Table of Contents

Welcome to *Hersheypark*®! We are happy to see you are participating in our Physics Day activities. This workbook offers a range of questions based on the Physics of our rides, and is designed to give students the opportunity to apply their knowledge in a hands-on environment while enjoying the day at *Hersheypark*!

This workbook was designed to apply teachings in your Physics class to real world experiences. Feel free to customize the activities and problem solving to your needs.

Hersheypark would like to thank and recognize several individuals who have worked together to be able to provide this educational resource. These individuals are continuing the tradition of educational enrichment within *Hersheypark*:

- Michelle Doll-Osterhout, Manheim Township High School
- Chris Manning, Manheim Township High School
- Anton Oberg, Manheim Township High School
- Jim Delaney, Manheim Township High School (retired)

Sample Itinerary

Hersheypark Physics Day offers students a unique opportunity to experience first-hand the physics concepts learned in the classroom. Over the years, many teachers have, through trial and error, developed ideas and procedures that make the Physics Day experience one of the most significant learning events of the year for their students. The following are some suggestions and advice when planning the trip:

Prior to the trip - administrative preparation:

_____ a. Plan financing for the trip.

_____ b. Present proposal to administration for approval.

_____ c. Determine procedures to be used at the Park. For example, what are your check-in locations? What will you do in the event of an emergency situation?

_____ d. Obtain permission slips from students.
Note: Be sure the students indicate any medical concerns (like allergies to bee stings) on their permission slips. Your district may or may not require you to bring a nurse.

_____ e. Line up transportation.

_____ f. Instruct students to download the *Hersheypark* app to have access to the map, ride wait times, and more.

_____ g. Make sure students are aware that *Hersheypark* is cashless. They can convert cash to prepaid debit cards at the Cash-to-Card kiosks stationed around the park.

_____ h. Establish itinerary to maximize educational opportunities.

Time schedule (for example purposes only, check Hersheypark.com for hours):

10 AM Gates open. Students can enter the front section of the park and ride the Carrousel.

11 AM Rides open throughout the park. Begin lab activities. Activities typically take between three and four hours to complete with good reliability, depending on the number of labs that students

complete. Lunch-time check-in is a good time to assess how activities are going.

3 PM Experimenting is typically complete by this time, making it a good time for a check-in. Materials can be collected. Some groups leave early in order to arrive at school at the end of the school day. Other schools give students free time to enjoy the Park until it closes.

Educational preparation:

_____ a. Establish and review safety requirements and emergency procedures.

_____ b. Pretest students on concepts to be reinforced by the field trip.

_____ c. Teach/review concepts that will be dealt with during the trip.

_____ d. Construct accelerometers.

_____ e. Assemble all materials needed for the trip. (lab manuals, pencils, calculators, stopwatches, accelerometers, and a plastic bag to carry materials)

_____ f. Determine the number of students per lab group and assign lab group members. (Groups of 3 or 4 seem to work best.)

_____ g. Set clear objectives and requirements for students (number of rides to analyze, evaluation procedures that will be applied, follow-up assignments, etc.)

Example: Students must complete worksheet packets on three to four rides.

Day of the trip:

_____ 1. Remind students of safety requirements and emergency procedures.

_____ 2. Remind students of check in times and locations.

_____ 3. Students should be prepared for sun or rain. Sunscreen is highly recommended.

_____ 4. Students should bring money/cashless payments.

After the trip:

______ 1. Schedule class time for follow-up discussion of concepts experienced.

______ 2. Evaluate student work.

______ 3. Post-test students on concepts.

______ 4. Put up a bulletin board. It's a great motivation for future classes!

We hope that your educational experience goes smoothly and that your students walk away with a deeper understanding of physics principles.

Equipment Overview

There are three pieces of equipment that are used in the lab manuals:
- Stopwatch
- Horizontal Accelerometer
- Vertical Accelerometer

Any timing device or cell phone can be used as a stopwatch. However, please keep in mind, cell phones, stopwatches and handheld timing devices are not permitted on *Hersheypark* attractions. The stopwatch can be used from the ground.

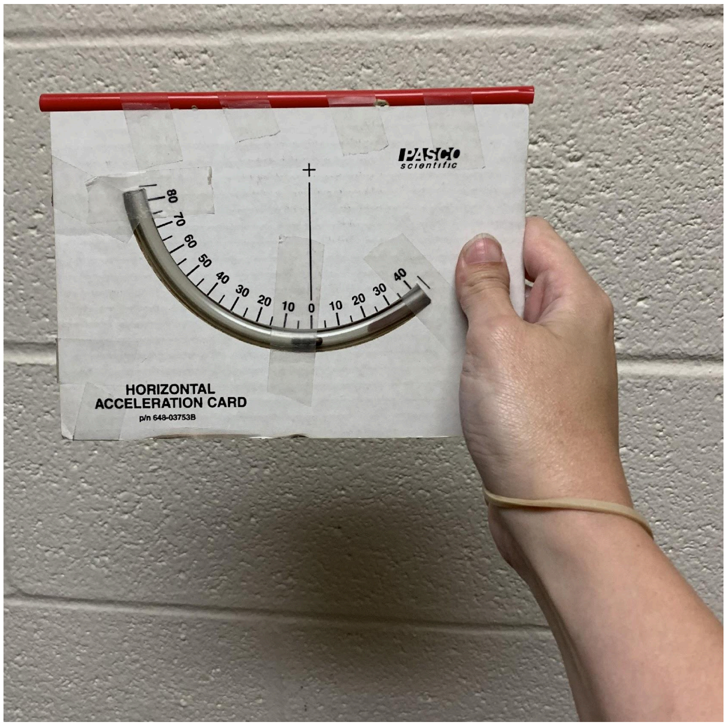
When timing, you should stand off to the side where you have a clear view of the ride at the location you are trying to time. For example, you might want to find the speed of a roller coaster at the bottom of the hill. Pick a spot at the bottom of the hill. Start timing when the front of the car reaches that location, and stop timing when the back of the car reaches that location. If you know the length of the roller coaster car, you can calculate the length of the car divided by time to determine the velocity at that point.

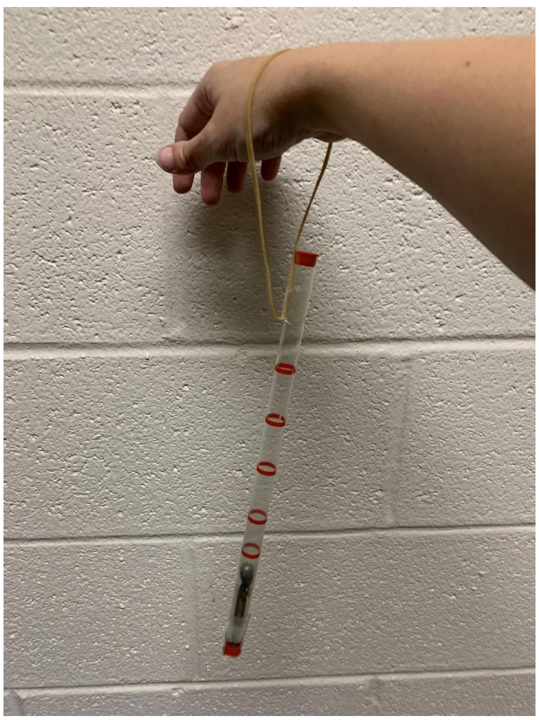
If you want to find the average velocity for the entire trip, you can also time the entire motion. Then you can take the total distance traveled and divide by time to get the average velocity for the complete motion. You mostly will want to find the velocity at different points when studying the rides at *Hersheypark*.

The horizontal and vertical accelerometers are pieces of equipment that can be purchased from Pasco Scientific at https://www.pasco.com/products/lab-apparatus/mechanics/rollercoasters-and-hovercraft/amusement-park-physics-kit-16-pack. They can also be made with your own materials instead.

This equipment may only be taken on the following rides:
- *Pirate*
- *Trailblazer*
- *Starship America*℠
- Carrousel
- *Scrambler*℠
- Tilt-A-Whirl
- *The Howler*℠
- *Comet*
- *Mix'd* Flavored by *Jolly Rancher*

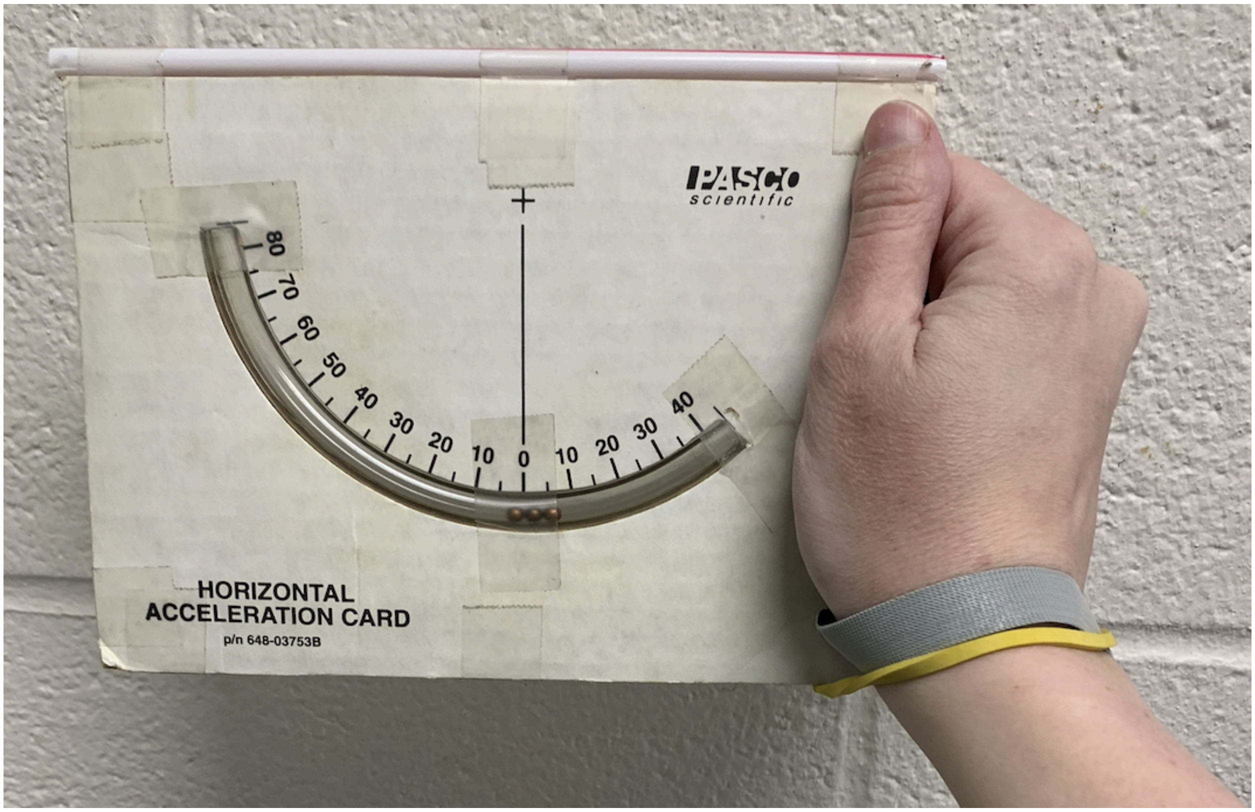
For the equipment to be permitted on the rides, it must be secured with two tight fitting straps. If the equipment is loose and dangles on a student's wrist like this:





It is NOT permitted!

The accelerometers must be secured tightly with two straps on the device, one velcro and one rubberband strap



This is mandatory for the accelerometers to be permitted on the rides!

Vertical Accelerometer

The vertical accelerometer is a small plastic tube that measures the acceleration in units of "g's" or multiples of 9.80 m/s/s. When you are holding it stationary in your hand (on Earth!), it should be reading one g. If it isn't, you need to recalibrate it.

Before the ride, make sure the accelerometer is secure. It must be attached to the student with two tight fitting straps on the wrist. That way if it falls and a student drops it, the accelerometer is still there. No one gets hurt.

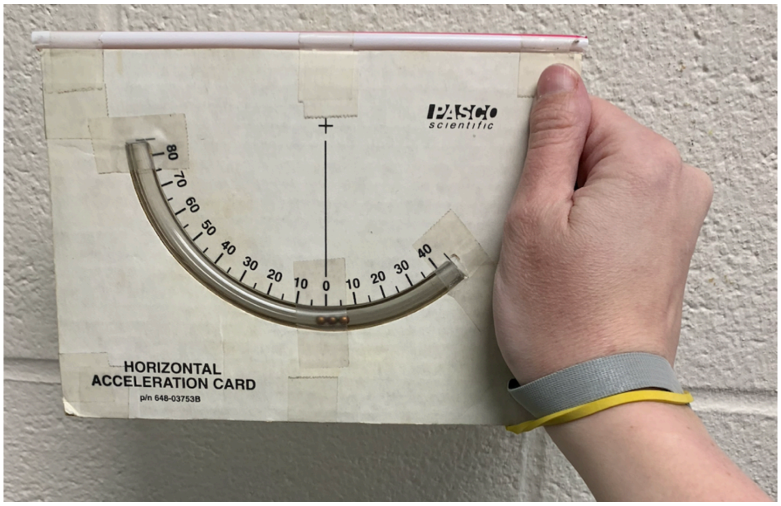
The accelerometer should be held perpendicular to the lap bar when taking measurements. If the ride turns, keep the accelerometer perpendicular to the ride.

Measurement in g's x 9.8 m/s/s = Acceleration in m/s/s

The vertical accelerometer consists of a spring with a weight on the end. By Hooke's Law, $F = -kx$ for the force that acts on the spring. By Newton's Second Law, $F / m = a$, so the distance the spring stretches can be related to the acceleration. You are measuring forces, but they are used to determine the acceleration.

When you are stationary, the spring is supporting its own weight. This is also what happens when you move up or down at a constant velocity. But when you accelerate up or down, there is a force that causes this. That force can be measured with the vertical accelerometer.

Horizontal Accelerometer



The horizontal accelerometer looks like a giant protractor with three small balls that move around. When taking a measurement, record the angle for the one in the center. The horizontal accelerometer can be used in two ways: on the ground and on the ride.

On the ground:

When using the horizontal accelerometer on the ground, you can use it to measure the angle of an object. Line up the straw at the top of the accelerometer with the object, and the angle of the accelerometer will be the same as the angle that the small balls have moved. This is the angle measurement on the accelerometer.

This technique allows you to use the horizontal accelerometer and a little bit of trig to find the height of different objects.

On the ride:

When taking the horizontal accelerometer on a ride, make sure you hold the accelerometer horizontally. The accelerometer should be securely attached using two snug fitting straps. Hold it against the lap bar or some other object to make sure you don't turn it by accident as you ride.

The tangent of the angle will give you the acceleration in g's. Why? This is a question you can pose to students to answer as a possible open-ended question related to the trip.

Video Analysis

Another option for studying rides is to use Video Analysis. Video devices are not permitted on any Hersheypark attractions. If you can make a video of the ride, you can study the motion with a program like Vernier Video Analysis. (https://www.vernier.com/product/video-analysis/). Programs like these allow the motion of an object to be followed frame by frame in a video permitting motion that occurs too quickly or is too complex than is easy to analyze using traditional means.

To record the video, make sure your camera is set-up perpendicular to the motion. The camera should be held stationary. At a minimum, brace your arm to keep the camera as still as possible. If you pan the camera to follow an object, you lose the stationary reference frame that you need to judge motion. You also need something in the frame that is a known length. This could be the length of the roller coaster car, the height at a certain point, or some other measurement that you know. The video will then be scaled to that measurement in real units—not just relative to pixels.

Please note that measuring devices, phones, cameras, or any other video recording device are not permitted on the rides. All riders must follow the directions of the ride operators at all times, and video analysis is a great tool to be used when taking videos from the ground.

Pirate

Equipment: stopwatch, vertical accelerometer

Engineering Specifications:

- Mass of boat: 9500 kg
- Maximum height of center of boat: 10.0 m
- Length of boat: 13.1 m
- Radius of pendulum: 13.6 m

A ride like *Pirate* is a very large pendulum. In an ideal situation, the potential energy, E_P, at the top of the swing should be equal to the kinetic energy, E_K, at the bottom of the swing. However, this is **not** an ideal situation. Why?

Question & Prediction 1:

In terms of a percentage, how does the E_P at the top of the ride compare to the E_K at the bottom of the ride?

The E_K at the bottom of the ride will be __________% to the E_P at the top.

Try It!!:

Find the E_P at the top using the height at the center of the boat and the mass of the boat. *Show all work!!*

E_P = ______________________

Find the E_K at the bottom in **two** different ways (do both please).

1. From the ground – Find the speed of the boat at the bottom by timing how long it takes from the complete length of the boat (from tip to stern) to pass the lowest point of the swing. *Show all work and clearly define all measurements!!*

t = ______________________

v = ______________________

E_K = ______________________

0. On the ride – Use the vertical accelerometer to measure the maximum acceleration (in g's) at the bottom of the ride. Then calculate the maximum acceleration in m/s^2. *Show all work and clearly define all measurements!!*

$a_{c,max}$ = ________________ g's

$a_{c,max}$ = ________________ m/s^2

We can use the centripetal acceleration equation to find the speed and then calculate the E_K at the bottom of the ride. The centripetal acceleration caused by the motion of the boat will be 1 g less than the maximum acceleration found above (since gravity causes a 1 g reading on the accelerometer when the boat is stopped at the bottom). *Show all work!!*

a_c = _______________ g's

a_c = _______________ m/s^2

v = ____________________

E_K = ____________________

Observations/Conclusions:

1. How do the kinetic energies compare?

0. What is the answer to question 1? *Show all work!!*

Question & Prediction 2:
How many g's of acceleration will you feel at the highest points on the ride?
____________ g's

Try It!!/Observations/Conclusions:
Using the vertical accelerometer, the acceleration at the highest point is ____________ g's.

Graph It!!:
Draw a Speed vs. Time graph representing the motion of the Pirate during at least one complete cycle of the ride.

Trailblazer

Equipment: stopwatch, vertical accelerometer

Engineering Specifications:

- Length of train: 14.6 m

Question & Prediction:

What is the radius of curvature of the final horizontal loop of this coaster ride?

Find a spot where you can see this final loop. Estimate its radius.

Radius = _______________ meters

Try It!!:

To answer this question, you'll need to take measurements both on and off the ride. We're going to use the centripetal acceleration equation to find the radius.

From the ground – determine the speed of the coaster as it moves around the final horizontal loop. To do this, pick a point on the loop and measure how long it takes for the full length of the coaster to pass that point. Then, calculate the speed. *Show all work!!*

t = ____________________

v = ____________________

On the ride - use the vertical accelerometer, holding it perpendicular to the safety bar with the bottom of the tube pointing to the floor, to measure the centripetal acceleration of the coaster while you are in the final loop. Then, the radius of the loop can be found. *Show all work!!*

a_c = _______________ g's

a_c = _______________ m/s^2

r = ____________________

Observations/Conclusions:

How close was your prediction to the measured value? Which one do you think is right?

Notice that the coaster and track is banked as it goes around the horizontal loop. What affect does this have on your calculation of the radius? Explain or show your work below.

Graph It!!:
Make a graph of the force on your seat against the time you are in the horizontal loop at the end of the ride.

Carrousel

Equipment: stopwatch, horizontal accelerometer

Engineering Specifications:

- Inner radius = 5.3 m
- Outer radius = 7.2 m

Questions & Predictions:

1. Where does a rider experience the greatest acceleration on this ride?

   A rider experiences the greatest acceleration on the ________________________.

2. What are the accelerations of a rider on the outer ring and the inner ring?

   The acceleration of a rider on the inner ring is ______________ g's.

   The acceleration of a rider on the outer ring is ______________ g's.

Try It!!:

You can answer the questions in two ways. Please use both methods.

From the ground – Using the data in the Engineering Specifications above, calculate the speeds and acceleration of a rider for both the inner ring and the outer ring of horses. To do this, first measure the time it takes for one revolution. Then use uniform circular motion equations to calculate the speed and centripetal acceleration (in m/s^2 & g's) for each ring. *Show all work and clearly define all measurements!!*

Inner ring:

T = ___________________

v = ___________________

a_c = ______________ m/s^2

a_c = ______________ g's

Outer ring:

v = ___________________

a_c = ______________ m/s^2

a_c = ______________ g's

On the ride – Use the horizontal accelerometer to measure the centripetal acceleration at each position. Be sure the accelerometer is horizontal – you can hold it against the post that you hold on to – and aim it toward the center of the circle.

Remember: The tangent of the angle gives the number of g's of acceleration. *Show all work and clearly define all measurements!!*

Inner ring:

θ = ____________________

a_c = _______________ g's

a_c = _______________ m/s^2

Outer ring:

θ = ____________________

a_c = _______________ g's

a_c = _______________ m/s^2

Observations/Conclusions:
What are the answers to the questions posed at the beginning of the lab?

1. ____

____

____

2. ____

____

____

Graph It!!:
As you ride further out from the center of the Carrousel, the centripetal acceleration changes. Sketch the graph that shows how the centripetal acceleration varies with the distance from the center of the ride (centripetal acceleration vs. radius).

Comet

equipment: stopwatch, vertical accelerometer

Engineering Specifications:

- Mass of full train: 4300 kg
- Vertical drop for the 1st hill: 24.4 m
- Length of train: 12.2 m

We know that, under ideal circumstances, the potential plus kinetic energies of a coaster at the top of a hill (using the bottom of the hill as the reference level) will equal the kinetic energy of the coaster at the bottom of that hill. But, again, this is **not** an ideal situation!

Question & Prediction 1:
In terms of a percentage, how does the kinetic energy of the *Comet* at the bottom of the first hill compare to its total energy at the top of the first hill?

The E_K at the bottom of the ride will be __________% of the E_{TOT} at the top.

Try It!!:
First, find the potential energy of the coaster at the top of the first hill using the data given in the Engineering Specifications. We're choosing the bottom of the hill to be the reference level where E_P = 0 Joules. *Show all work!!*

$E_{P,Top}$ = ______________________

Then, find the kinetic energy at the top. Determine the speed at the top of the hill by timing how long it takes for the complete length of the coaster train to pass the highest point of the hill then calculate the kinetic energy. Then, calculate the total energy at the top of the hill. *Show all work and clearly define all measurements!!*

t = ______________________

v_{TOP} = ______________________

$E_{K,TOP}$ = ______________________

$E_{T,TOP}$ = ______________________

Determine the speed at the bottom of the hill by timing how long it takes for the complete length of the coaster train to pass the lowest point at the bottom of the hill then calculate the kinetic energy. *Show all work and clearly define all measurements!!*

t = ______________________

v_{BOTTOM} = ______________________

$E_{K,BOTTOM}$ = ______________________

Observations/Conclusions:

1. What is the answer to question 1? Calculate the percentage. Was your prediction close? *Show all work!!*

2. How does the kinetic energy at the bottom compare to the total energy at the top?

Question & Prediction 2:

How does the vertical acceleration at the bottom of the second hill compare to the vertical acceleration at the bottom of the first hill?

The acceleration at the bottom of the second hill will be ______________________________

Try It!!

Using the vertical accelerometer on the ride, the acceleration at the bottom of

the first hill is _______________ g's

the second hill is _______________ g's

Observations/Conclusions:

Which hill had the greater acceleration at the bottom? Why is this true?

Graph It!!:

Draw a graph of the potential energy (using a solid line) AND kinetic energy (using a dotted line) of the train against the time of the ride.

Note: The time of 0 seconds is at the top of the first hill. The final time will be at the bottom of the second hill.

Mix'd Flavored by Jolly Rancher

equipment: stopwatch, vertical accelerometer

Engineering Specifications:

- Height of the 2^{nd} hill: 35.5 m
- Mass of the full train: 8260 kg
- Length of train: 18.3 m

We know that, under <u>ideal circumstances</u>, the potential plus kinetic energies of a coaster at the top of a hill (using the bottom of the hill as the reference level) will equal the kinetic energy of the coaster at the bottom of that hill. But, again, this is **not** an ideal situation!

Question & Prediction 1:
In terms of a percentage, how does the kinetic energy of the coaster at the bottom of the starting hill compare to its potential energy at the top of the starting hill?

The E_K at the bottom of the ride will be __________% to the E_P at the top.

Try It!!:
Since the ride begins its run at rest, it has only potential energy at the top. Find the potential energy of the coaster at the top of the starting hill using the data given in the Engineering Specifications. We're choosing the bottom of the hill to be the reference level where E_P = 0 Joules. *Show all work!!*

$E_{P,Top}$ = ______________________

Determine the speed at the bottom of the hill by timing how long it takes for the complete length of the coaster train to pass a point at the bottom of the hill (just where the track begins to level off) then calculate the kinetic energy. *Show all work and clearly define all measurements!!*

t = ______________________

v_{BOTTOM} = ______________________

$E_{K,BOTTOM}$ = ______________________

Observations/Conclusions:

1. What is the answer to the question stated above? Calculate the percentage. Was your prediction close? *Show all work!!*

0. How does the kinetic energy at the bottom compare to the potential energy at the top?

____

____

Question & Prediction 2:
The critical speed for an object moving in a vertical loop is the slowest speed the object can be moving at the top of the loop and not fall out. At this speed the rider would feel weightless. When in the loop on *Mix'd* Flavored by *Jolly Rancher*, is the coaster moving at the critical speed or higher?

The coaster is moving ____________________ the critical speed. *Fill in the blank*

If higher, how many g's of acceleration do you think the rider is experiencing?

If "faster than", how many g's do you think you'll experience? _______________ g's

Try It!!
Use the vertical accelerometer to measure the acceleration at the top of the vertical loop.
Hint: Have your partner say "Now!" when you are at the top of the ride – it's hard to tell when reading the accelerometer!

Observations/Conclusions:
What did you find out? Explain.

____

____

____

Graph It!!:
Draw a graph below that shows the kinetic energy of the coaster as it travels backwards from the highest point of the second lift through the loop.

Fahrenheit

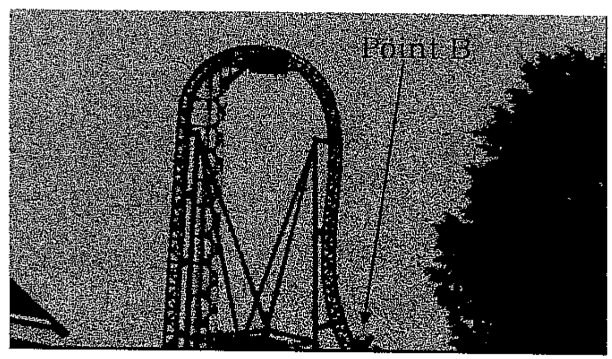
equipment: stopwatch

Engineering Specifications:
- Height of 1st hill: 36.9 m
- Mass of train: 5443 kg
- Train length: 8.2 m

The main feature of a ride like *Fahrenheit* is its first hill: a "97°" drop – a fall that doesn't go just straight down, but curves inward by 7°!

Question & Prediction 1:
If we fell straight downward, unhampered by air resistance, we'd accelerate at 9.8 m/s^2 downward. Will the design of this coaster cause our maximum acceleration (at the bottom of this first hill) to be equal to, less than, or greater than the gravitational acceleration?

The rider's maximum acceleration will be ___________________ the gravitational acceleration.



Try It!!:
Let's assume that the coaster's acceleration at the top of the first hill is 0 m/s^2 (point A on the picture) and that it reaches maximum acceleration near the bottom of the hill (point B on the picture). You will have to find a place where you can watch the coaster's acceleration from top to bottom of the hill (maybe while waiting in line?) To save time, we'll tell you that the initial speed of the coaster at the top point is about 4.3 m/s and the distance traveled by the train between pictures is about 28.5 meters. So, your mission is to determine the time it takes for the coaster to go from point A to point B. We'll also assume that the acceleration is increasing uniformly from point A to point B to make the maximum acceleration calculation easier – this should give us a roughly correct reading. Similar to the average velocity equation, the average acceleration is just the initial acceleration plus the final acceleration divided by 2, where the initial acceleration is 0 m/s^2. *Show all work and clearly define all measurements!!*

t = ___________________

a_{AVE} = _____________ m/s^2

$a_{f,MAX}$ = _____________ m/s^2

Question & Prediction 2:
Many people think that the lift to the top of the first hill is more nerve-wracking than the rest of the ride. It takes a lot of power to pull the coaster up the hill. Most of our automobiles have power ratings in the neighborhood of 90 to 200 horsepower (where 746 W = 1 hp). While the chain is lifting the coaster, how many cars could be powered with the same amount of energy?

While the chain is lifting the coaster, the power used by the ride is equivalent to the

power used by a minimum of ______________ cars.

Try It!!:
Using the Engineering Specification, determine the power used by calculating the work done on the coaster during the lift. Then, time how long it takes to get to the top – just as it starts up the hill until the middle of the train is at the top. *Show all work and clearly define all measurements!!*

$W = \Delta E_P$ = ____________________

t = ____________________

P = ________________ W

P = _______________ hp

# of cars = ____________________

Graph It!!:
Draw a graph showing the velocity vs. time of the coaster as it descends the first hill from point A to point B. You will want to calculate the final velocity before you create this graph.

Storm Runner

equipment: stopwatch

Engineering Specifications:

- Horizontal run during takeoff: 50.1 m
- Length of train: 12.2 m
- Height of "top hat": 45.7 m
- Mass of train: 9100 kg

Two of the most impressive aspects of a ride like *Storm Runner* are its takeoff and the 46 meter (150 ft) vertical ride to the peak of the "top hat"!

Question & Prediction 1:
What is the initial acceleration of the ride?

The rider will feel an acceleration of _______________ g's.

Try It!!:
You will have to find a place where you can watch the train's initial acceleration from rest to its maximum speed. Use a stopwatch to measure the time for this acceleration from the start to the bottom of the top hat (just before it starts its upward climb). Then find the average velocity for the train. The train's displacement along the horizontal part of the track is given in the Engineering Specifications above. Of course, the train does start from rest. *Show all work and clearly define all measurements!!*

t = ____________________

v_{AVE} = ____________________

v_f = ____________________

a = ______________ m/s^2

a = ________________ g's

Question & Prediction 2:
What is the minimum power the launching mechanism must expend ("minimum" because, due to friction, the motors must expend even more power!)

The minimum power expended by the launcher is ____________________ .

Try It!!:
First, we have to figure out the kinetic energy gained by the coaster during takeoff. Since the power used is equal to the rate at which the work is done by the motors, and the gain in kinetic energy is equal to the amount of work done by the motors, we can calculate the power used by dividing the kinetic energy by the time during which the work occurred. We measured this time in the previous section. Since the initial velocity is 0 m/s, the initial kinetic energy is also 0 J. Also note that there are 746 Watts in 1 horsepower. *Show all work!!*

$W = \Delta E_K =$ ____________________

$P =$ _________________ W

$P =$ _________________ hp

Question & Prediction 3:
How does the total energy of the coaster at the top of the first hill (the "top hat") compare to its total energy at the end of the initial acceleration?

> The total energy at the peak of the "top hat" should be _______________ the total energy at the beginning of the "top hat".

Try It!!:
We already know the kinetic energy of the coaster at the bottom of the "top hat". The potential energy will be 0 J if we consider the starting height to be 0 m. So, the total energy at the bottom is just the kinetic energy. At the top, you'll have to calculate both the potential and kinetic energies (since the coaster is moving at the top). To get the speed of the coaster at the top, we will need the length of the train and the time it takes for the coaster to pass the peak of the "top hat". *Show all work and clearly define all measurements!!*

$E_{TOTAL,BOTTOM} = E_{K,BOTTOM} =$ ____________________

$E_{P,TOP} =$ ____________________

$t =$ ____________________

$v_{TOP} =$ ____________________

$E_{K,TOP} =$ ____________________

$E_{TOTAL,TOP} =$ ____________________

Observations/Conclusions:
1. Some of the best standard automobiles can reach accelerations of about .8 g's to .9 g's. How does Storm Runner compare?

2. Most of our cars have power ratings in the neighborhood of 90 to 200 horsepower. How many cars could be powered during one of the launches of Storm Runner? *Show all work!!*

0. How do the total energies at the bottom and the peak of the "top hat" compare? Explain these results.

Great Bear

Equipment: stopwatch

Engineering Specifications:

- Radius of the 1st roll: 2.1 m
- Radius of the 2nd roll: 2.1 m

The constellation, Ursa Major (the Great Bear), can be identified in the night sky by the seven bright stars which most of us know as the Big Dipper. *Great Bear*, the ride, is also characterized by seven major features. The 360° rolls will be the focus of this activity.

As you stand on the ground by the *Wave Swinger*, you can observe the first roll that *Great Bear* undergoes. Walk over by the sooperdooperLooper to see the second roll the riders experience on *Great Bear*. In both cases, the riders' bodies move in a circular path around the track as they move forward. The seat of the ride provides a centripetal force to keep the rider moving in the circular path.

Questions & Predictions:

1. What is the maximum amount of centripetal acceleration the rider experiences within the rolls?

   The maximum amount of centripetal acceleration the rider feels will be __________ g's

0. Which roll will a rider experience a greater acceleration?

   The centripetal acceleration in the first roll will be _______________ the acceleration in the second roll. *Fill in the blank*

Try It!!:

We'll answer both questions by doing calculations from the ground.

<u>From the ground</u> – Stand in a position where you can observe *Great Bear*'s first roll. Measure the time (period) it takes for the front seats to make the complete roll (from the time it is hanging straight down as it starts the roll until it is hanging straight down again at the end of the roll). Next, we'll calculate the tangential speed and centripetal acceleration for the two rolls. *Show all work!!*

T_{FIRST} = ______________________

v_{FIRST} = ______________________

$a_{C,FIRST}$ = ________________ m/s^2

$a_{C,FIRST}$ = __________________ g's

Follow the same procedure for the second roll. *Show all work and clearly define all measurements!!*

T_{SECOND} = ______________________

v_{SECOND} = ______________________

$a_{C,SECOND}$ = ________________ m/s^2

$a_{C,SECOND}$ = __________________ g's

Observations/Conclusions:

How do the accelerations for the two rolls compare? Use your calculations and the accelerometer readings to back up your answers.

Graph It!!:

Just after going through the *Great Bear* loop, you travel around a structure called an Immelmann. Draw a graph that represents the vertical forces (with respect to your seat) that you feel as you move upward, across the top, then downward in the Immelmann.

Wave Swinger

Equipment: stopwatch, horizontal accelerometer

Engineering Specifications:

- Inner radius: 6.9 m
- Middle radius: 8.1 m
- Outer radius: 9.3 m

Questions, Estimations, & Predictions:

Before you make your predictions, circle the ring of swings on which you will base your predictions:

inner OR middle OR outer

1. What is the speed of a rider on the Wave Swinger?

   Watch the ride then estimate the speed of a rider in that ring: __________ m/s

0. What amount of centripetal acceleration does the rider experience?

   Estimate the centripetal acceleration of a rider (in g's): __________ g's

Try It!!:

From the ground – Find the average period of rotation of the swings (when at full speed). Then, using the data in the Engineering Specifications at the top of the page, calculate the circumference, the speed of a rider, and the rider's acceleration (in m/s^2). *Show all work and clearly define all measurements!!*

T = ____________________

Circumference = ____________________

v = ____________________

a_c = ____________________

From the ground – When the rider is at full speed, use the horizontal accelerometer to measure the centripetal acceleration in g's. Hold the top of the accelerometer parallel to the chains holding the swings. Record the angle measurement below. (To find the acceleration, the tan (90-θ) equals the rider's acceleration) *Show all work and clearly define all measurements!!*

θ = ____________________

a_c = _______________ g's

a_c = _______________ m/s^2

Observations/Conclusions:

1. Were your predictions correct? YES or NO
2. Is the acceleration a relatively large or small one? How do you decide?

Graph It!!:

Draw a graph that represents how the angle of the swing (from vertical) varies with respect to the speed of the swing around the circle – swing angle vs. speed.

Tidal Force

Equipment: stopwatch

Engineering Specifications:

- Mass of the full boat: 4100 kg
- Height of the hill: 30 m

Have fun riding, but this is one where all measurements are taken from the ground!!! Please be sure the accelerometers don't get wet on this ride. Let someone else hold your equipment while you ride.

Question & Prediction:

What is the acceleration of the boat as it is brought to a stop by the water and what is the stopping force applied by the water?

__________ g's of acceleration are experienced by the riders as the boat is brought to a stop.

Try It!!:

For simplicity, let's assume that the kinetic energy of the boat at the bottom of the run is equal to the potential energy of the boat at the top of the hill, we can calculate how fast the boat is moving at the bottom of the hill. *Show all work!!*

E_P = ______________________

v = ______________________

Now, we need to time how long it takes for the water to bring the boat to a slow constant velocity. Use the stopwatch to see how long it is from the time the boat just enters the water until the time the boat stops making its big splash. We'll estimate the speed of the boat when it stops splashing to be about 3 m/s. Also using the mass of the full boat given in the specs and the acceleration above, calculate the stopping force of the water. *Show all work and clearly define all measurements!!*

t = ______________________

a = ______________________

F = ______________________

Observations/Conclusions:

1. How many g's of acceleration does the boat undergo? *Show all work!!*

2. How does the stopping force compare to your weight in N (1 lb = 4.45 N)? *Show all work!!*

Graph It!!:

Draw a Velocity vs. Time graph and an Acceleration vs. Time graph that represents the motion of the boat from the time the splash starts until the time the splash ends. Assume that forward is the positive direction, and the acceleration is uniform.

Ride Measurements

The average weight of riders is assumed to be 150 lbs (68.04 kg).

Carrousel	English	Metric
Radii	25’	7.62 m
Inner horse	17’5”	5.31 m
Middle horse	20’5”	6.22 m
Outer horse	23’6”	7.16 m
Total ride time	2 minutes	2 minutes
Single rotation time	11 seconds	11 seconds
Comet	English	Metric
Height of first hill	84’2”	25.65 m
Height of valley	4’0”	1.22 m
Height of second hill	70’-6 ½”	21.5 m
Horsepower of chain motor	75	55950 watts
Area of front of car	8.6 sq. ft	0.80 m^2
Length of coaster train	40’0”	12.19 m
Riders each hour	1,100	1,100
Average speed	27 ft./sec	8.23 m/s
Minimum Speed	66 ft./sec	20.12 m/s
Second Major Curve: Radius	35’	10.67 m
Degrees	87 degrees	87 degrees
Entering height	54’2”	16.51 m
Exit height	50’11”	15.52 m
Minimum ride height	42”	1.07 m
Ride capacity	24 a train/2 trains	24 a train/2 trains
Round trip distance	2,950’	899.1
Round trip time	1 min. 49 sec.	1 min. 49 sec.
Mass of train	6,200 lbs empty 9,500 lbs full	2,812 kg 4,309 kg

Mix'd* Flavored by *Jolly Rancher	English	Metric
Height of hill	Lift 1: 21' 1" Lift 2: 116'5"	Lift 1: 36.90 m Lift 2: 35.48 m
Vertical drop of first hill	121'1"	36.90 m
Vertical drop of second hill	116'5"	35.48 m
Mass of train	14,000 lbs empty 18,200 lbs full	6,350 kg empty 8,255 kg full
Length of train	60'	18.29 m
Total ride time	1 min 40 sec	1 min 40 sec
Great Bear		
Mass of train	22,400 lbs	10 tons
Length of train	39'2"	11.93799 m
Distance from wheels to bottom of seat	6.5 ft	1.9812 m
Distance of track	2,800'	853.44 m
Height of loop (Top of Loop)	106'	32.3088 m
Height of loop (Bottom of Loop)	31'	9.4488 m
Height of first hill	11'6"	36.500652 m
Height at the bottom of first hill	10'4"	3.1490917 m
Distance around loop – beginning and ending at the same point	187'6"	57.15 m

Pirate	English	Metric
Horsepower of swing engine	100 hp	74600 watts
Riders each hour	1,200	1,200
Maximum swing angle	75 degrees	75 degrees
Ride capacity	54 adults	54 adults
Round trip time	1 ½ - 3 min. a ride	1 ½ - 3 min. a ride
Mass of boat	14,300 lbs. empty 21,050 lbs full	6,486 kg empty 9,548 kg full
Length of boat from tip of needle to stern	43' 0"	13.1 m
Maximum height of center of boat	44'6"	13.6 m
Radius swing (center fulcrum down center of boat)	44'6"	13.6 m
sooperdooperLooper®	English	Metric
Height of first hill	81'0"	24.69 m
Angle of first drop – steepest	Varies-38 degrees	Varies – 38 degrees
Height of loop	53'	16.15 m
Height of second hill	64'0"	19.51 m
Horsepower of chain motor	100 hp	24.69 m
Weight of coaster loaded	9,400 lbs	Varies – 38 degrees
Weight of coaster empty	8,000 lbs	16.15 m
Chain speed	6-8 ft/sec	19.51 m
Length of train	42'6"	74,600 watts
Round trip time	1 min. 57 sec	4,264 kg
Frontal area of train	9.3 sq. ft	0.86 m/s
Riders each hour	850	850
Average speed	22.34 ft/sec	6.81 m/s
Minimum speed	0-2 ft/sec	0-0.61 m/s
Minimum rider height	54"	1.37 m
Rider capacity	24 a train / 2 trains	24 a train / 2 trains
Round trip distance	2614.8'	797 m

Tidal Force	English	Metric
Mass of boat	6,000 lbs empty 9,000 lbs loaded	2,722 kg empty 4,082 kg loaded
Number of riders	20/boat – 3 boats	20/boat – 3 boats
Length of boat	18'9"	5.71 m
Height of lift	100'	30.5 m
Vertical drop	100'	30.5 m
Trailblazer	English	Metric
Height of hill	52'0"	15.85 m
Height of valley	18'0"	5.49 m
Height of loading area	10'0"	3.05 m
Horsepower of chain motors	50 hp	37,300 Watts
Weight of coaster	4,000 lbs empty 8,500 lbs loaded	1,814 kg 3,856 kg
Areas of front of car	10.3 sq. ft	0.96 m^2
Riders each hour	1,400	1,400
Average speed	175 ft./sec	53.34 m/s
Ride capacity	30 per train	30 per train
Round trip distance	1,890'	576 m
Length of coaster	48'0"	14.63 m
Measured radius of horizontal loop	36'0"	10.97 m

Other Activities

Study a Ride Assignment:
One alternate possible assignment for Physics Day is to give each group a different ride and ask them to explain the physics of the ride. What measurements can they take for the ride? What can they tell you about it? Keep it open ended but have them tell you as much about the ride as they are able to determine.

At the Park, they can take videos of different sections of the ride. They can use accelerometers on the ride to take measurements, and they can also use a stopwatch to time different parts of the motion. When you return to school, they can then analyze the videos with video analysis and write-up what they learned about that ride.

Create Your Own Lab:
If you have students in a second-year physics course, have them write their own labs! Students in the first-year course can complete the labs in the lab manual, but students in AP Physics 2, AP Physics C, or similar courses could write their own labs. Provide a copy of the lab manuals and the engineering specifications and instruct them to create their own labs to complete at the Park. Then they complete those labs while on the trip. They can create labs on thermos, electricity and magnetism, optics, and more!

Adapting the Labs:
If you want to adapt the labs to make them easier for your students, include the equations. Write the equations for each section of the manual. Then students know exactly what formula to use. These versions are not provided online because other students would then find these versions prior to the trip. But, please adapt the labs for your own students as appropriate.

Open-Ended Questions

If you would rather have your students answer some open-ended questions (either before, during, or after the trip), here are some suggestions to ask your students.

- When you use the horizontal accelerometer, you get an angle measurement. But, the tangent of that angle is the acceleration in g's. Why? Prove this!

- The log flume is a ride that sends riders down a long slope into a pond, producing a rather large wave. Does the size of the wave depend on the number of people in the car? What happens to the size of the wave if someone large is in the front of the flume? What if someone large is in the back of the flume? What if you wanted to ride the flume and not get where, where would you sit?

- Look at several different roller coasters in the Park and find ones that have vertical loops. Where in these rides are the loops located (toward the beginning, middle, or end)? Why are they placed there? Are there any roller coasters that are different from the rest in terms of the placement of the vertical loop?

- When a roller coaster enters a turn, it follows a track that is banked. Why do they bank turns for roller coasters? You may notice that some turns are banked at larger angles than other turns. Why do those turns require a larger angle?

- As a general rule, a roller coaster reaches its maximum speed at the bottom of the first hill. Using the information about the specifications of the Park's rides, devise a method for calculating the speed of a roller coaster at the bottom of the first hill and complete the calculation for one of the roller coasters at the Park.

- Compare all of the rides at *Hersheypark*. Which ride produces the greatest gravitational potential energy in a passenger on that ride? Explain how you would calculate the energy of this ride.

- Every ride at the amusement park has a ride capacity. The ride capacity is the number of people who can ride each hour. Devise and explain a method for calculating the ride capacity for a ride at the Park and then complete that calculation. What are the characteristics of rides with a low ride capacity? What are the characteristics of a ride with a high ride capacity?

- Where in the Park would you be moving with the greatest velocity? Support your answer with data. Where in the Park would you have the greatest acceleration? Support your answer with data.

- Of all the rides at the Park, which ride produces the greatest gravitational potential energy in a passenger on that ride? Explain how you would calculate the energy of this ride. Then calculate it!

- What technologies are used to control the potential and kinetic energy of the roller coaster cars as it moves from the station, through the ride, and back to the station?

- Some of the roller coasters in the Park are constructed primarily out of wood while others are constructed primarily out of steel. How has the use of these two different technologies influenced the designs of the classic roller coaster?

- The amount of time that you wait in line for a ride can be used to determine how many people were in front of you in the line when you joined it. Devise and explain a method for determining how many people were in front of you in line.

- Identify a point on a ride where the forces acting on you are balanced. Where are they unbalanced? Explain.

- What are some examples of Newton's Laws that you experience on the rides at the Park?

- On which rides do engineers use friction to their advantage when designing the ride? What do they do? On which rides do they want to minimize friction, and what do they do to accomplish this?

- Which ride at the Park gives you the strongest sensation of weightlessness? Explain the physics principles behind this!

- There are several rides at the Park that are large pendulum rides. Pick one of these rides and compare it to simple harmonic motion.

- On the bumper cars, what happens when you collide with another car with a similar mass? What about if one car has more mass? Explain the physics principles behind this.

- On a spinning ride like the carrousel or swings, do you feel like you're being pushed outward or pulled in? What's happening? Explain the physics.