Inquiry Labs for Physics at Six Flags Over Texas

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Catapulted Roller Coasters

(A catapulted coaster is one that uses means other than a lift hill to give the coaster train its initial energy.)

Featured Ride: Mr. Freeze (uses linear induction motors to give coaster initial energy)

Materials Needed: Stopwatch, horizontal and vertical accelerometers, calculator

Hints:
1) Count the number of cars in one train and estimate or pace off the length of one car. Measure the time it takes for the entire train to clear the queue house (from the end of the Batman ride line). Divide the total train length by the measured time to estimate the initial velocity of the train. ($v=d/t$)
2) Using both horizontal and vertical accelerometers, measure forward, side-to-side, and up-and-down accelerations at various points during the ride. Try to relate the readings to physical features in the ride, including the locations of the linear induction motors.
3) From the exit line for the ride, look down the acceleration tunnel to time the acceleration of the train from rest. This is the only location from which this measurement can be made.
4) Kinetic energy is calculated by using the formula $KE=\_\ mv^2$. When energy is conserved, potential energy equals kinetic energy and $\_\ mv^2=mgh$.
5) Centripetal acceleration causes objects to move in a circle, rather than in a straight line. ($a_c=v^2/r$)

Questions to Be Answered:
Intermediate:
1) How many times do linear induction motors apply an acceleration to the train? In what direction(s)?
2) How fast do the cars leave the queue house?
3) What is the initial acceleration of the train?
4) Which is larger, starting or stopping acceleration? Why might one be larger than the other?
5) Is the vertical acceleration experienced during the ride ever that of free fall?
Advanced:
6) Do the cars leaving the queue house have enough kinetic energy to reach the highest point in the ride?
7) Where should a rider feel the largest centripetal acceleration?
8) Is the ride in the reverse direction a reflection of the ride in the forward direction?

Investigative Steps: Describe your procedure here.

Data and Observations: Record and organize your results here.

Calculations and Conclusions: Explain your answers to the questions here.

Going Further: Are any motors accelerating the train at locations other than the beginning of the ride? What would necessitate those additional motors? Design and conduct an experiment to measure this effect.

Circular Rides

Featured Rides: Missile Chaser, Carousel, El Sombrero, Texas Tornado

Materials Needed: Stopwatch, horizontal and vertical accelerometers, calculator

Hints:
1) Using both horizontal and vertical accelerometers, measure forward, side-to-side, and up-and-down accelerations at various points during the ride. Try to relate the readings to motions and physical features of the ride.
2) Centripetal acceleration causes objects to move in a circle, rather than in a straight line. Centripetal acceleration is always directed toward the center of an object's circular path.
3)

Questions to Be Answered:
Intermediate:
1) How does speed affect centripetal acceleration?
2) Where should a rider experience maximum velocity on the ride?
3) How close are the centripetal accelerations of the ride to the acceleration of an object in free fall?
Advanced:
4) Once the ride reaches maximum motion, what is the car's angular velocity? centripetal acceleration? angular acceleration?
5) Sketch the path followed by a rider during the ride, from start to finish.
6) What is the relationship between linear velocity, angular velocity and centripetal acceleration?

Investigative Steps: Describe your procedure here.

<u>Data and Observations:</u> Record and organize your results here.

<u>Calculations and Conclusions:</u> Explain your answers to the questions here.

<u>Going Further:</u> What can be done (without breaking the ride rules, of course) to vary the centripetal acceleration that a rider experiences during the ride? Design and conduct an experiment to test this hypothesis.

Drop Rides

Featured Rides: Texas Chute-Out, Wildcatter, Splash Down, Superman Tower of Power

Materials Needed: Stopwatch, horizontal and vertical accelerometers, calculator

Hints:
1) Apparent weightlessness is a characteristic of systems in free fall.
2) $F_w=mg$ $d_y=v_it + \_\ gt^2$

Questions to Be Answered:
Intermediate:
1) How long is the free fall time on the ride?
2) How can it be demonstrated that riders are really in free fall during the ride?
Advanced:
3) Compare the deceleration of the ride at its end to the acceleration of the ride at its beginning.
4) Compare the deceleration of the ride at its end to ***g*** (acceleration due to gravity on Earth).

Investigative Steps: Describe your procedure here.

Data and Observations: Record and organize your results here.

Calculations and Conclusions: Explain your answers to the questions here.

Going Further:

1) Compare the fall on either the Wildcatter or the Chute-Out to the fall on the Splash Down or the downward portion of the Superman Tower of Power. Should they be the same? Are they? Design and conduct an experiment to measure any hypothesized differences between the rides.
2) Six Flags reports that the upward acceleration on the Superman Tower of Power is 3.5 g's and that the downward acceleration is –0.8 g's. Design and conduct an experiment to validate or disprove their claim.

Momentum/Impulse Rides

Featured Ride: Bumper Cars

Materials Needed: Stopwatch, horizontal accelerometer and calculator

Hints:
1) Momentum is the product of an object's mass multiplied by its velocity (p=mv).
2) Momentum is always conserved in any physical process ($p_{in}=p_{out}$).
3) In an elastic collision, both momentum and kinetic energy are conserved. In an inelastic collision, momentum is conserved but kinetic energy is not.
4) Impulse is defined as the change in momentum of an object. It is the result of the application of a force for a certain amount of time. The formula to calculate impulse is $\Delta p=m\Delta v=F\Delta t$.
5) The bumper cars operate on 90 V DC and each uses a 1-hp motor.
6) —

Questions to Be Answered:
Intermediate:
1) What should happen when a moving car hits a stationary car?
2) What should happen when a moving car hits another car moving in the same direction?
3) What should happen when a moving car hits another car moving in the opposite direction?
4) What is the maximum momentum of one car?
Advanced:
5) How much current does a single car use?
6) If each car acts as a resistance in parallel, how much total current is drawn during the ride?
7) What factors affect the outcome of a collision between two bumper cars?
8) Are collisions between two cars completely elastic, completely inelastic, or a combination of these?
9) Does the direction of the car's initial velocity affect the elasticity of the collision?

Investigative Steps: Describe your procedure here.

Data and Observations: Record and organize your results here.

Calculations and Conclusions: Explain your answers to the questions here.

Going Further: Collisions involving more than two objects should exhibit the same momentum behavior as collisions involving only two objects. Design and conduct an experiment to measure this behavior in a multi-object collision and compare the results to those of two-object collisions.

Gravity-Driven Roller Coasters

(These rides use a lift hill right at the beginning of the ride to give the coaster its initial energy.)

<u>Featured Rides:</u> Titan, Judge Roy Scream, Runaway Mine Train, La Vibora, Texas Giant, Log Ride, Runaway Mountain*

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**CBLs must be used to collect data on any ride that takes place entirely in the dark, since it is not possible to read mechanical instruments during the ride.*

<u>Materials Needed:</u> Protractor, stopwatch, horizontal and vertical accelerometers, calculator

<u>Hints:</u>
1) Refer to the data tables in Appendix B for the height of each coaster's lift hill.
2) According to the Law of Conservation of Energy, the potential energy of the train at the top of the lift hill should be equal to the kinetic energy of the train as it reaches the bottom of the first downhill track section.
3)

<u>Questions to Be Answered:</u>
<u>Intermediate:</u>
1) What is the potential energy of the train at the top of the first hill (the lift hill)?
2) What is the kinetic energy of the train at the bottom of the first downhill?
<u>Advanced:</u>
3) Compare the theoretical (calculated) velocity for the train with its measured velocity at the bottom of the first downhill.
4) Calculate the acceleration of the car as it goes down the lift hill.

<u>Investigative Steps:</u> Describe your procedure here.

Data and Observations: Record and organize your results here.

Calculations and Conclusions: Explain your answers to the questions here.

Going Further: The efficiency of a mechanical system is the ratio of its output energy to its input energy. What could cause one roller coaster to be more efficient than another? Design and conduct an experiment that compares the efficiencies of two different roller coasters between the top and bottom of their respective lift hills, and explain any observed difference.

Looping Roller Coasters

Featured Rides: Shockwave, Flashback, Batman the Ride

Materials Needed: Protractor, stopwatch, horizontal and vertical accelerometers, calculator

Hints:
1) Refer to the data tables in Appendix B for the height of each coaster's lift hill.
2) According to the Law of Conservation of Energy, the potential energy of the train at the top of the lift hill should be equal to the kinetic energy of the train as it reaches the bottom of the first downhill track section.

3)

For a loop:

Questions to Be Answered:
Intermediate:
1) What is the potential energy of the train at the top of the lift hill?
2) What is the kinetic energy of the train at the bottom of the first downhill?
3) What is the potential energy of the train at the top of the loop? (Use the first loop on Shockwave.)
4) What is the kinetic energy of the train at the bottom of the loop, as it is leaving the loop?
Advanced:
1) What is the acceleration of the train at the bottom of the loop, as it enters the loop? How many g's?
2) What is the acceleration of the train at the top of the loop? How many g's?

Investigative Steps: Describe your procedure here.

Data and Observations: Record and organize your results here.

Calculations and Conclusions: Explain your answers to the questions here.

Going Further:
1) Compare the forces recorded on the accelerometer with those calculated. Calculate the percent difference between the measured and calculated values.
2) Six Flags reports that the maximum G-force experienced by a rider on the Shockwave is 5.9 g's. Design and conduct an experiment to validate or disprove their claim.

Pendulum Rides

Featured Rides: Conquistador, Dive Bomber Alley *(NOTE: It is not necessary to ride the Dive Bomber in order to complete this experiment. All measurements can be made from a ground observation point. The cost of riding the Dive Bomber is not included in park admission cost.)*

Materials Needed: Protractor, stopwatch, calculator, horizontal and vertical accelerometers (needed only if ride is actually ridden by experimenter)

Hints:
1) The period (T) of a pendulum is the amount of time it takes to make one complete vibration (back and forth). It can be calculated using the formula: $\sqrt{-}$, where L is the length of the pendulum.
2) Use a protractor to measure the angle between the highest swing of the pendulum and horizontal (through pivot point of the pendulum). The maximum height to which the pendulum rises can then be calculated using the formula:

3) —

Questions to Be Answered:
Intermediate:
1) What is the estimated length of the pendulum? (Verify the actual length with the ride operator, if possible, before making calculations using pendulum length as a factor.)
2) Does the ride reach its theoretical (calculated) maximum height? If it does not, or if it exceeds the maximum (which can happen), what produces this difference?
Advanced:
3) How is this type of ride similar to a roller coaster? How is it different? Be specific and give at least 3 similarities and 3 differences between these rides.
4) What is the maximum velocity attained by the pendulum? How does this measurement compare with the theoretical maximum velocity based upon conservation of energy?

Investigative Steps: Describe your procedure here.

<u>Data and Observations:</u> Record and organize your results here.

<u>Calculations and Conclusions:</u> Explain your answers to the questions here.

<u>Going Further:</u> Does the total mass of the riders affect the behavior of the ride? Should it? Design and conduct an experiment to test this hypothesis.

Appendix A
Teacher Notes

General:
1) Students should be familiar with the equipment being used at the park. It is suggested that students use the same equipment for in-class lab activities prior to the field trip.
2) Mechanical accelerometers can be constructed from readily available materials (see **Appendix D**) or from prepackaged kits available from many science suppliers. Refer to **Appendix B** for more information about using calculator-based laboratory (CBL) equipment in these labs.
3) Students should also be familiar with the scientific inquiry process. It is suggested that students use this process for in-class lab activities prior to the field trip.
4) The data table in **Appendix C** is customized for Six Flags Over Texas. It is important to include as many statistics as possible for rides to be addressed in each lab. The Roller Coaster Database (www.rcdb.com) has extensive data available for teacher and student use.
5) The construction of a ride or its location relative to other rides may result in limitations to necessary observations. Where possible, those limitations have been incorporated into the "Hints" section of the affected lab.
6) Prelab activities should include a review of the concepts and formulas in the "Hints" section of each lab and a discussion of teacher expectations regarding student performance and behavior. The scoring rubric (a sample appears in **Appendix E**) should also be shared with students during prelab, so that they understand the teacher's grading guidelines.
7) Encourage students to extensively document both their experimental procedure and their observations. Procedures should be detailed enough so that another student can reproduce the experiment accurately. Drawings and sketches are acceptable ways to report observations and should be used as needed.
8) See **Appendix F** for a lab suitable for use with second year or Advanced Placement Physics students.

Catapulted Roller Coasters:
A catapulted coaster is given its initial kinetic energy by means other than a lift hill at the beginning of the ride.
(Note: If the ride starts with a motor-driven chain pulling a train of cars to the top of a very tall hill, it is a gravity-driven coaster and should be addressed in that lab.)

Circular Rides:
"Hints" and "Questions" that deal with angular quantities can be omitted if those topics are not usually covered in the student's physics curriculum.

Drop Rides:
These rides consist mainly of a vertical or nearly vertical drop that is partially a free-fall drop.

Momentum/Impulse Rides:
The operating voltage and motor power for each bumper car are listed in the "Hints" section of the lab.

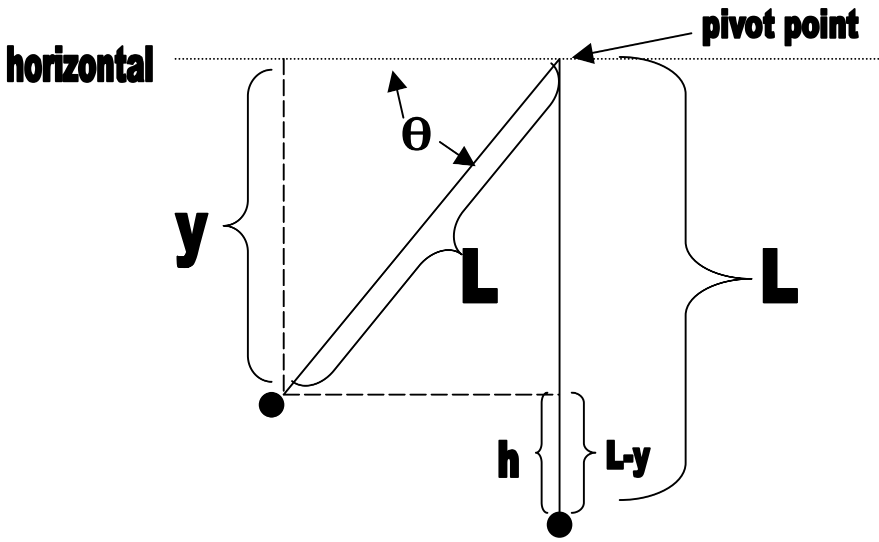
Gravity-Driven Roller Coasters:
See note for Catapulted Coasters lab above.

Looping Roller Coasters:
These are generally gravity-driven coasters that have vertical or nearly vertical loops in their tracks. It is important that students be able to orient their measured accelerations relative to Earth's gravity, especially at the top of each loop. This is illustrated in the "Hints" in the equations for the force on an object at the bottom or top of a loop.

Pendulum Rides:
The equation used in "Hint 2" is derived from: (see diagram below)

— so

and since it follows that
then factor out to get the form



Appendix B

Accelerations in the Real World

(adapted from *Physics with CBLs*, Vernier Software and Technology)

The portability of the CBL makes it an ideal tool for studying accelerations which occur in the "real world." Some interesting situations are the automobile and amusement park rides, as well as high-speed elevators, motorcycles, and go-carts.

The Accelerometer measures the acceleration in a specific direction. You will need to choose an appropriate time scale and direction to hold the Accelerometer to obtain meaningful information. Obtaining acceleration data from independent kinematics measurements can transform an informal study into a scientific inquiry.

A general procedure is given which must be modified slightly depending upon which study is performed. After the general procedure you will find several suggestions for acceleration investigations. You will need to plan an experiment around the motion to be studied, adjusting data collection parameters as needed.

OBJECTIVES

- Measure acceleration in a real-world setting.
- Compare the acceleration measured to the value calculated from other data.

MATERIALS

TI-82, 83, 83 Plus, 86, 89, 92, or 92 Plus
CBL System
Vernier adapter cable
PHYSICS program loaded in calculator
Low-g Accelerometer

GENERAL PROCEDURE

The following steps will guide you through configuring the CBL to collect acceleration data. You will probably need to modify either the time between samples or the number of points collected for your particular circumstances. Adjust these values as you design your experiment.

1. Connect the Vernier Low-g Accelerometer using the adapter cable to CH1 on the CBL unit. Use the black link cable to connect the CBL unit to the calculator. Firmly press in the cable ends.

2. Turn on the CBL unit and the calculator. Start the PHYSICS program and proceed to the MAIN MENU.

3. Set up the calculator and CBL for the Accelerometer.
   - Select SET UP PROBES from the MAIN MENU.
   - Select ONE as the number of probes.
   - Select ACCELEROMETER from the SELECT PROBE menu.
   - Confirm that the Accelerometer is connected to CH 1 and press ENTER.
   - Select USE STORED from the CALIBRATION menu.
   - Select LOW-G from the ACCELEROMETER menu.

4. Zero the Accelerometer in the orientation you plan to collect data. For example, if the Accelerometer is to be oriented horizontally during data collection, place the sensor on a horizontal surface with the arrow horizontal. Or, if you will be collecting data with the sensor oriented vertically, then place the sensor against a vertical surface with the arrow vertical.
   - Select ZERO PROBES from the MAIN MENU.

- Select CHANNEL 1 from the SELECT CHANNEL menu.
- Orient your Accelerometer as appropriate for your experiment, and wait for the reading on the CBL screen to stabilize.
- Press TRIGGER on the CBL unit.

5. Set up the calculator and CBL for data collection.
   - Select COLLECT DATA from the MAIN MENU.
   - Select TIME GRAPH from the DATA COLLECTION menu.
   - Enter “0.5” as the time between samples in seconds. You may want to change this value according to your experimental conditions. For example, estimate the desired time interval for data collection, and divide by the number of points you will collect. The result is the time between samples. (The TI-86, 89, and 92 Plus will allow you to collect up to 512 points. The TI-83 and 92 will allow up to 200 points. The TI-82 can collect at most 99 points. For all calculators the maximum number of points will be reduced if other programs or variables occupy memory.)
   - Enter “99” as the number of samples. For calculators other than the TI-82, you may choose to increase this value.
   - Press ENTER, then select USE TIME SETUP to continue. If you want to change the sample time or sample number, select MODIFY SETUP instead.

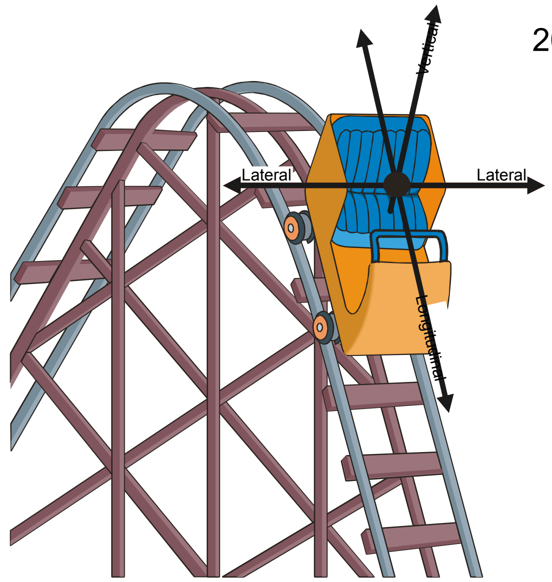
6. Orient the Accelerometer as appropriate for your experiment, and collect data when you are ready by pressing the ENTER key on the calculator. When data collection is finished, the calculator will show your graph.

7. View your acceleration graph and analyze data as needed.
   - Trace along the graph with the cursor keys to read out particular values.

AMUSEMENT PARKS

Many amusement parks feature a Physics Day where students take instruments on the rides and perform calculations. Using the CBL, the data collection can be extended so that the ride characteristics can be studied in more detail than is possible with traditional methods. Several categories of study are suggested below.

For any ride it is essential that you plan your data collection carefully. It is best to concentrate on a single portion of a ride, such as a particular loop or corner of a roller coaster. Decide which part of the ride you want to study, and estimate the length of time you will need to collect data. You may want to measure the time interval while watching others on the ride. The time between samples can then be calculated by dividing the desired time interval by the number of points you want to collect. Collect as many points as your calculator will handle without error.



Along with planning the data collection parameters, you must plan the orientation of the Accelerometer during the ride. Which axis of the acceleration do you want to record? Hold or fasten the Accelerometer so the arrow is parallel to this axis. The direction of the arrow will correspond to positive acceleration.

When describing the directions of accelerations on an amusement park ride, it is convenient to have a common vocabulary. The diagram defines the terms vertical, lateral and longitudinal. These designations are from the frame of reference of the rider.

Dips: Most roller coasters feature a dip following the first major climb, as well as several others during the course of the ride. If you know the speed of the train at the top of the hill and the vertical distance to the bottom, the speed of the train at the bottom can be calculated using conservation of energy. Knowing the radius of the curve at the bottom, the acceleration due to circular motion can be calculated using kinematics.

Using the CBL, the acceleration during such a dip can be measured as the train descends into the dip, and the maximum acceleration can be determined by tracing along the graph.

To record a single dip, first zero the Accelerometer with the arrow upward. On the ride, hold the Accelerometer vertically with the arrow upward relative to the rider. Set the data collection time to 15 seconds. Press ENTER just before the car starts over the edge of the first drop. Compare the readings obtained at the front of the train as compared to those at the center or at the back of the train. Explain any differences.

Vertical Loops: Many modern roller coasters feature vertical loops. To record acceleration data during loops, first zero the Accelerometer with the arrow upward. On the ride, hold the Accelerometer with the arrow upward relative to the rider. Set the data collection time to approximately 15 seconds and press ENTER just before the car enters the loop.

> How does the acceleration at the bottom of the loop compare to the value at the top of the loop? How does the value at the top compare to the acceleration due to gravity? What does the reading you get at the top mean? Is the loop circular in shape? If not, why not?

Corners: Most roller coasters have the cars riding on rails, and so the corners are nearly horizontal. If the axis of the Accelerometer is held level and perpendicular to the direction of the motion, the *lateral* acceleration will be recorded. Zero the Accelerometer while the axis is horizontal.

Set the time for 15–30 seconds, as determined by your study of the ride in advance. Press ENTER just before the train enters the horizontal curve.

> By measuring the speed of the ride, and estimating the radius of curvature, an independent value for the centripetal acceleration can be calculated using kinematics. Compare this value with the measured value. What aspect of the ride could lead to the two accelerations being different?

Starts And Stops: Many rides feature large accelerations. If the direction is forward or back, the reference is to *longitudinal* acceleration, while if it is up or down, it is *vertical*.

Rapid starts and stops are usually short lived. A data collection time period of 10–15 seconds is usually enough to capture the entire acceleration, allowing you to start the CBL just before the ride begins. If you wish to record the stopping of the car, again a short time is needed, possibly as short as 5–10 seconds. Study the ride in advance to choose an appropriate data collection time.

Some parks feature rides that have vertical rises and falls. Recording data on such a ride consists of choosing an appropriate time and holding the axis of the Accelerometer in a vertical direction throughout the ride. Zero the Accelerometer while the arrow is vertical.

> Which is larger, the starting or the stopping acceleration? Why might one be larger than the other? Is the vertical acceleration experienced during the ride ever that of free fall?

Scrambler: Some parks have rides known as scramblers. In the scrambler the rider's seat rotates about a pivot point with a small radius while that point is being carried around in a larger radius by the overall ride. If the axis of the Accelerometer is held so it is directed to the side of the rider, it will record the lateral acceleration throughout the ride. If the Accelerometer is pointed forward or backward relative to the rider, it will record the longitudinal acceleration. For these rides, zero the Accelerometer while the arrow is held horizontally. Some scramblers may even have vertical accelerations.

A time of 60–80 seconds is usually needed to record a complete ride. A decision on which axis to record should be made before getting on the ride.

> How close are the radial accelerations of the scrambler to that of the acceleration of an object in free fall?

Appendix C
Ride Statistics (according to Six Flags Over Texas)

Ride	Max. Ride Height	Angle of 1st Hill	Train Length	Empty Train Weight	Passengers per Train
Batman	33.2 m		12.2 m	89,000 N	32
Texas Giant	43.6 m	53° (drop)	15.8 m	66,750 N	24
Mine Train	10.7 m		14.6 m	40,050 N	30
Runaway Mtn	19.7 m	Almost 90° (drop)			12
Judge Roy	19.7 m	50° (climb)	14.9 m		24
Flashback	38.1 m				28
Shockwave	35.3 m	36° (drop)		66,750 N (loaded)	28
Wildcatter	39.0 m	90° (drop)		6,675 N	4
La Vibora	19.4 m			6,230 N	6
Mr. Freeze	71.9 m		10 m		20
Titan	77.7 m	61° (drop)			10
Chute-Out	56.7 m				
Log Flume	9.2 m		3 m	3,337.5 N	4
Superman Tower of Power	72.2 m	90° (climb and drop)			12 (per tower) (3 towers total)

Note: Complete data were not available for all rides in this table.

Appendix D
Construction of Mechanical Accelerometers

Vertical accelerometers:
1) Start with a clear plastic container that is approximately 30 cm tall and has a lid. Plastic tennis ball cans are good for this purpose.
2) Tie a fishing weight (approximately 15 g or 0.5 oz.) at the end of a rubber band. Through a hole in the lid, secure the rubber band to the lid by tying it to a paper clip on the top side of the lid.
3) Replace the lid on the can and lay it on its side with the rubber band fully extended but not stretched. Mark the can where the bottom of the weight falls as the “0 g” line. Stand the can upright and mark the can where the bottom of the weight now falls as the “1 g” line.
4) For 2, 3 and 4 g, use a bent paper clip to hang additional same-size fishing weights on the attached weight. As each new weight is added, mark can where the bottom of the weight falls with its respective value.
5) Attach a short length of string to one end of the accelerometer. A loop tied in the end of this string will permit a student to use it to tether the accelerometer to their wrist during rides.
6) To use, students should hold the accelerometer in a vertical orientation at the beginning of the ride and maintain that position throughout the ride. It is helpful to brace the device against a handhold or other part of the ride car that remains stationary relative to the rider.
7) Each year, check the calibration of each of these accelerometers and make any necessary adjustments prior to their use in the park.

Horizontal Accelerometers:
1) Start with a rigid plastic protractor or the image of a protractor printed or drawn on corrugated cardboard. It is suggested that the use of cardboard be avoided if the devices are to be used on water rides.
2) Tie approximately 15 cm of lightweight string to a small washer. Attach the other end of the string to the center of the protractor so that the washer hangs down over the protractor’s degree scale.
3) Tape a drinking straw to the flat edge of the protractor to facilitate elevation measurements made with this device.
4) To measure horizontal acceleration, orient the protractor with the flat edge upward and parallel to the ground. Allow the washer to swing freely alongside the protractor. When a measurement is needed, hold the string in place against the protractor to make an accurate reading.
5) To measure elevation, sight along the straw and allow the washer to swing freely alongside the protractor. While looking at the desired location, hold the string in place against the protractor to read the angle of elevation.

Appendix E
Sample Lab Report Scoring Rubric

3 = Very strong; 2 = Moderately strong; 1 = Weak; 0 = Not present

Defining Problem:					
State problem	3	2	1	0	
Background information	3	2	1	0	
Importance of solution to ride design	3	2	1	0	TOTAL________
Designing Experiment:					
What to test	3	2	1	0	
How to test	3	2	1	0	
Possible outcomes (hypotheses)	3	2	1	0	TOTAL________
Materials and Equipment:					
Proposed use	3	2	1	0	
Suitability for intended use	3	2	1	0	
Hazard assessment	3	2	1	0	TOTAL________
Experimental Procedure:					
Controlled variables	3	2	1	0	
Manipulated variables	3	2	1	0	
Multiple trials	3	2	1	0	TOTAL________
Calculations and Conclusions:					
Evaluation of hypotheses	3	2	1	0	
Suggestions for further research	3	2	1	0	

TOTAL SCORE_______

Reviewer Comments:

Appendix F
Second Year/Advanced Placement Physics Laboratory

Adapted from "Invent-a-Lab" at http://homepage.mac.com/cbakken/pga/honors.html

I. Introduction

A. The purpose of this lab is to determine a value for a physics-related quantity as it relates to a specific point on three specific rides, and evaluate the reasonableness of the values to the physical characteristics of the ride.

B. To accomplish this, you will design a method for measuring necessary quantities, collect data, and calculate your assigned values.

C. The procedure and data report format are of your design.

D. Team members should work together in the accomplishment of their individual measurement tasks.

II. Materials (one set per team)

LabPro unit, TI-89 graphing calculator, 3-axis accelerometer, stopwatch

III. Lab Report Format

A. Purpose: State the value to be determined that is assigned to your team and the rides your team will be measuring.

B. Materials: List all materials actually used in the procedure.

C. Procedure: Describe your experimental process in enough detail that your experiment could be accurately repeated by another student (without assistance from you). Estimation may be used for values that are difficult to measure directly, but any estimate must be supported with reasoning as to its accuracy and validity. Whenever possible, measure directly or obtain values from ride operators.

D. Data: Organize and report measurements made. Also report relevant qualitative observations, using drawings or sketches where appropriate.

E. Results: Show all formulas used to calculate values. Organize calculations in a clear and logical fashion.

F. Analysis and Conclusions: Discuss your results. Identify possible sources of error based on their likely effect on your calculations. Relate your calculated values to physical characteristics of each ride, and assess the reasonableness of your results. Make at least one suggestion for further research related to your assigned tasks.

G. Attach raw data sheet(s) to the back of the finished lab report.

IV. Lab Report Scoring

A. Each person is responsible for writing their own lab report.

B. Keep your report concise, but do not sacrifice essential details in the pursuit of brevity.

C. If your results appear to be fabricated, your report will be scored accordingly.

D. Lab reports are due one week after field trip.

V. Gravity-driven Roller Coasters—select one value and three different rides on which to measure that value. Compare values and relate them to each ride's characteristics. Are your values reasonable in comparison to each other?

A. Power output of motor that lifts train to top of first hill.

B. Angle and magnitude of centripetal force on riders at first major turn in ride.

C. Force of friction that stops the train at the end of the ride.

D. Coefficient of friction between track and train for ride during first major descent.