Six Flags Great Adventure Physics Packet

Groups Members - Physics teacher’s name:

_______________________ ____________________________

_______________________ ____________________________

_______________________ ____________________________

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MAKING MEASUREMENTS AND CALCULATING ANSWERS

Most measurements can be made while waiting in line for the ride, such as timing specific events. Acceleration Meter readings must be made during the course of the ride. Be sure that the Acceleration Meter is securely attached to your wrist using the rubber band or safety strap while using it during the ride.

The workbook is designed for you to answer each question using your knowledge of Physics to find an exact answer. There are also multiple choice answers that are provided to help you determine if your calculated answer is appropriate. **Realize that the answer you calculate may not / should not exactly match a potential multiple choice answer.** These potential answers have been created using actual measurements from previous years. Therefore, you should choose the multiple choice answer **that most closely matches** what you have calculated using your measurements. **Provide your exact solutions in the box provided** and show the accompanying work and calculations in the space provided for that question.

Instructor note: students will have to use specific given mass assumptions so that the multiple choice answers will work. Also, the assumption is that the Acceleration Meter readings that the students record will give comparable to established values.

ACCELERATION FACTORS

Acceleration Factor (AF): An acceleration factor enables you to express the magnitude of an acceleration that you are experiencing as a multiple of the acceleration due to gravity. This is also referred to as the g-force (even though we are not actually measuring force) or simply how many “g’s.” This acceleration is usually the result of the ride’s seat pushing on you to hold you up or change the direction that you are moving.

Acceleration Factors are very useful in making our measurements because while all riders will experience different forces while riding (because the force is dependent on rider mass, which varies person to person) each rider will experience the exact same acceleration.

If a rider needs to determine the individual force that they feel while riding they simply need to multiply their mass by their measured acceleration factor. For example, while standing still everyone experiences an acceleration factor of 1g (the acceleration due to gravity) and therefore the force acting on any person in this scenario is: $F_g = mg$ where g = the acceleration factor and m is the mass of the person.

To measure an Acceleration Factor: The Acceleration Meter **must be held in the direction of acceleration**. If you are moving in a circle, the Acceleration Meter should be pointed so that it is pointed towards the center of the circle. (This is considered the positive direction for circular motion.) **For most rides you will simply need to hold the acceleration meter perpendicular to the floor of the train/ride.**

EXAMPLES OF HOW TO USE AN ACCELERATION FACTOR

When you measure an Acceleration Factor:

EQUAL to 1, you feel **NORMAL. RIGHT NOW** you feel a force on your seat exactly equal to your weight as the seat supports you.

GREATER than 1, you **FEEL HEAVIER** than normal and feel pressed into the chair. In reality, the chair is pressing up on you which you interpret as being pushed down.

LESS than 1, you **FEEL LIGHTER** than usual and can feel as if you are almost lifting out of the chair. For example, this is how you feel when an elevator starts down suddenly. It is possible to have acceleration factors that are less than zero (negative) where you would feel like you are being thrown upwards (you would lose contact with your seat), however the acceleration meters are not capable of measuring this quantitatively.

For example: On a certain ride a 50 kg girl uses the acceleration meter to record an Acceleration Factor of 3. This corresponds to an acceleration of 3 g’s - three times the acceleration of gravity.

- What is acceleration that she is feeling as measured in m/s^2?
  - $3 \times 9.8\ m/s^2 = 29.4\ m/s^2$
- How heavy does this rider feel while experiencing this acceleration factor?
  - $F = ma = (50\ kg)(29.4\ m/s^2) = 1{,}470\ N$

USING THE ACCELEROMETER AND OTHER MEASURING TOOLS

There are three main tools you will need to make your measurements required to complete the questions in this workbook. You will need (at a minimum):

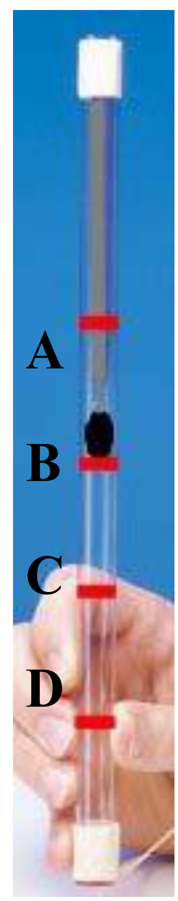
- Acceleration Meter
- Angle Meter
- Stopwatch / Timer

The Acceleration Meter (Accelerometer) and Angle Meter can be purchased from www.Pasco.com or they can also be homemade with a little ingenuity. If a stopwatch is not available, most cell phones have this functionality built in - just make sure it is capable of timing to the tenth of a second.

Acceleration Meter

Angle Meter / Horizontal Acceleration Card

Stopwatch



To use the Acceleration Meter hold it in the direction you are trying to measure. Most of the accelerations that you will measure are the result of going in a circle, so you would hold the meter with the top end pointed towards the center of the circle you are moving in. In most cases this will be perpendicular to the floor of the ride/roller coaster train.

The Acceleration Meter is usually a plastic tube with a mass suspended from a spring. There should be markings on the side of the tube in order to determine the acceleration reading. In the figure to the right the mass is the oval shaped dot in the tube. The person holding this tube is at rest, so the mass is at (B) and the net acceleration they feel is 1g - 9.8 m/s^2 - the acceleration due to gravity.

When on a ride, if the mass falls down to the second mark (C) that indicates that the rider is feeling an acceleration of 2g - 19.6 m/s^2. At the third mark (D) the acceleration would be 3g - 29.4 m/s^2. Most acceleration meters should have markings down to at 4g.

When riders feel lighter than they normally would (such as in freefall, or going over the top of a 'camel hump' on a roller coaster) the mass will move upwards to record an acceleration less than that of gravity. At point (A) on the meter the rider would feel 0g - 0 m/s^2 - weightlessness. It is also possible that the riders can experience negative g's while riding (the feeling of being thrown upwards and out of the seat), however these acceleration meters are not capable of measuring negative g's and will simply show 0g.

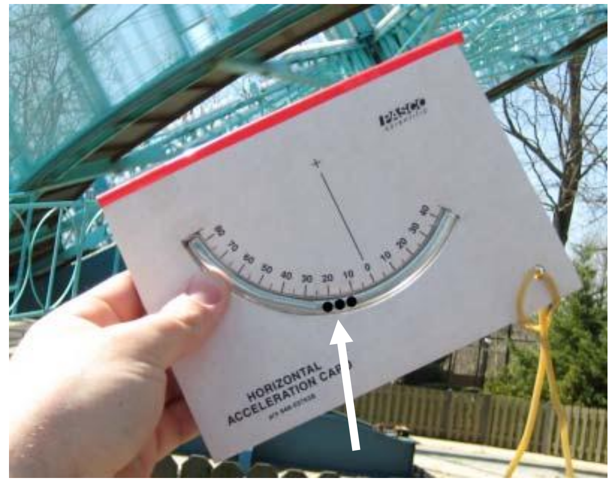
MAKING MEASUREMENTS

Angle Meter / Horizontal Acceleration Card:

Hold the Angle Meter so that its top or bottom side is parallel to the angle you are trying to measure.

There are three ball bearings inside the plastic tube that will move to indicate the angle. Record the angle value for the MIDDLE ball bearing.

On roller coasters you should be able to place the angle meter on the side armrest of the train to measure the angle.



Measuring the time for a train to go over the top of a hill:

You will need to make a time measurement using your stopwatch to determine how long it takes a roller coaster train to pass a particular point.

Choose a fixed point on the hill - it should be the highest point. (See arrow in figure on left)

Start the stopwatch when the front of the train reaches your chosen point.

Stop the stopwatch when the rear of the train passes your chosen point.

You can calculate the train's velocity using your measured time and the length of the train. $v = d / t$

Measuring the time to go up a lift hill:

Begin the stopwatch when the train reaches the base of the lift hill, and stop it when it reaches the top. (See arrows in figure on right)

You can either make your measurement using the front of the train or the rear of the train as your reference point - but choose one and stick with it.

Do not start the measurement when the front of the train begins up the hill and stop it when the rear of the train reaches the top!

FREE BODY DIAGRAMS AND NEWTON'S 2^{ND} LAW IN CIRCULAR MOTION

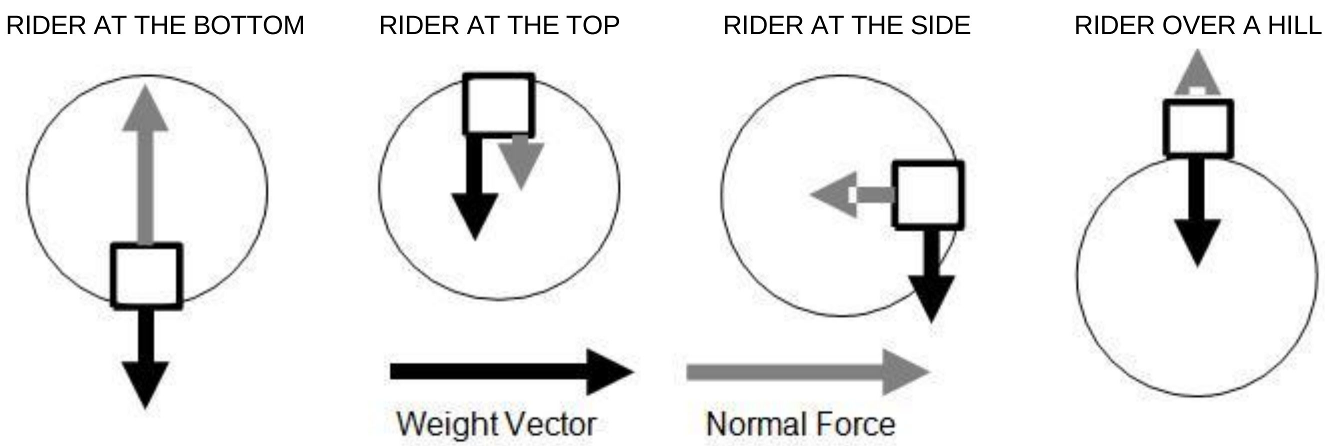
In order for an object to move in a circle, there must be some force acting on it that is pointed towards the center of the circle (the radial direction). The purpose of this force is to change the direction of the motion the object. In order to determine how large this unbalanced radial force must be, Newton's second law is applied.

$$\Sigma F_R = \frac{mv^2}{r}$$

- F_R is the radial force; the positive direction for this force is towards the center of the object's circular motion.
- m is the mass of the object moving in circular motion
- v is the linear velocity of the object
- r is the radius of the object's motion as it travels in circular motion

When a person on a ride experiences circular motion (as on a roller coaster) the major forces acting on them are their weight and the contact force between the person and their seat. Summing these forces allows for the radial force to be determined, from which other information (such as velocity or radius of motion) can be determined.

The key to correctly analyzing forces for riders in circular motion is drawing the proper free body diagram. Some sample free body diagrams for riders at different points are shown below:



The Acceleration Meter readings that you will take while riding tell you the amount of "g-force" that is acting on your body. One "g" is equal to the acceleration due to gravity. Two "g's" is twice the acceleration due to gravity, and so on. When you are at rest or moving at constant velocity the net acceleration acting on you is 1g acting on you (this is the regular force you feel due to the Earth's gravity). When your body is accelerated by a ride the force on you is increased due to this acceleration. Since every rider on a ride is accelerated at the same rate, but do not feel the same force (because each rider has a different mass, and F=ma) it is very convenient to use "g-force" to analyze forces when solving problems.

The reading you take with the Acceleration Meter tells you what force you feel acting on your body. If the meter reads 2 g's, then you feel a net acceleration double that of gravity and therefore you feel twice as heavy.

Equations

Kinematics

$v = d/t$

$v_f = v_i + at$

$d = v_i t + ½ at^2$ d is negative for bodies traveling downward

$v_f^2 = v_i^2 + 2ad$

$d = ½ (v_i + v_f)t$

$a = g = -10\ m/s^2$ in freefall

Dynamics

$F_{net} = ma$

$W = mg$ $g = 10\ m/s^2$

Vectors

Given vector **A**

$A_x = A \cos\theta$ = Horizontal component of **A**

$A_y = A \sin\theta$ = Vertical component of **A**

Graphical Method of Finding the Resultant:

Scale vectors to the available space. Repeatedly place the head of one vector to the tail of another vector until all vectors are connected. The resultant is drawn from the tail of the first vector to the head of the last vector. The tail of the resultant is at the tail of the first vector; the head of the resultant is at the head of last vector. Measure the resultant length and direction. Convert scale to the original dimensions.

Vector Resolution Method of Finding the Resultant:

$R_x = A \cos\theta_A + B \cos\theta_B + \ldots$

$R_y = A \sin\theta_A + B \sin\theta_B + \ldots$

$R = \sqrt{(R_x)^2 + (R_y)^2}$ $\theta = \tan^{-1}(R_y/R_x)$

R= R, θ

Inclined Plane Forces:

$W_{\|} = W \sin\theta$

$W\perp = W \cos\theta$

$N = W\perp$ With no additional vertical forces.

Inclined Plane Acceleration:

$a = g \sin\theta$ On a frictionless surface.

$g = -10\ m/s^2$

Percent Error

$$\%\ \text{error} = \frac{|\text{actual value} - \text{calculated value}|}{\text{actual value}} \times 100$$

Circular Motion

$$T = \frac{1}{f}$$

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

$$a_c = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2} = 4\pi^2 r f^2$$

$v = \sqrt{rg}$ $g = 10\ m/s^2$

$F_c = ma_c$

Momentum

$I = Ft$

$p = mv$

$\Delta p = mv_2 - mv_1 = m(v_2 - v_1) = m(\Delta v)$

$Ft = \Delta p$

Work, Power, and Efficiency

$W = Fd$

$P = W/t = Fv$

$$\%\ \text{efficiency} = \frac{W_o}{W_i} \times 100 = \frac{P_o}{P_i} \times 100$$

Energy

$KE = ½ mv^2$

$\Delta KE = KE_2 - KE_1 = ½ mv_2^2 - ½ mv_1^2$
$= ½m(v_2^2 - v_1^2)$

$Fd = \Delta KE$

$PE = mgh$ $g = 10\ m/s^2$

$\Delta PE = PE_2 - PE_1 = mgh_2 - mgh_1 = mg(h_2 - h_1)$

$PE_1 + KE_1 = PE_2 + KE_2$

Trigonometry Functions

$$\sin\theta = \frac{opp}{hyp} \quad \cos\theta = \frac{adj}{hyp} \quad \tan\theta = \frac{opp}{adj}$$

$$\theta = \sin^{-1}\frac{opp}{hyp} \quad \theta = \cos^{-1}\frac{adj}{hyp} \quad \theta = \tan^{-1}\frac{opp}{adj}$$

Reference Page

1.00 m = 3.25 feet
1.0 km = 0.62 mi
1.0 N = 0.22 lb
1.0 kg = 2.2 lb
1.0 hr = 3600 s

1) Show conversion of mi/hr to m/s.

1.0 mi/hr = __________ m/s

Show conversion of m/s to mi/hr

1.0 m/s = ___________ mi/hr

2) List the weight of any group member whose weight and mass will be used for a ride calculations. Convert the weight to Newtons and kilograms.

Person 1: ________________ lb = ________________ N = ________________ kg

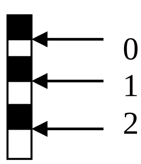
Person 2: ________________ lb = ________________ N = ________________ kg

Person 3: ________________ lb = ________________ N = ________________ kg

3) Walk a certain distance keeping track of the number of steps taken. Measure the distance traveled. Find the distance in one step. This can be accomplished at school at some time before or after the trip.

1 step = ________________ m

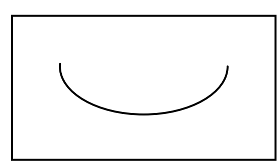
Vertical accelerometer



The vertical accelerometer measures the ratio of normal force to weight. This is called **a force factor**. The meter reads '1' at constant velocity.

Force factor = normal force÷weight

Horizontal (Lateral) Accelerometer



Measuring angles
Align the edge of the accelerometer to the edge of an angled ride. Read the angle from the accelerometer.

Measuring acceleration
$a = g \tan \theta$
Hold accelerometer horizontally while accelerating, then read angle of ball.

General guidelines

- Read carefully the whole packet before the day of the trip to understand the requirements.
- Where applicable, complete portions of the packet before arriving at the park.
- All of the first portion of the packet must be completed.
- One packet is needed for each different student's teacher per group.
- The packet is due when specified by your specific teacher.
- Choose another ride and activity if a ride's wait time is excessively long.
- It is imperative that you are on the bus by the specified time.
- **ENJOY!**

- **TRIP SPEED and VELOCITY (Are we there yet?)**
  Find out the bus odometer reading before the bus pulls out of the school parking lot. Record the time when the bus pulls out onto Grove Avenue. Record the time when the bus pulls up to the parking booth at Six Flags. Obtain the odometer reading when the bus pulls into the parking lot. Record the time when the bus pulls out of the Six Flags parking lot. Record the time when the bus pulls into the J.P. Stevens H.S. parking lot and record the odometer reading.

Odometer reading at school: __________ mi Time leaving school: _____________

Odometer reading at Six Flags: __________ mi Time returned to school: __________

Distance traveled: ___________ mi ___________ km

Time difference: ___________ min ___________ hours

Calculate speeds and velocities in this section in km/hr.

a) What is the average speed traveling to the amusement park?

b) What is the average speed traveling back to J.P. Stevens H.S.?

c) What is the average speed for the entire trip?

d) What is the average velocity for the trip? ___________________

e) Discuss the difference between average speed and average velocity?

- Ask the bus driver for permission to measure the speed from 0 to 15 mi/hr. Time the amount of time necessary for the speed change. Find the acceleration in m/s^2.

  Time to change speeds from 0 m/s to 15 mi/hr: ___________ s

  15 mi/hr = _________________ m/s Acceleration: _______________ m/s^2

  What percent is this acceleration of the acceleration due to gravity?

- **BUS SPEED DURING AN INTERVAL OF TIME (Are we speeding?)**

  While traveling continuously on a stretch of the turnpike, record your location from a mile-marker. Time how long it takes to travel at least two miles from that location.

  Initial position: ___________ Final Position: ____________ Time: ____________ s

  Distance: ___________ mi = ___________m Bus' Speed: ______________ m/s

  a) To determine if the bus is speeding convert the bus speed in m/s to mi/hr.

  b) Is the calculated speed a constant or average speed? Briefly explain.

  c) How does the above calculated speed compare to the average speed for the trip?

  d) Do you expect this speed to be greater or less than the average speed for the trip? Explain.

- Observe near and distant stationary objects while traveling on the turnpike. What is noticed about the rate of position change of near objects compared to distant objects?

- While rounding a curve or making a turn traveling to the amusement park, take note of your body lean.
  a) Does your body lean in the same direction or opposite direction of the turn?

  b) Why specifically does your body follow bus along the curve?

  c) What is the name of the force that causes you to round the curve?

At the park:

- **DISPLACEMENT**
  Refer to the Great Adventure Map located at the end of the packet. Use a scale of 1.0 cm = 30 m. Record the first three rides visited in the amusement park. At a later time, find and record the displacement between each location by drawing a displacement vectors on the map. Write the location number on the Great Adventure map. The park entrance will be the reference point used to determine the total displacement. The park entrance on the map is indicated with a '+'. Draw a vector indicating the total displacement. Measure the total displacement. **The map is located at the end of the packet.**

Location Number	**Ride**	**Displacement from previous position**	
		Magnitude (m)	**Direction (°)**
1			
2			
3			

a) What is your total displacement (magnitude and direction)? ______________________

b) Is the total displacement the same as the total distant traveled from the fountain to the third ride? Briefly explain.

- **ROLLER COASTER SPEED NEED**
  Time any three of the following roller coasters. Record the amount of time taken by the coaster car to make one complete trip. The roller coaster time can be recorded without riding the roller coaster. The track length of the roller coasters is as follows.

Superman: 840 m	**Nitro: 1640 m**	**Batman: 820 m**
Kingda Ka: 950 m	**Medusa: 1220 m**	**El Toro: 1350 m**
Scream Machine: 1160 m	**Runaway Train: 740 m**	**Skull Mountain: 420 m**

a) Roller Coaster : ____________________________ Time: ________________

Speed of Roller Coaster : ___________________

b) Roller Coaster : ____________________________ Time: ________________

Speed of Roller Coaster: ____________________

c) Roller Coaster : ____________________________ Time: ________________

Speed of Roller Coaster : ___________________

Do the speeds calculated represent a constant or average speed? Briefly Explain.

- **Dive into the *DAREDEVIL DIVE* (BUNGEE CORD DIVE)**
  Visit the *Daredevil Dive* at three different times and record the times. Record the amount of time taken for three complete oscillations (back and forth motion). Record this time and find the period for one oscillation.

Time 1: ___________ Time for 3 oscillations: ___________ Period: __________

Time 2: ___________ Time for 3 oscillations: ___________ Period: __________

Time 3: ___________ Time for 3 oscillations: ___________ Period: __________

Considering the high improbability of having equal mass at the end of the bungee cord during all three times, does mass affect the period of oscillation? Briefly explain.

- **CAROUSEL *CONNECTIONS***
  Visit the carousel (merry-go-round).
  a) Observe and record its period of rotation.

  Period of rotation: ____________

  b) Observe and record the number of oscillations (up and down motions) made by a horse in a given period of time. It may be necessary for someone to actually ride the horse to count the number of oscillations. Find the frequency of oscillation of the horse.

  Number of oscillations: __________ Time of oscillations:__________ s

  Frequency of oscillations: ___________

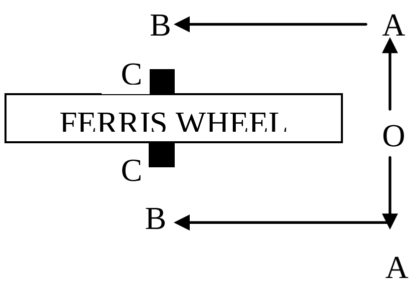
  c) Observe the motion of a horse. Indicate below to the left with arrows, the vertical motion of the horse as observed by a spectator of the ride. Indicate below to the right with an arrow, the horizontal motion of the horses.

  d) Sketch the shape of the path traced out by the horses?

  e) What type of wave motion is simulated by the carousel horse motion?

  f) Is the inner or outer portion of the carousel moving with a greater tangential speed?

- **DETERMINING THE TANGENTIAL SPEED OF THE FERRIS WHEEL**
  Visit the Ferris wheel. Due the railings that surround the Ferris wheel, the following procedure should be used to determine the Ferris wheel's radius. See the diagram below. Start at point O. Walk perpendicularly away from the Ferris wheel in either direction to point A, keeping count of the number of footsteps. Walk from point A to point B, parallel to the Ferris wheel, so as to be in direct line with the center of the Ferris wheel. Face the center of the Ferris wheel. Aim the lateral accelerometer towards the center hub (point C) of the Ferris wheel and record the angle registered by the accelerometer. Find the amount of time for one continuous complete rotation of the Ferris wheel.



Number of steps between OA: ___________

Distance of each step: ________________

Distance OA: _______________________

Angle to Ferris wheel top: _____________

Ferris wheel radius: __________________

Period of rotation:____________ Ferris Wheel tangential speed: ___________

Ride the Ferris wheel.

a) Do you feel heavier while the carriage is traveling up or down?

b) When do you feel your normal weight while the Ferris wheel is in motion?

c) View the Ferris wheel from one side and then the other. Note and record the direction of rotation from each view.

MISCELLANEOUS 'MUSEMENT MUSINGS

A)

Look closely at the man at the front of the ride. Who is it? You are correct if you guessed Mick Foley (a.k.a. Mankind, Cactus Jack) of World Wrestling Entertainment.

Mick Foley has a mass of 130 kg.

i) What is Mick's weight? ________________ N

ii) What is the normal force exerted on Mick by the seat?

iii) Graphically add N and W to scale and find the resultant.

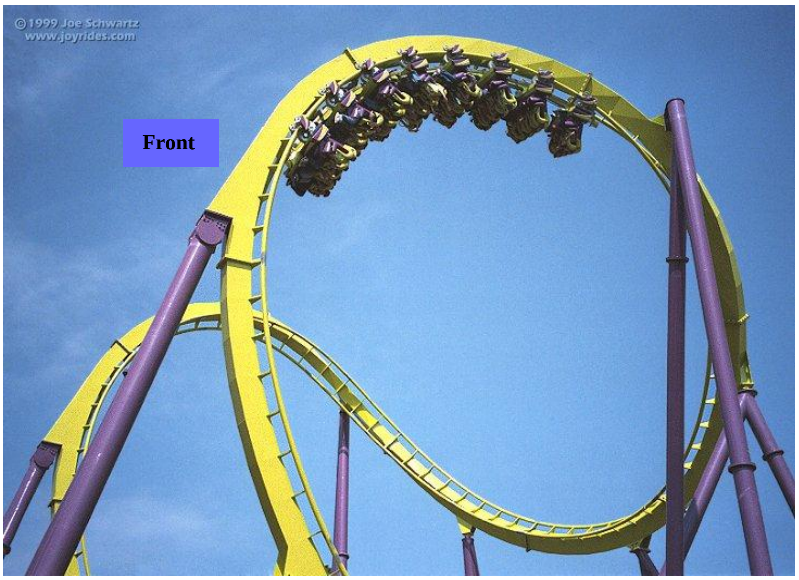
Graphical addition work space.	Scale:

iv) What is the resultant force magnitude? Call this F_R. ____________________

v) Does the resultant force direction match the impending motion of the cars?

vi) What is the instantaneous acceleration magnitude? $a = F_r/m$

B) Medusa Musings



Use the pictures to draw the vectors for each case.

i) Draw a vector to represent the tangential velocity at the center of the train of cars. Label this arrow v_t.

ii) Draw a vector to represent the centripetal force acting on the front of the train of cars. Label this arrow F_c.

iii) Draw a vector to represent the centripetal acceleration at the rear of the train of cars. Label this arrow a_c.

C)

Observe several roller coasters in the amusement park with inversions.

i) Sketch the shape of several loops of various roller coasters.

ii) Is the centripetal acceleration constant on the loop? Briefly explain.

Pick any five (5) of the following activities.

Sequentially number the selected activities by placing a number inside each box.

☐

"KONQUERING" KINGDA KA

Kingda Ka is the tallest and fastest rollercoaster in the world, rising to a height of 456 feet and obtaining a speed of 0 to 128 mi/hr in 3.5 seconds.

a) What is the height of Kingda Ka in meters?

b) What is the top speed in m/s?

c) What is the acceleration of Kingda Ka in m/s^2?

d) What multiple is this acceleration to the acceleration due to gravity? ___________

e) ***Hypersonic*** in Kings Dominion, Virginia accelerates from 0 to 90 mi/hr in 1.8 seconds. Which ride has the greater acceleration? Show calculations to support your answer.

f) What force value is exerted on a rider in the seat of Kingda Ka during its initial acceleration?

g) Time and record the amount of time necessary to rise to the apex of the curve and fall to the base. What is the speed of the car when it reaches the base?

Time to top: __________ s

Time to base: __________ s

Speed at base: __________ m/s

Calculate speed:

h) Should you expect these times to be equal? Why or why not?

i) Does the calculated speed make sense? Why or why not?

f) What is the acceleration of the car as it ascends towards the apex of the curve?

g) Is the car in freefall when it descends from the apex of the curve? Why or why not?

h) Using the distance fell, time, and $d = v_i t + \frac{1}{2} at^2$. Find a.

h) What is the feeling as the car approaches the apex of the curve?

Lighter **Heavier** **Same**

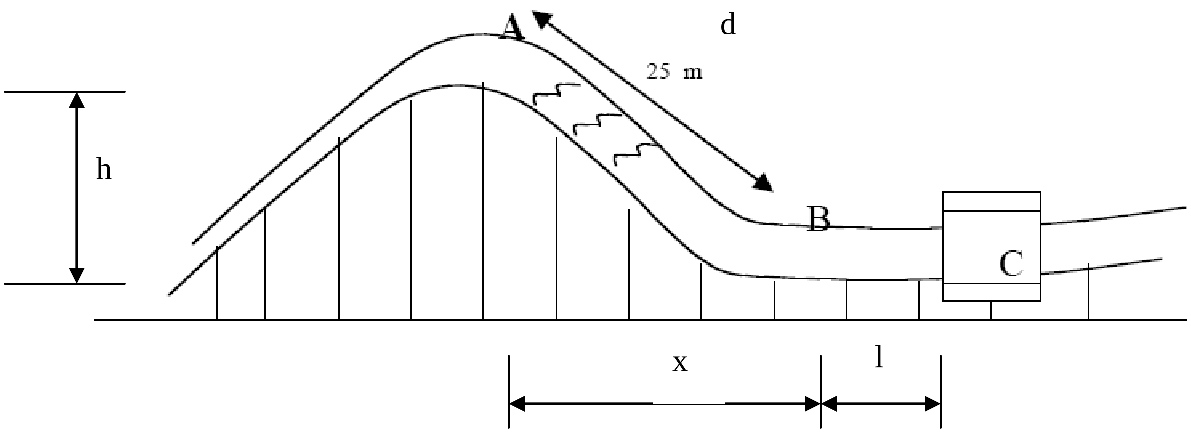
i) What is the feeling at the car descends from the apex of the curve?

Lighter **Heavier** **Same**

j) What is the feeling as the car goes over the smaller curve camel hump?

Lighter **Heavier** **Same**

☐ **SPLASH ONTO THE LOG FLUME**



Consider the mass of the flume to be 350 kg. Use an average mass of 60 kg for each person in the flume.

a) How many people are in the flume being observed? __________

b) What is the total mass of the flume with its occupants? ___________________ kg

c) Determine the height of the log flume by walking horizontally between points A and B. Use the Pythagorean to determine the height. Use trigonometry to determine the angle.

Number of steps taken: __________ x = horizontal distance walked: ___________ m

h = Log flume height = __________ m θ = angle of log flume incline: __________ °

d) Determine the speed of the log flume at the bottom of the drop using the energy method ($KE_1 + PE_1 = KE_2 + PE_2$). Use the mass from step b.

e) Determine the speed of the log flume from $a = g \sin \theta$. Then apply $v_f^2 = v_i^2 + 2ad$. The length of the incline of the log flume is'd'.

f) Time the amount of time necessary for the log flume to splash from the top of the hill.

t = time for the log flume to splash from the top of the hill: __________ s
Use $d = \frac{1}{2}(v_i + v_f)t$ to find the speed at which the log flume splashes.

g) Do all of the methods of finding the speed agree? If not, what may be some reasons they do not agree?

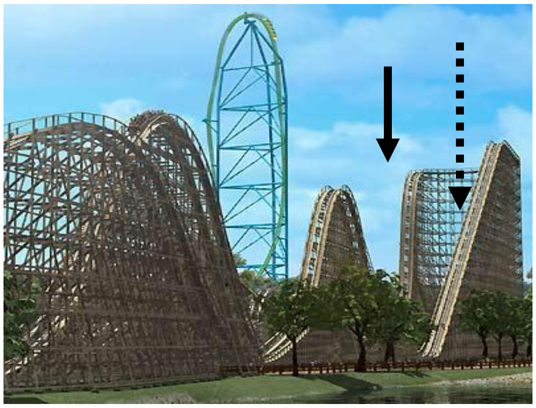
h) What is the observed motion of the riders when the flume splashes down? Explain.

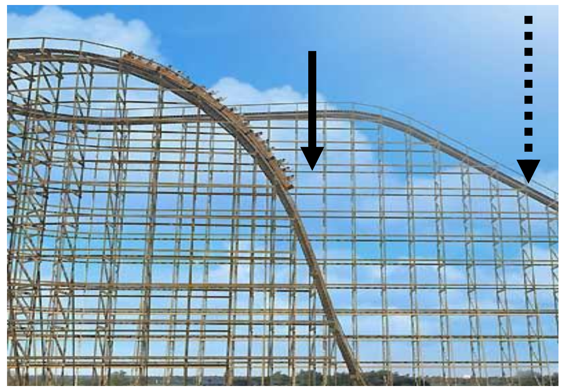
i) What is the motion of the log flume after splashing down?

j) Does the momentum change of the splashed water equal the momentum change of the flume?

k) Do you expect the water to be moving faster than the flume at splash down? Explain.

☐ **TAME *EL TORO* (THE BULL) #1 (Up the incline)**





El Toro has the steepest drop of any wooden rollercoaster in the world and is the third tallest (188 ft) and fastest (70 mi/hr) wooden rollercoaster.

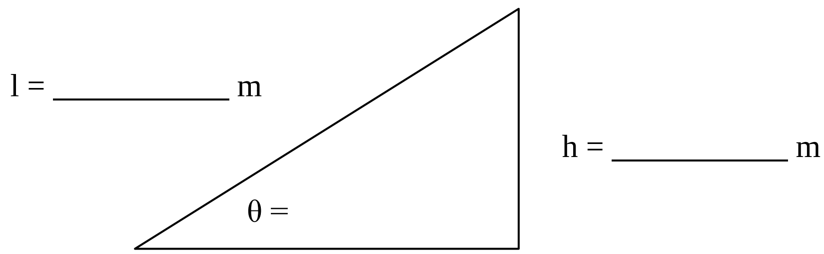
a) Use the lateral accelerometer to find the angle of the first incline, indicated with the dashed arrow.

θ = __________

b) The train is towed up the first incline at 15 mi/hr. What is this speed in m/s?

c) Time the amount of time needed to bring the train up to the top of the first incline.

d) From the speed of the train of cars and the time to the top of the incline, determine length of the first incline? Call this dimension l.



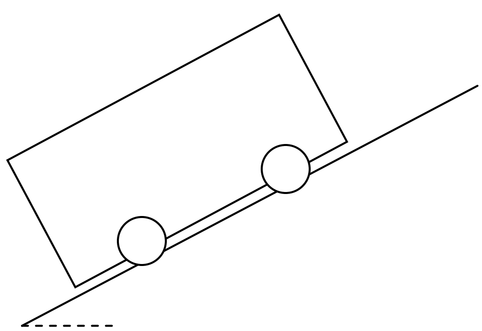
e) Label the diagram above with the missing information and calculate the height (h).

f) The actual height of El Toro is 188 ft. Convert this to meters.

g) What is the percent error between the calculated height and the actual height?

h) What are some reasons that may account for any discrepancy?

i) Label the diagram with the forces acting on a single car while traveling up the first incline?



h) The car is being towed up the incline at constant speed. What can be said about the net force acting on the car while it is being towed up the incline?

☐ **TAME *EL TORO* (THE BULL) #2 (…and away we go!)**

a) Use the lateral accelerometer to determine the angle of the first drop, indicated on the various diagrams above with a solid arrow. Call this θ.

θ = ________________ °

b) Time the amount of time necessary to reach the base of the incline. Call this time, t.

t = ______________ s

c) What is the mass of a rider on El Toro? m = ___________________ kg

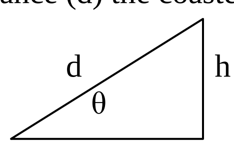
d) On an incline, the force due to gravity acting on an object is $W_{||} = W \sin \theta$. Find the parallel component of gravity acting on a rider during the first drop.

e) The impulse-momentum theorem says that an impulse on an object causes a change in momentum of the object. In equation form: $Ft = mv_f$, assuming that the object starts from rest. $F=W_{||}$. What is the speed of the person (and train) at the base of the hill?

f) The height (h) of El Toro is 188 ft. What is the height of El Toro in meters?

g) The distance, d the coaster travels down the incline can be obtained from the ride height, and angle of the incline. What is the distance (d) the coaster travels down the first hill?

d = ____________________ m



h) The work-kinetic energy theorem says that the work done on an object changes the kinetic energy of the object. In equation form: $Fd = \frac{1}{2} mv_f^2$, assuming that the object starts from rest. $F=W_{||}$. What is the speed of the person (and train) at the base of the incline?

i) Should the speed calculations using each method agree? (YES or NO)

j) The actually speed at the base of the incline is 70 mi/hr. What is this speed in m/s?

k) What is the percent error using the actual speed as the reference value?

Impulse-Momentum Theorem	Work-Kinetic Energy Theorem

l) Account for discrepancies between the actual and the calculated speeds.

m) What is the PE was lost by a rider at from the top to base of the first drop?

n) Use a vertical accelerometer on the ride.

Use the reading of **<u>less than one,</u>** **<u>equal to one</u>**, or **<u>greater than one</u>** to describe the reading at the various points.

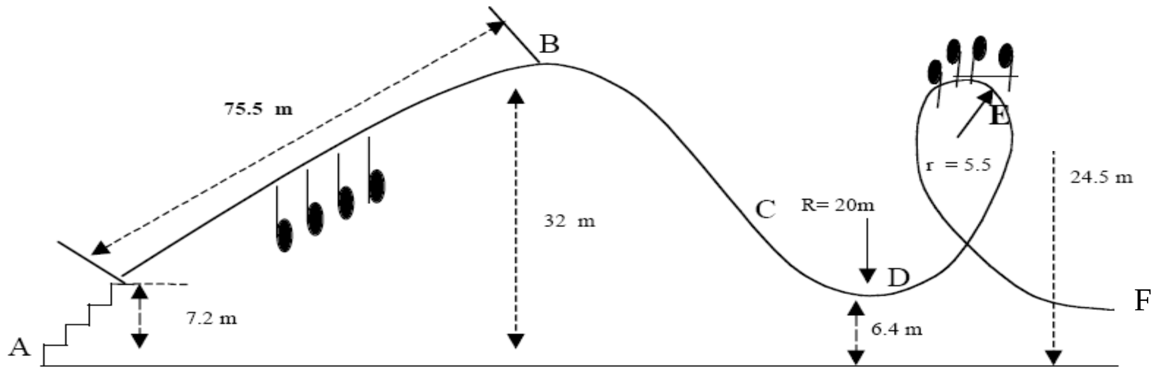
i) What is the reading while being towed up the first hill? ___________________________

ii) What is the reading while traveling down the first hill? ___________________________

iii) What is the reading while traveling up the second hill? ___________________________

iv) What is the reading at the top of the second hill? ________________________________

☐ **BATMAN**



All heights are measured from the reference level. The train of cars length is 18 m.

Take a vertical accelerometer onto the ride.

a) For Batman to save the day, what is the minimum speed needed for the train of coaster cars to round the vertical loop?

b) Determine the speed of the cars while rounding point E.

t = time for the length of cars to pass point E __________ s

v = train of cars length / t = ________________________ m/s

c) What is the mass of the person riding BATMAN? ________________________ kg

d) What is the normal force felt at the top of loop? $N=F_c-mg_{mag} = (mv^2/r) - mg_{mag}$

e) Try to read the accelerometer at point E. What did it read? ________

f) In this situation, force factor = N / mg_{mag} = N / W = ________________________

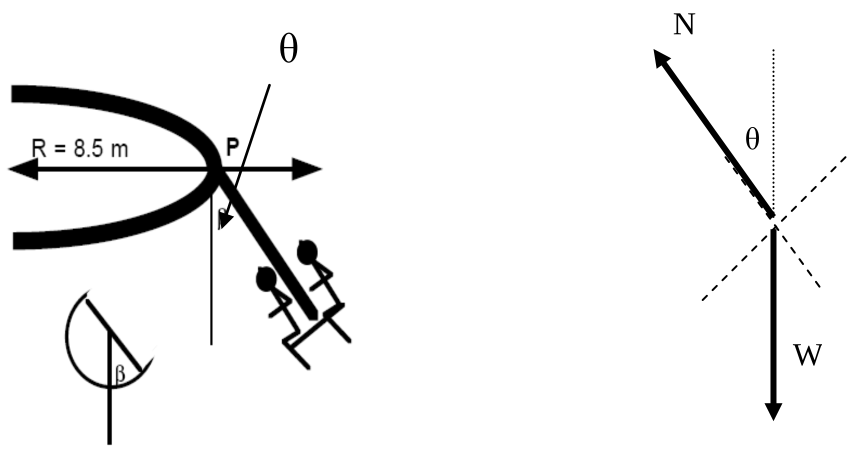
g) How close does the force factor come to the accelerometer reading?

h) At which location was the vertical accelerometer reading greatest? (B C D E F)
Why?

i) While rounding the curve do you feel you are being pulled toward its center?

YES **NO**

Explain.



Use the lateral accelerometer to measure the angle of the cars at the diagramed location.

j) θ = ____________________

k) Determine the speed of the cars while rounding the curve.

t = time for the length of cars to pass point P _____________ s

v = train of cars length / t = ___________________________ m/s

l) What is the centripetal acceleration of the cars? $a_c = v^2/R$

m) The normal force from the seat to the person is N. $N = W/\cos\theta$

n) Graphically add N and W below and find the resultant.

Graphical Method work space.	Scale:

o) What is the direction of the resultant?

p) What might the resultant be? ____

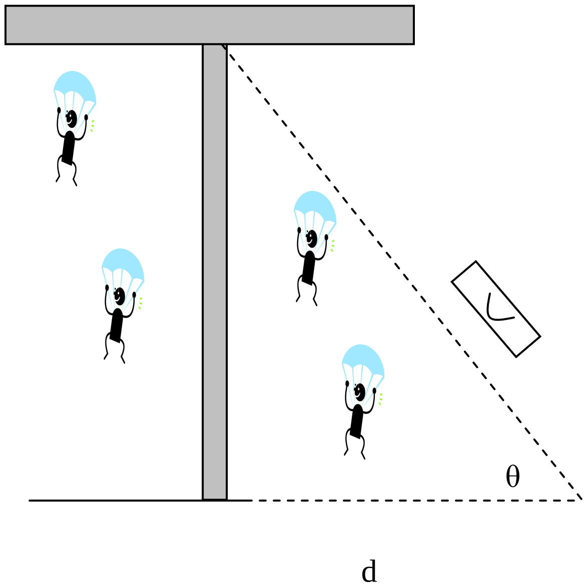
q) What is the resultant magnitude? R =____ N

r) Divide R by the mass of the person riding. What is the value with units?

s) Is R/m close to anything calculated on the previous page? ________________________

t) What is given by R/m? ____

☐



Visit the Parachute Perch ride. Measure the horizontal distance from the pole of the ride by taking several footsteps away from the ride. Record the horizontal distance from the ride. You may have to use the procedure used for the Ferris wheel because of the rails that surround the ride. Aim the horizontal accelerometer towards the top of the ride. Record the angle. Determine the height of the ride.

d = __________ θ = __________ h = __________

a) Using a single person above, draw vectors to represent the forces acting on a falling body.

b) Bring a vertical accelerometer onto the ride and hold it vertically. When the parachute is immediately released, note the motion of the accelerometer. Describe the initial motion of the vertical accelerometer bob.

c) What is the initial vertical accelerometer reading? _____________

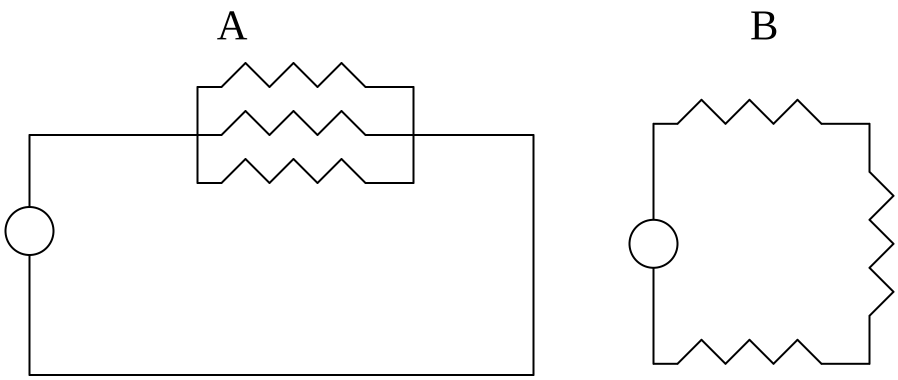
d) What is the reading on the vertical accelerometer while the parachute is falling? Briefly explain why this reading is expected.

e) Time and record how long it takes the parachute to fall to the ground. _________

f) Using a kinematics equation and the found height, calculate the time it should take the parachute to fall?

g) Is the parachute in freefall? How do you know? Use the previous calculation to partially support your answer.

BUMPER CAR BONANZA

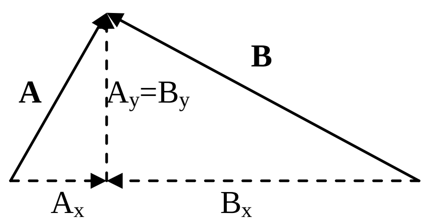


a) Which diagram above represents the circuit configuration of the bumper cars? Briefly explain why.

b) Observe the bumper cars. Is there more impact between the cars in a head on collision or by a collision on an angle? Briefly explain. (Hint: Use the diagram to aid you in your answer.)

c)

Figure not to scale



A = 150 kg m/s **B** = 400 kg m/s

An angle measurement of the vectors **A** and **B** on the diagram is necessary.

θ_A = ___________ θ_B = ___________

Use the vector resolution method to determine the resultant magnitude and direction of **A**+**B**.

d) What happens to the magnitude of the momenta of A and B as they are more horizontal?

e) Describe the motion of a person involved in a head on collision?

f) Is the resultant momentum of the system closer to vector **A** or **B**? Why?

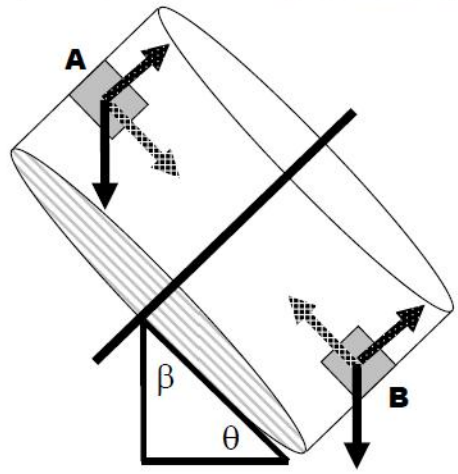
Measurements to Make:

Time for 5 revolutions at top speed: ___________

Period of Rotation: ________________________

Angle of ride to vertical at full tilt, β*: _________

Radius of ride: 6.0 meters
Rider mass: 60 kg



1) What angle (in degrees) does a rider have relative to the horizontal when the ride is at full tilt?

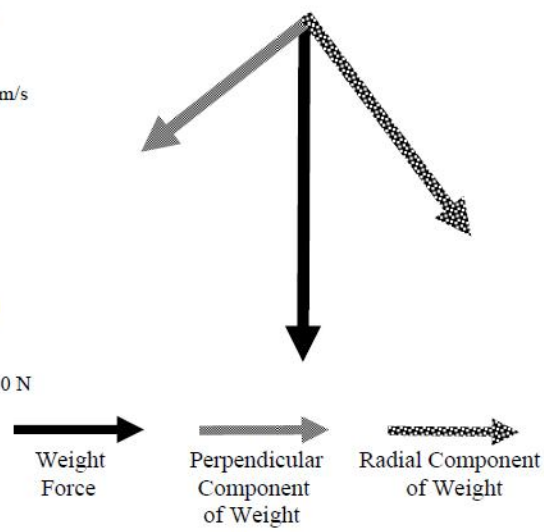
a) 5 b) 15 c) 25 d) 35 e) 55

2) What is your linear velocity, in m/s, as you are rotating at the ride's top speed?

a) 2 m/s b) 5 m/s c) 9 m/s d) 14 m/s e) 17 m/s

3) What is the net radial (centripetal) force, in Newtons, needed to keep you moving in a circle at this velocity?

a) 25 N b) 250 N c) 750 N d) 1000 N e) 1250 N



* Using your horizontal acceleration card measure the angle the ride makes with the horizontal (θ) as shown in the picture, then subtract that from 90° to find β

4) When the ride is horizontal (no tilt), the entire radial force is exerted by the wall on your back. What would be the Acceleration Meter reading when the ride is horizontal and moving at top speed (this is calculated, not measured)?

a) 0.25 b) 0.50 c) 0.75 d) 1.00 e) 1.25

For the next two questions the ride is tilted to its maximum angle, β (your measurement), and the rider is at position A (see the figure on the previous page). Your weight vector now has a component that is in the radial direction – here it is pointed towards the axis of rotation. Remember to assume that your mass is 60 kg.

5) What is the component of your weight, in Newtons, in the radial direction?

a) 25 N b) 75 N c) 150 N d) 350 N e) 500 N

6) What is the force, in Newtons, that the wall must contribute to keep you moving in a circle? (Remember that your weight now contributes to the radial force as calculated in the previous question.)

a) 50 N b) 100 N c) 250 N d) 400 N e) 550 N

For the next two questions we will examine what happens when you are at the lowest point with maximum tilt (position B in the figure on the previous page - 180° from your maximum height position). Your weight vector now has a component that is in the radial direction – but pointed away from the axis of rotation. Remember to assume that your mass is 60 kg.

7) When you are at the lowest point, what is the component of your weight, in Newtons, in the radial direction?

a) 25 N b) 75 N c) 150 N d) 350 N e) 500 N

8) When you are at the lowest point, what is the force (N) that the wall must contribute to keep you moving in a circle?

a) 500 N b) 1000 N c) 1500 N d) 2000 N e) 2500 N

9) What would the ride's minimum speed need to be, in m/s, so that you are not in danger of falling towards the ride's center when you are at position A and the ride is tilted at its maximum angle?

a) 2 m/s b) 6 m/s c) 10 m/s d) 15 m/s e) 19 m/s

10) This ride would become very uncomfortable if it was rotating fast enough so that you experienced a force of about 4 g's. When the ride is horizontal (not tilted), at what velocity, in m/s, would you experience this force?

a) 2 m/s b) 6 m/s c) 10 m/s d) 15 m/s e) 19 m/s

OPEN ENDED QUESTIONS:

LEVEL I: The ride operator thinks that the ride would be safer if he reduces the velocity at which the ride rotates. Why is this not a good idea?

LEVEL II: Show mathematically that the rider will not fall towards the center of the ride (with sufficient velocity) at a given angle θ, regardless of the mass of the rider.

Measurements to Make:

Time for one complete swing: _________

Maximum angle with the vertical: _________

Acceleration Meter Readings		
Position A	Position C	Position E

While in line record the period of the ride's motion and maximum angle with the vertical – do this when the ride is at its maximum amplitude using the ship's mast to measure against. While riding record g-force (Acceleration Meter) readings – you should sit as close to either end of the ship as possible for best results.

For the questions below answer as if you were sitting on the **RIGHT SIDE** of the ship (as you are looking at it as in the picture above). If you sat on the left side during the ride your answers will simply be opposite of what you experienced.

Position A Position B Position C Position D Position E

1) According to your Acceleration Meter, when the ride is in motion at what point in the ride do you feel the lightest?

a) A b) B c) C d) D e) E

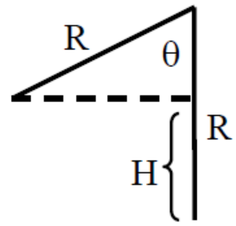
2) According to your Acceleration Meter, when the ride is in motion at what point in the ride do you feel the heaviest?

a) A b) B c) C d) D e) E

For the next six questions you will need to make calculations that require how high the rider is above their minimum height. To do this, use the conservation of energy and the fact that the radius of the ships motion is approximately 12 meters. Assume that very little energy is lost to friction. Consult the figure below that shows how to determine the rider's height above the minimum point. Theta is the angle that the ship made with the vertical as measured against the ship's mast.

3) Using your reading for the maximum angle you have made with the ground, calculate the height of the rider.

a) 3 m b) 6 m c) 9 m d) 15 m e) 20 m



4) Calculate the maximum potential energy (Position E) that a 60 kg rider has during the ship's swing.

a) 3,500 J b) 5,500 J c) 6,000 J d) 12,000 J e) 15,500 J

5) Calculate the maximum velocity that a 60 kg rider has during the ship's swing.

a) 2 m/s b) 10 m/s c) 18 m/s d) 26 m/s e) 34 m/s

6) The previous questions assumed that the rider was sitting at the center of the ship. If the rider was instead sitting on the far right or left end of the ship how would their maximum potential energy compare to a rider in the center? Explain why you made your choice.

a) It would be less b) It would be the same c) It would be more

7) If we assume that Position D is when the ship is at ½ the angle it makes with the vertical at Position E, then what fraction of the maximum potential energy will the rider have at Position D?

a) 10% b) 30% c) 50% d) 70% e) 90%

8)) If we assume that Position D is when the ship is at ½ the angle it makes with the vertical at Position E, then what fraction of the maximum velocity will the rider have at Position D?

a) 10% b) 30% c) 50% d) 70% e) 90%

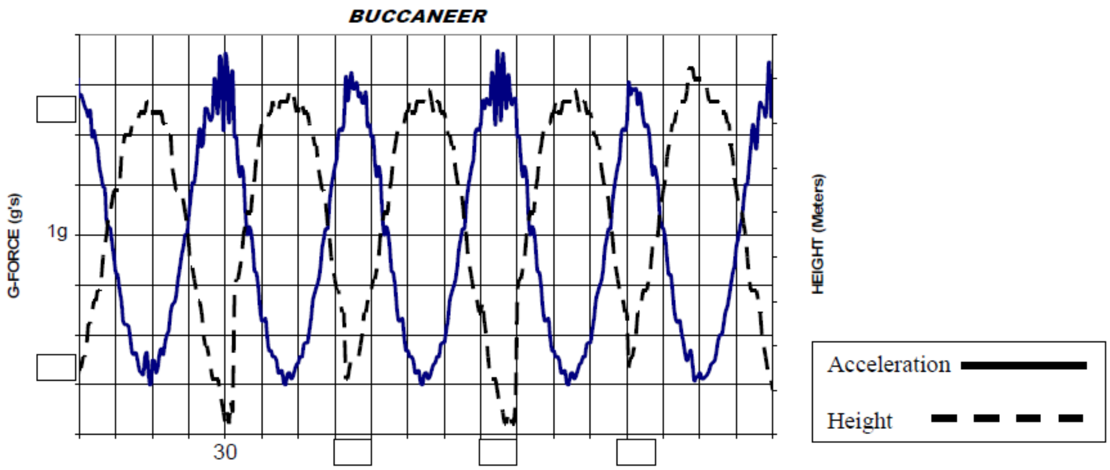
9)) The Buccaneer has the appearance of a large pendulum. Calculate the theoretical period that the Buccaneer would have based on its length of 12 meters. Is this close to your recorded period?

a) 2.0 s b) 3.5 s c) 7.0 s d) 10.5 s e) 14.0 s

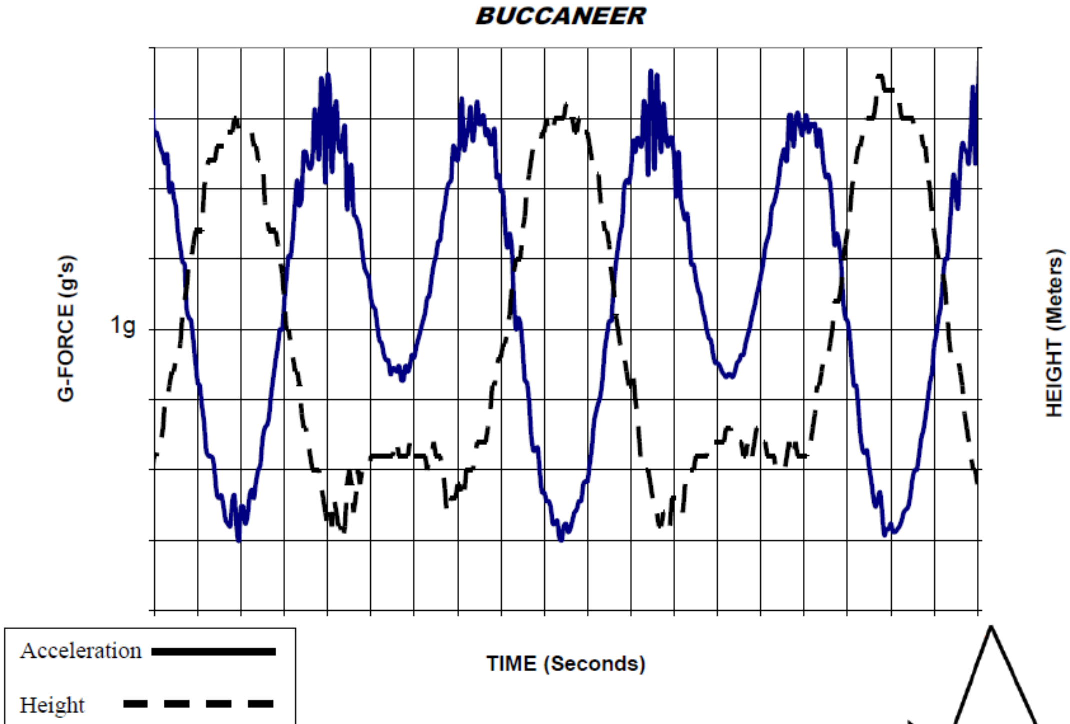
10))) Assuming that the Buccaneer does behave like a large theoretical pendulum, how by how much does the period of its swing increase by when it is fully loaded (total mass of 12,000 kg with passengers) vs. when it is empty (7000 kg)?
a) 0% b) 25% c) 50% d) 75% e) 100%

OPEN ENDED QUESTIONS:

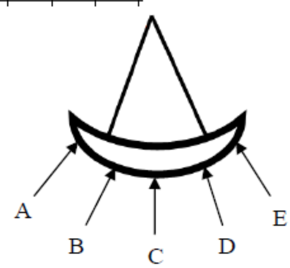
LEVEL I: Below is a graph actual data collected by a Buccaneer rider sitting in the middle of the ship using a computerized accelerometer and altimeter. The acceleration data (g-force) is represented with the solid line, and the altimeter (height) data is represented with the dashed line. A time data point and the 1-g data point have been added to their axis as reference values. Based on your measurements, fill in the empty boxes with the corresponding time and g-force values.



LEVEL II: Compare the graph from the previous question (where the rider was sitting in the middle of the ship) to the one below. The acceleration data (g-force) is represented with the solid line, and the altimeter (height) data is represented with the dashed line. Where in the ship was the person who collected that data sitting? How can you tell? (Answer below)



Where could the person have been sitting on the ship? (See figure on right)



What did you notice in the graph about the g-forces acting on that person that led you to believe this?

What did you notice about that person's altitude (height above the ground) that influenced your decision?

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THE BIG WHEEL

Measurements to Make:

Count the number of:		
Colored Sections	Cars Per Colored Section	Total Cars

Time for 5 revolutions (at top speed): __________

Number of lights between cars: __________
(see photo below – at the park count the lights between the two arrows on the ride)

1) In 2009 the Big Wheel's 7,824 incandescent lights were replaced with more energy-efficient LED lights. Each old (incandescent) light consumed 7 watts of power. The new LED lights only consume 2 watts of power each. How much power is saved due to this light conversion? (Include all the lights for your calculation.)

a) 5 kW b) 50 kW c) 500 kW d) 5 MW 50 MW

☐

2) The lights on the Big Wheel are turned on for an average of three hours per day during the 180 day operating season. How much energy, in kilowatt hours, does the Big Wheel's light conversion save during the course of a year?

a) 1,000 kWhr b) 10,000 kWhr c) 20,000 kWhr d) 40,000 kWhr e) 80,000 kWhr

☐

3) If the park is charged 18 cents per kilowatt hour, what is the yearly cost savings as a result of replacing these lights?

a) $1000 b) $5000 c) $10,000 d) $25,000 e) $100,000

4) What is the period of rotation for the Big Wheel when it is operating at full speed?

a) 10 s b) 20 s c) 40 s d) 80 s e) 160 s

5) The distance in between each light along the perimeter of the Big Wheel is 7.5 inches (19.05 cm). What is the circumference of the Big Wheel?

a) 50 m b) 75 m c) 100 m d) 125 m e) 150 m

6) What is the linear velocity of a car when the Big Wheel is at top speed?

a) 0.5 m/s b) 1.0 m/s c) 1.5 m/s d) 2.5 m/s e) 3.0 m/s

7) What is the radius of the Big Wheel?

a) 5 m b) 10 m c) 15 m d) 20 m e) 30 m

8) What is the centripetal acceleration on a Big Wheel rider at top speed? What is the direction of this acceleration?

a) 0.5 m/s^2 b) 1.5 m/s^2 c) 2.5 m/s^2 d) 3.5 m/s^2 e) 4.5 m/s^2

9) How much work does the Big Wheel do on a group of riders to raise them from the lowest point to the highest point on the wheel? The riders are in the same car and they have a combined mass of 300 kg.

a) 3000 J b) 30,000 J c) 75,000 J d) 125,000 J e) 225,000 J

10) How much power is required to lift this group of riders when the Big Wheel is operating at its top speed?

a) 3 kW b) 7.5 kW c) 15 kW d) 22.5 kW e) 30 kW

OPEN ENDED QUESTIONS:

LEVEL I: Notice the manner in which the ride operator loads the cars. The operator will not load too many consecutive cars (usually only two or three) with passengers; instead they try to space riders out evenly around the wheel. Why is this important to do in order to maintain safe and efficient operation of the Big Wheel?

LEVEL II: Imagine that you are the Big Wheel ride operator. You begin the day with 25 people waiting to be loaded onto the ride, 4 groups of 4 people, and 3 groups of 3 people (assume each person has approximately the same mass). There are 36 total cars. How would you space these groups out on the Big Wheel? Explain why you chose to space them this way. (Answer by drawing a picture or describing the angular separation between groups.)

NITRO

"Camel Hump" section

Measurements to Make:

About 1 minute into the ride you will go through a braking platform followed by a series of three "camel humps" immediately before returning to the station. (See pictures on right and on the top of next page.) It is during these camel humps that you will make Acceleration Meter readings.

Acceleration Meter at the top of the hump: ________

Acceleration Meter at the bottom of the hump: ________

Radius of curvature at camel humps: 35 m
Mass of the train: 2100 kg
Rider mass: 60 kg

1) Nitro's initial vertical drop is 65.6 meters. What is the potential energy of the train just before it falls?

a) 500,000 J b) 750,000 J c) 1,000,000 J d) 1,300,000 J e) 1,600,000 J

2) The length that the train is pulled up the lift hill is 120 meters (in order to reach the 65.6 m vertical drop height). How much force did the lift chain apply to the train to pull it up the hill?

a) 500 N b) 1500 N c) 7500 N d) 12,000 N e) 18,000 N

3) If we assume that the velocity of the train is nearly zero right before it falls, then what is the velocity of the train at the bottom of this initial drop?

a) 5 m/s b) 15 m/s c) 25 m/s d) 35 m/s e) 45 m/s

"Camel Humps"

4) Calculate the work done by gravity on you during the initial drop.

a) 5,000 J b) 10,000 J c) 20,000 J d) 30,000 J e) 40,000 J

5)) At the bottom of the first drop you experience approximately 4 g's (39.2 m/s^2). What is the approximate radius of curvature at the bottom of the initial drop?

a) 11 m b) 22 m c) 33 m d) 44 m e) 55 m

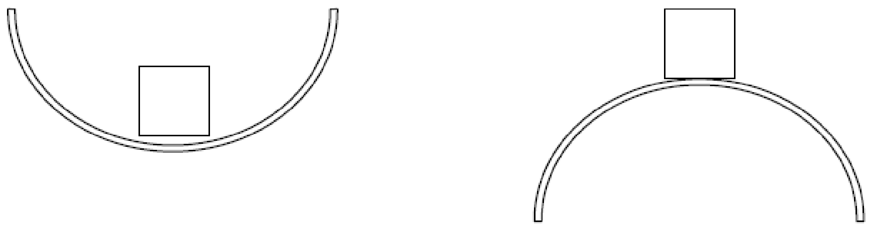
6) The train rises back up to 148 feet (45 meters) to get to the top of the next hill. According to the conservation of energy the velocity of the car at the top of this hill should be 20 m/s, but instead it is measured to be 15 m/s. An engineer inspects the track and finds that 10 meters of a flat section have been damaged and is no longer frictionless. What is the coefficient of friction over these 10 meters of track?

a) 0.5 b) 0.6 c) 0.7 d) 0.8 e) 0.9

7)) In the camel hump section of the ride, based on your Acceleration Meter reading and radius of curvature for the hump, what is your velocity at the top of the camel hump?

a) 5 b) 15 c) 25 d) 35 e) 55

8) Draw a free body diagram for a rider going over the top of a camel hump, and another diagram for a rider at the bottom of a camel hump (the box is the rider, the half-circle represents the radius of curvature for the hump). What is the difference between these two scenarios when applying Newton's 2^{nd} Law for circular motion?



a) There is no difference
b) When going over the top of the camel hump, the force of gravity vector is pointed up
c) The normal force is in the positive direction at the bottom of the hump and in the negative direction at the top
d) There is no normal force when going through the bottom of the camel hump
e) The force of gravity and the normal force are not in the radial direction

9) In the camel hump section of the ride, based on your Acceleration Meter reading and radius of curvature for the hump, what is your velocity <u>at the bottom</u> of the camel hump?

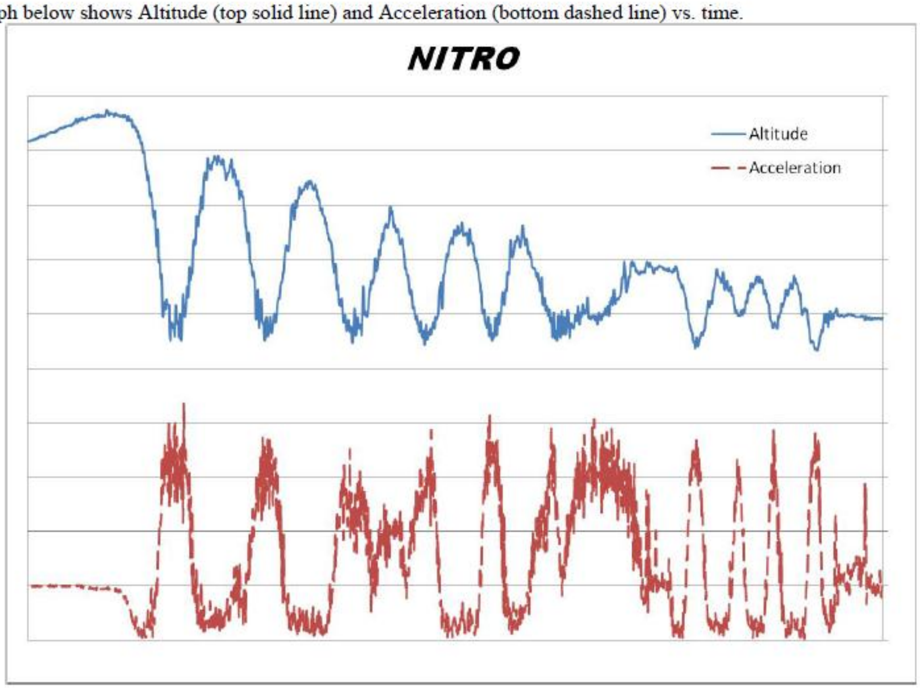
a) 5 b) 15 c) 25 d) 35 e) 55

10) What is the main reason for incorporating "camel humps" into the ride?

a) To slow down the car right before it returns to the station
b) To give the rider the alternating low-g and high-g acceleration in a short time period
c) To give the car enough momentum to make it back to the station
d) To keep the cost of manufacturing the ride low
e) It makes the ride look pretty

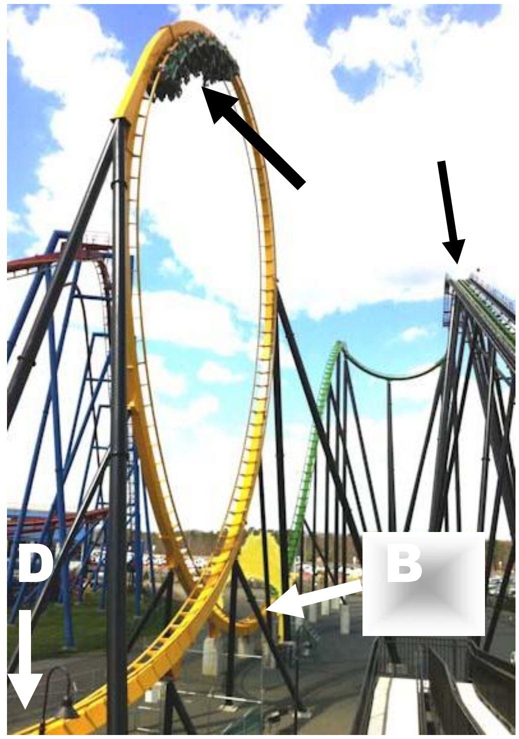
OPEN ENDED QUESTIONS:

The graph below shows Altitude (top solid line) and Acceleration (bottom dashed line) vs. time.



LEVEL I: On the Altitude section of the graph the last three 'bumps' represent the camel hump section that was the subject of the previous questions. What do you notice about both the Altitude and Acceleration graphs for this section? How are they similar and different when compared to themselves and each other?

☐ # GREEN LANTERN



Mass of the train: 3200 kg
Average Passenger Mass: 60 kg

Train Passenger Capacity (total # of seats)	Total Mass of Train plus Riders (kilograms)	Time for Train to climb Lift Hill (seconds)

There are three acceleration meter readings to make - they are at the very beginning of the ride in the Yellow section of the track. The first is at the base of the drop hill (where the track changes color from green to yellow). The second is at the top of the first loop (also yellow track). The third is at the base of the drop after the first loop where the track changes color back to green.

Acceleration Meter at Base of 1st Drop (Point B)	Acceleration Meter at Top of 1st Loop (Point C)	Acceleration Meter at Base after 1st Loop (Point D)	Time for Train to pass Point E (seconds)

1) Green Lantern's lift hill has an angle of 26 degrees and is 292 feet long. What is the vertical displacement of the train (and you) to reach Point A as a result of climbing the lift hill?

a) 21 m b) 39 m c) 62 m d) 80 m e) 99 m

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2) Calculate the work done by the roller coaster's electric motor to increase the train's gravitational potential energy by raising it up the lift hill (fully loaded with all passengers).

a) 1.0 MJ b) 1.9 MJ c) 3.0 MJ d) 3.8 MJ e) 4.7 MJ

☐

3) What is the minimum average power required from the roller coaster's electric motor to move the train and raise it up the lift hill (fully loaded with all passengers) in the time you measured?
a) 5 hp b) 30 hp c) 60 hp d) 90 hp e) 125 hp

4) The station that the train leaves from (where the base of the lift hill is located) is 5.2 meters above the ground. What is the fully loaded train's gravitational Potential Energy after climbing the lift hill at its highest point (Point A)?
a) 1.25 MJ b) 2.11 MJ c) 3.21 MJ d) 4.07 MJ e) 4.98 MJ

5) Using the conservation of energy, calculate the speed of the fully loaded train at Point B.
a) 22.7 m/s b) 29.4 m/s c) 36.3 m/s d) 40.9 m/s e) 45.2 m/s

6) Based on the Acceleration Meter reading you recorded for Point B and the velocity you calculated in the previous problem, what is the radius of the curve at Point B?
a) 11 m b) 21 m c) 29 m d) 43 m e) 65 m

7) At Point C the train is upside down in the loop. At this point the radius of the curve the train is moving through is approximately 9 meters. Based on your acceleration meter reading, how high is the train off the ground at Point C?
a) 8 m b) 17 m c) 29 m d) 38 m e) 45 m

8) Based on your acceleration meter readings at Points B and D, what can you say comparatively about the radius of the curves that the train goes through at each point? Remember to take into consideration the heights of Points B and D relative to the ground in determining your answer.

a) Point B has a greater radius of curvature
b) Point D has a greater radius of curvature
c) The radius of curvature at Points B and D are approximately equal

Explain:

Point E is a position near the end of the ride where the coaster train is at the level of the ground. A good place to observe the train at this point is as you exit the ride and pass by the booth that sells photographs of you taken on the ride (see photos below).

Photo Booth

Position to make measurement (Point E)

Stand here

9) Stand near Point E to observe the train as it goes by and measure how long it takes to pass a given point on the track. Use this time and the fact that the train is 39 feet long to determine the speed of the train at Point E.

a) 11 m/s b) 16 m/s c) 20 m/s d) 24 m/s e) 29 m/s

10) At Point E, the actual velocity of the train is less than the theoretical value obtained from the conservation of energy (by conservation of energy the theoretical speed of the train should be approximately 30 m/s). What is the most likely reason that the train was moving slower at Point E?

a) Friction between the wheels and the track
b) Air resistance due to the standing riders
c) Unequal masses of the riders (we assumed all riders to be 60 kg, which is probably untrue)
d) The roller coaster's motor turning off before Point E

Explain:

OPEN ENDED QUESTIONS:

Level I: Inspect the picture on the first page of the Green Lantern question set. You will notice that after Point A (top of the lift hill) the track takes a small U-shaped dip before going through the first big drop. This is called a “pre-drop” and its purpose is to reduce tension on the lift chain as the train transitions from the lift hill to the point where it is dropped. What effect does this have on the energy and speed of the train later in the ride (particularly at the bottom of the first large drop hill)?

Level II: The Green Lantern is unique among most roller coasters because the riders stand straight up during the ride. How does putting the riders in this orientation change the sensations that the riders feel across their body? Assume a rider is 1.75 meters tall, what is the difference in the acceleration the rider feels from the top of their head to the bottom of their feet? Calculate this using the parameters at Point B, which is at the base of the first large drop hill.

Notes:

<u>*SIX FLAGS GREAT ADVENTURE MAP*</u>

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