MATH & SCIENCE

OUTDOOR CLASSROOM WORKBOOK

QUESTIONS FOR GRADES 6- 12

To the Teacher

The Outdoor Classroom can be an exciting and educational time for students. Make the most of the instructional opportunities available. The activities were written to focus on interesting aspects of the rides at **Six Flags Fiesta Texas**. Some of the STEM concepts addressed are more appropriate for middle school while others are more appropriate for high school students.

Special thanks goes to Vernier Software & Technology for their generous loan of equipment. Thanks also go to Clarence Bakken for his help and inspiration. He got me hooked on using an amusement park as a physics laboratory. I hope you enjoy your day of fun with science, technology, engineering, mathematics, and discovery at **Six Flags Fiesta Texas!**

Rick Rutland, Five Star Education Solutions

Suggestions

1. Review the materials prior to coming to the park. Consider practicing some of the activities at school such as determining the height of the school flagpole via triangulation. The calculations are based on approximate or estimated data. The problem solving process is more important than a "right answer".
2. Consider using the videos of rides to determine times needed for the calculations. These could be done prior to coming to the park.
3. There are more activities included than can be realistically completed. Choose the activities/questions that you want your students to complete. Some of the questions would be appropriate for Middle School students while others would be better for High School physics. Focus on a small number of activities at the park. Decide if your students must complete all work at the park. When are you going to collect the completed work, that day, or later? Consider if you want to use some of the activities back at school.
4. Develop a plan to ensure a smooth day at the park. Arrange for permission slips, transportation, meals etc. Are you prepared in case the weather turns bad? The park will still be open, but some rides may not operate. Do you need emergency contact numbers for parents? Make sure all the students know when and where to meet at the end of the day.
5. You may want to schedule some location and scheduled times so students and other adults will be able to find you throughout the day. Allow a window of time so that students will not have to leave a ride line.
6. Assign students into groups to work on the activities. Make sure students know that they do not **all** have to ride. Each student group will need a calculator, a stopwatch (or their phone), and a sextant. (a sextant can be constructed easily and inexpensively.)
7. Please ask your students to **bring a photo ID** to the Outdoor Classroom Day so that they can use the high-tech equipment for collecting data. (*Since students*

usually work in groups of 2 to 4 on the activities, it is really only necessary to check out one set, and thus require only one I.D., per group.) Students borrow the equipment by trading a photo I.D. (such as a driver's license or school I.D.) for a data collection device and vest. The collateral will be returned to the students when they return the equipment. This equipment is available due to generous equipment lending by Vernier Software & Technology. Students may also want to bring a USB drive to obtain the data (it will be in a Logger Pro file).

8. **Consider volunteering to help** with the "high tech" data collection. Teachers and other chaperones are needed to operate laptop computers for downloading data, to collect/return IDs, to issue data vests, and to familiarize students with using the equipment. You don't need to know anything about the equipment--we can train volunteers on the day of the event. You could volunteer for a couple of hours or as much as the whole day.
9. The altimeters will occasionally read negative values. The altimeter reading is based upon barometric pressure. Moving at high speeds probably causes a slight change in pressure.
10. Students will need to time certain events on the rides. It might help if students video the ride. Then they could replay the video several times to gather the data.
11. There are several other rides that are not addressed in these activities. Consider assigning students to choose one or more to analyze.

Please note that the devices that are commonly called “accelerometers” are not really accelerometers! The devices work by detecting forces. They look at the force acting on a small mass, divide it by the object’s mass, and calculate the force per unit mass. The ratio, which ends up in units of N/kg, is the same regardless of the amount of mass. These units are conveniently equivalent to acceleration units (m/s^2), and thus the sensor has the ability to make direct measurements of acceleration for objects. The electronic devices are measuring the force on a tiny mass unit inside the device. The force is proportional to the acceleration that it is undergoing.

Some teachers call these devices Force Factor meters and label the graphs Force Factor. Other teachers prefer to label their graphs N/kg. We choose to use the term acceleration and will use m/s^2 as the unit.

Adapted from materials from California's Great America and Six Flags St. Louis

Resources

There are many sites with information and sample workbooks from various amusement parks. These are some that have been found most useful.

http: rcdb.com

This site has data for roller coasters from all over the world.

http://www.physicsday.org

This site is hosted by Clarence Bakken and has many resources related to the physics day at California's Great America.

http://www.slapt.org/resources/sixflags

This is part of the site for the St. Louis Area Physics Teachers group. There are many resources related to their physics day at Six Flags.

http://www.compadre.org

This site has many resources for physics. Search under amusement park to find related materials. *Amusement Park Physics, 2nd Edition: Supplemental Materials* has been posted by Clarence Bakken. The scrambler ride simulation and PowerPoint presentation on vertical loops are very helpful.

http://vip.vast.org/BOOK/HOME.HTM

Virginia Instructors of Physics: This site contains Tony Wayne's book and a variety of other related files.

http://www.vernier.com

Vernier Software and Technology sells the WDSS system as well as the Amusement Park Physics book.

Bakken, C. (2011) *Amusement Park Physics, 2nd ed*. American Association of Physics Teachers. ISBN 978-1-931024-12-9

Unterman, N. (1990) *Amusement Park Physics: A Teacher's Guide*. J. Weston Walch Pub. ISBN 0-8251-1681-3

Before you come to Outdoor Classroom

What to Bring:

1. **Workbook/handouts**

2. **Timing device**: At least one person in each group should have a timing device that can measure tenths of a second. This could be a digital watch or phone.

3. **Protractor-Sextant**: This device will be used for triangulation to determine heights. Construction directions are included below.

4. **Calculating device**: This can be a calculator or phone. It should have trig function capability (high school).

5. **Pen or pencil**

6. **Storage bag**: A one-gallon plastic zipper bag or small pack will help to keep materials together and organized.

7. **Picture ID**: A driver's license or school ID will be needed to leave as collateral in order to check out the electronic data collection devices.

Don't bring:

1. Clipboards or other heavy objects, which are not allowed on the rides.

2. Homemade vertical and horizontal accelerometers are allowed at some parks, but we will not use them at Fiesta Texas. They are difficult to read and not very accurate. There is also concern about them falling from rides. Students will be able to check out electronic devices to gather data. More details are provided below.

Electronic Data Collection:

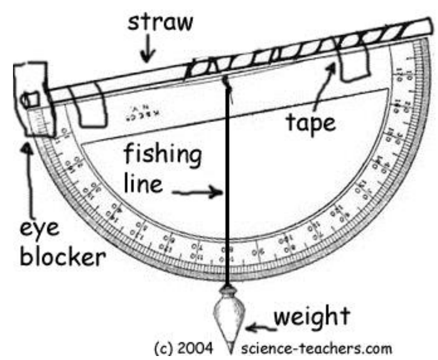
A generous donation from Vernier Software & Technology will allow students to check out devices to collect data on selected rides. The Wireless Dynamic Sensor System (WDSS) is about the size of a cell phone and will be secured in a Data Vest that students will wear. The WDSS will measure acceleration along 3 axes (x, y, z) as well as altitude. The device will be programmed and the students will be shown how to start data collection during the checkout process. The EDC booth will be located near the entrance to the Iron Rattler.

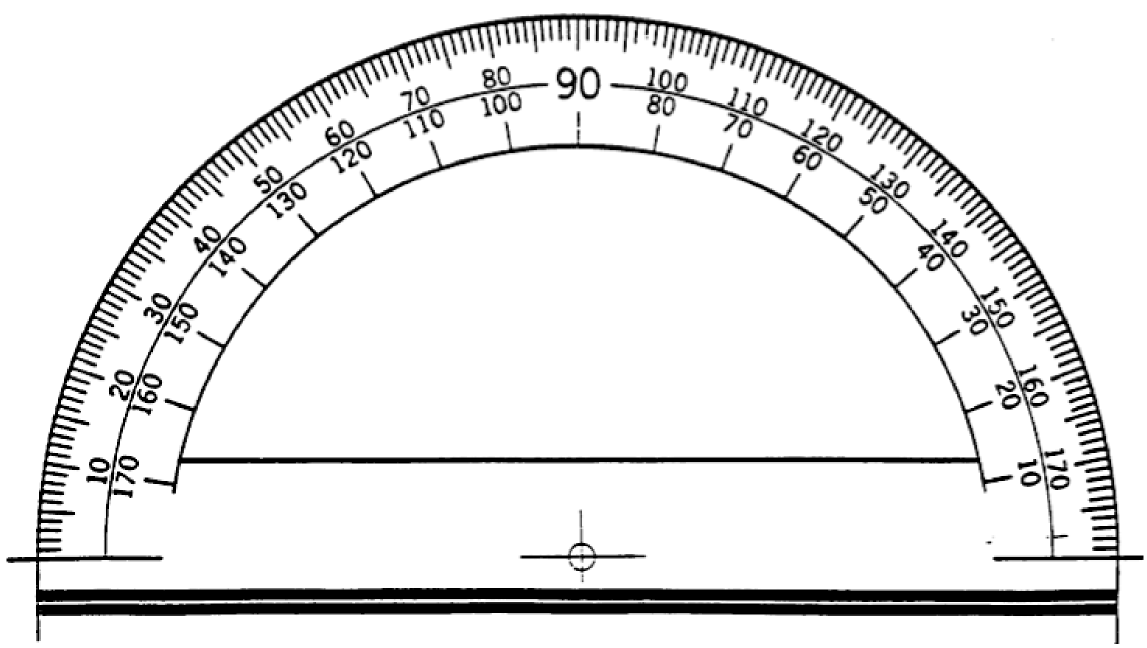
1. An item of value such as a driver's license, credit card etc. must be left as collateral in order to check out the equipment.

2. Only one device per group will be checked out.
3. The unit must be returned within one hour.
4. Students may want to bring a USB drive to collect their data. It will be in a Logger Pro file.
5. The unit may **ONLY** be used on the Iron Rattler. Data gathered from other rides may be available to students.
6. No units will be checked out after 2:00 PM.
7. Teachers and/or chaperones are needed to help manage the EDC booth. We will train you.

Constructing/using a simple sextant

Tape or glue a soda straw to a plastic or cardboard protractor. Tie a small weight to a string and hang it from the hole of the protractor (above the 90º mark). Sight through the tube at a distant object and record the angle. Subtract this angle from 90º to obtain the angle of elevation. In the example to the left, the angle read is 80º so the angle of elevation is 10º.





Cut out the protractor and glue to index card or cardboard.
Graphic taken from Six Flags St. Louis workbook.

Taking Measurements

It is a very good idea to read all of the questions for a ride before you start working on them. Many of the measurements that you will need can be taken while standing in line waiting for the ride. Use your time efficiently!

TIME

The times that are required to work out the problems can easily be measured by using a digital watch or a phone. When measuring the period of a ride that involves harmonic or circular motion, measure the time for several repetitions of the motion and divide by the number of repetitions. This will give a better estimate of the period of motion than just measuring one event. You may also want to measure a time two or three times and then average them.

DISTANCE

Since you are not allowed to interfere with the normal operation of the rides, you will not be able to directly measure many heights, diameters, etc. Many of the distances can be measured remotely using the following methods. They will give you a reasonable estimate. Try to keep consistent units, i.e. meters, centimeters, etc., to make calculations easier.

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 and you can get the average distance per step. Knowing this, you can pace off horizontal distances.

My pace = _____________ m

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, and by counting the number of cross members, distances along the track can be determined. This method can be used for both vertical and horizontal distances.

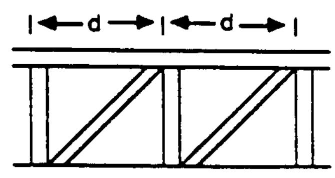
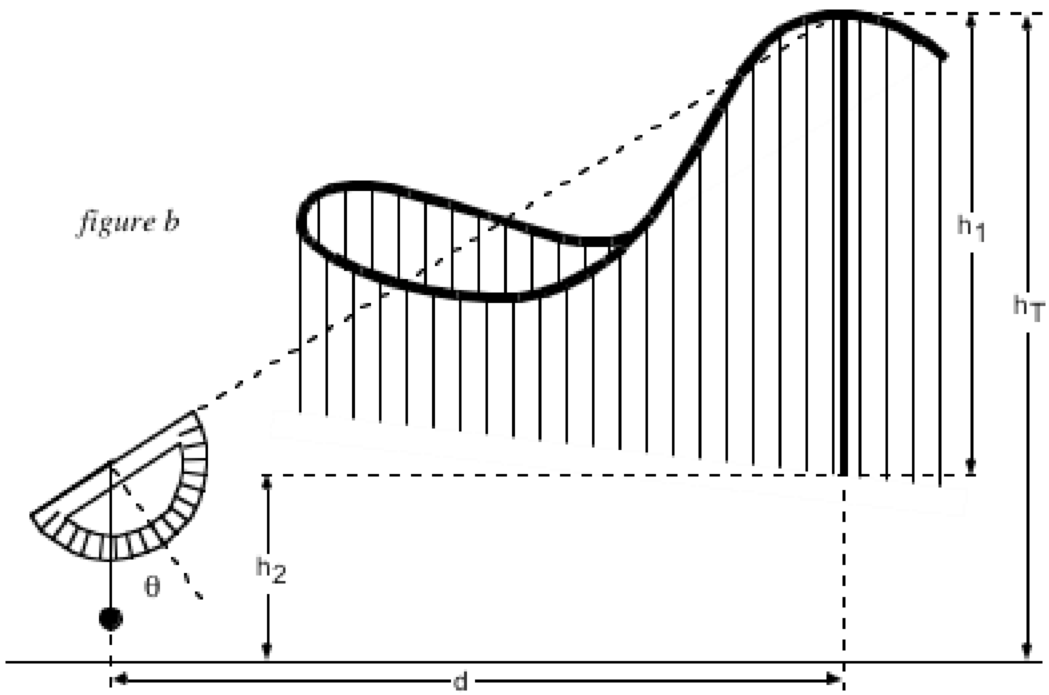
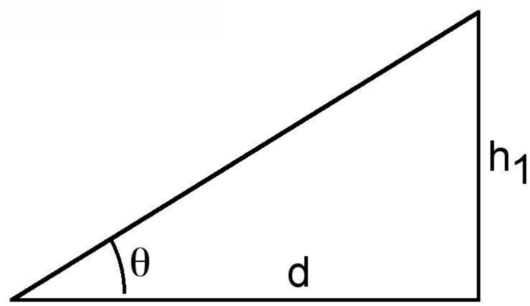


figure a

Triangulation: For measuring height by triangulation, a sextant can be used. Suppose the height $\mathbf{h_T}$ of a ride must be determined. First the distance **d** is estimated by pacing it off (or some other suitable method). Sight along the sextant to the top of the ride and read the angle θ. Add in the height of your sextant (h_2) to get the total height.





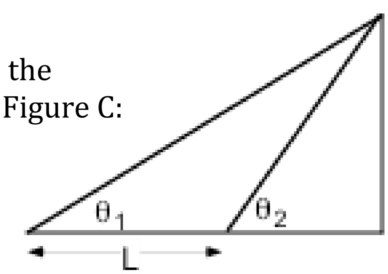
Then since

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

The height of the ride (h_T) is the sum of the distance from the ground to the sextant (h_2) and the distance from the sextant to the top of the ride (h_1).

$h_T = h_1 + h_2$

A similar triangulation can be carried out where you cannot measure the distance to the base of the ride. Use the law of sines as illustrated in Figure C:



Knowing **θ_1**, **θ_2**, and **L**, the height **h** can be calculated using the expression:

$$h = \left[\frac{\sin\theta_1 \sin\theta_2}{\sin(\theta_2 - \theta_1)}\right] L$$

SPEED

The average speed of an object is simply distance divided by time. For circular motion, it is the circumference divided by time, if the speed is constant.

$$v_{avg} = \Delta d / \Delta t = 2 \pi R / \Delta t \text{ (circular)}$$

To measure the instantaneous speed of a moving train, divide its length by the time it takes to pass a particular point on the track.

$$v_{inst} = \Delta d / \Delta t = \text{length of train / time to pass point}$$

In a situation where friction is ignored and the assumption is made that total mechanical energy is conserved, speed can be calculated using energy considerations:

$$GPE = KE$$

$$m g h = 1/2 m v^2$$

$$v^2 = 2 g h$$

$$v = \sqrt{2 g h}$$

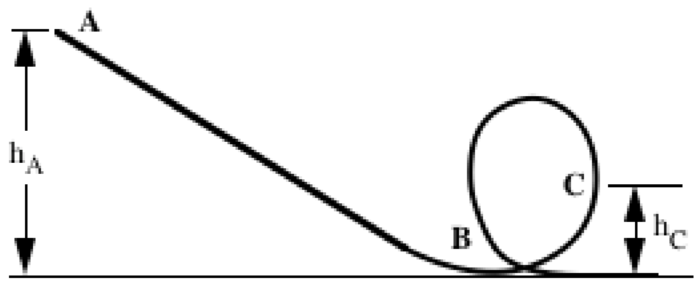


Figure D

Consider a more complex situation:

$$GPE_A + KE_A = GPE_C + KE_C$$

$$mgh_A + 1/2 mv_A^2 = mgh_C + 1/2 mv_C^2$$

Solving for v_C:

$$v_C = \sqrt{2 g (h_A - h_C) + v_A^2}$$

ACCELERATION

Centripetal Acceleration

Calculations of acceleration in uniform circular motion are possible. Where **R** is the radius if the circle and **T** is the period of rotation, centripetal acceleration can be determined by the equations given below.

Centripetal Acceleration: $a_c = v^2 / R = 4 \pi^2 R / T^2$

Direction of Acceleration

The net force that causes an object to accelerate is always in the same direction as the resulting acceleration. The direction of that acceleration, however, is often not in the same direction in which the object is moving. To interpret the physics of the rides using Newtonian concepts, you will need to determine the direction of the accelerations from the earth's (inertial) frame of reference. From this perspective, the following statements are true.

a) When an object traveling in a straight line speeds up, the direction of its acceleration is the same as its direction of motion.

b) When an object traveling in a straight line slows down, the direction of its acceleration is opposite its direction of motion.

c) When an object moves in a circle at a constant speed, the direction of its acceleration is toward the center of the circle.

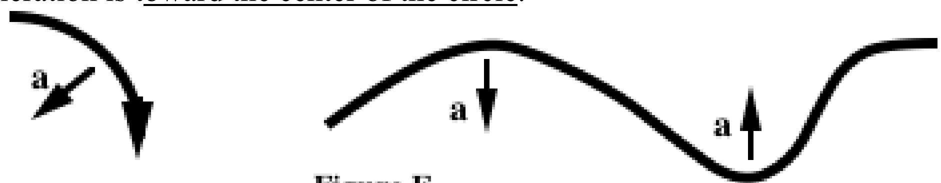


Figure E

d) When an object moves in a parabola (like those in a coaster ride), the direction of acceleration is along the axis of the parabola.

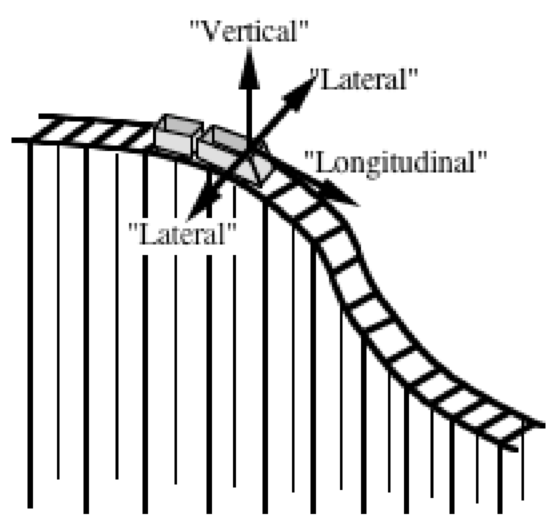
Naming the Directions

Vertical means perpendicular to the track (head to toe)

Longitudinal means in the direction of the train's motion (front to back)

Lateral means to the side relative to the train's motion **(**side to side)

Figure F



Accelerations on a Roller Coaster

Accelerations

Some accelerometers are calibrated in g's. The chart below contains examples of vertical accelerometer readings. A description of the sensation experienced is given.

Accelerometer Reading in g's	Sensation Experienced
3	3 times heavier than normal (maximum g's pulled by space shuttle astronauts)
2	Twice normal weight against the coaster seat
1	Normal weight against the coaster seat
0.5	Half of normal weight against the coaster seat
0	Weightlessness: No force of weight between the rider and the coaster seat
-0.5	Half the normal weight, but directed away from the coaster seat (as if the weight were measured on a bathroom scale mounted at rider's head!)

Your body has its own way of detecting accelerations. Let's take a look at how your "natural accelerometer" detects different kinds of accelerations.

When you experience …

Direction of Acceleration	Physics Term	Gut Feeling
Upwards	Vertical	You feel pressed into your seat. The greater the acceleration, the more squished you feel.
Downwards	Vertical	You feel like you are rising out of your seat. Your stomach feels like it's in your throat. You feel queasy.
Forwards	Longitudinal	You feel pushed back against your seat. Your head and shoulders may swing backwards.
Backwards	Longitudinal	You feel pushed forward against the safety harness. Your head and shoulders may lurch forward.
Left or Right	Lateral	You slide sideways across the seat. Your shoulder may be pressed against the side wall or your ride partner. Your head or knees may bang against the side wall.

Useful Equations				
Linear Motion				
$v = \Delta d/\Delta t$	$a = \Delta v/\Delta t$	$v_f = v_i + at$	$v_f^2 = v_i^2 + 2ad$	$d = v_i t + 1/2 at^2$
Work, Power, Energy, Momentum				
$F = ma$	$W = Fd$	$P = W/\Delta t$	$P = E/\Delta t$	$\Delta E = W$
$PE = mgh$	$KE = 1/2 mv^2$	$\rho = mv$	$Ft = m\Delta v$	$w = mg$
Circular Motion				
$C = 2\pi r$	$v = 2\pi r/T$	$F_c = mv^2/r$	$a_c = v^2/r$	$a_c = 4\pi^2 r/T^2$
$\omega = 2\pi/T$	$v = \omega r$	$a_c = \omega^2 r$		
Electricity				
$I = V/R$	$P = VI$	$R_t = R_1 + R_2 ...$	$1/R_t = 1/R_1 + 1/R_2 ...$	
Right Triangle Trig				
sin □ = opp./hypot.	cos □ = adj./hypot.	tan □ = opp./adj.		

Assume a mass of 60 kg for the mass of an average rider.
Assume 9.8 m/s^2 equals 1g.
Assume 4.2 J equals 1 calorie.

Table of tangents

Angle	Tan	Angle	Tan	Angle	Tan	Angle	Tan	Angle	Tan
1	.02	17	.31	33	.65	49	1.15	65	2.14
2	.03	18	.32	34	.67	50	1.19	66	2.25
3	.05	19	.34	35	.70	51	1.23	67	2.36
4	.07	20	.36	36	.73	52	1.28	68	2.48
5	.09	21	.38	37	.75	53	1.33	69	2.61
6	.11	22	.40	38	.78	54	1.38	70	2.75
7	.12	23	.42	39	.81	55	1.43	71	2.90
8	.14	24	.45	40	.84	56	1.48	72	3.08
9	.16	25	.47	41	.87	57	1.54	73	3.27
10	.18	26	.49	42	.90	58	1.60	74	3.49
11	.19	27	.51	43	.93	59	1.66	75	3.73
12	.21	28	.53	44	.97	60	1.73	76	4.01
13	.23	29	.55	45	1.00	61	1.80	77	4.33
14	.25	30	.58	46	1.04	62	1.88	78	4.70
15	.27	31	.60	47	1.07	63	1.96	79	5.14
16	.29	32	.62	48	1.11	64	2.05	80	5.67

Adapted from materials of Six Flags Fiesta Texas, California's Great America and Six Flags St. Louis.

Six Flags Fiesta Texas Approximate Data

Roller Coasters

Iron Rattler: Track length: 995.5 m Height 54.9 m Max. Speed 31.3 m/s Drop: 52.1 m @ 81º Length of train: 14 m; 24 seats Mass empty train: 7,020 kg Ride Time: about 2 minutes 300 hp motor on lift hill	**Superman Krypton Coaster:** Track length: 1,226.8 m Height: 51.2 m Max. Speed: 31 m/s Length of train: 13.7 m; 32 seats Mass empty train: 7,257 kg Height of loop: 36.6 m
Goliath: Track length: 820.8 m Height: 32.0 m Drop: 24.4 m Max. Speed: 22.4 m/s Length of train: 14.3 m; 28 seats Mass empty train: 7,500 kg	**Road Runner Express:** Track length: 731.5 m Height: 22.3 m Max. Speed: 19 m/s Length of train: 15.8 m; 28 seats Mass empty train: 7,711 kg
Boomerang: Track length: 285.0 m Height: 38 m Max. Speed: 21.0 m/s Length of train: 15 m; 28 seats Mass empty train: 6,350 kg Height of loop: 10 m	**Poltergeist:** Track length: 824.4 m Mass empty train: 4968 kg Length of train: 14.6 m; 24 seats Acceleration period: about 3 s Launch Energy: 4,500 A, 520 V

Park power comes in at 34,500 volts; peak usage is 7 Megawatts.

Others

Power Surge: Height: 17 m Length of boat: 5.2 m; 20 seats Mass of empty boat: 771 kg	**Fender Benders:** 90 Volts DC; 1 hp motor 300 lbs empty car
Scream! Height: 82 m 12 seats per tower; 3 towers	**Whirligig:** Radius of rotation (full speed): 11.3 m Period of rotation: about 6 s

A Walk in the Park!

Describe at least one place at the park that fits each of the descriptions below. The same ride may be used more than once, or not at all. Some descriptions may be met at a location other than a ride. Be sure to describe the location fully, don't just give the name of the ride - tell where on the ride this occurs.

1. The vertical acceleration is greater than +1 g:

2. The vertical acceleration is less than +1 g but greater than 0:

3. Potential Energy is being converted into Kinetic Energy:

4. Kinetic Energy is being converted into Potential Energy:

5. Other forms of energy are being converted into Heat:

6. The longitudinal acceleration is equal to or greater than 1 g:

7. The longitudinal acceleration is negative:

9. The lateral acceleration is significant:

10. Centripetal Force is directed horizontally:

11. Centripetal Force is directed vertically upwards:

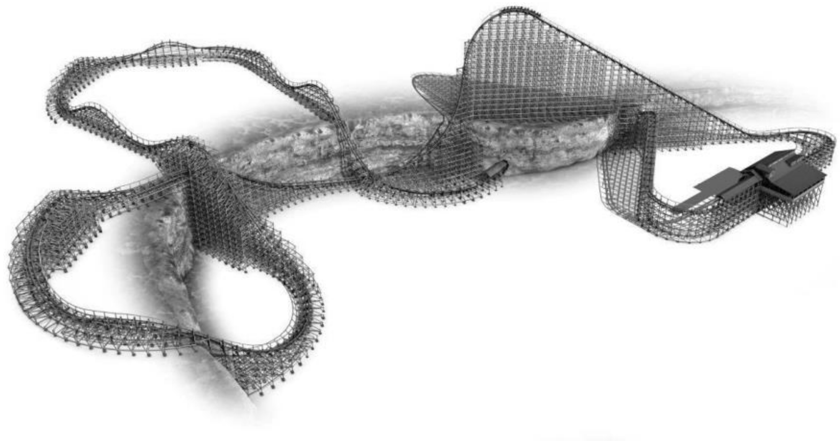
12. Centripetal Force is directed vertically downwards:

13. A place where the effects of friction are immediately apparent:

Teachers can choose to include as many of the items above as fit conveniently on a page or that their students can successfully master. More space per item could be provided through simple editing.

Roller Coasters:
Iron Rattler

There are several roller coasters in the park, but we will focus on the Iron Rattler. If there is time you may want to analyze other coasters as well.



Preliminary questions:

Roller coasters are sometimes called gravity machines. Why do you think so?

You friend says that moving at high speed is what makes rides exciting. Do you agree or disagree? Explain your thinking.

Observe the ride and answer the following questions:

Do the trains use motors for the entire trip or only part of it? Explain your reasoning.

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

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; just 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. Draw your sketch on the back of this page or another paper. This will be the ride profile.

Label your sketch with the following points: maximum Potential Energy, minimum Potential Energy, maximum Kinetic Energy, minimum Kinetic Energy, maximum velocity

Have some of your group be brave and ride the coaster. Describe your feelings at different points of the ride. Label the sketch where you feel the heaviest and where you feel the lightest (or weightless).

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

Some coaster enthusiasts say that passengers in the first car, middle car and last car experience the ride differently. What do you think? Use your observations of the ride and your gut feeling while riding the ride.

Making Measurements:

Before:

Time of ride	t =	______	sec
Length of track	L =	_______	m
Determine the length of the train.	L =	______	m
Determine the height of the lift hill	h =	______	m
Estimate the mass of a full train of passengers.	m =	______	kg
Time required to lift a loaded train up to the top of the first hill.	t =	______	sec
Time for train to pass a point at the bottom of the first hill.	t =	______	sec

Calculations:

Time the ride from beginning to end. Calculate the average speed of the ride.

Calculate the Potential Energy of the loaded train at the highest point. Assume that velocity at this point is essentially zero.

Calculate the velocity of the train at the bottom of the first drop using Conservation of Energy. (Assume PE = 0) v = _______ m/s

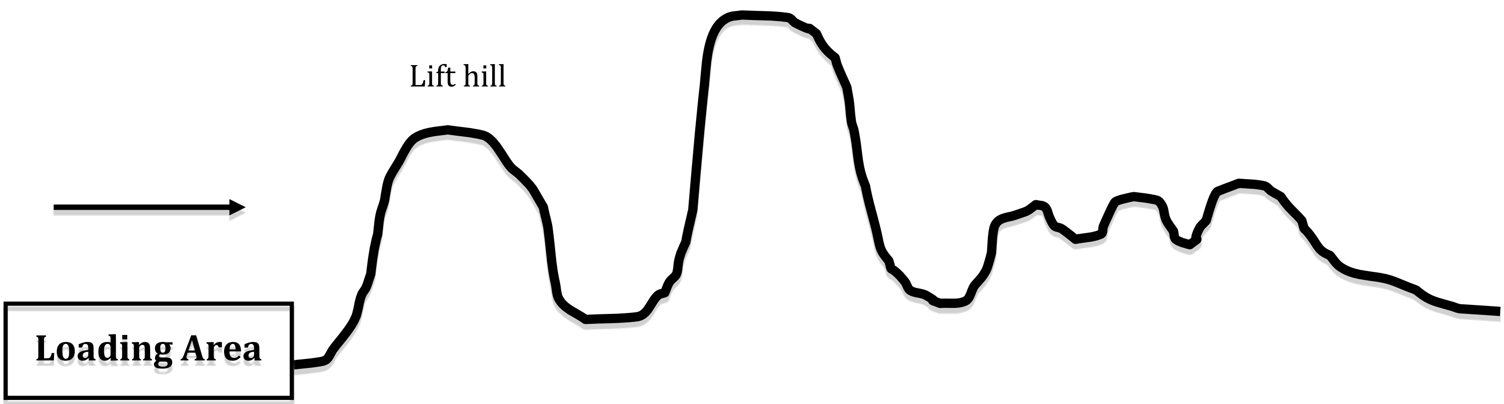
Measure the velocity of the train at the bottom of the first drop by timing the train past a fixed point. v = _______ m/s

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

Calculate how much work is done to lift the train to the highest point.
W = _______ J

Calculate the power of the lift system.
P = _______ watts

Fiesta Texas is considering a new gravity roller coaster. As part of the engineering team, you are sent this rough sketch to review. Should you approve it or send it back to the drawing board? Explain your reasoning.



Interesting facts:

The first roller coasters were built in 17th century Russia. People rode down steep ice covered slides in sleds made of wood or ice. They were sometimes known as Russian Mountains.

The Iron Rattler was designed to make use of an existing tunnel through a quarry wall. Approximately 50% of the engineer's time was used to make it fit that tunnel.

Electronic Data on Roller Coasters
Iron Rattler

The electronic data collection systems may be used to collect data on the Iron Rattler. You may add this electronic data to your other analysis of the Iron Rattler.

Before you ride

- Revisit the ride profile you made for the Iron Rattler. Mark the approximate position of a passenger every 10 seconds on your sketch. (This can be worked out either before or after riding.) You can use the Iron Rattler diagram to help. Add the ten locations from the Iron Rattler diagram to your ride profile.

Secure the measuring unit in the Data Vest and strap it on. The three axes of acceleration are straight ahead (longitudinal), directly to the side (lateral) and/or straight up and down (vertical).

- Accelerometer X: **vertical**
- Accelerometer Y: **lateral**
- Accelerometer Z: **longitudinal**

While you ride

Just before the ride starts you will want to begin collecting data. Press [Start/Stop]. The green light should start flashing. The device will stop collecting automatically.

After you ride

Return the data collection unit back to the Electronic Data Center (EDC). Download the data. If you have a USB drive, you will be given a copy of the data so you can do analysis later. The data may also be posted online so you can download it and work further with it later.

Questions:

Review the graphs of altitude vs. time and acceleration vs. time. Summarize the trends that you notice when you compare the graphs.

Add the ten locations from the Iron Rattler diagram to your altitude vs. time graph.

Use the ride profile and your electronic data graphs to analyze the ride.

1. Choose 4-5 locations on the ride. Discuss the readings from your graphs at these locations.
2. Compare the readings to your "gut" feelings from the ride.
3. Use the data to calculate the angle of the lift hill (going up).

Other data available

Iron Rattler: Compare front seat vs. back seat experience
Boomerang: Analyze vertical loop
Poltergeist: Analyze electromagnetic launch
Superman: Analyze a different looping coaster
Goliath: Analyze a different coaster
Roadrunner Express: Analyze a different coaster
Whirligig: Analyze a swinging ride
Scream!: Is there really free fall?
Power Surge: Analyze a water coaster
Crow's Nest: Analyze a big wheel

Adapted from materials from California's Great America

Looping Coasters: Boomerang

Several of the coasters have vertical loops. We will focus on the Boomerang. If you have time you may want to analyze other looping coasters. Sketch the shape of the vertical loop and discuss what you notice about the shape.

The very first looping coasters had circular loops, but the engineers soon changed to an irregular loop called a Klothoid (Clothoid). Why do you think so?

Explain why the Boomerang uses a motor to lift the train further up the second ramp before it returns backwards through the loop.

<u>Making Measurements:</u>

Before:

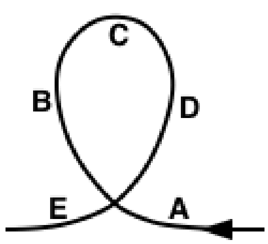
Determine the length of the train. L = _____m

Determine the height of the loop. h = ____m

Estimate the mass of a full train m = ____ kg

Time for train to pass:

Point A _____ s
Point C _____ s
Point E _____ s



Where was the train going the fastest in the loop? Why was it the fastest at that point?

Where was it going the slowest in the loop? Use physics principles to explain why the speed was the slowest in the place you identified.

Calculations:

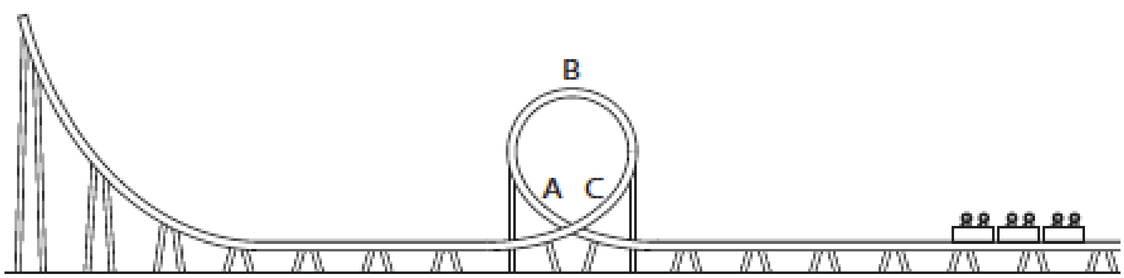
Calculate the speed of the train just before it enters the loop.

v = ________m/s

Calculate the speed of the train at the top of the loop.

v = ________m/s

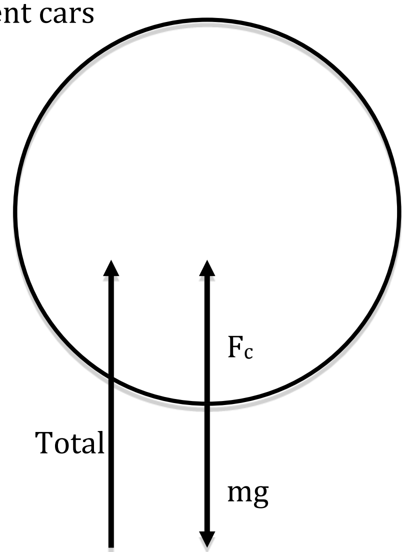
Calculate the KE, PE and total energy of the loaded train at the top of the loop.



The following acceleration data was collected for a looping coaster:

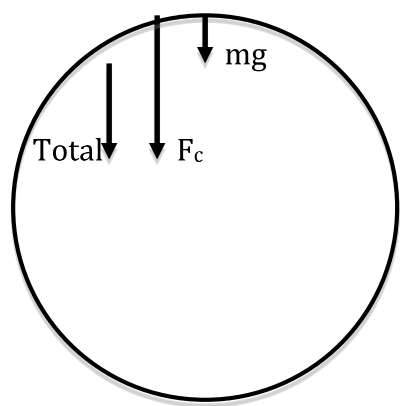
Point A (entering loop):	4.8g (front car)	3.4g (back car)
Point B (top of loop):	1.5g (front car)	1.4g (back car)
Point C (exiting loop):	3.2g (front car)	4.8g (back car)

It appears that there really is a difference in the ride experience depending on the car you are in. Explain the differences in acceleration in different cars of the train.



At the bottom of a loop, centripetal force and acceleration are directed upward. Weight and gravitational acceleration are directed downward. The total force or acceleration toward the center acting on the person is found by adding the two.

$F_{total} = F_c + mg$ or $a_{total} = a_c + g$



At the top of a loop, centripetal force and acceleration are directed downward. Weight and gravitational acceleration are also directed downward. The total force or acceleration toward the center acting on the person is found by subtracting the two.

$F_{total} = F_c - mg$ or $a_{total} = a_c - g$

Calculate the minimum velocity required for the train to make it around the top of the Klothoid loop (without restraining devices). Assume a radius of 3m at the top. This is known as critical velocity. At this point the centripetal acceleration is equal to g (any slower and you would fall out).

$g = v_c^2/r_t$ $v_c =$ ___________m/s

Calculate the total acceleration entering the bottom of the Klothoid loop. Assume a radius of 11m. Remember you must add "g"

$a_b = v_b^2/r + g$ $a_{total} =$ ________ m/s^2 = _______ g's

Calculate the total acceleration at the top of the Klothoid loop. Assume a radius of 3m. Remember you must subtract "g".

$a_t = v_t^2/r - g$ a_{total} = ________ m/s^2 = _______ g's

What would happen if the ride had been made with a circular loop instead of a Klothoid loop? Assume a circular loop with a diameter **equal** to the height of the Klothoid loop Assume a diameter of 10 m. Since it is circular, the radius at top and bottom is the same. Assume that the top and bottom velocities would be the same as the Klothoid.

Calculate the minimum velocity required for the train to make it around the top of the circular loop (critical velocity.)

$v_c = \sqrt{g r_t}$ v_c = ____________ m/s^2

Calculate the total acceleration entering the bottom of the circular loop. Remember you must add "g"

$a_b = v_b^2/r + g$ a_{total} = ________ m/s^2 = _______ g's

Calculate the total acceleration at the top of the circular loop. Remember that you must subtract "g".

$a_t = v_t^2/r - g$ a_{total} = ________ m/s^2 = _______ g's

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

Interesting Facts:

The Boomerang design is one of the most popular of all time. There are many "clones" of this ride all over the world. The name comes from what the designers call the first interaction, a "Boomerang". This is also sometimes known as a "Cobra Roll".

Poltergeist

The Poltergeist is different from the rest of the coasters. A physics student, without even seeing the start of the ride, concludes that the train must be catapulted out of the station at great speed. Why?

The Poltergeist uses Linear Induction Motors (LIM) to launch the train. The Poltergeist requires 4,500 amps and 520 volts of electricity for each launch.

Making Measurements:

Before:

Time how long the train is being accelerated during the launch.

t = ______ sec

Calculations:

Measure the velocity of the train at the end of the launch rail by timing the train past a fixed point.

v = ______ m/s

Calculate the acceleration from the change in velocity.

a = _______m/s = ______g’s

Estimate the mass of a fully loaded train. m = _________ kg

Calculate the amount of force needed to accelerate the loaded train to top velocity.

F = _______N

Use conservation of energy to calculate the maximum theoretical height that the train could rise to.

h = ______m

Calculate the electrical resistance of the launch system.

R = ________Ω

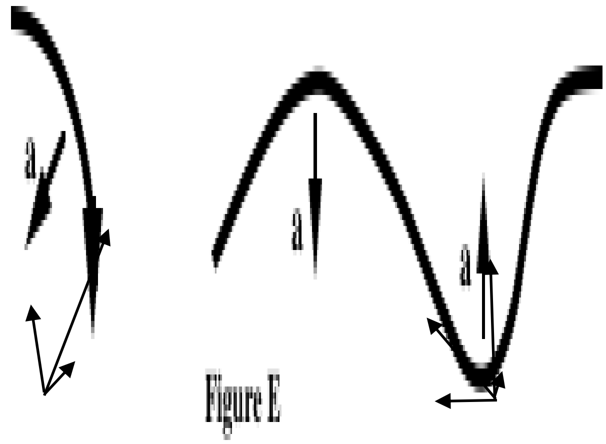
Calculate the power used during a launch.

____________ watts

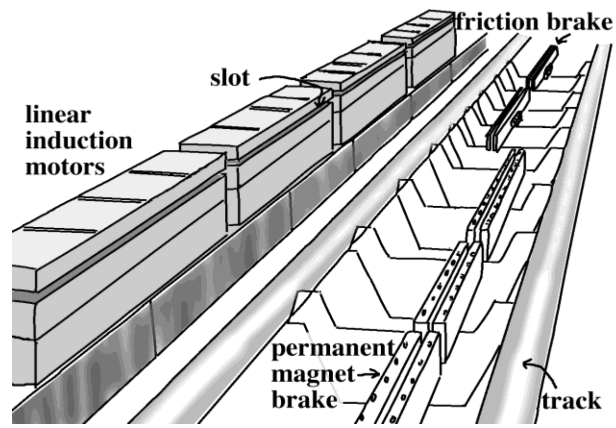
How much heat would be generated if the train was stuck and could not move, while the normal launch energy was expended?

In the movie *Back to the Future*, Dr. Brown created a time machine out of a DeLorean DMC-12 car. The time machine required 1.21 Gigawatts to operate. How does this compare to the launch energy of the Poltergeist?

Observe the train and launching system while waiting to board. The side fins on the train fit into the slots of the linear induction motors on both sides of the track. The motors use electromagnets to launch the train down the track. The fins are made of aluminum, and aluminum is not attracted to a magnet. How then can this system work?



The bottom of a Poltergeist train car



A section of the Poltergeist track inside the launch building.

LIM graphics from Six Flags St. Louis materials.

Interesting Fact:

The 0-60 mph acceleration of the Poltergeist is about the same as a Corvette.

Ameri-Go-Round (The Carousel)

The Ameri-Go-Round is a replica of a carousel that was first designed in the early part of this century. This carousel, containing hand-painted panels, animals, and chariots, sends riders back to the romantic times of carnivals and county fairs.

One of your friends thinks that all of the animals on the carousel are moving at the same velocity. Another friend thinks that they are moving at different velocities. What do you think? Explain your reasoning.

Count the number of stationary animals. Determine the number of stationary animals compared to the total number of animals, and express this fraction as a percentage.

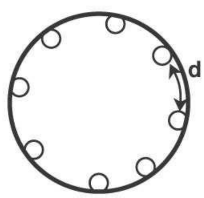
Making Measurements:

1. Determine the period of rotation (time it takes to make one revolution). Take several readings and average the values.

T = _________

2. As soon as you get on the platform, estimate 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. Using the circumference, calculate the radius for both the inner and outer ring of animals.

(Inner ring of animals) r_i = ______m
(Outer ring of animals) o_r = ______m

CALCULATIONS: show your work and clearly identify your final answers

1. Find the linear speed of an outside rider.

2. Find the linear speed of an inside rider.

3. What is the average linear speed in miles per hour (mph) that you traveled on the carousel? First make a mental estimate, and then do the calculations. You may use the approximate conversion of 20 m/s ≈ 45 mph, or work it out any other way you choose. Show your work.

Mental estimate = ___________ mph Calculation = ______________ mph

4. Calculate the centripetal acceleration of the outside rider in m/s^2 and g's.

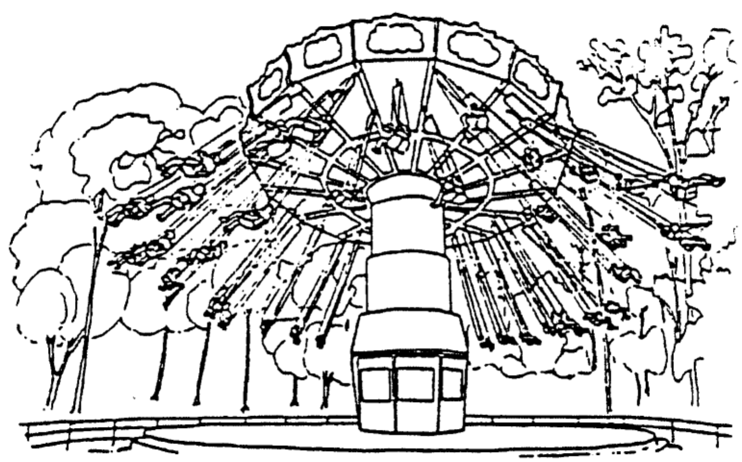
5. Calculate the centripetal acceleration of the inside rider in m/s^2 and g's.

6. Calculate the angular velocity for an inside and outside rider. Discuss how they compare.

7. Imagine that all riders are riding outside horses. Once the carousel is turning, the motor is turned off and the carousel continues to turn freely with no frictional loss. If all riders then move from the outside horses to inside horses while the carousel is turning, what effect would this have on the motion of the carousel? Explain.

Whirligig (Swings)

Your friend says that an adult will enjoy the swings more than a child since more weight will make them swing out farther. Predict what you think will happen before the ride starts. How will an empty swing behave compared to one with a rider? Draw a sketch of your prediction for an empty swing and one with a rider.



Observe the ride in motion. How did your prediction compare to what actually happened with an empty swing? Draw a diagram of the ride:

a.) at rest

b). rotating at full speed but not tilted

<u>Before:</u>

Measure the period of the swing when it is rotating at full speed but not tilted.

Estimate the angle of the chains with the vertical when the ride is rotating but not tilted.

<u>During:</u>

Describe your sensations when the ride is:

a). rotating but not tilted

b). rotating and tilted moving downward

c). rotating and tilted moving upward

<u>Calculations: Assume the ride is rotating at full speed and not tilted.</u>

Calculate the linear velocity of the swings.

Calculate the centripetal force acting on a rider.

Draw a vector diagram of the forces acting on you when the ride is rotating but not tilted.

Calculate the angle the chain makes with the vertical.

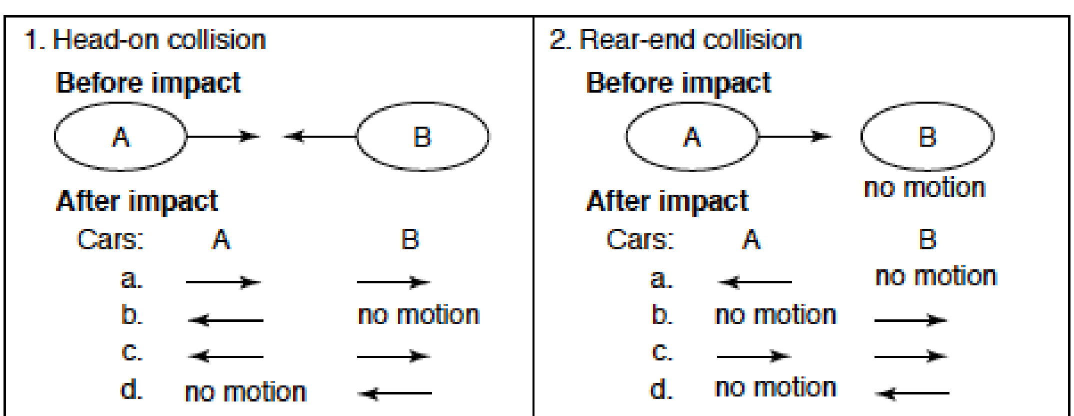
Calculate the tension in the chain.

Combine equations to show the effect (or lack thereof) of mass on the angle of the swing.

Fender Bender (Bumper Cars)

Observe the ride while waiting in line, then ride and answer the questions.

For each collision shown below, circle the appropriate set of arrows to indicate which direction the cars and riders move immediately after impact. Assume the masses of riders A and B are equal.



This question taken from Amusement Park Physics With a NASA Twist EG–2003–03–010–GRC

Estimate velocity of a car when at top speed.

Calculate the momentum of a car at full speed (be sure and account for the driver & passenger).

The cars have a rubber bumper filled with a large inflated inner tube. Compare what the collisions would be like if there was no bumper at all or a very soft bumper like clay. Explain your thinking

Do you think that the collisions are perfectly elastic? Justify your answer.

Assume that each car is identical, and acts as a resistance in parallel. How much total current is drawn during the ride? (Assume 20 cars are running)

Power Surge

Describe what happens to you at the bottom of the hill when the boat splashes. (More than you get wet!)

Estimate the mass of a fully loaded boat. m = ________ kg

Determine height of the lift hill h = _________ m

Calculate the Potential Energy at the top of the hill.

PE = ________ J

Calculate the velocity at the bottom of the hill, before the splash.

v = _________ m/s

Time how long the splash/surge lasts. The boat comes almost to a stop, then begins to float back to the loading area. t = _________ sec

Calculate the average force it takes to slow the boat during the splash. Use impulse.

F = _________ N

Wait, Wait, Wait!

Many of the rides in the park have queue lines like "mazes" in which people wait in line to ride the ride. Choose one such ride and analyze the waiting time.

Choose a ride that has a long line potential. Sketch the layout of the waiting area.

Ride:______________________________

Diagram of Waiting Area:

Data to collect:
Determine guest capacity of the ride (riders/hr)

count # seats
time ride
time load/unload

Ride capacity: ________riders/min _______ riders/hr

1. Identify a place in the waiting line from which you will estimate waiting time.
2. Count the number of people ahead of a person in line at your chosen location.
3. Estimate the waiting time, and show how you arrived at your estimation.
4. Observe 2-3 ride cycles (this can be done while waiting in line). Record how many passengers actually get on each time. Calculate the typical percentage of the ride that is filled.
5. Assume 0.8 m for a person's "space". Calculate length of a queue line for your ride with a wait time of 10 minutes. Explain your thinking.

6. You must be back at the gate to meet your class in half an hour. You are at the end of a long line. After a quick count you realize you are the 100th person in the line. Will you be able to ride and get off in time to meet your class? Show your thinking and calculations.

Interesting fact:

The lines we wait in are called queue lines. Queue is a term borrowed from the French in about 1748. It literally meant "tail", from the Latin cauda.

queue ***noun*** \ˈkyü\
:a braid of hair usually worn hanging at the back of the head
: a line of people who are waiting for something
: a series of instructions that are stored in a computer so that they can be processed later

www.merriam-webster.com

Round and Round We Go!

Charts and graphs are used to help keep track of many things we see and use. It is an important skill to be able to use charts and graphs to gather and interpret information. See how you do with this information from some of the circular rides you saw or rode at **Six Flags Fiesta Texas.** Your teacher may ask you to complete this assignment back at school.

Ride	Circumference	Diameter	Radius
Crow's Nest (Ferris Wheel)	**77.56 m**	**24.7 m**	**12.35 m**

Carousel	**65.94 m**	**21 m**	**10.5 m**
Wagon Wheel	**45. 84 m**	**14.6 m**	**12.3 m**
Whiriligig (Swings)	**35.48 m**	**11.3 m**	**5.65 m**

Describe the relationships between radius, diameter and circumference. It might be helpful to draw a graph with diameter or radius on the x-axis and circumference on the y-axis. Include a sketch of your graph.

Generate a formula for finding the circumference of a circular object from the radius or from the diameter.

Find the circumference of a ride given a radius of 11.2 m. What type of ride you think this might be.

Miscellaneous Questions

Have you ever stopped to think about how things work? There are simple machines around us everywhere, especially in a theme park. At the entrance to the Road Runner Express ride, before you walk up to get in line, there are examples of simple machines. Choose two or three, draw them and explain how they work.

Pick two different things from anywhere in the park that could be considered as different systems (one very large and one very small). Describe each one and identify all the parts that make it a system. Pick two different systems from anywhere in the park that interact with each other. Describe each system and describe how they interact and influence each other.

There are examples, all around us, of natural and manmade things breaking down or deteriorating (called weathering) because of their exposure to various outdoor conditions. While at the park look for as many examples of both chemical and physical weathering as you can find. Write down where you saw them. (Be specific. Did you see them on buildings, rocks, rides, etc.?) Describe what they looked like.

Fiesta Texas is built on an old abandoned limestone quarry site. Many quarries are located in the San Antonio area. Why is this so? What is a quarry and why is it important to the city's economy? Are other limestone quarries still operating in San Antonio?

Legal Notices

Workbook written by:

Rick Rutland

Five Star
Education Solutions

A Special Thanks to:

Vernier

Last Updated March 2014