac Newton answered this with his first law of motion which describes inertia and momentum. Inertia is the tendency of an object to continue its motion unless acted upon by an outside force. Momentum (p) is a measure of the amount of motion that an object with mass (m) has and can be calculated using the equation below. Further, due to the laws of conservation, momentum must be conserved, which means that the initial momentum of the objects, must be equal to the final momentum of the objects.

$$p = m * v \qquad\qquad p_i = p_f$$

Bumper cars are an excellent example of the conservation of momentum. As one car hits another, momentum is transfered and causes a change in motion. When calculating momentum for bumper cars, use velocity to the right as a positive quantity, and motion to the left as a negative quantity. Keep in mind that the momentum of a system is the sum of the individual momentums of each car.

Using the information and equations above, answer the following questions for Dodg'ems.

1. What are some forces that act against the momentum of a bumper car?

2. Car #1 is carrying a passenger with a mass of 65 kg and is traveling to the *right* at 10 m/s. Car #2 has a rider with a mass of 55 kg and is traveling to the *left* at 12 m/s. They head straight towards each other and collide. After the collision, the cars stick together.

    a. Calculate the momentum of Car #1.

    b. Calculate the momentum of Car #2.

    c. Calculate how fast the cars are going after the collision. Make sure to indicate which direction they head in.

THE PHYSICS OF ROLLERCOASTERS

It takes a lot of energy to generate the forces necessary to move a rollercoaster. When a force acts over a distance, the energy required for this motion is called **work**. Rollercoasters often utilize gravity to do a lot of the **work** for them; however, gravity only does **work** in a downward direction. One of the biggest design considerations for rollercoasters is picking mechanisms that will do work lifting the ride into the air such as chains, pulleys, springs, etc.

- While walking around the park, what are some ways that rollercoasters do work? (In other words, how do rollercoasters lift the ride into the air?)

As a rollercoaster is lifted higher and higher, it gains what is called **gravitational potential energy** (PE). As the rollercoaster falls back towards Earth, allowing the force of gravity to do work, its potential energy is converted to **kinetic energy** (KE). By the time the rollercoaster is returned to the surface of Earth all of the gravitational potential energy has been converted to kinetic energy, and thus conserved. The equations to calculate potential energy and kinetic energy are shown below.

$$KE = ½ * m * v^2 \qquad PE = m * g * h$$

g = acceleration due to gravity ($9.81\ {}^{m}/_{s^2}$)

h = height

Using the information and equations above, answer the following questions for NightHawk.

1. Suppose the mass of the NightHawk train car and its riders is 4500 kg. The first hill that NightHawk travels up is 35 meters high. What is the potential energy gained as NightHawk moves to the top of the hill?

2. After reaching the first hill, NightHawk plunges 31 meters down. How much potential energy does it have left at the bottom of the first hill?

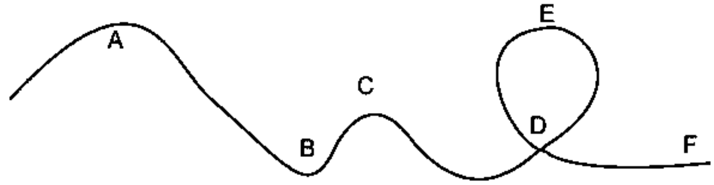
3. At the bottom of the hill, NightHawk is traveling at 22.8 m/s. What is the Kinetic Energy of NightHawk at the bottom of the hill?

4. What is the total energy that NightHawk has at the bottom of the first hill? (Hint: Add the remaining potential energy and kinetic energy together.)

5. Since energy is conserved, the answer to Question #4 and Questions #1 should be equal. Are they? What are some ways energy might have been lost during the ride?

6. What would happen if the second hill of a rollercoaster was higher than the first hill? Would this be a good rollercoaster design? Why or why not?

7. Use the knowledge you have gained about the motion of rollercoasters to determine which point(s) on the rollercoaster below match the following phrases:
   - Maximum velocity
   - Minimum velocity
   - Maximum potential energy
   - Minimum potential energy
   - Maximum kinetic energy
   - Minimum kinetic energy



THE PHYSICS OF ROLLERCOASTERS

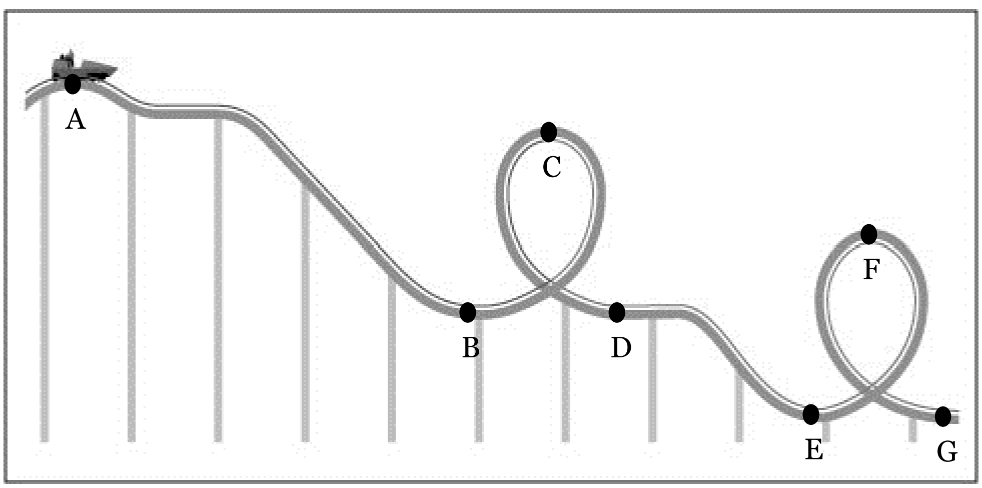
One of the fun aspects of rollercoasters is the ability to feel completely weightless. Although the rider never actually is weightless, the forces acting on a rider can give the perception of weightlessness. These altered feelings of weight can be described in terms of G-force. People constantly feel the force of gravity, or 1G. When the rollercoaster is accelerating downward, the seat or harness has a reduced force acting on the rider, giving the perception of reduced weight and a G-force less than one. When the rollercoaster is accelerating upward, the rider will feel heavy as he is pushed in to the seat and a G-force greater than one.

Often rollercoasters use the momentum of a downward hill to accelerate the train up the next hill; however, if the acceleration is too much, G-forces will become extreme. If G-forces exceed 4-6G, the rider will often blackout momentarily.

1. How might a rollercoaster designer take G-forces into consideration when planning a hill after a large drop?

2. Where on the ride Southern Star do you think riders feel weightless? Heaviest?

3. On the rollercoaster below, determine where G-forces will be equal, less than, or greater than 1G.



A-B: ____________________________ D-E: ______________________________

B-C: ____________________________ E-F: ______________________________

C-D: ____________________________ F-G: ______________________________

STATION: SWINGING CUP OF WATER & SPIRAL FUNNEL

Centripetal Force is a force created to keep an object moving in a circle. Anytime an object moves in a circular path, it has a centripetal force acting upon it. For example, the ScreamWeaver uses metal bars to create centripetal forces to swing the cars in a circle. Without this force, the cars would fly off in a straight line.

1. Circle which of the following creates the centripetal force:
    a. Cup
    b. Water
    c. String

2. What part of a rollercoaster keeps it traveling in a circle as it moves through a loop?

3. Relate the water in swinging cups to being pushed into your seat during a rollercoaster loop.

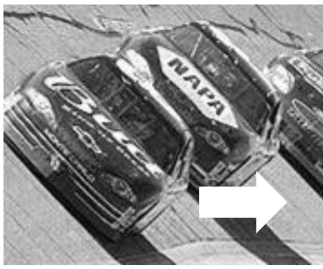
4. What would happen if you let the string go while you were swinging the cup? Why?

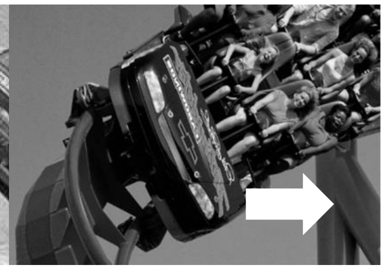
5. If you replaced the water with heavy metal, would the force from the cup swinging in a circle feel heavier or lighter? Why?

STATION: SWINGING CUP OF WATER & SPIRAL FUNNEL

"A Cool Experience for Young Scientists!"
Atomz Lab

1. Consider a race track. Have you ever noticed how the track banks at an angle around the curves? What force does this generate to help the cars turn in a circular path?





2. What do you notice about the washer as it travels down the banked edges of the funnel? Does the washer stand upright or lean like cars on a race track?

3. Where did the washer spin the fastest?

4. Describe your observations of different size washers in the funnel.

5. Which Carowinds rides have banked turns like a race track?

6. What would happen if the edges are banked too much? Where does this occur in the funnel?

STATION: NEWTON'S CRADLE & BUMPER MARBLES

Sir Isaac Newton's First Law of Motion states that an object at rest will remain at rest and an object in motion will continue in motion until an outside force acts on it. Dodg'ems demonstrates this every time two bumper cars hit each other. If one bumper car is sitting still, it will continue to sit still until another bumper car hits it, causing it to move. If a bumper car is moving, it will continue to move until it hits another bumper car, the wall, or the brakes are applied.

1. Explain how Newton's Cradle demonstrates the First Law of Motion. Relate it to balls in motion and at rest.

2. Newton's Cradle is an excellent demonstration of Newton's Third Law. Describe what happens in each of the situations below.

    a. Swing one ball.

    b. Swing two balls.

    c. Swing one ball from each side at the same time.

3. When you roll a marble down the ruler, it continues to roll at the same speed until it hits another marble.
    a. How is the Bumper Marble experiment similar to Newton's Cradle?

    b. Which Law of Motion does this demonstrate?

4. How much farther did the marble travel when hit with the heavier one?

STATION: SlingShot

Just like the ride SlingShot, a toy slingshot uses tension forces created by stretchy materials to cause motion. SlingShot always pulls a rider straight down, therefore its motion is always straight up after launch. If SlingShot pulled riders down at an angle, the riders would travel up and away.

1. Depending on the launch angle, the object will travel in different directions. How does the object's motion change for each of the following launches?

    a. Pull down to launch.

    b. Pull down and to the side to launch.

    c. Pull straight back to launch.

The weight of the object can also affect how it travels through the air. A lighter object will slow down quicker due to air resistance; whereas a heavier one has more momentum to keep it in motion.

1. Launch the heavy and the lighter object at the same angle.

    a. Which object had more momentum?

    b. Why?

STATION: ROLLERCOASTER TRACK

Based on all of the information you have learned throughout the workbook, use your definitions and knowledge to answer the following questions.

1. Different materials behave differently due to their weight or texture. **Predict** which ball will travel the rollercoaster track the fastest: metal, plastic, or wood. Why?

2. Run each of the balls through the track. Was your prediction correct?

3. On the back of this page, draw a diagram of the rollercoaster experiment. Label the following points:

    - Maximum potential energy
    - Maximum kinetic energy
    - Using the stopwatch, indicate the time it took for each marble to complete the track

4. On the diagram you drew for Questions #3, where would each of the following items occur:

    - A centripetal acceleration
    - The marble feels lighter
    - The marble feels heavier

STATION: ROLLERCOASTER TRACK

The design of a rollercoaster considers many different factors. Use the same marble on both tracks to answer the following questions.

1. Which rollercoaster took longer for the marble to complete? (Use the stopwatch to time the marble on both tracks.)

2. If you use the same marble on both tracks (one with loops and one with no loops), does it experience the same amount of friction, or does one track have more? Explain your answer.

3. Which track does the marble travel the fastest on?

   a. Loops
   b. No loops

4. What are some design considerations you might have when trying to build your own rollercoaster track?

We hope you enjoyed your stay at Carowinds!

Remember, learning science is fun!

Atomz Lab, LLC

9608 Longstone Lane
Charlotte, NC 28277

p: (704) 651-8989
e: atomzlab@gmail.com

www.atomzlab.com