Physics and Astronomy Night At Elitch Gardens

This curriculum book is developed by:

University of Denver
Physics and Astronomy

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Welcome to Physics and Astronomy Night at Elitch Gardens!

In this booklet, we provide a variety of materials for teachers and students to take advantage of some of the many educational opportunities at Elitch Gardens. Feel free to duplicate any of these materials. **Please do not distribute information in the last section. It contains ride specifications — these often contain the actual values that students are asked to estimate or calculate.** We have tried to provide materials that will give maximum flexibility for use in the classroom.

1. **Suggestions for Making Measurements.** In this section are some ideas on measuring time, distance, angles, and accelerations related to various rides, as well as some suggestions for equipment that can be built in the classroom loaded as an app, and brought to Physics Night. **NOTE!!! Accelerometers involving hanging weights will not be allowed on any ride on which the rider is inverted. e.g. Mind Eraser, Sidewinder, Boomerang**. There are suggested Smartphone apps that could be used on any ride to make measurements of height, speed, and acceleration. This section also includes definitions of physics quantities and information dealing with graphical interpretation.

2. **Estimation Problems**. This section invites students to make order of magnitude estimations concerning quantities at the park. Students will need to make some assumptions about quantities (*e.g.,* number of hot dogs consumed per person, the number of people who visit the park etc.) to determine the magnitude of some of the quantities. Answers are not provided, but the quality of the assumptions made and the consideration of influencing factors should be reflected in the teacher-based grading.

3. **Ride-related activities**. The activities for each ride are divided into three parts.
   Part 1 - These questions generally do not require any calculations or estimations. The questions ask for information about sensations and other observables. These questions should be appropriate for all students regardless of physics background.
   Part 2 - These questions generally require the students to make estimates or timings. For estimates, students are asked to describe their method. The calculations generally involve substituting into provided equations. This section would be most appropriate for physical science students or students in a physics course that does not emphasize mathematics.
   Part 3 - These questions generally provide minimal guidance for calculating quantities. They rely on a student's understanding of physics relationships and vectors including trigonometric relationships. This section would be most appropriate for physics students.

   Data for Parts 1 and 2 needs to be collected during Physics Night; however, the calculations and descriptions could be completed later at school. Part 3 information often relies on data from Part 2 and often requires that some measurements using accelerometers or protractors be made at the park. Much of the analysis of the data could be done at a later time.

4. **Physiology of Amusement Park Rides.** Questions on this page invite students to be thoughtful about a variety of physiological responses to typical rides.

5. **Specifications for Elitch Gardens Rides**. Data for several rides at Elitch Gardens are presented in this section. These data are provided to assist teachers in designing studies for their students, including the use of the activities materials provided in this booklet. Because some of these data may be relevant to Physics Night Challenges, we request that teachers do not give these data sheets to students.

Many teachers who use these materials have their students work in teams to gather data and complete the activity sheets. No student should be forced to participate in any ride. Most activities can be completed without actually riding the ride. Estimates and measurements can be made from the ground. Safety is a concern of Elitch Gardens and it should be for your students as well.

This booklet is the result of significant work done by Steven Iona at the University of Denver, Department of Physics and Astronomy, 2112 E. Wesley Ave. Denver, CO 80208. It is built upon earlier drafts done by Rob Davies and activities drawn from similar manuals used at Kennywood, Wyandot Lake, Six Flags-St. Louis, Six Flags –Texas, Vancouver, Lagoon, Playland, and Riverside theme parks. Mark Siemens, University of Denver, provided content and editorial review.

The entire Physics and Astronomy Night program, including this booklet, is a work in progress. Your comments and suggestions can improve the program. Please send your remarks to:

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Special Events
Elitch Gardens Theme Park & Water Park

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Tickets can be purchased online at ElitchGardens.com

Contents

Smartphone Apps for Making Measurements

There are many apps already available for little or no cost that transform smartphones into mobile physics laboratories allowing for experimentation and data collection. A few such apps are listed below. This is only a sampling of possible apps. Some are free, and some require purchase. Data can readily be logged, plotted, stored, and transmitted for further analysis later.

iPad / iPhone Applications

Vernier Video Physics (not free)
Mobile Science -Acceleration 1.0
Roller Coaster Rush
Convert Units
Footsteps - Pedometer
Stopwatch Analog+Digital
Multi Protractor
Coaster Physics (not free)
SPARKvue
Paper Toss

Android Applications

StopWatch and Timer
Audalyzer
Advanced Protractor
Grav-O-Meter
Angry Birds
Instant Heart Rate
Angular Velocity
Cardio Trainer
Paper Toss
Surveyor
Unit Converter - ConvertPad

Making Measurements

Time

Times can easily be measured using a watch with a second hand or a digital watch with a stopwatch mode. When measuring the period of a ride that involves harmonic or circular motion, measure the time for several repetitions of the motion, and then divide by the number of cycles. This will give a better estimate of the period of motion than just measuring one cycle. You may want to measure the time repeatedly and then average the values. The additional precision of a digital watch may be necessary for timing certain rides.

Distance

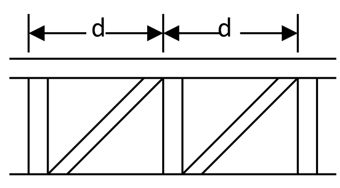
Since you cannot interfere with the normal operation of the rides, you will not be able to directly measure heights, diameters, etc. To give you a reasonable estimate, most of the distances can be measured remotely using one or more of the following methods. Try to keep consistent units (*i.e.* meters, centimeters, etc.) to make calculations easier.

1. Pacing

Determine the length of your stride by walking at your normal rate over a measured distance. Divide the distance by the number of steps to get an average distance per step. Knowing this, you can pace off horizontal distances at the park.

2. Ride Structure

Distance estimates can be made by noting regularities in the structure of the ride. For example, tracks may have regularly-spaced cross-members similar to those shown below. The total distance can be estimated by counting the number of cross members **d**. This method can be used for both vertical and horizontal distances.

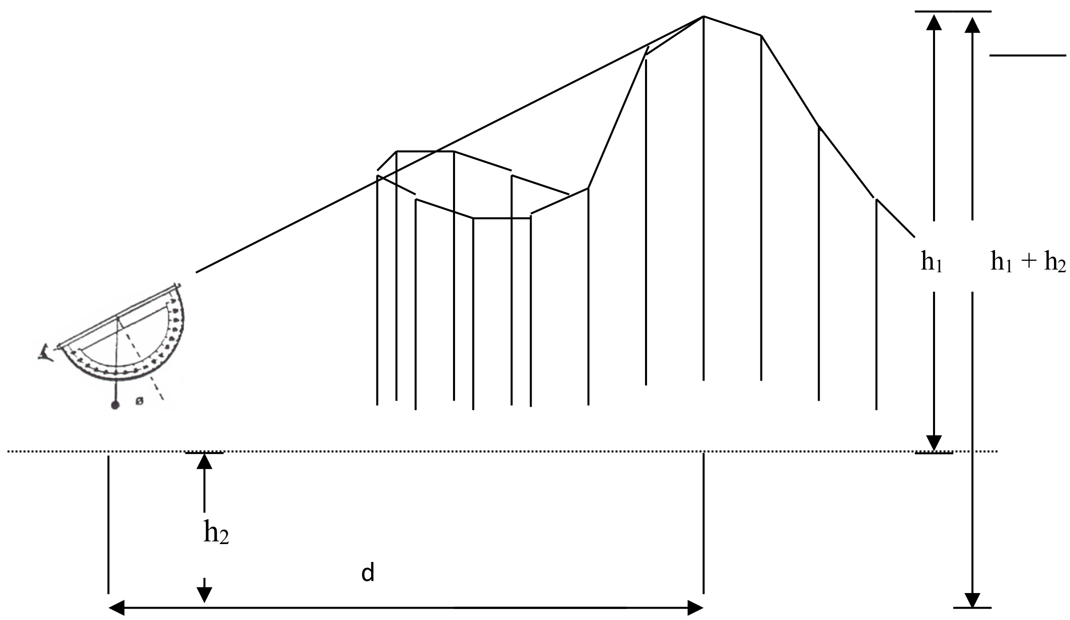


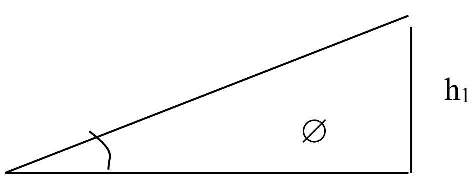
3. Triangulation

For measuring height by triangulation, a protractor-sextant can be constructed following the directions at: http://tqjunior.thinkquest.org/6169/sextant.htm or a kit can be purchased from companies such as PASCO or Central Scientific Company.

See the diagram on the next page.

a. Measure/estimate the distance between you and the ride — d: _________ m
b. Measure the height from the observer's eye to the ground. — h_2: __________m
c. Take a sighting at the highest point of the ride.
   Read off the angle of elevation. — Θ = __________



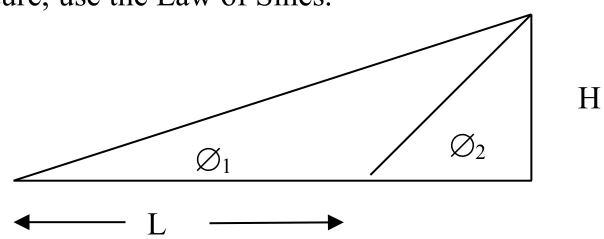


$h_1/d = \tan \varnothing$
$h_1 = d(\tan \varnothing)$

d. Multiply the tangent value by the distance from the ride: — h_1 = __________m
e. Add this to the height of the observer's eye to the ground: — h_2 = __________m
f. This number is the height of the ride: — h_T = __________m

4. Law of Sines

If you cannot measure the distance L because you can't get close enough to the base of the structure, use the Law of Sines.



a. Lay out a baseline distance L using a tape measure or pacing.

L = __________m

b. Measure the height from the observer's eye to the ground.

Observer's height h = __________m

c. Take a sighting at the highest point of the ride. Read off the angle of elevation and the distance of the baseline. Θ_1 = _____ Θ_2 = _____

Knowing $\varnothing_1$, $\varnothing_2$, and L, and the height h of the person, the height of the ride **H** can be calculated using the expression:

$$H = L * \frac{[\sin\phi_1 * \sin\phi_2]}{\sin(\phi_2 - \phi_1)} + h$$

Acceleration

Acceleration is a measure of how the velocity of an object is changing. The velocity may increase, decrease, or change direction. Each of these changes results from an acceleration.

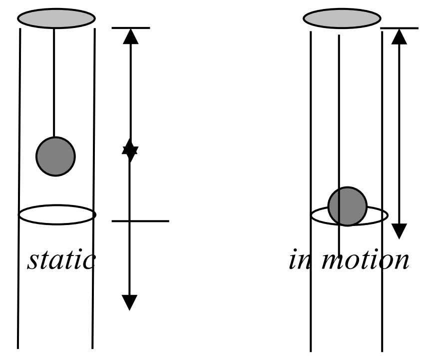
Accelerometers are designed to record the ***g*** forces felt by a passenger. Sometimes, they are calibrated in ***g***'s. A reading of **1*g*** equals an acceleration of **9.8 m/s²**. On Earth, we normally experience **1*g*** of acceleration vertically and no **g**'s laterally or longitudinally. Accelerometers are oriented to provide force data perpendicular to the track, longitudinally along the track, or laterally to the right or left of the track. The acceleration is always in the direction of the net force; however, the acceleration is not always in the same direction that the object is moving.

Note:

- When an object traveling in a straight-line speeds up, the direction of its acceleration is the same as its direction of motion.
- When an object traveling in a straight line slows down, the direction of its acceleration is opposite to its direction of motion.
- When an object moves in a circle at a constant speed, the direction of its acceleration is toward the center of the circle.

<u>Construction of Spring Accelerometers</u>
Directions can be found at: http://library.thinkquest.org/2745/data/meter.htm, or one can be purchased from places like PASCO or Central Scientific.

Vertical Acceleration



This **force device** can be calibrated to read in multiples of an object's weight. While a person is holding the device in an upright position, the mass is held up by the force of the spring. The length of the spring's stretch is directly related to this force. The ratio of this force to the weight of the object is called ***g force***.

If the person is holding the scale right side up, then:

$F_T = mg + ma_{(Ride)}$ or $ma_{(Total)} = mg + ma_{(Ride)}$

Since m is constant: $a_T = g + a_R$ or $\mathbf{a_R = a_T - g}$

(Note: a_R = acceleration on the ride, $g = 9.8\ m/s^2$)
If the person is holding the scale upside down against gravity as might be found at the top of a loop, then

$a_R = -(a_T + g)$ [ie. Acceleration is upwards]

In either situation, the acceleration can be calculated by knowing F_T (or a_T).

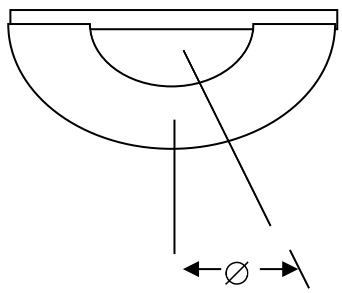
<u>Longitudinal Acceleration</u>
Acceleration of a person on a ride can also be determined by direct calculation. For example, the average acceleration of an object is defined as:

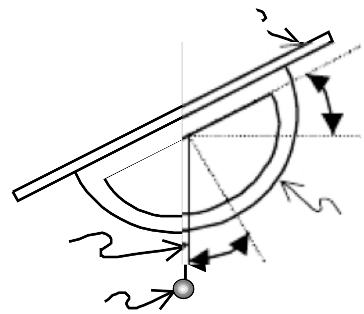
$$a_{avg} = \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{\text{change in speed}}{\text{change in time}}$$

Since it is possible to estimate speeds at both the top and bottom of the hill and the time it takes for the coaster to go down an incline; average acceleration can be found during that portion of the ride.

Lateral Acceleration

The protractor-sextant discussed earlier as a triangulation instrument may also be used to measure lateral accelerations. The device is held with the sighting tube horizontal, and the weight swings to one side as you round a curve. By measuring the angle, acceleration can be determined.





$a = g \tan\Theta$

Centripetal Acceleration

With uniform circular motion the distance that an object moves depends on the circumference of the circle $2\pi r$ and the time that it takes to move in a circle, T

$$v = \frac{2\pi r}{T}$$

The centripetal acceleration is given by: $$a_C = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2}$$

So that the centripetal force is $F_c = ma_c = mv^2/r = 4\pi^2 r/T^2$

where a_c is centripetal acceleration, r is radius of path, T is the period, v is tangential speed, F_c is centripetal force, and m is mass.

(NOTE!!! Accelerometers (other than apps on pocketed phones) will not be allowed on any ride on which the rider is inverted. e.g. Mind Eraser, Sidewinder, Boomerang

Speed / Velocity

Speed and velocity are used interchangeably here because we are working with forward motion only. When an object is moving at a constant speed, the speed is calculated by measuring the distance traveled in a certain amount of time.

For example, if you know the length of a train of cars in a ride, you can determine the time it takes for the train to pass a selected point on the track and then calculate the speed as follows:

$$\text{Average velocity} = \frac{\text{length of train}}{\text{time to pass a fixed point}}$$

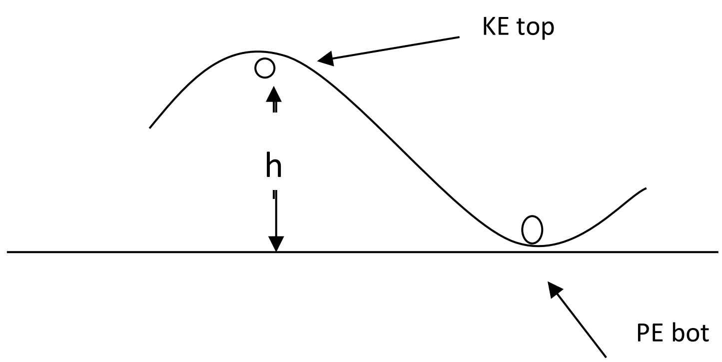
Using Conservation of Energy to measure heights and speeds

In most situations, we assume that total mechanical energy is conserved. As Potential Energy (PE) increases, Kinetic Energy (KE) decreases and vice versa. If you know the height of a hill on a roller coaster, you can calculate the approximate Potential Energy at the top and use Conservation of Energy to calculate the approximate speed at the bottom of the hill based on equal amounts of energy at each location. You could also use the speed of an object to calculate the Kinetic Energy and then predict the height to which it would rise. We ignore friction in these situations.

$$PE = mgh \quad \text{and} \quad KE = ½mv^2$$

change in PE + change in KE = 0 or in most cases the PE at the top = the KE at the bottom

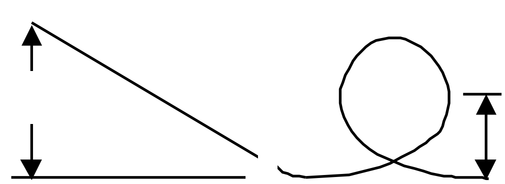
So according to Conservation of Energy: $mgh_{top} = ½mv^2_{bottom}$



$mgh_A + ½\, mv^2_A = mgh_B + ½\, mv^2_B$

or after solving for v_B:

$v^2_B = (2g(h_B – h_A) + v^2_A$



Normal Force

The normal force is due to a surface and is perpendicular to the surface. As you stand on the ground, the normal force is the force pushing up on you due to the ground. If you are seated, it is the force exerted on you by the seat. If you are moving at some angle, the normal force is always perpendicular to the surface.

Force Factor

Force Factor is a descriptive term that indicates the magnitude of the forces as a multiple of the force associated with gravity. So, a Force Factor of 2 means that the force is twice the weight of the person. A Force Factor of 0 means that the object has no net force on it. Students are encouraged to calculate the relationship between "Force Factor" and "g's" of acceleration. This notation of Force Factor is also used to describe "g-forces" where the value is the multiple of the acceleration of gravity.

Work

Work has meanings in common usage and in physics. When work is a calculated physics quantity, it is based on an object moving as a result of a force. Assuming that the object moves in the same direction as the force,

Work = force along direction of motion * distance moved

Centripetal Force

A centripetal force is a resultant force that points toward the center of a circle. In the case of a banked curve, the centripetal force is the resultant force associated with the normal force of the track on a car. It might be based on a frictional force and keeps you on a rotating platform like a carousel. It might be as a result of gravity if you were upside down at the top of a vertical loop. The resultant force can be found using the following:

$$F_c = mv^2/r$$

Where v is the speed of the moving object, m is its mass, and r is the radius of the circle.

Power

Power is a rate of transferring energy. For example, one would calculate the same change in gravitational potential energy for a person going up a set of stairs. It would be the same whether the person ran up the stairs or walked slowly up the stairs. Power gives a measure to the rate at which the change took place.

Power = (Change in energy)/(change in time)

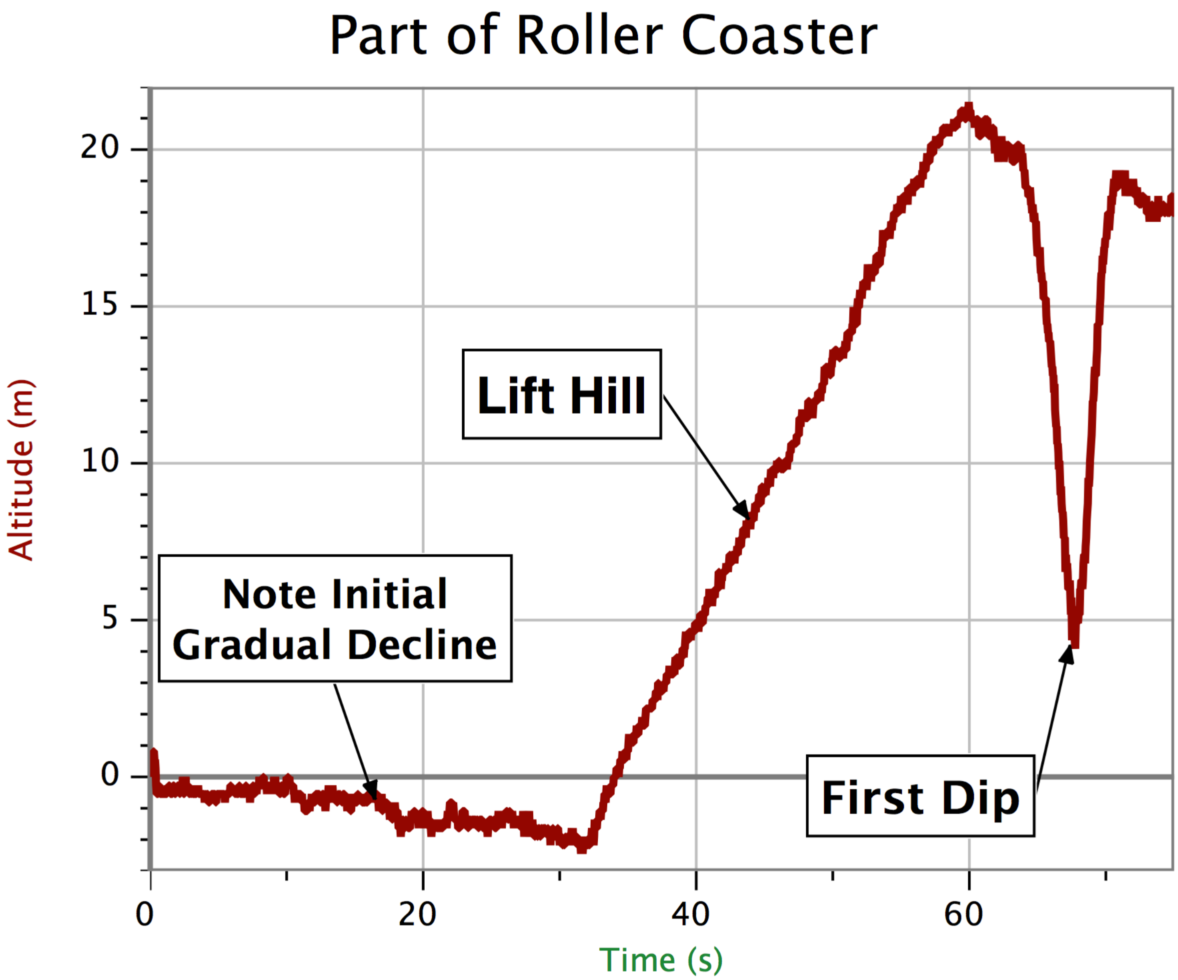
Graphing Clues

If you use data-collecting software, whether on your smartphone, or from computer-interfaced equipment, you can use the following to help interprets some of the graphs.

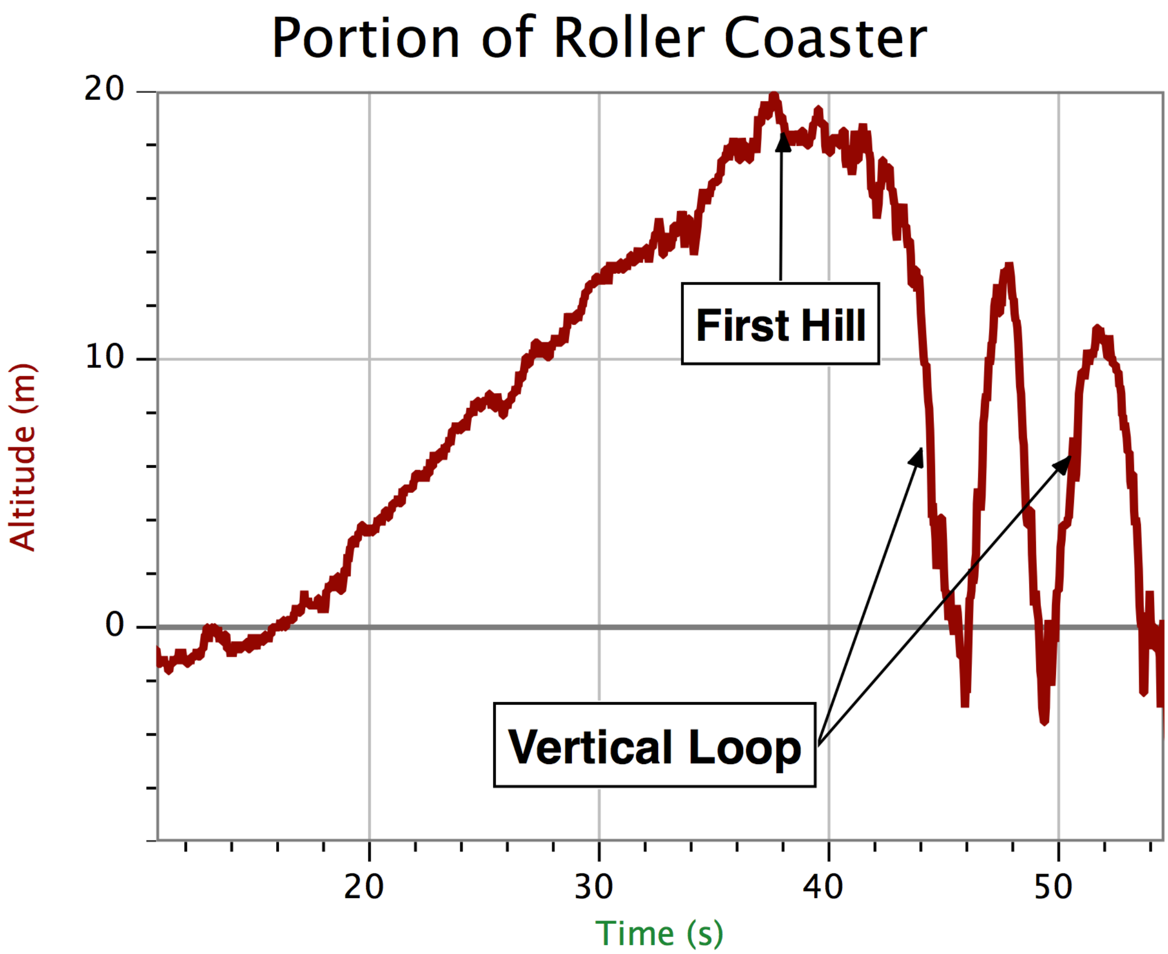
Altitude versus Time

Can you identify specific features from this graph?

Lift Hill – where a coaster goes up to gain Potential Energy. If there is a definite lift hill, then it is probably a roller coaster. If not, it's probably not a roller coaster



This next graph comes from a ride with a vertical loop. The loop often occurs near the bottom of the first hill.

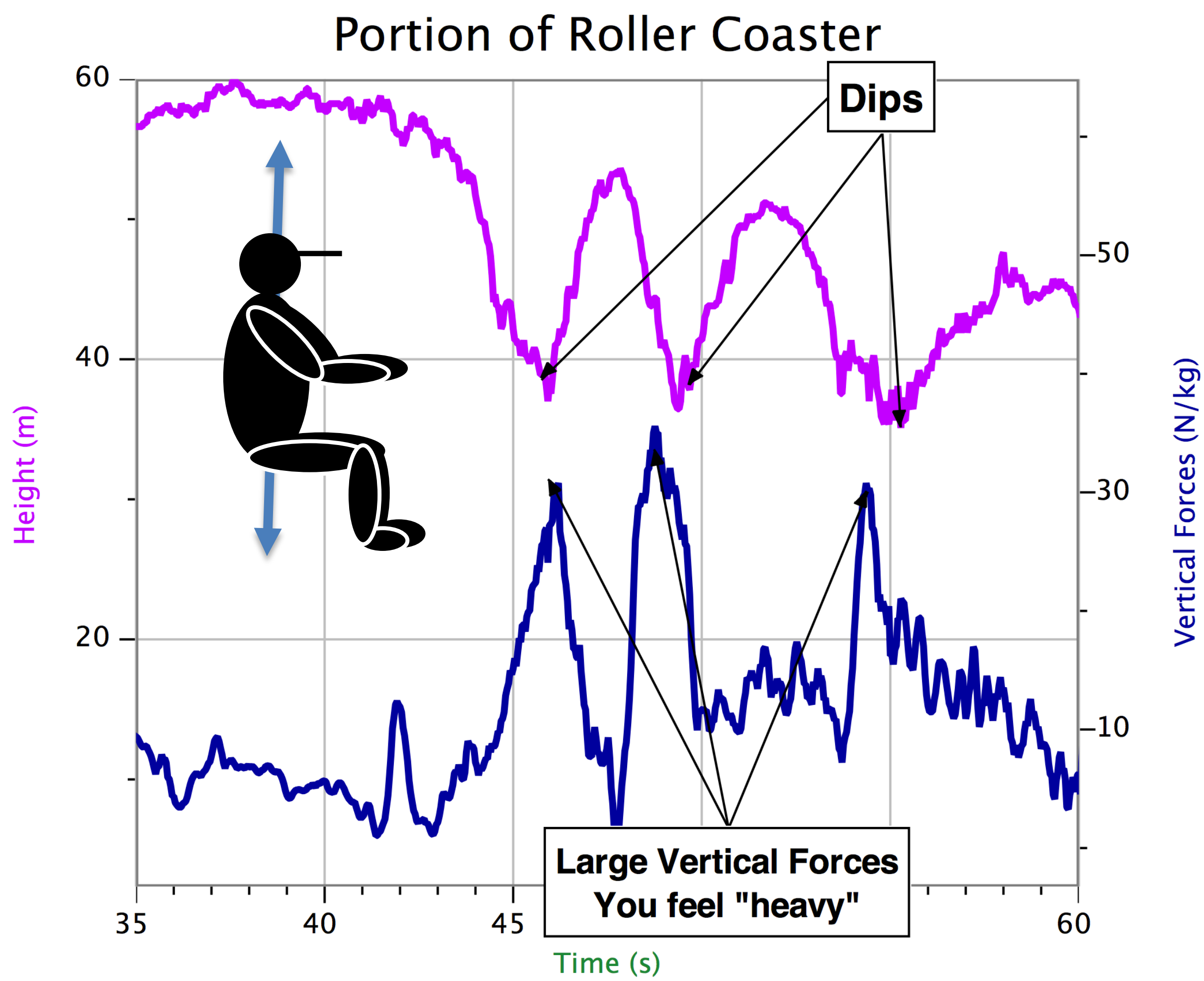


- Note how time cannot go backwards in the same way that distance can, so a loop shows up as "M".
- Can you see the lift hill portion clearly here?
- Note: Not all the lines on your graphs will be perfectly smooth due to slight bouncing of the cars and other factors.

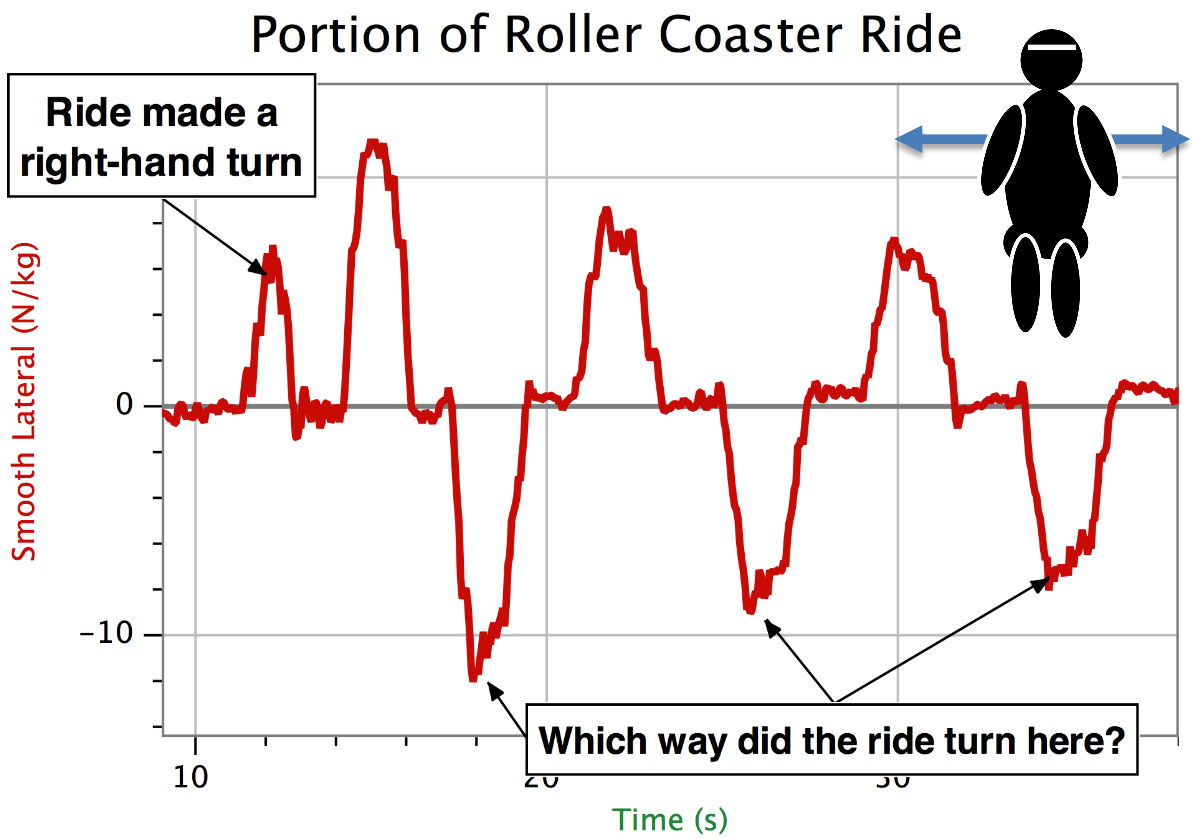
Vertical Forces:
Vertical forces are those that are directed up and down along the spine of the rider.

Big vertical forces occur when riders go through dips on Roller Coasters as shown in the graph below.

Lateral Forces:
When undergoing lateral forces, the rider will feel pushed sideways. The graph will often look like a series of zigzags.

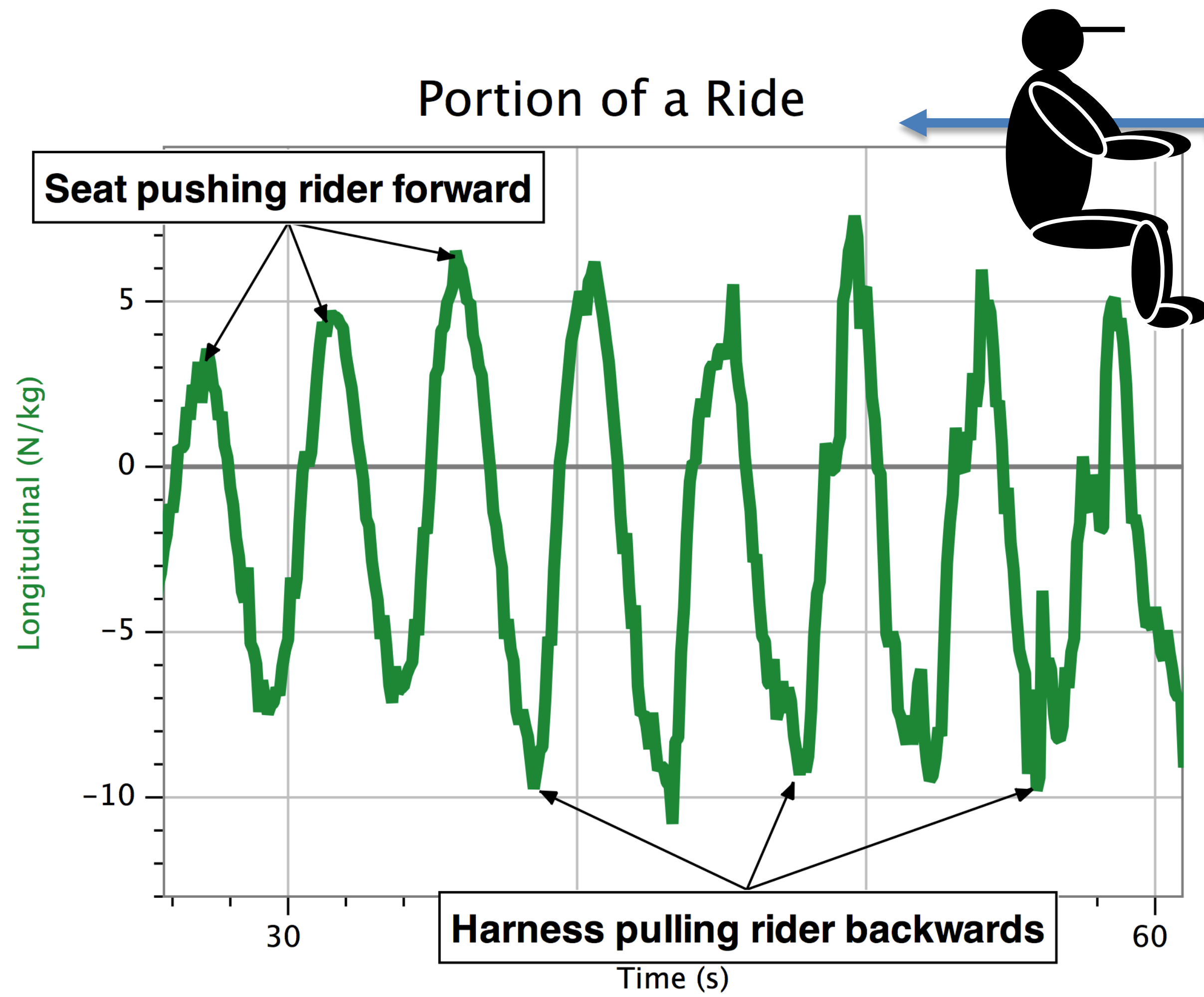


Can you identify the directions of the various turns given the clue you were given?


Portion of Roller Coaster Ride
Ride made a right-hand turn
Which way did the ride turn here?
Smooth Lateral (N/kg)
0
−10
10
20
30
Time (s)

Longitudinal Forces – Longitudinal forces push the rider to the front or to the back

This ride repeats itself with regularity. Would it be a roller coaster or perhaps a circular ride?



ESTIMATION PROBLEMS

These questions require that you make some estimates. These are not guesses, they are estimates based oninformation you believe to be true. Generally, you will need to use several bits of information and perform calculations to arrive at an answer. Please justify your estimates and show your work.

Some information that might assist you:

- Elitch Gardens is open about 120 days a year
- Elitch Gardens is open 10 hours a day

JUSTIFY ALL YOUR ANSWERS (Give reasons for your answers!)

1. MILK BOTTLE STAND. Estimate how many baseballs are thrown at the milk bottles in the course of one day.

2. OBSERVATION TOWER. Estimate the volume of air inside the entire Observation Tower complex including the tower assembly.

3. PICNIC TABLES
   a) Estimate the number of picnic tables at Elitch Gardens.
   b) If a gallon of paint covers an area of 500 $ft.^2$ (46.38 m^2), estimate how many gallons of paint would be needed to paint all the picnic tables in Elitch Gardens?

4. Estimate the number of PEPPERONI SLICES that are used per day in the park?

5. Estimate the number of FRENCH FRIES sold per day in the park.

6. Estimate the distance traveled by the STATIONARY TIGER on the outside edge of Carousel in one year.

7. Estimate the number of FUNNEL CAKES sold per day at the park.

8. Estimate the total number of PASSENGERS THE MIND ERASER carries during one year of operation.

9. Estimate the number of SHINGLES on the roof of the Carousel entrance building.

10. Estimate the number of GRAINS OF SALT that are on all of the soft pretzels sold per day in Elitch Gardens.

11. Estimate the average total DISTANCE WALKED by a guest at Elitch Gardens this year.

12. Assume that a serving of COTTON CANDY could be completely unwound into a single

very long thread. Estimate the length of the Cotton Candy thread.

13. CORN DOGS are sold throughout the park. Estimate the number of corn dogs sold at the park during the last year.

14. Many people order some type of food covered in melted cheese. These foods include backed potatoes, french fries, and taco chips. Estimate the number of gallons of MELTED CHEESE used in one season at Elitch Gardens.

15. Estimate the number of BOLTS needed to construct the track of the Twister Roller Coaster.

16. Estimate the number of LIGHT BULBS on the Big Wheel.

17. Estimate the number of gallons of WATER that evaporate into the air, in one season, from the clothing, shoes, and hair of people that get wet on the Disaster Canyon ride.

18. Estimate the number of DIPPINDOTS servings sold at Elitch Gardens during the season?

19. Estimate the number of PAPER CUPS that are used at Elitch Gardens in one season?

20. Estimate how many TRASH CAN LINERS are used at Elitch Gardens in one season?

21. If you rode all the rides, how many linear METERS OF QUEUE LINE (waiting line) would you have walked through? (Assume that all queue lines are opened for maximum capacity.)

22. If the Big Wheel came off its support and rolled to the state capital, estimate how many revolutions would it make?

23. Estimate the NUMBER OF FLOWERS in bloom in the park today.

24. Estimate the number of people who simultaneously can RIDE THE RIDES in the park today.

25. Estimate how many people would be able to stand INSIDE THE PENNY ARCADE during a rainstorm.

Suggested Scoring Rubric

Developed by Ed Henke Langley, HS Pittsburgh, PA

1-point: No attempt to answer the question

2-points: Attempted to answer, but the answer is just numbers. The process is not clear

3-points: Identifies more than half the numbers. Shows calculations. Process is clear

4-points: Identifies most numbers. Shows most calculations. Explains calculations with a word equation or dimensional analysis. Process is clear

5-points: Identifies all numbers. Shows all calculations. Explains calculations with a word equation or dimensional analysis. Process is clear

MIND ERASER

Mind Eraser

Name(s)__________________________ Name(s)__________________________

Part 1

The Mind Eraser combines the physics concepts of work, potential energy, kinetic energy, power, centripetal force, and acceleration to provide for maximum excitement.

Write complete answers to each of the following questions on your own paper.

Things to notice as you ride or watch:

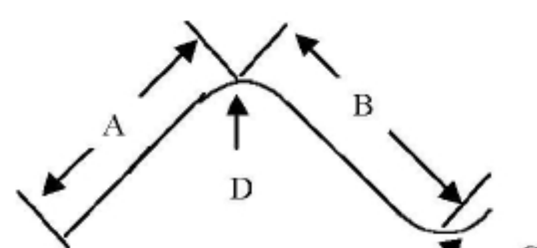
1. How does the size of the hills change during the ride?
2. Why is the first hill higher than the second?
3. Why is the first hill of the ride the highest point on the ride?
4. As the car goes up the second hill, does it gain or lose speed?
5. As the car goes down the second hill, does it gain or lose speed?
6. When you enter the Mind Eraser, you climb up a set of stairs to get on. What is the advantage to ride designers to having you start above ground?
7. In terms of forces, explain why the ride uses a long shallow climb up the first incline instead of a short steep one.
8. Let's say that the diagram below illustrates the second hill, where riders go toward the right. Using letters from the diagram, label the following:

   I. Place(s) with increasing Gravitational Potential Energy _____

   II. Place(s) with maximum Gravitational Potential Energy _____

   III. Place(s) with increasing Kinetic Energy _____

   IV. Place(s) with maximum Kinetic Energy _____



9. Riders are most often scared as they travel down the first drop.
    a. Describe the sensations.
    b. What would happen to the riders if they were not in their seat harnesses?

10. During the ride, the riders are sometimes upside down.
    a. Describe the sensations while upside down.
    b. What would happen to the riders if they were not in their seat harnesses?

11. Is there a difference in sensation, speed or anything else when you ride in the front-car position versus when you ride in the back-car position? Why do you think this is true?

12. Some people feel dizzy immediately following the ride; however, after a few minutes, the feeling goes away. What might be happening in their inner ear during this recovery period?

Mind Eraser

Name(s)__________________________ Name(s)__________________________

Part 2

Equipment – stopwatch, calculator

Write complete answers to each of the following questions on your own paper.

1. Estimate the height of the first hill from the bottom of the first hill on the downward side.

   Estimated height of first hill ______________ m
   Describe how you estimated this distance.

2. The mass of the train is 7500 kg.
   Describe how you could estimate this mass.

3. Calculate the energy to raise the train to the top of the first hill (as measured from the bottom of the first hill); the power required in watts; and the power required in horsepower. (Note: acceleration due to gravity = 9.8 m/s^2.)

   Energy used (J) = mass of train (kg) * acceleration due to gravity (m/s^2) * height (m)
   This is the change in Potential Energy as measured from the bottom of the first hill

   Power (W) = Energy used (J) / time of travel up first hill (s)

   Power (hp) = Power (W) / 746 W/hp

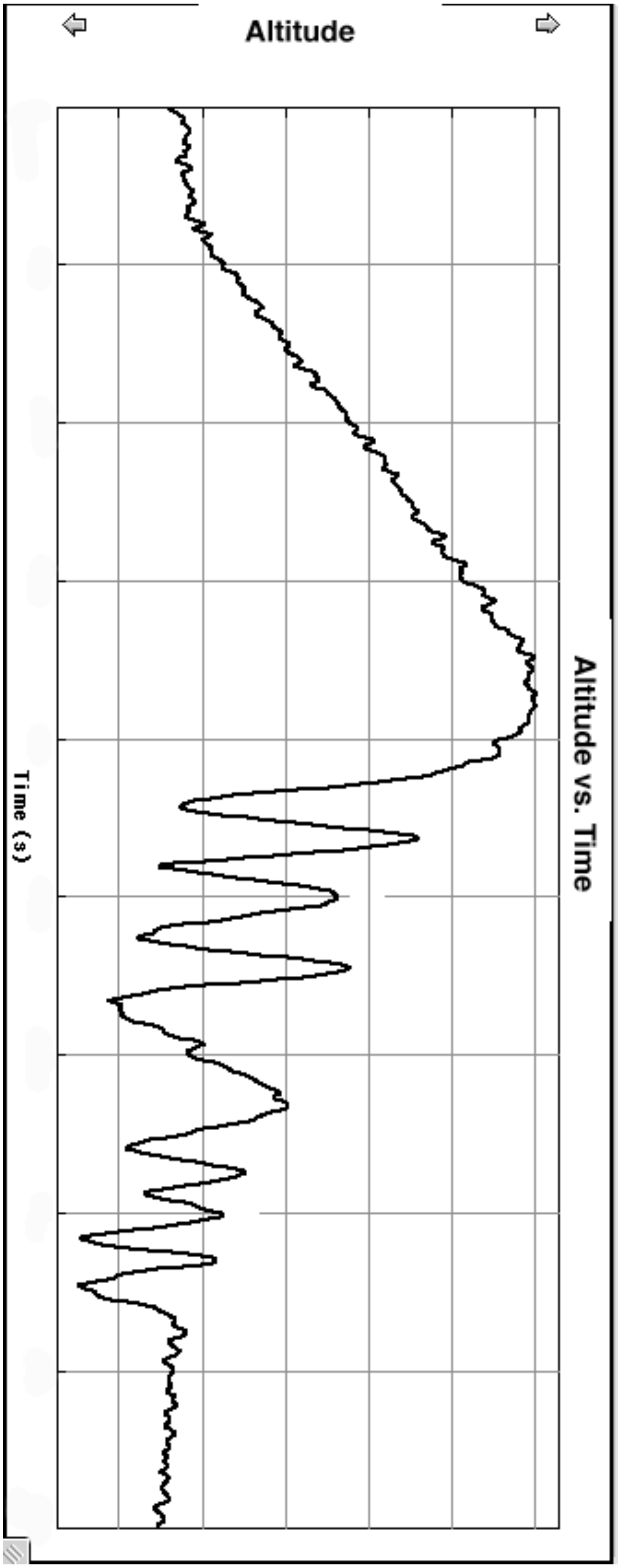
4. Estimate the speed of the train at the top of the first hill.

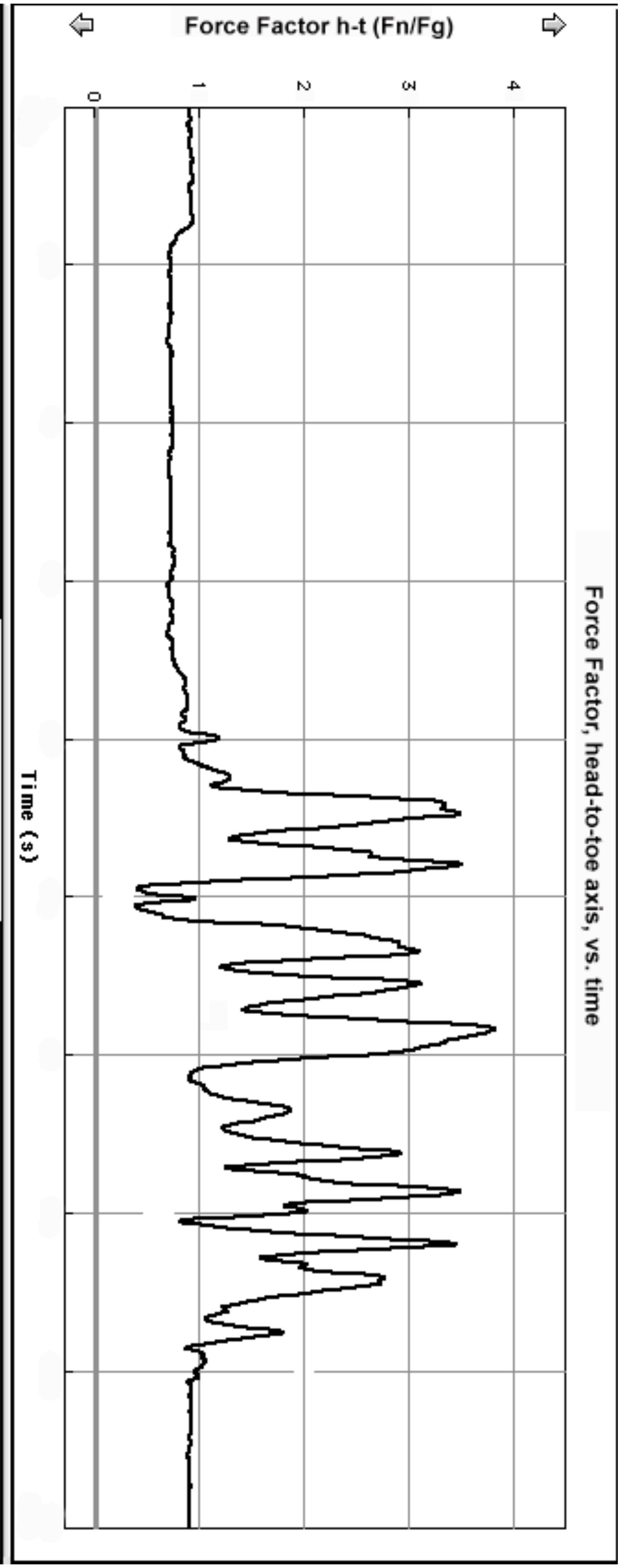
   Estimated speed at the top of the first hill = ________ m/s
   Describe how you determined this speed.

5. Using repeated measurements, determine the time for a cart to travel down the first hill.
   Times measured: ________ s ________ s ________ s

   Average time to travel down the first hill = ________ s

The graphs on the next page were made from data collected by carrying a Force Factor meter and an altimeter on a similar ride. A Force Factor meter measures the force in multiples of the force due to gravity. So, a Force Factor of 2 means that the force is twice the weight of the person. A Force Factor of 0 means that the rider has no net force on him.


Altitude
Altitude vs. Time
Time (s)


Force Factor h-t (Fn/Fg)
Force Factor, head-to-toe axis, vs. time
0
1
2
3
4
Time (s)

6. At what point on ride does the Force Factor meter give its maximum reading?

7. What aspects of the ride at this point might make it a maximum at that point?

8. What is the sign (+ or -) of the Force Factor when you are upside-down?

9. What is the direction of the normal force at that point?

10. Bonus fun: What force factor is measured on the long ascent up the first hill? What could be a possible explanation for this?

Mind Eraser

Name(s)_________________________ Name(s)_________________________

<u>Part 3</u>
Equipment: stopwatch, calculator, accelerometer/force-meter

Show all your work, any assumptions you made, the reasoning you used, and any measured or estimated values. Write complete answers to each of the following questions on your own paper. Some of these questions are repeated from Part 2.

1. Height of first hill from the station ______m

2. Height of first hill from the bottom of the first hill ______m

3. Length of the incline up the first hill _____m

4. Time for the train to pass a point at the top of the first hill _______ s

5. Time for the train to pass a point at the bottom of the first hill _______ s

6. Time for the train to go from the top of the first hill to the bottom of the first hill _______ s

Knowing that the length of the train is 15 m, determine:

7. Speed of the train at the top of the first hill _______ m/s

8. Speed of the train at the bottom of the first hill _______ m/s

9. Calculate the acceleration of the train going down the hill. _______ m/s^2

10. How does the value for acceleration compare to the acceleration due to gravity ($9.8 m/s^2$)?

11. The acceleration due to gravity for a free falling object is $9.8 m/s^2$. Use this value to calculate the predicted maximum speed of the Mind Eraser at the bottom of the first hill

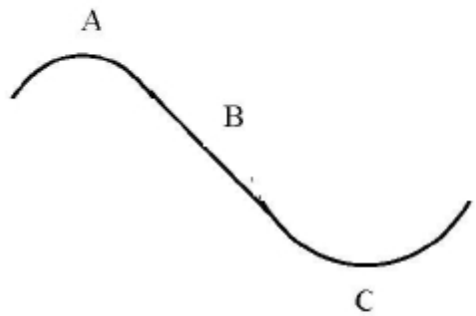
    Predicted Maximum speed (m/s) =
    Square root [2 * (acceleration due to gravity (m/s^2)* height (m)]

12. What is your mass ____ kg?

13. What is *your* Gravitational Potential Energy at the top of the first hill? _________ Joules

14. How much power is used to get *you* up the first hill? __________ Watts

15. What force is applied to get *you* up the first hill? _________ Newton



16. What is the average speed of the train on the first hill from A to C?

17. What was *your* Kinetic Energy at the bottom of the first hill?

18. What was *your* Gravitational Potential Energy at the bottom of the first hill?

19. Summarizing the data above:
    - What is your Potential Energy at the top of the first hill A (as measured from the bottom of the first hill)? _________ J
    - What is your Kinetic Energy at the top of the first hill A? _________ J

20. Compare the change in Gravitational Potential Energy to the change in Kinetic Energy as you moved from the top to the bottom of the first hill. Does your data show that energy was conserved?

21. If there had been no friction, what would be the maximum speed at the bottom of the first hill?

Using an accelerometer app or electronic accelerometer (not one with hanging masses) during the entire ride:

22. Where does the accelerometer read closest to zero? How do you feel at this point?

23. What does the near-zero reading tell you about the shape of the track at that point?

24. Where does the meter give a maximum reading?

25. What is it about the shape of the track that makes it a maximum here?

TOWER OF DOOM

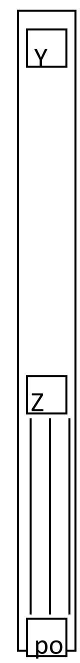
Name(s)_

Part 1:
Write complete answers to each of the following questions on your own paper.
(Note: if you do not wish to ride the elevator; answer these questions by imagining what you would experience. **Indicate if you participated in the ride or imagined the sensations.)**

1. While you are riding the elevator upward, put your hands between your thighs and the seat.
   a. While the elevator is moving *upward*, at what point do you feel the *greatest* force? (Circle one) (i) Near the bottom (ii) in the middle (iii) near the top of the motion *Why?*
   b. While the elevator is moving *downward,* at what point do you feel the *least* force? (Circle one) (i) Near the bottom (ii) in the middle (iii) near the top of the motion *Why?*

2. Riders are most often scared as they travel downward.
   a. Describe the sensations.
   b. What would happen to a rider without the seat harness?

Observe the motion of the cars as they are pulled to the top of the tower and then dropped. The labeled points in the diagram are X at the top, Y at the point where braking begins when going down, and Z at the bottom.



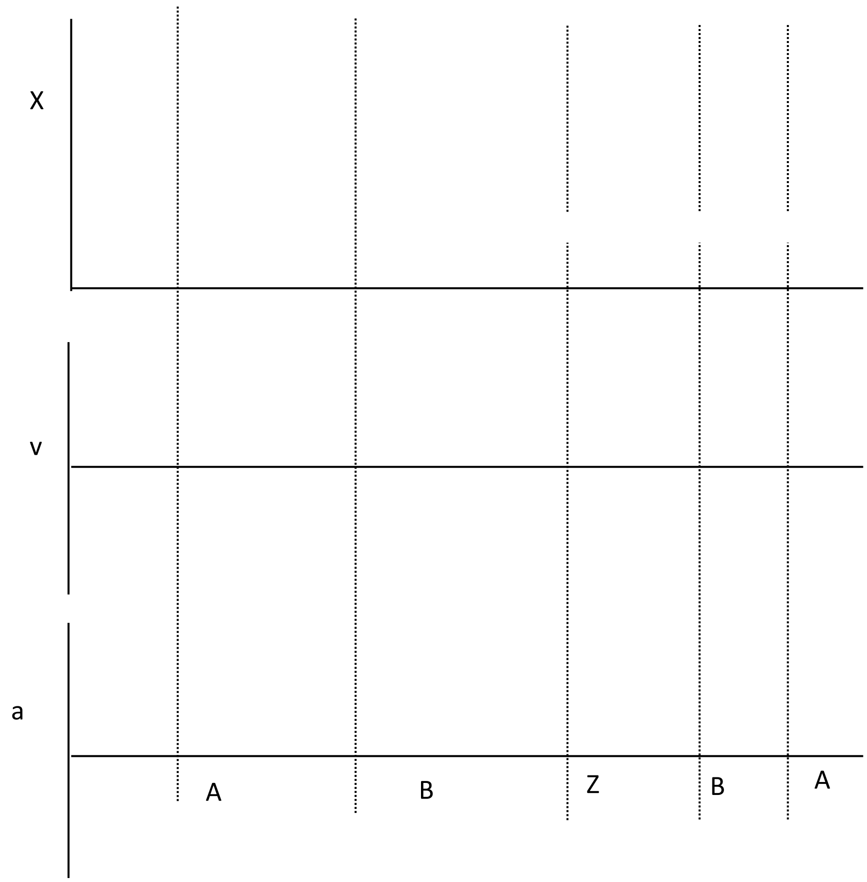
3. At which of the following points is the ride's:
   a. Speed the greatest? _____
   b. Gravitational Potential Energy the greatest? _____
   c. Gravitational Potential Energy the least? _____
   d. Kinetic Energy the greatest? _____
   e. Acceleration the greatest? ______
   f. Normal force greater than the gravitational force on a rider? ______
   g. Gravitational force greater than the normal force on a rider? ______

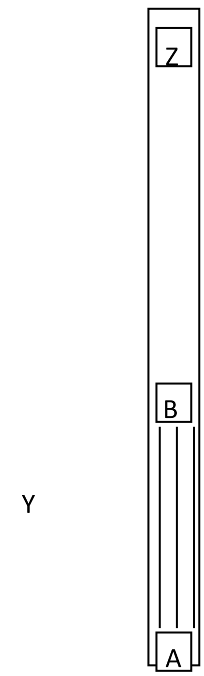
X

The braking system on The Tower of Doom is passive and requires no friction or input of power. Long aluminum fins are attached to the lower portion of the tower. The back of each car has very strong magnets that straddle the aluminum fins and stop the falling car. This braking is due to a phenomenon known as Lenz's Law. Whenever a solid conducting material moves in a magnetic field it generates an opposing magnetic field, so the motion actually creates a braking force.

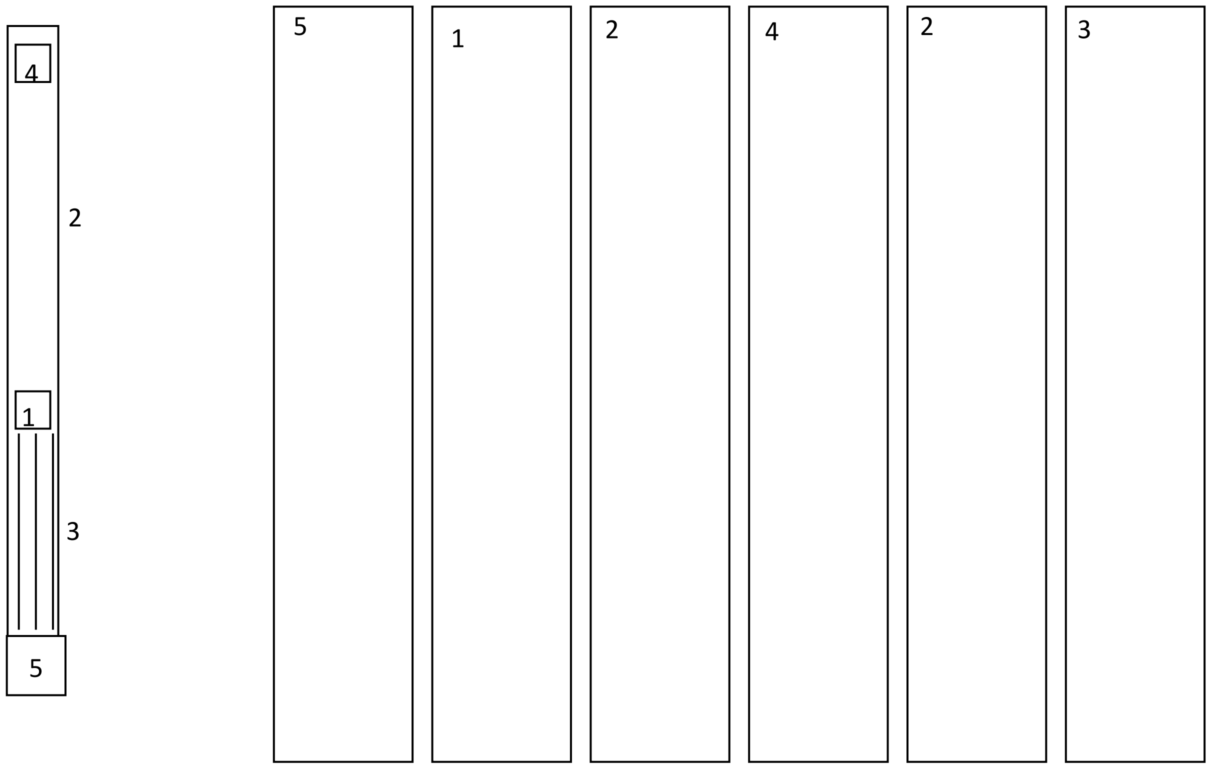
4. Carefully observe the motion of the car on the way up. Does the velocity increase, decrease, or stay the same when the car leaves the aluminum fin region of the tower? What would account for this change?

5. Sketch qualitative position-time, velocity-time, and acceleration-time graphs for one complete cycle of the ride. The letters indicate the times the ride reaches the indicated positions. Treat upward as the positive direction.





Draw qualitative free body force diagrams for a rider at each of the points indicated.



TOWER OF DOOM

Name(s)__________________________ Name(s)__________________________

Part 2
Equipment: stopwatch, calculator
Write complete answers to each of the following questions on your own paper.

1. Estimate the distance that the seats drop during the ride before beginning to slow to a stop.
   Estimated distance of fall ______________ m
   Describe how you estimated this distance.

2. Using repeated measurements, determine the time it takes the seat to "fall" that distance.

   Times measured: ________ s ________ s ________ s

   Average time to fall = ________ s

3. Calculate the Average Speed of the fall using the formula.

   $$\text{Average Speed Falling (m/s)} = \frac{\text{Distance traveled (m)}}{\text{Average time for trip (s)}}$$

4. The maximum speed is equal to twice the average speed if the seat starts at rest and accelerates uniformly during the trip.

   The maximum speed is = __________________ m/s

5. Calculate the acceleration of the cart as it moves down the tower.

   Falling Acceleration (m/s^2) =
   [Max speed (m/s) – speed at top of tower (m/s)] / time to travel down the tower (s)

6. Using repeated measurements, determine the time it takes the seat to rise from the top portion of the bottom slowing section to the top of the tower.

   Times measured: ________ s ________ s ________ s

   Average time to rise = ________ s

7. The time it takes to fall downward with constant acceleration starting from rest can also be determined using $d = (0.5)at^2$. If the elevator were in free-fall, about how long would it take to go from top to the bottom of the "free-fall" section ($g = 9.8\ m/s^2$)?
   ____________ s

8. How do these two times compare and what conclusion can you make about the ride as free-fall?

9. Calculate the Average Speed of the fall using the formula.

$$\text{Average Speed falling (m/s)} = \frac{\text{Distance traveled (m).}}{\text{Average time for trip (s)}}$$

10. What is your mass ______ kg (If you do not know your mass, use 60 kg)

11. Calculate your Maximum Kinetic Energy during the falling portion
    Kinetic Energy at bottom (J) =
    (0.5) * mass (kg) * Maximum Speed (m/s) * Maximum Speed (m/s)

12. Calculate your Maximum Gravitational Potential Energy at the top of the tower (use acceleration due to gravity = 9.8 m/s^2)
    Maximum Gravitational Potential Energy at top (J) =
    mass (kg) * acceleration due to gravity * distance the ride drops (m)

13. Compare the maximum values of Gravitational Potential Energy and Kinetic Energy and make conclusions about energy conservation during the ride.

TOWER OF DOOM

Name(s)__________________________ Name(s)__________________________

Part 3
Equipment: stopwatch, calculator

Show all your work, any assumptions you made, the reasoning you used, and any measured or estimated values. Write complete answers to each of the following questions on your own paper. Some answers are based on data measured or calculated in Part 2.

1. How could you convince someone that the maximum speed of the ride at the bottom of the tower is equal to twice the average speed of the seat?

2. How much work is done to lift a 70 kg person from the top of the slowing area to the top of this ride?

3. Using the difference in heights (and Gravitational Potential Energies) between the top and the bottom of the ride (let's say that the "bottom" is the place just prior to slowing), predict the maximum speed at the bottom of the ride (assuming that the change in PE is equal but opposite to the change in KE).

4. Compare the predicted speed at the bottom based on energy conservation above with the measured maximum speed at the bottom assuming free fall for a mass of 70 kg. What is the percent difference based on the measured speed?

5. Draw free body force diagrams for these places:

At top of tower just after being dropped	At the top of the braking section	At the point of maximum braking

6. Use Newton's second law ($\Sigma \mathbf{F} = m\mathbf{a}$) and your force diagram above to calculate the rider's acceleration just after being dropped from the top point.

7. Use Newton's second law ($\Sigma \mathbf{F} = m\mathbf{a}$) and your force diagram above to calculate the rider's acceleration at the top point of the braking section.

8. Use Newton's second law ($\Sigma \mathbf{F} = m\mathbf{a}$) and your force diagram above to calculate the rider's acceleration at the point of maximum braking.

9. For this ride, the average stopping force can be found by using the impulse-momentum theorem: $m\Delta v = F_{net}\Delta t$.
   a. Calculate the change in momentum ($m\Delta v$) of a 700-kg car and riders during braking.

   b. Calculate the average braking force on the car and riders. (Hint: The braking force is not the same as the net force.)

For the purposes of the questions that follow, let us estimate that the mass of a car with four riders is 700 kg.

10. Calculate the Gravitational Potential Energy of the car and riders at the top of the ride relative to the ground.

11. Explain why the energy supplied by the ride to lift the car to the top is greater than the Gravitational Potential Energy of the car at the top.

12. Calculate the maximum Kinetic Energy of the car.

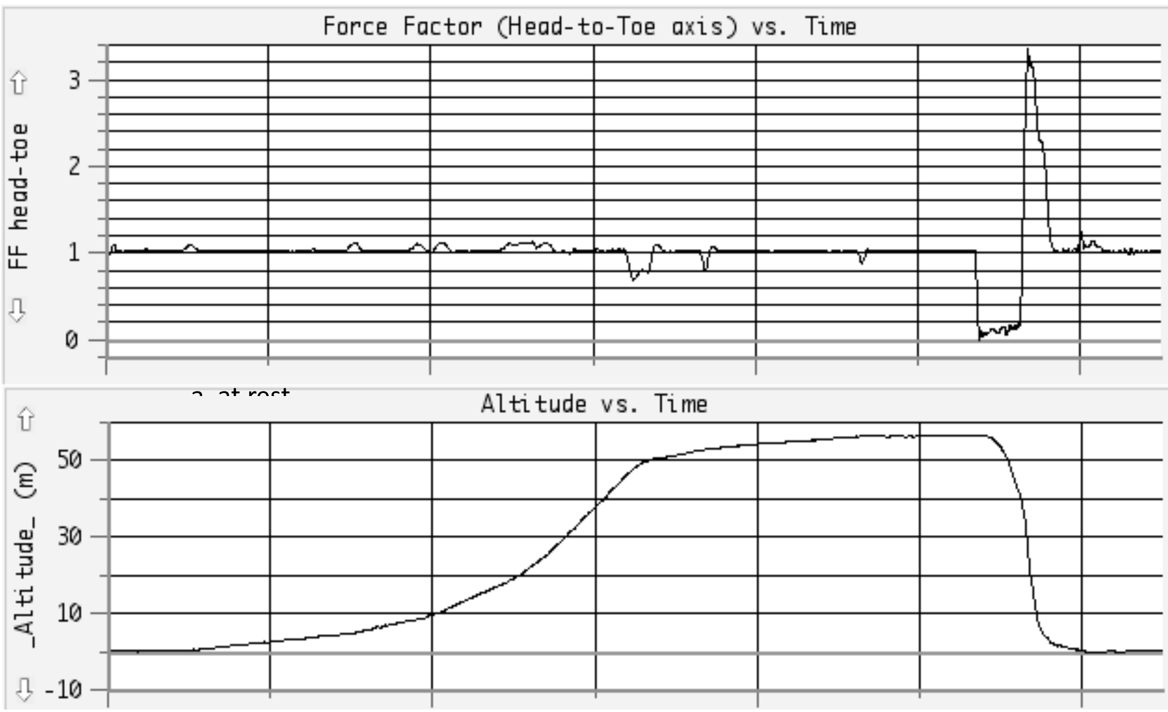
13. Calculate the Gravitational Potential Energy of the car relative to the ground at the moment braking begins.

14. What ultimately happens to all of the Gravitational Potential Energy that a car has at the top?

The graphs below show data for a similar ride.

15. Use the graph to find the maximum height the car reaches.

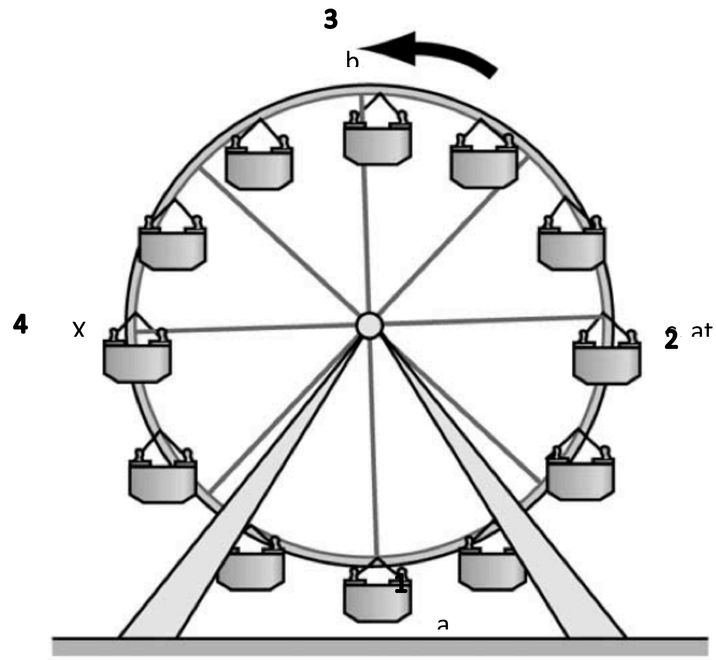
16. Determine the distance the car falls before braking.



BIG WHEEL

Name(s)__________________________ Name(s)__________________________

Part 1
Write complete answers to each of the following questions on your own paper.



Assume the wheel turns smoothly.
While on the ride, sit on your hands to feel how your apparent weight (the normal force) may change.

1. At what position in the above diagram would you feel a greater apparent weight than usual?

2. At what position in the above diagram would you feel a smaller apparent weight than usual?

3. At what position in the above diagram, would you expect to experience “stomach butterflies”?

4. How do these “stomach butterfly” sensations relate to the effect of gravity on the material (food, drink) inside your stomach?

5. While on the ride, close your eyes and keep them closed for what you feel are two revolutions. Notice your position relative to the ground just before closing your eyes and right after opening them.
    a. How close were you to judging two revolutions?
    b. How did you know when you were moving up or down, since you had your eyes closed?

6. Apparent weight is what a bathroom scale would read if you were sitting on it during the ride. When the ride is <u>not</u> moving, the bottom of the seat is pushing against your backside with a force equal to your weight.
   a. Going up (Point 1): I predict that the apparent weight would be (greater than, less than, equal to) the gravitational weight.

   b. At the top (Point 2): I predict that the apparent weight would be (greater than, less than, equal to) the gravitational weight.

   c. Going down (Point 3): I predict that the apparent weight would be (greater than, less than, equal to) the gravitational weight.

   d. At the bottom (Point 4): I predict that the apparent weight would be (greater than, less than, equal to) the gravitational weight

BIG WHEEL

Name(s)__________________________ Name(s)__________________________

Part 2

Equipment: stopwatch, calculator

Write complete answers to each of the following questions on your own paper.

1. Measure the time that the ride takes to complete several continuous revolutions.

   Number of revolutions =__________
   Time for all revolutions = ______________ s
   Average time for one revolution = period = ___________ s
   Average number of revolutions/second = frequency = __________rev/s

2. If you stayed on this ride for 8 hours, how many revolutions would you complete?

3. Estimate the diameter of the wheel.

   Estimated diameter ______________ m
   Describe how you estimated this distance.

4. Multiply the diameter by pi (π = 3.14) to get the circumference of the Big Wheel.

   Circumference = ________ m

5. Calculate the average speed of a rider on the Big Wheel using the following:

   Average speed (m/s) = circumference (m) / average time for one revolution (s)

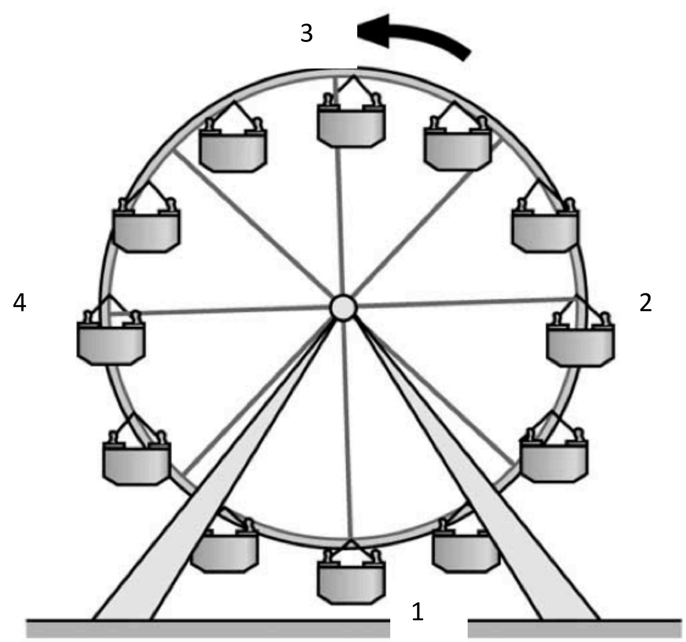
BIG WHEEL

Name(s)__________________________ Name(s)__________________________

Part 3
Equipment: stopwatch, calculator, accelerometer

Show all your work, any assumptions you made, the reasoning you used, and any measured or estimated values. Write complete answers to each of the following questions on your own paper. Some of these answers are based on data and calculations from Part 2.

1. Determine the frequency and period of rotation of the passenger gondolas.
2. What are the average linear and angular speeds of the passenger gondolas?
3. Draw free body diagrams (force diagrams) for the gondola at each of the four numbered positions.



4. How do these force diagrams confirm the predictions that you made about the apparent weight at each location?

5. Centripetal force = mv^2/r. If the wheel could move fast enough, there would be a speed at which you would have no apparent weight at the top of the ride.
   At what speed is this? (Note: Mass doesn't matter).

6. If the Big Wheel were twice the diameter, how would the experience be different for the riders assuming the period remained the same?

7. Using an accelerometer, record the values at each of the four positions:

   Point 1 __________ m/s^2 Point 3 __________ m/s^2

   Point 2 __________ m/s^2 Point 4 __________ m/s^2

8. How do these values relate to your apparent weight predictions and force diagrams?

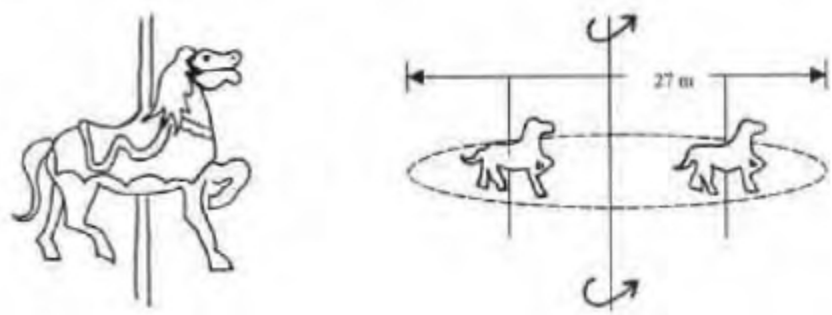
CAROUSEL


ELITCH GARDENS
PHILADELPHIA TOBOGGAN
ELITCH GARDENS
DIRECTORY

CAROUSEL

Name(s)__________________________ Name(s)__________________________

Part 1
Write complete answers to each of the following questions on your own paper.

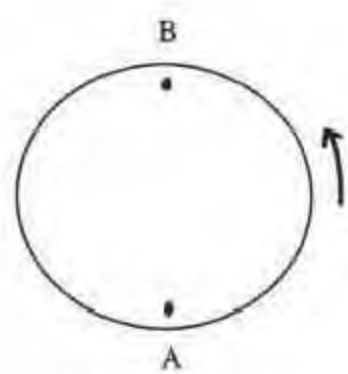


1. Describe the direction of rotation of the horses as viewed from above.

2. Suppose that you drop a coin onto the Carousel floor as you sit on one of the horses. Where does it land relative to you (e.g., directly below, in front of, or behind you)?

3. Now suppose that you stand near the edge of the Carousel and drop a coin off the edge of the Carousel onto the ground.
When the coin hits the ground, where does it land relative to you? (e.g., directly below, in front of, or behind you)?

4. Is the floor of the ride level? (parallel to the ground)? If not, which way does it tilt? Why?



5. If you were to throw a ball from position A on the diagram to someone at position B while the ride was turning, where would you aim the ball?

6. How did you make this prediction?

7. Draw the path of the ball as seen by someone viewing the toss from above the ride as the ball moves from position A to B.

8. Draw the path as seen by a person on the ride at point B.

9. As the ride turns, is your body "thrown" slightly to the inside or outside of the carousel?

10. Do all the animals on the Carousel go up and down at the same time?

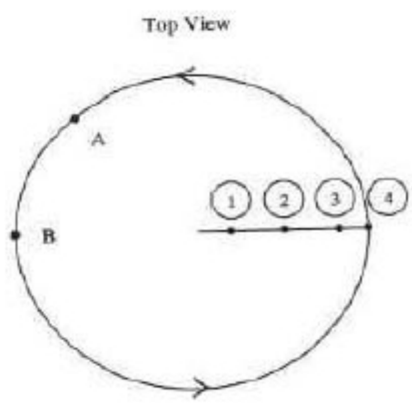
11. Does the animal next to you move up and down as you do?

12. Do you feel slightly lighter or heavier when your horse is going up? Why?

13. Do you feel slightly lighter or heavier when your horse is going down? Why?

14. Do you feel different when riding a horse on the outside vs. the inside of the Carousel? If so, describe the differences when on the outside horse versus the inside horse?

15. How does the *angular* velocity (number of degrees moved /second) of the outer horse compare to that of an inner horse? (Are their revolution rates the same? If not, which is larger?)



16. At which number position on the diagram above would you have the greatest linear speed?

17. At which number position would you have the smallest linear speed?

CAROUSEL

Name(s)__________________________ Name(s)__________________________
Part 2

Write complete answers to each of the following questions on your own paper.
Equipment: stopwatch, calculator, accelerometer

1. Take three repeated measurements of the time for a horse to make *several* continuous revolutions.
   Number of revolutions =__________
   Time for all revolutions = ______________ s _______ s _______ s
   Average time for one revolution = period = ___________ s
   Average number of revolutions/second = frequency = __________rev/s

2. Estimate the radius of the Carousel from the center to an outside horse
   Estimated radius to outside horse ______________ m
   Describe how you estimated this distance.

3. Multiply the radius by two to get the diameter. Multiply the diameter by pi ($\pi = 3.14$) to get the circumference of the horse path.

   Circumference at outside horse = ________ m

4. Calculate the average linear speed of an outside horse using the following:

   Average linear speed on outside (m/s) =
   circumference (m) / average time for one revolution (s)

5. Calculate the centripetal acceleration of an outside horse
   Outside centripetal acceleration (m/s^2) =
   average speed (m/s) * average speed (m/s) / distance from the ride center to the horse (m)

6. Estimate the radius of the Carousel to an inside horse
   Estimated radius to inside horse ______________ m
   Describe how you estimated this distance.

7. Multiply the radius by two to get the diameter. Multiply the diameter by pi ($\pi = 3.14$) to get the circumference of the horse path.

   Circumference of inside horse path = ________ m

8. Calculate the average linear speed of an inside horse using the following:

Average linear speed (m/s) = circumference (m) / average time for one revolution (s)

9. Calculate the centripetal acceleration of an inside horse

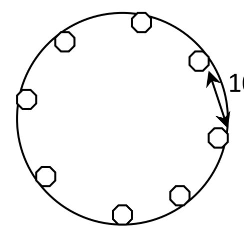
Inside centripetal acceleration (m/s^2) =
average speed (m/s) * average speed (m/s) / radius of inside horse (m)

10. Count the number of horses in the outer ring __________
Count the number of horses in the inner ring __________

11. What is the angle (number of degrees) between horses?

on the outer ring? __________^{o}

on the inner ring? __________^{o}



12. If you are moving in a circle, a *force* toward the center of the circle is needed to make you move in that circle. Answer the following questions by using the a horizontal accelerometer or pendulum.
Get on a horse that does *not* move up and down. Before the Carousel starts, hold the string with your hand, in front of you, and let the weight hang beneath your hand. (If you are using an accelerometer, skip to question 13.)

   a. When the Carousel is starting up, which way does the weight move? (toward the center of the Carousel or toward the outside the Carousel, in the direction the horse is facing or the opposite direction to the way the horse is facing)

   b. When the Carousel is moving at constant speed, does the weight move? (toward the center of the Carousel or toward the outside the Carousel, in the direction the horse is facing or the opposite direction to the way the horse is facing)

   c. When the Carousel is slowing down and coming to a stop, which way does the weight move? (toward the center of the Carousel or toward the outside the Carousel, in the direction the horse is facing or the opposite direction to the way that the horse is facing)

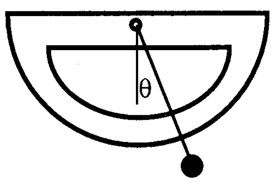
   d. When the Carousel is moving at constant speed, does the string pull the weight? (toward the center of the Carousel or toward the outside the Carousel, in the direction the horse is facing or the opposite direction to the way the horse is facing)

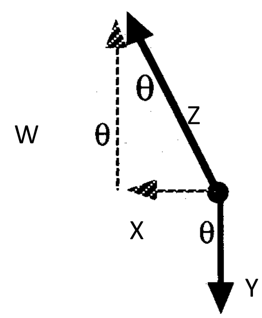
13. Sit on an animal in the inner ring. Once the carousel reaches full speed, measure the centripetal acceleration angle using your protractor-sextant. If you are using a Smartphone accelerometer record those values in the next question). Make sure the protractor is level and you are measuring the angle at which the weight is hanging from the vertical.

(inner circle of animals) θ_i = ________°

Then measure the acceleration angle of an animal on the outer ring when the carousel is at maximum speed.

(outer circle of animals) θ_o = ________°





$a_c = g \tan \theta$

14. The centripetal acceleration can be calculated using ($g = 9.8$ m/s^2)

$a_c = g*\tan\Theta$

The centripetal acceleration for the inner ring = ____ m/s^2

The centripetal acceleration for the outer ring = ____ m/s^2

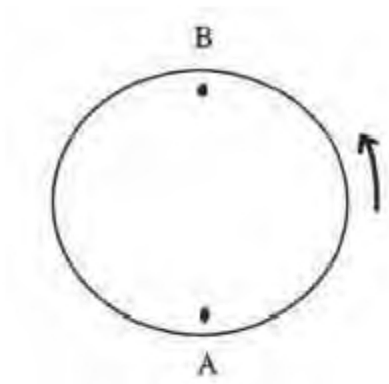
15. Using these acceleration values, how does the radial force (ma_c) on the inner horse compare with that on the outer horse?

CAROUSEL

Name(s)_________________________ Name(s)_________________________

Part 3
Equipment: stopwatch, calculator, accelerometer

Show all your work, any assumptions you made, the reasoning you used, and any measured or estimated values. Write complete answers to each of the following questions on your own paper. Some of these answers are based on data and calculations from Part 2.



1. If the carousel is moving,

- At position (A), draw an arrow representing the linear velocity at that instant. Also, draw an arrow that represents the acceleration. (Label them **v** and **a**)

- At position (B); draw an arrow representing the linear velocity and acceleration. (Label the **v** and **a**)

2. Assume the following drawing shows you on the horse at position (B). Draw all the force vectors that are acting on you at this point. (Free Body Diagram)

3. Your mass is ______ kg. (If you do not know your mass, use 60 kg)

4. Calculate the centripetal force acting on you while you are riding an outer horse.
   Centripetal force = _________ N

5. Calculate the centripetal force acting on you while you are riding an on an inner horse.
   Centripetal force = _________ N

6. Draw to scale a horizontal vector representing the centripetal force on you when you are on an inside horse. Add to it a vertical vector equal in magnitude to your weight but moving directed upwards. This is the Normal Force. These are the components of the net force applied on you by the horse.
   Use a ruler and protractor and this diagram to find the net applied force.

7. Using your vector diagram, discuss what you expect to happen to the forces as you change from an inner to an outer horse.

8. Centripetal accelerometer readings on:
   a. Inner horse = ___________
   b. Outer horse = __________

9. Use an accelerometer and record the meter readings as the horse goes up and down.
   At bottom going up _______ in middle going up _______ arriving at top ________
   At top starting down ______ in middle going down _____ arriving at bottom _____

10. How do the readings on the accelerometer relate to the force sensations you experienced?

11. How does the radial force meter reading on the inner horse compare with that on the outer horse?

12. Angular velocity is a useful way to describe circular motion. The angular velocity, ω, can be determined by the formula below. Calculate the angular velocity of the Carousel in radians/sec. (t = time for one revolution)

$$\omega = \frac{2\pi}{t}$$

ω= _________ radians/sec

13. Centripetal acceleration can be determined with $a_c = v^2/r$ and linear velocity can be found using $v = \omega r$.
Combining these two equations we get $a_c = \omega^2 r$. Calculate the centripetal accelerations for the inner and outer ring of animals.

a_c for inner ring = ________ m/s^2
a_c for outer ring = ________ m/s^2

14. Earlier, you determined the centripetal acceleration from the angle θ. Using these values, determine the centripetal acceleration

a_c for inner ring = ________ m/s^2
a_c for outer ring = ________ m/s^2

15. Compare your measured value for centripetal acceleration with that calculated from the angular velocity. Which method of finding centripetal acceleration is the least reliable? Give reasons for your answer.

16. At which location on the Carousel do you experience the greatest centripetal acceleration? Why?

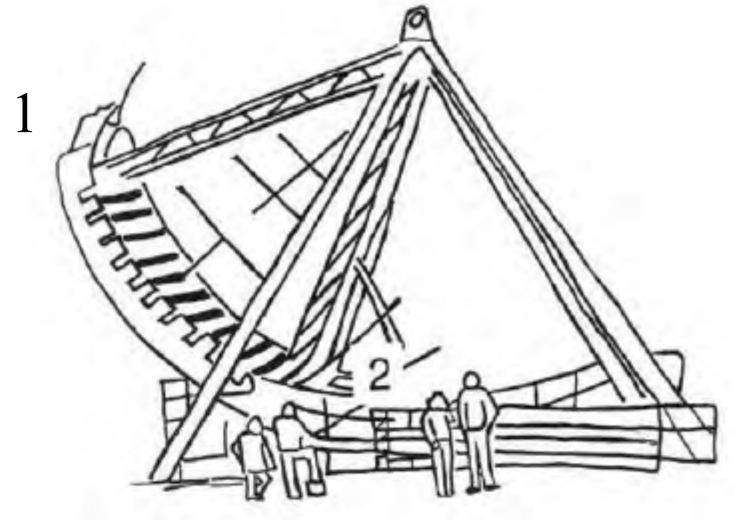
SEA DRAGON

i.

THE SEA DRAGON

Name(s)__________________________ Name(s)__________________________

Part 1
Write complete answers to each of the following questions on your own paper.



1. Your weight doesn't change while riding The Sea Dragon, but your *sensation* of weight does change while on the ride. What force is responsible for your *sensation* of weight?

2. Using the diagram above answer the following:

    a. At which location (1 or 2) might you feel "weightless"?

    b. At which location (1 or 2) might you experience the greatest speed?

    c. At which location (1 or 2) might you feel the heaviest?

3. At what point in the swing of the boat does it feel like the boat is moving the fastest?

4. For the biggest thrill during the ride, which seat on the boat would you recommend? One near the end or one near the middle?
   What reasoning can you give for your answer?

5. Determine the period of the ride by timing one back and forth swing for a small initial oscillation T = _______________ seconds.

6. Was the period affected by the size of the oscillations? Explain.

7. At what point during the swing of the ride does a rider have the greatest Gravitational Potential Energy and at what point of the swing is a rider's Kinetic Energy the largest?

8. In each arc, where did you feel:
   a. The strongest push against your back?

   b. The most pressure against your seat?

   c. The least pressure against your seat?

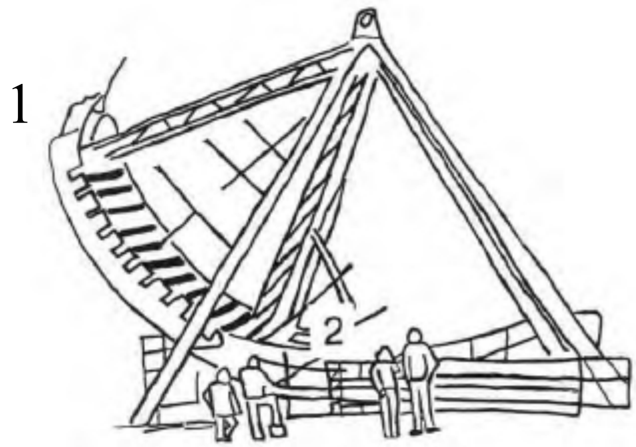
THE SEA DRAGON

Name(s)__________________________ Name(s)__________________________

Part 2

Equipment: stopwatch, accelerometer, calculator

Write complete answers to each of the following questions on your own paper.



1. Using repeated measurements, measure the time for the ride to complete several continuous back and forth motions.

   Number of round trips =__________
   Time for all round trips = ______________ s ____ s _____ s
   Average time for one round trip = period = ___________ s
   Average number of trips/second = frequency = __________trips/s

2. If you stayed on this ride for 8 hours, how many round trips would you complete?

3. Estimate the length of the pendulum.

   Estimated length ______________ m
   Describe how you estimated this distance.

4. Estimate the length of the seating area.

   Estimated length ______________ m
   Describe how you estimated this distance.

5. Using multiple measurements, determine the time for the seating area to pass by Point 2 at the bottom of the swing.

   Time for seating area to pass Point 2 = ______________ s ____ s _____ s
   Average time to pass point 2 = ___________ s

6. Determine the average speed of the seating area at Point 2.

$$\text{Average Speed at Point 2 (m/s)} = \frac{\text{Total length of seating area (m)}}{\text{Average time to pass Point 2 (s)}}$$

7. Determine the centripetal acceleration of the seating area at Point 2.

Centripetal acceleration (m/s^2) =
Average Speed at Point 2 * Average Speed at Point 2 / length of the pendulum (m)

8. The mass of the seating area is 1300 kg.
Describe how you could estimate this mass.

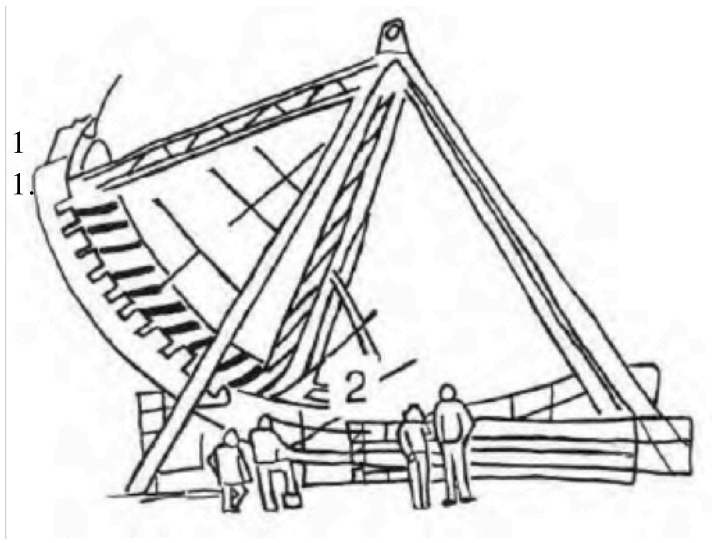
9. Determine the centripetal force on the seating area.
F_c = mass * centripetal acceleration

THE SEA DRAGON

Name(s)__________________________ Name(s)__________________________

Part 3
Equipment: stopwatch, calculator, accelerometers

Show all your work, any assumptions you made, the reasoning you used, and any measured or estimated values. Write complete answers to each of the following questions on your own paper. Some of these answers are based on data and calculations from Part 2.



1. Using the method discussed on the triangulation section of "Suggestions for Making Measurements," find the height of the middle of the seating area when it is at its highest point.

   Height = distance away * (Tan Ø)
   Height =________ (m)

   (Don't forget the height of your eye above the ground)
   Height of the Sea Dragon = Height from above + height of your eye from the ground

   Height of Sea Dragon =________ + ________ = ___________ m

2. What is the average speed of the seating area when traveling through Point 2?

3. The mass of the seating area is 1300 kg.
   Describe how you could estimate this mass.

4. Calculate the Kinetic Energy of the seating area at **Point 2**
   Kinetic Energy at Point 2 (J) =
   (0.5) * mass (kg) * Average Speed at Point 2 (m/s) * Average Speed at Point 2 (m/s)

5. Calculate the Gravitational Potential Energy of the Seating Area at **Point 1** (use acceleration due to gravity = 9.8 m/s^2)
   Gravitational Potential Energy at Point 1 (J) =
   mass (kg) * acceleration due to gravity * max height of middle of seating area (m)

Note: The Kinetic Energy of the seating area at the maximum height is 0 J.
Note: The Gravitational Potential Energy of the seating area at the bottom of the arc is 0 J.

6. Calculate the change in Kinetic Energy
   Change in Kinetic Energy (J) =
   Kinetic Energy at Point 2 – Kinetic Energy at max height

7. Calculate the change in Gravitational Potential Energy
   Change in Gravitational Potential Energy (J) =
   Gravitational Potential Energy at Pt 2 – Gravitational Potential Energy at max height

8. Did the change in Kinetic Energy match the change in Gravitational Potential Energy?
   Are they exactly the same (including sign)?

   Why would you expect them to have equal magnitudes?

9. The acceleration due to gravity for a free falling object is 9.8 m/s^2. Use this value to calculate the maximum predicted speed of the Sea Dragon at the bottom of the swing

   Maximum speed (m/s) =
   Square root [2 * (acceleration due to gravity)* max ht of middle of seating area (m)]

10. How do the points of greatest Gravitational Potential Energy compare to the: [answer: (the same) or (different than)?
    a. points of lowest accelerometer readings ________________________
    b. points of maximum accelerometer readings ________________________
    c. points of minimum velocity ________________________
    d. points of maximum velocity ________________________

11. How do the points of greatest kinetic energy compare to the: [answer: (the same) or (different than)?

   a. points of lowest accelerometer readings ________________________
   b. points of maximum accelerometer readings ________________________
   c. points of minimum velocity ________________________
   d. points of maximum velocity ________________________

12. When the seating area is full of people, how much energy needs to be supplied by the motors to get the "dragon" swinging to its maximum height?

13. If you have a vertical accelerometer or a Smartphone accelerometer, hold it in front of you during the ride.
   a) In what part of the ride was the acceleration the largest?

   b) Describe the acceleration changes during the swinging arc.

14. Consider the swinging boat as a pendulum. In a simple pendulum, the mass is considered to be concentrated at the end of a weightless string.
   A simple pendulum at small displacements exhibits simple harmonic motion with the period **t** of the pendulum's swing expressed by the following relationship:

   $t = 2\pi\sqrt{L/g}$ Where **L** = the length of the pendulum's string.

   Calculate the period of the Sea Dragon if it were a pendulum. ___________ s

15. If a difference exists between the measured period and the theoretical period from the above equation, what do you believe is the reason for the difference?

Using an accelerometer or Force Factor meter:

16. Align your accelerometer **head-to-toe** and record the maximum swing readings:
   a. moving forward through the lowest point ________
   b. at the highest point ________

17. Explain why the accelerometer reading at Point 1 is less than when the ride is not moving.

18. Align your accelerometer **front-to-back** and record the maximum swing readings:
   a. moving forward through the lowest point _______
   b. at the highest point _______

19 Where did the maximum Force Factor occur? Is this point the same for every seat? Explain.

20 Explain the differences you found between the accelerometer readings at Point 2 and the centripetal acceleration calculated in Part 2.

21 On the following diagrams draw free body diagrams indicating all forces acting at this location.

(A) At Point 2

(B) At Point 1

22. What two forces are acting on you during the ride?

a. ______________________________

b.______________________________

23. Use your Force Factor measurements to make quantitative free body diagrams for a 60-kg rider:

W	X	Y

24. From the centripetal force, predict the 60-kg rider's velocity at the lowest point.

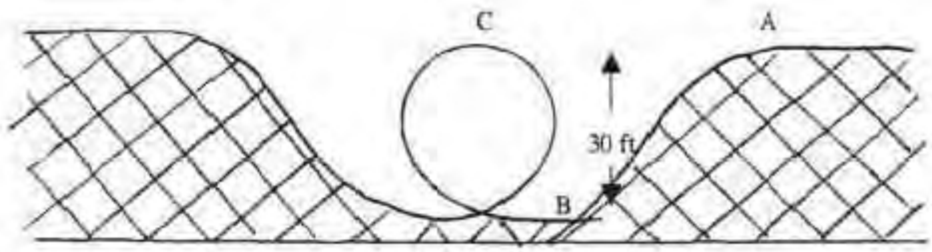
25. How does this calculated value compare to the values determined earlier?

THE SIDEWINDER

THE SIDEWINDER

Name(s)________________________ Name(s)________________________

Part 1
Write complete answers to each of the following questions on your own paper.

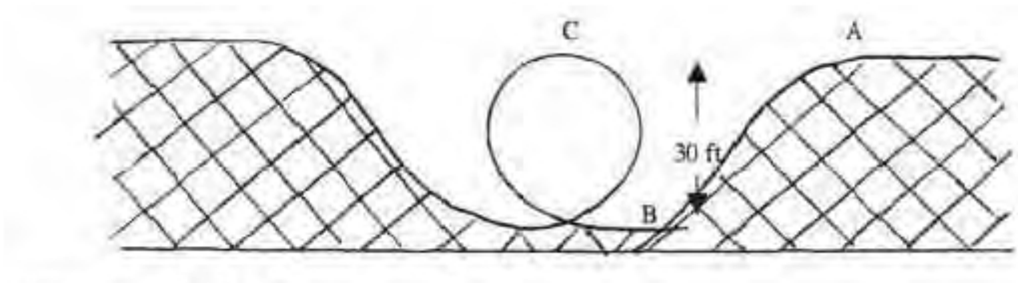


1. Riders are most often scared as they travel upside down.
    a. Describe the sensations.
    b. What would happen to a rider without the seat harness?
2. At which point during the ride do you feel the heaviest?
3. At which point during the ride do you feel the lightest?
4. Why don't objects fall out of your pockets when you are upside down at the top of the loop?
5. At which point during the ride do you feel you are moving the fastest?
6. Energy is put into the ride at its beginning. Is energy put into the ride anywhere else? Explain.
7. While circling around inside the loop, your body is pushed (away from) (toward) the loop's center.

THE SIDEWINDER

Name(s)_________________________ Name(s)_________________________

Part 2
Write complete answers to each of the following questions on your own paper.
Equipment: stopwatch, calculator, ruler



MEASUREMENTS

1. Measure the height of the station where you enter the ride using two different methods:

   Method 1. Measure the height of one step and count the number of steps to get the height at the top of the ride:

   Measure the height of one step = ___________m

   Number of steps = __________

   Height to top = __________m (Station at Points A and C)

   Method 2. Use another method to estimate the height to the top of the ride.

   Estimated height ______________ m

   Describe how you estimated this distance.

2. Compare the two height calculations as follows:
   Average value = (height from Method 1 + height from Method 2) / 2

   Percent difference:
   Percent difference: =
   (height from Method 1 – height from Method 2) / Average Value of height

3. Which height measurement do you think is more accurate? Why?

4. Estimate the radius of the loop.
   How did you determine this value?
   How does this radius compare to the 30 ft. radius labeled above?

5. From a position on the ground, use multiple measurements to determine an average time it takes the train to pass **Point B** (the bottom of the hill before the coaster goes into the loop) on the diagram. That is: start your stopwatch when the front of the train reaches Point B, and stop it when the back of the train reaches Point B.

   Times measured: ________ s ________ s ________ s

   Average time for train to pass Point B ________ s

6. If the length of the train is 12 m, calculate the average speed of the train at **Point B**.

   Average Speed at Point D (m/s) = Total length of train (m) / Average time to pass Point B (s)

7. Estimate the height of Point B from the ground.
   Estimated height ______________ m
   Describe how you estimated this distance.

8. From a position on the ground, use multiple measurements to determine an average time it takes the train to pass **Point C** (at the top of the loop) on the diagram.

   Times measured: ________ s ________ s ________ s

   Average time for train to pass Point C ________ s

9. If the length of the train is 12 m, calculate the average speed of the train at **Point C**.

   Average Speed at Point C (m/s) = Total length of train (m) / Average time to pass Point C (s)

10. The mass of the train and passengers is 2100 kg.
    Describe how you could estimate this mass.

11. Calculate the Kinetic Energy of the train at **Point C**
    Kinetic Energy at Point C (J) =
    (0.5) * mass (kg) * Average Speed at Point C (m/s) * Average Speed at Point C (m/s)

12. Calculate the Kinetic Energy of the train at **Point B**
    Kinetic Energy at Point B (J) =
    (0.5) * mass (kg) * Average Speed at Point D (m/s) * Average Speed at Point B (m/s)

13. Calculate the Gravitational Potential Energy of the train at **Point C** (use acceleration due to gravity = 9.8m/s^2)

Gravitational Potential Energy at Point C (J) =
mass (kg) * acceleration due to gravity * height of Point C

14. Calculate the Gravitational Potential Energy of the Train at **Point B** (use acceleration due to gravity = 9.8 m/s^2)
Gravitational Potential Energy at Point B (J) =
mass (kg) * acceleration due to gravity * height of Point B

15. Calculate the change in Kinetic Energy as the train moves from **Point B** to **Point C**

Change in Kinetic Energy (J) = Kinetic Energy at Point C – Kinetic Energy at Point B

16. Calculate the change in Gravitational Potential Energy as the train moves from **Point B** to **Point C**

Change in Gravitational Potential Energy (J) =
Gravitational PE at Point B – Gravitational PE at Point C

17. Calculate the centripetal force on the train at **Point C**
Centripetal Force at Point C (J) =
mass (kg) * Avg Speed at Pt C (m/s) * Avg Speed at Pt C (m/s) / radius of loop (m)

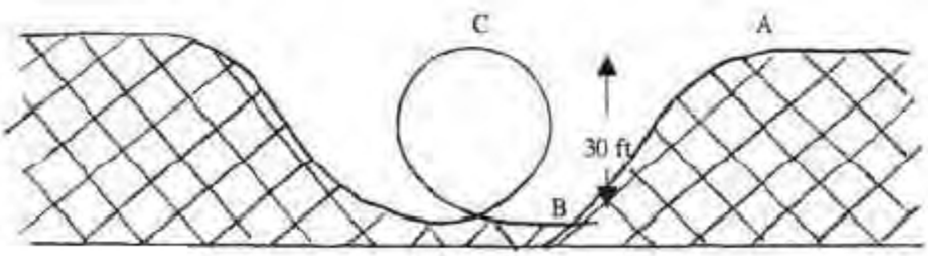
18. Calculate the centripetal force on the train at **Point B**
Centripetal Force at Point D (J) =
mass (kg) * Avg Speed at Pt B (m/s) * Avg Speed at Pt B (m/s) / radius of loop (m)

THE SIDEWINDER

Name(s)__________________________ Name(s)__________________________

Part 3
Equipment: stopwatch, calculator, accelerometer

Show all your work, any assumptions you made, the reasoning you used, and any measured or estimated values. Write complete answers to each of the following questions on your own paper. Some of these answers are based on data and calculations from Part 2.



1. How much work is done by a 75 kg person in climbing the stairs to reach this ride?

2. Estimate how many times must the 75 kg person climb the stairs of this ride to "burn off" the in a soft during, french-fries, and a hamburger. (Note: 1 food Calorie = 4200 J)

3. Using the measured speed at Point C and the difference in heights between points B and C, predict speed at Point B assuming that energy is conserved.

4. Compare the predicted speed at the bottom (Point B) with the measured speed at the bottom. What is the percent difference based on the measured speed?

5. Predict the initial speed of the train just after launch. Show how you made this prediction.

6. If the train was launched using a spring, estimate the spring constant. Show how you made this prediction.

7. For the most exciting ride, the centripetal force at Point C should equal the gravitational force. How did the values you calculated compare to this ideal situation?

7. Using an accelerometer, what is the acceleration as the ride begins (launch)?

8. What force must be applied to launch the ride?

9. Using an accelerometer, what is the acceleration as the ride stops on the other side?

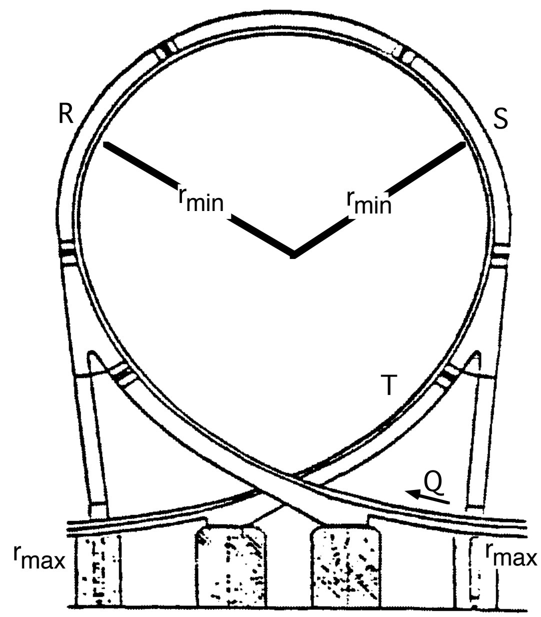
10. What force must be applied over the braking distance in order to stop the train?

11. Draw and label a qualitative free body force diagram for a rider at the top of the loop.

12. Use an accelerometer to determine the head-to-toe acceleration at the top.

13. Use the acceleration to determine the <u>normal</u> force on a 60.0 kg person at the top of the first loop.

14. The loop is not a circle, but a clothoid. A clothoid loop has an ever-decreasing radius as the rider enters the loop at point Q and climbs to point R. From point R to point S the loop is circular with a constant radius. At point S the radius begins to increase until it reaches its maximum value again at point T. What is the advantage of this curve over a circular loop?



Accelerometers mounted in the front and rear cars to a coaster can be used to measure the force component perpendicular to the rider's seat (facing forward) as the coaster travels through a clothoid loop. The table below gives those data recorded for this situation. Use these data to answer the questions that follow.

ACCELEROMETER DATA GOING THROUGH THE LOOP

	Front Car	**Back Car**
Entering loop	4.8 g	3.4 g
Top of loop	1.5 g	1.4 g
Exit of loop	3.2 g	4.8 g

15. Explain the differences in accelerometer readings for front and back cars:
    a. entering the loop.

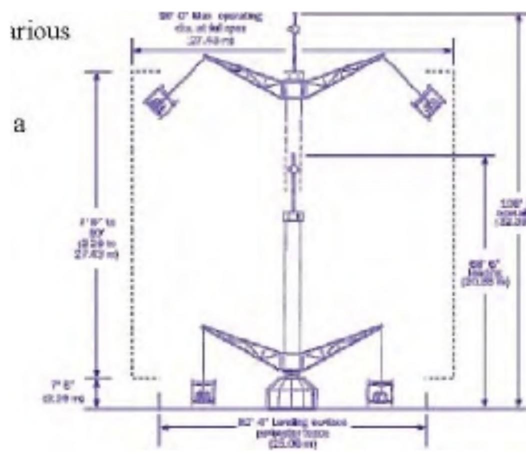
    b. exiting the loop.

THE DRAGON WING

The Dragon Wing

Name(s)_________________________ Name(s)_________________________
Part 1
Write complete answers to each of the following questions on your own paper.

The suspended seats of the ride will swing out at some angle when they travel in a circle. The angle depends upon the radius of the circular path and the speed of the wheel.



1. What sensations do you feel when the ride is moving, but not tilted?

2. What sensations do you feel when the ride is going up when tilted?

3. What sensations do you feel when the ride is going down when tilted?

4. What sensations do you feel as the speed increases?

5. Which goes higher----an empty swing or one with someone in it?

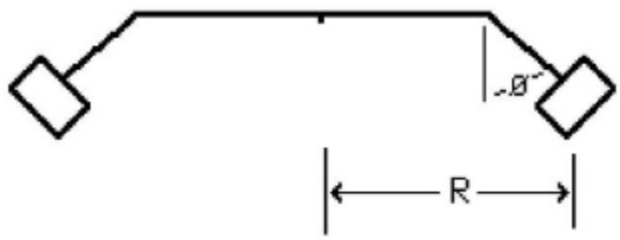
6. What happens to the seats as the speed increases?

7. Watch the ride from the beginning until it reaches full speed. What happens to the angle of the chain attached to the seats as the ride increases in speed? Why?

THE DRAGON WING

Name(s)__________________________ Name(s)__________________________

Part 2
Write complete answers to each of the following questions on your own paper.
Equipment: stopwatch, calculator, protractor



1. Using repeated measurements, determine the time to complete several continuous revolutions of the ride.
   - Number of revolutions =___________
   - Time for all revolutions = _________ s _____ s ________ s
   - Average time for one revolution = period =____________ s
   - Average number of revolutions/second = frequency = ___________rev/s

2. If you stayed on this ride for 8 hours, how many revolutions would you complete?

3. Using repeated measurements, determine
   - The distance from the center of rotation to the chain attachment
   - Length of chain
   - Angle of swing to rotation axis

   Describe how you made these measurements.

4. Determine the largest radius attained by the riders.
5. Multiply the radius by 2 to determine the diameter.
6. Multiply the diameter by pi ($\pi = 3.14$) to get the circumference of the largest horizontal circle covered by the riders.

   Circumference = _________ m

7. Calculate the average speed of the riders using the following:
   Average speed (m/s) = circumference (m) / average time for one revolution (s)

8. Determine the centripetal acceleration of a rider.
   Centripetal acceleration (m/s^2) =
   Average Speed * Average Speed / radius of riders (m)

9. Use an accelerometer sideways to measure the centripetal acceleration of a rider.

THE DRAGON WING

Name(s)__________________________ Name(s)__________________________

Part 3
Equipment: calculator, accelerometer

Show all your work, any assumptions you made, the reasoning you used, and any measured or estimated values. Write complete answers to each of the following questions on your own paper. Some values are based on data from Parts 1 and 2.

1. What is the average linear speed of the ride?

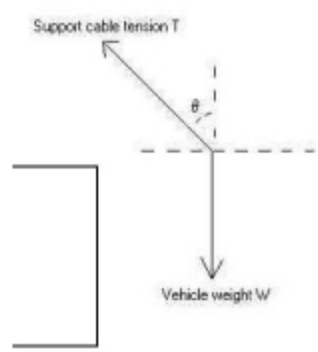
2. What is the average angular speed of the ride?

3. Draw a vector diagram of the forces acting on you during the ride. Use the angle of the swing to make your vector diagram as accurate as possible.

4. Draw free body diagrams that show all of the forces that act on the rider:

   a. When the ride is at rest b. When the rider is moving.

5. The force diagram for the passenger vehicle looks like the figure below. The horizontal component of the cable tension is T * sin θ = Fc. The vertical component is T * cos θ = Weigh. Using the maximum speed and radius calculated before, along with the mass of a passenger, determine the centripetal force. Then calculate the value of θ. Compare this to an actual value measured for the ride.



6. The electrical power required to operate the Dragon Wing is approximately 128 kilowatts. (1 kilowatt = 1000 watts. 1 watt = 1 joule/second) If electrical energy costs 7.5 cents per kWhr, calculate the electrical energy cost of one ride.

7. What is your maximum Force Factor reading before the ride tilt, when the rider is vertical (i.e. perpendicular to the ground) __________

8. What is your maximum Force Factor reading before the ride tilts, when the rider is tilted parallel to the chains __________

9. Use this tilted Force Factor meter reading to calculate the centripetal force on a 70-kg rider.

10. What is the weight of a 70 kg rider?

11. Using your free body force diagram and your answers for weight and net force (centripetal force), determine the angle relative to the vertical that the rider should swing.

12. Using the measured angle and your free body force diagram, determine the net force (centripetal force) on the rider. How does this answer compare to your answer above?

TROIKA

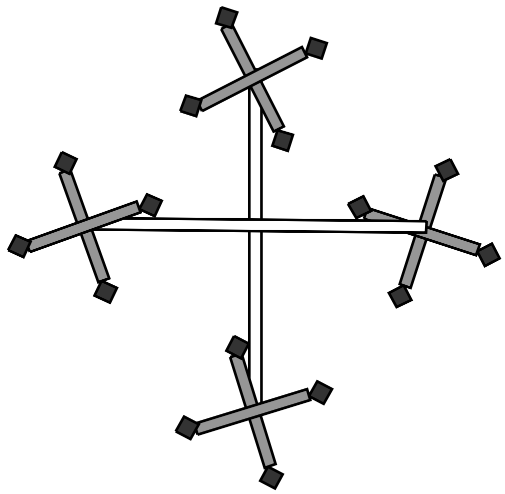
TROIKA

Name(s)___________________________ Name(s)___________________________

Part 1

Write complete answers to each of the following questions on your own paper.

This ride is made up of clusters of seats at the end of arms.



1. As viewed from *above*, is the motion *clockwise* or *counterclockwise* of:
   The arms _____________________ Each cluster _____________________

   Concentrate your attention on one rider, and follow this single rider's motion for at least one full rotation of a rider around the primary axis at the center of the ride. Be sure to choose your frame of reference to be viewing the ride from above the ride.

2. Draw the path of the rider for one full turn of the primary axis.

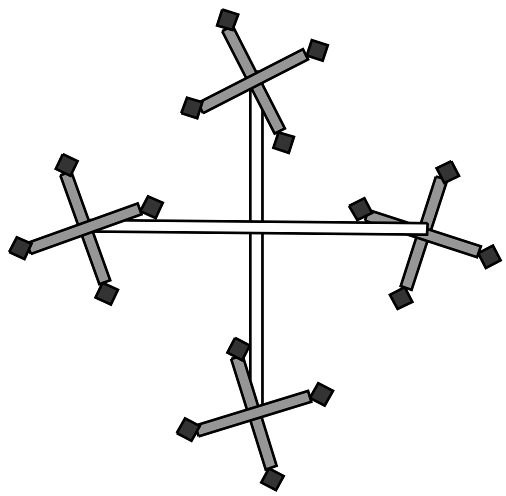
3. Label the following on your drawing:
   a. Points of greatest (GS) and lowest (LS) speed.
   b. Points of greatest (GA) and lowest (LA) acceleration magnitude.
   c. Points of greatest (GF) and lowest (LF) net force magnitude.

4. How many rotations does the rider make about each axis?

TROIKA

Name(s)__________________________ Name(s)__________________________

Part 2
Write complete answers to each of the following questions on your own paper.
Equipment: stopwatch, calculator



1. Estimate the length of the primary arm, out from the primary axis.

   Estimated length _______________ m
   Describe how you estimated this distance.

2. Multiply the radius of the primary (arm) axis by two to get the diameter. Multiply the diameter by pi (π = 3.14) to get the circumference of the primary (arm) axis.

   Circumference at primary (arm) axis = ________ m

3. Estimate the length of the secondary arm, out from the cluster axis.

   Estimated length _______________ m
   Describe how you estimated this distance.

4. Multiply the radius of the secondary (cluster) axis by two to get the diameter. Multiply the diameter by pi (π = 3.14) to get the circumference of the secondary (cluster) axis.

   Circumference at secondary (cluster) axis = ________ m

5. Using repeated measurements, determine the time for a primary arm around the primary axis to make *several* continuous revolutions.
   Number of revolutions =__________

   Time for all revolutions = ______________ s _______ s _______ s
   Average time for one revolution = period = ___________ s
   Average number of revolutions/second = frequency = __________rev/s

6. Using repeated measurements, determine the time for only the secondary arm about the cluster axis to make *several* continuous revolutions.
   Number of revolutions =__________
   Time for all revolutions = ______________ s _______ s _______ s
   Average time for one revolution = period = ___________ s
   Average number of revolutions/second = frequency = __________rev/s

7. Calculate the average linear speed of objects at the end of the primary arm using the following:

   Average linear speed of primary arm (m/s) =
   circumference of primary arm (m) / average time for one revolution (s)

8. Calculate the centripetal acceleration of objects at the end of the primary (arm) axis

   Centripetal acceleration of primary arm (m/s^2) =

   average speed (m/s) * average speed (m/s) / radius primary (arm) axis (m)

9. Calculate the average linear speed of objects at the end of the secondary axis using the following:

   Average linear speed of secondary cluster (m/s) =
   circumference of secondary cluster (m) / average time for one revolution (s)

10. Calculate the centripetal acceleration of objects at the end of only the secondary (cluster) axis

   Centripetal acceleration of secondary cluster (m/s^2) =

   average speed (m/s) * average speed (m/s) / radius of secondary (cluster) axis (m)

11. What values would you predict for the maximum and minimum linear speeds for passengers on the ride

Maximum linear speed = ___________ m/s

Minimum linear speed = ___________ m/s

TROIKA

Name(s)__________________________ Name(s)__________________________

Part 3
Equipment: calculator, accelerometer

Show all your work, any assumptions you made, the reasoning you used, and any measured or estimated values. Write complete answers to each of the following questions on your own paper. Some data may be used from Parts 1 and 2.

1. Measure and record the maximum and minimum horizontal accelerometer readings as directed along a radius of the cluster.
   - Maximum reading of accelerometer __________ m/s^2
   - Minimum reading of accelerometer___________ m/s^2

2. Is this acceleration inward or outward?

3. Where does the maximum and minimum acceleration occur?

4. Compare the calculated acceleration with the acceleration you measured with an accelerometer.

5. Using the accelerometer values, what values would you predict for the maximum and minimum linear speeds for passengers on the ride?
   Maximum linear speed = ___________ m/s
   Minimum linear speed = ___________ m/s

5. How do these values compare to the actual measured maximum and minimum values?

Physiology of Amusement Park Rides

For each of the rides listed below, measure your pulse rate and breathing rate before and after the ride. Indicate any symptoms that you had by placing the numbers of those appropriate from the list below.

Symptoms:		
1. Dry Mouth	5. Cold hands/feet	9. Upset stomach
2. Dizziness	6. Enlarges eye pupils	10. Fast breathing
3. Tense muscles	7. Trembling	11. Stomach Butterflies
4. Unable to move	8. Sweaty hands	12. Other

	Pulse Rate		**Breathing Rate**		**Symptoms**	
Ride	***Before***	***After***	***Before***	***After***	***Before***	***After***
Troika						
Boomerang						
Tea Cups						
Sidewinder						
Sea Dragon						
Rainbow						
Big Wheel						
Mind Eraser						
Tower of Doom						
Twister II						
Shipwreck Falls						
Spider						
Tilt-A-Whirl						

Questions:

1. Amusement park rides are designed to give the illusion of danger and speed. Which rides, based on the symptoms that you had, seem to give the greatest illusion?
2. Based on your observations, how could an amusement park design a ride to give greater illusion of speed and danger?
3. On a separate sheet, describe a ride that you would design.

Resources

Internet

http://newton.dep.anl.gov/app/nau_links.htm
http://www.joyrides.com/links.htm http://www.coasterclub.org/
http://curie.uncg.edu/~mturner/title.html http://www.learner.org/exhibits/parkphysics/
http://www.esc2.net/TIELevel2/projects/roller/default.htm
http://www.cinternet.net/~bowersda/history.htm
http://www.nsta.org/programs/laptop/lessons/h5.htm
http://www.learner.org/exhibits/parkphysics/
Annenberg site with simulations and opportunities to design rides. Background information provided.
http://curie.uncg.edu/~mturner/title.html
Descriptions of experiments and activities on rides and playground equipment.
http://www.funderstanding.com/k12/coaster/
Design a roller coaster
http://www.vast.org/vip/book/home.htm
Complete book on roller coaster design
http://solomon.physics.sc.edu/~tedeschi/midway/bigtop.html
South Carolina book on-line
http://www.physics.emich.edu/amusement/
Eastern Michigan University lessons.
http://library.thinkquest.org/2745/
http://library.thinkquest.org/C005075F/
Amusement Theme Park Physics
http://gbhsweb.glenbrook225.org/gbs/science/phys/projects/yep/coasters/rcstupa.html
Physics of Roller Coaster Project:
http://themeparks.miningco.com/travel/themeparks/cs/physicsofrides/index.htm
The Physics of Rides
http://themeparks.miningco.com/travel/themeparks/cs/ridesafety/index.htm
Ride Safety

Books

Amusement Park Physics: A Teacher's Guide
Nathan A. Unterman / Paperback / Published 1990 J Weston Walch; ISBN: 0825116813
http://www.vernier.com/cmat/amusementparkphysics.html

Amusement Park Physics
Carole Escobar (Editor) / Paperback / Published 1994 American Assn of Physics Teachers; ISBN: 0917853539

Actual Data about the Rides

Do not share this information with students

Carousel

Period of Revolution	19.5 s
Radius	27 ft.

The Mind Eraser

Total time of ride	1 min 45 sec
Height of first hill	125 ft.
Mass of train	7500 kg
Track length	740 m
Track gauge	1217 mm
Lift motor	129 kW DC
Length of train	15 m
Power usage	300 kVA
number of trains	2
coaches per train	10
passengers	2/coach
passenger mass	150 kg per coach

Big Wheel

Period of revolution	24 s
Diameter	80 ft.
number of gondolas	20
passengers	6 adults or 8 children per gondola
passenger mass	583 kg/gondola
Drive motors	8 x 7.5 hp = 60 hp
total power	130 kW
drive motors power	70 kW
lights power	60 kW
Line voltage	220 V, 3 phase, 60 Hz
Lighting voltage	110 V

Boomerang

Track length	662 m

Track gauge	1219 mm
Train length	18.5 m
number of trains	1
coaches per train	4
passengers	4 per coach
passenger mass	300 kg per coach
Power Usage	190 kVA

Bat Wing

Capacity	16
number of vehicles	
passenger mass	154 kg/vehicle
average ride speed	8.6 rpm
ride duration	3 min 55 s
Max diameter at full rpm	27.43 m
Drive motors power	5 x 700 V, 3 phase, 60 Hz
hydraulic motors power	750kVA
total power	160 kVA

Sea Dragon

Length of support arm	40 ft.
Length of ship	35 ft. 6 in
Max speed	35.7 ft./s
motor power	75 kW
lights power	25 kW

Sidewinder

Diameter of loop	30 ft.
Heights at top of loop	60 ft.
height of station	50 ft.
Acceleration at start	0-35 mph in 3 s

Tower of Doom

Time up	8 s
Time down	4 s
Height	260 ft.

Power	480 kW

Concessions (number/year)

Hot Dogs	232,640
Hamburgers	303,000
Ketchup	2,862 gallons
Mustard	891 gallons
Funnel Cakes	96,912