”A Place Where Learning is Fun!”

Education Days

Student Manual

Middle 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. They use lots of pulleys, gears, levers and other mechanical devices to transfer these forces throughout the rides. 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. 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.

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.

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

Inertia: The resistance of any 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.

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

Kinetic energy: The energy of an object in motion.

Potential energy: The energy stored by an object ready to be used.

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 amusement park rides, 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 they 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 (v) 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 is equal to that of gravity.

1. The Drop Tower lifts riders 174 feet into the air and allows them to drop 100 feet before the braking mechanisms kick in. What is the Drop Tower's acceleration while it falls the first 100 feet?

2. Using your phone, 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. Using your phone, time how long the Drop Tower takes to lift back up into the air before falling again. Record it below.

4. Compare the answers to Question #2 and Questions #3. Which motion had greater acceleration, falling downward or being thrust back up into the air?

5. The acceleration gained from the Drop Tower falling comes from gravity. Where does the acceleration to lift the Drop Tower back up into the air come from?

THE PHYSICS OF ROLLERCOASTERS

Objects that move in a circular path undergo a special form of acceleration known as **centripetal acceleration**. Centripetal acceleration creates a force that keeps objects in a circular path. Anytime an object moves along a curve, it is undergoing centripetal acceleration.

1. Which of the following rollercoasters use centripetal acceleration and forces?

    a. Yo-Yo Scrambler
    b. WindSeeker
    c. Southern Star
    d. ScreamWeaver
    e. Flying Ace Balloon Ride
    f. All of the above

2. The Character Carousel uses centripetal forces to move riders in a gentle circle. What would happen if one of the horses broke off and was able to move on its own?

    a. It would continue to move in a circle
    b. It would fly off the carousel

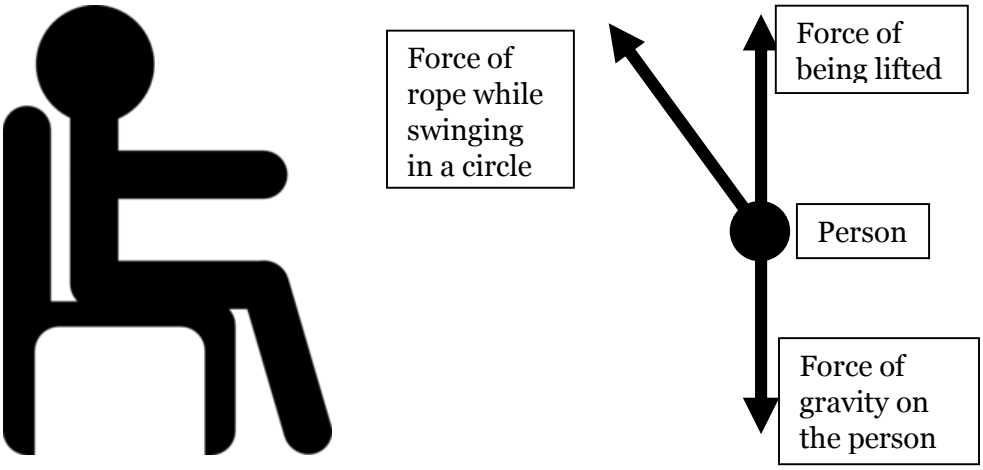
    Why?

3. Although all of the horses move together as one on the Character Carousel, not all of the horses travel at the same speed. To prove this, pick a horse to follow and try to keep up with it as it moves in a circle. Describe what you notice as you follow the horse.

4. What if you moved further away from the Carousel; would you have to move faster or slower to keep up with the same horse?

THE PHYSICS OF ROLLERCOASTERS

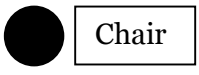
All rollercoasters are a careful and artful balance of forces. In order for the rides to create extreme speeds, they must undergo some form of force to move them. Forces can be drawn using arrows to show the direction. For example, a person sitting on a chair is shown below.

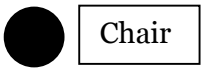


1. If you were riding on the WindSeeker, how would the direction of the rope pulling on your chair change in each of the following situations? Draw an arrow to show the direction the rope pulls you.

   a. Being lifted into the air

   b. Being swung in a circle





THE PHYSICS OF ROLLERCOASTERS

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

- Tension Force: a force produced by a rope or string pulling on an object
- Frictional Force: results when two surfaces attempt to slide past one another, always points in the opposite direction of motion, always points against motion
- Normal Force: a force that occurs when a surface pushes back on an object, keeps objects from falling through a surface, acts perpendicular to the surface
- Gravitational Force: results when two objects pull one another together, most commonly the Earth pulling all objects towards the core
- Air Resistance Force: a type of frictional force that occurs when an object travels through the air, always points against motion
- Centripetal Force: the force that keep an object in a circular path, always points to the center of the circular path

1. Use the forces listed above to help you determine the types of forces that act on a rider while on each of the following rides.

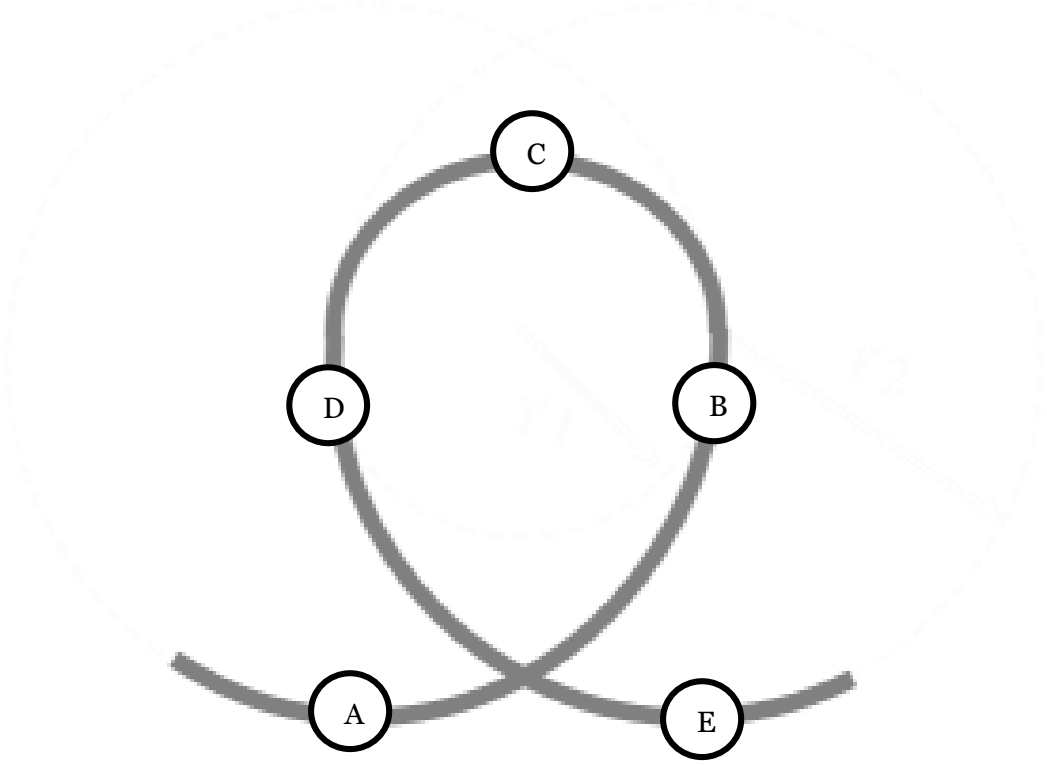
    a. SlingShot

    b. Carolina Cyclone

    c. Drop Tower

THE PHYSICS OF ROLLERCOASTERS

Using the information provided above about forces, draw and label the forces at each point on the diagram below for a Carolina Cyclone rider in a loop. 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 is a measure of the amount of motion that an object has. The heavier and faster an object travels, the more momentum it has.

1. For each of the pairs listed below, pick the object that has more momentum.

    a. A marble rolling down a hill or a bowling ball rolling down the same hill?

    b. A car traveling at 100 miles per hour or a car traveling at 1 mile per hour?

So what happens when two objects, each with their own momentum, collide? The answer can be complicated depending on the mass and speed of the objects; however, it is seen very easily with bumper cars like those used in Dodg'ems.

2. While watching Dodg'ems, look to see what happens for each of the situations below and describe what you see.

    a. Two cars slam into each other at the same speed.

    b. One car hits another car from behind.

THE PHYSICS OF ROLLERCOASTERS

Rollercoasters take a lot of energy to provide the fun that riders know and love, but where does this energy come from? Some of the energy comes from machines, while other energy comes from gravity. As an object is lifted into the air, it gains **potential energy** from gravity. The higher you lift it, the more potential energy it gains. If you release the object, the energy stored inside the object in the air is converted to **kinetic energy**, or motion energy. An object that is not moving has no kinetic energy, but as it speeds up, its kinetic energy increases.

1. From the list below, circle the ways that rollercoasters get their potential energy.

    a. Pulley
    b. Ropes & Chains
    c. Sunlight
    d. Wheels
    e. Stairs

2. Which has more *potential* energy:

    a. A rollercoaster at the top of a hill
    b. A rollercoaster at the bottom of a hill

3. Which has more *kinetic* energy:

    a. A rollercoaster resting at the top of a hill right before it starts to slide down it
    b. A rollercoaster zooming through the bottom of a hill

4. What type of energy is used to climb the next hill? What type of energy does a rollercoaster gain as it goes up the next hill?

THE PHYSICS OF ROLLERCOASTERS

As a rollercoaster moves down a hill, its potential energy from gravity is converted to kinetic energy as it speeds up; however, some of the energy is lost due to friction. When two surfaces slide past one another, such as a rollercoaster train and the tracks, friction produces heat and uses up some of the potential energy.

1. Rub your hands together quickly for 30 seconds. What do you notice about the temperature of your hands as you do this?

2. A rollercoaster never goes higher than the first hill. How does friction play a role in this?

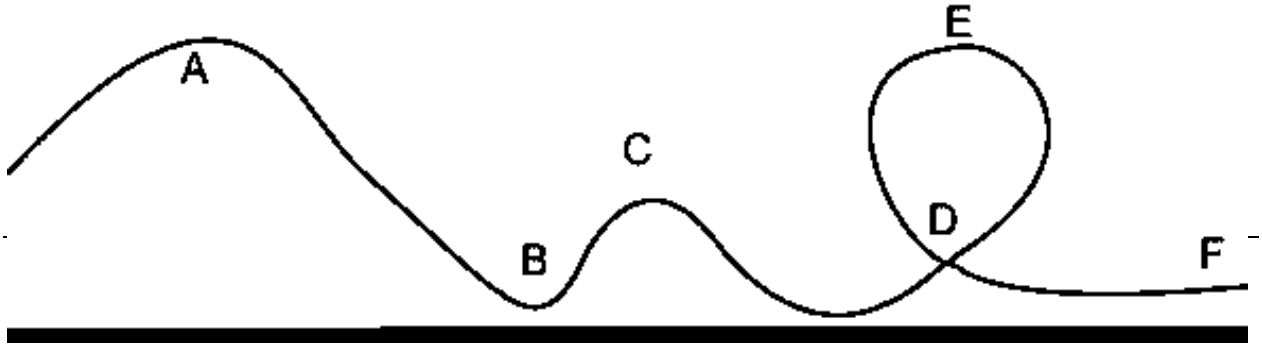
3. Based on what you have learned about potential and kinetic energy, where on the rollercoaster (below) would each of the following would occur? (Fill in the blank with the matching letter.)

   Maximum Potential Energy: _____

   Minimum Potential Energy: _____

   Maximum Kinetic Energy: _____

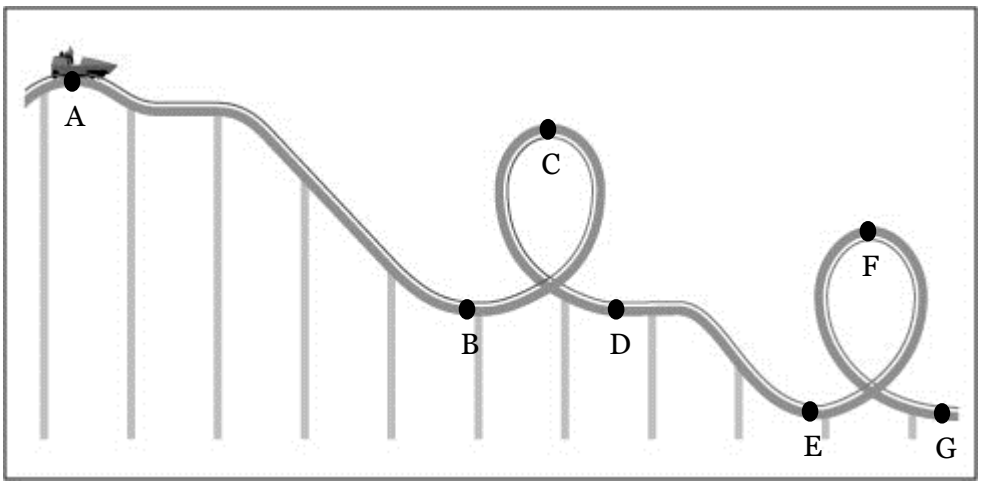
   Minimum Kinetic Energy: _____



THE PHYSICS OF ROLLERCOASTERS

One of the fun aspects of rollercoasters is the ability to feel completely weightless. Weight is a measure of how hard gravity pulls on an object; the heavier an object is, the more gravity pulls on it. Although the rider is never actually weightless, he/she can have the feeling of weightlessness. When the rollercoaster is accelerating downward, it falls with gravity so he/she feels lighter. When the rollercoaster is accelerating upward, the rider will feel heavy as he moves against gravity.

1. On the rollercoaster below, determine which rollercoaster sections will make the rider feel *lighter* or *heavier*.



A to B: _____

B to C: _____

C to D: _____

D to E: _____

E to F: _____

F to G: _____

2. If the rider is traveling on a flat section of track, would the rider feel heavier, lighter, or normal?

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?

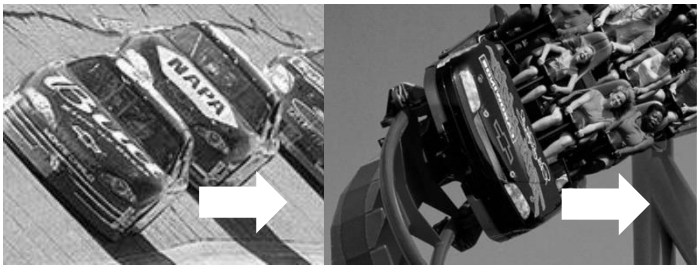
3. Relate the water in swinging cups to being pushed into your seat during a rollercoaster loop.

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

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!

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