Six Flags OVER TEXAS

Physics Day

TO THE TEACHER:

The activities included in our ***Physics Day Study Guide*** were written to focus on specific and interesting questions about the rides and activities at ***Six Flags Over Texas***. They incorporate mathematics and physics concepts for various levels from IPC to Physics and from Algebra I through Precalculus. We recommend that you look at these activities carefully to choose which ones are appropriate for your students. Students should be given a reasonable set of well-defined lesson goals to accomplish while at the park.

It is suggested that students work in groups of 2 or 4. Students will have a more enjoyable and successful ***Physics Day at Six Flags Over Texas*** if you discuss measurement and data-gathering tools, strategies, and concepts with them before they come to the park. If they will be using non-technological devices while at the park, these should be constructed and used for practice in advance. Instructions are included in this Guide for constructing inexpensive measuring devices, and at the end of the Study Guide is a list of resource websites where you can get additional ideas.

After their hands-on experience at *Six Flags Over Texas*, students' understanding of the following physical and mathematical concepts will be strengthened.

Physics concepts:
- Forces
- Kinematics: Linear and Rotational
- Laws of Conservation of Energy and Momentum
- Measurement of Qualitative and Quantitative Data
- Newton's Laws of Motion
- Work, Power, and Energy

Mathematics concepts:
- Data Collection and Analysis
- Linear, Quadratic, Trigonometric, Rational and Polynomial Functions
- Mathematical Modeling
- Measurement and Estimation
- Triangulation

At the end of many of the sections we have included ideas to extend the study of a particular subject. The books and websites listed toward the end of the Study Guide can serve as good references for expanding the instructions given here.

In preparing this packet, we have used several resources. We would especially like to thank and acknowledge the "Fiesta Texas Physics Workbook" (1997) by Wesley Hausenfluke and Jeff Kurth, Roller Coaster Physics (1998) by Tony Wayne, and "Physics Day Handbook" by Michigan's Adventure, from which instructions and activities were taken and adapted to complete this Guide.

We hope your students enjoy their day of discovery at Six Flags Over Texas!

We welcome any questions, comments, and/ or suggestions for improving these instructions and ensuring a successful learning experience for all students.

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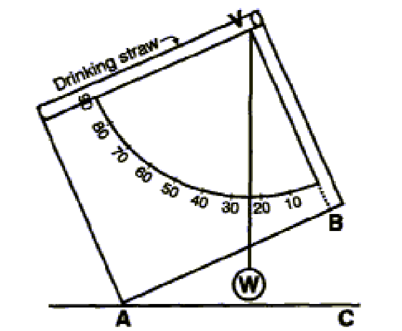
PREPARATION FOR PHYSICS DAY

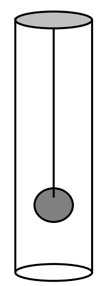
LIST OF EQUIPMENT NEEDED

(at least one item per group of students)

1. **Watch** or other timing device that can measure fractions of a second.
2. **Protractor-sextant -** This device is a protractor with a weight hanging from a string that passes through the vertex. The kit from *Central Scientific Company* includes a horizontal accelerometer with a protractor printed on foam board and a straw mounted on the top so it can also be used to determine angles of elevation. http://tqjunior.thinkquest.org/6169/sextant.htm



3. **Spring accelerometer** - There are several designs available to measure the acceleration of the rider in units of *"g"*. *Central Scientific Company* sells an accelerometer made with a weight hanging on a spring inside a plastic tube. Other accelerometers replace the spring with an elastic band. http://library.thinkquest.org/2745/data/meter.htm



4. **Measuring tape -** A thick string or cord about 2-3 meters in length with a mark every 10cm could be substituted for the tape.
5. **Graphing calculator and data collection device (CBL/ EA-100)** or calculator (with trigonometric functions)
6. **Pencil and paper**
7. **Plastic bag -** a one-gallon Zip Lock bag will keep the workbook, calculator, and all other materials together.
8. **Safety cords** or **fanny pack** must be used to attach or hold measurement instruments to the wrist or waist of the rider.
9. **Study Guide** (workbook)

MAKING MEASUREMENTS

Time

Times required to calculate a problem 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, then divide by the number of repetitions. This will give a better estimate of the period of motion than just measuring one repetition. You may want to measure the time two or three times and then average them. A digital watch will be required for timing certain rides.

Distance

Since you cannot interfere with the normal operation of the rides, you will not directly be able to 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.

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 as shown in **figure a**. The distance **d** can be estimated by counting the number of cross members. This method can be used for both vertical and horizontal distances.

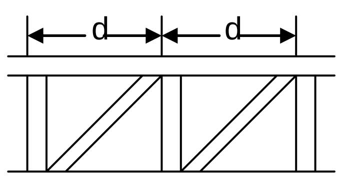


figure a

3. Triangulation

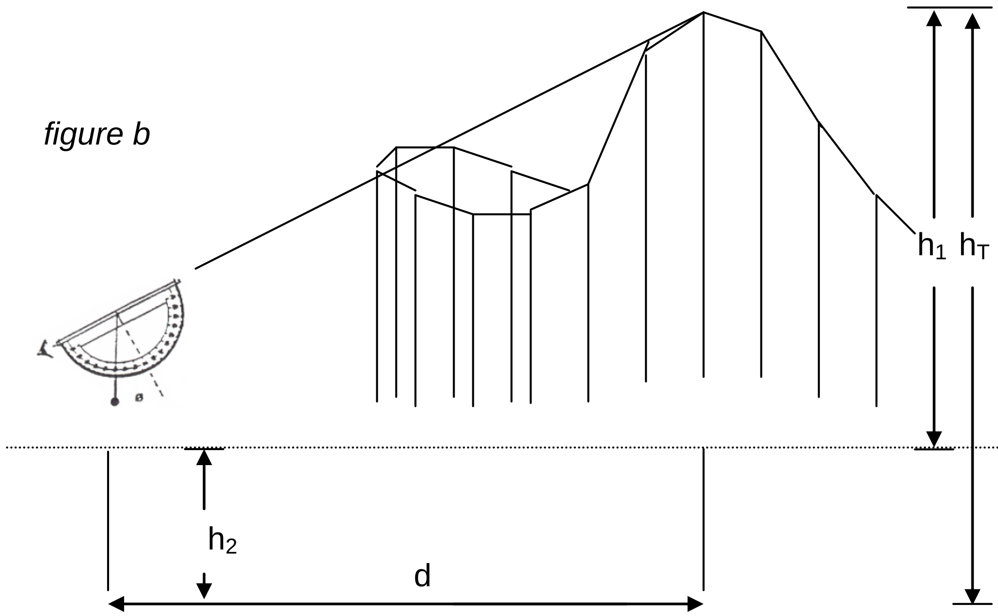
For measuring height by triangulation, a protractor-sextant can be constructed following the directions from the following web site: http://tqjunior.thinkquest.org/6169/sextant.htm or a kit can be purchased from *Central Scientific Company (Amusement Park Physics).*

a. Measure the distance between you and the ride by using a measuring tape or pre-measured string. d: __________m

b. Measure the height from the observer's eye to the ground. $h_{2:}$ __________m

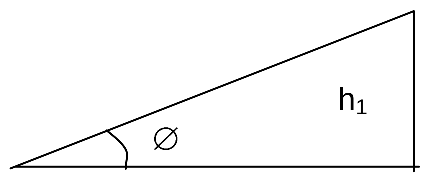
c. Take a sighting at the highest point of the ride. Read off the angle of elevation. ∅ = __________

figure b



$h_1/d = \tan \varnothing$

$h_1 = d(\tan \varnothing)$

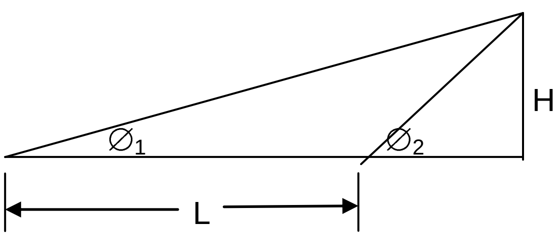


d. Multiply the tangent value by the distance from the ride: h_1 = __________m

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 can't 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 with a length between 10 and 20 meters by pacing the distance or using a tape measure or pre-measured string. The baseline should be laid out radially from the object. L = __________m

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

c. Take a sighting at the highest point of the ride. Read off the angle of elevation and the distance of the baseline. $\varnothing_1$ = _____ $\varnothing_2$ = _____

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

$$h = \left[\frac{\sin \varnothing_1 \text{ X } \sin \varnothing_2}{\sin(\varnothing_2 - \varnothing_1)}\right] L + \text{observer's height}$$

ACCELERATION and ACCELEROMETERS

Accelerometers are designed to record the ***g*** forces felt by a passenger; they are calibrated in ***g***'s. A reading of ***1g*** equals an acceleration of **9.8 m/s²**. On Earth we normally experience ***1g*** 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. **Remember:**

1. When an object traveling in a straight line speeds up, the direction of its acceleration is the same as its direction of motion.
2. When an object traveling in a straight line slows down, the direction of its acceleration is opposite its direction of motion.
3. When an object moves in a circle at a constant speed, the direction of its acceleration is toward the center of the circle.
4. When an object moves in a parabola (like those in a roller coaster ride), the direction of acceleration is along the axis of the parabola.

Listed below are the sensations of various *g* forces. These are rough estimates but may be helpful in estimating accelerations on the various rides.

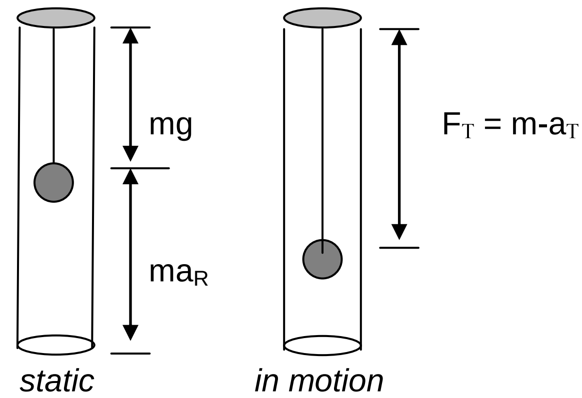
Accelerometer Reading	Sensation
+3.0 g	3 times heavier than normal
+2.0 g	Twice normal weight
+1.0 g	Normal Weight
+0.5 g	½ Normal weight
+0.0 g	Weightlessness (no force between rider and coaster)
- 0.5 g	½ Normal weight, but directed away from the coaster seat

Construction of Spring Accelerometers
http://library.thinkquest.org/2745/data/meter.htm

- **A spring accelerometer:** Hang one weight from the spring and mark the position. This represents *1*g; *g* is the new unit of weight. Suspend 2 weights and mark this the *2g* position. Continue this procedure for up to 5 weights. Since the stretch of the spring should be linear, all the markings will be equally spaced. Because the spring's force is sometimes less than *1*g, also mark the *0g* position. The *0g* position occurs where the spring is not stretched at all. Additional directions for a spring accelerometer can be found at the website listed above, or one can be purchased from *Central Scientific Company (Amusement Park Physics).*
- **A spring scale and fishing weight:** A weight is taped securely to the end of the spring scale. The weight should be about 1/6 of the full scale reading. For example, if you have a *20N* scale (2000 grams), the weight would need to be approximately *3N* (300 grams).

1. Vertical Acceleration

A simple device for measuring vertical accelerations is a 0-5 Newton spring scale with a 100g mass attached. The plastic tube with elastic and fishing weight approximate this equipment. The forces on the mass are drawn where F_T is the reading on the scale. The forces on the masses are shown in the diagram.



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 $a_R = a_T - g$

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).

2. Longitudinal Acceleration

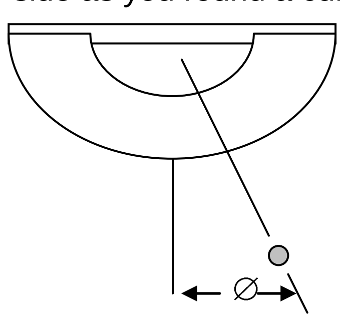
Acceleration of a person on a ride can also be determined by direct calculation. Down an incline, the average acceleration of an object is defined as:

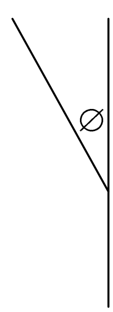
$$a_{ave} = \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{\text{change in speed}}{\text{change in time}}$$

Using methods previously discussed, it is possible to estimate speeds at both the top and bottom of the hill and the time it takes for the coaster to make the trip. Thus, average acceleration can be found during that portion of the ride.

3. 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.





T cos∅ = mg
T sin∅ = ma

solving for a

a = g tan∅

4. Centripetal Acceleration

With uniform circular motion remember that: $v = \frac{2\pi r}{t}$

and the centripetal acceleration is given by: $a_C = \frac{v^2}{r} = \frac{4\pi^2 r}{t^2}$

Or, $F_c = ma_c = mv_c/r = 4P^2r/T^2$

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.

5. 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.

If you know the length of a train, for example, 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:

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

In most situations, we assume that total mechanical energy is conserved. As Potential Energy increases, Kinetic Energy 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. 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 and usually assume that the speed at the top of the hill is 0.

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

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

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

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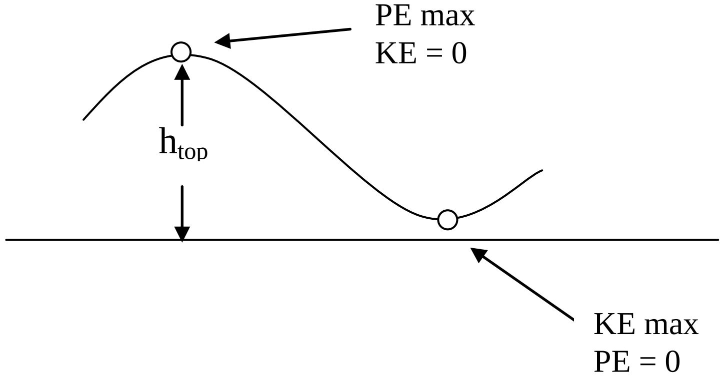


ROLLER COASTERS

The Texas Giant	**Batman, the Ride**	**Mr. Freeze**
Titan	**Shockwave**	
Mine Train	**Flashback**	

Observe one of the coasters <u>in the left-hand column above</u> and answer the following questions:

Coaster chosen: ______________________________

1. Do the trains use motors for the entire trip or only part of it? From where do the trains get the energy to complete the course? Explain your reasoning.

2. Observe the wheel assembly on the trains. Draw a sketch and describe why you think the wheels are made that way.

3. Coasters typically wind around and around to conserve space. Draw a sketch of what the coaster would look like if it were straightened out. Do not take out the loops and curves but draw it as if it were laid out in a straight line. If the coaster is extremely long, just draw the first 5 or 6 hills and drops.

4. Draw a graph of vertical distance from the ground vs. time for this ride.

5. Where is the highest point of the ride? Why do you think so?

6. Label your previous sketch with the following points:
   maximum Potential Energy   minimum Potential Energy
   maximum Kinetic Energy   minimum Kinetic Energy   maximum velocity

7. Have some of your group be brave and ride the coaster (if more than 1 person in your group rides, try to sit in different areas of the ride – front, middle, rear) and then have them describe their feelings at different points of the ride. Label the points on your sketch where they felt the heaviest and where the lightest (weightless). Some coaster enthusiasts say that passengers in the first car, middle car and last car experience the ride differently. What did you think? Use your observations of the ride, your “gut feeling” while riding the ride and your measuring device to support your conclusion.

8. Where was the acceleration the greatest? What caused this large acceleration? (Remember that acceleration is a vector quantity and depends on two things)

9. Compare the second highest point with the highest point. Discuss the height of the hill, velocity of the train, Potential Energy and Kinetic Energy.

Making Measurements:

Before:

10. Determine the length of the train. L_{train} = ______m

11 Determine the height of the first hill. h_{hill} = ______m

12. Estimate the mass of a full train of passengers. m_{train} = _____kg

13. Time required to lift a loaded train up to the top of the first hill. t = ____ sec

14. Time for train to pass a point at the bottom of the first hill. t = ____ sec

During:

15. If you have an instrument (Spring Accelerometer or CBL), measure the acceleration component perpendicular to the track. Record where this reading is greatest during the ride (Do this later). a = _________m/s^2 = ______*g*'s

Calculations:

16. Calculate the Potential Energy of the loaded train at the highest point. Assume that velocity is essentially zero. PE = mgh PE = ______J

17. Calculate the velocity of the train at the bottom of the first drop using Conservation of Energy. (assume PE = 0) PE= mgh, KE = 1/2 mv^2 v = _______ m/s

18. Measure the velocity of the train at the bottom of the first drop by timing the train past a fixed point. v = d/t v = _______ m/s

19. Compare your answers for velocity of the train. Do they agree? Should they? Explain.

20. Measure the velocity of the train at the second highest point by timing the train past a fixed point. Calculate the height of the second highest point using conservation of energy. PE= mgh, KE = 1/2 mv^2 h = ______m

21. Calculate how much work is done to lift the train to the highest point. W = Fd W = _______J

22. Calculate the power of the lift system. P = W/t P = _______ watts

ROLLER COASTERS: Looping Roller Coasters

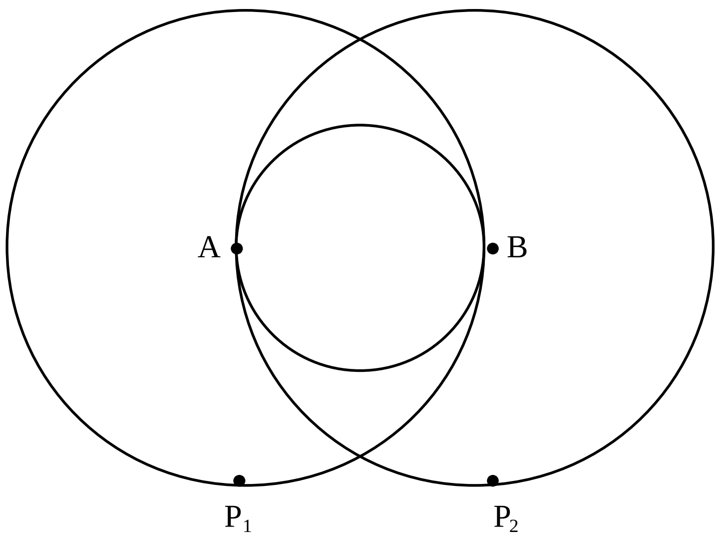
Flashback ▪ Shockwave ▪ Batman, The Ride

Observe one of the <u>looping coasters</u> in the park and answer the following questions.

Coaster chosen: ________________________________

1. Looping coasters have vertical loops. Sketch the shape of these loops and discuss what you notice about the shape.

2. A simple irregular loop can be simulated using the combination of parts of circles of different radii.
   a. Can you see an irregular loop in the following regular circles that is similar to the ones in the looping coaster? Outline it.



   b. Suppose points A and B are centers of the two larger circles and endpoints of a diameter of the smaller circle. What is the height of the loop in terms of the length AB?
   c. Approximately what is the length of the loop from point P1 to point P2 in terms of the length AB?

3. Other irregular loops can be formed similarly by using circles of varying radii. Can you sketch such an irregular loop?

EXTENSION: The irregular loop you've been describing is the Clothoid (Klothoid) or Spiral of Archimedes loop. Research the Clothoid loop and describe how it is formed.

Making Measurements:

Before:

4. Determine the length of the train. L_{train} = ______m

5. Determine the height of the loop. h_{loop} = _____m

During:

6. If you have an instrument (Spring Accelerometer or CBL) measure the radial acceleration just before entering the loop. a_b = ______ g's = ________m/s^2

7. Use your instrument to measure the radial acceleration at the top of the loop.
a_t = ______ g's = ________m/s^2

Calculations:

8. Calculate the speed of the train just before it enters the loop. $v = \Delta d / \Delta t$ v = _______m/s

9. Calculate the speed of the train at the top of the loop. $v = \Delta d / \Delta t$ v = _______m/s

10. Using the acceleration you measured, calculate a radius of curvature for the track where the train enters the loop. $a_b = v_b^2/r$, $r_b = v_b^2/a_b$ r = ______m

11. Using the acceleration you measured, calculate a radius of curvature for the track at the top of the loop. $a_t = v_t^2/r$, $r_t = v_t^2/a_t$ r = ______m

12. Compare the radii that you calculated.

13. Using the radius of curvature that you determined, calculate the minimum velocity required for the train to make it around the top of the loop (without restraining devices).
This is known as critical velocity. $g = v_c^2/r_t$, $v_c = \sqrt{gr_t}$ v_c = _________m/s

14. What would happen if the ride had been made with a circular loop instead of a clothoid loop? Assume a circular loop with a diameter equal to the height of the clothoid loop. The velocities calculated would be the same.

15. Calculate the radial acceleration at the bottom of the circular loop.
$a_b = v_b^2/r_b$ a_b = _________ m/s^2 = ________ g's

16. Calculate the radial acceleration at the top of the circular loop.
$a_t = v_t^2/r_t$ a_t = _________ m/s^2 = ________ g's

17. Calculate the minimum velocity required for the train to make it around the top of the circular loop (critical velocity). $v_c = \sqrt{gr_t}$ v_c = ________m/s^2

18. Compare the clothoid and circular loop data. Why do you think clothoid loops are used instead of circular ones?

ROLLER COASTERS: Mr. Freeze

1. Mr. Freeze is different from the rest of the coasters. As a physics student, without even seeing the start of the ride, you conclude that the train must be catapulted out of the station at great speed. Why?

Making Measurements:

Before:

2. Estimate the length of the launch rail where the train is being accelerated. d = _______m

3. Time how long the train is being accelerated during the launch. t = _______ sec

During:

4. If you have an instrument (horizontal accelerometer or CBL), measure the horizontal acceleration during launch. a = ________m/s^2 = _____ g's

Calculations:

5. Measure the velocity of the train at the end of the launch rail by timing the train past a fixed point. $v = \Delta d/\Delta t$ v = _______ m/s

6. Calculate the acceleration from the change in velocity. $a = \Delta v/\Delta ta$ = ________m/s = _______g's

7. Calculate the amount of force needed to accelerate the loaded train to top velocity. F = ma F = ________N

8. Calculate the theoretical height to which the train could be raised to using conservation of energy. PE= mgh, KE = $1/2\ mv^2$ h = _______m

9. Does the train actually achieve the theoretical height? Explain why or why not.

Mr. Freeze uses Linear Induction Motors (LIM) to launch the train.
The launch system utilizes about 520 volts and 6000 amps during each launch.

10. Calculate the electrical resistance of the launch system. V =I/R R = ________

11. Calculate the power used during each launch. P=VI P= ________ watts

12. How much heat would be generated if the train was stuck and could not move, while the normal launch energy was expended?

EXTENSION: Research LIM's and describe how they operate.

ROLLER COASTERS: With No Instruments

adapted from: <u>Roller Coaster Physics</u> by Tony Wayne

Choose one of the coasters in the park to observe and answer the following questions.

Coaster chosen: ______________________________

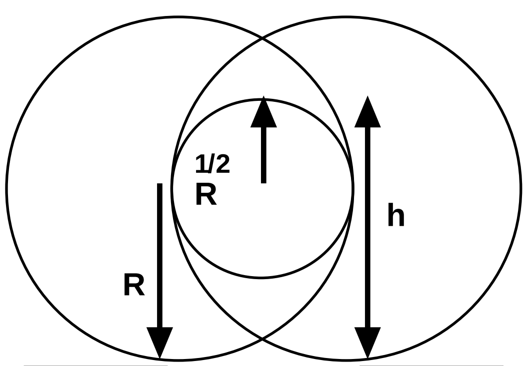
1. Determine the length of the coaster train.
2. What is the published length of the track?
3. Estimate the mass of the loaded train.
4. Determine the vertical height of the first hill.
5. How fast is the train traveling over the top of the first hill?
6. How much time does it take for the middle of the train to be lifted to the top of the first hill?
7. What is the velocity of the train at the bottom of the dip after the first hill?
8. Use conservation of energy and calculate the height of the drop from the first hill.

Choose one of the <u>looping coasters</u> in the park to observe and answer questions 9-13.

Coaster chosen: ______________________________

9. What is the velocity of the train as it enters the bottom of the first loop?
10. What is the velocity of the train as it passes the top of the loop?
11. Calculate the height of the loop.

Suppose the loop was designed using very simple geometry. Below is a loop that is designed from splicing together two large circles with a smaller circle. Outline the loop on the diagram below. The smaller circle's radius is half the radius of the larger circles. Use information calculated above to determine the radii of the two circles.



12. Large circle radius________ Small circle radius _______
13. Use information calculated above to calculate the *g*'s felt by the rider:

    Entering the bottom of the loop _____ At the top of the loop _____

Choose a third coaster in the park to observe and answer the following questions:

Coaster chosen: ______________________________

14. Calculate the velocity of the train as it travels over the 2nd hill.

15. What is the velocity of the train at the bottom of the dip after the 2nd hill?

16. Assuming the initial total mechanical energy of the train is ZERO, how much total mechanical energy is gained by lifting the train to the top of the first hill.

17. The train has to lose its total mechanical energy by the time it reaches the end of the ride. Assuming that 2/3 of the initial energy at the top of the first hill is lost due to friction during the length of the entire ride, what is the average force of friction opposing the train's motion as it travels along the entire length of the track?
(HINT: Use energy and work)

18. Compute the power needed to raise the train to the top of the first hill.

19. If electricity costs $0.40 / (kw•hr), how much does it cost to raise the train to the top of the first hill?

20. Estimate how many runs the train makes in one hour.

21. How much does it cost to run the coaster for a 14-hour day?

PENDULUM RIDES

The Conquistador

The Conquistador is a ship that acts as a ***pendulum***. While riding the Conquistador, you experience free fall at times and a sensation of weightlessness at times.

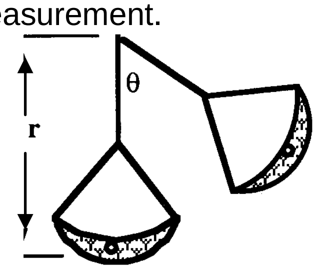
Making Measurements:

1. Observe the “propulsion system” underneath the ship. Describe how it works to power the ride.

2. Measure the time for the boat to make *3 to 5* complete oscillations while the propulsion system is disengaged.

   # of oscillations _________ t = ___________ sec

3. Using triangulation, measure the radius of the boat’s path (from pivot point to center of boat). This measurement corresponds to the length of the pendulum. Explain how you arrived at your measurement.



   r = __________ m

4. Using a protractor, measure the maximum angle that the boat swings from the vertical. θ = __________°

5. While riding the ride, use a spring accelerometer to measure the centripetal acceleration at your highest position (a_t) of the ride and at your lowest position (a_b) of the ride.

   a_t = ___________ g’s = ____________m/s^2

   a_b = ___________ g’s = ____________m/s^2

6. Describe your sensations of weight:
   a. at rest.
   b. moving through the lowest point.
   c. at the highest point.

7. Sketch a graph showing height above ground of the center of the boat vs. time.

8. Sketch a graph showing horizontal displacement of the center of the boat from rest vs. time.

Calculations

9. Calculate the period (T) for the boat. $T_{boat} = t$ / # of oscillations = _________sec/oscillation

10. Using the centripetal acceleration values and measured radius, calculate the velocity of the boat at its highest position (v_t) and at its lowest position (v_b).

$$a = \frac{v^2}{r}$$

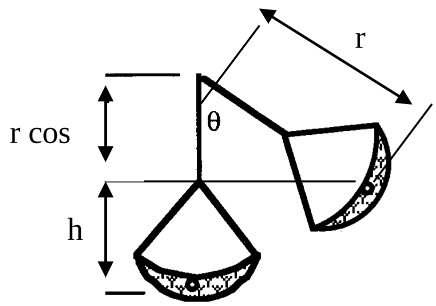
$v_t = \sqrt{a_t r}$ and $v_b = \sqrt{a_b r}$ v_t = ________ and v_b = ________

11. Calculate the period (T) of a simple pendulum with a length (L) equal to the radius (r) you obtained.

$$T = 2\pi\sqrt{\frac{L}{g}}$$

$T_{pendulum}$ = ______________ sec

12. Using the angle θ and radius r, calculate the maximum height (h) that the center of the boat rises.



$h = r – r\cos\theta = r(1 – \cos\theta)$

h_{boat} = ________ m

13. Since the total energy (potential and kinetic) is the same throughout the swing, the energy at the bottom (kinetic) equals the energy at the top (potential). Therefore, the following equations can be used to calculate the maximum velocity of the pendulum as it swings through its lowest position.

$$E_{bottom} = E_{top}$$

v_b = ___________ m/s

$$\frac{1}{2}mv_b^2 = mgh \qquad v_b = \sqrt{2gh}$$

<u>Questions</u>

14. In a simple pendulum, the mass is considered to be concentrated at the end of a weightless string. How does the *Conquistador* differ in its construction?

15. Do you think that the *Conquistador* acts like a simple pendulum? Why or why not? (Compare your calculations for the boat and the simple pendulum.)

<u>Extension</u>:

- Investigate the component of the acceleration tangent to the motion.
- Investigate properties of a <u>physical</u> pendulum.

CIRCULAR RIDES

Making Measurements

1. Measure the diameter of 2 circular rides (examples: the Carousel, Texas Tornado) by stepping off the distance from an area beside the ride. Estimate the maximum number of people who can ride at one time. Record the time it takes for the ride to complete one revolution (it is best to take this time once the ride has reached its maximum speed). Also record the time the ride runs from start to finish. Complete the table.

Ride	Diameter in Meters	Max. People at one time	Time of One Revolution	Total Time for Ride
a.				
b.				

Calculations

2. Angular velocity is a useful way to describe circular motion. The angular velocity (ω), in radians per second, is determined by $\omega=2\pi/t$, where **t** is the time in seconds it takes for the ride to make one revolution. Calculate the angular velocity of each of the circular rides you chose. Record the angular velocities in the following table.

3. Linear velocity can also be calculated for circular motion. The linear velocity (v) in meters per second is determined by $v=\omega r$, where **r** is the radius of the circle in meters. Calculate the linear velocity of each of the rides and record each in the table.

Ride	Angular Velocity	Linear Velocity
a.		
b.		

Questions

4. In which of the rides you considered does the rider travel the greatest distance during one ride? What is the distance covered?

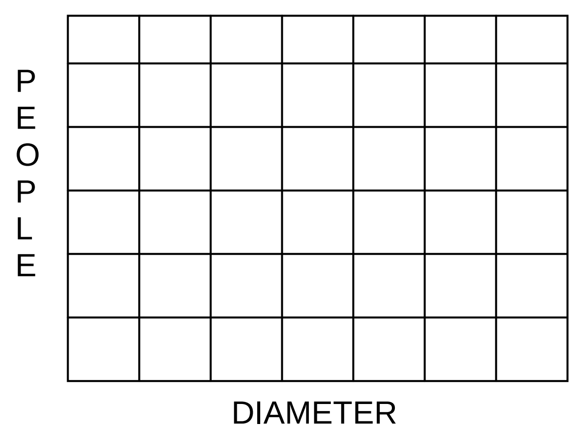
   Ride: ____________________________   Distance: _______________m

5. Which ride has the greatest angular velocity? __________________________

6, Which has the greatest linear velocity? ________________________________

7. Would these have to be the same ride? Explain.

9. Look at the maximum number of people and the diameter of each ride. Make a scatter plot of the number of people vs. diameter on the graph.
   Be sure to show the scales on both axes.
   Does there seem to be any correlation?
   If so, find an equation that models the correlation.



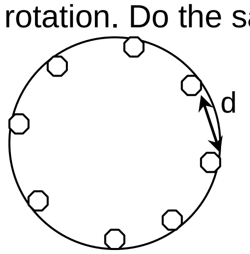
CIRCULAR RIDES: The Carousel

The **Carousel** is a replica of rides that were first designed in the early part of the 1900's. This carousel, with its hand-painted panels, animals, and chariots, sends riders back to the romantic times of carnivals and county fairs.

Making Measurements:

1. Determine the period of rotation by measuring the time for two rotations. $t_{\text{two rotations}}$ = ___________ sec   t = t/2 = ___________ sec

2. As soon as you get on the platform, determine the circumference of the inner ring of animals by measuring the distance between two adjacent animals and then counting the number of animals in one complete rotation. Do the same for the outer ring of animals.



(inner ring of animals) C_i = _________ m

(outer ring of animals) C_o = _________ m

3. Sit on an animal in the inner ring. Once the carousel reaches full speed, measure the centripetal acceleration using your protractor-sextant. Make sure the protractor is level and you are measuring the angle at which the weight is hanging from the vertical. Then measure the centripetal acceleration while riding one of the outer ring animals.

(inner circle of animals) θ_i = ________°

(outer circle of animals) θ_o = ________°

4.While the carousel is spinning at full speed, describe any forces that you "feel" acting on you.

Calculations:

5. Using the measured circumference, calculate the radius for both the inner ring and outer ring of animals.

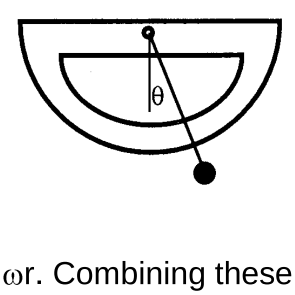
$C = 2\pi r$

(inner ring of animals) r_i = _______ m

(outer ring of animals) r_o = __________ m

6. 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.

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



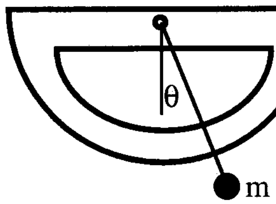
ω= _________ radians/sec

7. 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 $ac = \omega^2 r$. Calculate the centripetal accelerations for the inner and outer ring of animals.

a_c for inner ring = ________ m/s^2 = ________ g's

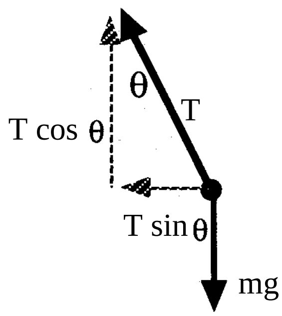
a_c for outer ring = ________ m/s^2 = ________ g's

8. While undergoing uniform circular motion, the forces on the suspended mass can be broken down into vertical and horizontal components. The sum of the vertical components should equal to zero.



$$\Sigma F_y = 0$$
$$mg = T \cos \theta$$

The horizontal component of the string will equal the centripetal force.



$$\Sigma F_x = T \sin \theta = ma_c$$

Since the tangent of the angle is defined as opposite over adjacent, we can then write the equations:

$$\tan \theta = \frac{T \sin \theta}{T \cos \theta} = \frac{ma_c}{mg} = \frac{a_c}{g}$$

$$a_c = g \tan \theta$$

Use this approach to calculate the centripetal acceleration from the angle θ.

a_c for inner ring = ________ m/s2 = ________ g's

a_c for outer ring = ________ m/s2 = ________ g's

Questions

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

10. 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.

11. While on the rotating Carousel, what is the direction of the net force on you?

12. If you dropped a coin while standing on the outer edge of the Carousel while it is spinning, describe the path along which the coin would move.

Extension

- Describe the up and down motion of the animals.
- Investigate amplitude, frequency and harmonic motion.

CIRCULAR RIDES: Gunslinger (Swings)

1. Before the ride starts, predict how an empty swing will behave compared to one with a rider. Draw a sketch.

2. Draw a diagram of the ride:
   a) at rest
   b) rotating but not tilted
   c) rotating and tilted

3. Is there a difference in the radius? Explain.

4. How did your prediction compare to what actually happened with an empty swing?

5, Describe your sensations when the ride is:
   a) rotating but not tilted
   b) rotating and tilted moving downward
   c) rotating and tilted moving upward

Making Measurements:

Before:

6. Measure the period of the swing:
   a) rotating but not tilted
   b) rotating and tilted

7. Measure the angle when the ride is rotating but not tilted.

During:

8. If you have an instrument (horizontal accelerometer or CBL), determine the range of the radial accelerations.

9. If you have an instrument (spring accelerometer or CBL), determine the range of readings. (Hold it vertical to your frame of reference)

Calculations:

10. Calculate the centripetal force acting on you when the ride is rotating but not tilted.

$F_C = mv^2/r$ F = ________N

11. Calculate the tension in the chain when the ride is rotating but not tilted.
12. Draw a vector diagram of the forces acting on you when the ride is rotating but not tilted.
13. Draw vector diagrams of the forces acting on you when the ride is rotating and tilted.
14. Draw diagrams when you are at the top of the swing and when you are at the bottom.

WATER RIDES

Aquaman

Ozarka Splash (Log Flume)

1. During much of the ride the boats are free floating. Describe how you could estimate the flow rate of the water and determine the time to circulate all the water in the ride once.

2. Describe what happens to you at the bottom of the hill when the boat splashes (more than "you get wet!") What causes this?

<u>Calculations:</u>

3. If you have an instrument (horizontal accelerometer or CBL), determine your horizontal acceleration during the splash. a = ________g's = _________m/s^2

4. Calculate the Potential Energy at the top of the hill. PE = mgh PE = _________ J

5. Calculate the velocity at the bottom of the hill <u>before</u> the splash. $v = \Delta d/\Delta t$ v = ________ m/s

6. Calculate the velocity at the bottom of the hill <u>after</u> the splash. $v = \Delta d/\Delta t$ v = __________ m/s

7. Time how long the splash lasts. t = __________ sec

8. Calculate the force it takes to slow the boat during the splash. Use impulse. $Ft = m\Delta v$ F = _______ N

9. Calculate the amount of work on the boat while it is being slowed. W = Fd W = _________ J

THE TRAIN

Because the train makes a complete circuit around the park, it offers several opportunities for measurement and estimation:

Making Measurements

1. Estimate the length of the train engine and one of its passenger cars.

   Engine: ______________m   Passenger car: ________________m

2. Find a railroad crossing and measure the width of the crossing. Measure the time it takes for the engine to cross the crossing. Be precise; measure from the time the front of the engine enters the crossing to the time the front of the engine leaves the crossing.

   Width of crossing: ___________m   Time for engine to cross: __________sec

3. Estimate the length of the entire train and explain the method you used for your estimation.

   Length of train: ______________________

4. Estimate the number of people who can ride the train at one time and tell how you arrived at your estimation.

   Maximum number of people on train:________________

5. Time the train ride. Time the ride from beginning to end. Also time any stops the train makes during a complete circuit.

   Time for one complete circuit: _______min.   Actual time the train is moving: _______min.

6. Describe the motion of the train. Does it seem to run at a uniform speed? If not, where does it run the fastest? Where does it run the slowest?

Calculations

7. Using the measurements you made for the time it took for the train engine to cross a crossing, calculate the speed of the train. After riding the train, do you think this is a good estimate of the average speed of the train? If not, estimate the average speed.

   Crossing speed: ______________m/sec   Average speed: ______________m/sec

8. Use the average speed and the actual running time to estimate the length of one circuit of the track.

   Length of track: _____________m

9. Assuming that the train moves at a constant speed, devise a way to calculate the total length of track. **DO NOT DO ANYTHING DANGEROUS!** Draw sketches and show examples of all calculations that you used to solve this problem. Clearly explain your thinking.

WAITING TIMES

Six Flags Over Texas has queue lines, like “mazes,” in which people wait for the rides. Choose a ride that has a potentially long queue line and answer the following questions:

Ride Chosen:______________________________

Making Measurements

1. Sketch the layout of the waiting area. Identify three places in the waiting line from which you will estimate waiting time. Label them A, B, and C on your diagram. Count the number of people ahead of a person in line at each of your points, A, B, and C.

   A:___________ B:____________ C:___________

2. How many people board the ride each time it loads? ________________
3. What is the time interval between loading times? ___________________

Calculations

4. Estimate the waiting time from each of your points, A, B, and C, and show how you arrived at your estimation.

RESOURCE WEB LINKS

Classroom Implementation of Amusement Park Physics:
http://www.newton.dep.anl.gov/app/nau_links.htm

Internet Project Resource Page *Amusement Park Rides (Roller Coasters)*:
http://k12science.ati.stevens-tech.edu/ike/summer99/resourcerc.html

Amuse me Theme Park Physics: http://library.thinkquest.org/C005075F/

Roller Coaster Physics: http://141.104.22.210/Anthology/Pav/Science/Physics/book/home.html

Physics of Roller Coaster Project:
http://www.glenbrook.k12.il.us/gbssci/phys/projects/yep/coasters/rcstupa.html

Amusement Park Physics Lessons: http://curie.uncg.edu/~mturner/title.html

The Physics of Amusement Parks: http://library.thinkquest.org/2745/

Michigan's Adventure Physics Day: http://www.miadventure.com/physics.htm

Hockaday Physics: http://home.hockaday.org/HockadayNet/academic/physics/SixFlags/sixflags.htm

The Physics of Rides: http://themeparks.miningco.com/travel/themeparks/cs/physicsofrides/index.htm

Roller Coaster Designers: http://www.coasters.net/designers/

Six Flags Over Texas Roller Coasters: http://www.worldofcoasters.com/census/six_flags_over_texas.html

Ride Safety: http://themeparks.miningco.com/travel/themeparks/cs/ridesafety/index.htm

Annenberg: Amusement Park Physics: http://www.learner.org/exhibits/parkphysics/coaster.html

Interactive Roller Coaster: http://www.funderstanding.com/k12/coaster/

CBL Based Amusement Park Physics: http://lhs.lps.org/instruct/amuseweb/lesson_plan.htm

DATA FROM ROLLER COASTER DATABASE (www.rcdb.com)

Six Flags Over Texas

Batman: Length 823m; Height 32m; Inversions 5; Speed 80.5kph; Duration 2 min; Capacity 1400 riders/hr
Texas Giant: Length 1499.6m; Height 43.6m; Drop 41.8m; Inversions 0; Speed 104.6kph; Duration 2 min: 30sec; Angle of Descent 53°
Shockwave: Length 1097.3m; Height 35.4m; Inversions 2; Speed 96.6 kph; Duration 2 min
Flashback: Length 266.7m; Height 38.1m; Inversions 3; Speed 77.2 kph; Duration 1min: 48sec; 750 riders/hr
Mr. Freeze: Length 396.2m; Height 66.4 m; Inversions 1; Speed 112.7kph
Mine Train: Length 731.5m; Height 10.7m; Inversions 0; Duration 3 min

SIX FLAGS OVER TEXAS APPROXIMATE DATA

ROLLER COASTERS

Batman
- Height: 109 ft 6 in
- Max. Speed: 56 mph
- Length of Train: 40ft
- Weight (empty train): 20000 lbs; 32 seats
- Height of Loops: 77 ft, 68 ft

The Texas Giant
- Height: 143 ft
- Max. Speed: 62 mph
- Length of Train: 52 ft
- Weight (empty train): 15000 lbs; 24 seats

■ Uses 250hp dc motor at 400 amps at 500 volts, full load

Shockwave
- Height: 116 ft
- Max. Speed: 60 mph
- Length of Train: 49 ft
- Weight (empty train): 12000 lbs; 28 seats
- Loop: 70 ft tall

Flashback
- Height: 125 ft
- Max. Speed: 50 mph
- Length of Train: 54 ft
- Weight (empty train): 14000 lbs; 28 seats

■ Driven by a 150hp 480-volt electric motor

Mr. Freeze
- Height: 236ft
- Max. Speed: 65 mph
- Length of Train: 42ft
- Weight (empty train): 11000 lbs; 20 seats

■ Accelerates from 0-70 mph in 3.8s
■ Uses Linear Induction Motors (LIM) for launch (44 pairs of LIM motors at 600 volts AC and 4600 amps)

Mine Train
- Height: 35 ft
- Max. Speed: 35 mph
- Length of Train: 48 ft
- Weight (empty train): 9000 lbs; 30 seats
  - Climb up first hill: 4.8ft/sec.

■ Accelerates up the first hill

WATER RIDES

Aquaman
- Height: 50 ft
- Length of Boat: 18 ft

■ Two 15hp pumps
■ About 250,000 gallons water

Log Ride
■ Conveyor Belt travels at 3ft/sec
■ Main Drop 30 ft
■ 160,000 gallons water

Roaring Rapids
■ 2 pumps; 400hp each
■ 2,000,000 gallons water

OTHER RIDES

Train
- Length of Track: 1 mile
- Average Speed: 10-12mph

Park power comes in at 12500 volts; peak demand 6.5 Megawatts.

WORKSPACE: ____

Six Flags
OVER TEXAS

MAP LEGEND

First Aid · Security/Lost & Found · Restrooms · Wheelchair Restrooms · Telephones · Baby Care/Lost Parents · Guest Relations · Public Lockers · Kennels · ATM · Designated Smoking Area